Appendix A: LTCP Requirements (Crosswalk)

Appendix A. Consent Decree Compliance Crosswalk			
Consent Decree item	**Consent Decree reference and description**	**LTCP Section**	**Comments**
Appendix C, LTCP Requirements			
A.1 through. A.5	A. Public and Regulatory Agency Participation Program.	4.2	Describes the public and regulatory agency participation program preformed for the LTCP
B.1 and B.2.	B. Hydraulic Model Development and Hydraulic Model Report	2.6 Appendix B	Describes the hydraulic modeling for the LTCP. East Waterway CSO Basin 107 Hydraulic Model Report is included in Appendix B
C.1.	*" . . . The LTCP shall be conducted using the LTCP guidelines, but the alternatives analysis shall be modified in order to meet the performance criteria. . . "*	3.1	Describes long term control plan approach
C.2	*"The LTCP shall build upon the alternative analysis work that was performed as part of the development of the City's 2010 CSO Reduction Plan Amendment (2010 Plan). . . ."*	3.4	Describes how the LTCP used the 2010 CSO Reduction Plan as the starting basis for the CSO control measure alternative analysis
C.3	*" . . the City's assessment shall include, at a minimum, an evaluation of the technical feasibility and applicability of each alternative or combination of alternatives at each CSO Outfall or grouping of CSO Outfalls.*	3.4 3.5 3.6	Describes the screening of CSO Control measures for each outfall Describes the various combinations of CSO control measures were developed and evaluated for individual outfalls or grouping of outfalls Describes the combination of CSO control measures were grouped into aggregate options
C.4	*For each alternative or combination of alternatives evaluated as part of the LTCP, the City's assessment shall include a determination of the estimated "project costs," . . ."*	3.7	Describes the project cost methodology used to determine capital costs, annual costs, total project cost and life cycle (net present value) costs

Appendix A. Consent Decree Compliance Crosswalk			
Consent Decree item	**Consent Decree reference and description**	**LTCP Section**	**Comments**
C.5	*"Assessment of CSO Control Measures: In developing the LTCP, the City must conduct or document prior analysis of alternatives for reducing the City's CSOs. The assessment must include, at a minimum, (a) an evaluation of the annual performance capabilities and effectiveness, measured in terms of CSO activation frequencies and overflow volumes, of various CSO control alternatives to meet performance criteria for controlling CSOs, pursuant to WAC 173-245 and RCW 90.48.480; (b) an analysis of design and development capabilities for the CSO control alternatives, including basin-specific information on flow management, topographical or hydrological constraints, and construction capacities; (c) an evaluation of project costs, including capital costs, annual operations and maintenance costs, and total present worth, for the CSO control alternatives; (d) the screening of selected CSO control alternatives, involving additional evaluation of the geotechnical environment and property information, as well as the preparation of the appropriate environmental review, for the identified project area; and (e) the basis for the City's selection of the preferred alternatives to implement as the CSO Control Measures in the LTCP.. . "*	Chapter 2 Chapter 3 Chapter 4 CSO Alternative Analysis Report (December 31, 2014)	Chapter 2 describes the hydrological and hydraulic constraints, and the development of hydraulic models for alternative evaluation Chapter 3 describes how the LTCP used the 2010 CSO Reduction Plan as the starting basis for the CSO control measure alternative analysis, and the development of the Draft LTCP options Chapter 4 describes the evaluation of project costs and the rating and ranking of the Draft LTCP options. The chapter also describes the final decision making process for the selection of the recommended LTCP CSO control measures for the Final LTCP. Consent Decree Appendix B requires a CSO Alternative Analysis Report be submitted for EPA approval by December 31, 2014. The report will present the basis of the City's selection of the recommend CSO control measures.
C.6	*"The LTCP shall include an evaluation of the City's financial capability to fund the selected alternative or combination of alternatives. . . "*	4.5 Appendix C	Describes the financial assessment performed in accordance with EPA's February 1997 "Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development" SPU Financial Capability Assessment
C.7	*"The LTCP shall include the selection of CSO Control Measures, including the construction of all Wastewater Collection System improvements, necessary to ensure compliance with the technology-based and water quality based requirements . . ."*	3.1	Describes long term control plan approach including compliance with performance criteria

Appendix A. Consent Decree Compliance Crosswalk			
Consent Decree item	**Consent Decree reference and description**	**LTCP Section**	**Comments**
C.8	*"The LTCP shall include an expeditious schedule for the design, construction, and implementation of all CSO Control Measures..."*	4.4	Described the implementation schedule and critical milestones for all CSO Control Measures
C.9	*"The City's assessment of the costs, benefits, and effectiveness of the alternatives evaluated for reducing CSOs;"*	4.1	Describes the evaluation process for monetary and non-monetary factors to rate and rank the alternatives
C.10	*"The City's basis for determining that the CSO Control Measures set forth in the LTCP will ensure that the City's CSOs comply with the CSO Control Policy, and those portions of the CWA and its implementing regulations, RCW 90.48.110, WAC 173-245, and the City's NPDES Permit that apply to CSO control;*	CSO Alternative Analysis Report (December 31, 2014)	Consent Decree Appendix B requires a CSO Alternative Analysis Report be submitted for EPA approval by December 31, 2014. The report will include hydraulic modeling evaluation to demonstrate that the recommended CSO control measures will meet the performance criteria
C.11	*"The City's basis for determining that the schedule for implementing the LTCP attains Construction Completion of all CSO Control Measures as expeditiously as practicable, and in no event later than December 31, 2025 for Construction Completion of all CSO Control Measures. . ."*	4.4 LTCP Implementation Schedule Report (December 31, 2014)	Describes the implementation schedules and critical milestones for the various CSO Control Measures. Consent Decree Appendix B requires a LTCP Implementation Schedule be submitted for EPA approval by December 31, 2014. The report will include a detailed implementation schedule for the recommended LTCP CSO control measures

Appendix A. Consent Decree Compliance Crosswalk			
Consent Decree item	**Consent Decree reference and description**	**LTCP Section**	**Comments**
C.12	*"The City's Financial Capability Assessment, conducted pursuant to Section II.C.8 of the CSO Control Policy and further addressed in EPA's guidance document entitled, "Combined Overflows – Guidance for Financial Capability Assessment and Schedule Development."*	4.5	Describes the financial assessment performed in accordance with EPA's February 1997 "Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development"
		Appendix C	SPU Financial Capability Assessment
		LTCP Financial Analysis Report (December 31, 2014)	Consent Decree Appendix B requires a financial analysis for the recommended LTCP option be submitted for EPA approval by December 31, 2014. The report will include an evaluation of the City's financial capability to fund the selected alternative or combination of alternatives, consistent with EPA's February 1997 "Combined Sewer Overflows – Guidance for Financial Capability Assessment and Schedule Development"
C.13	*"The LTCP shall include, as attachments, all documents and reports generated in order to develop the LCTP."*	Appendices	The appendices will consist of technical reports that provide additional documentation for the LTCP.
D.1 through. D.3	D. Post-Construction Monitoring Program	4.7	Describes the post-construction monitoring program for the CSO Control Measures.
		Final PCMP (May 31, 2015)	Detailed Post Construction Monitoring Plan required under the Consent Decree will be submitted for EPA approval as a separate document by May 31, 2015.

Appendix B:

- East Waterway NPDES 107 Hydraulic Model Report
- SPU/KC Interceptor Model Calibration Report

Seattle Public Utilities

Protecting Seattle's Waterways

Long-Term Control Plan Hydraulic Model Report

East Waterway NPDES107

January 2014

Seattle Public Utilities
Long-Term Control Plan Hydraulic Model Report
East Waterway NPDES107

January 2014

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SPU Project No. C-308039
SPU Consultant Contract No. C10-048

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List of Abbreviations

Term	Definition
ACU-SWMM	Automated Calibration and Uncertainty Analysis for Storm Water Management Model
City	City of Seattle
CSO	combined sewer overflow
CSS	combined sewer system
DWF	dry weather flow
EBI	Elliott Bay Interceptor
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ft^3	cubic foot/feet
GIS	geographic information system
GWI	groundwater inflow
HARN	High Accuracy Reference Network
HGL	hydraulic grade line
ID	identifier
KC	King County
lf	lineal foot/feet
LTCP	Long-Term Control Plan
MG	million gallon(s)
mgd	million gallon(s) per day
MGS	MGS Engineering Consultants, Inc.
MH	maintenance hole
MSL	mean sea level
NAD	North American Datum
NAVD88	North American Vertical Datum of 1988
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PCSWMM	software interface to SWMM5 (CHI, Inc.)
PS	pump station
RG	rain gauge
RS	regulator station
ROW	right-of-way
SCADA	supervisory control and data acquisition
Sea-Tac	Seattle-Tacoma International Airport
SPU	Seattle Public Utilities
SWMM5	EPA Storm Water Management Model, Version 5
WWTP	wastewater treatment plant

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SECTION 1

Introduction

A hydraulic model of the East Waterway NPDES107 Combined Sewer Overflow (CSO) Area was developed to assess the performance of the existing system, predict wet weather flows, estimate the frequency and volume of CSO events, and support the analysis of system modifications and new CSO control facilities that will make up the City of Seattle (City)'s Long-Term Control Plan (LTCP). This report summarizes the project background, development, and calibration of the computer model of the combined sewer system (CSS) in the East Waterway NPDES107 CSO Area and fulfills the requirements for a Hydraulic Model Report as described in Appendix C, Item B.2 of the Consent Decree lodged July 3, 2013.

The East Waterway CSO Area covers 58.7 acres (0.09 square mile) in southeast Seattle; it is bounded by S Hanford Street to the north, the East Waterway/Puget Sound to the west, industrial properties to the south, and East Marginal Way S to the east (see Figure 1-1). The East Waterway CSO Area comprises the NPDES107 Basin, which drains toward a single overflow point near the intersection of East Marginal Way S and S Spokane Street. The wastewater generated in this basin flows by gravity to the King County (KC) mainline along Colorado Avenue South for conveyance to the West Point Wastewater Treatment Plant (WWTP).

The CSS in the NPDES107 CSO Area conveys both sanitary and stormwater flow. The area is partially separated. Storm sewers collect and convey street runoff and a portion of private-property runoff. Stormwater from partially separated areas of the East Waterway CSO Area is discharged into the East Waterway. The East Waterway CSO Area includes a permitted CSO outfall that discharges overflows to the East Waterway in large precipitation events when the capacity of the CSS is exceeded.

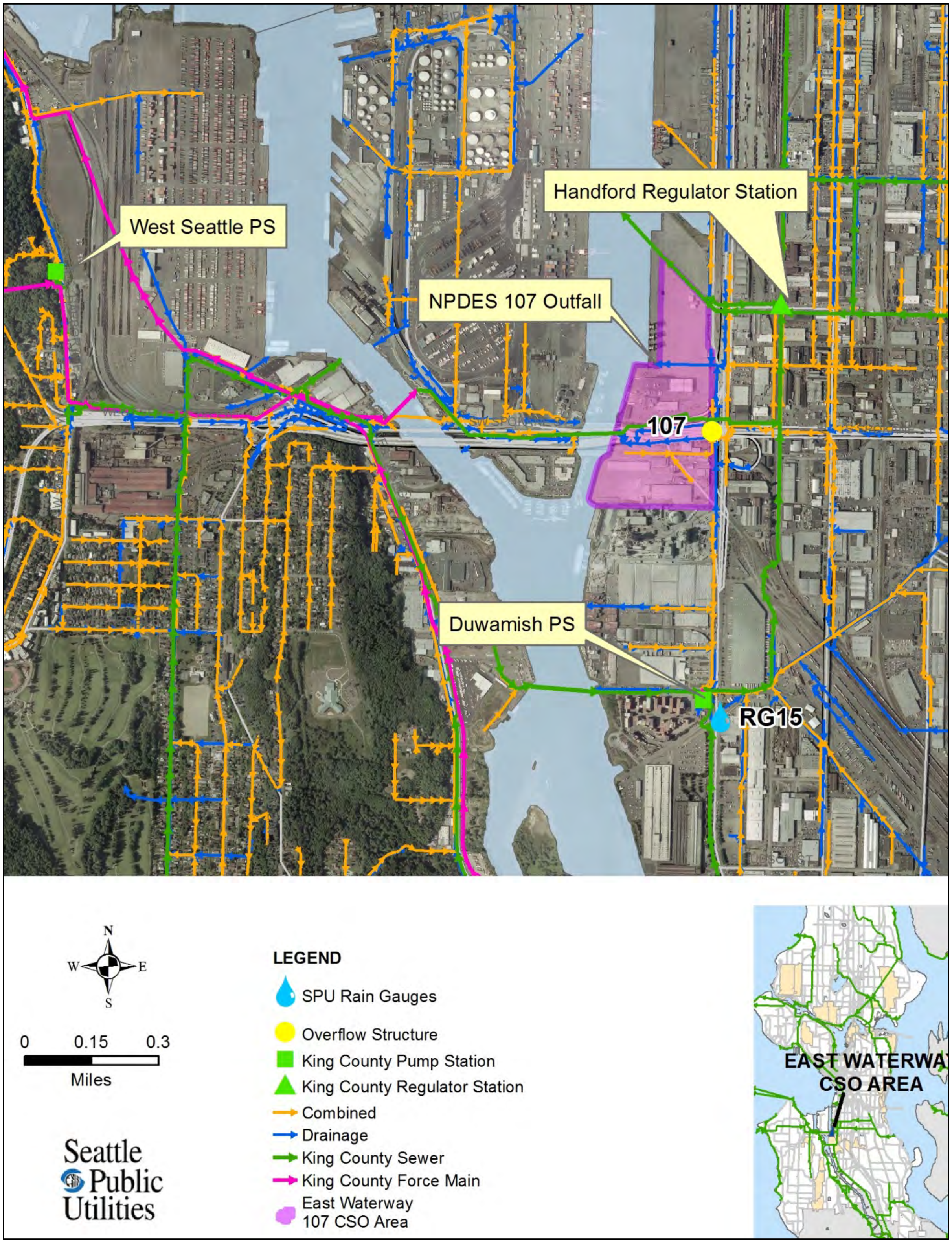

Figure 1-1. East Waterway CSO Area

1.1 Project Background

The National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating the discharge of pollutants into waters of the United States. In Washington, the Washington State Department of Ecology (Ecology) has delegated authority to administer the program and issue NPDES permits. The City's wastewater collection system is regulated by NPDES permit WA0031682, issued by Ecology to the City of Seattle, Seattle Public Utilities (SPU). SPU is responsible for meeting the terms of the NPDES permit and the associated Consent Decree lodged July 3, 2013. One of SPU's responsibilities is to develop an LTCP to identify, evaluate, and recommend projects throughout the city that would control CSOs in compliance with federal, state, and local regulations.

The City's 2010 CSO Reduction Plan identifies the East Waterway CSO Area as one of the basins to be covered in the comprehensive LTCP and to be controlled after 2015. The East Waterway CSO Area has one outfall to the East Waterway of the Duwamish River, designated in the NPDES permit as Outfall 107. For clarity, it is designated as NPDES107 in this report and in SPU's modeling work.

1.2 Project Objectives

The goal of the hydraulic modeling task was to develop a tool that supports the evaluation of CSO control alternatives. The hydraulic model is also a valuable tool for understanding the sewer system hydraulics, the response of the sewer system to various precipitation events, and the characteristics of CSOs. To achieve the project goals, the modeling task accomplished the following objectives:

- characterize the hydrology of the basins in the East Waterway CSO Area
- characterize the performance of the existing diversion structures, outfall structures, and conveyance pipes
- simulate and evaluate hydraulic grade lines (HGLs) and flow rates throughout the East Waterway CSO Area under varying conditions based on historical precipitation and known boundary conditions

SPU's modeling approach and essential attributes of model development and usage are summarized in the SPU Design Standards and Guidelines, Chapter 7: Drainage and Wastewater System Modeling (2010).

1.3 Study Area

The East Waterway CSO Area is bounded by the East Waterway in the west, and its topography is very flat. The study area is shown in Figure 1-1, which shows the East Waterway CSO Area and the corresponding NPDES basins, as well as the significant components of the King County system.

The East Waterway CSO Area has no upstream hydraulic relationship to other Seattle NPDES basins. However, the HGL at the overflow structure is influenced by the HGL in King County's Elliott Bay Interceptor (EBI), which collects and conveys sanitary and storm sewer flow from a large portion of the city of Seattle. All the collected CSS flows are directed to the EBI for conveyance, treatment, and discharge at the West Point WWTP.

1.4 Description of the Hydraulic Model

This section provides a description of the attributes and characteristics of the hydraulic model, the selected software, and SPU's implementation of the hydraulic model.

1.4.1 Attributes and Characteristics Required

In general, a hydraulic model contains three essential components:

- the network of sewer infrastructure (pipes, pumps, and other structures comprising the model hydraulics)
- tributary basins served by the sewer network (the source of flows to the network comprising the model hydrology)
- boundary conditions (i.e., flow and water levels that represent the system beyond the model boundaries and influence the model results)

To meet the requirements of the Consent Decree lodged July 3, 2013 (Appendix C Item B.2), the hydraulic model must be capable of predicting dry weather wastewater flows, wet weather surface runoff, and groundwater inflow (GWI) from the tributary basins for any arbitrary rainfall pattern and record length. This flow must be dynamically routed through the sewer network allowing prediction of flow rates and HGLs throughout the system, and allow determination of how CSO frequency and volume will change under various control alternatives.

1.4.2 Selected Software

SPU chose the United States Environmental Protection Agency (EPA)'s Stormwater Management Model Version 5 (EPA SWMM5) as its standard modeling platform, and this software was used in development of the LTCP. The model was selected after comparison with other software by a panel of modeling experts and based on the following established criteria: performance, ease of use, cost, must have specific features and attributes of a hydraulic model necessary to complete the most common type of modeling, must be open-source, and satisfies the requirements of the Draft Consent Decree.

1.4.2.1 Description of the EPA SWMM5 Software

As described in the SWMM5 User's Manual, SWMM5 is a dynamic rainfall-runoff simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM5 operates on a collection of subcatchment areas that receive precipitation and generate runoff. The routing portion of SWMM5 conveys this runoff through a system of pipes, channels, storage, pumps, and regulators. SWMM5 tracks the quantity of runoff generated within each subcatchment, and the flow rate and flow depth in each pipe and channel during a simulation period comprising multiple time steps. The LTCP models used the following methodology for flow generation and flow routing; more complete descriptions are available in the SWMM5 User's Manual:

- **Flow routing:** Dynamic wave routing, which solves the complete one-dimensional Saint Venant equations, is used. This method allows accurate simulation of the hydraulics of any general network including storage, backwater, and pressurized flow, without resorting to simplifications.
- **Pervious surface infiltration:** Infiltration of rainfall on pervious surfaces uses the Green-Ampt method. Infiltration is the source for groundwater recharge and eventually infiltration into the sewer system.
- **Surface runoff:** Surface runoff from impervious and pervious surfaces is generated using the standard SWMM5 nonlinear reservoir method.
- **Groundwater inflow to sewer system:** GWI to the sewer system is generated using the SWMM5 groundwater module. This module balances infiltration from the surface, evapotranspiration, percolation between layers and to deep groundwater, and infiltration to the sewers.
- **Dry weather flows:** Dry weather flows (DWFs) from residences and businesses were estimated from flow monitoring and water use records. Diurnal variation in DWF was developed from flow monitoring records.

1.4.2.2 Modeling Wet Weather Flows from Separated Areas

The same methodology is used for separated areas and for combined areas. Wet weather flows from separated areas, if any, consist of DWF, surface runoff if evident in flow monitoring records or system characteristics, and GWI.

1.4.3 SPU Implementation

SPU models incorporate the entire network in each basin. Where necessary, the interface between SPU facilities and King County facilities has been explicitly included in the model as described below.

1.4.3.1 Characteristics of Model

The NPDES107 Basin model is comprehensive, including all combined sewer conduits and special structures (pump stations, overflow weirs, storage tanks, outfalls, flow control elements, etc.) in the system, as shown in Figure 1-1. Drainage conduits and associated tributary areas are included, as necessary, to simulate inflows to the combined system and loadings to outfalls. The included system elements are described in detail in Section 4 of this document.

1.4.3.2 Coordination with King County

All SPU CSO basins eventually discharge to the King County interceptor system through various facilities. In some cases, the King County system operation may directly impact CSOs in the SPU system. Where this direct interface exists, the boundary condition (time series of HGL in the King County interceptor) was developed in coordination with King County.

The NPDES107 Basin discharges to the EBI between the Duwamish Pump Station (PS) outlet and the Hanford Regulator Station (RS). This connection influences CSO events at the outfall structure. Therefore, the reach of the EBI between the Duwamish PS and the Hanford RS were included in the model (extracted from the SPU system-wide model; Aqualyze, 2013), and a boundary condition was applied to represent HGL in the EBI at the location of the Hanford RS. In addition, the EBI conveys sanitary and storm flow from a large portion of Seattle. In the model, the input from the King County Duwamish PS was developed from supervisory control and data acquisition (SCADA) data provided by King County. The key components of the King County system are shown in Figure 1-1, and more detail about the connections between the City's system and King County's system is provided in Section 4.1.

1.4.4 Limitations of the Hydraulic Model

The LTCP hydraulic models were developed from SPU geographic information system (GIS) data, as-built record drawings, survey data, and SPU rainfall and flow data. They reflect the state of the system at the end of the calibration period.

The EPA SWMM5 software is a tool for analysis of systems of either existing or new systems and proposed modifications; it is not a design tool. Thus, any future changes in the system (including retrofits, maintenance, and future CSO projects), will need to be reflected in modifications to the models with validation based on post-construction monitoring results. In addition, the EPA SWMM5 software manuals state restrictions on its use to urban watersheds, which do not apply to the SPU LTCP models.

1.5 Summary of Model Development History

SPU developed a model of the King County interceptor system and the key components of the City's system in 2013, referred to as the system-wide model (Aqualyze, 2013). The portion of the model between the Duwamish PS and the Hanford RS was extracted from the system-wide model and included in the East Waterway CSO Area model. There was no existing model of the East Waterway CSO Area. The model was built using various sources from SPU including GIS data, record drawings, and survey. More detail of the model build process is provided in Section 3.1.

1.6 Supporting Documentation

Several documents have been prepared to support the LTCP modeling efforts. In addition to this report, the reports and plan documents listed below were created to support the development of the SWMM5 model:

- SPU/King County Interceptor Model Calibration (Aqualyze, 2013). The model calibration report describes the development and calibration of the system-wide model.
- SPU Long-Term Control Plan Flow Monitoring Report Volume 1: Flow Monitoring Summary Report (CH2M HILL, Brown and Caldwell, GHD, 2010). The executive summary of Volumes 2–5 of the report serves as an overview and summary of the entire monitoring project.
- SPU Long-Term Control Plan Flow Monitoring Report Volume 2: Quality Assurance Project Plan: Flow Monitoring Plan 2008–2009 (CH2M HILL, Brown and Caldwell, GHD, July 16, 2009). The QAPP describes the monitoring goals and objectives, parameters to be studied, quality objectives and procedures, and data management procedures for the first wet weather season of flow monitoring.
- SPU Long-Term Control Plan Flow Monitoring Report Volume 3: Quality Assurance Project Plan: Flow Monitoring Plan 2009–2010 (CH2M HILL, Brown and Caldwell, GHD, May 31, 2010). The QAPP describes the monitoring goals and objectives, parameters to be studied, quality objectives and procedures, and data management procedures for the second wet weather season of flow monitoring.
- SPU Long-Term Control Plan Flow Monitoring Report Volume 4: Phase 1 Flow Monitoring Report (CH2M HILL, Brown and Caldwell, GHD, 2010). The Flow Monitoring Report documents the results of the first wet weather season of flow monitoring conducted in the uncontrolled CSO basin areas with the objective of accurately characterizing the performance of the uncontrolled CSO basin CSS and facilities before, during, and after storm events.
- SPU Long-Term Control Plan Flow Monitoring Report Volume 5: Phases 2–3 Flow Monitoring Report (CH2M HILL, Brown and Caldwell, GHD, 2010). The Flow Monitoring Report documents the results of the summer and second wet season of flow monitoring conducted in the uncontrolled CSO basin areas with the objective of accurately characterizing the performance of the uncontrolled CSO basin CSS and facilities before, during, and after storm events.

- SPU Design Standards and Guidelines, Chapter 7: Drainage and Wastewater System Modeling (2010). The modeling plan provides guidelines for development and calibration of hydraulic and hydrologic models of City of Seattle sewer basins constructed in support of long-term CSO control planning.

1.7 Report Contents and Organization

This section provides an overview of the report contents and a crosswalk detailing where each of the items in the Consent Decree lodged July 3, 2013, is addressed in the report.

1.7.1 General

This section describes the organization of the report.

- **Section 2** documents the basin characterization including the conveyance system, climate, land use, soil, and a detailed description of the NPDES basins within the study area.
- **Section 3** documents the data used to build the hydraulic model, including data sources and documentation, and a description of the flow monitoring data that were collected for model calibration.
- **Section 4** documents the model development, including how the model extent was defined, the boundary conditions used in the model, the development of DWFs, the subcatchment delineation method, and a summary of the model hydrology and hydraulics.
- **Section 5** describes the model calibration, including a description of the calibration process, calibration events, and locations and the selected model parameters.
- **Section 6** describes the model verification, and a comparison of modeled overflow volumes to reported overflow volumes.
- **Section 7** provides the summary and conclusions.

1.7.2 Conformance to Consent Decree Requirements

This report contains the required contents listed in Appendix C, Item B.2 of the July 3, 2013, Fully Entered Consent Decree. Table 1-1 is a crosswalk that describes where the Consent Decree requirements are addressed.

Table 1-1. Crosswalk to Consent Decree Requirements			
Consent Decree item	Consent Decree description	Section	Comments
2a	Description of the hydraulic model	1.2 1.3 1.4	• Section 1.2 describes modeling objectives. • Section 1.3 describes the study area. • Section 1.4 describes the hydraulic model, the selected software, and SPU's implementation.
2b	Specific attributes, characteristics, and limitations of the hydraulic model	1.4 2	• Section 1.4 describes the attributes, characteristics, and limitations. • Section 2 describes the model area characteristics.
2c	Identification of all input parameters, constants, assumed values, and outputs	4.5 4.6 5.5 6 Appendix E	• Section 4.5 includes tables listing input parameters, constants, and assumed values for subcatchments and aquifers. • Section 4.6 includes input parameters, constants, and assumed values for hydraulic model elements (pipes, maintenance holes, and special structures). • The model parameters from the calibration are listed in Section 5.5 developed by comparison of model prediction to observed depths. • Section 6 presents the model output depths compared to observations at overflow structures. • Appendix E includes hydrographs of predicted depth compared to observed values.
2d	A digitized map(s) and schematics that identify and characterize the portions (including the specific gravity sewer lines) of the wastewater collection system included in the hydraulic model	1 2.1 3.3 4.3 Appendix D	• Section 1 includes an overview map of the East Waterway CSO Area. • A schematic, showing the East Waterway CSO basin in relation to other LTCP basins and the King County system, is included in Section 2.1. • Section 3.3 shows a schematic map of the East Waterway flow meters. • Section 4.3 shows a schematic map with dry weather flows. • Appendix D includes a digital map of the basin.
2e	Identification of input data used	3.1.1	• Section 3.1.1 lists all the data sources used in model construction and model calibration.

Table 1-1. Crosswalk to Consent Decree Requirements			
Consent Decree item	**Consent Decree description**	**Section**	**Comments**
2f	Configuration of the hydraulic model	4	• Section 4 describes the hydraulic model extent, boundary conditions, subcatchment delineation methods, and model hydraulics.
2g	Procedures and protocols for performance of sensitivity analyses (i.e., how the hydraulic model responds to changes in input parameters and variables)	5 5.4	• Section 5 describes the model calibration. • Section 5.4 describes the manual calibration and sensitivity of input parameters.
2h	Procedures for calibrating the hydraulic model to account for values representative of the wastewater collection system using actual data (e.g., flow data)	5.1 5.4	• Section 5.1 describes the calibration process. • Section 5.4 describes the model calibration and results.
2i	Procedures to verify the hydraulic model's performance using actual data (e.g., flow data)	6	• Section 6 describes the model verification using level data from the overflow structures.
2j	Procedures for modeling wet weather flows from separate sewer areas	1.4.2.3	• Section 1.4.2.3 describes how wet weather flows from separated areas are modeled.

SECTION 2

Basin Characterization

This section describes the conveyance system, climate, land use, and soils in the East Waterway CSO Area. The conveyance system is also described in greater detail in Section 4.

2.1 Conveyance System

The East Waterway CSO Area, located in southeast Seattle, includes the NPDES107 Basin. The NPDES107 Basin occupies approximately 58.7 acres and is bounded by S Hanford Street to the north, the East Waterway/Puget Sound to the west, industrial properties to the south, and East Marginal Way S to the east (see Figure 1-1). The East Waterway model also includes portions of the East Marginal Way S storm drain, and portions of the KC EBI.

The NPDES107 Basin model contains more than 8,670 lineal feet (lf) of public sewer, ranging between 10 and 96 inches in diameter, and more than 45 connecting structures, the majority of which are maintenance holes (MHs). All pipes and connecting structures within the basin itself are included in the model, in addition to part of the EBI. Private sewer laterals are not included in the model, but were used to verify connections. A summary of the sewer mainline pipes in the East Waterway model is provided in Table 2-1. Pipes owned by other agencies (e.g., Port of Seattle, State of Washington) were included in the model where they were necessary to maintain network connectivity.

Table 2-1. Summary of Combined Sewer Pipe in the NPDES107 Basin Model (includes EBI)

Diameter (inches)	Length of pipe (lf)	Percent of total
10 or less	564	6.5
12	642	7.4
14–18	2,011	23.2
20–23	0	0.0
24–29	11	0.1
30–35	21	0.2
36–54	0	0.0
84	5330	61.4
96	97	1.1
Total	**8,676**	**100**

The NPDES107 Basin model also contains part of the East Marginal Way S storm drain, including more than 5,600 lf of storm drainage pipe ranging between 8 and 54 inches in diameter, and more than 40 connecting structures. Private drainage laterals are not included in the model, but were used to verify connections. A summary of the storm drainage pipes in the East Waterway model is provided in Table 2-2.

Table 2-2. Summary of Storm Drainage Pipe in the NPDES107 Basin Model

Diameter (inches)	Length of pipe (lf)	Percent of total
10 or less	800	14.3
12	977	17.4
14–18	1,422	25.7
20–23	0	0.0
24–29	849	15.2
30–35	0	0.0
36–42	794	14.2
54	739	13.2
Total	**5,601**	**100.0**

Figure 2-1 shows a schematic of the East Waterway CSO Area in relation to the other LTCP basins and the King County system.

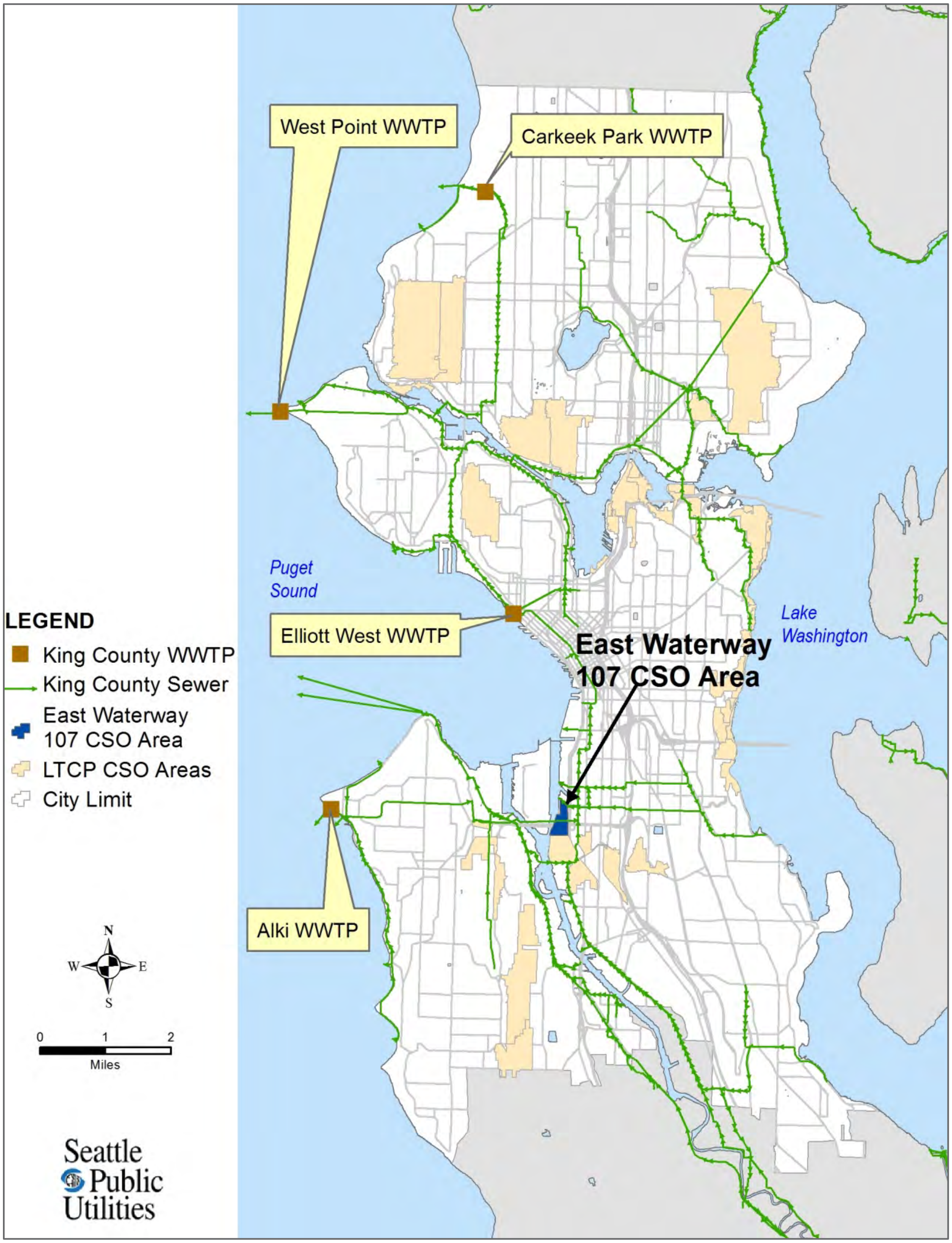

Figure 2-1. Schematic of the East Waterway CSO Area

2.2 Climate

Seattle typically has moderate, dry summers and mild, wet winters. Regional climate data are reported at Seattle-Tacoma International Airport (Sea-Tac). Average annual precipitation is 37.1 inches.

The Seattle area experiences three distinctive categories of storm types (MGS, 2003), as described below:

- Short-duration storms are primarily warm season events that produce high intensities over isolated areas; they are often the controlling storm types for sizing conveyance structures in urbanized areas.
- Intermediate-duration storms occur throughout the year but are most common in the fall and early winter seasons. These storms often contain moderate to high intensities for a period of several hours and precipitation commonly occurs over 6 to 18 hours.
- Long-duration storms are primarily late fall and winter season events, characterized by low to moderate intensities and durations of 24 hours or more. Long-duration storms are associated with continental-scale water systems originating over the Pacific Ocean and precipitation occurs over very large areas. The long-duration storm is usually the controlling storm type for the design and analysis of stormwater detention facilities where both runoff volume and peak discharge are primary considerations (MGS, 2003).

In addition to the regional climate data reported at Sea-Tac, the City of Seattle operates a network of rain gauges (RGs) across the city. The closest gauge to the East Waterway CSO Area is RG 15, which is located at the King County Duwamish PS at the intersection of East Marginal Way S and Diagonal Avenue S, south of the East Waterway CSO Area boundary. The locations of this rain gauge and others in SPU's network are shown in Figure 2-2.

The total monthly precipitation recorded at RG 15 during the flow monitoring and model calibration period is shown in Figure 2-3, in comparison with the monthly long-term average precipitation recorded at Sea-Tac. In comparison with long-term averages at Sea-Tac, RG 15 was drier than Sea-Tac during the 2008–09 and 2011–12 wet seasons but wetter than Sea-Tac during the 2009–10 and 2010–11 wet seasons. RG 15 characterized the spatial distribution of rainfall in the basin very well, as determined by comparing rainfall and flow data.

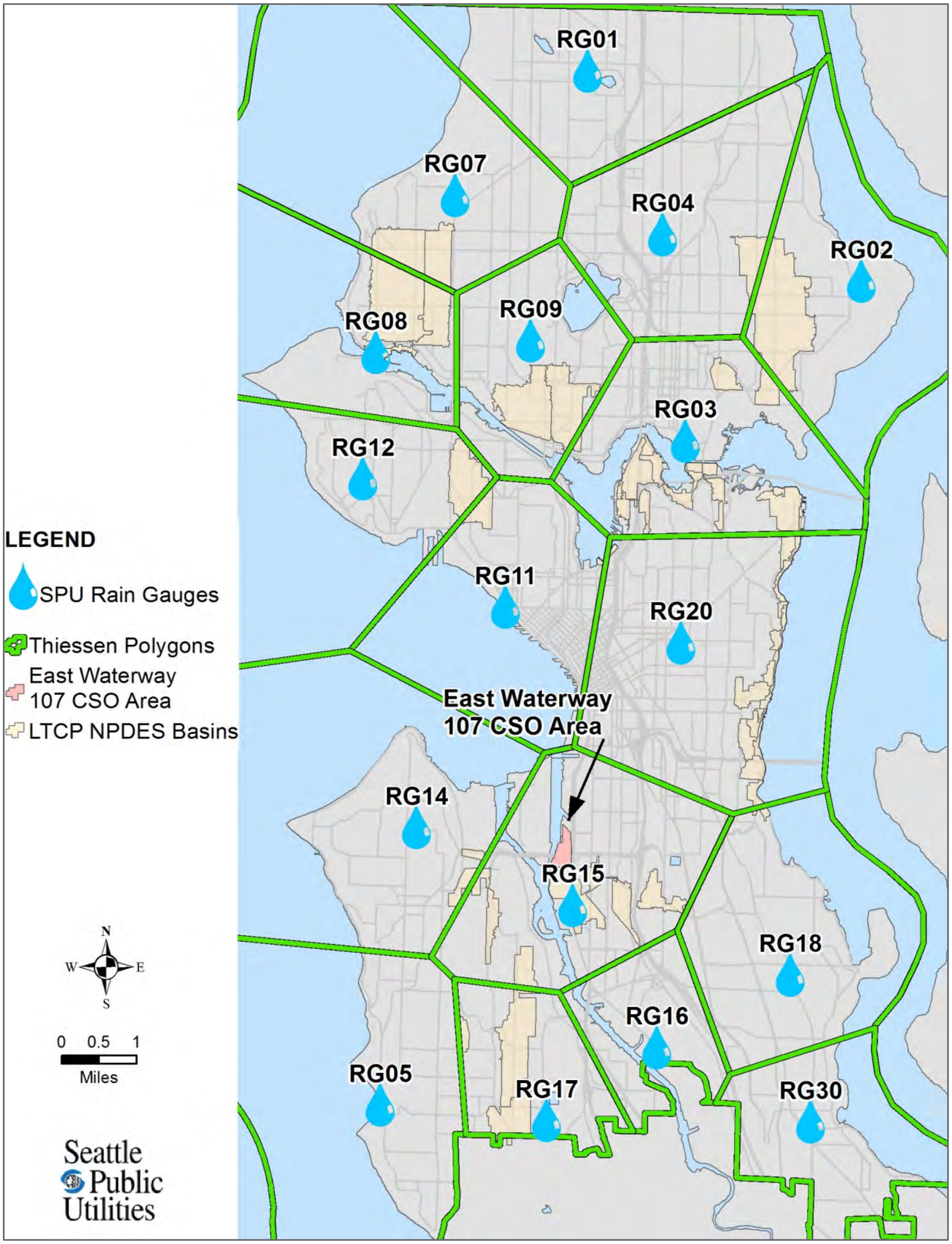

Figure 2-2. SPU rain gauge network, Thiessen polygons, and East Waterway CSO Area

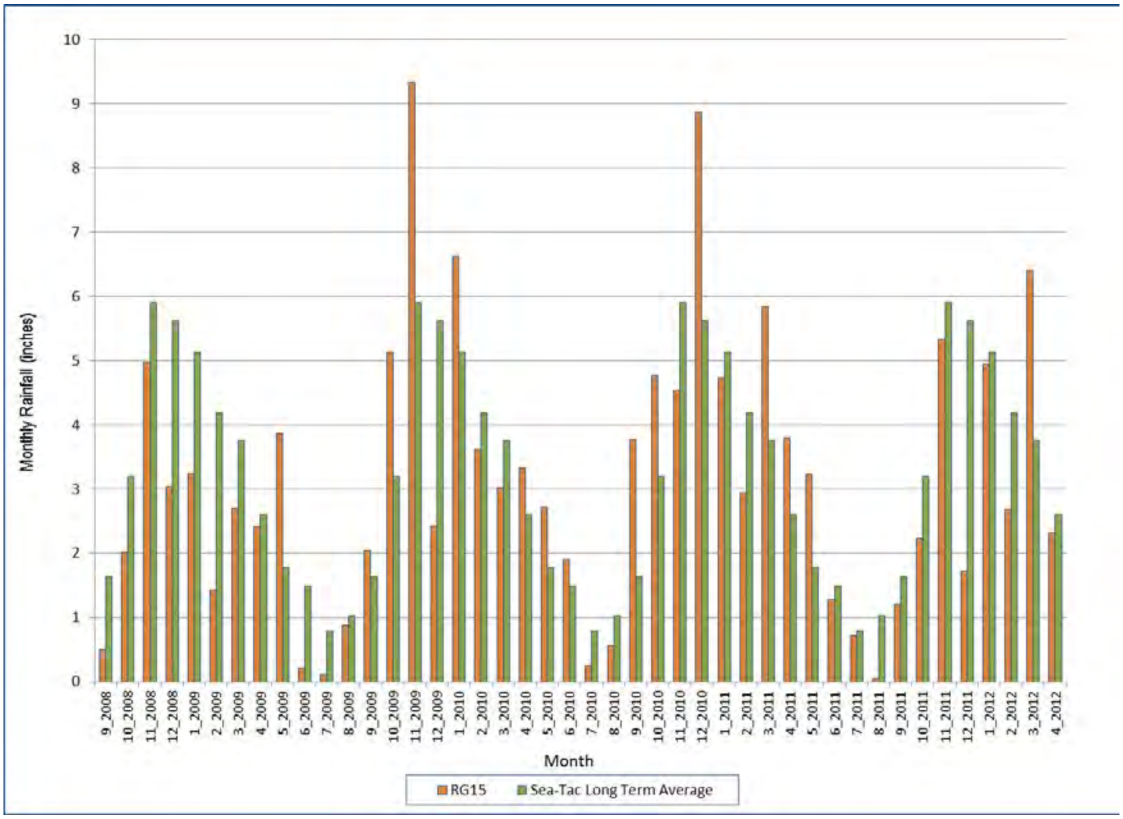

Figure 2-3. Monthly rainfall during the model calibration and verification period

2.3 Land Use

Land use in the East Waterway CSO Area is predominantly industrial. The land use in the East Waterway CSO Area is shown in Figure 2-4.

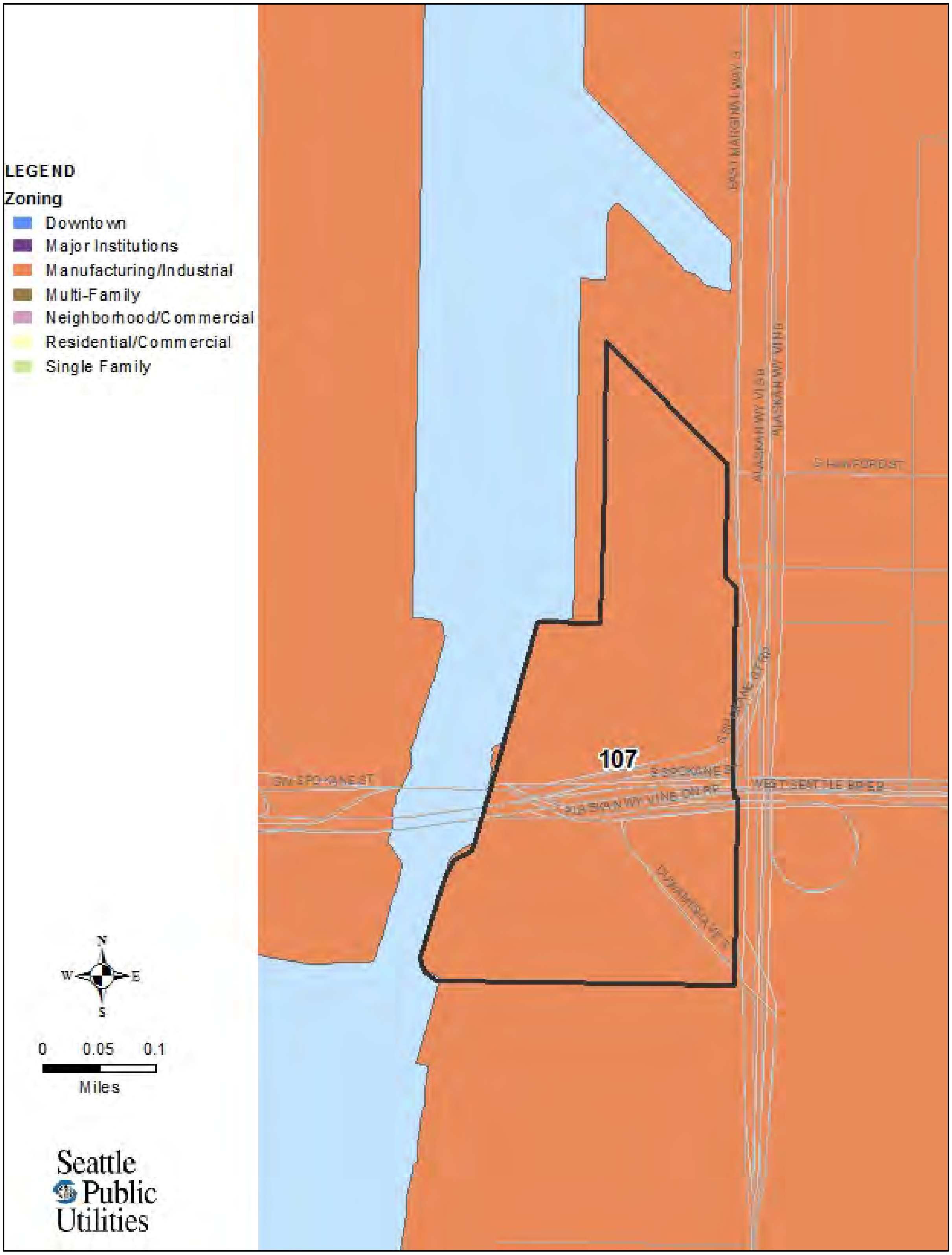

Figure 2-4. East Waterway CSO Area land use

2.4 Soils

Soils in the NPDES107 Basin are classified as “modified,” which indicates artificial filled or modified land containing silt, sand, debris, and slag according to the U.S. Geological Survey. The locations of the different soil types are shown in Figure 2-5.

Soil and aquifer parameters were developed using guidance provided by SPU, based on the principal soil types in each basin.

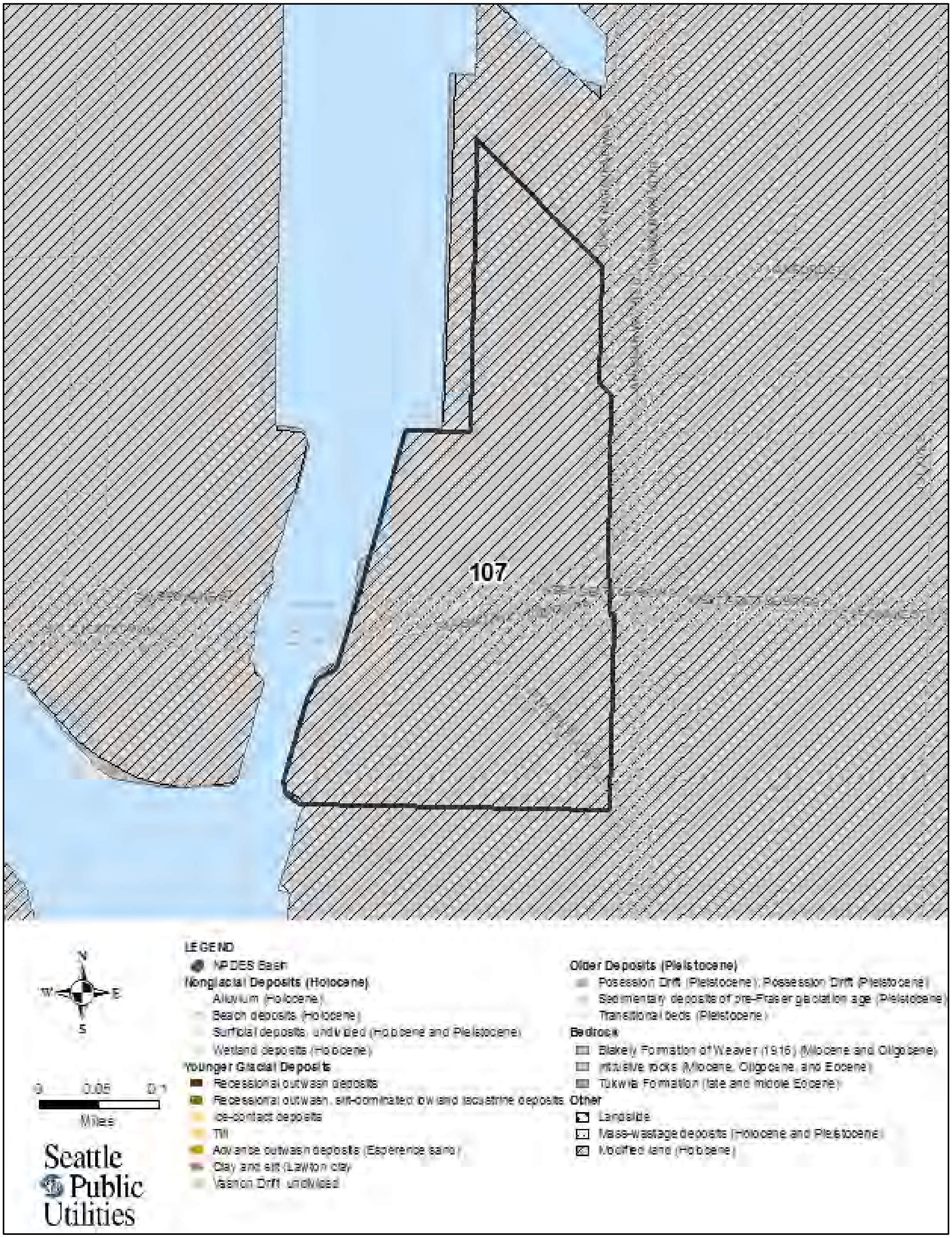

Figure 2-5. East Waterway CSO Area soil types

2.5 NPDES107 Basin

This section provides a description of the NPDES107 Basin including the control structures and overflow history.

The NPDES107 Basin is approximately 58.7 acres in area. The basin is partially separated. The NPDES107 overflow structure is located in MH 056-097. The overflow structure consists of an elevated outfall pipe that connects to the storm drainage system in East Marginal Way S. Overflows occur when the water level in the overflow structure rises above the elevation of the overflow pipe. The resulting overflows discharge to the East Waterway via the tidally influenced storm drainage system. A flap gate is installed on the overflow pipe between MH 056-097 and the storm sewer at MH D056-076.

Monitoring data collected at this location indicated that 34 overflows were recorded from July 2007 through June 2013. Overflows in the Duwamish NPDES107 Basin from July 2007 through June 2013 are summarized in Table 2-3.

Table 2-3. Reported Combined Sewer Overflows in the NPDES107 Basin
July 2007 through June 2013

End date of overflow	Duration (hrs:min)	Volume (gal)
12/3/2007	28:45	2,008,192
3/23/2008	0:05	1,820
11/7/2008	11:35	625,537
1/8/2009	5:25	165,998
4/2/2009	1:35	244,327
5/5/2009	2:15	402,134
10/14/2009	0:44	12,772
10/17/2009	15:54	239,803
10/26/2009	4:50	486,610
11/7/2009	12:36	146,038
11/17/2009	13:03	418,365
11/19/2009	2:06	183,001
11/22/2009	3:02	785,230
11/26/2009	3:50	295,660
1/4/2010	1:20	79,758
1/8/2010	1:44	49,692
1/11/2010	6:08	868,057
1/13/2010	1:04	28,842
1/15/2010	1:54	20,952
4/21/2010	1:12	20,883
9/19/2010	28:46	569,936
10/10/2010	3:04	166,775
11/1/2010	7:56	997,810
12/8/2010	1:20	29,478
12/12/2010	16:50	1,317,790
12/13/2010	0:58	17,761

Table 2-3. Reported Combined Sewer Overflows in the NPDES107 Basin July 2007 through June 2013		
End date of overflow	**Duration (hrs:min)**	**Volume (gal)**
1/13/2011	24:12	193,122
3/10/2011	13:56	244,984
5/15/2011	1:58	15,175
11/23/2011	24:42	311,631
12/28/2011	0:34	2,587
3/15/2012	1:48	84,733
3/29/2012	2:08	12,294
5/3/2012	0:50	12,428
11/19/2012	11:02	242,586
1/9/2013	1:04	638

A summary of the CSO control facility in the NPDES107 CSO Area basin is presented in Table 2-4. More details of the structure are included in Section 4.

Table 2-4. NPDES107 Basin Characteristics						
Basin	**Control facility ID**	**Overflow receiving water**	**Storage volume (gallons)**	**Type of storage**	**Hydraulic control**	**Other special structures**
NPDES107	None	Duwamish River East Waterway	None	None	Elevated overflow pipe	None

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SECTION 3

Data Sources

This section describes the sources of data used to construct the model, the methods used to verify the data, and the procedures followed to address missing or conflicting data.

3.1 Data and Documentation

The East Waterway CSO model was developed using information from several sources. To promote consistency among the different CSO basin models and to support ongoing management of these models by SPU staff, SPU and the project team worked together to identify appropriate data sources (e.g., data types, government agencies) for gathering data and identified a prioritization scheme when multiple data sources are available (e.g., survey elevations prioritized over GIS elevations). The following sections describe in detail the data sources and data hierarchy used to develop the East Waterway CSO model.

3.1.1 Data Sources

Construction of the East Waterway CSO model required compiling data from multiple agencies. In general, SPU's GIS data, record drawings, and recent field surveys were used to develop the system information in the SWMM5 hydraulic model. SCADA data supplied by King County were used for flow inputs and boundary condition development. Elliott Bay water level information from the National Oceanic and Atmospheric Administration (NOAA) and SPU was used as a boundary condition. Precipitation data were obtained from the network of rain gauges maintained by SPU. Table 3-1 lists the types of data used for the East Waterway model and the sources of the data.

Table 3-1. East Waterway Model Development Data Sources

Data description and purpose	Data source and date	File name(s)
Pipes and maintenance holes		
Configuration and specifications (for hydraulic analysis): invert elevations, ground elevations, size, length and connectivity, sewer type	SPU system-wide model (2013)	G6-WPTP_full_draft_QC3_storm6.inp
	SPU GIS files (August 2013)	npdes107.gdb Maintenance holes = DWW_mainline_connect_pt_pv Pipes = DWW_mainline_ln_pv

Table 3-1. East Waterway Model Development Data Sources		
Data description and purpose	**Data source and date**	**File name(s)**
Overflow structure		
Configuration and specifications (for hydraulic analysis): weir heights/ elevations	SPU Survey	See Appendix B
	ADS Environmental Services Site Report (2011) and Detailed Drawing (2011)	ADS Site Report for MH 056-097 dated 2/1/2011 ADS Detailed Drawing for MH 056-097 dated 2/1/2011
Puget Sound water surface elevation (for boundary conditions)	NOAA data download (data from station 9447130)	http://tidesandcurrents.noaa.gov/waterlevels.html?id=9447130
Surface (for hydrologic analysis)		
Infrastructure	SPU GIS files (August 2013)	npdes107.gdb Catch basins = DWW_catch_basin_pt_pv Maintenance holes = DWW_mainline_connect_pt_pv Pipes = DWW_mainline_ln_pv Laterals = DWW_non_mainline_ln_pv
Parcel	SPU GIS files (September 2011)	Parcels = parcel.shp
Roof outline	SPU GIS files (August 2013)	npdes107.gdb Buildings outline = CGDB_BLD2009_PLGN
Road and street	SPU GIS files (September 2011)	Street network/segments = snd.shp Street center line = roads_cl.shp
Topographic	SPU GIS files, 2-foot contours (1999)	2-foot contours = contour.shp
Precipitation and evaporation (for hydrologic analysis)		
Precipitation	City of Seattle rain gauge network, as modified and compiled by MGS Environmental Consultants, Inc. (1976–2012).	RG15_1976-2012.dat
Evaporation	Evapotranspiration based ETo (grass) from Washington State University Puyallup Station (1977–2013)	ETo_02.24.2013.dat
Flow and depth meter		
Field measurements (for calibration)	ADS permanent meter data, FlowWorks (2007–13)	http://www.flowworks.com/index.php
	King County flow and level data from SCADA	DuwPSdischarge.dat WseaPSflow.dat HanfLvl.dat

3.1.2 Data Hierarchy and Documentation

The data used to develop the hydraulic characteristics of the East Waterway hydraulic model were obtained from a variety of sources, including the SPU system-wide model, SPU GIS data, record drawings, and recent field surveys. Once all the data were compiled and brought into SWMM5, initial reviews of the system were completed to identify missing data. In most instances, interpolation was used to fill missing elevation data. Interpolated data were estimated from nearby known data points; for example, unknown maintenance hole invert elevations were computed using elevations and slopes of the pipes upstream and downstream of the missing data. SPU conducted field surveys at the overflow structure to obtain data with greater accuracy, filling all critical data gaps. Field survey data are provided in Appendix B.

Data sources had varying degrees of accuracy. When multiple sources of similar information were in conflict, data were used given the following assumed confidence hierarchy, with 1 being the highest level of confidence:

1. Survey data
2. As-built record drawings
3. Side-sewer cards
4. GIS
5. Interpolated between known points
6. Inferred/assumed based on best available knowledge

Data values for the majority of model nodes (maintenance holes) and conduits (pipes) were derived from SPU's GIS data. Whenever other data sources were used instead, the model's description field was edited to describe the data source, how the value was modified, when the modification occurred, and who performed the modification.

3.2 Horizontal and Vertical Datum

The horizontal and vertical data of the hydraulic model are consistent with SPU's GIS datums as follows:

- horizontal: North American Datum (NAD) of 1983 HARN State Plane Washington North FIPS 4601 feet
- vertical: North American Vertical Datum of 1988 (NAVD88)

Many of the record drawings used in the model development are based on the older City of Seattle Vertical Datum. To convert to NAVD88 used in the model, 9.7 feet were added to each elevation referenced in the drawings, unless otherwise specified on the drawings. The conversion value of 9.7 was provided by SPU.

SCADA data of water surface elevation at the King County Duwamish PS and Hanford RS, and water surface elevation from the King County's model simulation, were converted to NAVD88. The King County datum is mean sea level (NGVD [MSL] 1947) plus 100 feet; 96.4 feet were subtracted from King County data to convert them to NAVD88. Elevation and datum conversions are described in the City of Seattle Standard Plans for Municipal Construction, Standard Plans 001 and 001a.

3.3 Flow Monitoring Data

Flow monitoring data were collected from one permanent station operated by ADS. This information was used to calibrate and validate wet weather response. The East Waterway flow monitoring site, type and purpose of the site, and installation dates are provided in Table 3-2.

Table 3-2. NPDES107 Flow Monitoring Site

Basin	Site ID	Type	Purpose of monitoring this location	Data usage in model	Installation date	Removal date
NPDES107	NPDES107_056-097[a]	Level and velocity	Permanent meter to monitor CSO events	Used for hydrologic calibration and validation	7/26/2007	NA

a. *Velocity sensor installed in overflow pipe, February 2011. Earlier measurements relied on only a depth sensor in the overflow structure.*

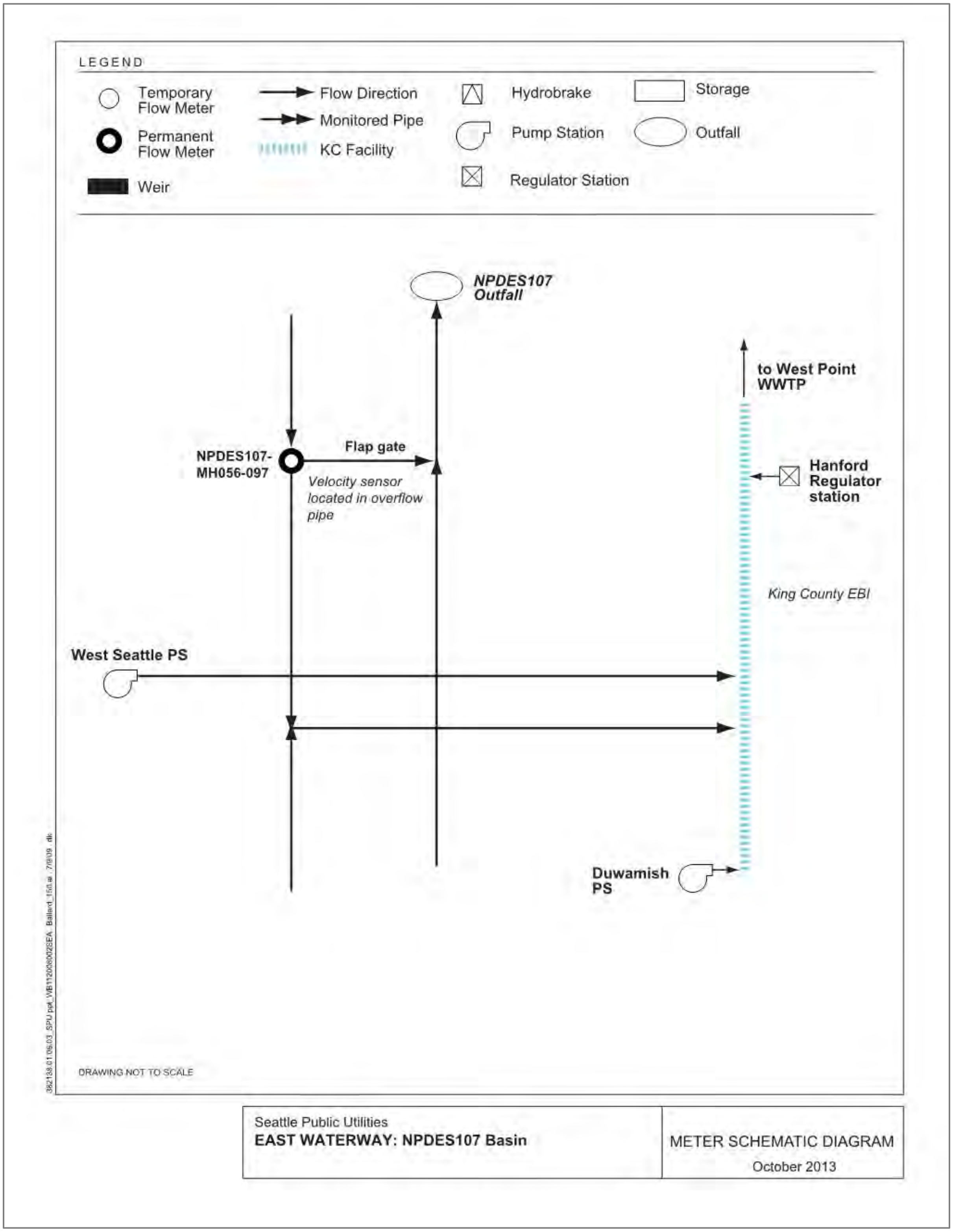

Figure 3-1. East Waterway Basin meter schematic

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SECTION 4

Model Development

This section describes the development of the East Waterway CSO Area model. It covers the following stages of model development:

1. Define the model extent
2. Set model boundary conditions
3. Develop average DWFs and diurnal flow hydrographs
4. Delineate building, parcel, and right-of-way (ROW) subcatchments
5. Assign hydrologic model parameters
6. Review the system hydraulics and assign flow and hydraulic parameters for special structures

4.1 Model Extent

The East Waterway CSO Area model was set up to meet the project goal and objectives stated in Section 1.2. The East Waterway CSO Area model covers the entire NPDES107 Basin, which is a terminal basin without any upstream flows. The CSS for the East Waterway CSO Area discharges to the King County EBI near the intersection of Colorado Avenue S and 1st Avenue S (MH 056-109). This location is downstream of the KC Duwamish PS and upstream of the Hanford RS. The KC West Seattle PS also discharges to the EBI downstream of the inflow from the NPDES107 CSO Area. These KC facilities were included in the model. In addition, an SPU pipe drains an industrial area of approximately 20 acres to the EBI at MH 056-368, which is immediately upstream of the inflow from the NPDES107 CSO Area.

The CSS overflows to the storm drainage line in East Marginal Way S, which ultimately discharges to the East Waterway at MH D056-068, north of the West Seattle Bridge. The storm line drains an area of approximately 44 acres.

The East Waterway CSO Area model includes all SPU-owned sanitary and combined sewer pipes 8 inches in diameter and larger, associated maintenance holes, and special flow control structures such as CSO diversion structures and outfalls in the East Waterway CSO Area. The storm drainage system downstream of the CSO structure is also included in the model to better reflect the boundary condition and impacts from the storm system on the CSO control structure. The physical system represented in the model is based primarily on GIS information. GIS pipe data attributes were used to assist in the model extent delineation—in particular, the pipe connectivity (from/to nodes), “owner,” “probable flow,” "permitted flow," and "system type" fields. Additional information, such as general NPDES basin delineation information and record drawings, were referenced; however, primary emphasis was placed on the connectivity information contained within the GIS.

4.2 Boundary Conditions

The East Waterway CSO Area model contains downstream boundary conditions at the transition to the King County system and the CSO outfall and overflow structures. It also includes external inflows to represent the pumped inflows from the KC West Seattle PS and KC Duwamish PS. Table 4-1 lists the downstream boundary conditions and the external inflows.

One overflow structure is located in the East Waterway CSO Area, identified as NPDES107. Overflow from the structure discharges into a 42-inch-diameter storm line in East Marginal Way S that discharges flow into the East Waterway. During high tides, water enters the storm line. High tide elevations frequently exceed the elevation of the NPDES107 overflow pipe. To simulate any potential effect of the tide and to convey the CSOs to the outfall, the East Marginal Way S storm line is included in the basin model. A tide elevation time series from NOAA station 9447130 is used as the boundary condition of the NPDES107 outfall. The boundary condition at the CSO outfall is treated as time-varying water surface elevation, using the publicly available tide data published by NOAA for station 9447130. The water level data are available from the following Web site: http://tidesandcurrents.noaa.gov/waterlevels.html?id=9447130.

The East Waterway model exit is at MH 050-096, which is the junction of the EBI and inflow from the Hanford RS. The water level at this location is a key component affecting the hydraulic response in the NPDES107 Basin. King County operates the regulator station to maximize flows to the West Point WWTP by regulating flow using automated gates. During periods of heavy rain, King County closes the regulator gate at the Hanford RS, reducing or preventing flow into the EBI when the level in the EBI exceeds a specified set point. For the calibration period, the downstream boundary condition was simulated using a time series of elevation in the EBI at the Hanford RS, developed from King County SCADA data.

The pumped inflows from both the KC West Seattle PS and the Duwamish PS also influence the water level in the EBI. Time series of inflows from both pump stations were developed from King County SCADA data.

Table 4-1. Downstream Boundary Conditions and External Inflows			
No.	Name	Location	Description
1	NPDES107 outfall	East Waterway	Time varying (use NOAA[a] data)[b]
2	King County EBI level at Hanford Regulator	050-096	Time varying
3	King County West Seattle PS flow	056-370	Time varying
4	King County Duwamish PS flow	056-203	Time varying

a. *KC = King County; NOAA = National Oceanic and Atmospheric Administration.*

b. *NOAA tide data is measured at Washington State Ferry Terminal in Seattle. The data are available via the NOAA Web site, http://tidesandcurrents.noaa.gov/waterlevels.html?id=9447130*

4.3 Dry Weather Flows

Dry weather flows were developed using land use type, parcel areas, and industry standard flow rates based on land use categories. The East Waterway CSO Area is entirely industrial and typically consists of warehouse-type developments (i.e., low water usage). A large portion of the basin is occupied by parking lots and other transportation-related activities and is therefore not expected to contribute dry weather loadings to the CSS.

In order to develop dry weather flows, the aerial photo and land use type were reviewed to determine whether the parcel would contribute dry weather flows to the CSS. Parcels with land use types such as warehouse and general-purpose industrial were assumed to contribute DWF loadings to the CSS. It was assumed that parcels with land use types such as vacant and ROW/utility would not contribute DWF loadings to the CSS. Parcels with DWF loadings were assigned a DWF of 1,000 gallons per acre per day. This flow rate is for Non Wet-Process-Type industry from Metcalf & Eddy, Inc. “Wastewater Engineering, Treatment and Reuse.”

The weekday and weekend diurnal patterns developed for the Duwamish NPDES111(B) Basin were applied in the East Waterway model. NPDES111(B) is a nearby basin with similar industrial land use. The weekly flow pattern is shown in Figure 4-1.

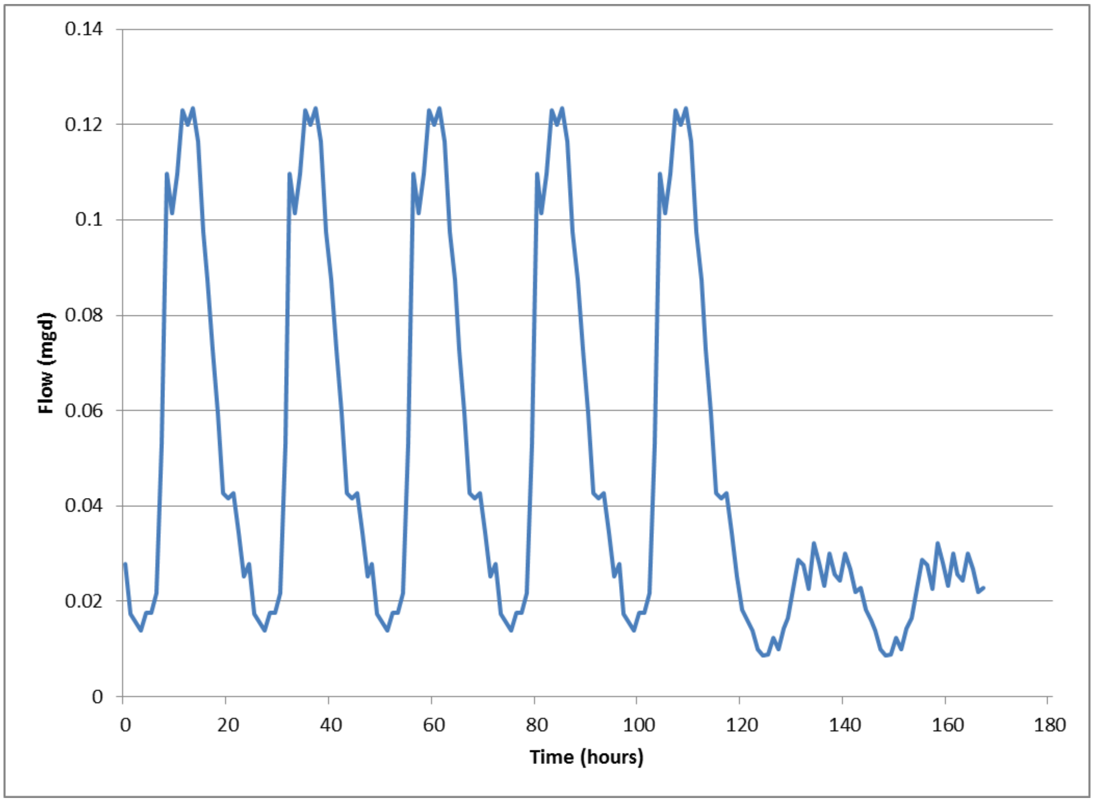

Figure 4-1. Weekday diurnal pattern in NPDES107

Figure 4-2 is a modified version of the flow monitoring schematic shown in Section 3. The figure has been updated to show the values for DWF used in the model.

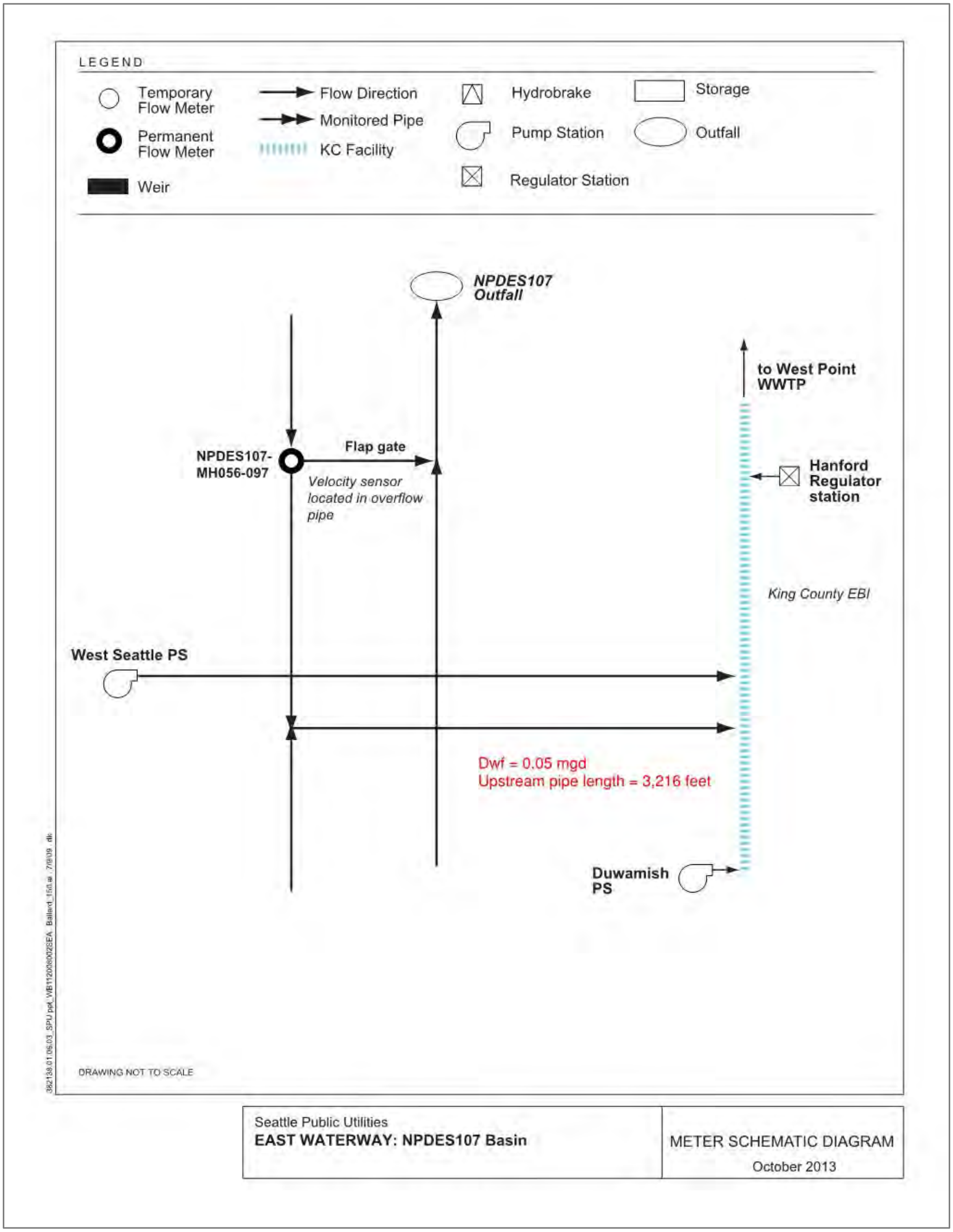

Figure 4-2. Schematic dry weather flow summary for the East Waterway CSO Area

4.4 Subcatchment Delineation

A modified version of the subcatchment delineation method used for the SPU LTCP basins was used to delineate the subcatchments in the East Waterway model. The majority of the model area, including the ROW, drains to the separate storm drainage system. The storm drainage catchments were delineated using GIS information including drainage mainlines, drainage laterals, catch basins, parcel and ROW boundaries, and aerial photos.

The subcatchments draining to the combined system were also developed from a review of the GIS data listed above in addition to sewer mainlines, sewer laterals, and building footprints. Buildings that did not have a drainage lateral were assumed to drain to the combined system. Isolated parcels areas with no storm drainage infrastructure, or with catch basins that were connected to the combined system were also assigned to the combined system.

Complete documentation of subcatchment delineation is provided in Appendix C.

4.5 Model Hydrology

Each of the subcatchments was assigned initial hydrologic parameters, based on impervious surface area, soil conditions, and other characteristics that affect runoff. Table 4-2 lists the key parameter types, data sources, and values used to characterize the East Waterway CSO Area subcatchments. Section 5 describes how some of these parameters were calibrated to match flow monitoring data. The soils discussion in Section 2.4 describes how the groundwater- and infiltration-related parameters values were determined, using guidance provided by SPU.

The SWMM5 model used the Green-Ampt method to compute the fraction of precipitation that infiltrates into the soil layer. The routing of infiltrated water (e.g., infiltration to sewers, deep percolation, and evapotranspiration) was computed using SWMM5's groundwater module. The NPDES107 CSO Area model was set up with one groundwater aquifer for the catchments connected to the storm drainage system and one aquifer for the catchments connected to the CSS. Table 4-3 below describes the groundwater parameters used to characterize hydraulic behavior in the local soils.

Table 4-2. Model Subcatchment Data Fields, Sources, and Values

Data field	Description
Name	Name of subcatchment. Format combines type (BLD, SD, C) and outlet maintenance hole (ex. BLD_056-103).
X-coordinate, Y-coordinate	Location of subcatchment centroid.
Description	Field is used to describe the type of subcatchment (ex. building connected to CSS).
Tag	Field is used to specify whether the subcatchment is connected to the combined (C) or drainage (D) system.
Outlet node	Names of outlet maintenance holes (IMS_ID attribute from GIS).

Table 4-2. Model Subcatchment Data Fields, Sources, and Values	
Data field	**Description**
Area (ac)	Area calculated from GIS.
Width (ft)	Width calculated as square root of catchment area.
Slope (%)	Slope of subcatchment calculated from basin topography using GIS. For building, a slope of 5% was used.
Imperv (%)	Impervious percentage.
N imperv	Manning's n for overland flow over the impervious portion of the subcatchment. Typical value used from PCSWMM manual (0.012).
N perv	Manning's n for overland flow over the pervious portion of the subcatchment. Typical value used from PCSWMM manual (0.24).
Dstore imperv (in.)	Depth of depression storage on the impervious portion of the subcatchment. Typical value used from PCSWMM manual (0.07).
Dstore perv (in.)	Depth of depression storage on the pervious portion of the subcatchment. Typical value used from PCSWMM manual (0.15).
Zero imperv (%)	Percent of the impervious area with no depression storage. Value of 5% used for all subcatchments.
Subarea routing	Choice of internal routing of runoff between pervious and impervious areas, selected OUTLET for all subcatchments to indicate runoff from both areas flows directly to outlet (a maintenance hole in the CSS).
Percent routed (%)	All runoff is routed (100%).
Curb length	Not used.
Snow pack	Not used.
Groundwater	Indicates if the subcatchment has a groundwater component. Subcatchments necessary to replicate groundwater response seen in meter data include groundwater.
Aquifer name	Name of aquifer that supplies groundwater (1 aquifer per calibration basin).
Receiving node	Name of node that receives groundwater from the aquifer.
Surface elevation (ft)	Set equal to the rim elevation of the receiving MH.
Groundwater flow coeff.	Value of A1 in the groundwater flow formula. Set to 0 for building and ROW subcatchments. Values for parcel subcatchments determined through calibration (see Section 5).
Groundwater flow expon.	Value of B1 in the groundwater flow formula. Set to 0 for building and ROW subcatchments. Values for parcel subcatchments determined through calibration (see Section 5).
Surface water flow coeff., Surface water flow expon., Surface-GW interaction coeff.	Not used.
Fixed surface water depth (ft)	Set to zero to use the computed depth in the node.
Threshold groundwater elev. (ft)	Aquifer water table elevation, which must be reached before any groundwater flow occurs. Value set to elevation of node where aquifer was placed.
Suction head (in.)	Average value of soil capillary suction along the wetting front. Typical value used from soil characteristic table provided by SPU.

Table 4-2. Model Subcatchment Data Fields, Sources, and Values	
Data field	**Description**
Conductivity (in./hr)	Soil saturated hydraulic conductivity. Typical value used from soil characteristic table provided by SPU.
Initial deficit (fraction)	Difference between soil porosity and initial moisture content. The initial deficit for a completely drained soil is the difference between the soil's porosity and its field capacity. Typical value used from soil characteristic table provided by SPU.

Table 4-3. Model Groundwater Aquifer Data Fields, Sources, and Values	
Data field	**Description**
Name	User-defined name of aquifer, incorporates calibration meter name and soil type
Porosity (fraction)	Porosity based on soil type, based on soil characteristics table provided by SPU
Wilting point (fraction)	Wilting point based on soil type, based on soil characteristics table provided by SPU
Field capacity (fraction)	Field capacity based on soil type, based on soil characteristics table provided by SPU
Conductivity slope (unitless)	Set to 0
Tension slope (in.)	Set to 150
Upper evaporation fraction (fraction)	Set to 0.1
Lower evaporation depth (ft)	Set to 0
Lower GW loss rate (in./hr)	Values determined through calibration (see Section 5)
Bottom elevation (ft)	Set to 4.69 ft
Water table elevation (ft)	Values determined through calibration (see Section 5)
Unsaturated zone moisture (fraction)	Set equal to Field Capacity

4.6 Model Hydraulics

This section describes the East Waterway CSO Area model hydraulics, including the parameters used to represent pipes, nodes, and special structures. An overview of the SWMM5 model is shown in Figure 4-3.

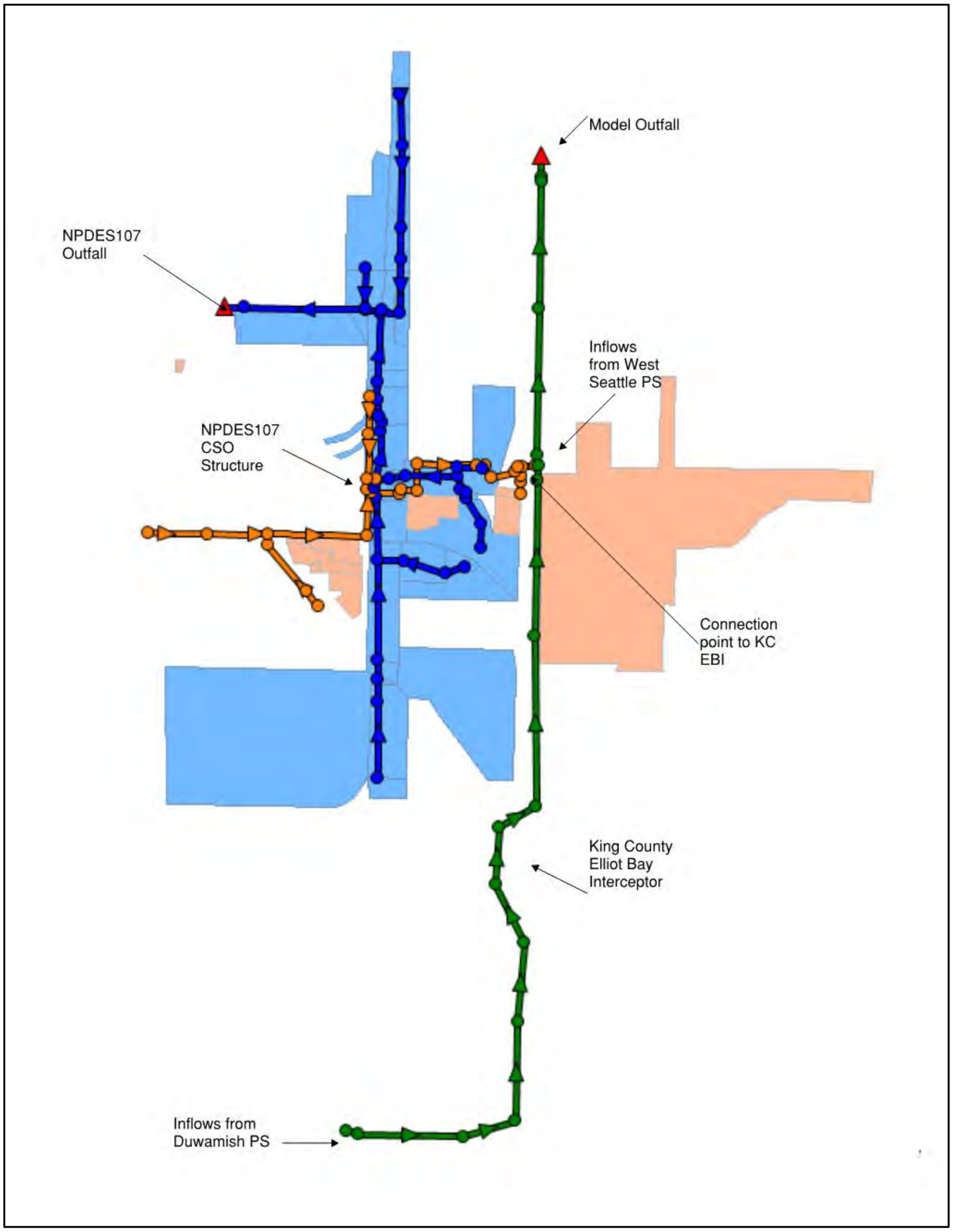

Figure 4-3. Overview of East Waterway SWMM5 model

(blue = storm; orange = combined; green = KC EBI)

4.6.1 Pipes and Nodes

A description of the pipes and nodes in the East Waterway model was provided in Section 2.1. Table 4-4 lists the data fields and sources used in the SWMM5 model to characterize the pipes (referred to as Conduits in SWMM5). Table 4-5 lists the same information for the maintenance holes in the SWMM5 model (referred to as Junctions in SWMM5). Where constant values were applied to all pipes and nodes, these values are listed in Table 4-4 and Table 4-5.

Table 4-4. Model Pipe Data Fields, Sources, and Values

Data field	Description
Name	Pipe ID; matches SPU GIS ID. Format = upstreamID_downstreamID (e.g. 031-026_031-027).
Inlet, outlet	Names of inlet and outlet maintenance holes (e.g., 034-021).
Description	Field is used to list data source when a source other than GIS was used.
Tag	Used to specify whether flow type is combined (C), separated (S), or drainage (D).
Length (ft)	Pipe length.
Roughness	Manning's roughness coefficient. Set equal to 0.013 for all pipes.
Inlet offset (ft)	Elevation of upstream end of pipe. Set to equal upstream maintenance hole node elevation unless data suggested otherwise.
Outlet offset (ft)	Elevation of downstream end of pipe. Set to equal downstream maintenance hole node elevation, unless a drop was noted.
Cross-section	Shape of pipe conduit. All pipes in model are circular.
Geometry (ft)	Diameter of pipe.

Table 4-5. Model Maintenance Hole Data Fields, Sources, and Values

Data field	Description
Name	Maintenance hole ID; matches SPU GIS ID; e.g., 034-021.
X-coordinate, Y-coordinate	Location of maintenance hole.
Description	Field is used to list data source when a source other than GIS was used.
Tag	Used to specify whether flow type is combined (C), separated (S), or drainage (D).
Inflows	Specifies whether DWF is assigned to the maintenance hole.
Invert elevation (ft)	Invert elevation of structure.
Depth (ft)	Depth from rim to invert.
Initial depth (ft)	Not used.
Surcharge depth (ft)	Not used.
Ponded area (sf)	Used to keep MH overflow volume within the model. Value was carried set to 5,000 square feet.
Baseline (mgd)	Not used.
Time series	Used only when external flows are assigned to a maintenance hole. Occurs twice in the East Waterway model for upstream boundary condition (flows from the West Seattle PS and flow from the Duwamish PS).
Average flow (mgd)	Average flow rate for dry weather flow.
Time pattern 1	Weekday diurnal flow pattern used to distribute "average" flow to each hour of the weekdays.
Time pattern 2	Weekend diurnal flow pattern used to distribute "average" flow to each hour of weekend days. The weekend pattern multiplies the weekday pattern.

4.6.2 Special Structures

The East Waterway CSO Area model contains two special CSO hydraulic structures. These structures required special configuration in the SWMM5 model. This section describes these structures and their setup in the SWMM5 model.

Table 4-6. NPDES107 CSO Area Model Special Structures

Structure	Location	Notes
NPDES107 CSO structure	056-097	Modeled as pipe with elevated inlet elevation (10.66 feet) with flap gate
Hanford low head structure	EBI MHs 056-116 to 056-217	Modeled as a 12.5 foot wide by 2.9 feet high closed rectangular section

4.6.2.1 NPDES107 Overflow Structure

The overflow structure in the NPDES0107 Basin is located near the intersection of East Marginal Way S and S Spokane Street (under the West Seattle Bridge).

The overflow structure consists of an elevated overflow pipe at MH 056-097. When the water level reaches the elevation of the overflow pipe, flow spills into the East Waterway via a 42-inch-diameter storm drain. A flap gate is installed on the overflow line between MH 056-097 and MH 056-359. Based on recent flow monitoring data, the flap gate is known to leak, allowing backflow into the combined sewer from the storm drain during high tides. SPU is scheduling a retrofit of this flap gate to prevent the backflow. The model therefore assumes that the flap gate does not allow backflow.

Figure 4-4 provides a schematic view of the overflow structure. Survey data of the structure is provided in Appendix A.

4.6.2.2 Hanford Low Head Structure

The EBI crosses under the KC Hanford trunk line between SPU MH 056-116 and MH 056-217. The EBI section beneath the Hanford trunk is a rectangular box 12.5 feet wide by 2.9 feet high. Smooth transitions are included from the 84-inch-diameter upstream sewer into the rectangular section and from the rectangular section to the 96-inch-diameter downstream sewer. This section was modeled by changing the circular section originally included between these MHs to a closed rectangular section with the appropriate dimensions. The as-built drawings of the structure are included in Appendix A.

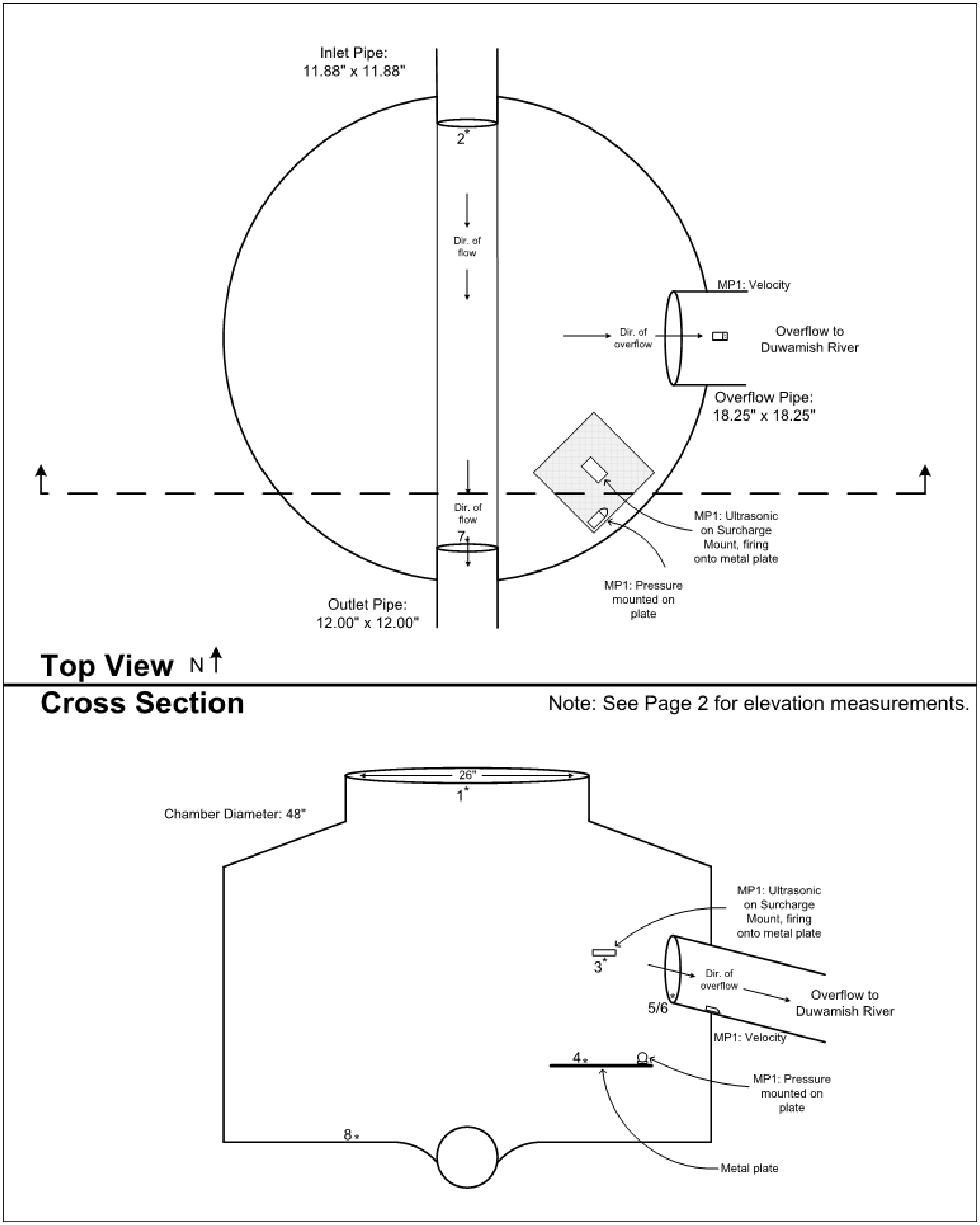

Figure 4-4. Schematic of overflow structure at MH 056-097

SECTION 5

Model Calibration

The model was calibrated to five storm events at two locations, using manual calibration routines and rainfall and depth data collected during the calibration period (January 2010). Rainfall and depth data collected from February 2010 through April 2012 were used for model verification.

5.1 Calibration Process

Calibration is the process of adjusting modeling input parameters so that the model output matches as closely as possible the monitored conditions within the system. For the East Waterway CSO Area model, the following data sources were used for calibration:

- one permanent monitoring site at the CSO basin outfall owned by SPU and maintained by ADS
- SCADA records from the King County Duwamish PS
- precipitation data from RG 15

After model development was completed and the simulations ran successfully without errors or significant warnings, the model was calibrated using manual calibration routines only. The automated calibration routine developed for the SPU LTCP basins (ACU-SWMM) was not used in the calibration process for the East Waterway model for the following reasons:

1. No hydrology data were available for use in model calibration. The only available data within the basin itself are the depth measurements from the permanent meter.
2. The area is almost entirely impervious and no groundwater response is shown in the permanent meter data, thus reducing the number of calibration parameters significantly.
3. The model was not found to be sensitive to flow generation parameters; the hydraulic response in the NPDES107 Basin is dependent on the HGL in the King County EBI.

5.2 Calibration Events

Precipitation data gathered at SPU's RG 15 from January 2010 to April 2012 were used to generate flow in the model. Large rainfall (storm) events that resulted in overflows in January 2010 were used for model calibration. Overflow events from February 2010 through April 2012 were used for model verification.

Table 5-1 lists significant storm events that were considered for the model calibration. Storm events that occurred outside the calibration period were used for model verification and are discussed in Section 6.

Table 5-1. Significant Storm Events for Calibration and Verification

Storm start date	Nominal storm duration (hrs)	RG15 precipitation (in.)	Return period[a]
1/4/2010	36	0.97	2 mo
1/8/2010	30	1.02	2 mo
1/11/2010	20	1.11	6 mo
1/13/2010	48	1.16	6 mo
1/15/2010	8	0.52	2 mo
4/21/2010	12	0.89	6 mo
9/17/2010	9	1.36	3 yr
10/9/2010	48	2.25	1 yr
11/1/2010	13	1.31	2 yr
12/8/2010	2	0.3	6 mo
12/11/2010	26	3.56	59 yr
12/13/2010	3	0.32	59 yr[b]
1/12/2011	44	1.76	6 mo
3/9/2011	26	1.74	2 yr
5/14/2011	20	1.47	9 mo
11/22/2011	62	3.3	3 yr
12/28/2011	30	1.16	2 mo
3/15/2012	48	1.66	1 yr
3/29/2012	18	1.16	6 mo

a. Maximum recurrence noted at any duration from 5 minutes to 72 hours.

b. Calculated return period includes the rainfall period on 12/11/2010.

5.3 Calibration Locations

Table 5-2 lists the calibration locations. The model was calibrated using a comparison of elevation, overflow volumes and durations at the NPDES107 overflow MH, and elevation measurements from King County SCADA at the Duwamish PS outlet. These locations are shown schematically in Section 3.3 and Section 4.6.

Table 5-2. Calibration Locations

Meter	Type of measurement	Comment
NPDES107_MH056-097	Elevation	Permanent meter at overflow structure
Duwamish PS outlet (MH 056-203)	Elevation	King County SCADA measurement

5.4 Calibration Results

Model calibration focused on adjustment of the downstream boundary condition data at the Hanford RS to match the model-predicted elevation at the Duwamish PS outlet to KC SCADA data, and a comparison of the elevation, overflow volumes, and overflow durations at the NPDES107 overflow structure. It was found that the overflow duration and volume at NPDES107 were not sensitive to changes in model input parameters and that the HGL, and thus overflows, in the NPDES107 CSO Area were driven by the water level in the EBI. A comparison between the model-computed level in the EBI at the inflow point from the East Waterway CSO Area (MH 056-109) and the measured level at the NPDES107 CSO structure is shown in Figure 5-1. The figure indicates that in January 2010 overflows occurred only at the NPDES107 CSO structure when the water level in the EBI is above the NPDES107 overflow elevation (i.e., 10.66 feet).

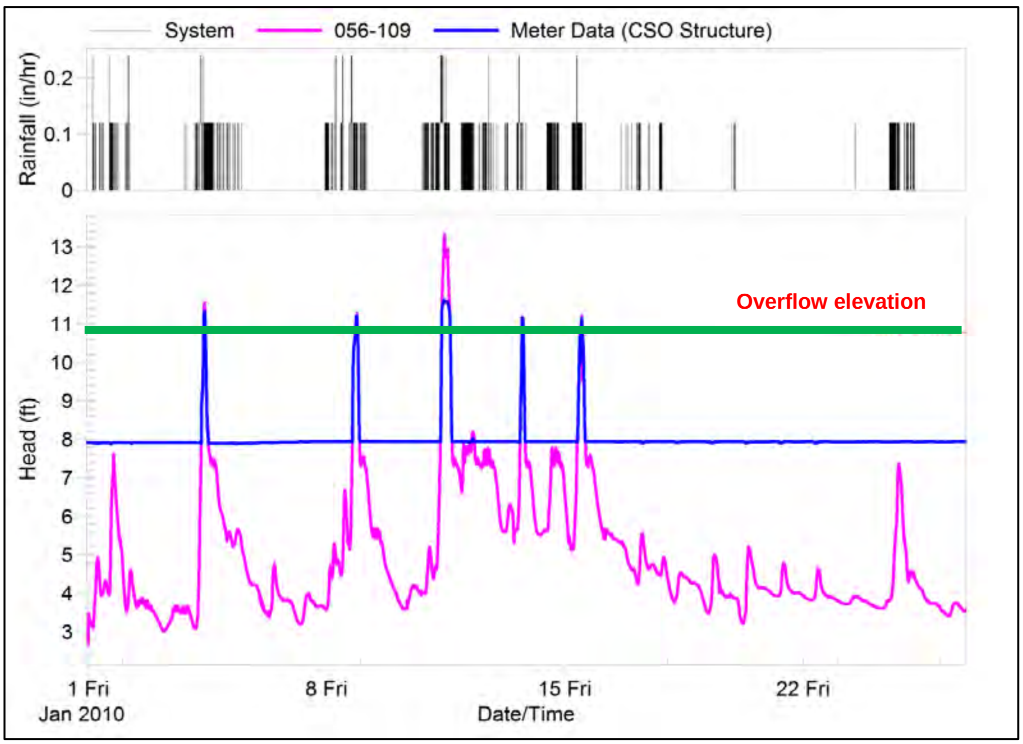

Figure 5-1. Comparison of measured elevation at NPDES107 CSO structure and EBI

(blue = NPDES107 meter data; pink = measured level in EBI; green = NPDES107 overflow elevation)

The manual calibration of basin hydrology focused on varying the impervious area of the subcatchments in the NPDES107 CSO Area. The results of the manual calibration for the January 15, 2010, storm event are shown in Figure 5-2 for the following three scenarios:

1. All catchments have 100 percent impervious area and therefore no groundwater is included in the model.
2. All catchment impervious areas reduced to 90 percent and groundwater is included in the model.
3. All catchments have 100 percent impervious area (i.e., no groundwater) and catchment areas were increased by 50 percent above the area measured in GIS.

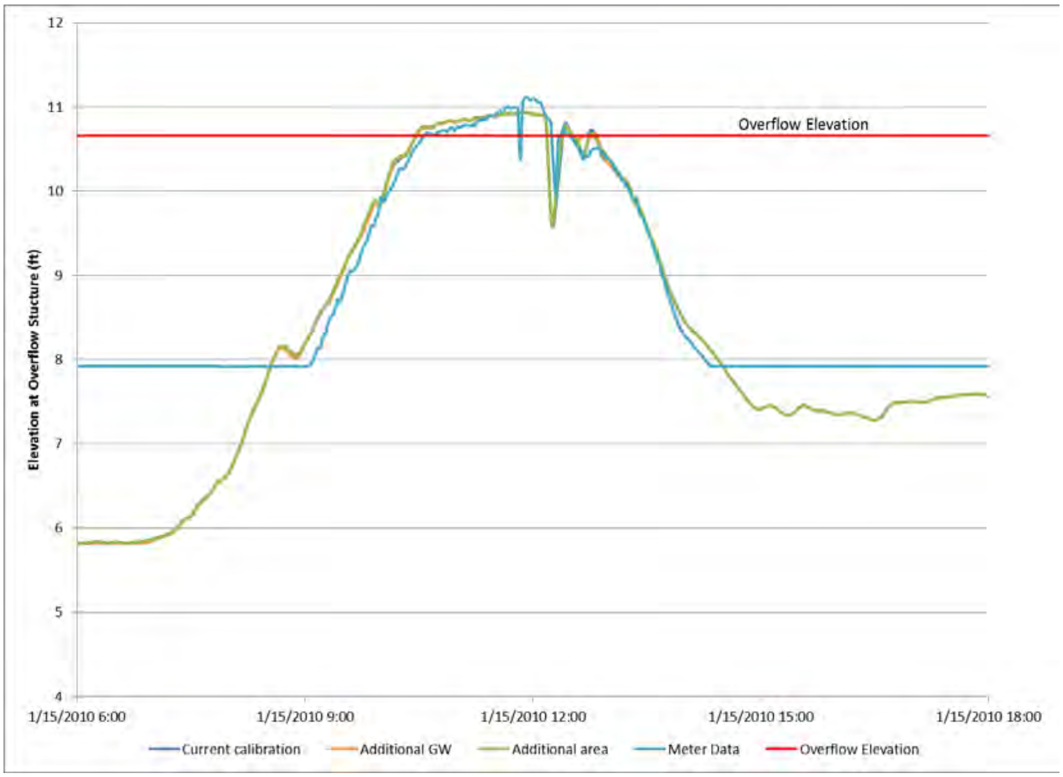

Figure 5-2. Manual calibration of hydrology at the NPDES107 CSO Structure (MH 056-097)

Based on the calibration results described above, it was decided to set the subcatchment impervious percentage to 100 percent, as this most accurately reflects the actual land use conditions in the NPDES107 CSO Area. The model therefore does not include any contributions from groundwater.

The findings described above indicated the need to develop an accurate simulation of the water level in the EBI in order to accurately estimate overflows at the NPDES107 CSO structure. Reliable SCADA data at the discharge of the King County Duwamish PS were available for comparison. Matching these data requires an accurate estimate of the corresponding water level at the Hanford RS boundary of the model.

Examination of the SCADA data for interceptor level at the Hanford RS and the downstream Lander RS and discussions with King County staff indicated that the level data from SCADA are incomplete during periods of high elevation. The Hanford RS interceptor level sensor "pegs out" at a reading of about 8 feet, reporting falsely until the level recedes below that value. At the Lander RS, the sensor does not record levels above about 10 feet of elevation. Using either of the SCADA data series as the downstream boundary condition resulted in the model reporting significant error in predicted versus reported peak elevation at the Duwamish PS discharge.

It was apparent that the missing data in the RS level time series would need to be filled in order to finalize the model. This was accomplished as follows:

- The SCADA data from the Lander RS was adjusted upward by the difference in elevation of the EBI at the Hanford and Lander RSs. This was done to take advantage of the fact that the Lander sensor "pegs out" at a higher elevation than the Hanford sensor.
- An algorithm was developed to fill in the missing portions of the adjusted Lander data by subtraction of 1.5 to 2.0 feet from the Duwamish PS discharge elevation, depending on the discharge rate.

The result of the extrapolation of missing data is shown in Figure 5-3.

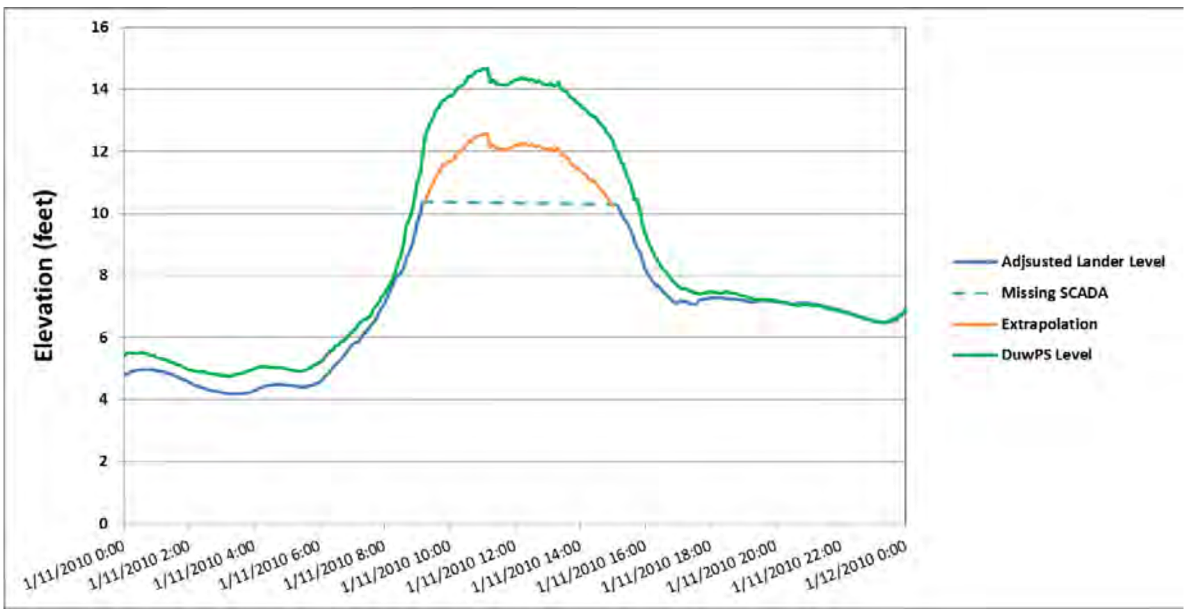

Figure 5-3. Extrapolation of missing downstream boundary data

A comparison was made between the measured and simulated elevation at the Duwamish PS outlet using the extrapolated data at the downstream boundary. There was excellent agreement between the measured and simulated elevations during the calibration period, as shown in Figure 5-4 and Table 5-3.

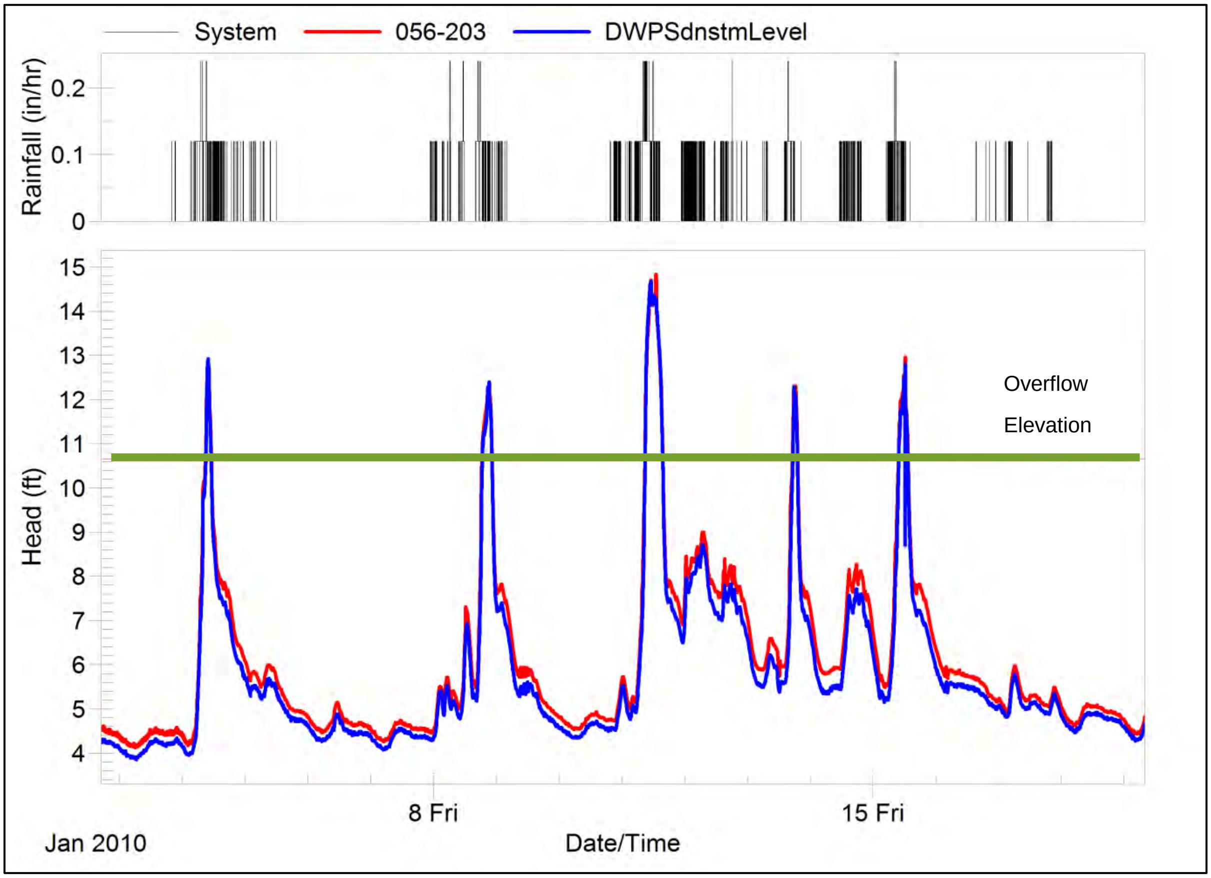

Figure 5-4. Duwamish PS outlet structure calibration results

(blue = meter data; red = model; green = overflow elevation)

Table 5-3. Comparison of Elevation at Duwamish PS Outlet (January 2010 Events)

Event date	Elevation (ft)		
	Meter	Model	Difference
1/4/2010	12.92	12.83	-0.7%
1/8/2010	12.40	12.33	-0.5%
1/11/2010	14.68	14.84	1.1%
1/13/2010	12.29	12.31	0.2%
1/15/2010	12.79	12.97	1.4%

A comparison of the elevation at the NPDES107 CSO structure for the five overflow events that occurred in January 2010 is shown in Figure 5-5. The model shows a good correlation between elevation at the overflow structure and the overflow duration. There are some larger differences between the reported and simulated overflow volumes. The ADS overflow calculation method prior to February 2011 used only depth in the overflow structure compared to the depth of the overflow pipe. The overflow rate was computed using a circular weir formula. This method did not account for the water surface elevation in the receiving storm sewer, possible head loss in the flap gate at the connection, and that the circular weir formula loses accuracy when depth exceeds the pipe center line. It is believed that this technique led to over-estimation of volumes, particularly in the large event on January 11, 2010.

A comparison of elevation, overflow volumes, and overflow durations is provided in Table 5-4 through Table 5-6. The model typically underestimates the water surface elevation and overestimates duration at the overflow structure. Possible reasons for these differences include head losses that occur in the flap gate on the overflow pipe and differences in the inlet elevation of the overflow pipe. There was some discrepancy between the value in GIS (11.14 feet), the value measured by ADS (10.78 feet), and the value from SPU survey (10.66 feet). The model uses the value of 10.66 feet from the SPU survey in accordance with the data hierarchy discussed in Section 3.1.2.

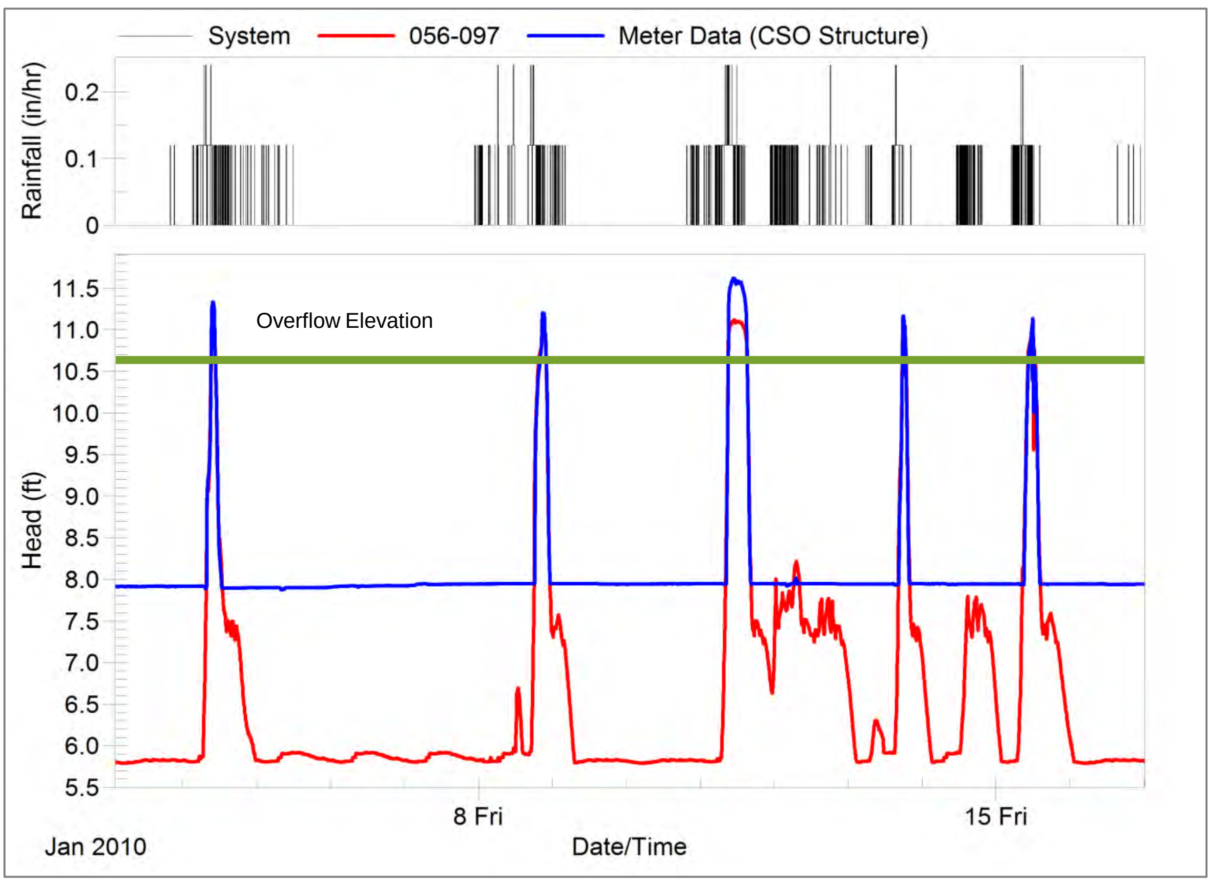

Figure 5-5. NPDES107 CSO structure calibration results

(blue = meter data; red = model; green = overflow elevation)

Table 5-4. Comparison of Elevation at Overflow Structure (January 2010 Events)			
Event date	Maximum elevation (ft)		
	Meter	Model	Difference
1/4/2010	11.31	10.99	-2.9%
1/8/2010	11.21	10.94	-2.4%
1/11/2010	11.60	11.12	-4.2%
1/13/2010	11.15	10.92	-2.1%
1/15/2010	11.12	10.94	-1.6%

Table 5-5. Comparison of Overflow Volumes (January 2010 Events)			
Event date	Overflow volume (MG)		
	Meter	Model	Difference
1/4/2010	0.080	0.060	-25.1%
1/8/2010	0.050	0.047	-5.7%
1/11/2010	0.868	0.554	-36.2%
1/13/2010	0.0029	0.035	19.8%
1/15/2010	0.021	0.044	108.5%

Table 5-6. Comparison of Overflow Durations (January 2010 Events)			
Event date	Overflow duration (hrs)		
	Meter	Model	Difference
1/4/2010	1.33	1.50	12.8%
1/8/2010	1.73	2.33	34.9%
1/11/2010	6.13	6.25	2.0%
1/13/2010	1.07	1.25	16.8%
1/15/2010	1.90	1.07	8.9%

5.5 Model Parameters

Table 5-7 provides a summary table of the parameters in the model.

Table 5-7. Model Parameter Values	
Parameter	Value
Subcatchment impervious (%)	100
N imperv	0.024
N perv	0.24
Dstore imperv (in.)	0.07
DStore perv (in.)	0.24
Zero imperv (%)	5
A1[a]	0.5
B1[a]	2.5

Table 5-7. Model Parameter Values	
Parameter	Value
Suction head (in.) [a]	3.5
Conductivity (in./hr) [a]	0.5
Initial deficit (fraction) [a]	0.25
Porosity [a]	0.5
Wilting point [a]	0.14
Field capacity [a]	0.27
Conductivity slope [a]	0
Tension slope [a]	120
Upper evaporation fraction [a]	0.1
Lower evaporation depth (ft) [a]	0
Lower GW loss rate (in./hr) [a]	0.002
Threshold GW elev (ft) [a]	5.69
Aquifer bottom elevation (ft) [a]	4.69
Initial aquifer water table elevation (ft) [a]	4.69
Unsaturated zone moisture [a]	0.27

a. *Model impervious is set to 100%; Green-Ampt and groundwater parameters are therefore not active in model computations. Values above are included in the model and are typical values determined from other LTCP basin modeling efforts.*

5.6 Calibration Summary

The calibration process described above has resulted in a final parameter set for the NPDES107 CSO Area. In general, the calibration process produced a good agreement between simulated and monitored elevations.

The East Waterway CSO Area model is calibrated to the best available data and is of sufficient quality to meet the project objectives.

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SECTION 6

Model Verification

This section provides a description of the model verification process. For the NPDES107 Basin, the reported elevation at the Duwamish PS outlet during CSO events from January 2010 through April 2012 were compared to model results to evaluate the effectiveness of the model to simulate the water level in the EBI. The reported CSO events from January 2010 through April 2012 were also compared to model results to evaluate the effectiveness of the model to simulate existing overflow conditions.

Figure 6-2 summarizes the comparison of recorded and simulated maximum heads during reported CSO events at the Duwamish pump station outlet. Table 6-3 provides numerical data for the Figure 6-2 comparison. There is generally excellent correlation between the recorded and simulated values, with the exception of the March 15, 2012, event. During this event, reliable King County SCADA data were not available for the boundary condition development, and thus the model did not correctly simulate the elevation in the EBI on that date.

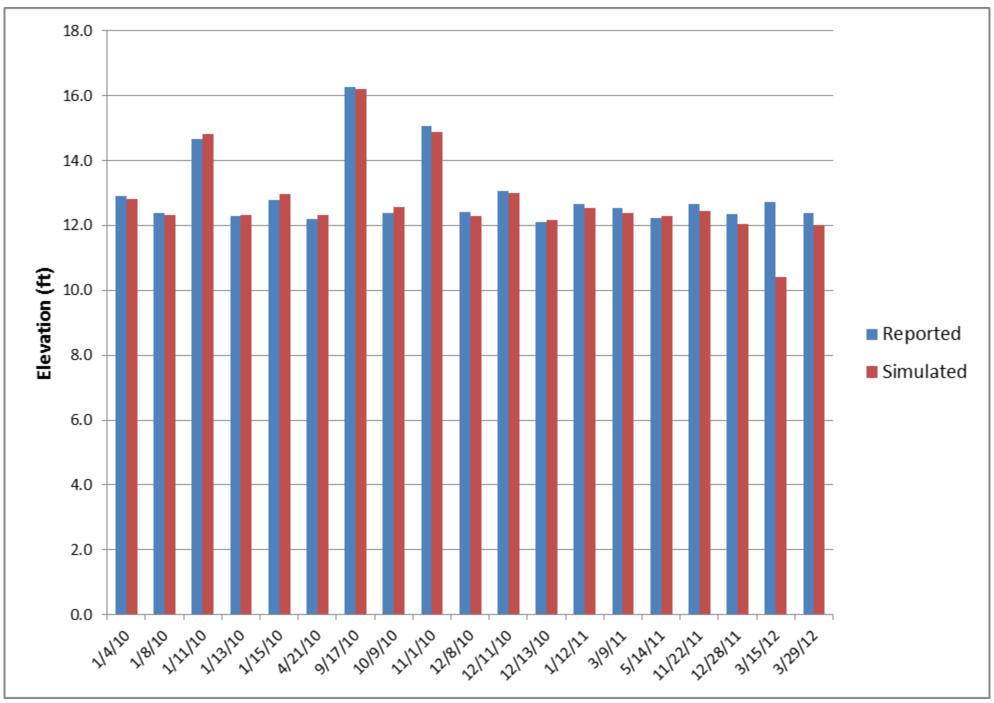

Figure 6-1. Simulated and reported maximum head values at the Duwamish PS outlet during reported overflow events from January 2010 through April 2012

SCADA data were incomplete on March 15, 2012.

Table 6-1. Comparison of Simulated and Reported Maximum Head Levels at the Duwamish PS Outlet During Reported Overflow Events

End date of overflow	Head (ft)		Percent difference (%)
	Reported	Simulated	
1/4/2010	12.92	12.83	-0.7%
1/8/2010	12.40	12.33	-0.5%
1/11/2010	14.68	14.84	1.1%
1/13/2010	12.29	12.31	0.2%
1/15/2010	12.79	12.97	1.4%
4/21/2010	12.19	12.32	1.1%
9/17/2010	16.27	16.21	-0.3%
10/9/2010	12.38	12.58	1.6%
11/1/2010	15.06	14.89	-1.1%
12/8/2010	12.41	12.29	-1.0%
12/11/2010	13.05	13.01	-0.3%
12/13/2010	12.10	12.19	0.7%
1/12/2011	12.66	12.54	-0.9%
3/9/2011	12.54	12.39	-1.2%
5/14/2011	12.22	12.29	0.6%
11/22/2011	12.66	12.46	-1.6%
12/28/2011	12.34	12.06	-2.3%
3/15/2012[a]	12.72	10.42	-18.1%
3/29/2012	12.40	12.01	-3.1%

a. SCADA data were incomplete on March 15, 2012.

Table 6-2 provides the number of overflows reported and simulated by the model at the NPDES107 overflow structure from January 2010 through April 2012. In this period, 19 events were reported and 19 events were simulated. The only reported overflow that was not simulated by the model occurred on March 15, 2012. During this event, King County SCADA data were not available for the boundary condition development, and thus the model did not correctly simulate the elevation in the EBI. The model simulated one additional overflow event that was not reported on January 21, 2012. The model-simulated event was small volume and short duration (less than 0.01 million gallons [MG] volume and less than 2-hour duration). The ADS data indicate that the water level in the CSO structure was above the overflow elevation during this event and thus an overflow may have occurred that was not reported.

Table 6-2. NPDES107 Comparison of Simulated and Reported CSO Frequencies (January 2011-April 2012)	
Number of reported events	**Number of simulated events**
19	19

Figure 6-2 summarizes the comparison of recorded and simulated maximum heads during reported CSO events for the NPDES107 Basin overflow structure at MH 056-097. Table 6-3 provides numerical data for the Figure 6-2 comparison.

Figure 6-2 demonstrates that the East Waterway CSO Area model is generally accurate at predicting water level in the NPDES107 overflow structure during CSO events. With the exception of the March 15, 2012, event simulated maximum heads at the CSO track closely (within 5 percent) with the recorded maximum heads during CSO events.

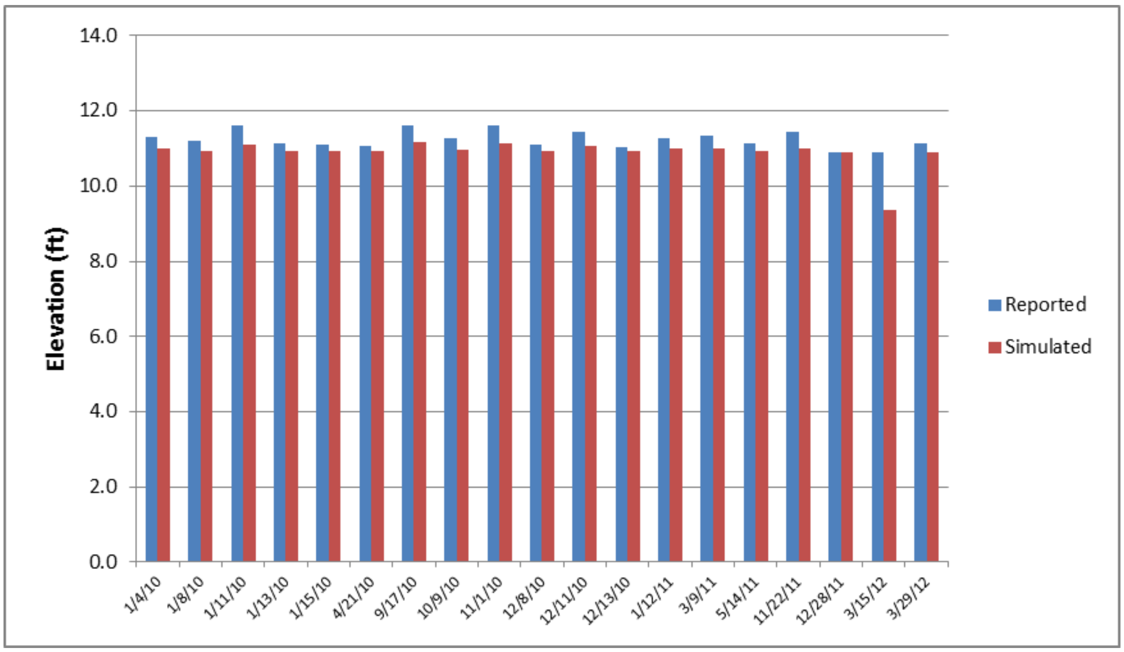

Figure 6-2. Simulated and reported maximum head values in the overflow structure during reported overflow events from January 2010 through April 2012 for the NPDES107 Basin

SCADA data were incomplete on March 15, 2012.

Table 6-3. NPDES107 Basin: Comparison of Simulated and Reported Maximum Head Levels at Overflow Structure during Reported Overflow Events			
End date of overflow	Head (ft)		Percent difference (%)
	Reported	Simulated	
1/4/2010	11.31	10.99	-2.9%
1/8/2010	11.21	10.94	-2.4%
1/11/2010	11.60	11.12	-4.2%
1/13/2010	11.15	10.92	-2.1%
1/15/2010	11.12	10.94	-1.6%
4/21/2010	11.07	10.91	-1.4%
9/17/2010	11.62	11.17	-3.9%
10/9/2010	11.26	10.96	-2.7%
11/1/2010	11.63	11.15	-4.1%
12/8/2010	11.11	10.92	-1.7%
12/11/2010	11.46	11.05	-3.5%
12/13/2010	11.05	10.92	-1.2%
1/12/2011	11.26	10.99	-2.4%
3/9/2011	11.35	10.99	-3.2%
5/14/2011	11.12	10.94	-1.6%
11/22/2011	11.43	11.00	-3.7%
12/28/2011	10.88	10.88	0.0%
3/15/2012[a]	10.91	9.35	-14.3%
3/29/2012	11.14	10.91	-2.0%

a. SCADA data were incomplete on March 15, 2012.

SECTION 7

Summary and Conclusions

The East Waterway NPDES107 CSO Area model was constructed with EPA SWMM5 Build 5.0.022 software by using information from various sources including the City's GIS, as-built drawings, and surveys. The model was calibrated by using a manual calibration process to monitoring data collected in January 2010. Results from the model were verified against level data collected at the King County Duwamish PS outlet and at the overflow structure during overflow events between February 2010 and April 2012. The comparison of observed and simulated water levels at the PS outlet and the NPDES107 overflow structure indicates that the model is suitable for the evaluation of CSO reduction alternatives.

The model calibration process indicated that the hydraulic response, and thus overflows, in the NPDES107 Basin are due to a high HGL in the King County EBI.

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SECTION 8

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Appendix A: Survey and Record Drawings

Submitted Electronically

Appendix B: Dry Weather Flow Documentation

Submitted Electronically

Appendix C: Subcatchment Delineation

Submitted Electronically

Appendix D: Digital Mapping

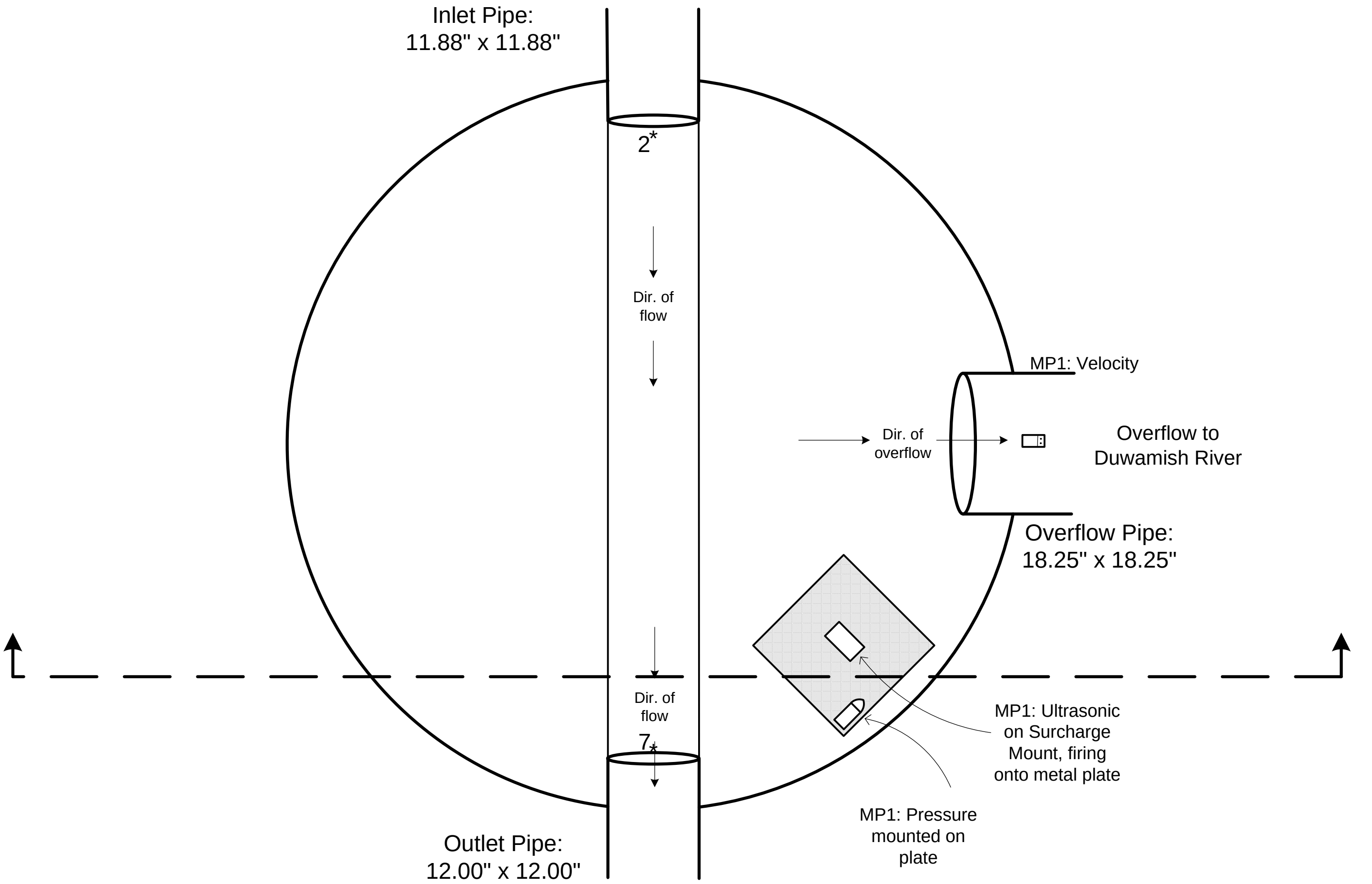
Submitted Electronically

Appendix E: Calibration Summary

Submitted Electronically

APPENDIX A TABLE OF CONTENTS

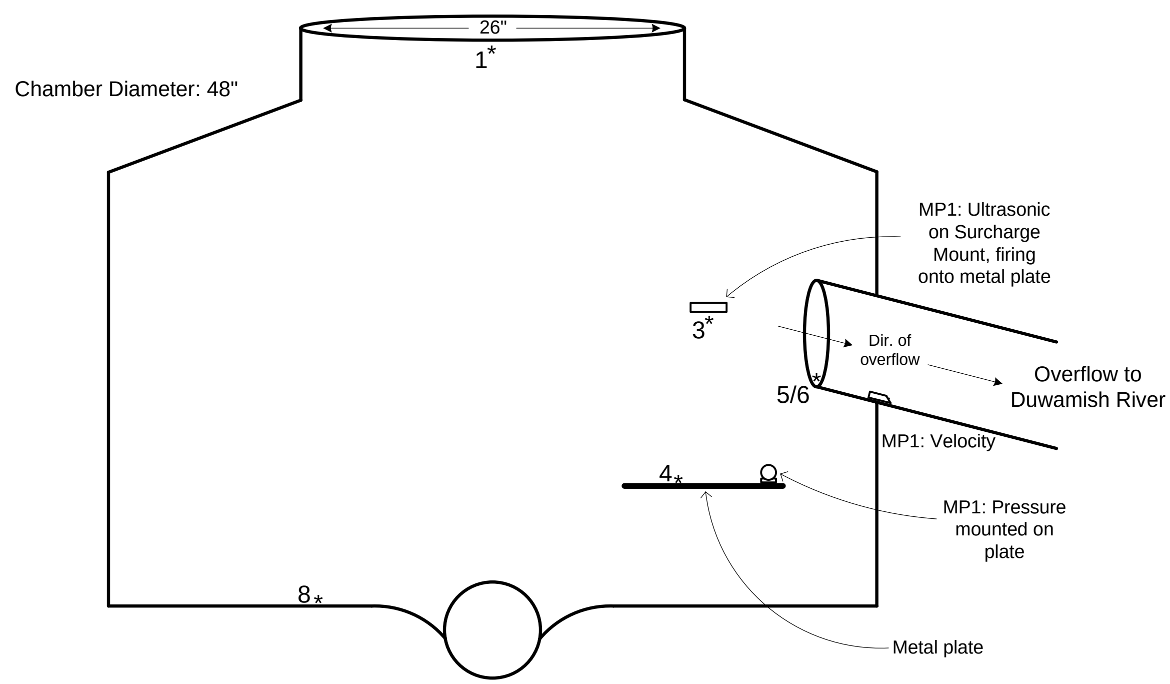
ADS Environmental Services, 4455 South 134th Place, Tukwila, WA 98168	Site Name: NPDES107_MH056097	Retrofit / Reconfig: ADS 02/01/11	Field Drawing: DS 08/10/10	Rev. 3	Pg. 1 of 2	Seattle Public Utilities CSO Monitoring
		Work Done: Velocity installed in overflow pipe	Computer Drawing: SH 05/04/10	Not to Scale		



Top View N

Cross Section

Note: See Page 2 for elevation measurements.



MH Elevations

Point #	Description of Point	Distance to Rim	Elevation
1	Rim, X @ N	0.00"	16.56'
2	Base of invert @ inlet	135.63"	5.26'
3	Face of MP1 ultrasonic	55.88"	11.90'
4	Top of plate	101.75"	8.08'
5	Base of invert @ overflow	69.38"	10.78'
6	Point of overflow	69.38"	10.78'
7	Base of invert @ outlet	135.88"	5.24'
8	Bench, average	126.00"	6.06'
Elevation measurements adjusted to known SPU-measured rim elevation (16.56').			

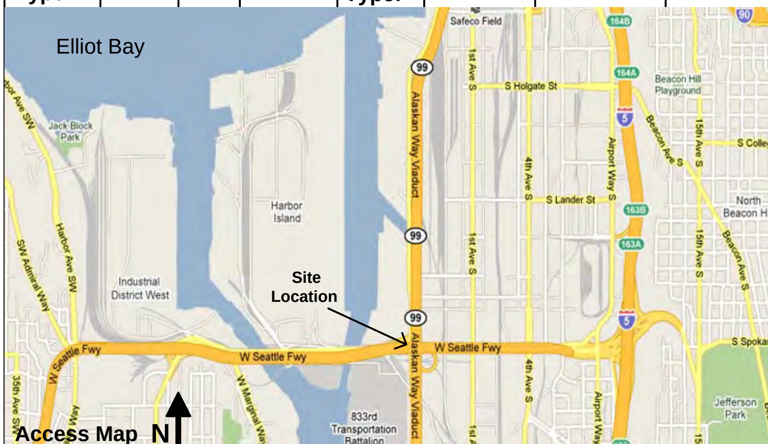
Point of O/F 66.25" (ADS measurement)
Point of O/F 65.40" (SPU survey), being used as High High alarm

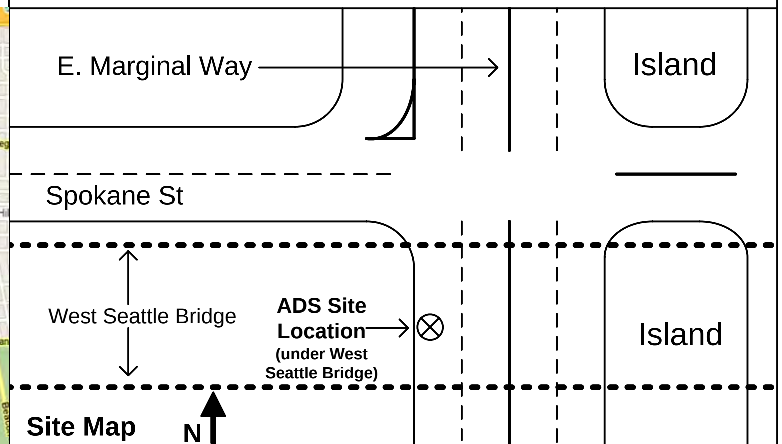
ADS ENVIRONMENTAL SERVICES — ADS Site Report — Quality Form

Project Name: Seattle - CSO	**City / State:** Seattle, WA		**FM Initials:** SW
Site Name: NPDES107_MH056097	**Monitor Series:** FS 5000 AG	**Manhole #:**	056-097
Address/Location: E. Marginal Way & S. Spokane St. (located in outside lane on south bound direction of E. Marginal Way		**Pipe Height:**	**MP1**: 11.88"
		Pipe Width:	**MP1**: 11.88"
		Thomas Bros Map Page:	594 J3

System Type:	Sanitary	Storm	Combined	**Mini System Type:**	Residential	Commercial	Industrial
			X		X	X	

Current Monitor S/N and IP address can be found on Intelliserve @ http://www.adsintelliserve2.com/Seattle/ in site parameters tab

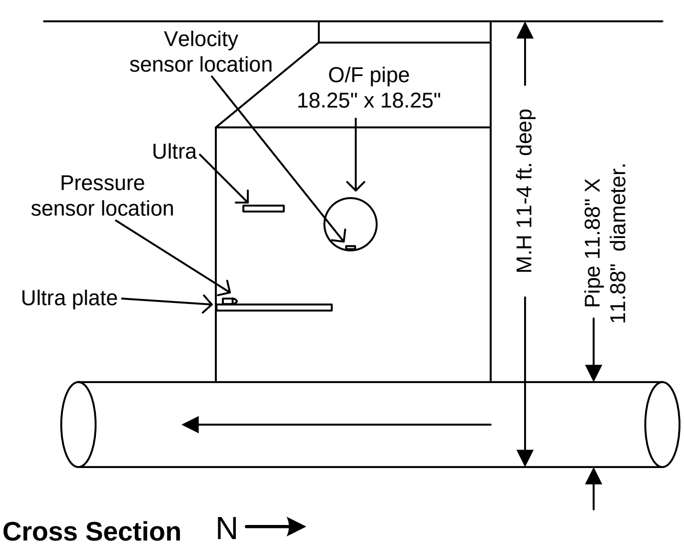




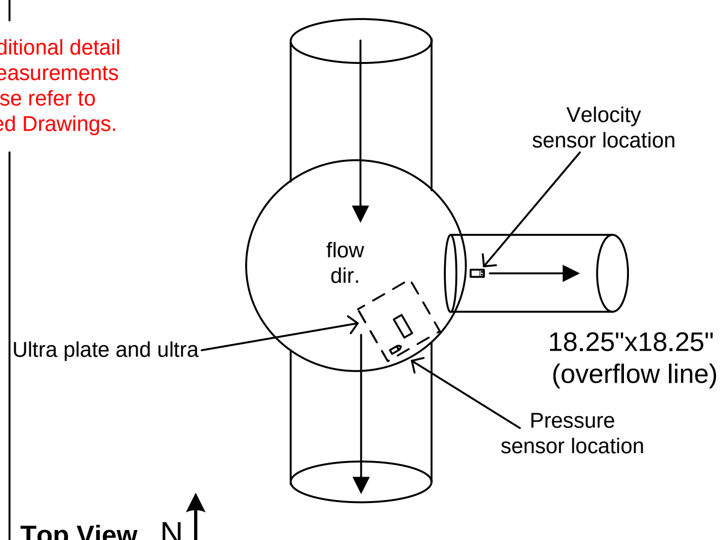
Investigation/Installation Information

Date/Time of Investigation:	**Date:** 1/8/2007 **Time:** 08:00	**Date/Time of Install:**	**Date:** 7/26/2007 **Time**: 13:11
Site Hydraulics: Smooth Slow Flow		**Installation Type:**	**MP1:** Special, ultra installed on surcharge mount above overflow line firing to a plate, pressure mounted on plate, velocity mounted in overflow line facing downstream, set of backwards bi-directional
Upstream Influences (Distance):	No Influences	**Sensors Devices:**	**MP1:** Ultra/Pressure/Velocity
Downstream Influences (Distance):	No Influences	**Alarm Setpoints:**	**High:** 32.70" **High High:** 65.40" (SPU survey)
Evidence of Surcharge? (Height):	67.00"	**Rain Gage Zone:**	**Primary:** 15 **Secondary:** 14, 11
Depth of Flow (Inches):	4.50" +/- .25"	**Manhole Depth:**	11' 4"
Peak Velocity (FPS):	1.83 fps	**Manhole Material / Condition:**	Concrete / Good
Silt? (Depth / Type):	1.00" / sandy	**Pipe Material / Condition:**	Concrete / Good

Site Drawings:



For additional detail and measurements please refer to Detailed Drawings.



Additional Site Information / Comments:

Pressure (5 PSI, accuracy +/- 0.25% for range of 0.25 – 11.5 ft.)
Ultra moved to surcharge mount above overflow line on 9.3.09
Velocity removed and pressure moved to ultra plate on 8.10.10
Velocity installed in overflow line facing downstream, set of backwards bi-directional on 2.1.11

Rev.4 2/1/11

Flow Monitoring Site Safety Plan

Project Name: Seattle CSO	**Site ID:** NPDES107_MH056097	**Site Classification:** (see below)

Note: Class 5 Site Safety Plans must be approved by the Corporate Safety Manager

*** Hazards found at this site (Discuss checked items below)**

Type	#	Special Hazard	
Communications	1	The site is in a communications "Dead-Zone"	☐
Traffic	2	The site is located in or adjacent to an intersection	X
	3	The site is located on hill, curve, or where motorists visibility of the site or other vehicles is reduced	☐
	4	The site is located ina high speed (>45MPH) or high density roadway roadway	☐
	5	Site traffic is congested at peak hours	☐
Access	6	Site has access obstacles (rough terrain, fences, deep easement, etc.)	☐
Worksite	7	Worksite contains hazards (terrain, slope, obstructions, etc.)	☐
	8	Elevated work requiring a ladder / work near an unguarded edge. Raised manhole (indicate height below)	☐
	9	Pedestrian control necessary as the site is located in or near a walkway, school, playground, etc.	☐
	10	Work may be performed during darkness; requiring additional site lighting	☐
	11	Site is located in a high crime area (check with client & local authorities if unsure)	☐
Confined Space	12	Confined Space does not have useable rungs	☐
	13	Confined Space depth is greater than 50 feet	☐
	14	Confined Space has internal platforms, weirs or other obstructions that interfere with or prevent unobstructed vertical retrieval	☐
	15	Work requires lateral movement that would interfere with or prevent unobstructed vertical retrieval	☐
	16	Flow is hazardous due to depth, velocity, pipe diameter, or is industrial process flow	☐
	17	Confined Space subject to surcharge during / after a rain event	X
	18	CO, H2S, low O2 or other toxic / flammable gases present or anticipated	☐
	19	Confined Space has active drop connections	☐

*** Hazards found at this site (Discuss checked items below)**

Site located adjacent (just south) to an intersection, follow traffic control plan (TA-22) and close lane before intersection so cars are not merging in the intersection.
This is a combined sewer site which may surcharge, do not access manhole during or immediately after rain event w/out contacting Field Manager

*** Site Classification**

	Class	Description
X	1	2-person crew. Standard procedures and equipment. No special requirements
☐	2	Worksite (non-traffic) with access obstacles and or worksite hazards
☐	3	Traffic site requiring special scheduling, additional personnel and / or traffic control equipment, or outsourcing
☐	4	Confined Space Entry requiring special scheduling, additional personnel and / or safety equipment
☐	5	Special Operation requiring a separate safety plan. *Must be approved by Corporate Safety Manager*

*** Site Specific Safety Requirements. Must Complete for any site Class 2 & Above**

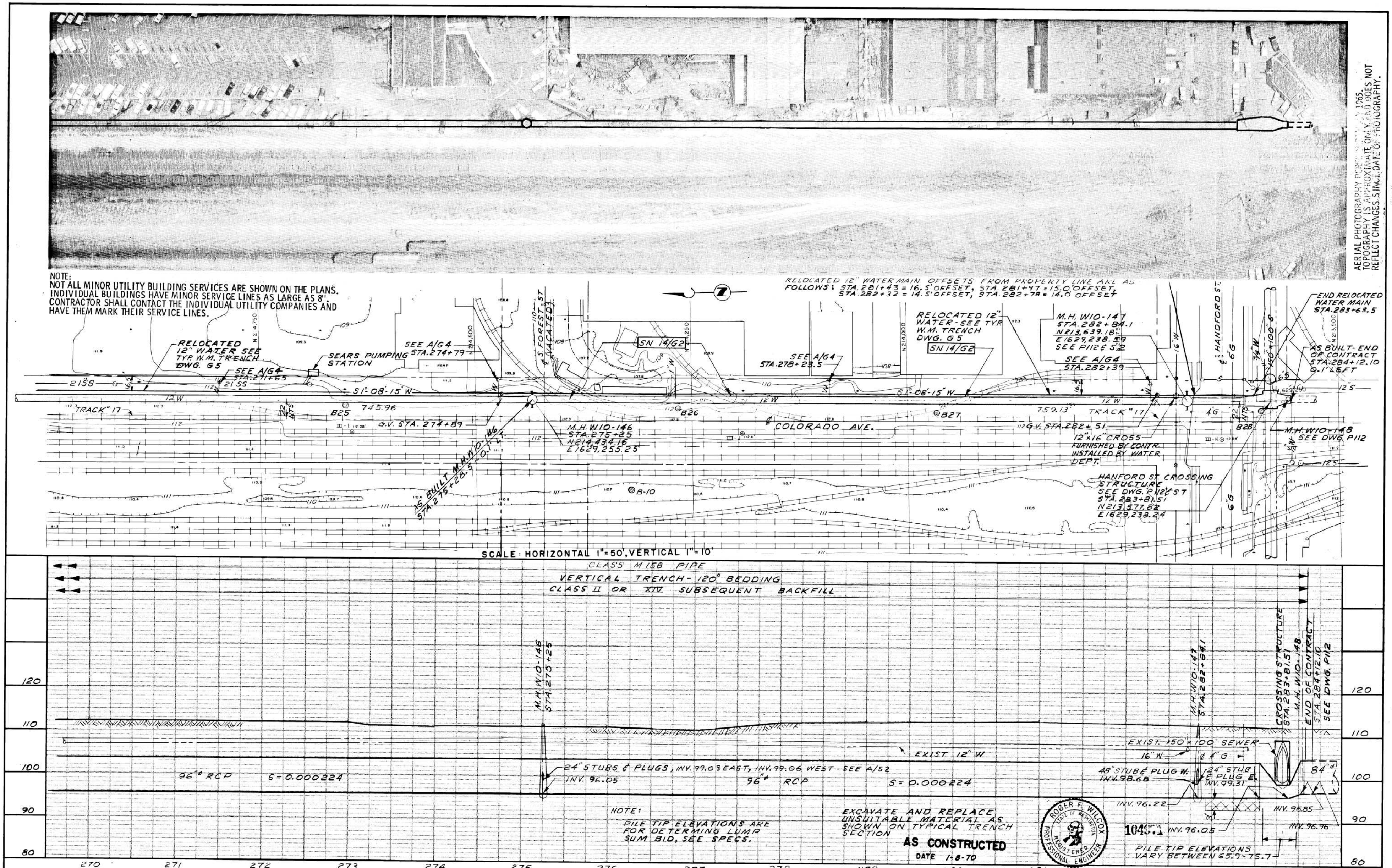
No Site Specific Safety Requirements

Traffic Control Plan

Note: All worksites located in a roadway or immediately adjacent to a roadway, where the operation may impede the normal flow of traffic, are required to have a Traffic Control Plan. Standard Traffic Control Plans are to be carried in the vehicle and referred to when setting up the worksite. Special Traffic Control Plans are to be are to be developed when required by clients or regulating agencies or when a standard Traffic Control Plan is not sufficient to control traffic at the worksite.

- ☐ This worksite does NOT require a traffic control Plan
- X Standard Traffic Control Plan TA-22 is to be used at this work site
- ☐ This site requires a special Traffic Control Plan which is attached

Approved	**Reviewed**
Field Mgr Name: Sean Winder	Project Mgr Name: Mike Pina
Signature: Signed copy can be obtained from ADS	Signature: Signed copy can be obtained from ADS
Date: 9/3/08	Date: 9/3/08



DESIGNED JFL	METROPOLITAN ENGINEERS		
DRAWN OLO	BROWN AND CALDWELL	CAREY AND KRAMER	
CHECKED JFL	HILL AND INGMAN	R W BECK AND ASSOCIATES	

MUNICIPALITY OF METROPOLITAN SEATTLE

SUBMITTED: Design Engineer – Metropolitan Engineers
RECOMMENDED: Project Engineer – Metropolitan Engineers
APPROVED: Chief Engineer – Metropolitan Engineers
APPROVED: For Metropolitan Engineers
APPROVED: For Municipality of Metropolitan Seattle

SCALE AS NOTED

FILE W210J

DATE FEB. 1968

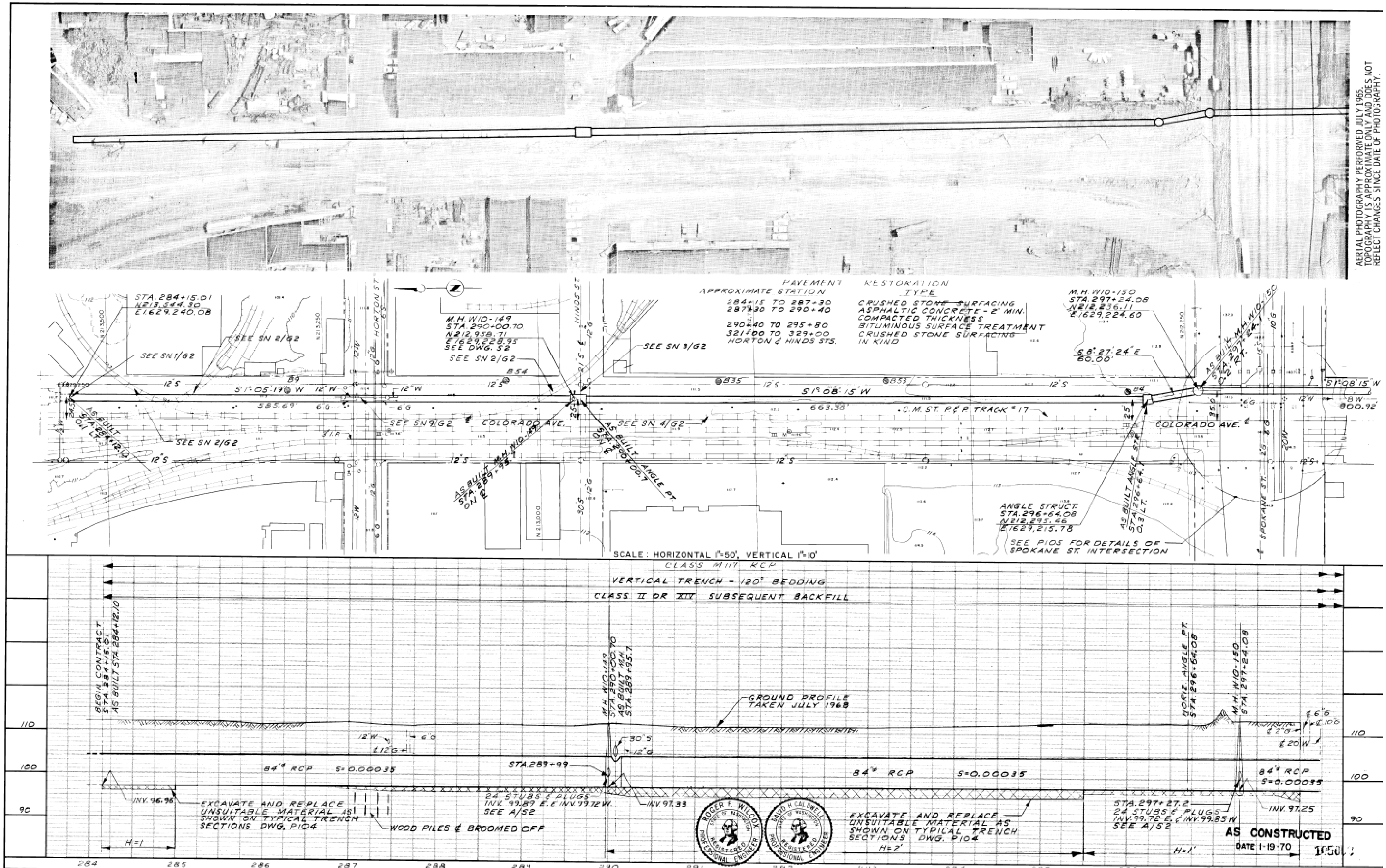
WEST POINT SYSTEM

ELLIOTT BAY INTERCEPTOR – SECTION 5

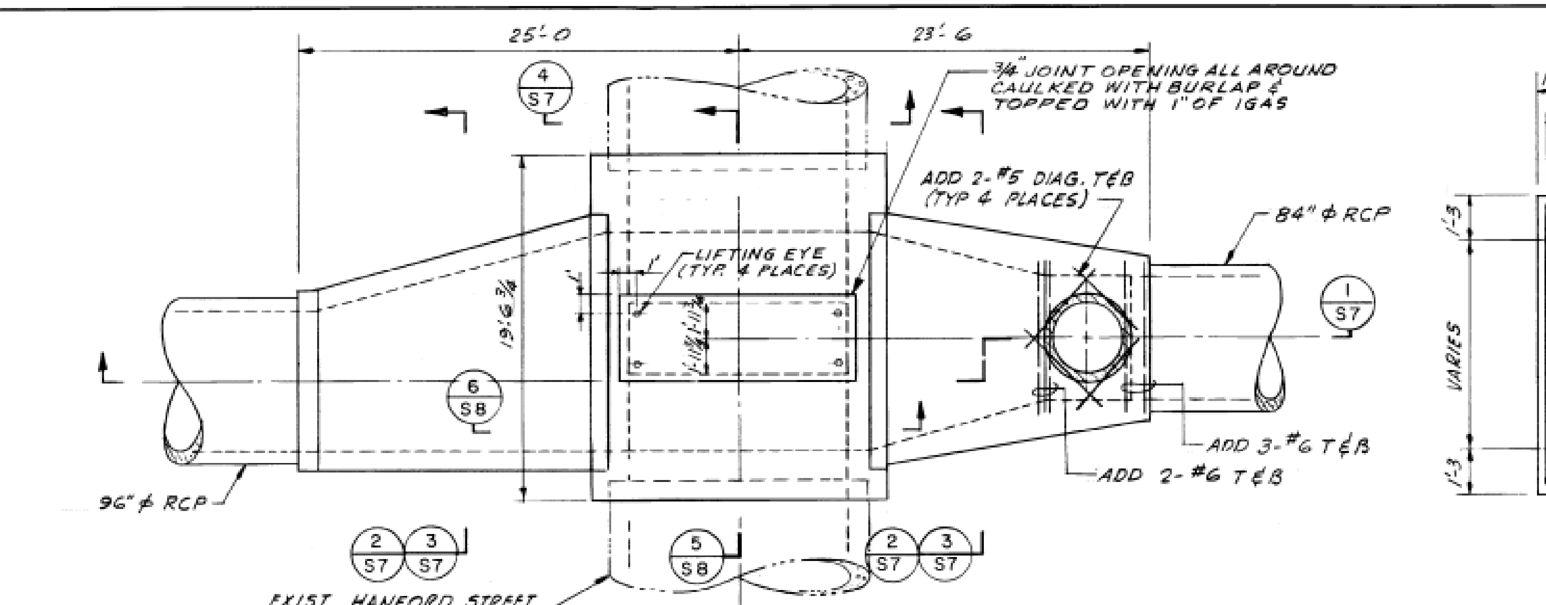
STA. 270+00 TO STA. 284+15.01 (END)

DRAWING NUMBER P107

SHEET NUMBER 20 OF 30

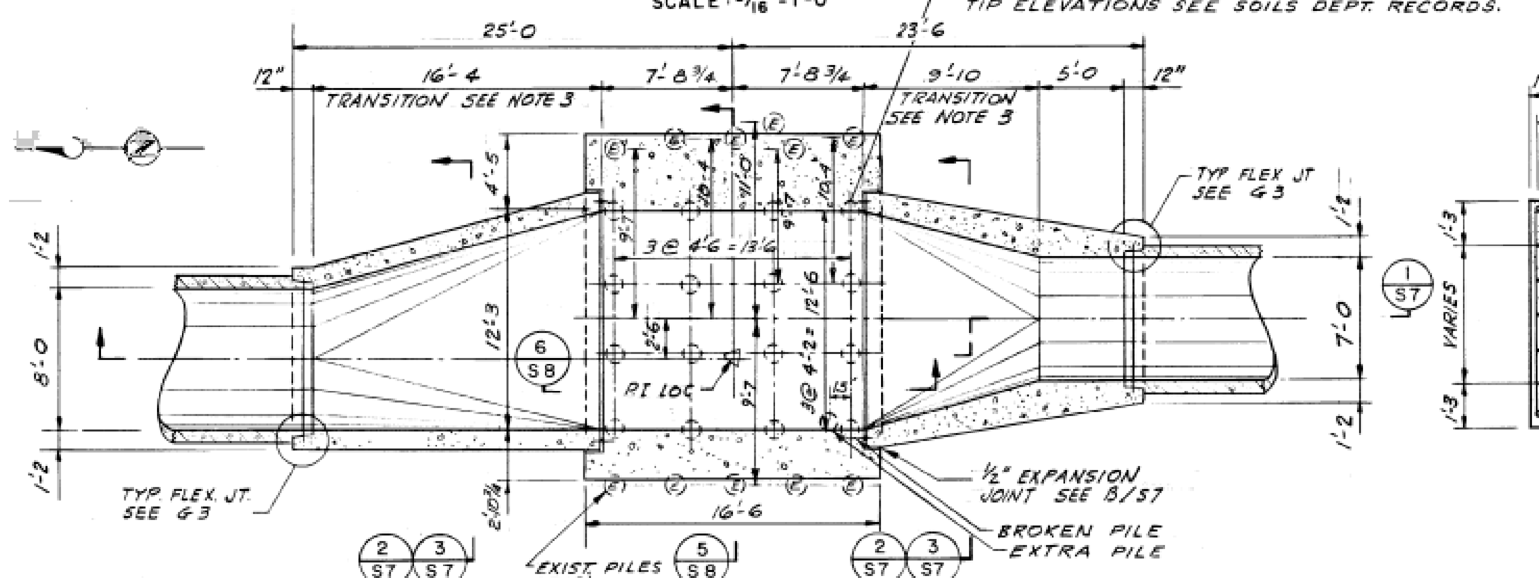


DESIGNED JFL DRAWN DLO CHECKED JSS	METROPOLITAN ENGINEERS BROWN AND CALDWELL — CAREY AND KRAMER HILL AND INGMAN — R.W. BECK AND ASSOCIATES	MUNICIPALITY OF METROPOLITAN SEATTLE SUBMITTED: Design Engineer - Metropolitan Engineers; RECOMMENDED: Project Engineer - Metropolitan Engineers; APPROVED: Chief Engineer - Metropolitan Engineers; APPROVED: For Metropolitan Engineers; APPROVED: For Municipality of Metropolitan Seattle SCALE AS NOTED	FILE W210K DATE JULY 1968	WEST POINT SYSTEM
ELLIOTT BAY INTERCEPTOR - SECTION 4 STA. 284+15.01 TO STA. 298+00	DRAWING NUMBER P101	SHEET NUMBER 6 OF 10		



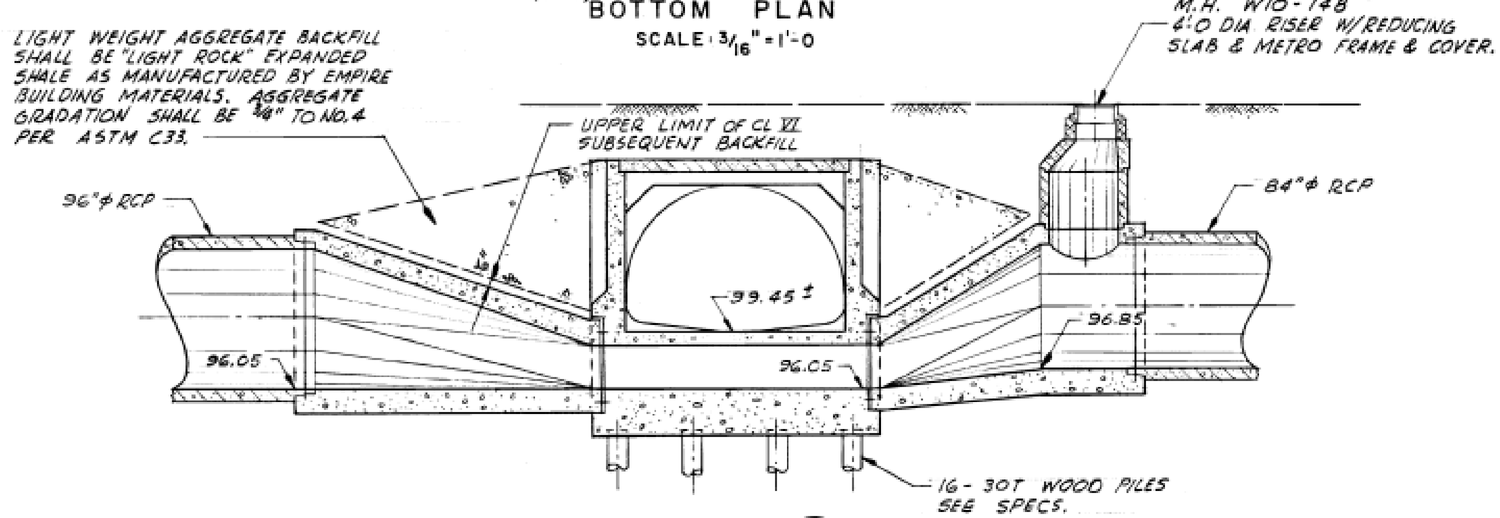
TOP PLAN

SCALE: 3/16" = 1'-0



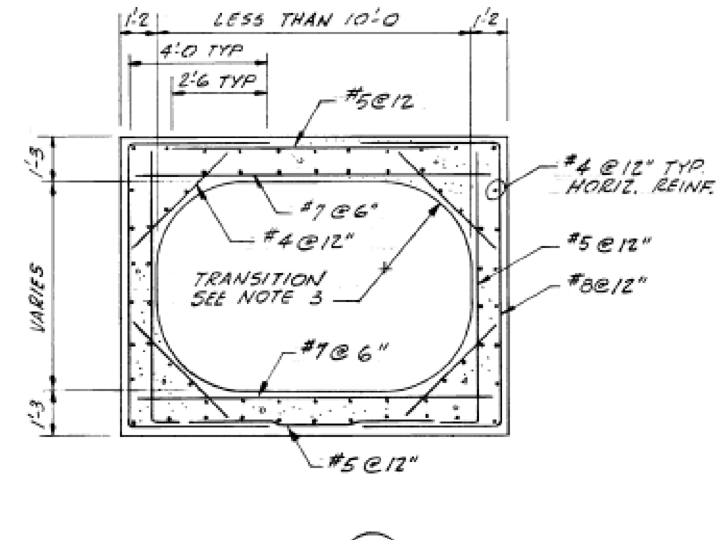
BOTTOM PLAN

SCALE: 3/16" = 1'-0



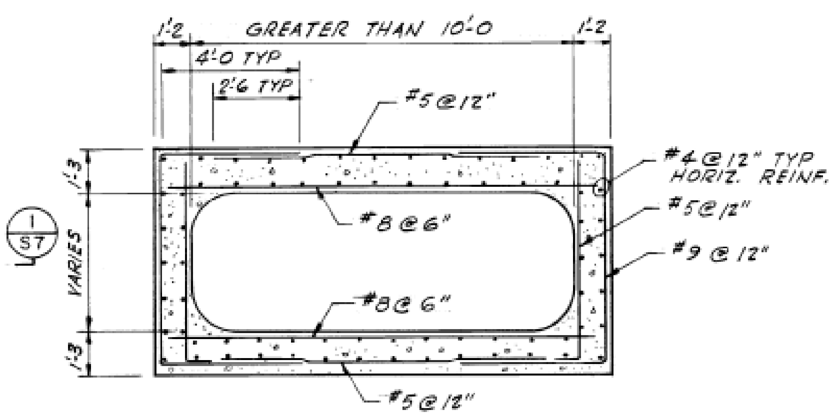
SECTION 1/S7

SCALE: 3/16" = 1'-0



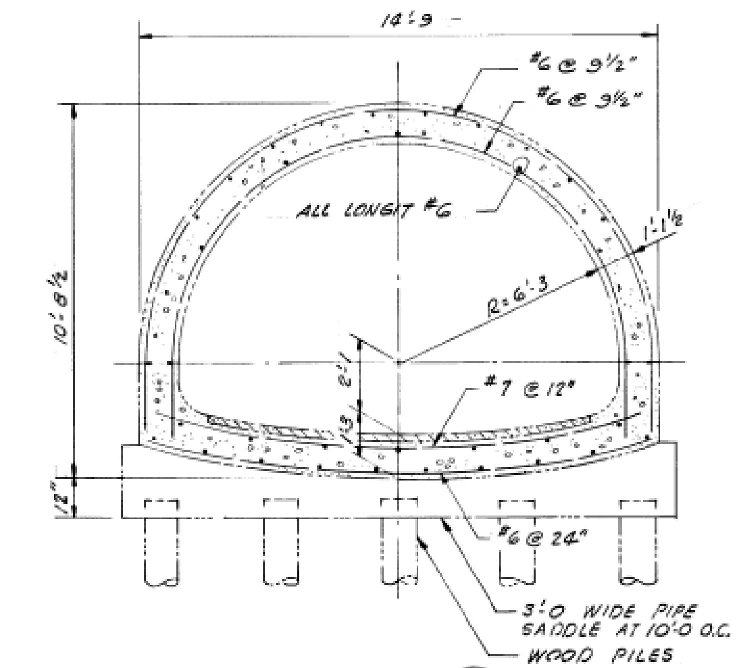
SECTION 2/S7

SCALE: 3/8" = 1'-0



SECTION 3/S7

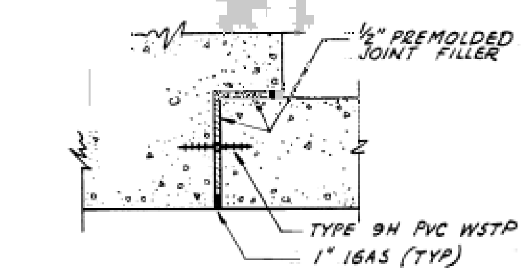
SCALE: 3/8" = 1'-0



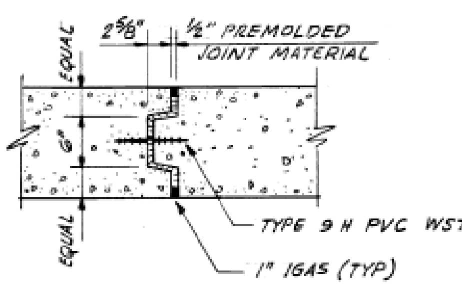
SECTION 4/S7

EXIST HANFORD STREET SEWER

SCALE: 3/8" = 1'-0



DETAIL B/S7



DETAIL C/S6

TYPICAL EXPANSION JOINTS

NO SCALE

NOTES:

1. SEE P112 FOR LOCATION OF STRUCTURE, SPECIAL PROVISIONS, AND BYPASSING REQUIREMENTS.
2. ALL CONTACT SURFACES SHALL BE CLEANED AND COATED WITH EPOXY BONDING COMPOUND PRIOR TO CASTING CONCRETE.
3. TRANSITIONS FROM CIRCULAR TO RECTANGULAR SHALL BE MADE WITH A RADIUS VARYING UNIFORMLY FROM R CIRCULAR CONDUIT TO R EQUALS 0 AT THE RECTANGULAR PORTION.
4. EXTEND EXISTING CONDUIT REINFORCING INTO NEW STRUCTURE 18 INCHES.
5. REMOVAL OF EXISTING SECTION OF HANFORD STREET CONDUIT SHALL BE DONE IN A MANNER SO THAT NO DAMAGE OCCURS TO THE REUSED ABUTTING PORTIONS.
6. THE CONTRACTOR SHALL SUBMIT BULKHEAD DETAILS, BYPASSING PROVISIONS AND SCHEDULING TO THE ENGINEER FOR REVIEW PRIOR TO CONSTRUCTION.

104803

AS CONSTRUCTED

DATE 1-8-70

MARTIN C. DIRKS — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER

ROGER F. WILCOX — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER

DESIGNED MCD DRAWN WG CHECKED MCD	METROPOLITAN ENGINEERS BROWN AND CALDWELL — CAREY AND KRAMER HILL AND INGMAN — R W BECK AND ASSOCIATES	MUNICIPALITY OF METROPOLITAN SEATTLE SUBMITTED (Design Engineer - Metropolitan Engineers) — RECOMMENDED (Project Engineer - Metropolitan Engineers) — APPROVED (Chief Engineer - Metropolitan Engineers) — APPROVED (For Metropolitan Engineers) — APPROVED (For Municipality of Metropolitan Seattle) SCALE AS NOTED	FILE W 210 J DATE FEB 1968	WEST POINT SYSTEM	ELLIOTT BAY INTERCEPTOR - SECTION 5 HANFORD STREET CROSSING STRUCTURE PLANS, SECTIONS AND DETAILS	DRAWING NUMBER S7 SHEET NUMBER 12 OF 30

MH 056 - 097

9-22-09

ANDERSON / WILSON

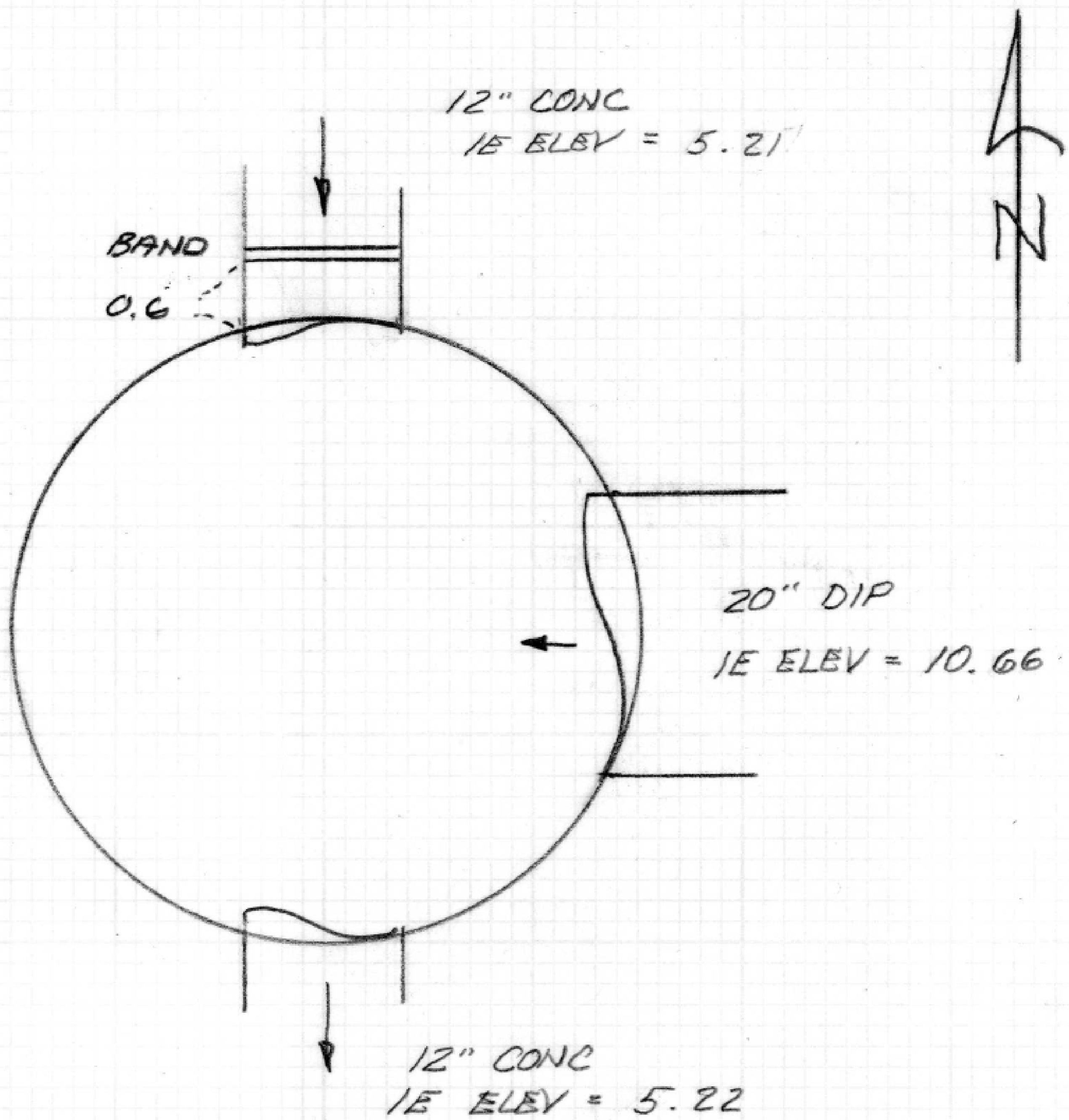
FBK 3741 PG 43

ALL ELEVATIONS
NAVD 88

BM CHISELED "X"
ON NORTH RIM OF MH

ELEV. 16.56

4' DIAMETER
CONC STRUCTURE



Non Wet-Process-Type Industrial So	Flowrate, gal/unit/day			
Source	**Unit**	**Low**	**Typical**	**High**
Light Industrial	Acre	1000		1500
Medium Industrial	Acre	1500		3000

[1]Source: Metcalf & Eddy, Inc. Wastewater Engineering Treatment and Reuse. 4th ed. New York: McGraw-Hill, 2003.

Dry weather flow development process:

** Clipped SPU Parcel GIS layer to the NPDES107 Basin boundary

**Reviewed land use description, aerial photo and sanitary laterals to determine whether parcel contributes dry weather flow loadings. Excluded private roads, vacant land, other utilities

**Parcels with the following land use were assumed to have no dry weather flow contribution: Water body, utility, ROW, vacant

** Other parcels were assumed to have no dry weather flow contribution based on review of aerials (e.g. no buildings or sanitary loadings, drains out of the basin, parking lots)

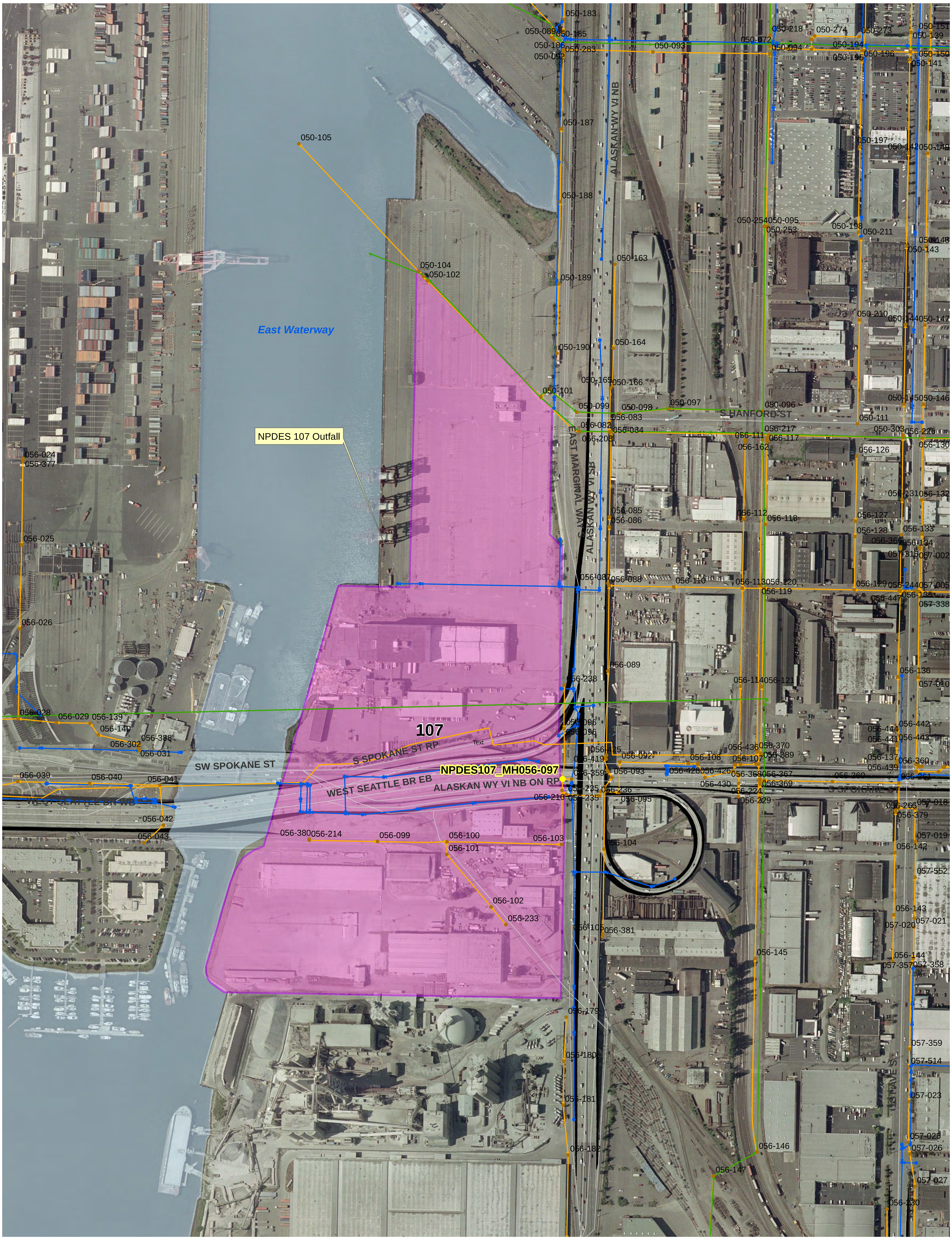
** It was assumed that all parcels are classified as Light Industrial for water consumption purposes. The area does not have industries with high water use

** The assigned dwf flow rate was based on low end of the published flow rates in Metcalf and Eddy, and calculated from parcel area

Parcel Information Exported from GIS					Notes and Calculations			
PIN	**Land Use Description**	**Address**	**Category Description**	**Area (acre)**	**Notes**	**DWF loading assigned**	**ADSF (MGD)**	**Assigned Model MH**
7666207550	Industrial(Gen Purpose)	3600 EAST MARGINAL WAY S	Industrial	0.9245		Yes	0.0009	056-095
7666700315	Terminal(Marine/Comm Fish)	3627 DUWAMISH AVE S	Terminal/Warehouse	13.8443		Yes	0.0138	056-102
7666700275	Warehouse		Terminal/Warehouse	1.1769		Yes	0.0012	056-103
7666700281	Industrial(Gen Purpose)		Industrial	1.0285		Yes	0.0010	056-103
7666700285	Warehouse	3633 EAST MARGINAL WAY S	Terminal/Warehouse	1.1427		Yes	0.0011	056-103
7666207555	Industrial(Gen Purpose)	45 S SPOKANE ST	Industrial	0.3593		Yes	0.0004	056-229
7666207570	Industrial(Gen Purpose)	49 S SPOKANE ST	Industrial	0.1694		Yes	0.0002	056-229
7666207560	Industrial(Gen Purpose)	3626 COLORADO AVE S	Industrial	0.7756		Yes	0.0008	056-229
7666700325	Warehouse	3687 DUWAMISH AVE S	Terminal/Warehouse	1.6874		Yes	0.0017	056-233
7666207905	Terminal(Marine/Comm Fish)	2917 EAST MARGINAL WAY S	Terminal/Warehouse	29.1342		Yes	0.0291	056-238
072404HYDR	Water Body			0.0001	Water body	No	0	
7666207917	Utility, Public	2999 1/2 EAST MARGINAL WAY S	Utility	0.0137	Utility	No	0	
182404HYDR	Water Body			0.0022	Water body	No	0	
7666700560	Vacant(Industrial)		Vacant	2.4416	Vacant land	No	0	
7666700270	Right of Way/Utility, Road		Utility	0.5522	Utility	No	0	
7666207550	Industrial(Gen Purpose)	3600 EAST MARGINAL WAY S	Industrial	0.0178	Reviewed aerial; ROW	No	0	
7666207552	Right of Way/Utility, Road		Utility	1.1666	Utility	no	0	
7666207555	Industrial(Gen Purpose)	45 S SPOKANE ST	Industrial	0.1676	Reviewed GIS; no sanitary connection	no	0	
182404HYDR	Water Body			0.0188	Water body	No	0	
7666700280	Right of Way/Utility, Road		Utility	0.2781	Utility	No	0	
7666700885	Right of Way/Utility, Road		Utility	0.1423	Utility	no	0	
7666700755	Right of Way/Utility, Road		Utility	0.3123	Utility	no	0	
7666700560	Vacant(Industrial)		Vacant	0.3161	Vacant land	no	0	
1824049047	Warehouse	3628 EAST MARGINAL WAY S	Terminal/Warehouse	0.4967	Reviewed GIS; drains out of basin	No	0	
7666207560	Industrial(Gen Purpose)	3626 COLORADO AVE S	Industrial	0.1535	Reviewed GIS; no sanitary connection	No	0	
1824049098	Vacant(Industrial)		Vacant	0.1705	Vacant land	no	0	
1824049055	Industrial(Heavy)	3648 EAST MARGINAL WAY S	Industrial	3.3321	Reviewed GIS; drains out of basin	no	0	
1824049003	Industrial(Gen Purpose)		Industrial	5.1171	Reviewed GIS; drains out of basin	no	0	
7666700350	Industrial(Heavy)	3801 EAST MARGINAL WAY S	Industrial	0.0307	Reviewed GIS; drains out of basin	No	0	
1824049064	Utility, Public		Utility	0.2724	Utility	No	0	
1824049088	Right of Way/Utility, Road		Utility	0.0031	Utility	No	0	
1824049027	Right of Way/Utility, Road		Utility	0.0001	Reviewed GIS; drains out of basin	No	0	

GIS files available upon request

GIS File Name	Description
DWW_catch_Basin_pt_pv	File provided by SPU; contains all the catch basin in the NPDES107 basin; used to determine connections to the storm drainage system
DWW_mainline_endpt_pv	File provided by SPU; contains all the maintenance holes (storm, combined, sanitary) in the NPDES107 basin; used to assign where model subcatchments are routed
DWW_mainline_ln_pv	File provided by SPU; contains all the mainline pipes (storm, combined, sanitary) in the NPDES107 basin; used to delineate the basin boundaries
DWW_non_mainline_ln_pv	File provided by SPU; contains all the laterals (storm, combined) in the NPDES107 basin; used to determine whether buildings, parcels and roads were connected to the storm or CSS systems
NPDES107_Storm_Delineation_v2	Delineation of subcatchments connected to the storm drainage system. The field "OUTLET" is the maintenance hole to which the subcatchment is routed in the model
NPDES107_CSS_parcel_delineation	Delineation of parcel areas connected to the CSS. The field "OUTLET" is the maintenance hole to which the subcatchment is routed in the model
15inchSewer_catchment	Delineation of the subcatchment directly connected to the EBI via a 15-inch diameter SPU sewer
BLG_NPDES107	Contains all the buildings within the model area and designates whether they are connected to storm, CSS or directly to the East Waterway
NPDES107_CSS_Delineation_v2	Contains the delineated NPDES107 boundary
NPDES107_Storm_BasinBoundary	Contains the delineated boundary of the East Marginal Way Storm drain included in the NPDES107 mode



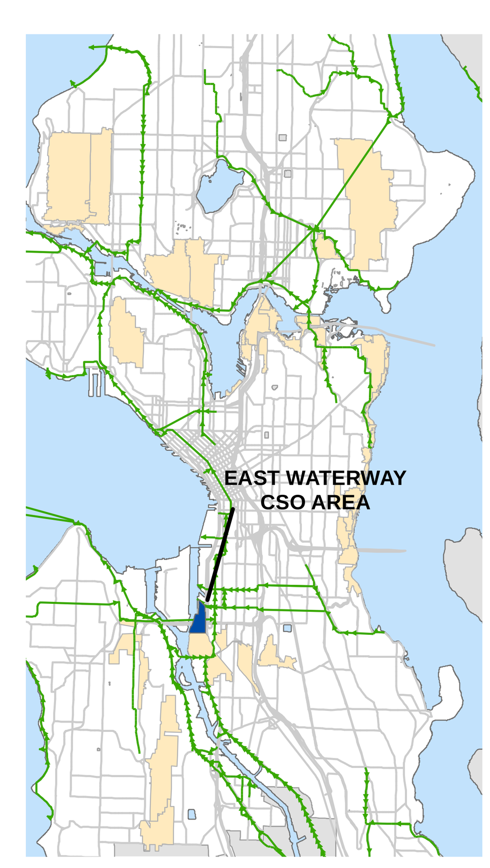
N
W E
S

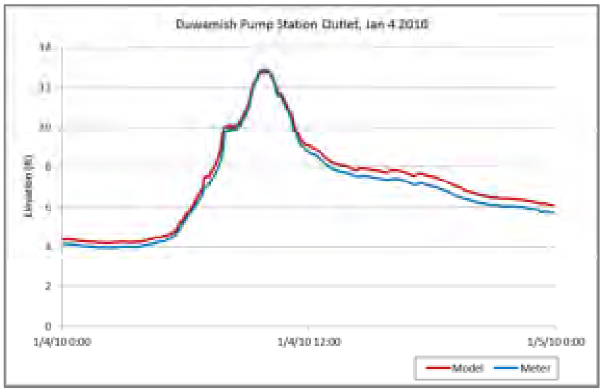
0 300 600

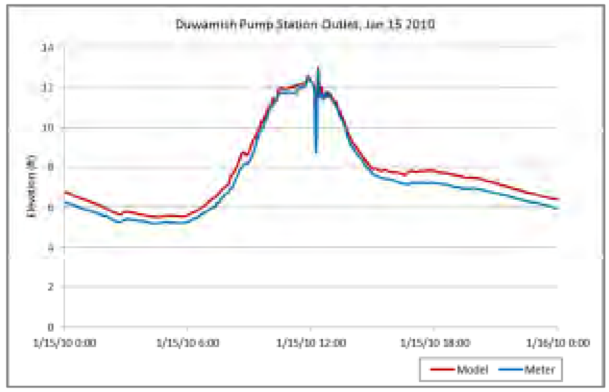
Feet

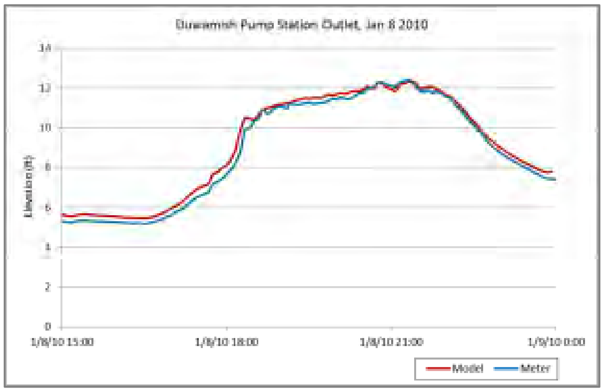
EAST WATERWAY 107 CSO BASIN

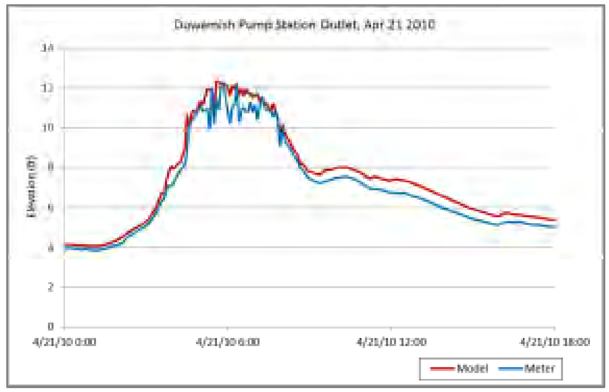
- SPU Rain Gauges
- Overflow Structure and Permanent Meter
- King County Sewer
- Combined
- Drainage
- East Waterway 107 CSO Area

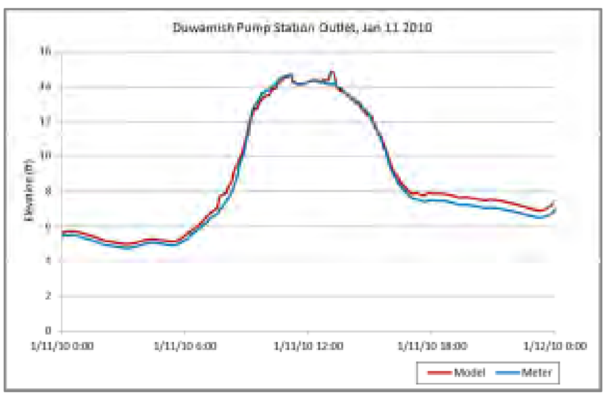


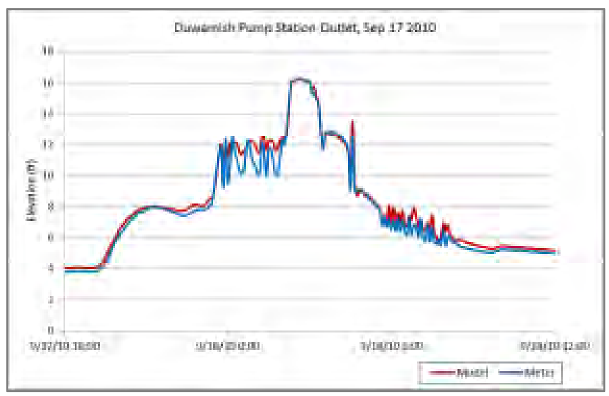

Duwamish Pump Station Outlet, Jan 4 2010
Elevation (ft)
1/4/10 0:00
1/4/10 12:00
1/5/10 0:00
Model
Meter

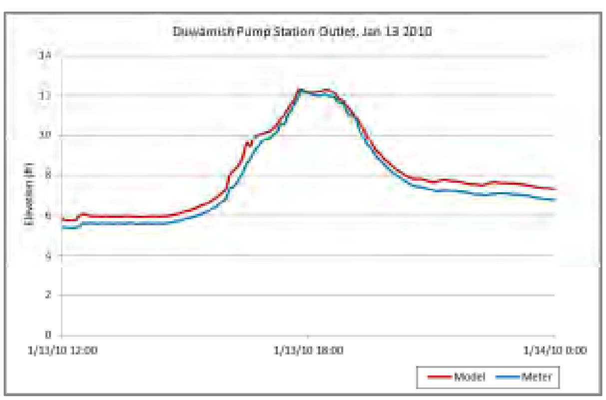

Duwamish Pump Station Outlet, Jan 15 2010
Elevation (ft)
1/15/10 0:00
1/15/10 6:00
1/15/10 12:00
1/15/10 18:00
1/16/10 0:00
Model
Meter

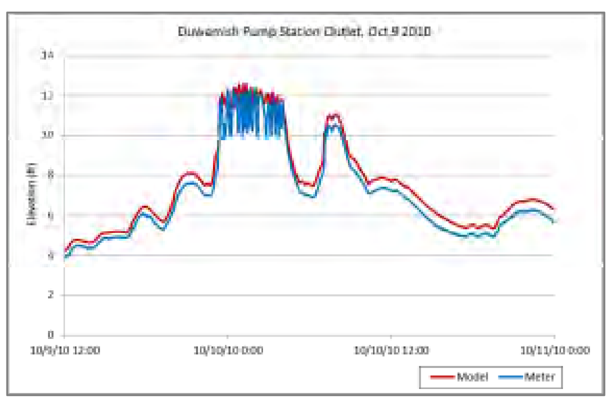

Duwamish Pump Station Outlet, Jan 8 2010
Elevation (ft)
1/8/10 15:00
1/8/10 18:00
1/8/10 21:00
1/9/10 0:00
Model
Meter

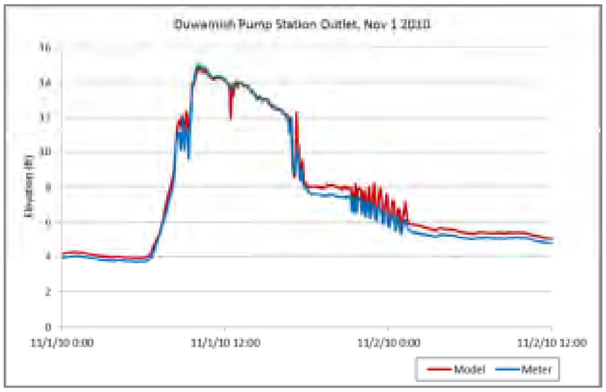

Duwamish Pump Station Outlet, Apr 21 2010
Elevation (ft)
4/21/10 0:00
4/21/10 6:00
4/21/10 12:00
4/21/10 18:00
Model
Meter

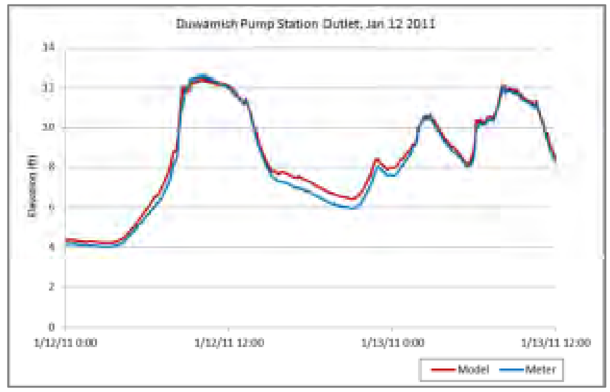

Duwamish Pump Station Outlet, Jan 11 2010
Elevation (ft)
1/11/10 0:00
1/11/10 6:00
1/11/10 12:00
1/11/10 18:00
1/12/10 0:00
Model
Meter

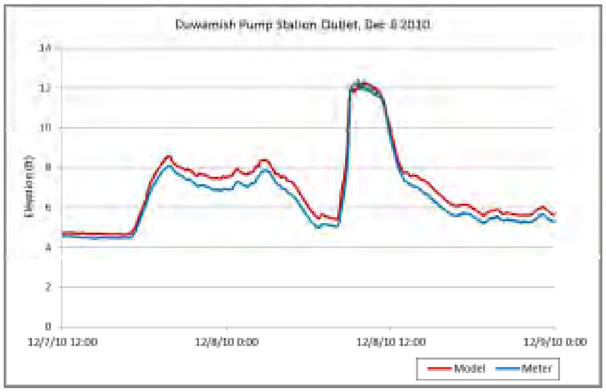

Duwamish Pump Station Outlet, Sep 17 2010
Elevation (ft)
Model
Meter

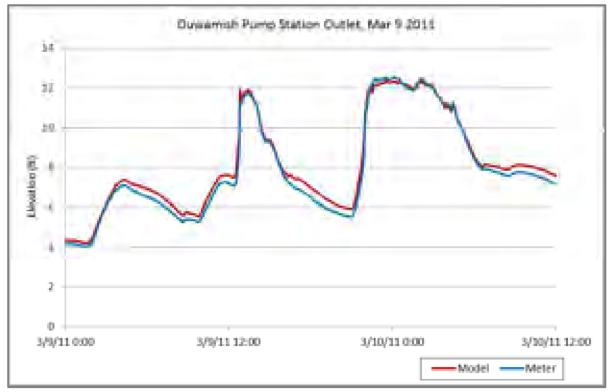

Duwamish Pump Station Outlet, Jan 13 2010
Elevation (ft)
1/13/10 12:00
1/13/10 18:00
1/14/10 0:00
Model
Meter


Duwamish Pump Station Outlet, Oct 9 2010
Elevation (ft)
10/9/10 12:00
10/10/10 0:00
10/10/10 12:00
10/11/10 0:00
Model
Meter


Duwamish Pump Station Outlet, Nov 1 2010
Elevation (ft)
11/1/10 0:00
11/1/10 12:00
11/2/10 0:00
11/2/10 12:00
Model
Meter


Duwamish Pump Station Outlet, Jan 12 2011
Elevation (ft)
1/12/11 0:00
1/12/11 12:00
1/13/11 0:00
1/13/11 12:00
Model
Meter


Duwamish Pump Station Outlet, Dec 8 2010
Elevation (ft)
12/7/10 12:00
12/8/10 0:00
12/8/10 12:00
12/9/10 0:00
Model
Meter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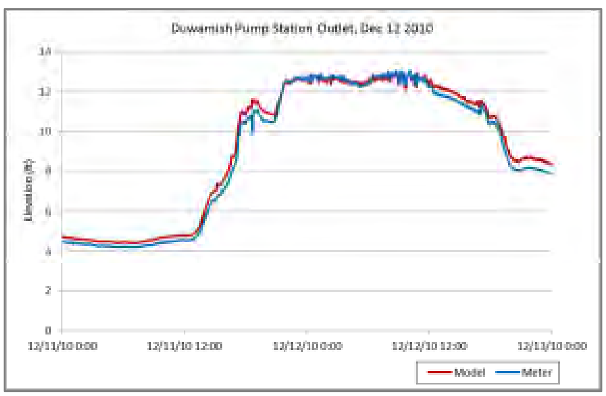
Model
Meter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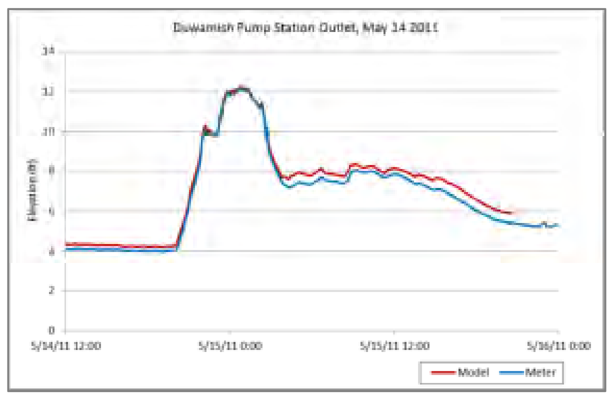
12/13/10 0:00
Model
Meter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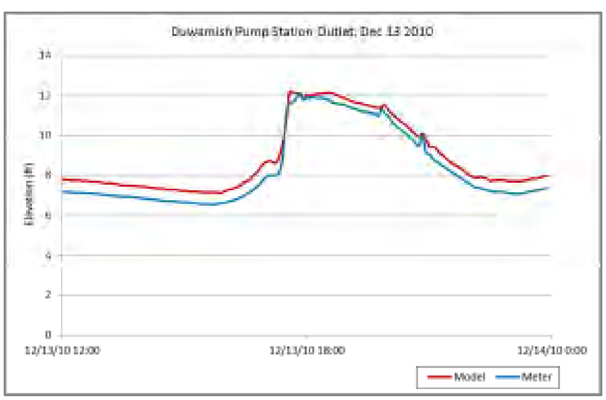
Model
Meter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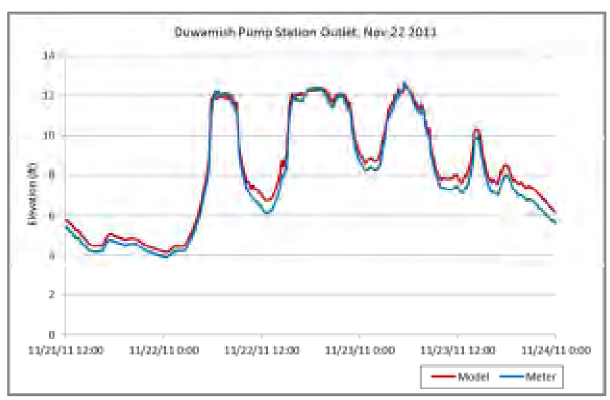
12/14/10 0:00
Model
Meter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Elevation (ft)
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11/22/11 12:00
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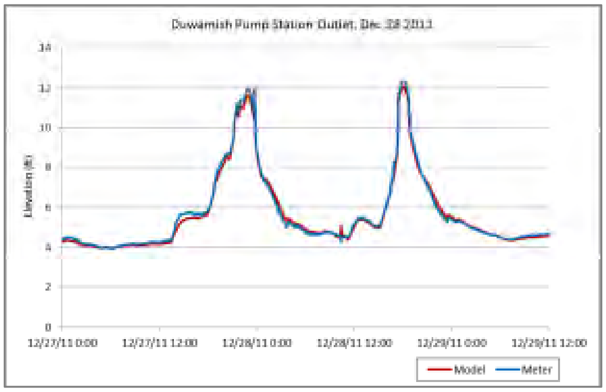
11/23/11 12:00
11/24/11 0:00
Model
Meter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Elevation (ft)
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2
4
6
8
10
12
14
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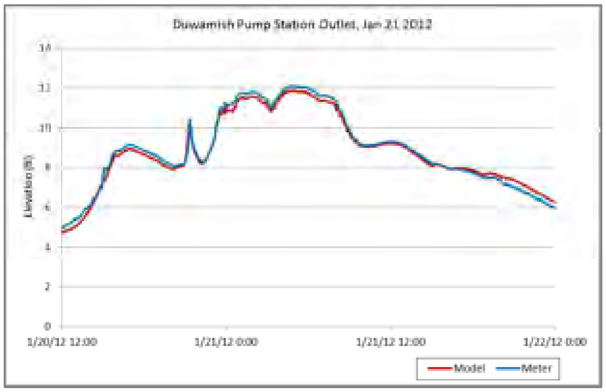
Model
Meter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Elevation (ft)
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2
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10
12
14
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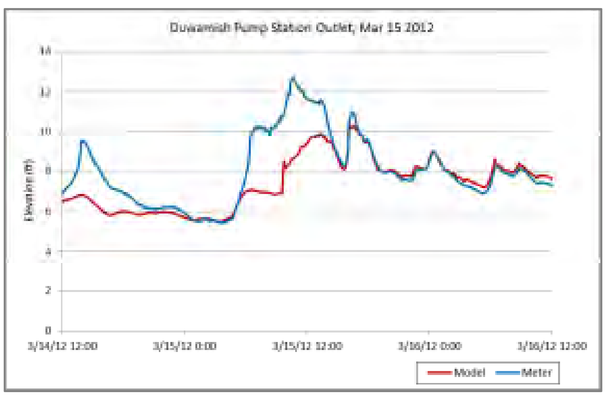
Model
Meter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6
8
10
12
14
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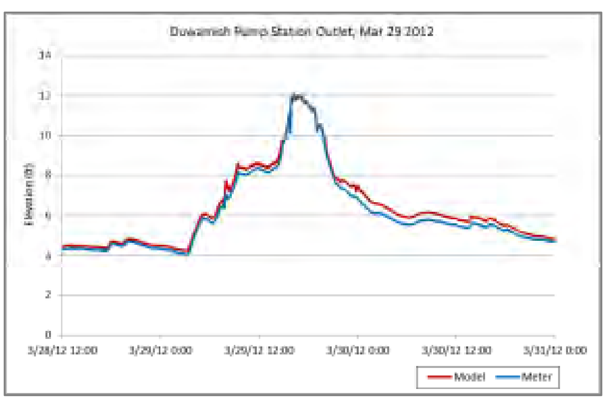
3/16/12 12:00
Model
Meter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Elevation (ft)
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2
4
6
8
10
12
14
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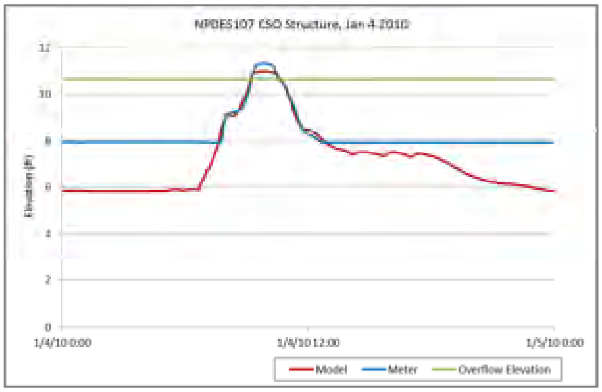
Model
Meter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Elevation (ft)
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2
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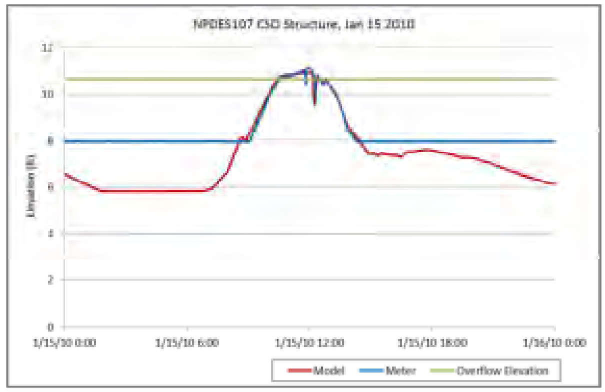
6
8
10
12
1/4/10 0:00
1/4/10 12:00
1/5/10 0:00
Model
Meter
Overflow Elevation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Elevation (ft)
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2
4
6
8
10
12
1/15/10 0:00
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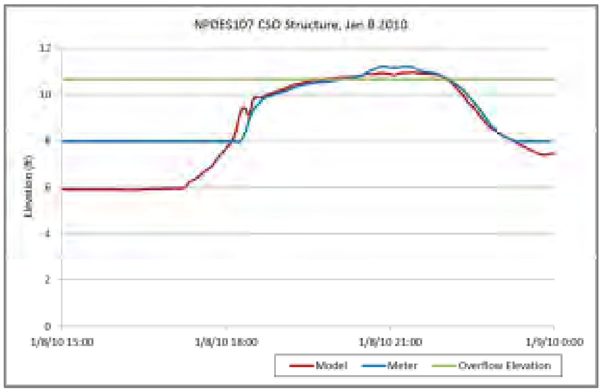
1/15/10 12:00
1/15/10 18:00
1/16/10 0:00
Model
Meter
Overflow Elevation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Elevation (ft)
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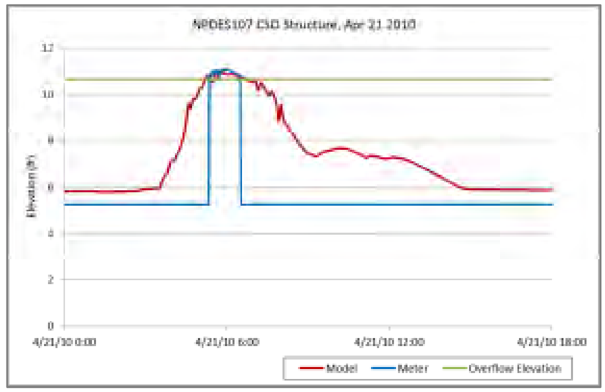
2
4
6
8
10
12
1/8/10 15:00
1/8/10 18:00
1/8/10 21:00
1/9/10 0:00
Model
Meter
Overflow Elevation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2
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6
8
10
12
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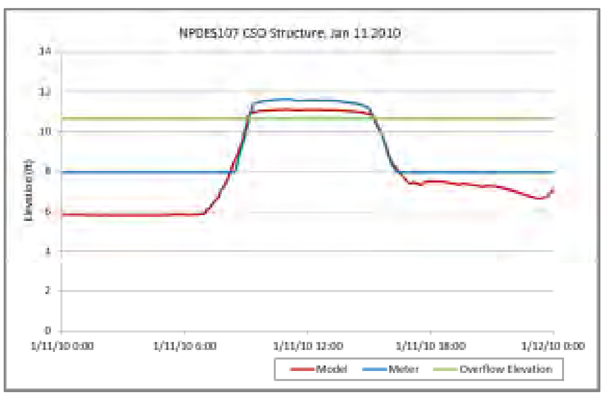
Model
Meter
Overflow Elevation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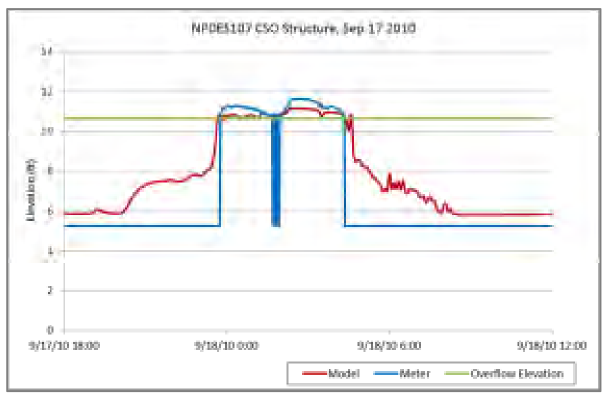
Model
Meter
Overflow Elevation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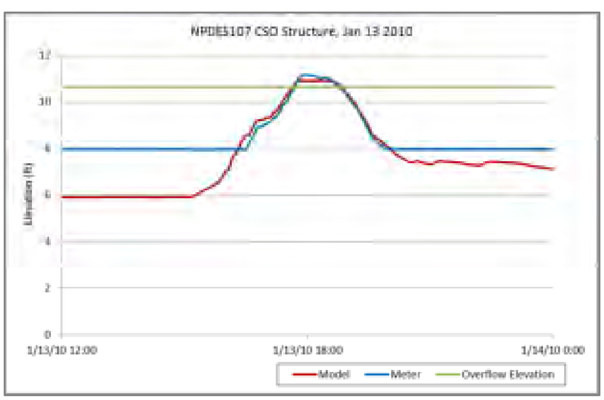
Model
Meter
Overflow Elevation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10
12
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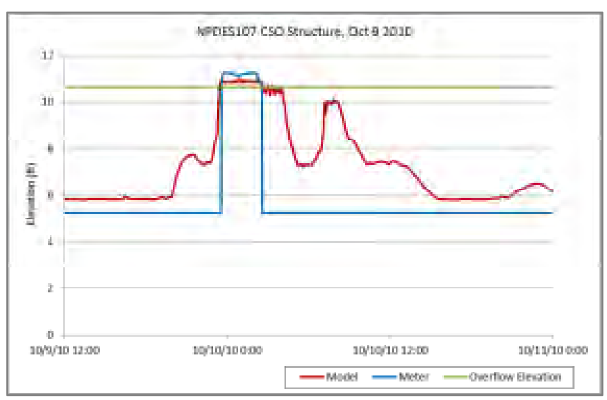
Model
Meter
Overflow Elevation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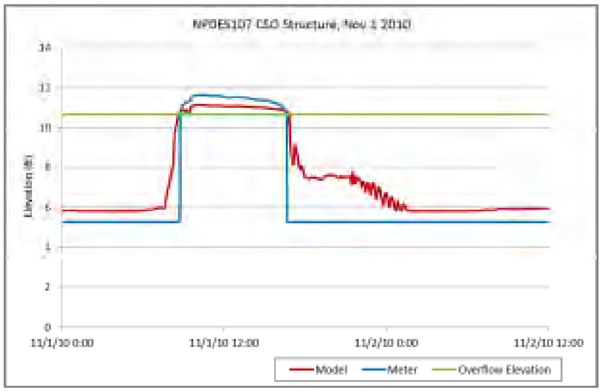
Model
Meter
Overflow Elevation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Meter
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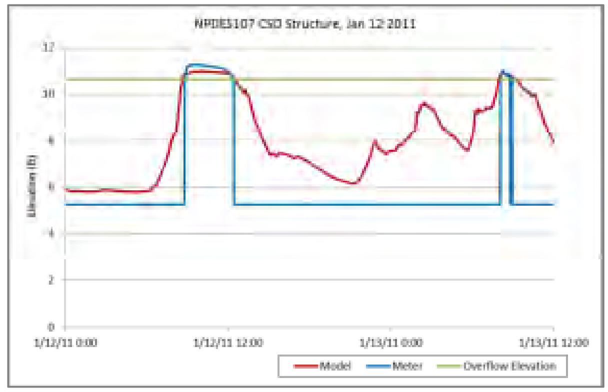
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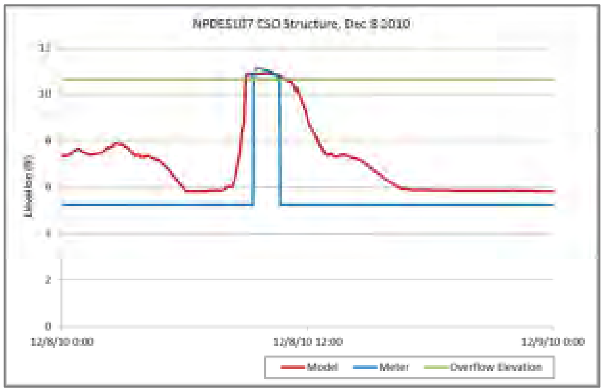
Meter
Overflow Elevation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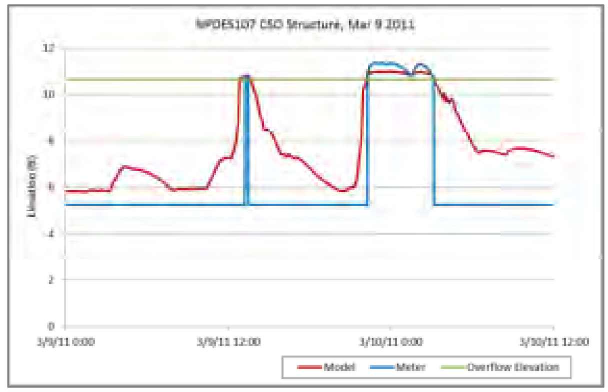
Model
Meter
Overflow Elevation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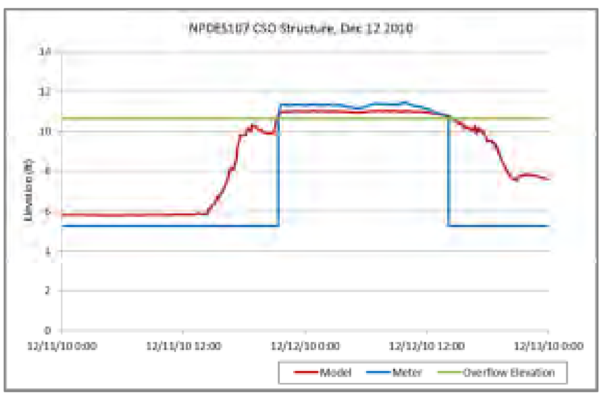
Meter
Overflow Elevation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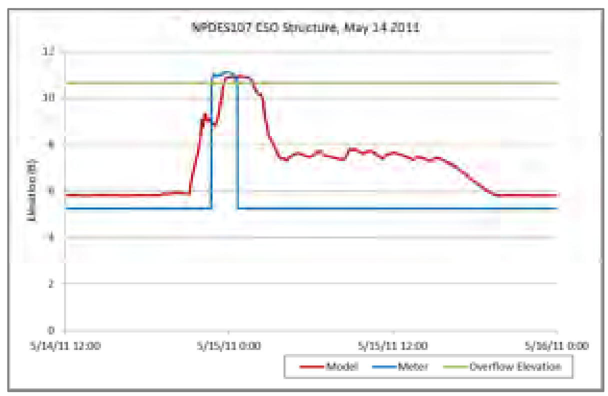
Model
Meter
Overflow Elevation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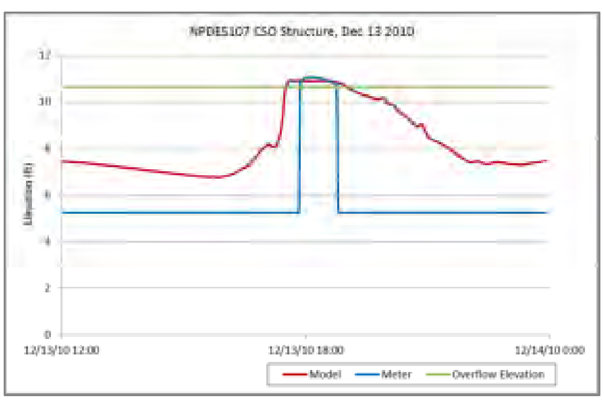
Meter
Overflow Elevation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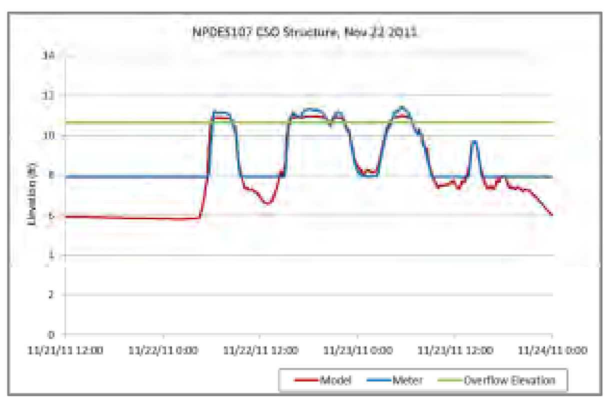
Model
Meter
Overflow Elevation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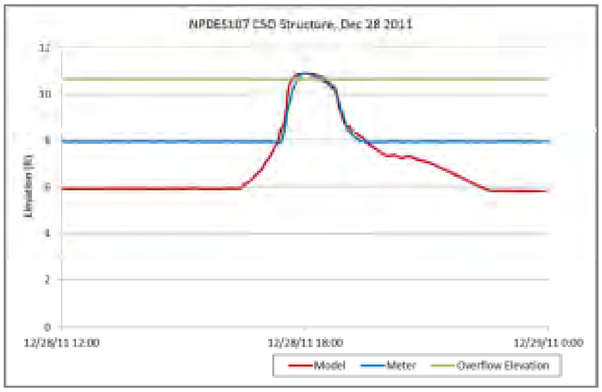
Model
Meter
Overflow Elevation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Elevation (ft)
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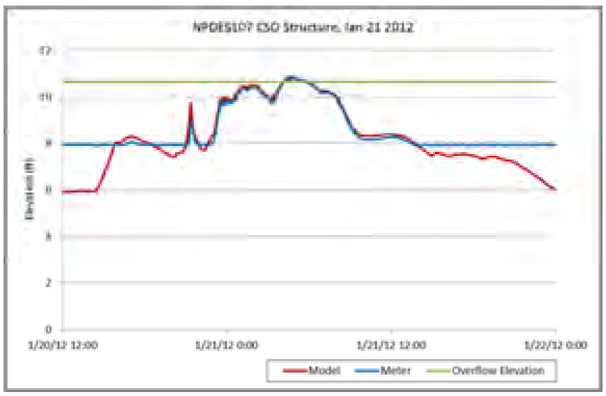
Model
Meter
Overflow Elevation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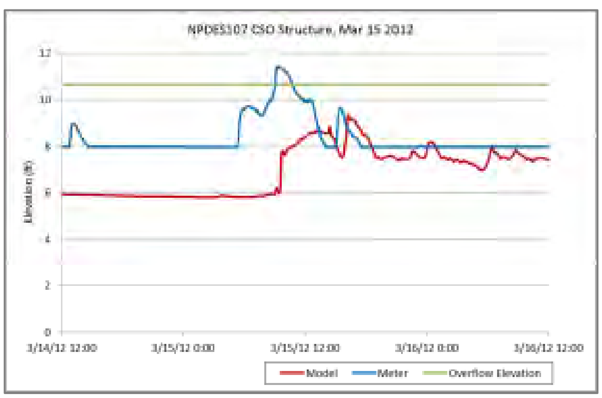
1/22/12 0:00
Model
Meter
Overflow Elevation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8
6
4
2
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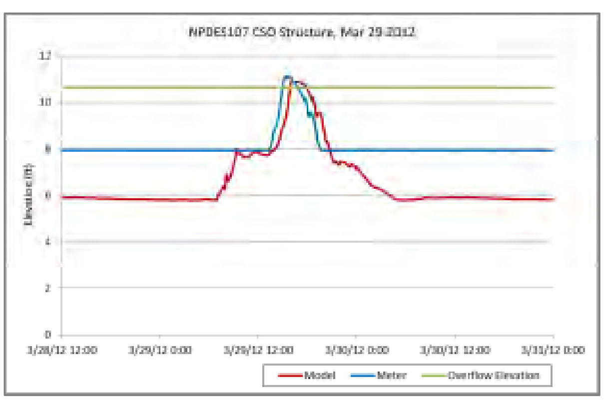
3/15/12 12:00
3/16/12 0:00
3/16/12 12:00
Model
Meter
Overflow Elevation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Elevation (ft)
12
10
8
6
4
2
0
3/28/12 12:00
3/29/12 0:00
3/29/12 12:00
3/30/12 0:00
3/30/12 12:00
3/31/12 0:00
Model
Meter
Overflow Elevation

Seattle Public Utilities

Protecting Seattle's Waterways

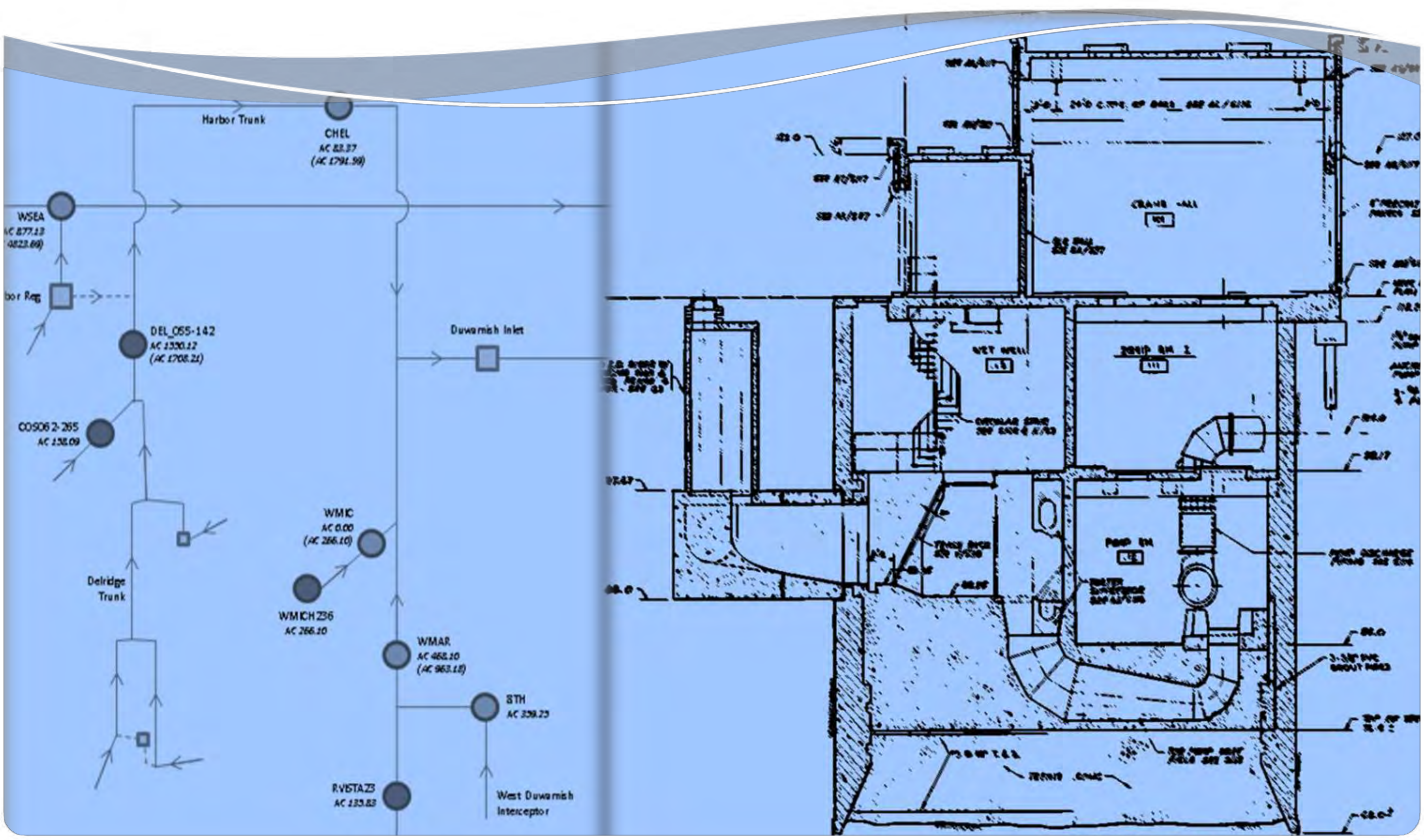
SPU/KC Interceptor Model Calibration

Final Report

(R00-43-15-01)

AQUALYZE

6/12/2013



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Seattle Public Utilities

SPU/KC Interceptor Model Calibration

SPU Contract R00-43-15-01

Final Report

Date: 6/12/2013

Project Manager: Rizwan Hamid, P.E.

Lead Modeler: Andrew Henson, P.E.

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List of Abbreviations

DWF	Dry Weather Flow
EBI	Elliot Bay Interceptor
KC	King County
KCI	King County Interceptor
LCTR	Lake City Tunnel Regulator
MGD	Million Gallons per Day (1 MGD = 694.44 gpm)
MH	Maintenance Hole
NAV88	North American Vertical datum of 1988
NOAA	National Ocean and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
PID	Proportional-Integral-Derivative
PS	Pump Station
QA/QC	Quality Assurance/Quality Control
RTC	Real Time Control
SCADA	Supervisory Control and Data Acquisition
SPU	Seattle Public Utilities
SWMM5	Storm Water Management Model developed by EPA (EPA SWMM 5.0.022)
USACE	United States Army Corps of Engineers
WPTP	West Point Treatment Plant
WSU	Washington State University

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1. Introduction

Seattle Public Utilities (SPU) contracted with Aqualyze, Inc. to build the King County Interceptor (KCI) model in the Environmental Protection Agency's Storm Water Management Model version 5.0.022 (EPA SWMM5). This model contains King County (KC) pipes that collect combined sewer flow from the SPU system and carry it to the West Point Treatment Plant (WPTP) located at 1400 Discovery Park Blvd in Seattle. The WPTP instantaneous maximum capacity is 440 MGD and an average dry-weather flow of 110 MGD (King County 2012)

King County owns, maintains, and operates the major interceptor sewer lines that exist within the Seattle city limits. The collection system is a combination of separated sanitary and combined sewer system. To handle extreme wet-weather peak discharge, several combined sewer overflow (CSO) outfalls are located along way. The KCI system is the primary point of discharge for all of SPU's sewers at various county maintenance hole (MH) locations throughout the City. The hydraulic grade line (HGL) of the interceptor system affects the backwater condition within SPU's sewers which can impact the flow carrying capacities of these pipes. A reliable tool is needed to draw direct correlations between the performance of the interceptor system and its impact on SPU's collection system under any dry-weather or severe wet-weather scenario.

Preliminary hydraulics of the interceptor model were developed as part of an earlier effort (Aqualyze, 2011). The current effort includes development of the tributary basin (primarily the SPU collection system) hydrology within the SWMM5 model. The model hydrology was calibrated against the observed data provided by King County at critical locations throughout the system. The observed data was a combination of temporary flow monitoring conducted by King County and the SCADA data maintained by the County at their regulator and pump stations. Formal data quality review was not within the scope of this project; however, in several cases questionable data were encountered when the basic mass balance principle was violated. Best judgment was practiced in using or discarding such data.

The following sections describe details of the process used in developing an independent and calibrated hydraulic/hydrologic model of the KCI system.

2. Study Area

The project study area encompasses the extents of the KCI system which have a direct influence on the HGL of SPU's collection system. Bounded to the north by the Snohomish/King County limits, east by Lake Washington, west by Puget Sound and south by both the WPTP service area and the City of Seattle limits, approximately 51,000 acres of sewered area comprise the study area seen below in Figure 1. The topography of the project area is very diverse ranging from moderately flat with slopes <2% to severely inclined with slopes reaching 50%, with a variety of land use types including residential, commercial, and industrial.

The majority of the study area is bounded by water on the east and west sides. West Seattle, located in the southwest portion of the study area, is separated from the central portion of Seattle by the Duwamish River. Also, the northern portion of the city is separated from central Seattle by Salmon Bay, Lake Union, Portage Bay, and Union Bay located west to east, respectively. These various bodies of water have different effects on the SPU system depending on their location with respect to the Puget Sound. The Puget Sound and the portion of the Duwamish River included in the study area are both considered to be tidally influenced. Salmon Bay, Lake Union, Portage Bay, Union Bay, and Lake Washington have levels that are directly related to the operation of the Ballard Locks, which are located at the western extents of Salmon Bay below Ballard within the City of Seattle limits.

All flows within the study area flow to WPTP, with the exception of the Henderson/Norfolk area. Located in southeast central Seattle, all dry weather flow (DWF) and a portion of the wet weather flow from this area is diverted through the Allentown Trunk towards the Renton Treatment Plant. The study area does not include WPTP itself however, as modeling of the treatment plant itself is outside of the scope of this project.

The WPTP is situated approximately in the west central portion of the city, therefore the general flow path from areas north of the Ship Canal and Lake Union flow south and west while flows from the south areas generally travel north and west. There are several key pump stations, regulator stations, outfalls, storage facilities, wet weather treatment facilities, and interceptor sections that determine the timing and magnitude of combined sewer flow. The interceptor pipes provide the backbone of the system and provide connection points for SPU's pipe networks. Two key interceptors are the North Interceptor that runs east to west along the north side of the Ship Canal and Lake Union, and the Elliot Bay Interceptor (EBI) that runs south to north beginning in south Seattle and continuing to just past the Interbay PS.

Given such a large service area, several pump stations assist in conveying flow to the WPTP. Flows from the south part of the city are conveyed to WPTP via Duwamish and Interbay pump station. KC has the ability to use these stations to help manage flow and ensure the WPTP does not exceed its capacity.

Figure 1 presents an overview of the study area, highlighting the key locations described above, and Appendix 1 provides a map of all locations.

Figure 1: Project Study Area

3. Data Collection and Analysis

3.1. Flow Data

Monitoring data used for calibration purposes was obtained via multiple sources. Located throughout the study area, flow monitors provided the metered data of collection system flow rates in specific conduits. Additional data from the King County's Supervisory Control and Data Acquisition (SCADA) system was obtained for all the regulator/pump station structures within the system. This provided a wealth of data related to the specific real-time automated operation of these complex hydraulic structures.

3.1.1. Metered Data

Metered data, obtained from King County operations via SPU included flow, depth, and velocity readings in addition to a site sheet with location-specific information regarding meter placement. The monitoring locations for this data were typically located at various connection points from the SPU system into the KC system. This data required some processing in order to be used during calibration (note: full QA/QC of the provided data was outside of the scope of this project). For example, the data sets for some locations were comprised of multiple non-contiguous time series files, each with a varying time step, as well as a mixture of data classification tags indicating quality between raw and final. Furthermore, some data had accounted for Daylight Savings Time (DST) while others did not, which resulted in a data shift that was revealed during processing. Additional unexplained shifts in data, which could not be attributed to DST, were also revealed during processing. All such issues were handled with best engineering judgment for use in calibration. Typically, peaks in flow data were shifted to better correspond with rainfall data and/or with flow patterns of additional meters in the same structure.

3.1.2. SCADA Data

SCADA data, obtained from King County operations via SPU included flow, depth, and gate/valve position readings collected at a loosely defined set of locations for each strategic hydraulic structure. The data tag by which individual time series files were identified corresponded to a particular meter placement within the generalized configuration of each structure. It is to be noted that the tagging scheme varied by structure type: i.e. regulator station versus pump station.

Similarly as with the metered data, some processing of this data was required in order for the information to be useful during calibration (note: full QA/QC of the provided data was outside of the scope of this project). All of the level data provided was in the KC Metro datum, and a conversion factor of -96.4 was used to convert to SPU datum. In some cases the data dropped out for long periods or was obviously incorrect (i.e. flow magnitudes well outside of expected values). Also, the data needed to be shifted to account for DST. These and any other issues encountered were handled with best engineering judgment.

Table 1 provides a summary of data collected for each calibration location. The contributing area from the basin and total, including the upstream tributaries, is also summarized for reference.

Table 1: Flow Monitoring Data Summary

Meter Name	Begin Date	End Date	Basin [Net] Area (Ac)[1]	Tributary [Gross] Area (Ac)[1]
11AVENWCSO	8/31/2009	9/4/2012	1,285.08	3,915.76
30TH	1/1/2010	4/1/2012	1,020.36	2,173.38
53RD	7/1/2010	4/1/2012	1,402.36	1,402.36
8TH	1/1/2010	3/31/2012	359.25	359.25
ARBRETUM	9/1/2009	8/20/2012	692.97	692.97
BALL	1/1/2010	3/31/2012	1,201.70	5,117.46
BARTON PS	9/1/2009	8/9/2012	1,080.42	1,080.42
BEACHCSO	9/1/2009	8/9/2012	497.43	2,544.20
BELV	1/1/2010	4/1/2012	1,153.03	1,153.03
BRAN	1/1/2010	3/31/2012	130.11	185.62
CARK	1/1/2010	4/1/2012	1,962.47	2,630.68
CHEL	1/1/2010	3/31/2012	83.37	1,791.59
COS004-219	6/30/2011	8/13/2012	378.94	378.94
COS005-157	7/21/2011	8/8/2012	386.31	386.31
COS006-204	6/27/2011	8/29/2012	253.44	245.47
COS006-247	6/27/2011	8/29/2012	39.24	39.24
COS015-092	9/1/2009	7/25/2012	142.53	427.24
COS022-209	1/12/2012	9/12/2012	98.64	98.64
COS022-209N	2/17/2012	9/6/2012	26.31	26.31
COS023-066	12/8/2011	9/12/2012	56.87	56.87
COS056-166	4/27/2012	9/6/2012	536.95	536.95
COS062-265	12/14/2011	9/5/2012	158.09	158.09
COS063-059	7/14/2011	9/6/2012	55.51	55.51
DEL_055-142	11/25/2011	4/27/2012	1,550.12	1,708.21
DENL	1/1/2010	3/31/2012	216.99	216.99
DENU	1/1/2010	3/31/2012	976.16	1,529.36
DEXT	1/1/2010	3/31/2012	630.61	630.61
DUWA	1/1/2010	3/31/2012	1,238.68	6,884.22
EMAR	1/1/2010	3/31/2012	902.15	902.15
GLAKELU4B-02	6/30/2011	8/13/2012	1,349.67	1,317.16
GLAKELU6-02	6/29/2011	8/13/2012	855.20	2,551.30
HANF	1/1/2010	3/31/2012	521.12	2,819.72
HEND	1/1/2010	3/31/2012	826.78	826.78

Meter Name	Begin Date	End Date	Basin [Net] Area (Ac)[1]	Tributary [Gross] Area (Ac)[1]
HFORDS04	9/30/2009	8/29/2012	1,333.91	1,333.91
HNFORD200	10/21/2010	9/12/2012	1,599.59	2,298.60
INTE	1/1/2010	3/31/2012	1,452.33	20,401.46
KING	1/1/2010	3/31/2012	137.75	137.75
LAN2	1/1/2010	3/31/2012	617.31	1,951.22
MATT	1/1/2010	4/1/2012	8,093.95	10,531.61
MICH	1/1/2010	3/31/2012	999.97	999.97
MONT	1/1/2010	3/31/2012	656.06	2,404.55
MURR	1/1/2010	3/31/2012	966.36	2,046.78
NBCHW	9/1/2009	8/15/2012	668.21	668.21
NORF	1/1/2010	3/31/2012	0.00	3,997.91
RAIN	1/1/2010	3/31/2012	699.01	699.01
RVISTA23	7/16/2009	8/8/2012	135.83	135.83
SLKCT004	8/1/2009	8/15/2012	1,629.96	1,424.98
SMAGCSO1	9/1/2009	9/4/2012	586.19	586.19
SWLKWASH	9/1/2009	8/20/2012	1,055.51	1,055.51
THORN001	9/8/2009	8/15/2012	4,370.94	4,366.76
UNIV	1/1/2010	4/1/2012	1,692.24	6,896.99
VALLEYCON	9/1/2009	9/12/2012	553.19	553.19
WMAR	1/1/2010	3/31/2012	468.10	963.18
WMIC	12/1/2010	3/31/2012	0.00	266.10
WMICH236	8/6/2009	8/13/2012	266.10	266.10
WSEA	1/1/2010	4/1/2012	877.13	4,823.69
WWTP	1/1/2010	3/31/2012	4,356.65	50,854.64

[1] Basin and Tributary Areas determined from GIS shapefiles of basin delineations provided by KC via SPU. Basin boundaries were revised where necessary and the area was recomputed

Figures 2-1 through 2-4 present the connectivity of pump stations, regulator stations, and additional flow monitors used in calibration. The system is broken down into 4 quadrants (NE, NW, SE, & SW) with each quadrant shown on a separate sheet. Tributary basin areas corresponding to Table 1 are summarized along with key interceptor labels for reference. These schematics were developed to better understand the inter-connectivity of meters and basins. Figure 3 presents the same locations on the map in real coordinates.

Figure 2-1: Flow Monitoring Schematic (NE)

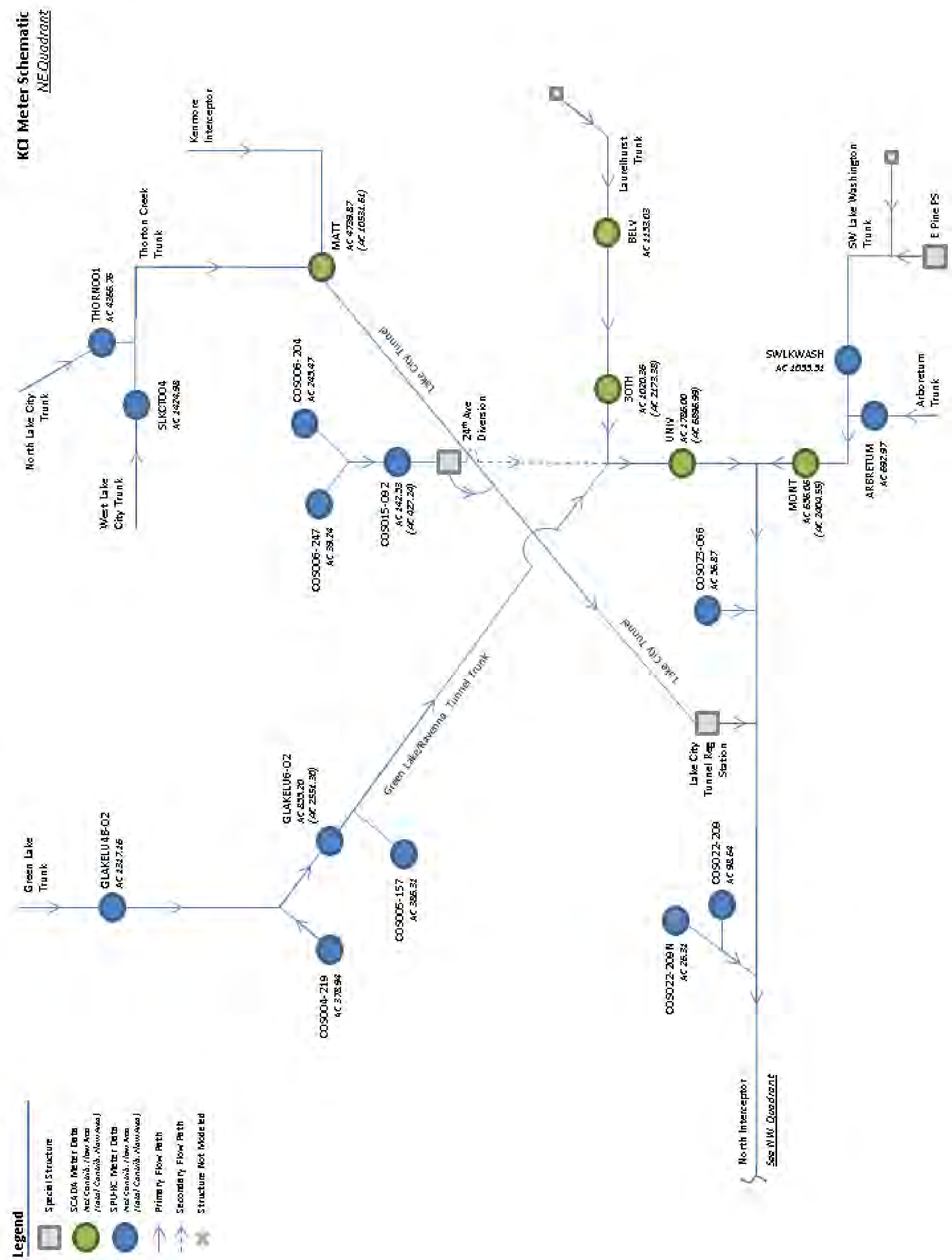


Figure 2-2: Flow Monitoring Schematic (NW)

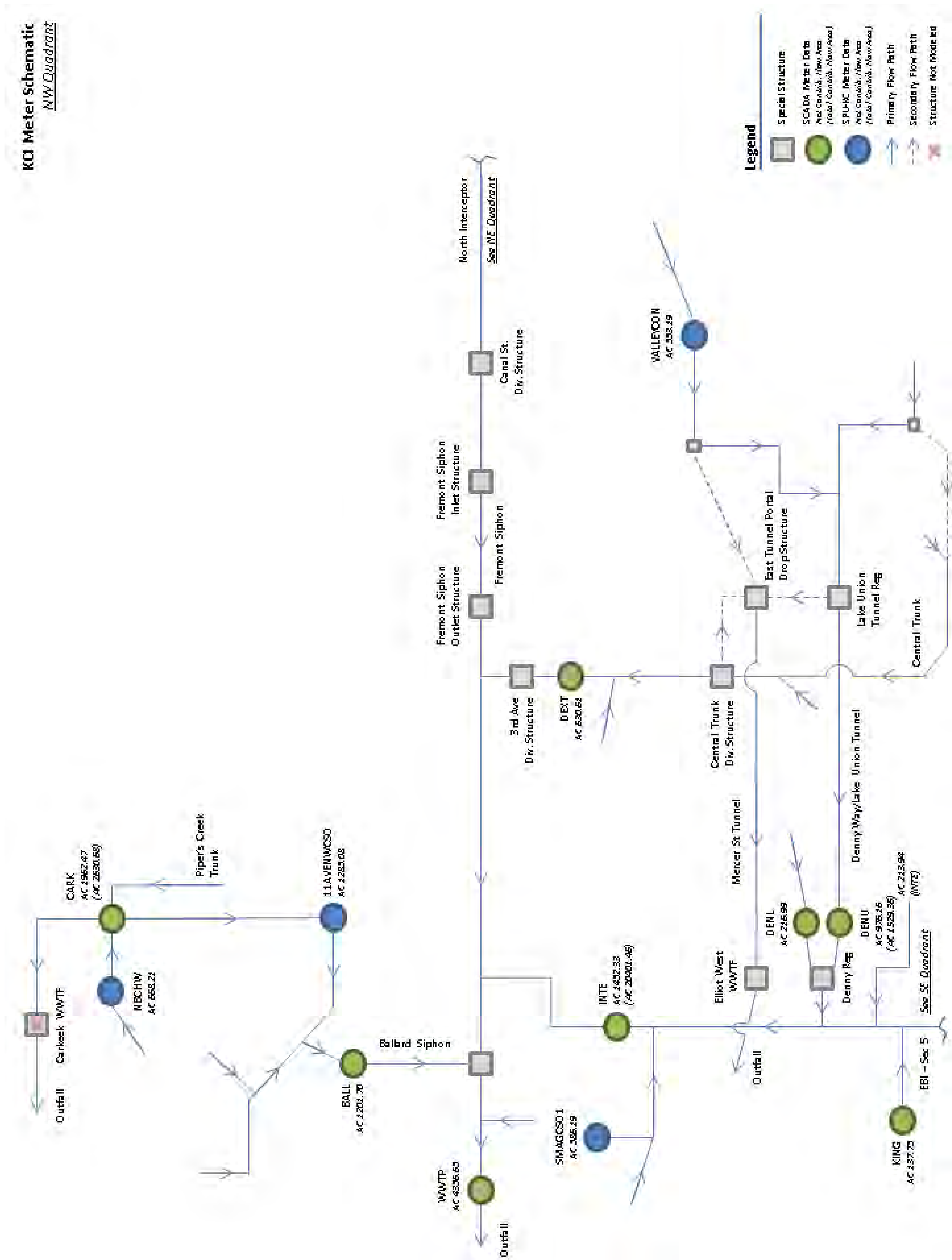


Figure 2-3: Flow Monitoring Schematic (SW)

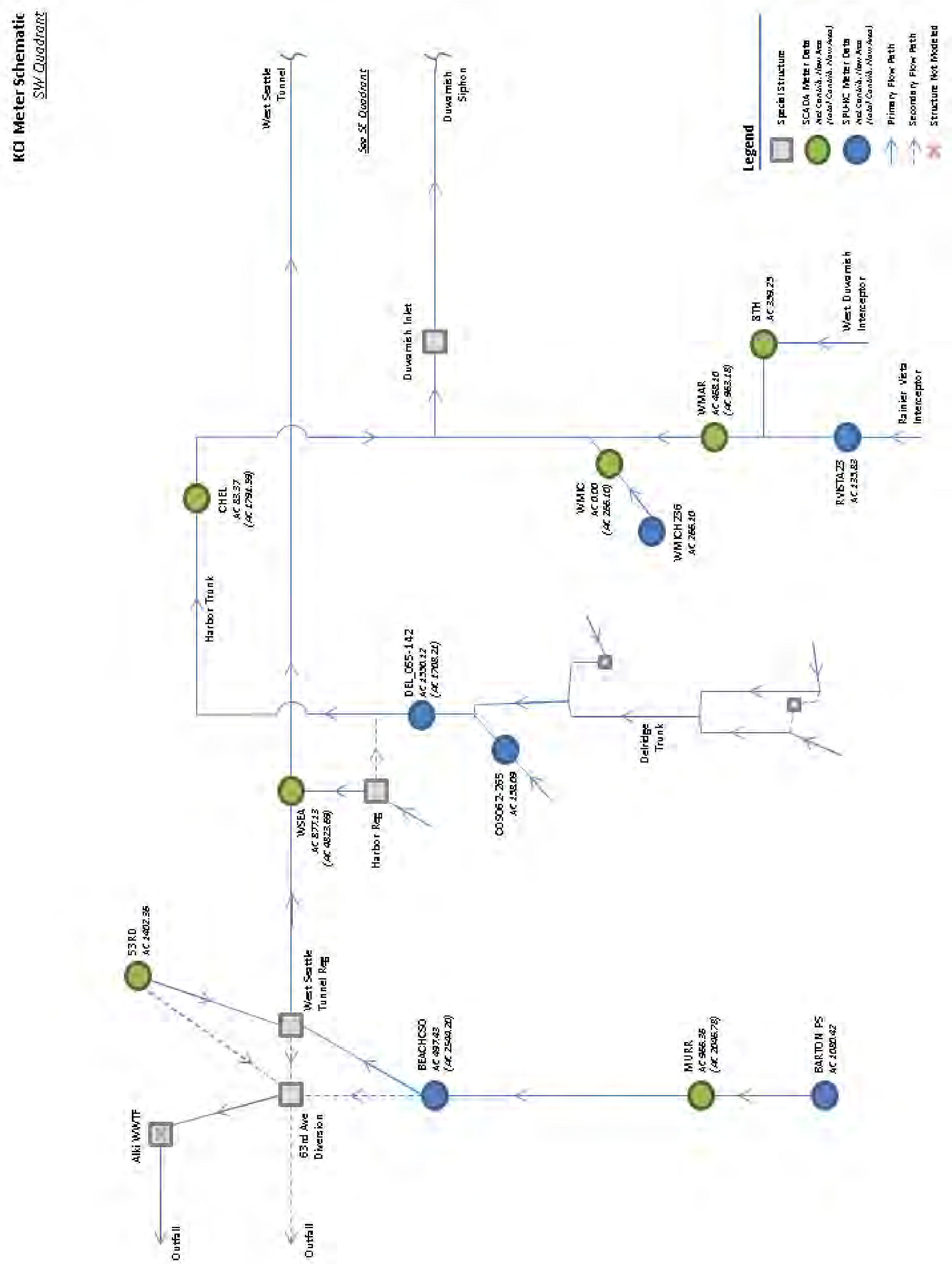


Figure 2-4: Flow Monitoring Schematic (SE)

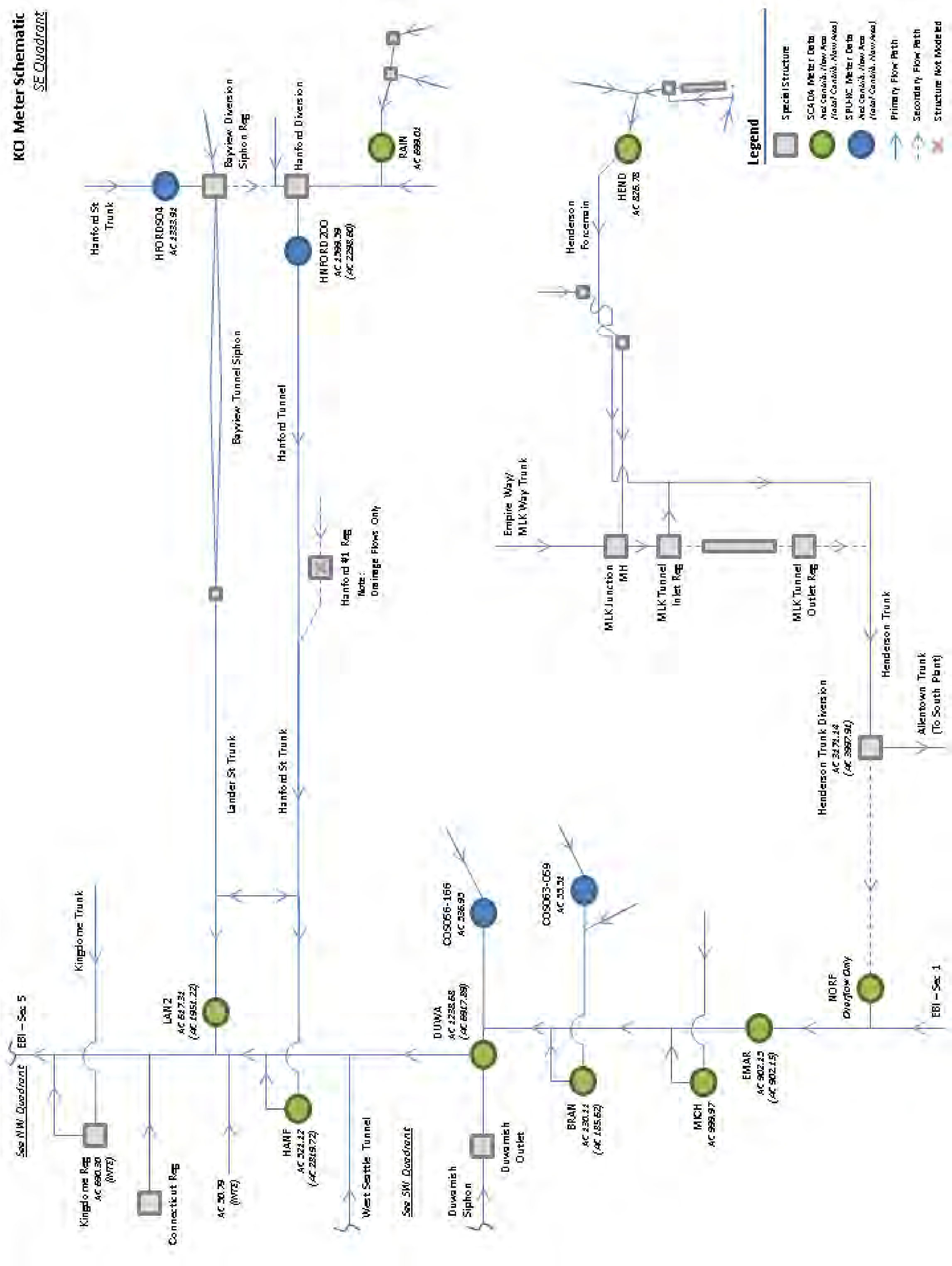


Figure 3: Flow Meter Location Map

N:\Projects\SPU\R00-43-15-01\TM\Figures\Figure2-MeterLocationOverview.mxd

3.2. Rainfall Data

Rainfall data from SPU rain gages was used as the precipitation input for the model. SPU maintains a network of 17 rain gages located throughout the city. Thiessen polygons, based on the location of each rain gage, were created in order to associate the sub-catchments in the model with the appropriate gage. SPU initially provided the rainfall data, and it was supplemented as needed with information obtained from FlowWorks at the following website: www.flowworks.com (requires login access). The data gathered from the FlowWorks website was in 1 minute increments which were then converted to 5 minute time steps for use in the model. The units for all rainfall data is in inches. Table 2 provides a list of all the rain gages used as well as their sampling locations.

Table 2: Rain Gage Summary

Rain Gauge Name	Location
RG01	Haller Lake Shop
RG02	Mathews Beach Pump Station
RG03	UW Hydraulics Lab
RG04	Maple Leaf Reservoir
RG05	Fauntleroy Ferry Dock
RG07	Whitman Middle School
RG08	Ballard Locks
RG09	Woodland Park Zoo
RG10[1]	Rainier Elementary
RG11	Metro-KC Denny Regulating
RG12	Catherine Blaine Jr.
RG14	West Seattle High School
RG15	Metro-KC Diagonal Pump
RG16	Metro-KC E Marginal Way
RG17	West Seattle Engr. Shop
RG18	Hillman Engr. Shop
RG25[2]	Garfield Community Center

1 RG10 not used in model as majority of coverage area is outside of model extents. RG18 data used for those subcatchments that are near RG10

2 RG20 was replaced with RG25 in 2009

Note – all rain gage files contain data from 9/1/2008 to 12/1/2012

3.3. Other Data

The following sections discuss other data types used in the model.

3.3.1. Boundary Conditions

The model contains outfalls that represent discharges into bodies of water surrounding the study area. Each of these outfalls is assigned a time varying boundary condition of stage versus time to account for downstream water surface elevations that might influence model behavior. The main bodies of water are Puget Sound, Lake Washington, the Ship Canal, Lake Union, and the Duwamish River.

The United States Army Corps of Engineers (USACE) controls the levels of Lake Union, Lake Washington, and the Ship Canal at the Ballard Locks on a yearly cycle that ranges between 16.75 and 18.75 feet. The data for the outfalls into these water bodies, which are publicly available, were obtained from the USACE. The raw data was adjusted to the North American Vertical datum of 1988 (NAV88) by subtracting 3.25 feet.

The levels in Puget Sound and the Duwamish River are tidally influenced. The National Ocean and Atmospheric Administration (NOAA) has a monitoring station located in Puget Sound that records the water level. Time varying elevation data was obtained from the NOAA website (NOAA). This website contains information for NOAA station 9447130 located in Puget Sound. The data was downloaded in the NAVD88 datum for local time.

In addition, Puget Sound and a portion of the Duwamish River are salt water and the water produced by the model is hypothetically fresh water. Because the density of salt water slightly differs from that of fresh water, the relative head seen by the model differs between the two types of water. Therefore, the salt water level data needed to be converted to an equivalent fresh water level for use in the model. This conversion, shown in Appendix 2 as provided by SPU, takes into account the ratio of the two densities as well as the difference between the depth of the outfall compared to the water level. Thus, each outfall in these two water bodies is assigned a unique level data time series. An access database was developed to convert the raw data to an appropriate outfall boundary condition.

3.3.2. Evapotranspiration

Evapotranspiration data is also utilized during model simulation. Washington State University (WSU) collects and maintains the data in daily total inches at the Puyallup, WA campus. SPU provided the original time series which was supplemented as needed with from the Washington Agricultural Weather Network Version 2.0. The data was downloaded from the Washington State University website.

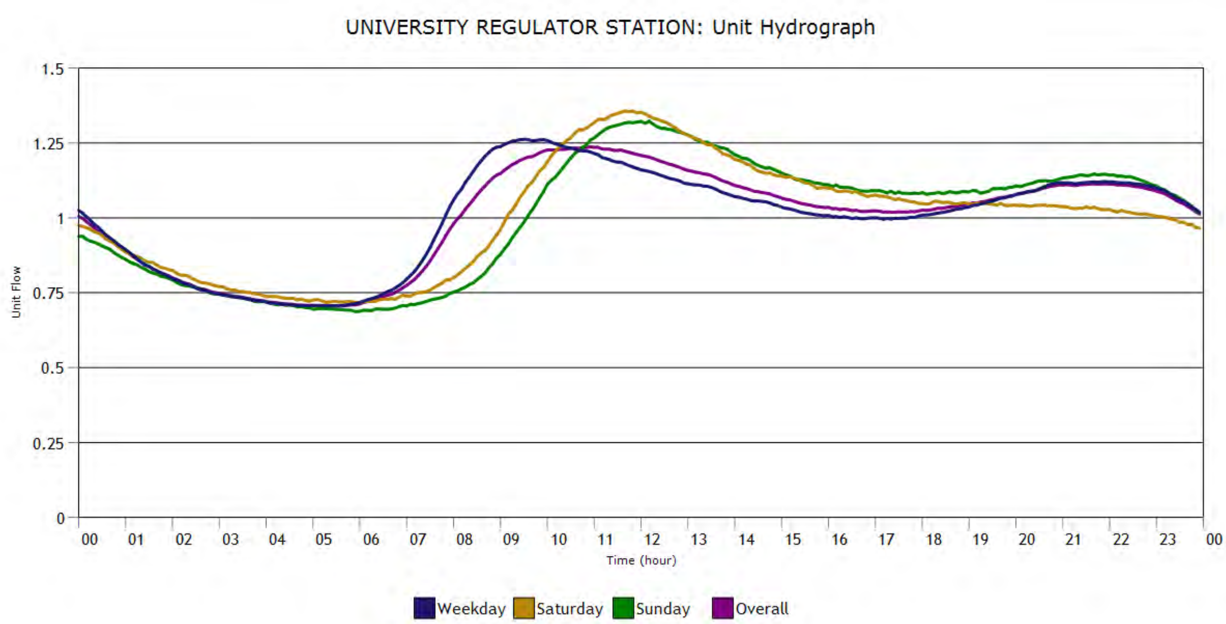
3.4. Dry Weather Flow (DWF)

The DWF component of flow is a relatively small part of the total flow that represents the diurnal fluctuations of the average DWF over the course of a day. The DWF averages and 24-hr patterns were derived from each location used in calibration. Flow analysis of the observed data was performed using Aqualyze, Inc.'s QP Manager software to determine DWF average flow and pattern for 56 monitored locations. QP Manager is a propriety software package designed to manage and process large amounts of flow and rainfall data, and provides tools to analyze dry and wet weather data. A DWF period was selected for each monitoring and SCADA location available. The time patterns and average DWF rates derived from each flow monitoring location were assigned to the appropriate upstream nodes in the model to depict dry-weather flow.

Using the schematic shown in Figure 2-1 through 2-4, flow balance was performed using the average DWF rate by meter basin to ensure data quality and consistency. Flow balancing is a process to check for flow continuity at a given location such that the total average flow entering a facility adds up to the stored plus the flow leaving the facility. There were instances when this principle was not satisfied. In such instances a DWF rate was computed by using a DWF unit rate by acreage (gallon per day per acre) of the upstream meter multiplied by the tributary area of the meter in question.

Figure 4 presents an example of the time pattern at the University Regulator Station using SCADA data. A spreadsheet of patterns used in the model is provided as part of Appendix 3.

Figure 4: DWF Pattern



4. Model Development

4.1. Hydraulics

A preliminary hydraulic model of the combined sewer network (pipes, manholes, and special structures) maintained by KC that lies within the Seattle city limits was previously built in the EPA SWMM5 platform by Aqualyze (Aqualyze, 2011). The construction of this model utilized as-built data provided by KC and SPU to supplement the SPU GIS data and add detail to KC special structures located in the system. A listing of all special structures is provided in Appendix 4 and as-built drawings in Appendix 5 (digital). The KC system was initially determined by the “OWNER” field in SPU’s “dwumnl” GIS layer. All nodes and links maintained the SPU GIS id (S_IMSID or D_IMSID). As the hydraulics were refined using the aforementioned as-built data, pipes owned by SPU were added where needed for modeling purposes (i.e. in order to properly load a sub-catchment). Significant updates were required in order to depict the real time control (RTC) operations of the KCI system.

Prior to the current effort, Brown& Caldwell (B&C) refined the original model hydraulics as necessary. These refinements included adding SPU system pipes to allow for proper sub-catchment loading, as well as flow control operation settings at all regulator stations and pump stations with input from KC.

Under the current contract, Aqualyze received the B&C refined model and added further refinements as seen fit based on the following:

- Available meter data required the addition of SPU pipes in order to utilize the data for model calibration
- Flow control settings were either missing or working improperly (i.e. regulator sluice gate showing instability)
- SPU special structures located near the KC system had direct influence on system operation (i.e. nearby SPU NPDES overflow location reduced peak flows during large events or SPU pump stations effected flow rates)
- Model behavior during calibration suggested hydraulics were incorrect, in which case further as-built data was requested from SPU

Every effort was made to indicate the hydraulic refinements in the “description” field in the SWMM5 .inp file using the flowing format: “AQ (mm/dd/yyyy): refinement description and source (modeler initials)”.

Table 3 summarizes the hydraulic structures contained in the model. The table also summarizes the structure type and description. Appendix 1 provides a full-size map of the KCI service area identifying the key locations.

Table 3: Model Hydraulics Summary

Structure ID	Description	Structure Type
WMICH	W Michigan Street Regulator	Regulator Station
8TH	8th Avenue Regulator	Regulator Station
CHEL	Chelan Avenue Regulator	Regulator Station
HARB	Harbor Regulator	Regulator Station
WSEAREG	West Seattle Regulator	Regulator Station
HFORDST1	Hanford Street Regulator #1	Regulator Station
HFORDST2	Hanford Street Regulator #2	Regulator Station
LAN2	Lander Street Regulator #2	Regulator Station
DENL	Denny Way Local Regulator	Regulator Station
DENU	Denny Lake Union Regulator	Regulator Station
CONN	Connecticut Street Regulator	Regulator Station
KDOM	Kingdome Regulator	Regulator Station
LUTREG	Lake Union Tunnel Regulator	Regulator Station
KING	King Street Regulator	Regulator Station
BALL	Ballard Regulator	Regulator Station
UNIV	University Regulator	Regulator Station
MONT	Montlake Regulator	Regulator Station

Structure ID	Description	Structure Type
DEXT	Dexter Avenue Regulator	Regulator Station
LCTR	Lake City Tunnel Regulator	Regulator Station
BRAN	Brandon Street Regulator	Regulator Station
MICH	S Michigan Street Regulator	Regulator Station
MLKIN	MLK Tunnel Inlet Regulator	Regulator Station
MLKOUT	MLK Tunnel Outlet Regulator	Regulator Station
NORF	Norfolk Regulator	Regulator Station
WMAR	West Marginal Way PS	Pump Station
BART	Barton Street PS	Pump Station
MURR	Murray Street PS	Pump Station
WSEAPS	West Seattle PS	Pump Station
53RD	53rd Avenue SW PS	Pump Station
RAIN	Rainer Avenue PS	Pump Station
PS005	46th Avenue South PS (#005)	Pump Station
INTE	Interbay PS	Pump Station
EWPS	Elliot West PS	Pump Station
PS077	32nd Avenue W PS (#077)	Pump Station
30TH	30th Avenue PS	Pump Station
BELV	Belvoir PS	Pump Station
PS007	East Lee Street PS (#007)	Pump Station
EPINE	East Pine PS	Pump Station
MATT	Matthews Park PS	Pump Station
NBPS	North Beach PS	Pump Station
CARK	Carkeek PS	Pump Station
DUWA	Duwamish PS	Pump Station
DUWAPS	Duwamish PS	Pump Station
EMARPS	East Marginal Way PS	Pump Station
HENDPS	S Henderson Street PS	Pump Station
MATTDIV	Matthews Park CSO Diversion	Diversion Structure
BEACHDIV	Beach Drive SW Diversion	Diversion Structure
BAYVDIV	Bayview Diversion Overflow Structure	Diversion Structure
HANFDIV	Hanford Diversion	Diversion Structure
BAYVSIPIN	Bayview Diversion Siphon Inlet Stucture	Diversion Structure
MAGDIV	Magnolia Diversion	Diversion Structure
AWV069	Overflow Structure 069	Diversion Structure

Structure ID	Description	Structure Type
AWV070	Overflow Structure 070	Diversion Structure
VALLEYSTDIV	Valley Street Diversion	Diversion Structure
EPINEDIV	Overflow Structure 027	Diversion Structure
USDENUDIV	Steward Street/Denny Way Diversion	Diversion Structure
BALLUSDIV2	Overflow Structure 150	Diversion Structure
BALLUSDIV1	Overflow Structure 152	Diversion Structure
NBUSDIV	North Beach PS Inlet Diversion	Diversion Structure
FREM147DIV1	Overflow Structure 147A	Diversion Structure
FREM147DIV2	Overflow Structure 147B	Diversion Structure
FREM174DIV	Overflow Structure 174	Diversion Structure
FORTLAWT	Old Fort Lawton Tunnel Bypass	Diversion Structure
USMURRDIV	Overflow Structure 090	Diversion Structure
HFORD04DIV	Upstream Hanford Diversion	Diversion Structure
24THAVEDIV	24th Avenue Diversion	Diversion Structure
PS7DIV2	Overflow Structure 025	Diversion Structure
PS7DIV1	Overflow Structure 024	Diversion Structure
CENTDIV	Central Trunk Diversion	Diversion Structure
DEXCSODIV	Dexter Avenue Diversion	Diversion Structure
11TH	11th Avenue Diversion	Diversion Structure
CARKBYPAS	Carkeek Influent Bypass	Diversion Structure
3RDAVEW	3rd Avenue W Diversion	Diversion Structure
CANALST	Canal Street Emergency Diversion	Diversion Structure
DUWAW	Duwamish Siphon Inlet Structure	Diversion Structure
DUWAE	Duwamish Siphon Outlet Structure	Diversion Structure
HENDDIV	Henderson Trunk Diversion	Diversion Structure
047DIVC	Overflow Structure 047C	Diversion Structure
BELVDIV	Overflow Structure 015B	Diversion Structure

4.2. Hydrology

The earlier version of the KCI model included the hydraulics and input hydrographs as provided by the County. Each hydrograph represented the flow generated by the tributary basins that were loaded in the model. The limitation of such a model is that it is dependent upon the method that generates the hydrographs, which in this case were various models maintained by King County. In order to be independent of the County hydrographs, hydrology of the tributary basins needed to be included in the model. Once the hydrology is included in the model and calibrated to observed data, the KCI model becomes a stand-alone tool for SPU to use for any time period for which the precipitation records are available. The following sections describe the model setup to include its own hydrology.

4.2.1. Sub-basin Delineation

King County's sewer basin delineation was used as a starting point to add hydrology to the KCI model. These included 372 basins within the SPU service area contributing to the KCI system, and another 25 basins serving areas outside the SPU service area but flowing into the KCI system running through the City. These basins comprised the tributary subcatchments in the model, and were loaded at 182 maintenance holes (MH).

Some modifications were made when these basins were converted to the model subcatchments. These include minor basin boundary revisions, separating the building areas as separate subcatchments, and extending the subcatchments into SPU's service area.

The basin boundaries were revised in cases where the obvious discrepancies were found using SPU's GIS data of the collection system. There were cases where the hydraulics were extended upstream into the SPU system to account for SPU's NPDES outfalls. In such cases the basin boundaries were refined as needed. Some key locations where this was done include Ballard, Windermere, Leschi, Genesee, Henderson, and Delridge.

Each subcatchment was divided into two components: catchment (C) and building (BLD). In the model, the C subcatchment is represented as the actual polygon shape according to King County delineation, and the BLD subcatchment as a square. The C subcatchments represent areas contributing overland sheet flow while the BLD subcatchments represent direct connection of roofs to the combined sewer system. Areas corresponding to the BLD within each subcatchment were computed and then subtracted from the total catchment area to determine the area of the C subcatchment.

In addition to the daily wastewater flow, the collection system is subjected to infiltration and inflows from combined, partially combined, and separated basins. The City's service area is a combination of combined, separated, and partially combineds systems. For combined basins, both types of subcatchments within the basin were directly connected to the sewer system, while for partially combined basins only the BLD subcatchments were directly connected to the sewer system. This leaves the subcatchments in the fully separated basins entirely disconnected from the sewer system. The reason for including these subcatchments in the model is their indirect contribution to groundwater infiltration. Each subcatchment is connected to an underlying aquifer, the properties of which control the vertical rise and fall of the groundwater table. Once the groundwater table reaches an assigned threshold elevation for the subcatchment, the flow is introduced into the sewer system as groundwater infiltration.

4.2.2. Parameter Estimation

The key subcatchment hydrologic input parameters include total area, percent imperviousness, average slope, hydraulic width, Green-Ampt infiltration parameters, and groundwater parameters. Some parameters were calculated utilizing available GIS information while others were inferred from previously calibrated models as part of other SPU projects.

In order to model the wet weather response to the sewer system, several surface and sub-surface parameters were computed as initial estimates that were used during model calibration. Table 4 summarizes these parameters, along with the source of initial value used in the model.

Table 4: Initial Estimates of Subcatchment, Groundwater, and Aquifer Parameters

Parameters	Source of Initial Value
Total Area (acres)	Computed using basin boundaries in GIS
Percent imperviousness	Computed using total area, building footprints, ROW boundaries, and aerial ortho imagery in GIS. For previously calibrated areas, average value was inferred.
Overland flow width (ft)	Computed as a function of total area. For previously calibrated areas, average value was inferred.
Average slope (%)	Computed using and overlay of 2-ft contours and basin boundaries in GIS
Pervious and impervious depression storage (inch)	Assumed SWMM5 defaults
Threshold elevation at which groundwater infiltration is allowed (ft)	Inferred from monitoring MH per LTCP protocols
Green-Ampt infiltration parameters	Average of typical value weighted by soil type from SPU's geology layer.
Groundwater flow equation's coefficient and exponent	1 for both A1 and B1 as a starting value and 0 for the rest.
Soil porosity (fraction)	Average of typical value weighted by soil type from SPU's geology layer.
Hydraulic Conductivity (in/hr)	Average of typical value weighted by soil type from SPU's geology layer.
Lower groundwater loss rate (in/hr)	10% of conductivity value
Conductivity	Average of typical value weighted by soil type from SPU's geology layer.
Conductivity slope	1 as a starting value
Tension slope	120 as a starting value
Upper Evaporation Fraction	0.1 as a starting value
Lower Evaporation Depth	0 as a starting value
Field capacity	Average of typical value weighted by soil type from SPU's geology layer.
Wilting point	Average of typical value weighted by soil type from SPU's geology layer.
Initial water table elevation	1 foot below monitoring MH invert
Aquifer bottom elevation	Same as initial water table elevation
Unsaturated zone moisture	Same as field capacity

5. Model Calibration

Model calibration is the process of adjusting or determining model parameters to simulate observed system behavior and obtain a good match. The following data sources were used during calibration:

- KC SCADA Data for regulator structures, pump stations, and key locations throughout the system (see section 3.1.1 for more information)
- Flow meters installed by KC at select locations within the SPU system (see section 3.1.2 for more information)
- Precipitation data from SPU rain gages (see section 3.2 for more information)

Typically, the model was calibrated to the provided flow data and the other data types (depth, gate positions, etc.) were used for validation and/or to assist in determining system operation (e.g. using gate position to determine a control rule setting). The following sections cover the calibration process and results.

5.1. Calibration Methodology

The model parameters primarily used in calibration include the following:

- Subcatchment percent imperviousness
- Subcatchment threshold elevation at which groundwater infiltration is allowed (ft)
- Groundwater flow equation's coefficient and exponent
- Aquifer lower groundwater loss rate (in/hr)
- Aquifer conductivity slope
- Aquifer bottom elevation

For detailed explanation of these parameters, refer to EPA SWMM5 User's Manual (EPA, 2010).

A sub-model was created based on each data sampling (metered or SCADA) location that contained the tributary sub-catchments and hydraulic structures. This simplified the calibration process by isolating calibration parameters to a particular location and greatly reducing model run times. The most upstream data sampling locations were calibrated first. If a sampling location had an upstream flow monitor (Figure 2-1 through 2-4), then the upstream location was calibrated first.

Model calibration is an iterative process. Once the parameters of interest were selected, they were adjusted to best match the observed flow at every data sampling location (metered or SCADA). The surface runoff parameters were first adjusted, followed by the groundwater infiltration parameters. Surface runoff parameters, such as the percent imperviousness, dictate the peak flows. The initial values as computed from GIS were used as the starting point (in some cases, weighted parameters from previously calibrated models were used as a starting point). Based on over- or under-prediction for a given flow monitoring location (metered or SCADA), these values were adjusted by fixed percentages for all tributary subcatchments until an approximate match was obtained.

The next step was to focus on the groundwater infiltration component. This component primarily impacts the recession limb of the hydrograph and the behavior between storm events, and to a lesser degree the peak flow. While instantaneous peaks are important when looking at an independent sharp storm event, the infiltration component is equally important when looking at back-to-back storms. A storm of moderate intensity during elevated groundwater period can conceivably have a greater impact on flow in the system than a high intensity storm during a dry period. Therefore, it is important to depict the groundwater infiltration patterns in continuous simulations.

For combined or partially combined subcatchments, the percent imperviousness directly impacted the peak flow. For separated system subcatchments, percent imperviousness indirectly impacted the groundwater infiltration with the increase or decrease in pervious area. The shape of the groundwater infiltration was controlled primarily by the conductivity slope of the aquifer and the groundwater flow equation's exponent. The conductivity slope is defined as the slope of log (conductivity) versus the soil moisture deficit curve. Higher values of either parameter stretch the infiltration curve out longer. The threshold elevation controlled the volume of groundwater infiltration allowed into the sewer system. The higher the threshold elevation the more the aquifer has to fill before infiltration is introduced into the sewer system.

Storm events for the rainfall data were established for rain gages associated with the monitoring location. Once a good visual correlation was noted, indicating that the flow trends correlated with the input rainfall and were within the same order of magnitude as the observed flow values, it was considered a draft calibration point with the option to refine parameters further during the calibration of downstream meter locations.

The model was run from September of 2009 to March of 2012 with the first year dedicated to building up the antecedent conditions (spin-up time). Storm events ranging from September of 2010 to March of 2012 were analyzed during calibration. System flow response at particular sampling locations was analyzed for approximately fifteen different storm events during the calibration process. Storms ranged in intensity, magnitude and durations. The largest event by total rainfall was the December 11, 2010 storm with 3.43 inches of rainfall over 24-hours at RG25. This is approximately a 50-year recurrence interval storm per Table E-18 in Appendix C of SPU's Stormwater Manual (SPU 2009). The largest event by peak intensity was the March 8, 2011 storm with peak intensity of 1.92 in/hr at RG25. This translates to approximately a 4-year recurrence interval for the 5-min rainfall time step, per Table 5 in Appendix C of SPU's Stormwater Manual (SPU 2009). The rainfall statistics are expected to be different at different stations due to spatial variability. RG25 was used for these statistics due to its central location.

5.2. Calibration Results

The KCI model was calibrated at 56 locations throughout the system. A systematic process was used involving groupings of sub-models from upstream to the downstream as described in section 5.1. Table 5 summarizes the key subcatchment parameters after calibration. Adjustments were made to the preliminary estimates of these parameters. Refer to section 4.2.2 for parameter estimation process.

The average building imperviousness used for the whole system is 52.5%, ranging from 15.0% to 100.0%.

The average catchment imperviousness for the whole system is 29.2%, ranging from 7.0% to 75.3%. The low imperviousness values indicate uncertainty in the actual connectivity of building within individual basins versus what is understood from SPU's GIS data that was used to categorize basins into separated, combined, or partially combined.

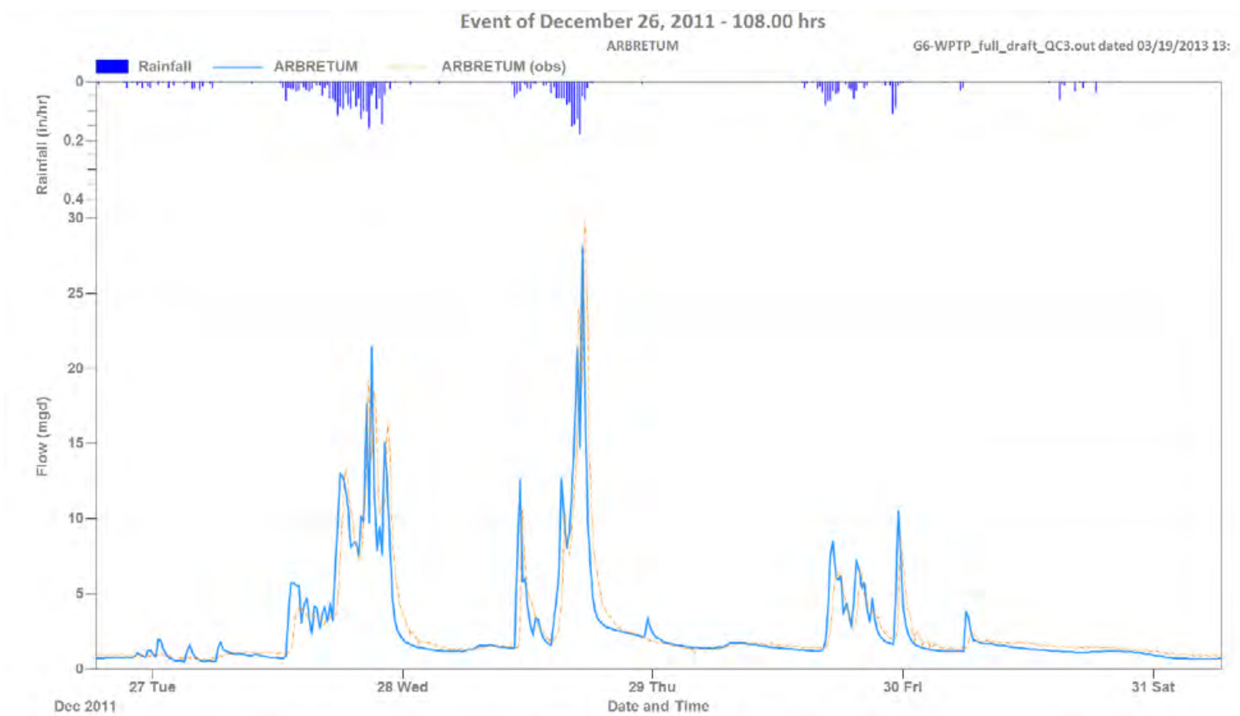
Table 5: Average Calibrated Parameters by Calibration Location

Meter Basin	BLDG Avg. Impervious (%)	BLDG Avg. Width (ft)	BLDG Avg. Slope (%)	C Avg. Impervious (%)	C Avg. Width (ft)	C Avg. Slope (%)
11AVENWCSO	40	1179	20.00	30	2048	7.80
30TH	30	116	20.00	31	240	4.10
53RD	22	972	22.22	31	2645	6.86
8TH	31	639	20.00	24	1709	1.63
ARBRETUM	75	875	40.00	21	2291	7.80
BALL	80	359	40.00	33	1267	6.24
BARTON PS	69	1857	19.10	13	2453	6.98
BEACHCSO	26	1158	20.00	16	2907	4.76
BELV	30	957	20.00	19	2366	5.80
BRAN	60	880	20.00	50	1266	0.25
CARK	66	1857	35.00	22	4850	4.22
CHEL	90	528	40.00	57	1376	7.40
COS004-219	36	1307	20.00	16	3141	2.80
COS005-157	60	1249	20.00	25	2860	2.75
COS006-204	30	559	20.00	27	2315	3.85
COS006-247	50	619	20.00	27	1152	3.20
COS015-092	40	773	20.00	27	1548	3.05
COS022-209	58	1000	20.00	7	730	5.70
COS022-209N	50	516	40.00	10	300	5.70
COS023-066	55	789	20.00	39	400	6.50
COS056-166	38	239	20.00	45	494	2.50
COS062-265	100	924	20.00	19	2782	7.70
COS063-059	66	831	40.00	66	1763	1.00
DEL_055-142	53	418	40.00	21	1236	6.13
DENL	64	1552	40.00	25	3444	8.30
DENU	79	1334	34.35	50	2678	5.11
DEXT	63	763	40.00	45	1625	5.79
DUWA	40	523	20.00	35	1993	3.15

Meter Basin	BLDG Avg. Impervious (%)	BLDG Avg. Width (ft)	BLDG Avg. Slope (%)	C Avg. Impervious (%)	C Avg. Width (ft)	C Avg. Slope (%)
EMAR	58	326	20.00	30	726	0.64
GLAKELU4B-02	76	1001	35.00	24	2838	2.03
GLAKELU6-02	30	919	20.00	24	1012	2.88
HANF	50	780	20.00	44	1759	1.84
HEND	22	1219	20.00	17	3211	5.40
HFORDS04	15	323	20.00	20	2515	1.87
HNFORD200	47	1294	20.00	27	4504	3.37
INTE	74	607	25.68	56	1446	4.78
KING	75	1581	6.10	75	1867	6.10
LAN2	50	909	20.00	19	2754	1.45
MATT	80	1067	40.00	23	3129	5.51
MICH	35	747	20.00	31	1868	2.09
MONT	42	593	39.11	23	1452	5.81
MURR	30	1314	20.00	24	3339	5.60
NBCHW	43	713	15.00	27	3328	6.46
NORF	51	926	29.52	27	2625	5.20
RAIN	37	1059	20.00	25	2868	4.20
RVISTA23	40	952	20.00	21	2612	5.00
SLKCT004	71	1203	37.14	25	3103	3.90
SMAGCSO1	40	1233	20.00	25	2807	5.40
SWLKWASH	68	426	40.00	25	1066	11.55
THORN001	75	1074	39.13	23	3008	3.23
UNIV	50	832	39.04	37	1946	4.70
VALLEYCON	57	297	20.00	22	713	7.30
WMAR	60	550	20.00	42	1438	3.72
WMICH236	46	649	30.00	18	2506	6.70
WSEA	71	893	26.66	30	2575	10.28
WWTP	40	682	21.05	23	1706	8.00

As described in section 5.1, up to 15 storm events were analyzed during the calibration process. Three storms at each calibration location were plotted along with peak flow and volume statistics, including the percent difference between the observed and predicted values. Total rainfall depth in inches and peak rainfall intensity in inches/hour for the corresponding storm event are also shown on the figure for reference. Figure 5 shows an example plot. Appendix 6 presents three plots per calibration site similar to Figure 5. Each set of plots is preceded by a cover sheet summarizing key information about the calibration location including location ID, description, corresponding model conduit, data source, net basin area, and cumulative contributing area.

Figure 5: Typical Calibration Plot (ARBRETUM Meter)



	Rainfall	Calibrated	Observed	% Difference
Peak Value	0.18 in/hr	28.12 MGD	29.82 MGD	-5.72
Total Value	1.30 in	11.88 MG	12.41 MG	-4.33

The target of +20% match on peak flow and total volume is consistent with SPU's LTCP model calibration protocols. A summary of percent difference between observed and predicted peak flow and volume for each event at every calibration location is provided in Appendix 7. Average of the 3 storms is also presented. Out of 56 locations only 3 locations did not satisfy an average percent difference of +20% for peak flow, and 10 locations did not satisfy the same for total volume.

6. Discussion

The following sections provided in-depth discussions of the calibration process at several key locations throughout the system. Each section discusses the location of the regulator/pump station, upstream areas and their land-use make-up, data used in calibration, issues with data quality, and other specific information relevant to modeling and calibration.

6.1. Norfolk Regulator Station

The Norfolk Regulator Station (NORF) is located west of the Henderson area at the intersection of E Marginal Way S and S Norfolk Street directly under Boeing Field International Airport. NORF is a unique structure in that it only sees flow during peak storm events with all normal dry weather flows being diverted south to Renton Treatment Plant via Allentown Trunk. King County's Henderson Trunk Diversion (WE*HNDRSON.ALLENTOWN)/(SPU MH 305-018) sees flow from approximately 20,402 acres of combined, partially combined, and separated sewer system. Though Renton Treatment Plant receives the DWF component for essentially the entire southeastern densely populated portion of Seattle, the area, its hydrology and its hydraulics have been modeled to the best of their ability on par with the remainder of the model rather than creating on large lumped basin to simulate flows and loading directly at the Henderson Trunk Diversion. The predominant land use is single-family residential throughout the Henderson area continuing west towards NORF. The key upstream tributary structures include Henderson Trunk Diversion, Henderson/MLK Treatment Facility which is comprised of the Tunnel Inlet Regulator, Tunnel Outlet Regulator/Treatment Plant, and Tunnel Drain Plug Value, as well as Henderson Avenue PS (HEND). See Figure 2-4 for reference to understand the flow paths and connectivity.

The upstream model was calibrated at HEND and sub-models were used in creation and refinement of flow controls at MLK Tunnel. The tributary areas as well as additional contributing upstream meters for each of these locations are presented in Figure 2-4. A SPU diversion structure located at the intersection of Rainer Avenue S and S Henderson Street and its associated outfall (NPDES 047C) was added during calibration to act as a loading point for the Dunlap and lower Rainier Valley flows and to account for the attenuation in peak flows experienced at the MLK Tunnel Inlet Regulator due to SPU's outfalls. Dry weather flow for the NORF meter basin was computed using the basin loading rate (gallon per day per acre) and pattern from the HEND basin since they have similar land use.

NORF experiences higher than expected influent flows in the model due to upstream over-prediction in the Henderson Trunk which in turn causes issues with upstream controls, specifically at the MLK Tunnel Inlet Regulator. This over prediction can be attributed to lack of upstream flow meter data to calibrate upper tributary basins as well as the complex hydraulic controls implemented at various structures in the vicinity of the Henderson/MLK Treatment Facility. During calibration, every effort was made to accurately model the crucial hydraulic components of the treatment facility. As-built drawings and SPU side sewer cards were used along with available level and gate position SCADA data to represent the actual configuration, operation, and subsequent hydraulic effect on the SPU and KCI systems.

NORF consists of two effluent sluice gates and one storage junction (WE*HNDRSON.NORFOLK)/(SPU MH 304-017); both sluice gates, modeled as orifices, are controlled by RTC rules. NORF itself is a rather simple structure, overflows from the Henderson Trunk Diversion travel through an 84-inch circular pipe entering the 340-sqft 14.23-ft deep regulator storage at an offset of 5.3-feet from the chamber bottom. Once in the regulator, flow can leave via either the 24-inch circular regulator sluice gate offset 4.8-ft or during an overflow event through the 4.5-ft wide by 4-ft tall rectangular overflow sluice gate offset 1-ft. The regulator sluice gate acts as the primary flow path for any overflows from the Henderson Trunk Diversion, discharging into Section 1 of the EBI. The overflow sluice gate acts as the secondary flow path with the downstream EBI at capacity. King County CSO Reports 2010 and 2011 (King County 2012) report zero overflows at NORF. However, as a result of over-prediction in upstream tributary basins and other hydraulic complexities, the NORF overflow sluice gate opens more frequently in the model than documented.

The SCADA data used to calibrate NORF was first analyzed to determine the most suitable SCADA Tag. The two SCADA tags considered for calibration were trunk flow and regulator diverted flow. Due to unique downstream hydraulic configuration, Interceptor Flow was not able to be accurately used for calibration; additionally data was suspect. Due to its unique configuration and flows, as well as its use as a dummy overflow in the model, NORF was ultimately calibrated using Trunk Flow SCADA data to refine the regulator sluice gate and in-turn the effluent flow discharged into the EBI. See Appendix 8 for SCADA data explanation.

6.2. Chelan Regulator Station

The Chelan Regulator Station (CHEL) is located in the West Seattle area near Chelan Avenue SW and north of the West Seattle Bridge. CHEL is served by approximately 1,792 acres of combined and separated sanitary sewers. The predominant land use is single-family residential with some industrial areas in the north. The key upstream tributary area includes the Delridge basin, and some portion of the Harbor Regulator. See Figure 2-3 for reference to understand the flow paths and connectivity.

The model was calibrated at two locations upstream of the regulator station. These included MH 062-265 that serves approximately 158 acres and MH 055-142 that serves approximately 1,584 acres. Tributary to MH 055-142 are SPU's NPDES basins 168, 169, 170. The KCI model was extended into the SPU's system to include the two storage tanks for NPDES basins 168 and 169. In the absence of these tanks, along with their hydraulic controls, the model would over-predict the flow coming to CHEL due to the lack of storage and CSOs occurring in the Longfellow Creek under large storm events. The Delridge basins were calibrated at MH 055-142 prior to calibrating CHEL. Area tributary to MH 055-142 was also calibrated. No usable SCADA data was available for Harbor Regulator Station, which could not be calibrated independently.

CHEL receives flow through a 54-inch pipe into a storage junction approximately 120 sq-ft in area. During normal operations the flow exits the structure through a 30-inch pipe towards the Duwamish Pump Station. A 54-inch weir and a 54-inch rectangular sluice gate at CHEL are located to transfer the flow to the CSO outfall when the head at the influent node (MH 055-319) cannot be held at 12.6-ft (City of Seattle datum).

The SCADA data used to calibrate CHEL was first analyzed to determine the most suitable SCADA Tag. Appendix shows a sampling of various data tags available for CHEL. Under dry weather conditions the Trunk Flow and the Interceptor Flow don't match. Since no flow is going to the outfall under dry conditions, and there is no additional contribution before the Interceptor Flow, the two were expected to match. Judgment had to be used to determine the most suitable data Tag to be used. Based on upstream contributions and downstream flow balance requirements, the Interceptor flow was considered more valid and was used to determine the dry weather flow and pattern, and was also used in calibration.

6.3. West Seattle Pump Station

The West Seattle Pump Station (WSEA) is located in the West Seattle area Harbor Avenue SW across from the Port of Seattle. WSEA serves approximately 4,824 acres of combined sewer system. The predominant land use is single-family residential. The key upstream tributary structures include Barton Pump Station (PS) (BART), Murray PS (MURR), 53rd Avenue PS (53RD), 63rd St PS (63RD), and portions of the Harbor Regulator Station (HARB). See Figure 2-3 for reference to understand the flow paths and connectivity.

The upstream model was calibrated at BART, MURR, 53RD, and the BEACHCSO flow monitoring location at MH 060-002. The tributary areas for each of these locations are presented in Table 1. 63RD and HARB SCADA data was deemed unreliable and these basins were lumped with WSEA during calibration. The 63RD St PS is a complex structure and sends flow to two outfalls and the Alki Treatment Facility. Since the flows going to treatment and outfalls do not impact the downstream system, via West Seattle Tunnel, the model was simplified (See Appendix 8).

WSEA receives flow from the 114-inch West Seattle Tunnel and a 54-inch pipe from HARB into a storage junction approximately 144 sq-ft in area and eventually to 360 sq-ft and 36-ft deep wet well via 48-inch pipe. WSEA is equipped with 4 pumps that are included in the model; however, the pump station is modeled using a single equivalent pump curve derived from the SCADA data.

The SCADA data used to calibrate WSEA was first analyzed to determine the most suitable SCADA Tag. There were only two SCADA data Tags available for WSEA; total station flow and force main flow. The total station flow was used to determine the dry weather flow and pattern, and was also used in calibration (Appendix 8).

6.4. Duwamish

Located in the south central area of the SPU service area, the Duwamish Pump Station serves approximately 6,884 acres of a wide variety of flow types and land uses. The key tributary areas upstream include flow from the Elliot Bay Interceptor (EBI) Section 3, the Duwamish Siphon that carries flow from West Seattle, and from SPU's service area in the Duwamish basin. Based on the available SCADA data, the pump station has a maximum pumping capacity of approximately 78 MGD. See Figure 2-3 for reference to understand the flow paths and connectivity.

The Duwamish Pump Station consists of three pumps, a wet well, and an incoming modulated sluice gate. The station pumping capacity is represented by only one pump in the model for simplification. As the inflow to the pump station exceeds pumping capacity and the water surface in the wet well rises, the influent gate begins to close once the set point is reached. This results in water backing up into the upstream system and is necessary because no overflow structure exists at the pump station. SCADA data for the gate position was available and was used in determining gate operation. The data indicates that the gate rarely closes all the way and the set point location was assumed based on the available data.

SCADA data was used as the source for calibration. In general, the data quality showed good wet weather response. However, when conducting flow balance with SCADA data from adjacent special structures, the SCADA data at the Duwamish pump station for total flow seemed to slightly under-predict, especially for dry weather flow. Therefore, the DWF rate for the areas directly tributary to the Duwamish PS were determined in the flow balance exercise as opposed to directly from the SCADA data.

The influence of the sluice gate was one of the major challenges for the Duwamish Pump Station calibration. When this gate closes the upstream system has a tendency to flood. However, if the gate were not present in the model, too much flow would be sent downstream and cause calibration issues at the next special structure which is the Hanford Regulator 2. A balance between the two was achieved.

6.5. Lander2/Hanford2 Regulator Stations

Hanford #2 Regulator Station (HANF) and Lander #2 Regulator Station (LAN2) are located close to each other in the Central District and directly impact each other through their operations. HANF is located near East Marginal Way S and S Hanford Street while LAN2 is located just a few blocks north near Colorado Avenue S and S Lander Street. HANF serves approximately 2,820 acres of combined sewer system with single-family residential land use east of Interstate 5 (I-5) and industrial area west of I-5. LAN2 serves approximately 1,951 acres of similar land use. The key upstream tributary structure to HANF includes the Ranier Ave PS (RAIN) that serves the Genesee basin of SPU's system. See Figure 2-4 for reference to understand the flow paths and connectivity.

The upstream model was calibrated at RAIN and two other flow monitoring locations: HFORDS04 at MH 052-090 and HNFORD200 at MH 058-103. The tributary areas for each of these locations are presented in Figure 2-4. Since SPU's NPDES basins exist upstream of RAIN, the model was extended into the SPU's system in include SPU's PS#5 and its associated CSO outfall to collectively account for CSOs from SPU's NPDES basins.

HANF and LAN2 receive flow from the Hanford Tunnel and Bayview Tunnel Siphon respectively. The pipe leading to HANF is at 150-inch x 100-inch Arch and the one leading to LAN2 is a 96-inch. A 48-inch pipe on Occidental Avenue S between S Lander St and S Hanford ST connects the two systems hydraulically.

A 48-inch x 48-inch sluice gate controls the flow to the Elliott Bay Interceptor (EBI) from HANF. The operation of this gate is controlled through a PID setting to maintain a head of 4.5 ft (City of Seattle datum) in the EBI at MH 050-096. The 150-inch x 100-inch Arch pipe, upstream of HANF, extends to the CSO outfall where 144-inch x 96-inch sluice gate controls the flow going to Puget Sound. The operation of this gate is controlled through a PID setting to maintain a head of 9.7 ft (City of Seattle datum) at MH 050-101 which is the influent junction to HANF.

A 24-inch x 48-inch sluice gate controls the flow to the Elliott Bay Interceptor (EBI) from LAN2. The operation of this gate is controlled through a PID setting to maintain a head of 6.85 ft (City of Seattle datum) in the EBI at MH 050-072. As this gate closes the flow backs up in the upstream system and flows to HANF via the 48-inch pipe down Occidental Avenue S. A 50-ft overflow weir also exists on the influent side of LAN2 at an offset of 8.5 ft, which is above the crown of the influent pipe. This weir acts as a relief measure and discharges excess flow to the drainage system, and was modeled as free outfall for the purpose of this project.

The SCADA data used to calibrate HANF was first analyzed to determine suitable SCADA Tags. The regulator diverted flow tag was used to determine the dry weather flow and pattern, and was also used in calibration (Appendix 8). Other data tags available for HANF included the interceptor flow in the EBI upstream of the HANF discharge point, interceptor flow in the EBI downstream of the HANF discharge point, and the outfall flow. While the model was calibrated to the flow through the regulator, and not the CSOs, the outfall flow was used as a reference during the calibration process. The regulator diverted flow also used to calibrate LAN2. Gate positions and set points were verified in the model using the SCADA data tags to ensure model operations consistent with observations from SCADA (Appendix 8).

6.6. Lake City Tunnel Regulator Station

The Lake City Tunnel Regulator (LCTR) is located on the northeast corner of the intersection of 7th Avenue NE and NE 40th Street in northeast Seattle. The main function of this structure is to regulate flow out of the Lake City Tunnel into the North Interceptor. The Matthews Beach PS contributes the majority of the flow into the tunnel, with smaller flows entering via the Ravenna Ave Connections (SPU MH 015-102). The primary land use of the tributary area is residential with some commercial. See Figure 2-1 for reference to understand the flow paths and connectivity.

The regulator consists of an 8-ft x 8-ft rectangular sluice gate that is controlled by the level on the North Interceptor. The inlet to the regulator gate is at SPU MH 023-265. The Lake City Tunnel is an 8-ft diameter tunnel that stretches approximately 3.3 miles (17,400 feet).

The SCADA data offered limited use for calibration. SCADA data for trunk flow (tag LCTR_FYF818437_VALUE) and trunk diverted flow (LCTR_FYF818436_VALUE) contained similar values. However, when looking at flow balance between the SCADA data for the LCTR and Matthews Beach PS showed the LCTR was much lower (see Appendix 8). Also, calibration was performed at the pump station and upstream of the Ravenna connection. Therefore, the LCTR was not used as a calibration location.

The gate operation still needed to be verified. A PID control rule is used to determine the opening for the regulator gate in the model. In a previous version, a set point elevation of 26.6 at SPU MH 023-261 was specified in the control rule. However, the invert of the manhole is 23.6, which means the LCTR gate was closing when the North Interceptor was less than half full (for reference, the North Interceptor is nine feet in diameter downstream of the LCTR regulator). This suggested that the set point location was incorrect. Based on the set point in SCADA data, it appeared that the gate was controlled by the level in the North Interceptor further downstream near the Fremont Siphon. Unfortunately, repeated model iterations offered limited benefits. It eventually was determined to adjust the set point level until the regulator reacted more reasonably. Even after adjustment of the control rule, flooding occurs at nodes upstream of the LCTR gate under larger storm events. This was determined to be favorable compared to allowing excess flow to enter the North Interceptor. Future recommendations include further refinement of this structure and input from King County as to the exact set point for gate operation.

A SCADA data set contained under the LCTR group was labeled “Fremont Siphon”. Because the exact location of this sapling point was unknown, it was not used as a calibration location but rather as a flow “check” after final model simulations. The data seemed reasonable according to expected flows at the Fremont siphon (approximately 200 MGD during storm events). During larger storm events, the model showed a slight over-prediction at this location, but it was considered within acceptable range

6.7. University Regulator Station

The University Regulator Station (UNIV) is located in the south part of University of Washington near NE Pacific Street just west of Montlake Boulevard NE. UNIV is served by approximately 6,897 acres of combined sanitary sewers and some separated sewers. The predominant land use is single-family residential with some commercial and portions of University of Washington. The key upstream tributary areas to the north include the Windermere basin served by Belvoir PS (BELV), 30th Avenue PS (30TH), and several other flow monitoring locations: GLAKELU4B-02 (MH 232-332), COS004-219 (MH 004-219), GLAKELU6-02 (MH 005-095), and COS005-157 (MH 005-157). See Figure 2-1 for reference to understand the flow paths and connectivity. From the south, additional areas contribute to UNIV including Leschi, Madison Park, and Arboretum basins via the Montlake Regulator Station (MONT). See Figure 2-1 for reference to understand the flow paths and connectivity.

The model was calibrated at each upstream location identified above. Since SPU’s NPDES basins exist upstream of BELV, the model was extended into the SPU’s system in include SPU’s NPDES 15 outfall to collectively account for CSOs from SPU’s NPDES basins in Windermere. Similarly, in the Leschi basin the model extended into the SPU system to include basin NPDES outfalls 024, 025, and 027. Calibration at MONT could not be achieved because of data anomalies in SCADA data. The observed SCADA data did not appear to be valid when flow balance was performed. Therefore, calibration was moved to the next downstream location, which was UNIV.

UNIV receives flow through a 118-inch pipe into a 240-ft long and 138-inch diameter pipe and a storage junction approximately 290 sq-ft in area. During normal operations the flow exits the structure through a 54-inch x 54-inch sluice gate and a 96-inch pipe into the North Interceptor. This gate is operated to maintain a head of 32.35 ft (City of Seattle datum) in MH 024-042 in the North Interceptor. A 60-inch x 60-inch sluice gate controls the flow to the CSO outfall when the head at the influent node (MH 024-039) cannot be held at 39.85-ft (City of Seattle datum).

The SCADA data used to calibrate UNIV was analyzed to determine the most suitable SCADA Tag. Appendix 8 shows a sampling of various data tags available for UNIV. Under dry weather conditions the Trunk Flow and the Interceptor Flow did not match. Since no flow is going to the outfall under dry conditions, and there is no additional contribution before the Interceptor Flow, the two were expected to match. Best judgment had to be used to determine the most suitable data Tag to be used. Based on upstream contributions, the Trunk Flow tag was considered more valid and was used to determine the dry weather flow and pattern, and was also used in calibration.

6.8. Interbay Pump Station

The Interbay Pump Station (INTE) is located just west of the Queen Anne area on W Garfield Street across from Pier 90 at Smith Cove. INTE serves approximately 20,402 acres of combined sewer system, essentially taking flow from the entire southern portion Seattle. The predominant land use is single-family residential from Magnolia to the west and heavy commercial/multi-family residential from Belltown and the Central Business District to the south. The key upstream tributary structures include the Denny Way Regulators (DENU, DENL), Hanford #2 Regulator (HANF), Lander #2 Regulator (LAN2), and Duwamish PS (DUWA). Available SCADA data suggests a maximum pumping rate of approximately 104 MGD. See Figure 2-2 for reference to understand the flow paths and connectivity.

The upstream model was calibrated at SMAGCSO, DENL, DENU, DEXT, KING, LAN2, HANF, and DUWA. The tributary areas as well as additional contributing upstream meters for each of these locations are presented in Table 1. SPU's 32nd Avenue W PS (#077) and its associated outfall (NPDES 064) were added just upstream of King County's Magnolia diversion structure (WW*SMAG.W10-78A)/(SPU MH 026-089) which resides in the same vicinity as the PS during calibration to act as a loading point for upper Magnolia flows. SPU's University Street and Vine Street diversion structures, upstream hydraulics, and their associated outfalls (NPDES 069, 070) were added during calibration to account for the attenuation in peak flows experienced by the EBI due to SPU's outfalls. INTE experiences higher than expected influent flows in the model due to upstream over prediction in the EBI which in turn causes issues with upstream controls, specifically at HANF and LAN2 regulators.

INTE consists of three pumps, a wet well (WW*EBI8.INTERBAY)/(SPU MH 027-130), and an incoming modulated sluice gate. Flow from the 30-inch S Magnolia Interceptor combined with flow from the 102-inch EBI (Section 7) pass through 35-feet of 102-inch circular pipe which enters the 72-inch wide x 102-inch tall influent sluice gate structure before reaching the 432 sq-ft by 12-ft deep wet well. INTE is modeled using a single equivalent pump curve derived from SCADA data. The modeled pumps discharge into two 48-inch force mains which then combine together into one 96-inch gravity main which is Section 8 of the EBI. Though SCADA data for the gate position exists, the control rule was not modeled due to information obtained regarding manual throttling of the sluice gate by operators at WPTP during large storm events which at this point in time does not follow a consistent logic. As a result of disregarding the operation of the influent sluice gate, INTE will consistently pump at a higher rate during storm peak periods due to the lack of influent flow control to the wet well. This creates additional flow in the North Interceptor and WPTP during those times. The effluent flows from INTE are limited by the maximum pumping capacity regardless of the flows allowed into the wet well. As the inflow to the pump station exceeds pumping capacity and the water surface in the wet well rises, water backs up into the EBI and S Magnolia Interceptor because of the lack of overflow structure at the pump station.

The SCADA data used to calibrate INTE was first analyzed to determine the most suitable SCADA Tag. The two SCADA tags considered for calibration were total station flow and force main flow. Total Flow data was questionable due to multiple data dropouts and anomalies. Due to unique influent hydraulic configuration, upstream flow was not able to be accurately used for calibration; additionally data was also suspect. The total station flow was used to determine the dry weather flow and pattern, and was also used in calibration (Appendix 8).

6.9. Ballard Regulator and Siphon

The Ballard Regulator (BALL) is located on Shilshole Ave NW between 20th Ave NW and NW Dock Pl, on the north side of the Ship Canal. The regulator structure (SPU MH 011-248) also serves as the entrance to the Ballard Siphon which carries combined sewer flow from the northwest portion of Seattle and under the Ship Canal. The tributary area of BALL is approximately 5,100 acres consisting primarily of residential land use with some commercial areas. King County special structures tributary to BALL include the 11th Ave CSO, Carkeek Pump Station and WWTF, and the North Beach Pump Station. The main purposed of this structure is to regulate flow into the Ballard Siphon (and in turn the North Interceptor) and provide an overflow location for those times when the system is at or above capacity. The siphon outlet (SPU MH ID 020-152) is located at W Commodore Way between 23rd Ave W and 24th Ave W, on the south side of the Ship Canal. See Figure 2-2 for reference to understand the flow paths and connectivity.

The regulator structure consists of a 48-inch diameter regulator sluice gate, a 48-inch diameter overflow sluice gate, and a 6-ft long overflow weir. In the model, the regulator sluice gate operation set point is at MH 020-152, which is the siphon outlet at the North Interceptor (12' tunnel). The overflow gate is always closed leaving the overflow weir as the primary overflow location. The siphon consists of two-36-inch diameter tubes.

The structures had mixed data quality that could have impacts on predicted flows at BALL. The North Beach PS has two overflow locations, one prior to the station wet well and one at the station wet well. As-built data for the overflow location was not available at the time of model calibration, so this should be considered for future model refinements. Due to the configuration of the Carkeek PS and WWTF, time series needed to be summed in order for use for calibration. Ultimately, the station was calibrated to "Pump Station Discharge" (tag CARK_FB520112) SCADA data. Some flooding is seen in the Piper Creek trunk, which is tributary to the Carkeek PS, during larger storm events. Just upstream of the BALL is the 11th AVE CSO structure. There was a King County meter placed on the upstream side of the structure that provided good data for calibration.

There were several data sources available to use as calibration data for BALL, but most useful were

"Trunk Flow" (tag BALL_FYF815437) SCADA data and the King County meters located in each of the two siphon tubes. During QC of the data sources, it was determined to use the sum of the two siphon meters for dry weather flow calibration and to use trunk flow for storm event calibration. Initial calibration runs were conducted in a model that had an outfall prior to the BALL with a boundary condition applied from available SCADA level data. This offered the advantage of removing influence from the modeled operation of the regulator gate. However, during final calibration and the model was extended to include the North Interceptor, regulator gate operation influences flow in the Ballard Trunk.

In general, model runs for the entire system showed over-prediction in the North Interceptor at the siphon outlet. Because the set point for the BALL at the North Interceptor, over-prediction at this location causes the regulator gate at BALL to close more often than it should. When it closes, flow in the Ballard Trunk slows down and overflows at the weir occur. In this case, it was assumed that additional overflow at Ballard were more desirable than passing additional flow downstream. Therefore, the set point was not revised in order to alter gate operations.

Also included in the SCADA data at BALL were "interceptor flow" (tag BALL_FYF815435) and "upstream flow" (tag BALL_FYF815432), both of which are in the North Interceptor upstream and downstream of the siphon outlet. These locations were not used for calibration, but were used as a final flow "check" once the entire system model was run. The flows in these two data sets appeared reasonable, but after closer inspection indicated that they might be under-reporting. Appendix 8 offers a flow balance look at the incoming structures at this location including BALL, INTE, LCTR Fremont location, and the Dexter Regulator. The sum of peaks and volumes for larger storm events indicates that this is the case.

7. Conclusions and Recommendations for Future Model Use and Updates

The SWMM5 model, calibrated for this project, not only represents the hydraulics of the King County interceptor system in great detail but also includes the service area hydrology. The completion of an independent model that generates its own hydrologic response is a big step forward for SPU to have their own independent tool to assess impacts of KC interceptors on SPU's collection system. The KCI model has been developed and calibrated to SPU's LTCP protocols. The calibration results show similar standards with regard to percent match on peak flow and volume. Furthermore, King County's Storm #6 was routed through the calibrated KCI model as a verification run which showed comparable results to the County's hydrograph. The future user is encouraged to keep the objectives of this project and model limitations in mind when using the KCI model.

As discussed throughout Section 6 of this document, various limitations and uncertainties were faced during the model calibration process. These include SCADA data quality, set points of the regulator stations, lumping of SPU's service area sub-basins, representation of SPU's NPDES outfalls, flow contributions from outside the SPU service area, and manual operations of facilities by the County during large storm events.

Appendix 8 summarizes in detail how the SCADA data at each regulator and pump station was evaluated to determine the most reliable data tag to be used for calibration. It is our understanding that quality control of SCADA data, as well as monitored data provided by King County, was not performed by County staff. The project team performed limited quality control of the data used in calibration. Model calibration was primarily performed using the flow data. Future usage of the KCI model should include model verification using additional monitored data as well as verification of depth or HGL at key locations throughout the system.

Several SPU sub-basins include their own NPDES outfalls. The locations of these outfalls may be relatively close to the KCI connection point or much further upstream in SPU's collection system. Since the basins tributary to various SPU-KCI connection points were modeled as lumped basins, not every SPU NPDES outfall was included in the model. However, disregarding the volume lost to these outfalls can lead to over-estimation of flow entering the KCI system if the KCI model only includes the County-owned pipes. Therefore, the project team extended the KCI model into SPU's system in several cases where SPU's NPDES outfalls were close to the KCI connection point. These basins include Henderson, Genesee, Delridge, Leschi, Central Waterfront, Magnolia, Valley Street Connection, Windermere, Fremont and Ballard. However, the extension into the SPU system did not include every single NPDES outfall, but only those close to the KCI. It should be noted that the primary objective of this project was to develop a system-wide model of the King County Interceptor system and that of the contributing SPU sub-basins. However, future refinements to the model should consider extending the KCI model into the SPU system to pick every NPDES outfall. Effectively, this will mean adding a simplified version of SPU's LTCP and other basin models to the KCI model.

Since the County operates their system with the priority to protect the WPTP, several manual operations take place under large storm events. There are no set rules for such operations and are not included in the KCI model. The model results, when evaluated for such events, should be considered as such.

Due to the uncertainty in the location of regulator station set points, it is highly recommended that a map of exact locations of KC sensors, along with the corresponding control setting, be obtained from the County and updated in the model on a routine basis to keep the model current.

The SWMM5 model and all associated data files to run the model are provided in Appendix 9.

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Appendix C: SPU Financial Capability Assessment

Seattle Public Utilities | Protecting Seattle's Waterways

Long Term Control Plan

Financial Capability Assessment

May 2014

Seattle Public Utilities
Long Term Control Plan
Financial CapabilityAssessment

May 2014

Prepared by:
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SECTION 1

Introduction

1.1 Purpose

This document was prepared in accordance with the July 3, 2014 Consent Decree requirements outlined in Appendix C, LTCP Requirments for a financial capability assessment. The specific requirement is listed in Appendix C, Paragraph C.6 as follows: *"6. The LTCP shall include an evaluation of the City's financial capability to fund the selectedalternative or combination of alternatives, consistent with EPA's February 1997 "CombinedSewer Overflows – Guidance for Financial Capability Assessment and Schedule Development" and relevant financial factors as deemed appropriate by the United States and the State."*

1.2 Introduction

The City began building public sewers in 1882 in order to protect public health and quality of life. Over half of the current system was built in the first three decades of the 20th century, long before sewage treatment was contemplated. Consistent with the then current practice, combined sewers were built to carry both stormwater and wastewater. This practice not only saved the expense of building a second pipe, it also provided dilution to flush the sewers and the discharge sites. Wastewater was discharged untreated at nearby sites along Puget Sound, the Duwamish Waterway, Lake Washington, Lake Union, and the Ship Canal. As the community realized that untreated sewage discharges caused water quality problems, the City began to separate the combined stormwater and wastewater systems and to build sewage treatment plants. By the 1950s, the City had over 1,000 miles of combined sewers and 500 miles of separate sanitary sewer lines, and was operating three primary sewage treatment plants and numerous rudimentary treatment devices at discharge sites. The City formed the Sewer Utility within the Engineering Department in 1955, and began charging City residents and businesses for wastewater service the following year.

1.3 Wastewater Services

In 1958, a regional sewage treatment agency, the Municipality of Metropolitan Seattle ("Metro"), was formed to provide a regional solution to water quality problems. The City, rather than expanding its own treatment facilities, entered into a contract with Metro for sewage treatment. Metro is responsible for and has built major treatment plants along with an extensive regional interceptor system to route sewage to the plants and stop discharges into Lake Washington.

The wastewater system currently serves a population of nearly 627,000, substantially all of which are within the City limits. Residential accounts generate, on average, about 36% of total wastewater volumes and 36% of total wastewater revenues. Table 1-1 below presents an overview of key wastewater operating statistics for the past five years. Between 2009 and 2013, wastewater volumes declined by an average of 1.5% per year, due primarily to programmatic water conservation efforts. In 2012, volume rose to nearly 2010 levels as a result of increased economic activity, but returned to a downward trajectory in 2013.

Table 1-1. Wastewater System Operating Statistics					
	2009	**2010**	**2011**	**2012**	**2013**
Population Served					
	602,000	612,000	612,100	616,500	626,600
Wastewater Revenues (000)					
Residential	$69,020	$68,834	$73,964	$86,548	$89,478
Commercial	$114,821	$115,273	$129,626	$150,387	$154,998
Total Wastewater Revenues	$181,821	$184,107	$203,590	$236,935	$224,476
Billed Wastewater Volume (MG)					
Residential	7,995	7,824	7,400	7,707	7,594
Commercial	13,246	13,049	12,803	13,217	13,218
Total Billed Wastewater Volume	21,241	20,873	20,203	20,923	20,811
Gallons Used per Day per Capita					
	96.7	93.4	90.4	93.0	91.0

Residential customers are charged based on actual water consumption from November through April and the lesser of actual consumption or average winter water consumption from May through October. Commercial customers are charged based on actual water consumption throughout the year unless they install submeters to measure actual use of the wastewater system.

City ordinance allows SPU to pass through increases in the County's wastewater treatment charges based on adopted wholesale rates and projected billed consumption. The County, which treats virtually all of the City's wastewater, increased its wholesale treatment rate 10.2% in 2013, after holding the rate constant in 2012. The increase in the County's charges is passed through to SPU customers. The County's treatment charge for 2014 is being held constant at the 2013 level.

In 2012, the City Council adopted a 2014 wastewater rate of $11.00 per hundred cubic feet ("ccf"). This rate increased to $11.75 per ccf due to the County's 10.2% treatment rate increase.

1.4 Drainage Services

Stormwater run-off in the City is conveyed through one of three modes: storm drains, a combined stormwater and wastewater system, and a ditch, culvert and creek system. Beginning in the late 1960s, the City converted some of the existing combined stormwater and drainage system to a two-pipe system, one for stormwater run-off and the other for sanitary sewage. A ditch, culvert and creek system exists in areas of the City that originally were part of unincorporated King County and later were annexed by the City. Each of the three conveyance modes now represents about one-third of the system.

To address flooding of private property adjacent to major creeks carrying City stormwater, new trunk lines and detention ponds have been built and regulatory controls have been added for new residential and commercial developments. Also, several efforts are underway to reduce pollutants in stormwater that can contribute to water quality problems in receiving waters. SPU is responsible for coordinating the City's stormwater management programs.

Drainage fees are billed to all property owners in Seattle, except for certain exempt properties (submerged lands, houseboats, piers, City streets, State highways and other streets that provide the same drainage service as City streets), and is billed on the King County property tax statement. In accordance with RCW 35.67.200, City ordinances provide that the City has a lien for all delinquent and unpaid drainage service charges, and that delinquent drainage service charges bear interest at the rate of 8% per year. Average collection levels since 2000 are over 99%.

The City's drainage system serves approximately 213,000 accounts in a developed urban area; the system has experienced little change from year to year in the number of customers. Residential customers make up approximately 69% of the total customers. In 2013, the ten largest customers of the drainage system were the City, the Port of Seattle, King County, Seattle Public Schools, University of Washington, BNSF Railway, Seattle Housing Authority, Union Pacific Railroad, Seattle Community Colleges, and the U.S. government. In 2013, revenue billed to these ten customers totaled $16.7 million, or approximately 19.7% of drainage service revenues.

1.5 Combined System Expense

Stormwater and wastewater flows are conveyed through both separated (i.e. drainage only or sanitary sewer only) and combined pipes which convey both wastewater and stormwater to the King County wastewater treatment system. Combined system infrastructure includes pipes, detention structures (to reduce combined sewer overflows) and pump stations.

Prior to 2008, the costs associated with the combined system and treatment costs for wastewater/stormwater flows originating from the combined system were assigned entirely to wastewater. The 2008-2009 rate proposal initiated the sharing of the combined system costs (operation and maintenance, wastewater treatment, and capital). To prevent a significant spike in drainage rates, the allocation was phased over a six year period (from 2008-2014), incrementally shifting one-sixth of these costs from the wastewater to the drainage line of business every year (with the exception of 2010 where there was no formal rate study). The adopted 2013-2014 rates completed this allocation shift, with drainage receiving its' full allocation of 55% of related CIP and O&M costs and 6% of treatment costs. In the 2014 rate study, this amounted to $52.9M in total combined system related operating expense ($8.4M in treatment, $2.9M million in O&M $13.1 in debt service) and $28.5M in annual capital expense.

1.6 Rates

As discussed in the previous section, the City of Seattle operates an integrated storm and sanitary sewerage system. SPU finances the acquisition, operation, and maintenance of Seattle's drainage and wastewater system through the Drainage and Wastewater Enterprise Fund (DWF), established in 1989. Prior to the creation of the drainage and wastewater utility, rate payers funded wastewater services through user fees under the Seattle Sewer Utility. The City used tax revenues to fund annual drainage system operating expenses, while Local Improvement Districts (LIDs), developers, and General Obligation bonds funded the development of the initial trunk drainage system.

Although funded through separate rate structures, stormwater (“drainage”) and sanitary sewer (“wastewater”) operating and capital expenses are budgeted, tracked, and reported jointly. SPU’s financial systems track drainage and wastewater rate revenues separately, although they are reported jointly on financial statements. DWF also issues joint debt to finance drainage and wastewater capital projects.

1.6.1 Wastewater Rates

Residential customers are charged based on actual water consumption from November through April and the lesser of actual consumption or average winter water consumption from May through October. Commercial customers are charged based on actual water consumption throughout the year unless they install submeters to measure actual use of the wastewater system.

City ordinance allows SPU to pass through increases in the County’s wastewater treatment charges based on adopted wholesale rates and projected billed consumption. The County, which treats virtually all of the City’s wastewater, increased its wholesale treatment rate 10.2 percent in 2013, after holding the rate constant in 2012. The increase in the County’s charges is passed through to SPU customers. Table 1-2 shows the wastewater rates from 2008 through 2014.

Table 1-2. Wastewater Rates

	2008	2009	2010	2011	2012	2013	2014
Volume rate per ccf	$7.75	$8.89	$8.98	$10.28	$10.68	$11.65	$11.75

1 CCF equals 748 gallons.

1.6.2 Drainage Rates

The City charges drainage fees based on a property’s estimated impact on the drainage system. In 2008, SPU implemented a new drainage rate design to increase equity among drainage customers and between wastewater and drainage customers. Previously, all residential customers paid the same annual flat fee, regardless of parcel size. Under the updated structure, owners of single-family and duplex properties of less than 10,000 square feet pay an annual flat fee based on the size of their property. Owners of all other properties, including single family and duplexes on parcels of 10,000 square feet or greater, are charged based on the percent of impervious surface and billable lot size. In addition, drainage rates are set to fund a portion of the City’s combined drainage and storm sewer system infrastructure. SPU began offering rate credits in 2009 to property owners installing water quality and flow control facilities that mitigate the impact of their runoff on the City’s drainage system. To date, these credits have not had a material impact on gross system revenues.

The 2013 and 2014 drainage rates, which reflect the new design, are shown in Table 1-3.

Table 1-3. 2013 and 2014 Drainage Rates			
Rate Category	**Percent Impervious**	**2013 Annual Charge**	**2014 Annual Charge**
Small Residential		per parcel	per parcel
(less than 10,000 square feet)			
< 3,000 sq. ft.		$164.05	$180.96
3,000-4,999 sq. ft.		$212.92	$234.87
5,000-6,999 sq. ft.		$289.11	$318.92
7,000-9,999 sq. ft.		$365.97	$403.70
General Service/Large Residential		per 1,000 sq.ft.	per 1,000 sq.ft.
Undeveloped	0-15%		
Regular		$23.31	$25.71
Low Impact		$13.65	$15.06
Light	16-35%		
Regular		$36.05	$39.76
Low Impact		$28.35	$31.27
Medium	36-65%		
Regular		$52.35	$57.75
Low Impact		$42.11	$46.45
High	66-85%	$70.23	$77.48
Very High	86-100%	$83.08	$91.65

Section 2

Phase One: The Residential Indicator

2.1 Cost Per Household

As discussed in Section 1, while the Utility's Drainage and Wastewater lines of business each have their own unique fee structure, the fund is managed jointly. Since each line of business has a separate customer base, the 'Residential Indicator' outlined in 'EPA Worksheeet 1' is done individually for each line of business and then combined moving forward for the rest of the analysis as shown in Table 2-1.

Table 2-1. EPA Worksheet 1 - Cost per Household

Wastewater

Cost Per Household - Wastewater		Line Number	
Current WWT Costs			
Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 191,396,323.74	100	
Annual Debt Service (Principle and Interest)	$ 16,599,205.89	101	
Subtotal	$ 207,995,529.63	102	*Ln 100+1(*
Projected WWT and CSO Costs (Current Dollars)			
Estimated Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 514,820.06	103	
Annual Debt Service (Principal and Interest)	$ 7,891,956.69	104	
Subtotal	$ 8,406,776.75	105	*Ln 103+1(*
Total Current and Projected WWT and CSO Costs	$ 216,402,306.38	106	*Ln 102+1(*
Residential Share of Total WWT and CSO Costs	$ 191,743,279.47	107	
Total Number of Households in Service Area	152,872	108	
Cost per Household	$ 1,254.27	109	*Ln 107/1(*

Drainage

Cost Per Household - Drainage		Line Number	
Current WWT Costs			
Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 57,019,928.25	100	
Annual Debt Service (Principle and Interest)	$ 24,452,996.63	101	
Subtotal	$ 81,472,924.87	102	*Ln 100+1(*
Projected WWT and CSO Costs (Current Dollars)			
Estimated Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 629,224.51	103	
Annual Debt Service (Principal and Interest)	$ 9,645,724.85	104	
Subtotal	$ 10,274,949.36	105	*Ln 103+1(*
Total Current and Projected WWT and CSO Costs	$ 91,747,874.23	106	*Ln 102+1(*
Residential Share of Total WWT and CSO Costs	$ 63,806,042.90	107	
Total Number of Households in Service Area	147,934	108	
Cost per Household	$ 431.31	109	*Ln 107/1(*

Combined Total Cost Per Household

Cost Per Household		Line Number	
Current WWT Costs			
Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 248,416,251.99	100	
Annual Debt Service (Principle and Interest)	$ 41,052,202.52	101	
Subtotal	$ 289,468,454.51	102	*Ln 100+1(*
Projected WWT and CSO Costs (Current Dollars)			
Estimated Annual Operations and Maintenance Expenses (Excluding Depreciation)	$ 1,144,044.57	103	
Annual Debt Service (Principal and Interest)	$ 17,537,681.54	104	
Subtotal	$ 18,681,726.11	105	*Ln 103+1(*
Total Current and Projected WWT and CSO Costs	$ 308,150,180.61	106	*Ln 102+1(*
Residential Share of Total WWT and CSO Costs	$ 255,549,322.37	107	
Total Number of Households in Service Area		108	
Cost per Household	$ 1,685.59	109	*Ln 107/1(*

2.2 Medium Household Income

2.2.1 Medium Household Income

EPA Worksheet 2 - Medium Household Income (MHI) is shown in Table 2-2.

Table 2-2. EPA Worksheet 2 – Medium Household Income (MHI)

Median Household Income (MHI)		Line Number	
1 Census Year MHI	$61,856.00	201	
MHI Adjustment Factor	1.08	202	
Adjusted MHI	$66,819.41	203	*Ln 201x202*
Annual WWT and CSO Control Cost	$ 1,685.59	204	*Ln 109*
Residential Indicator: Annual Wastewater and CSO Control Costs per Household as a percent of Adjusted Median Household Income (CPH as % MHI)	2.52	205	*(Ln 204/203)x100*

2.2.2 Low Income Utility Credit

The City subsidizes qualified low-income customers by giving them discounts on their utility services. Low income assistance customers may receive their discount in one of three ways: 1) as a credit to their SPU wastewater bill; or 2) where no wastewater bill is received, as a credit to the customer's City Light Bill; or 3) in the form of a credit voucher. The latter two options are typically applicable to renters who pay drainage, wastewater, and water utility fees indirectly as part of their rental payment.

For customers who do not receive a wastewater bill, a fixed credit is calculated which is equal to 50 percent of a typical residential bill for the class of customer receiving the credit[1]. The discounts adopted by SPU for 2013 through 2014 are shown in Tables 2-3 and 2-4.

Table 2-3. Wastewater Low Income Utility Credit (Monthly)

Customer Type	2013 Adopted	2014 Adopted
Receives SPU Bill	50% discount	50% discount
Single family & duplex	$25.03	$25.25
Multi-family	$17.46	$17.62

[1] The typical residential bill is calculated by multiplying the rate per ccf by average monthly consumption. The discounts assume an average monthly usage of 4.3 ccf for a single family and 3.0 ccf for multi-family.

Table 2-4. Drainage Low Income Utility Credit (Monthly)		
Customer Type	**2013 Adopted**	**2014 Adopted**
Single Family	$12.26	$13.27
Duplex	$6.13	$6.64
Multi-Family	$1.31	$1.42

Section 3

Phase Two: Permittee Financial Indicators

3.1 Capital Program

Significant investments in the drainage and wastewater system by the City did not begin until the late 1990s. Indeed, prior to 1993, the DWF financed the majority of its capital related expenses on a pay-as-you-go basis within its operating expenses. Federal and environmental regulations associated with the Clean Water Act, Endangered Species Act, maintenance of the City's National Pollutant Discharge Elimination System (NPDES) permit, and the National Oceanic and Atmospheric Administration (NOAA) Fisheries listings have driven significant increases in capital spending since the late 1990's. The major growth projected for the 2014 capital plan is for continued implementation of Combined Sewer Overflow (CSO) requirements, already a major driver of CIP spending during the past several years. Table 3-1 presents the change in average annual CIP spending since 2000 and the associated impact on debt outstanding and annual debt service obligations.

Table 3-1. DWF Actual and Projected Capital Spending and Debt Statistics

	2000-2005	2006-2013	2014 (Projected)
Avg. Annual CIP (2010 dollars, in millions)	$44.9	$90.9	$90.6
Debt outstanding end of period (nominal dollars, in millions)	$294.9	$636.8	$634.7
Annual debt service end of period (nominal dollars, in millions)	$21.2	$41.1	$41.1

Significant investments in the drainage and wastewater system by the City did not begin until the late 1990s. Federal and environmental regulations associated with the Clean Water Act, Endangered Species Act, maintenance of the City's National Pollutant Discharge Elimination System (NPDES) permit, and the National Oceanic and Atmospheric Administration (NOAA) Fisheries listings have driven significant increases in capital spending during the past 15 to 20 years.

During the past 15 years, spending on drainage-specific improvements has been nearly twice that spent on wastewater-specific improvements. System maturity and regulation explain this trend. The wastewater system was established decades ago, and consequently, spending on wastewater-specific capital improvements has remained remarkably constant across the past 15 years, focusing primarily on rehabilitation of existing pipe and pump infrastructure.

Up until the mid-1990's, drainage-specific spending focused on alleviating major flooding problems that damaged property or affected public safety, addressing insufficiencies in the trunk drainage system developed in the 1970s

The 1995 comprehensive drainage plan expanded efforts for creek protection and water quality enhancement, which became an even higher priority in the late 1990s when Chinook salmon were listed as a threatened species under the Endangered Species Act. A major storm in 1996 caused extensive landslide damages to both city facilities and private properties prompting increased spending to protect drainage infrastructure from future landslides.

Both drainage and wastewater revenues fund certain “shared capital projects” related to technology systems, environmental remediation of historical contamination, and other joint infrastructure projects such as updating utilities for the Alaska Way Viaduct tunnel replacement.

Rates revenues for both service lines also fund improvements related to the combined sewer system. Prior to 2008, sewer revenues exclusively funded combined system expense. However, since 2008 drainage rates have begun to fund a portion of these expenses as stormwater is conveyed in combined pipes and is also a major driver of combined sewer overflows during intense storm events. Capital improvements addressed toward meeting NPDES requirements for CSO discharges have grown rapidly since the EPA issued a consent decree to the City of Seattle in 2008 regarding the control of combined sewer overflows, growing from 13% of DWF Capital expense in 2007 to a projected 44% by 2014.

3.2 Financing of Capital Program

The DWF capital program is funded through a combination of current year operating revenues (“cash-financing”) and proceeds from periodic revenue bond issues (debt-financing). Annual debt service payments, typically spread over 30 years, represent the annual cost to the fund of issuing revenue bonds.

Prior to 2002, the DWF policy was to put “excess cash balances” towards the CIP, funding the balance of the program with debt. Growth in the DWF capital program beginning in the late 1990s, and associated increases in debt outstanding, spurred a 2003 review of the fund’s financial policies and adoption of more conservative debt management policies, including funding 25 percent of annual capital expenditures with operating cash and 75 percent with debt. Debt management will continue to be a focus of DWF financial policies in light of continued increases in CIP spending and outstanding debt.

Rate increases are required when there is an incremental increase in the annual cost of financing capital expenditures. Increases in CIP spending will result in a dollar-for-dollar increase to CIP cash financing, assuming a constant percentage funded from year to year. However, this rule does not apply to the debt financed portion of the CIP budget. Debt is used to finance total CIP expense (less the cash financed portion) in a given period, not just the incremental change in spending from the prior year. Therefore, any capital spending, even if it is less than the prior year, will generate an increase in debt service. SPU expects to meet or exceed debt service coverage, cash balance, cash financing of the CIP, and net income targets in 2014.

Table 3-2 presents the Drainage and Wastewater Fund financial policies adopted via Resolution 30612 in 2003.

Table 3-2. Drainage and Wastewater Fund Adopted Financial Policies

Policy Metric	Target/Guidance
Debt Service Coverage	1.8x
Cash to CIP	25 percent minimum cash financing (4-year rolling average)
Year-End Cash	Year-end balance of one month wastewater treatment expense
Net Income	Generally positive
Facility Maintenance	Seek to maintain capital assets in sound working condition
Variable Rate Debt	Limited to 15 percent of total debt
Debt-to-Assets	<70 percent

The outcome of the Fund's financial policies has been strong bond ratings from both Moody's and Standard and Poor's as outlined in Table 3-3. EPA Worksheet 3 – Bond Rating. While the fund does not utilize 'full market property value' as a metric for determining financial viability, the calculation in Table 3-3 shows that citywide, there is prudent management of debt.

Table 3-3. EPA Worksheet 3 – Bond Rating

Bond Rating		
		Line Number
Most Recent Revenue Bond		
Date	6/6/2012	
Rating Agency	Moody's Bond Record and Standard & Poor's Corporation	
Bond Insurance (Yes/No)	No	
Rating	Aa1/AA+	302
Summary Bond Rating	Strong	303

Note: Line 301 references a General Obligation Bond which is not applicable to SPU.

EPA Worksheet 4 - Overall Net Debt as a Percent of Full Market Property Value is shown in Table 3-4.

Table 3-4. EPA Worksheet 4 – Overall Net Debt as a Percent of Full Market Property Value

	Overall Net Debt as a Percent of Full Market Property Value			
			Line Number	
1	Direct Net Debt	$530,280,000.00	401	
2	Debt of Overlapping Entities (proportionate share of multijurisdictional debt)	$1,510,041,301.00	402	
	Overall Net Debt	$2,040,321,301.00	403	*Ln 401+402*
3, 4	Market Value of Property	$117,686,522,416.00	404	
	Overall Net Debt as a Percent of Full Market Property Value	1.73	405	*(Ln 403/404)*100*

Notes

Remaining Debt in 2013 for DWF

Overlapping Debt, page 20 of OS, 'Net Direct and Overlapping Debt'

http://www.seattle.gov/BUSINESS/investors/documents/Seattle-GO-2013-OS.pdf

State constitution requires assessment of property at 100% of its true and fair value

http://www.kingcounty.gov/Assessor/QuickAnswers/Residents.aspx#E63C75F19C234D59B4DF005B7F8035E6

Market Value of Property from 2013 Official Statement for General Obligation Bonds

http://www.seattle.gov/BUSINESS/investors/documents/Seattle-GO-2013-OS.pdf

The City of Seattle supports a strong economy with healthy employment, median income, and property values all above the national average. Tables 3-5 through 3-9 documents these statistics and their sources in the EPA financial capability formats required for EPA Worksheets 5 through 8.

Table 3-5. EPA Worksheet 5 – Unemployement Rate

	Unemployment Rate		
			Line Number
	Unemployment Rate - Permittee	7.40%	501
1	Source	US Bureau of Labor Statistics	
	Unemployment Rate - County	6.80%	502
2	Source	US Bureau of Labor Statistics	
Benchmark			
	Average National Unemployment	7.80%	503
3	Source	US Bureau of Labor Statistics	

Notes

1 *LAUS (Series ID: LAUMT53426603,LAUMT53426604,LAUMT53426605,LAUMT53426606)*

2 *LAUS (Series ID: LAUPS53025003)*

3 *Labor Force Statistics from the Current Population Survey (Seried ID: LNS14000000)*

Table 3-6. EPA Worksheet 6 – Medium Household Income

Median Household Income		
		Line Number
Median Household Income - Permittee	$66,819.41	601 *Ln 203*
Benchmark		
1 Census Year National MHI	$49,276.00	602
MHI Adjustment Factor	1.08	603 *Ln 202*
Adjusted National MHI	$53,229.97	604 *Ln 602*603*

Notes

1 *U.S. Census Bureau, Current Population Survey, 2011 Annual Social and Economic Supplement.*

Table 3-7. EPA Worksheet 7 – Property Tax Revenues as a Percent of Full Market Property Value

Property Tax Revenues as a Percent of Full Market Property Value		
		Line Number
Full Market Value of Real Property	$117,686,522,416	701 *Ln 404*
Property Tax Revenues	$363,522,729	702
Property Tax Revenues as a Percent of Full Market Property Value	0.31	703 *Ln 702/701*100*

Table 3-8. EPA Worksheet 8 – Property Tax Revenues Collection Rate

Property Tax Revenue Collection Rate		
		Line Number
Property Tax Revenue Collected	$376,686,752.45	801 *Ln 702*
Property Taxes Levied	$382,656,189.00	802
Property Tax Revenue Collection Rate	0.9844	803 *Ln (801/802)*100*

3.3 Financial Capability Indicator Benchmarks

Table 3-9 presents the benchmarks used to assess the financial capability of the City of Seattle in accordance with EPA financial capability requirements.

Table 3-9. Permittee Financial Capability Indicator Benchmarks

Indicator	Strong	Mid-Range	Weak
Bond Rating	AAA-A (S&P) Aaa-A (Moody's)	BBB (S&P) Baa (Moody's)	BB-D (S&P) Ba-C (Moody's)
Overall Net Debt as a Percent of Full Market Property Value	Below 2%	2%-5%	Above 5%
Unemployment Rate	More than 1 Percentage Point Below the National Average	+/- 1 Percentage Point of National Average	More than 1 Percentage Point Above the National Average
Median Household Income	More than 25% Above Adjusted National MHI	+/- 25% of Adjusted National MHI	More than 25% Below Adjusted National MHI
Property Tax Revenues as a Percent of Full Market Property Value	Below 2%	2%-4%	Above 4%
Property Tax Collection Rate	Above 98%	94%-98%	Below 94%

Tables 3-10, EPA Worksheet 9 – Summary of Permittee Financial Capabilty Indictors and 3-11, EPA Worksheet 10 – Financial Capability Matrix Score document the City's various financial indicators that culminate in the financial capability score.

Table 3-10. EPA Worksheet 9 – Summary of Permittee Financial Capabilty Indictors

Indicator	**Column A:** Actual Value	**Column B:**	**Line Number**
Bond Rating	Strong	3	901 *Ln 303*
Overall Net Debt as a Percent of Full Market Property Value	1.73	3	902 *Ln 405*
Unemployment Rate	7.4%	2	903 *Ln 501*
Median Household Income	$66,819.41	3	904 *Ln 601*
Property Tax Revenues as a Percent of Full Market Property Value	0.31	3	905 *Ln 703*
Property Tax Revenue Collection Rate	98.4%	3	906 *Ln 803*
Permittee Indicators Score		2.83	907 *Sum Col B/# Entries*

Table 3-11. EPA Worksheet 10 – Financial Capability Matrix Score

Financial Capability Matrix Score		
		Line Number
Residential Indicator Score	2.52	1001 *Ln 205*
Permittee Financial Capability Indicators Score	3.00	1002 *Ln 907*
Financial Capability Matrix Category	Medium Burden	1003

Based on the Financial Capability Matrix score calculated in Table 3-11. EPA Worksheet 10 – Financial Capability Matrix Score, the City's 'Residential Indicator Score' is in the 'High' category and the 'Financial Capability Indicator Score' is in the 'Strong' category, ranking the proposed projects as 'Medium Burden' for rate payers.

Table 3-12. Financial Capability Matrix

Permittee Financial Capability Indicators Score (Socioeconomic, Debt and Financial Indicators)	**Residential Indicator** (Cost per Household as a % of MHI)		
	Low (Below 1.0%)	Mid-Range (Between 1.0 & 2.0%)	High (Above 2.0%)
Weak (Below 1.5)	Medium Burden	High Burden	High Burden
Mid-Range (Between 1.5 and 2.5)	Low Burden	Medium Burden	High Burden
Strong (Above 2.5)	Low Burden	Low Burden	Medium Burden

Section 4

CSO Schedule Development

The Draft LTCP, May 2014, prepared detailed implementation schedules for the various LTCP options and additional scheduling information is described in the Draft LTCP Section 4.4.2 Prioritization and Scheduling Criteria.

For each CSO Control Measure, the Consent Decree requires the implementation schedule to specify the critical milestone dates for the following project activities: Engineering Report, Plans and Specifications, Construction Start, Construction Completion and Achievement of Controlled Status. Because the CSO projects range in construction complexity and project costs, the CSO projects have project durations ranging from 3 years to 14 years based on the City project implementation experience.

The LTCP used two methods to determine the priority of projects which most reduce the discharge of pollutants. The first method followed the EPA guidelines for Sensitive Areas, which determines which basins have the largest impact on receiving water bodies and human health. The results of Sensitive Areas analysis was previously shown on Figure 2-23. The LTCP will give the highest priority to controlling overflows to the highest ranked sensitive areas. The second method was to compare the relative cost-effectiveness of each CSO project on a total project cost per gallon of CSO discharge volume reduced. The LTCP will give the highest priority to controlling overflows to the CSO projects with the lowest cost per CSO discharge gallon reduced.

For the Final LTCP, May 2015, a detailed evaluation will be prepared for the recommended LTCP option in accordance with the EPA financial capability assessment requirements.

Appendix D: LTCP Option Rating and Ranking Report (MODA)

Seattle Public Utilities | Protecting Seattle's Waterways

Long Term Control Plan

Draft LTCP Options Rating and Ranking

May 2014

Seattle Public Utilities

Draft LTCP Options Rating and Ranking

May 2014

Prepared for:
Seattle Public Utilities
Seattle Municipal Tower, Suite 4900
700 Fifth Avenue
Seattle, Washington 98124-4018

Prepared by:

CH2MHILL

1100 112th Ave NE Ste 500
Bellevue, WA 98004-4511

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SECTION 1

Introduction

The Draft LTCP has performed a "rating and ranking" of the LTCP options in accordance with the EPA requirements in the "Combined Sewer Overflows Guidance for Long-Term Control Plan, 1995". This memorandum describes the methods and results of the evaluation of the rating and ranking of options for the Seattle Public Utilities (SPU) Draft Long-Term Control Plan (LTCP) May 29, 2014.

SECTION 2

MODA Methodology

2.1 Methodology Overview

The LTCP options were evaluated using multi-objective decision analysis (MODA). MODA is a generalized term often used for a suite of analytical techniques referred to in the literature as multi-attribute utility theory (MAUT).1 MAUT is derived from the basic von Neumann-Morgenstern axioms of preference2 and thus upon a utility function, which allows the comparison of risky outcomes through the computation of expected utility. The specific form of MAUT used in the IP is a simplified form called the Simple Multi-Attribute Rating Technique with Swings3 (SMARTS).

The MODA methodology used for the Long Term Control Plan consists of the following steps.

1. **Establish evaluation criteria:** The evaluation criteria were developed during a series of workshops with SPU staff and the Integrated Plan team. Criteria development also included coordination with King County, the LTCP Sounding Board, and the Ballard/Fremont/Wallingford Advisory Committee. The criteria represent the values and objectives of SPU and other stakeholders that are relevant to making decisions about long-term control plan options.
2. **Develop measurement scales and score options:** Measurement scales describe the extent to which projects meet each evaluation criterion. Once the LTCP options were determined and fully defined (describe elsewhere), each option was scored against each criterion.
3. **Establish relative value weights:** Relative value weights are subjective expressions of the relative value of each criterion within the context of the decision being made. The context is important because an otherwise important criterion that does not vary substantially among projects is not particularly important for decision making. This leads to the concept of swing weighting (as described in SMARTS), in which a

1 Keeney, R.L., and H. Raiffa. 1976. Decisions with Multiple Objectives. New York. John Wiley.

2 Von Neumann, J., and O. Morgenstern. 1947. Theory of Games and Economic Behaviour, Princeton University Press.

3 Edwards, W., F. Barron. 1994. "SMARTS and SMARTER: Improved Simple Methods for Multi-Attribute Utility Measurement." Organizational Behavior and Human Decision Processes. 60, 306-325 (1994).

trained facilitator helps groups reflect both on the relative importance of each criterion and the extent to which each criterion varies among projects when establishing weights.

For the LTCP, weights were established using a modified Delphi process in which a team of SPU senior managers provided weights, the weights were shown to the group, and the differences discussed. From there, a discussion was held that resulted in a consensus set of weights that were used in the evaluation.

4. **Normalize scores and calculate results:** All scores were normalized to a 0-1 scale using linear transformation. The normalized scores were multiplied by the weight for each criterion then multiplied by 100 (a scalar for presentation) resulting in a total value score for each project.

   As typically conducted at SPU, cost was not a weighted parameter. This is because SPU and its advisor's experience with weighting has demonstrated that technical staff are typically not comfortable (or skilled) at making explicit tradeoffs between cost and non-monetary criteria. Cost is addressed by comparing non-monetary value against cost in a value-cost tradeoff analysis.

5. **Present the results**: The results of the analysis are presented as total value scores for each project, and graphics that show the composition of value for each project and total value compared to cost.

2.2 LTCP Options

For the LTCP, four system-wide options were developed under one of two basic concepts; SPU meets their Consent Decree mandated control responsibilities through implementation of independent control measures, or SPU participates in one or more shared projects with King County to take advantage of potential cost/impact reduction opportunities. Individual control measures for each CSO area were developed by SPU to support an independent neighborhood system-wide solution. The independent neighborhood solution has two concepts: All storage tanks or a combination of storage tanks and a CSO storage tunnel.

One option under the shared project strategy is to combine facilities when both agencies must construct storage facilities in close proximity to one another. This resulted in the Shared Storage Option. Another option under the shared project strategy is to consolidate CSO storage for seven SPU storage volumes and three King County storage volumes in a deep tunnel. This resulted in the Ship Canal Tunnel Option. During development of the Ship Canal Tunnel option, the feasibility of another potentially cost-effective shared tunnel solution, the West Ship Canal Tunnel (combining volumes from Ballard, Fremont/Wallingford, and 3rd Avenue W Regulator) was identified and evaluated. This option became the West Ship Canal Tunnel Option.

Table 1 presents the LTCP CSO areas and explains how they fit into the four CSO control options.

Table 1. LTCP Options

CSO Areas	LTCP Options			
	Neighborhood Storage	**Shared Storage**	**Shared West Ship Canal Tunnel**	**Shared Ship Canal Tunnel**
Ballard	Off-line storage tank or deep tunnel with Fremont/Wallingford	Off-line storage tank	Shared deep tunnel with Fremont/ Wallingford	Shared deep tunnel
Magnolia	Off-line storage pipe	Off-line storage pipe	Flow diversion to North Interceptor	Flow diversion to North Interceptor
North Union Bay	Collection system improvement	Shared off-line storage tank	Collection system improvement	Shared deep tunnel
Central Waterfront	Off-line storage pipe	Off-line storage pipe	Off-line storage pipe	Off-line storage pipe
Fremont/ Wallingford	Off-line storage tank or deep tunnel with Ballard	Shared off-line storage tank	Shared deep tunnel with Ballard	Shared deep tunnel
Duwamish	2 off-line storage pipes	2 off-line storage pipes	2 off-line storage pipes	Flow diversion to Duwamish Interceptor
Delridge	3 off-line storage pipes	3 off-line storage pipes	3 off-line storage pipes	Flow diversion to Harbor trunk plus 2 off-line storage pipes
Montlake	3 off-line storage pipes	Shared off-line storage tank	3 off-line storage pipes	Shared deep tunnel
Leschi	3 off-line storage pipes plus 1 off-line storage tank	Shared off-line storage tank	3 off-line storage pipes plus 1 off-line storage tank	Shared deep tunnel
East Waterway	Off-line storage tank	Flow diversion to HLKK treatment plant	Flow diversion to HLKK treatment plant	Flow diversion to HLKK treatment plant
Portage Bay	Off-line storage pipe	Off-line storage pipe	Off-line storage pipe	Shared deep tunnel

Figures 1 through 4 show the component basin projects included in each of the four LTCP options. Additionally, attached to each area map is an explanation of the option itself and how the option plans to address the uncontrolled basins.

2.2.1 Neighborhood Storage Options

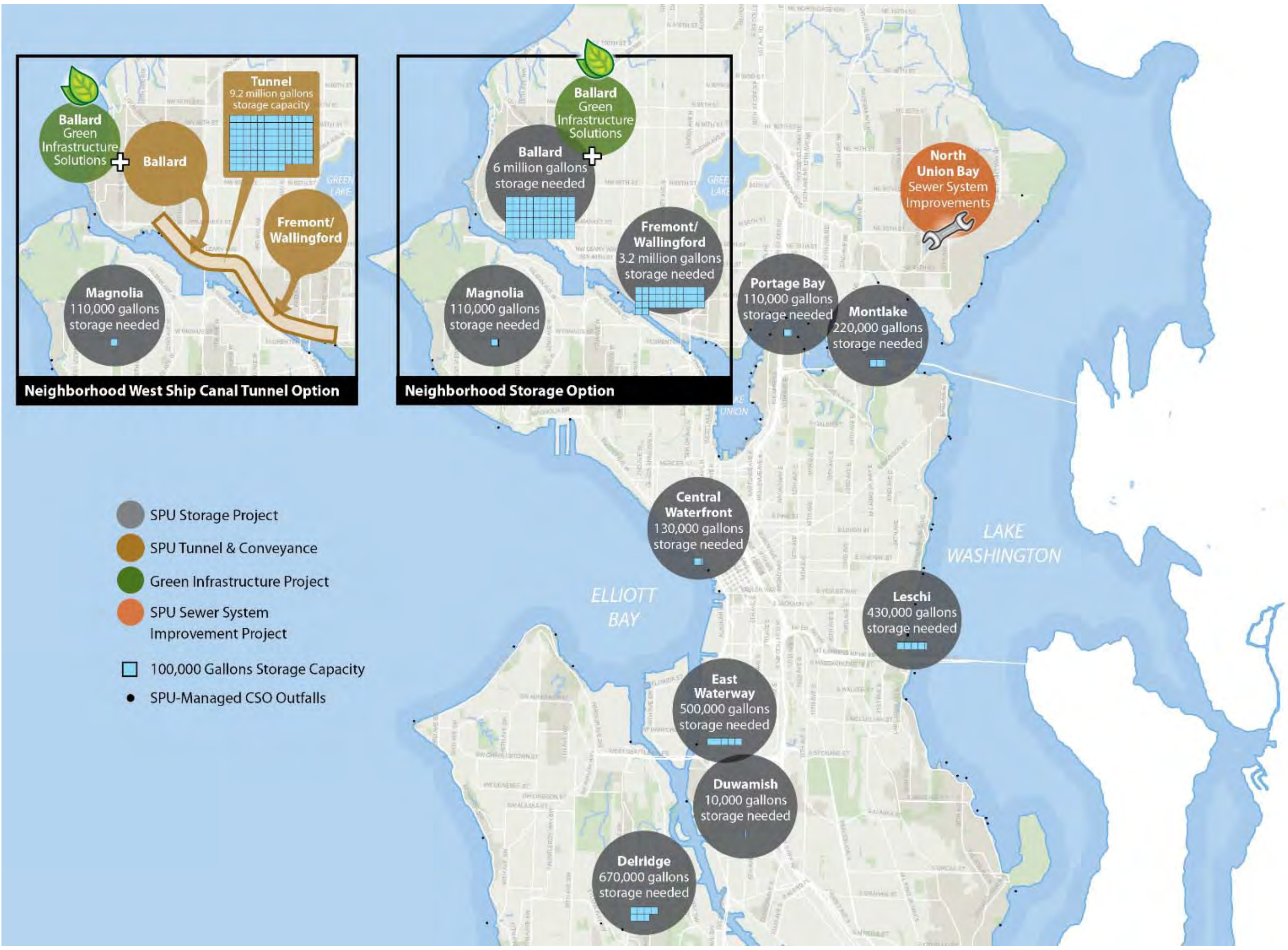

Figure 1. Neighborhood Storage Options

Under the Neighborhood Storage Option, the City would build underground storage facilities in Ballard, Fremont/Wallingford, Magnolia, Portage Bay, Montlake, Leschi, Central Waterfront, Duwamish, Delridge, and East Waterway CSO areas, and sewer system improvements in the North Union Bay CSO area. This option involves building the largest number of storage facilities throughout the city.

There are two variations in the Neighborhood Storage Option: one would provide storage in tanks/pipes only, and the other would include a tunnel (Neighborhood West Ship Canal Tunnel) in combination with tanks and pipes. The storage tank/pipe option involves the greatest number of affected locations. The Neighborhood West Ship Canal Tunnel Option was developed because the two CSO areas with the largest storage volumes (Ballard and Fremont/Wallingford) are relatively close to one another. The Neighborhood West Ship Canal Tunnel Option likely reduces the number of facilities and neighborhood impacts.

Implementation of the North Union Bay sewer system improvements will require City coordination with King County because additional flows will be transferred to the King County system. Specifically, the City and King County will need to analyze the impacts of the proposed project on the downstream system and agree on an approach to address those impacts.

2.2.2 Shared West Ship Canal Tunnel Option

Figure 2. Shared West Ship Canal Tunnel Option

The Shared West Ship Canal Tunnel Option combines three of the largest CSO areas into a single deep tunnel. The West Ship Canal Tunnel is proposed as a shared option because the three CSO areas (two from the City and one from King County) with the largest control volumes are relatively close to one another. The tunnel would extend from Fremont/Wallingford to Ballard and would provide the storage needed to address sewage overflows in Ballard, Fremont/Wallingford, and King County's 3rd Avenue West CSO basins. The tunnel would eliminate the need for a separate King County CSO project at an outfall near 3rd Avenue West.

Prior to implementing any shared projects between the City and King County, a shared project agreement would need to be signed between the two agencies.

Within this option, the remaining CSO areas would be controlled by their respective neighborhood control measures except for Magnolia and East Waterway, where flow diversions to King County's system are proposed. Any City flow diversion projects would require coordination with King County. Specifically, the City and King County would need to analyze the impacts of the proposed flow diversion projects on the downstream system and agree on an approach to address those impacts.

2.2.3 Shared Ship Canal Tunnel Option

Figure 3. Shared Ship Canal Tunnel Option

The Shared Ship Canal Tunnel Option combines the control volumes from six of City CSO areas along the Ship Canal and Lake Washington, and three of the largest King County CSO areas along the Ship Canal in a deep tunnel extending from the University District to Fremont/Wallingford. The tunnel would provide the storage needed to address sewage overflows in the City's CSO areas of Ballard, Fremont/Wallingford, Portage Bay, Montlake, North Union Bay, and Leschi. The tunnel would also eliminate the need for three separate King County CSO projects at outfalls near Pacific Street (University Regulator), Montlake Avenue (Montlake Regulator), and 3rd Avenue West.

The remaining City CSO areas (Magnolia, Duwamish, East Waterway, and the northernmost Delridge CSO basin) would be diverted to King County under the assumption that flow diversions could be incorporated into mutual interagency agreements. The Central Waterfront and the southern Delridge CSO neighborhoods would continue to be served by their respective neighborhood control measures.

Prior to implementing any shared projects between the City and King County, a shared project agreement would need to be signed between the two agencies. Specifically, the City and King County would need to analyze the impacts of the proposed project on the downstream system and agree on an approach to address those impacts.

2.2.4 Shared Storage Option

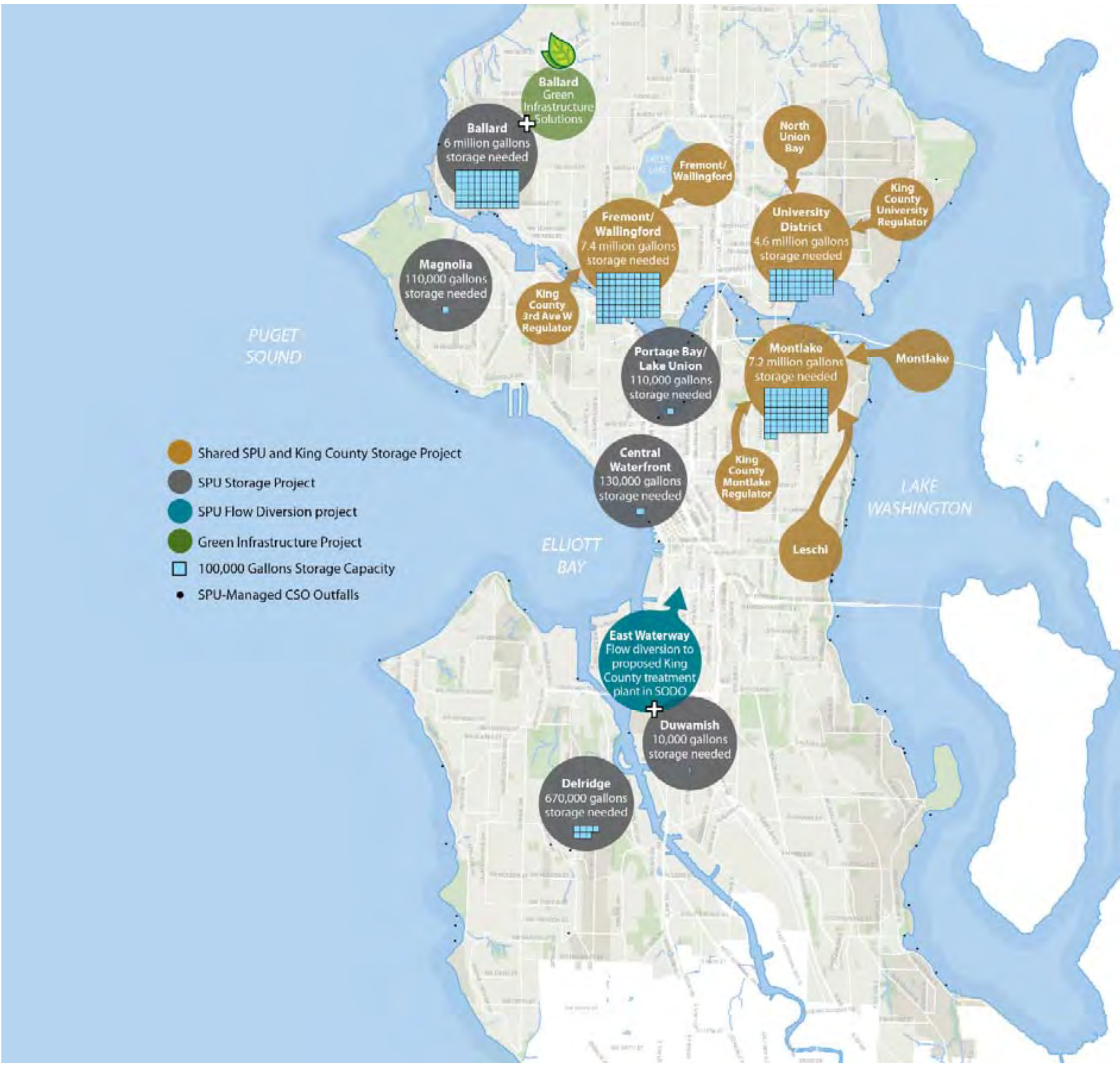

Figure 4. Shared Storage Option

Under the Shared Storage Option, the City and King County would jointly build larger but fewer storage tanks in three CSO areas: Fremont/Wallingford / King County 3rd Avenue West. CSO; North Union Bay / King County University Regulator CSO: and Montlake / Leschi / King County Montlake Regulator. These three shared storage projects were recommended in the approved 2012 King County CSO plan. In the Duwamish CSO area, the City would divert flows to a treatment facility proposed by King County. All other LTCP CSO areas would have the same storage facilities as proposed under the Neighborhood Storage Option.

Prior to implementing any shared projects between the City and King County, a shared project agreement would need to be signed between the two agencies. Specifically, the City and King County would need to analyze the impacts of the proposed project on the downstream system and agree on an approach to address those impacts.

2.3 Option Project Costs

The LTCP must have reasonable project cost estimates for long-range financial planning and evaluation. SPU has developed cost models for planning-level construction costs, allied soft costs, annual operation and maintenance cost, total project costs and net present value (NPV). The cost models were validated through a comparison with the actual construction bid prices for the Windermere and Genesee CSO projects.

The initial conceptual development and evaluation of feasible control measures applied to uncontrolled CSO area basins was completed using a cost model developed by King County called Tabula. Tabula produces a Class 5 construction cost estimate. To permit a more detailed and flexible evaluation of control measures, SPU developed a new cost model (LTCP Conceptual Cost Calculator or 3C). The tool combines features of both APWA (WSDOT) and CSI formats to allow estimates for linear and vertical construction elements and quantity/activity inputs feed into schedule and quantity/equipment hour takeoffs.

The cost estimating tool uses definitions and soft cost values as presented in SPU's Cost Estimating Guidelines to generate a total project cost. The level of detail in the 3C estimate is considered to approach a Class 4 estimate. A multi-agency tunnel evaluation workshop conducted in 2011 recommended that all deep tunnel control measures be evaluated using a "bottom up" (rather than a parametric) construction cost estimate. The costs for all of the control measures presented in this LTCP have been estimated using either the 3C tool or the "bottom up" estimate models. This includes the various King County alternatives against which the shared options are compared.

Facilities constructed under the LTCP will require commissioning costs beyond those typically encountered to complete construction. These "shakedown" costs have been capitalized. Non-capital costs include recurring annual operation and maintenance expenses, fees paid to King County for treatment of additional flows, ongoing flow monitoring for system control, and post-construction monitoring to demonstrate Consent Decree compliance.

An operation and maintenance cost model was developed for purposes of control measure comparison. This cost model incorporated existing SPU operating experience with storage facilities and conveyance systems augmented by recent monitoring and construction commissioning data. All comparison of control measure costs used in the final selection process were made using a net present value calculation based on a discount rate of 3% and a 100 year life cycle and include salvage value. In addition to initial capital costs and ongoing operating costs, the NPV calculation incorporated future replacements for depreciated equipment on 5, 10, 25, and 50 year cycles.

Preliminary cost shares for the various shared options were based on a cost allocation methodology developed by the City and King County. To calculate the cost shares, the existing King County recommended CSO project costs were estimated using the LTCP 3C cost model for comparison with the LTCP option costs. The NPV costs were calculated as 100-year life-cycle costs and are summarized in Table 2. The costs are in April 2013 dollars based on an ENR Seattle Construction Cost Index of 9430 and are considered a Class 4 estimate. The typical Range of Estimate of Uncertainty defined by AACE for a Class 4 Estimate is -20% to +30%.

Table 2. LTCP Value Score Comparison with Net Present Value			
LTCP Option	**City NPV Cost Share, $M**	**Lower NPV Cost Range $M (-20%)**	**Upper NPV Cost Range $M (+30%)**
Neighborhood—West Ship Canal Tunnel	$384	$307	$499
Shared Storage	$361	$289	$469
Neighborhood—Storage Tanks	$373	$298	$485
Shared Ship Canal Tunnel	$352	$282	$458
Shared West Ship Canal Tunnel	$309	$247	$402

2.4 Evaluation Criteria and Scales

2.4.1 Evaluation Criteria

The project team consisted of both SPU and external consultant staff with specialized expertise in the following areas: engineering, construction, permitting, environmental impact statements, real property, operations and maintenance, environmental/social justice, project management, and economics (Triple Bottom bottom Line). The team collaborated over a series of meetings to develop and refine a set of evaluation criteria for the LTCP. Development of the criteria included input from King County, the Intergrated Plan team, the LTCP Sounding Board, and the Ballard/Fremont/Wallingford Advisory Committee. The evaluation criteria are shown in Table 3.

Table 3. Evaluation Criteria	
Main Objectives	**Sub-objectives**
1. Technical Complexity and Performance Risk	Does implementation require complex coverall system controls? How many individual CSO facilities are needed to implement control strategy? How does King County Boundary Conditions impact City CSO facility operations?
2. Flexibility	Can the LTCP option meet changing control criteria and flow conditions?
3. Constructability	Are construction risks associated with the LTCP option significant? What is the expected permitting/regulatory /land use compliance complexities and how difficult is it expected to be to obtain permits and approvals?
4. Consent Decree Compliance Schedule	Does the LTCP option meet the City Consent Decree Construction Completion Milestone Date of Dec 31, 2025? Does the LTCP shared option meet the King County Consent Decree Dates for the University, Montlake and 3rd Avenue West CSO projects? of

Table 3. Evaluation Criteria	
Main Objectives	**Sub-objectives**
5. King County Concurrence on Shared Projects	Has King County indicated their concurrence or objections to LTCP shared options to the City?
6. Construction Impacts (Short-Term)	What level of disruption will occur? Are the cumulative construction impacts significant?
7. Community Impacts (Long-Term)	Can the facility be designed to be compatible with the community, and how will O&M activities impact the community?
8. Environmental/ Social Justice	What are the LTCP option's overflow and operation impacts and benefits? Does the alternative result in unequal impacts & benefits to historically underserved communities and low-income populations during construction or operation of the facility.
9. Environmental	Will the construction impact wetlands, streams, shorelines, habitats, and/or endangered species?
10. Ease of O&M and Safety	What level of staffing is required for operation and shutdown (how often is the facility used, how long is the facility in use, how many operators are required, what level of operator experience is required, what are travel times)? What are peak staff required? Does the facility have access requirements in the right of way or require confined space entry? Are traffic control procedures required? Does access require a street use permit or lane closure?

2.5 Option Scoring

After establishing the evaluation criteria, performance measures are required to determine how well alternatives perform against the objectives. Performance measures may be quantitative or qualitative, depending upon the objective and the availability of data for each measure. For the LTCP, all non-monetary objectives were scored using a 1-3 constructed scale, where the worst potential outcome was given a score of 1, and the best possible outcome was given a score of 3. Note that this doesn't mean that there will always be one alternative with a score of one and one with a score of -three: some objectives do not vary appreciably and thus have scores clustered around the midpoint of the range (i.e., scores of two).

The performance measures are shown in Table 4.

Table 4. Performance Measures		
Performance Measures (High, Medium, Low)		
High = 3.0 (Best)	**Medium = 2.0**	**Low = 1.0 (Worse)**
1. Technical Complexity and Performance Risk		
Overall option system operation is less complex because a large number of independent CSO outfall storages have been combined into fewer CSO control facilities. (e.g. - Tunnels). Reduces the requirements for coordinating operations of numerous independent CSO storage facilities for a large number of CSO outfalls. King County interceptor capacity does not impact City CSO facility release rates and/increase City storage requirements. King County will not request additional capital costs to accommodate City CSO Flows	Overall option system operation is moderately complex because some CSO outfall storages have been combined into a single CSO control facility. (e.g. - Shared tanks or tunnels). Reduces the requirements for coordinating operations of several independent CSO storage facilities for a specific geographic area. King County interceptor capacity may impact City CSO facility release rates and/increase City storage requirements. King County may request additional capital costs to accommodate City CSO Flows	Overall option system operation is very complex because each CSO outfall storage must control overflows independently have been combined into fewer CSO control facilities. (e.g. - Tanks at each outfall). Requires coordinating operations of numerous independent CSO storage facilities to achieve performance standard. King County interceptor capacity will significantly limit City CSO facility release rates and/increase City storage requirements. King County will request major capital costs to accommodate City CSO Flows
2. **Flexibility**		
Yes, with minimal modifications of controls and minimal modification of existing infrastructure. Significant space available for future expansion. E.g. - Tunnels will rate high	Yes, with moderate modifications to controls and infrastructure. Limited space for future expansion. e.g. Shared City/KC storage will rate medium	Yes, with significant modifications to controls and infrastructure. No Space for future expansion e.g. Neighborhood storage will rate lowest
3. Constructability		
Site is not constrained, is on stable, low-slope sites, with groundwater elevations not affected during construction or operation. Adequate area for access and staging and operation of special equipment can be accommodated. There are several potential sites available for purchase for the alternative including publicly- and privately owned property. Property may be used for multiple benefit (meet regulatory needs and provide an	Site may be constrained, low to moderate slopes, requires some dewatering, and robust foundations including piles or tiebacks; access and staging are not required for adequate construction sequencing. Contractor may have to provide offsite staging and operations. There are limited acceptable sites for the alternative. Use of property may require mitigation to make construction feasible and/or the facility publically acceptable. Adequate transport routes	Site is constrained, steep slopes with groundwater and soils conditions that increase instability if disturbed, requiring careful construction sequencing, with several move-in, move-out stages to accommodate specialty contractors as well as conventional construction. Contractor must provide offsite staging and operations. Locating a site is difficult. (e.g. potential sites have cultural and/or historical status, binding covenants which preclude utility structures, or are not subject to

Table 4. Performance Measures		
Performance Measures (High, Medium, Low)		
High = 3.0 (Best)	**Medium = 2.0**	**Low = 1.0 (Worse)**
amenity to the community). Multiple transport routes/modes are available.	are available.	condemnation by City.) Condemnation may be required. Significant mitigation may be required to make the facility publically acceptable. Constrained transport routes are available.
4. Consent Decree Compliance Schedule		
All City Facilities meet Consent Decree "Construction Completion" milestone by December 31, 2025. Shared King County/City Facility meets milestone dates stated in the King County Consent Decree.	Shared King County/City Facility does not meet the City Consent Decree "Construction Completion" milestone by December 2025 but is deferred based on approved King County Consent Decree without penalty from EPA/Ecology.	No Shared King County/City Facilities meet the City Consent Decree "Construction Completion" milestone by December 31, 2025, and EPA/Ecology impose penalties. Shared King County/City Facility does not meet milestone dates stated in the King County Consent Decree, and EPA/Ecology impose penalties.
5. King County Concurrence on Shared Projects		
King County Consent Decree requires King County to build shared storage solution with City or King County participation is not needed. (Shared + Neighborhood)	King County and the City are continuing discussion. (West Ship Canal)	King County CSO Plan does not recommend ship canal tunnel (Shared Tunnel)
6. Construction Impacts (Short-Term)		
Disruption during construction is lowest in terms of number of sites, area affected, and construction duration and intensity. Mitigation options are available, potential public benefits and cumulative impacts are relatively lowest (including King County facilities).	Disruption during construction is moderate in terms of area affected, number of sites, and construction duration and intensity. Mitigation options available which offset impacts. Cumulative impacts are moderate.	Disruption during construction is highest in terms of area affected, number of sites affected, and construction duration and intensity. Mitigation options are limited. Cumulative impacts are relatively highest.

Table 4. Performance Measures		
Performance Measures (High, Medium, Low)		
High = 3.0 (Best)	**Medium = 2.0**	**Low = 1.0 (Worse)**
7. Community Impacts (Long-Term)		
Facility is compatible with the surrounding community, and minimal staff will be present infrequently. Traffic, odor, noise and/or visual impacts from the facility would require limited mitigation to be acceptable to the community.	Facility and grounds can be designed to screen facility, and minimal staff visits are necessary. Traffic, odor noise and/or visual impacts from the facility would require mitigation to be acceptable to the community.	The facility will negatively impact the community, and there would be staff on-site regularly. Traffic, odor, noise and/or visual impacts from the facility would require significant mitigation to be acceptable to the community.
8. Environmental/ Social Justice		
LTCP option provides social, environmental, health and economic benefits to historically underserved communities and low-income populations, at levels equal to or greater than those experienced by White Middle and high income populations.	No net change in social, environmental, health, and economic impacts or benefits to historically underserved communities and low-income populations.	Alternative causes adverse and inequitable social, environmental, health, and economic impacts to historically underserved communities and low-income communities.
9. Environmental		
It is unlikely that the LTCP option would adversely impact wetlands, streams, shorelines, habitats, and/or endangered species. Mitigation options are available. City-wide cumulative impacts are lowest for most environmental resources.	It is likely that the LTCP option would impact wetland and/or stream buffers, and/or streams, but endangered species, habitats, and/or shoreline areas will unlikely be impacted. Mitigation options are available. City-wide cumulative impacts are moderate for all environmental resources.	It is likely that the LTCP option would adversely impact a number of high value wetlands, streams, shorelines, habitats, and/or endangered species. Mitigation options are limited. City-wide cumulative impacts are high for a number of environmental resources.
10. Ease of O&M and Safety		
The facility requires no operating staff or can be remotely operated. Peak staff times require < 1 operator. The facility can be shut down with minimal staff time. Cleanup work is automated or can be scheduled to be integrated with other staff duties.	The facility can generally be remotely operated. An operator may need to be present periodically for sampling, chemical make-up, chemical delivery acceptance or other discrete tasks. Peak staff times require 1-2 operators. The facility can be shut down with	The facility requires operator attention during the event. Peak staff times require 2 or more operators. The facility requires significant effort for shut down (e.g., vac/boom truck, several days for cleanup). Cleanup work is generally manual with 2 or more personnel required

Table 4. Performance Measures		
Performance Measures (High, Medium, Low)		
High = 3.0 (Best)	**Medium = 2.0**	**Low = 1.0 (Worse)**
The facilities only require annual preventive maintenance. The processes have minimal mechanical/instrumentation components (i.e., storage tank). Reliable in intermittent use. The facility does not have right-of-way access requirements or non permit required confined space entry. No traffic control procedures are required during operations and maintenance.	minimal staff time. Cleanup work is generally automated; however, 1-2 personnel may be required. The facilities require monthly maintenance such as bumping pumps. The processes have an increasing level of mechanical/instrumentation components (I.e., pump station). The facility has right-of-way access requirements or permit required confined space entry during non-routine operation and/or maintenance procedures. Traffic control procedures are required during non-routine operations and maintenance procedures. Work is in a moderately populated (residential or commercial) environment.	for more than one day. Most procedures of shutdown need to be conducted immediately. The facilities require monthly maintenance such as bumping pumps. The processes have an increasing level of mechanical/instrumentation components (I.e., treatment facility). Equipment is prone to failure with intermittent use. The facility has right-of-way access requirements or permit required confined space entry during routine operation and/or maintenance procedures. Traffic control procedures are required during routine operations and maintenance procedures. Work is in a densely populated (residential or commercial) environment.

Each option then was scored against the MODA evaluation criteria by members of the project team. Scores for each criterion were assigned by project staff based on team member's knowledge of the projects. The resulting scores are shown in Table 5.

Table 5. Rating Scores

Evaluation Criteria	Scores				
	Neighborhood-Storage Tanks	Neighborhood-West Ship Canal Tunnel	Shared Storage	Shared Ship Canal Tunnel	Shared West Ship Canal Tunnel
1. Technical Complexity and Performance Risk	1.0	2.0	2.5	1.0	1.0
2. Flexibility	1.0	2.5	2.0	1.0	1.0
3. Constructability	1.0	1.5	1.5	2.0	2.0
4. Consent Decree Compliance Schedule	3.0	3.0	1.0	1.0	1.0
5. King County Concurrence on Shared Projects	3.0	3.0	2.0	1.0	1.0
6. Construction Impacts (Short-Term)	1.0	1.5	1.0	2.5	2.0
7. Community Impacts (Long-Term)	1.5	2.0	2.0	2.5	2.5
8. Environmental/ Social Justice	2.0	1.5	2.0	1.5	2.0
9. Environmental	1.5	1.5	2.0	2.5	2.0
10. Ease of O&M and Safety	1.0	2.0	2.5	1.0	1.0

When scoring criteria used a constructed scale (i.e., qualitative, 1-3), the team provided a rationale for the score given to each project for each criterion. The rationale provided for each score is provided in the Appendix.

2.6 Relative Value Weights

Assigning weights to objectives is a subjective exercise based on the values of the stakeholder(s). Weighting was done after the performance measures were developed, so project team members could include in their consideration the extent to which the full set of LTCP options vary in performance. The weight assigned to an objective is a measure of that objective's relative contribution to the decision goal as it is varied from the lower end of its measurement scale to the upper end of that scale. Table 6 presents the weights developed for the objectives hierarchy.

Table 6. Criteria Weighting

Evaluation Criteria	Relative Importance Weight	% of Total
1. Technical Complexity and Performance Risk	100	12%
2. Flexibility	70	8%
3. Constructability	100	12%
4. Consent Decree Compliance Schedule	100	12%
5. King County Concurrence on Shared LTCP Options	100	12%
6. Construction Impacts (Short-Term)	60	7%
7. Community Impacts (Long-Term)	80	9%
8. Environmental/Social Justice	80	9%
9. Environmental	80	9%
10. Ease of O&M and Safety	80	9%

SECTION 3

Rating and Ranking Results

The Draft LTCP performed a "rating and ranking" of the LTCP options in accordance with the EPA requirements from the "Combined Sewer Overflows Guidance for Long-Term Control Plan, 1995". The Draft LTCP ranking results are presented in Table 7.

Table 7. LTCP Value Score Comparison with Net Present Value

LTCP Option	Value Score	City NPV Cost Share, $M	Lower NPV Cost Range $M (-20%)	Upper NPV Cost Range $M (+30%)
Neighborhood—West Ship Canal Tunnel	54.4	$384	$307	$499
Shared Storage	42.9	$361	$289	$469
Neighborhood—Storage Tanks	32.9	$373	$298	$485
Shared Ship Canal Tunnel	27.6	$352	$282	$458
Shared West Ship Canal Tunnel	25.9	$309	$247	$402

Because the Net Present Values for the LTCP options are within the accuracy range for a Class 4 estimate (-20% to +30%), the LTCP option Net Present Value costs are essentially the same and all the LTCP options can be considered equivalent in costs.

The LTCP options were then ranked based on the total value scores shown on Table 6, LTCP Option Rating. The Draft LTCP option rankings (highest to lowest) are:

1. Neighborhood West Ship Canal Tunnel (highest ranked option)
2. Shared Storage
3. Neighborhood—Storage Tanks
4. Shared Ship Canal Tunnel
5. Shared West Ship Canal Tunnel (lowest ranked option)

The Neighborhood West Ship Canal Tunnel option is the highest ranked LTCP option and will meet the City's Consent Decree construction completion milestone date (2025). The Shared Storage option is the second highest ranked LTCP option; however two of the shared storage tank projects (North Union Bay and Montlake) proposed in King County's CSO Plan will not meet the City's 2025 completion date. The Neighborhood Storage Tank option will meet the City's Consent Decree construction completion milestone date (2025). The Shared Ship Canal Tunnel option will require 14 years to design and construct and will not meet the City's Consent Decree construction completion date (2025) and will not meet the King County's Consent Decree 3rd Avenue West completion date (2023). The Shared West Ship Canal Tunnel option is the lower ranked LTCP option and will require 11 years to design and construct; this option will meet the City's Consent Decree construction completion milestone date (2025); however, it will not meet the County's Consent Decree construction completion milestone date for 3rd Avenue West (2023).

SECTION 4

Final LTCP Option Decision Making Activities

4.1 City and King County CSO Project Coordination

The City recognizes the importance of strong coordination with King County in controlling CSOs in the City. All of the proposed LTCP options have elements which may have an impact on King County's downstream wastewater system. Three of the proposed LTCP options include shared City/King County projects along the Ship Canal. Several of the proposed LTCP options include sewer system improvements which will convey additional wastewater volume to the downstream King County system. Regardless of which LTCP option is selected, coordination between the City and King County is critical to successfully designing, constructing, and eventually operating the proposed CSO control projects in the City.

The City and King County are continuing to work together closely to analyze and recommend LTCP options that are more cost-effective, produce better environmental outcomes, and minimize disruption to communities. King County must also reach its own independent conclusions about the benefits of a shared project to the regional system, and the implications of such as project to its own Long Term Control Plan and Consent Decree. Selection of a shared City/King County project will be dependent on the City's and County's analytical results as well as a number of joint factors mutually agreed upon in a City/County Coordination Plan. These factors include such things as which agency will be responsible for the design/construction/operations of the shared facility, each agency's project cost-share, operational and implementation roles and responsibilities, the process for dispute resolution, and the ability to fulfil regulatory and contractual obligations. If the City and King County choose to implement a shared City/King County project, then a shared project agreement between the two agencies will be necessary prior to designing and constructing the project. In addition, the City and King County will analyze the impacts of any recommended project on the downstream King County system and agree on an approach to addressing those impacts prior to constructing the project.

4.2 LTCP Option Selection Schedule

Figure 5 summarizes the schedule for selecting the recommended LTCP option. By May 30, 2014, the Draft LTCP with the option rating and rankings will be submitted for EPA and Ecology review and comment. In addition, SPU will issue a public notice and will hold a public hearing and official public comment period for the Draft LTCP. After the comment period and receiving EPA and Ecology comments, additional evaluation will be performed (CSO Alternative Analysis Report, Implementation Plan and Financial Plan) and a preferred LTCP option will be recommended by the end of 2014. The preferred LTCP option will be documented in the CSO Alternative Analysis Report to be submitted to EPA/Ecology by December 30, 2014 as required by the July 3, 2013 Consent Decree.

In early 2015, the City Council will review and adopt the Final LTCP through a City Ordinance process. By May 30, 2015, the Final LTCP will be submitted to EPA and Ecology for Final Approval. By the end of 2015, the Final Plan is anticipated to be approved by EPA and Ecology and LTCP implementation will commence in late 2015 or early 2016. Construction completion of all approved LTCP projects shall be completed by December 31, 2025.

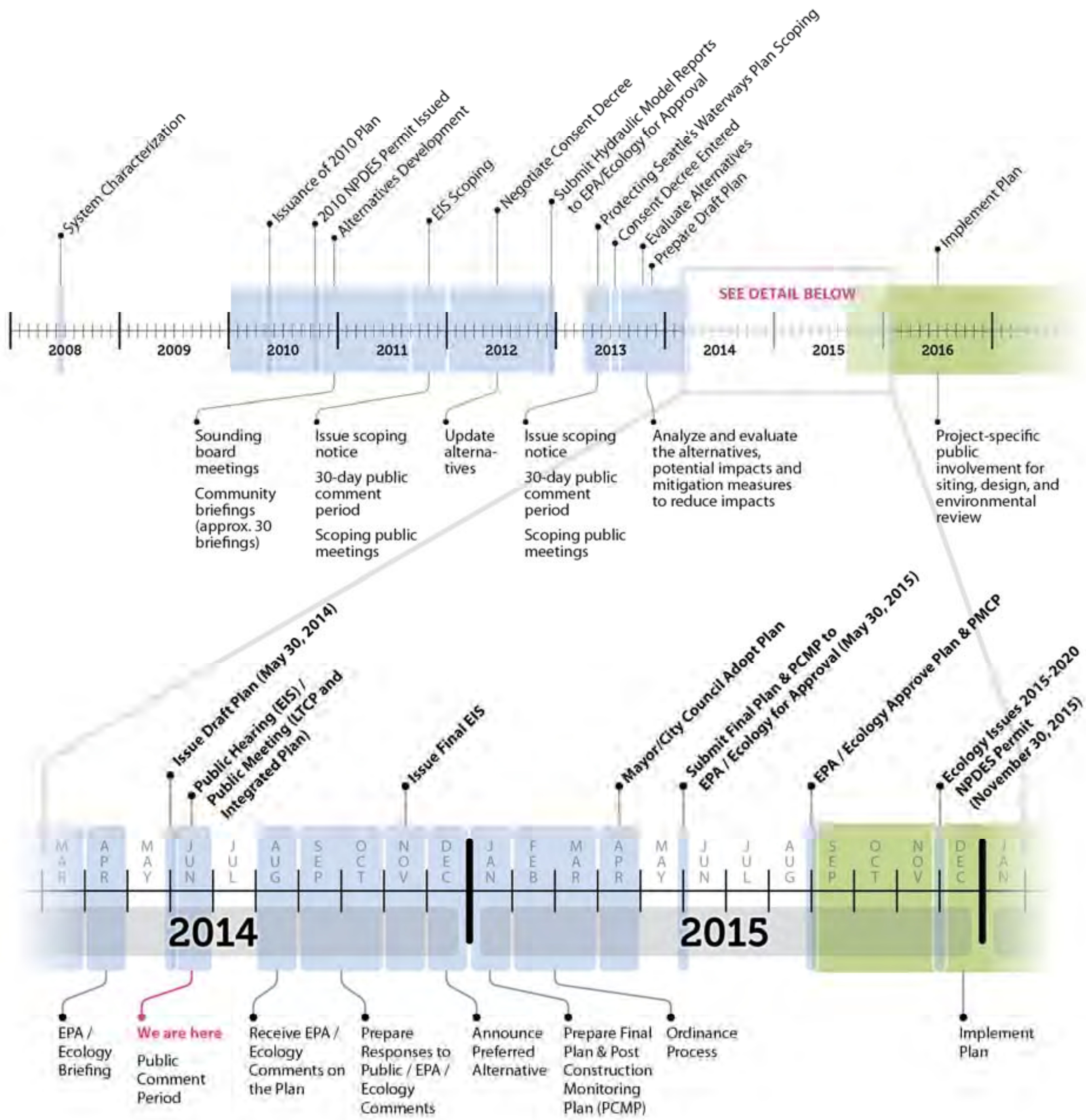

Figure 5. LTCP Option Selection Schedule

Appendix E: Phase 4 Flow Monitoring Report

Seattle Public Utilities | Protecting Seattle's Waterways

Final Phase 4 Flow Monitoring Report

2011–2012 Wet Season

March 2013

Seattle Public Utilities
Long-Term Control Plan Flow Monitoring Report

March 2013

Prepared for:

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SPU Project No. C-308039
SPU Consultant Contract No. C10-048

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List of Abbreviations

Term	Definition
ADS	ADS Environmental Services, manufacturer of flow meters such as the FlowShark and Pulse
City	City of Seattle
CSO	combined sewer overflow
CSS	combined sewer system
DDF	depth-duration-frequency
DW	dry weather
DWF	dry weather flow
Ecology	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
LTCP	Long-Term Control Plan
mgd	million gallons per day
MGS	MGS Engineering Consultants, Inc.
MH	maintenance hole
MP	monitoring point
NPDES	National Pollutant Discharge Elimination System
PS	pump station
QAPP	Quality Assurance Project Plan
Report	Flow Monitoring Report
RG	rain gauge
SCADA	supervisory control and data acquisition
Sea-Tac	Sea-Tac International Airport
SOP	standard operating procedure
SPU	Seattle Public Utilities
WW	wet weather

Executive Summary

This Seattle Public Utilities (SPU) Long-Term Control Plan (LTCP) Flow Monitoring Report (Report) documents the results of the LTCP Flow Monitoring project conducted within two combined sewer overflow (CSO) basins in SPU's combined sewer system (CSS), Leschi and North Union Bay. The LTCP Flow Monitoring project began on 10/1/2008 and continued through 3/31/2012. The data collection effort was divided into four phases:

- Phase 1 covered the wet weather period from 10/1/2008 through 5/31/2009.
- Phase 2 covered the dry weather period from 6/1/2009 through 8/31/2009.
- Phase 3 covered the wet weather period from 9/1/2009 through 5/31/2010.
- Phase 4 covered the wet weather period from 10/1/2011 through 3/31/2012.

The data collected during Phase 1 are documented in Volume 4 of the LTCP Flow Monitoring Report (Phase 1 Flow Monitoring Report, 2010). The data collected during Phases 2 and 3 are documented in Volume 5 of the LTCP Flow Monitoring Report (Phases 2 and 3 Flow Monitoring Report, 2010). This Report assesses the quality of the data collected at each meter for Phase 4.

The goal of the CSO LTCP is to develop and submit to the United States Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) a final CSO control plan by May 2015 that performs the project development (monitoring, modeling, and planning) and preliminary engineering for all of the City of Seattle (City)'s CSO basins. The LTCP will identify a recommended list of CSO reduction projects that will be carried into design and construction in the future to meet the City's required CSO reduction targets. The goal of the LTCP Phase 4 Flow Monitoring project is to collect continuous rainfall depth, level, velocity, and operational data for refined model calibration in the Leschi and North Union Bay CSO Basins during the wet season, 10/1/2011 through 3/31/2012, to supplement data collected earlier in the program. The data will be used to characterize the hydrologic and hydraulic performance of the CSS and support development of the LTCP.

Flow monitoring is the collection of simultaneous measurements of velocity and depth (which are used to compute flow), as well as rainfall and operational data, at strategic points within the system. The objectives of the Phase 4 LTCP Flow Monitoring project are as follows:

- adequately and accurately characterize the hydrologic and hydraulic performance of the CSS by collecting rainfall depth, level, velocity, and operational data:
  - hydrologic performance is defined as the hydrologic response of a sub-basin to rainfall
  - hydraulic performance is defined as the operating characteristics of structures and facilities in the CSS, including in-line and offline storage, HydroBrakes, gates, weirs, diversions, regulators, and pump stations (PSs)
- capture data before, during, and after a wide range of storm events with a range of antecedent moisture conditions
- recommend storm events for model calibration and future flow monitoring in the event that the desired storms do not occur during the project monitoring period

The initial phases of the LTCP Flow Monitoring project focused on 12 areas: Ballard, Delridge/Longfellow, Duwamish, Fremont/Wallingford, Interbay, Leschi, Madison Park/Union Bay, Magnolia, Montlake, North Union Bay, Portage Bay/Lake Union, and West Seattle. Phase 4, discussed in this Report, focuses on those areas that used 2011–12 wet season data in their calibration and model verification: Leschi and North Union Bay shown on Figure ES-1. To achieve the data objectives, 28 meters were in place at the beginning of Phase 4 monitoring; 13 of these meters were located at permanent metering locations and 15 meter locations were installed on a temporary basis. The new sites are categorized as follows:

- Eight temporary meters were installed within the Leschi CSO Area to acquire additional data for system characterization, hydraulic calibration, and model verification.
- Seven temporary meters were installed within the North Union Bay CSO Area to acquire additional data for system characterization and model verification.

Additional data were obtained from the following sources:

- 13 SPU-maintained permanent flow meters installed at National Pollutant Discharge Elimination System (NPDES) outfalls
- supervisory control and data acquisition (SCADA) data from SPU pump stations associated with the CSO basins
- precipitation data from SPU's rain gauges (RGs) 02 and 25
- SCADA data from King County monitoring locations as necessary to provide boundary conditions for the CSO basin models

To ensure the highest possible data quality, monitoring data were screened during the wet weather season. The screening focused on consistency and completeness of meter response. When data screeners noted anomalies, these were reviewed and marked as action items for the metering contractor, if appropriate. Overall, these screening activities resulted in the collection of data that can confidently be used in model calibration.

Rainfall during the fall and winter of the Phase 4 monitoring period can be characterized as generally slightly lower than average in volume and number of events at both of these gauges. October 2011, November 2011, and January 2012 were average in total rainfall, whereas December 2011 and February 2012 were significantly lower than average in total rainfall. March 2012 rainfall was significantly higher than average in total rainfall.

The objectives for the Phase 4 LTCP Flow Monitoring project were as follows:

- adequately and accurately characterize the hydrologic and hydraulic performance of the CSS by collecting rainfall depth, level, velocity, and operational data
- capture data before, during, and after a wide range of storm events with a range of antecedent moisture conditions
- recommend storm events for model calibration and future flow monitoring in the event that the desired storms do not occur during the project monitoring period

After the conclusion of Phase 4 monitoring and in combination with the data collected during Phases 1, 2, and 3, all of the above-stated objectives of the monitoring have been exceeded at each gauge. In addition, the characteristics of the rainfall that occurred provide excellent opportunities to calibrate both the impervious runoff and groundwater flows in the models. No further monitoring is required to meet the project objectives. The events identified in Table 3-1 and Table 3-2 are recommended for model calibration and verification.

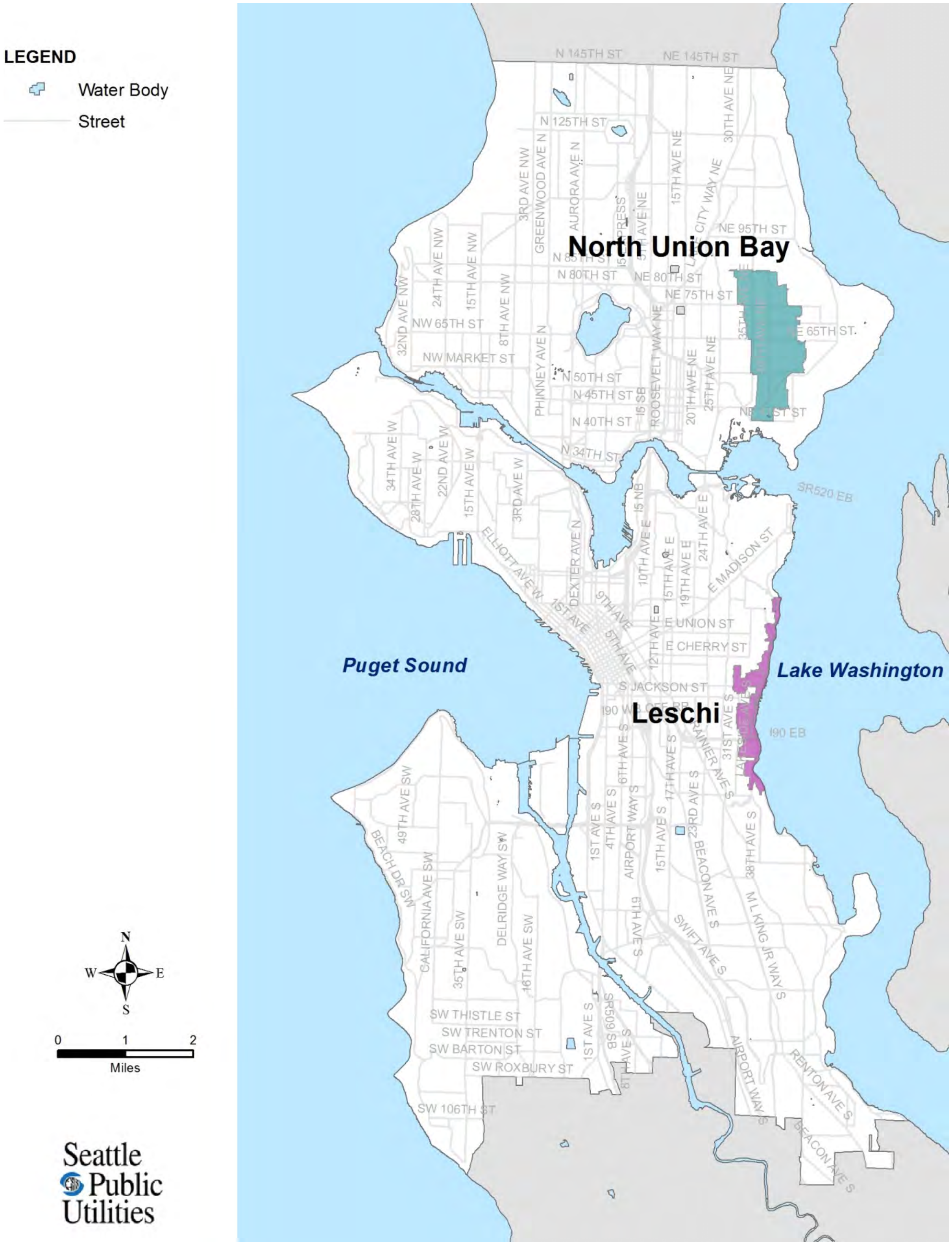

Figure ES-1. LTCP Long-Term Control Plan flow monitoring areas

SECTION 1

Introduction

Seattle Public Utilities (SPU) is currently implementing a program to reduce combined sewer overflow (CSO) events. The Long-Term Control Plan (LTCP) will develop options to reduce CSO events in the most cost-effective manner. One of the requirements of the LTCP is to have accurate hydraulic models of the combined sewer system (CSS). SPU has undertaken flow monitoring of the CSS over a 3-year period to capture sufficient data to calibrate the hydraulic models. The LTCP is a two-phase program: LTCP Development and LTCP Completion.

The LTCP Development phase was initiated in October 2008 and was completed in December 2011. This phase included a rigorous 2-year flow monitoring program (Phases 1–3). The results of the Phases 1–3 Flow Monitoring Program are documented in Volumes 4 and 5 of the Flow Monitoring Data Report (2010c, 2010d). The LTCP Completion phase will perform CSO basin model re-calibration due to significant improvements in the SWMM5 software used for hydraulic/hydrologic model development of the current basin models. As part of this LTCP Completion phase, existing and new monitoring locations in the Leschi and North Union Bay CSO Areas were monitored during the 2011–12 wet weather period.

This report describes the methodology and results of the Phase 4 monitoring effort.

Phase 1 was conducted during the first wet weather season from 10/1/2008 through 5/31/2009. Phase 2 was conducted during the dry weather season from 6/1/2009 through 9/30/2009, Phase 3 was conducted during the wet weather season from 10/1/2009 through 5/31/2010, and Phase 4 was conducted during the wet weather season from 10/1/2011 through 3/31/2012.

1.1 Goals

The goal of the CSO LTCP is to develop and submit to the United States Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) a final CSO control plan by May 2015 that performs the project development (monitoring, modeling, and planning) and preliminary engineering for all of the City of Seattle (City)'s CSO basins. The LTCP will identify a recommended list of CSO reduction projects that will be carried into design and construction in the future to meet the City's required CSO reduction targets. The goal of the LTCP Phase 4 Flow Monitoring project is to collect continuous rainfall depth, level, velocity, and operational data for refined model calibration in the Leschi and North Union Bay CSO Basins during the wet season, 10/1/2011 through

3/31/2012, to supplement data collected earlier in the program. The data will be used to characterize the hydrologic and hydraulic performance of the CSS and support development of the LTCP.

1.2 Monitoring Objectives

The objectives of flow monitoring for this phase are as follows:

- adequately and accurately characterize the hydrologic and hydraulic performance of the CSS by collecting rainfall depth, level, velocity, and operational data
- capture data before, during, and after a wide range of storm events with a range of antecedent moisture conditions
- recommend storm events for model calibration and future flow monitoring in the event that the desired storms do not occur during the project monitoring period

1.3 Study Boundaries

The study boundaries for the Phase 4 monitoring area comprise two CSO areas located within the city of Seattle: Leschi and North Union Bay NPDES018. These areas comprise a number of basins draining to an overflow point, which is designated by a National Pollutant Discharge Elimination System (NPDES) number. The North Union Bay area also includes NPDES019 which is considered controlled, and is not discussed in this report. A CSS, which serves these basins primarily, conveys wastewater and runoff from directly connected rooftops, streets, and area drains to the King County interceptor system and ultimately to the King County West Point Treatment Plant. The study boundaries include permanent flow meters at each overflow structures in the basins, a network of temporary monitoring locations throughout the basins, and a network of rain gauges (RGs) throughout the city. An overview of the study and locations is shown in Figure 1-1 and Figure 1-2.

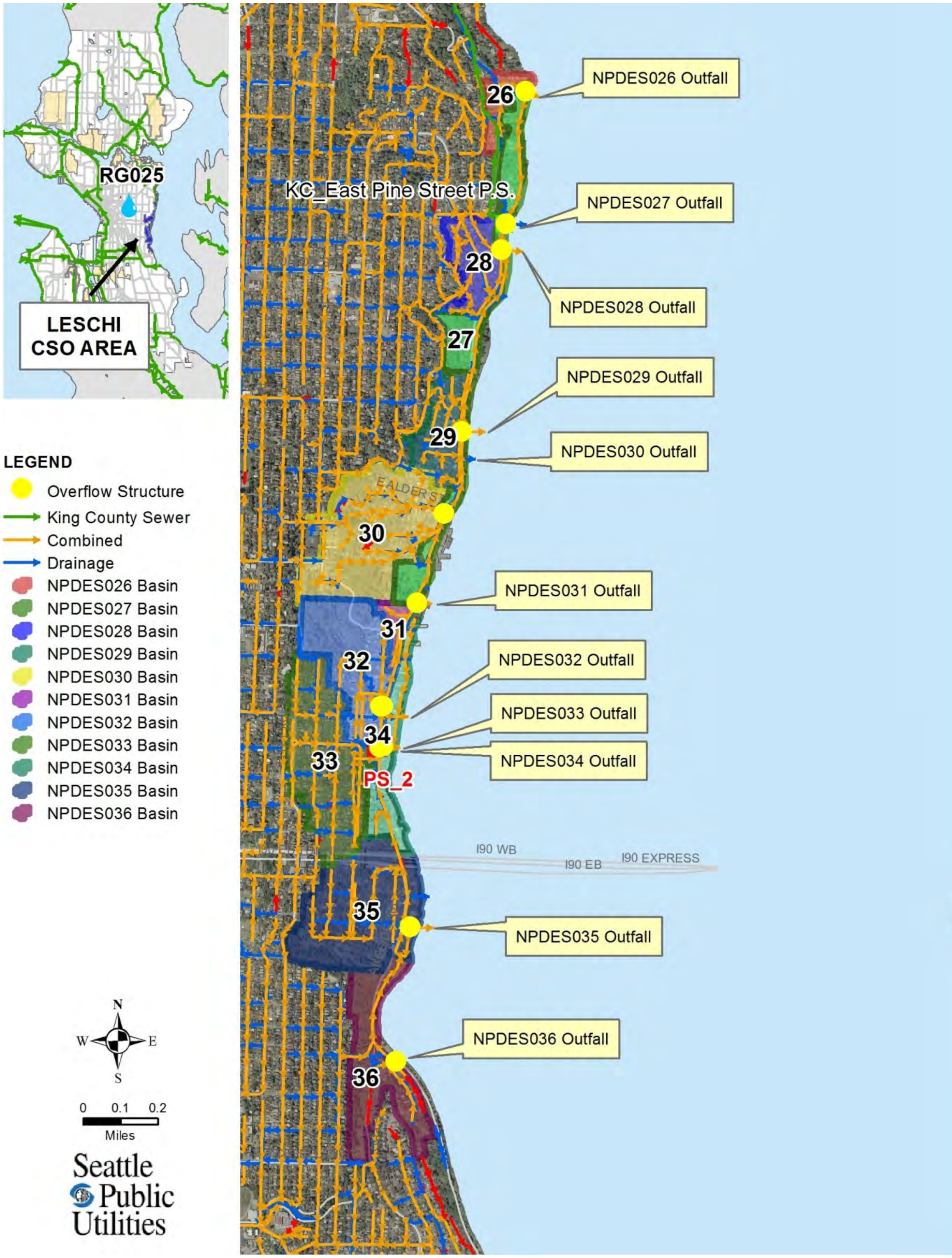

Figure 1-1. Leschi CSO Area overview map

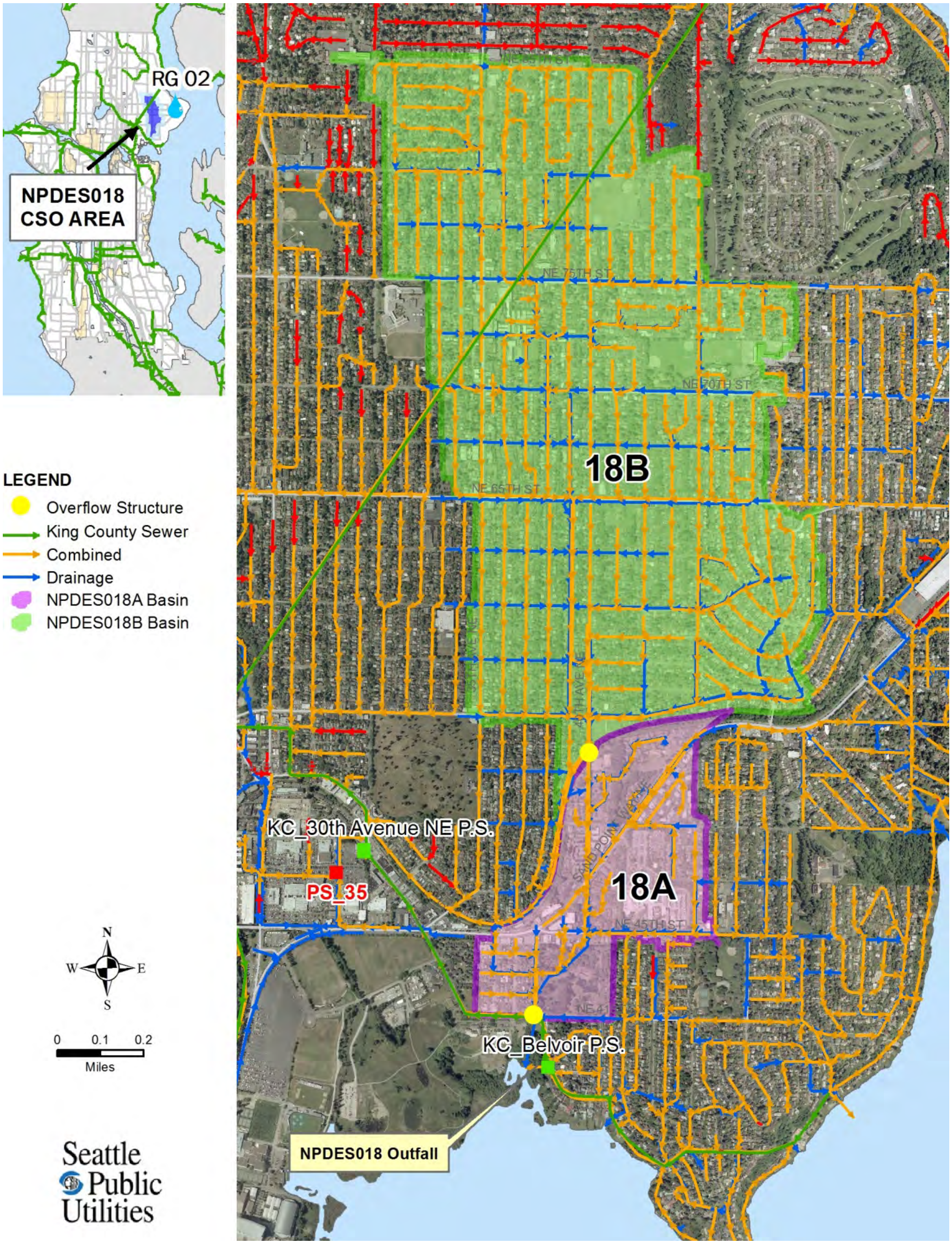

Figure 1-2. NPDES018 CSO Area overview map

1.4 Report Organization

This Report documents Phase 4 of data collection, from 10/1/2011 through 3/31/2012. The organization of the Report is summarized below:

- Section 1: Introduction
- Section 2: Methodology
- Section 3: Monitoring Data
- Section 4: Suitability of Data for Hydrologic and Hydraulic Modeling Efforts

The appendices of this Report contain data site sheets by basin that are meant to supply more quantitative information for each site. The data site sheets include the following information:

- purpose of each location
- site installation photos
- upstream pipe traces
- period meter installed and collecting data
- field-verified pipe diameter
- extent of scatter-of-depth and velocity data
- flow regime
- range of depth, velocity, and flow during monitoring period

The data collected from temporary monitoring locations, NPDES-permitted CSO outfall monitors, and SPU rain gauges are stored on IntelliServe and FlowWorks, both of which are Web site databases developed by ADS Environmental Services (ADS). The FlowWorks Web site also contains information such as silt/sediment measurements, field verification measurements, site maintenance, and data finalization notes for all permanent meters.

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SECTION 2

Methodology

This section provides an overview of the methodology used to monitor flow, rainfall, pump stations, and overflows in the CSS. More detailed information can be found in the Quality Assurance Project Plan (QAPP), Long-Term Control Plan: Flow Monitoring Plan 2008–2009 (QAPP December 2009).

2.1 Monitoring Locations

This section presents a description of the different types of monitoring locations from which data were collected during the Phase 4 monitoring review period.

2.1.1 Permanent Monitoring Locations

The Leschi CSO Area has 11 permitted outfalls. The North Union Bay CSO Area has two permitted outfalls, one that is controlled (NPDES019) and one that is uncontrolled (NPDES018). Each CSO outfall has a unique discharge point.

ADS operates and maintains meters at each overflow structure associated with each permitted outfall. These meters comply with the City's NDPES requirements for reporting CSO events to the Washington State Department of Ecology (Ecology). The ADS meters cover all the Leschi and North Union Bay permitted outfalls. As part of this LTCP monitoring review, 13 of the existing permanent ADS monitoring points were reviewed for data quality.

2.1.2 Temporary Monitoring Locations

In addition to the permanent monitoring locations, a total of 15 temporary sites were monitored during the Phase 4 period. ADS was responsible for installing and maintaining the temporary meters as well as the permanent meters. For the Phase 4 monitoring period, eight temporary monitoring meters were installed within the Leschi CSO Area. Four of these meters measured both level and velocity, whereas four meters monitored depth only. A total of seven temporary monitoring meters were installed within the North Union Bay CSO Area. Six of these meters measured both level and velocity, whereas one meter monitored depth only.

The meters were strategically located so as to represent the hydrologic characteristics of the subcatchments within the whole basin. Sites were also selected to provide data for the characterization of key structures (HydroBrakes, sluice gates, weirs, storage tanks, etc.) in the basins. By the end of the Phase 4 monitoring period, all of the temporary meters were removed, as the project team determined that they had captured sufficient data suitable for model calibration.

Appendix A contains basin schematic maps for both the Leschi and North Union Bay CSO Areas, showing the relative location of each meter within the basin. Appendices B, Leschi, and C, North Union Bay, provide for each meter a unique data sheet that lists the specific attributes for each meter, including the meter model type, address, installation date, upstream pipe length, and recorded data hydrographs used in this evaluation.

2.1.3 Rainfall Monitoring Locations

SPU maintains a network of rain gauges throughout the city. ADS collected the data from SPU's network and reviewed, corrected, and finalized the data. Thiessen polygons were created for the SPU rain gauges to determine which rain gauge would be used for each flow meter location. It was determined that the meter locations for North Union Bay CSO Area were located within the area covered by RG 02 and that the meter locations within the Leschi CSO Area were covered by RG 25. The data from these gauges were sufficient for model calibration and analysis. Figure 3-1 shows the locations of all the SPU rain gauges.

2.2 Equipment

The parameters of concern for flow monitoring of the sewer system included velocity, water surface levels, and flow rates.

Ultrasonic or pressure sensors were used to measure depth in pipes, hydraulic control structures, or detention tanks at 5-minute intervals. (The NPDES locations change to 2-minute data when depth reaches a set point.) A Doppler velocity sensor typically measures velocity. The sensor transmits a continuous sound wave and measures the frequency shift of returned echoes reflected by air bubbles or suspended particles in the flow. Specific configurations vary by site.

Water surface levels were measured directly using an ultrasonic instrument where free surface conditions existed, or by using a pressure sensor. At most sites both ultrasonic and pressure sensors were used to measure water surface levels. For this project, measuring the depth within a cross-section of flow and the average velocity within that cross-section determined the flow rates, as used by the continuity equation, which multiplies the area of flow by the average velocity. CSO events are typically measured by applying weir equations to the measured depth over a weir.

During the Phase 4 monitoring period, site verifications were performed to ensure that the meters were accurately measuring both velocity and depth. Site gain (peak- to average-velocity ratio) and any depth adjustments were evaluated throughout the monitoring period. Measurement quality was reviewed and validated according to the SPU Hydraulics SOP

HYDR Q1100: Data Review, Assessment, Validation and Verification (Seattle Public Utilities, June 2008).

The different types of flow monitoring equipment used for this project are summarized in the following subsections.

2.2.1 ADS FlowShark

The ADS FlowShark is an area-velocity flow meter that measures depth and velocity; the continuity equation is used to calculate flow. Three types of data acquisition sensors are available for the FlowShark: an ultrasonic depth sensor, a pressure depth sensor, and a velocity sensor.

The primary depth measurement device is the ADS quad-redundant ultrasonic level sensor mounted at the top of the pipe. It operates by measuring the elapsed time for an ultrasonic signal to travel to the flow surface and back, and calculates the distance to the flow surface. This information and the programmed pipe geometry are used to compute depth of flow.

A pressure depth sensor can also be used. It measures the depth of flow by recording the difference in atmospheric pressure and water height pressure. The pressure sensor is often used as a backup measurement to the ultrasonic depth sensor. It is also used to record depth in surcharged maintenance holes (MHs) where the ultrasonic depth measurement cannot be used.

The ADS V-3 digital Doppler velocity sensor measures peak velocity in the cross-sectional area of flow. An ultrasonic carrier is transmitted upstream into the flow and is reflected by suspended particles, air bubbles, or organic matter with a frequency shift proportional to the velocity of the reflecting objects. The reflected signal is received by the sensor and processed using digital spectrum analysis to determine the peak flow velocity.

2.3 Data Collection, Processing, and Analysis of the Permanent and Temporary Meters

This section provides a description of the techniques that were employed to ensure the integrity of the data, and the procedures used by ADS for the processing and analysis of the data reviewed during the project from both the permanent and temporary meters.

During the Phase 4 monitoring period, field crews visited each monitoring location to retrieve data if remote communications were not available, verified proper meter operation, and documented field conditions. The following quality assurance steps were taken to sure the integrity of the collected data (ADS Quality Assurance and Implementation Plan, ADS Environmental Services, June 2009):

Measure power supply: A dry-cell battery pack powered the meter. Power levels were recorded and battery packs were replaced, if necessary. A separate battery provided backup power to memory, which allowed the primary battery to be replaced without the loss of data.

Maintenance: Maintenance was performed if requested by the data analyst or determined by the field crew to be needed. Maintenance tasks included sensor “scrubbing” (removal of debris) and replacement of system parts if a malfunction of a part occurred. Maintenance was both preventive and reactive for the flow meter and sensors. Maintenance records were posted to the FlowWorks Web site on request.

Perform confirmations and validate depth and velocity: Once equipment and sensor installation was accomplished, a member of the field crew descended into the maintenance hole to perform a field measurement of depth and velocity to confirm their agreement with the meter. Because the ADS V-3 velocity sensor measures peak velocity in the wetted cross-sectional area of flow, velocity profiles were also taken to develop a relationship between peak and average velocity in lines that meet the hydraulic criteria. If the site conditions did not allow a velocity profile, a standard gain value was used to calculate average velocity.

Measure silt level: During site confirmation, a member of the field crew descended into the maintenance hole and measured and recorded the depth of silt at the bottom of the pipe. These data were used to compute the true area of flow.

Confirm meter synchronization: The field crew checked the flow meter clock for accuracy. If the meter and computer time were different by more than 5 minutes, the meter was activated with the current computer time. The data for this project were also synchronized with those of the temporary flow meters.

Upload and review data: Data collected by the meter were uploaded and reviewed for comparison with previous data. Data for this project were collected remotely via wireless communication and uploaded to the ADS IntelliServe and FlowWorks system. In the event that the signal strength did not permit remote data collection, the data were collected as per the current ADS Contract Scope of Work. All readings were checked for consistency and screened for deviations in the flow patterns, which indicated system anomalies or equipment failure.

Flow meters were generally programmed to collect data at 15-minute intervals throughout the monitoring period unless circumstances dictated a more frequent sample rate (for example, rapidly changing flows due to pump station influence). For this project, the flow meters were programmed to collect data at 5-minute intervals and 2-minute intervals when depths reached a set point, to achieve high-resolution data that were suitable for model calibration.

The meter stored raw data consisting of (1) the air range (distance from sensor to top of flow) for each active ultrasonic depth sensor pair and (2) the peak velocity. If the meter was equipped with a pressure sensor, then a depth reading from this sensor was also stored. When the field personnel collected the data, the air range was converted to depth data based on the pipe height and physical offset (distance from the top of the pipe to the surface of the ultrasonic sensor) and/or the offset from a weir. The data were imported into the ADS Profile™ software, and a data analyst examined the data to verify their consistency. The data analyst also reviewed the daily field reports and site visit records to identify conditions that would affect the collected data.

The data analyst reviewed the velocity profiles and line confirmation data developed by the field personnel to identify inconsistencies and verify velocity data reliability. Velocity profiles were reviewed and an average-to-peak velocity ratio was calculated for the site. This ratio was used in converting the peak velocity measured by the sensor to the average velocity used in the continuity equation.

The data analyst reviewed the meter selection for which the depth sensor entity was used to calculate the final depth information. Any silt levels present at each site visit were reviewed and representative silt levels were established.

Selections for the above parameters were constant or changed during the Phase 1 monitoring period. While the data analysis process was described in a linear manner, it often required an iterative approach to complete it accurately.

Final data: ADS reviewed and finalized the data in Profile. Both the raw and finalized data are available for download from either IntelliServe or FlowWorks. Finalized entities available for download include DFinal (depth), Vfinal (velocity), and Qfinal (flow).

Only the final data that were provided from IntelliServe or FlowWorks were used for the assessment discussed in this Report.

Photographs of the upstream pipe, band, and any other object of concern were taken and organized on ADS site sheets for each specific site, as summarized in Appendix B for the Leschi meters and in Appendix C for the North Union Bay meters.

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SECTION 3

Monitoring Results

This section presents the monitoring results from the Phase 4 monitoring period, including collection of rainfall data and monitoring of the Leschi and North Union Bay CSO Areas.

3.1 Rainfall

Rainfall data were collected for the LTCP Flow Monitoring project through the City rain gauge network. Data from RGs 02 and 25[1] are applicable to the North Union Bay and Leschi CSO Areas, respectively. Both gauges were assigned to the respective CSO area for review of flow monitoring results. This section describes those data, compares the gauges to each other, and compares the data to historical precipitation statistics.

The Phase 4 monitoring period was from 10/1/2011 to 3/31/2012. Unless otherwise noted, stated values are for this Phase 4 period. The long-term average rainfall at Sea-Tac International Airport (Sea-Tac) for this period is 27.91 inches. During the Phase 4 monitoring period, the actual total measured precipitation at Sea-Tac was 28.51 inches, indicating a slightly higher than normal rate of precipitation during this period. Total precipitation at both RG 02 and RG 25 used in this review varied from that recorded at Sea-Tac in the same period, ranging from 22.9 inches at RG 02 to 24.3 inches at RG 25. A map of the SPU rain gauge network is presented in Figure 3-1. Figure 3-2 shows cumulative precipitation for the monitoring period for both of the LTCP rain gauges compared to that of Sea-Tac.

The fall and winter rainfall of the monitoring period can be characterized as generally slightly lower than average in volume and number of events at both of these gauges. Figure 3-3 shows the monthly long-term Sea-Tac average rainfall together with the observed rainfall at RG 02 and RG 25. The October 2011, November 2011, and January 2012 rainfall were average in total rainfall, whereas December 2011 and February 2012 were significantly lower than average in total rainfall. March 2012 rainfall was significantly higher than average in total rainfall.

[1] RG 25 was added to replace RG 20, which was removed from the network due to the sale of the property where the rain gauge was located.

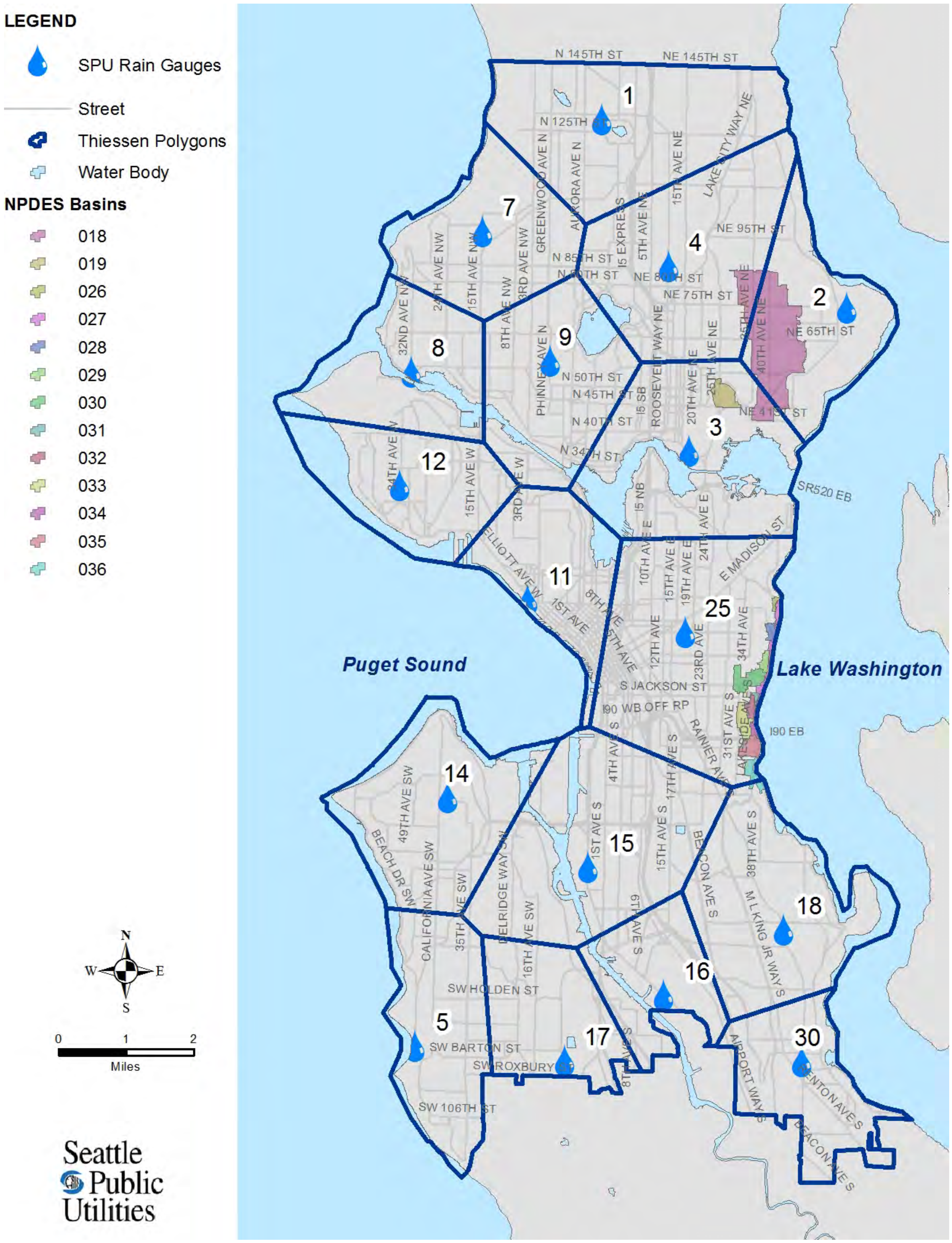

Figure 3-1. Thiessen polygons for each of the SPU rain gauges; north and south borders are the city limits

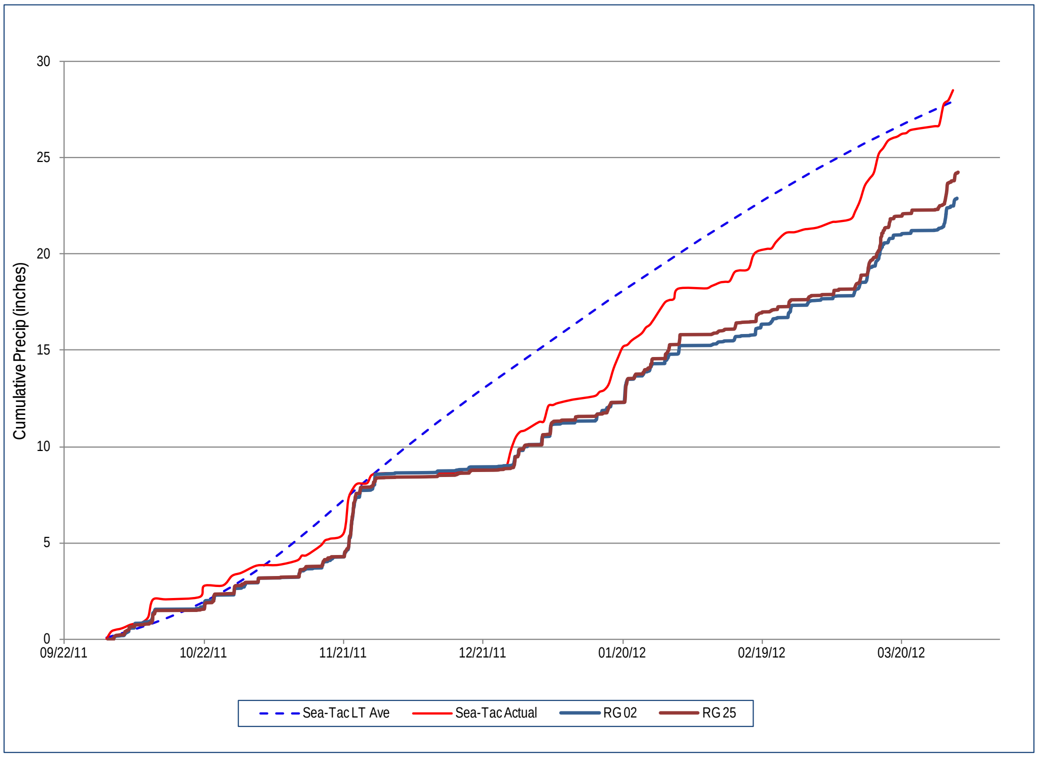

Figure 3-2. Cumulative precipitation for SPU rain gauges 02 and 25 and actual and historical average at Sea-Tac

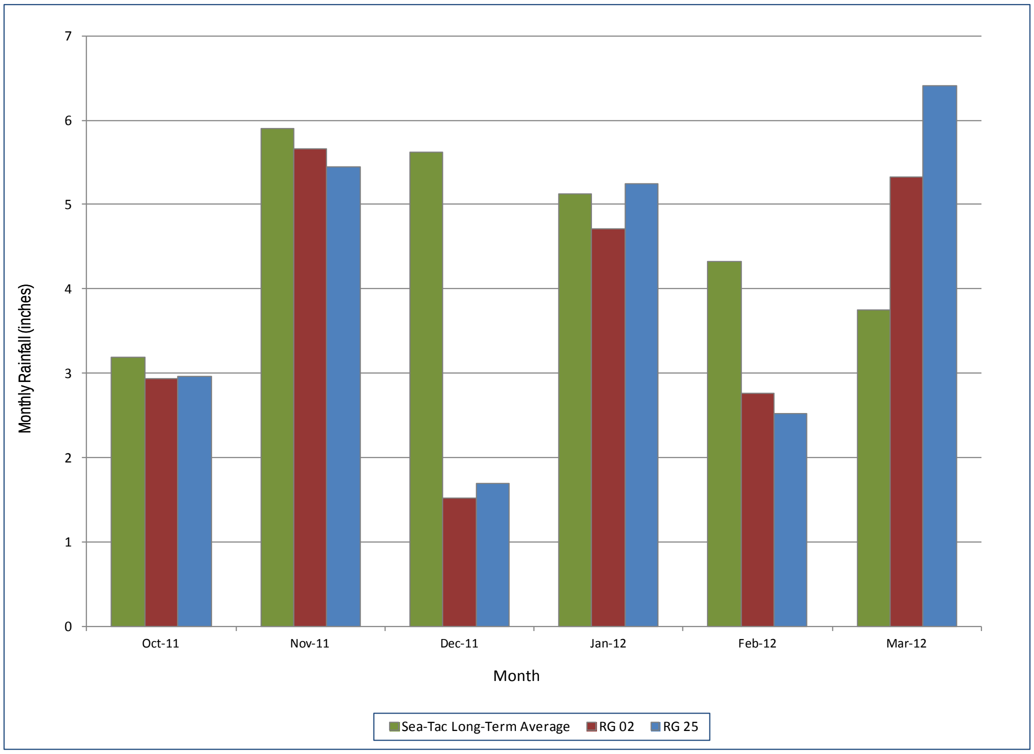

Figure 3-3. Monthly total precipitation for SPU rain gauges 02 and 25 and long-term average total depth by month indicated from Sea-Tac records

3.1.1 Summary of Rainfall Analysis

A rainfall analysis was conducted using StormScan, version 2.0, a tool developed by MGS for SPU. StormScan computes precipitation magnitude, duration, and frequency statistics for selected storm dates. From the monitoring period, 10 storm event periods representing the largest events were chosen for return-period analysis at each rain gauge. Table 3-1 provides a summary of the rainfall analysis conducted for RG 02, and Table 3-2 provides the results for RG 25.

The selected storm events are shown in the first columns of each table. The subsequent columns are the results of the analysis conducted with StormScan.

The 7-day storm depth values represent the total rainfall volume that occurred over a 7-day period around each event. These data provide an indication of the potential effect of each event because much of the tributary area will respond to prolonged higher-volume storms; they are not intended to imply that rainfall occurred on each of the 7 days around the event. A comparison of both gauges shows a variation of less than 0.5 inch.

The short-duration return period values represent the maximum recurrence frequency for each event constructed by comparing the maximum rainfall depths at any duration with the short-term (5-minute to 3-hour) depth-duration-frequency (DDF) curves, as discussed in previous volumes for Phases 1, 2, and 3. Uncontrolled CSO basins with significant impervious area respond greatly to high short-term intensities.

A comparison of both gauges shows that peak rainfall intensities were somewhat variable, as expected. As indicated in Table 3-1 for RG 02, the largest short-term intensity event was a 0.5-year recurrence storm, which was observed on the 11/26/2011 event. Several 0.2-year and 0.3-year events occur in winter 2012. As indicated in Table 3-2 for RG 25, the largest short-term intensity event was a 3.2-year recurrence event, which was observed on the 3/14/2012 event. Several 0.2-year and 0.3-year events occurred in fall and winter 2011–12.

The long-duration return period values represent the maximum recurrence frequency for each event when comparing the maximum rainfall depths at any duration in the long-term (6 hours to 168 hours, or 7 days) DDF curves. DDF graphs for both short and long durations can be found in Appendix A of the Phase 1, 2, and 3 reports. These graphs, taken from Analysis of Precipitation-Frequency and Storm Characteristics for the City of Seattle (MGS Engineering Consultants, Inc., 2003), show the difference in frequency of selected storms between the rain gauges at different durations.

A comparison of both gauges shows that the largest long-duration return period storm at both RG 02 and RG 25 occurred during the 11/22/2011 storm event, with RG 02 recording a 2.5-year return period storm and RG 25 recording a 3.2-year return period storm. Previous work on this LTCP project has shown that the largest sewer overflows are associated with long-durations storms. A review of the CSO events that occurred in both the North Union Bay and Leschi CSO Areas shows that the 11/22/2011 event produced overflows at several NPDES basins, thus being a good storm to be used for calibration.

Table 3-1. Summary of Precipitation Analysis for Rain Gauge 02

Selected events			7-day storm depths (in.)	Short duration return period (5 min to 3 hr)[a]	Long-duration return period (6 hr to 7 days)[a]	Rarest storm duration
Event number	Start date	End date				
1	10/10/2011 6:00	10/11/2011 15:30	1.37	0.2 yr	< 2 mo	45 min
2	10/22/2011 2:45	10/22/2011 22:45	0.45	< 2 mo	< 2 mo	5 min
3	10/28/2011 12:25	10/28/2011 18:00	0.96	< 2 mo	< 2 mo	5 min
4	11/22/2011 0:00	11/23/2011 19:05	3.38	0.3 yr	2.5 yr	72 hr
5	11/26/2011 23:00	11/28/2011 2:00	4.3	0.5 yr	0.3 yr	2 hr
6	12/27/2011 3:10	12/28/2011 0:00	0.54	< 2 mo	< 2 mo	5 min
7	1/2/2012 15:05	1/2/2012 20:05	1.5	0.2 yr	< 2 mo	2 hr
8	1/4/2012 8:45	1/5/2012 3:00	1.51	0.2 yr	0.2 yr	2 hr
9	1/31/2012 20:30	2/1/2012 6:00	1.27	0.1 yr	< 2 mo	45 min
10	3/14/2012 8:05	3/16/2012 8:05	2.75	0.3 yr	0.2 yr	5 min

a. *Maximum recurrence noted at any duration in the series from 5 minutes to 3 hours.*

b. *Maximum recurrence noted at any duration in the series from 6 hours to 7 days.*

< indicates frequency is between that indicated and the next lower value.

Table 3-2. Summary of Precipitation Analysis for Rain Gauge 25

Selected events			7-day storm depths (in.)	Short duration return period (5 min to 3 hr)[a]	Long-duration return period (6 hr to 7 days)[b]	Rarest storm duration
Event number	Start date	End date				
1	10/10/2011 6:00	10/11/2011 15:30	1.23	0.2 yr	< 2 mo	1 hr
2	10/22/2011 2:45	10/22/2011 22:45	0.4	< 2 mo	< 2 mo	5 min
3	10/28/2011 12:25	10/28/2011 18:00	1.19	0.1 yr	< 2 mo	3 hr
4	11/22/2011 0:00	11/23/2011 19:05	3.52	0.3 yr	**3.2 yr**	72 hr
5	11/26/2011 23:00	11/28/2011 2:00	4.08	0.3 yr	0.3 yr	2 hr
6	12/27/2011 3:10	12/28/2011 0:00	0.7	0.1 yr	0.1 yr	24 hr
7	1/2/2012 15:05	1/2/2012 20:05	1.76	0.2 yr	0.2 yr	3 hr
8	1/4/2012 8:45	1/5/2012 3:00	1.58	0.2 yr	0.2 yr	3 hr
9	1/31/2012 20:30	2/1/2012 6:00	1.65	0.3 yr	0.1 yr	45 min
10	3/14/2012 8:05	3/16/2012 8:05	3.19	**3.2 yr**	**0.4 yr**	10 min

a. Maximum recurrence noted at any duration in the series from 5 minutes to 3 hours.

b. Maximum recurrence noted at any duration in the series from 6 hours to 7 days.

< indicates frequency is between that indicated and the next lower value.

3.1.2 Snowfall

Seattle typically receives some snowfall on an annual basis but heavy snow is rare. Average annual snowfall, as measured at Sea-Tac, is 8.1 inches. Throughout the Phase 4 monitoring period, several snow events were recorded at Sea-Tac. Snow events were recorded on the following dates: 11/18/2011, 1/14–20/2012, 2/26–29/2012, 3/6/2012, 3/12–13/2012, and 3/17/2012.

Most of these events produced small amounts of snowfall with the exception of one event, considered the worst winter storm of the 2011–12 season, which produced 6.8 inches of snow on 1/18/2012. This storm produced very heavy, widespread snowfall for a large portion of the Pacific Northwest and was followed by a rare accumulation of nearly an inch of ice. Seattle recorded 19 hours of nearly continuous freezing rain and drizzle from the evening of the 18th through most of the day on the 19th.

3.1.3 Review of Events Used for Model Calibration

The storm events used in this rainfall analysis were chosen in part because they represent storm events with a wide range of antecedent moisture conditions and recurrence intervals. As can be seen in both Table 3-1 and Table 3-2, variation is seen between the storm events with respect to both short-duration and long-duration return periods. These variations in storm characteristics are recommended for use in model calibration. Within these storm events there are excellent rainfall data for calibration purposes. The largest storm events captured during the Phase 4 monitoring period are discussed below.

The storm event of 11/22/2011 lasted approximately 63 hours and included a total rainfall volume of approximately 3.5 inches. The 7 days preceding this event had a total rainfall of approximately 0.9 inch, and there was approximately 2.7 inches of rain in the preceding 30 days. Overflows were observed in both North Union Bay NPDES basins and in four of the Leschi NPDES basins. The short-term rainfall intensities were 0.3-year recurrence for both gauges, whereas the longer-term intensities were 2.5-year recurrence for RG 02 and 3.2-year for RG 25.

The storm event of 1/4/2012 lasted approximately 20 hours and included a total rainfall volume of approximately 1.5 inches. The 7 days preceding this event had a total rainfall of approximately 1.0 inch, and there was approximately 2.0 inches of rain in the preceding 30 days. The short-term rainfall intensities and long-duration recurrences for both gauges were 0.2-year recurrence.

The storm event of 3/14/2012 lasted approximately 47 hours and included a total rainfall volume of approximately 3.0 inches. The 7 days preceding this event had a total rainfall of approximately 1.5 inches, and there was approximately 3.5 inches of rain in the preceding 30 days. Antecedent snowfall was also observed on 3/12–13/2012. Overflows were observed in the Leschi NPDES028 and NPDES029 Basins. The short-term rainfall intensities were 0.3-year and 3.2-year recurrence for RGs 02 and 25, respectively. This storm had a 0.2-year and 0.4-year recurrence for the long-duration return period in both RGs 02 and 25, respectively.

In general, events with minimal preceding rainfall provide a specific advantage for calibration of the impervious hydrologic portion of the models. The lack of preceding rainfall in several of these large events can limit the initial runoff from impervious areas. Examples include the 10/22/2011 and 12/27/2011 events.

Storms with larger volume and antecedent rainfall are expected to result in groundwater infiltration, which will assist in setting parameters for the groundwater module of the models. The late 11/26/2011 and 3/14/2011 events are key in this regard.

In conclusion, at the end of Phase 4 of the LTCP monitoring period and in combination with Phase 1, 2, and 3 monitoring, the recorded meter data and precipitation data at the respective gauges are considered sufficient for use in model calibration and verification. Furthermore, the events identified in Table 3-1 and Table 3-2 are recommended for model calibration.

3.2 Leschi CSO Area

Located on the western shore of Lake Washington along Lake Washington Boulevard, the Leschi CSO Area extends from approximately S McClellan Street to E John Street. The Leschi CSO Area consists of the NPDES026 through NDPES036 Basins. NPDES032 contains two overflow structures, designated here as NPDES032(A) and NPDES032(B) for convenience.

Combined sewage flows south from the NPDES026 Basin and north from the NPDES036 Basin and collects at the East Pine Street pump station in the NPDES027 Basin. The flow is then pumped into the King County interceptor and flows toward the Montlake regulator. Flow is conveyed through the basins in a line that starts in the south as a 16-inch-diamater pipe and ends in the NPDES027 Basin as a 24-inch-diameter pipe. This line runs along the shoreline of Lake Washington and is referred to herein as the Leschi trunk sewer.

RG 20, located west of the Leschi CSO Area at the TT Minor Elementary School campus, was used to monitor rainfall for the Leschi monitoring locations for Phases 1, 2, and 3. Due to construction activities at this location, an alternate rainfall gauge, RG 25, was installed in summer 2010. RG 25 is located at the Garfield Community Center, which is located approximately 0.7 mile southeast of the TT Minor Elementary School campus. For the Phase 4 monitoring period, only RG 25 precipitation data were used for calibration and verification of the Leschi CSO Area.

ADS maintains 12 permanent flow monitoring locations at overflow structures within the Leschi CSO Area and maintained 8 temporary flow monitoring locations to monitor combined sewage flow during the Phase 4 monitoring period. At the conclusion of Phase 4, no temporary meters remained installed in the Leschi CSO Area. No further data were required for the purposes of model calibration. The 12 permanent flow monitoring locations remained in place to monitor overflow events.

Detailed site information on Leschi monitoring locations can be found in Appendix B; a basin schematic is contained in Appendix A.

3.2.1 NPDES026 Basin

The NPDES026 Basin, located in the northernmost part of the Leschi CSO Area, is approximately 10 acres in area. Combined sewage from the NPDES026 Basin flows south and combines with the flows from the NPDES027 Basin before draining into the East Pine Street pump station. Overflows from this partially separated basin are directed to Lake Washington when water levels exceed the side-cast weir elevation located just east of Denny-Blaine Place in MH 038-081.

One permanent monitoring location to verify overflows monitored the basin during Phase 4 of the monitoring period and will remain in place and continue to monitor for overflows. The basin had no overflows during Phase 4.

3.2.1.1 NPDES026_MH038081

NPDES026_MH038081 is a permanent monitoring site that records level, and is therefore classified as a wet weather site. The site was installed on 8/22/2007 to identify and quantify CSO events occurring from the NPDES026 Basin. The level data are used to calculate the volume of CSO events using a weir equation.

NPDES026_MH038081 is located at the NPDES026 Overflow Structure. The quality of the level data was classified as “Good” for the Phase 4 monitoring period because of the consistent and repeatable response of the data and no data gaps.

The quality of the meter readings is consistent with the meter classification for Phases 1 and 2. During the Phase 3 monitoring period, the site was jet-cleaned to remove accumulated debris, and as a result, the level dropped and conditions became more difficult for capturing reliable data by the ultrasonic sensor. During Phase 3, the data were classified as having “Some Limitations.”

NPDES026_MH038081 is a permanent meter and will remain in place and continue to monitor overflows.

3.2.2 NPDES027 Basin

The NPDES027 Basin, which extends along the east side of the Leschi CSO Area along Lake Washington, is approximately 38 acres in area. The partially separated basin drains to the King County East Pine Street pump station, which is located along the shore of Lake Washington. All of the flows from the north in the Leschi CSO Area that do not overflow at the upstream overflow structures pass through the NPDES027 Basin.

One permanent monitoring location to verify overflows and one temporary monitoring location monitored the basin during the Phase 4 monitoring period. The temporary monitoring location was removed in March 2012. The permanent meter will remain in place and continue to monitor for overflows. The basin had no overflows during Phase 4.

3.2.2.1 LES27_042-274A

LES27_042-274A was a temporary monitoring site that recorded level only. This meter was located just downstream of the permanent meter NPDES028_MH042275. The meter was installed on 11/3/2011 to determine the head loss between the trunk line and overflow chamber at the NPDES028 Basin. It was installed only for the Phase 4 monitoring period and was used for hydraulic calibration.

The data were classified as “Excellent” for Phase 4 based on a consistent and repeatable response to dry and wet weather periods. The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.

3.2.2.2 NPDES027_MH042269

NPDES027_MH042269 is a permanent flow monitoring site that records level only. The site was installed on 7/31/2007 to identify and quantify CSO events occurring from the NPDES027 Basin. The level data are used to calculate the volume of CSO events using a weir equation. Overflows occur when the level in LES27_DWF-042269 reaches 27.84 inches.

Data quality was classified as “Good” for the Phase 4 monitoring. Although the data at the site captured a clear and consistent dry weather diurnal pattern, and responded well during all the storm events, there was a data lag between 10/20/2011 and 10/28/2011 and a data gap between 12/21/2011 and 12/23/2011. This ranking is consistent with the classification given during the Phase 2 and 3 monitoring periods. As noted in Volume 5 of the Flow Monitoring Report (2010), due to the configuration of the site, finalization of these data entails an offset correction to the recorded depth levels. For the Phase 1 monitoring period, the data quality was classified as “Excellent” due to the clear relationship evident between level and velocity. All data for Phase 4 are suitable for model calibration and verification.

NPDES027_MH042269 is a permanent meter and will remain in place and continue to monitor overflows.

3.2.3 NPDES028 Basin

The NPDES028 Basin, located in the northern part of the Leschi CSO Area, is approximately 20 acres in area. A side-cast overflow weir in MH 042-275 conveys the excess flows from this basin to Lake Washington through a 15-inch-diameter outfall pipe.

One permanent monitoring location to verify overflows monitored the basin during the Phase 4 period and will remain in place and continue to monitor for overflows. The basin overflowed two times during Phase 4.

3.2.3.1 NPDES028_MH042275

NPDES028_MH042275 is a permanent wet weather monitoring site that records level only. The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES028 Basin. The level data are used to calculate the volume of CSO events using a weir equation.

NPDES028_MH042275 is located at the NPDES028 Overflow Structure. For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The data quality was classified as “Good” for Phase 4 due to some unusual spikes in the hydrograph during the storm on 11/22/2011. Caution should be applied when using the data from this period for calibration. Also, the site report noted that the pipe experienced backward flows that would affect the site hydraulics. Figure 3-4 provides photographs of this location, showing both the view of the maintenance hole and the site installation.

Figure 3-4. Photographs of the NPDES028_MH042275: view of maintenance hole and site installation

For the Phase 2 and 3 monitoring periods, the site data were classified as “Excellent” because of the response to the storm events and the capturing of clear and consistent data. For the Phase 1 period, the data quality was classified as “Good.”

NPDES028_MH042275 is a permanent meter and will remain in place to continue to monitor overflows.

3.2.4 NPDES029 Basin

The NPDES029 Basin, located near the center of the Leschi CSO Area, is approximately 21 acres in area. One CSO control facility is located within the NPDES029 Basin. CSO Facility 18 includes 300 feet of an in-line, 18-inch-diameter storage pipe, one HydroBrake, and two overflow structures. In addition to the 18-inch-diameter in-line storage, another 12-inch-diameter pipe located to the north provides additional storage.

The basin was monitored by two temporary meters and one permanent meter during the Phase 4 period, during which the basin overflowed three times. At the conclusion of Phase 4, no temporary meters remained in the NPDES029 Basin. The permanent meter location will continue to be monitored to verify overflows.

3.2.4.1 LES29_042-302A

LES29_042-302A was a temporary monitoring site that recorded level only. The meter was installed on 11/3/2011 to measure level at the HydroBrake for hydraulic calibration in the

NPDES029 Basin. The meter was located just upstream of the HydroBrake in CSO Facility 18. The data quality was classified as "Good" for Phase 4, as the meter captured all the significant rainfall events with consistent diurnal patterns.

The data were classified as "Excellent" in Phase 1. However, as is the same for Phase 4, the data were classified as "Good" in Phases 2 and 3 because the site would surcharge due to large storm events. The meter also experienced battery failure during Phases 2 and 3, and did not record data during the large storm event in October 2009.

Although it does not affect the data quality ranking, it should be noted that this site is susceptible to surcharging conditions because it is located just upstream of the HydroBrake with an inflow pipe diameter of 37.8 inches.

The meter was removed on 3/23/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

3.2.4.2 LES29_042-305B

LES29_042-305B was a temporary monitoring site that recorded both level and velocity. The site was installed on 11/2/2011 to measure the flow and level in the Leschi trunk sewer upstream of the outfall from the NPDES029 Basin. LES29_042-305B was in the Leschi trunk sewer at MH 042-305.

Although both level and velocity were measured, only the level data were assessed for this phase, as the velocity data were considered to be of poor quality. The level data quality was classified as "Good" for Phase 4, as it showed a consistent diurnal pattern throughout the period with a good response to storm events. This quality rating is consistent with the overall ratings given for Phases 1, 2, and 3.

The Leschi trunk sewer was cleaned during the Phase 1 period, and thus its data prior to the cleaning was classified as having "Some Limitations." During the Phase 1 period, it was also noted that the site experienced backwater conditions and reverse flow during large events.

The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification. All data for Phase 4 are suitable for model calibration.

3.2.4.3 NPDES029_MH042303

NPDES029_MH042303 is a permanent wet weather monitoring site that records level only.

The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES029 Basin. The data are used to calculate the volume of CSO events using a weir equation.

NPDES029_MH042303 is located at the NPDES029 Overflow Structure. For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The data quality was classified as “Good.” The data show a clear dry weather flow pattern and the meter responded well to storm events.

This site has a history of pressure depth data not matching the depths recorded by the ultrasonic meters. For the Phase 2 and 3 monitoring periods, two sensors had been installed, MP1 and MP2, which showed a clear dry weather flow pattern and a good meter response to storm events. However, MP1 failed to record data during the October and November storm events and also exhibited backwater conditions during these large storm events, which were caused by the Leschi trunk sewer backing up into the overflow control structure. Because of this, the data quality for MP1 was classified as having “Some Limitations” for Phases 2 and 3. MP 2, however, was classified as “Excellent” for the Phase 2 and 3 monitoring periods. Data quality was classified as “Excellent” for the Phase 1 monitoring period, as the data showed a clear relationship between level and velocity.

NPDES029_MH042303 is a permanent meter and will continue to be monitored to verify overflows.

3.2.5 NPDES030 Basin

The NPDES030 Basin is a 45-acre basin (109 acres potential during periods of high flow) with one CSO facility, CSO Facility 17. The NPDES030 Basin contains high-flow diversion weirs that divert flows into this basin under extremely high flow conditions. Under normal operating conditions, flows in the western portion of this basin are directed to the north and away from the NPDES outfall.

The CSO structure in the NPDES030 Basin consists of an overflow weir at MH 042-322, located at 219 Lake Washington Boulevard. Flows that overtop the side weir enter into a 15-inch-diameter, 14-foot-long overflow line. The overflow pipe connects to the drainage system that eventually discharges overflows into Lake Washington about 900 feet north of the connection to a 24-inch-diameter drainage line. An automatic sluice gate (retrofit from the previous HydroBrake) is located upstream of this CSO structure. When the gate lowers, flow is backed up into an in-line storage pipe.

One permanent meter monitored the basin during Phase 4. The permanent meter captures both dry and wet weather data, collecting both level and velocity. The overflow point in the Leschi NDPES030 Basin will continue to be monitored on a permanent basis. The basin overflowed one time during Phase 4.

3.2.5.1 NPDES030_MH042322

NPDES030_MH042322 is a permanent monitoring site that records level only. The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES030 Basin. The level data are used as an alarm for CSO events and to calculate the volume of

CSO events using a weir equation. For the Phase 4 monitoring period, level data were used for calibration and verification.

The data quality was classified as “Good” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. The data responded adequately to major storm events. However, the data screening reports reported a base flow depth drop from 3.5 inches to 2.0 inches during the period of 11/2/2011 and 12/28/2011, which could have resulted from the debris or silt buildup in the line. This should be considered while using the data for calibration.

NPDES030_MH042322 is a permanent meter and will continue to monitor for overflow events in the future.

3.2.6 NPDES031 Basin

The NPDES031 Basin is a 7-acre partially separated basin. The CSO structure in the basin consists of an overflow weir at MH 046-033, located at 300 Lakeside Avenue S. Flows that overtop the side weir enter into a 208-foot-long, 8-inch-diameter overflow line.

One temporary site and one permanent site monitored the basin during Phase 4. No overflow events occurred in the basin during Phase 4. The overflow point within the Leschi NDPES031 Basin will continue to be monitored on a permanent basis.

3.2.6.1 LES31_046-042A

LES31_046-042A was a temporary monitoring site that recorded level in the Leschi trunk sewer near the permanent meter in the NPDES031 Basin. This site was installed on 11/3/2011 to compare the level in the Leschi trunk sewer to the elevation of the overflow weir at the permanent site.

The site is not conducive to accurate velocity measurement due to siltation in the Leschi trunk sewer. The quality of the level data was classified as “Good” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. During Phase 4, a data outage on 12/12/2011 lasted for 9 hours. And as noted from the Phase 2 and 3 monitoring periods, this site is susceptible to debris buildup. All level data from Phase 4 are suitable for use in model calibration.

The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.

3.2.6.2 NPDES031_MH046033

NPDES031_MH046033 is a permanent monitoring site that records both level and velocity. The site was installed on 8/21/2007 to identify and quantify CSO events occurring from the NPDES031 Basin.

The permanent site is classified as a dry weather site; therefore, the site was expected to provide repeatable and reliable velocity data. The level data are used to alarm for CSO events and the continuity equation was used from the monitoring conducted in the overflow line.

The level data quality was classified as “Good” for Phase 4, as the meter captured all the major storm events. However, the velocity data were classified as having “Some Limitations” because the meter did not provide repeatable and reliable data. For the Phase 2 and 3 monitoring periods, the data quality was classified as “Excellent.” Data quality was classified as “Good” for the Phase 1 monitoring period, as it showed a clear relationship between level and velocity.

NPDES031_MH046033 is a permanent meter and will continue to be screened in the future.

3.2.7 NPDES032 Basin

The NPDES032 Basin, which consists of two hydraulically separate sub-basins that share one outfall, is approximately 25 acres in area. The first sub-basin, NPDES032(A), comprises the majority of area and flow. The second sub-basin, NPDES032(B), has a contributing area of less than 1 acre. CSO Facility 16 is a control facility located in the NPDES032 Basin. The facility contains four control structures: a 6,000-gallon in-line storage tank, a HydroBrake, and two overflow weirs. Low flows in the NDPES032(B) Sub-basin are directed to the 18-inch-diameter Leschi trunk sewer and low flows in NPDES032(A) are conveyed through a HydroBrake into the 18-inch-diameter Leschi trunk sewer. The Leschi trunk sewer then conveys flows to the East Pine Street pump station. Overflows from both NPDES032(A) and NPDES032(B) are directed to the 12-inch-diameter outfall pipe to Lake Washington. NPDES032(A) and NPDES032(B) each overflowed once during Phase 4.

One temporary site and two permanent sites monitored the NPDES032 Basin during Phase 4. The permanent site at NPDES032(A) collects level and velocity data and is used for monitoring CSO events as well as dry weather data. The permanent site at NPDES032(B) collects level data only and is used to monitor CSO events. The two overflow points within the Leschi NDPES032 Basin will continue to be monitored on a permanent basis.

3.2.7.1 LES32_046-163A

LES32_046-163A was a temporary monitoring site that recorded level and velocity downstream from the HydroBrake in the NPDES032(A) Sub-basin. The site was installed on 11/3/2011 to characterize the HydroBrake.

As noted for the previous phases, this site experiences reverse flow through the HydroBrake from the Leschi trunk sewer into the basin storage and heavy silt in the Leschi trunk sewer prevents collection of good velocity data. Thus, due to poor-quality velocity data, as noted for the previous phases, only level data were used for hydraulic calibration and verification in Phase 4.

The quality of the level data for Phase 4 was classified as having “Some Limitations” because there were data gaps from 12/19–26/2011 and on 1/4/2012. Although periods of data are suitable for model calibration and verification, these data must be selected carefully. For Phases 1, 2, and 3, the quality of the level data was classified as “Excellent.”

The meter was removed on 3/13/2012 during Phase 4 monitoring, as it was determined that suitable data had been collected for the purposes of model calibration and verification.

3.2.7.2 NPDES032A_MH046157

NPDES032A_MH046157 is a permanent monitoring site that records both level and velocity. The site was installed on 8/22/2007 to identify and quantify CSO events occurring from the NPDES032(A) Sub-basin.

The permanent site was classified as a dry weather site; therefore, the site was expected to provide repeatable and reliable velocity data. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

For the Phase 4 monitoring period, the level data were classified as “Excellent,” whereas the velocity data were qualified as having “Some Limitations.” For the Phase 2 and 3 monitoring periods, the data quality was classified as having “Some Limitations” because it was determined through previous flow balancing calculations that velocity values were being overestimated. For the Phase 1 monitoring period, the quality of the level data was classified as “Excellent” and the velocity data were classified as having “Some Limitations” for the same reasons as stated above.

NPDES032A_MH046157 is a permanent meter and will continue to monitor overflows in the future. One overflow event occurred at this site during the Phase 4 monitoring period.

3.2.7.3 NPDES032B_MH046078

NPDES032B_MH046078 is a permanent monitoring site that records level only. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES032(B) Sub-basin. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The quality of the data for Phase 4 was classified as “Good,” as overall the meter’s response to storm events was adequate.

Previous examination of level data collected at LES032_046-163A indicated that overflows occur due to the water surface elevation in the Leschi trunk sewer exceeding the elevation of the overflow weir. For Phases 1, 2, and 3, the level data were classified as “Excellent.”

NPDES032B_MH046078 is a permanent meter and will continue to monitor for overflow events in the future. One overflow event occurred at this site during the Phase 4 monitoring period.

3.2.8 NPDES033 and NPDES034 Basins

The NPDES033 and NPDES034 Basins have a combined area of 75 acres. During periods of high flow, both basins act as one CSS control facility. CSO Facility 15 stores combined flow from both basins. This CSS control facility includes 122 feet of 84-inch-diameter offline storage pipe, two HydroBrakes, two overflow weirs, and one pump station (PS 2). A weir located in MH 046-172A directs excess flow in the NPDES033 Basin to a large HydroBrake also located in MH 046-172A, and then into the offline 84-inch-diameter storage pipe associated with SPU PS 2. When the level behind the other HydroBrake in the overflow control structure at MH 046-171A for the NPDES033 Basin reaches the level of the overflow weir, overflow is conveyed to Lake Washington through the 20-inch-diameter outfall pipe. The NPDES034 Basin contributes partially separated flow from the north and south of CSO Facility 15, which is conveyed to PS 2. During high-flow periods, when the capacity of PS 2 is exceeded, flow overtops a weir in MH 046-176 and is sent to the offline, 84-inch-diameter storage pipe. When the storage pipe is full, water continues to rise above the weir until it reaches the invert of the NPDES034 Overflow Structure, which is approximately 1.4 feet above the MH 046-176 weir. Overflow from the NPDES034 Basin is conveyed to Lake Washington through a 15-inch-diameter outfall pipe.

During Phase 4, one temporary meter was installed in CSO Facility 15 to record depth in the storage facility. Permanent meters were also located at each basin overflow structure. No overflows were reported at either basin during the Phase 4 monitoring period. At the conclusion of Phase 4 no temporary meters remained in either basin. The two permanent meters will remain in place to continue monitoring for overflows.

3.2.8.1 LES33_046-174A

LES33_046-174A was a temporary monitoring site that recorded level in the in-line storage pipe in the NPDES034 Basin. The site was installed on 11/4/2011 to capture data on storage utilization in the 84-inch-diameter offline storage pipe. LES33_046-174A was located upstream from PS 2 in CSO Facility 15.

The quality of the level data was classified as having “Some Limitations” for Phase 4 due to outages experienced from 12/28/2011 through 1/5/2012. Although some periods of data are suitable for model calibration, these data should be selected carefully. The data quality was classified as “Excellent” for Phases 1, 2, and 3 because the meter responded well to storm events and there were no data gaps during significant storms.

The meter was removed in 3/18/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.

3.2.8.2 NPDES033_MH046171

NPDES033_MH046171 is a wet weather permanent monitoring site that records both level and velocity. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES033 Basin. The level data are used to calculate the volume of CSO events using a weir equation. Although velocity data have been recorded at this site, previous assessments of these data have shown the data quality to be poor, and thus for Phase 4, only level data were finalized.

NPDES033_MH046171 is located at the NPDES033 Overflow Structure downstream from CSO Facility 15. For the Phase 4 monitoring period, the quality of the level data was classified as “Excellent,” which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. All level data for Phase 4 are suitable for model calibration.

This monitoring site is a permanent site and will continue to monitor overflow events in the future.

3.2.8.3 NPDES034_MH046054

NPDES034_MH046054 is a permanent monitoring site that records both level and velocity. The site is classified as a dry weather flow site; therefore, the site was expected to provide repeatable and reliable velocity data. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES034 Basin. The level data are used to calculate the volume of CSO events using a weir equation.

NPDES034_MH046054 is located at the NPDES034 Overflow Structure, downstream from CSO Facility 15. For the Phase 4 monitoring period, the quality of the data was classified as “Excellent” because the meter demonstrated a consistent and repeatable dry weather diurnal pattern. All the data collected for Phase 4 are suitable for hydraulic calibration purposes. See the scattergraph in Figure 3-5 below, which shows the velocity and depth data collected during the wet weather flow period for this site.

For the Phase 2 and 3 monitoring periods, the data quality was classified as having “Some Limitations.” As discussed in the Phase 2 and 3 report, Volume 5 (2010), those data showed a distinct relationship above about 2 inches of water. Below a level of 2 inches in the pipe though, the scattergraph was wide, indicating that the meter was picking up multiple velocities at a given depth as shown in Figure 3-5. For the wet weather flow period, the data captured a clear scatter. For the Phase 1 monitoring period, the quality of the level and velocity data was classified as “Good.”

This monitoring site is a permanent site and will continue to monitor overflow data in the future.

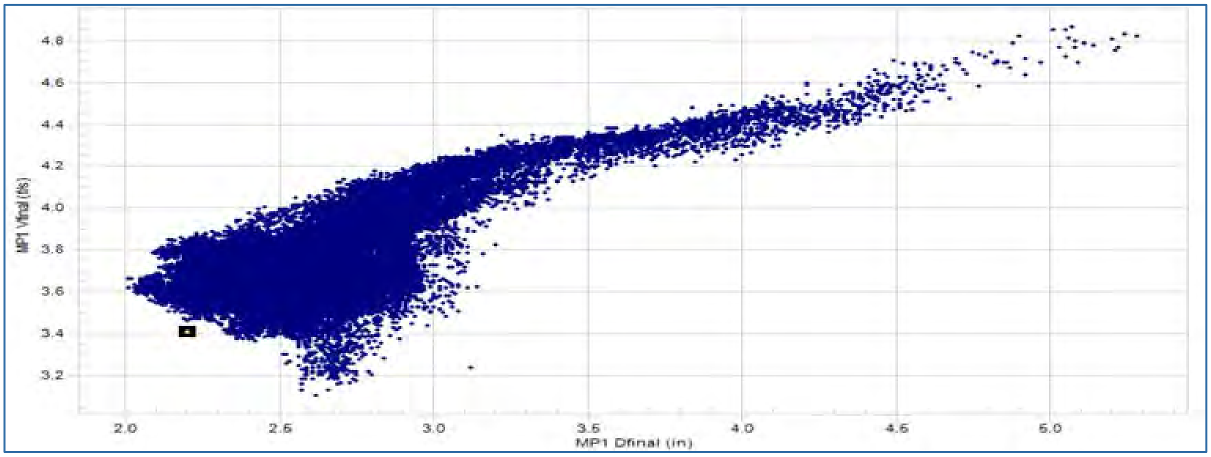

Figure 3-5. Wet weather flow period narrower than dry weather flow period captured at NPDES034_MH046054

3.2.9 NPDES035 Basin

The NPDES035 Basin is a 51-acre basin with one CSS control facility. CSO Facility 14 includes 65 feet of an offline, 72-inch-diameter storage pipe, one sluice gate, one flap valve, three weirs, and one HydroBrake. The HydroBrake and an overflow structure are located in MH 046E-138 at the intersection of Lakeside Avenue S and S Massachusetts Street. A sluice gate controls the flows and during high flow closes partially to fill the storage pipe in CSO Facility 14. Once the storage pipe is filled, flows overflow the bypass weir over the sluice gate and proceed to the overflow structure where the HydroBrake controls flow. Once the HydroBrake backs up the upstream line to the level of the overflow weir, flows are discharged into Lake Washington at the NPDES035 outfall.

One permanent meter monitored the NPDES035 Basin during Phase 4. The permanent meter is classified as a wet weather site and is used only to verify overflows; it does not monitor dry weather flows. The basin had no overflows during Phase 4.

3.2.9.1 NPDES035_MH046E138

NPDES035_MH046E138 is a permanent monitoring site that records level. The site was installed on 7/26/2007 to identify and quantify CSO events occurring from the NPDES035 Basin. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

NPDES035_MH046E138 is located at the NPDES035 Overflow Structure downstream from CSO Facility 14. The data quality for the meter was classified as “Excellent” for Phase 4 as the site captured a consistent diurnal pattern and responded well during storm events. This is consistent with the classifications in all the previous phases. All level data are suitable for the purposes of model calibration.

This is a permanent monitoring site that will continue to monitor for overflows in the future.

3.2.10 NPDES036 Basin

The NPDES036 Basin, located in the southern part of the Leschi CSO Area, is approximately 46 acres in area. This basin has one CSS control facility. CSO Facility 13 includes 1,200 feet of an in-line, 16-inch-diameter storage pipe (the original drainage for the basin), one HydroBrake, and an overflow structure.

Two temporary meters and one permanent meter monitored the basin during Phase 4. The permanent meter is classified as a wet weather site and is used only to verify overflows; it does not monitor dry weather flows. The basin had no overflows during Phase 4. Both temporary meters were removed prior to the conclusion of Phase 4.

3.2.10.1 LES36_046E-141A

LES36_046E-141A was a temporary monitoring site that recorded both level and velocity downstream from the HydroBrake in the NPDES036 Basin. The site was installed on 11/2/2011 to characterize the HydroBrake performance in the NPDES036 Basin. This meter was used to characterize the HydroBrake.

Although the meter was classified as “Good” for the previous phases, in Phase 4, it was classified as having “Some Limitations” because night velocity gaps were observed from 11/2/2011 through 12/14/2011. Ramping over the sensor was also suspected due to debris in the pipe (see Figure 3-6), affecting the monitoring data for Phase 4. Although periods of data are suitable for model calibration and verification, these data must be selected carefully.

The meter was removed on 3/13/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

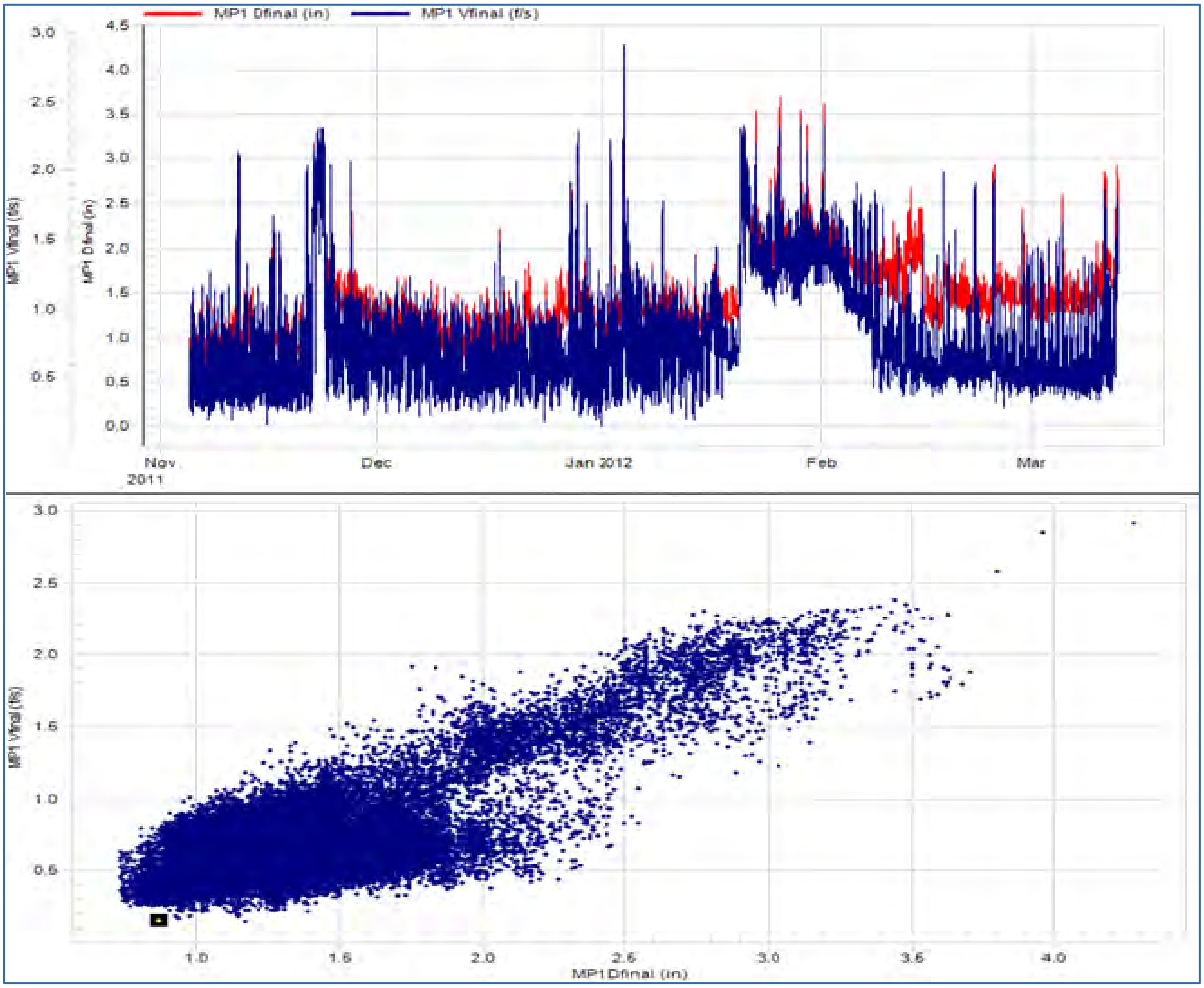

Figure 3-6. Ramping observed in LES36_046E-141A suspected due to debris in the pipe

3.2.10.2 LES36_046E-142A

LES36_046E-142A was a temporary monitoring site that recorded both level and velocity upstream from the HydroBrake in the NPDES036 Basin. The site was installed on 11/2/2011 to characterize the HydroBrake performance in the NPDES036 Basin, providing depth upstream in the storage pipe. Although the meter was replaced several times before the Phase 2 monitoring period, the velocity data reviewed for Phase 4 were still considered poor, and were not used. As discussed for the previous phases, the velocity data at this site has been inconsistent and is recommended to be used with caution and only for verification of the downstream monitoring site. The depth data at this location served as a critical parameter for HydroBrake characterization.

The level data in Phase 4 were classified as “Good,” which is consistent with the previous phases. The meter adequately responded to the storm events with consistent diurnal patterns. A surcharged condition was observed in the pipe during the storm on 11/22/2012, so caution must be taken while using the data from this period.

The meter was removed on 3/13/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

3.2.10.3 NPDES036_MH046E150

NPDES036_MH046E150 is a permanent monitoring site that records level only. The site was installed on 7/26/2007. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation. During storm events, the downstream HydroBrake at MH 046E-142 restricts and controls flows from the NPDES036 Basin to the downstream system. When NPDES036 Basin storage is exceeded, flow is diverted over the weir to the NPDES036 Basin outfall. All data are considered suitable for model calibration and verification.

NPDES036_MH046E150 is located at the NPDES036 Overflow Structure. For the Phase 4 monitoring period, the data quality was classified as “Excellent,” as the meter showed consistent diurnal patterns throughout the period. For the Phase 2 and 3 monitoring periods, the data quality was classified as “Good” because a fold in the pipe liner caused a puddle under the level sensor. For the Phase 1 monitoring period, the data quality was classified as “Good” because although the level data have a consistent and repeatable pattern and a lack of data gaps, a distinct signature change was observed midway through the period, post April 2009.

This monitoring site is a permanent site and will continue to monitor overflows in the future.

3.2.11 Combined Sewer Overflows

ADS reported that eight CSO events occurred in the Leschi CSO Area during Phase 4. Table 3-3 lists the CSO events reported during the monitoring period.

Table 3-3. Combined Sewer Overflows in Leschi CSO Area 10/1/2011 through 3/31/2012			
Outfall	**Start date of overflow**	**Duration (hrs:min)**	**Volume (gal)**
NPDES026	--	--	--
NPDES027	--	--	--
NPDES028	11/23/2011	0:03	104
	3/15/2012	0:05	2,148
NPDES029	11/11/2011	0:05	564
	11/22/2011	1:00	22,944
	3/15/2012	1:44	8,070
NPDES030	11/23/2011	0:03	13
NPDES031	--	--	--
NPDES032(A)	11/23/2011	0:34	7,896
NPDES032(B)	11/23/2011	1:16	7,071
NPDES033	--	--	--
NPDES034	--	--	--
NPDES035	--	--	--
NPDES036	--	--	--

Figure 3-7 below shows the maximum water level recorded by ADS at each of the overflow structures in the basin as a percentage of the weir height. Note that when flows exceeded 100 percent an overflow occurred, as denoted by the red dashed line.

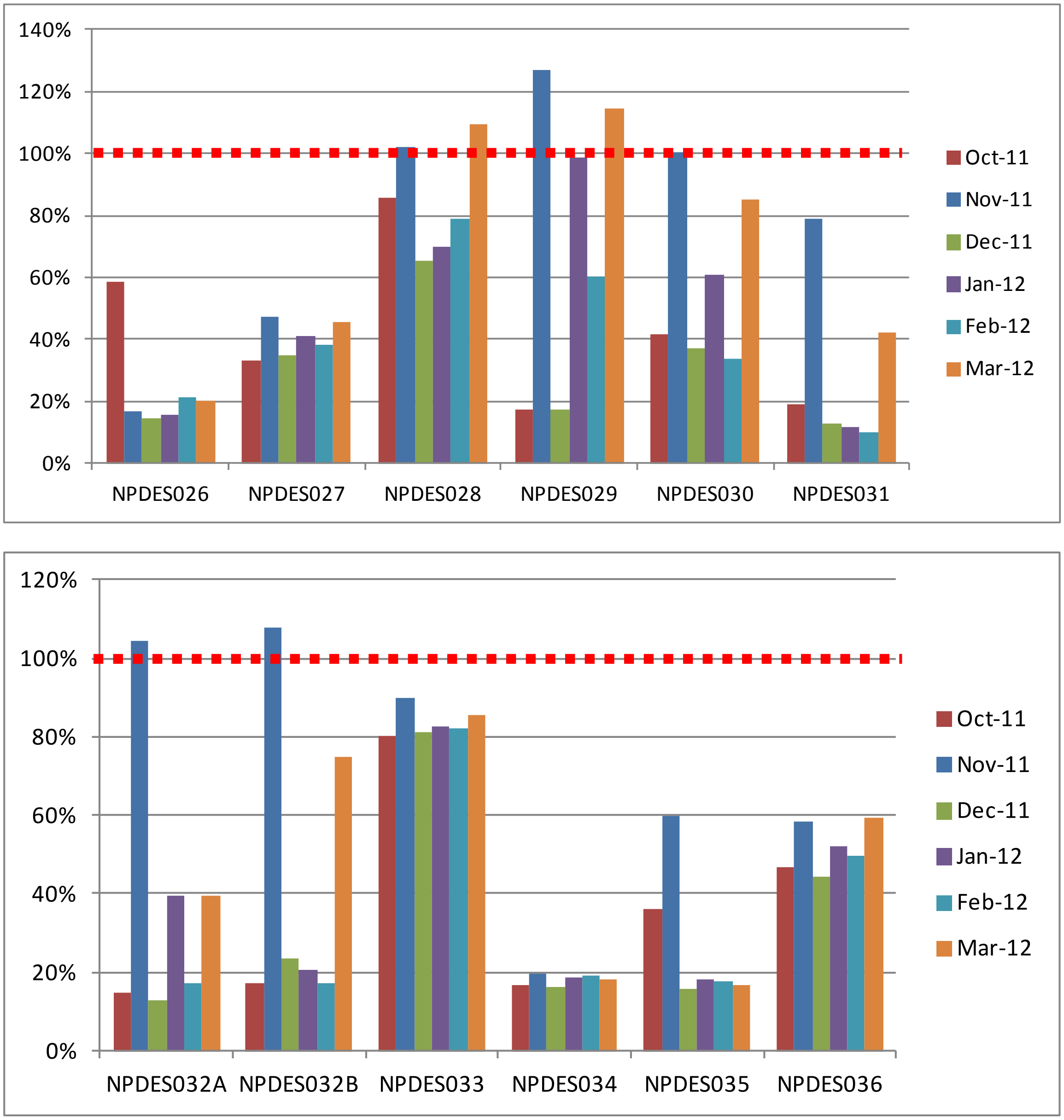

Figure 3-7. Maximum recorded levels over weir heights in Leschi CSO Area for major events

3.2.12 Facility Operations

Eleven permitted outfalls are located in the Leschi CSO Area; all discharge excess combined sewer flows to Lake Washington. Eleven CSS control facilities are located within the Leschi CSO Area as well. The CSS facilities in the NPDES026, NPDES027, NPDES028, and NPDES031 Basins and the NPDES032(B) Sub-basin consist only of overflow structures with no storage pipes or HydroBrakes. The CSS control facilities in the NPDES029, NPDES033, NPDES034, and NPDES036 Basins and the NPDES032(A) Sub-basin consist of an overflow structure, storage, and a HydroBrake. The CSS control facilities in the NPDES030 and NPDES035 Basins consist of an overflow structure, storage, HydroBrake, and sluice gate. Two sluice gates, which are retrofit projects that were once HydroBrakes, are located upstream of the NPDES030 and NPDES035 Overflow Structures. HydroBrake characterization curves for the Leschi CSO Area were created using data collected during major storm events; these facilities are further described below.

Figure 3-8 shows the estimated storage utilization at the Leschi NPDES029, NPDES032, NPDES033, NPDES034, and NPDES036 Basins, which have storage pipes. Storage utilization was estimated by using the maximum depth recorded at the closest monitoring locations within these basins. The water depth was compared to the invert level and crown level of the storage pipe in order to estimate the percentage of the volume that was used. As depicted in Figure 3-8, during all overflow events NPDES029 storage was fully utilized. During the November 2011 CSO storm event the NPDES032 storage facility was utilized at 99 percent. No overflow events occurred at NPDES033, NPDES034, or NPDES036 during the Phase 4 monitoring period. Note that no depth data were recorded in October 2011, and depth in the NPDES030 storage structure is not available.

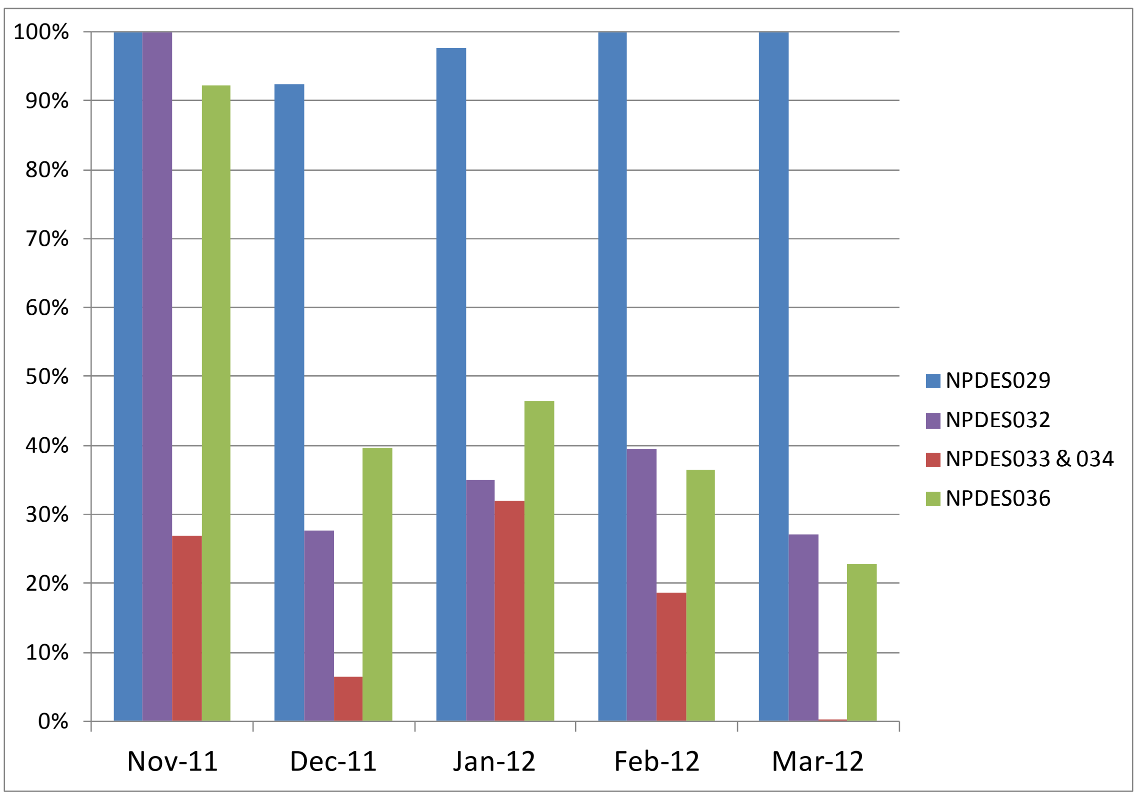

Figure 3-8. Storage utilization for Leschi NPDES029, NPDES032, NPDES033, NPDES034, and NPDES036 Basins

3.3 North Union Bay CSO Area

The North Union Bay Area consists of the NPDES018 and NPDES019 CSO Basins. NPDES019 is considered controlled and is not discussed in this report. The NPDES018 basin includes two overflow structures that are designated here as NPDES018(A) and NPDES018(B) for convenience.

Flow originates in the northern part of the NPDES018(B) Sub-basin and flows southwest toward the King County system downstream of the 30th Avenue NE PS. A sideflow weir located at MH 016-197 allows a small portion of the NPDES018(B) Sub-basin flows to flow into the NPDES018(A) Sub-basin.

The lower portion of the North Union Bay CSO Area, the NPDES018(A) Sub-basin, discharges to the King County interceptor system at the Laurelhurst trunk, which conveys wastewater along the north side of Union Bay to the University regulator station. The NPDES018(A) connection is located shortly downstream of King County's Belvoir PS. Flows from both portions of the North Union Bay CSO Area are then conveyed to the West Point Treatment Plant via the north interceptor.RG 02 is located at Warren G. Magnuson Park, 7022 Sand Point Way, to the east of the North Union Bay CSO Area boundary. RG 03 is located at the University of Washington (UW Harris Hydraulics Lab), NE Pacific Street and 15th Avenue NE, to the west of the North Union Bay CSO Area boundary. RG 02 is used for the NPDES018(B) area and RG 03 is used for the NPDES018(A) area.

ADS collected temporary monitoring data in the NPDES018(B) Sub-basin from October 2011 through March 2012. This Phase 4 flow monitoring was conducted to help refine the characterization of the hydrology and hydraulic performance of the NPDES018(B) storage facility and overflow weir. During earlier phases of the monitoring program (prior to February 2010), the permanent monitoring equipment at the NPDES018(B) overflow structure was installed incorrectly, which limited the number of available storms for model calibration. The 2011–12 temporary flow monitoring period captured additional storm flow data that were used to refine the hydraulic model calibration.

ADS maintained two permanent monitoring sites at overflow structures within the North Union Bay CSO Area and seven temporary monitoring sites to measure combined sewage flow during the Phase 4 monitoring period. At the end of Phase 4, only the two permanent monitoring locations remained in place to verify overflows.

Detailed information on the North Union Bay CSO Area can be found in Appendix C; a basin schematic is in Appendix A.

3.3.1 NPDES018(B) Sub-Basin

The NPDES018 Basin contains two sub-basins: NPDES018(A) and NPDES018(B). Only permanent flow monitoring data were collected in NPDES018(A) during Phase 4. In

NDPES018(B), flow monitoring data were collected at seven temporary sites and one permanent location. Following the end of Phase 4, all temporary meters were removed and the permanent monitoring installations remained. In June 2010, the NPDES018(A) overflow weir was raised about 3.5 inches. In October 2010, the NPDES018(B) overflow weir was raised about 12 inches.

3.3.1.1 NU18_016-056A

NUB18_016-056A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/8/2011 for hydrology calibration and calculation of flow from the northern portion of the NPDES018(B) Sub-basin.

The meter was located downstream of the previous temporary monitoring installations at NUB18_007-436A and NUB18_007-438A. This meter was not installed for any of the previous phases. Data quality for Phase 4 was classified as “Good” because the meter generally showed a narrow wet weather scattergraph. However, there were some scatters in the dry weather conditions for early January.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

3.3.1.2 NUB18_016-084A

NUB18_016-084 was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/6/2011 to calculate flows and characterize hydrology for the northeast part of the NPDES018(B) Sub-basin. The site is located just upstream of the Phase 1 NUB18_016-083 monitoring location.

This meter was not installed for any of the previous phases. Although the wet weather scattergraph is narrow, the scattergraph for the dry weather condition is thicker and scattered. For this reason, the data quality for Phase 4 was classified as “Good” for characterizing wet weather flows but with “Some Limitations” for dry weather conditions. In addition, between 12/12/2011 and 1/12/2012, a change in signature was observed. The classic “comma” shape observed indicates the lack of a clear pattern for the dry weather conditions as shown in Figure 3-9.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

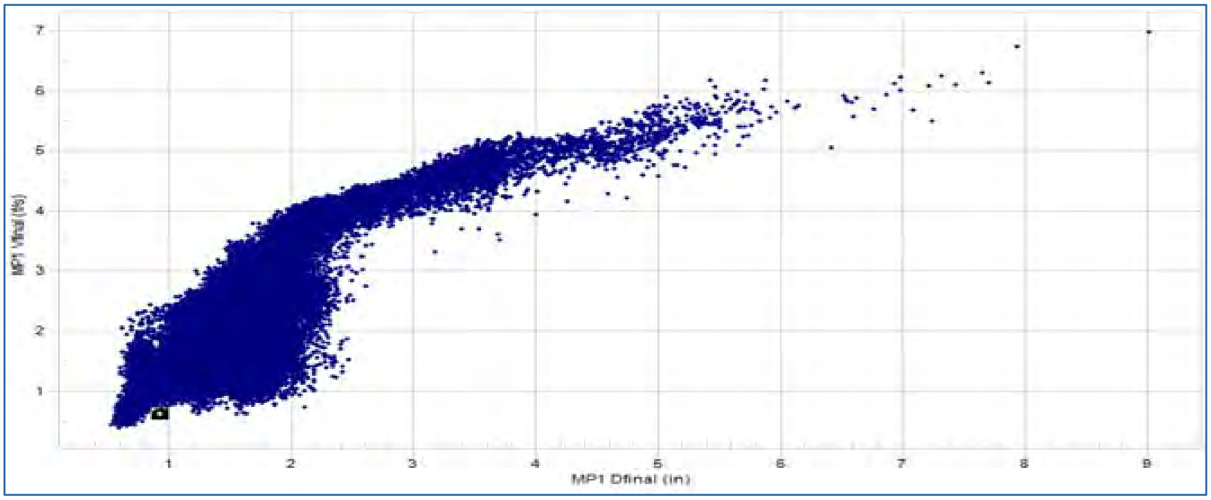

Figure 3-9. "Comma" shape indicates lack of clear pattern for dry weather conditions for NUB18_016-084A

3.3.1.3 NUB18_016-076A

NUB18_016-076A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to calculate flows and characterize hydrology for the northwest part of the NPDES018(B) Sub-basin.

The meter was located downstream of the previous temporary flow monitoring installations at NUB18_016-021A and NUB18_016-021B. Data quality was classified as "Good" for the Phase 4 monitoring period because the meter exhibits a consistent and repeatable response for most of the wet weather events. Data issues include a poor response of the data during the storm on 10/27/2011 and broad velocity scatter during dry weather periods as shown in Figure 3-10. However, neither of these issues presents a significant concern for model calibration.

This monitoring installation site was also used during the Phase 1 flow monitoring for the same purpose as Phase 4. Data quality was classified as "Excellent" for the Phase 1 monitoring period because of the consistent and repeatable response of the data during dry and wet weather periods with a lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

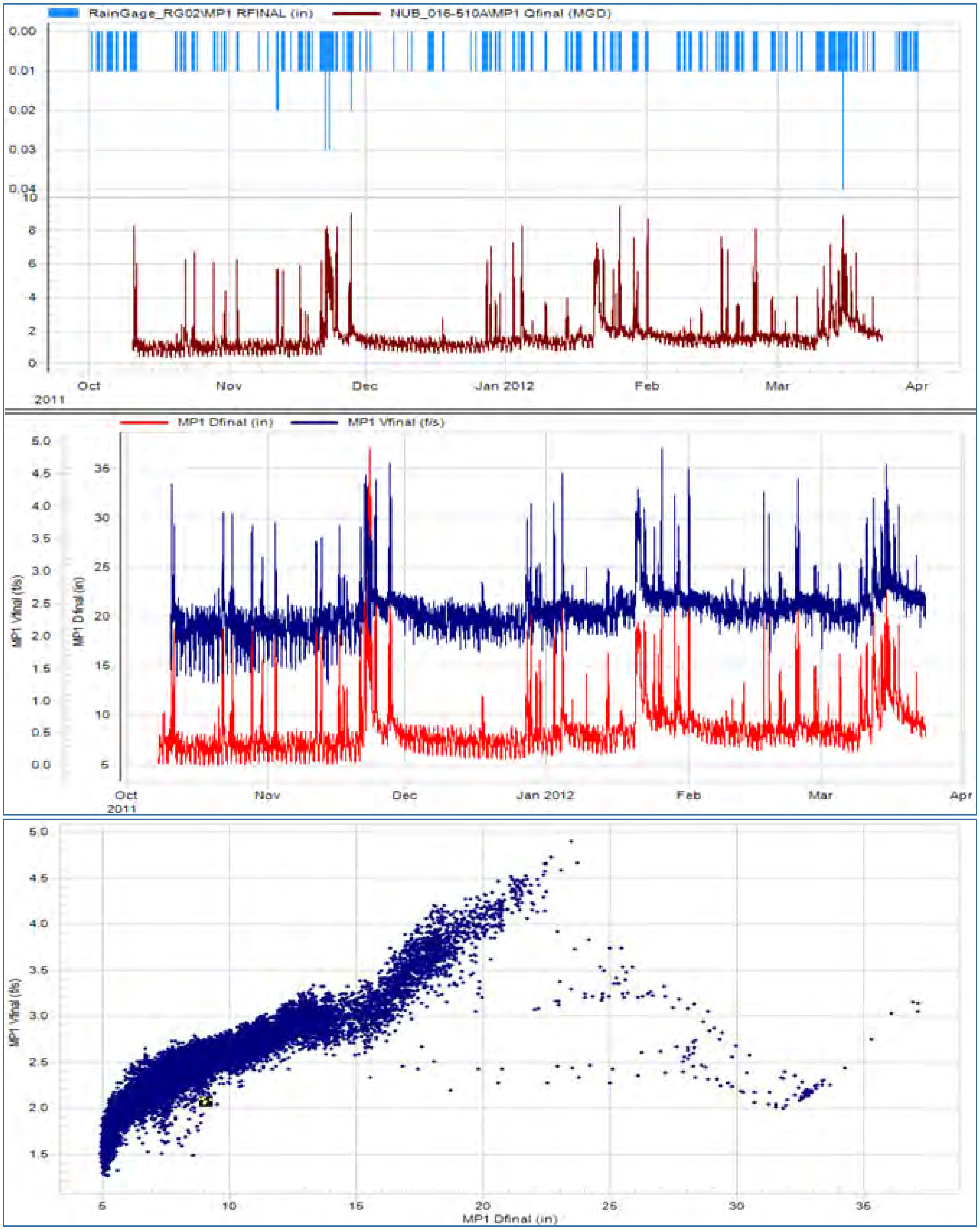

Figure 3-10. NUB18_016-076A classified as "Excellent" for its consistent diurnal patterns and narrow scatterplot

3.3.1.4 NUB18_016-510A

NUB18_016-510A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to characterize the hydrology and hydraulics downstream of the temporary flow monitors at NUB18_016-056A, NUB18_016-084, and NUB18_016-076A. Data collected at NUB18_016-510A were also used to compute flow balancing for the upstream meters and to characterize the behavior of the weir structure located upstream at 016-078.

The meter was located downstream from structure NUB18_016-078C; it was located in the main sewer pipe that directs dry weather flow around the storage tank to the HydroBrake on the south end of CSO Facility 24. An overflow pipe is located on the shelf of the maintenance hole that is overtopped when the depth reaches 21 inches. The overflow pipe diverts flows to the north end of the storage tank when the HydroBrake starts to back up flows in the system.

The data exhibit a consistent narrow scatter pattern with the exception of the 3/15/2012 period, when there was a change in the dry weather scattergraph (following a prolonged wet period). Therefore, data quality was classified as “Good” for the Phase 4 monitoring period.

This monitoring installation site was also used during the Phase 1, 2, and 3 flow monitoring phases for the same purpose as Phase 4. Data quality was classified as “Good” for the Phase 1, 2, and 3 monitoring periods because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

3.3.1.5 NUB18_016-505A

NUB18_016-505A was a temporary monitoring installation that recorded level only during the Phase 4 monitoring period. The site was installed on 10/6/2011 to characterize water levels just upstream of the HydroBrake and storage utilization at CSO Facility 24.

The data quality was classified as “Excellent” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. Data quality was classified as “Excellent” for these monitoring periods because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

3.3.1.6 NUB18_016-518A

NUB18_016-518A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to monitor flows downstream of the NPDES018(B) storage facility and the HydroBrake at CSO Facility 24. The level data were also used to characterize the operations of the HydroBrake.

The meter was located on the downstream side from the HydroBrake at CSO Facility 24. The data at the site captured a dry weather pattern that showed occasional scatter caused by debris in the pipe. During storm events, the site showed consistent flow patterns, resulting from its location downstream from the HydroBrake.

Analysis of the flow data from this site, including flow balancing and calibration of the storage structure performance in the hydraulic model, indicated that the NUB18_016-518A meter systematically under-predicted flow rates. As a result, the data quality was classified as “Poor” for Phase 4. Alternative methods will be used to supply needed information. The meter was removed on 3/24/2012.

3.3.1.7 NUB18_007-436A

NUB18_007-436A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to calculate flows and characterize hydrology for the northeastern part of the NPDES018(B) Sub-basin.

The meter was located downstream of the previous installations at NUB18_007-094A and NUB18_007-183A. During the Phase 4 monitoring period, significant velocity dropouts were observed during storm periods that took place between 1/10/2012 and 2/3/2012, when velocity readings exceeded approximately 11 feet per second. However, because the scattergraph data for both dry and wet weather periods are narrow, indicating a consistent response of flow to rainfall across the entire monitoring period, the data quality was classified as “Good.”

This monitoring installation site was also used during the Phase 1 flow monitoring phase for the same purpose as Phase 4. Data quality was classified as “Excellent” for the Phase 1 monitoring period because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected.

3.3.1.8 NPDES018B_MH016509

NPDES018B_MH016509 is a permanent monitoring site that records both level and velocity. The site has two monitors: MP1, located in the incoming pipe, and MP2, located in the overflow line. MP1 is used to estimate water levels on the upstream side of the weir and to alarm CSO events from NPDES018(B). The MP2 meter records both level and velocity. The resulting flows are used to calculate the discharge volume for CSO events.

The data quality was classified as having “Some Limitations” for Phase 4. The MP1 meter records depths only during large events when the adjacent storage facility fills. The recorded depths are consistent with the temporary monitoring data collected in the storage facility at NUB18_016-505. The MP2 meter records flows only when a CSO event occurs. ADS utilizes a reverse installation for the MP2 meter that scans velocities in the downstream direction. During the December 2010 CSO event, the MP2 meter recorded flow rates in excess of 40 million gallons per day (mgd).

During Phases 1–4, the sum of the temporary monitoring data flows in the upstream system did not exceed 30 mgd. It seems unlikely that during the December 2010 event, the overflow rate would exceed the total system flows recorded during other events. Due to the reverse installation and questions about the flow rates recorded during the December 2010, the “Some Limitations” rating was applied to this location. This classification is the same as was reported during the Phases 2–3 monitoring period.

3.3.1.9 NPDES018A_MH025380

NPDES018A_MH025380 is a permanent monitoring site that records both level and velocity. The site is classified as a wet weather site because it is expected to provide high-quality level data only; thus, only level data are finalized for the site. The site was installed on 7/16/2007 to quantify CSO events occurring from the NPDES018(A) Sub-basin. The level data are used to alarm CSO events and to calculate the volume of CSO events using a weir equation.

NPDES018A_MH025380 is located at the upstream end of the storage tank within CSO Facility 25. During storm events, the velocity and level data responded consistently. Data quality was classified as “Excellent” for the Phase 4 monitoring period because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps. This classification matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. All data from Phase 4 are suitable for use in model calibration.

3.3.2 Combined Sewer Overflows

ADS reported that during Phase 4, two CSO events occurred in the NPDES018(A) Sub-basin, while one CSO event occurred in the NPDES018(B) Sub-basin. Table 3-4 lists the CSO events that occurred during the monitoring period.

Table 3-4. Combined Sewer Overflows in NPDES018 CSO Area 10/1/2011 through 3/31/2012			
Outfall	**Start date of overflow**	**Duration (hrs:min)**	**Volume (gal)**
NPDES018(A)	11/23/2011	0:30	4,275
	3/29/2012	4:10	39,730
NPDES018(B)	11/23/2011	8:90	878,758

Figure 3-11 shows the maximum water level recorded at each of the overflow structures in the basin as a percentage of the weir height. Overflows were computed using the measured depth recorded by the MP1 sensors and the High-High alarm set points, as set by ADS. Note that when flows exceeded 100 percent an overflow occurred, as denoted by the red dashed line.

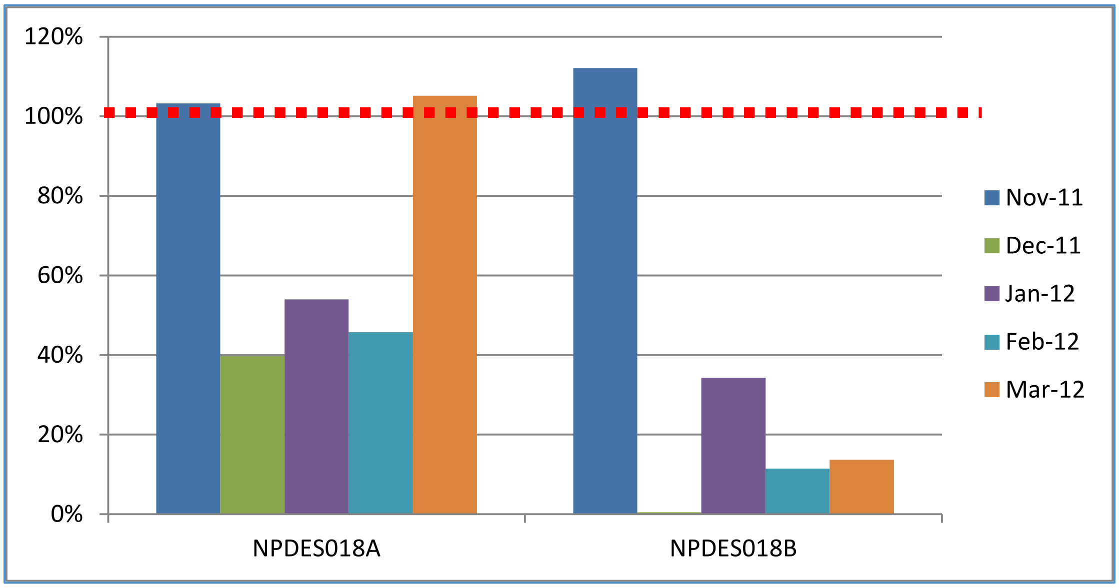

Figure 3-11. Maximum recorded levels in the NPDES018 CSO Area compared to weir heights for major events

3.3.3 Facility Operations

The NPDES018 Basin contains the following CSS control structures:

- CSO Facility 24: offline storage, HydroBrake, and NPDES018(B) Overflow Structure
- CSO Facility 25: in-line storage, HydroBrake, and NPDES018(A) Overflow Structure

3.3.3.1 NPDES018(A)

CSO Facility 25 is located within the NPDES018(A) Sub-basin. The CSO facility consists of an overflow weir at MH 025-380, which is located in NE 41st Street just to the west of NE Surber Drive. Wastewater flows from two separate upstream pipes and enters this structure and changes direction, heading directly west into a 72-inch-diameter sewer, 743 feet long, that forms an in-line storage facility.

The following paragraphs reflect the state of the system during the Phase 4 monitoring period. A retrofit of the structure that will affect system performance was implemented following completion of Phase 4 monitoring.

A HydroBrake structure is located at the downstream end of the storage facility to regulate outflows. The CSO structure is located at the upstream end of the in-line storage in MH 025-380. When wastewater fills the storage to a depth of the overflow weir, CSO events occur. Based on site investigations, the high water mark in the in-line storage (about two-thirds full near the HydroBrake) was noted to be clearly visible, indicating that CSO events occur before the in-line storage volume is fully utilized. The storage facility has a total storage volume capacity of about 150,000 gallons, although a substantial portion of this potential storage volume is not available due to the height of the CSO weir. The overflow structure for the NPDES018(A) Sub-basin is located on the east end of the storage pipe at MH 025-380. Once the level at the upstream end of the storage pipe exceeds the level of the overflow weir, flow is diverted into the 54-inch-diameter CSO outfall pipe into the storm drain system, which discharges to Lake Washington.

The HydroBrake at the outlet of the NPDES018(A) storage facility, at MH 024-072, restricts outflows during storm events to utilize the storage facility and preserve conveyance capacity in the downstream system. The performance of the HydroBrake was evaluated by collecting monitoring data collected during the Phase 2 and 3 monitoring periods, on the upstream side of the HydroBrake, and downstream at MH 024-059. These data were used to compute a relationship between differential head (upstream minus downstream) and flow through the HydroBrake.

No monitoring data were collected at MH sites 024-072A or 024-059 during the Phase 4 monitoring period. Therefore, a determination of storage pipe utilization during this period was not conducted.

3.3.3.2 NPDES018(B)

CSO Facility 24 is located within the NPDES018(B) Sub-basin. The facility consists of a HydroBrake located at MH 016-505 at 4875 39th Avenue NE, and two offline storage pipes with a combined storage volume of 1.7 million gallons, located along 39th Avenue NE.

The storage pipes in the control facility consist of two square 10-by-10-foot conduits. NUB18B_016-505A was used to determine the utilization of the storage pipes. Figure 3-12 shows the estimated storage utilization at NPDES018(B) storage pipes. Storage utilization was estimated by using the maximum depth recorded at MH 016-505A. The water depth was compared to the invert level and crown level of the storage pipe in order to estimate the percentage of the volume that was used. One CSO event occurred during the Phase 4 monitoring period.

Under normal flow conditions, the storage tank fills up from the HydroBrake (south end of storage pipes) back into the storage pipe. In high-flow conditions, the storage pipes start filling from the north as weirs at MH 016-078 and MH 016-510 are overtopped and direct flow toward the storage tank. The NPDES018(B) Overflow Structure is located on the north end of the storage tanks at MH 016-509, and discharges into a storm drain leading to Lake Washington.

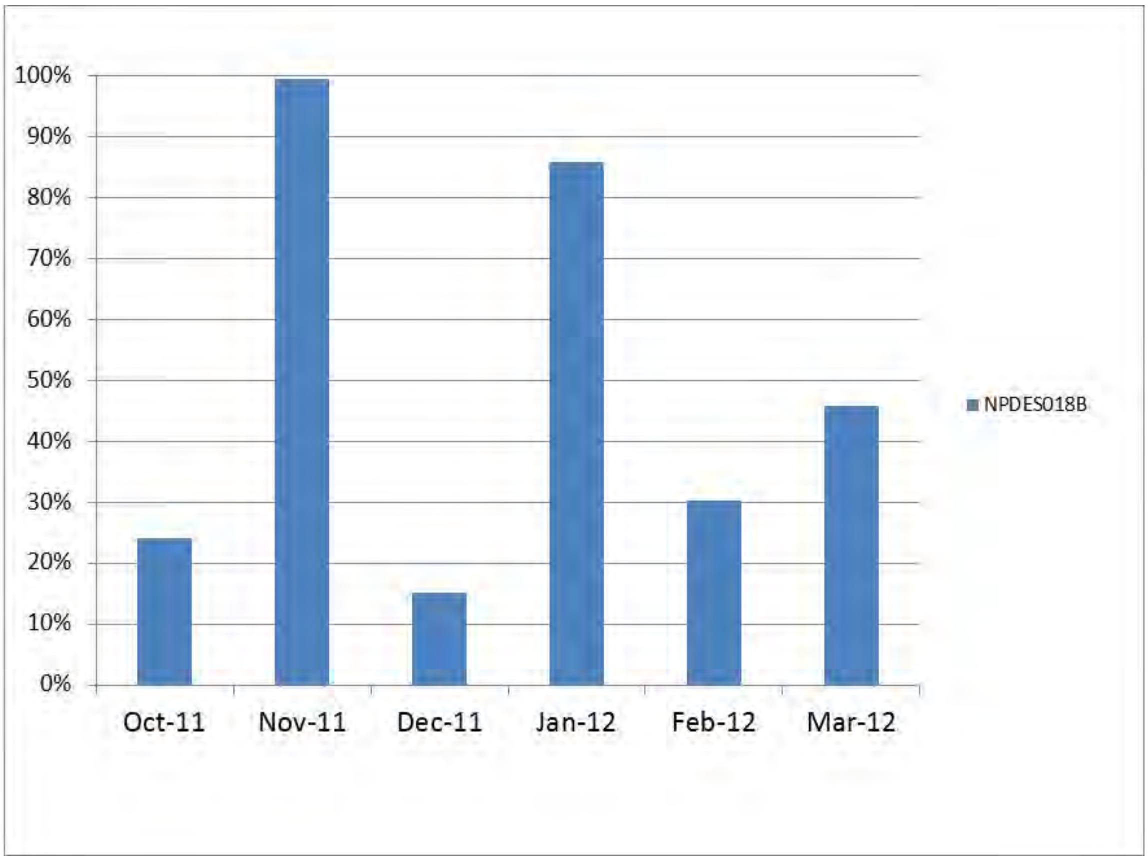

Figure 3-12. Storage utilization for the NPDES018(B) Sub-basin

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SECTION 4

Suitability of Data for Hydrologic and Hydraulic Modeling Efforts

This section presents an assessment as to whether the data collected during Phase 4 are sufficient for model calibration and verification purposes. The data were assessed according to the Quality Assurance Project Plan (QAPP), December 2009.

4.1 Wet Weather Model Calibration Periods

The monitoring period rainfall can be characterized generally as below in volume and number of events at both RG 02 and RG 25. Figure 3-3 shows the monthly long-term Sea-Tac average rainfall together with the observed rainfall at RG 02 and RG 25 for the Phase 4 monitoring period, October 2011 through March 2012. December 2011 and February 2012 showed minimal rainfall in both gauges. Significant events occurred in November 2011 and March 2012 in both the Leschi and North Union Bay CSO Areas. October 2011 and January 2012 had average total rainfall, while March 2012 was above average in total rainfall.

As described in Section 3, all objectives for rainfall monitoring were exceeded in the Phase 4 LTCP gauges. Ten events were identified as useful for model calibration. These events cover a variety of antecedent moisture conditions, rainfall intensities, and volumes that will enhance the model calibrations.

4.2 Dry Weather Model Calibration Periods

Unlike Phases 1, 2, and 3, the Phase 4 monitoring period did not assess any dry weather flow data.

4.3 Future Flow Monitoring

At the conclusion of Phase 4, all flow monitoring goals and objectives were achieved. No additional flow monitoring is required for the purposes of model calibration.

4.4 Data Quality Summary

The data obtained from each of the monitoring locations were assessed and classified for their suitability for use in model calibration and verification as described in Section 14 of the QAPP, December 2009. A detailed description of the data quality per monitoring site can be found in Section 3.

In summary, the data at the majority of monitors were rated either “Good” or “Excellent.” In cases where data were rated “Some Limitations” or “Poor,” portions of the data still can be used for the modeling, either to confirm or supplement other data. This together with the desirable rainfall patterns captured provides a solid foundation for model calibration and verification.

4.5 Use of Data in Model Calibration

The data collected during Phase 4 of the flow monitoring program will serve the following uses during model calibration and verification:

- determine the wet weather hydrology of each meter basin
- determine dry weather flows and associated diurnal patterns
- develop HydroBrake head-discharge relationships
- confirm hydraulic performance of structures

SECTION 5

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Appendix A: Basin Schematics

Submitted Electronically

Seattle Public Utilities | Protecting Seattle's Waterways

Appendix B: Leschi Data Site Sheets

Submitted Electronically

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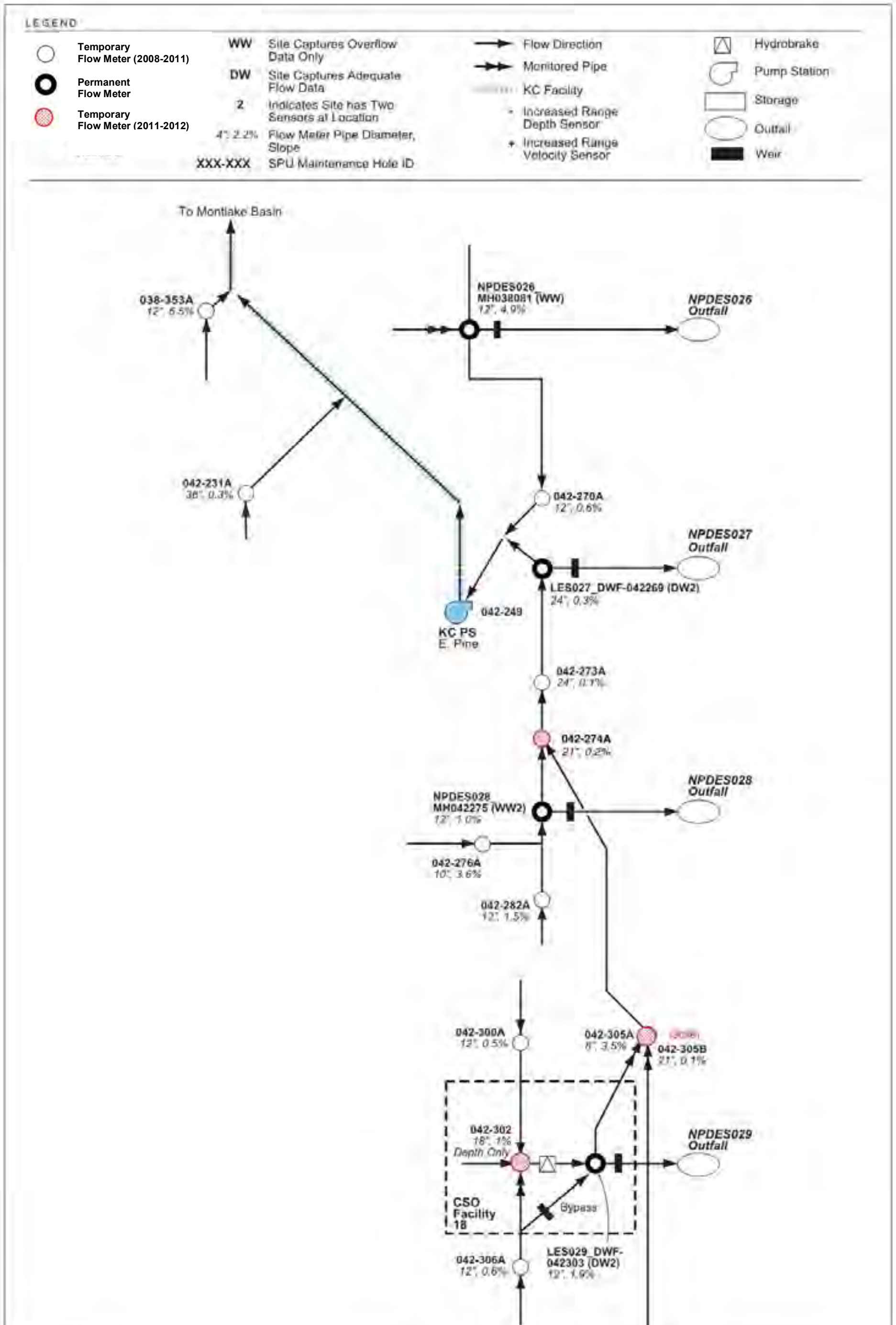
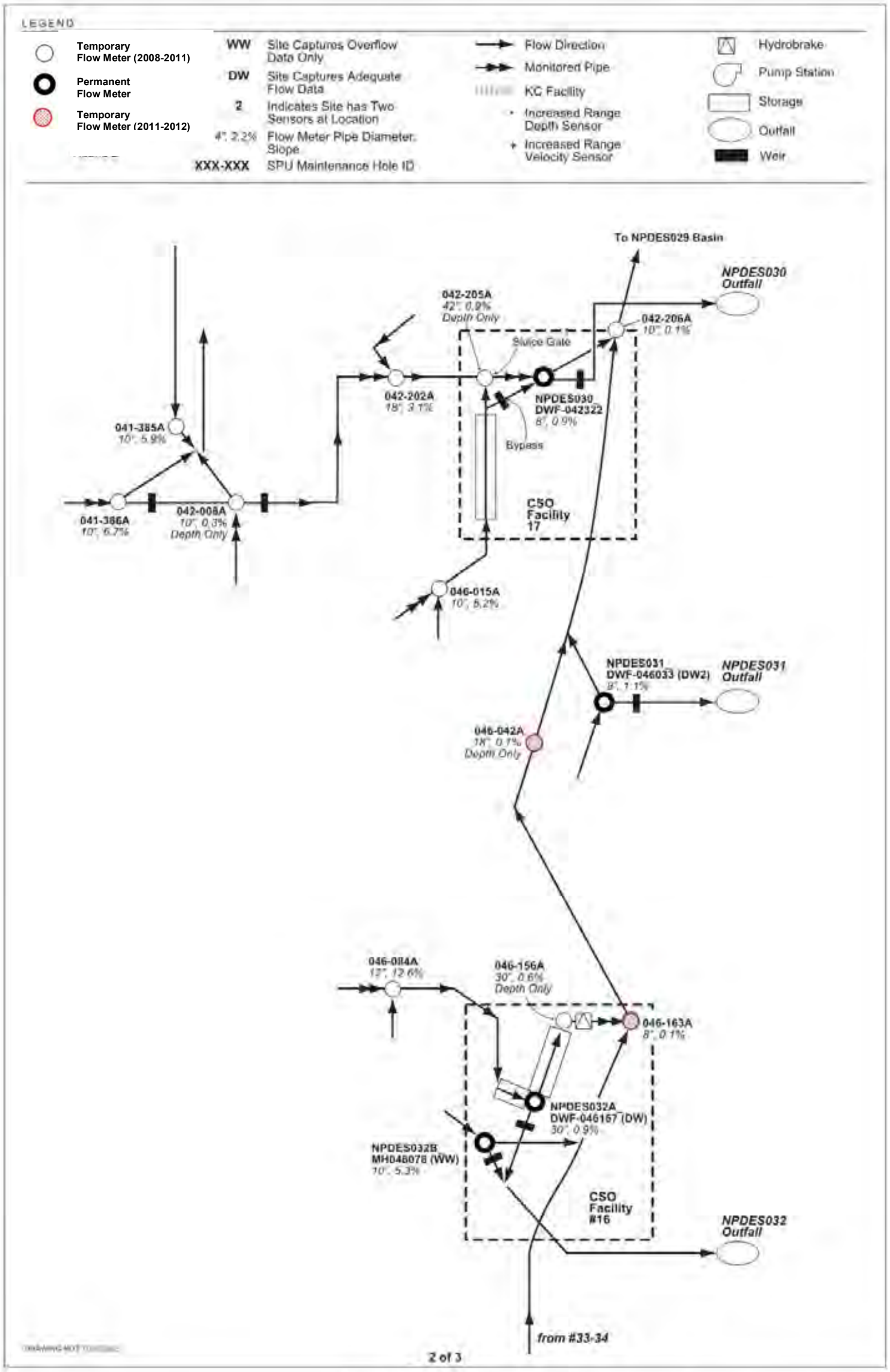
Appendix C: North Union Bay Data Site Sheets

Submitted Electronically

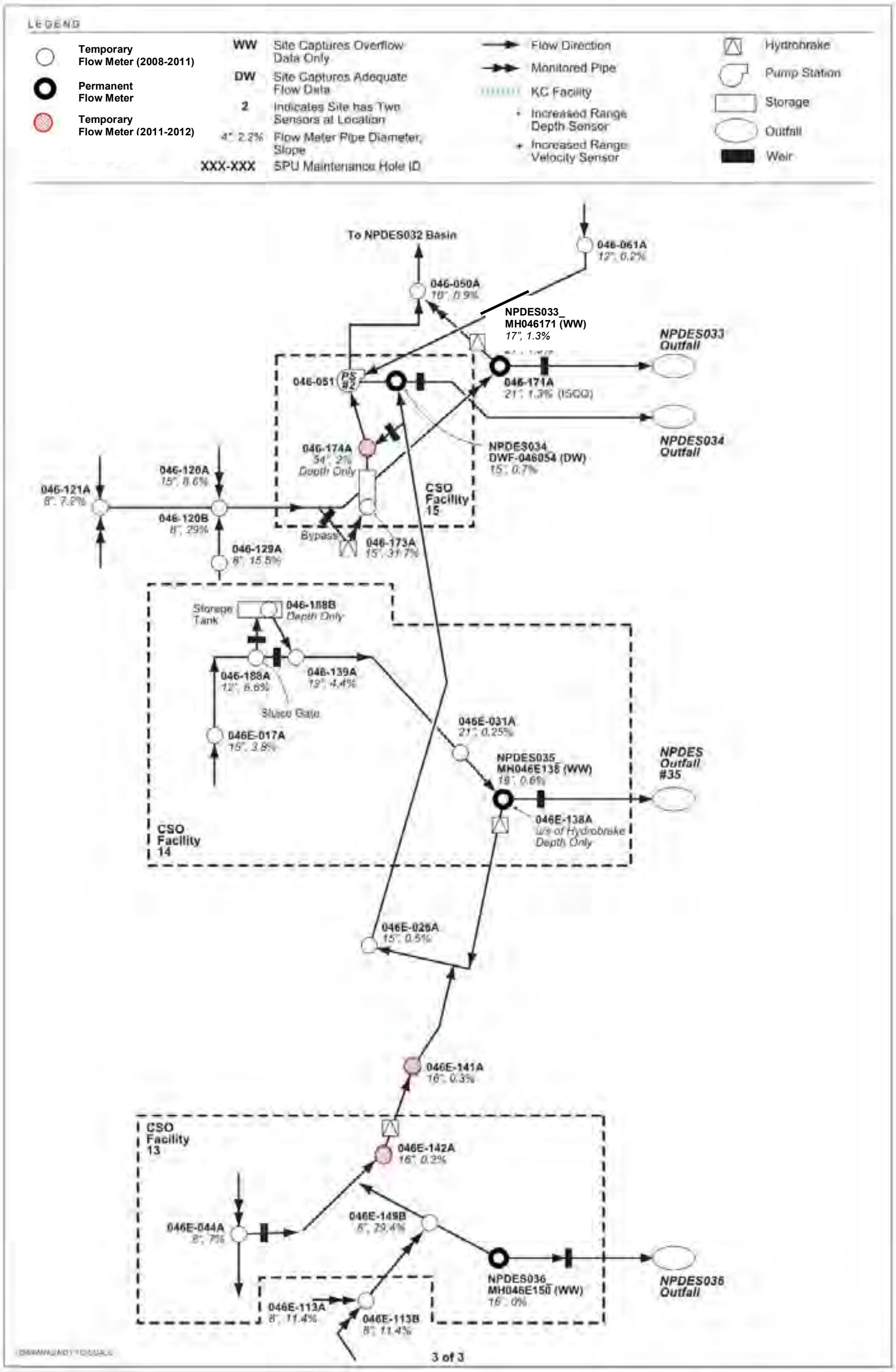


Seattle Public Utilities **LESCHI: NPDES026, 027, 028, 029 Basins**	METER SCHEMATIC December 2012



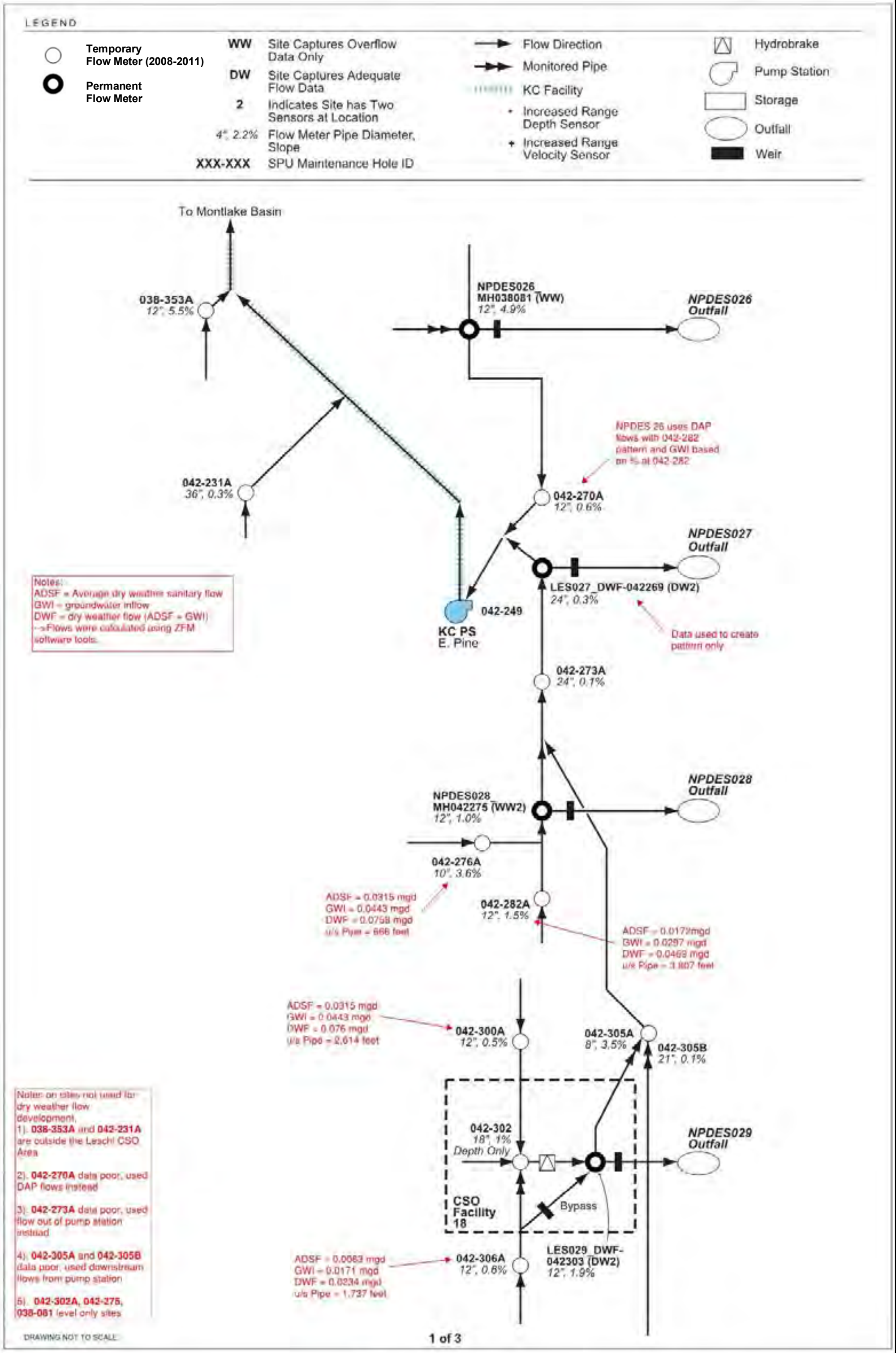
Seattle Public Utilities
LESCHI: NPDES030, 031, 032 Basins

METER SCHEMATIC
December 2012

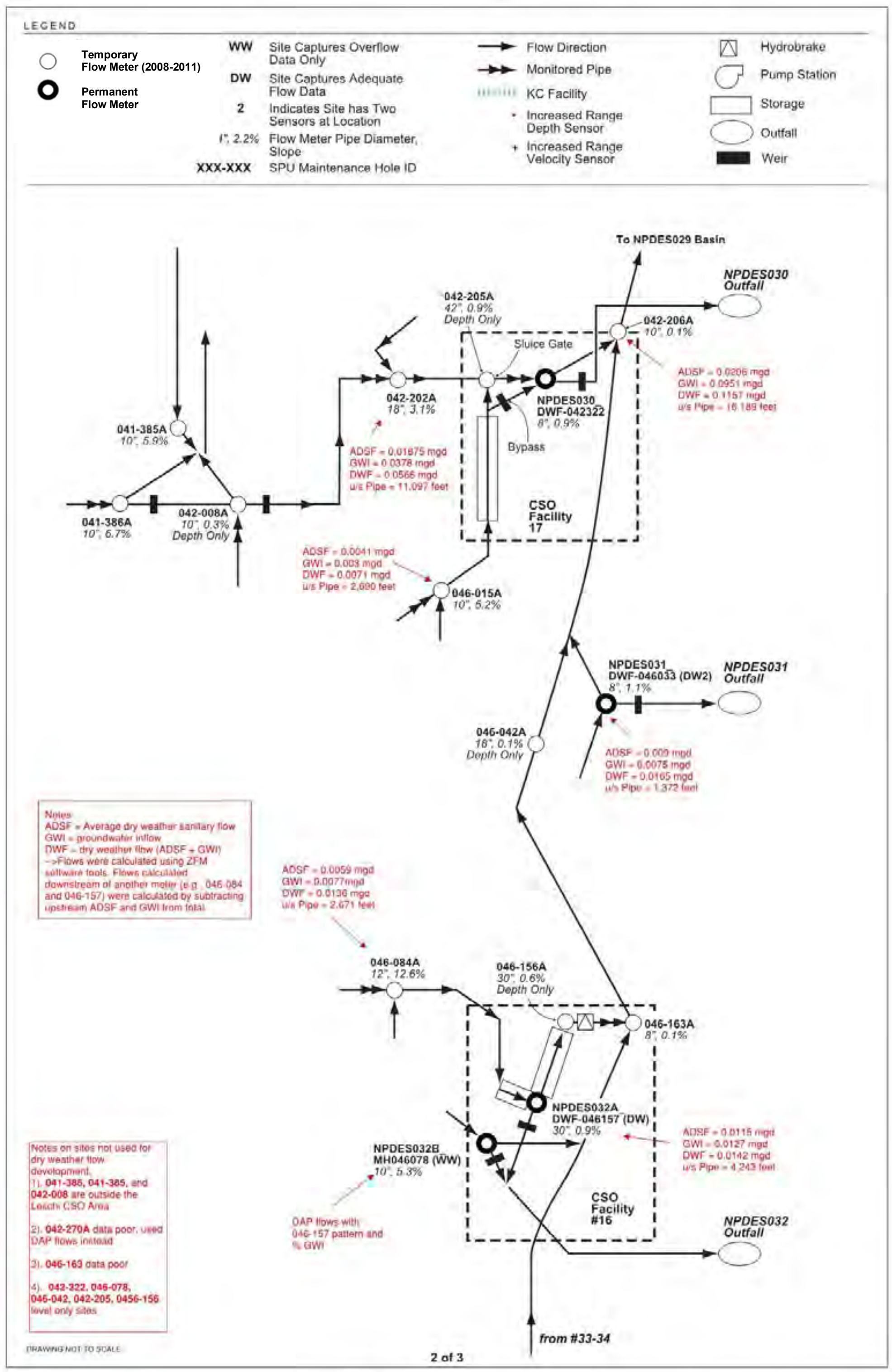


Seattle Public Utilities
LESCHI: NPDES033, 034, 035, 036 Basins

METER SCHEMATIC
December 2012

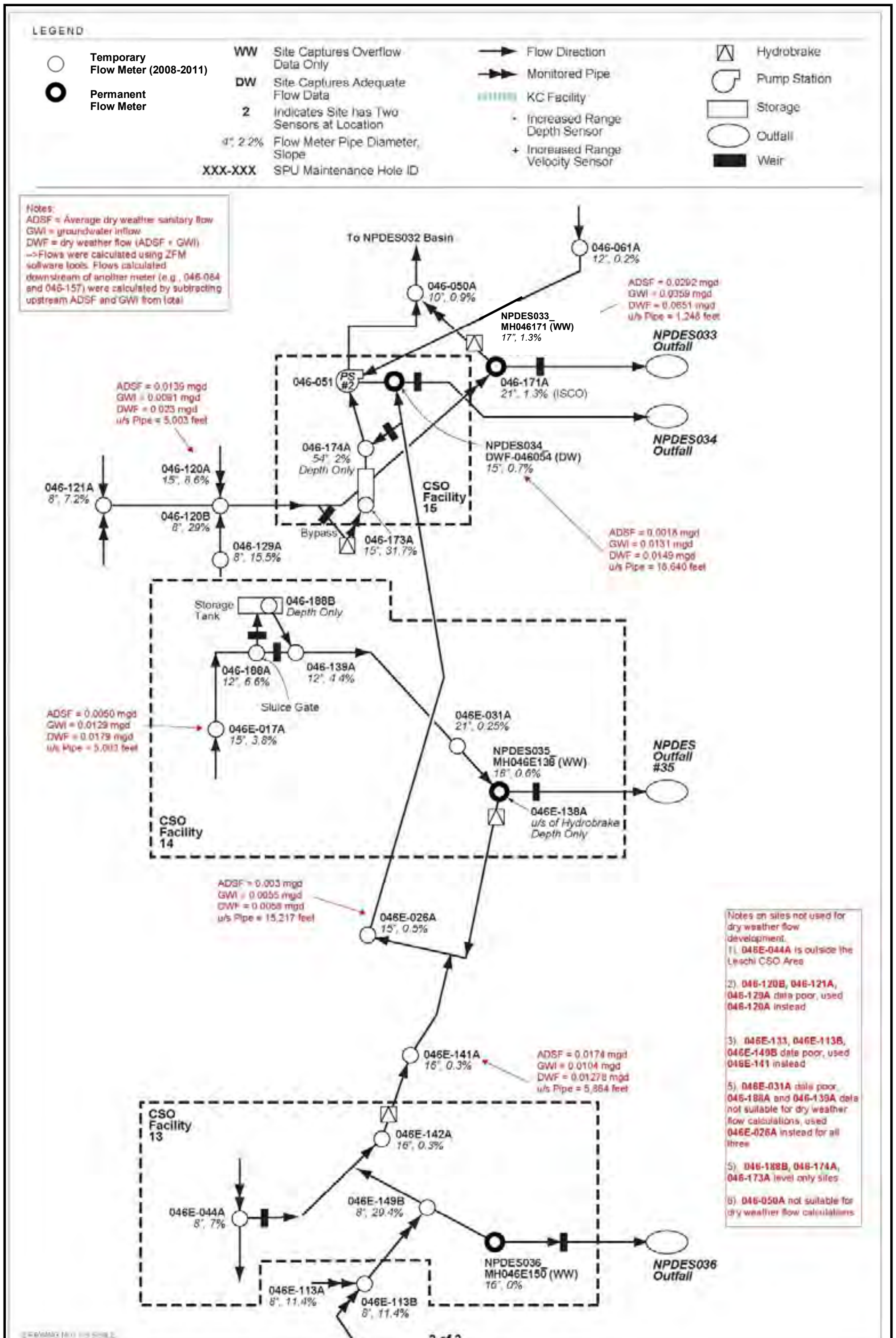


Seattle Public Utilities **LESCHI: NPDES026, 027, 028, 029 Basins**	METER SCHEMATIC December 2012



Seattle Public Utilities
LESCHI: NPDES030, 031, 032 Basins

METER SCHEMATIC
December 2012



Seattle Public Utilities
LESCHI: NPDES033, 034, 035, 036 Basins

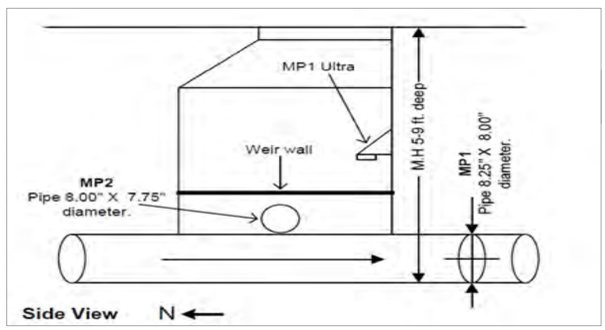
METER SCHEMATIC
December 2012

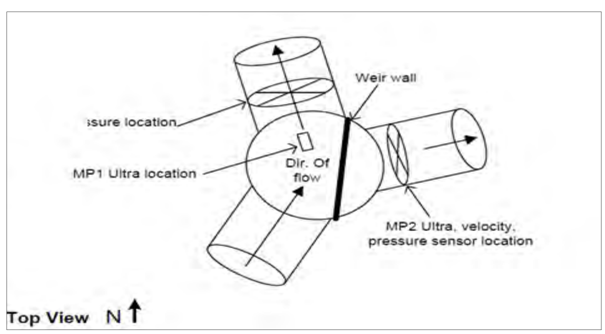
NPDES031_MH046033 Address: 4223 E Lee Street

Data Quality Ranking	Good
Pipe ID	046-128_046-033
Pipe Diam (width x height inches)	8 x 8.25
Upstream Slope	1.1%
Meter Type	ADS FS 5000 BG
Installation Type	Incoming pipe
Installation Date	8/21/2007
Removal Date	--
Data Collection Period (days)	1684
Rain Gauge	25
Upstream Pipe Length (ft)	1,372

Site Narrative

NPDES031_MH046033 is a permanent monitoring site that records both level and velocity. The site was installed on 8/21/2007 to identify and quantify CSO events occurring from the NPDES031 Basin.
The permanent site is classified as a dry weather site; therefore, the site was expected to provide repeatable and reliable velocity data. The level data are used to alarm for CSO events and the continuity equation was used from the monitoring conducted in the overflow line.
The level data quality was classified as “Good” for Phase 4, as the meter captured all the major storm events. However, the velocity data were classified as having “Some Limitations” because the meter did not provide repeatable and reliable data. For the Phase 2 and 3 monitoring periods, the data quality was classified as “Excellent.” Data quality was classified as “Good” for the Phase 1 monitoring period, as it showed a clear relationship between level and velocity.
NPDES031_MH046033 is a permanent meter and will continue to be screened in the future.



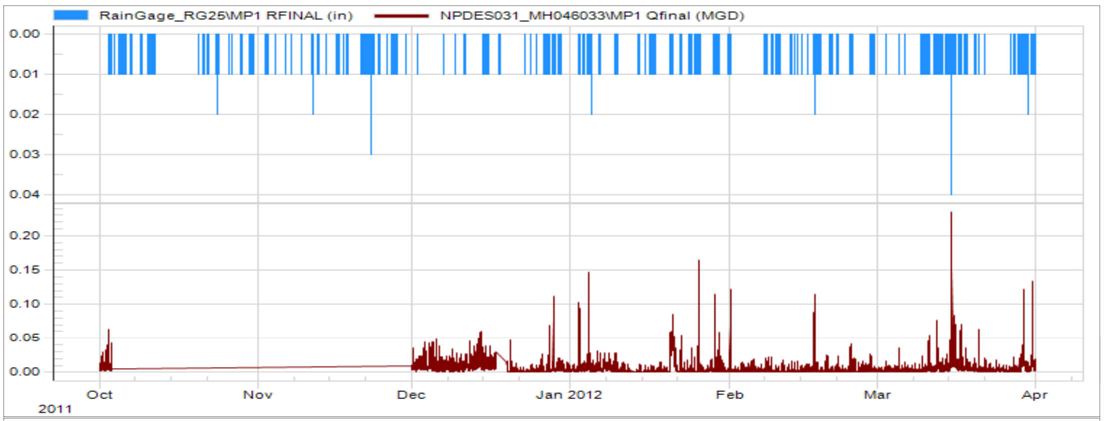


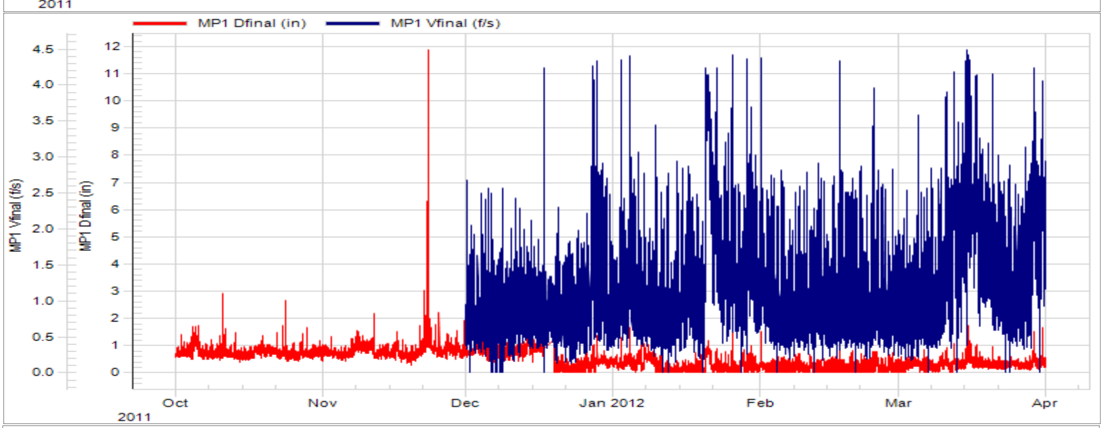
Upstream Pipe Trace (red)	Site Schematic

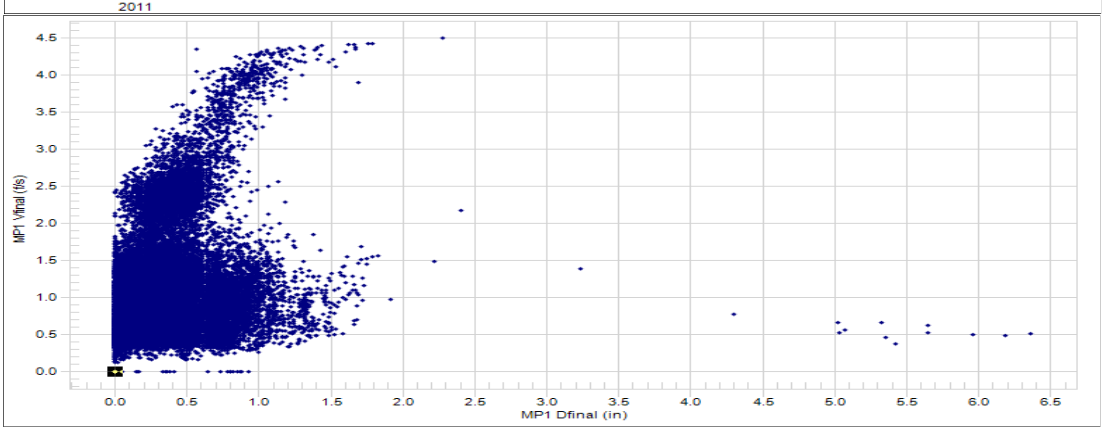
NPDES031_MH046033

View of MH | Site installation

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







Note: Final velocity values available only from December 2011 through March 2012

LES32_046-163A **Address:** **534 Lakeside Ave S at S Lane St**

Data Quality Ranking	Some Limitations
Pipe ID	046-156_ 046-163
Pipe Diam (width x height inches)	8 x 8.25
Upstream Slope	0.1%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	11/3/2011
Removal Date	3/13/2012
Data Collection Period (days)	131
Rain Gauge	25
Upstream Pipe Length (ft)	4,392

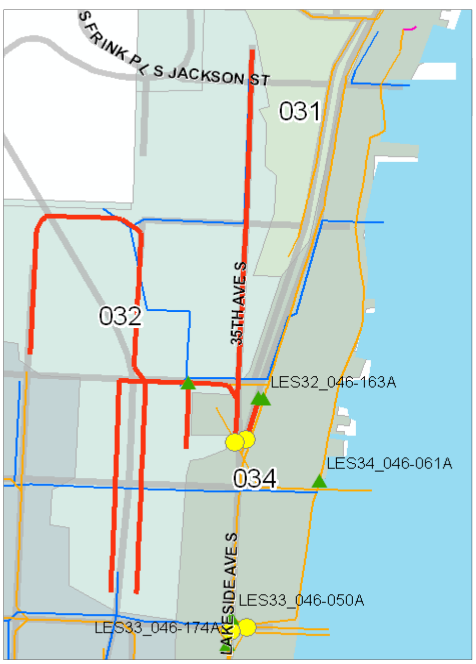
Site Narrative

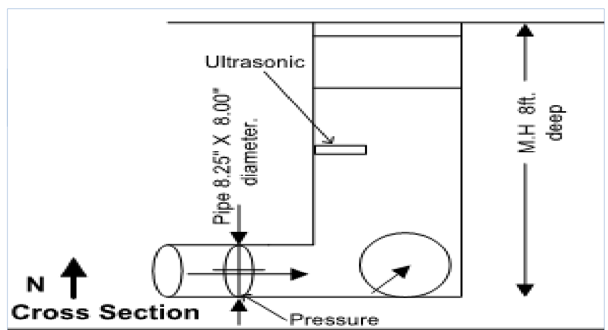
LES32_046-163A was a temporary monitoring site that recorded level and velocity downstream from the HydroBrake in the NPDES032(A) Sub-basin. The site was installed on 11/3/2011 to characterize the HydroBrake.

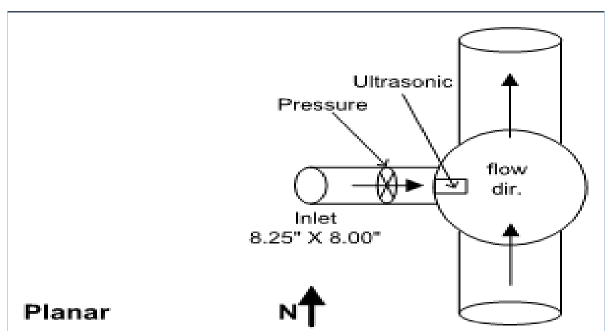
As noted for the previous phases, this site experiences reverse flow through the HydroBrake from the Leschi trunk sewer into the basin storage and heavy silt in the Leschi trunk sewer prevents collection of good velocity data. Thus, due to poor-quality velocity data, as noted for the previous phases, only level data were used for hydraulic calibration and verification in Phase 4.

The quality of the level data for Phase 4 was classified as having “Some Limitations” because there were data gaps from 12/19–26/2011 and on 1/4/2012. Although periods of data are suitable for model calibration and verification, these data must be selected carefully. For Phases 1, 2, and 3, the quality of the level data was classified as “Excellent.”

The meter was removed on 3/13/2012 during Phase 4 monitoring, as it was determined that suitable data had been collected for the purposes of model calibration and verification.

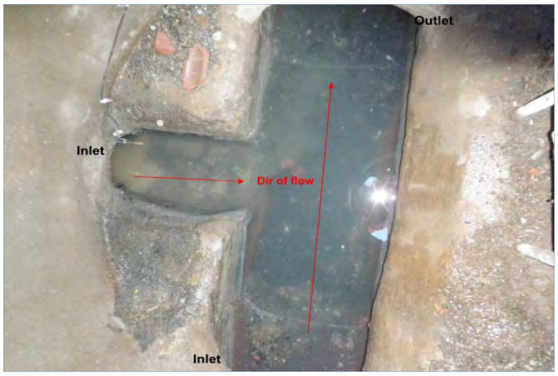


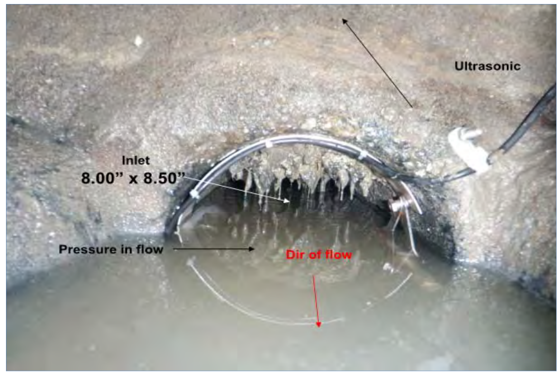




Upstream Pipe Trace (red) **Site Schematic**

LES32_046-163A

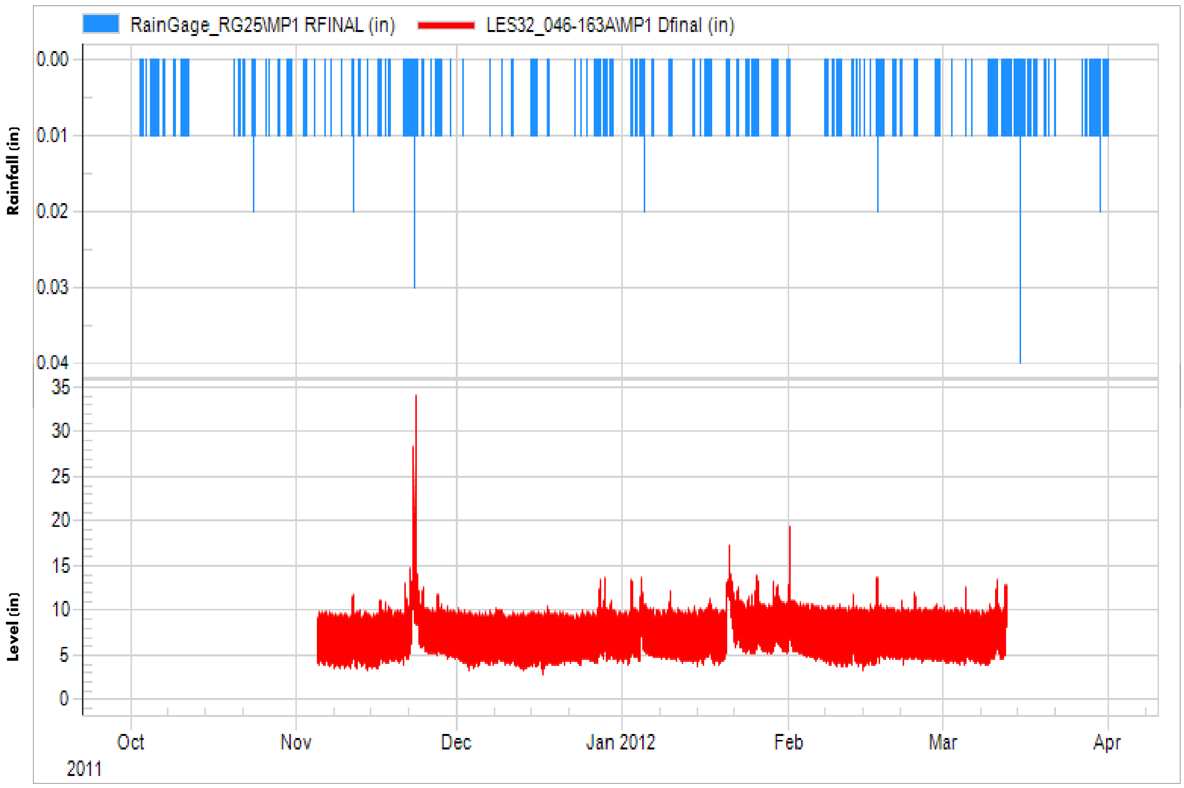




View odwn MH looking North

View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012



NPDES032A_MH046157 **Address:** **35th Ave. S. @ Lakeside Ave. S.**

Data Quality Ranking	Excellent (Level Only)
Pipe ID	046-158_046-157
Pipe Diam (width x height inches)	29.75 x 30
Upstream Slope	0.9%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	8/22/2007
Removal Date	--
Data Collection Period (days)	1683
Rain Gauge	25
Upstream Pipe Length (ft)	4,243

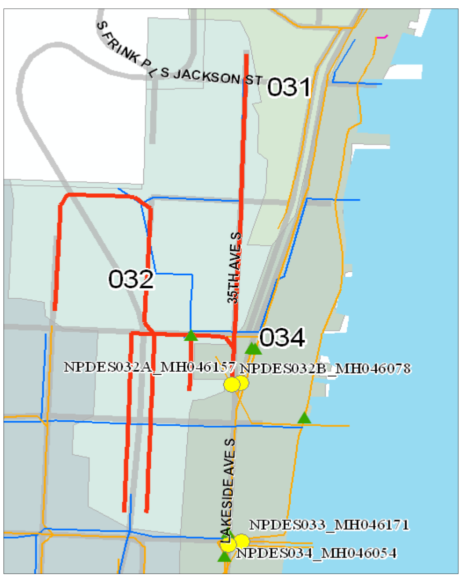
Site Narrative

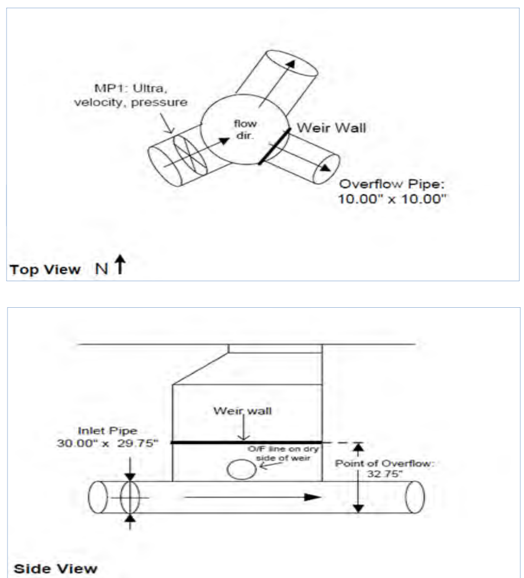
NPDES032A_MH046157 is a permanent monitoring site that records both level and velocity. The site was installed on 8/22/2007 to identify and quantify CSO events occurring from the NPDES032(A) Sub-basin.

The permanent site was classified as a dry weather site; therefore, the site was expected to provide repeatable and reliable velocity data. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

For the Phase 4 monitoring period, the level data were classified as “Excellent,” whereas the velocity data were qualified as having “Some Limitations.” For the Phase 2 and 3 monitoring periods, the data quality was classified as having “Some Limitations” because it was determined through previous flow balancing calculations that velocity values were being overestimated. For the Phase 1 monitoring period, the quality of the level data was classified as “Excellent” and the velocity data were classified as having “Some Limitations” for the same reasons as stated above.

NPDES032A_MH046157 is a permanent meter and will continue to monitor overflows in the future. One overflow event occurred at this site during the Phase 4 monitoring period.



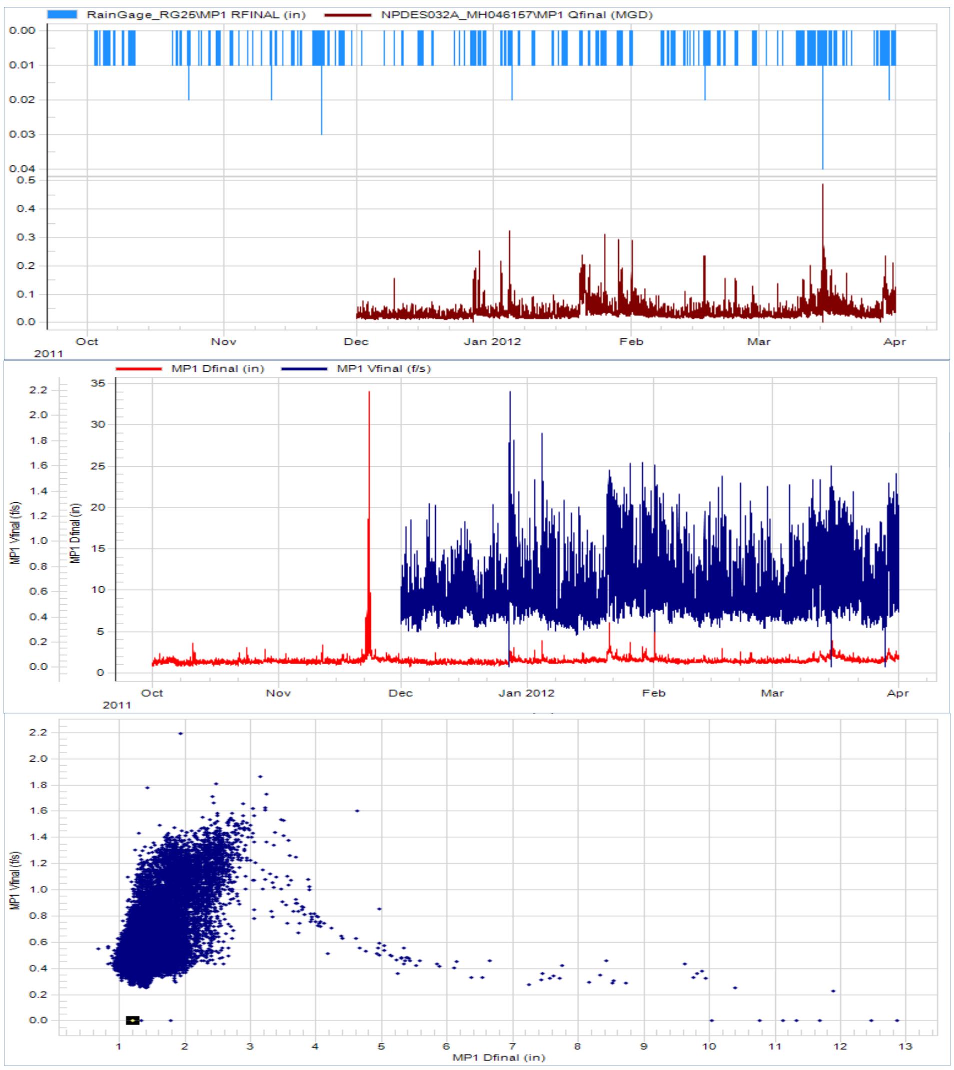


Upstream Pipe Trace (red) **Site Schematic**

NPDES032A_MH046157

View of MH	Site installation

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012



Note: Flow data was only available from December 2011- March 2012.

NPDES032B_MH046078 **Address:** **715 35th Ave S**

Data Quality Ranking	Good
Pipe ID	046-079_046-078
Pipe Diam (width x height inches)	9.75 x 10
Upstream Slope	5.3%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/30/2007
Removal Date	--
Data Collection Period (days)	1706
Rain Gauge	25
Upstream Pipe Length (ft)	124

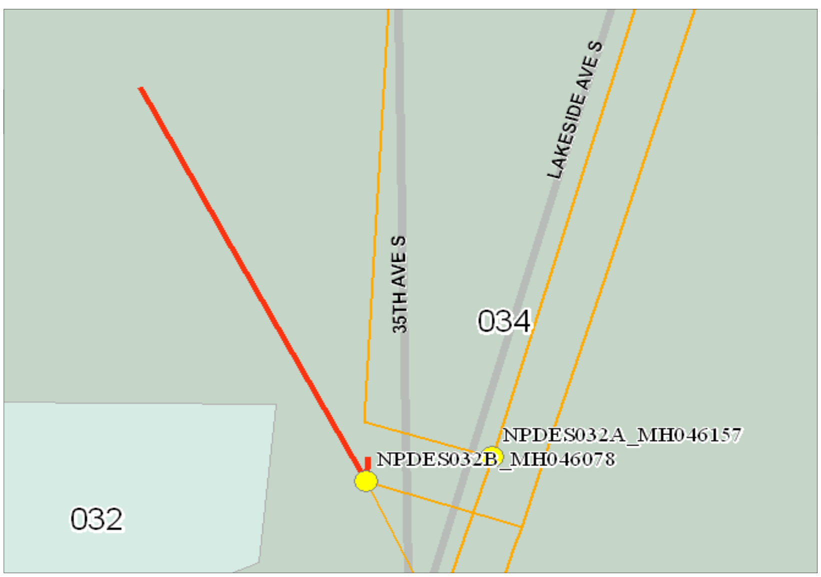
Site Narrative

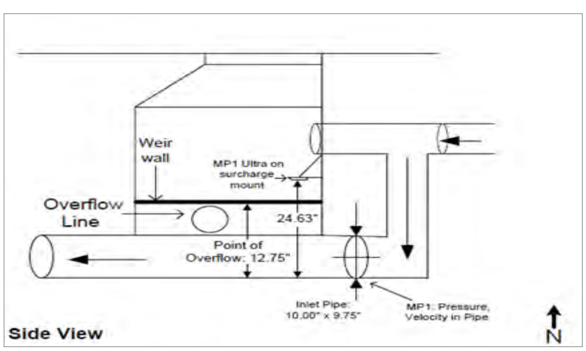
NPDES032B_MH046078 is a permanent monitoring site that records level only. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES032(B) Sub-basin. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

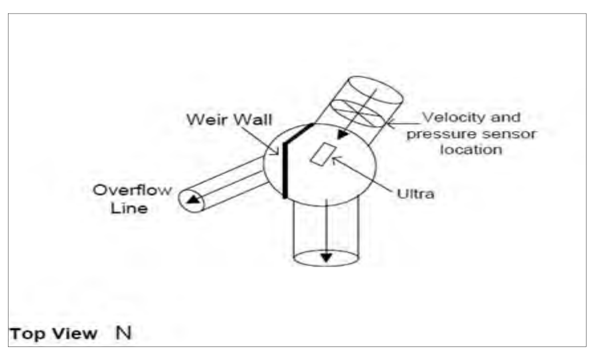
For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The quality of the data for Phase 4 was classified as “Good,” as overall the meter’s response to storm events was adequate.

Previous examination of level data collected at LES032_046-163A indicated that overflows occur due to the water surface elevation in the Leschi trunk sewer exceeding the elevation of the overflow weir. For Phases 1, 2, and 3, the level data were classified as “Excellent.”

NPDES032B_MH046078 is a permanent meter and will continue to monitor for overflow events in the future. One overflow event occurred at this site during the Phase 4 monitoring period.





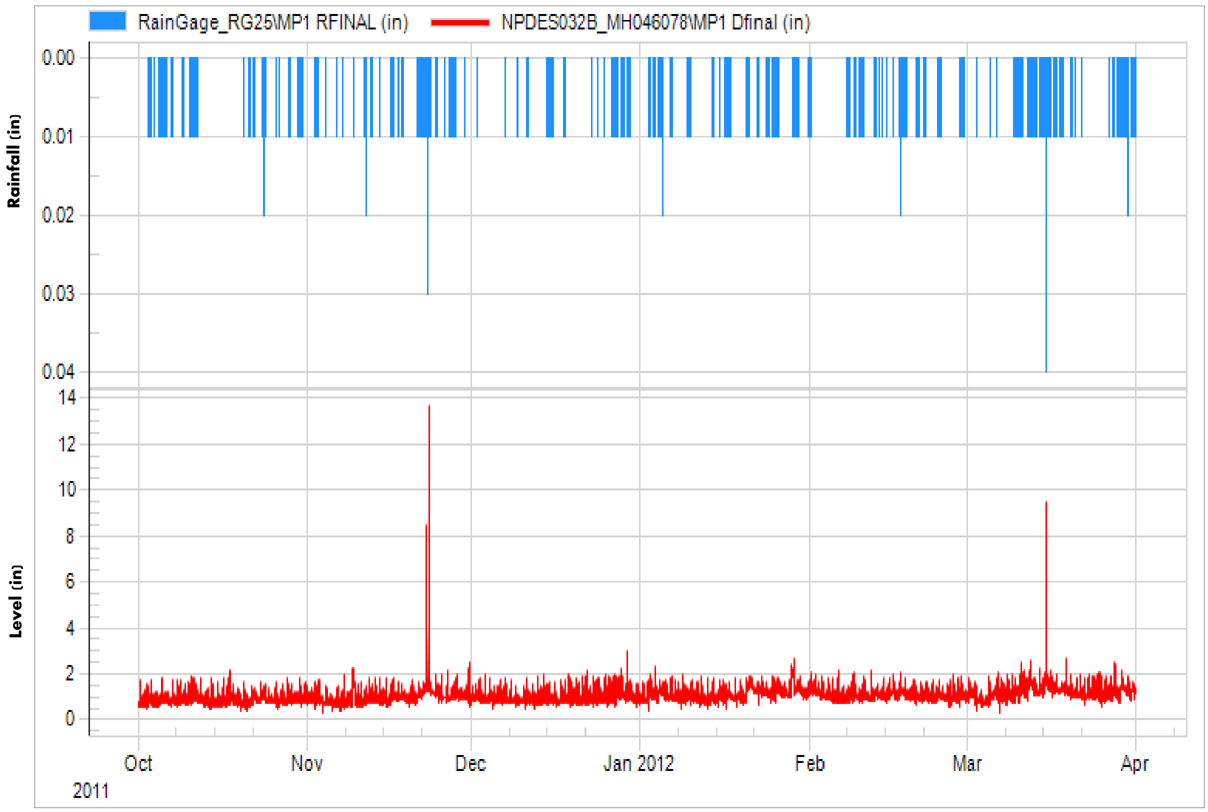


Upstream Pipe Trace (red)	Site Schematic

NPDES032B_MH046078

View of MH	Site installation

Hydrograph 10/1/2011 to 3/31/2012



LES33_046-174A **Address:** **900 Lakeside Ave**

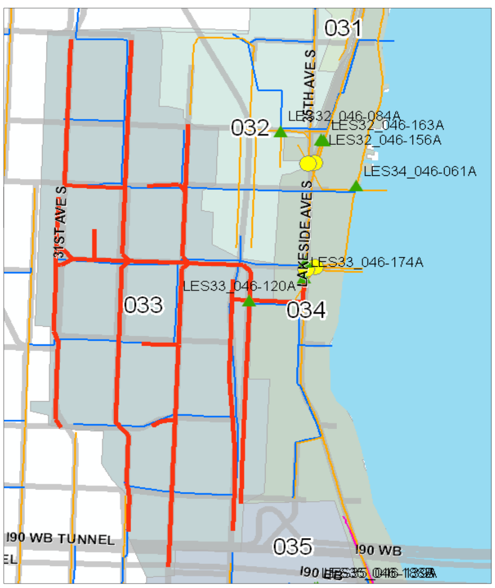
Data Quality Ranking	Some Limitations
Pipe ID	046-177_ 046-174
Pipe Diam (width x height inches)	54 x 52.75
Upstream Slope	2.0%
Meter Type	ADS 5000 AG
Installation Type	Level Only
Installation Date	11/4/2011
Removal Date	3/18/2012
Data Collection Period (days)	135
Rain Gauge	25
Upstream Pipe Length (ft)	12,399

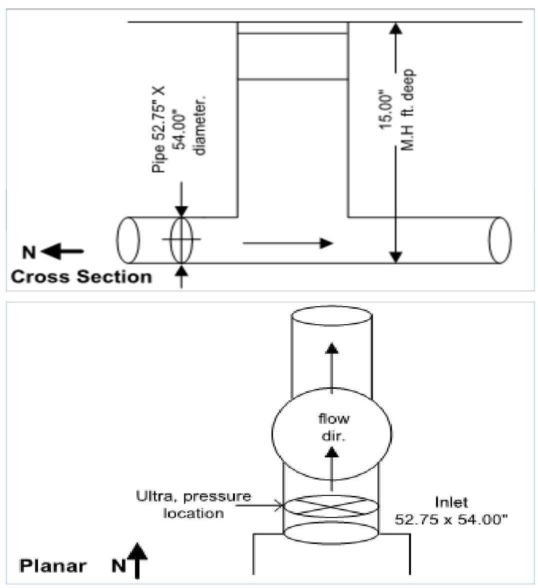
Site Narrative

LES33_046-174A was a temporary monitoring site that recorded level in the in-line storage pipe in the NPDES034 Basin. The site was installed on 11/4/2011 to capture data on storage utilization in the 84-inch-diameter offline storage pipe. LES33_046-174A was located upstream from PS 2 in CSO Facility 15.

The quality of the level data was classified as having “Some Limitations” for Phase 4 due to outages experienced from 12/28/2011 through 1/5/2012. Although some periods of data are suitable for model calibration, these data should be selected carefully. The data quality was classified as “Excellent” for Phases 1, 2, and 3 because the meter responded well to storm events and there were no data gaps during significant storms.

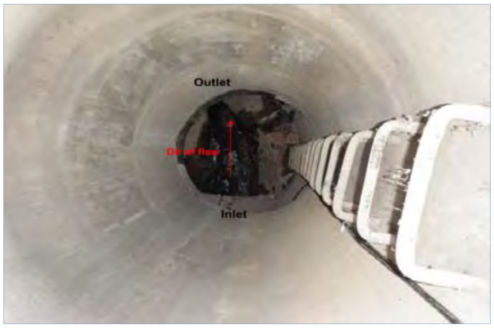
The meter was removed in 3/18/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.





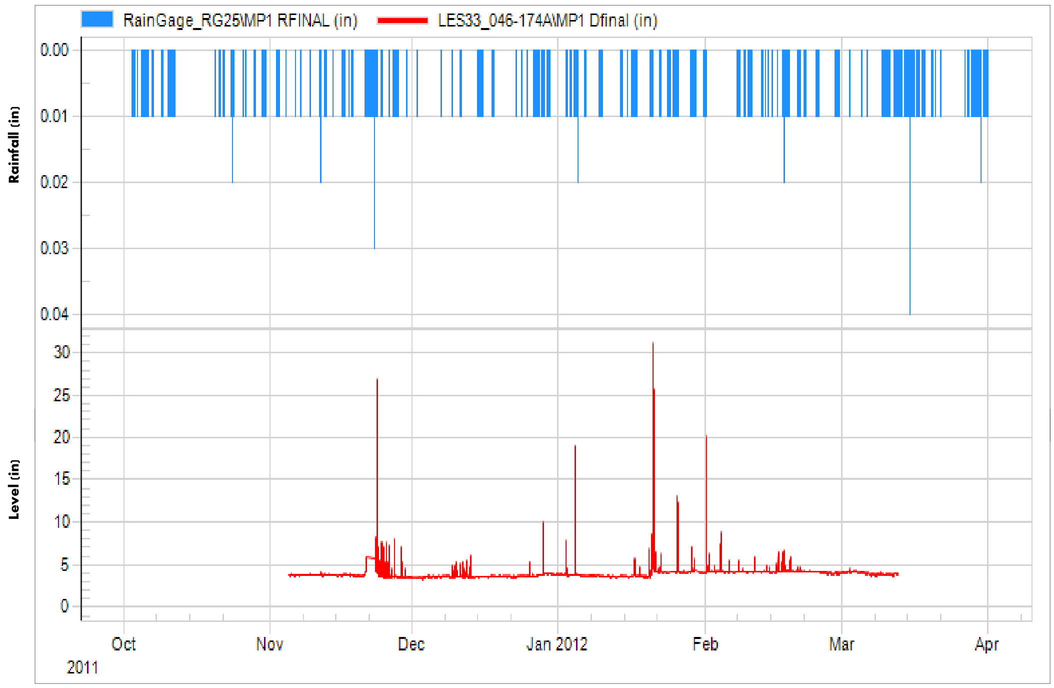
Upstream Pipe Trace (red) **Site Schematic**

LES33_046-174A



View down MH looking North	View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012



NPDES033_MH-046171 (WW) **Address:** **900 S. Charles St. @ Lakeside Av. S.**

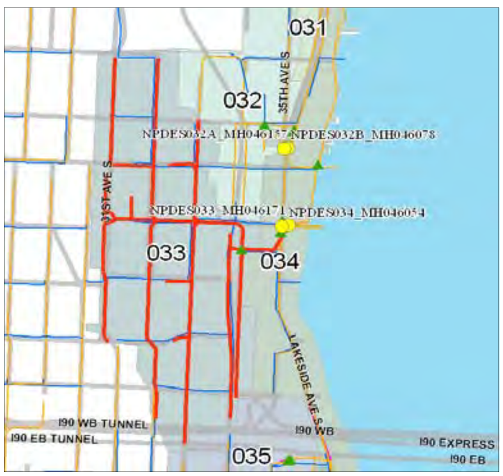
Data Quality Ranking	Excellent
Pipe ID	046-172_046-171
Pipe Diam (width x height inches)	17 x 16.38
Upstream Slope	1.31%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/30/2007
Removal Date	--
Data Collection Period (days)	1706
Rain Gauge	25
Upstream Pipe Length (ft)	17,348

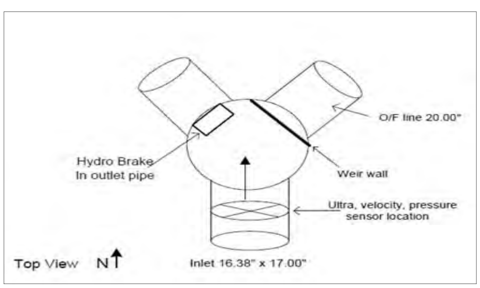
Site Narrative

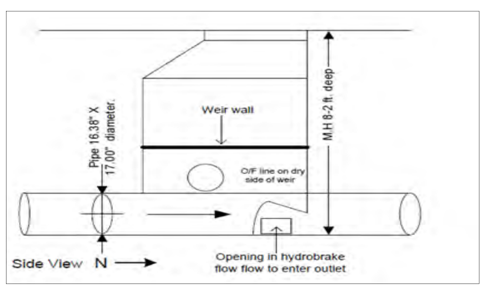
NPDES033_MH046171 is a wet weather permanent monitoring site that records both level and velocity. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES033 Basin. The level data are used to calculate the volume of CSO events using a weir equation. Although velocity data have been recorded at this site, previous assessments of these data have shown the data quality to be poor, and thus for Phase 4, only level data were finalized.

NPDES033_MH046171 is located at the NPDES033 Overflow Structure downstream from CSO Facility 15. For the Phase 4 monitoring period, the quality of the level data was classified as “Excellent,” which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. All level data for Phase 4 are suitable for model calibration.

This monitoring site is a permanent site and will continue to monitor overflow events in the future.





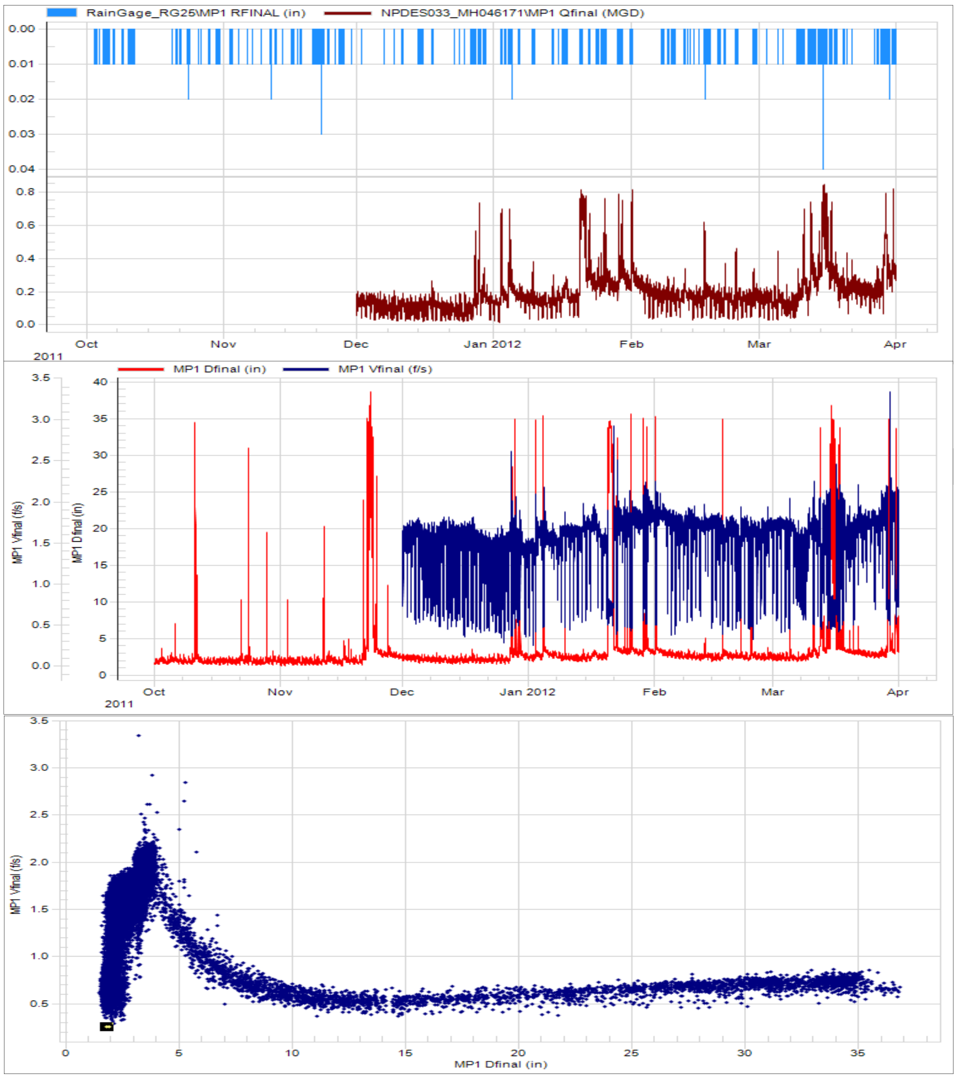


Upstream Pipe Trace (red) **Site Schematic**

NPDES033_MH-046171 (WW)

View of MH	Site installation

Hydrograph and Scattergraph 10/1/2012 to 03/31/2012

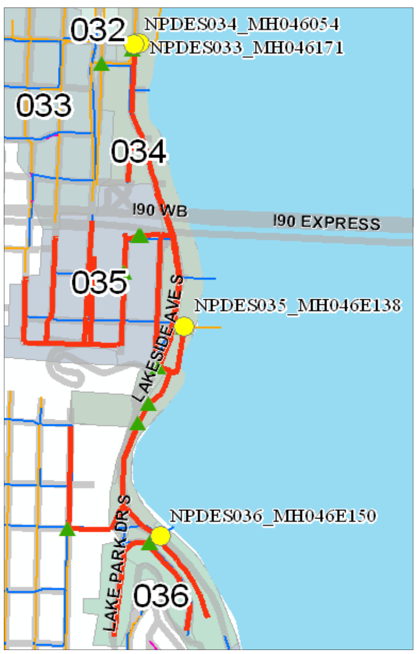


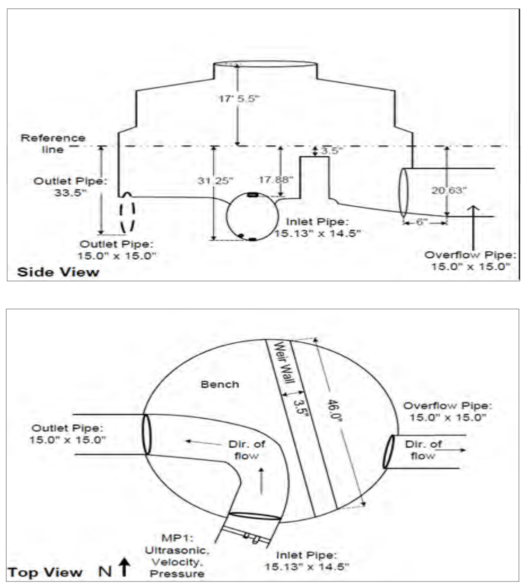
NPDES034_MH046054 **Address:** **Lakeside Ave. S. @ S. Charles St.**

Data Quality Ranking	Excellent
Pipe ID	046-176_046-054
Pipe Diam (width x height inches)	14.5 x 15.13
Upstream Slope	0.7%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/30/2007
Removal Date	--
Data Collection Period (days)	1706
Rain Gauge	25
Upstream Pipe Length (ft)	18,640

Site Narrative

NPDES034_MH046054 is a permanent monitoring site that records both level and velocity. The site is classified as a dry weather flow site; therefore, the site was expected to provide repeatable and reliable velocity data. The site was installed on 7/30/2007 to identify and quantify CSO events occurring from the NPDES034 Basin. The level data are used to calculate the volume of CSO events using a weir equation.
NPDES034_MH046054 is located at the NPDES034 Overflow Structure, downstream from CSO Facility 15. For the Phase 4 monitoring period, the quality of the data was classified as "Excellent" because the meter demonstrated a consistent and repeatable dry weather diurnal pattern. All the data collected for Phase 4 are suitable for hydraulic calibration purposes. See the scattergraph in Figure 3 5 below, which shows the velocity and depth data collected during the wet weather flow period for this site.
For the Phase 2 and 3 monitoring periods, the data quality was classified as having "Some Limitations." As discussed in the Phase 2 and 3 report, Volume 5 (2010), those data showed a distinct relationship above about 2 inches of water. Below a level of 2 inches in the pipe though, the scattergraph was wide, indicating that the meter was picking up multiple velocities at a given depth as shown in Figure 3 5. For the wet weather flow period, the data captured a clear scatter. For the Phase 1 monitoring period, the quality of the level and velocity data was classified as "Good."
This monitoring site is a permanent site and will continue to monitor overflow data in the future.



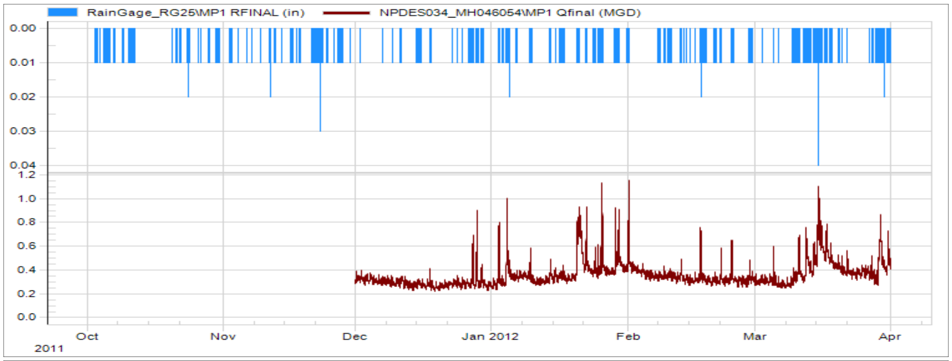


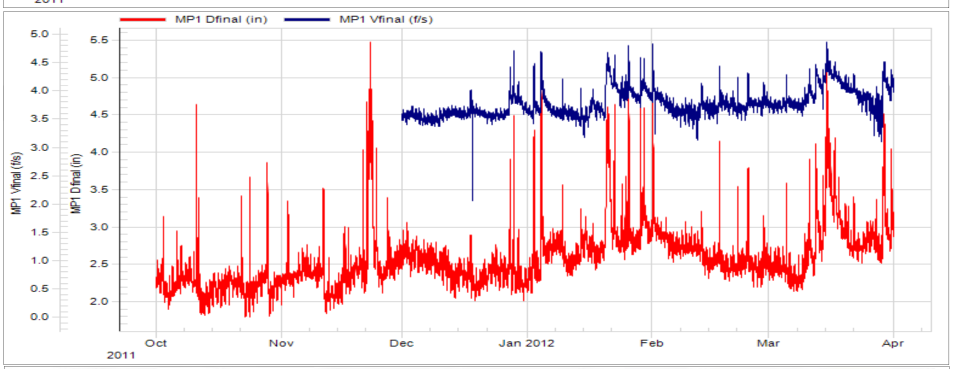
Upstream Pipe Trace (red)	Site Schematic

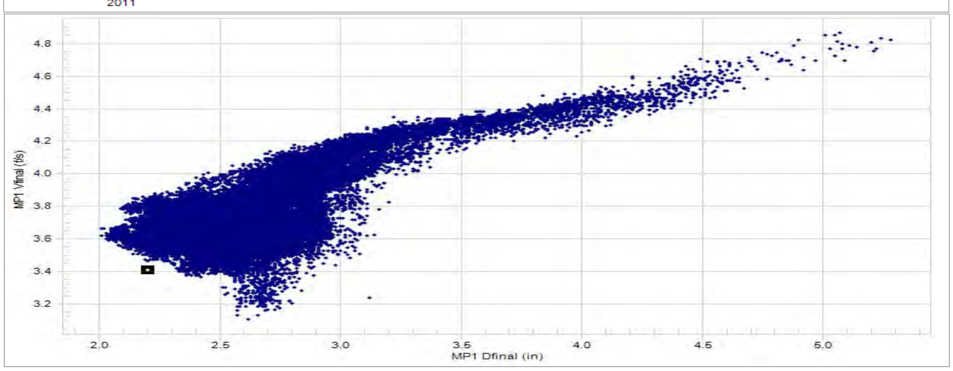
NPDES034_MH046054

View of MH	Site installation

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NPDES035_MH046E138 | Address: | 1700 Lakeside Ave S.

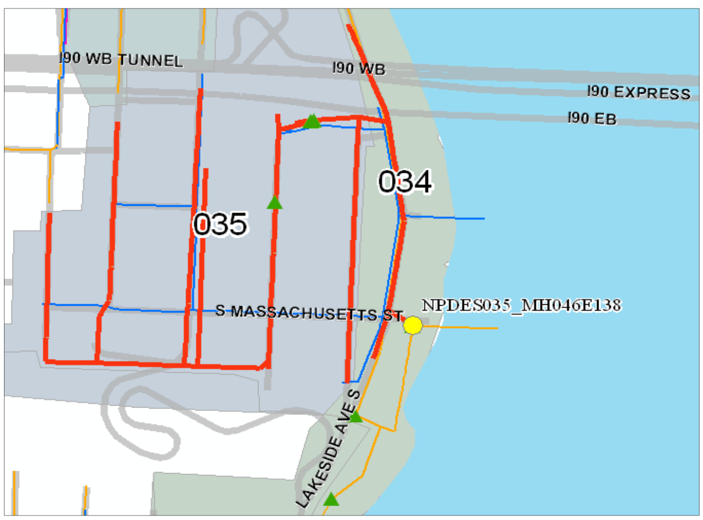
Data Quality Ranking	Excellent
Pipe ID	046E-138_046E-028
Pipe Diam (width x height inches)	17.5 x 18.25
Upstream Slope	0.6%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/26/2007
Removal Date	--
Data Collection Period (days)	1710
Rain Gauge	25
Upstream Pipe Length (ft)	8,404

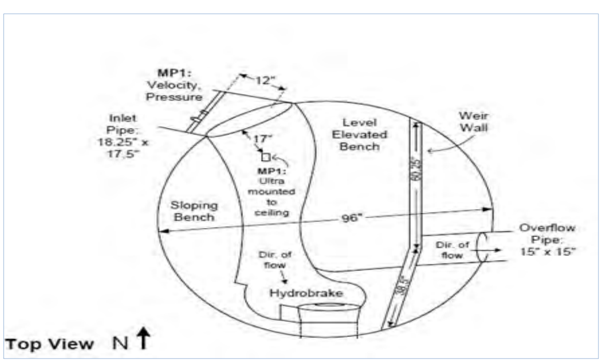
Site Narrative

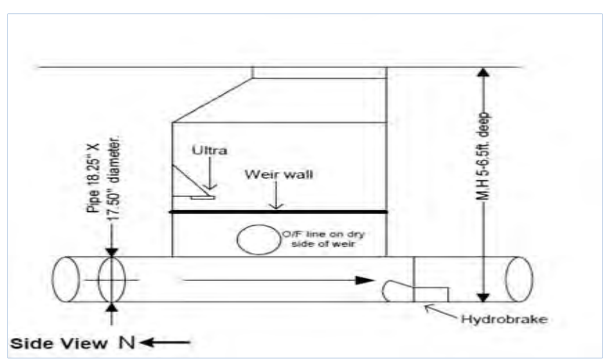
NPDES035_MH046E138 is a permanent monitoring site that records level. The site was installed on 7/26/2007 to identify and quantify CSO events occurring from the NPDES035 Basin. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation.

NPDES035_MH046E138 is located at the NPDES035 Overflow Structure downstream from CSO Facility 14. The data quality for the meter was classified as “Excellent” for Phase 4 as the site captured a consistent diurnal pattern and responded well during storm events. This is consistent with the classifications in all the previous phases. All level data are suitable for the purposes of model calibration.

This is a permanent monitoring site that will continue to monitor for overflows in the future.





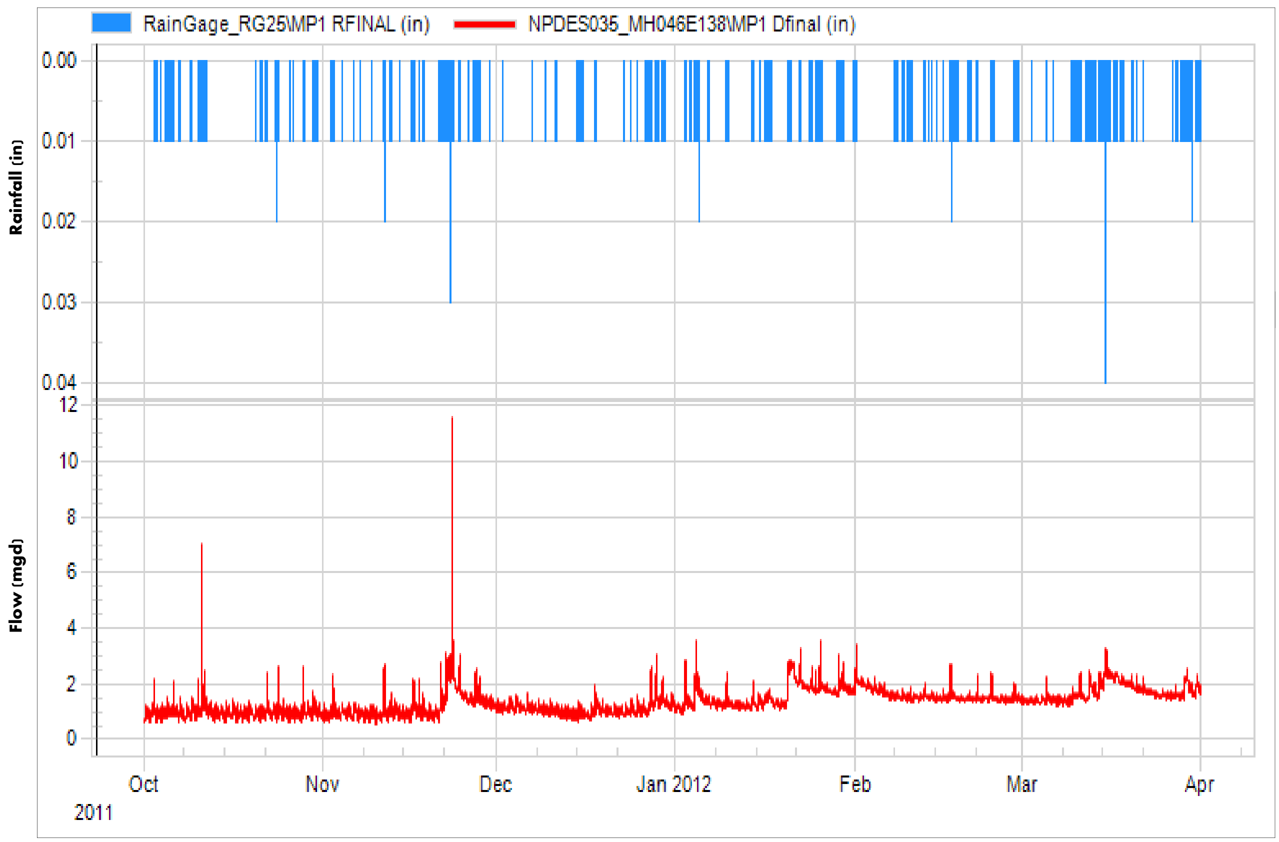


Upstream Pipe Trace (red) | **Site Schematic**

NPDES035_MH046E138

View of MH	Site installation

Hydrograph 10/1/2011 to 3/31/2012



LES36_046E-141A **Address:** **Coleman Park (between grass and sidewalk)**

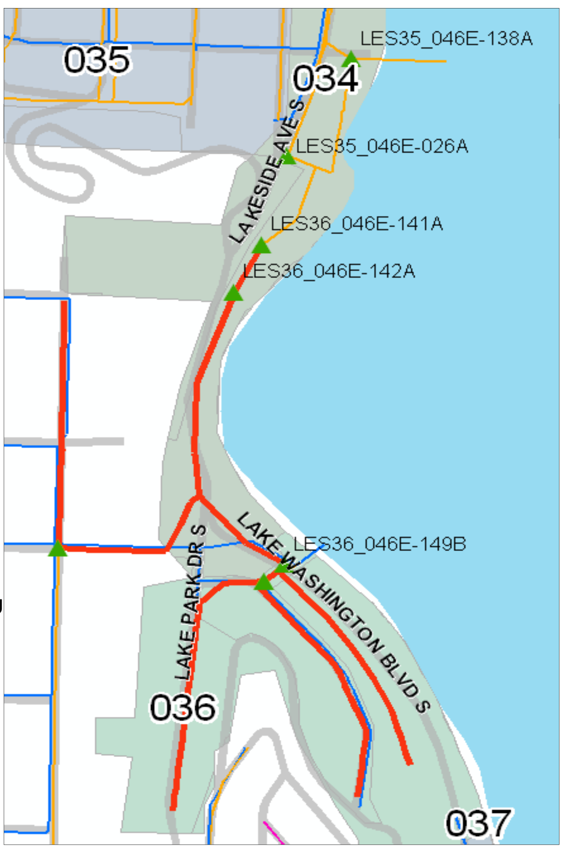
Data Quality Ranking	Some Limitations
Pipe ID	046E-142_ 046E-141
Pipe Diam (width x height inches)	16.25 x 16.5
Upstream Slope	0.30%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	11/2/2011
Removal Date	3/13/2012
Data Collection Period (days)	132
Rain Gauge	25
Upstream Pipe Length (ft)	5,864

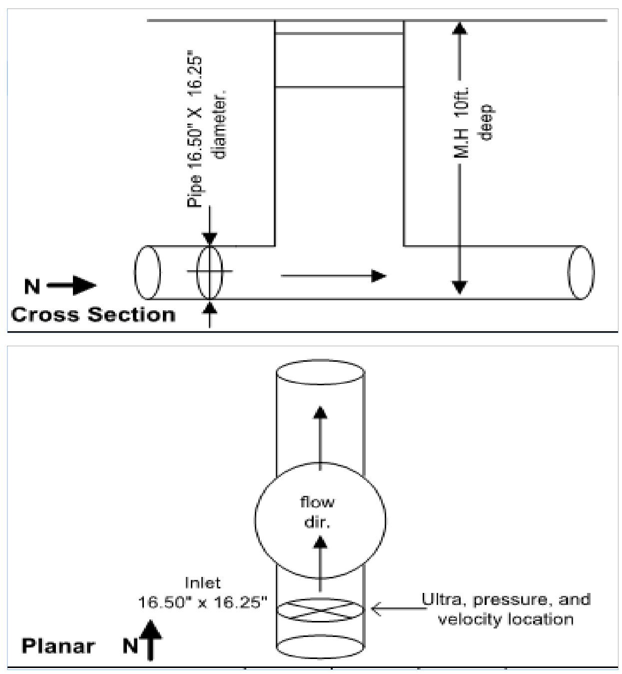
Site Narrative

LES36_046E-141A was a temporary monitoring site that recorded both level and velocity downstream from the HydroBrake in the NPDES036 Basin. The site was installed on 11/2/2011 to characterize the HydroBrake performance in the NPDES036 Basin. This meter was used to characterize the HydroBrake.

Although the meter was classified as “Good” for the previous phases, in Phase 4, it was classified as having “Some Limitations” because night velocity gaps were observed from 11/2/2011 through 12/14/2011. Ramping over the sensor was also suspected due to debris in the pipe (see Figure 3 6), affecting the monitoring data for Phase 4. Although periods of data are suitable for model calibration and verification, these data must be selected carefully.

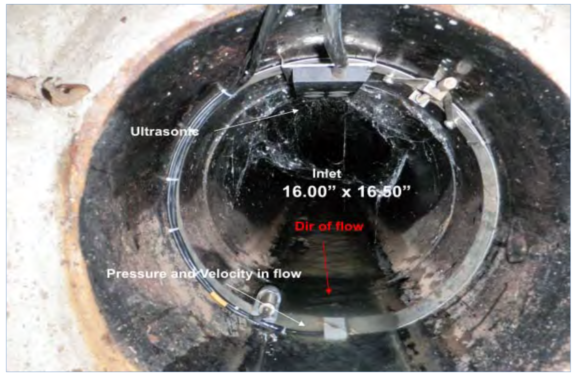
The meter was removed on 3/13/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.





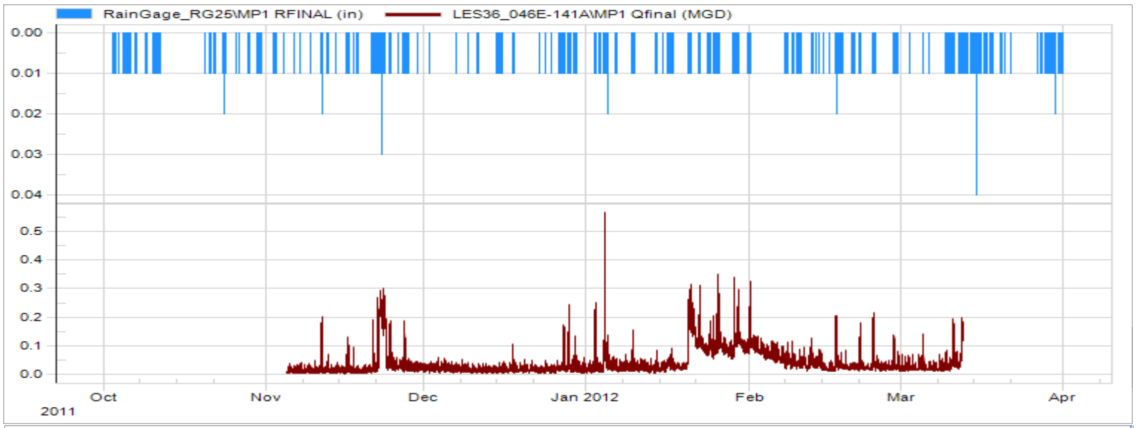
Upstream Pipe Trace (red) **Site Schematic**

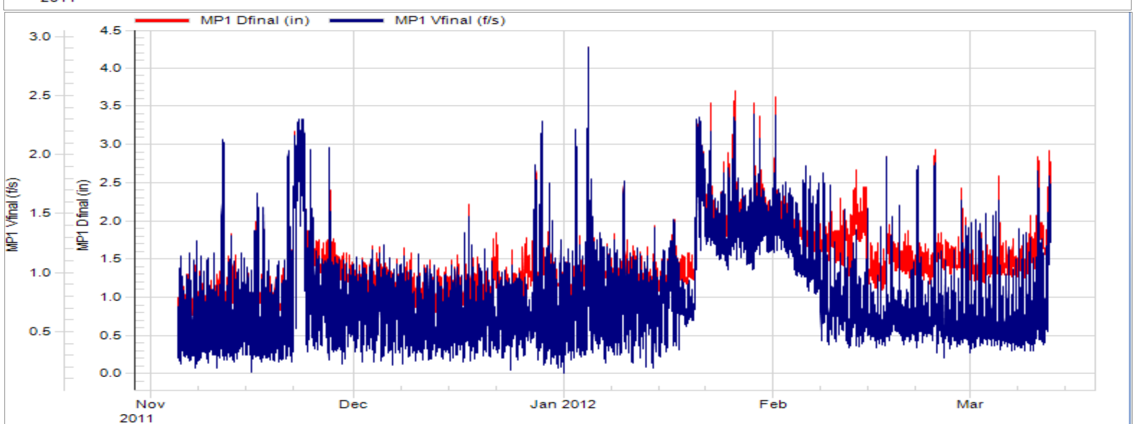
LES36_046E-141A

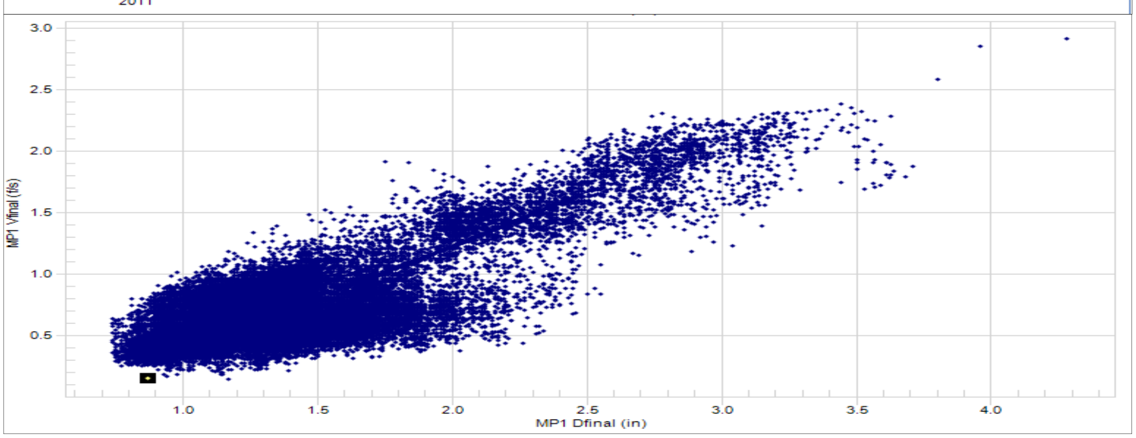


View down MH looking North | View of inlet and sensor placement

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012





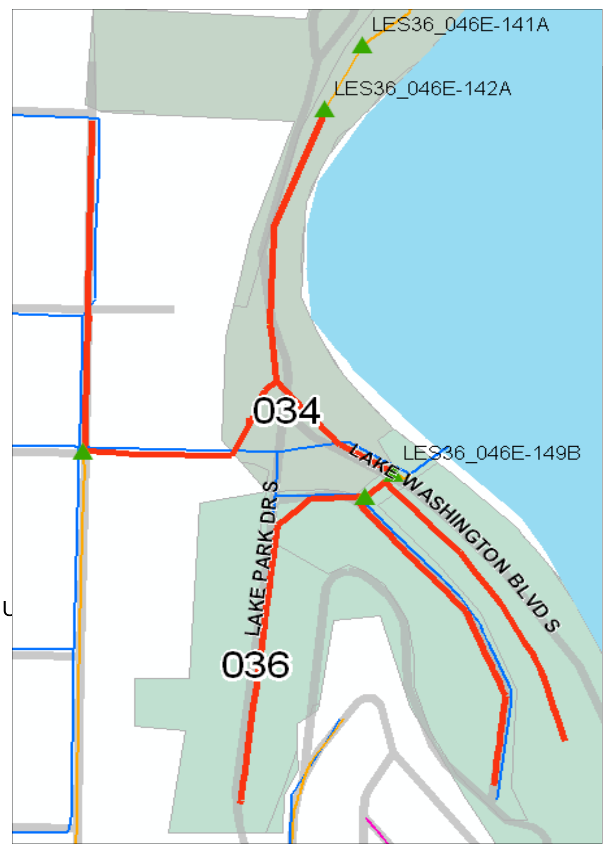


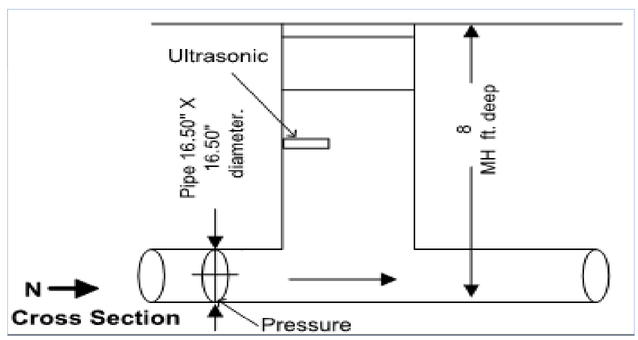
LES36_046E-142A **Address:** **Coleman Park (in access rd to park)**

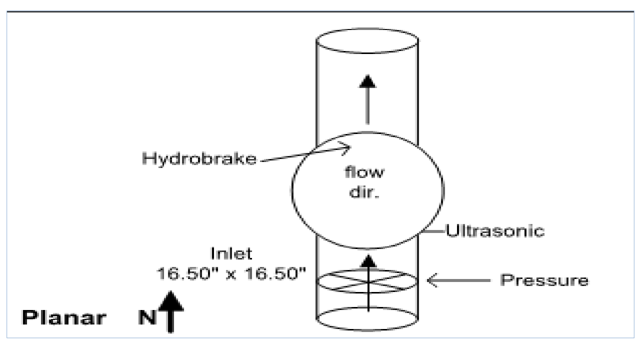
Data Quality Ranking	Good
Pipe ID	046E-143_ 046E-142
Pipe Diam (width x height inches)	16.5 x 16.5
Upstream Slope	0.3%
Meter Type	ADS 5000 AG
Installation Type	Upstream Pipe
Installation Date	11/2/2011
Removal Date	3/13/2012
Data Collection Period (days)	132
Rain Gauge	25
Upstream Pipe Length (ft)	5,664

Site Narrative

LES36_046E-142A was a temporary monitoring site that recorded both level and velocity upstream from the HydroBrake in the NPDES036 Basin. The site was installed on 11/2/2011 to characterize the HydroBrake performance in the NPDES036 Basin, providing depth upstream in the storage pipe. Although the meter was replaced several times before the Phase 2 monitoring period, the velocity data reviewed for Phase 4 were still considered poor, and were not used. As discussed for the previous phases, the velocity data at this site has been inconsistent and is recommended to be used with caution and only for verification of the downstream monitoring site. The depth data at this location served as a critical parameter for HydroBrake characterization.
The level data in Phase 4 were classified as “Good,” which is consistent with the previous phases. The meter adequately responded to the storm events with consistent diurnal patterns. A surcharged condition was observed in the pipe during the storm on 11/22/2012, so caution must be taken while using the data from this period.
The meter was removed on 3/13/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

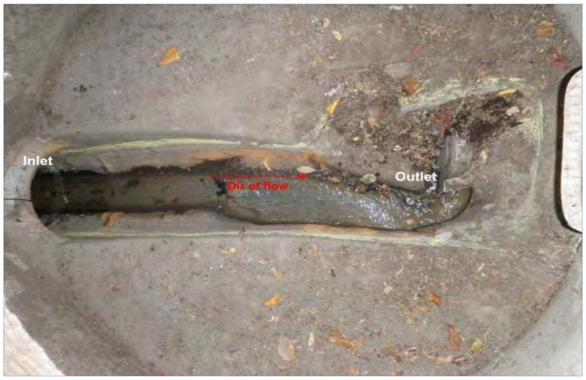




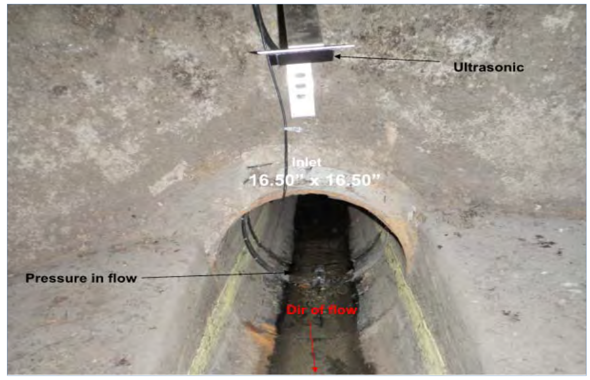


Upstream Pipe Trace (red) **Site Schematic**

LES36_046E-142A

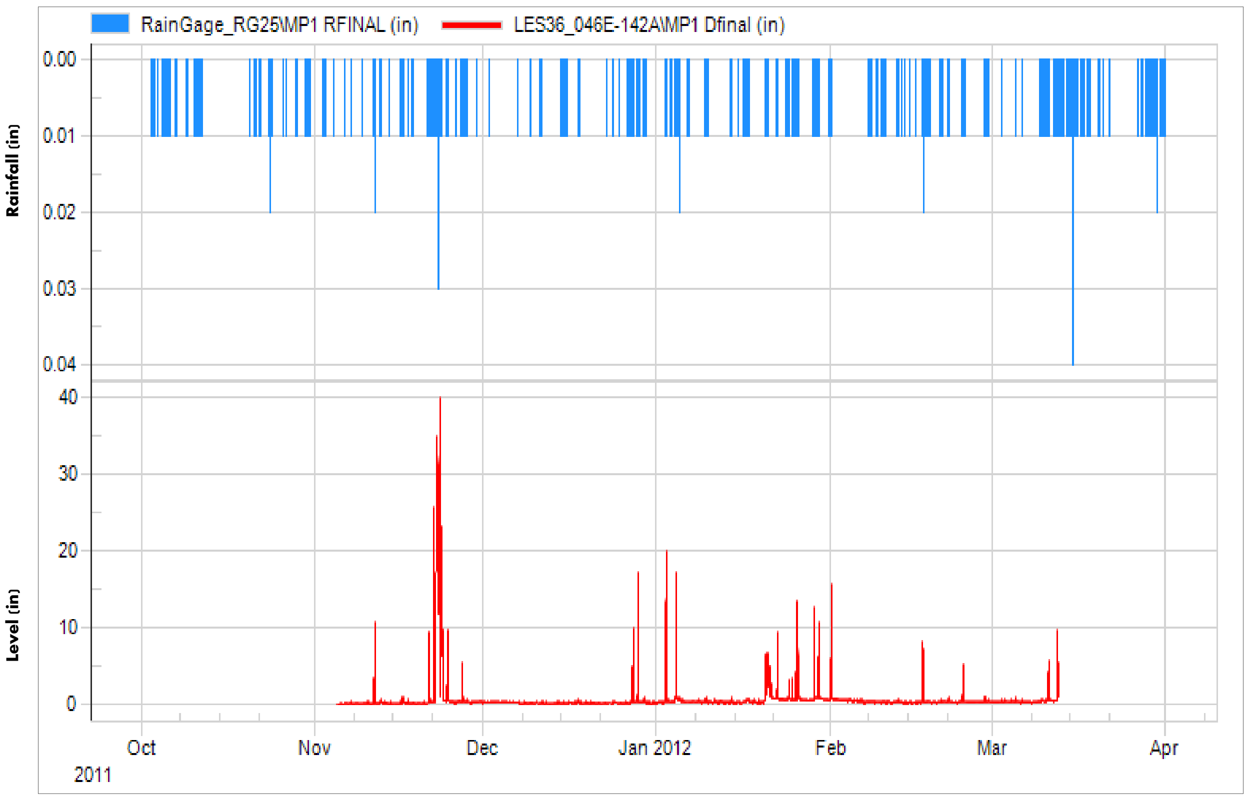


View down MH looking southwest



View of inlet and sensor placement

Hydrograph 10/1/2011 to 03/31/2012

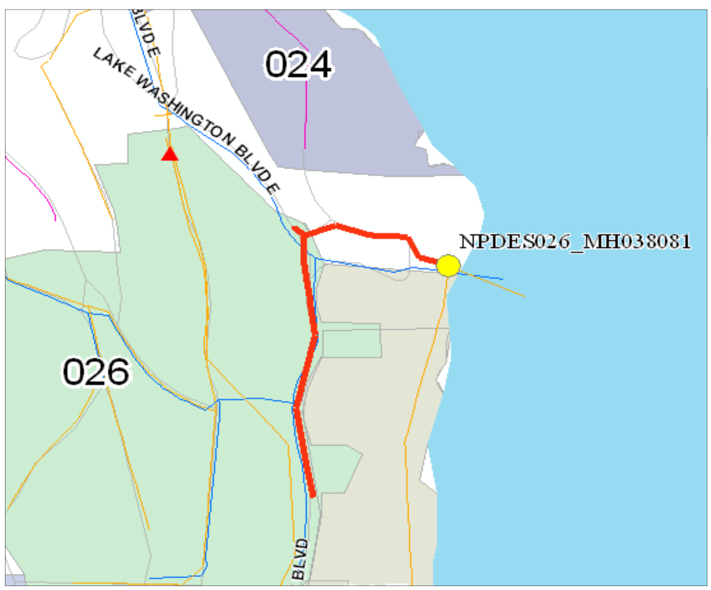


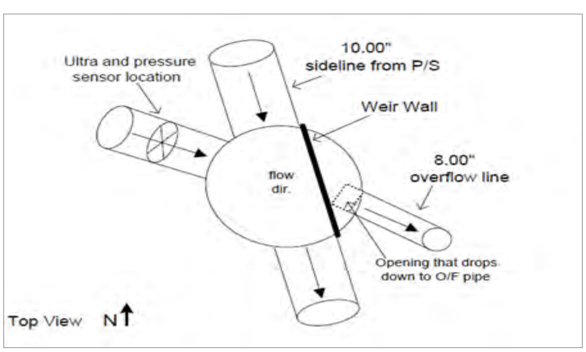
NPDES26_MH038081 (WW) Address: 4000 Denny Blaine PL

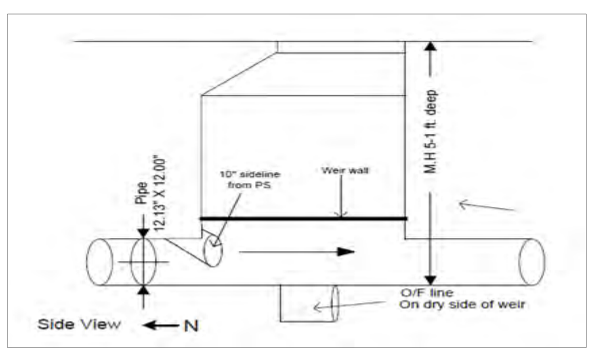
Data Quality Ranking	Good
Pipe ID	038-080_038-081
Pipe Diam (width x height inches)	12 x 12.13
Upstream Slope	4.90%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	8/22/2007
Removal Date	--
Data Collection Period (days)	1683
Rain Gauge	25
Upstream Pipe Length (ft)	1,186

Site Narrative

NPDES026_MH038081 is a permanent monitoring site that records level, and is therefore classified as a wet weather site. The site was installed on 8/22/2007 to identify and quantify CSO events occurring from the NPDES026 Basin. The level data are used to calculate the volume of CSO events using a weir equation.
NPDES026_MH038081 is located at the NPDES026 Overflow Structure. The quality of the level data was classified as “Good” for the Phase 4 monitoring period because of the consistent and repeatable response of the data and no data gaps.
The quality of the meter readings is consistent with the meter classification for Phases 1 and 2. During the Phase 3 monitoring period, the site was jet-cleaned to remove accumulated debris, and as a result, the level dropped and conditions became more difficult for capturing reliable data by the ultrasonic sensor. During Phase 3, the data were classified as having “Some Limitations.”
NPDES026_MH038081 is a permanent meter and will remain in place and continue to monitor overflows.

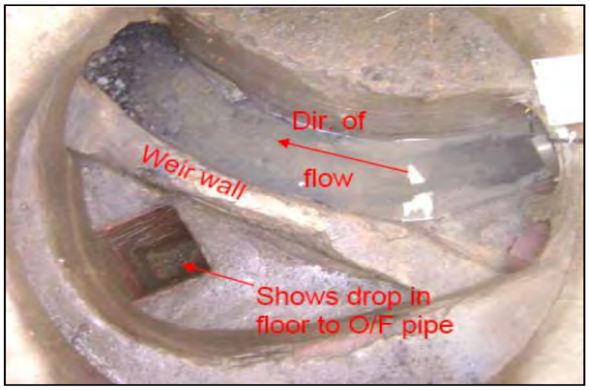






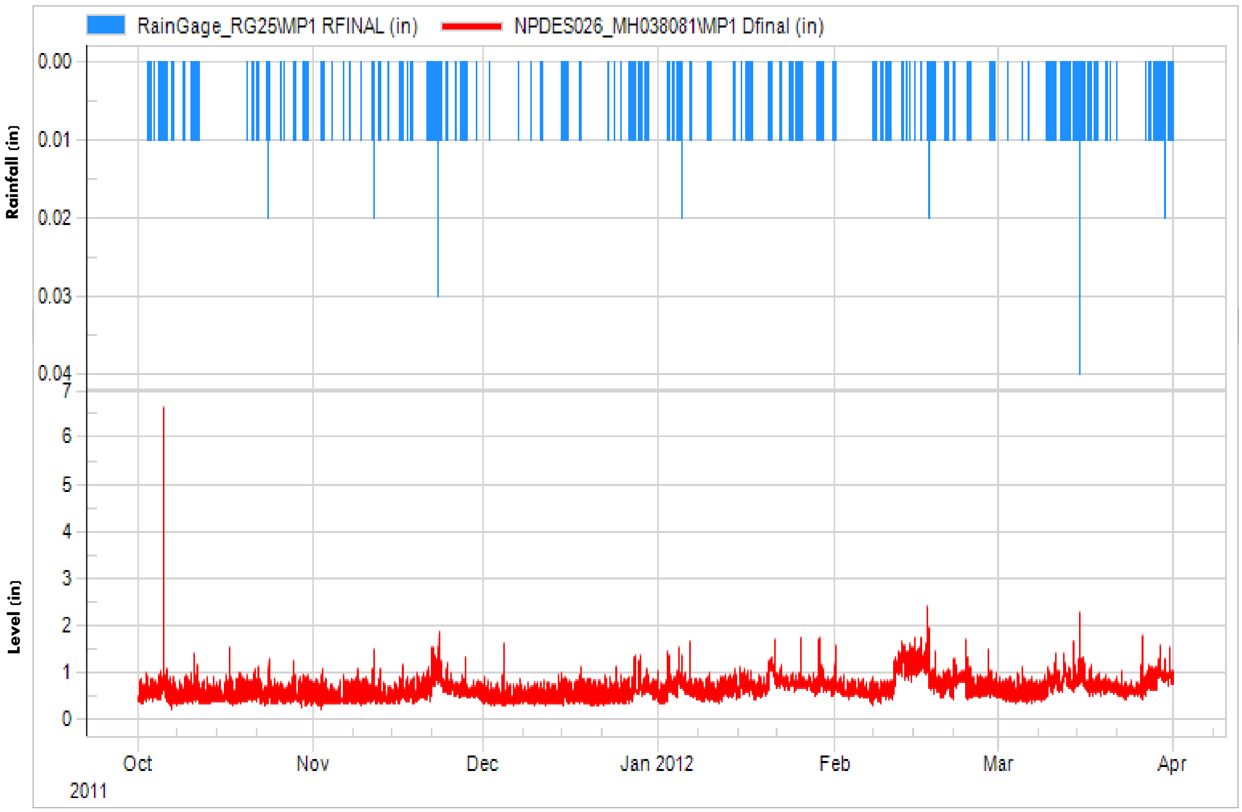
Upstream Pipe Trace (red) | Site Schematic

NPDES26_MH038081 (WW)



View of MH	View of outlet and MP2 sensors with relation to weir wall

Hydrograph 10/1/2011 to 3/31/2012



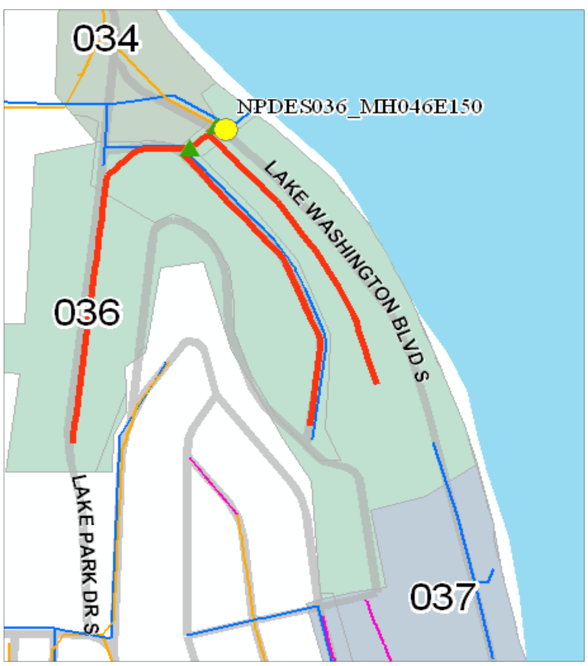
NPDES036_MH046E150	Address:	2318 Lake Washington BLVD S.

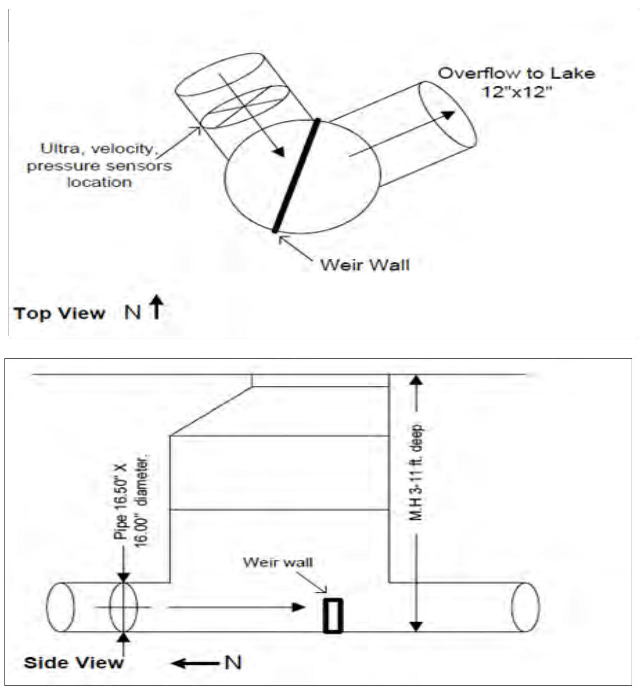
Data Quality Ranking	Excellent
Pipe ID	046E-149_046E-150
Pipe Diam (width x height inches)	16 x 16.5
Upstream Slope	0.0%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/26/2007
Removal Date	--
Data Collection Period (days)	1710
Rain Gauge	25
Upstream Pipe Length (ft)	2,928

Site Narrative

NPDES036_MH046E150 is a permanent monitoring site that records level only. The site was installed on 7/26/2007. The level data are used to alarm for CSO events and to calculate the volume of CSO events using a weir equation. During storm events, the downstream HydroBrake at MH 046E-142 restricts and controls flows from the NPDES036 Basin to the downstream system. When NPDES036 Basin storage is exceeded, flow is diverted over the weir to the NPDES036 Basin outfall. All data are considered suitable for model calibration and verification.

NPDES036_MH046E150 is located at the NPDES036 Overflow Structure. For the Phase 4 monitoring period, the data quality was classified as “Excellent,” as the meter showed consistent diurnal patterns throughout the period. For the Phase 2 and 3 monitoring periods, the data quality was classified as “Good” because a fold in the pipe liner caused a puddle under the level sensor. For the Phase 1 monitoring period, the data quality was classified as “Good” because although the level data have a consistent and repeatable pattern and a lack of data gaps, a distinct signature change was observed midway through the period, post April 2009. This monitoring site is a permanent site and will continue to monitor overflows in the future.



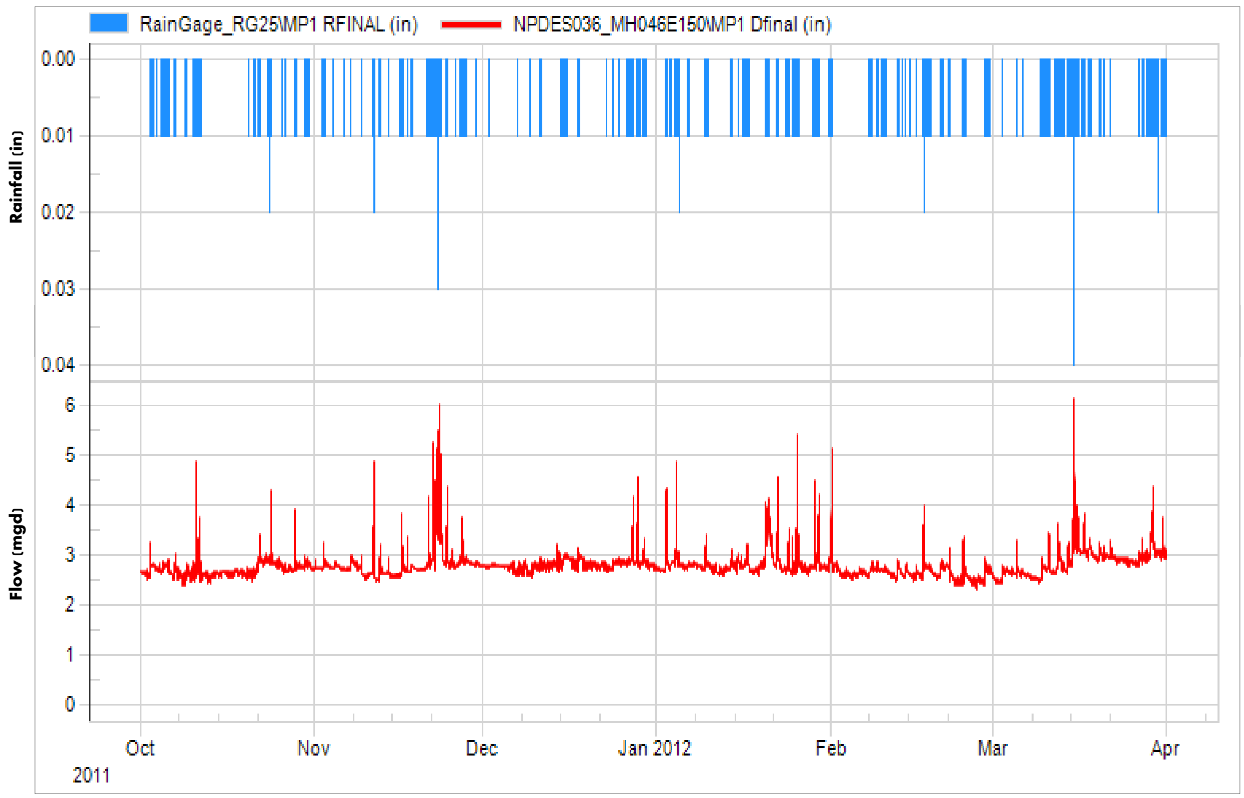


Upstream Pipe Trace (red)	Site Schematic

NPDES036_MH046E150

View of MH	Site installation

Hydrograph 10/1/2011 to 3/31/2012



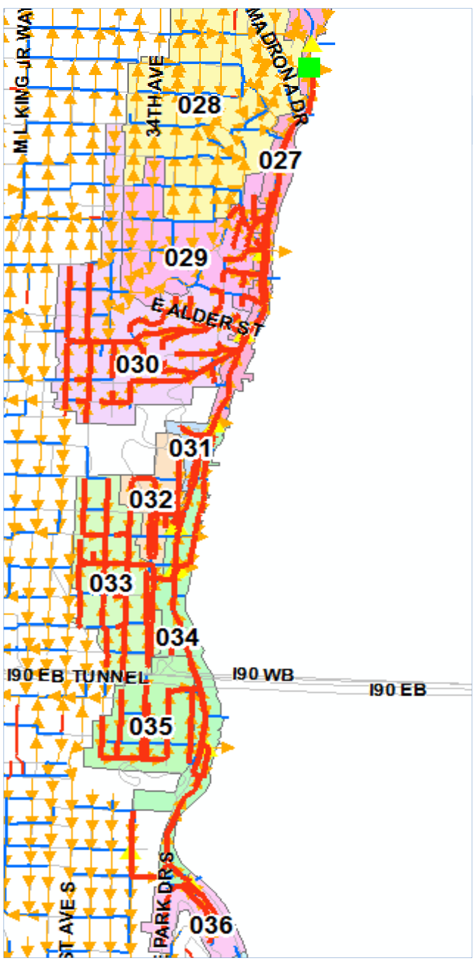
LES27_042-274A Address: 1454 Lake Washington Blvd.

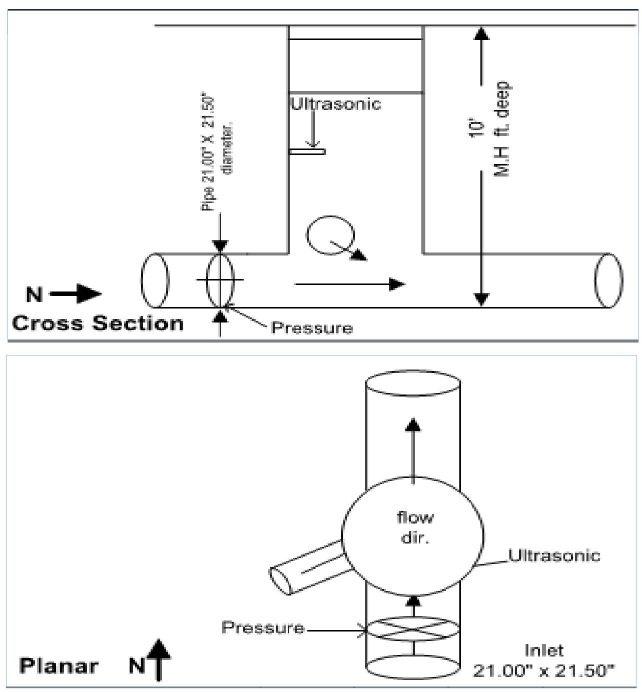
Data Quality Ranking	Excellent
Pipe ID	042-279_042-274
Pipe Diam (width x height inches)	21.5 x 21
Upstream Slope	0.20%
Meter Type	ADS 5000 AG
Installation Type	Incoming pipe
Installation Date	11/3/2011
Removal Date	3/13/2012
Data Collection Period (days)	131
Rain Gauge	25
Upstream Pipe Length (ft)	69,031

Site Narrative

LES27_042-274A was a temporary monitoring site that recorded level only. This meter was located just downstream of the permanent meter NPDES028_MH042275. The meter was installed on 11/3/2011 to determine the head loss between the trunk line and overflow chamber at the NPDES028 Basin. It was installed only for the Phase 4 monitoring period and was used for hydraulic calibration.

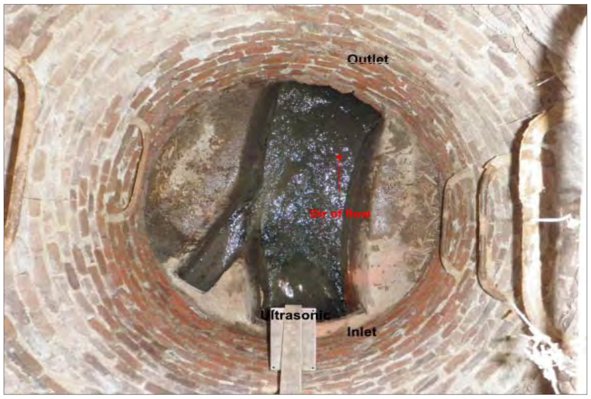
The data were classified as "Excellent" for Phase 4 based on a consistent and repeatable response to dry and wet weather periods. The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.





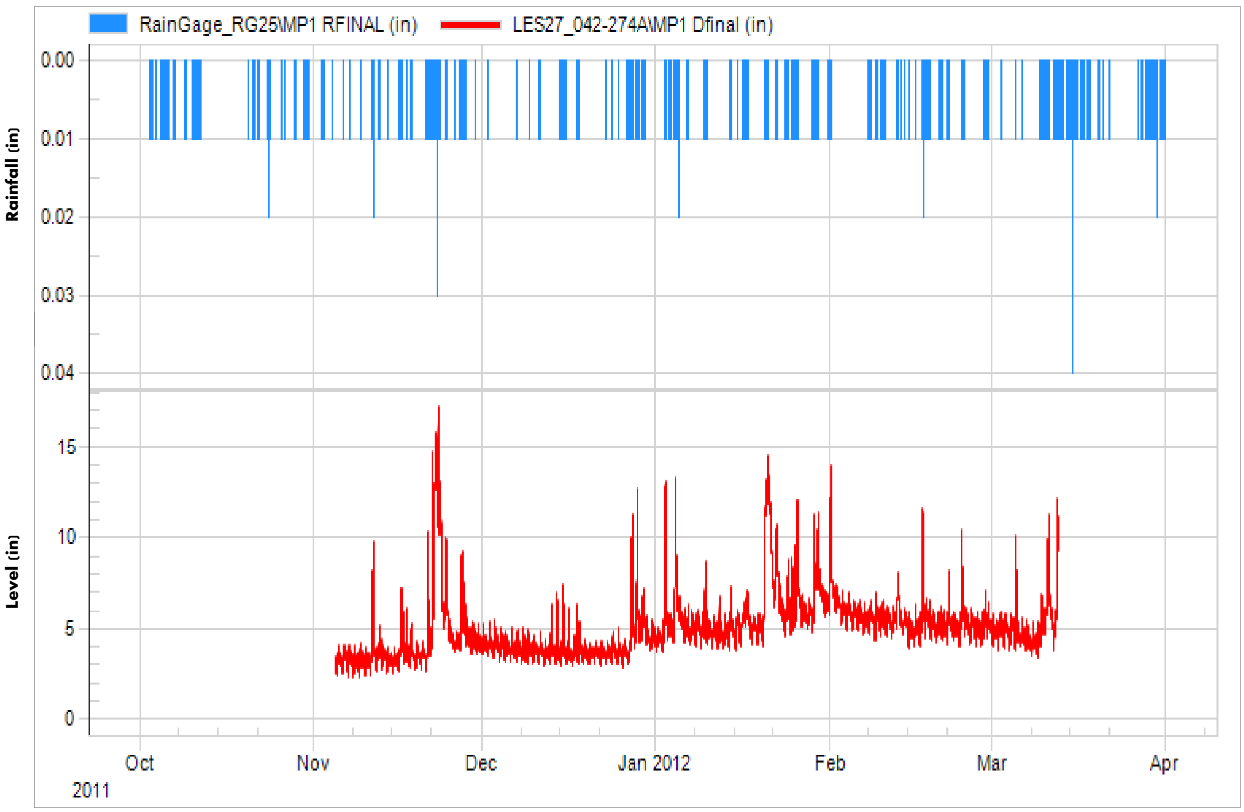
Upstream Pipe Trace (red) **Site Schematic**

LES27_042-274A



View down MH looking North	View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012



NPDES027_MH042269 **Address:** **Metro Pump Station off Lake Washington Blvd**

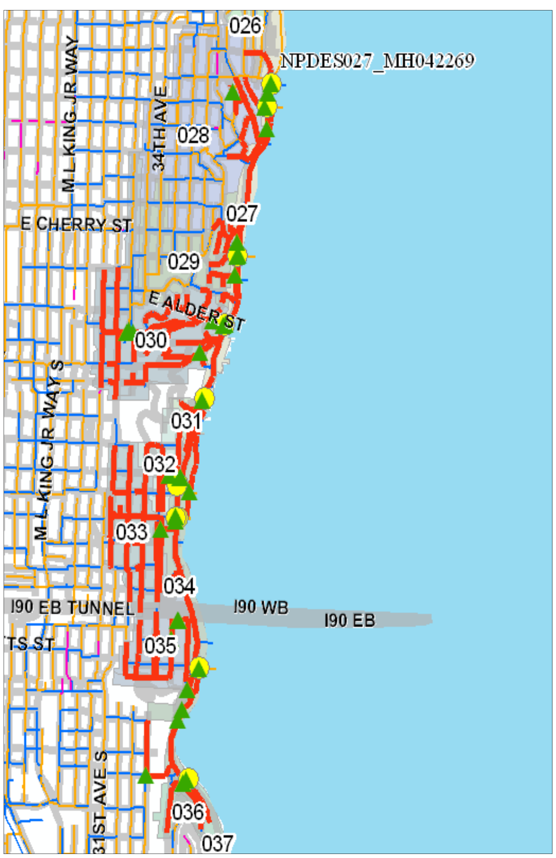
Data Quality Ranking	Good
Pipe ID	042-226 042-269
Pipe Diam (width x height inches)	22.5 x 22.0
Upstream Slope	0.30%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	7/31/2007
Removal Date	--
Data Collection Period (days)	1705
Rain Gauge	25
Upstream Pipe Length (ft)	75,294

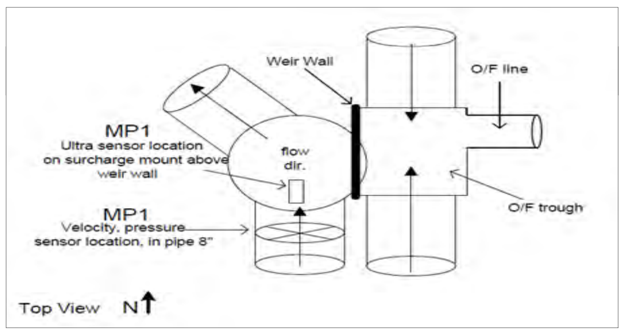
Site Narrative

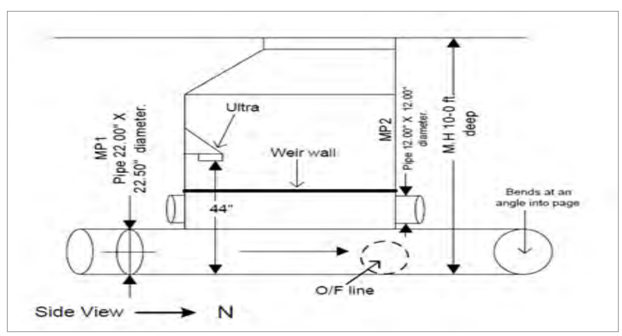
NPDES027_MH042269 is a permanent flow monitoring site that records level only. The site was installed on 7/31/2007 to identify and quantify CSO events occurring from the NPDES027 Basin. The level data are used to calculate the volume of CSO events using a weir equation. Overflows occur when the level in LES27_DWF-042269 reaches 27.84 inches.

Data quality was classified as “Good” for the Phase 4 monitoring. Although the data at the site captured a clear and consistent dry weather diurnal pattern, and responded well during all the storm events, there was a data lag between 10/20/2011 and 10/28/2011 and a data gap between 12/21/2011 and 12/23/2011. This ranking is consistent with the classification given during the Phase 2 and 3 monitoring periods. As noted in Volume 5 of the Flow Monitoring Report (2010), due to the configuration of the site, finalization of these data entails an offset correction to the recorded depth levels. For the Phase 1 monitoring period, the data quality was classified as “Excellent” due to the clear relationship evident between level and velocity. All data for Phase 4 are suitable for model calibration and verification.

NPDES027_MH042269 is a permanent meter and will remain in place and continue to monitor overflows.

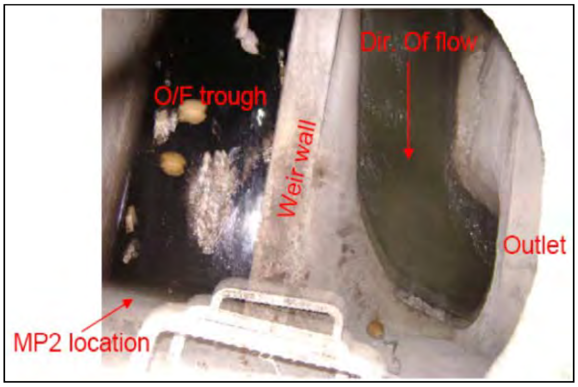






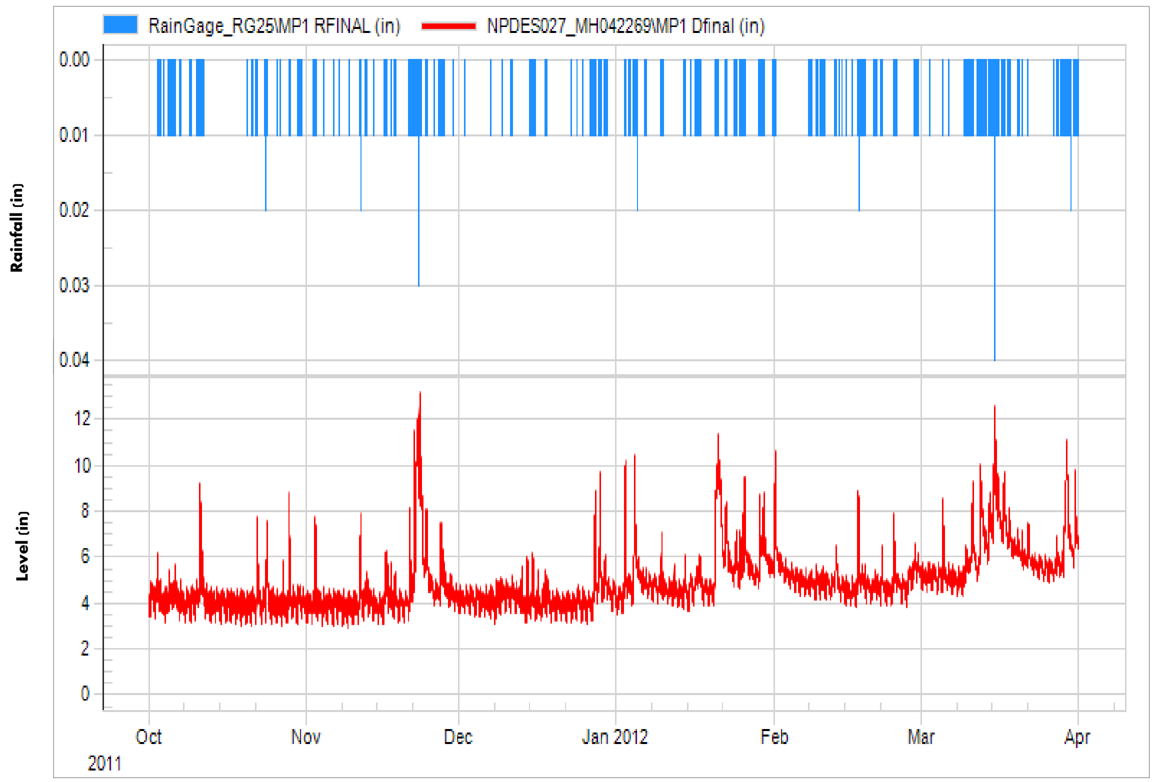
Upstream Pipe Trace (red)	Site Schematic

NPDES027_MH042269



Maintenance Hold View	View of site installation

Hydrograph 10/1/2011 to 3/31/2012



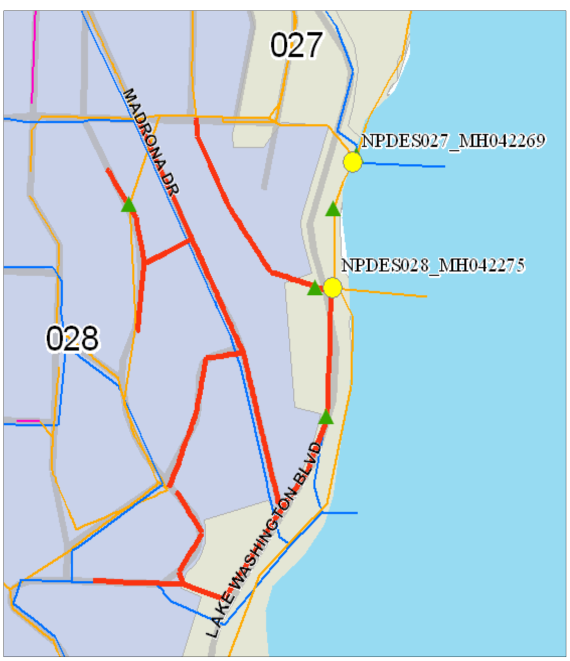
NPDES028_MH042275 **Address:** 1454 Lake Washington BLVD

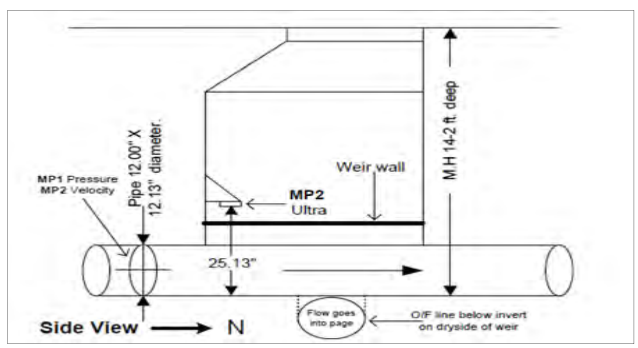
Data Quality Ranking	Good
Pipe ID	042-277_042-275
Pipe Diam (width x height inches)	12.13 x 12
Upstream Slope	1.0%
Meter Type	ADS FS 5000 BG
Installation Type	Incoming Pipe
Installation Date	8/1/2007
Removal Date	--
Data Collection Period (days)	1704
Rain Gauge	25
Upstream Pipe Length (ft)	4,900

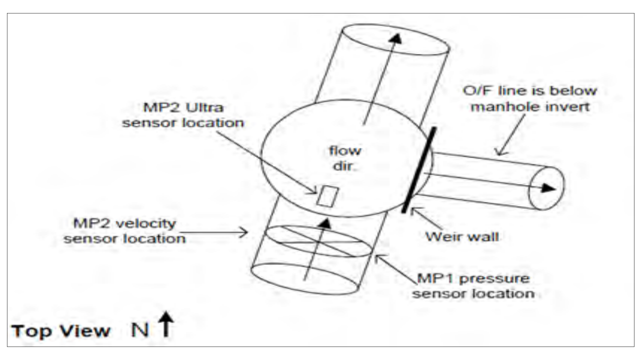
Site Narrative

NPDES028_MH042275 is a permanent wet weather monitoring site that records level only. The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES028 Basin. The level data are used to calculate the volume of CSO events using a weir equation. NPDES028_MH042275 is located at the NPDES028 Overflow Structure. For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The data quality was classified as "Good" for Phase 4 due to some unusual spikes in the hydrograph during the storm on 11/22/2011. Caution should be applied when using the data from this period for calibration. Also, the site report noted that the pipe experienced backward flows that would affect the site hydraulics. For the Phase 2 and 3 monitoring periods, the site data were classified as "Excellent" because of the response to the storm events and the capturing of clear and consistent data. For the Phase 1 period, the data quality was classified as "Good."

NPDES028_MH042275 is a permanent meter and will remain in place to continue to monitor overflows.





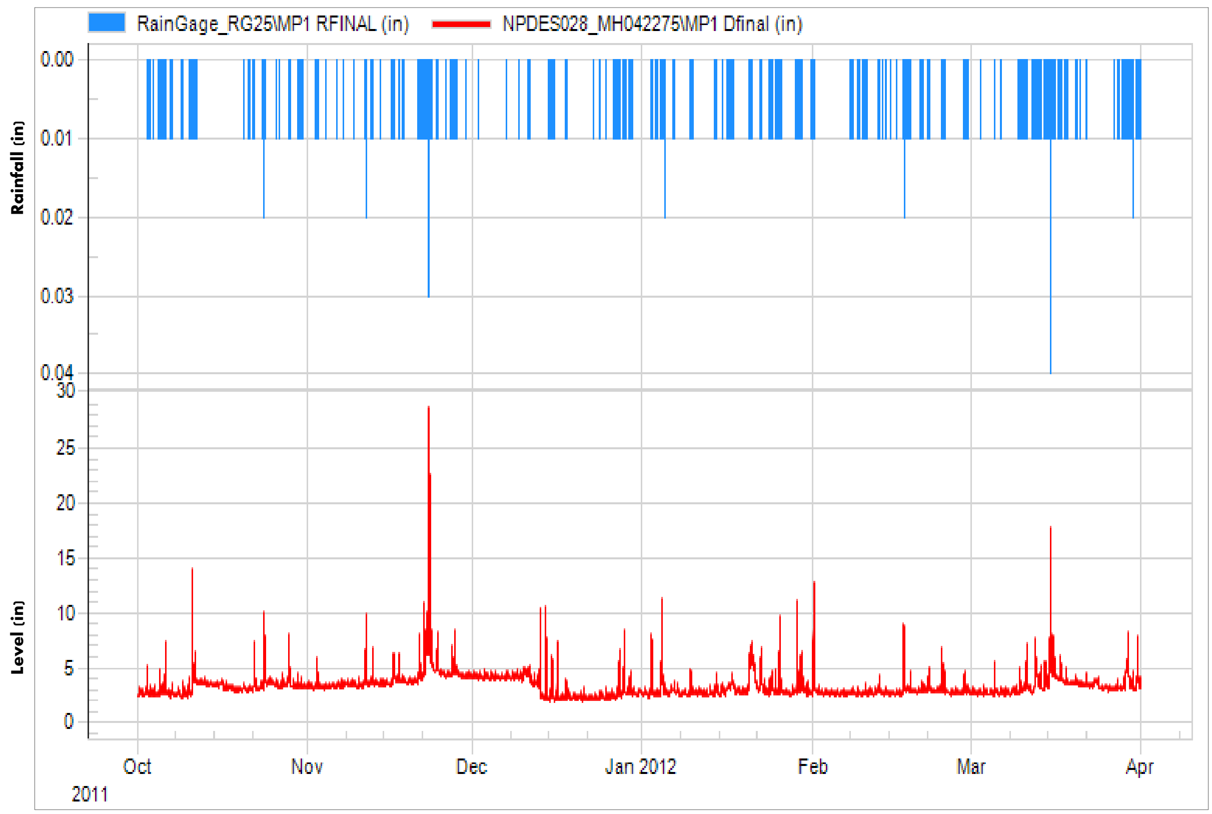


Upstream Pipe Trace (red)	Site Schematic

NPDES028_MH042275

View of MH	Site installation

Hydrograph 10/1/2011 to 3/31/2012



LES29_042-302A **Address:** Lk Wa Blvd. at Fullerton (S bound ln of LK Wa.)

Data Quality Ranking	Good
Pipe ID	042-325_ 042-302
Pipe Diam (width x height inches)	37.88 x 37.88
Upstream Slope	1.0%
Meter Type	ADS 5000 AG
Installation Type	Level Only
Installation Date	11/3/2011
Removal Date	3/23/2012
Data Collection Period (days)	141
Rain Gauge	25
Upstream Pipe Length (ft)	2,044

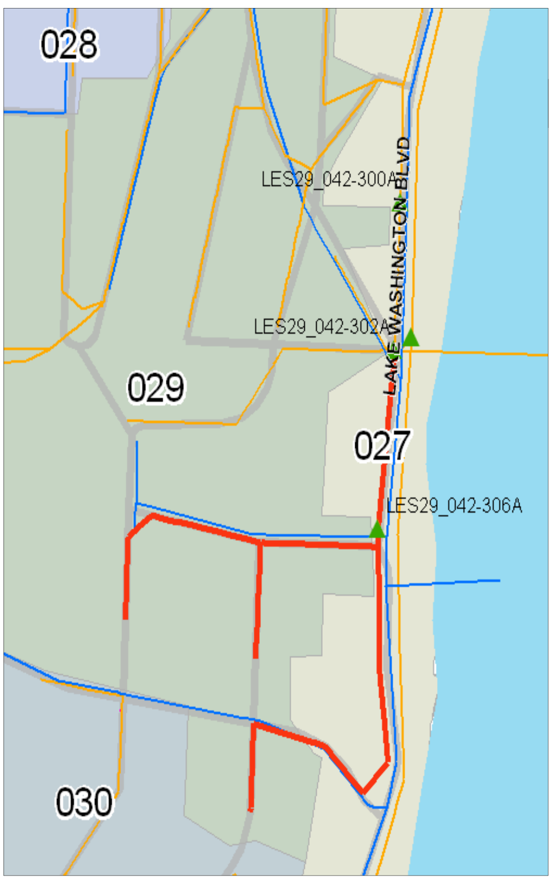
Site Narrative

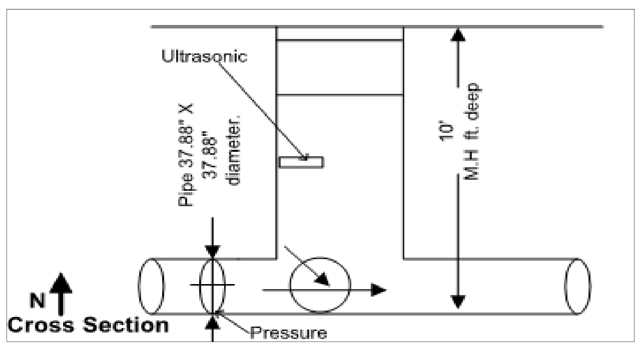
LES29_042-302A was a temporary monitoring site that recorded level only. The meter was installed on 11/3/2011 to measure leve at the HydroBrake for hydraulic calibration in the NPDES029 Basin. The meter was located just upstream of the HydroBrake in CSO Facility 18. The data quality was classified as “Good” for Phase 4, as the meter captured all the significant rainfall events with consistent diurnal patterns.

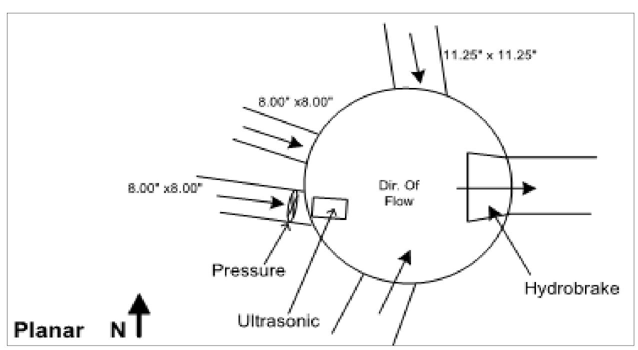
The data were classified as “Excellent” in Phase 1. However, as is the same for Phase 4, the data were classified as “Good” in Phases 2 and 3 because the site would surcharge due to large storm events. The meter also experienced battery failure during Phases 2 and 3, and did not record data during the large storm event in October 2009.

Although it does not affect the data quality ranking, it should be noted that this site is susceptible to surcharging conditions because it is located just upstream of the HydroBrake with an inflow pipe diameter of 37.8 inches.

The meter was removed on 3/23/2012, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

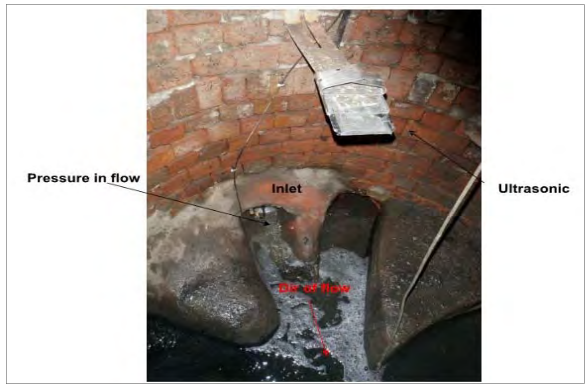






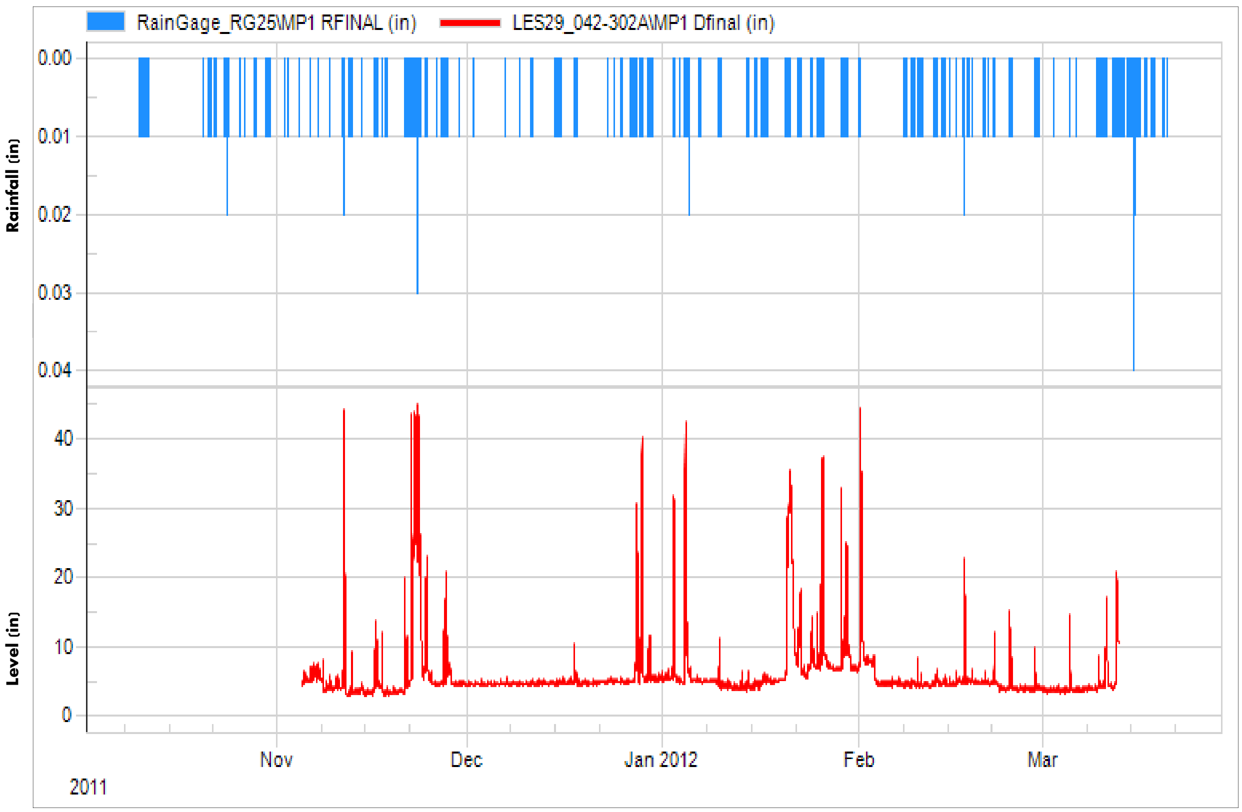
Upstream Pipe Trace (red)	Site Schematic

LES29_042-302A



View down MH looking North	View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012



Note: Dfinal data available only from 11/5/2011 - 3/31/2012

LES29_042-305B **Address:** **Across street from Fullerton Ave (21in pipe to S)**

Data Quality Ranking	Good
Pipe ID	042-308_ 042-305
Pipe Diam (width x height inches)	21.25 x 21
Upstream Slope	0.1%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	11/2/2011
Removal Date	3/13/2012
Data Collection Period (days)	132
Rain Gauge	25
Upstream Pipe Length (ft)	60,553

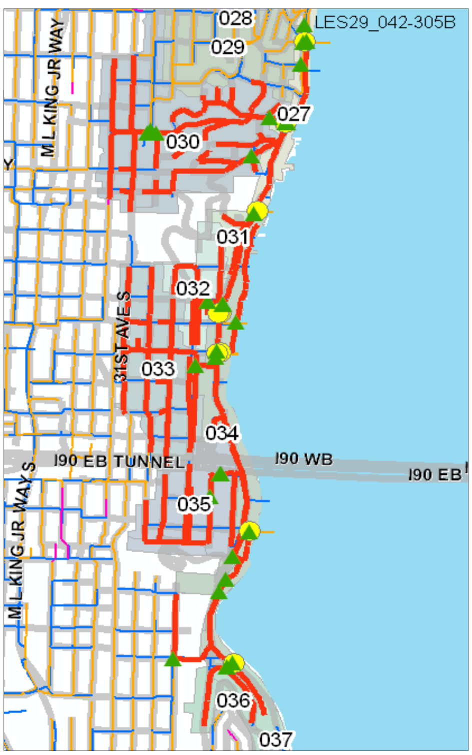
Site Narrative

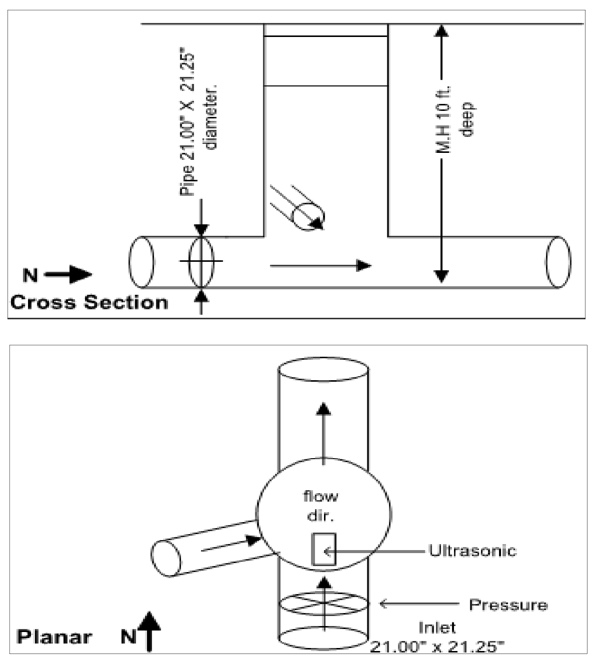
LES29_042-305B was a temporary monitoring site that recorded both level and velocity. The site was installed on 11/2/2011 to measure the flow and level in the Leschi trunk sewer upstream of the outfall from the NPDES029 Basin. LES29_042-305B was in the Leschi trunk sewer at MH 042-305.

Although both level and velocity were measured, only the level data were assessed for this phase, as the velocity data were considered to be of poor quality. The level data quality was classified as "Good" for Phase 4, as it showed a consistent diurnal pattern throughout the period with a good response to storm events. This quality rating is consistent with the overall ratings given for Phases 1, 2, and 3.

The Leschi trunk sewer was cleaned during the Phase 1 period, and thus its data prior to the cleaning was classified as having "Some Limitations." During the Phase 1 period, it was also noted that the site experienced backwater conditions and reverse flow during large events.

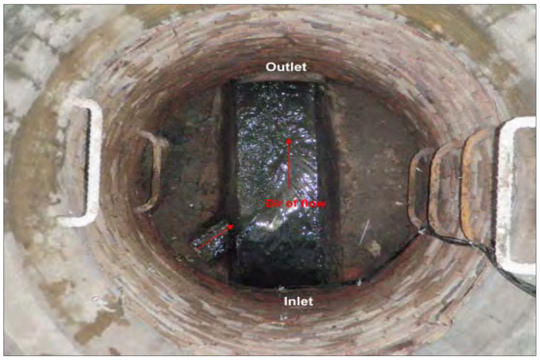
The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model





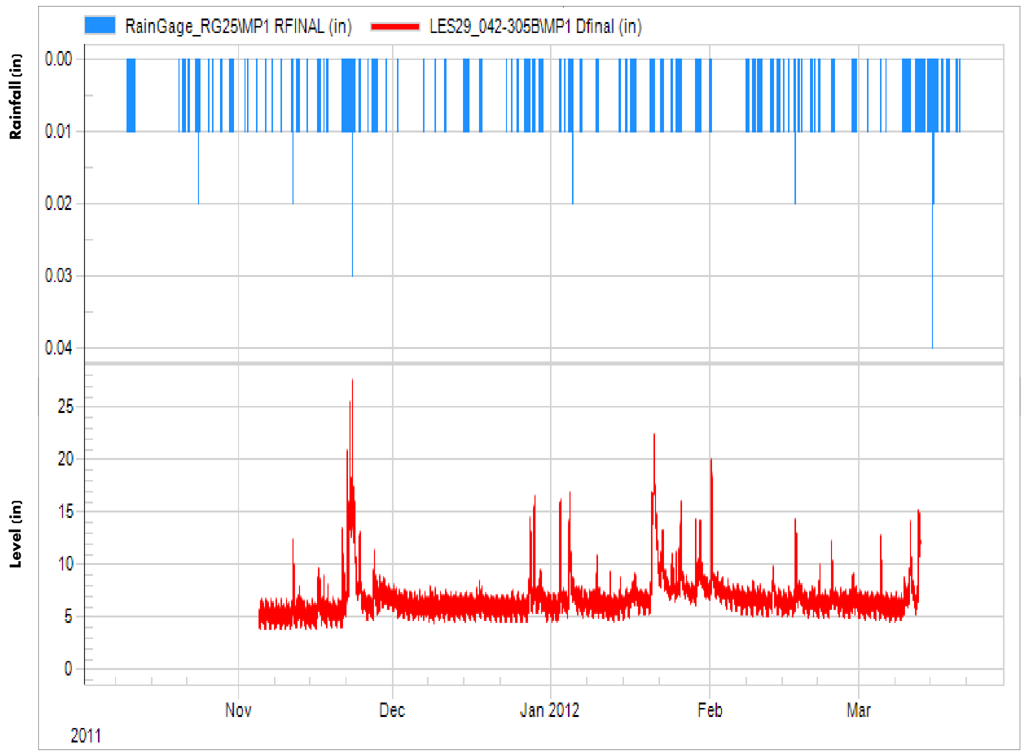
Upstream Pipe Trace (red) **Site Schematic**

LES29_042-305B



View down MH looking North	View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012



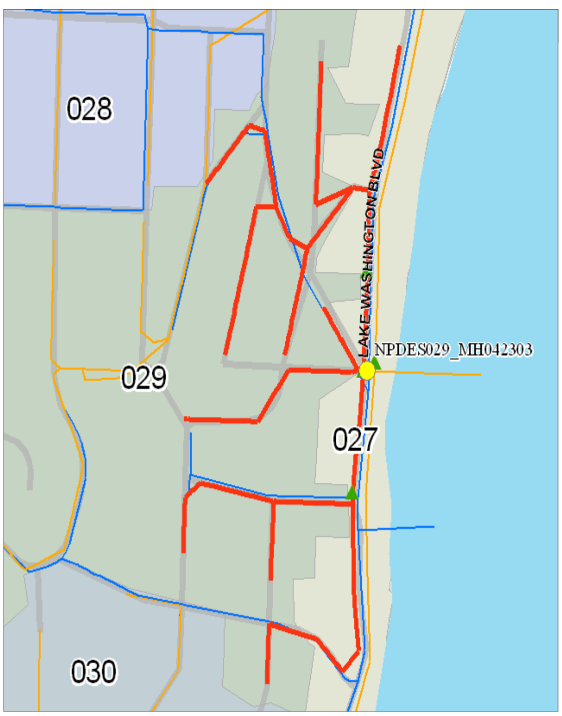
Note: Dfinal data available only from 11/5/2011 - 3/31/2012

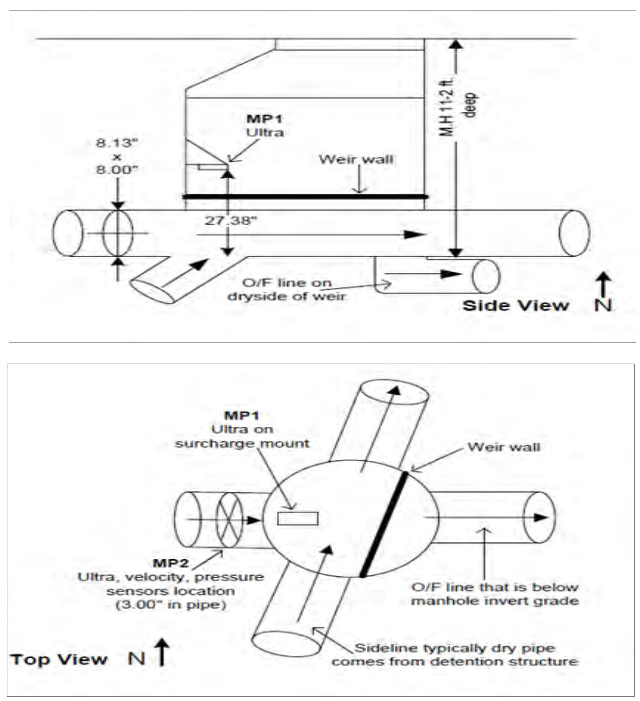
NPDES029_MH042303 **Address:** **Fullerton Ave. and 600 Lake Washington BLVD**

Data Quality Ranking (MP1)	Good
Pipe ID	042-302_042-303
Pipe Diam (width x height inches)	8.13 x 8
Upstream Slope	1.9%
Meter Type	ADS FS 5000 BG
Installation Type	Incoming pipe
Installation Date	8/1/2007
Removal Date	--
Data Collection Period (days)	1704
Rain Gauge	25
Upstream Pipe Length (ft)	5,719

Site Narrative

NPDES029_MH042303 is a permanent wet weather monitoring site that records level only.
The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES029 Basin. The data are used to calculate the volume of CSO events using a weir equation.
NPDES029_MH042303 is located at the NPDES029 Overflow Structure. For the Phase 4 monitoring period, level data were used for hydraulic calibration and verification. The data quality was classified as "Good." The data show a clear dry weather flow pattern and the meter responded well to storm events.
This site has a history of pressure depth data not matching the depths recorded by the ultrasonic meters. For the Phase 2 and 3 monitoring periods, two sensors had been installed, MP1 and MP2, which showed a clear dry weather flow pattern and a good meter response to storm events. However, MP1 failed to record data during the October and November storm events and also exhibited backwater conditions during these large storm events, which were caused by the Leschi trunk sewer backing up into the overflow control structure. Because of this, the data quality for MP1 was classified as having "Some Limitations" for Phases 2 and 3. MP 2, however, was classified as "Excellent" for the Phase 2 and 3 monitoring periods. Data quality was classified as "Excellent" for the Phase 1 monitoring period, as the data showed a clear relationship between level and velocity.
NPDES029_MH042303 is a permanent meter and will continue to be monitored to verify overflows.



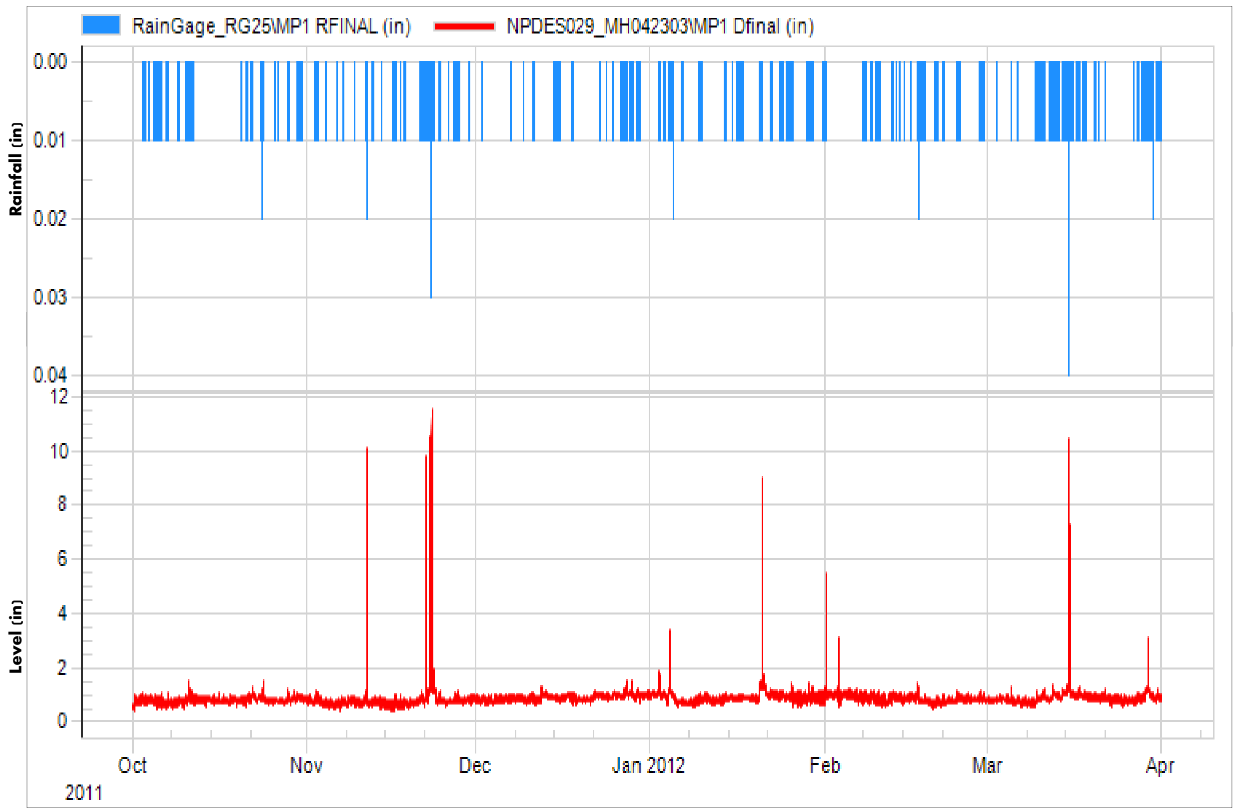


Upstream Pipe Trace (red) **Site Schematic**

NPDES029_MH042303

View of MH	Site installation

Hydrograph 10/1/2011 to 3/31/2012



NPDES030_MH042322 **Address:** **303 Alder St. @ Lake Washington BLVD**

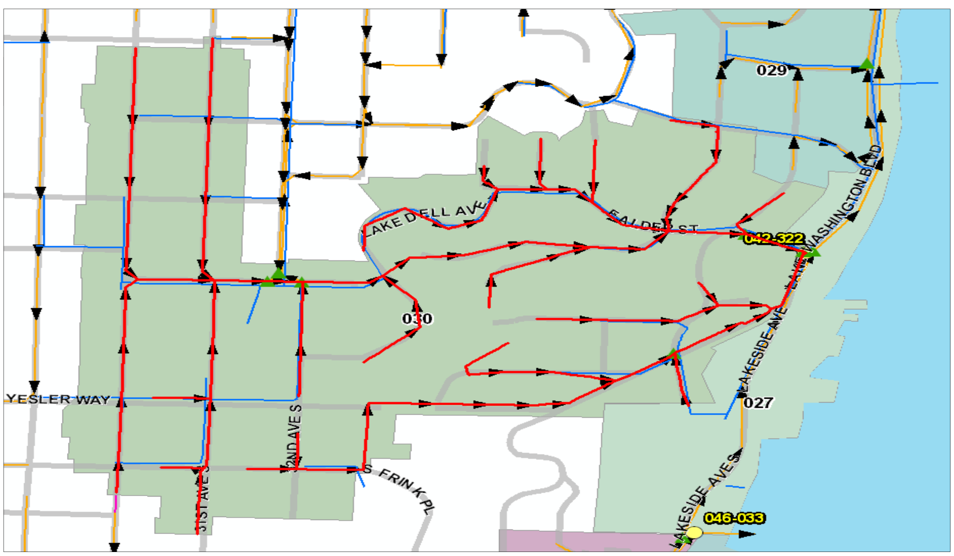
Data Quality Ranking	Good
Pipe ID	042-205_042-322
Pipe Diam (width x height inches)	7.75 x 7.75
Upstream Slope	0.9%
Meter Type	ADS FS 5000 AG
Installation Type	Incoming Pipe
Installation Date	8/1/2007
Removal Date	--
Data Collection Period (days)	1704
Rain Gauge	25
Upstream Pipe Length (ft)	16,177

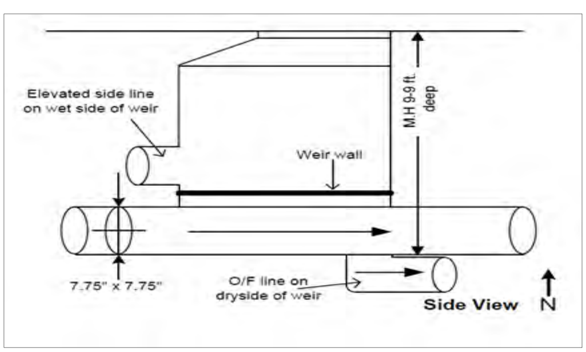
Site Narrative

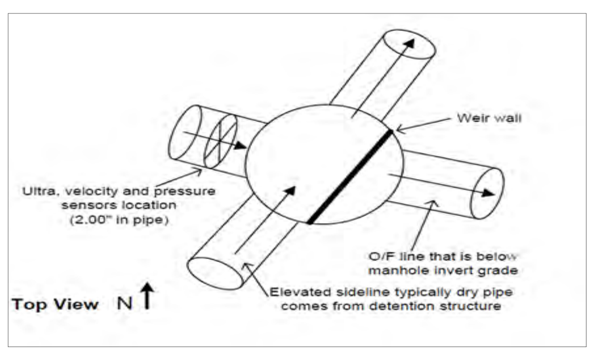
NPDES030_MH042322 is a permanent monitoring site that records level only. The site was installed on 8/1/2007 to identify and quantify CSO events occurring from the NPDES030 Basin. The level data are used as an alarm for CSO events and to calculate the volume of CSO events using a weir equation. For the Phase 4 monitoring period, level data were used for calibration and verification.

The data quality was classified as “Good” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. The data responded adequately to major storm events. However, the data screening reports reported a base flow depth drop from 3.5 inches to 2.0 inches during the period of 11/2/2011 and 12/28/2011, which could have resulted from the debris or silt buildup in the line. This should be considered while using the data for calibration.

NPDES030_MH042322 is a permanent meter and will continue to monitor for overflow events in the future.

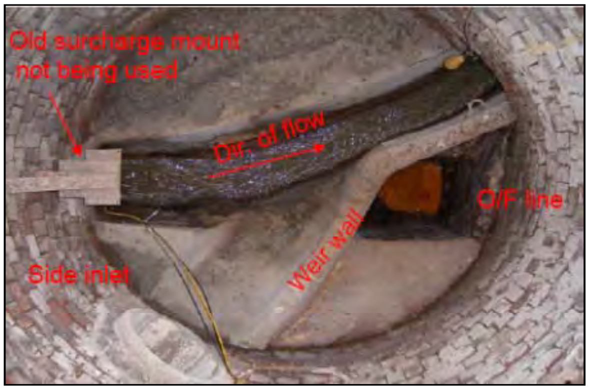






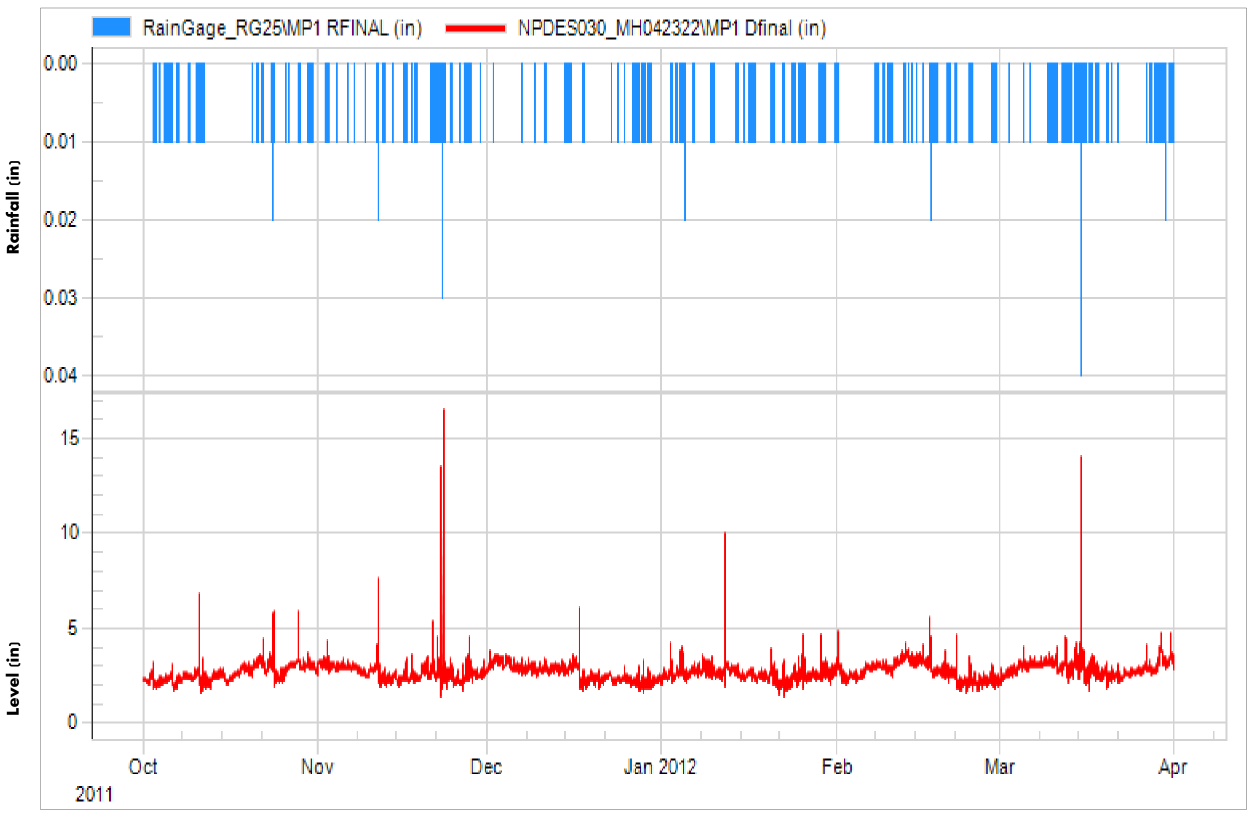
Upstream Pipe Trace (red) **Site Schematic**

NPDES030_MH042322



View down manhole looking North	View of inlet and side line

Hydrograph 10/1/2011 to 3/31/2012

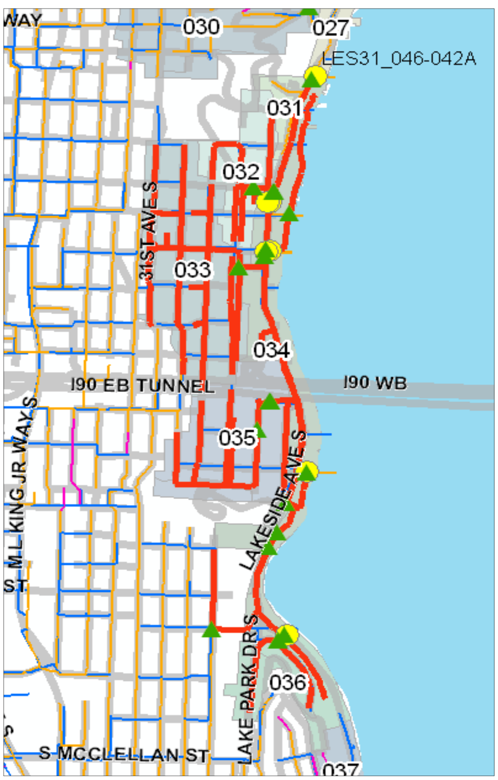


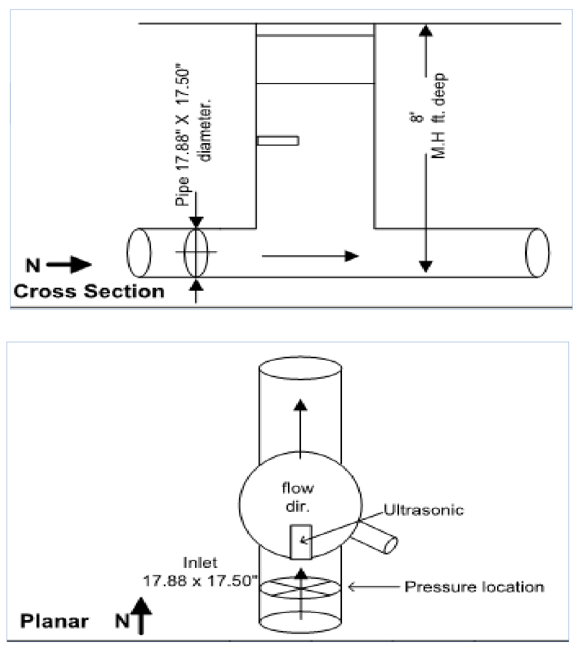
LES31_046-042A **Address:** **309 Lakeside Ave.**

Data Quality Ranking	Good
Pipe ID	046-043_ 046-042
Pipe Diam (width x height inches)	17.5 x 17.88
Upstream Slope	0.1%
Meter Type	ADS 5000 AG
Installation Type	Level Only
Installation Date	11/3/2011
Removal Date	3/13/2012
Data Collection Period (days)	131
Rain Gauge	25
Upstream Pipe Length (ft)	40,320

Site Narrative

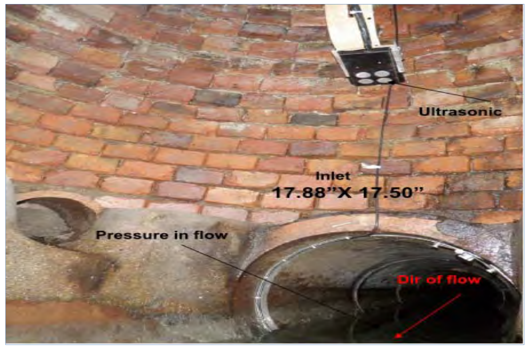
LES31_046-042A was a temporary monitoring site that recorded level in the Leschi trunk sewer near the permanent meter in the NPDES031 Basin. This site was installed on 11/3/2011 to compare the level in the Leschi trunk sewer to the elevation of the overflow weir at the permanent site.
The site is not conducive to accurate velocity measurement due to siltation in the Leschi trunk sewer. The quality of the level data was classified as “Good” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. During Phase 4, a data outage on 12/12/2011 lasted for 9 hours. And as noted from the Phase 2 and 3 monitoring periods, this site is susceptible to debris buildup. All level data from Phase 4 are suitable for use in model calibration. The meter was removed on 3/13/2012, as it was determined that suitable data had been collected for the purposes of model calibration and verification.





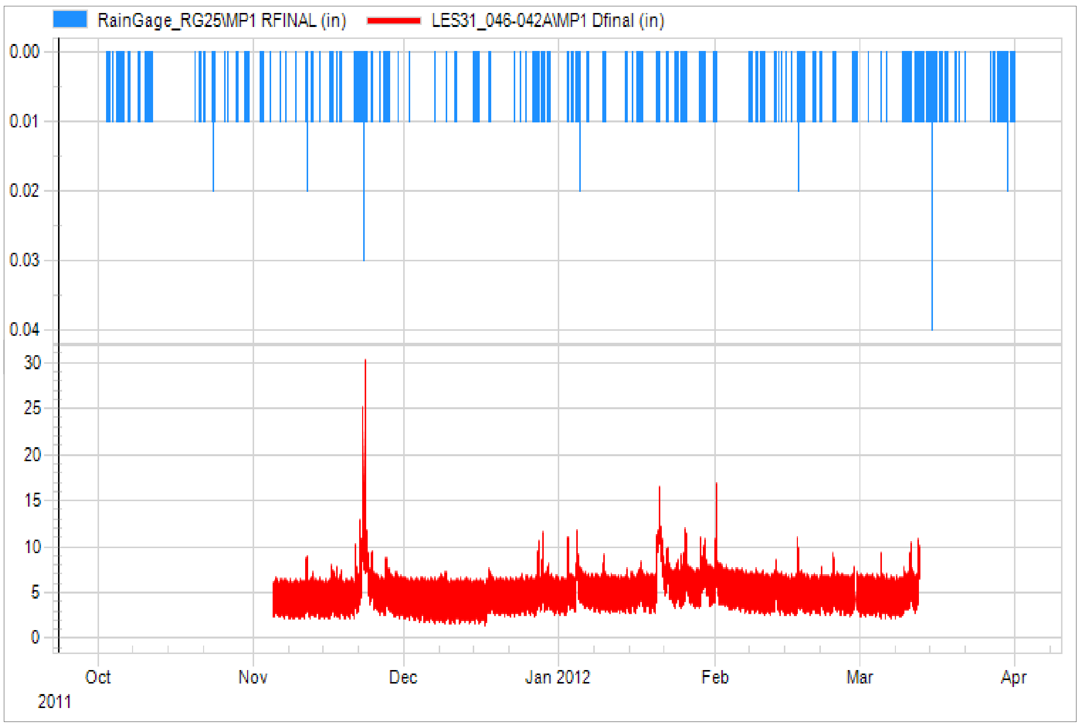
Upstream Pipe Trace (red)	Site Schematic

LES31_046-042A

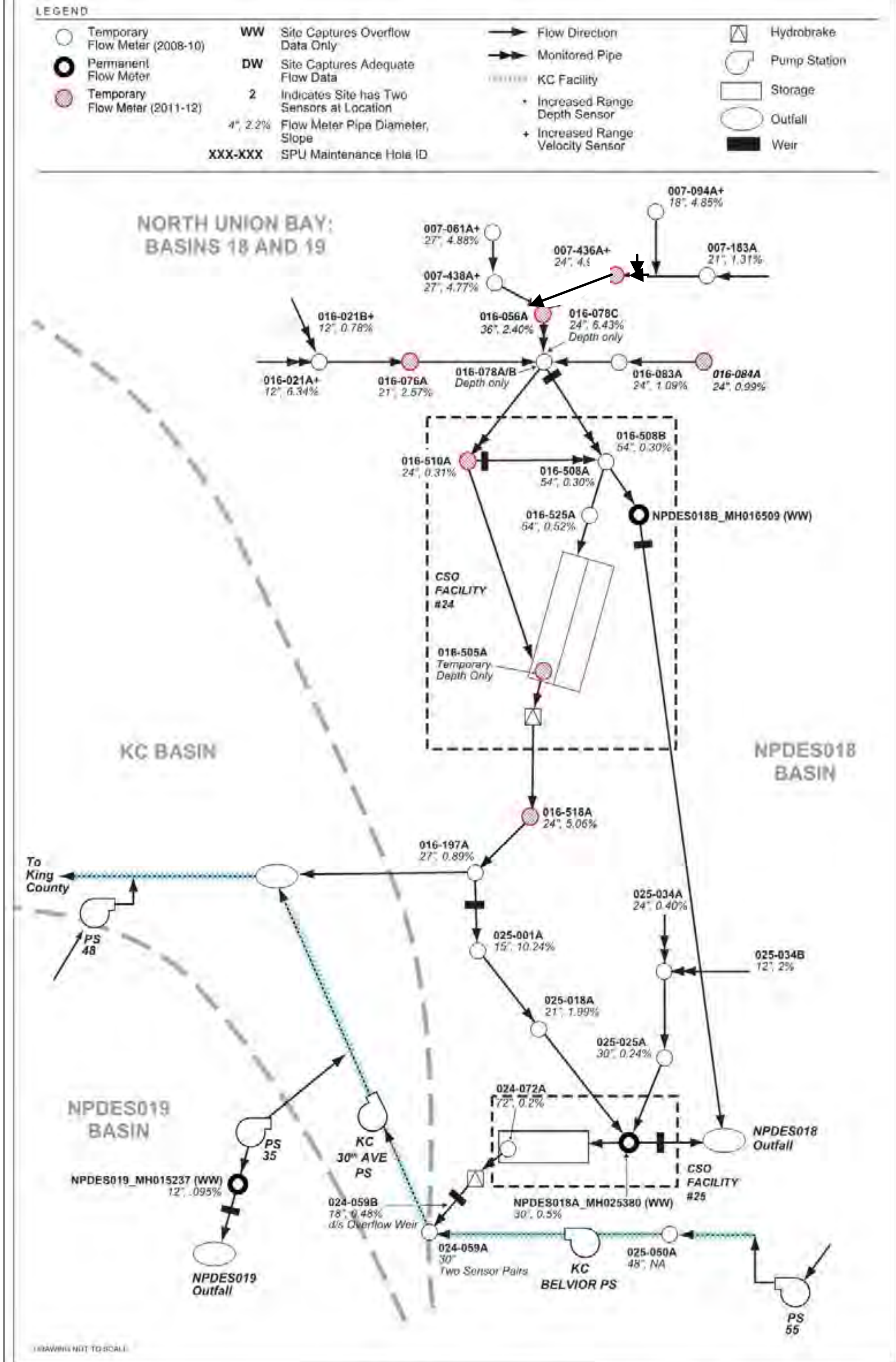


View down MH looking North	View of inlet and sensor placement

Hydrograph 10/1/2011 to 3/31/2012

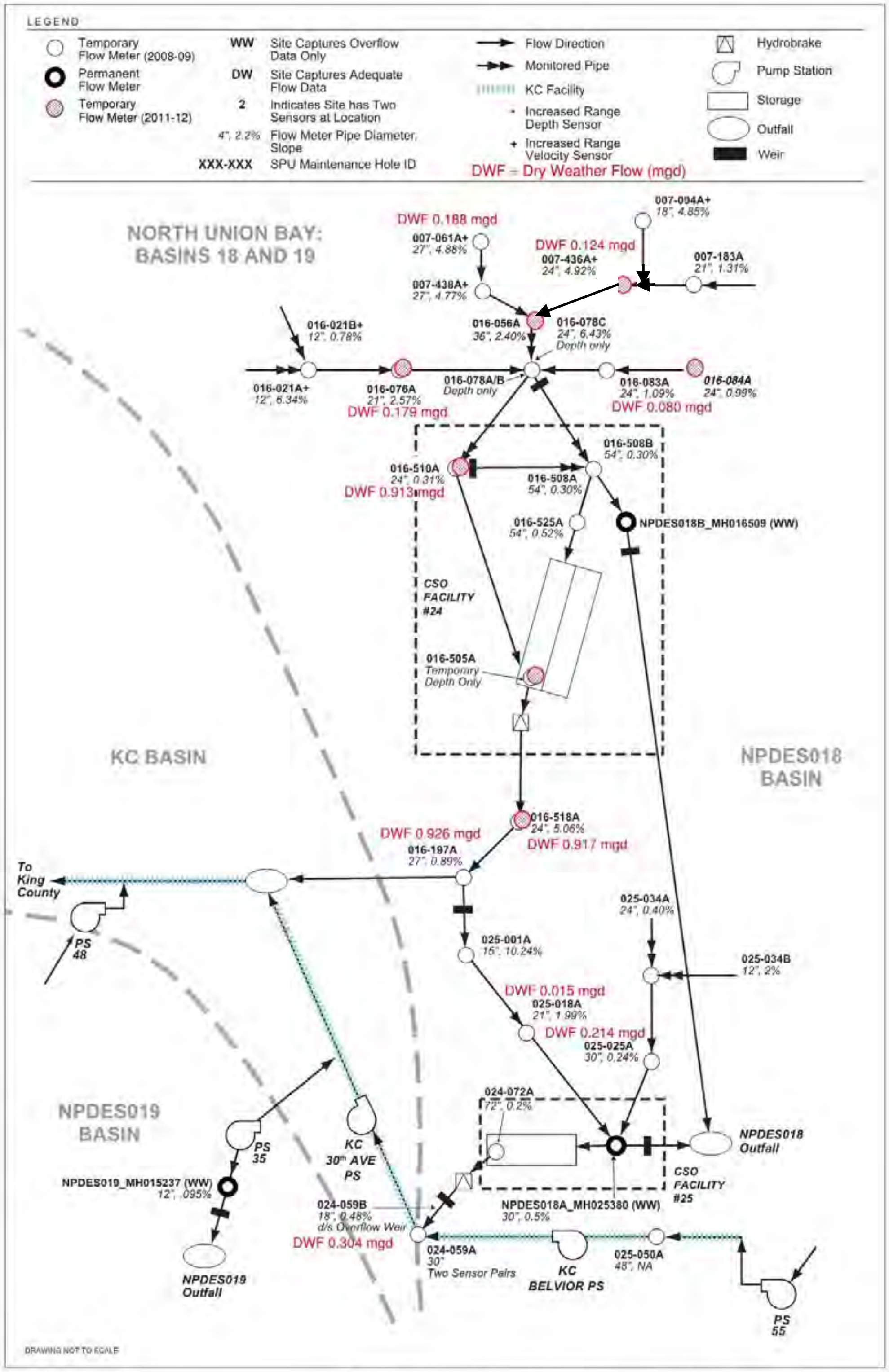


Note: Dfinal data available only from 11/5/2011 - 3/31/2012



Seattle Public Utilities
NORTH UNION BAY: NPDES018, 019 Basins

METER SCHEMATIC
December 2012



Seattle Public Utilities
NORTH UNION BAY: NPDES018, 019 Basins

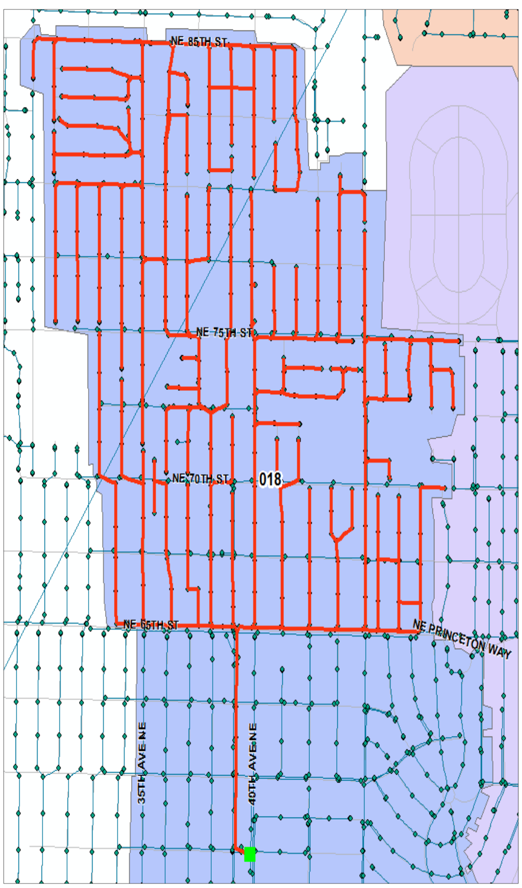
METER SCHEMATIC
December 2012

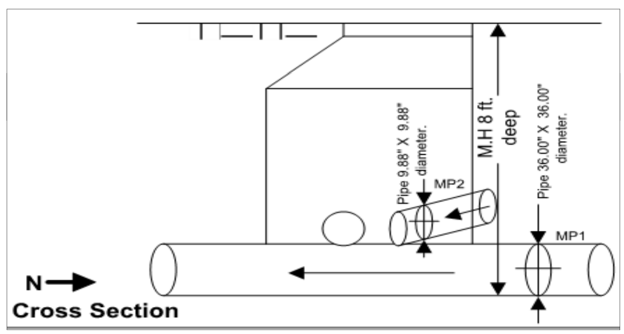
NUB_016-056A	Address:	40th Ave NE/NE 57th St

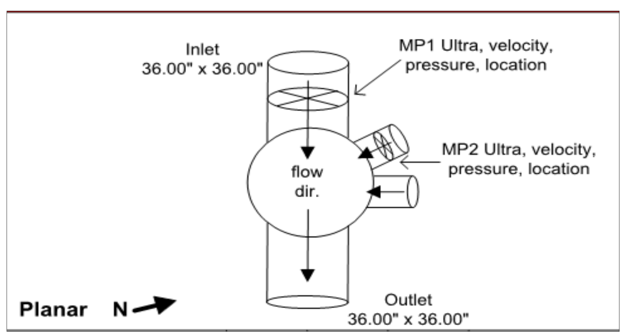
Data Quality Ranking	Good
Pipe ID	016-055_016-056
Pipe Diam (width x height inches)	36 X 36
Upstream Slope	2.40%
Meter Type	ADS 5000 BG
Installation Type	Incoming Pipe
Installation Date	10/8/2011
Removal Date	3/24/2012
Data Collection Period (days)	168
Rain Gauge	2
Upstream Pipe Length (ft)	87,778

Site Narrative

NUB18_016-056A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/8/2011 for hydrology calibration and calculation of flow from the northern portion of the NPDES018(B) Sub-basin.
The meter was located downstream of the previous temporary monitoring installations at NUB18_007-436A and NUB18_007-438A. This meter was not installed for any of the previous phases. Data quality for Phase 4 was classified as “Good” because the meter generally showed a narrow wet weather scattergraph. However, there were some scatters in the dry weather conditions for early January.
The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.





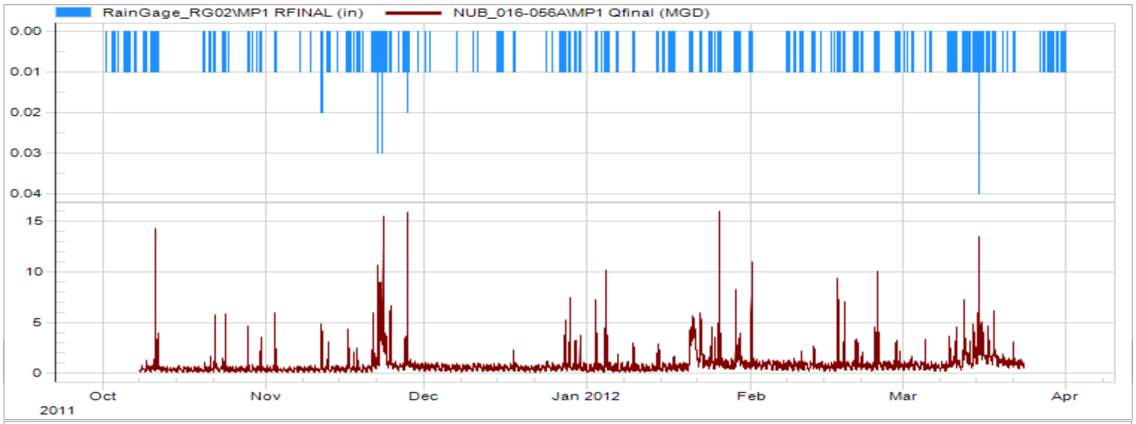


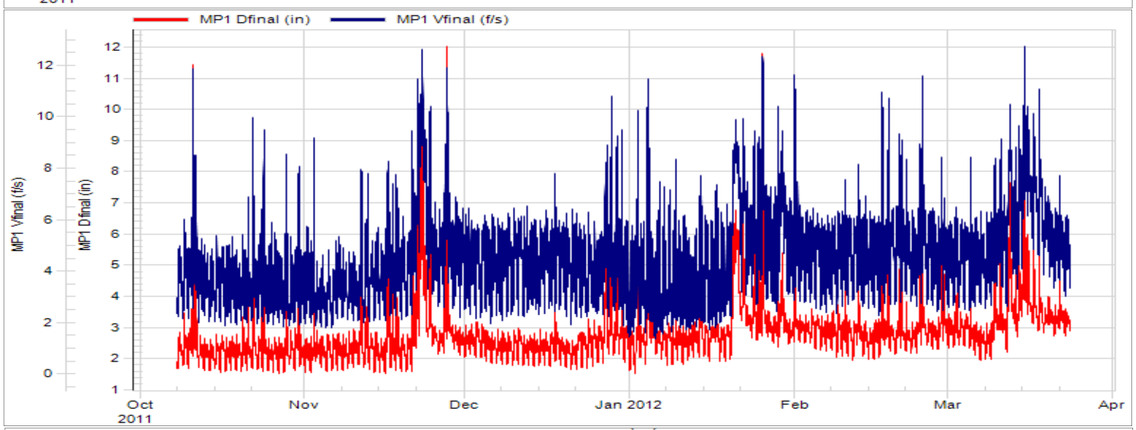
Upstream Pipe Trace (red) **Site Schematic**

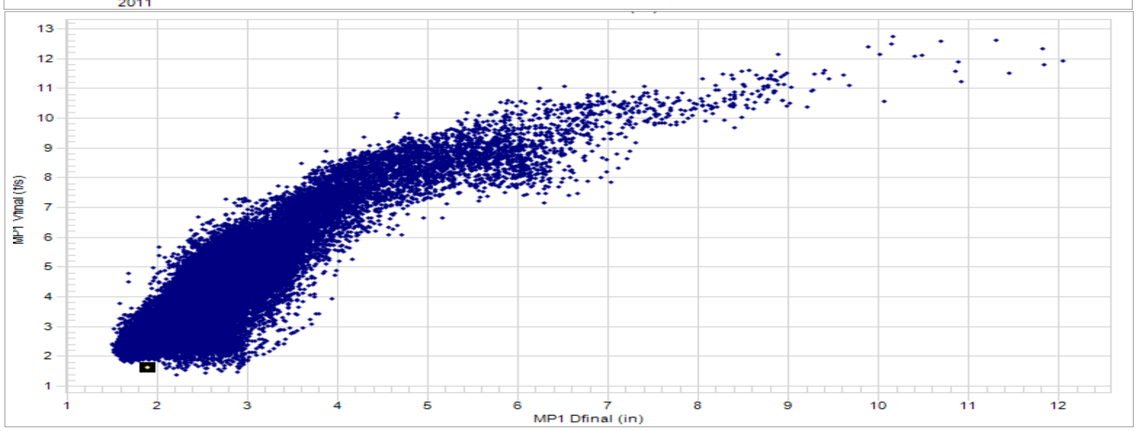
NUB_016-056A

Inlet with MP1 sensor placement | **Side inlet with MP2 sensor placement**

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NUB_016-084A	Address:	4327 NE 55th St NE

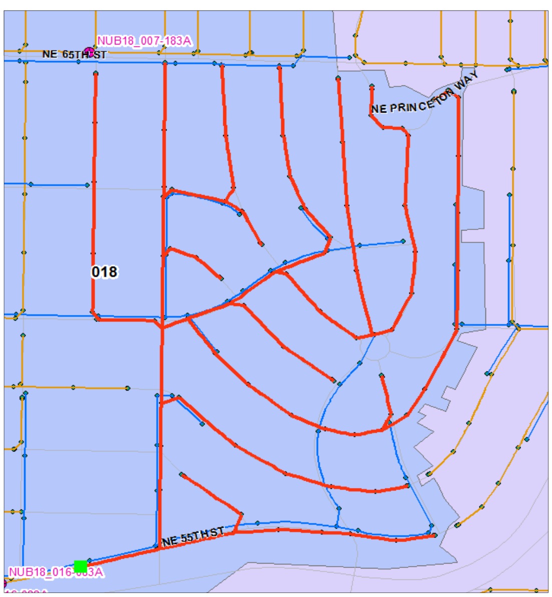
Data Quality Ranking	Good
Pipe ID	016-085_016-084
Pipe Diam (width x height inches)	24 X 23.5
Upstream Slope	0.99%
Meter Type	ADS 5000 AG
Installation Type	Incoming pipe
Installation Date	10/6/2011
Removal Date	3/24/2012
Data Collection Period (days)	170
Rain Gauge	2
Upstream Pipe Length (ft)	18,469

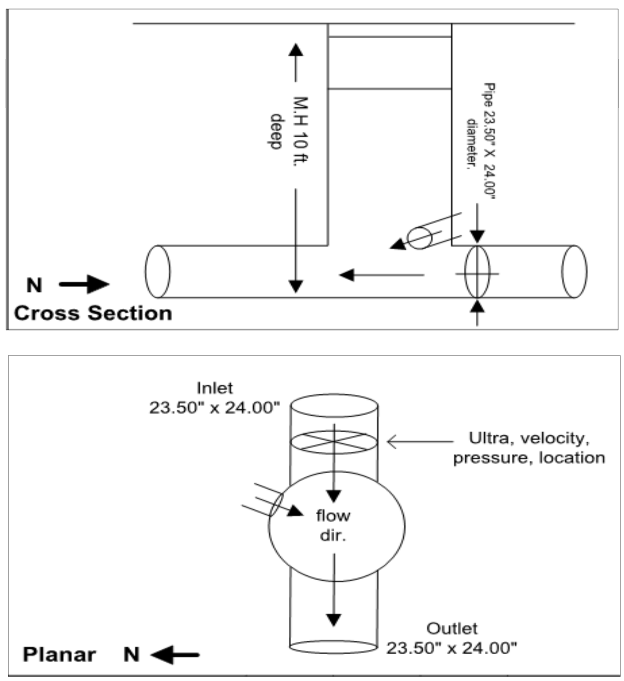
Site Narrative

NUB18_016-084 was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/6/2011 to calculate flows and characterize hydrology for the northeast part of the NPDES018(B) Sub-basin. The site is located just upstream of the Phase 1 NUB18_016-083 monitoring location.

This meter was not installed for any of the previous phases. Although the wet weather scattergraph is narrow, the scattergraph for the dry weather condition is thicker and scattered. For this reason, the data quality for Phase 4 was classified as “Good” for characterizing wet weather flows but with “Some Limitations” for dry weather conditions. In addition, between 12/12/2011 and 1/12/2012, a change in signature was observed. The classic “comma” shape observed indicates the lack of a clear pattern for the dry weather conditions as shown in Figure 3 9.

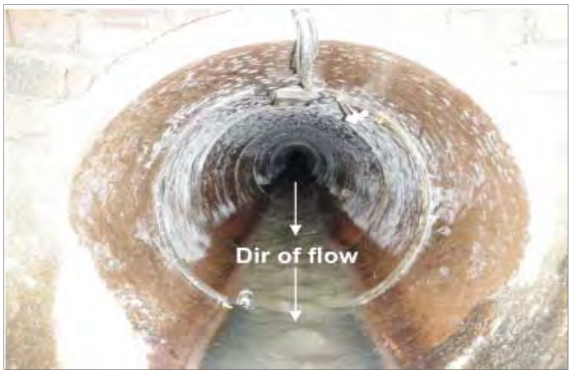
The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

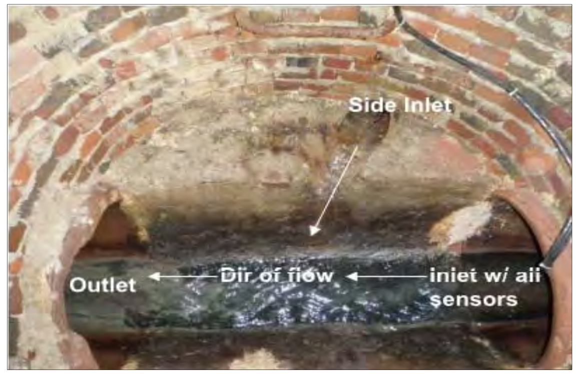




Upstream Pipe Trace (red)	Site Schematic

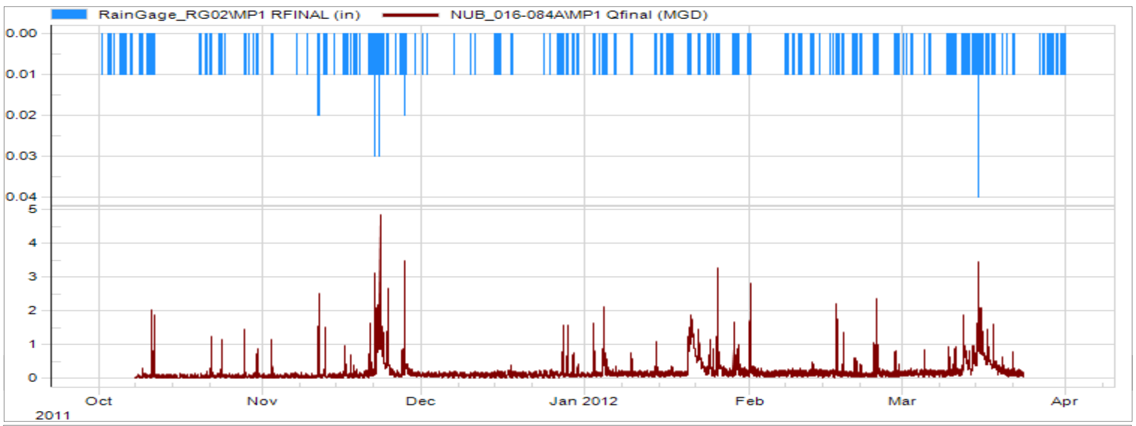
NUB_016-084A

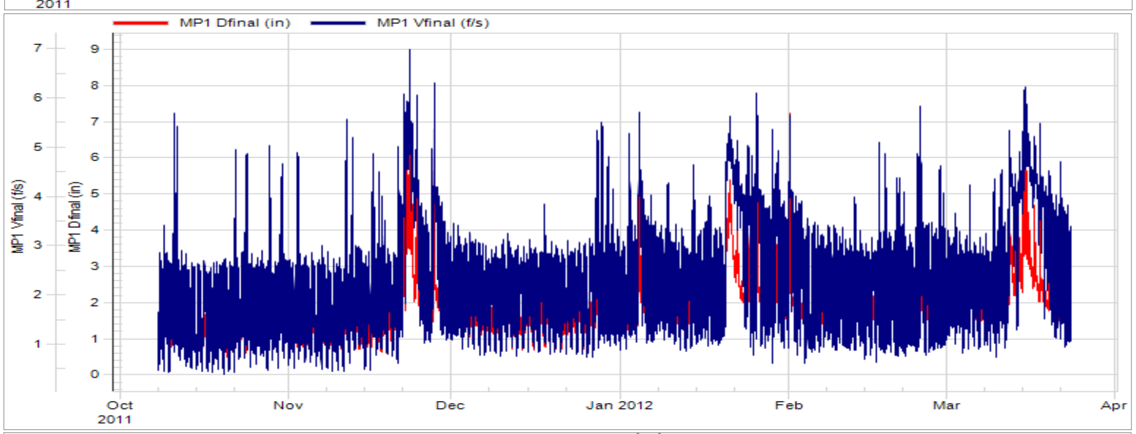


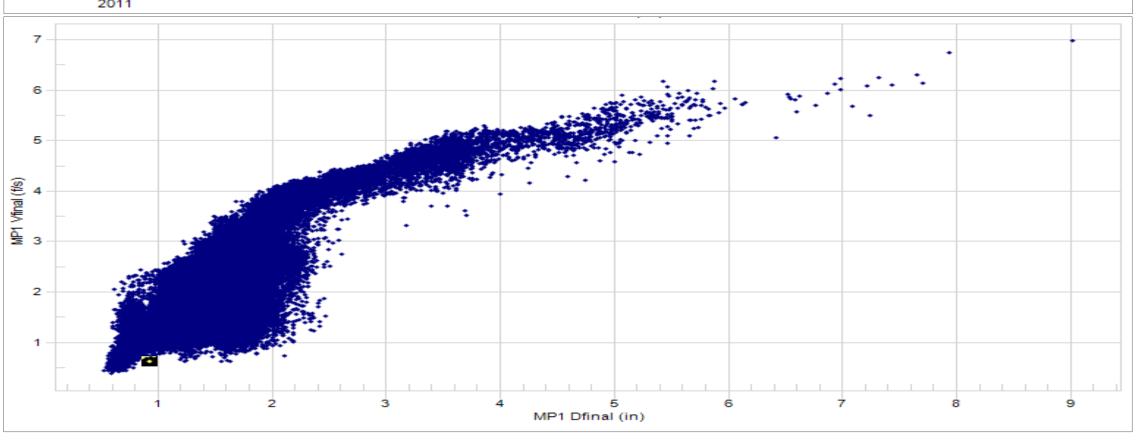


Inlet with sensor placement	View down MH facing North. Inlet and side inlet

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NUB_016-076A	Address:	NE 55th St and 40th Ave NE

Data Quality Ranking	Good
Pipe ID	016-041_ 016-076
Pipe Diam (width x height inches)	20.75 x 20.75
Upstream Slope	2.57%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	10/5/2011
Removal Date	3/24/2012
Data Collection Period (days)	171
Rain Gauge	2
Upstream Pipe Length (ft)	14,278

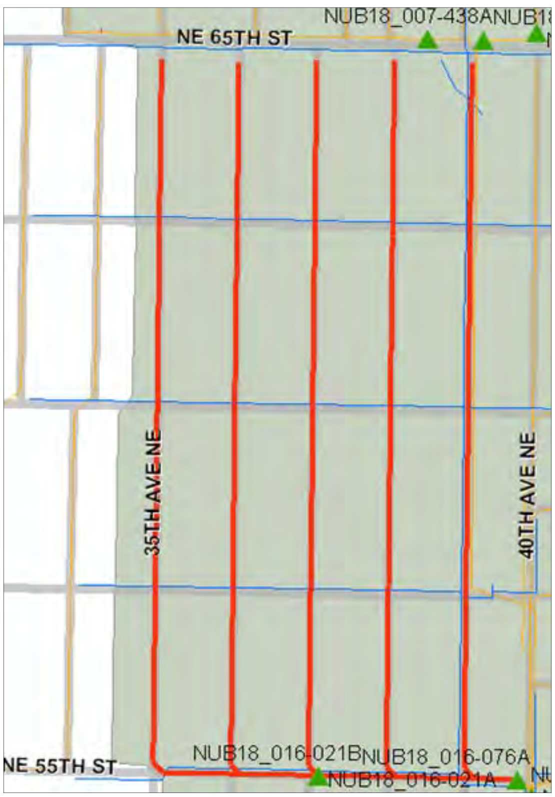
Site Narrative

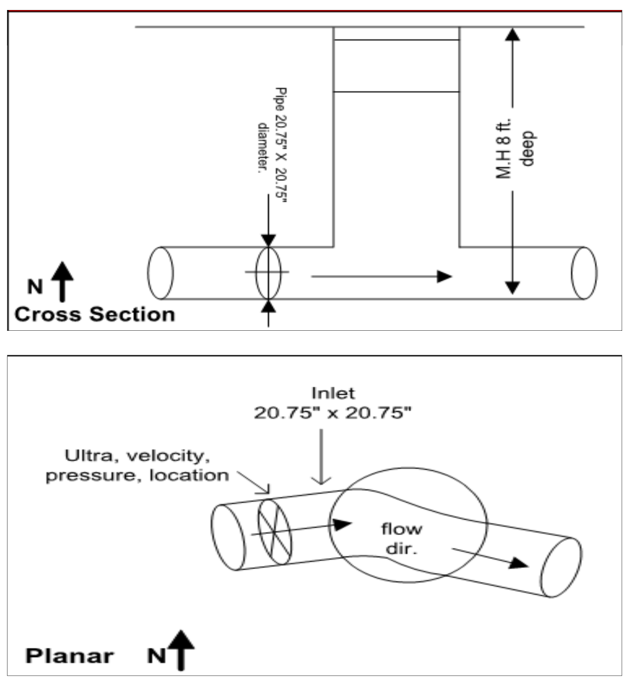
NUB18_016-076A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to calculate flows and characterize hydrology for the northwest part of the NPDES018(B) Sub-basin.

The meter was located downstream of the previous temporary flow monitoring installations at NUB18_016-021A and NUB18_016-021B. Data quality was classified as “Good” for the Phase 4 monitoring period because the meter exhibits a consistent and repeatable response for most of the wet weather events. Data issues include a poor response of the data during the storm on 10/27/2011 and broad velocity scatter during dry weather periods as shown in Figure 3 10. However, neither of these issues presents a significant concern for model calibration.

This monitoring installation site was also used during the Phase 1 flow monitoring for the same purpose as Phase 4. Data quality was classified as “Excellent” for the Phase 1 monitoring period because of the consistent and repeatable response of the data during dry and wet weather periods with a lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for



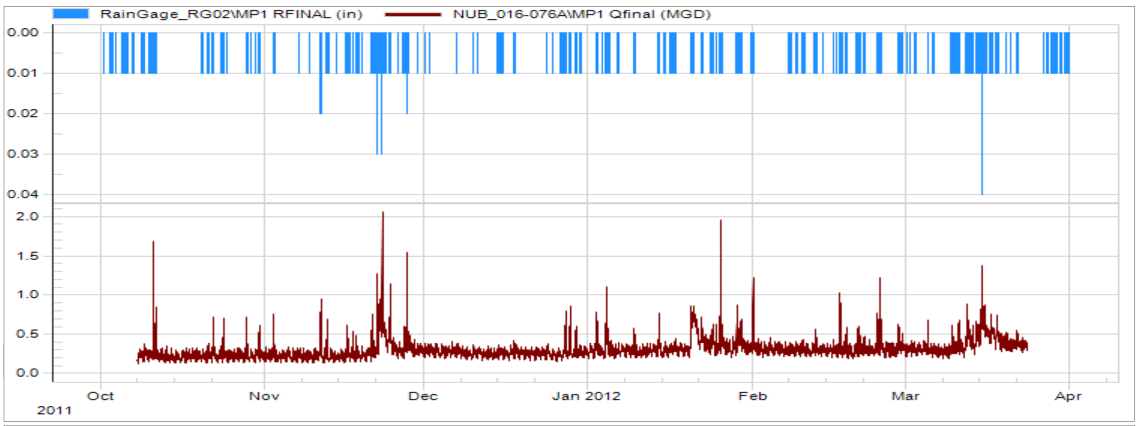


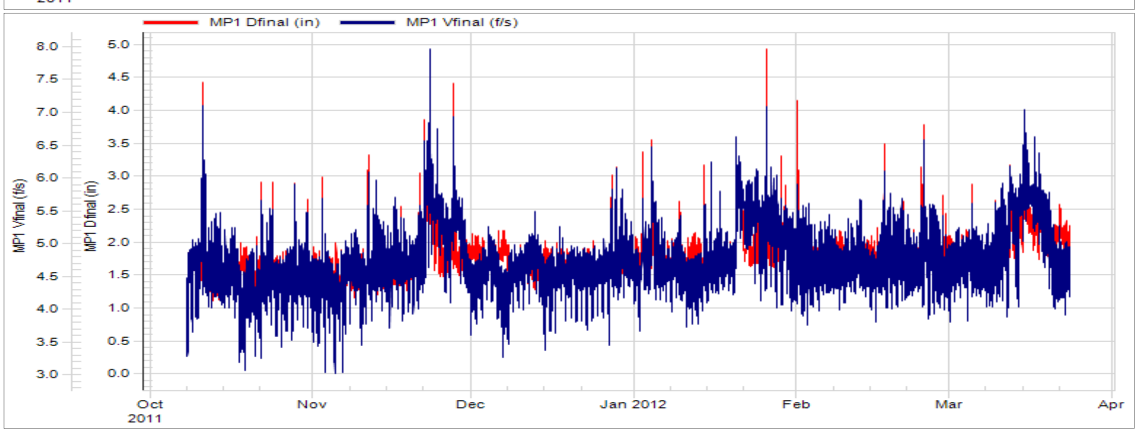
Upstream Pipe Trace (red)	Site Schematic

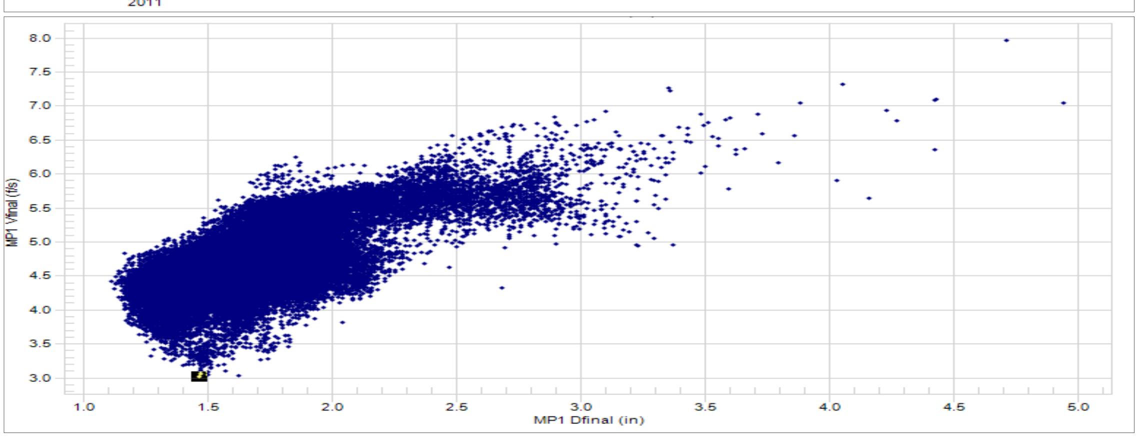
NUB_016-076A

View down MF facing North	Inlet with sensor placement

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NUB18_016-510A **Address:** **40TH Ave NE and NE 52nd Pl**

Data Quality Ranking	Good
Pipe ID	016-077_ 016-510
Pipe Diam (width x height inches)	23.38 x 23.50
Upstream Slope	0.31%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	10/5/2011
Removal Date	3/24/2012
Data Collection Period (days)	171
Rain Gauge	2
Upstream Pipe Length (ft)	135,490

Site Narrative

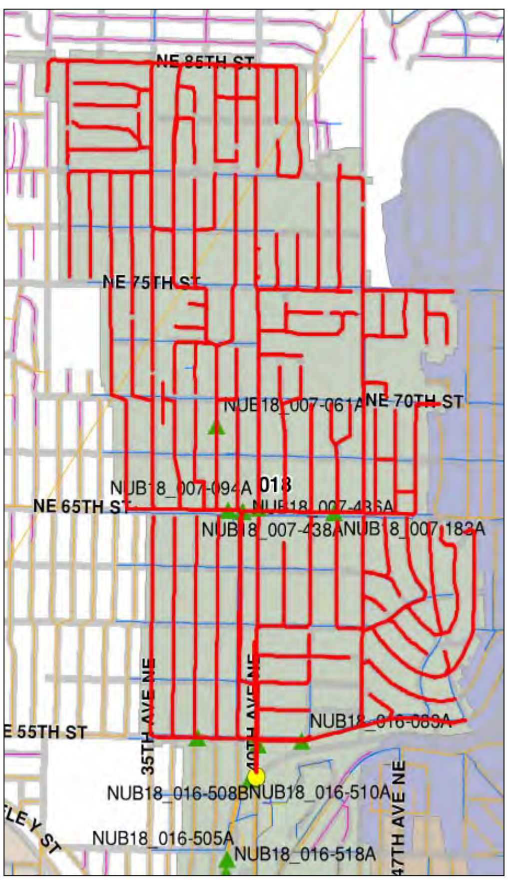
NUB18_016-510A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to characterize the hydrology and hydraulics downstream of the temporary flow monitors at NUB18_016-056A, NUB18_016-084, and NUB18_016-076A. Data collected at NUB18_016-510A were also used to compute flow balancing for the upstream meters and to characterize the behavior of the weir structure located upstream at 016-078.

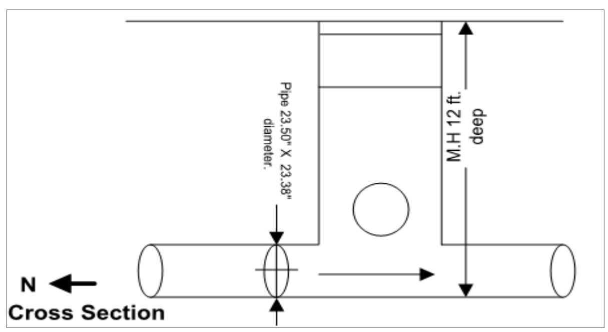
The meter was located downstream from structure NUB18_016-078C; it was located in the main sewer pipe that directs dry weather flow around the storage tank to the HydroBrake on the south end of CSO Facility 24. An overflow pipe is located on the shelf of the maintenance hole that is overtopped when the depth reaches 21 inches. The overflow pipe diverts flows to the north end of the storage tank when the HydroBrake starts to back up flows in the system.

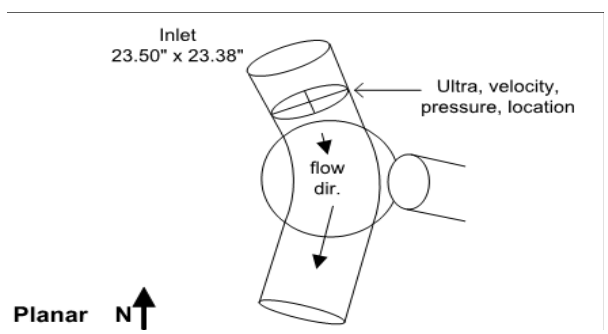
The data exhibit a consistent narrow scatter pattern with the exception of the 3/15/2012 period, when there was a change in the dry weather scattergraph (following a prolonged wet period). Therefore, data quality was classified as “Good” for the Phase 4 monitoring period.

This monitoring installation site was also used during the Phase 1, 2, and 3 flow monitoring phases for the same purpose as Phase 4. Data quality was classified as “Good” for the Phase 1, 2, and 3 monitoring periods because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.





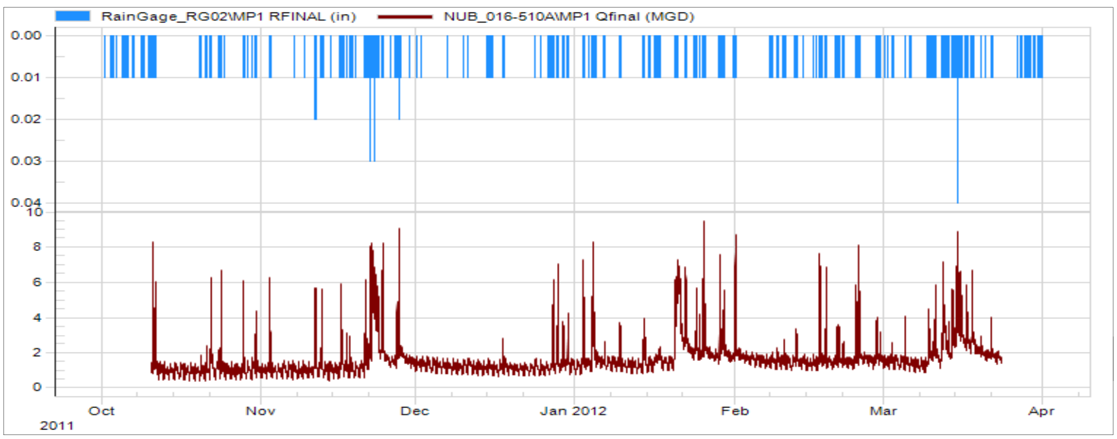


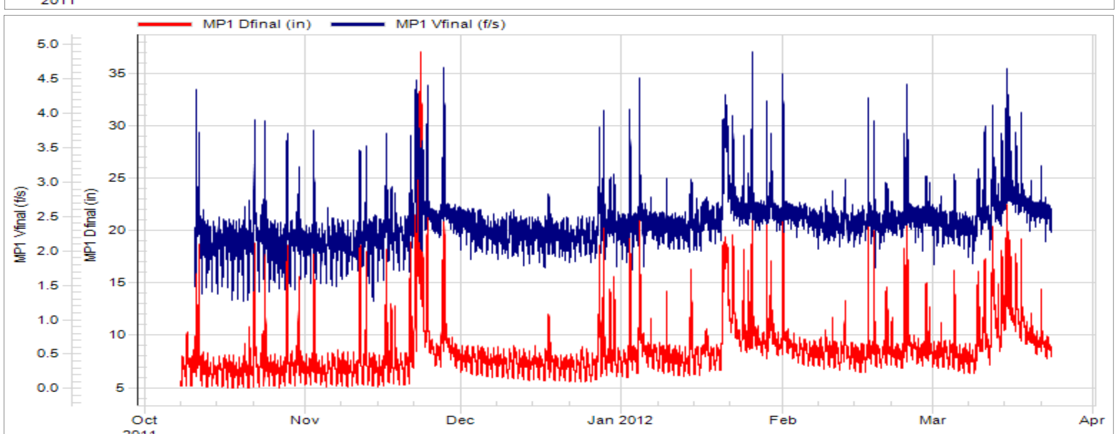
Upstream Pipe Trace (red) **Site Schematic**

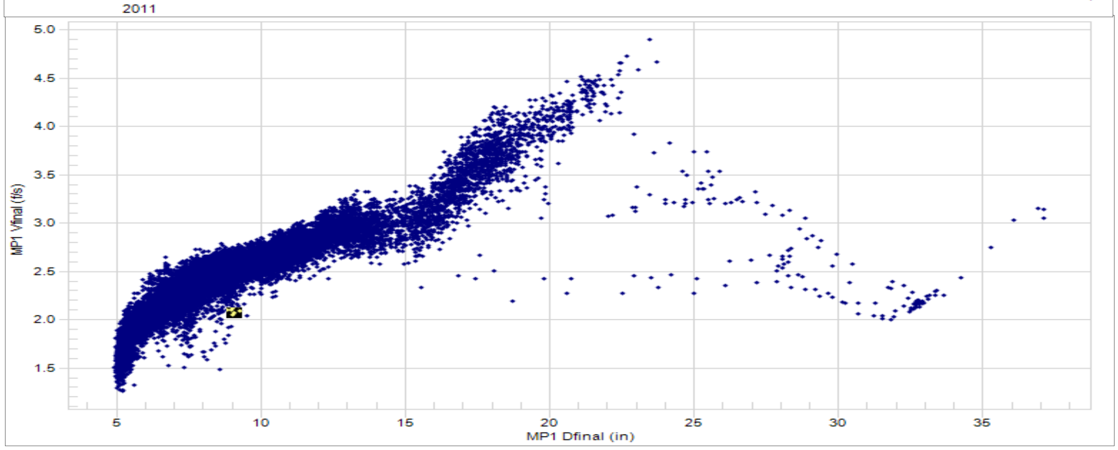
NUB18_016-510A

View down MH facing East	Inlet with sensor placement

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012





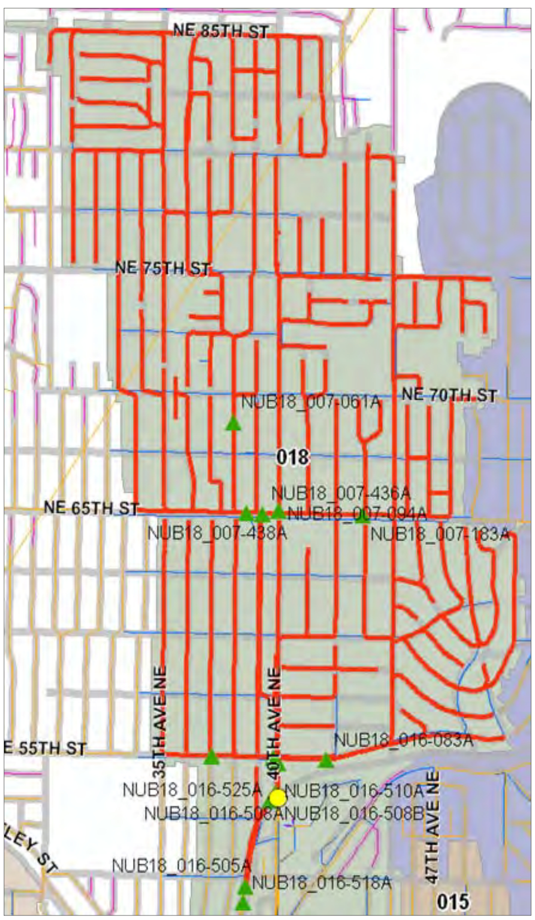


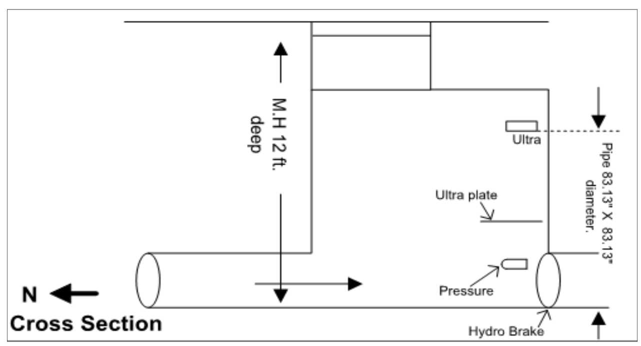
NUB18_016-505A	Address:	4875 39th Ave NE

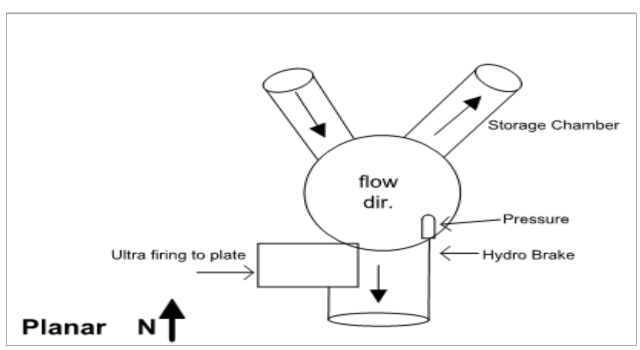
Data Quality Ranking	Excellent
Pipe ID	016-524_ 016-505
Pipe Diam (width x height inches)	83.13 x 83.13
Upstream Slope	n/a (Level Only)
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	10/6/2011
Removal Date	3/24/2012
Data Collection Period (days)	170
Rain Gauge	2
Upstream Pipe Length (ft)	135,864

Site Narrative

NUB18_016-505A was a temporary monitoring installation that recorded level only during the Phase 4 monitoring period. The site was installed on 10/6/2011 to characterize water levels just upstream of the HydroBrake and storage utilization at CSO Facility 24.
The data quality was classified as “Excellent” for Phase 4, which matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. Data quality was classified as “Excellent” for these monitoring periods because of the consisten and repeatable response of the data during dry and wet weather and lack of data gaps.
The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected for the purposes of model calibration and verification.

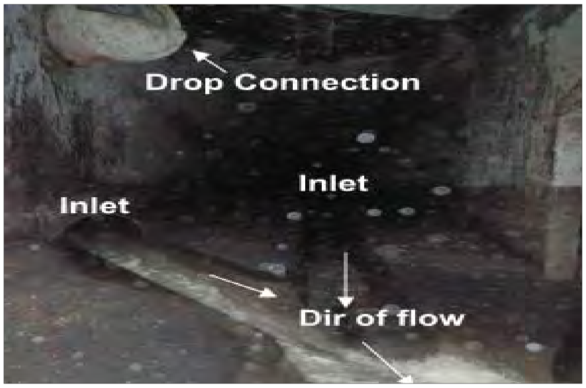


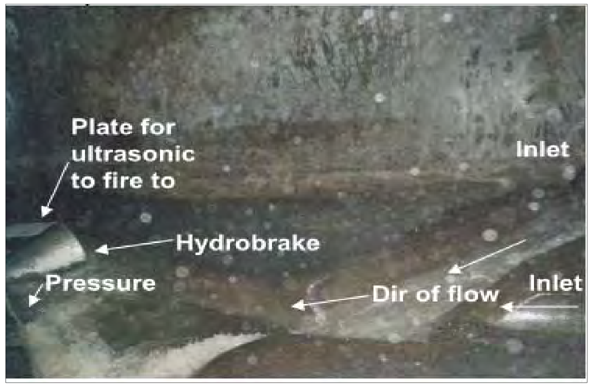




Upstream Pipe Trace (red)	Site Schematic

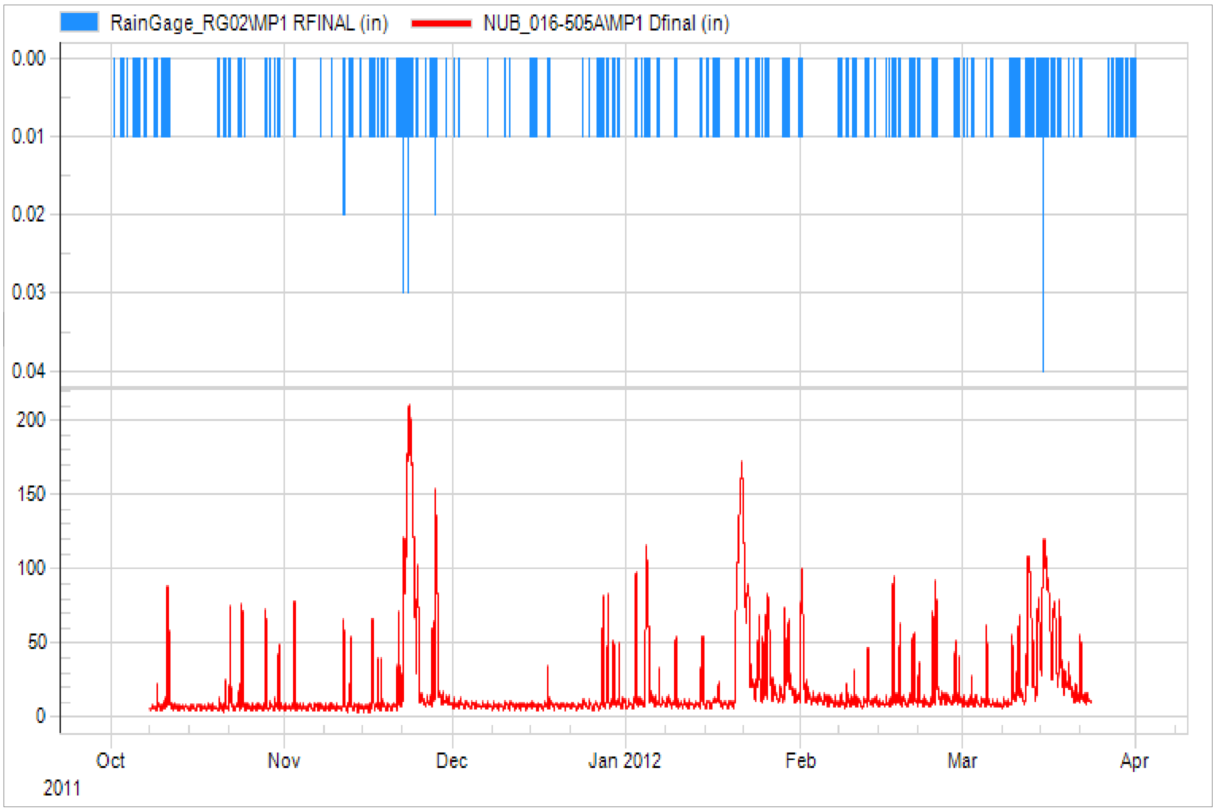
NUB18_016-505A





Inlets with drop connections and storage chamber	Side view of inlets, hydrobrake, and pressure

Hydrograph 10/1/2011 to 3/31/2012



NUB18_016-518A	Address:	4822 39th Ave NE and Burk Gilman Trail

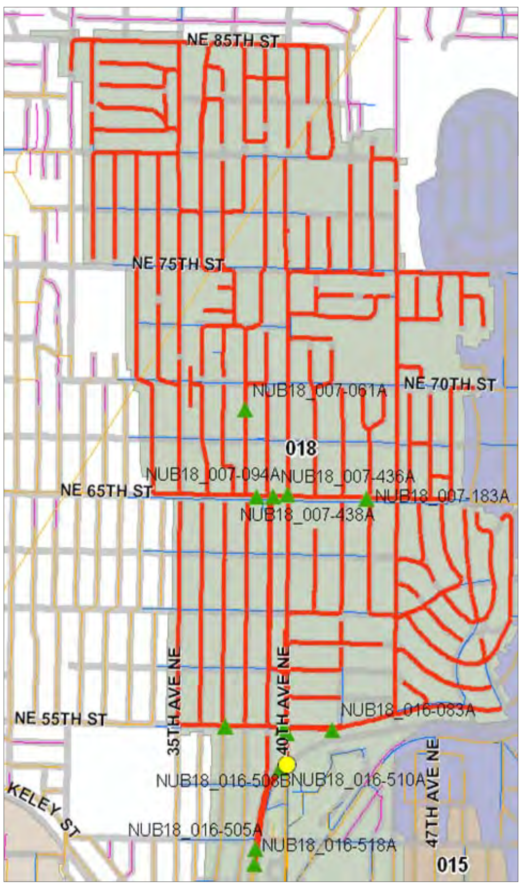
Data Quality Ranking	Poor
Pipe ID	016-532_ 016-518
Pipe Diam (width x height inches)	23.63 x 24
Upstream Slope	5.06%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	10/5/2011
Removal Date	3/24/2012
Data Collection Period (days)	171
Rain Gauge	2
Upstream Pipe Length (ft)	137,050

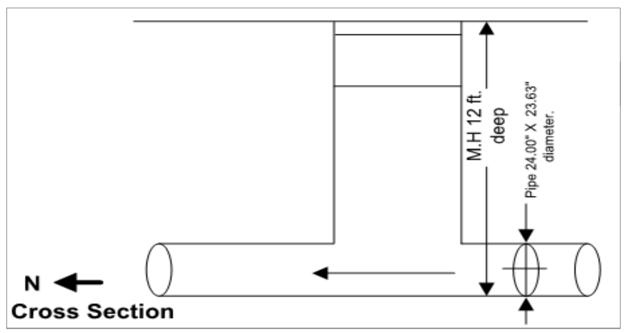
Site Narrative

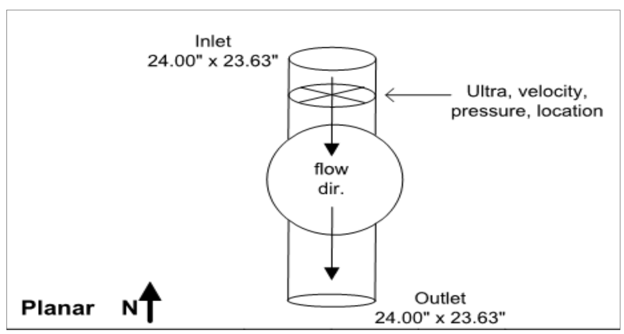
NUB18_016-518A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to monitor flows downstream of the NPDES018(B) storage facility and the HydroBrake at CSO Facility 24. The level data were also used to characterize the operations of the HydroBrake.

The meter was located on the downstream side from the HydroBrake at CSO Facility 24. The data at the site captured a dry weather pattern that showed occasional scatter caused by debris in the pipe. During storm events, the site showed consistent flow patterns, resulting from its location downstream from the HydroBrake.

Analysis of the flow data from this site, including flow balancing and calibration of the storage structure performance in the hydraulic model, indicated that the NUB18_016-518A meter systematically under-predicted flow rates. As a result, the data quality was classified as “Poor” for Phase 4. Alternative methods will be used to supply needed information. The meter was removed on 3/24/2012.

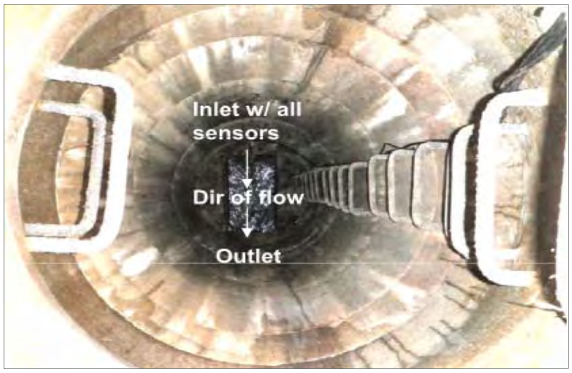






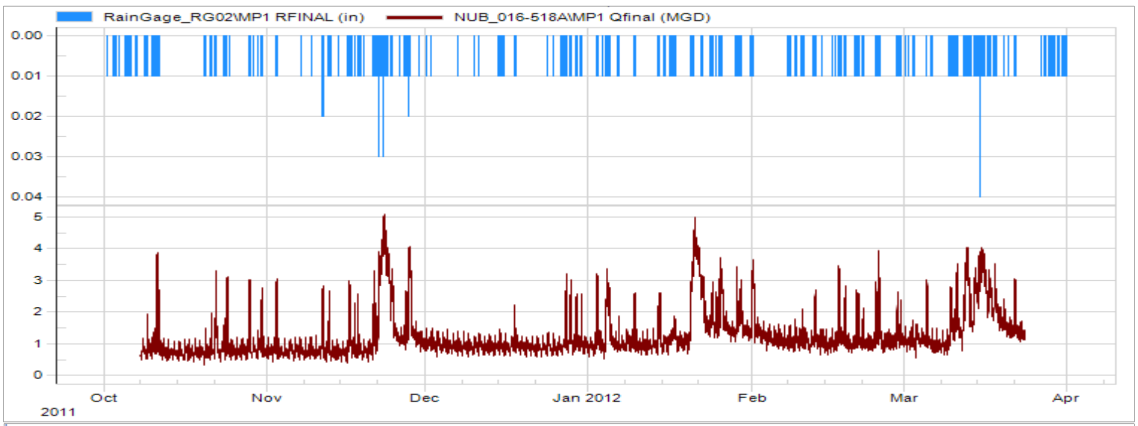
Upstream Pipe Trace (red)	Site Schematic

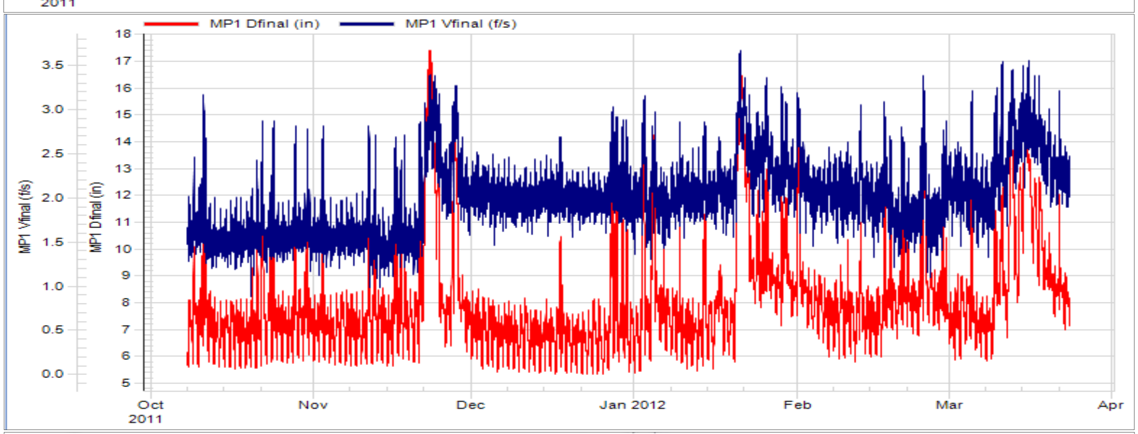
NUB18_016-518A

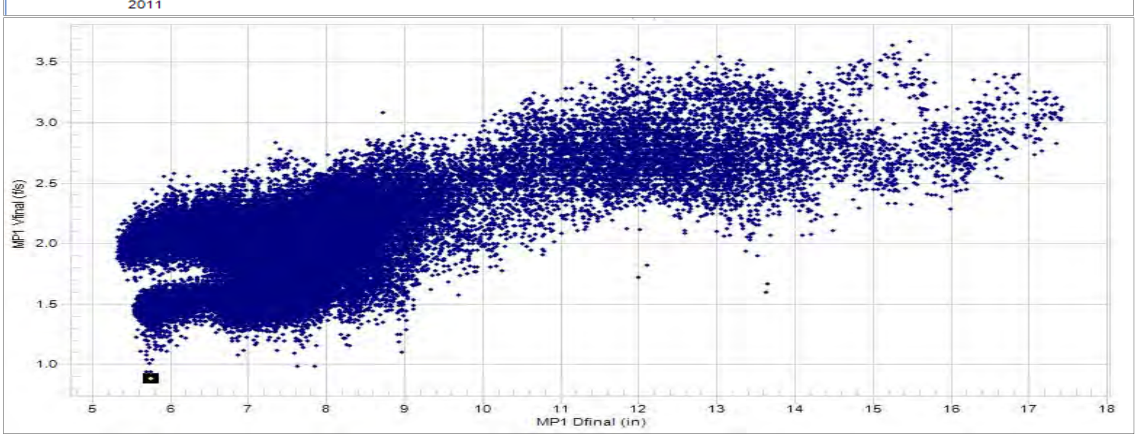


View down MH facing North	Inlet with MP1 sensor placement

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NUB18_007-436A	Address:	NE 65th St @ 34th Ave NE

Data Quality Ranking	Good
Pipe ID	007-093_ 007-436
Pipe Diam (width x height inches)	24 x 24
Upstream Slope	4.92%
Meter Type	ADS 5000 AG
Installation Type	Incoming Pipe
Installation Date	10/5/2011
Removal Date	3/24/2012
Data Collection Period (days)	171
Rain Gauge	2
Upstream Pipe Length (ft)	32,965

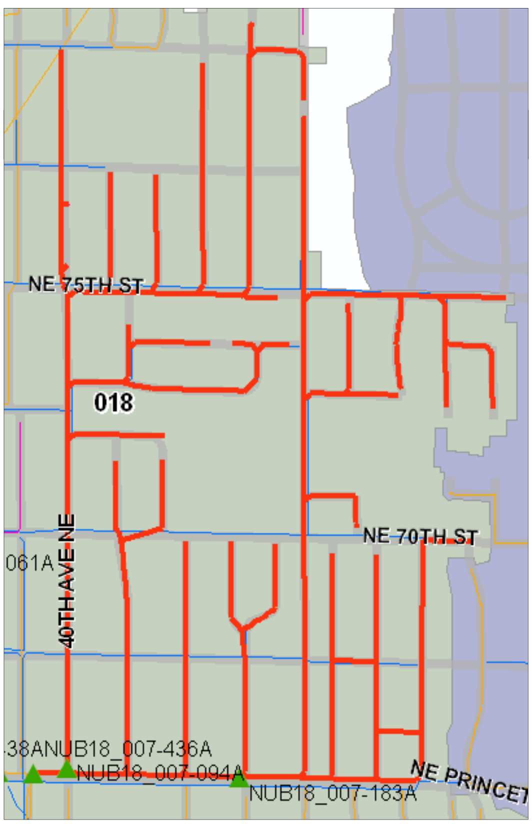
Site Narrative

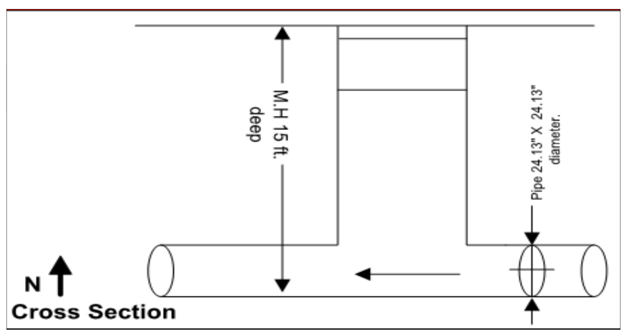
NUB18_007-436A was a temporary monitoring installation that recorded both level and velocity. The site was installed on 10/5/2011 to calculate flows and characterize hydrology for the northeastern part of the NPDES018(B) Sub-basin.

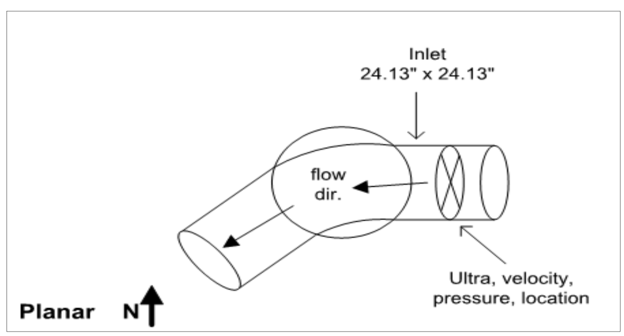
The meter was located downstream of the previous installations at NUB18_007-094A and NUB18_007-183A. During the Phase 4 monitoring period, significant velocity dropouts were observed during storm periods that took place between 1/10/2012 and 2/3/2012, when velocity readings exceeded approximately 11 feet per second. However, because the scattergraph data for both dry and wet weather periods are narrow, indicating a consistent response of flow to rainfall across the entire monitoring period, the data quality was classified as “Good.”

This monitoring installation site was also used during the Phase 1 flow monitoring phase for the same purpose as Phase 4. Data quality was classified as “Excellent” for the Phase 1 monitoring period because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps.

The site was removed on 3/24/2012, during Phase 4 monitoring, as it was determined that sufficient suitable data had been collected.

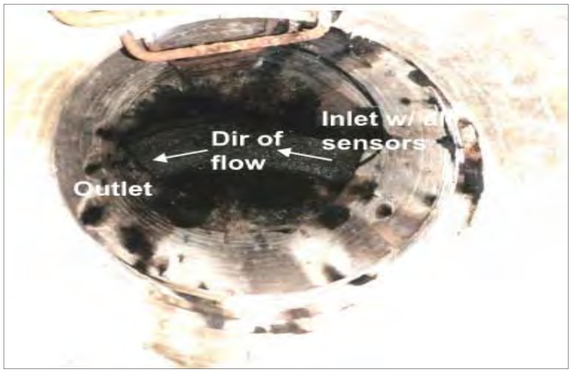






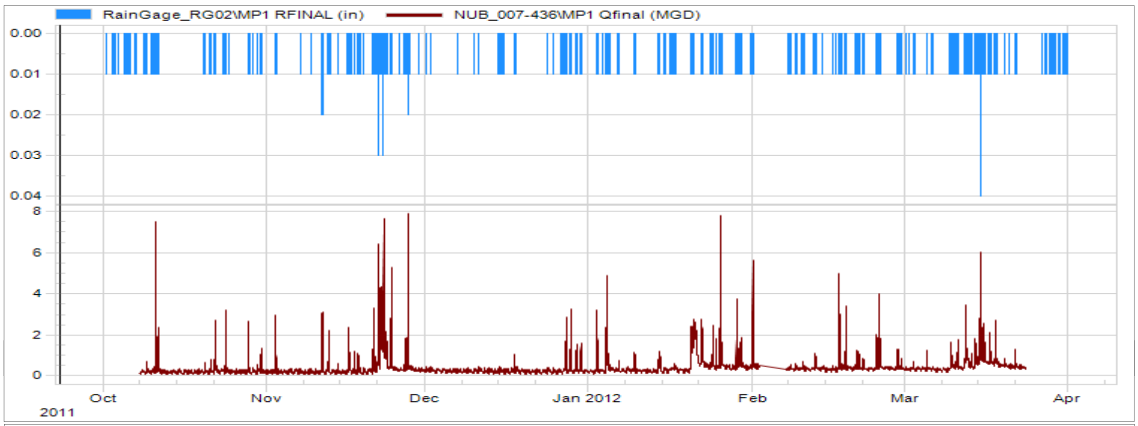
Upstream Pipe Trace (red)	Site Schematic

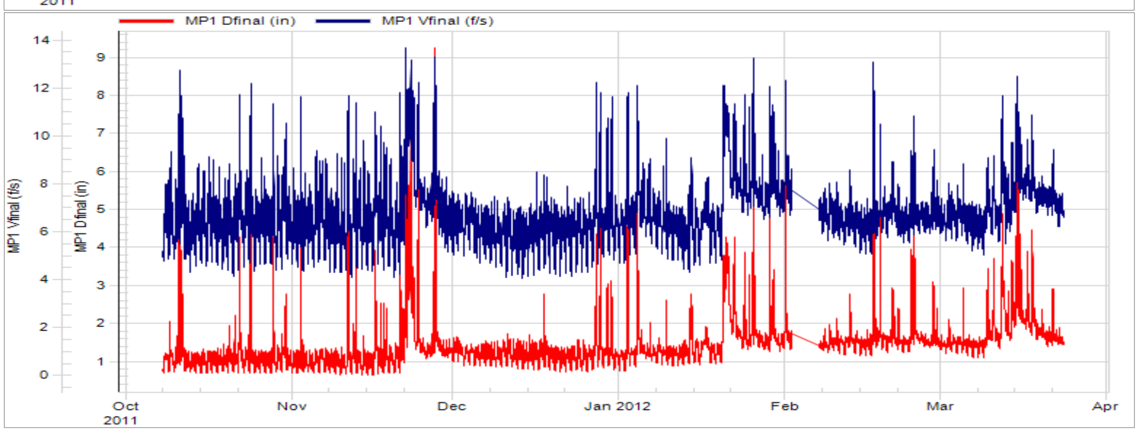
NUB18_007-436A

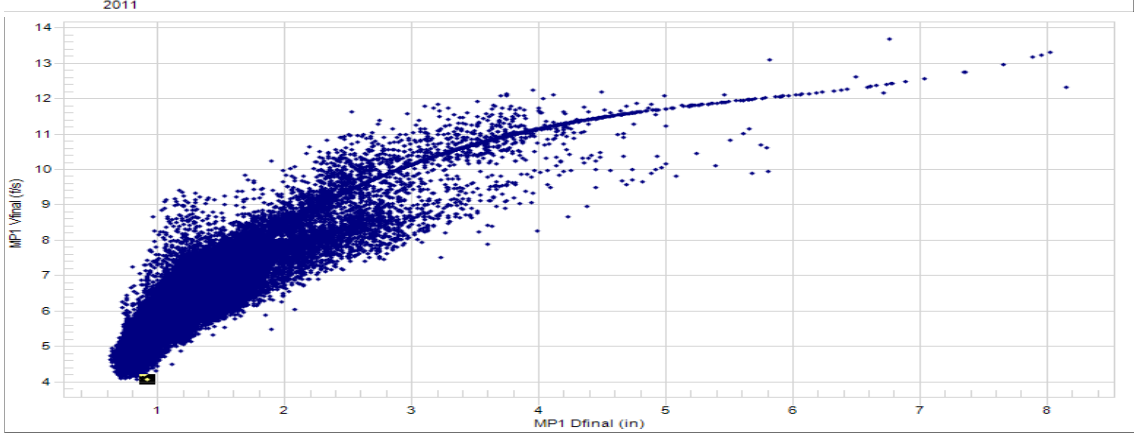


View down MH facing North | Inlet with sensor placement

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







NPDES018B_MH016509	Address:	40th Ave. NE & NE 52nd Pl

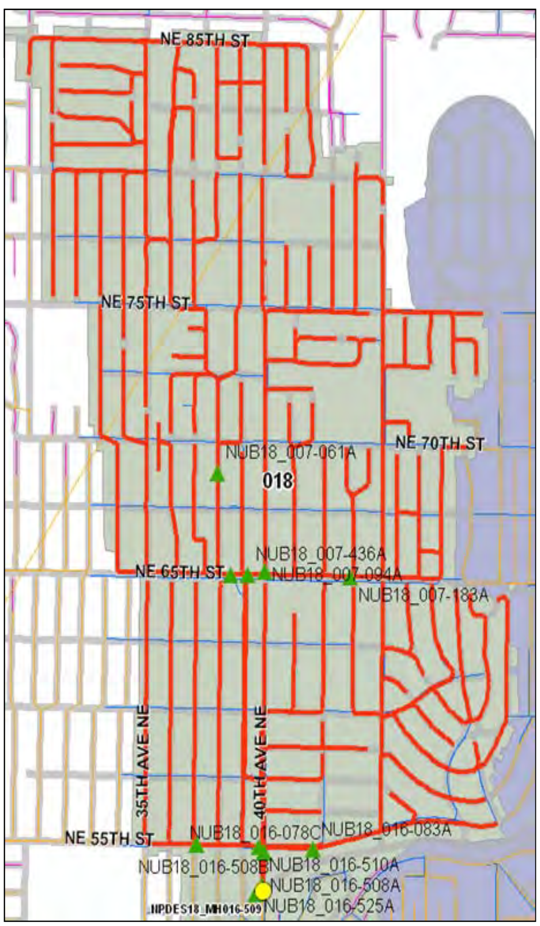
Data Quality Ranking	Some Limitations
Pipe ID	016-508_016-509
Pipe Diam (width x height inches)	54 x 54
Upstream Slope	28.00%
Meter Type	ADS 5000 BG
Installation Type	Incoming Pipe
Installation Date	12/8/2006
Removal Date	--
Data Collection Period (days)	1940
Rain Gauge	2
Upstream Pipe Length (ft)	133,053

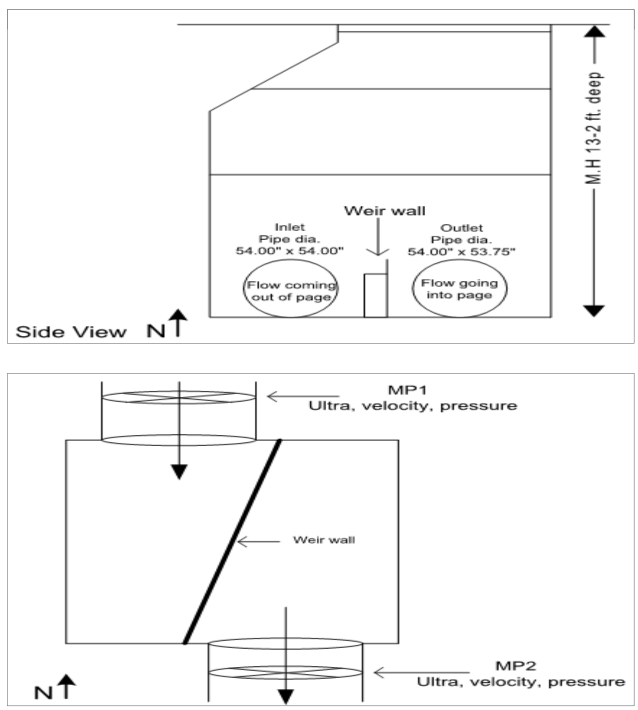
Site Narrative

NPDES018B_MH016509 is a permanent monitoring site that records both level and velocity. The site has two monitors: MP1, located in the incoming pipe, and MP2, located in the overflow line. MP1 is used to estimate water levels on the upstream side of the weir and to alarm CSO events from NPDES018(B). The MP2 meter records both level and velocity. The resulting flows are used to calculate the discharge volume for CSO events.

The data quality was classified as having “Some Limitations” for Phase 4. The MP1 meter records depths only during large events when the adjacent storage facility fills. The recorded depths are consistent with the temporary monitoring data collected in the storage facility at NUB18_016-505. The MP2 meter records flows only when a CSO event occurs. ADS utilizes a reverse installation for the MP2 meter that scans velocities in the downstream direction. During the December 2010 CSO event, the MP2 meter recorded flow rates in excess of 40 million gallons per day (mgd).

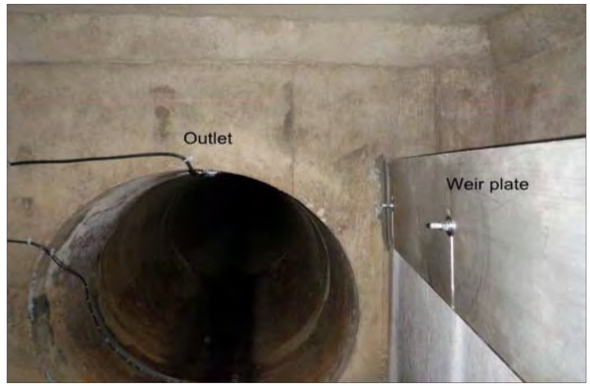
During Phases 1–4, the sum of the temporary monitoring data flows in the upstream system did not exceed 30 mgd. It seems unlikely that during the December 2010 event, the overflow rate would exceed the total system flows recorded during other events. Due to the reverse installation and questions about the flow rates recorded during the December 2010, the “Some Limitations” rating was applied to this location. This classification is the same as was reported during the Phases 2–3 monitoring period.





Upstream Pipe Trace (red)	Site Schematic

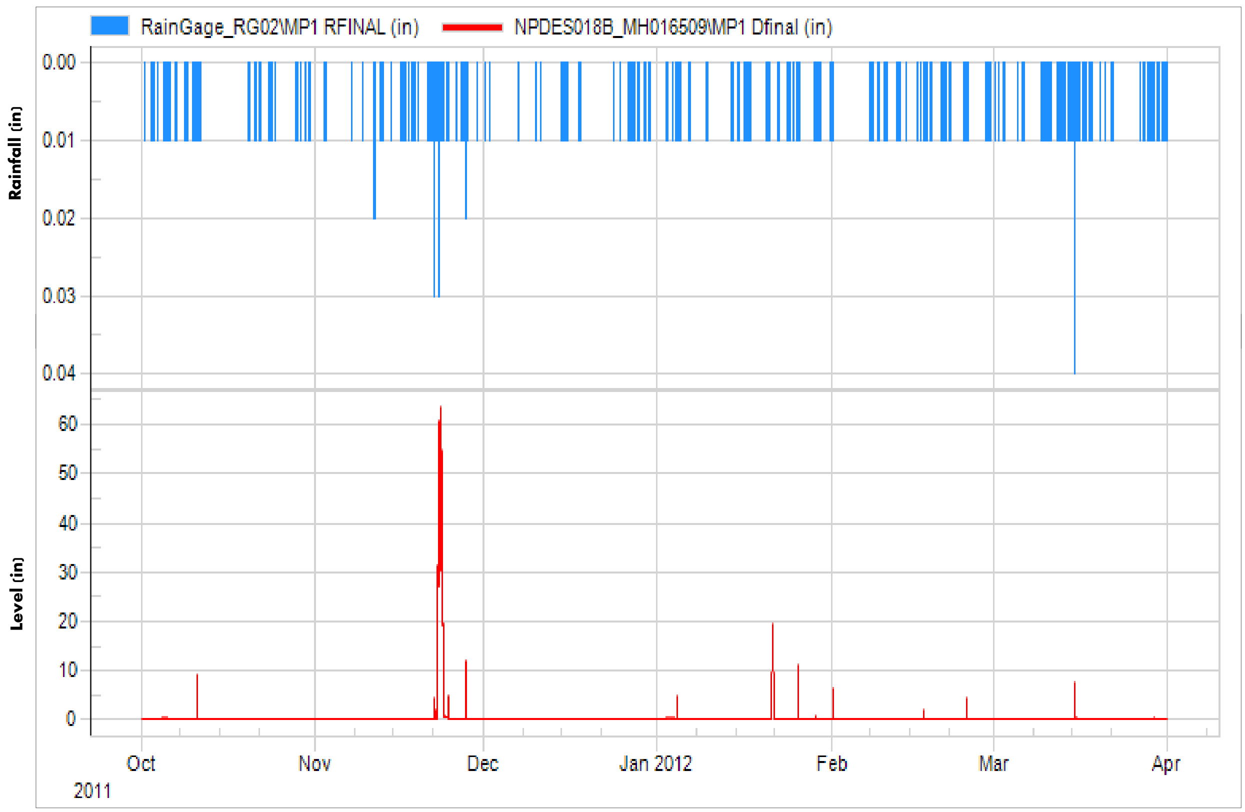
NPDES018B_MH016509



View of inlet and MP1 sensor placement and weir wall

View of outlet and MP2 sensors with relation to weir wall

Hydrograph 10/1/2011 to 3/31/2012



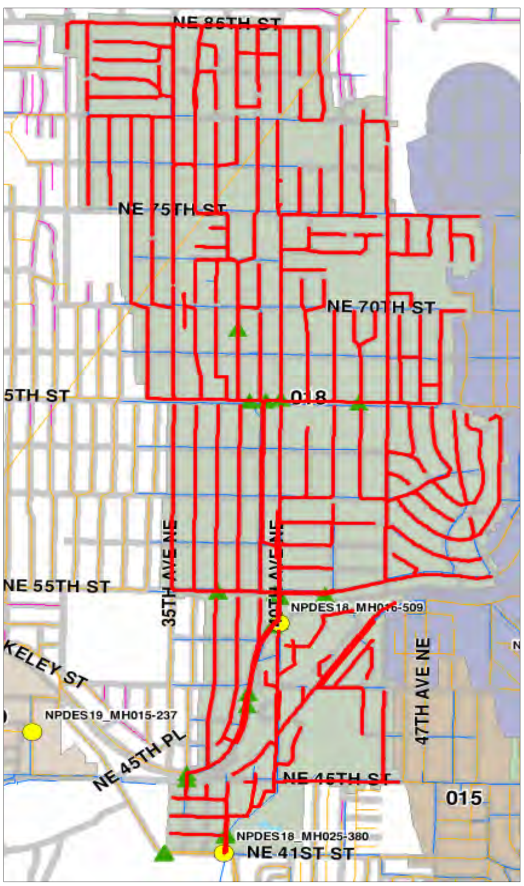
NPDES018A_MH025380	Address:	3718 NE 41st

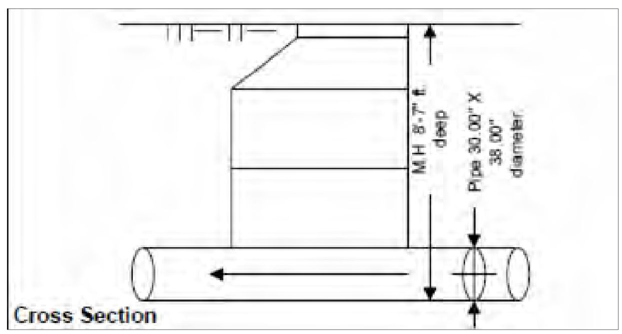
Data Quality Ranking	Excellent
Pipe ID	025-024_025-380
Pipe Diam (width x height inches)	30 x 28
Upstream Slope	0.50%
Meter Type	ADS FlowShark® AG
Installation Type	Incoming Pipe
Installation Date	7/16/2007
Removal Date	--
Data Collection Period (days)	1720
Rain Gauge	3
Upstream Pipe Length (ft)	163,986

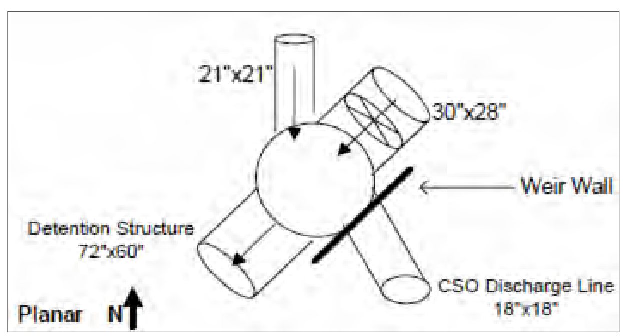
Site Narrative

NPDES018A_MH025380 is a permanent monitoring site that records both level and velocity. The site is classified as a wet weather site because it is expected to provide high-quality level data only; thus, only level data are finalized for the site. The site was installed on 7/16/2007 to quantify CSO events occurring from the NPDES018(A) Sub-basin. The level data are used to alarm CSO events and to calculate the volume of CSO events using a weir equation.

NPDES018A_MH025380 is located at the upstream end of the storage tank within CSO Facility 25. During storm events, the velocity and level data responded consistently. Data quality was classified as “Excellent” for the Phase 4 monitoring period because of the consistent and repeatable response of the data during dry and wet weather and lack of data gaps. This classification matches the quality classification of the data collected during the Phase 1, 2, and 3 monitoring periods. All data from Phase 4 are suitable for use in model calibration.





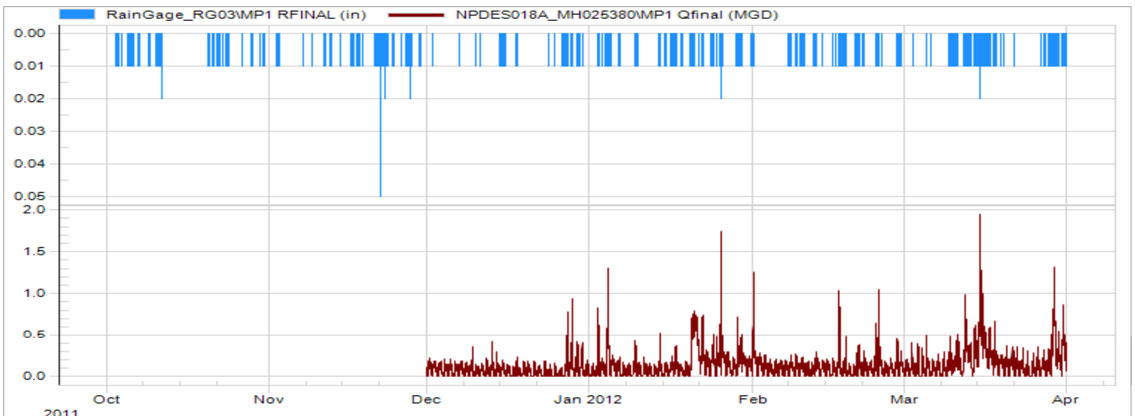


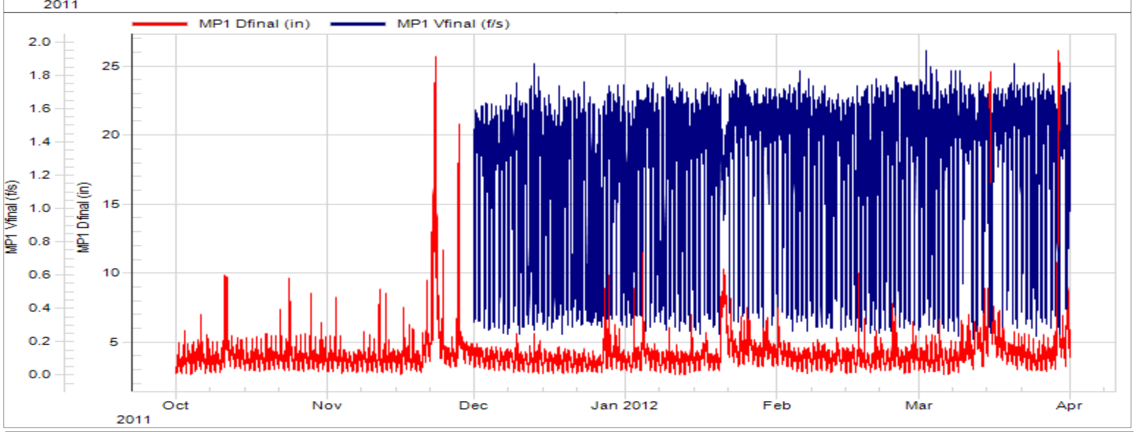
Upstream Pipe Trace (red)	Site Schematic

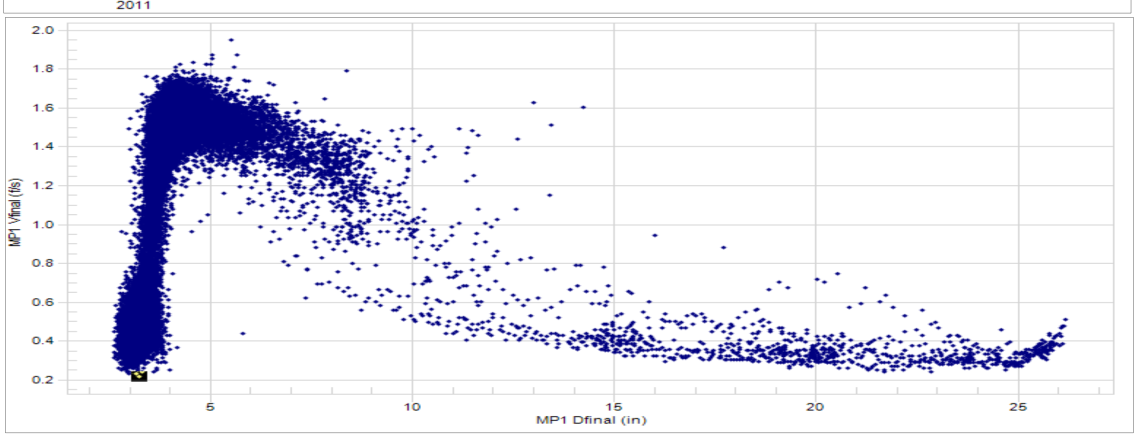
NPDES018A_MH025380

View of Maintenance Hole 025-380 **View of Meter Installation**

Hydrograph and Scattergraph 10/1/2011 to 03/31/2012







Note: Final velocity was available only for December through March