Genesee Combined Sewer Overflow Reduction Project: Hydrologic and Hydraulic Modeling Report

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Executive Summary

The *Genesee Area Combined Sewer System Hydrologic and Hydraulic Modeling Report* documents the development of a computer model for the combined sewer system in the Genesee Area in southeast Seattle. The combined sewer system conveys both domestic wastewater and stormwater flows and is subject to combined sewer overflows (CSOs) during heavy precipitation events. The model will be used to assess the performance of the existing sewer and CSO systems and to analyze potential measures to control CSOs in the Genesee Area. The City of Seattle is implementing a capital program to reduce CSOs citywide down to an average of one untreated discharge per outfall per year.

Background and Project Objectives

The Genesee Area occupies 690 acres (1.05 square miles) and is bounded by Lake Washington on the east, Rainier Avenue on the west, Mount Baker Boulevard on the north, and South Orcas Street on the south. The Genesee Area has a partially separated sewer system with seven CSO outfalls discharging to the lake that are designated by NPDES permit as CSO outfalls 37, 38, 40, 41, 42, 43, and 165.

Based on the historical CSO frequency measurements collected between 1998 and 2009, NPDES basins 37, 38, and 42 are controlled (meaning that they meet the project goal of a long-term average of one CSO per year), and NPDES basins 40, 41, 43, and 165 are uncontrolled. Structural improvements were recently completed at NPDES Basin 165, and it is now controlled.

Combined Sewer and CSO System

The Genesee Area is hydraulically isolated and tributary only to the King County combined sewer system. The combined system conveys wastewater from the main lines in the basins to the trunk line along Lake Washington (also called the lake line), to the King County Hanford Street Trunk B that runs along Charlestown Street (also called the Charlestown Street Trunk), into the King County Rainier Avenue Pump Station, and ultimately to the King County West Point Treatment Plant. The CSO control structures contain weirs that allow overflows if the capacity of the system in the downstream portion of the Genesee Area is exceeded. Overflows from the control structures are conveyed to the NPDES CSO outfalls, which discharge directly to Lake Washington.

Flows from Basin 165 are pumped from City of Seattle Pump Station 6 to the lake line. Flows from subsequent basins (basin 43, 42, 41, 40, and a portion of Basin 38) enter the lake line by gravity at discrete locations along the alignment. The combined flow in the lake line travels north to City of Seattle Pump Station 5, where it is pumped into the King County system. Flows from the northern section of Basin 38 flow by gravity and enter King County's system near the discharge of Pump Station 5. Flows from Basin 37 flow by gravity to the King County System at the Hanford Street Trunk B.

Model Development

A comprehensive model was developed for the Genesee Area to understand the hydrologic response to rainfall within the area and the hydraulics associated with the collection and overflow systems. A Wallingford Software InfoWorks model of the Genesee Area (originally built in 2001 and revised in 2006) was updated, extended, and refined for this analysis.

The development of the InfoWorks model was comprised of the following phases:

- Collection of data to support model construction
- Hydraulic model construction, including pipes, maintenance holes, and CSO facilities
- Hydrologic model construction including dry weather flow, wet weather flow, and groundwater infiltration
- Incorporation of boundary conditions such as downstream conditions and Lake Washington level into the model

The model developed for the Genesee Area includes the following:

- NPDES basins 165, 43, 42, 41, 40, 38, and 37
- SPU Pump Station 6 in NPDES Basin 165
- SPU Pump Station 5 in NPDES Basin 38
- NPDES CSO outfalls 165, 43, 42, 41, 40, 38, and 37
- Overflow structures 165, 43, 42, 41a, 41b, 40, 38, 37
- CSO facilities 9, 10, 11, and 12
- King County's Rainier Avenue Pump Station and the Hanford Street Trunk B

Monitoring and Precipitation Data

Monitoring data collected in the Genesee Area sewer system were the primary data used to assess the accuracy of the model and served as the basis for model calibration. The data consisted of depths and flows with corresponding precipitation amounts. Field observations, inspection reports, and survey information were also used to prepare the model for calibration.

For the Genesee model, the following data sources for the period January 2008 through January 2009 were used for calibration:

- Eight permanent monitoring sites at the NPDES CSO outfalls owned by Seattle Public Utilities (SPU) and maintained by ADS Environmental Inc. (ADS)
- Twenty-one temporary monitoring sites in the system to measure hydrologic and hydraulic conditions in the system
- Precipitation data from Rain Gage 18 owned by SPU and maintained by ADS
- Three monitoring sites operated for the SPU RainCatchers project (also known as the Lakewood RainCatchers project) maintained by Herrera Environmental Consultants

- Supervisory control and data acquisition (SCADA) data from SPU pump stations 5 and 6
- King County-provided data from monitoring site 059-443 installed near the bottom of the Genesee Area in Charlestown Street and SCADA data from the Rainier Avenue Pump Station
- Closed-circuit television inspections performed along the lake line downstream of Pump Station 6

From the precipitation monitoring, 10 key events were selected for the associated rain gauge based on the following criteria:

- Events with varied durations (long and short events)
- Events that approximate the once-per-year overflow event (November 6, 2008, event)
- Events that have high return intervals at varied durations (greater than 2 months)
- Events that cause varied overflow response

Due to local monitoring conditions, not all of these events were used to calibrate every basin. For some events and some monitors, flow-monitoring data did not correspond with recorded precipitation, likely because the rain gauge did not experience the same rainfall as others in different microclimates within the Genesee Area.

Model Calibration

The Genesee model was calibrated for 10 storm events at 29 locations. Calibration consisted of using rainfall, flow, and depth data collected during the flow-monitoring study (January 2008 through May 2009). Model output was compared to data from the permanent flow-monitoring sites at each of the area's overflow structures, and from temporary flow-monitoring sites installed throughout the Genesee Area during the 2008/2009 wet season.

The wet weather models were calibrated using the Generalized Likelihood Uncertainty Estimation (GLUE) approach, as developed by Beven and Binley (1992) and implemented for CSO models by MGS Engineering Consultants (2008, 2009). The GLUE process performs a large number of model runs with input parameter sets chosen randomly from within a defined range. The results were analyzed to identify "best fit" parameter sets, which are the sets that most accurately simulate observed conditions. Best fit parameter sets were selected for individual calibration groups which were then used in the uncertainty analysis.

The InfoWorks model was executed and the simulated output was compared to the measured flow and depth for each calibration event. Over 3,000 simulations were performed for the GLUE analysis using the following approach:

- Standardized bias, volume, and peak data were used to compute the goodness-of-fit between the simulation and measured data. Goodness-of-fit measures were weighted by meter and event. Meter weighting was required because equipment failure resulted in incomplete flow or depth records at some locations.

- The parameter sets were ranked by goodness-of-fit to identify best fit parameter sets for each calibration group.

The GLUE model runs were analyzed to determine the best fit parameter set for the individual calibration groups. Generally, the GLUE process resulted in reasonable parameters for all the calibration groups. The average goodness-of-fit for the most downstream monitor site in Genesee (maintenance hole [MH] 059-443) was 105 percent. This indicates that the simulated volumes predicted by the model were 5 percent higher than the measured volumes recorded by the monitor sites.

Long-Term System Performance Analysis

Long-term system performance of the Genesee system under existing and future conditions was determined from an uncertainty analysis using the calibrated model with an adjusted long-term rainfall record. The future condition evaluation determined an estimated CSO control volume with consideration of uncertainties associated with change in future rainfall patterns (i.e., due to climate change), model accuracy, and other potential sources.

The existing condition performance analysis provides additional evidence that NPDES CSO outfalls 40, 41, and 43 are not meeting SPU's long-term performance target, with an estimated 143, 186, and 176 CSOs occurring over the 31-year analysis period, respectively. The analysis also showed that NPDES CSO Outfall 165 is uncontrolled, but the control volume is less than 5,000 gallons, which is viewed as within the margin of error of the model. Additionally, recent retrofits (slip-lining and raising the overflow weir in Overflow Structure 165, August 2008) will likely decrease the overflow frequency. The performance analysis also showed that storage at CSO facilities is fully utilized during overflow events.

The calibrated InfoWorks model and an adjusted rainfall record (to account for uncertainties) were used to evaluate the future long-term performance of the Genesee system to develop an estimate of the CSO control volume. The CSO control volume is defined in terms of the volume of water that must be withheld (that is, stored, treated, or otherwise managed) in order to reach the one-overflow-per-site-per-year average. This study assumed that the volume of the 32nd-ranked overflow event within the 31-year data represents the existing-conditions control volume. The best-estimate control volume for each NPDES CSO outfall for the existing condition is presented in Table ES-1.

TABLE ES-1
Best-Estimate Control Volumes

Basin	Control Volume (gallons)
Basin 43	187,000
Basin 41	188,000
Basin 40	203,000

The project team, Combined Sewer Overflow (CSO) Program Director, and CSO Program Manager agreed to use control volumes derived from the hydraulic and hydrologic models including uncertainty factors for change in future rainfall precipitation, modeling, monitoring, and other potential sources. These control volumes, as modified by the rainfall scaling factors, will be used for modeling alternatives in the feasibility analysis and may be updated during preliminary engineering as new data become available.

Acronyms

ADS	ADS Environmental
BMPs	best management practices
City	City of Seattle
CSO	combined sewer overflow
CSS	combined sewer system
DWF	dry weather flow
Ecology	Washington State Department of Ecology
GIS	geographical information system
GLUE	Generalized Likelihood Uncertainty Estimation
gpcd	gallons per capita per day
MG	million gallons
MGD	million gallons per day
MH	maintenance hole
MLLW	mean lower low water
NAD	North American Datum
NAVD88	North American Vertical Datum of 1988
NPDES	National Pollutant Discharge Elimination System
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
PF	diurnal peaking factor
PSRC	Puget Sound Regional Council
RG	Rain Gage
SCADA	supervisory control and data acquisition
SPU	Seattle Public Utilities
USACE	United States Army Corps of Engineers

Glossary

basin	The area tributary to a permitted NPDES CSO outfall.
best-estimate control volume	The CSO control volume determined as the volume of the 32nd–ranked overflow event using scaled 31-year precipitation data. This scaling factor and associated control volume is a conservative assumption to account for potential future uncertainties in precipitation.
calibration group	A group of calibration points whose parameters are set to be equal during the randomized parameter sampling of automated calibration. These flow-monitoring catchments may or may not be part of the same basin.
calibration point	A flow-monitoring site selected for model calibration. One or more meters from a given calibration point may be used to calibrate the model. Not all meters were used for calibration. See Section 5.4 for a discussion of calibration points. One or more calibration points make up a calibration group. The net area tributary to a calibration point is a flow-monitoring catchment.
control volume	The CSO control volume is defined in terms of the volume of water that must be withheld (that is, stored, treated, or otherwise managed) in order to reach the one-overflow-per-NPDES-site-per-year average.
controlled	Refers to an NPDES CSO outfall (and associated basin) that is overflowing less than or equal to an average of one untreated discharge per year.
existing conditions control volume	The CSO control volume determined as the volume of the 32nd-ranked overflow event using unscaled 31-year precipitation data. This volume does not account for future uncertainties such as climate change.

flow-monitoring catchment Multiple subcatchments make up a flow-monitoring catchment, which is the net tributary area contributing flow to a given flow-monitoring site (often identified by its maintenance hole identifier, such as 059-451) or calibration point. One or more flow-monitoring catchments make up a basin, through which flows are measured by a permanent monitoring site. Multiple flow-monitoring catchments also can make up a calibration group.

HydroBrake A passive flow-control device that uses vortex action to provide near constant head and constant discharge for varying differential hydrostatic heads. HydroBrakes regulate the flow of combined sewage to downstream conveyance facilities and cause the excess flow to be diverted to storage or the outfall. See Section 4.3.3 for a description of HydroBrakes.

meter A single entity of data from a flow-monitoring site. Meters are used to develop some model components, and some meters are used for model calibration. An example of a single meter is 059-451 MP1 Depth, which is located at monitoring site 059-451.

monitoring site A single monitoring site may contain multiple meters. For instance, monitoring site 059-451 includes meters MP1 Depth, MP2 Depth, and MP2 Velocity.

sensor Multiple sensors may make up a meter. For instance, the ultrasonic sensor and pressure sensor together make up the depth meter.

subcatchment The smallest area unit in the model. Each subcatchment is linked to a node where flows enter the CSS system. Multiple subcatchments make up a flow-monitoring catchment. The term "subcatchment" matches InfoWorks model terminology.

uncontrolled Refers to an NPDES CSO outfall (and associated basin) that is overflowing more frequently than an average of one untreated discharge per year.

usable storage volume The volume of a storage tank or storage pipe below the storage control elevation (usually a weir). See Section 4.3.4 for a description of storage systems.

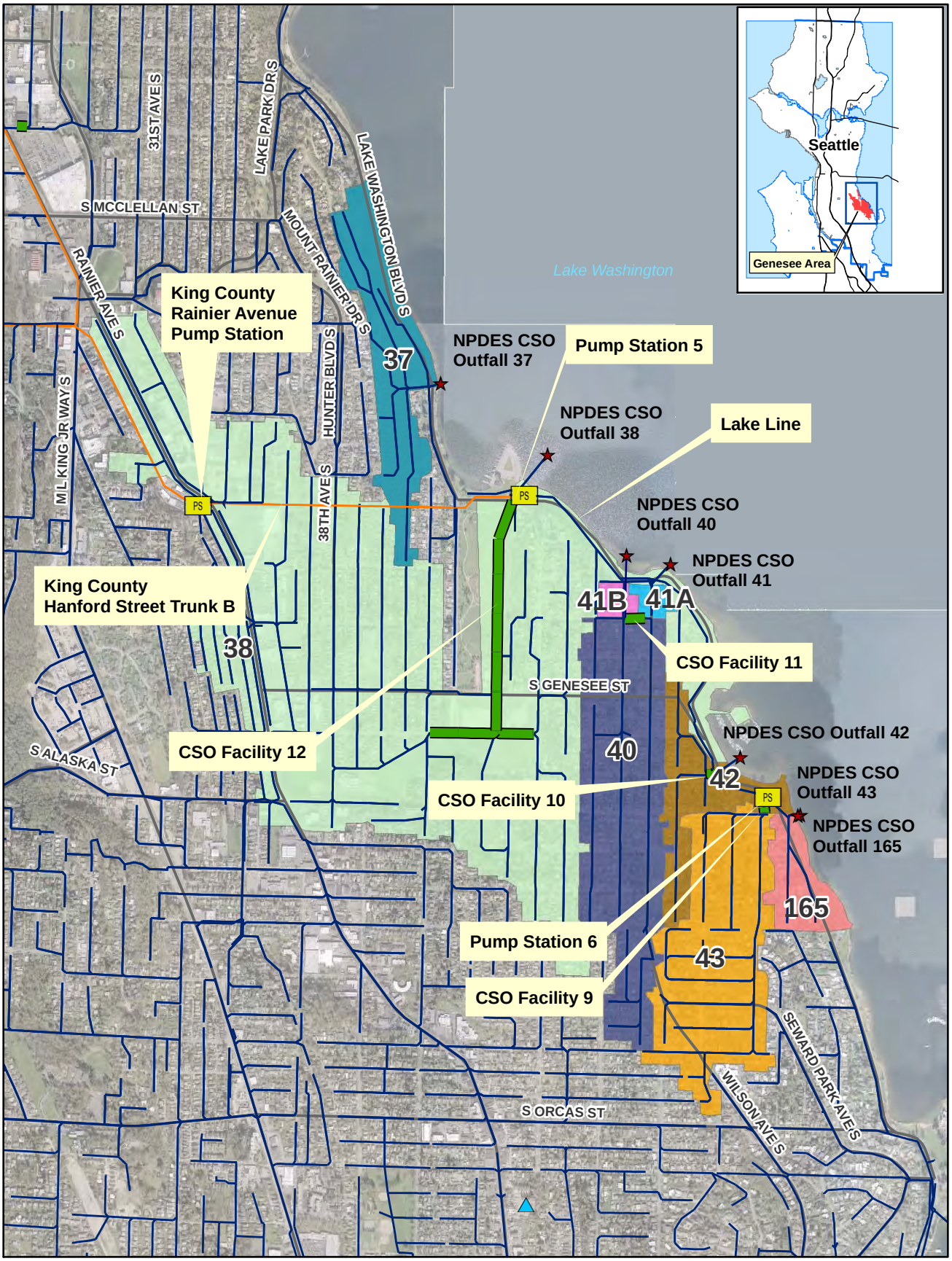
1.0 Introduction

The Genesee Combined Sewer Overflow (CSO) Area is 690 acres (1.05 square miles) located in southeast Seattle, just north of Seward Park. The area is bounded by Lake Washington on the east, Rainier Avenue on the west, Mount Baker Boulevard on the north, and South Orcas Street on the south. The Genesee Area is served primarily by a partially separated sanitary sewer system that conveys wastewater and runoff from directly connected rooftops and area drains to the trunk line along Lake Washington (also called the lake line), to the King County Hanford Street Trunk B that runs along Charlestown Street (also called the Charlestown Street Trunk), into the King County Rainier Avenue Pump Station, and ultimately to the King County West Point Treatment Plant. CSO outfalls discharge directly to Lake Washington. Stormwater from separated portions of the Genesee Area is discharged to Lake Washington through multiple storm drain outfalls. Figure 1-1 is a map of the area.

The combined sewer system (CSS) in the Genesee Area conveys both sanitary and stormwater flow. During large precipitation events, the capacity of the CSS is exceeded and the system overflows to Lake Washington as a CSO. The Genesee Area has seven CSO outfalls discharging to the lake. A computer model of the CSS in the Genesee Area will be used to assess the performance of the existing system and analyze system modifications and new CSO control facilities that will meet the City of Seattle's CSO reduction goal. This report summarizes the development, refinement, and calibration of the computer model of the CSS in the Genesee Area.

1.1 Project Background

The Washington State Department of Ecology (Ecology) administers the City of Seattle's (City's) National Pollutant Discharge Elimination System (NPDES) permit for CSO outfalls. Pursuant to its NPDES permit and applicable state and federal laws concerning CSOs, the City is implementing a CSO Reduction program that aims to achieve the greatest reasonable reduction of CSOs at the earliest possible date. The City's 2010 CSO Reduction Plan Amendment identifies the Genesee Area as one of its highest-priority CSO basins to control during the period between 2010 and 2015. The Genesee Area's seven CSO outfalls discharging to the lake are designated in the NPDES permit as CSO outfalls 37, 38, 40, 41, 42, 43, and 165. The CSO basins discharging through these outfalls are referred to as NPDES basins 37, 38, 40, 41, 42, 43, and 165. Figure 1-1 shows the Genesee NPDES basins.



LEGEND

- PS Pump Station
- Outfall
- Rain Gage 18
- King County Combined Sewer Pipe
- SPU Combined Sewer Pipe
- CSO Facility
- NPDES Basin

0 500 1,000
Feet

FIGURE 1-1
Genesee Area, Basins and CSO Outfalls
Modeling Report
SPU Genesee Area

CH2MHILL

Based on historical CSO frequency measurements collected between 1998 and 2009, NPDES basins 37, 38, and 42 are controlled (meaning that they meet the project goal and regulatory requirement of a long term average of one CSO per year), and NPDES basins 40, 41, 43, and 165 are uncontrolled. Structural improvements were recently completed at NPDES Basin 165 (September 2008), and that basin now controlled.

In 2006, Seattle Public Utilities (SPU) updated the InfoWorks computer model of the Genesee Area (first developed in 2001) and calibrated it to more recent flow-monitoring data. The consultant updating the model made the following key observations and recommendations for SPU to consider prior to further optimization of the model:

- Recommended that the accuracy of CSO monitoring be improved
- Observed that the model results for NPDES basins 38, 40, 41, and 165 are influenced by restricted downstream conveyance capacities—the lake line trunk, King County Hanford Street Trunk B, SPU pump stations 5 and 6, and King County Rainier Avenue Pump Station

SPU tasked CH2M HILL with expanding the 2006 Genesee CSO Model (discussed further in Section 1.5) to further review these areas, specifically adding Genesee basins 37 and 38 as well as SPU pump stations 5 and 6 and the King County Rainier Avenue Pump Station.

To assist the City in developing CSO reduction strategies and facility improvements in the three NPDES basins that require new control measures to comply with regulations (NPDES basins 40, 41, and 43), the 2006 Genesee CSO Model was updated to account for the following:

- Additional areas (basins 37 and 38, and the King County Rainier Avenue Pump Station)
- Recent flow-monitoring data
- New HydroBrake curves
- Updated overflow weir information (based on recent SPU surveys)

Other parts of the model, such as subcatchment delineation, impervious area computation, and population estimates, needed to be revised to support investigation of the flow routing options and feasibility of green stormwater infrastructure alternatives.

1.2 Project Objectives

The purpose of the hydraulic modeling task was to develop a tool that allows for the evaluation of CSO design alternatives. Construction of the hydraulic model will also facilitate a thorough understanding of the sewer system, the response of the sewer system to various precipitation events, and the characteristics of CSOs. Meeting this purpose involves the following objectives:

- Characterization of the performance of the existing diversion structures, outfall structures, storage facilities, conveyance pipes, and HydroBrakes
- Simulation of SPU pump stations 5 and 6 and the King County Rainier Avenue Pump Station
- Characterization of the hydrologic performance of the basins in the Genesee Area

- Simulation and evaluation of hydraulic grade lines and flow rates throughout the Genesee Area under varying conditions based on historical precipitation and known boundary conditions
- Prediction of long-term CSO frequencies, volumes, and flow rates
- Identification of hydraulic capacity deficiencies and opportunities within the Genesee Area.

SPU's needs and goals for the model, as well as essential attributes of the model, are summarized in the *Genesee Modeling Plan* (CH2M HILL, 2008b).

1.3 Study Boundaries

The Genesee Area is adjacent to Lake Washington in southeast Seattle. The Genesee Area topography is approximately half relatively flat to mildly sloping (Basin 38) and half moderately to steeply sloping in the basins near the lake. The study area is depicted in Figure 1-1, which shows the Genesee Area and the corresponding NPDES basins, as well the significant components of the King County system.

The Genesee Area is an isolated area with no upstream or downstream relationship to any other Seattle NPDES basin. All the collected CSS flows from the Genesee Area flow directly to the King County collection system at a single location, just upstream of the King County Rainier Avenue Pump Station, which is included in this study. The operational performance of the Rainier Avenue Pump Station in terms of pumped flow rate versus wet-well depth is used as a downstream hydraulic boundary condition.

The modeling study area for the Genesee Area includes the following:

- NPDES basins 37, 38, 40, 41, 42, 43, and 165, with City of Seattle Pump Stations 5 and 6
- NPDES overflow structures 37, 38, 40, 41A, 41B, 42, 43, and 165
- CSO facilities 9, 10, 11, and 12
- King County Rainier Avenue Pump Station and the King County Hanford Street B Trunk

1.4 Supporting Documentation

Several documents have been prepared to support the modeling efforts for the CSO reduction project. In addition to this report, the reports and plan documents listed below were created to support the development of the InfoWorks CSS model:

- *Quality Assurance Project Plan: Genesee Area Flow Monitoring Study* (CH2M HILL, 2008a). The QAPP described the monitoring goals and objectives, parameters to be studied, quality objectives and procedures, and data management procedures.
- *Genesee CSO Reduction Project Flow Monitoring Report: January 2008 through May 2009* (CH2M HILL, 2009a). The Flow Monitoring Report documented the results of 17 months of flow monitoring conducted in the Genesee Area with the objective of

accurately characterizing the performance of the Genesee Area CSS and facilities before, during, and after storm events.

- *South Genesee Combined Sewer Overflow Reduction Plan Project: Genesee Modeling Plan* (CH2M HILL, 2008b) documented the proposed approach to modeling the Genesee Area.

1.5 Summary of Existing 2001 and 2006 Models

SPU contracted Earth Tech Inc. in 2001 to create a hydraulic model and a summary report titled *Sewerage System Modeling and Assessment Project – Basin Group C Model Development Report* (Earth Tech, 2001). The report addressed the operation of combined sanitary sewer facilities that were modeled in the City's CSO Plan Amendment. The report described the methodology used in the development of the computer model and the documented simulation results for NPDES basins 39, 40, 41, 42, 43, and 165. The model was constructed in InfoWorks version 3.0. Earth Tech based the construction of the model on the City's geographical information system (GIS) data, record drawings, and the available sewer cards. The model was calibrated using flow-monitoring data collected between February and April 2000, with the exception of Basin 43, which was calibrated for the period of November 7 through November 28, 1999.

Earth Tech updated the model in the summer of 2006 and tried to further calibrate the model with raw data collected from September 2004 to January 2006. An updated modeling report was provided with this 2006 update (Earth Tech, 2006). Additional flow data were collected at 17 locations in the Genesee Area from 2006 to 2007 and reviewed by SPU personnel for data quality and completeness. The period of record appears to contain data from Geotivity, ISCO, and ADS Environmental (ADS) monitoring equipment. Using the same period, CH2M HILL evaluated the data to determine if the data were sufficient to calibrate and verify the expanded hydraulic model. As presented to SPU in August 2007, the data were determined to be insufficient to meet the project needs because of lack of quality data during storm events.

Based on Earth Tech's findings, SPU recognized that downstream areas with restricted conveyance capacities have significant influence on the Genesee Area. For the purpose of this project, SPU tasked CH2M HILL with expanding the existing InfoWorks model to include NPDES basins 37 and 38, SPU pump stations 5 and 6, and the King County Rainier Avenue Pump Station.

2.0 Genesee Area Characterization

2.1 Conveyance System

The CSS in the Genesee CSO Area generally flows from southeast to northwest. Flows from Basin 165 enter the lake line at the southeast end of the basin and are lifted by SPU's Pump Station 6. Downstream of Pump Station 6, flows from basins 43, 42, and 41 enter the lake line. Flows from Basin 40 flow into Basin 41. The cumulative flow from these two basins flows into the lake line, which is joined with flows from a small portion of Basin 38. After these cumulative flows are lifted at SPU's Pump Station 5, flows from the remainder of Basin 38 are directed into the Hanford Street Trunk B. Flows from Basin 37 join with flows from basins 38 through 43 and 165; these cumulative flows are pumped by King County's Rainier Avenue Pump Station and ultimately flow to the King County West Point Treatment Plant. Each basin has a CSO overflow structure, the overflows of which are directed to Lake Washington. Figure 2-1 presents a schematic of the Genesee Area conveyance system.

The Genesee Area contains more than 135,000 linear feet of pipe ranging from 8-inch-diameter to 144-inch-diameter. SPU operates and maintains more than 95 percent of the pipe in the Genesee Area; King County operates and maintains the remainder of the pipe, which consists of the Hanford Street Trunk B. Approximately 900 connecting structures connect to the mainline pipe; 90 percent of these connecting structures are maintenance holes. Table 2-1 presents pipe length statistics.

In addition to the mainline pipe, the Genesee Area contains approximately 330,000 linear feet of lateral connections between parcels and the CSS. Four CSO control facilities in the area consist of in-line and offline storage pipe ranging from 54-inch-diameter to 144-inch-diameter, with a combined usable storage volume of more than 500,000 gallons. Each storage pipe (control facility) has a HydroBrake and an overflow weir to control CSOs. These CSO control facilities are described in greater detail in the individual basin discussions below.

Recent maintenance and modifications to the Genesee CSO system include:

- Cleaning along the lake line to address constricted flow between Maintenance Hole (MH) 060W-012 and MH 060W-019 (completed in 2009).
- The weir at Overflow Structure 165 was raised approximately 12 inches (completed September 26, 2008).
- Pipes in Basin 165 were cleaned, rehabilitated, and slip-lined (completed in 2009).

2.2 Climate

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

The City of Seattle operates a network of rain gauges across the city; the closest to the Genesee Area is Rain Gage 18 (RG 18), located outside of the Genesee Area at Aki Kurose Middle School on South Graham Street. RG 18 is 2.1 miles from the farthest upstream point in the Genesee Area (see Figure 1-1.). RG 18 receives an annual average of 35.0 inches of precipitation (1978 to 2007). Figure 2-2 shows the average rainfall distribution by month at RG 18. SPU is searching for another rain gauge site within the Genesee Area to supplement data from RG 18.

2.3 Land Use

Land use in the Genesee Basin is predominantly single-family residential with some multi-family and commercial areas along and near Rainier Avenue. In addition, much of Genesee Park and Playfield lies within the Genesee Basin, as well as Lake Washington Boulevard and its associated pedestrian trail. Figure 2-3 shows land use in the Genesee Area.

2.4 Soils

Soils in the Genesee Area are primarily glacial till (Qvt), with some areas of alluvium (Qal), tertiary bedrock (Tb), and small portions of modified land (m). Figure 2-4 shows the distribution of soils within the Genesee Area. A portion of Basin 38 is underlain with alluvium, which tends to have higher infiltration rates. The rest of the area is mostly glacial till in the north and bedrock in the south; both soil types have low infiltration rates. The portion of Basin 38 identified as modified land is a historical landfill that was capped and is currently used as Genesee Park.

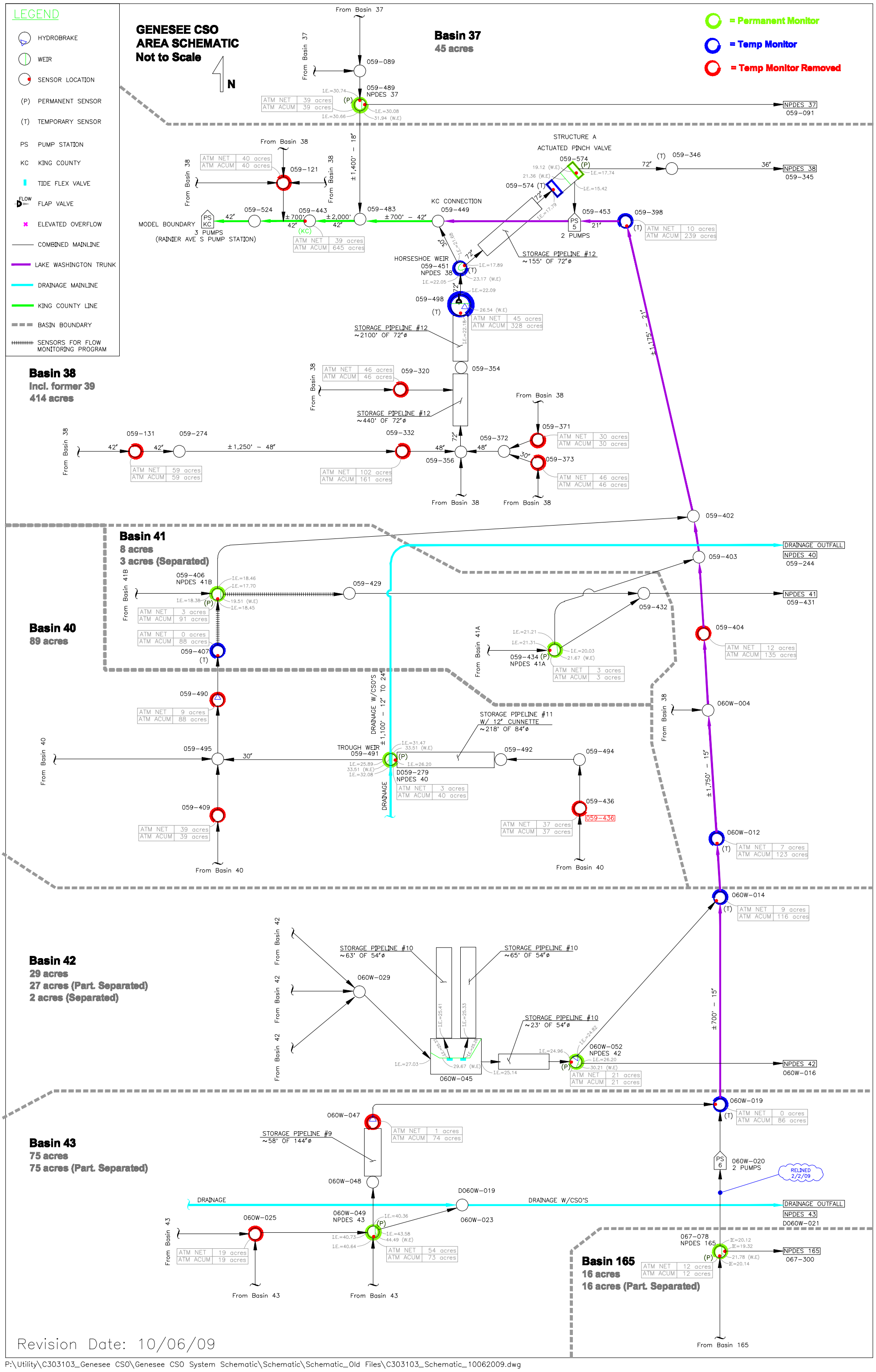
2.5 Population

The total population of the Genesee Area is estimated to be 4,346 based on 2000 Census data (Puget Sound Regional Council, 2007). This equates to an average of 6.45 people per acre. The eight basins have population densities ranging from 4.49 people per acre in Basin 165 to 7.11 people per acre in Basin 38. Table 2-2 presents population distribution by basin. The Genesee Area is not expected to undergo significant conversions of single family to multi-family housing. Thus, the population of this area is expected to remain steady.

2.6 Basins

2.6.1 Basin 165

Basin 165 is the southernmost basin in the Genesee Area and is 11.6 acres in size. Approximately 50 percent of the area in the basin is partially separated, and the remaining area is fully combined. In a partially separated area, drainage from most streets and new homes is directed to a separate stormwater system. In a fully combined area, all drainage from streets and homes is directed to a combined sewer system. Flows from Basin 165 are conveyed to the lake line by Pump Station 6, which has a pumping capacity of 0.65 million gallons per day (MGD) based on drawdown tests discussed further in Section 4.3.20 and Appendix A. Overflows at Basin 165 occur when the capacity of Pump Station 6 is exceeded. Data collected during the January 2008 – June 2009 monitoring period indicated that two overflows occurred, although data for one of the overflows are anomalous. A number of improvements were made in Basin 165 in 2008 and 2009 in an effort to decrease overflows.



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The improvements included root-cutting, pipe rehabilitation (in situ cured-in-place lining), and raising the CSO weir at Overflow Structure 165 by approximately 12 inches.

TABLE 2-1
Summary of Combined Sewer Pipe in the Genesee Model

Diameter (inches)	Length of Pipe Owned by King County (feet)	Length of Pipe Owned by SPU (feet)	Total Length (feet)	Percent of Total
8	-	71,330	71,330	52.7
10	-	13,655	13,655	10.1
12	-	11,877	11,877	8.8
14-18	-	16,918	16,918	12.5
20-23	-	3,854	3,854	2.8
24-29	-	1,966	1,966	1.5
30	-	1,622	1,622	1.2
36	-	1,168	1,168	0.9
42	2,565	2,067	4,632	3.4
48	-	1,823	1,823	1.3
54	-	145	145	0.1
66	2,413	-	2,413	1.8
72	-	3,625	3,625	2.7
84	-	217	217	0.2
144	-	65	65	0.0
Total	4,978	130,332	135,310	100

2.6.2 Basin 43

Basin 43 is in the southeastern portion of the Genesee Area and is 73.7 acres in size. Approximately 80 percent of the basin is partially separated; the remaining area is fully combined. Flows from Basin 43 pass through CSO Facility 9 before entering the lake line and continuing to Pump Station 5. CSO Facility 9 contains an overflow weir upstream of an in-line storage pipe and HydroBrake. The 144-inch-diameter storage pipe has a usable volume of 55,000 gallons. Flows over the Overflow Structure 43 combine with stormwater flows in a storm drain pipe that discharges into Lake Washington. Data collected during the January 2008 – June 2009 monitoring period indicate six overflows occurred. Basin 43 is the location for the Lakewood RainCatchers study, which is evaluating the use of decentralized strategies (a form of source control) for reduction of CSOs to Lake Washington (Herrera, 2007).

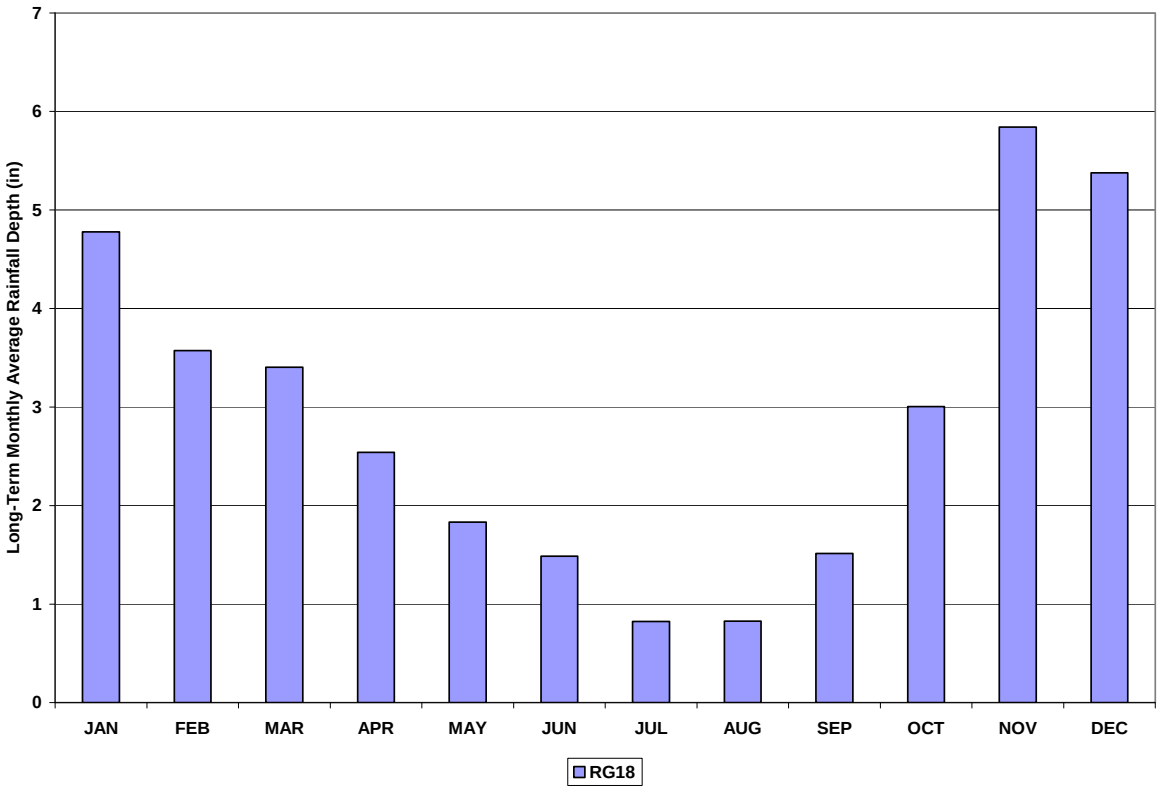


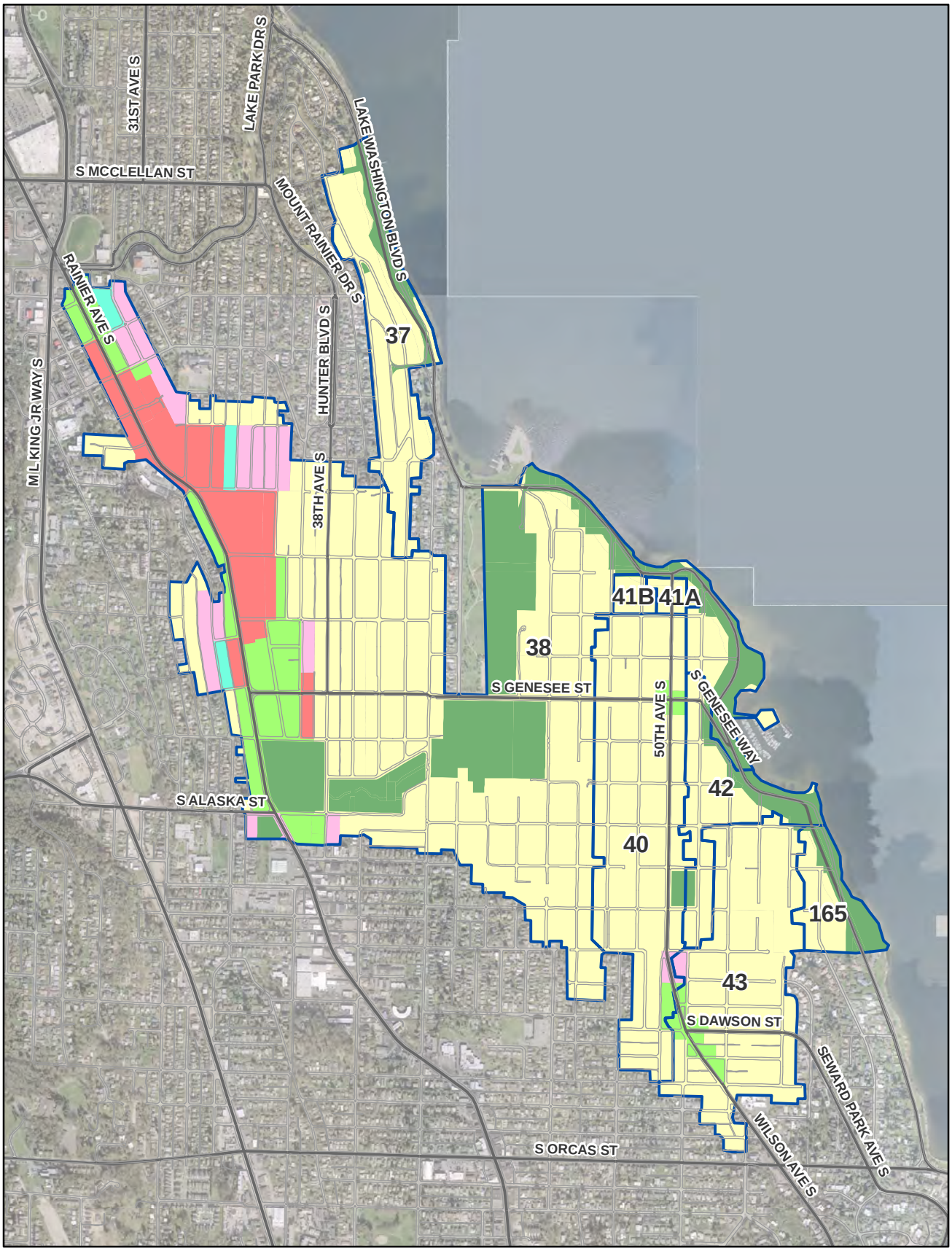
FIGURE 2-2: MONTHLY AVERAGE RAINFALL IN THE GENESEE CSO AREA (1978 TO 2007)

2.6.3 Basin 42

Basin 42 is in the southeastern portion of the Genesee Area and is 28.2 acres in size. Approximately 90 percent of the basin is partially separated; the remaining area is fully combined. Flows from Basin 42 pass through CSO Facility 10 before entering the lake line and continuing to Pump Station 5. CSO Facility 10 contains both a HydroBrake and two parallel 54-inch-diameter storage pipes with a usable storage volume of 17,000 gallons. The CSO facility was upgraded in 2006 by installation of a sharp-crested weir, installation of baffles for floatables control, and conversion of the in-line storage to offline storage. The sharp-crested weir improves the measurement of frequency and volume of CSOs and is adjustable. The conversion from in-line to offline storage ensures that storage is used only when no system capacity is available downstream. Data collected during the January 2008 – June 2009 monitoring period indicated that one overflow occurred at Overflow Structure 42.

2.6.4 Basin 41

Basin 41 is located in the central portion of the Genesee Area and is divided into separate tributary areas by overflow structures 41A and 41B. These areas are 2.8 and 2.7 acres in size, respectively. The area tributary to overflow structure 41A is a combined system that flows directly into the lake line. Data collected during the January 2008 – June 2009 monitoring period indicate no overflows at this location.



LEGEND

- Commercial
- Multi-Family
- Mixed Use
- Neighborhood Commercial
- Single Family
- Park
- Basin

0 500 1,000
Feet

FIGURE 2-3
Land Use in Genesee Area
Modeling Report
SPU Genesee Area

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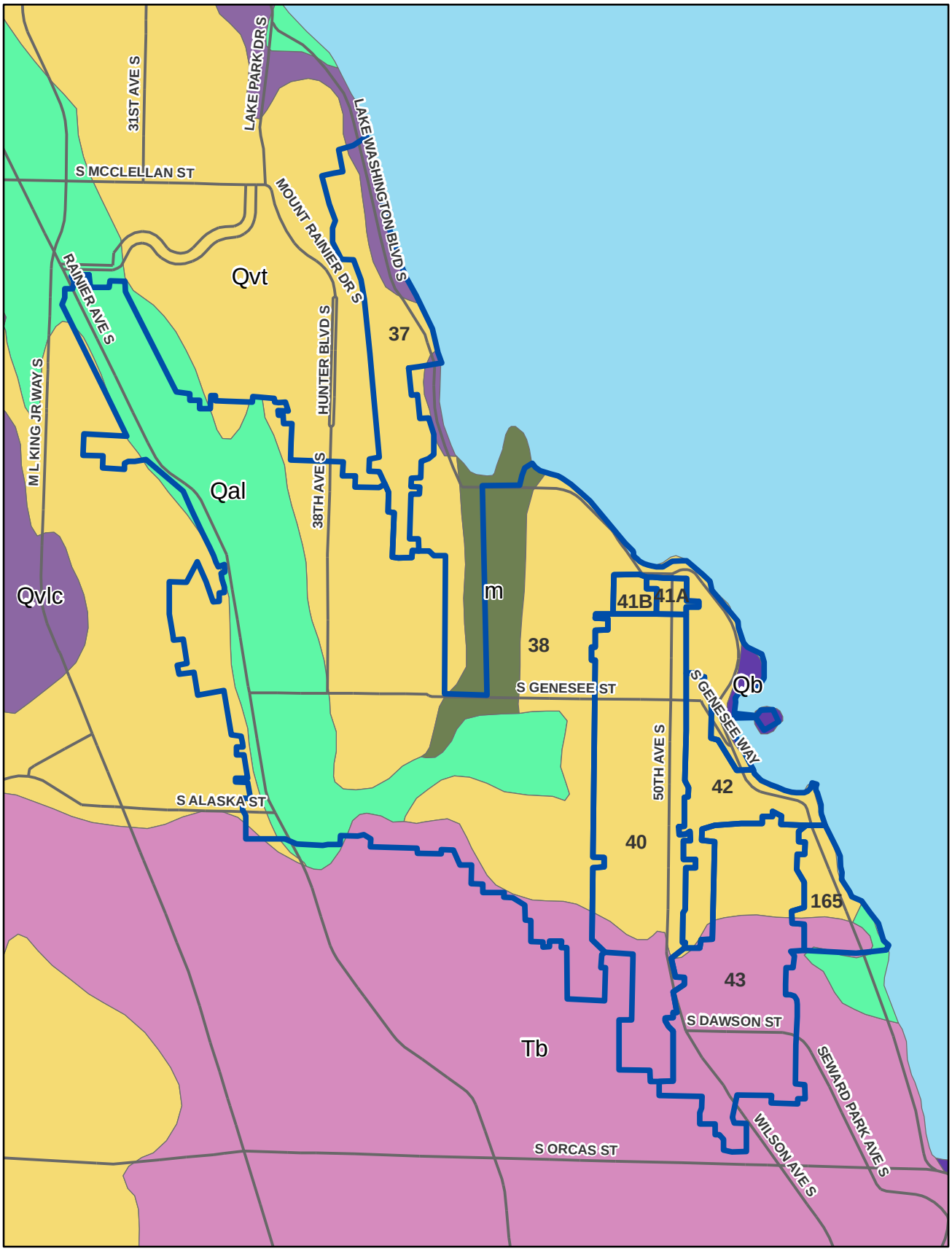
SEA \\SIMBA\PROJ\SEATTLEPUBLICUTILCSO\373008WA1GENMODEL\GIS\LAYOUT\H&HREPORT\GENESEE_LANDUSE_FIG2-4.MXD TJANTZEN 4/2/2010 12:38:29



Qal (silt/sand/gravel)
Qb (sand/gravel)
Qvlc (silt/clay) (Lawton Clay)
Qvt (till/hardpan)
Tb (sandstone) (Blakely Fm)
m (silt/sand/debris/slag)
water
Basin

0 500 1,000
Feet

FIGURE 2-4
Soil Type in Genesee CSO Area
Modeling Report
SPU Genesee Area

CH2MHILL

SEA \\SIMBA\PROJ\SEATTLEPUBLICUTILCSO\373008WA1GENMODEL\GIS\LAYOUT\H&HREPORT\GENESEE_SOIL_FIG2-4.MXD TJANTZEN 4/2/2010 12:46:27

TABLE 2-2
Population in the Genesee CSO Area

	Basin							Total Genesee CSO Area
	37	**38**	**40**	**41**	**42**	**43**	**165**	
Population	202	3,094	500	37	122	339	52	4,346
Area (acres)	39.1	435.4	87.7	5.5	20.8	73.7	11.6	674
Population Density (people/acre)	5.17	7.11	5.70	6.73	5.87	4.60	4.49	6.45

The area tributary to overflow structure 41B is a partially separated system. As noted above in the description of the conveyance system, flows from Basin 40 are passed through the HydroBrake in CSO Facility 11 into Basin 41 and then into the lake line. Because the weir in Overflow Structure 41B is the lowest along the lake line, this structure serves as a relief point for the entire lake line. Data collected during the January 2008 – June 2009 monitoring period indicate that 13 CSO events occurred at this overflow structure.

The NPDES CSO Outfall 41 pipe is severely damaged, making the measurement of overflows at this location difficult. The outfall pipe likely causes a backwater condition during overflow periods. Because overflow rates and volumes are calculated using a weir equation that assumes free flow over the weir, it is likely that the reported overflow volumes are much higher than those that actually occur. Repair of this pipe is currently planned for fall of 2010.

2.6.5 Basin 40

Basin 40 is located in the south-central portion of the Genesee Area and is the second largest of the all the basins with an area of 87.7 acres. More than 90 percent of the basin is partially separated; the remaining area is combined. Flows from this basin pass through CSO Facility 11 and Basin 41 before entering the lake line and proceeding to Pump Station 5. CSO Facility 11 consists of an in-line storage pipe and overflow weir upstream of a HydroBrake. The 84-inch-diameter storage pipe has a usable storage volume of 62,000 gallons. The weir in Overflow Structure 40 is an elevated half-pipe that acts as a double-sided weir. Overflows into this pipe join storm drain flows into Lake Washington. Data collected during the January 2008 – June 2009 monitoring period indicate three overflow events at this location.

2.6.6 Basin 38

Basin 38 is located in the western portion of the Genesee Area, and is the largest basin at 435.4 acres. Basin 38 includes area from what was historically Basin 39. The NPDES CSO 39 Outfall was abandoned and redirected to discharge through the NPDES CSO 38 Outfall on January 12, 2006. Approximately 30 percent of Basin 38 is combined; the remaining area is partially separated.

Flows from a small portion of this basin enter the lake line and are pumped by Pump Station 5 into the Hanford Street Trunk B. Pump Station 5 has a pumping capacity of 2.19 MGD based on drawdown tests discussed further in Section 4.3.21 and Appendix A. Flows from most of this basin are slowed and detained by the 72-inch-diameter, 383,000-gallon (usable volume) in-line storage tank and associated HydroBrake that make up CSO Facility 12. A weir above the HydroBrake and the slope of the storage pipe limit the usable storage volume to just over half of the total storage pipe. Flows through the HydroBrake or over the HydroBrake weir encounter a horseshoe weir at MH 059-451. Sewage normally flows around the horseshoe weir, is joined by flows from Pump Station 5 at the grit chamber, and flows into the Hanford Street Trunk B. During large storm events, depths exceed the horseshoe weir height at MH 059-451 and flow into a 72-inch-diameter storage pipe behind the two weirs that make up Overflow Structure 38. Extreme high flows overtop the second of these two weirs and flow into Lake Washington. Data collected during the January 2008 – June 2009 monitoring period indicate one overflow event at this location.

2.6.7 Basin 37

Basin 37 the northernmost basin in the Genesee Area and is 39.1 acres in size. Approximately 20 percent of this basin is combined; the remaining area is partially separated. Flows from this basin directly enter the Hanford Street Trunk B downstream of Pump Station 5 and Basin 38. The pipe leading to Overflow Structure 37 is relatively steep, and rarely experiences high depths. Data collected during the January 2008 – June 2009 monitoring period indicate no overflow events at this location.

3.0 Data Collection

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

3.1 Data Filling and Metadata

The data used to develop the Genesee model were obtained from a variety of sources, including the 2006 Genesee CSO Model, SPU GIS, record drawings, and field surveys. Metadata is information about the data that includes the data source, field names and data codes, and horizontal and vertical projections. The following are sources of GIS metadata that CH2M HILL used in the project:

- http://www.ci.seattle.wa.us/GIS/docs/availdata.htm#property (City of Seattle GISWEB Available Datasets)
- "Geoguide" (Seattle Public Utilities - Information Technology, 2007)

The model was developed primarily from the 2006 Genesee CSO Model (see Section 1.5) and SPU's GIS data. Once all the data were compiled and brought into InfoWorks, initial reviews of the system were completed to identify missing data. Section 3.2 presents a comprehensive data gap analysis on the quality of data from these sources. In most instances where the reviews identified gaps, interpolation was used to fill the data gaps. Field surveys were conducted at overflow structures to obtain data with greater accuracy, and all critical data gaps were filled.

User-defined flags within the model indicated data sources of individual model elements, including data fields populated through interpolation. Table 3-1 is a list of user-defined flags that denote sources of data used within the Genesee model.

3.2 Gap Analysis Results

To determine the extent of information needed to develop the updated model, a review of the 2006 Genesee CSO Model and available data was completed and is summarized as follows:

- The physical connectivity (pipes and nodes) in the 2006 Genesee CSO Model of basins 39, 40, 41, 42, 43, and 165 closely correlated to the GIS and were generally sufficient to meet the project objectives.
- The GIS contained adequate data in Basins 37 and 38 to expand the model without the need for extensive surveying throughout the area. Data gaps were filled through interpolation and these data were documented in the model as "interpolated" using data flags (see Table 3-1).

TABLE 3-1
Genesee Model Data Flags

ID	Description	Color
#D	System Default	
AB	Record Drawing Information	
AD	ADS Monitor Installation Report or Detailed Drawings	
AS	Assumed Information	
DM	Developed for Model[1]	
GC	GIS Data Corrected	
GS	Imported from GIS	
FS	Field Survey	
IF	Inferred Data	
IN	Interpolated	
PD	Population Data, Derived from Puget Sound Regional Council	

[1] – Refers to data from other sources or that are the product of model-specific analysis. An example is the weir coefficient determined from HDR (2008) and Street et al. (1996).

- Updated data for SPU's pump stations 5 and 6 and King County Rainier Avenue Pump Station were needed. Drawdown tests were conducted at the SPU pump stations in June 2007 to verify capacity. For the King County Rainier Avenue Pump Station, limited supervisory control and data acquisition (SCADA) data and information from King County were used for the basis of the pump station capacity. A discussion of the SCADA data provided by King County can be found in Section 4.4.3 of the Flow Monitoring Report (CH2M HILL, 2009a).
- Flow-monitoring data upstream and downstream of the SPU pump stations in combination with the 2007 drawdown tests and SPU SCADA data were sufficient for modeling the pump stations.
- A review of available flow-monitoring data in August 2007 determined that there were insufficient flow-monitoring data to support hydraulic modeling on basins upstream of the CSO outfalls, and that the general hydrology of the basin models needed to be improved for the purposes of this project. From January 2008 through May 2009, 20 temporary monitors were installed and maintained to obtain water level and velocity information at sites that support simulating the HydroBrakes, detention facilities, and hydrologic loading upstream in the Genesee Basin. Data from these temporary monitors along with three monitors from SPU's RainCatchers program and data from one monitor provided by King County complement the existing eight permanent monitors installed for the City's NPDES reporting.
- Model catchments and load points were adjusted to reflect the flow-monitoring basin delineation. These adjustments resulted in changes to the impervious and pervious areas within each catchment of Earth Tech's 2006 Genesee model. The adjustments were made

using data from the GIS sewer system, drainage system catchment areas, digital terrain model, and land use shapefiles.

- The CSO diversion structure configurations were updated and completed using data from ADS detailed drawings and site installation sheets, as well as data from surveys conducted by SPU in February and March 2009. Most of the surveys were conducted using three-dimensional laser scanning technology.
- In reviewing the previous monitoring data, it was difficult to confirm the reported CSO overflow volumes due to questionable data sets and incorrect empirical weir formulas. After correcting the weir equations, there was still uncertainty in the current calculations used to predict the overflow volumes. This uncertainty is due to the general monitoring environment and structure configurations within each of the CSO monitoring sites.
- The King County SCADA data CH2M HILL reviewed for the King County Rainier Avenue Pump Station appeared to be significantly different from more recent drawdown tests. Communication with King County's Wastewater Treatment Division (King County, 2008) resulted in using the "Total Flow" tagged data as the best source of flow data through the station.

3.3 Sources of Information and Data Hierarchy

Construction of the Genesee model required compiling data from multiple agencies. In general, SPU's GIS, record drawings, and other non-record record drawings, supplemented with survey and field investigations, were used to develop the system information in the hydraulic model. Flow-monitoring and SCADA data were used for flow inputs. Lake Washington water level information from the United States Army Corps of Engineers (USACE) was used as a boundary condition. Precipitation data were obtained from the network of rain gauges maintained by SPU. Table 3-2 lists the types of data used for the Genesee model and the sources of the data.

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

1. Survey data
2. Record drawings
3. GIS
4. Interpolated between known points
5. Inferred/assumed based on best available knowledge

3.4 Horizontal and Vertical Datums

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

- Horizontal: North American Datum (NAD) 1983 HARN StatePlane Washington North FIPS 4601 Feet (North American Datum of 1983)
- Vertical: NAVD88 (North American Vertical Datum of 1988)

TABLE 3-2
Model Development Data Sources

Data Description and Purpose	Data Source and Type	Dates
Pipes and Maintenance Hole Data		
Configuration and specifications (for hydraulic analysis): invert elevations, ground elevations, size, length and connectivity, sewer type	SPU GIS files	2007, 2009
	SPU record drawings	1929 – 1931, 1968 – 1970, 1985, 1998, 2005
	ADS site install and detail drawings	2007 - 2009
	SPU survey	2008 - 2009
CSO Facility Data		
Configuration and specifications (for hydraulic analysis): facility size, slopes, elevations	SPU record drawings	1929 – 1931, 1968 – 1970, 1985, 1998, 2005
	ADS site install and detail drawings	2007 - 2009
HydroBrake stage-discharge curves	Manufacturer's data	1995
	ADS meter data	2008 - 2009
Overflow Structure Data		
Configuration and specifications (for hydraulic analysis): weir heights/elevations	SPU record drawings	1929 – 1931, 1985, 2005
	ADS site install and detail drawings	2007 - 2009
	SPU survey	2009
Lake Washington water surface elevation (for boundary conditions)	USACE data download	2008 - 2009
Pump Station Data		
Configuration and specifications (for hydraulic analysis)	SPU record drawings	1929 – 1931, 1970, 1998
	King County record drawings	1929 – 1931, 1970
Flow-discharge operations	Field draw-down tests	2007
	SPU SCADA data	2008 - 2009
	King County SCADA data	2008 - 2009
	ADS flow monitoring	2007 - 2009
Population Data		
2007 Puget Sound Regional Council (PSRC) population data	SPU GIS files	2007
Parcel data (for hydrologic analysis)	SPU GIS files	2007
Surface Data		
Road and street data (for hydrologic analysis)	SPU GIS files	2007
Sidewalk data (for hydrologic analysis)	SPU GIS files	2007

TABLE 3-2
Model Development Data Sources

Data Description and Purpose	Data Source and Type	Dates
Topographic data (for hydrologic analysis)	Puget Sound LiDAR Consortium	2000
Impervious surface data (for hydrologic analysis)	Black and Veatch	2005
Rainfall Data		
Rain gauge data	City of Seattle rain gauge network	1978 - 2009
Flow and Depth Meter Data		
Field measurements (for calibration)	ADS meter data	2007- 2009
	King County meter data	2008 - 2009
	Herrera meter data	2008 - 2009

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, 9.6 feet was added to each elevation referenced in the drawings, unless otherwise specified on the drawing. The conversion value of 9.6 was provided by SPU, is based on a City benchmark at 46th Avenue South and Lake Washington Boulevard (field book 2445-L, pg. 11), and is consistent with SPU Standard Plan No. 001.

To convert Lake Washington water elevations to NAVD88 from the USACE data, 3.25 feet was subtracted from each lake elevation value. This conversion is based on *Datum Planes Vicinity of Lake Washington* (USACE, 2008).

3.5 Flow-Monitoring Data

Flow-monitoring data collected prior to January 2008 were determined to be insufficient for model development and calibration purposes (CH2M HILL, 2007 and HDR, 2008). Because of this, additional flow-monitoring data were collected from January 2008 through May 2009 from a set of monitors that included 20 temporary monitors operated by ADS, eight permanent monitors operated by ADS, one temporary flow monitor operated by Flow Monitoring and Analysis, Inc., and one permanent flow monitor operated by King County. This information was used to develop dry weather flows and to calibrate and validate wet weather response. A discussion of these data, results, quality assessment, and related information is available in *Genesee CSO Reduction Project Flow Monitoring Report: January 2008 through May 2009* (CH2M HILL, 2009a).

4.0 Model Development

The Genesee Area system includes combined and partially separated sewer systems. The comprehensive model of the system comprises three subsystem models:

- Hydraulic conveyance system model to simulate the combined and sanitary sewer system pipes and route the runoff and inflow from the hydrologic and dry weather models
- A hydrologic runoff model to simulate wet weather flows in the system
- A dry weather flow model to simulate sanitary inflows from residential, commercial, and industrial users and groundwater infiltration

4.1 Modeling Platform

The Genesee CSO Area InfoWorks CS version 3.0 model updated by Earth Tech in 2006 was converted to InfoWorks version 9.5, extended, and refined by CH2M HILL as described in this report. As described in the Genesee Modeling Plan, the CSS network from basins 37 and 38 was added to the model, hydraulic structures were updated, and the model was calibrated with new flow-monitoring data. InfoWorks CS is a product of Wallingford Software, Ltd.

4.2 Boundary Conditions

4.2.1 Lake Level

Lake Washington's water level is a boundary condition at all of the CSO outfall nodes. Since the outfalls and lake are hydraulically connected, the lake level affects the hydraulics at each of the outfalls. Lake Washington's level fluctuates on a yearly cycle controlled by the USACE at the Chittenden Locks. Lake level elevation data are available from the USACE Seattle District Water Management Section. These data are based on the mean lower low water (MLLW) USACE Locks Datum, which is 3.25 feet below the NAVD88 (3.25 feet is subtracted from the MLLW Locks Datum elevation). Time series lake level data are available for the monitoring period (2008) as well as the historical record from 1978 to 2008 (needed for the uncertainty analysis).

4.2.2 Model Outfall

King County Rainier Avenue Pump Station conveys flows from the entire Genesee Area. The station controls flow between the Genesee Area and King County's regional conveyance system (King County, 1993). A review of SCADA data collected from King County for the Rainier Avenue Pump Station indicates that the data can be used to develop a flow-head (Q-H) relationship for the model. The King County Rainier Avenue Pump Station pumps flow through an 18-inch force main to MH 059-445, where it joins a 60-inch SPU gravity pipe from the south and flows into a 66-inch King County gravity pipe along Rainier Avenue. The SCADA data used to develop pumping capacity account for downstream conditions,

including friction losses in the force main and outfall conditions. For this reason, the model outfall was modeled as a "free outfall" with the peak capacity of the King County Rainier Avenue Pump Station based on the SCADA data. Additional information on the Rainier Avenue Pump Station can be found in Section 4.3.22. CH2M HILL constructed the model such that the outfall is MH 058-189 near South Walden Street and Rainier Avenue. The maintenance hole has an invert elevation of 37.1 feet, and the upstream pipe has a 66-inch diameter. The outfall water elevation was set at 36 feet, simulating the free outfall.

4.2.3 Model Extents

Combined Sewer System

The CSS model consists of all pipes in the combined and separated areas that convey wastewater, specifically all pipes 8 inches and greater, excluding service laterals (side sewers). To determine the extent of the modeled system, CH2M HILL used SPU's GIS as the primary source of information. The "PRBLE_FLOW" attribute from the GIS shapefile dwumh.shp was used as the primary means to distinguish between combined, sanitary sewer, and drainage pipes. Where the "PRBLE_FLOW" attribute conflicted with the best understanding of actual pipe use, other data sources were used for system type identification, including parcels, buildings, and lateral pipes GIS data.

Drainage System

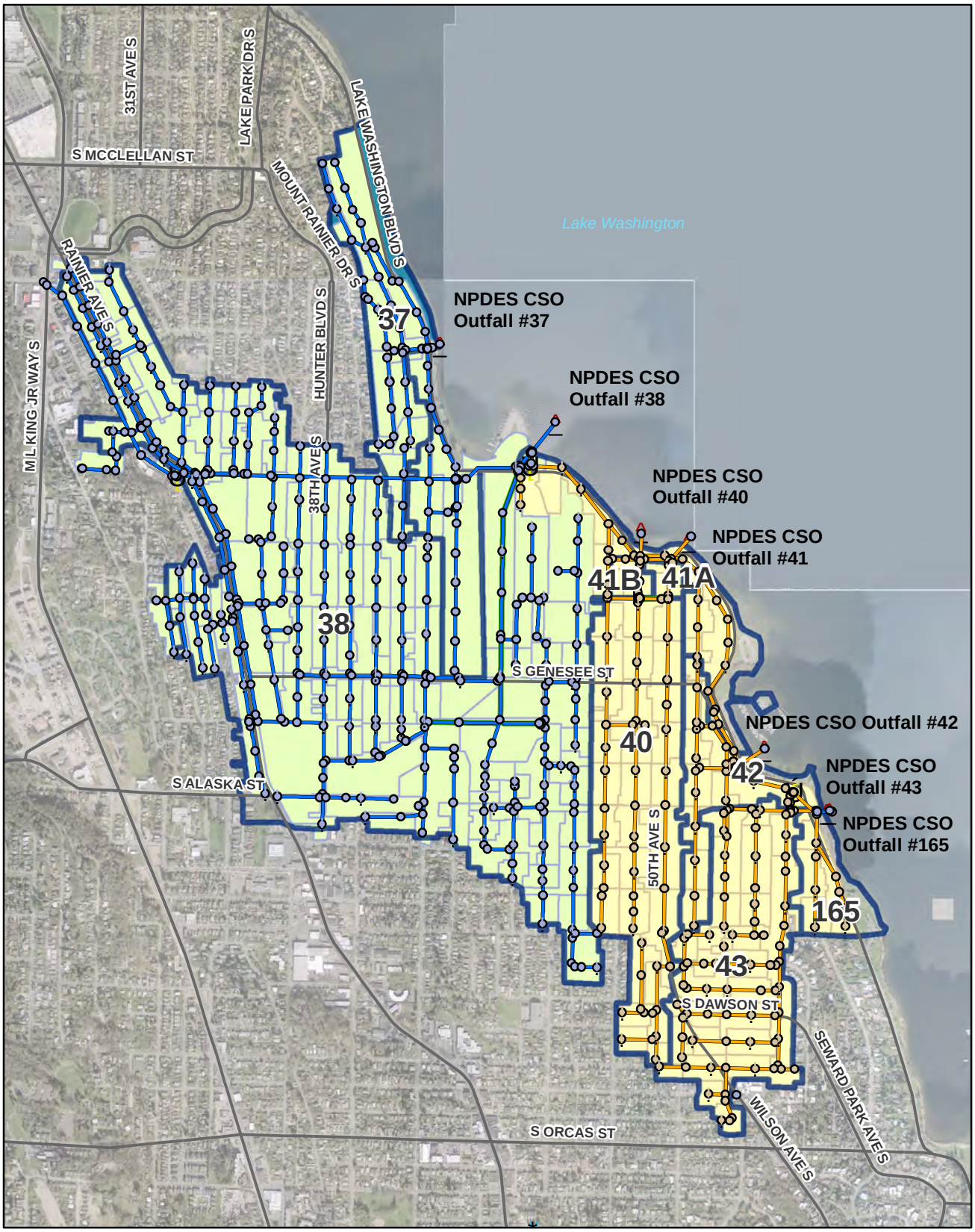
As model development and GIS subcatchment delineation of the CSS occurred, the project team also delineated and created load points for the storm drainage system within the limits of the Genesee CSO Area. Delineating subcatchments and associated load points for the sanitary/combined sewer systems and stormwater drainage system may potentially be of use in future model applications.

Figure 4-1 shows the extent of the Genesee hydraulic model.

4.3 Model Hydraulics

The sewer system in InfoWorks is represented as a series of nodes that are connected by links. Inflows to the system are introduced at selected nodes throughout the system. In the model, nodes represent maintenance holes, blind connections, pump station wet wells, and outfalls. Links convey flow through the system. In the model, links represent pipes and force mains. In addition, flow can pass between nodes through pumps, weirs, orifices, sluice gates, and flap gates. This section outlines the construction of the InfoWorks hydraulic model according to the major components:

- Links
- Nodes
- Pumps
- Weirs
- Detention systems
- HydroBrakes
- Valves



Model Load Points

- Existing Model
- New Model

Model Nodes

- Existing Model
- New Model

Model Links

- Existing Model
- New Model

Model Catchments

- 2006 Genesee CSO Model
- 2010 Genesee CSO Model

Pump Station

0 500 1,000
Feet

FIGURE 4-1
Extent and Features of the Genesee Hydraulic Model
Modeling Report
SPU Genesee Area

CH2MHILL

4.3.1 Links

Links represent the sewers and force mains modeled in InfoWorks. A link is defined as a straight line passing flow between two nodes (upstream node to downstream node). Links can be standard shapes (e.g., circular, egg, and square) or user-defined shapes for irregular pipes. Within the Genesee model, each pipe was assumed to be circular based on GIS data. Link locations are defined by their upstream and downstream node identifiers. Links in the model are developed based on connectivity to the sewer system. A typical link profile, as viewed in InfoWorks, can be found in Figure 4-2. The profile is of the lake line from NPDES 41B regulator downstream to Pump Station 5.

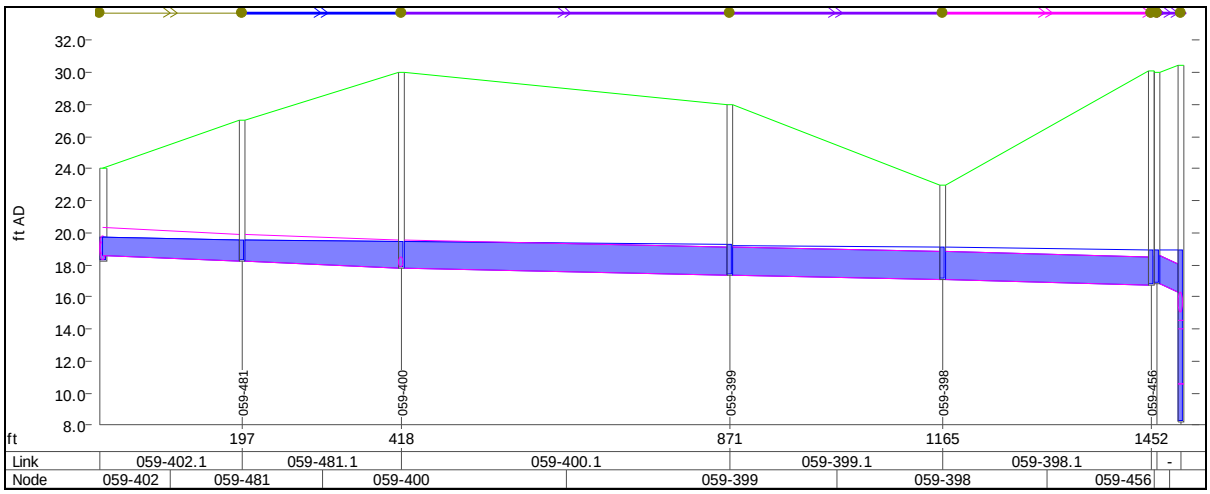


FIGURE 4-2: LAKE LINE PROFILE

Table 4-1 presents the types of data required to define links in InfoWorks.

TABLE 4-1
InfoWorks Data Requirements for Links

Description	Units	Sample Data	Sample Data Source
Upstream Node ID		046E-090	GIS
Downstream Node ID		059-072	GIS
System Type		Combined	GIS
Asset ID		046E-090 059-072	GIS
(Pipe) Length	ft	325.0	GIS
(Pipe) Shape		CIRC	GIS
(Pipe) Width	in	8.0	GIS
(Pipe) Height	in	8.0	GIS
(Pipe) Roughness		0.013	Field observation or default
Upstream Invert Level	ft AD[a]	87.800	GIS
Downstream Invert Level	ft AD[a]	86.600	GIS

[a]ft AD = feet above NAVD88 datum

Special structures such as weirs, pumps, and HydroBrakes are modeled as links in InfoWorks. To be consistent with SPU's modeling standards and guidelines, a dummy node and a link were inserted to model the special structure. During the model construction, SPU personnel were consulted to provide anecdotal information, including areas of sedimentation, heavy root intrusion, misaligned pipe, or other conditions that will greatly affect the hydraulic capacity of the system. This approach helped identify areas where it was prudent to increase the roughness coefficient and create specific pipe cross sections that reflect the reduced pipe capacity observed during the flow-monitoring study. The default roughness coefficient Manning's n of 0.013 was used for each pipe without specific condition data.

4.3.2 Nodes

Nodes are structural elements like maintenance holes, blind connections, outfalls, or user-defined structures (such as pump station wet wells). The nodes also represent points throughout the sewer system that may accept inflow, such as the runoff calculated by the hydrologic model. To ensure connectivity between the hydrologic and the hydraulic system model, each inlet node defined in the hydrologic model must correspond to a node in the hydraulic model.

For the Genesee model, each node defined as a maintenance hole in the GIS was included in the model. Tees or cleanouts were included in the model to maintain spatial reference, but these were "sealed" and the ground level set equal to the top of the pipe. Nodes defined as "plugs" (usually at the terminus end) were not included in the model. Table 4-2 presents the types of data required to define nodes in InfoWorks.

4.3.3 HydroBrakes

There are four CSO control facilities in the Genesee Area, each with one HydroBrake and all of which are included in the hydraulic model. HydroBrakes are passive flow control devices that use vortex action to provide a near constant discharge for varying differential hydrostatic heads. HydroBrakes regulate the flow of combined sewage to downstream conveyance facilities and cause the excess flow to be diverted to storage or the outfall. The HydroBrake functions to regulate the flow to downstream pipes reducing the volume and frequency of CSOs. Because flow is restricted through the device during periods of wet weather, CSS flows are stored in the detention system facilities.

A HydroBrake is represented in the model as a user-defined link of zero length, forming a stage-discharge relationship between two nodes. The vortex invert level determines when the control first comes into operation. The stage-discharge relationship was developed from the flow monitoring conducted between January 2008 and June 2009. The difference in the level upstream and downstream of the HydroBrake, called differential head, and the corresponding flow through the HydroBrake were determined and used as the basis for the stage discharge curve in the model.

Due to the characteristics of the rainfall experienced during the monitoring period and the status of the HydroBrake, the upper end of some of the HydroBrakes' performance range was not activated. Where this was the case, the upper operation points were determined by extrapolation. The HydroBrake stage discharge curves as inputted into the model are presented in the subsequent sections on CSO control facilities.

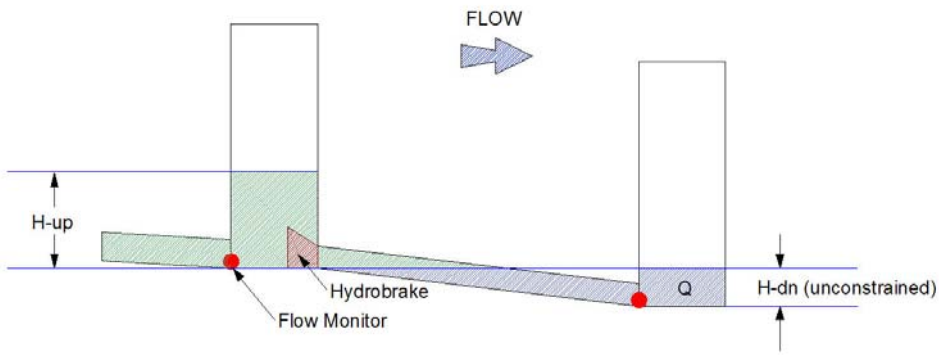
TABLE 4-2
InfoWorks Data Requirements for Nodes

Description	Units	Sample Data	Sample Data Source
Node ID		059-398	GIS
Node Type		Maintenance hole	GIS
System Type		Combined	GIS
X-coordinate	ft	1282611.9	GIS
Y-coordinate	ft	213245.8	GIS
Ground Level	ft AD[a]	96.000	GIS
Flood Level	ft AD[a]	96.000	GIS
Chamber Floor Level *(maintenance holes only)*	ft AD[a]	87.800	Record drawings or field survey data if available. Otherwise, default set to lowest invert from GIS.
Chamber Roof Level *(maintenance holes only*	ft AD[a]	88.467	The greater of: 2 feet lower than ground elevation, or crown of incoming pipes.
Chamber Plan Area	square ft	7.9	Default set to 28.3 (equivalent to 6-ft-diameter). Survey and record drawings for significantly different hydraulic structures.
Shaft Plan Area	square ft	7.9	Default set to 12.6 (equivalent to 4-ft-diameter). Survey and record drawings for significantly different hydraulic structures.
Flood Type (maintenance holes only)		Stored	"Lost" as default, except at nodes upstream of force mains, which were set to "sealed."
Level (storage nodes only)	ft	324	Record drawings or field survey.
Plan Area (storage nodes only)	square ft	34.5	Record drawings or field survey.

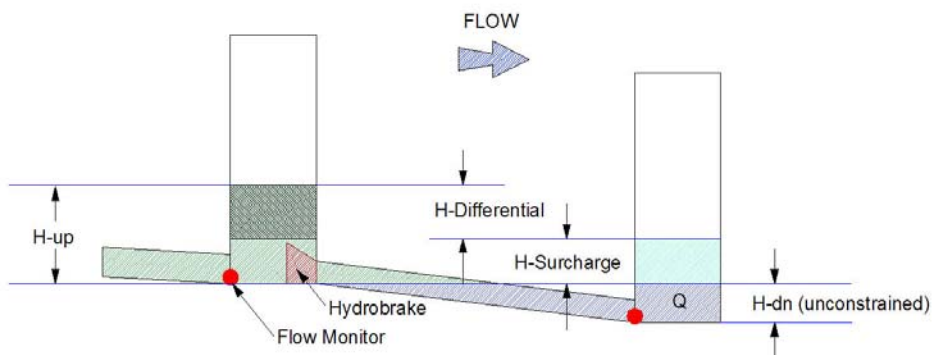
[a]ft AD = feet above NAVD88 datum

4.3.4 Storage Systems

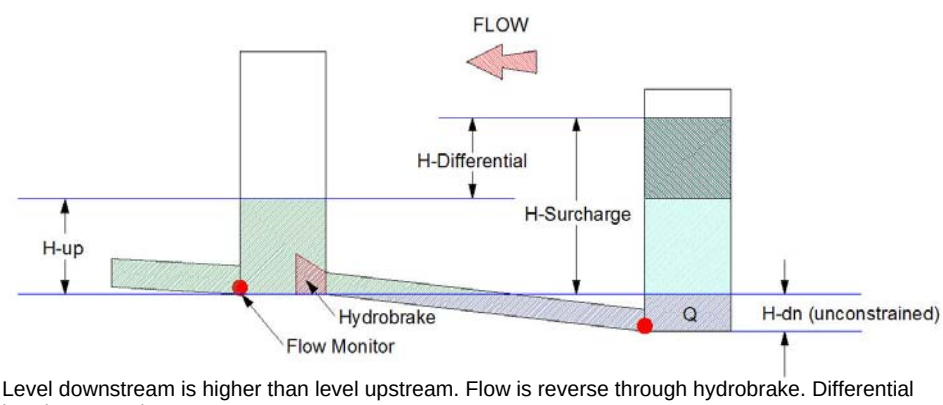
Each of the four CSO control facilities in the Genesee Area has a storage system to store runoff during periods of wet weather. These in-line and offline pipes are controlled through HydroBrakes and weirs. The storage pipes were modeled as links within the system. The volume of the portion of the storage pipe that fills below the overflow weir is known as the "usable volume" (termed "active volume" in previous reports). Figure 4-4 describes the measurement of usable volume. Figure 4-5 depicts the schematics of the detention systems input into the InfoWorks model. The operations of each detention system are discussed in the context of the individual CSO facility in the following sections.



Level at downstream monitor is lower than hydrobrake outlet. Differential head = upstream head (H-up).



Level at downstream monitor is higher than hydrobrake outlet, but lower than upstream level. Differential head = H-up – H-Surcharge.



Level downstream is higher than level upstream. Flow is reverse through hydrobrake. Differential head = H-Surcharge – H-up.

FIGURE 4-3: HYDROBRAKE DIFFERENTIAL HEAD CALCULATION METHODS - TYPICAL

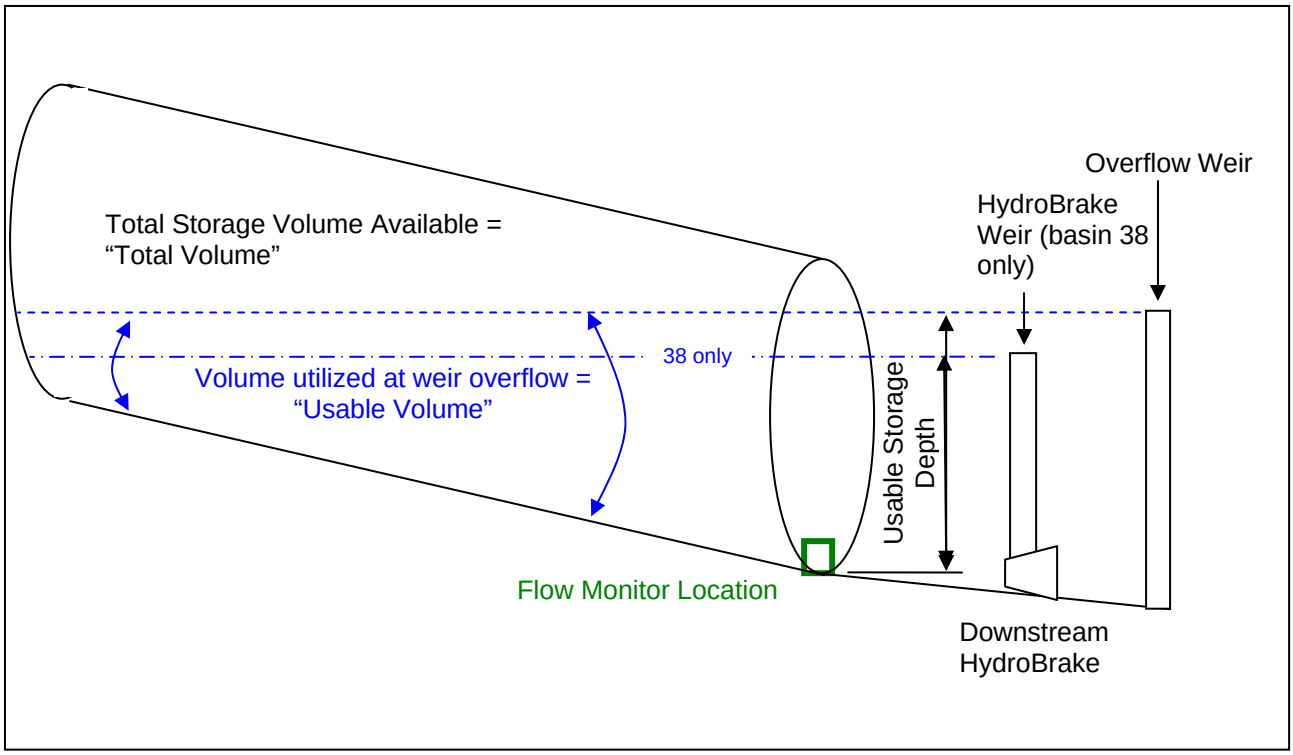


FIGURE 4-4: USABLE STORAGE DEPTH AND VOLUME

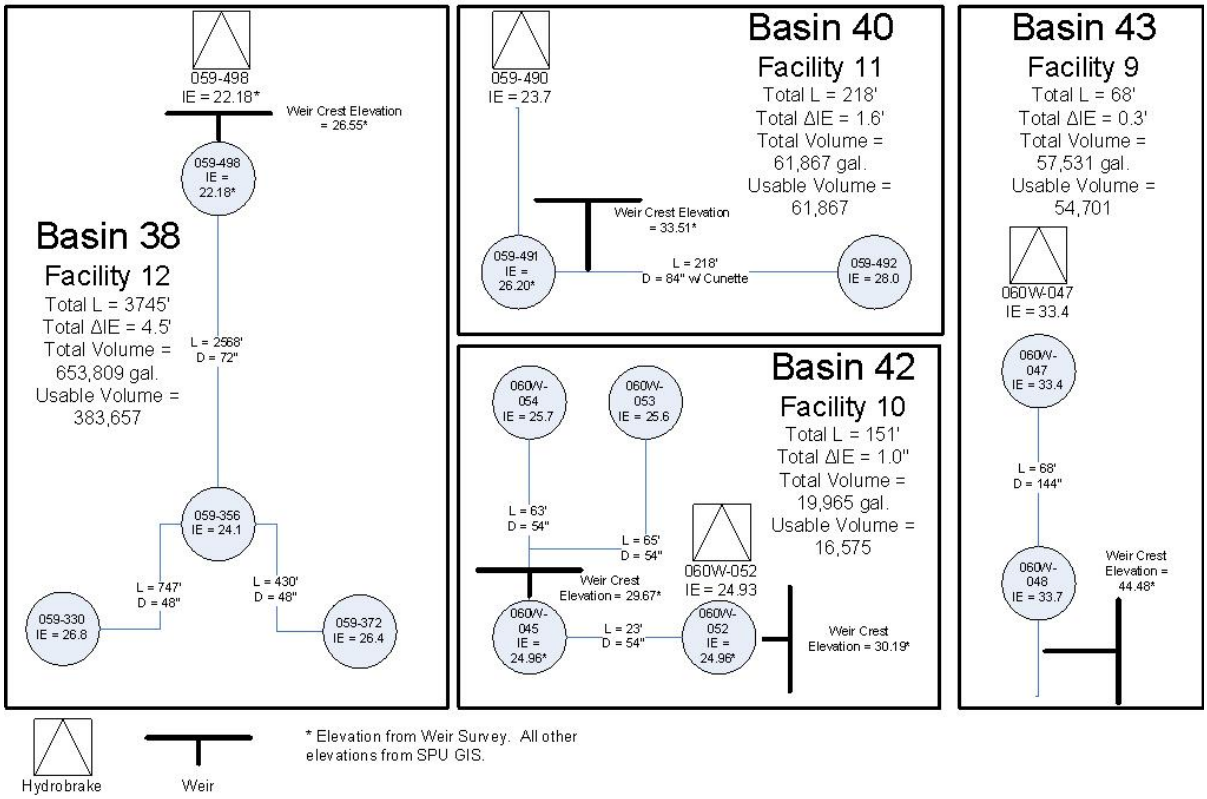


FIGURE 4-5: SCHEMATIC OF GENESEE STORAGE FACILITIES

4.3.5 Weirs

A weir is a dam, depression, or notch through or over which water flows. The flow through or over a weir can be quantified using equations derived from the Bernoulli equation or other empirically derived equations. The types of weirs in the Genesee Area are broad-crested rectangular and sharp-crested rectangular. In the InfoWorks model, a weir is represented as a connection (link) between two nodes. There are 12 weirs in the Genesee hydraulic model located primarily at eight CSO regulators (four are located at Basin 38 at SPU Pump Station 5 and two are located at CSO Facility 10). See Table 4-3 for weir information. Photos of overflow weirs can be found in the Flow Monitoring Report (CH2M HILL, 2009a). CH2M HILL performed a search of all the available information pertaining to the weirs within the Genesee Area (ADS install sheets, record drawings, and recent field surveys). CH2M HILL developed a weir summary table and a technical memorandum titled *Genesee Weir Elevations for use in InfoWorks CSO Model* (CH2M HILL, 2009b). This weir summary table can be found as Table 2-3 in the *Genesee Flow Monitoring Report* (CH2M HILL, 2009a), and the technical memo can be found in Appendix K of the Flow Monitoring Report. Table 4-3 lists the pertinent InfoWorks weir values used at each of the weirs within the Genesee Area. The operation of each of these weirs is described in more depth in the subsequent sections on CSO control facilities and outfalls.

TABLE 4-3
InfoWorks Modeled Weir Data

Description	Upstream Node Name	Downstream Node Name	Link Type	System Type	Crest Elevation (ft AD)[a]	Weir Width (ft)	Roof Height (ft)	Discharge Coefficient
Overflow Weir in Overflow Structure 37	059-489	059-489W	WEIR	Combined	32.93	5.46	2.4	0.46
Storage Weir in Overflow Structure 38	059-346	059-346W	WEIR	Combined	21.332	7.91	4.13	0.62
Overflow Weir in Overflow Structure 38	059-346 W	059346W2	WEIR	Combined	19.127	7.97	6.13	0.62
Horseshoe-shaped Weir in Basin 38, MH 059-451	059-451	059-451W	WEIR	Combined	23.17	24.225	5.28	0.46
Overflow Weir in Overflow Structure 40	059-491	059-491W	WEIR	Combined	33.51	19.95	1.47	0.46
Overflow Weir in Overflow Structure 41A	059-434	059-434W	WEIR	Sanitary	21.631	4.96	6.22	0.46

TABLE 4-3
InfoWorks Modeled Weir Data

Description	Upstream Node Name	Downstream Node Name	Link Type	System Type	Crest Elevation (ft AD)[a]	Weir Width (ft)	Roof Height (ft)	Discharge Coefficient
Overflow Weir in Overflow Structure 41B	059-406	059-406W	WEIR	Combined	19.511	5.71	7.79	0.46
Storage Weir in CSO Facility 10	060W-045	060W-045W	WEIR	Combined	29.667	8.41	1.75	0.62
Overflow Weir in CSO Control Structure 42	060W-052	60W052W	WEIR	Combined	30.197	7.46	2.37	0.62
Overflow Weir in Overflow Structure 43	060W-049	060W-049W	WEIR	Combined	44.478	7.25	7.93	0.46
Overflow Weir in Overflow Structure 165	067-078	D067-147	WEIR	Combined	21.79	4.40	2.96	0.46
HydroBrake Bypass Weir in CSO Facility 12, MH 059-498	059-498	059-498H	WEIR	Combined	26.551	6.88	1.96	0.46

[a]ft AD = feet above NAVD88

The equation used by InfoWorks to model flow over the weir is the following:

$$Q_0 = C_d \sqrt{g} B D_u^{3/2}$$

Where Q_0 =is the free outfall discharge, C_d is the discharge coefficient, g is acceleration due to gravity, B is the width of the weir, and D_u is the upstream depth with respect to the crest . Values for C_d, and B can be found in Table 4-3. Rating curves showing Q_0 relative to D_u can be found the subsequent sections on CSO facilities and outfalls. These rating curves show Q_0 up to a maximum D_u of 1.0 feet. Model behavior above D_u of 1.0 foot continues to follow the weir equation until D_u = Roof Height, at which point the model node behaves as a sluice gate.

The *roof height* is a modeling parameter that indicates the height of the chamber roof above the weir crest. When the water level is above the roof elevation, InfoWorks switches the equation it uses to route flow over the weir. Note that this parameter is given as a height, not an elevation referenced to a datum.

4.3.6 Valves

One pinch valve in the Genesee Area is included in the model. The pinch valve is located at the downstream end of Overflow Structure 38 (also called "Structure A") that regulates flow into Pump Station 5. The operations and modeling of this valve are discussed in the section on CSO Facility 12.

4.3.7 Pumps

In the InfoWorks model, a pump is represented as a connection (link) between two nodes. The performance of a pump in the model can be simulated in a number of ways, including fixed-discharge, rotodynamic, and variable-speed. There are three pump stations in the Genesee model—SPU pump stations 5 and 6 and the King County Rainier Avenue Pump Station. These pumps are discussed in more detail in Sections 4.3.20 through 4.3.22.

Drawdown Tests

Drawdown tests were performed at SPU pump stations 5 and 6 in June 2007 to obtain average pump capacity across the pumping range. Drawdown tests consisted of measuring the time required to draw and fill the wet well. After calculating the area of the wet well, the pump station's pump rate was calculated based on the rate of change in wet-well depth during the pump cycles. Technical memorandums summarizing the results of the drawdown tests are included in Appendix A.

The drawdown tests were conducted across the pumping range (below the lowest influent pipe to just above the sump in the wet well). No indications of excessive water levels were evident during the test; however, to account for the increased pumping rates during submerged wet-well conditions, the discharge–head (Q-H) curve developed from the drawdown test was increased to account for the decrease in total dynamic head. The static lift of the pump stations is approximately 14 feet. As a result, the effect of approximately 2 to 3 feet of increased water level above the drawdown pump range is not expected to be significant.

For all pump stations, field observations, facility drawings, and SCADA records were used to configure the pump stations. Field observations consisted of reviewing the local SCADA displays and denoting the float switch on/off levels, measuring wet-well cross-sectional areas, and identifying relative influent line locations.

4.3.8 CSO Facility 9

CSO Facility 9 in Basin 43 is located north of South Alaska Street, between 54th Avenue South and Lake Washington Boulevard South (see Figure 1-1). The facility consists of one 144-inch-diameter in-line storage pipe between MH 060W-059 and MH 060W-047. A HydroBrake in CSO Control Structure 43 at MH 060W-047 controls the hydraulic grade line in the storage pipe. A weir in Overflow Structure 43 at MH 060W-049 (13 feet upstream of the storage pipe) limits the maximum hydraulic grade line in the storage pipe. Figure 4-6 presents a plan view of the InfoWorks layout for CSO Facility 9.

Operations

During normal operations, flows from Basin 43 are conveyed past Overflow Structure 43 in MH 060W-049, through the CSO Facility 9 storage pipe and through the HydroBrake in

Control Structure 43 to the lake line, where Basin 43 flow joins discharge from Pump Station 6 and Basin 165. As flow from Basin 43 increases, the HydroBrake in MH 060W-047 restricts flow and the storage pipe fills. As levels in the storage pipe reach 44.48 feet NAVD88, combined wastewater spills over the Overflow Facility 43 overflow weir and joins stormwater at MH D060W-019, flowing to the NPDES CSO Outfall 43.

Storage Pipe

Flows are stored in a 65-foot-long, 144-inch-diameter in-line concrete pipe . The usable storage depth at the downstream end of the storage pipe is limited to 133 inches by the Overflow Structure 43 weir elevation of 44.48 feet NAVD88 . The usable storage volume is 55,000 gallons, and the total storage volume is 57,000 gallons.

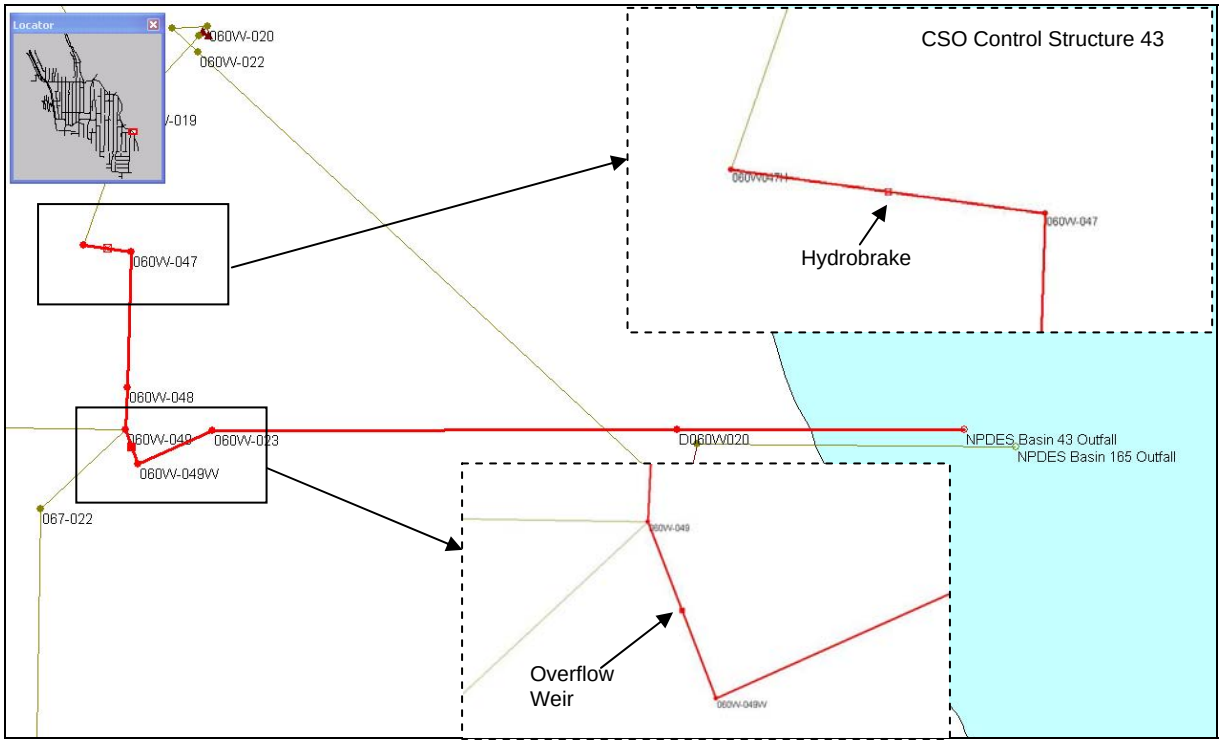


FIGURE 4-6: INFOWORKS PLAN VIEW AND DETAIL FOR CSO FACILITY 9

HydroBrake

The HydroBrake in Control Structure 43 at MH 060W-047 controls flow from the upstream storage to the lake line downstream. It is represented in the model as a vortex-type dummy link of zero length from 060W-047 to dummy node 060W-047H . Flow through the HydroBrake is defined through a user-defined stage-discharge curve. Although a manufacturer's curve is available for this HydroBrake, the model curve was developed using flow measurements at a monitor in MH 060W-019 and differential head between monitors in MH 060W-019 and MH 060W-047. Data from January 2008 through May 2009 were used to develop the model stage-discharge curve, shown in Figure 4-7. The points defining both the manufacturer's curve and the model curve are presented in Table 4-4.

Flow-monitoring data indicated that the HydroBrake in Control Structure 43 at MH 060W-047 was less restrictive during periods of less intense rainfall, but during periods of greater

intensity (November 2008 and January 2009), the HydroBrake was more restrictive. Reviews with maintenance personnel indicated that the changes in performance could not be aligned with maintenance status of the HydroBrakes. During such analysis, the project team reviewed CSO frequency reports and the flow-monitoring data and determined that the more restrictive condition should be applied in the model as it better represented the system during the larger storms that were likely to cause overflows.

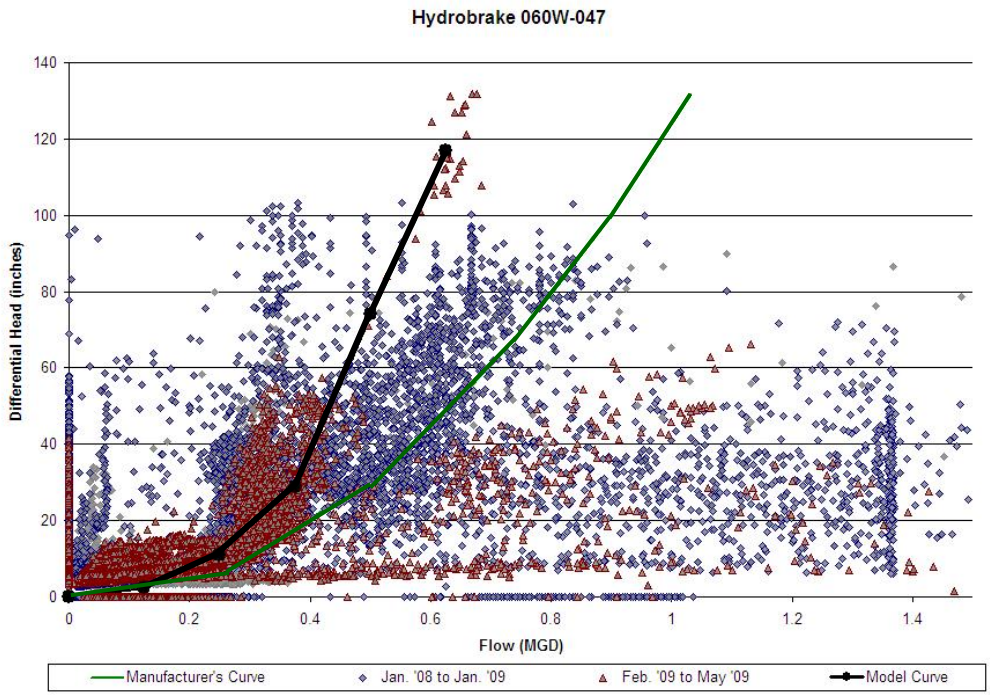


FIGURE 4-7: STAGE-DISCHARGE CURVE FOR HYDROBRAKE IN CSO FACILITY 9 (BASIN 43)

TABLE 4-4
HydroBrake Stage Discharge Curve Used in Model for CSO Facility 9 (Basin 43)

Manufacturer's Curve		Model Curve	
Differential Head (inches)	**Flow (MGD)**	**Differential Head (inches)**	**Flow (MGD)**
0.0	0.00	0.0	0
15.0	0.35	2.5	0.125
31.7	0.51	11.0	0.25
48.4	0.62	29.0	0.375
65.1	0.72	74.0	0.5
81.8	0.81	117.0	0.625
98.5	0.89		
115.2	0.96		
131.9	1.03		

Overflow Weir

Overflow Structure 43, located at MH 060W-049, contains a weir allowing excess flows from CSO Facility 9 to exit the system via the NPDES CSO Outfall 43. The dimension (weir width = 7.25 feet) and elevation (crest = 44.48 feet NAVD88) for this control structure based on a 3D laser scanning survey were entered into the model. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 43 Overflow Weir is presented in Figure 4-8.

The weir is represented in the model as a weir-type dummy link of zero length from 060W-049 to dummy node 060W-049W.

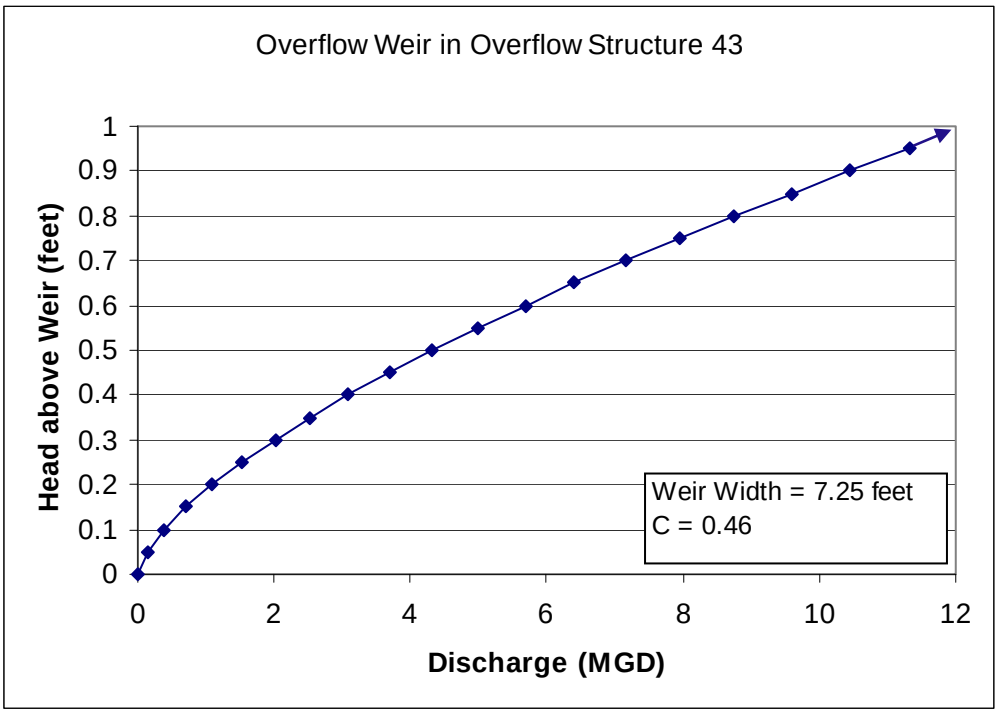


FIGURE 4-8: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 43

4.3.9 CSO Facility 10

CSO Facility 10 in Basin 42 is located southwest of Lake Washington Boulevard South, between South Genesee Way and 53rd Avenue South (see Figure 1-1). The facility consists of one in-line storage pipe between MH 060W-052 and 060W-045, and two parallel offline storage pipes: one between MH 060W-045 and 060W-054 and one between MH 060W-045 and MH 060W-053. Flows to and from the offline storage pipes are regulated by a weir and two Tideflex valves at MH 060W-045 (installed as part of the 2005 CSO retrofit program). A gate valve at the upstream end of each of the offline storage pipes (MH 060W-054 and 060W-053) allows the storage pipes to be drained, bypassing the HydroBrake and overflow weir. This valve at MH 060W-057 is normally closed. A HydroBrake and weir in CSO Control Structure 42 at MH 060W-052 regulate flow from Basin 42,through the storage pipe to the lake line. A plan view of the InfoWorks layout for CSO Facility 10 is found in Figure 4-9.

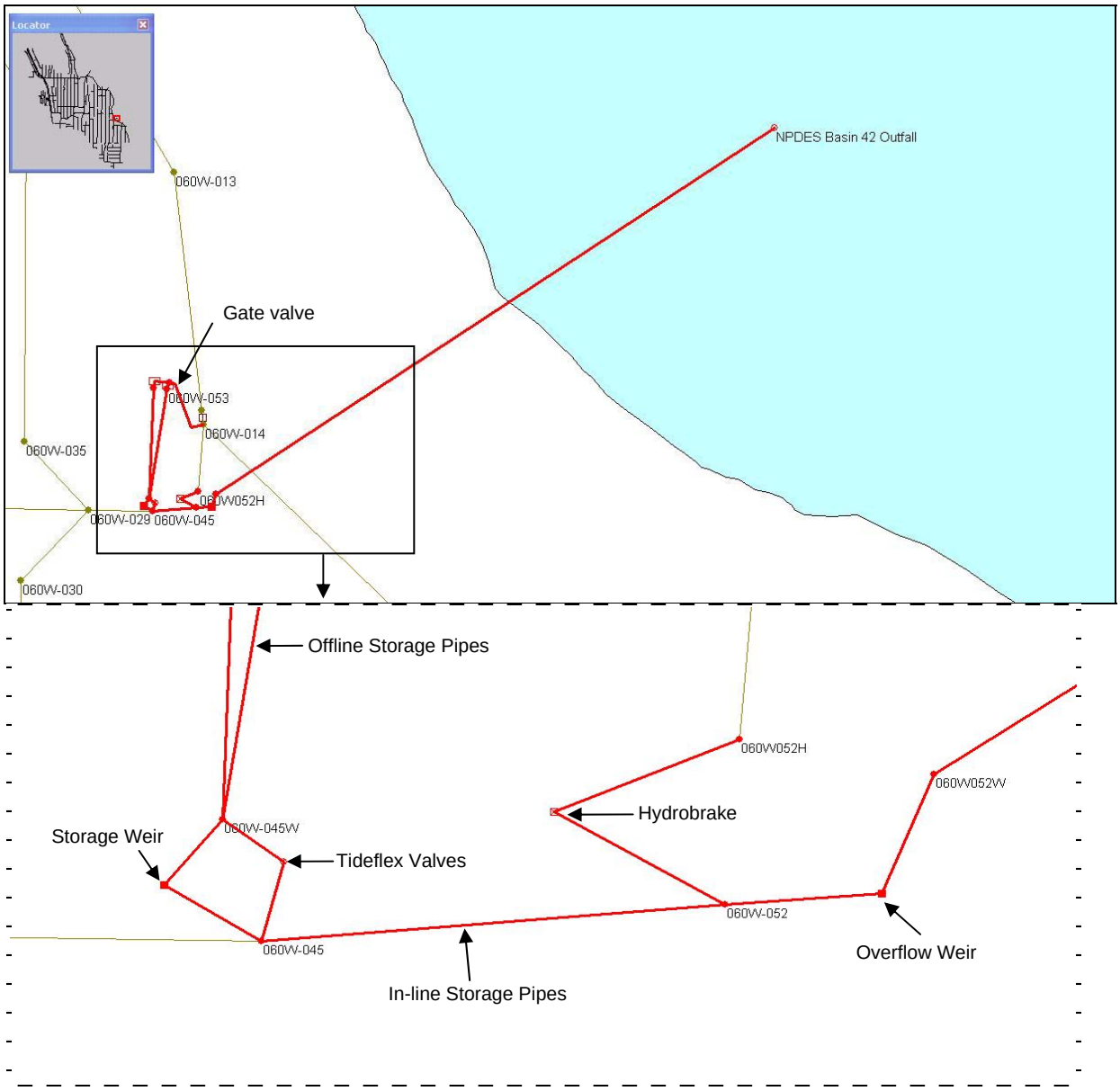


FIGURE 4-9: INFOWORKS PLAN VIEW AND DETAIL FOR CSO FACILITY 10

Operations

During normal operations, flows from Basin 42 are conveyed past the storage weir in MH 060W-045, past the CSO Control Structure 42 overflow weir in MH 060W-052, through the HydroBrake in MH 060W-052, and to the lake line. As flow from Basin 42 increases, the HydroBrake in MH 060W-052 restricts flow. When levels at 060W-045 reach 29.67 feet NAVD88, flow spills over the storage weir and into the two offline storage pipes. As levels continue to rise in MH 060W-52 above 30.21 feet NAVD88, combined wastewater spills over the CSO Control Structure 42 overflow weir and is discharged to Lake Washington via the NPDES CSO Outfall 42.

Storage Pipe

Flows are stored in one in-line and two parallel offline storage pipes. The in-line pipe is 23 feet of 54-inch-diameter pipe. The two 54-inch-diameter parallel offline storage pipes are both 61 feet long. The usable storage volume is 17,000 gallons, and the total storage volume is 20,000 gallons.

HydroBrake

The HydroBrake in MH 060W-052 controls flow from Basin 42 and the CSO Facility 10 storage pipes to the lake line. It is represented in the model as a vortex-type dummy link of zero length from 060W-052 to dummy node 060W-052H. Flow through the HydroBrake is defined through a user-defined stage-discharge curve. Although a manufacturer's curve is available for this HydroBrake, the model curve was developed using flow measurements at a monitor in MH 060W-014 and differential head between monitors in MH 061W-014 and MH 060W-052. Data from January 2008 through May 2009 were used to develop the model stage-discharge curve, shown in Figure 4-10. The points defining both the manufacturer's curve and the model curve are presented in Table 4-5.

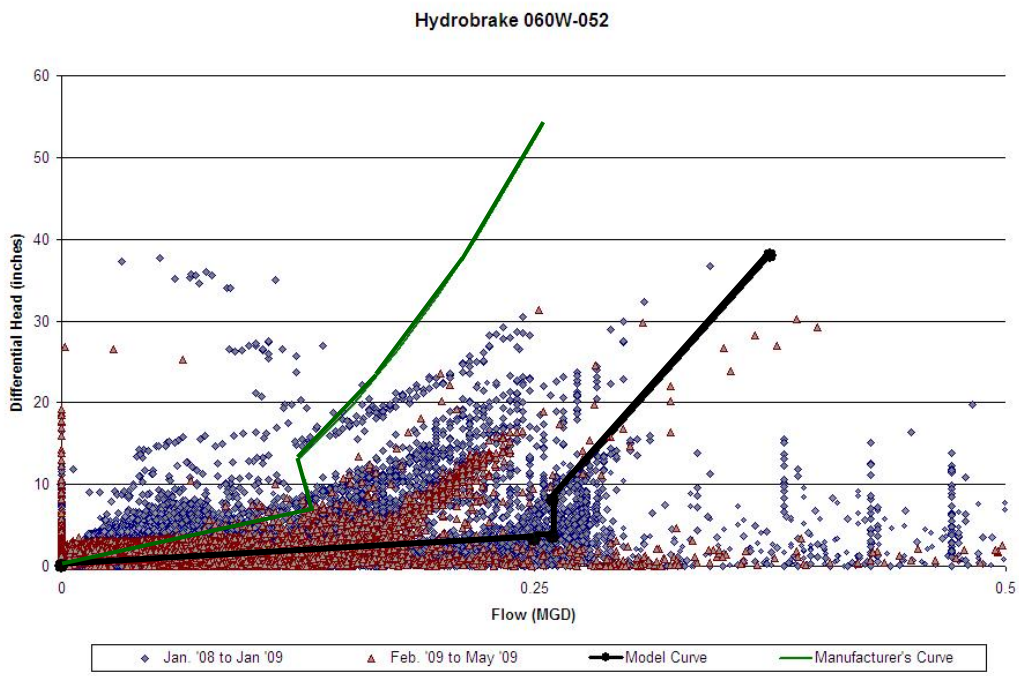


FIGURE 4-10: STAGE-DISCHARGE CURVE FOR HYDROBRAKE IN CSO FACILITY 10 (BASIN 42)

Storage Weir

A storage weir added to MH 060W-045 as part of the 2005 CSO retrofit program allows high flows to spill over into two parallel offline storage pipes in CSO Facility 10. The dimension (weir width = 8.41 feet) and elevation (crest = 29.67 feet NAVD88) for this control structure based on a 3D laser scanning survey were entered into the model. A theoretical broad-crested weir coefficient (C_d = 0.62) was used based on weir coefficient values used by ADS on similar weirs throughout the Genesee Area. The weir rating curve for the CSO Facility 10 storage weir is presented in Figure 4-11.

TABLE 4-5
HydroBrake Stage Discharge Curve Used in Model for CSO Facility 10 (Basin 42)

Manufacturer's Curve		Recommended Model Curve	
Differential Head (inches)	**Flow (MGD)**	**Differential Head (inches)**	**Flow (MGD)**
0.0	0.00	0.0	0.00
6.1	0.14	3.3	0.25
13.0	0.12	3.6	0.26
19.8	0.15	8.0	0.26
26.6	0.18	38.0	0.38
33.5	0.20		
40.3	0.22		
47.1	0.24		
53.9	0.25		

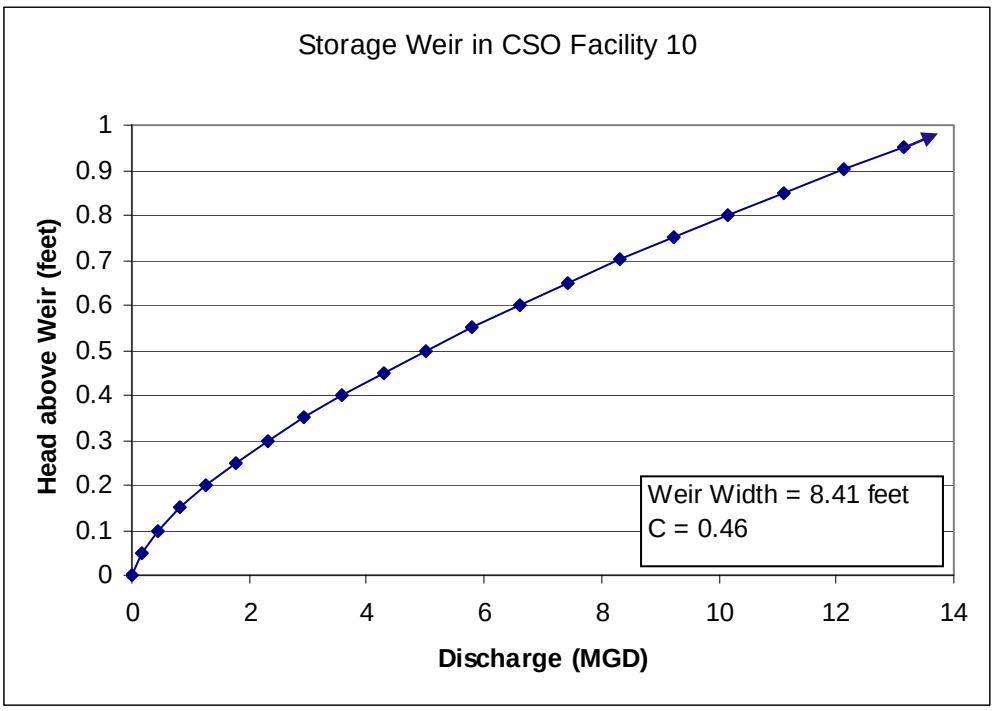


FIGURE 4-11: WEIR RATING CURVE FOR STORAGE WEIR IN CSO FACILITY 10

Overflow Weir

CSO Control Structure 42, located at MH 060W-052, contains a weir allowing excess flows from CSO Facility 10 to exit the system via the NPDES CSO Outfall 42. An adjustable plate was added to this weir as part of the 2005 CSO retrofit program. The dimension (weir width = 7.46 feet) and elevation (crest = 30.20 feet NAVD88) for this control structure based on a 3D laser scanning survey were entered into the model. A theoretical sharp-crested weir

coefficient (C_d = 0.62) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 42 Overflow Weir is presented in Figure 4-12.

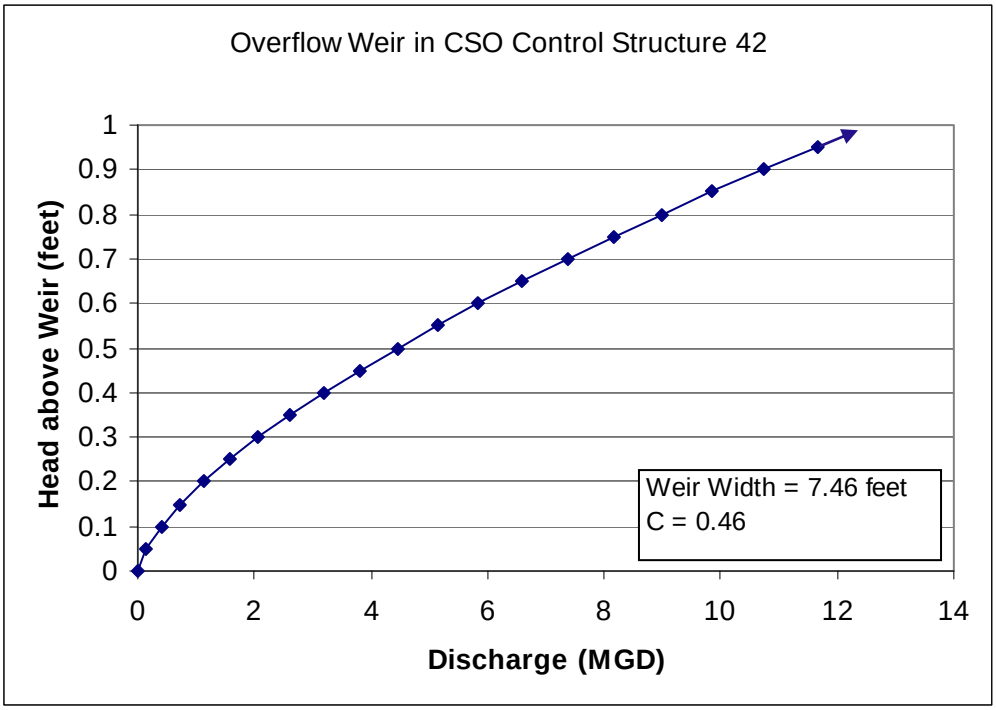


FIGURE 4-12: WEIR RATING CURVE FOR OVERFLOW WEIR IN CSO CONTROL STRUCTURE 42

4.3.10 CSO Facility 11

CSO Facility 11 in Basin 40 is located on South Dakota Street between 49th Avenue South and 50th Avenue South (see Figure 1-1). The facility consists of an 84-inch-diameter in-line storage pipe between MH 059-491 and 059-492. A HydroBrake in CSO Control Structure 40 at MH 059-490 regulates flow from Basin 40 through the storage pipe to the lake line. A through weir in Overflow Structure 40 at MH 059-491 controls the level in the storage pipe. Figure 4-13 presents a plan view of the InfoWorks layout for CSO Facility 11.

Operations

During normal operations, flows from Basin 40 are conveyed through the CSO Facility 11 in-line storage pipe and through the HydroBrake, after which they are joined by flows from Basin 41 and pass Overflow Structure 41B to join the lake line. As flow from Basin 40 increases, the HydroBrake in CSO Control Structure 40 at MH 059-490 restricts flow, causing the upstream storage pipe to fill. As levels in the storage pipe reach 33.51 feet NAVD88, combined wastewater spills over the through weir in Overflow Structure 40 at MH 059-491, where it joins stormwater and flows to the NPDES CSO Outfall 40.

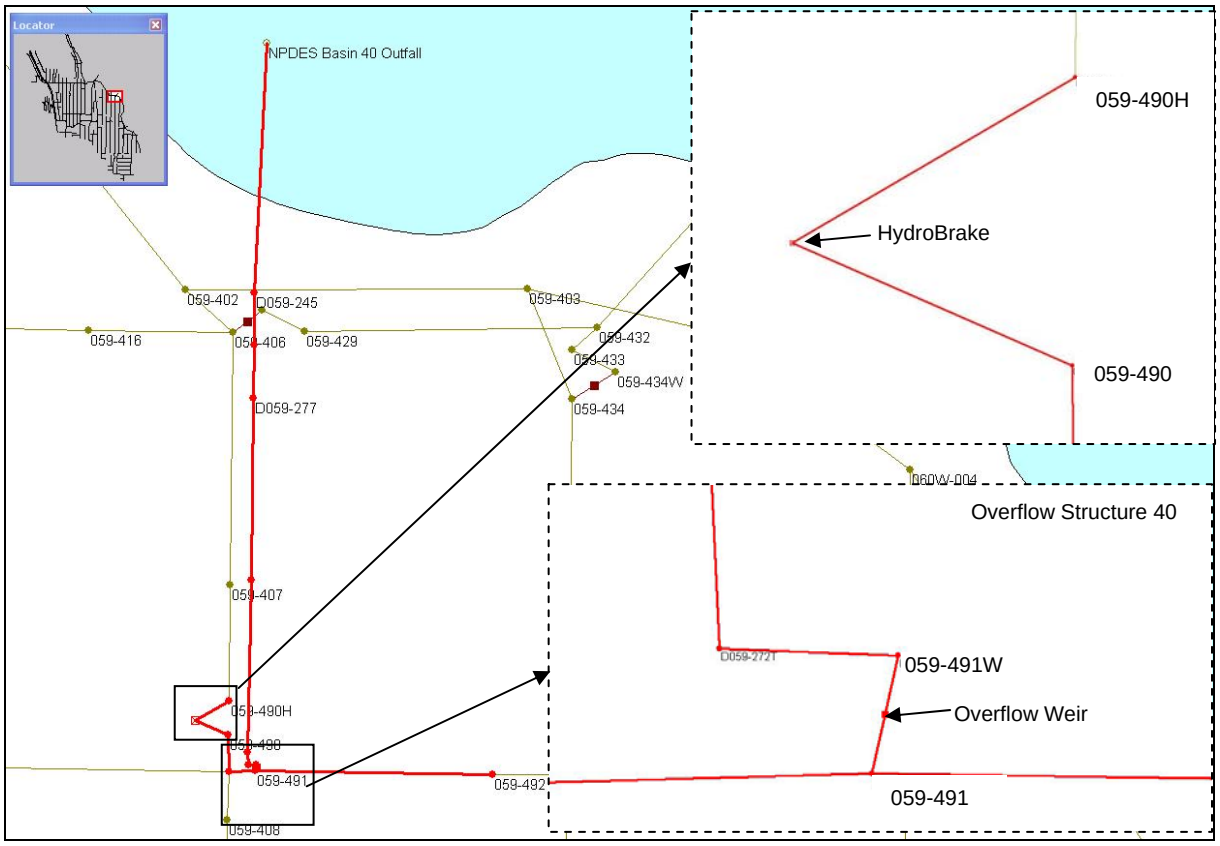


FIGURE 4-13: INFOWORKS PLAN VIEW AND DETAIL FOR CSO FACILITY 11

Storage Pipe

Flows are stored in a 217-feet-long, 84-inch-diameter in-line storage pipe. The available storage depth is allowed to fill completely before overflowing via the Overflow Structure 40 weir elevation at 33.51 feet NAVD88 (corresponding to 87.72 inches of depth within the storage pipe). The usable and total storage volume is approximately 62,000 gallons.

HydroBrake

The HydroBrake in CSO Control Structure 40 at MH 059-490 controls flow in Basin 40 and the CSO Facility 11 storage pipe to Basin 41, and flow to the lake line downstream. It is represented in the model as a vortex-type dummy link of zero length from MH 059-490 to dummy node 059-490H. Flow through the HydroBrake is defined through a user-defined stage-discharge curve. Although a manufacturer's curve is available for this HydroBrake, the model curve was developed using flow measurements at a monitor in MH 059-407 and differential head between monitors in MH 059-407 and MH 059-490. Data from January 2008 through May 2009 were used to develop the model stage-discharge curve, shown in Figure 4-14. The points defining both the manufacturer's curve and the model curve are presented in Table 4-6.

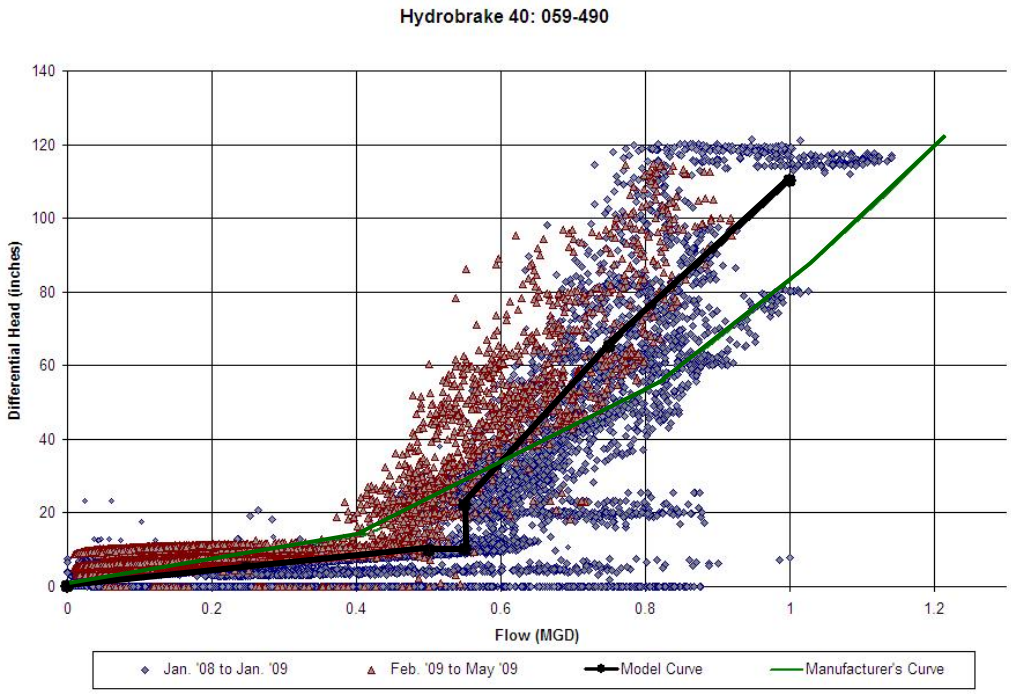


FIGURE 4-14: STAGE-DISCHARGE CURVE FOR HYDROBRAKE IN CSO FACILITY 11 (BASIN 40)

TABLE 4-6
HydroBrake Stage Discharge Curve Used in Model For CSO Facility 11 (Basin 40)

Manufacturer's Curve		Recommended Model Curve	
Differential Head (inches)	**Flow (MGD)**	**Differential Head (inches)**	**Flow (MGD)**
0	0	0	0
13.95	0.41	7	0.25
29.45	0.60	9.8	0.5
44.95	0.74	10	0.55
60.45	0.85	22	0.55
75.94	0.96	65	0.75
91.44	1.05	110	1
106.94	1.13		
122.44	1.21		

Overflow Weir

Overflow Structure 40, located in MH 059-491 (also known by its drainage system identifier, MH D059-279), contains a through weir allowing excess flows from CSO Facility 11 to exit the CSS via the shared NPDES CSO Outfall 42 and stormwater outfall. The through weir is a half section of a suspended concrete 24-inch-diameter pipe acting as a double-sided through weir. The dimension (combined double weir width = 19.95 feet) and elevation (crest = 33.51

feet NAVD88) for this overflow structure based on a 3D laser scanning survey were entered into the model. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 40 Overflow Weir is presented in Figure 4-15.

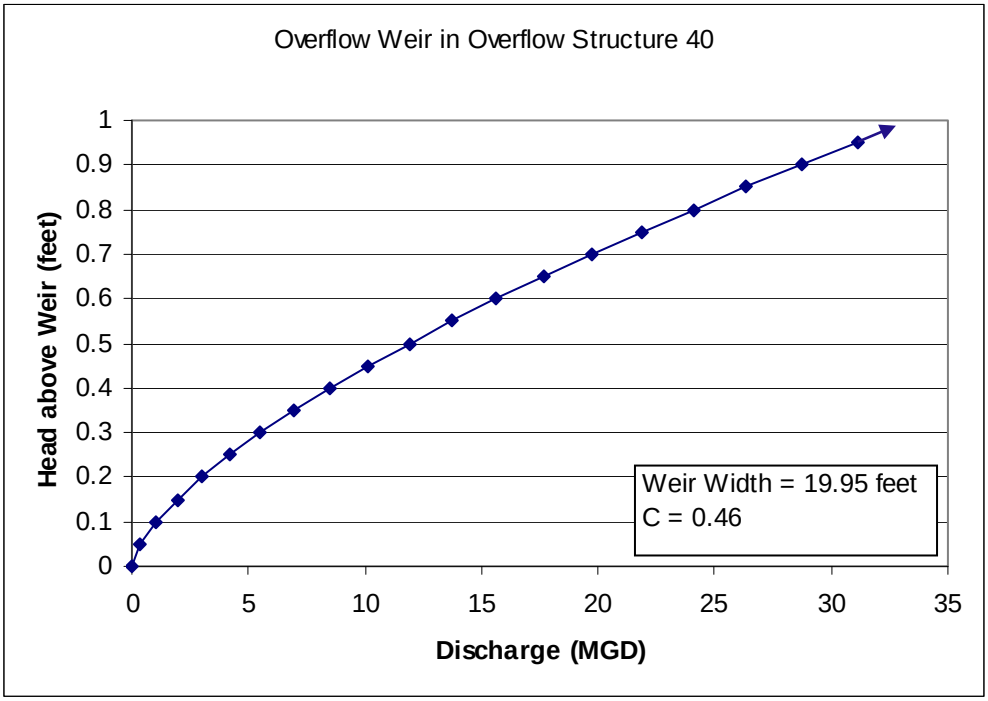


FIGURE 4-15: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 40

4.3.11 CSO Facility 12

CSO Facility 12 in Basin 38 is located in Genesee Park, parallel to and east of 43rd Avenue South, between Lake Washington Boulevard South and South Alaska Street (see Figure 1-1). The facility consists of two 48-inch-diameter in-line storage pipes between MH 059-330 and MH 059-356 and between MH 059-372 and MH 059-356, draining to a 72-inch-diameter in-line storage pipe between MH 059-356 and MH 059-451. All three in-line storage pipes are regulated by a HydroBrake and HydroBrake bypass weir in MH 059-498. A horseshoe-shaped weir in MH 059-451 diverts flow into the CSO Overflow Structure 38 at MH 059-574. A plan view of the InfoWorks layout for CSO Facility 12 is found in Figure 4-16.

Operations

During normal operations, flows from the east and west portions of Basin 38 flow through the in-line 48-inch-diameter storage pipes, merge into the 72-inch-diameter storage pipe at MH 059-356, flow through the HydroBrake in MH 059-498, and pass the horseshoe-shaped weir in MH 059-451. At this point, flows from Basin 38 merge with those from Pump Station 5, flow through the King County grit chamber, and join Hanford Street Trunk B.

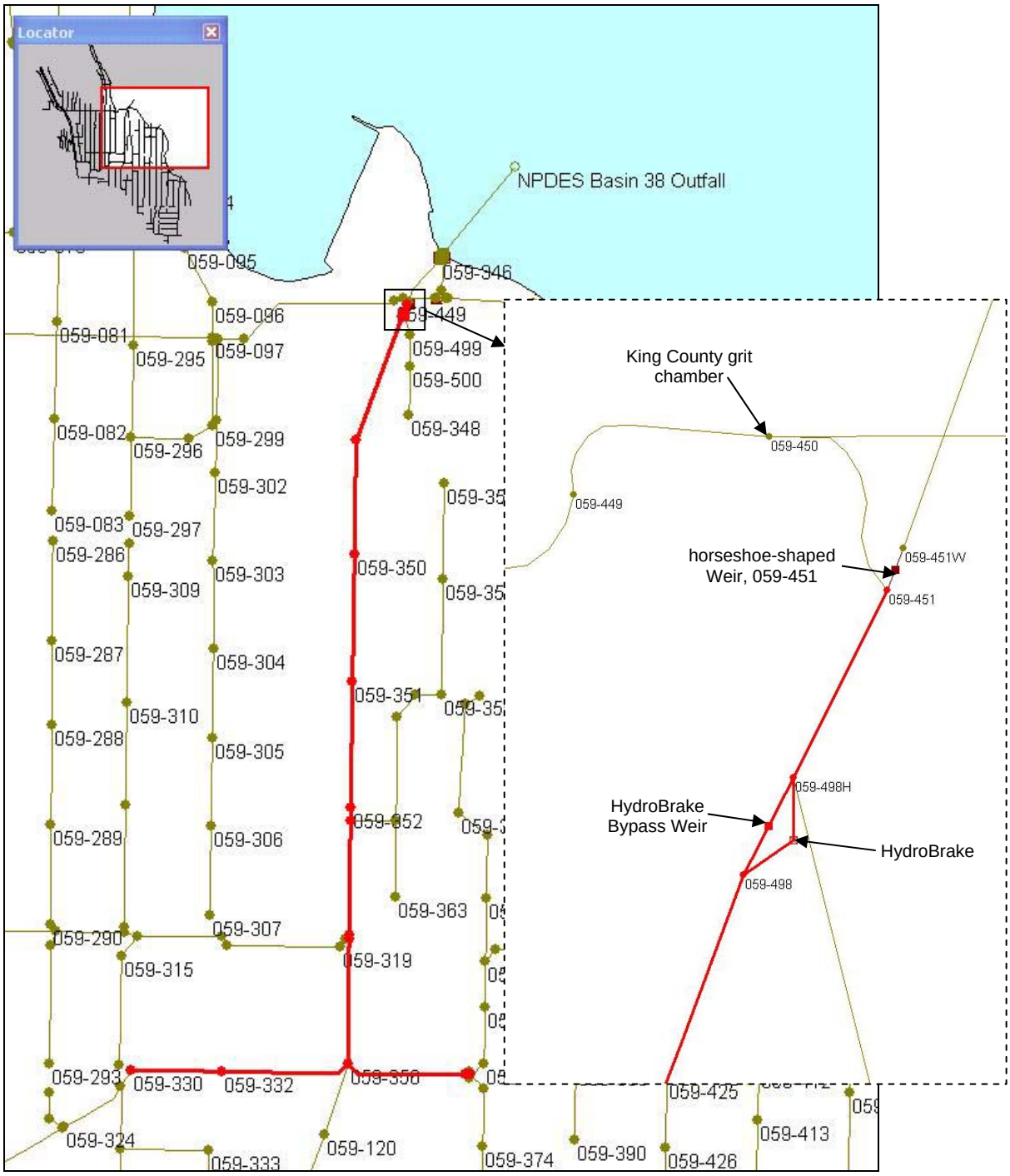


FIGURE 4-16: INFOWORKS PLAN VIEW AND DETAIL FOR CSO FACILITY 12

As flows from Basin 38 increase, the HydroBrake in MH 059-498 restricts flow, filling the 48-inch-diameter storage pipes and the 72-inch-diameter storage pipe. When levels in the storage pipes exceed 26.55 feet NAVD88, flows spill over the HydroBrake bypass weir above the HydroBrake and are conveyed to the horseshoe-shaped weir in MH 059-451. Levels in the system at MH 059-451 above 23.17 feet NAVD88 spill over the horseshoe-shaped weir and enter Overflow Structure 38.

Storage Pipe

Flows are stored in two 48-inch-diameter in-line storage pipes and in one 72-inch-diameter in-line storage pipe. The west 48-inch-diameter pipe is 728 feet long; the east pipe is 442 feet long. The 72-inch-diameter pipe is 2,552 feet long. The total volume of the entire control facility is 654,000 gallons, but is reduced to a usable volume of 384,000 gallons by the storage weir in MH 059-498.

HydroBrake

The HydroBrake in MH 059-498 controls flows from most of Basin 38 and CSO Facility 12 storage pipes to Hanford Street Trunk B and to the Overflow Structure 38. It is represented in the model as a vortex-type dummy link of zero length from MH 059-498 to dummy node 059-498H. Flow through the HydroBrake is defined by a user-defined stage-discharge curve. A manufacturer's curve is not available for this HydroBrake, so the only source of information for the model curve is flow-monitoring data from January 2008 through May 2009. Flow measurements at a monitor in MH 059-498 and differential head between monitors in MH 059-451 and 059-498 are used to define the model curve, shown in Figure 4-17. Because data with monitored flow rates above 5 MGD were reconstituted and could not be verified, the model curve is nearly vertical above flow rates of 5 MGD. The points defining the model curve are presented in Table 4-7.

HydroBrake Bypass Weir

A bypass weir above the HydroBrake in MH 059-498 controls the level in CSO Facility 12. The dimension (weir width = 6.88 feet) and elevation (crest = 26.55 feet NAVD88) for this control structure based on a 3D laser scanning survey were entered into the model. A theoretical broad-crested weir coefficient (C_d = 0.46) was used based on weir coefficient values used by ADS on similar weirs throughout the Genesee Area.

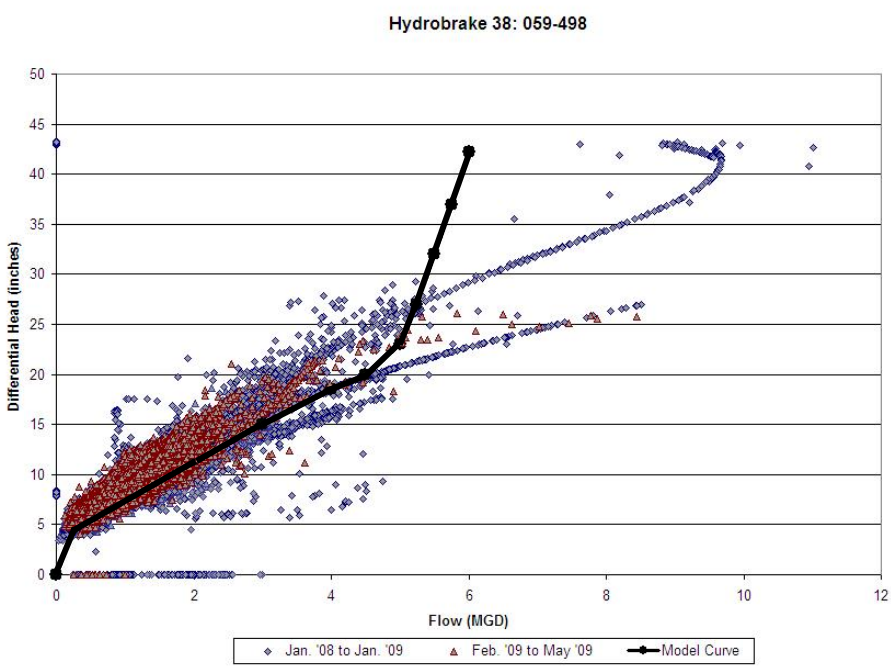


FIGURE 4-17: STAGE-DISCHARGE CURVE FOR HYDROBRAKE IN CSO FACILITY 12 (BASIN 38)

TABLE 4-7
HydroBrake Stage Discharge Curve Used in Model for CSO Facility 12 (Basin 38)

Manufacturer's Curve		Recommended Model Curve	
Differential Head (inch)	**Flow (MGD)**	**Differential Head (inch)**	**Flow (MGD)**
A manufacturer's stage-discharge curve is not available for the HydroBrake in Basin 38, in MH 059-498		0	0
		4.7	0.25
		8	1
		11.5	2
		15	3
		18.5	4
		20	4.5
		23	5
		27	5.25
		32	5.5
		37	5.75
		42.2	6

The weir rating curve for the HydroBrake bypass weir is presented in Figure 4-18.

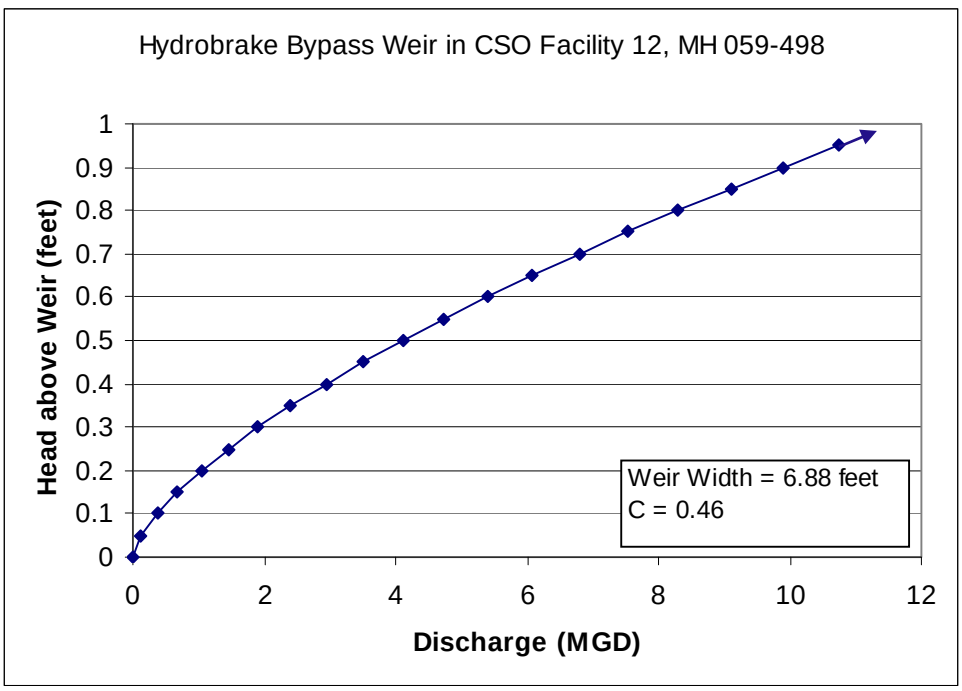


FIGURE 4-18: WEIR RATING CURVE FOR HYDROBRAKE BYPASS WEIR IN CSO FACILITY 12, MH 059-498

Horseshoe Weir

A horseshoe-shaped weir in MH 059-451 allows high flows backed up behind the grit chamber in MH 059-450 to spill over into Overflow Structure 38. The weir was surveyed using traditional manual point measurements, not the 3D laser scanning technology used on

most other weirs in the Genesee Area. The results of this survey were the basis for the model dimension (weir width = 24.23 feet) and elevation (crest = 23.17 feet NAVD88). A theoretical broad-crested weir coefficient (C_d = 0.46) was used based on best available information and engineering judgment. The weir rating curve for the Horseshoe Weir is presented in Figure 4-19.

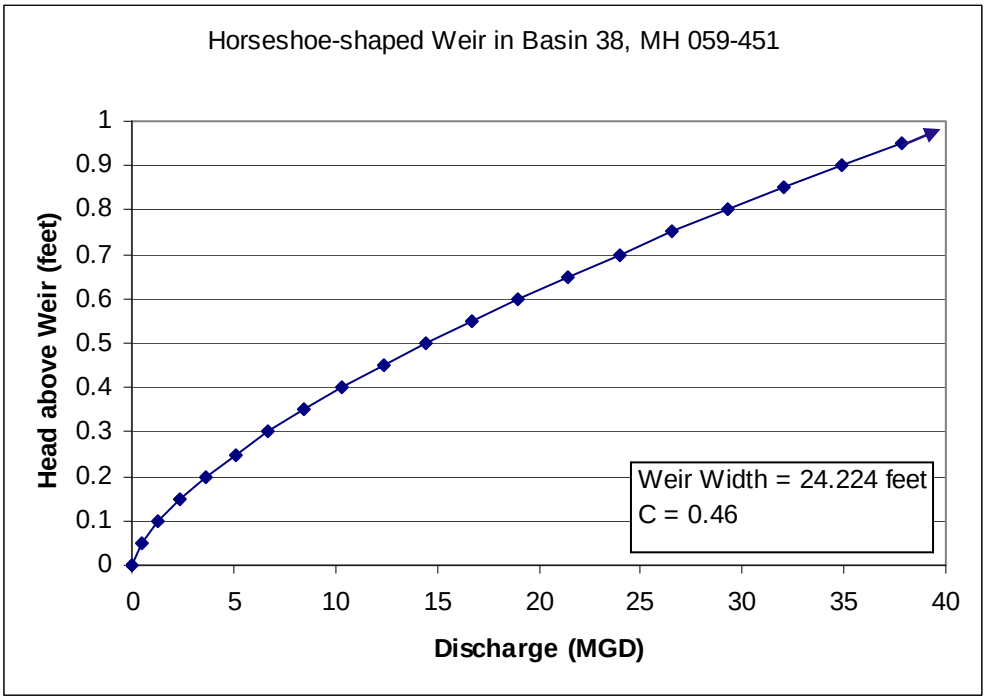


FIGURE 4-19: WEIR RATING CURVE FOR HORSESHOE-SHAPED WEIR IN BASIN 38, MH 059-451

4.3.12 NPDES CSO Outfall 165

Overflow Structure 165 is located east of Lake Washington Boulevard South and South Alaska Street (see Figure 1-1). The structure consists of an overflow weir in MH 067-078 and NPDES CSO Outfall 165. Pump Station 6 is located downstream of this structure. Recent retrofits have raised the level of the overflow weir (September 26, 2008), and slip-lined the pipes between MH 067-078 and MH 060W-022 (January, 2009). A plan view of the InfoWorks layout for NPDES CSO Outfall 165 is found in Figure 4-20.

Operations

During normal operations, flows from Basin 165 are conveyed past the overflow weir in Overflow Structure 165 at MH 067-078 to Pump Station 6, where they are pumped into the lake line. When the capacity of Pump Station 6 is exceeded, levels rise above 21.79 feet NAVD88 and spill over the overflow weir, and flows are directed to NPDES CSO Outfall 165 and Lake Washington.

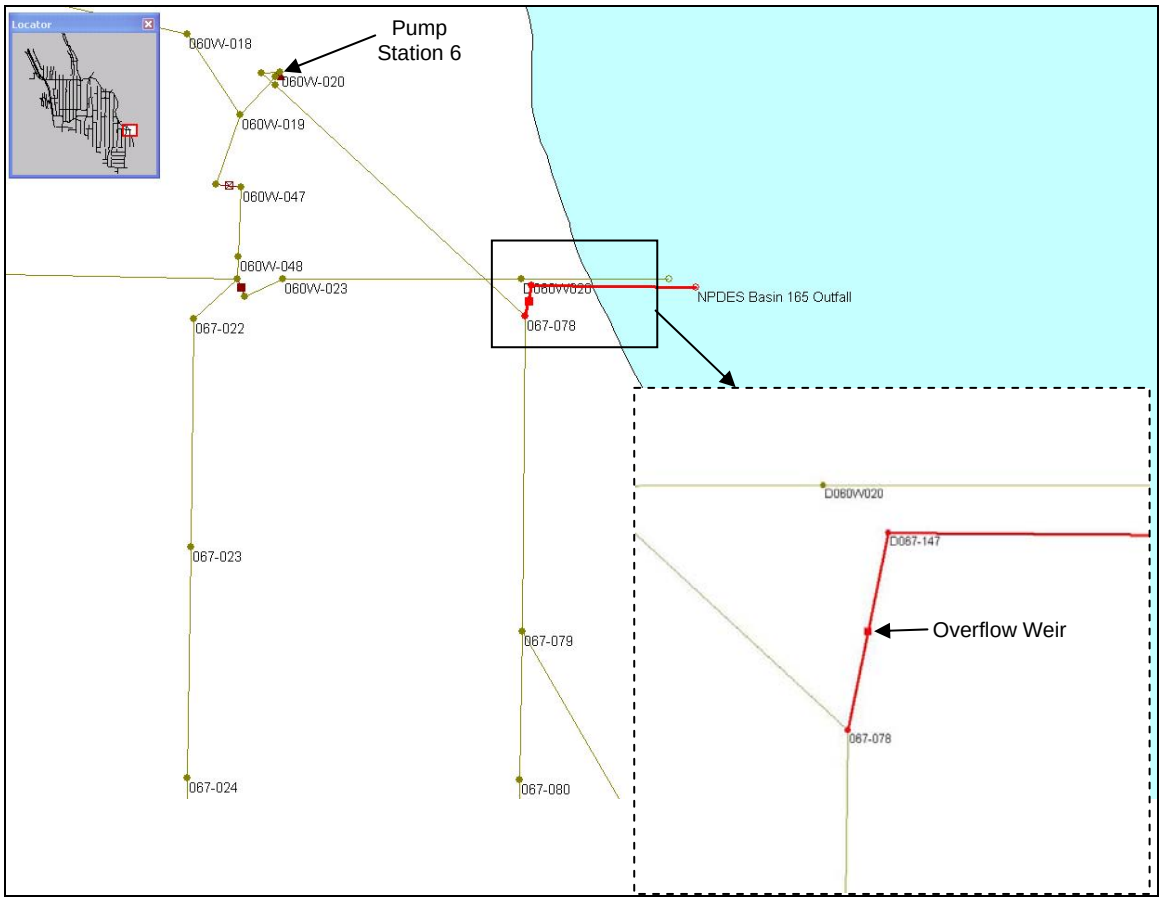


FIGURE 4-20: INFOWORKS PLAN VIEW AND DETAIL FOR NPDES CSO OUTFALL 165

Overflow Weir

The overflow weir in Overflow Structure 165, located in MH 067-078, allows excess flows from Basin 165 to flow to NPDES CSO Outfall 165. The dimension (weir width = 4.40 feet) and elevation (crest = 21.79 feet NAVD88) of this weir were entered into the model based on a traditional survey on December 31, 2008; this survey occurred after the weir was raised approximately 12 inches on September 26, 2008. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 165 Overflow Weir is presented in Figure 4-21.

Outfall

The outfall is a 12-inch-diameter reinforced concrete pipe that extends 43 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 10.8 feet NAVD88. It is represented in the model by a link from D067-147 to Basin 165 Outfall. The lake level boundary conditions are defined at the Basin 165 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

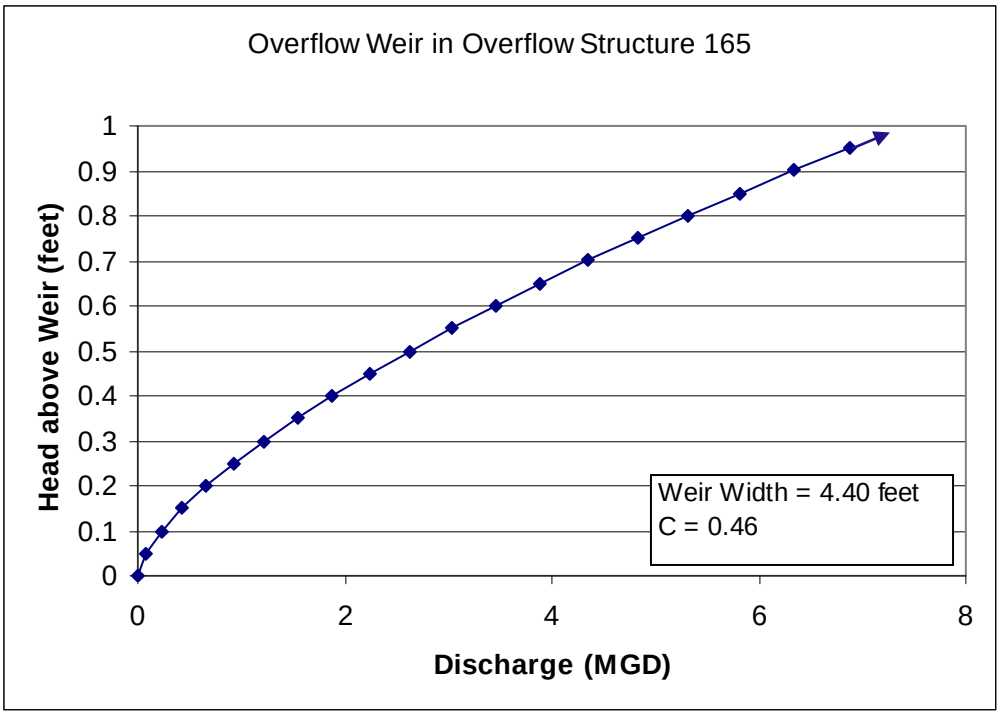


FIGURE 4-21: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 165

4.3.13 NPDES CSO Outfall 43

Overflow Structure 43 is located at South Alaska Street, between 54th Avenue South and Lake Washington Boulevard South (see Figure 1-1). The structure consists of an overflow weir in MH 060W-049 and NPDES CSO Outfall 43. Flows in Control Structure 43 are controlled by CSO Facility 9 (see Section 4.3.8).

Operations

During normal operations, flows from Basin 43 are conveyed past the overflow weir in Overflow Structure 43 at MH 060W-049, through CSO Facility 9 (see Section 4.3.8), and to the lake line at MH 060W-019. When the capacity of CSO Facility 9 is exceeded, flows spill over the weir in MH 060W-049 and are conveyed to the NPDES CSO Outfall 43 and Lake Washington.

Overflow Weir

The overflow weir for Overflow Structure 43, located in MH 060W-049, is described in the discussion of CSO Facility 9 (see Section 4.3.8).

Outfall

The outfall is a 21-inch-diameter reinforced concrete pipe that extends 70 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 6 feet NAVD88. It is represented in the model by a link from D060W-020 to Basin 43 Outfall. The lake level boundary conditions are defined at the Basin 43 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

4.3.14 NPDES CSO Outfall 42

Control Structure 42 is located southwest of Lake Washington Boulevard South, between South Genesee Way and 53rd Avenue South (see Figure 1-1). The structure consists of an overflow weir and HydroBrake in MH 060W-052, and NPDES CSO Outfall 42. Flows in Control Structure 42 are controlled by CSO Facility 10 (see Section 4.3.9).

Operations

During normal operations, flows from Basin 42 are conveyed through CSO Facility 10 (see Section 4.3.9), past the overflow weir in MH 060W-052 and to the lake line at MH 060W-014. When the capacity of CSO Facility 10 is exceeded, flows spill over the weir in MH 060W-052 and are conveyed to the NPDES CSO Outfall 42 and Lake Washington.

Overflow Weir

The overflow weir for Control Structure 42, located in MH 060W-052, is described with CSO Facility 10 (see Section 4.3.9).

Outfall

The outfall is a 12-inch-diameter cast iron pipe that extends 165 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 10.8 feet NAVD88. It is represented in the model by a link from 060W-052H to Basin 42 Outfall. The lake level boundary conditions are defined at Basin 42 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

4.3.15 NPDES CSO Outfall 41

Two overflow structures allow flow to be conveyed to NPDES CSO Outfall 41: Overflow Structure 41A and Overflow Structure 41B.

Overflow Structure 41A is located near Lake Washington Boulevard South and 50th Avenue South (see Figure 1-1). The structure consists of an overflow weir in MH 059-434. Overflow Structure 41B is located near Lake Washington Boulevard South and 49th Avenue South (see Figure 1-1). The structure consists of an overflow weir in MH 059-406. Both structures are connected to NPDES CSO Outfall 41, which has a crushed outfall pipe. Construction to repair this crushed outfall pipe is currently planned for the fall of 2010. A plan view of the InfoWorks layout for NPDES CSO Outfall 41 is found in Figure 4-22.

Operations

During normal operations, flows from the area tributary to Overflow Structure 41A are conveyed past the overflow weir in MH 059-434 to the lake line. Flows from the area tributary to Overflow Structure 41B combine with flows from Basin 40, and are conveyed past the overflow weir in MH 059-406 to the lake line.

When the capacity of the lake line is exceeded, levels rise above 19.51 feet NAVD88 and spill over the Overflow Structure 41B weir and are conveyed to NPDES CSO Outfall 41 and Lake Washington. Levels that rise above 21.63 feet NAVD88 spill over the Overflow Structure 41A weir and are conveyed to NPDES CSO Outfall 41 and Lake Washington.

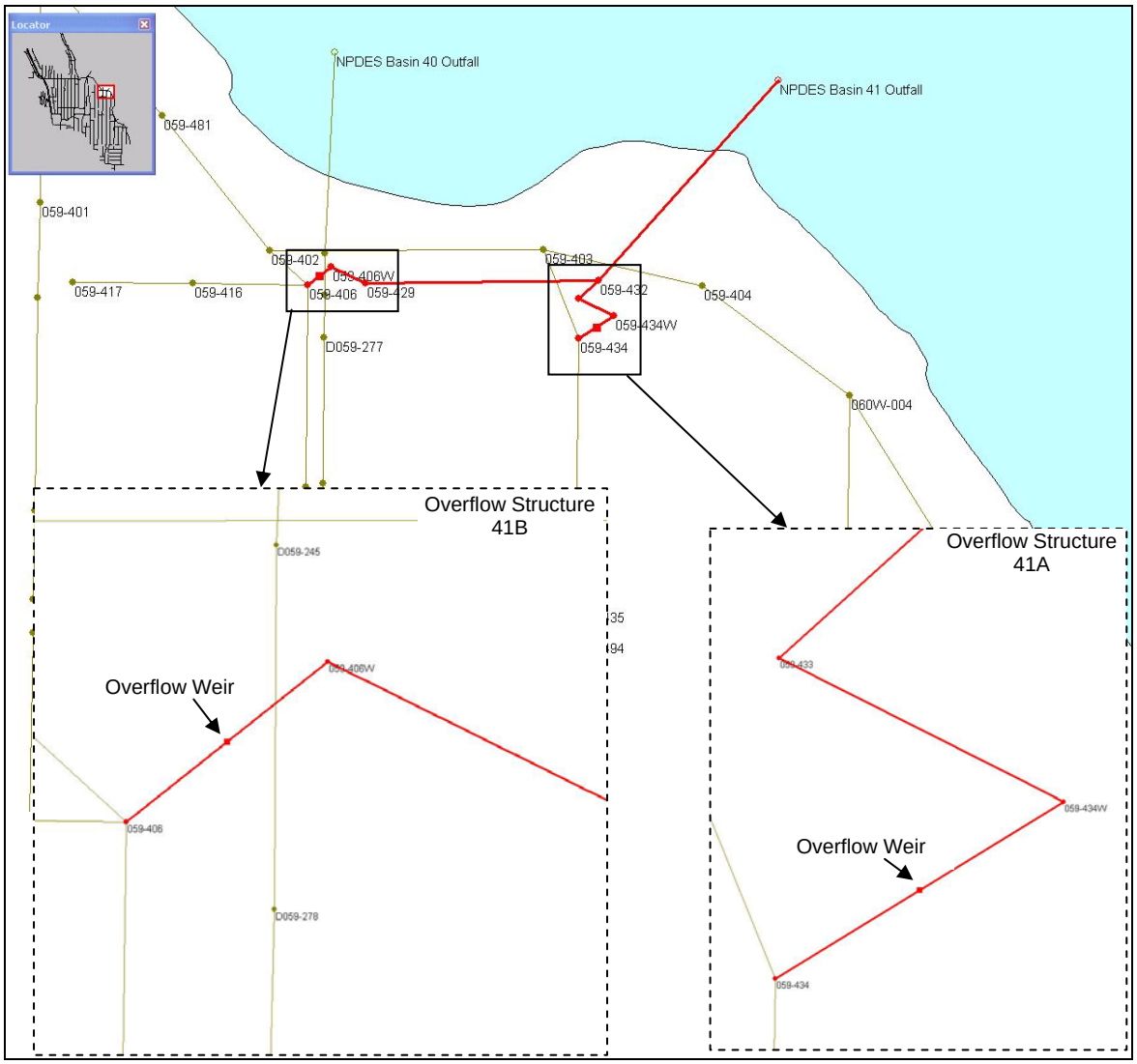


FIGURE 4-22: INFOWORKS PLAN VIEW AND DETAIL FOR NPDES CSO OUTFALL 41

Overflow Structure 41A Weir

The Overflow Structure 41A weir, located in MH 059-434, allows excess flows from Basin 41 and the lake line to flow to NPDES CSO Outfall 41. The dimension (weir width = 4.96 feet) and elevation (crest = 21.63 feet NAVD88) of this weir were entered into the model based on a 3D laser scanning survey. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 41A Overflow Weir is presented in Figure 4-23.

Overflow Structure 41B Weir

The Overflow Structure 41B weir, located in MH 059-406, allows excess flows from Basin 40, Basin 41, and the lake line to flow to NPDES CSO Outfall 41. The dimension (weir width = 5.71 feet) and elevation (crest = 19.51 feet NAVD88) of this weir were entered into the model based on a 3D laser scanning survey. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported

overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 41B Overflow Weir is presented in Figure 4-24.

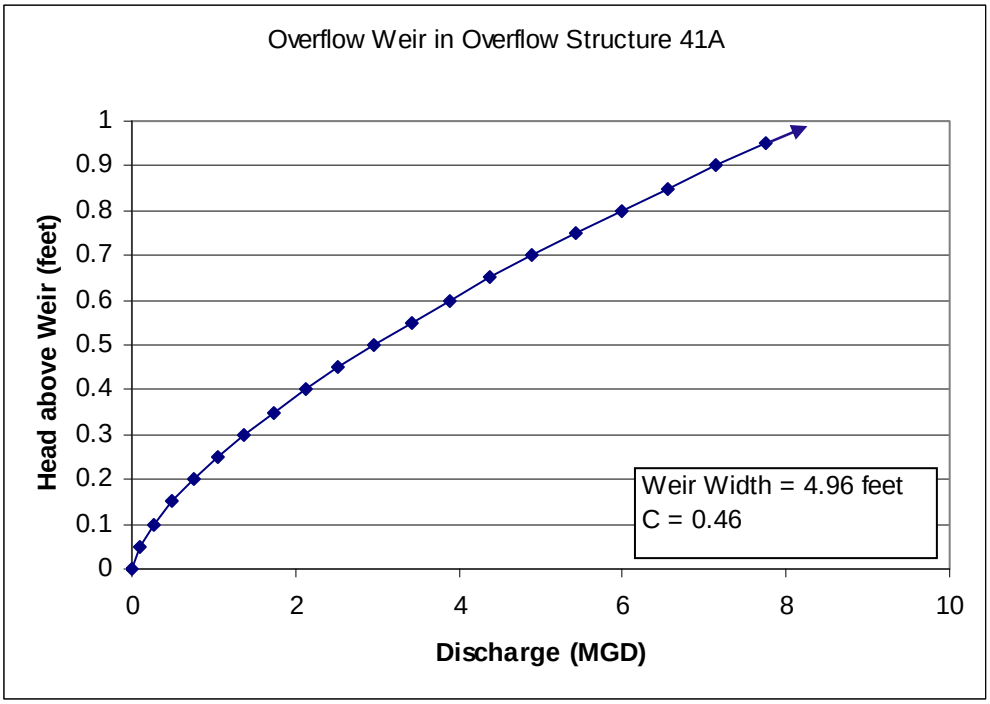


FIGURE 4-23: WEIR RATING CURVE FOR NPDES 41A OVERFLOW WEIR

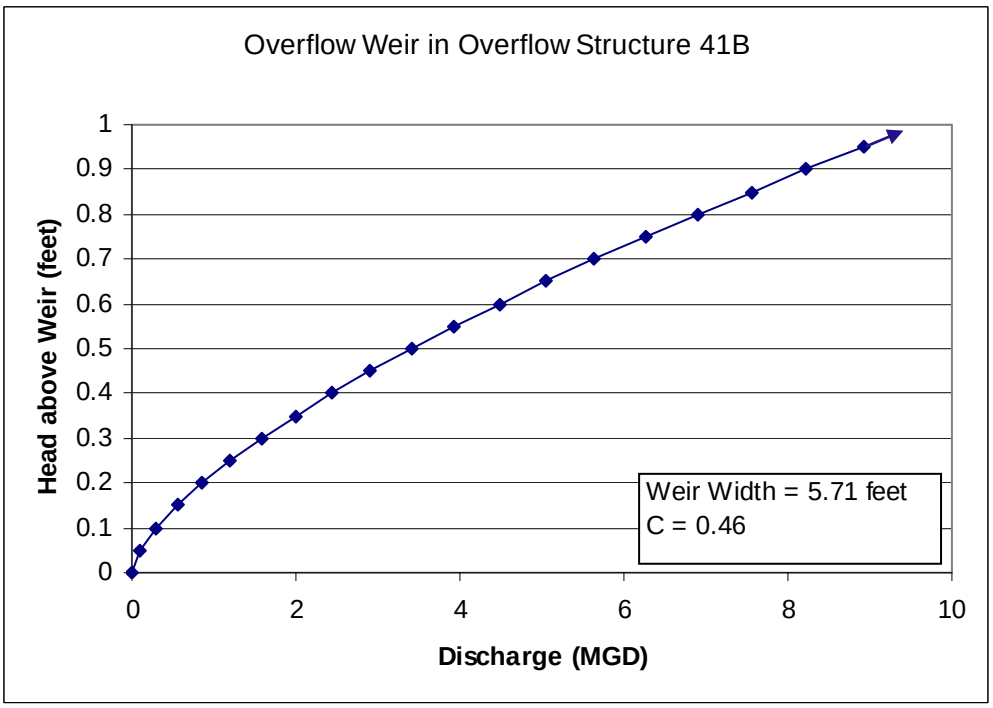


FIGURE 4-24: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 41B

Outfall

The outfall is a 15-inch-diameter Armco iron pipe connected to 14-inch PVC pipe that extends 81 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 9.2 feet NAVD88. It is represented in the model by a link from 059-432 to Basin 41 Outfall. The lake level boundary conditions are defined at Basin 41 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1). Field investigations indicate that the NPDES CSO Outfall 41 is severely damaged, the implications of which are discussed in Section 2.6.4.

4.3.16 NPDES CSO Outfall 40

Operations

Overflow Structure 40 is located on South Dakota Street, between 49th Avenue South and 50th Avenue South (see Figure 1-1). The structure consists of an overflow through weir in MH 059-491 and NPDES CSO Outfall 40, which is shared with a stormwater outfall. Flows in Control Structure 40 are controlled by CSO Facility 11 (see Section 4.3.10).

Overflow Weir

The overflow weir for Overflow Structure 40, located in MH 059-491, is described with CSO Facility 11 (see Section 4.3.10).

Outfall

The outfall is a 12-inch-diameter concrete pipe connected to a 24-inch-diameter concrete pipe that extends 50 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 12.4 feet NAVD88. It is represented in the model by a link from D059-245 to Basin 40 Outfall. The lake level boundary conditions are defined at Basin 40 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

4.3.17 NPDES CSO Outfall 38

Overflow Structure 38 is located in Stan Sayres Memorial Park, north of the intersections of Lake Washington Boulevard South and 45th Avenue South (see Figure 1-1). The structure consists of: a 72-inch-diameter storage pipe between MH 059-451 and 059-574; a storage weir, an overflow weir, a baffle wall and a pinch valve in MH 059-574; and NPDES CSO Outfall 38. Figure 4-25 presents a plan view of the InfoWorks layout for NPDES CSO Outfall 38.

Operations

During normal flow, flows do not enter Overflow Structure 38.

During high flows, flow can enter Overflow Structure 38 from over the horseshoe-shaped weir in MH 059-451 or from high levels in the Pump Station 5 wet well. Flows that spill over the horseshoe-shaped weir pass through a 72-inch-diameter in-line storage pipe and through a pinch valve underneath the storage weir in Overflow Structure 38 to Pump Station 5. As the Pump Station 5 wet well level exceeds 16.67 feet NAVD88, the pinch valve beneath the storage weir closes, causing the 72-inch-diameter storage pipe between MH 059-451 and MH 059-574 to fill. When levels in the downstream portion of the 72-inch-diameter pipe exceed 21.33 feet NAVD88, flows overtop the storage weir, fill the chamber between

the storage weir and the overflow weir, and flow over the overflow weir at an elevation of 19.13 feet NAVD88 and are conveyed to NPDES CSO Outfall 38.

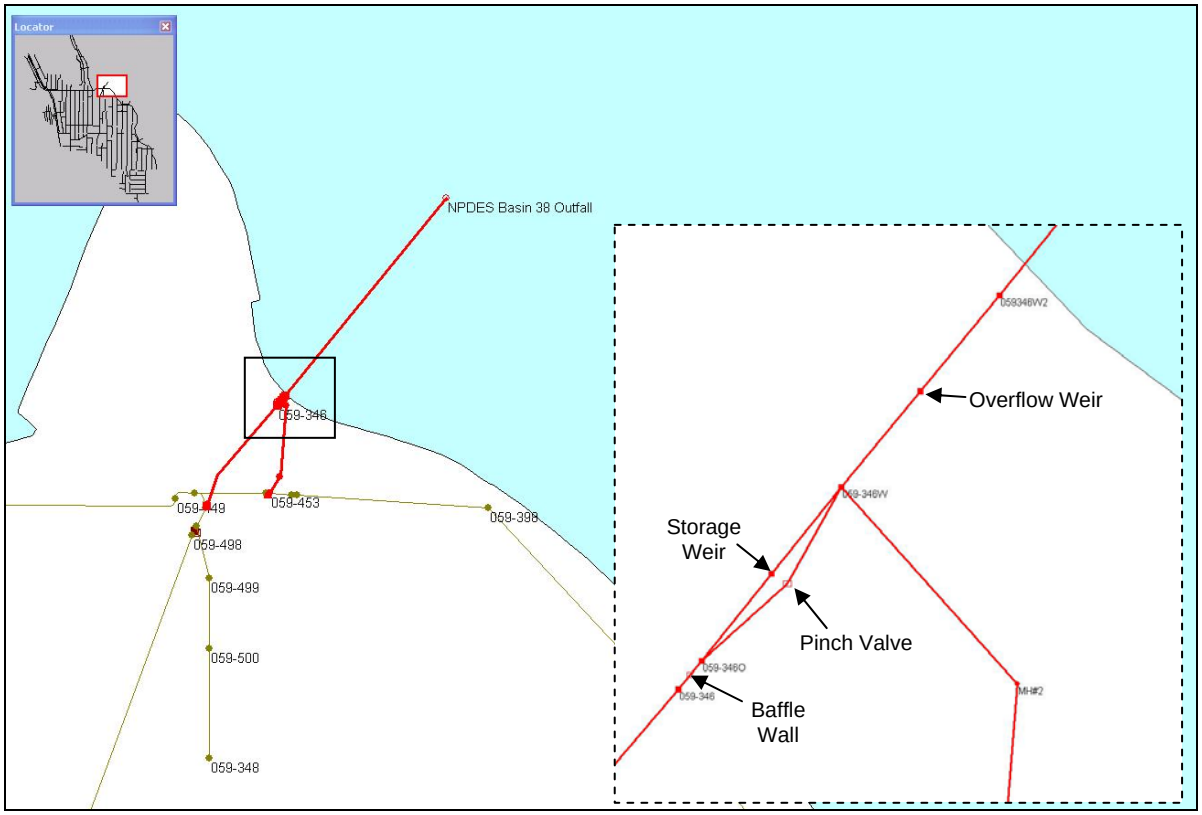


FIGURE 4-25: INFOWORKS PLAN VIEW AND DETAIL FOR NPDES CSO OUTFALL 38

Storage Weir

Overflow Structure 38, located in MH 059-574, contains two weirs and a pinch valve, regulating flow to and from the 72-inch-diameter storage pipe, and to and from the Pump Station wet well. The storage weir is upstream of the overflow weir; its dimension (width = 7.91 feet) and elevation (crest = 21.33 feet NAVD88) were entered into the model based on 3D laser scanning survey information. A theoretical sharp-crested weir coefficient (C_d = 0.62 feet) was used. This coefficient was based on values used by ADS on similar weirs in the Genesee Area. The weir rating curve for the storage weir in Overflow Structure 38 is presented in Figure 4-26.

Pinch Valve

A pinch valve underneath the storage weir in Overflow Structure 38 allows flows from the downstream portion of the 72-inch-diameter storage pipe to freely flow to the Pump Station 5 wet well.

The operation of this valve is based on water level in the Pump Station 5 wet well—the valve is normally open, but fully closes when Pump Station 5 wet-well level exceeds 16.67 feet NAVD88 to make use of the storage in the downstream portion of the 72-inch-diameter storage pipe.

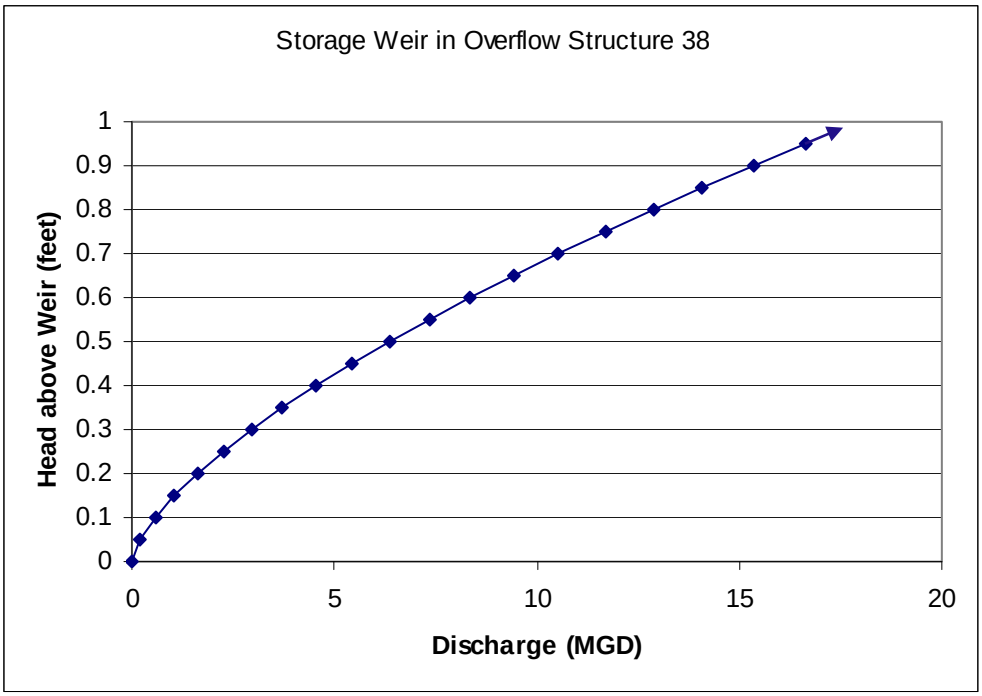


FIGURE 4-26: WEIR RATING CURVE FOR STORAGE WEIR IN OVERFLOW STRUCTURE 38

During field observations conducted in spring 2008, the valve appeared to be malfunctioning. The water level in Overflow Structure 38 was raised, indicating the valve was closed although it was not during a period of wet weather. SPU maintenance personnel fixed the valve and will continue to monitor the operation of this valve. For the model, the intended operation as discussed above (normally open until water level rises in the wet well) was incorporated into the model. Its operation was incorporated in the model using real-time control functionality in a link between 059-346O and 059-346W.

Overflow Weir

The overflow weir in Overflow Structure 38 (MH 059-574), allows excess flows from Pump Station 5 and CSO Facility 12 to overflow into Lake Washington via NPDES CSO Outfall 38. The dimension (weir width = 7.97 feet) and elevation (crest = 19.13 feet NAVD88) for this control structure based on a 3D laser scanning survey were entered into the model. A theoretical sharp-crested weir coefficient (C_d = 0.62) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the overflow weir in Overflow Structure 38 is presented in Figure 4-27.

Outfall

The outfall is a 72-inch-diameter concrete pipe that reduces to a 36-inch-diameter cast iron pipe at the end (Herrera, 2006). The outfall pipe extends 396 feet from the Lake Washington shoreline to an invert depth of -16.8 feet NAVD88. It is represented in the model by a link from 059-346W2 to Basin 38 Outfall. The lake level boundary conditions are defined at Basin 38 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

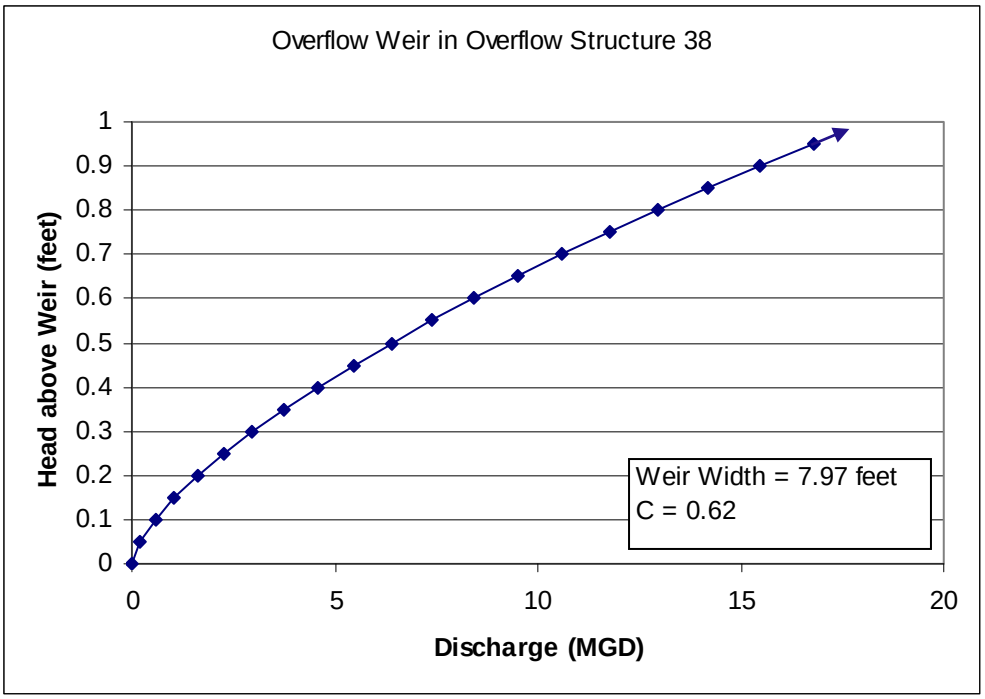


FIGURE 4-27: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 38

4.3.18 NPDES CSO Outfall 37

Overflow Structure 37 is located near Lake Washington Boulevard South and South Horton Street (see Figure 1-1). The structure consists of an overflow weir in MH 059-489 and NPDES CSO Outfall 37. A plan view of the InfoWorks layout for NPDES CSO Outfall 37 is found in Figure 4-28.

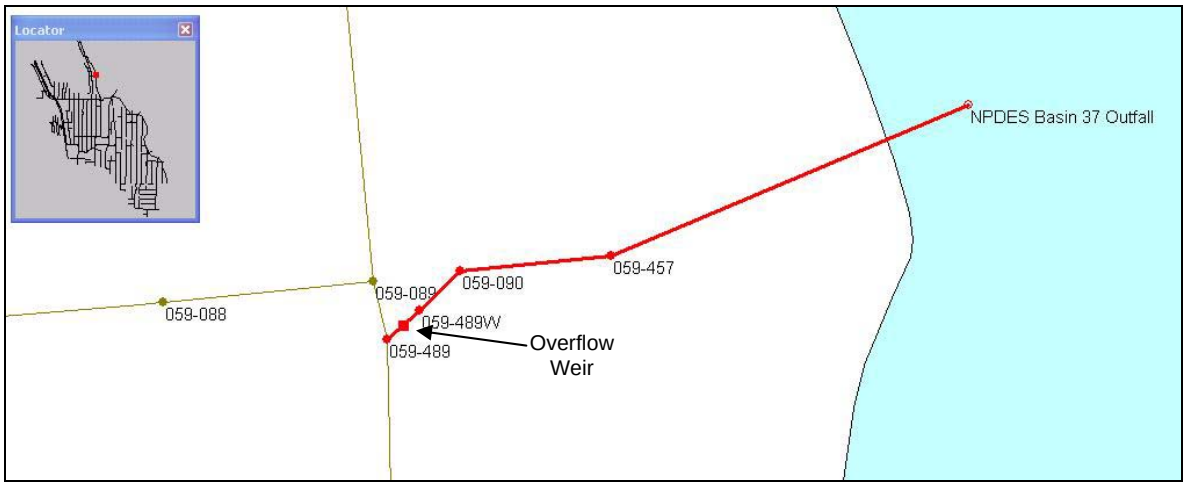


FIGURE 4-28: INFOWORKS PLAN VIEW AND DETAIL FOR NPDES CSO OUTFALL 37

Operations

During normal operations, flows from Basin 37 are conveyed past the overflow weir in MH 059-489 directly to MH 059-483 along the Hanford Street Trunk B. Levels that exceed 31.93 feet NAVD88 spill over the weir in MH 059-489 and are conveyed NPDES CSO Outfall 37.

Overflow Weir

The overflow weir in Overflow Structure 37, located in MH 059-489, allows excess flows from Basin 37 to flow to NPDES CSO Outfall 37. The dimension (weir width = 5.46 feet) and elevation (crest = 31.93 feet NAVD88) of this weir were entered into the model based on a 3D laser scanning survey. A theoretical broad-crested weir coefficient (C_d = 0.46) was used. This coefficient was based on values used by ADS for measuring reported overflow volumes; it was recommended by HDR (2008) and was verified in Street et al. (1996). The weir rating curve for the NPDES 37 Overflow Weir is presented in Figure 4-29.

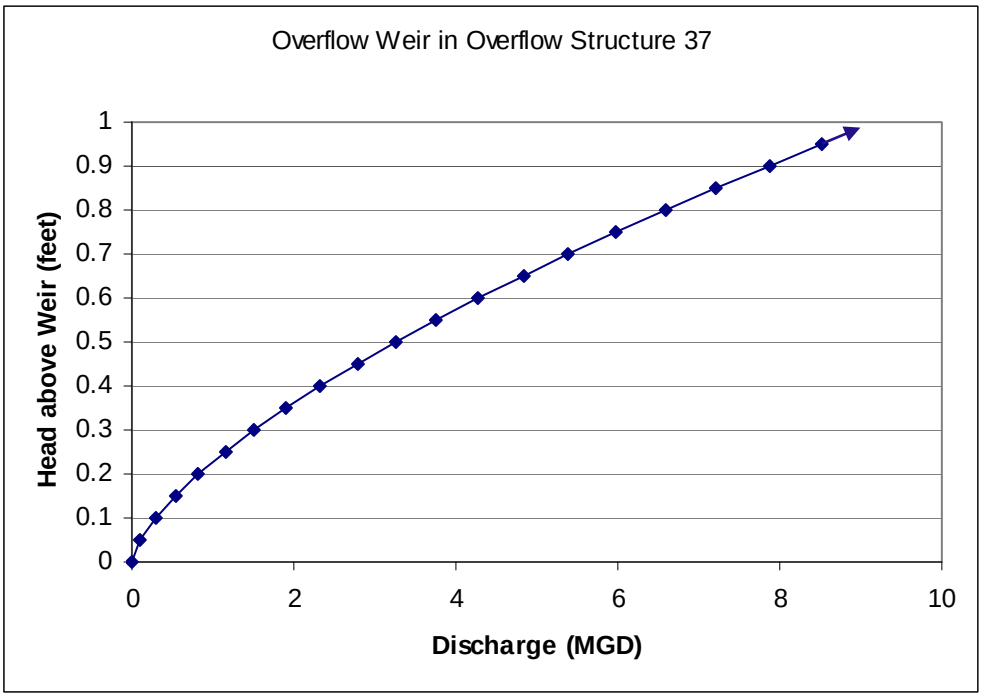


FIGURE 4-29: WEIR RATING CURVE FOR OVERFLOW WEIR IN OVERFLOW STRUCTURE 37

Outfall

The outfall is a 12-inch-diameter corrugated metal pipe that extends 32 feet from the Lake Washington shoreline (Herrera, 2006) to an invert depth of 15 feet NAVD88. It is represented in the model by a link from 059-457 to Basin 37 Outfall. The lake level boundary conditions are defined at Basin 37 Outfall node using USACE lake level records at the Chittenden Locks (see Section 4.2.1).

4.3.19 King County System

The King County System in the Genesee Area consists of a grit chamber, the Hanford Street Trunk B, the Rainier Avenue Pump Station, and the force main from the pump station. The

grit chamber is located just downstream of Pump Station 5, at Lake Washington Boulevard South and South Alaska Street in MH 059-450. The Hanford Street Trunk B consists of a 42-inch-diameter trunk that runs between the grit chamber and Rainier Avenue Pump Station, along Charlestown Street. The Rainier Avenue Pump Station is located at MH 059-446, 3761 Rainier Avenue South. A plan view of the InfoWorks layout for King County System is found in Figure 4-30.

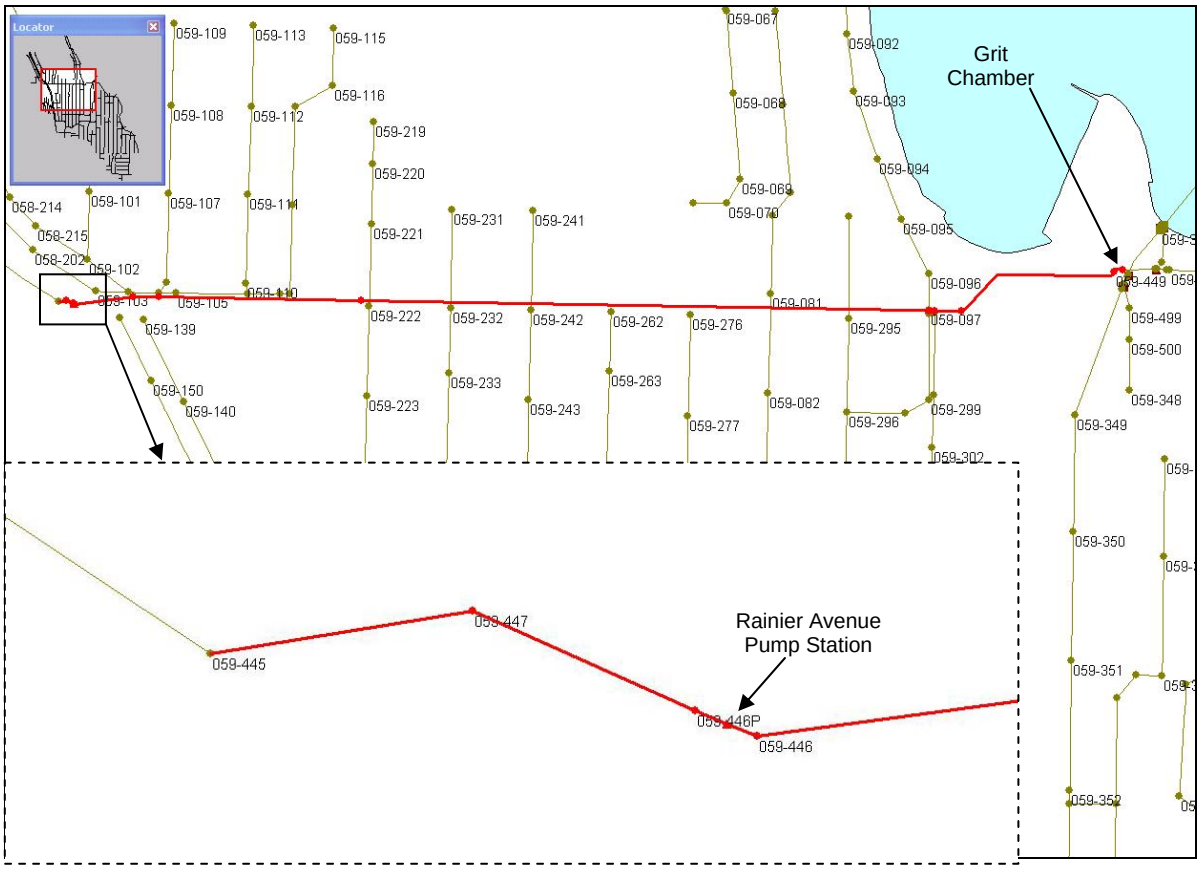


FIGURE 4-30: INFOWORKS PLAN VIEW AND DETAIL FOR THE KING COUNTY SYSTEM

Grit Chamber

In 1931 the City installed a grit chamber at the current interface between the King County and City facilities at Stan Sayres Memorial Park (node 059-450). It was acquired by King County in 1962. Discharge from Pump Station 5 and normal flows from the horseshoe-shaped weir at MH 059-451 pass through this chamber. The grit chamber was designed to remove sand, gravel, and other heavy constituents by allowing them to settle out before the water entered the Hanford Street Trunk B. In around 1973 King County permanently filled the sediment chamber to eliminate grit collection at this location. When originally constructed the grit chamber may have operated sufficiently. However, as the Genesee Area became more developed the grit chamber became overwhelmed and would require frequent cleaning. King County elected to fill it in and handle the associated grit from the Genesee area at their treatment plant. For this reason, it is modeled as a node with associated volume. The grit chamber is modeled as node 059-450 with an equivalent volume and invert and ground elevations based on King County record records. According to the record

drawings, the chamber has an approximate volume of 2,000 cubic feet. The outlet of the grit chamber is an ogee weir with an approximately 20-inch by 42-inch circular outlet. To investigate whether this caused a restriction at the structure, a sluice gate with an equivalent area was used to model the outlet. No effect on the flow from the structure was noted. To maintain consistency with the system information contained in GIS, the sluice gate was removed from the base model for subsequent alternative modeling. See notes in the model for additional information.

Hanford Street Trunk B

The Hanford Street Trunk B is a 42-inch-diameter sewer trunk that was constructed as a hand-dug tunnel in 1931 by the City and was acquired by King County in 1962. The trunk extends from the grit chamber (node 059-450) to the Rainier Avenue Pump Station (node 059-446). Due to the trunk's depth (130 feet below ground surface at its lowest point), there is limited access for maintenance and condition assessment. Therefore, the Hanford Street Trunk B is modeled as a standard 42-inch-diameter link.

Rainier Avenue Pump Station

See Section 4.3.22 for a description of the Rainier Avenue Pump Station.

4.3.20 Pump Station 6

Pump Station 6 pumps flows from Basin 165 to the lake line, and is located at MH 060W-020, Lake Washington Boulevard South and South Alaska Street (see Figure 1-1). The facility consists of two pumps and a wet well chamber. A plan view of the InfoWorks layout for Pump Station 6 is found in Figure 4-31.

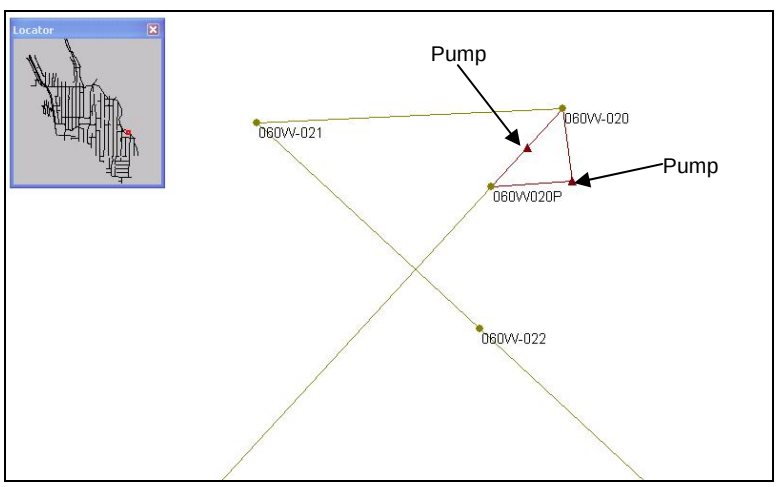


FIGURE 4-31: INFOWORKS DETAIL PUMP STATION 6

Operation

All flows from Basin 165 are lifted approximately 14 feet by Pump Station 6 through a 4-inch-diameter force main to the lake line, where they are conveyed to Pump Station 5. Flows exceeding the capacity of Pump Station 6 overflow through the NPDES CSO Outfall 165 (see Section 4.3.12).

Pumps

Pump Station 6 operates two alternating fixed-speed pumps and is controlled by levels in the wet well. Switch on and off rates, as well as pumping capacity verified through a field draw-down test, are presented in Table 4-8. Additional information from the field draw-down test is provided in Appendix A.

TABLE 4-8
SPU Pump Station 6 Data Fields

Description	Units	Pump Station 6 Pump 1	Pump Station 6 Pump 2
Upstream Node ID		060W-020	060W-020
Downstream Node ID		060W-020P	060W-020P
Link Type (Pump type)		SCRPMP	SCRPMP
System Type		Combined	Combined
Switch On Level	ft AD[a]	17.79	18.79
Switch Off Level	ft AD[a]	15.69	15.69
Pump Capacity	MGD	0.41	0.24

[a]ft AD = feet above NAVD88

CH2M HILL modeled SPU Pump Station 6 as two *scrpmp* pump types between node 060W-020 and dummy node 060W-020P. The *scrpmp* pump type is independent of the downstream head but has a discharge that increases with the upstream water level. Configuration requires a head ascending discharge table shown in Table 4-9 and Figure 4-32.

TABLE 4-9
Pump Station 6 Stage-Discharge Curve Values

Head (ft)	Discharge (MGD)
0	0
13.54	0.41
16.13	0.41
26.23	0.61

Wet Well

The wet well provides in-line storage during pumping operations and is represented in the model by node 060W-020 with a cross-sectional area equal to that measured during the field draw-down test (see Appendix A) of 38.5 square feet.

Outfall

The outfall for Pump Station 6 is the NPDES CSO Outfall 165, which is described in Section 4.3.12.

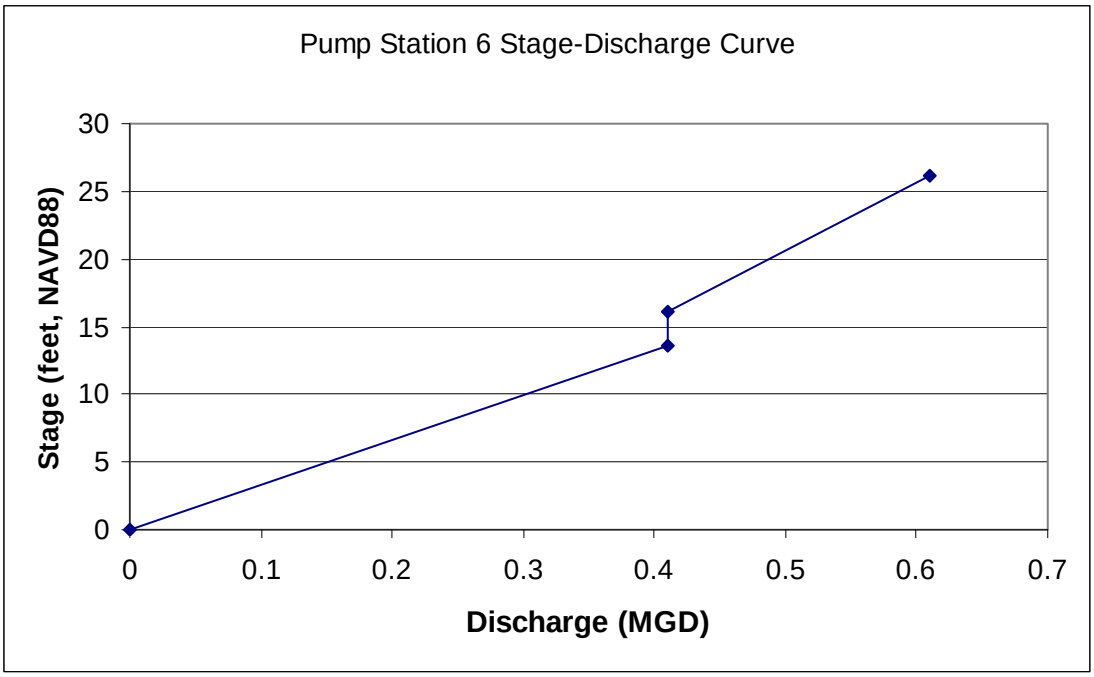


FIGURE 4-32: PUMP STATION 6 STAGE-DISCHARGE CURVE

4.3.21 Pump Station 5

Pump Station 5 pumps flow from basins 165, 43, 42, 41, 40, and a portion of 38 from the lake line to the Hanford Street Trunk B. The pump station is located in Stan Sayres Memorial Park, north of the intersections of Lake Washington Boulevard South and 45th Avenue South, and east of Overflow Structure 38 (see Figure 1-1). The facility consists of two pumps and a wet well chamber. A plan view of the InfoWorks layout for Pump Station 5 is found in Figure 4-33.

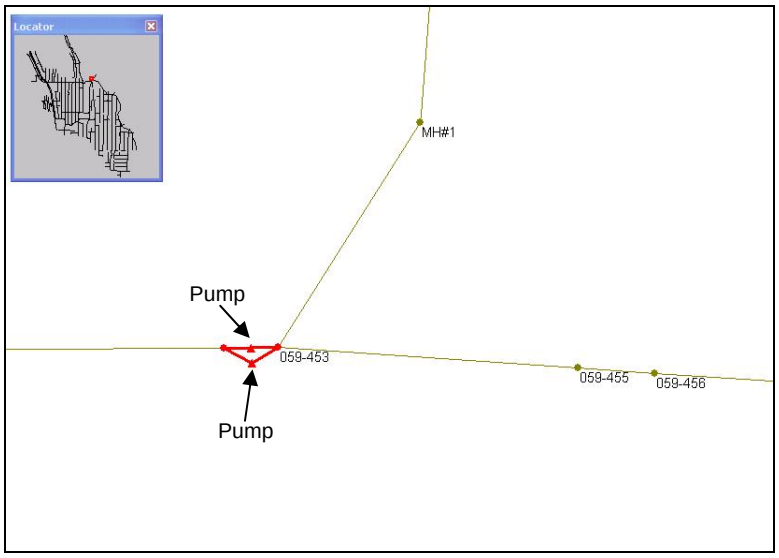


FIGURE 4-33: INFOWORKS DETAIL PUMP STATION 5

Operation

All flows from the lake line are lifted approximately 14 feet by Pump Station 5 through a 10-inch-diameter force main to Hanford Street Trunk B, where they are conveyed to the Rainier Avenue Pump Station. In addition to flows from the lake line, a connection between the wet well and the chamber between Weir 1 and Weir 2 of Overflow Structure 38 allows flows over Weir 1 to be pumped to Hanford Street Trunk B. Flows exceeding the capacity of Pump Station 5 overflow through NPDES CSO Structure 38.

Pumps

Pump Station 5 operates two alternating fixed-speed pumps, and is controlled by levels in the wet well. Switch on and off rates, as well as pumping capacity verified through a field draw-down test, are presented in Table 4-10. Additional information from the field draw-down test is provided in Appendix A.

TABLE 4-10
SPU Pump Station 5 Data Fields

Description	Units	Pump Station 5 Pump 1	Pump Station 5 Pump 2
Upstream Node ID		059-453	059-453
Downstream Node ID		059-453P	059-453P
Link Type (Pump type)		SCRMPM	SCRPMP
System Type		Combined	Combined
Switch On Level	ft AD[a]	14.70	15.20
Switch Off Level	ft AD[a]	10.70	10.70
Pump Capacity	MGD	1.29	0.90

[a]ft AD = feet above NAVD88

CH2M HILL modeled SPU Pump Station 5 as two *scrpmp* pump types between node 059-453 and dummy node 059-453P. The *scrpmp* pump type is independent of the downstream head but has a discharge that increases with the upstream water level. Configuration requires a head ascending discharge table, shown in Table 4-11 and Figure 4-34.

Wet Well

The wet well provides in-line storage during pumping operations and is represented in the model by node 059-453 with a cross-sectional area equal to that measured during the field draw-down test (see Appendix A) of 180 square feet.

Outfall

The outfall for Pump Station 5 is the NPDES CSO Outfall 38, which is described in Section 4.3.17.

TABLE 4-11
Pump Station 5 Stage-Discharge Curve Values

Head (ft)	Discharge (MGD)
0	0
10	1.3
14.04	1.3
17.52	1.61
30.5	1.72

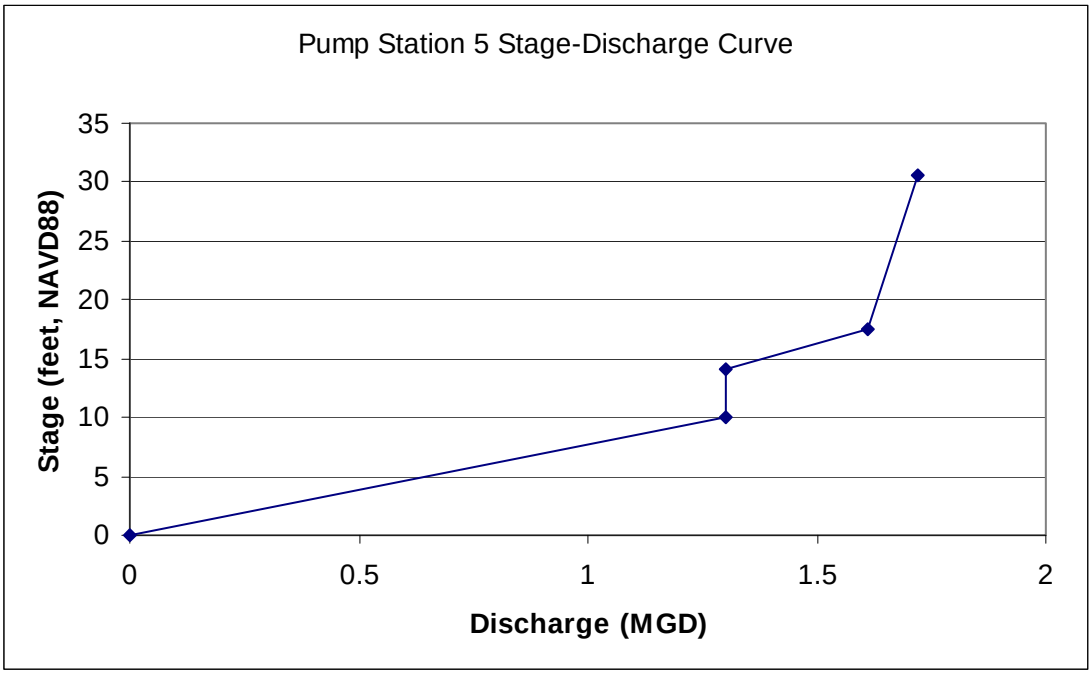


FIGURE 4-34: PUMP STATION 5 STAGE-DISCHARGE CURVE

4.3.22 Rainier Avenue Pump Station

The Rainier Avenue Pump Station pumps flow from the entire Genesee Area as well as some areas not considered part of the Genesee Area. The pump station is located at MH 059-450, 3761 Rainier Avenue South. The facility consists of three variable-speed pumps and a wet well chamber. A plan view of the InfoWorks layout for the pump station can be found in the inset of Figure 4-30.

This pump station was constructed in 1931 by the City, was acquired by King County in 1962, and was updated in 1973. This pump station operates as a variable-speed pump station with a total pump capacity of 15 MGD and a 9 MGD firm capacity (largest pump out of service) based on the *Offsite Facilities and Miscellaneous Structures Manual* (King County, 1993).

Operation

All flows from the Hanford Street Trunk B are lifted approximately 34 feet by the Rainier Avenue Pump Station through one 18-inch-diameter force main to the Rainier-Hanford Trunk (King County, 1993). Overflows from the Rainier Avenue Pump Station are discharged to the NPDES CSO Outfall 38.

Pumps

CH2M HILL modeled the Rainier Avenue Pump Station as a stage-discharge curve developed from the King County SCADA data. The three pumps were replaced with one pump set as a *scrpmp* pump type with a maximum pump capacity of 12.8 MGD based on SCADA and manufacturer's data (Table 4-12). The maximum pump capacity will be adjusted to the stated firm capacity of 9 MGD during alternatives analysis. To simulate the variable speed operation of the pumps, the stage-discharge curve was adjusted to include a zero flow at a low head operation (Figure 4-35 and Table 4-13). This adjustment decreased the time needed to perform a model simulation and removed model instabilities caused by the complex RTC pump operations.

TABLE 4-12
Rainier Avenue Pump Station Data Fields

Description	Units	Rainier Avenue Pump Station Pump 1
Upstream Node ID		059-446
Downstream Node ID		059-446P
Link Type (Pump type)		SCRPMP
System Type		Combined
Switch On Level	ft AD[a]	17.19[2]
Switch Off Level[b]	ft AD[a]	17.18
Pump Capacity	MGD	12.187

[a]ft AD = feet above NAVD88
[b]Set to nearly bottom of pumping range. As level in wet well decreases to pump shutoff level, pump station discharge is reduced to zero MGD. Needed in order to simulate variable speed pump without RTC to reduce simulation time.

Wet Well

The wet well provides in-line storage during pumping operations and is represented in the model by node 059-446 with a cross-sectional area equal to that printed in the record drawings of 81.1 square feet.

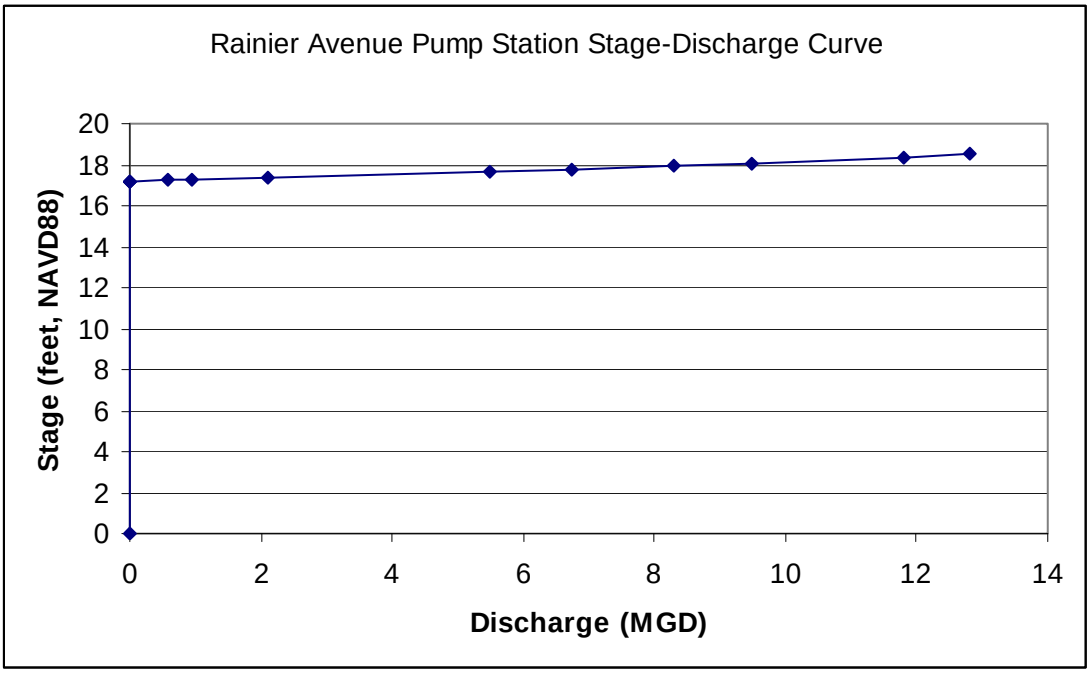


FIGURE 4-35: RAINIER AVENUE PUMP STATION STAGE-DISCHARGE CURVE

TABLE 4-13
Rainier Avenue Pump Station Stage-Discharge Curve

Stage (ft)	Discharge (MGD)
0	0
17.181	0
17.18131599	0.004
17.18171095	0.009
17.22753642	0.5912
17.25427658	0.9321
17.34626445	2.102
17.62990077	5.492
17.74740365	6.739631336
17.91049623	8.307
18.04785133	9.492
18.35737233	11.794
18.51605235	12.81682028

Outfall

The outfall for the Rainier Avenue Pump Station is the NPDES CSO Outfall 38, which is described in Section 4.3.17.

4.4 Model Hydrology

In a hydrologic model, physical parameters describing urban subcatchments (the basic area unit required by a hydrologic model) are used to determine the magnitude of stormwater runoff. This runoff is introduced into the hydraulic model of the CSS at locations specified for each subcatchment (load points), after which the hydraulic model routes the runoff flow through the sewers to the King County system or CSO outfalls.

The subcatchments are primarily described in terms of total area and contributing area, percent impervious, surface slope, and subcatchment width. Table 4-15 presents the data requirements that define the individual subcatchments. Detailed data for each subcatchment can be found in Appendix B.

TABLE 4-15
InfoWorks Data Requirements for Subcatchments

Description	Units	Example Data	Data Source	Comment
Subcatchment ID		059-398	GIS	Unique identifier
System Type		Combined	CH2M HILL analysis	
(Inlet) Node ID		059-398	GIS	Maintenance hole where flow from subcatchment is loaded into model
Total Area	acres	4.3	GIS	Total area of the subcatchment as measured in GIS. Some of this area may drain to the drainage system. Used for information only.
Contributing Area	acres	3.5	GIS	Portion of the total area draining to the CSS, equal to the sum of the areas from the 6 runoff surface types
(Subcatchment Center) X-coordinate	ft	1284379.9	GIS	
(Subcatchment Center) Y-coordinate	ft	211185.1	GIS	
Land Use ID		1	GIS. A single land use ID per flow-monitoring catchment was used to describe a combination of runoff surfaces in each subcatchment. Every subcatchment had areas specified for each of the six	Available soil information was used to distinguish between varying infiltration characteristics. Land use is based on the delineation of the flow-monitoring catchments used to calibrate the subcatchment.

TABLE 4-15
InfoWorks Data Requirements for Subcatchments

Description	Units	Example Data	Data Source	Comment
			runoff surfaces (sometimes zero), described in Section 4.4.2. [a]	
Population	Residential dwelling units	100	GIS—land use and available data sources (Puget Sound Regional Council census data)	Population per subcatchment was multiplied by a flow per capita rate to determine sanitary flow contribution.
Wastewater Profile		1	Flow monitoring	A weekend and a weekday profile was developed from each monitor.
Rainfall Profile		1	Historical precipitation (Rain gauge 18)	
Area Measurement Type	percent			Defines how much of a subcatchment belongs to a given runoff surface type. [a] Enables "Runoff Area #" fields below.
(Subcatchment) Slope	%	8.2	GIS	Based on topography.
Dimension (Subcatchment Width)	ft	244	GIS	Developed from area; used width of Minimum Area Bounding Rectangle (MABR) GIS method.
Runoff Surface 1 (to 6 as needed)[a]	acres	0.2	GIS	Absolute areas of the 6 runoff surface types[a] within each subcatchment. See Figure 4-36.

[a] Impervious surface types: Buildings – Runoff Area 1; Road/alley – Runoff Area 2; Decks/patios – Runoff Area 3; Driveways/sidewalks – Runoff Area 4; Parking lots – Runoff Area 5
Pervious surface type: Runoff Area 6

Data to be used for the subcatchment delineation and attribute definitions are from SPU. Information provided by SPU pertains to topography (contours), the road network within Genesee, sewer pipes and maintenance holes, and zoning classification.

4.4.1 Subcatchment Delineation

Combined Sewer System Subcatchment Delineation

The Genesee Area was divided into 201 subcatchments with an average size of just under 3.5 acres. A subcatchment is an area that drains to a single point that contains the dry weather sanitary flow and wet weather runoff flow contribution from the area. Subcatchments were delineated based on topography from GIS and refined as needed according to the layout of the combined sewer network.

Subcatchments can contain multiple land use types and usually are composed of a combination of pervious and impervious areas. These areas are largely defined by the type

of land use (buildings, roads/alleys, decks/patios, driveways/sidewalks, parking lots, and pervious areas) and type of system (combined or partially separated). Pervious lands such as grassy surfaces have the ability to absorb a portion of the precipitation through the process of infiltration. Every soil type has an infiltration rate, and once the rate of infiltration is exceeded by the rate of precipitation, surface runoff occurs. Impervious lands include paved roadways, parking lots, rooftops, and other similar surfaces. Impervious land may have small depressions that store some of the initial precipitation, but once these spaces are filled, additional precipitation results in immediate surface runoff from impervious lands. Both sources of runoff are collected by the sewer system.

System Type Designation

One of the first steps in subcatchment delineation is the delineation of *System Type* boundaries. For the Genesee Area, there is a combination of two types of systems: *Separated* and *Combined.* Because street runoff surfaces are characterized separately between the two types of systems, subcatchment boundaries follow system type boundaries.

Separated areas are those areas where stormwater drainage systems exist that collect and route stormwater. In the case of the Genesee Area, the *Separated* areas are actually only partially separated, because some storm runoff is routed to the sanitary system via connected roof drains and other similar connections. Surface runoff areas typically served by the stormwater pipes include streets, sidewalks, and large pervious surfaces found in parks. Often a stormwater drainage pipe was not in the vicinity of the contributing surface; however, topography in the GIS indicated that stormwater runoff would likely follow the street to an inlet into the stormwater system. In such instances, these areas would be designated as a separated area, although a stormwater drainage line was not nearby. Because a portion of the Total Area of separated subcatchments does not drain to the sanitary system, the Contributing Area is smaller than the Total Area.

In *Combined* areas, stormwater drainage pipes do not exist to route flows from the street and parking lot surfaces. In these instances, the subcatchment is delineated to route flow into the CSS, and the Contributing Area is equal to the Total Area.

For each subcatchment there is one load point—the maintenance hole where dry weather model and hydrologic model flow is routed into the hydraulic model. Load points were selected based on the relative size of contributing areas and configuration of the system. Load points, at a minimum, are located at the ends of each terminal pipe (no upstream pipes).

Stormwater Drainage System Subcatchment Delineation

Stormwater subcatchments were developed concurrently with the development of the CSS model. This step allowed for potential development of a stormwater model in the future. The net effect was subcatchments with a greater resolution (smaller area) than originally configured. Stormwater system inlets and drainage pipes were used to refine the subcatchment delineation used in the CSS model. CSS subcatchments align with the stormwater drainage system subcatchments (share identical boundaries). Contributing runoff surfaces were calculated for the CSS. If a subcatchment was delineated strictly to account for a flow into the stormwater drainage system, contributing areas were set to zero in the combined sewer model. Another difference was the assigned hydraulic load point—each system had a unique maintenance hole load point representing where the

subcatchment contributed flow to each respective system (combined sewer versus stormwater).

4.4.2 Runoff Surfaces

Runoff surfaces are used to generate a runoff volume that is routed through the system. The volume and timing of runoff depend on the types of surfaces generating runoff. Two general categories for these surface types are impervious and pervious. Impervious surfaces typically generate faster and larger runoff than pervious surfaces. Within each subcatchment, impervious surfaces were delineated into the following runoff surface types:

- Buildings – Runoff Surface 1
- Road/alley – Runoff Surface 2
- Decks/patios – Runoff Surface 3
- Driveways/sidewalks – Runoff Surface 4
- Parking lots – Runoff Surface 5

All surfaces that drain to the CSS that were not classified as one of the above-identified impervious surfaces were classified as a pervious surface. Within each subcatchment, pervious surfaces were delineated into the following category:

- All pervious surfaces - Runoff Surface 6

Table 4-16 summarizes the runoff surface areas used in the Genesee model for each Basin. Detailed information on each subcatchment determined during subcatchment delineation can be found in Appendix B.

Within each delineated subcatchment, the runoff surfaces are used to generate a runoff volume that is routed through the system. A variety of GIS data sources were used to quantify the contributing areas for each runoff surface, including the following:

- Aerial images
- Buildings
- Sidewalks
- Streets—edge of pavement
- Parcel/land use
- Black and Veatch runoff surfaces (Black and Veatch, 2006)
- Pipes (storm, sewer, small-diameter laterals)
- Maintenance holes and catch basins/inlets
- Stormwater pipes and smaller-diameter lateral information

The GIS data were the primary source of information used to quantify the contributing areas. The contribution of a particular surface to the combined sewer is documented in the GIS as the GIS existed in 2009. Pivot tables based on the GIS were developed to export data directly into the subcatchment grid tables in the InfoWorks model. The pivot tables and maps showing the subcatchment delineation are included in Appendix B. As additional field verifications are performed and GIS information is updated, the same data export process into the model can be used to update the model.

TABLE 4-16
Runoff Surface Areas Used in the Genesee Model

Surface Area	Basin								Total Area
	37	38	40	41A[C]	41B[C]	42	43	165	
Total Area (acres)	39.1	444.0	87.7	2.8	2.7	28.2	73.7	11.6	689.8
Contributing Area (acres)	32.8	322.7	65.0	2.8	2.1	23.1	56.7	9.9	515.0
Buildings Area - Runoff Surface 1 (acres)	4.6	43.9	12.7	0.3	0.4	3.0	11.3	1.5	77.7
Road/Alley Area - Runoff Surface 2 (acres)	1.3	9.5	0.4	0.2	0.0	1.3	1.3	0.5	14.6
Decks/Patios Area - Runoff Surface 3 (acres)	0.7	2.0	0.8	0.1	0.1	0.3	0.8	0.2	4.9
Driveways/Sidewalks Area - Runoff Surface 4 (acres)	1.6	6.2	0.3	0.3	0.0	0.5	1.1	0.5	10.4
Parking Lots Area - Runoff Area 5 (acres)	0.0	2.7	0.1	0.0	0.0	0.1	0.1	0.0	2.9
Pervious Area - Runoff Area 6 (acres)	24.6	258.4	50.7	2.0	1.6	17.7	42.1	7.2	404.4
Percent Impervious[a]	21%	14%	16%	30%	19%	19%	20%	23%	16%
Percent Pervious[b]	63%	58%	58%	70%	61%	63%	57%	62%	59%

[a] Ratio of impervious contributing area to total area.
[b] Ratio of pervious contributing area to total area.
[C] Surface Areas tributary to the Control Structures 41A and 41B within Basin 41.

The GIS fields *PRBLE_FLOW* (Probable Flow) and *USE_PERMIT* (Permitted Use) in the pipe shapefiles were used to determine if large impervious surfaces (for example, roofs and parking lots) should be directed to the storm drainage system or included as a contributing surface to the CSS. Figure 4-36 describes the process used to determine impervious and pervious surfaces for structures and parcel areas using a series of GIS spatial and attribute queries.

Runoff Volume Model

The runoff volume model defines how much precipitation falling on each runoff surface type (buildings, roads, driveways, etc., as listed above) is converted to surface runoff that enters the combined sewer system. The impervious surface types were set to use the Fixed Runoff Volume model, which calculates runoff as a fixed percentage of rainfall minus surface depression storage. For the pervious surface type, the Green-Ampt Infiltration model was used, which calculates runoff via the Green-Ampt equation based on the infiltration capacity, suction head, and porosity of the surface soils. Initial values entered into the model for the pervious surface parameters are typical for loam soils underlain by glacial till, which is common for the Genesee Area.

Runoff Routing Model

InfoWorks provides five different potential models for routing stormwater runoff. The model that InfoWorks refers to as SWMM was selected for the Genesee model because it has been widely applied in the United States. This routing method uses a combination of a non-linear reservoir and kinematic wave routing to move the runoff over the ground surface to the inlet node.

Groundwater Infiltration Model

Flow in sewer systems frequently exceeds the sum of stormwater runoff and domestic and industrial inflows. This residual flow is usually attributed to groundwater infiltration, which enters the sewer system through cracks. Unlike runoff, which responds to a rainfall event in minutes, infiltration inflows have a much slower response. There are two main types of infiltration:

- Rainfall-induced infiltration results from soil water infiltrating directly into the sewer network. This has an effect on flow within hours or days of the storm.
- A proportion of rainfall percolates deeper into the groundwater reservoir, and in the weeks or months following the storm, the groundwater level may be sufficiently high to cause groundwater infiltration.

During initial calibration of the Genesee Area, it was noted that the model was not adequately simulating the effects due to antecedent hydrologic conditions. Simulated flows were returning to dry weather conditions too fast following a storm, or a series of storms prompted the same response in the model. Neither observation was consistent with flow-monitoring data. The modeling team added the InfoWorks Groundwater Infiltration Model (GIM) to account for the antecedent hydrologic conditions by including the interdependent effects of the soil storage reservoir and the deeper ground storage reservoir on the CSS. The soil storage reservoir is subject to evapotranspiration, and the groundwater

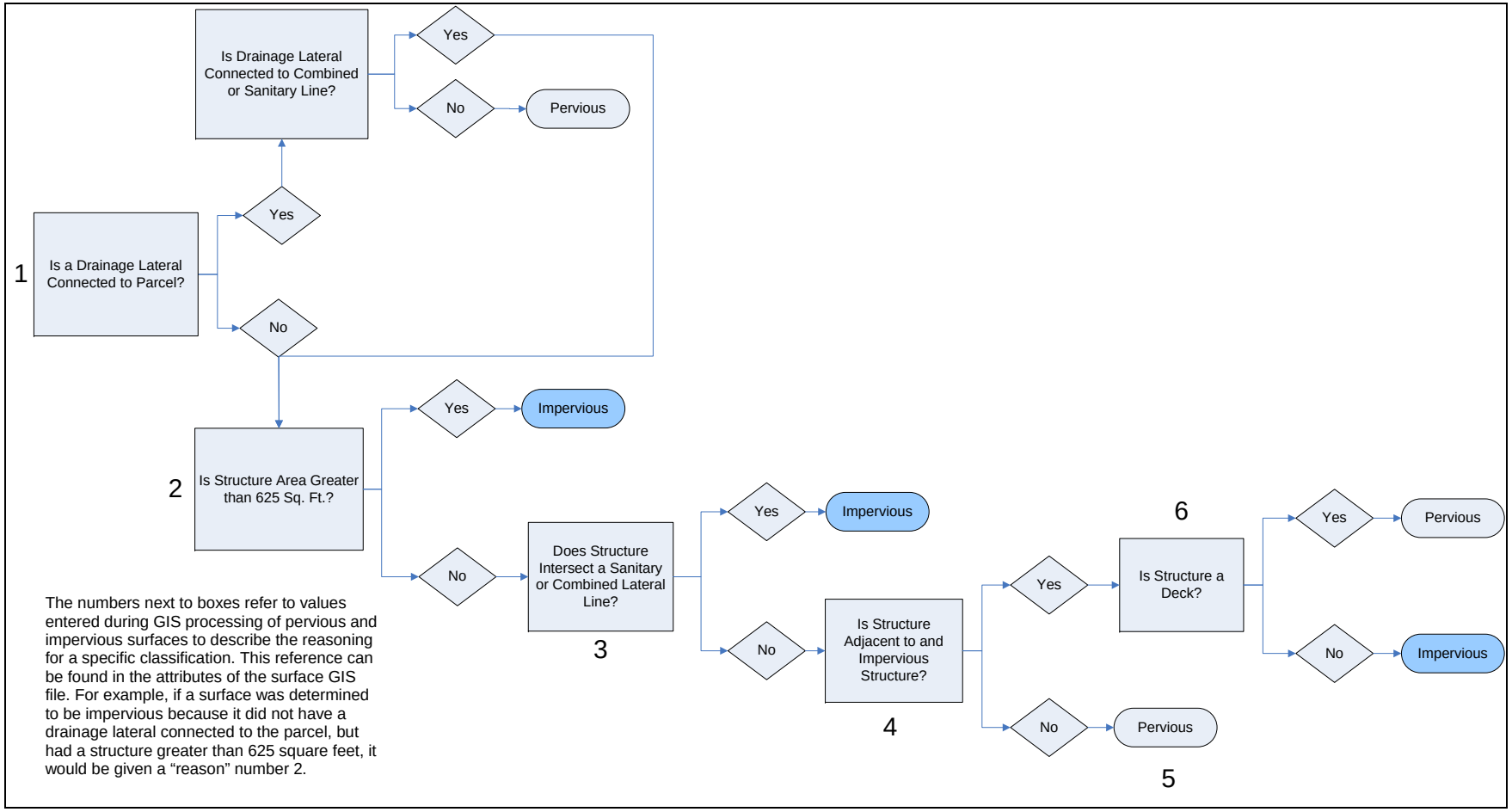


FIGURE 4-36: DECISION TREE FOR IMPERVIOUS/PERVIOUS SURFACE DELINEATION

infiltration model allowed for a more representative simulation of the system following extended periods of both dry and wet weather.

Table 4-17 shows the parameters needed for the groundwater infiltration model. Because the groundwater infiltration model is simplified, it requires some degree of calibration. Each set of groundwater infiltration data is linked to a subcatchment through a Groundwater Infiltration ID.

TABLE 4-17
Groundwater Infiltration Data Requirements

Description	Units	Sample Data	Data Source	Comment
Groundwater Infiltration ID		GI-01		Aligned with Land Use ID
Soil Depth	ft	1.265	Derived through calibration	Depth of upper soil layer (seasonal variation in initial abstraction)
Percolation/Baseflow/ Infiltration Coefficient		0.679/7.579 /7.614	Derived through calibration	Recession of flow rate from upper soil layer, from lower ground layer and into the sewer from ground storage Affects hydrograph shape.
Percolation Threshold	%	48.930	Derived through calibration	Percentage saturation level of the soil at which water starts to percolate downwards
Percolation Percentage Infiltrating	%	56.670	Derived through calibration	Percentage of percolation flow that infiltrates directly into the CSS
Porosity of Soil/Ground		6.831/6.948	Derived through calibration	Coefficients representing the porosity of the soil (upper storage reservoir) and ground (lower storage reservoir)
Baseflow/Infiltration Threshold Level	ft	1.981/4.450	Derived through calibration	Relative levels in the soil column at which secondary infiltration (base flow) and groundwater infiltration (infiltration) occurs.

4.4.3 Dry Weather Flow

Dry weather flow consists of base sanitary flow (BSF) and groundwater infiltration. BSF is the result of wastewater generated by human activities and typically varies during the day. Groundwater infiltration is the result of water entering sewers in the ground from saturated areas and high water tables through cracks and misalignments in the sewers. Groundwater infiltration is typically at a constant rate but varies seasonally. In the Genesee CSS model, BSF and the lowest seasonal groundwater infiltration were addressed simultaneously as a combined base sanitary flow-groundwater infiltration estimate referred to as dry weather

flow (DWF). The additional groundwater infiltration is incorporated into the model as part of the groundwater infiltration module.

DWF patterns and rates were developed for each subcatchment within a flow-monitoring catchment using average flow data from the January 2008 to June 2009 flow-monitoring period. The team used SLIICER for processing many months of flow-monitoring data into general flow statistics for each flow-monitoring point. SLIICER is a data-processing tool developed by ADS, the flow-monitoring contractor used for the Genesee flow-monitoring program. The SLIICER analysis used the following logic to determine days used for dry weather analysis:

1. Dry weather candidate days were identified. These were days that did not have more than 0.1-inch cumulative precipitation depth in the previous 24 hours, 0.3 inch in the previous 72 hours, or 1 inch in the previous week.
2. Dry weather candidate days that had an average flow greater than 115 percent or less than 85 percent of average daily flow of the data set were excluded
3. Finally, those dry weather candidate days that had inconsistent diurnal patterns with the rest of the data set were also excluded.

The days that remained were analyzed to calculate total average flow, net average flow contribution from the flow-monitoring catchment, and the diurnal pattern at each flow-monitoring location used for flow load see Figure 4-37 for a screen shot of the SLIICER program. Each is described in greater detail below.

Total Average Flow

Total average flow is the average dry weather flow that is in the pipe at a location. Total average flow includes the individual contribution of that flow-monitoring catchment as well as all other upstream catchments. A total average flow was calculated for both weekdays and weekends.

Net Average Flow

To calculate the DWF contributed within each subcatchment, a wastewater generation rate for all the subcatchments in a given flow-monitoring catchment was needed in the model. The net average flow represents that flow-monitoring catchment's discrete, individual flow contribution to the system. Net average flow is calculated by subtracting the upstream dry weather flow contribution from the total average dry weather flow (as measured by the monitor and calculated from SLIICER) for a given flow-monitoring location. SLIICER provided a net average flow contribution; however, due to the Darigold facility industrial discharge discussed below and flow imbalances, DWF contribution was manually calculated. Table 4-18 below shows the monitored gross flow and net average daily flow calculated for each flow-monitoring catchment. Weekend and weekday hourly peaking factors for each flow-monitoring catchment can be found in Appendix C.

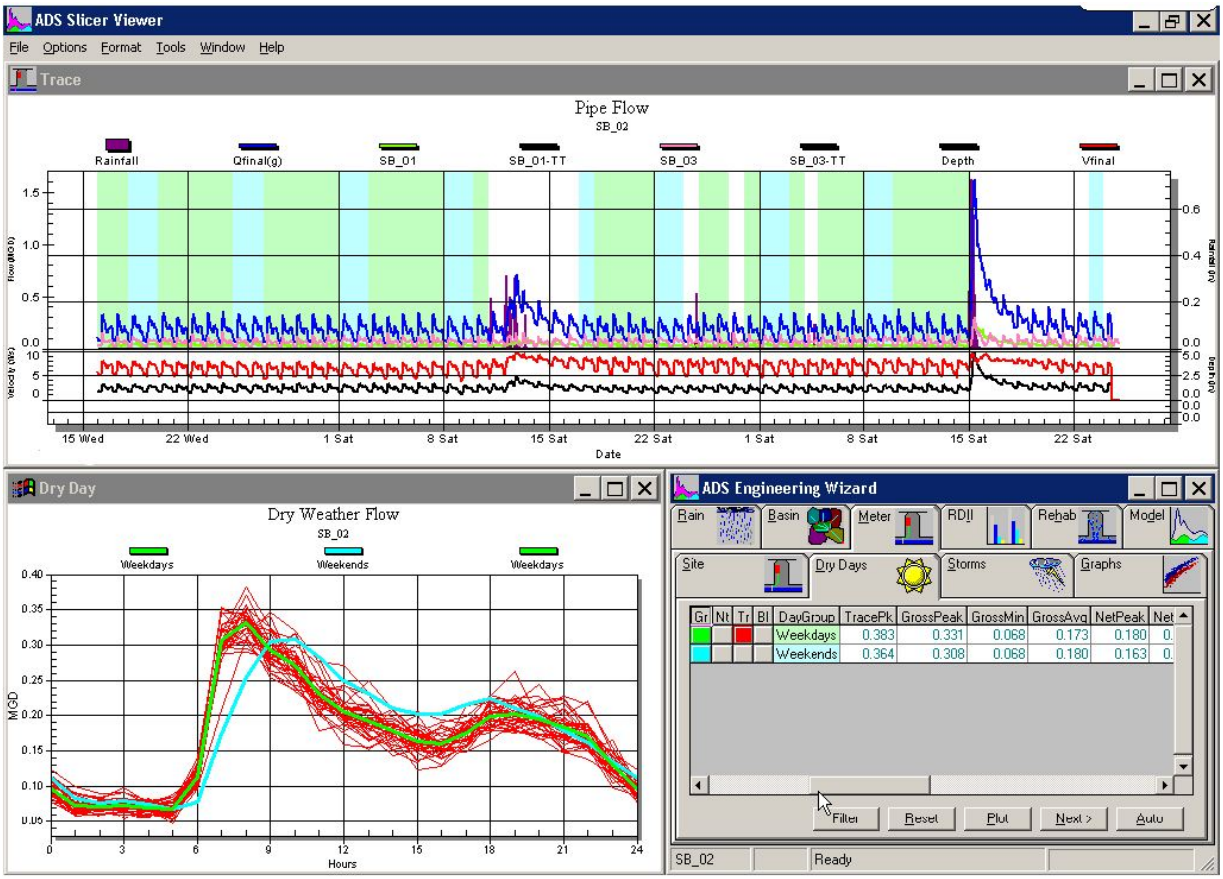


FIGURE 4-37: SCREEN SHOT OF SLIICER PROGRAM DURING DRY WEATHER FLOW ANALYSIS

Diurnal Pattern

The diurnal pattern is the predictable flow pattern evident in the system on a typical dry weather day. A distinct diurnal peak flow pattern was developed for both weekdays and weekends for each monitoring catchment using net average flow patterns. Following the SLIICER analysis listed above, an average of 14 weekdays and 6 weekend days were used to calculate the diurnal pattern for each of the flow monitoring sites. The final processing yielded an hourly ratio of the peak flow to the daily net average flow for each monitoring site.

TABLE 4-18
Monitored Gross and Net Average Daily Flow

Wastewater Profile Number	Flow-monitoring Catchment ID	Monitor Flow (MGD)		Net Flow (MGD)		Catchment Population
		Weekday	Weekend	Weekday	Weekend	
1	GEN38_059121	0.073	0.087	0.073	0.087	230
2	GEN38_059131	0.474	0.457	0.336[a]	0.457	392
3	GEN38_059320	0.027	0.028	0.027	0.028	307

TABLE 4-18
Monitored Gross and Net Average Daily Flow

Wastewater Profile Number	Flow-monitoring Catchment ID	Monitor Flow (MGD)		Net Flow (MGD)		Catchment Population
		Weekday	Weekend	Weekday	Weekend	
4	GEN38_059332	0.435	0.429	0.020	0.010	818
5	GEN38_059371	0.020	0.020	0.020	0.020	202
6	GEN38_059373	0.028	0.033	0.028	0.033	397
7	GEN38_059398	0.249	0.268	0.000	0.000	66
8	GEN38_059404	0.112	0.117	0.000	0.000	78
9	GEN38_060W012	0.117	0.129	0.000	0.000	49
10	GEN40_059409	0.026	0.028	0.026	0.028	225
11	GEN40_059436	0.036	0.041	0.036	0.041	195
12	GEN40_059490	0.056	0.075	0.000	0.000	59
13	GEN42_060W047	0.041	0.041	0.000	0.000	22
14	NPDES037_MH059489	0.096	0.096	0.096	0.096	202
15	NPDES040_MH059491	0.056	0.062	0.020	0.020	21
16	NPDES041A_MH059434	0.026	0.027	0.026	0.027	19
17	NPDES041B_MH059406	0.127	0.133	0.070	0.060	18
18	NPDES042_MH060W052	0.023	0.028	0.023	0.028	122
19	NPDES165_MH067078	0.034	0.036	0.034	0.036	52
20	GEN 059-443	0.947	0.917	0.026	0.026	256
21	GEN 059-446	0.025	0.025	0.025	0.025	107
22	GEN 059-498	0.426	0.434	0.000	0.000	299
23	GEN 060W-026	0.007	0.008	0.007	0.008	45
24	GEN 067-014	0.002	0.008	0.002	0.008	42
25	GEN 067-024	0.031	0.113	0.012	0.041	44
26	GEN 067-029	0.019	0.072	0.019	0.072	186

[a]Net flow for Flow Monitoring Catchment GEN38_059131 does not include *industrial discharge.*

Industrial Inflow

In addition to typical DWF, the Genesee Area has a significant industrial discharge from the Darigold dairy processing facility located in flow-monitoring catchment 059-131. These industrial flows behave differently than normal DWF and were incorporated into the model separately. In this case, discharges from the industrial facility increase dry weather sanitary flow loads from approximately 0.6 MGD to a peak of 2.5 MGD. The portion of flow above the base flow was isolated within the flow-monitoring data, and a time series for the

industrial discharge was developed as an input into flow-monitoring catchment 059-131 at MH 059-125, the manhole estimated to be nearest the Darigold flow contribution.

Population

Total population was compiled for each monitoring catchment by overlaying 2000 Census data (Puget Sound Regional Council, 2007) data with the monitoring catchment delineation. See Section 2.5 for details on population within the Genesee Area Basins and Table 4-17 for population within each flow-monitoring catchment.

Per Capita Flows

Dividing the net average flow for a given flow-monitoring catchment by the total flow-monitoring catchment population yields a per capita wastewater generation rate (WWcap,avg in the equation below). This per capita rate generated for the entire flow-monitoring catchment can then be applied to individual subcatchments. This distribution of flows to subcatchments allows for adjustment of model flows based on population changes at the subcatchment scale.

For some flow-monitoring catchments, the per capita wastewater generation rate appeared to be abnormally large or small. Per capita wastewater generation rates were higher than 1000 gallons/person/day for wastewater profiles 2, 7, 8, 9, 13, 15, 16, 17, 20, and 22. Rates were lower than 100 gallons/person/day for wastewater profiles 3, 5, 6, and 24. Although these values seem unrealistic, they were kept in the model because they were supported by flow-monitoring data. Reasons for these abnormal values are many, and may include incorrect population estimates and high groundwater infiltration.

Dry Weather Flow Calculation

Using values described in the sections above, InfoWorks computes DWF for each subcatchment to be routed through the system using the following equation:

$$DWF = [Pop] \times [WW_{cap\ avg}] \times [PF]$$

where:

Pop = population (for an individual subcatchment)

WWcap,avg = average per-capita wastewater generation rate, including dry season groundwater infiltration (gallons/capita/day, or gpcd)

PF = diurnal peaking factor

5.0 Model Calibration

The Genesee model was calibrated for 7 storm events at 29 locations, using manual and automated calibration routines, and rainfall, flow, and depth data collected during the Genesee Flow Monitoring Study.

5.1 Calibration Process

Calibration is the process of adjusting modeling input parameters so that the model matches as closely as possible accurately measured data or observed conditions within the system. Monitoring data consisting of depth and flow with corresponding precipitation were the primary data source used to assess the accuracy of the model and to serve as the basis for calibration. In addition to flow-monitoring data, field observations, inspection reports, and survey information were also used in the calibration.

For the Genesee model, the following data sources for the period January 2008 through January 2009 were used for calibration:

- Eight permanent monitoring sites at the combined sewer overflow basin outfalls owned by Seattle Public Utilities and maintained by ADS
- Twenty-one temporary monitoring sites in the system to measure hydrologic and hydraulic conditions in the system
- Precipitation data from Rain Gage 18, owned by SPU and maintained by ADS
- Three monitoring sites operated for the SPU RainCatchers project (also known as the Lakewood RainCatchers project), maintained by Herrera Environmental Consultants
- Supervisory control and data acquisition data from SPU pump stations 5 and 6
- King County-provided data from monitoring site 059-443 installed near the bottom of the Genesee Area in Charlestown Street and SCADA data from the Rainier Avenue Lift Station
- Closed-circuit television inspections performed along the lake line downstream of Pump Station 6

After model development was completed and simulations successfully run without errors or significant warnings, the model was calibrated through a series of iterative steps as follows:

- Dry weather flow calibration: The objective of this calibration phase was to ensure the model accurately simulated the conditions during dry weather—the periods without effects due to precipitation. During the calibration phase, adjustments to the model focused on diurnal patterns, load point locations, industrial loading, and net flow-monitoring catchment contributions. Dry weather flow calibration is discussed in more depth in Section 4.4.3 of this report.

- Initial wet weather calibration: Precipitation data from Rain Gage 18 were incorporated and input parameters manually adjusted until the modeling results generally agreed with the monitoring data for the largest storms, in particular the August and November 2008 storm events. The following parameters were iteratively adjusted and results compared to available data: Fixed Runoff Coefficient, Green-Ampt Suction, Green-Ampt Conductivity, Soil Depth, and Percolation Percentage Infiltrating. Through this process, parameters that would be included in the next calibration step were identified, as well as their sensitivity and upper and lower bounds for each parameter. Initial wet weather calibration is discussed in more depth in Section 5.5 of this report. Table 5-3 in that section lists the parameters varied during initial calibration, as well as the actual parameters used for each flow-monitoring catchment.
- Automated calibration (GLUE): The last calibration step was an automated calibration process named Generalized Likelihood Uncertainty Estimation (GLUE). An automated routine, GLUE randomly varies the set of input parameters in between upper and lower boundaries established for each parameter. For each set of parameters, a simulation is performed and a goodness-of-fit comparison to the monitored data is calculated based on volume, peak flow rate, and standard deviation of volume. Flow-monitoring catchments are grouped into calibration groups based on network configuration. For example, those flow-monitoring catchments upstream of a CSO facility (storage tank and HydroBrake) would be grouped. The GLUE routine is first applied to upper calibration groups. Modeling parameters that resulted in the best fit were selected and locked-in, and GLUE was repeated for the next downstream calibration groups.
- Parameters sampled and used during automated calibration can be found in Appendix D. Goodness-of-fit comparisons for each calibration group can be found in Appendix E. Resulting hydrographs for describing the goodness-of-fit for the selected parameter sets are found in Appendix F. The resulting calibrated model can be found in Appendix G.

5.2 Calibration Events

Precipitation data gathered at SPU's Rain Gage 18 for the duration of the flow-monitoring period were used to generate flow in the model. A definition of 0.3-inch minimum depth and 6-hour inter-event period was used to classify the precipitation into discrete events. Maximum depths were calculated for multiple durations for each storm and compared to precipitation-magnitude-frequency estimates based on the 38-year record summarized in *Analysis of Precipitation-Frequency and Storm Characteristics for the City of Seattle* (MGS Engineering Consultants, Inc., 2003). Using these data, the return interval was calculated for each event at multiple durations. The duration resulting in the largest return interval for a given event is known as the critical duration. Each significant event and its corresponding largest return interval are plotted in Figure 5-1. Table 5-1 summarizes depths at multiple durations for each storm.

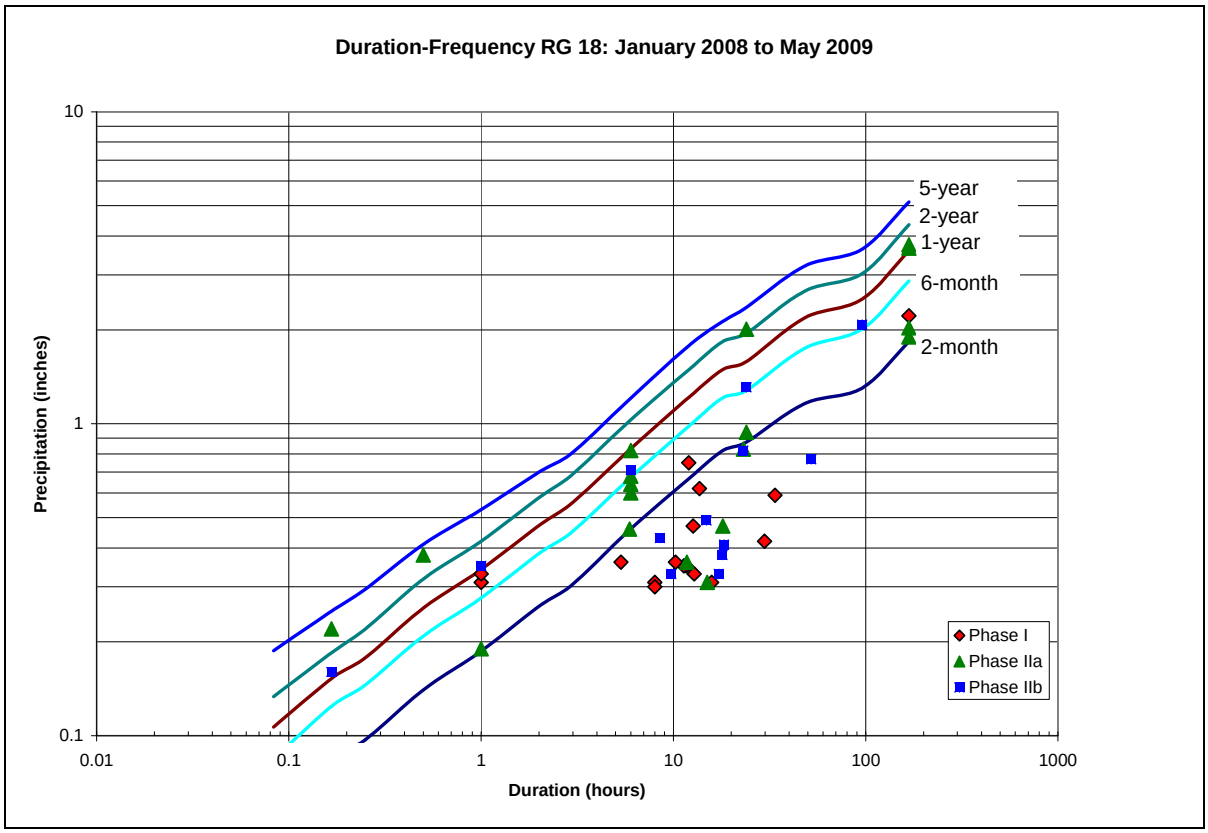


FIGURE 5-1: DURATION AND FREQUENCY FOR SIGNIFICANT STORMS IN MONITORING PHASE I (JANUARY 2008 TO JUNE 2008), PHASE IIA (JULY 2008 TO JANUARY 2009), AND PHASE IIB (FEBRUARY 2009 TO MAY 2009)

Events captured between January 1, 2008, and January 31, 2009, were potential calibration events. Additional events captured between February 1, 2009, and May 31, 2009, were available for validation. However, during the automated calibration review period, the use of validation storms to further adjust the model was explored. The team concluded that given the extensive simulations performed and evaluated (more than 3,100 unique simulation parameter sets were evaluated), further adjustment of the final calibrated model based on validation storms would not be warranted. A review of long-term simulation results that included the period of February through May 2009 showed consistency between simulated and monitored CSOs. During the monitoring period of January 1, 2008, to May 31, 2009, 248 storms were captured using no minimum depth criteria.

Applying a 0.3-inch minimum depth criterion results in 48 total storms. Of these, 24 events had a return interval of 2 months or greater. In addition to these 24, three events with less than a 2-month return interval resulted in basin overflows. The resulting 27 events are considered "significant events" and are included in Figure 5-1 and Table 5-1. Twenty-two of these 27 events occurred during the model calibration period. Of the 22 available calibration events, 10 were selected based on multiple criteria that included the following:

- Select events with varied durations (long and short events)
- Select events that approximate the once-per-year overflow event (November 6, 2008, event)

TABLE 5-1
Rainfall Depths at Multiple Durations for Significant Events

Calibration Storm Number	Event Date	Total Rainfall (inches)	Event Duration (hours)	Rainfall Depth (inches)										Number of Overflows	Return Period (months)
				5 min	10 min	30 min	1 hr	6 hr	12 hr	24 hr	48 hr	96 hr	168 hr		
1	1/9/08 21:05	0.47	13	0.02	0.03	0.07	0.11	0.38	0.46	**0.47**	0.70	0.85	1.49	1	<2
	2/8/08 13:55	0.35	11	0.01	0.02	0.04	0.06	0.26	**0.35**	0.35	0.39	0.70	0.91		<2
2	3/1/08 16:35	0.13	2	0.03	0.06	0.09	0.12	0.13	0.13	0.21	0.37	0.38	0.41	2	<2
	3/23/08 4:55	0.75	10	0.02	0.04	0.11	0.19	0.46	**0.75**	0.75	0.75	0.88	1.09	1	2
	3/25/08 14:25	0.31	16	0.02	0.03	0.07	0.11	0.20	0.27	**0.31**	0.31	0.94	1.27		<2
3	3/29/08 15:50	0.50	11	0.03	0.05	0.11	0.14	0.41	0.50	0.63	1.00	1.01	**2.22**	1	3
4	5/21/08 18:20	0.44	2	0.06	0.12	0.22	**0.31**	0.44	0.44	0.45	0.81	0.81	0.81		6
	6/2/08 22:50	0.62	14	0.02	0.03	0.08	0.15	0.48	0.59	**0.62**	0.62	0.66	0.66		2
5	6/6/08 5:00	0.48	14	0.05	0.09	0.21	**0.33**	0.41	0.47	0.48	0.60	0.88	1.48		9
	8/19/08 20:45	0.66	11	0.02	0.04	0.10	0.16	0.52	**0.66**	0.66	0.81	0.81	0.81		2
6	8/24/08 12:50	0.95	11	0.04	0.07	0.13	0.22	**0.64**	0.95	0.95	0.95	0.95	2.04	1	4
	8/25/08 12:20	0.65	8	0.10	0.16	**0.38**	0.53	0.64	0.65	1.00	1.60	1.60	2.54		24
	10/3/08 6:20	0.72	31	**0.06**	0.08	0.10	0.10	0.30	0.47	0.63	0.73	0.75	0.75		2
7	10/13/08 18:50	0.40	7	0.12	**0.22**	0.28	0.30	0.39	0.40	0.40	0.40	0.41	0.42		24
	11/2/08 5:40	0.65	28	0.03	0.05	0.13	**0.19**	0.33	0.39	0.58	0.83	1.14	1.19		2
	11/3/08 18:35	0.86	14	0.02	0.04	0.08	0.14	**0.60**	0.82	0.88	1.32	1.69	2.05	1	4
8	11/6/08 1:35	2.26	32	0.03	0.05	0.13	0.24	0.80	1.43	**2.01**	2.26	2.43	4.22	3	24
	11/11/08 0:00	1.02	46	0.02	0.03	0.09	0.15	0.41	0.66	0.81	1.02	1.06	**3.66**		12
9	12/24/08 12:15	1.03	28	0.02	0.04	0.11	0.21	**0.68**	0.77	0.89	1.03	1.06	1.45	2	6
	12/28/08 14:45	0.31	9	0.03	0.05	0.11	0.18	0.28	0.31	0.56	0.64	0.82	**2.03**	1	2
	12/31/08 21:55	0.76	31	0.02	0.03	0.07	0.13	0.38	0.51	0.62	0.76	0.89	**1.90**		2
	1/4/09 16:40	0.91	16	0.03	0.06	0.18	0.33	**0.82**	0.88	0.91	0.92	0.93	2.03		9
10	1/6/09 15:25	2.05	36	0.03	0.05	0.11	0.20	1.02	1.44	1.56	2.09	2.96	**3.75**	6	12

Notes:

Bold face type represents the rainfall depth corresponding to the critical duration for frequency analysis.

Events selected for calibration shown with gray shading.

- Select events that have high return intervals at varied durations (greater than 2 months)
- Select events that cause varied overflow response

Due to local monitoring conditions, some of the 10 events were not used to calibrate every single calibration group. For some events and some monitors, flow-monitoring data did not correspond with recorded precipitation, probably because the rain gauge does not fully represent microclimates in some parts of the Genesee Area. (See Section 5.7 for a discussion of implications of time shifts in precipitation data.)

5.3 Target Calibration Criteria

The calibration period from January 2008 through the end of January 2009 was used along with the following criteria established in the Genesee modeling plan to evaluate the calibration for wet weather events:

- Simulated peak flows should be between 20 percent above and 15 percent below monitored flow for the highest peak of each rain event.
- Simulated flow volume should be between 20 percent above and 15 percent below monitored flow volume for each rain event evaluated by goodness-of-fit measure.
- Simulated peak flow depth should be between 1 foot above and 0.5 foot below measured flow depth for each rain event.
- Simulated flow hydrographs should follow the measured hydrograph in magnitude and shape until flow has substantially returned to dry-weather flow rates. This criterion is measured during a visual analysis of the top model runs as verified by the GLUE statistics.

The various statistical measurements for assessing goodness-of-fit during the GLUE analysis are documented in the *CSO Technical Guidance Manual* (MGS Engineering Consultants, Inc., 2008).

5.4 Calibration Points

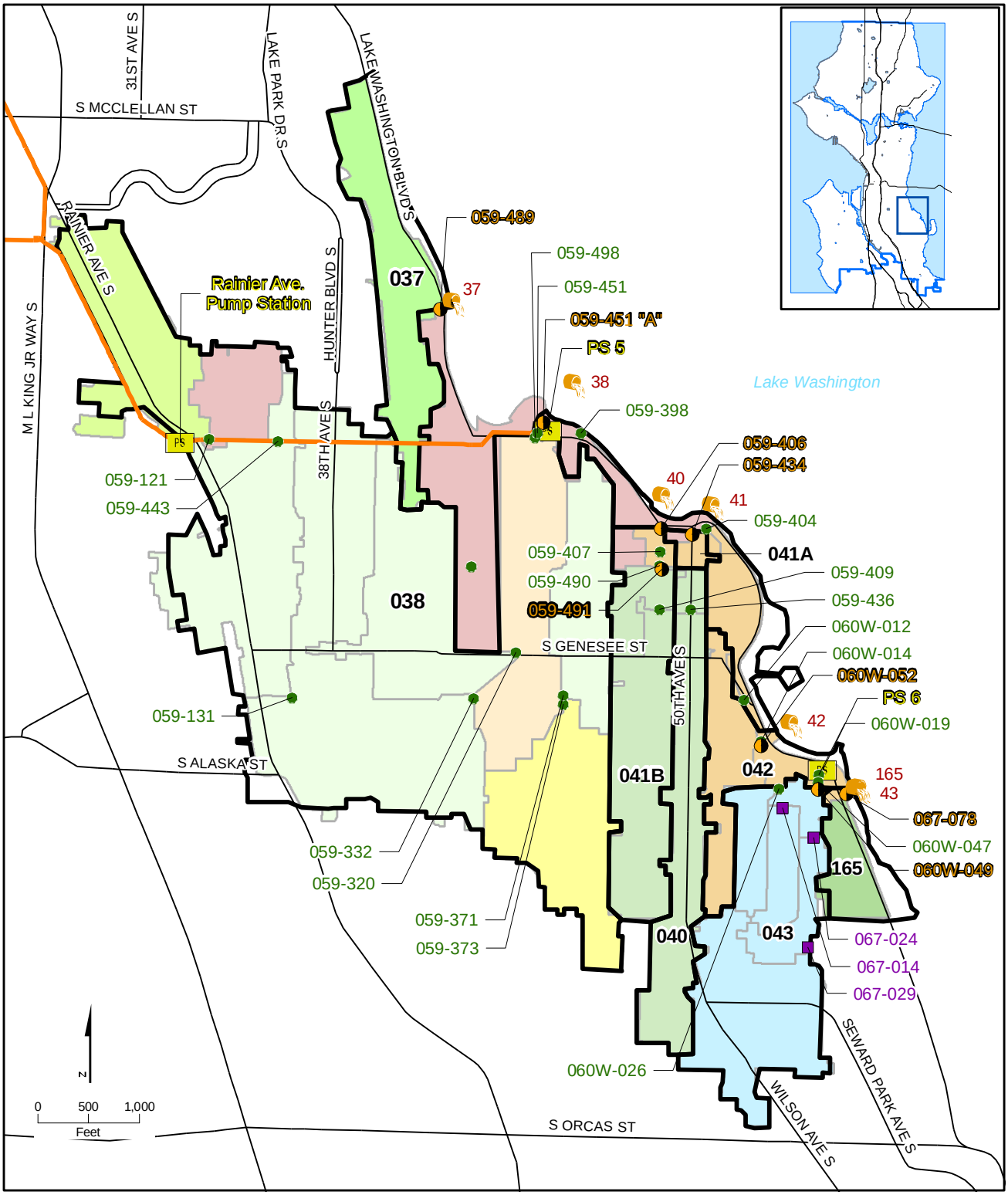
Flow and depth data collected during the flow-monitoring study were reviewed for suitability for use as calibration points in the Genesee InfoWorks model. Table 5-2 lists the flow-monitoring sites selected as calibration points based on the review. Calibration focused primarily on matching flow, except at CSO facilities where depth was also considered. Some of the flow-monitoring sites listed in Table 5-2 were selected for calibration of hydraulic structures and were not used for wet weather calibration. The modeling team decided to exclude some calibration points from automated calibration due to unsuitable data quality or inconsistencies between the precipitation and measured flow response. The reasons for exclusion in automated calibration are discussed in Section 5.6. Excluded monitoring sites may have been used for verification of system performance and for initial calibration.

Figure 5-2 shows the calibration points and the corresponding calibration groups used for the wet weather calibration. Subcatchments are grouped according to the flow-monitoring catchment in which they are located. Wet weather modeling parameters (runoff-surface and ground-infiltration flow contributions) are common to each subcatchment located within the

flow-monitoring catchment and identified in the Land Use IDs assigned in the InfoWorks subcatchment grid. Calibration points were assigned to calibration groups to simplify the selection of model parameter sets in the final calibrated model. The use of calibration points and calibration groups is described in detail in Section 5.6.

TABLE 5-2
Calibration Points in the InfoWorks Model of the Genesee Area

Calibration Point MH ID	Calibration Point Use	Automated Calibration Group
Basin 165		
067-078	Flow/Depth	Upper Calibration Group 165
Basin 43		
067-014	Not Used	
067-029	Flow	
067-024	Not Used	
060W-026	Not Used	Upper Calibration Group 43
060W-049	Flow/Depth	
060W-047	Not Used	
060W-019	Flow	
Basin 42		
060W-052	Depth	
060W-014	Not Used	
Control Structure 41A		Middle Calibration Group 42, 41, 38
059-434	Not Used	
Control Structure 41B		
059-406	Not Used	
Basin 40		
059-436	Flow	
059-409	Flow	
059-491	Not Used	Upper Calibration Group 40
059-490	Not Used	
059-407	Not Used	
Basin 38		
059-131	Flow	
059-320	Flow	
059-332	Flow	Upper Calibration Group 38
059-371	Flow	
059-498	Not Used	
059-373	Flow	Upper Calibration Group 38, 059-373
059-121	Flow	Upper Calibration Group 38, 059-121
060W-012	Flow	Middle Calibration Group 42, 41, 38
059-404	Flow	
059-451	Flow/Depth	Middle Calibration Group 38, 059-451
059-443	Flow	Lower Calibration Group 38
059-398	Flow	
059-346	Not Used	Not Used
059-451 NPDES 38	Not Used	
Basin 37		
059-489	Flow/Depth	Upper Calibration Group - 37



LEGEND

- Permanent Monitoring Point
- Temporary Monitoring Point
- RainCatchers Monitor
- Pump Station
- Outfall

Calibration Groups

- Lower Group - 38
- Middle Group - 059-451
- Middle Group - 42, 41A, 41B, 38
- Upper Group - 165
- Upper Group - 38
- Upper Group - 38: 059-121
- Upper Group - 38: 059-373
- Upper Group - 40
- Upper Group - 43
- Upper Group -37

0 500 1,000
Feet
N

FIGURE 5-2
Calibration Points and Groups
Modeling Report
SPU Genesee Area

CH2MHILL

\\Simba\proj\SeattlePublicUtilCSO\373008WA1GENModel\GIS\Layout\H&HReport\CalibrationGroups_Fig5-2.mxd

5.5 Initial Calibration

After model construction was finished, the model was reviewed for completeness before automated simulations could be performed. This review involved a manual initial calibration of the model. The purpose of the initial calibration was to verify that the model as constructed could adequately simulate combined sewer flows in the Genesee Area in preparation for the automated calibration process. Initial calibration consisted of iterative adjustment of model elements affecting both hydraulic and hydrologic responses.

5.5.1 Hydraulic Adjustments

During initial calibration, the simulated hydraulics and associated coefficients of the special structures were iteratively determined prior to starting GLUE. Specifically, local hydraulic parameters were locked-in at CSO outfall weirs, pump stations, and HydroBrakes.

In Basin 43 the HydroBrake appears to have two very different stage discharge curves throughout the monitoring period: one for smaller storms and another for larger storm events. The modeling team selected the stage discharge curve that was most representative during larger events approximating a control storm. Operational configurations in the model were also evaluated and adjusted, as these too would be outside the automated calibration process. These operational configurations included the real-time control (RTC) of the pinch valve located in MH 059-574 (Overflow Structure 38) near Pump Station 5 and the pump flow rates.

Iterative initial hydrologic calibration (see Section 5.5.2) highlighted the need to refine the system. For example, an orifice to simulate blockage due to sediment was inserted into the model at MH 060W-014 in the lake line to rectify an inconsistency in water levels measured during flow monitoring in the vicinity of the lake line around CSO Control Structure 42 and CSO Facility 10.

During flow-monitoring data review, the modeling team discovered a significant industrial discharge (or "trade flow") upstream of the monitoring site at MH 059-131. This irregular weekday discharge from the Darigold dairy processing facility results in larger than typical wet weather CSS response in the CSS at all points downstream of MH 059-131. Initially, this flow was loaded into the model as a daily discharge at a consistent time and at a constant volume. Due to the variable nature of the actual discharge, the modeling team determined it best to load this trade flow as a variable time series developed directly from the flow-monitoring data.

Changes were also made to the model to optimize simulation speed and performance. Because the automated calibration process depends on the model performing thousands of simulations to identify potential parameter sets, optimizing simulation speed and performance greatly enhances the efficiency of the automated calibration process. The following is a summary of the methods used to increase model stability with the goal of decreasing the time needed for a simulation.

Node and link failure alerts reported by InfoWorks during simulation were noted and reviewed because these indicated structures in the model requiring iterative computations. Many of the nodes were in the proximity of pump stations. A sensitivity analysis was

performed to evaluate whether the pressurized force main was the cause of the alerts. After review, it was assessed that maintaining the force mains within the model had no effect on the failure alerts or simulation time.

In an attempt to decrease the run-time of the model while maintaining model stability, the following elements were assessed:

Time step. Decreasing the time step did result in a more stable model; however, it resulted in increased time needed for the simulation. Ultimately, the team concluded a 300-second simulation time step yielded adequate results with a minimum time needed for each simulation.

Real-time control. Analysis showed that RTC greatly impacted simulation time. The model configuration of the King County Rainier Avenue Lift Station's variable-frequency-drive pumps was changed from using RTC to a fixed pump with pump discharge curves (developed from King County SCADA and pump performance testing results) adjusted to simulate the turndown of the pumps.

The above changes reduced simulation times from approximately 2 hours to 15 minutes.

5.5.2 Hydrologic Adjustments

Hydrologic adjustments made during initial calibration consisted of changes to model parameters affecting the volume of runoff entering the CSS. These parameters included fixed runoff coefficient, percolation percentage infiltrating, and initial loss. Through consultation with InfoWorks modeling experts, fixed runoff coefficient and percolation percentage infiltrating were determined to be the two most sensitive parameters.

Initial calibration of these parameters also assisted in identification of particularly sensitive model parameters and reasonable parameter ranges in preparation for automated calibration. The methods used to develop these ranges as well as the numeric value of the parameter ranges are presented in Section 5.6.

The November 2008 storm (storm #8 in Table 5-1) was used as the primary storm for the initial calibration as reviews indicated the storm was of sufficient intensity and depth, caused overflows in the system, and was representative of storms that would be used during the GLUE calibration. Additional storms were added to evaluate the pervious surfaces infiltration Green-Ampt model. A review of the results verified that the delayed infiltration component of the typical storm response in the Genesee Area was not being adequately represented in the model—the simulated flows following the storm were lower than the monitored data, thus not fully reflecting the effects of antecedent rain. As a result, Ground Infiltration Model (GIM) and associated parameters were added to the model for adjustment during automated calibration.

The parameters summarized in Table 5-3 were those developed from the initial calibration.

Figure 5-3 shows a comparison of the initial calibration results and the monitored flow at the King County monitoring site at MH 059-443—the most downstream monitoring site in the Genesee Area. After reviewing the results and comparison to measured and observed conditions in the model, the model was deemed sufficiently constructed to proceed into the GLUE calibration.

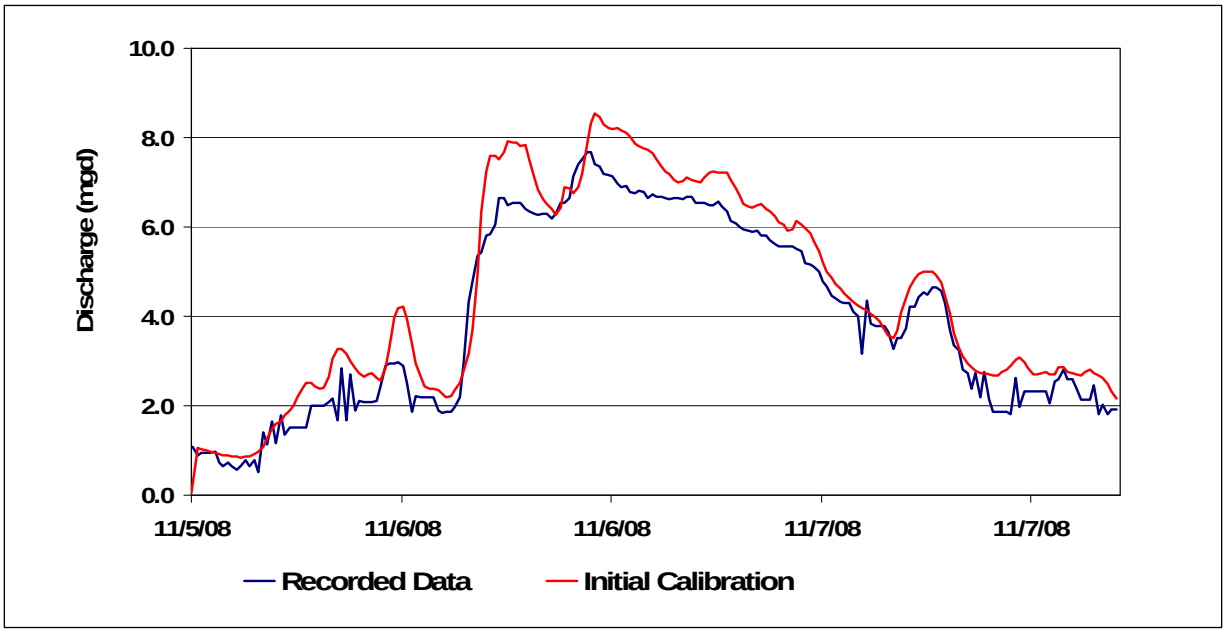


FIGURE 5-3: INITIAL CALIBRATION MODELING RESULTS AT KING COUNTY MONITOR 059-443

5.6 Automated Calibration using GLUE Methodology

After initial calibration, the Genesee hydraulic model was calibrated using the automated GLUE calibration and validation process developed by Beven and Binley (1992) and implemented for CSO models by MGS Engineering Consultants, Inc. (2008, 2009). The GLUE process used Microsoft Visual Basic macros embedded in a Microsoft Excel spreadsheet to execute multiple simulations using different randomly selected parameter sets with each of the model simulations. The results from each simulation were then analyzed using multiple goodness-of-fit statistical methods to compare the simulated runs against monitored data. In essence, GLUE is a Monte Carlo sampling process based on the understanding that given enough simulations, a randomized computer can more thoroughly examine the possible parameter space than can traditional model calibration methods. This process is adopted in order to assess the aggregate inherent uncertainties in the modeling process, namely those associated with the model inputs, the model itself, and the monitored data. The GLUE process is documented in detail in the MGS Engineering Consultants, Inc. guidance manual (MGS Engineering Consultants, Inc., 2009). The significant steps in the GLUE process are outlined below:

- Sixteen InfoWorks hydrologic model parameters were identified to be sampled, 3 for the impervious surfaces and 13 for the pervious surfaces.

TABLE 5-3
Initial and Automated Calibration Modeling Parameters

Initial Calibration Model Parameter Name	Flow Monitoring Catchment ID and Associated InfoWorks Runoff Surface ID	Initial Calibration Parameters																											Automated Calibration Parameter Range (see Section 5.6)	
		059-121	059-131	059-320	059-332	059-371	059-373	059-398	059-404	060W-012	059-409	059-436	059-490	060W-047	NPDES 37 059-489	NPDES 40 059-491	NPDES 41A 059-434	NPDES 41B 059-406	NPDES 42 060W-052	NPDES 165 067-078	059-443	059-446	059-498	060W-026	067-014	067-024	067-029	Storm		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Min	Max
Runoff Routing - Impervious		0.012																											0.01	0.03
Runoff Routing - Pervious		0.5																											0.1	0.6
Initial Loss (foot or feet [ft]) - Impervious		0.000233																											0.000525	0.002329
Initial Loss (ft) - Pervious		0.000919																											0.002067	0.009186
Fixed Runoff Coefficient		0.80	0.1	1		0.50	0.45	0.40		0.50	0.65	0.80	0.45			0.55	0.40	0.45		0.75	0.45		0.40	0.45			0.75	0.45	0.1	1
Green-Ampt Suction (in)		9.42																												
Green Ampt Conductivity (inches per hour [in/hr])		0.26	0.02				2.709843	0.26		0.1	0.26	0.13	0.26							0.13	0.26						0.13	0.26	0.02	2.709843
Green-Ampt Deficit		0.32																												
Soil Depth (ft)		2.5					0	10								1.5	2.5								1.5	2.5			0	10
Percolation Coefficient		0.51																											0.1	10
Baseflow Coefficient		0.01																											0.1	10
Infiltration Coefficient		4.8																											0.1	8.5
Percolation Threshold		17.74																											0	60
Percolation Percentage Infiltrating		15					0	60			15	20	25	15		20		15		20	15		20	15	20	15	20	15		
Soil Porosity		11.38																											1	40
Ground Porosity		29.38																											1	40
Baseflow Threshold Level (ft)		5																											0	7
Infiltration Threshold Level (ft)		10																											0	20

- Maximum and minimum values for each parameter were specified to limit sampling to a realistic range of values.
- A parameter set was developed using a combination of parameter values randomly sampled from within the range and applied to the InfoWorks model.
- The InfoWorks model was executed in batch mode from January 1, 2008, to January 31, 2009, and the simulated output was compared to the observed flow and depth measured for each calibration event.
- Weighting factors were applied to specific wet weather events and individual flow monitors.
- Percent of recorded volume (above threshold), percent of recorded peak, and standard deviation of percent of recorded volume were used to compute the goodness-of-fit between the simulated and observed data for flow and depth above a given threshold value for the duration of the calibration rainfall events.
- The parameter sets were ranked by goodness-of-fit to identify the best-fit parameter sets for consideration in the final calibrated model.
- Five candidate parameters sets were plotted against the recorded data for a final review and selection of the parameter set to be locked into the model.

Figure 5-4 depicts a flow chart of the processes described above. The following subsections describe the settings used for automated calibration. Table 5-4 lists the general settings used for GLUE.

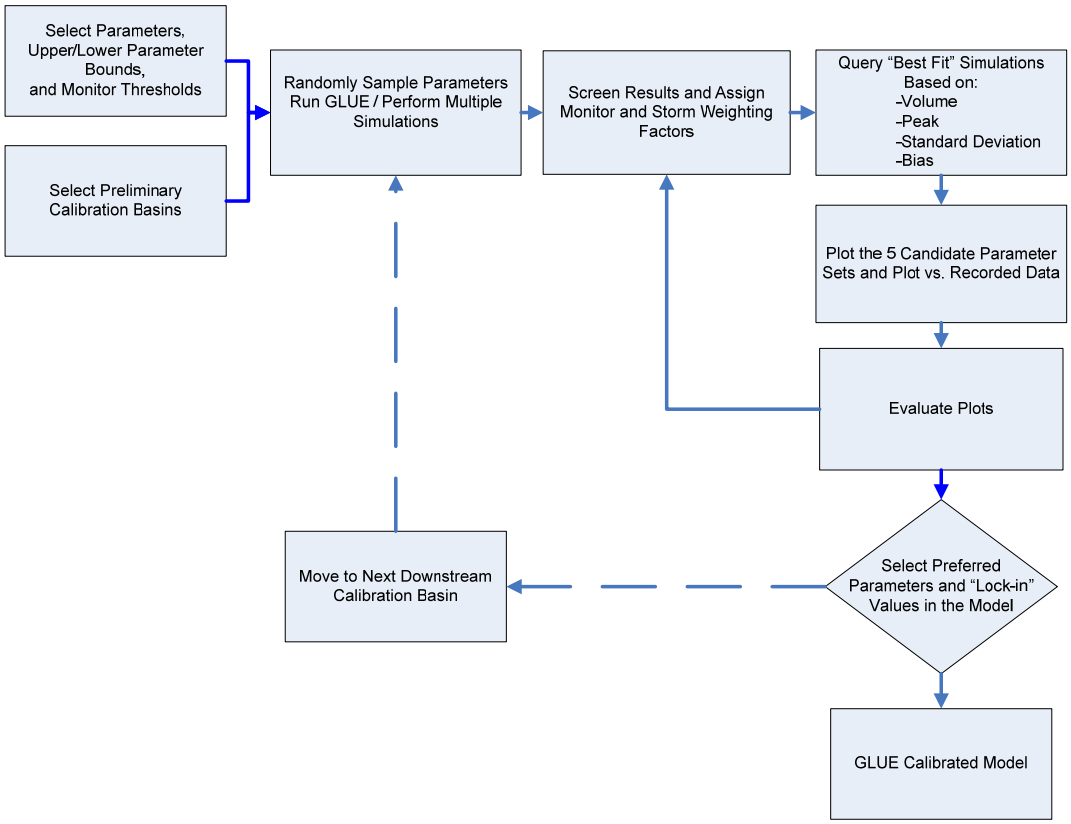


FIGURE 5-4: FLOW CHART OF THE AUTOMATED CALIBRATION PROCESS

5.6.1 Automated Calibration Sampled Parameters and Ranges

The Genesee model parameter sampling ranges were selected using guidance from the InfoWorks help files, physical properties and principles, experience from the Windermere CSO model (performed by Tetra Tech), and information gained through the initial calibration process. The sampling range was developed to be wide enough to give the model the flexibility to fully explore all reasonable possibilities, with the understanding that the automated calibration process may use some parameters as surrogates for otherwise difficult to calibrate elements in the model. The parameters and their upper and lower bounds are identified in Table 5-5. Randomly sampled parameters for over 3000 simulations can be found in Appendix D.

TABLE 5-4
Automated Calibration Settings

InfoWorks Element	Automated Calibration Setting
InfoWorks Catchment Group Path	>CG~Genesee Networks[a]
InfoWorks Network Path	>CG~Genesee Networks>NET~8/21/2009[a]
InfoWorks Rain Path	>CG~Genesee Networks>RAING~Rainfall Group>RAIN~RG18 1.1.2008 to 1.31.2009[a]
InfoWorks Waste Water Path	>CG~Genesee Networks>WWG~Wastewater Group>WW~Genesee Diurnal Curves_May1[a]
Selection Path for Links to Save Runoff	>CG~Genesee Networks>SELG~Selection List>SEL~GLUE Selection List[a]
Groundwater Infiltration	>CG~Genesee Networks>IFNG~Ground Infiltration Group>IFN~Ground Infiltration[a]
Level History	>CG~Genesee Networks>LEVG~Level Group>LEV~Lake Washington 1.1.1978 to 1.31.2009[a]
RTC Scenario	>CG~Genesee Networks>RTCG~RTC>RTC~RTC - Structure_A Pinch Valve[a]
Inflow	>CG~Genesee Networks>INFG~Inflow Group>INF~Darigold[a]
Start Date/Time	1/1/2008 12:00:00AM
End Date/Time	1/31/2009 12:00:00AM
InfoWorks Minimum Timestep (seconds)	300
Dry Weather Flow Multiplier	2
Dry Weather Flow Outflow Threshold (million gallons per day [MGD])	3
Dry Weather Flow Outflow Lag (minutes)	1440
Dry Weather Flow Precip Threshold (inches per hour [in/hr])	0.021
Dry Weather Flow Check Pumps (1 for yes, 0 for no)	0

[a] This automated calibration setting is a path used in the GLUE interface instructing GLUE where to find specific elements within the InfoWorks model. Path syntax is defined by the GLUE program code.

Once selected for each calibration group, the five candidate parameter sets (see Section 5.8) were compared with this range. Although the selected parameter set may have values close to the upper or lower end of the range, the majority of the candidate parameter sets did not,

TABLE 5-5
Final Range of InfoWorks Parameters Used for Automated Calibration Sampling

Calibration Adjustment Type	Calibration Adjustment Sub-Type	Model Name	Parameter Name	Value Sampling Range Min	Value Sampling Range Max	Justification/Source
Volume/ Magnitude	Initial Loss	Fixed	Initial Loss (ft) - Impervious	5.25E-04	2.33E-03	Equation 1 in Infoworks Help: "Initial Loss Type"- Slope method = 0.000071/(S^0.5). S = 1% to 20%
		Green-Ampt	Initial Loss (ft) - Pervious	2.07E-03	9.19E-03	Equation 1 in Infoworks Help: "Initial Loss Type"- Slope method = 0.00028/(S^0.5). S = 1% to 20%
		Ground Infiltration	Percolation Threshold	0	60	The distribution is chosen based on a qualitative analysis of the final Windermere GIM values. The minimum Baseflow Threshold Level was lowered from 0 to -7 to allow for Baseflow Threshold to be below Infiltration Threshold in approximately 75% of the sampled parameter sets.
			Baseflow Threshold Level (ft)	-7	7	
			Infiltration Threshold Level (ft)	0	20	
			Soil Depth (ft)	0	3	
			Soil Porosity	1	40	
			Ground Porosity	1	40	
	Flow Volume	Fixed	Fixed Runoff Coefficient	0.1	1	A wide range of possible values to fully capture all possible scenarios and to allow for adequate compensation for unknown model uncertainties.
		Green-Ampt	Soil Conductivity (inches per hour [in/hr])	0.02	2.71	Based on geographic information system soils data from City of Seattle (geology.shp), basin is composed of types Qal, Qvt, and Tb (Alluvium, Vashon Till, and Blakeley Formation). SCS soil classes and data from Rawls, Gimenez and Grossman (1998) indicate soil conductivities ranging from 0.02 to 2.71 in/hr.
		Ground Infiltration	Percolation Percentage Infiltrating	0	60	The distribution is chosen based on a qualitative analysis of the final Windermere GIM values
Hydrograph Shape	Routing (Time to Peak)	SWMM	Runoff Routing - Impervious	0.01	0.03	Infoworks Help: SWMM Model
			Runoff Routing - Pervious	0.1	0.6	Infoworks Help: SWMM Model
	Lag	Ground Infiltration	Percolation Coefficient	0.1	10	The distribution is chosen based on a qualitative analysis of the final Windermere GIM values
			Baseflow Coefficient	0.1	10	
			Infiltration Coefficient	0.1	8.5	

indicating that as far as goodness-of-fit was concerned, the parameter set range was sufficiently wide and unrestrictive of the true value.

Parameter sensitivity analysis based on the initial calibration process and some of the first automated calibration results indicated that the model was more sensitive to changes in some parameters and less sensitive to changes in others. Fixed runoff coefficient and percolation percentage infiltrating are the most sensitive parameters. Figures 5-5 and 5-6 below show the response of an example automated calibration group (Upper Calibration Group 40) to random sampling of one of the more sensitive parameters (fixed runoff coefficient) and a less sensitive parameter (soil depth). In both of these figures, the x-axis represents the rank of a particular simulation using the percent of recorded volume (% volume) goodness-of-fit statistic. The y-axis represents the randomly sampled value of a given parameter. When results are plotted against fixed runoff coefficient values, a general pattern emerges, indicating that changes in the given parameter have a large effect on results (Figure 5-5). The general lack of pattern in Figure 5-6 indicates that model results are less sensitive to changes in soil depth. The full scatter of points along the y-axis (0.1 to 1 for fixed runoff coefficient and 0 to 3 feet for soil depth) in both of these figures shows that the potential parameter space was thoroughly sampled using randomized parameter selection.

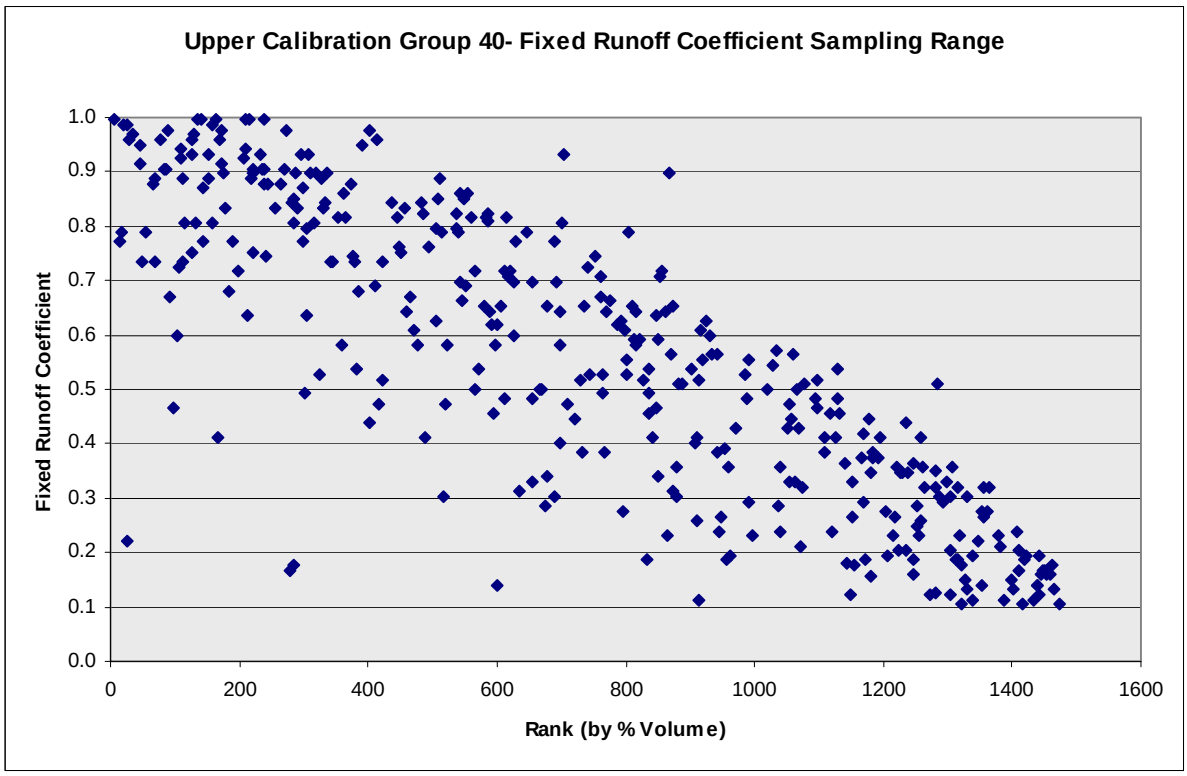


FIGURE 5-5: EXAMPLE RESPONSE OF 1,473 SIMULATIONS TO CHANGES IN FIXED RUNOFF COEFFICIENT

In order to reduce the number of simulations necessary to thoroughly sample the potential parameter space, some of the least sensitive parameters, such as Green and Ampt Suction and Deficit, were set constant at the value used for initial calibration.

5.6.2 Automated Calibration Meter Thresholds

To assess the goodness-of-fit during a wet weather response, simulated values are compared to meter data above applied thresholds. To establish the thresholds for the goodness-of-fit for each flow-monitoring catchment, the meter data were reviewed to evaluate a flow value above the peak dry weather flow, but below the wet weather component for each of the potential calibration storms (see Table 5-6 for a list of the threshold values used at each of the calibration points). Flow is in millions of gallons per day (MGD) and depth is in feet for the threshold values.

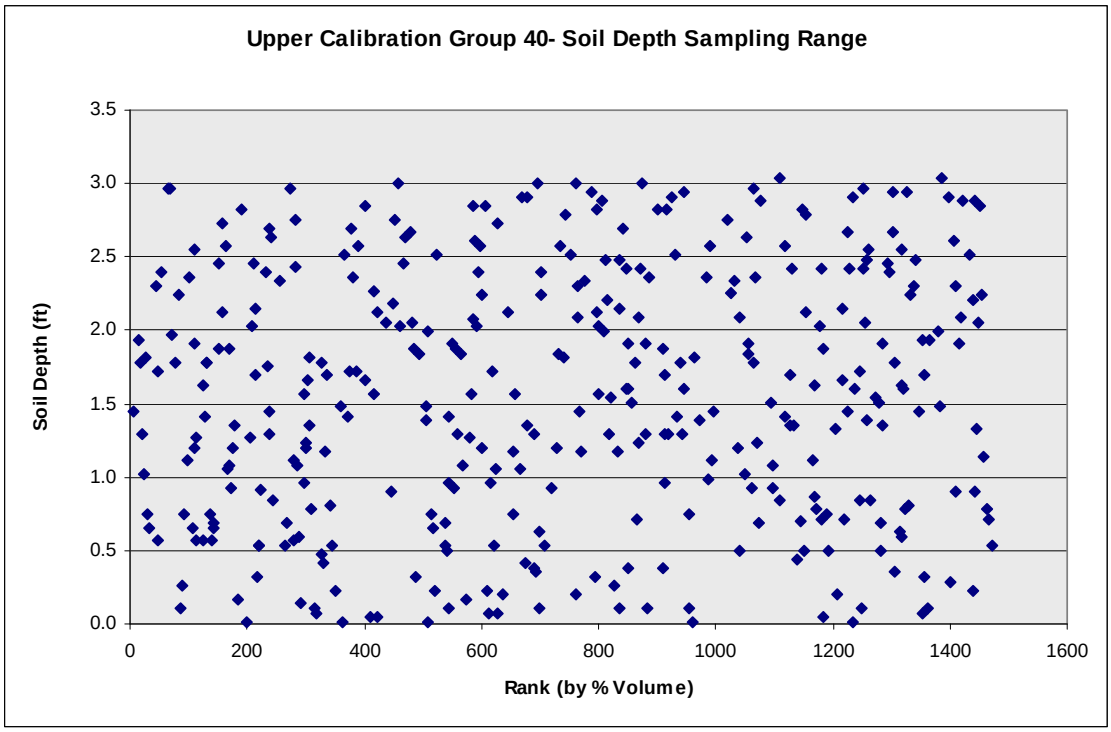


FIGURE 5-6: EXAMPLE RESPONSE OF 1,473 SIMULATIONS TO CHANGES IN SOIL DEPTH

In order to reduce the goodness-of-fit statistical bias created by the trade flow from the Darigold dairy processing facility (see Section 5.5.1), a "time threshold" was added to the post-processing routine. For calibration points affected by this flow, a given period of time was excluded from goodness-of-fit statistics calculation. The exact period was selected by identifying periods influenced by trade flow directly from flow-monitoring data.

5.6.3 Automated Calibration Groups

The flow-monitoring catchments within Genesee are hydraulically connected, meaning that variations in flows in the upstream catchments will affect the hydraulic response in the downstream catchments. Therefore, the Genesee flow-monitoring catchments were divided into three calibration phases: the upper calibration groups, middle calibration groups, and lower calibration groups. Structures such as pump stations and HydroBrakes, which separate the hydraulics from one flow-monitoring catchment to the next, were the basis for establishing the calibration groups. The GLUE process focused on finding and locking-in parameters for the upper calibration groups before focusing on the middle and lower calibration groups. Similarly, the middle calibration groups were locked-in before GLUE

was run for the lower calibration groups. For a delineation of the calibration groups, refer to Table 5-2 and Figure 5-2.

TABLE 5-6
Calibration Thresholds

Flow-monitoring Site	Calibration Use	Threshold Value (MGD/ft)
Basin 165		
067-078	Flow/Depth	0.100/0.350
Basin 43		
067-029	Flow	0.131
060W-049	Flow/Depth	0.430/0.200
060W-019	Flow	0.036
Basin 42		
060W-052	Depth	0.180/0.212
Control Structure 41A		
Control Structure 41B		
Basin 40		
059-436	Flow	0.156
059-409	Flow	0.120
Basin 38		
059-131	Flow	0.420
059-320	Flow	0.070
059-332	Flow	0.550
059-371	Flow	0.075
059-451	Flow/Depth	0.650/0.000
059-373	Flow	0.127
059-121	Flow	0.150
060W-012	Flow	0.330
059-404	Flow	0.365
059-443	Flow	0.192
059-398	Flow	0.590
Basin 37		
059-489	Flow/Depth	0.160/0.400

Flow-monitoring sites that were not used as calibration points (see Table 5-2) are not included in this list: 067-014, 067-024, 060W-026, 060W-047, 060W-014, 059-434, 059-406, 059-491, 059-490, 059-407, 059-498, 059-346, 059-451 NPDES 38. A discussion of why these points were not used is included in Section 5.7.

5.6.4 Automated Calibration Event and Meter Weighting Factors

After completing a batch of simulations (typically between 600 and 1,100), the calibration groups were post-processed to calculate a goodness-of-fit statistic for each meter and storm combination. Weighting factors were assigned to the storm events and meters to calculate a global goodness-of-fit, which then served as a query tool to identify candidate best-fit modeling parameter sets. The goals were to assign greater weighting to those storm/runoff events that are near the once-per-year frequency and greater weighting to those meters where there was greater confidence in the flow measurements.

Initially, the team focused on evenly weighting the events and meters in the calibration groups with the objective of identifying parameter sets that resulted in sufficient correlation to meter flow and depth measurement over a majority of storms. Using this method, the overall fit was not acceptable. This situation highlighted the difficulties in identifying those combinations of meters and storm events for which confidence was expressed regarding the

quality of the flow data and storm data. The team attributed the difficulties in the initial attempt at calibration to the following possible issues:

- Meters that were primarily installed to provide information on the hydraulics of a structure, as opposed to those monitors installed to measure the hydrologic response, were included. Measurements obtained at these sites are less sensitive to the hydrologic parameter adjustments in the model. Examples include those meters installed in the vicinity of HydroBrakes to provide data to develop stage-discharge curves. These meters were never meant for calibrating hydrologic response, and were removed from the calibration group in subsequent calibration iterations.
- Monitoring sites from outside the Genesee monitoring program were included. These sites were installed for purposes other than CSO model calibration and were reviewed for data quality by others. The data from some of these sites were not suitable for CSO model calibration. Examples include the monitoring sites installed to support the RainCatchers program.
- The rain gauge used for the project covered a large area and may not be fully representative of the microclimates that exist within some portions of the Genesee Area.
- For simulation stability, particularly for dry pipes, InfoWorks requires a base flow to be inserted in each pipe. It is set in the parameter simulation dialog fields and inserts a flow with a water level equal to the setting's percentage of the pipe diameter. The default is flow added to each pipe equivalent to 5 percent of the pipe diameter. A sensitivity analysis was performed to evaluate whether the 5 percent default could be reduced, thus minimizing the effect of the base flow factor. However, the reduced values resulted in simulation instabilities. The conclusion was that the 5 percent value would be needed for all simulations. The added flow is removed (conserved) in the volume calculations; however, the depth offset was apparent in all of the monitor/model comparison plots, particularly for large-diameter pipes. The added 5 percent of pipe diameter to the flow depth imparts difficulty in calibrating to depth, especially at locations where the typical flow depth is a small fraction of the total pipe depth. Depth was used for calibration at weir locations where the modeling team verified that the depth measurements were reliable.

Prior calibration work on the Windermere CSO Area and for some Genesee CSO flow-monitoring catchments had shown that a suitable model parameter set could be found when both high quality flow data and precipitation representative of the flow-monitoring catchment were apparent. Therefore, the inability to locate any parameter sets from approximately 1,000 simulations raised the possibility of problems with the flow data, representative precipitation, or a flaw in the model structure. Each of these possibilities was examined, revealing in some cases flaws in the model structure that were found and addressed (such as the varying HydroBrake performance evident in Basin 43). In other cases, the quality of the flow data or representativeness of the precipitation data was lacking and the meter or storm event was given lower weighting or was removed from consideration.

With these issues in mind, the team shifted the focus to examining events where the model predictions and recorded data had a greater visual consistency and focused less attention on

storms that did not compare well to the recorded data for all monitors. Similarly, the team focused on the hydrologic monitoring sites that recorded the most consistent and reliable data. Except for locations where the suitability of depth data was significantly higher than flow data, the team focused more on comparison of flow. In general, depth measurements are more accurate than flow because this entity is measured directly and because redundant sensors measure depth. However, because 5 percent of depth is added to total pipe flow for simulation stability, depth is rarely used as a calibration entity.

Weights were then applied to the combination of monitors and storm events that reflected the modeling team's judgment of the quality of the flow data and the importance of the storm event. These weightings led to identification of parameter sets that were capable of reasonably replicating recorded sewer flows for the varying storm events. Meter and event weightings are provided in Tables 5-7 and 5-8.

5.7 Best Fit Parameter Sets and Goodness-of-Fit

The advantage of the GLUE automated calibration process is its ability to simulate thousands of random parameter combinations within appropriate parameter ranges established by the modeler. Finding the best of these many combinations, or the best-fit parameter set, strictly by visually comparing modeled and metered hydrographs is infeasible given the number of potential hydrographs. For example, the Genesee Area with 28 calibrated entities (flow or depth), potentially 10 calibration storms, and 1,000 automated parameter sets, results in nearly 200,000 potential hydrographs to evaluate. To simplify the identification of a best-fit parameter set, a series of statistics is used to describe the overall comparison between a given set of modeled and metered hydrographs, also known as the goodness-of-fit. Six separate statistics are generated using the GLUE post-processing tool:

- Nash-Sutcliffe efficiency
- Standardized root mean square error (RMSE)
- Standardized bias
- Percent of recorded volume
- Standard deviation of percent of recorded volume
- Percent of recorded peak

Local statistics for each meter-storm combination are weighted by applying user-defined weights to create global statistics for each model simulation. The weighted statistics are known as global goodness-of-fit statistics. The six sets of statistics listed above are generated for both the local and global scenarios. The global goodness-of-fit statistics can be used to screen many potential parameter sets and to help identify the best fit parameter set. The methods used to create these statistics, as well as a more in-depth discussion of goodness-of-fit theory, can be found in *Methods for Estimating Control Volumes for CSO Reduction: Technical Guidance Manual* (MGS Engineering Consultants, Inc., February 2009). The spreadsheets used for global goodness-of-fit for each of the calibration groups can be found in Appendix E.

Ideally, RMSE is the best tool for comparing modeled with metered hydrograph values for each discrete time stamp in the user-defined comparison period. The difference between these points is aggregated for the entire comparison period, resulting in a single number to describe the global goodness-of-fit. However, the utility of RMSE depends on a near-perfect

TABLE 5-7
Calibration Event Weighting Factors

Event Date	1/8/08	2/29/08	3/28/08	5/21/08	6/6/08	8/24/08	10/13/08	11/5/08	12/24/08	1/6/09	
Event Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Upper Calibration Group 165	0.05	0.15	0.2	0	0	0.2	0.15	0.2	0.05	0	1
Upper Calibration Group 43	0	0.066	0.1	0.067	0.067	0.2	0	0.3	0	0.2	1
Upper Calibration Group 40	-	0.175	0.175	0	0	0.3	0	0.3	0	0.05	1
Upper Calibration Group 38	0.15	0.05	0.15	0	0	0.2	0	0.2	0.2	0.05	1
Upper Calibration Group 38, 059-373	0.1	0.1	0.1	0	0	0.25	0	0.25	0.1	0.1	1
Upper Calibration Group 38, 059-121	0.05	0.05	0.05	-	0.2	0.2	0.1	0.1	0.2	0.05	1
Upper Calibration Group 37	0.05	0.15	0.05	0.1	0	0.35	0.05	0.15	0	0.1	1
Middle Calibration Group 42, 41, Mid 38	0	0	0	0	0	0.4	0	0.4	0	0.2	1
Middle Calibration Group 38, 059-451	0.05	0.05	0.1	0	0.1	0.25	0	0.1	0.1	0.25	1
Lower Calibration Group 38	0.05	0.1	0.1	0	0	0.3	0	0.3	0.05	0.1	1

Notes:
Events weighted with “0” (shaded grey) had zero weighting due to modeler’s judgment.
Dash (-) indicates no data recorded at indicated calibration group for indicated event.

TABLE 5-8
Calibration Meter Weighting Factors

Event Date	1/8/08	2/29/08	3/28/08	5/21/08	6/6/08	8/24/08	10/13/08	11/5/08	12/24/08	1/6/09
Event Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Upper Calibration Group 165										
NPDES165 067-078 Q	0.75	1	0.75	-	0	0.75	0.75	0.75	1	-
NPDES165 067-078 D	0.25	-	0.25	0	0	0.25	0.25	0.25	-	0
Total	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**
Upper Calibration Group 43										
067-029 RC	-	0.333	-	0.333	0.333	0.05	0	0.05	0	0.05
NPDES43 060W-049 Q	0	0.333	0.5	0.333	0.333	0.1	0	0.1	0	0.1
060W-019	0	0.334	0.5	0.334	0.334	0.1	-	0.1	0	0.1
NPDES43 060W-049 D	0	0	0	0	0	0.75	0	0.75	0	0.75
Total	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**
Upper Calibration Group 40										
059-436	-	0.333	0.333	0	0	0.333	0	0.333	0	0.333
059-409	-	0.667	0.667	0	0	0.667	0	0.667	0	0.667
Total	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**1**
Upper Calibration Group 38										
059-131	0.5	0.5	0.55	0	0	0.5	0	0.5	0.5	0.5
059-320	0.2	0.2	0.25	0	0	0	0	0	0.2	0.2
059-332	0.15	0.15	-	0	0	0	0	-	0.15	0.15
059-371	0.15	0.15	0.2	0	0	0.5	0	0.5	0.15	0.15
Total	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**1**	**1**
Upper Calibration Group 38, 059-373										
059-373	1	1	1	0	0	1	0	1	1	1
Upper Calibration Group 38, 059-121										
059-121	1	1	1	-	1	1	1	1	1	1
Upper Calibration Group 37										
059-489 Q	0	0.25	0	-	-	-	1	1	0.25	0.25
059-489 D	1	0.75	1	1	-	1	-	0	0.75	0.75
Total	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**

TABLE 5-8
Calibration Meter Weighting Factors

Event Date	1/8/08	2/29/08	3/28/08	5/21/08	6/6/08	8/24/08	10/13/08	11/5/08	12/24/08	1/6/09
Event Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Middle Calibration Group 42, 41, 38										
NPDES 42 060W-052 Depth	0.2	0.2	0.2	0	0	0.2	0	0.2	0.2	0.2
060W-012 Flow	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.4	0.4
059-404 Flow	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.4	0.4
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Middle Calibration Group 38, 059-451										
059-451 Q	0.75	0.75	0.75	0	0.75	0.8	0	0.75	0.75	0.75
059-451 D	0.25	0.25	0.25	0	0.25	0.2	0	0.25	0.25	0.25
Total	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**
Lower Calibration Group 38										
059-443 KC	-	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
059-398	1	0.5	-	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Notes:
Flow-monitoring sites that were not used as calibration points (see Table 5-2) are not included in this list: 067-014, 067-024, 060W-026, 060W-047, 060W-014, 059-434, 059-406, 059-491, 059-490, 059-407, 059-498, 059-346, 059-451 NPDES 38. A discussion of why these points were not used is included in Section 5.7.
Events/monitors weighted with “0” (shaded grey) had zero weighting due to modeler’s judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

match between the drivers of model flow (monitored gauge precipitation) and the drivers of metered flow (actual flow-monitoring catchment precipitation). Because the gauge used for the Genesee model covers a large area and may not fully represent microclimates in some parts of the Genesee Area, these two flow drivers do not always match up, and time shifts of up to 15 minutes occur between peaks in the model and metered hydrographs.

These shifts result in poor RMSE values for what would otherwise be well-matched hydrographs (see Figure 5-7 for a description of this occurrence). The modeling team investigated the variability of these shifts among the flow meters. Normally, systematic shifts common to all flow monitors are easily remedied by artificially shifting the precipitation data to better match the flow-monitoring record. After reviewing the data, the modeling team determined that these shifts were too variable for adjustments to the precipitation record to be effective and that an alternate method of goodness-of-fit assessment would be necessary.

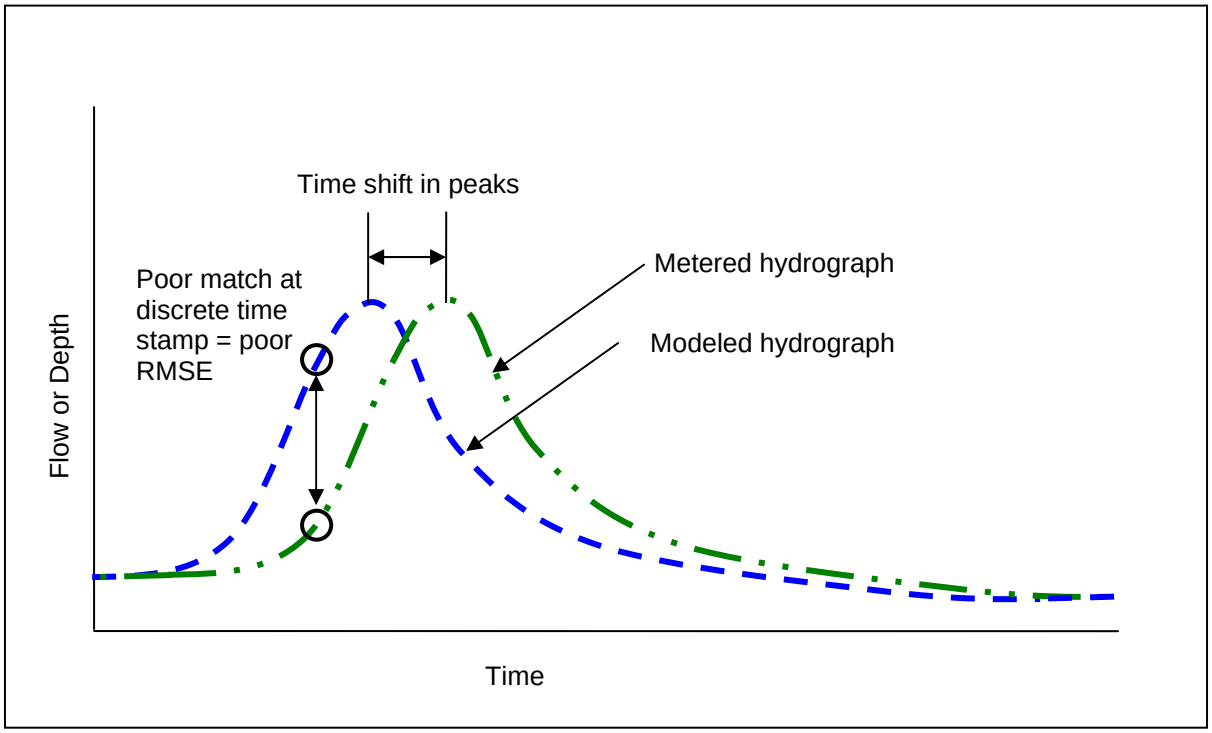


FIGURE 5-7: TIME SHIFT IN HYDROGRAPH PEAKS CAUSES POOR RMSE VALUES

Instead of RMSE, a combination of percent of recorded volume, percent of recorded peak, and standard deviation of percent of recorded volume was used to screen parameter sets and to select a reasonable number to graph. As many as five parameter sets at a time were graphed for each calibration group, and the best-fit parameter set was selected based on visual comparison by the team. Because indicators other than RMSE were used to screen parameter sets, and because the goodness-of-fit statistics do not account for matching below a given flow and depth threshold, some hydrographs of candidate parameter sets presented difficulties in matching the receding limb of the metered hydrograph. Visual assessment of the five candidate parameter sets were used to consider the receding limb in choosing the selected parameter set.

An important indicator of the success of automated calibration is the ability of the simulated hydrographs for various parameter sets to both overpredict and underpredict flow peaks and volumes. Consistent overprediction or underprediction indicates a systematic error in the model or in the meter data. Ideally, the selected best-fit parameter set will overpredict some storm events and underpredict some events, indicating few systematic errors and smaller overall model uncertainty. The use of model uncertainty as a factor in calculating precipitation scaling factors for uncertainty analysis is discussed in Chapter 7.

5.8 Automated Calibration Results

The following sections describe the automated calibration results for each of the automated calibration groups. Each section provides a brief description of an automated calibration group, the reasoning and process behind decisions on storm and meter weighting, global goodness-of-fit for the candidate parameter sets, detailed goodness-of-fit statistics for the selected parameter set (Tables 5-9 through 5-28), and example hydrographs for the selected parameter set (Figures 5-8 through 5-27).

The Genesee Area has complex hydrology and each of the monitoring sites has complex hydraulics. Therefore, the example hydrographs include the event that shows the closest match to the observed data and one that has an average match from the monitoring site that was most highly weighted in each calibration group. Events with hydrographs that showed poor matches to the observed data were deweighted and effectively removed from the calibration. Global goodness-of-fit statistics for the selected parameter sets, as well as the selected parameter set values for all the automated calibration groups, can be found in Tables 5-29 and 5-30. A full set of calibration hydrographs is presented in Appendix F.

5.8.1 Upper Calibration Groups

After completing nearly 1,500 automated calibration simulations, the team moved into post-processing the calibration groups and various individual calibration points. Once the initial post-processing run was complete, the team applied various weightings to select the best fit parameter sets. The upper calibration groups are composed of Basin 165, Basin 43, Basin 40, Basin 37, and a portion of Basin 38.

Upper Calibration Group 165

The permanent monitoring site at 067-078 measures all of the flow from Basin 165. The tributary area for this calibration group is about 16 acres, and the basin is considered to be partially separated. The parameter set for this calibration group was locked-in early in the GLUE process to minimize the impact in the calibration of the downstream calibration groups.

The recorded flow and depth data from 067-078 were used to calibrate this calibration group. After evenly weighting this calibration point for depth and flow, the model apparently overpredicted depth at this site, likely attributable to InfoWorks adding 5 percent of the pipe diameter. Therefore, to find the selected parameter set, the team proceeded to weight the flow data heavier than the depth data. This change in weighting resulted in better statistical matches (see Table 5-9). The calibrated model most closely matched the peak and the volume of the monitored flows for storm events 2, 6, and 8. The calibrated model did not match the monitored flows as closely for storm events 1, 4, 5,

and 9. Event weightings were distributed in accordance with this comparison between monitor and model data (see Table 5-10). Figure 5-8 shows a hydrograph of the closest match to the metered data, and Figure 5-9 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

Upper Calibration Group 43

The calibration parameter set for Upper Calibration Group 43 was evaluated using calibration points 060W-049 (flow and depth), 060W-019 (flow), and RainCatcher 067-029 (flow). Because the purpose of RainCatcher sites 067-024 and 067-014 was not for CSO model calibration, the team elected not to use these sites for calibration.

TABLE 5-9
Global Goodness-of-Fit for Upper Calibration Group 165

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
1	R1_06042009-205	76%	101%	51%	142%
4	742_06022009-38	70%	98%	45%	129%
5	R1_06042009-340	71%	97%	46%	126%
6	**R1_06042009-378**	**71%**	**98%**	**45%**	**129%**
15	R1_06042009-334	62%	92%	31%	133%

TABLE 5-10
Calibration Performance: Upper Calibration Group 165

Model Run: R1_06042009-378											
Global Goodness-of-Fit for RMSE				71%							
Global Goodness-of-Fit for Volume				98%							
Standard Deviation of Volume				45%							
Global Goodness-of-Fit for Peak				129%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.05	0.15	0.2	0	0	0.2	0.15	0.2	0.05	0	
NPDES165 067-078 Q											
RMSE	29%	67%	50%	-	130%	46%	203%	41%	61%	-	72%
Volume	85%	63%	59%	-	183%	122%	194%	75%	95%	-	99%
Peak	126%	65%	115%	-	202%	130%	196%	100%	206%	-	125%
NPDES165 067-078 D											
RMSE	37%	-	43%	83%	167%	20%	203%	37%	-	87%	65%
Volume	63%	-	60%	160%	199%	93%	192%	69%	-	37%	95%
Peak	80%	-	83%	208%	316%	115%	229%	141%	-	43%	133%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

Because flow at 060W-047 is overpredicted due to HydroBrake influence, this site was used for HydroBrake calibration only. The monitoring site at 060W-026 was removed mid-project

due to poor monitoring conditions and is not used for calibration. The metered data at 060W-019 is impacted by small surges of backwater due to Pump Station #6 discharges just downstream of the monitoring site. These small surges are unique to the meter data and are not replicated in simulated flow. Because these small surges fall out in the total volume and peak statistics, the pumping impact does not affect automated calibration.

The tributary area for this calibration group is about 75 acres and is considered to be partially separated. As with Upper Calibration Group 165, the parameter set for this basin was locked-in early in the GLUE process to minimize the impact on the downstream calibration groups.

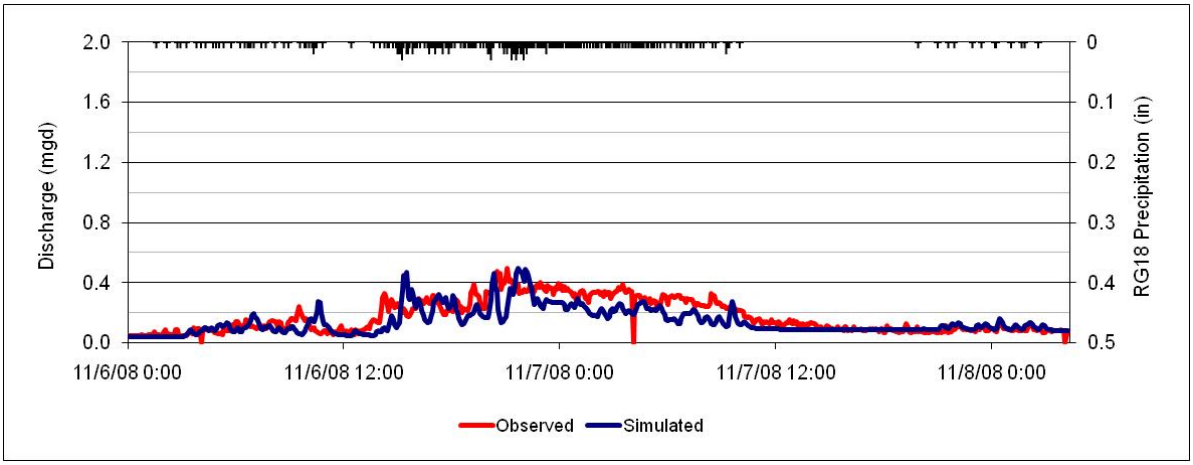


FIGURE 5-8: NPDES165 067-078Q EVENT 8 (CLOSE MATCH)

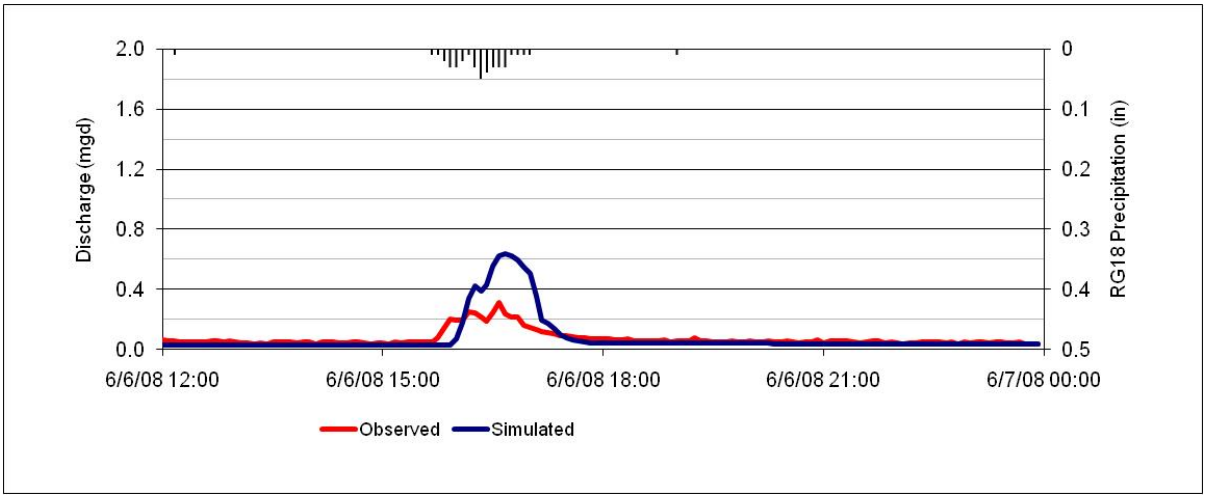


FIGURE 5-9: NPDES165 067-078Q EVENT 5 (AVERAGE MATCH)

A shift in the performance of the HydroBrake is apparent throughout the monitoring period. It is less restrictive for the less intense storms and more restrictive during the larger storm events. The team elected to use the HydroBrake curve that accurately represents these larger storms events. By using this curve, the model over predicts depth at CSO Control Structure 43 during the less intense storms. Therefore, the team removed these events from the weighting.

Basin 43 is known to be uncontrolled; therefore, the team assessed that an evenly weighted approach was not best for this calibration group. To be certain a parameter set matching the overflow frequency of the metered data was selected, the team chose to put most of the calibration group's weighting on depth at the permanent site and on the larger events. See Tables 5-11 and 5-12 for Upper Calibration Group 43 calibration results. Figure 5-10 shows a hydrograph of the closest match to the monitored data, and Figure 5-11 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

TABLE 5-11
Global Goodness-of-Fit for Upper Calibration Group 43

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
2	R1_06042009-16	81%	100%	42%	98%
30	R1_06042009-198	78%	96%	42%	98%
3	**R1_06042009-384**	**86%**	**100%**	**48%**	**102%**
7	R1_06042009-53	88%	101%	51%	99%
28	R1_06042009-136	93%	96%	54%	105%

TABLE 5-12
Calibration Performance: Upper Calibration Group 43

Model Run: R1_06042009-384											
Global Goodness-of-Fit for RMSE				0%							
Global Goodness-of-Fit for Volume				100%							
Standard Deviation of Volume				48%							
Global Goodness-of-Fit for Peak				102%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0	0.066	0.1	0.067	0.067	0.2	0	0.3	0	0.2	
067-029 RC											
RMSE	-	87%	-	117%	119%	62%	141%	59%	87%	80%	75%
Volume	-	21%	-	122%	54%	58%	114%	55%	60%	46%	56%
Peak	-	238%	-	260%	233%	111%	439%	78%	238%	53%	117%
NPDES43 060W-049 Q											
RMSE	67%	72%	68%	93%	81%	69%	109%	65%	58%	67%	70%
Volume	38%	45%	37%	160%	117%	52%	123%	56%	48%	49%	62%
Peak	85%	54%	103%	198%	159%	67%	204%	82%	83%	26%	81%
060W-019											
RMSE	89%	141%	82%	134%	115%	81%	-	50%	89%	91%	84%
Volume	41%	54%	46%	115%	73%	79%	-	122%	81%	55%	84%
Peak	34%	29%	38%	21%	25%	19%	-	66%	35%	19%	36%
NPDES43 060W-049 D											
RMSE	60%	64%	100%	391%	362%	112%	68%	65%	477%	92%	86%
Volume	159 %	157%	178%	400%	332%	177%	164%	131%	322%	71%	127%
Peak	111 %	87%	266%	632%	483%	176%	116%	72%	1350%	100%	110%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

Upper Calibration Group 40

The calibration parameter set for Upper Calibration Group 40 was determined by using the two hydrologic calibration points 059-436 and 059-409. The tributary area for this calibration group is about 41 acres and is considered separated. Just like Upper Calibration Groups 165 and 43, the parameter set for this calibration group was locked-in early in the GLUE process to minimize the impact to the downstream calibration groups, namely, Middle Calibration Group at overflow structures 41A and 41B.

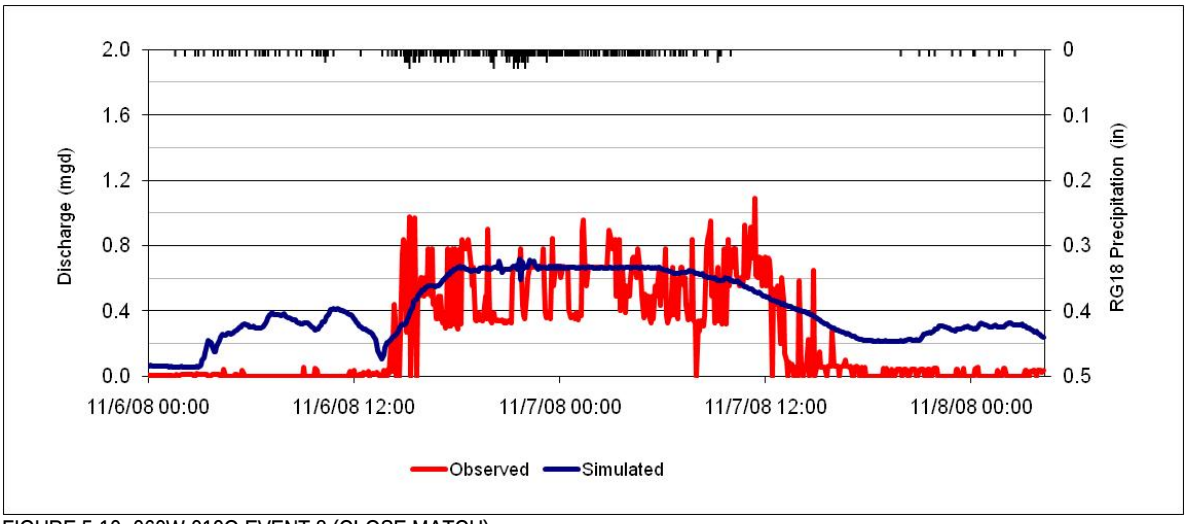


FIGURE 5-10: 060W-019Q EVENT 8 (CLOSE MATCH)

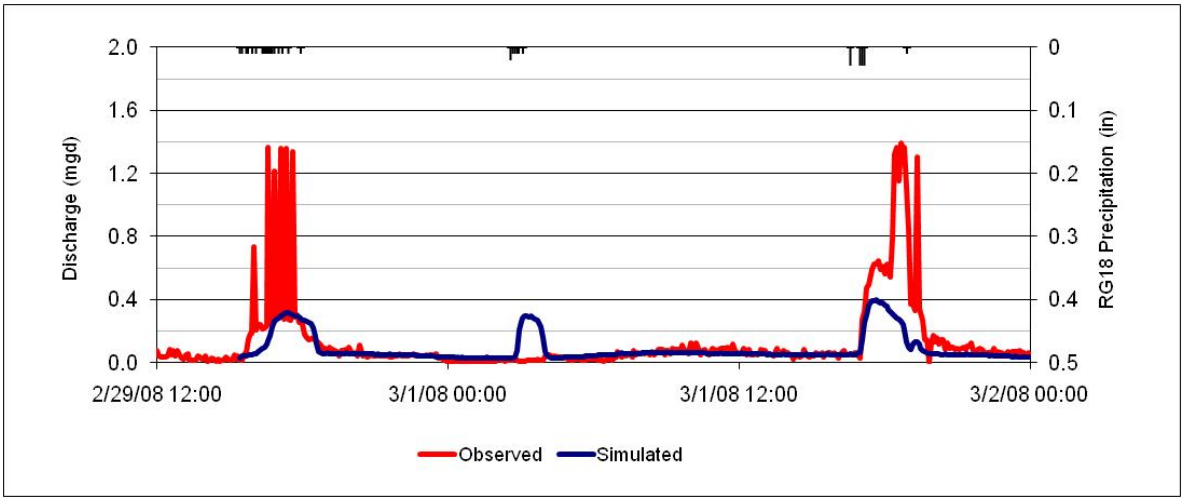


FIGURE 5-11: 060W-019Q EVENT 2 (AVERAGE MATCH)

As with Basin 43, Basin 40 is known to be uncontrolled; therefore, several monitoring site and storm weighting iterations were performed within the goodness-of-fit worksheet to find the best parameter sets. Initially, the team focused on evenly weighting 059-436, 059-409, 059-490, and depth and flow at the permanent site, and on not using 059-407 because of adverse effects from the upstream HydroBrake. However, the data at the permanent site (059-491) were not suitable due to the presence of a HydroBrake and activation of storage during larger events; therefore this approach was abandoned. Next, the team looked at de-

weighting the permanent site (depth and flow) to identify the effect it would have on the goodness-of-fit measures. This approach did yield better goodness-of-fit statistics, but hydrograph results were unsatisfactory. The team revised the approach, removing 059-490 and focusing the parameter selection on the larger events at the hydrologic sites 059-436 and 059-409; this approach produced the best goodness-of-fit parameter sets (see Table 5-13). Detailed goodness-of-fit statistics for the selected parameter set can be found in Table 5-14. Figure 5-12 shows a hydrograph of the closest match to the monitored data, and Figure 5-13 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

TABLE 5-13
Global Goodness-of-Fit for Upper Calibration Group 40

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
3	R1_06042009-173	50%	100%	31%	102%
14	458_05122009-01	48%	101%	29%	105%
28	**R1_06022009-65**	**48%**	**102%**	**24%**	**102%**
38	R1_06042009-215	47%	103%	26%	99%
247	742_06012009-30	43%	87%	22%	80%

TABLE 5-14
Calibration Performance: Upper Calibration Group 40

Model Run: R1_06022009-65											
Global Goodness-of-Fit for RMSE				48%							
Global Goodness-of-Fit for Volume				102%							
Standard Deviation of Volume				24%							
Global Goodness-of-Fit for Peak				102%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	-	0.175	0.175	0	0	0.3	0	0.3	0	0.05	
059-436											
RMSE	-	61%	48%	179%	164%	39%	228%	36%	55%	60%	45%
Volume	-	78%	61%	256%	205%	110%	191%	92%	82%	57%	88%
Peak	-	63%	134%	306%	280%	118%	332%	100%	214%	51%	102%
059-409											
RMSE	-	63%	42%	153%	228%	63%	292%	50%	61%	34%	54%
Volume	-	92%	100%	230%	263%	138%	251%	126%	123%	86%	117%
Peak	-	81%	167%	235%	321%	141%	299%	142%	308%	87%	133%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

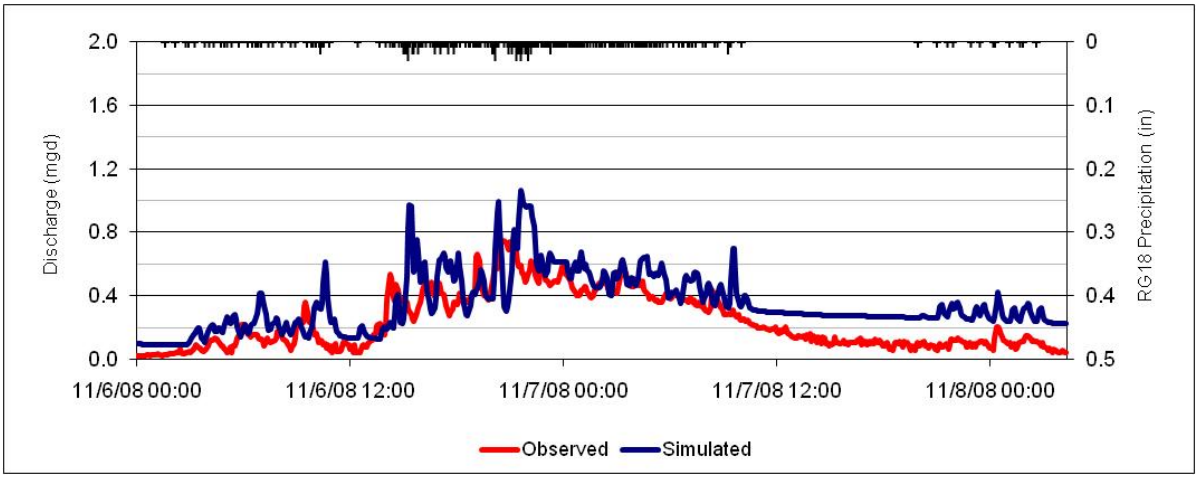


FIGURE 5-12: 059-409 EVENT 8 (CLOSE MATCH)

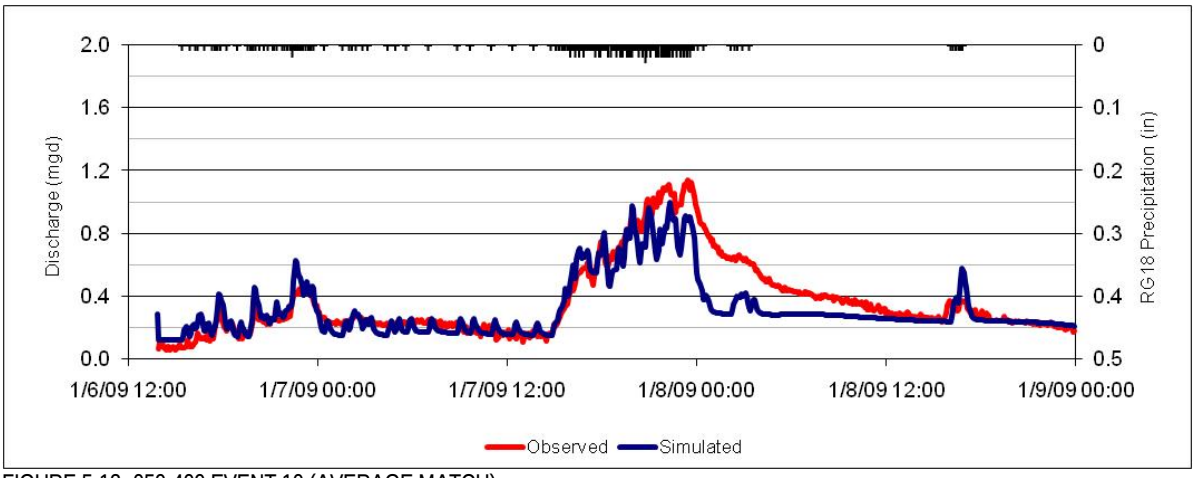


FIGURE 5-13: 059-409 EVENT 10 (AVERAGE MATCH)

Upper Calibration Group 37

The calibration parameter set for Upper Calibration Group 37 was evaluated by using the permanent monitoring site at 059-489 for depth and flow. The tributary area for this calibration group is about 45 acres and is considered partially separated. Because this basin directly discharges into the Hanford Street Trunk B, the team waited to lock-in this upper calibration group because flows here do not impact the other calibration groups in the Genesee Area.

During the flow-monitoring period, this site consistently had questionable flow data and good depth data; the team therefore weighted depth more heavily during post-processing. The calibrated model most closely matched the peak and the volume of the monitored flows for storm events 2, 6, and 8. The calibrated model did not match the monitored flows as closely for storm events 1, 3, 5, 7, and 9. Event weightings were distributed in accordance with this comparison between monitor and model data. See Tables 5-15 and 5-16 for Upper Calibration Group 37 calibration results. Figure 5-14 shows a hydrograph of the closest match to the monitored data, and Figure 5-15 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

TABLE 5-15
Global Goodness-of-Fit for Upper Calibration Group 37

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
9	R1_06042009-122	214%	100%	43%	95%
62	R1_06042009-178	219%	99%	41%	96%
197	458_06052009-68	218%	103%	47%	97%
220	R1_06022009-75	191%	96%	37%	104%
879	**540_05142009-5**	**94%**	**53%**	**29%**	**155%**

TABLE 5-16
Calibration Performance: Upper Calibration Group 37

Model Run: 540_05142009-5											
Global Goodness-of-Fit for RMSE				31%							
Global Goodness-of-Fit for Volume				69%							
Standard Deviation of Volume				25%							
Global Goodness-of-Fit for Peak				79%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.05	0.15	0.05	0.1	0	0.35	0.05	0.15	0	0.1	
059-489 Q											
RMSE	23%	76%	38%	-	-	-	106%	53%	41%	65%	69%
Volume	99%	57%	107%	-	-	-	88%	58%	67%	45%	58%
Peak	80%	42%	92%	-	-	-	360%	51%	94%	40%	80%
059-489 D											
RMSE	72%	111%	93%	46%	-	14%	-	17%	20%	29%	46%
Volume	40%	29%	25%	59%	-	94%	-	109%	113%	92%	69%
Peak	23%	13%	15%	57%	-	107%	-	108%	128%	60%	66%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

Upper Calibration Group 38

Upper Calibration Group 38 was divided into three smaller calibration groups. The largest of these calibration groups included calibration points 059-131, 059-320, 059-332, and 059-371. The tributary area for this calibration group is about 237 acres and is considered partially separated. The second calibration group was inadvertently created by an incorrect set-up during post-processing. Ideally, the area tributary to calibration point 059-373 (46 acres) would have been included in the Upper Calibration Group 38; however, it was mistakenly omitted from the post-processing worksheet. The team discussed the implication of bringing this calibration point into the first group and then reprocessing the data, but the team concluded that the data quality and goodness-of-fit were adequate and to move

forward with the basin separated. The last calibration group includes the area tributary to calibration point 059-121, roughly 40 acres. Because this area discharges directly into the Hanford Street Trunk B, the area was not grouped with any other flow-monitoring basins into a calibration group.

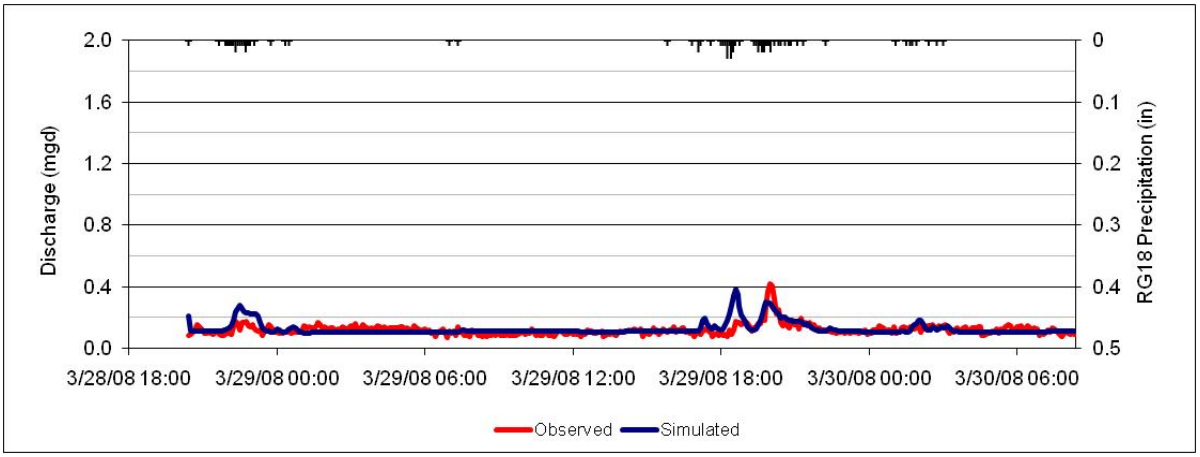


FIGURE 5-14: NPDES37 059-489 Q EVENT 3 (CLOSE MATCH)

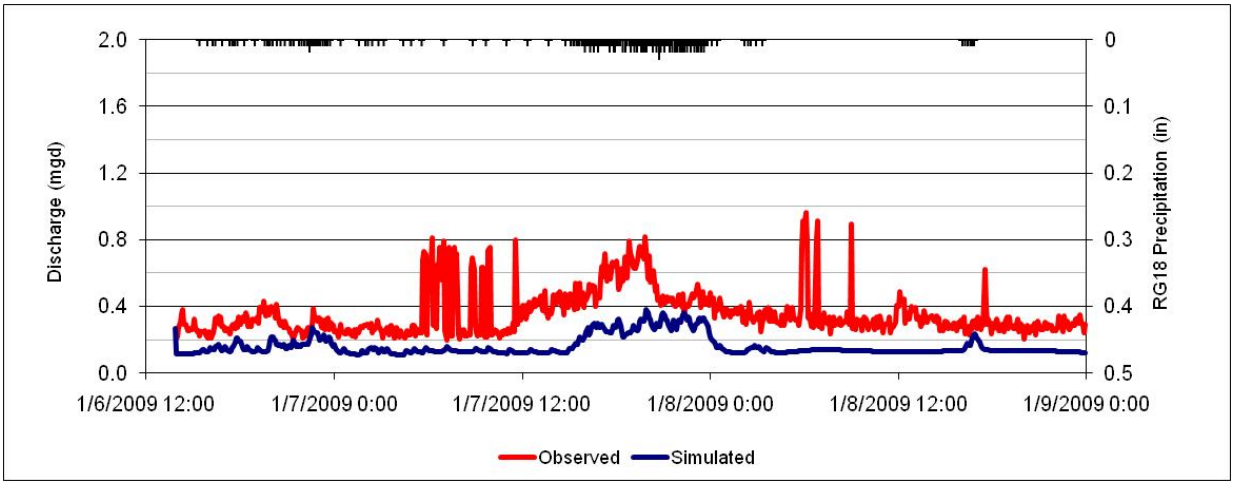


FIGURE 5-15: NPDES37 059-489 EVENT 10 (AVERAGE MATCH)

All the calibration points within Upper Calibration Group 38 were calibrated using flow only. The largest of the three calibration groups originally focused on equally weighting the three sites, and again, the team disliked the plots and statistics of the preferred goodness-of-fit parameter sets. The secondary approach was used, and more weight was put on the better hydrologic sites (059-131 and 059-320). Because events 4, 5, and 7 were extremely flashy and not representative of the rain that fell in this area, these events were de-weighted. The calibrated model most closely matched the peak and the volume of the monitored flows for storm events 2, 6, and 8. Event weightings were distributed in accordance with this comparison between monitor and model data.

Because the other two calibration groups included only one monitoring site, they were all weighted as 100 percent for the selected events. Similar to the rest of Upper Calibration Group 38, the model for 059-373 did not match the monitored flows closely for events 4, 5,

and 7. Event weightings were distributed in accordance with this comparison between monitor and model data.

Data for the upper calibration group 059-121 event 4 was missing as a result of equipment malfunctions and was thus not included in calibration. The calibrated model most closely matched the peak and the volume of the monitored flows for storm events 5, 6, and 9, and weighted the site accordingly. Events 5 and 9 are normally deweighted, but appeared to do well at this site and were thus weighted higher than normal.

See Tables 5-17 through 5-22 for Upper Calibration Group 38 calibration results. Figures 5-16, 5-18, and 5-20 show hydrographs of the closest match to the monitored data for the three subdivisions of Upper Calibration Group 38. Figures 5-17, 5-19, and 5-21 show hydrographs of one of the average match calibration hydrographs for each of the three subdivisions in Upper Calibration Group 38. See Appendix F for additional calibration results.

TABLE 5-17
Global Goodness-of-Fit for Upper Calibration Group 38

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
25	R1_06042009-197	41%	100%	25%	99%
112	540_05122009-09	52%	98%	21%	100%
156	**R2_06022009-54**	**37%**	**97%**	**16%**	**101%**
204	458_06032009-06	41%	97%	24%	102%
280	540_05212009-49	60%	95%	18%	120%

5.8.2 Middle Calibration Groups

Once the upper calibration groups' selected parameter sets were locked into the InfoWorks model, another 1,200 automated calibration simulations were completed with the goal of finding a parameter set for the middle calibration groups. Two middle calibration groups are included: one middle calibration group is composed of Middle Calibration Groups 42, 41, and a portion of the lake line in Middle Calibration Group 38; the other middle calibration group is composed of calibration point 059-451. Both middle calibration groups are separated, and they have tributary areas of 101 and 45 acres, respectively.

Middle Calibration Group 42

Ideally, Middle Calibration Group 42 would be included in the upper calibration group category since Basin 42 is a terminal basin. However, throughout the flow-monitoring period the team noticed a constriction in the line between 060W-012 and 060W-014. This constriction caused frequent backups in the lake line that surcharged the system in Middle Calibration Group 42. With this in mind, the team decided to run the model with Upper Calibration Groups 165 and 43 locked-in before attempting to lock in Middle Calibration Group 42. Because of influence from the upstream HydroBrake, the team decided to remove 060W-014 from automated calibration and use this monitoring site for HydroBrake stage-

TABLE 5-18
Calibration Performance: Upper Calibration Group 38

Model Run: R2_06022009-54											
Global Goodness-of-Fit for RMSE				37%							
Global Goodness-of-Fit for Volume				97%							
Standard Deviation of Volume				16%							
Global Goodness-of-Fit for Peak				101%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.15	0.05	0.15	0	0	0.2	0	0.2	0.2	0.05	
059-131											
RMSE	27%	33%	27%	23%	30%	27%	32%	53%	26%	46%	33%
Volume	88%	99%	96%	107%	99%	94%	103%	92%	112%	83%	96%
Peak	96%	89%	101%	89%	104%	98%	80%	100%	112%	116%	102%
059-320											
RMSE	29%	156%	29%	115%	182%	63%	108%	79%	54%	33%	48%
Volume	74%	38%	96%	183%	155%	131%	99%	160%	128%	119%	98%
Peak	73%	15%	94%	149%	220%	140%	45%	104%	158%	77%	102%
059-332											
RMSE	29%	53%	-	52%	54%	60%	64%	-	27%	43%	32%
Volume	84%	122%	-	147%	136%	149%	133%	-	96%	68%	92%
Peak	115%	53%	-	128%	127%	131%	67%	-	102%	75%	98%
059-371											
RMSE	32%	124%	37%	113%	136%	31%	89%	43%	44%	39%	42%
Volume	77%	36%	71%	166%	118%	99%	105%	119%	111%	74%	94%
Peak	66%	22%	90%	89%	143%	96%	102%	93%	197%	61%	105%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

discharge curve creation only. To ensure that overflows were adequately predicted, depth from the permanent meter in Basin 42, 060W-052 was included in automated calibration.

Flows from this site were not included as a result of adverse effects on velocity data from the downstream HydroBrake.

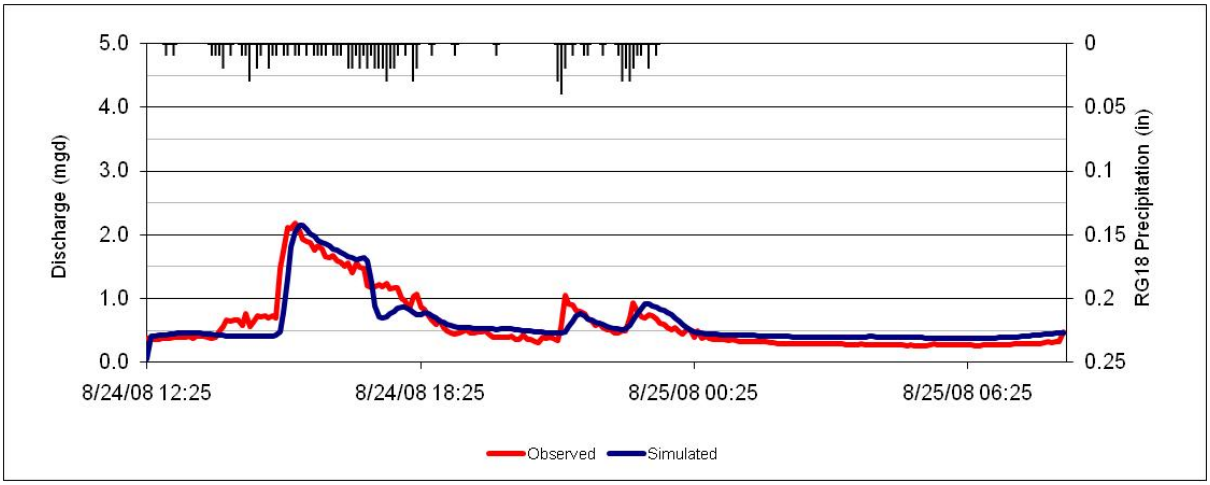


FIGURE 5-16: 059-131 EVENT 6 (CLOSE MATCH)

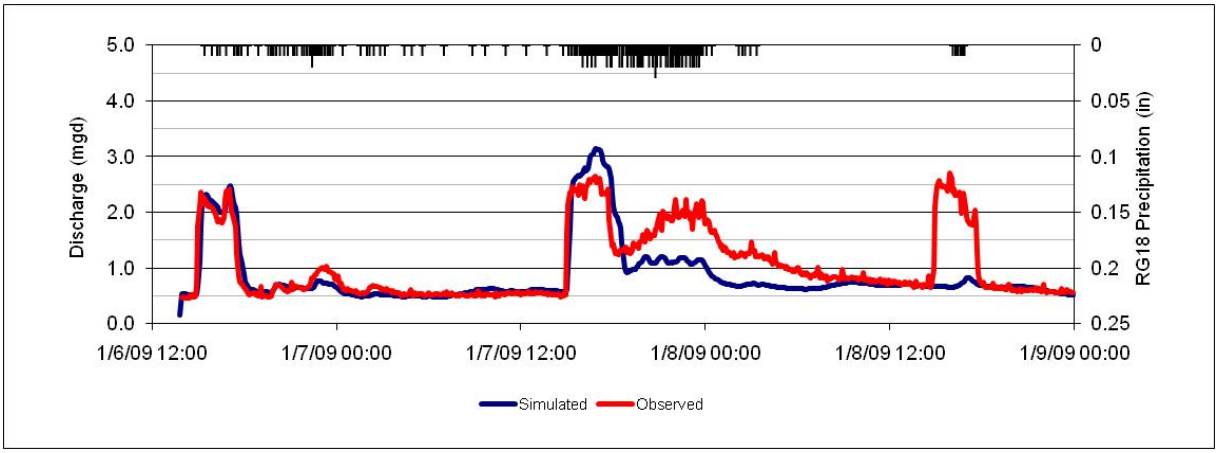


FIGURE 5-17: 059-131 EVENT 10 (AVERAGE MATCH)

TABLE 5-19
Global Goodness-of-Fit for Upper Calibration Group 38, 059-373

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
1	458_06052009-03	91%	100%	81%	100%
3	742_06032009-06	43%	100%	30%	106%
60	R1_06022009-63	86%	95%	71%	105%
63	**R1_06042009-298**	**46%**	**105%**	**33%**	**101%**
589	R2_06042009-48	52%	67%	23%	89%

TABLE 5-20
Calibration Performance: Upper Calibration Group 38, 059-373

Model Run: R1_06042009-298											
Global Goodness-of-Fit for RMSE				46%							
Global Goodness-of-Fit for Volume				105%							
Standard Deviation of Volume				33%							
Global Goodness-of-Fit for Peak				101%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.1	0.1	0.1	0	0	0.25	0	0.25	0.1	0.1	
059-373											
RMSE	37%	84%	23%	69%	94%	39%	118%	48%	55%	39%	46%
Volume	65%	46%	80%	151%	149%	119%	107%	136%	142%	77%	105%
Peak	73%	38%	91%	108%	178%	127%	82%	101%	183%	55%	101%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

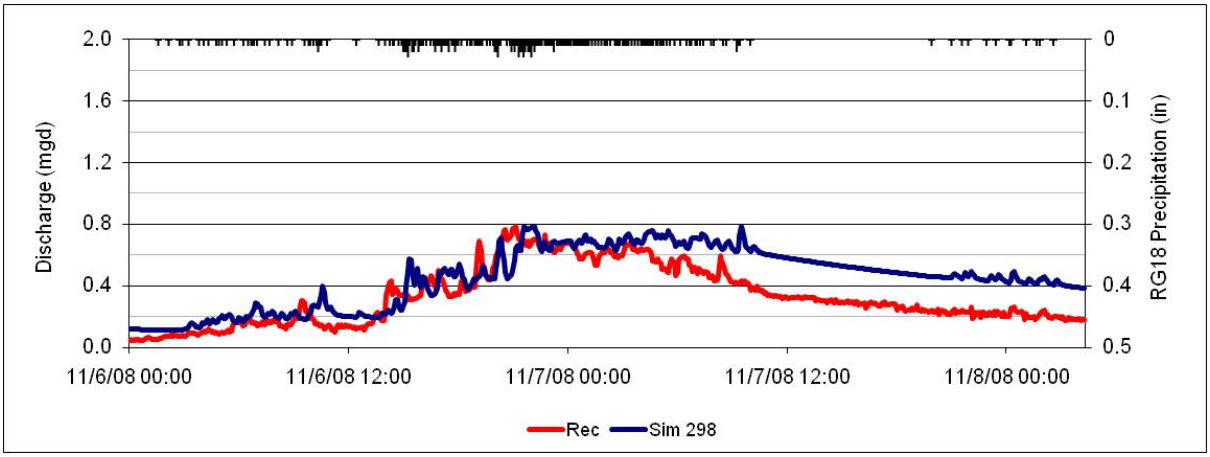


FIGURE 5-18: 059-373 EVENT 8 (CLOSE MATCH)

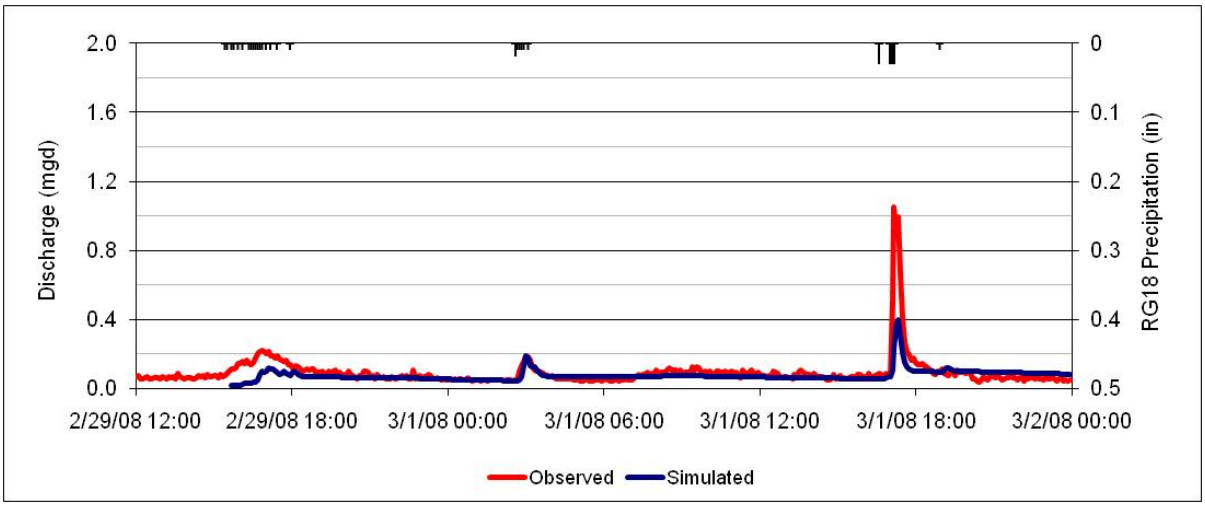


FIGURE 5-19: 059-373 EVENT 2 (AVERAGE MATCH)

TABLE 5-21
Global Goodness-of-Fit for Upper Calibration Group 38, 059-121

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
12	**540_06012009-19**	**52%**	**99%**	**27%**	**96%**
16	R1_06022009-11	65%	99%	39%	98%
55	R2_06042009-10	51%	103%	23%	96%
90	540_05212009-07	44%	96%	19%	99%
494	R1_06042009-374	63%	118%	26%	147%

TABLE 5-22
Calibration Performance: Upper Calibration Group 38, 059-121

Model Run: 540_06012009-19											
Global Goodness-of-Fit for RMSE				52%							
Global Goodness-of-Fit for Volume				99%							
Standard Deviation of Volume				27%							
Global Goodness-of-Fit for Peak				96%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.05	0.05	0.05	-	0.2	0.2	0.1	0.1	0.2	0.05	
059-121											
RMSE	38%	92%	37%	-	63%	37%	68%	64%	46%	32%	52%
Volume	68%	48%	78%	-	103%	94%	57%	140%	128%	97%	99%
Peak	55%	21%	52%	-	139%	78%	50%	82%	145%	68%	96%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

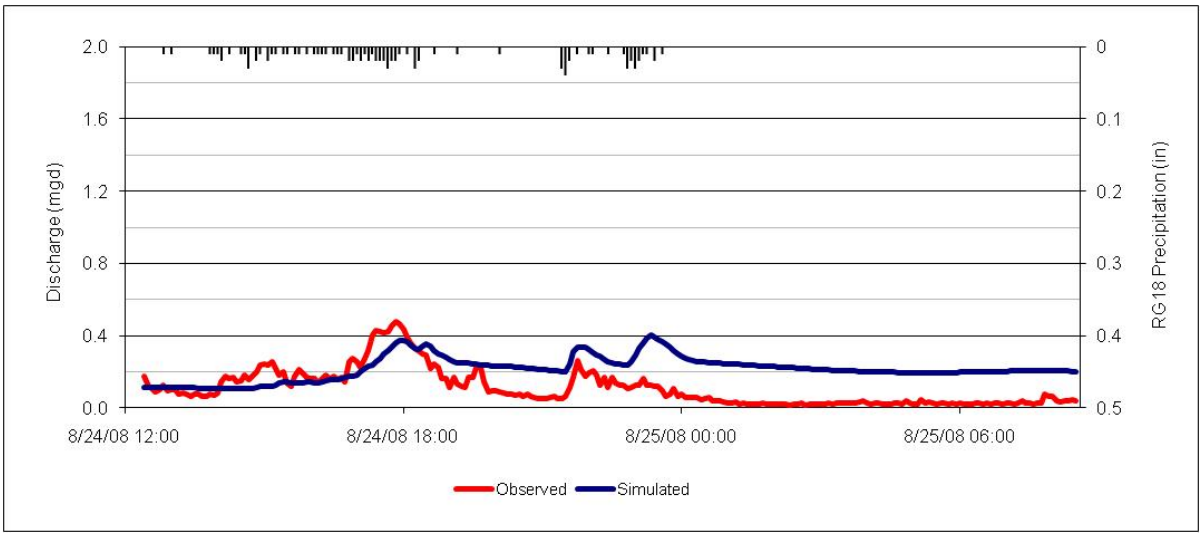


FIGURE 5-20: 059-121 EVENT 6 (CLOSE MATCH)

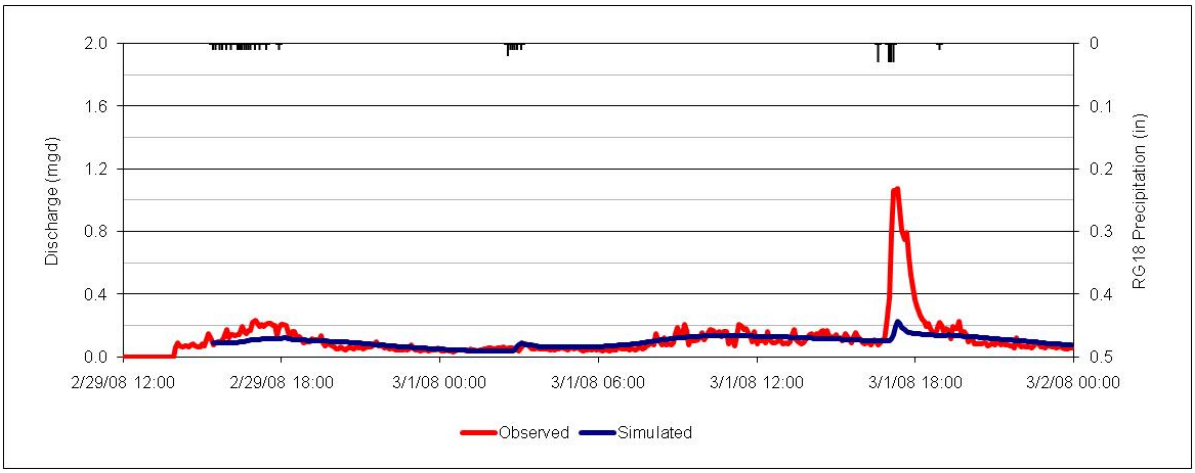


FIGURE 5-21: 059-121 EVENT 2 (AVERAGE MATCH)

Middle Calibration Group Overflow Structure 41A

Middle Calibration Group Overflow Structure 41A is the smallest calibration group within the Genesee Area with only 3 acres in tributary area, and because of its size, it does not contribute much flow and is a difficult area for calibration. Due to very low flows, the only potential calibration point within this basin (permanent monitoring site at 059-434) was not used for automated calibration. However, when selecting parameter sets, the team screened this site to ensure that the preferred parameter sets did not cause excessive overflows.

Middle Calibration Group Overflow Structure 41B

The portion of Basin 41 associated with Middle Calibration Group Overflow Structure 41B is uncontrolled. Because Basin 41 is the lowest basin in the Genesee Area, it is always the first to overflow during major storm events. As with Middle Calibration Group Overflow Structure 41A, 41B has only one potential calibration point at the permanent monitoring site 059-406. Unfortunately, this site has a questionable flow and depth characteristic during CSO events because a crushed overflow pipe caused a submerged weir condition. The team decided to model this outfall as a free outfall because its repair is planned for the fall of

2010. With these factors in mind, the team decided not to use magnitude of depth and flow at this site to select the best goodness-of-fit parameter set. The preferred parameter sets were instead selected on the basis that simulated overflows were consistent with the occurrence of overflows in the meter data.

Middle Calibration Group 38

Middle Calibration Group 38 is composed of two hydrologic sites: 060W-012 and 059-404. These sites were included in a middle calibration group in order that hydrologic parameters in upstream areas would be locked-in prior to the calibration of this intermediate area. The team had higher confidence in both these sites, along with the permanent depth meter at Basin 42, and thus included these sites in the goodness-of-fit parameter selection for this calibration group. See Tables 5-23 and 5-24 for Middle Calibration Group 42, 41, 38 calibration results. Figure 5-22 shows a hydrograph of the closest match to the monitored data, and Figure 5-23 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

Middle Calibration Group 38 also included the calibration point 059-451, which measures flows over the horseshoe weir. Depth is overpredicted at this site, resulting from the 5 percent of depth added by InfoWorks. The added depth is equivalent to 3.6 inches when wet weather flow ranges from 5 to 10 inches. The site just upstream, 059-498, was not suitable for automated calibration because of adverse HydroBrake effects. Because of the added depth and the influence of the upstream HydroBrake on flow data at 059-451 and after reviewing possible goodness-of-fit parameter sets, the team elected to use the parameter set that was used in the large upper calibration group. See Tables 5-25 and 5-26 for Middle Calibration Group 38, 059-451 calibration results. Figure 5-24 shows a hydrograph of the closest match to the monitored data, and Figure 5-25 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

TABLE 5-23
Global Goodness-of-Fit for Middle Calibration Group 42, 41, 38

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
8	**R1_08142009-92**	**25%**	**100%**	**21%**	**103%**
140	R1_08142009-55	39%	96%	23%	97%
173	742_08142009-16	28%	95%	24%	107%
120	R1_08142009-60	27%	102%	22%	105%
146	742_08142009-42	27%	96%	25%	102%

TABLE 5-24
Calibration Performance: Middle Calibration Group 42, 41, 38

Model Run: R1_08142009-92											
Global Goodness-of-Fit for RMSE				25%							
Global Goodness-of-Fit for Volume				100%							
Standard Deviation of Volume				21%							
Global Goodness-of-Fit for Peak				103%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0	0	0	0	0	0.4	0	0.4	0	0.2	
NPDES 42 060W-052 Depth											
RMSE	81%	141%	101%	18%	37%	56%	64%	37%	72%	58%	49%
Volume	39%	54%	33%	110%	94%	55%	66%	97%	57%	49%	71%
Peak	34%	13%	31%	119%	122%	55%	61%	101%	112%	88%	80%
060W-012 Flow											
RMSE	37%	45%	28%	63%	59%	19%	43%	15%	49%	26%	19%
Volume	71%	67%	76%	161%	130%	113%	130%	106%	111%	81%	104%
Peak	91%	67%	94%	173%	166%	104%	118%	114%	175%	97%	107%
059-404 Flow											
RMSE	30%	40%	31%	64%	49%	14%	44%	28%	54%	19%	21%
Volume	74%	66%	74%	160%	132%	112%	141%	125%	124%	88%	112%
Peak	92%	71%	87%	156%	163%	108%	139%	119%	197%	104%	112%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

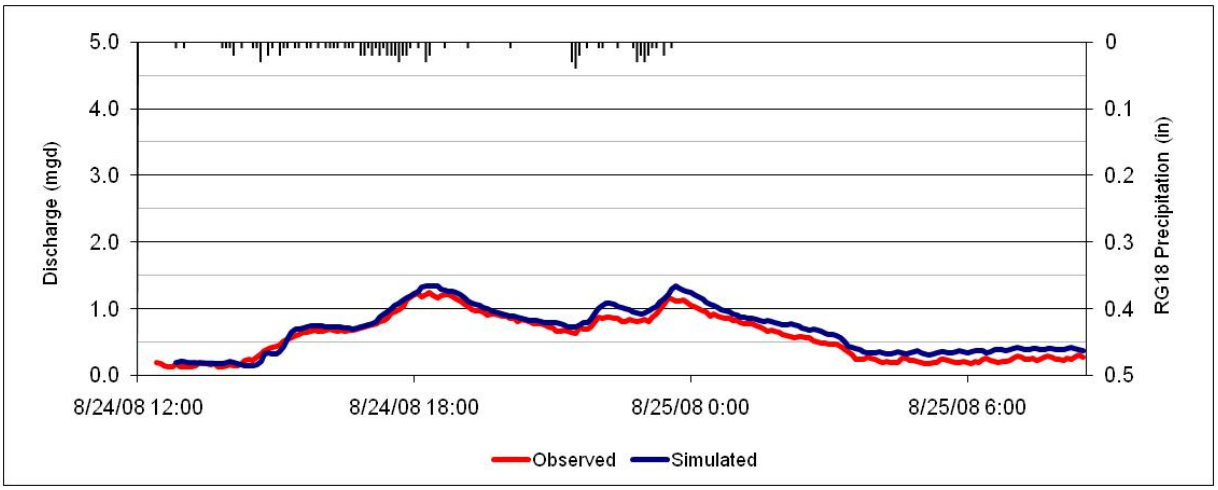


FIGURE 5-22: 059-404 EVENT 6 (CLOSE MATCH)

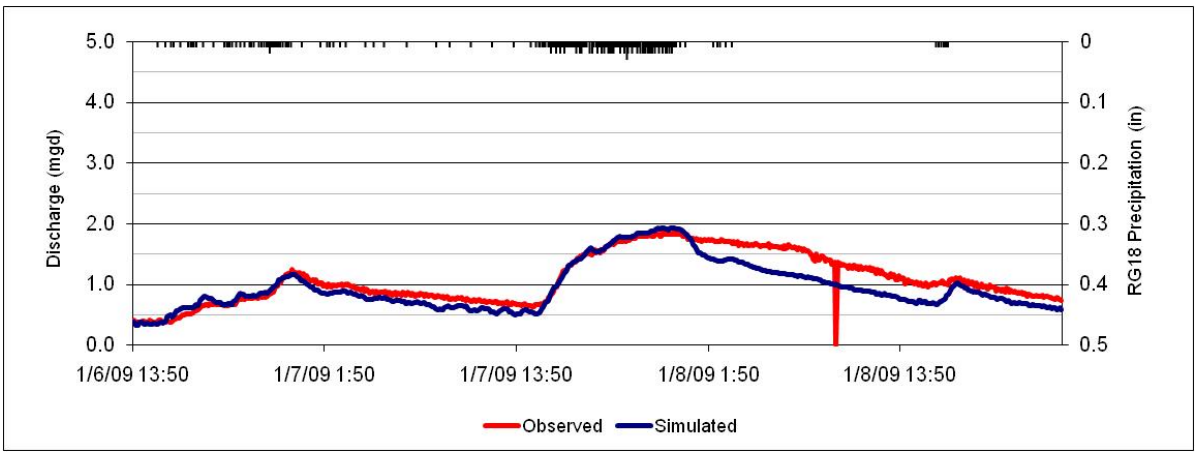


FIGURE 5-23: 059-404 EVENT 10 (AVERAGE MATCH)

TABLE 5-25
Global Goodness-of-Fit for Middle Calibration Group 38, 059-451

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
1	R1_08142009-237	50%	100%	43%	72%
2	R2_08142009_128	49%	100%	43%	72%
3	R1_08172009-30	50%	100%	43%	72%
579	R2_08142009-209	49%	104%	42%	78%
646	**R2_06022009-54**	**50%**	**105%**	**43%**	**74%**

TABLE 5-26
Calibration Performance: Middle Calibration Group 38, 059-451

Model Run: R2_06022009-54											
Global Goodness-of-Fit for RMSE				49%							
Global Goodness-of-Fit for Volume				105%							
Standard Deviation of Volume				43%							
Global Goodness-of-Fit for Peak				74%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.05	0.05	0.1	0	0.1	0.25	0	0.1	0.1	0.25	
059-451 Q											
RMSE	93%	50%	45%	56%	63%	24%	32%	57%	37%	26%	40%
Volume	66%	69%	72%	150%	99%	94%	120%	66%	111%	83%	86%
Peak	16%	55%	55%	130%	55%	77%	109%	41%	99%	73%	66%
059-451 D											
RMSE	108%	131%	81%	198%	123%	114%	244%	53%	78%	27%	81%
Volume	198%	222%	175%	297%	217%	208%	324%	146%	174%	93%	167%
Peak	56%	104%	119%	224%	111%	98%	205%	102%	146%	74%	99%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

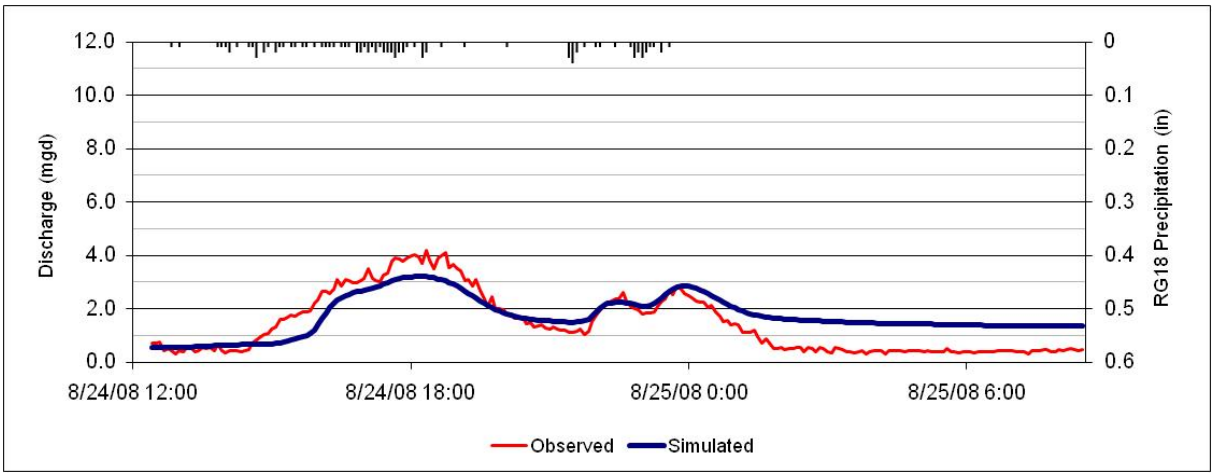


FIGURE 5-24: 059-451 Q EVENT 6 (CLOSE MATCH)

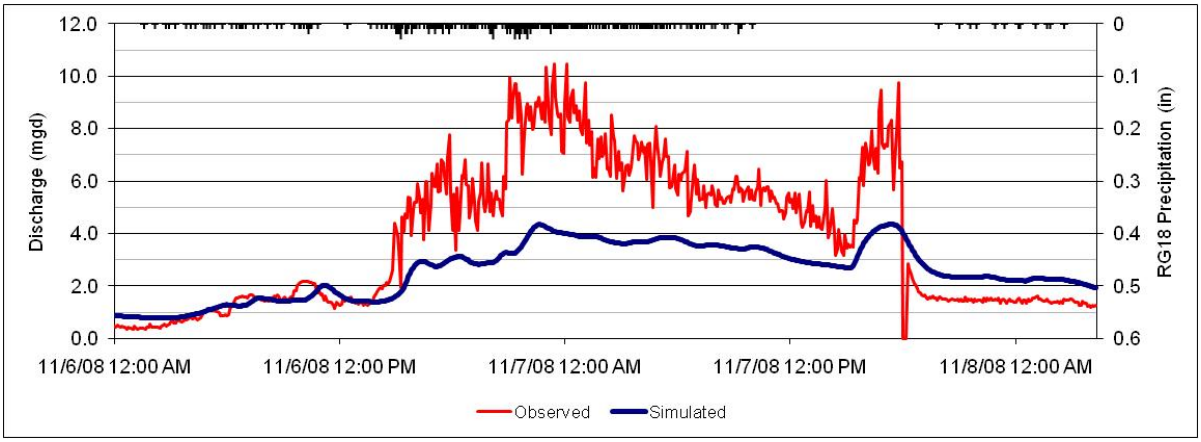


FIGURE 5-25: 059-451 Q EVENT 8 (AVERAGE MATCH)

5.8.3 Lower Calibration Group and Model Outfall

With the middle calibration group parameters locked-in to the InfoWorks model, another 500 automated calibration simulations were completed to analyze the lower calibration group. The lower calibration group is composed of two overflow-monitoring locations, 059-398 and the King County monitoring site, 059-443. Because they only measure overflows, the monitoring sites at 059-346 and 059-451 NPDES 38 were not used for automated calibration. Note that the parameter sets for 059-398 and 059-443 did not have a significant impact on the hydrographs because of the relatively small contribution from the two monitoring locations (approximately 49 acres tributary area) compared to the upper and middle calibration groups' flow contribution.

The calibration point 059-443 is significant in that it represents the monitoring site farthest downstream in the Genesee CSO model. Flows from this site enter the King County Rainier Avenue Pump Station and are conveyed to the King County system. Hydrographs at this site represent performance from most of the model. However, because flow-monitoring catchment 059-443 had a relatively small net tributary area, and because the meter was not maintained by the project team, this calibration point was not heavily weighted.

The monitoring equipment was malfunctioning during Event 1 at 059-443 and Event 3 at 059-398; thus data for these events were not used for calibration. Flashy events in the late

spring and summer did not calibrate well and thus were given lower weightings. The calibrated model most closely matched the peak and the volume of the monitored flows for storm events. Event weightings were distributed in accordance with this comparison between monitor and model data.

Each of the parameter sets considered for final selection had negligible effect. A parameter set was selected and incorporated into the model, thus concluding the calibration of the Genesee model. See Tables 5-27 and 5-28 for Lower Calibration Group 38 calibration results. Figure 5-26 shows a hydrograph of the closest match to the monitored data, and Figure 5-27 shows a hydrograph of one of the average match calibration hydrographs for the selected parameter set. See Appendix F for additional calibration results.

TABLE 5-27
Global Goodness-of-Fit for Lower Calibration Group 38

Rank	Model Run	Global Goodness-of-Fit for RMSE	Global Goodness-of-Fit for Volume	Standard Deviation of Volume	Global Goodness-of-Fit for Peak
8	**R1_08242009-184**	**33%**	**104%**	**20%**	**94%**
73	R2_08242009_2-272	33%	105%	20%	94%
59	R1_08242009-29	33%	105%	21%	96%
56	R2_08242009_2-51	33%	105%	21%	97%
77	R2_08242009_2-07	36%	105%	21%	97%

Global goodness-of-fit statistics for the parameter sets and selected parameter set values for all the automated calibration groups are presented in Tables 5-29 and 5-30. Calibration hydrographs are included in Appendix F.

TABLE 5-28
Calibration Performance: Lower Calibration Group 38

Model Run: R1_08242009-184											
Global Goodness-of-Fit for RMSE				4%							
Global Goodness-of-Fit for Volume				104%							
Standard Deviation of Volume				20%							
Global Goodness-of-Fit for Peak				94%							
Event Date	1/8/ 2008	2/29/ 2008	3/28/ 2008	5/21/ 2008	6/6/ 2008	8/24/ 2008	10/13/ 2008	11/5/ 2008	12/24/ 2008	1/6/ 2009	Event Weighted
Event Number	1	2	3	4	5	6	7	8	9	10	
Event Weight	0.05	0.1	0.1	0	0	0.3	0	0.3	0.05	0.1	
059-443 KC											
RMSE	-	63%	36%	76%	54%	43%	74%	28%	36%	32%	38%
Volume	-	91%	70%	168%	114%	117%	121%	120%	104%	73%	105%
Peak	-	56%	68%	159%	120%	100%	113%	98%	119%	71%	89%
059-398											
RMSE	24%	40%	-	34%	74%	28%	65%	23%	52%	24%	28%
Volume	82%	78%	-	118%	143%	125%	155%	115%	122%	82%	109%
Peak	86%	75%	-	105%	138%	121%	139%	91%	158%	88%	102%

Notes:
Events/meters shaded grey had zero weighting due to modeler's judgment.
Dash (-) indicates no data recorded at indicated meter for indicated event.

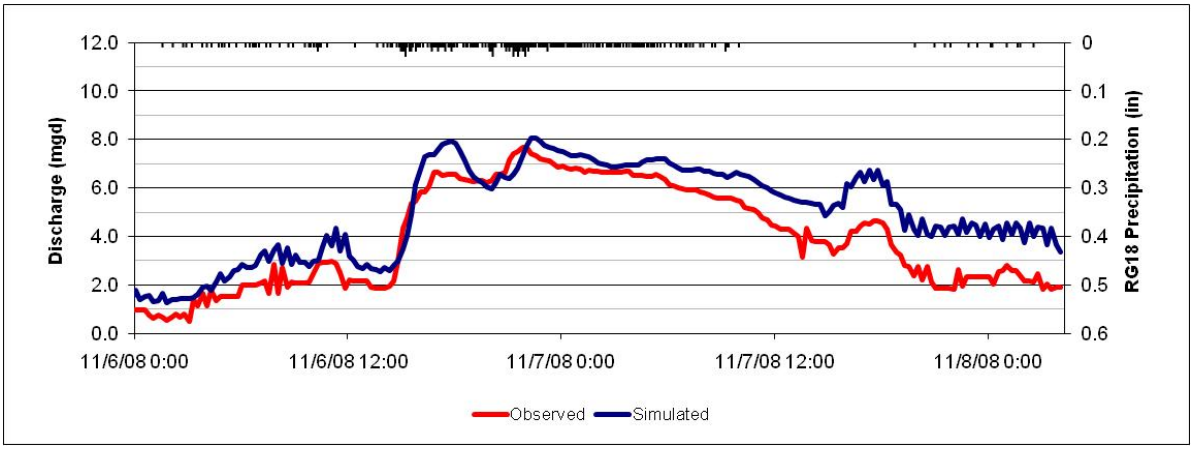


FIGURE 5-26: 059-443 EVENT 8 (CLOSE MATCH)

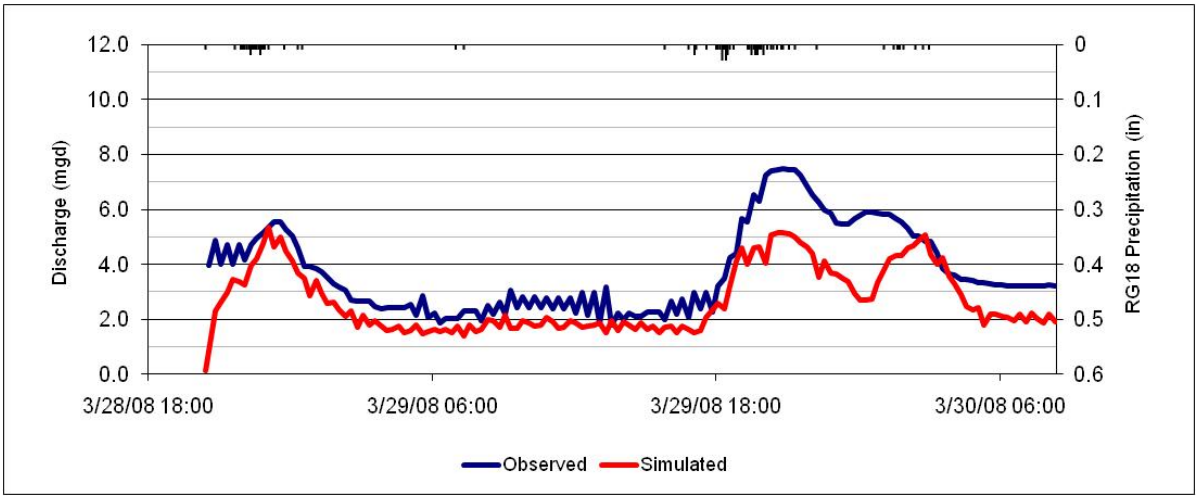


FIGURE 5-27: 059-443 EVENT 3 (AVERAGE MATCH)

5.9 Conclusions

The automated calibration process described above has resulted in 10 different final parameter sets, one for each of the 10 calibration groups. The difficulties encountered in calibrating these particular calibration groups are discussed in Section 5.7. The calibration process resulted in 7 of the 10 calibration groups meeting the calibration criteria as stated in Section 5.3 (20 percent above/15 percent below for volume and peak flow, etc.). Three of the calibration groups did not meet the calibration criteria: upper calibration groups 37 and 165, and Middle Calibration Group 38 (see Tables 5-30 and 5-31). It is important to note that the calibration groups not meeting the target criteria are located in controlled basins.

The model was developed and calibrated based on the best available data, including surveys of critical structures, 18 months of flow monitoring, and SPU's comprehensive GIS. The fact that three of the calibration groups did not meet the calibration criteria established for the project indicates the difficulty in modeling complex combined sewer systems. The model was developed to quantify CSOs, characterize the hydraulic performance within the system, and support alternative development to control to the once-per-year CSO standard.

The calibrated Genesee model meets these project objectives; however, there are qualifiers or limitations to its use as follows:

- Greater confidence is placed on the frequency of simulated CSOs than on the volume. This conclusion is similar to the analysis of CSO monitoring site data.
- Simulated flows and depths within monitoring catchments are generally sufficient for hydraulic analysis and alternative development for storms used to establish the control volume.
- HydroBrakes were difficult to calibrate due to inconsistent responses. The model is sufficient to assess the feasibility of alternatives incorporating real-time control to regulate flow in the system, including the placement or removal of HydroBrakes.

The Genesee model is calibrated to the best available data and is of sufficient quality to meet the project objectives. The calibrated model can be found in Appendix G. Uncertainties associated with simulating a complex combined sewer system were incorporated as described in Chapter 7.

TABLE 5-29
Selected Parameter Values

		Automated Calibration Group		Upper Calibration Group 165	Upper Calibration Group 43	Upper Calibration Group 40	Upper Calibration Group 38	Upper Calibration Group 38, 059-373	Upper Calibration Group 38, 059-121	Upper Calibration Group 38, 059-451	Upper Calibration Group 37	Middle Calibration Group 42, 38, 41A, 41B	Lower Calibration Group 38
		Monitoring Site		NPDES165 067-078	067-029 RC, 067-014 RC, 067-024 RC, NPDES43 060W-049, 060W-047, 060W-019	059-436, 059-409, 059-490MP1, NPDES40 059-491	059-131, 059-320, 059-332, 059-371	059-373	059-121	059-451	NPDES 37 059-489	NPDES 42 060W-052, 060W-014, 060W-012, 059-404, NPDES 41A 059-434, NPDES 41B 059-406	059-443 KC, 059-398
		InfoWorks Runoff Surface IDs		19	13, 23, 24, 25, 26	10, 11, 12, 15	2, 3, 4, 5	6	1	22	14	8,9, 16,17, 18	7,20,21
		Selected Parameter Set Simulation ID		R1_06042009_378	R1_06042009_384	R1_06022009_65	R2_06022009_54	R1_06042009_298	540_06012009_19	R2_06022009_54	540_05142009_5	R1_08142009_92	R1_08212009_184
Automated Calibration Model Parameter Name and Units		**Parameter Sampling Range**											
		Min	**Max**										
Runoff Routing (Impervious)	-	0.0100	0.0300	0.0296	0.0183	0.0209	0.0287	0.0247	0.0107	0.0287	0.0129	0.0238	0.0154
Runoff Routing (Pervious)		0.100	0.600	0.334	0.393	0.588	0.170	0.424	0.205	0.170	0.123	0.526	0.488
Initial Loss (Impervious)	foot or feet (ft)	0.000525	0.002329	0.000673	0.001537	0.000587	0.002199	0.002252	0.001906	0.002199	0.001057	0.001554	0.001606
Initial Loss (Pervious)	ft	0.00207	0.00919	0.00454	0.00868	0.00435	0.00240	0.00851	0.00484	0.00240	0.00289	0.00280	0.00914
Fixed Runoff Coefficient	-	0.100	1.000	0.909	0.755	0.771	0.335	0.345	0.346	0.335	0.185	0.208	0.193
Green and Ampt Conductivity	inches per hour (in/hr)	0.020	2.710	2.110	2.453	1.517	2.690	0.311	0.670	2.690	1.701	1.684	2.671
Soil Depth	ft	0.00	10.00	2.08	9.38	1.55	4.86	1.02	1.27	4.86	6.85	3.28	2.93
Percolation Coefficient	-	0.100	10.000	3.336	3.658	2.134	0.927	1.331	0.679	0.927	9.752	0.748	2.396
Baseflow Coefficient	-	0.100	10.000	9.561	2.433	0.847	6.550	4.252	7.579	6.54985	1.5355	4.233	8.930
Infiltration Coefficient	-	0.100	8.500	0.683	7.791	3.750	6.984	2.940	7.614	6.984	8.374	6.429	2.919
Percolation Threshold	-	0.000	60.000	12.938	55.313	21.510	4.230	23.962	48.930	4.230	40.500	56.910	10.913
Percolation Percentage Infiltrating	-	0.000	60.000	51.638	24.712	43.230	26.010	53.063	56.670	26.010	10.500	46.590	0.412
Soil Porosity	-	1.000	40.000	11.262	8.824	5.582	7.025	38.952	6.831	7.025	11.335	4.023	21.646
Ground Porosity	-	1.000	40.000	39.732	30.177	39.513	3.009	35.052	6.948	3.009	35.515	32.220	14.528
Baseflow Threshold	ft	0.00	7.00	4.65	0.97	-2.44	4.96	-3.12	1.98	4.96	3.46	0.72	3.30
Infiltration Threshold	ft	0.00	20.00	19.21	13.86	2.77	0.79	12.86	4.45	0.79	2.70	10.79	14.84

TABLE 5-30
Global Goodness-of-Fit Statistics for Selected Parameter Sets

Automated Calibration Group	Upper Calibration Group 165	Upper Calibration Group 43	Upper Calibration Group 40	Upper Calibration Group 38	Upper Calibration Group 38, 059-373	Upper Calibration Group 38, 059-121	Upper Calibration Group 37	Middle Calibration Group 42, 41, 38	Middle Calibration Group 38, 059-451	Lower Calibration Group 38
Flow-monitoring Catchments	NPDES165 067-078	067-029 RC, 067-014 RC, 067-024 RC, NPDES43 060W-049, 060W-047, 060W-019	059-436, 059-409, 059-490MP1, NPDES40 059-491	059-131, 059-320, 059-332, 059-371	059-373	059-121	NPDES 37 059-489	NPDES 42 060W-052, 060W-014, 060W-012, 059-404, NPDES 41A 059-434, NPDES 41B 059-406	059-451	059-443 KC, 059-398
InfoWorks Runoff Surface IDs	19	13, 23, 24, 25, 26	10, 11, 12, 15	2, 3, 4, 5	6	1	14	8,9, 16,17, 18	22	7,20,21
Selected Parameter Set Simulation ID	R1_06042009_378	R1_06042009_384	R1_06022009_65	R2_06022009_54	R1_06042009_298	540_06012009_19	540_05142009_5	R1_08142009_92	R2_06022009_54	R1_08212009_184
Global Goodness-of-Fit for RMSE	71%	86%	48%	37%	46%	52%	94%	25%	50%	33%
Global Goodness-of-Fit for Volume	98%	100%	102%	97%	105%	99%	53%	100%	105%	104%
Standard Deviation of Volume	45%	48%	24%	16%	33%	27%	29%	21%	43%	20%
Global Goodness-of-Fit for Peak	129%	102%	102%	101%	101%	96%	155%	103%	74%	94%

Note: Statistics shaded grey do not meet the Target Calibration Criteria stated in Section 5.3.

TABLE 5-31
Compliance with Calibration Criteria

Calibration Group and Calibration Points	Goodness-of-Fit Volume	Goodness-of-Fit Peak
Upper Calibration Group 165: Global Goodness-of-Fit	98%	129%
NPDES165 067-078 Q	99%	125%
NPDES165 067-078 D	95%	133%
Upper Calibration Group 43: Global Goodness-of-Fit	100%	102%
067-029 RC	56%	117%
NPDES43 060W-049 Q	62%	81%
060W-019	84%	36%
NPDES43 060W-049 D	127%	110%
Upper Calibration Group 40: Global Goodness-of-Fit	102%	102%
059-436	88%	102%
059-409	117%	133%
Upper Calibration Group 38: Global Goodness-of-Fit	97%	101%
059-131	96%	102%
059-320	98%	102%
059-332	92%	98%
059-371	94%	105%
Upper Calibration Group 38, 059-737: Global Goodness-of-Fit	105%	101%
059-373	105%	101%
Upper Calibration Group 38, 059-121: Global Goodness-of-Fit	99%	96%
059-121	99%	96%
Upper Calibration Group 37: Global Goodness-of-Fit	69%	79%
059-489 Q	58%	80%
059-489 D	69%	66%
Middle Calibration Group 42, 41, 38: Global Goodness-of-Fit	100%	103%
NPDES 42 060W-052 Depth	71%	80%
060W-012 Flow	104%	107%
059-404 Flow	112%	112%
Middle Calibration Group 38, 059-451: Global Goodness-of-Fit	105%	74%
059-451 Q	86%	66%
059-451 D	167%	99%
Lower Calibration Group 38: Global Goodness-of-Fit	104%	94%
059-443 KC	105%	89%
059-398	109%	102%

Note: Statistics shaded grey do not meet the target calibration criteria stated in Section 5.3.

6.0 Existing System Performance

Long-term results from the calibrated model were used to evaluate the existing performance of the Genesee combined sewer system. The unadjusted long-term rainfall record (31 years, 1978 to 2008) was used to evaluate existing conditions. The evaluation characterized the frequency, volume, and duration of combined sewer overflows (CSOs), and assessed the performance of CSO control facilities and pump stations. The evaluation also identified capacity limitations in critical pipe links and surface flooding at maintenance holes (MHs). The intent of the analysis was to provide a basic understanding of the performance of the combined sewer system in meeting the project objective of characterizing existing system performance.

6.1 Characteristics of Combined Sewer Overflows

Table 6-1 summarizes overflow statistics for the National Pollutant Discharge Elimination System (NPDES) CSO outfalls. An overflow event threshold of 5,000 gallons was used to define an overflow event; thus, modeled overflows less than 5,000 gallons are not included in this report. The InfoWorks model predicted overflows at all the Genesee basins except Basin 37. The largest number and greatest volume of overflows were predicted for NPDES CSO Outfall 41.

TABLE 6-1
Summary Overflow Statistics for NPDES CSO Outfalls: Long-Term Simulation 1978-2009

NPDES CSO Outfall	Number of Overflows	Average Annual Number of Overflows	Total Overflow Volume (MG)	Total Duration of Overflows (hours)
37	0	0.0	0.0	0
38	15	0.5	7.9	196
40	143	4.6	17.9	1,932
41	186	6.0	20.1	3,005
42	17	0.5	1.6	220
43	176	5.7	17.1	1,264
165	29	0.9	0.3	118
Total	**566**	**18.3**	**64.9**	**6,734**

The 5,000-gallon threshold was chosen by the project team in order to direct attention away from smaller, potentially spurious events that may be outside the accuracy of the model, and instead direct attention toward the larger events to which the model was calibrated. Other CSO study areas have used a threshold of 10,000 gallons. This threshold was reduced for the Genesee Area because in general this area experiences smaller flows than other CSO study areas.

Figure 6-1 displays the duration and volume of each CSO event predicted by the model at each active CSO outfall. Because overflows with volumes above 5,000 gallons were not observed at NPDES CSO Outfall 37, Figure 6-1 and subsequent figures do not include this outfall. As expected, Figure 6-1 shows an increase in overflow volume with increases in overflow duration. The overall density of the scatter indicates the general frequency of overflows at a given location. The spread along the x-axis indicates the variability in the duration of overflow events. Note that the inter-event time between overflow events is 24 hours, and the listed overflow duration is the total time from start of overflow to end of overflow. Because of this, some of the longer durations shown in Figure 6-1 may only have flow over the weir for a portion of the listed duration. For this reason, the longer duration overflow events have wider scatter in the total overflow volume. The spread along the y-axis indicates the variability in the volume of overflow events. The relation between overflow volume and overflow duration is flattest for Basin 165, where the volume does not increase significantly with duration. The unique trend at Basin 165 may be due to multiple factors, including that the basin is extremely small, is not affected by the lake line hydraulics in the same way as basins 40 through 43, and is controlled entirely by Pump Station 6. It may also be that the longer duration overflows at this outfall rarely have flow over the weir for the entire overflow duration, but are instead short periods of flow over the weir interspersed by longer periods less than 24 hours of no flow over the weir.

Figure 6-2 shows the number of annual overflow volumes for each of the CSO outfalls predicted by the model over the simulation period. Of the 31 years included in the simulation, 2007 had the largest combined overflow volume; 1981 had the second largest. Basins 40, 41, and 43 have the highest number of overflows (505 overflows, or 89 percent of all the overflows in the long-term simulation) and the greatest overall volume (85 percent of the total overflow volume). Although Basin 38 has infrequent overflows and a smaller cumulative overflow volume than basins 40, 41, and 43, Basin 38's few overflows have very large volumes.

Figure 6-3 illustrates the exceedance percentages for overflow volume and event duration for the NPDES CSO outfalls as predicted by the model. Exceedance is defined as the percentage of events equaling or exceeding a selected volume or duration. The values in this figure display the normalized volume and duration characteristics, allowing a relative comparison of the overflow events.

Figure 6-3 shows that Basin 38 has the largest overflow events with more than 50 percent greater than 100,000 gallons. Basin 165 has the smallest overflow events: 40 percent with overflows less than 10,000 gallons. Basins 40, 41, 42, and 43 have overflows approximately the same volume as basins 38 and 165.

Basins 38, 41, and 42 typically have longer overflow durations than the other three active basins (40, 43, and 165); more than 50 percent of the overflows from basins 38, 41, and 42 last longer than 10 hours. During the less frequent overflows (less than 20 percent of all overflows), the six active basins (38, 40, 41, 42, 43, and 165) have approximately equally long overflows. Basin 40 had the longest total overflow: 385 hours (16 days) in August 1992.

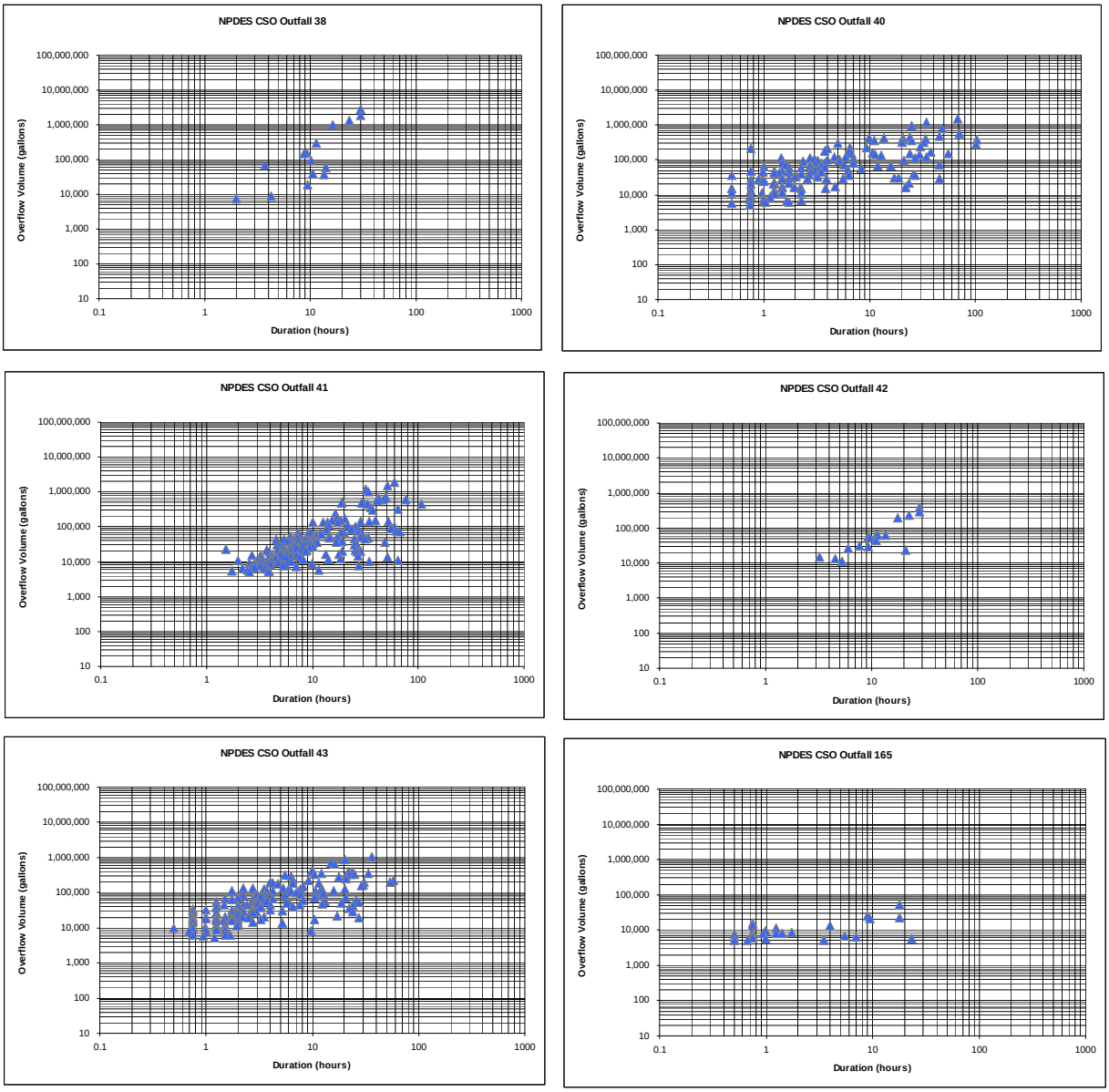


FIGURE 6-1. Volume and Duration Characteristics of Predicted Combined Sewer Overflows

6.2 Combined Sewer System Response to Rainfall

The performance of the combined sewer system's responses to precipitation was evaluated for each CSO basin. The combination of precipitation depth and duration that resulted in simulated overflows was reviewed. The rainfall record from the City's Rain Gage 18 was analyzed to identify precipitation events with the potential to cause overflows at the CSO outfalls. Significant precipitation events were defined as events with more than 0.3 inch of rainfall separated by an inter-event period of 6 hours. Overflow events for each of the CSO outfalls were also defined using an inter-event interval of 24 hours. Each of Figures 6-4 through 6-9 displays all the significant storm events measured at Rain Gage 18; the storm events that caused overflows at specific outfalls are highlighted. Basin 37 is not included in

these figures as overflows above 5,000 gallons were not recorded during the 31-year simulation. The threshold between overflow and non-overflow events is estimated based on the smallest storms at multiple durations that caused overflow events. Storm events above this threshold cause nearly all overflow events. Table 6-2 lists the smallest events in durations of 6, 12, and 24 hours that trigger overflows at each basin.

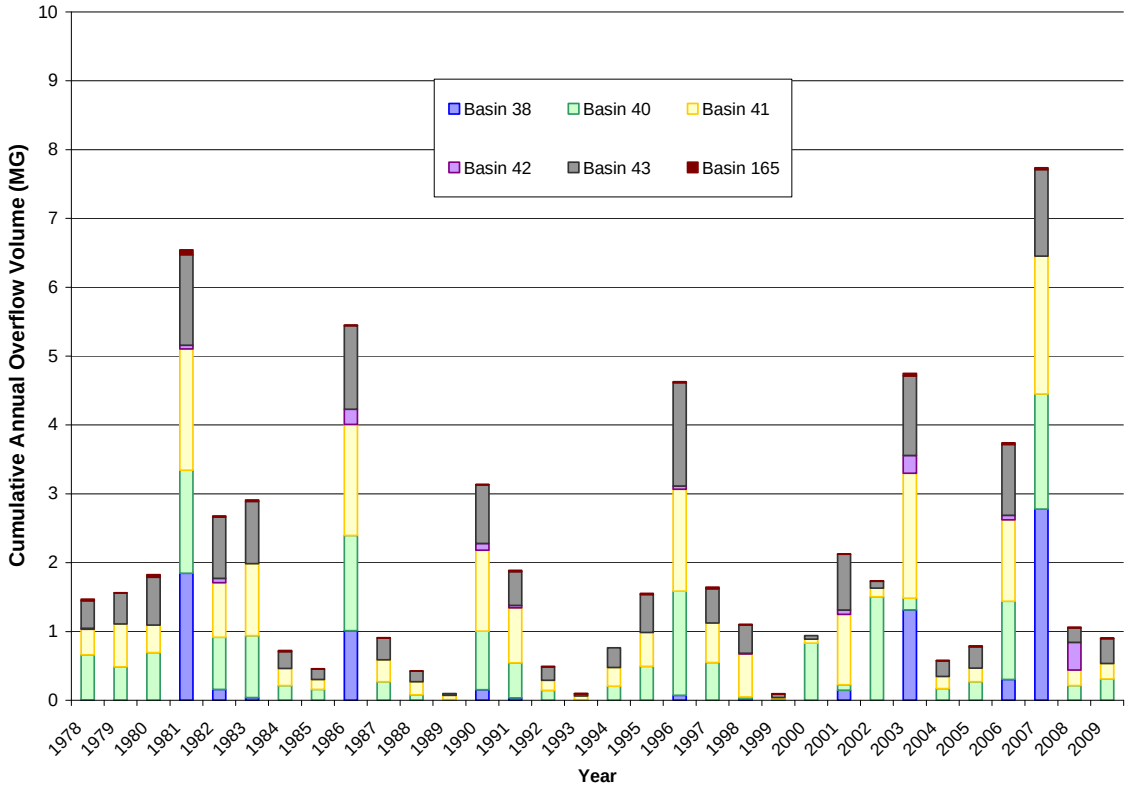
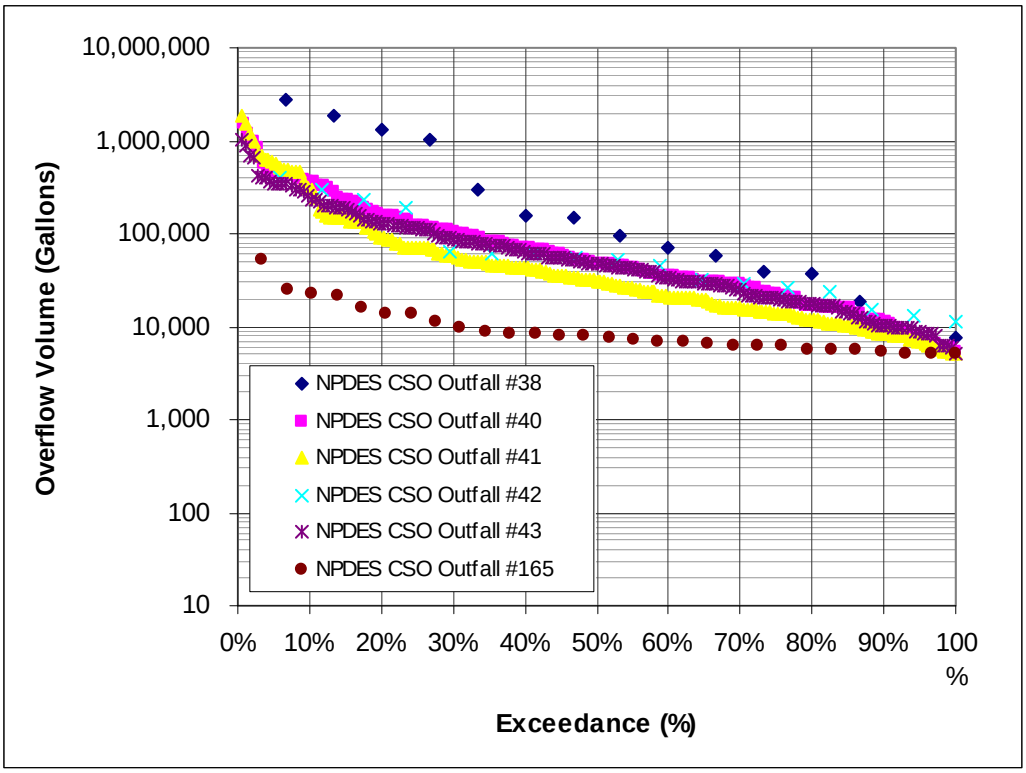


FIGURE 6-2. Annual Predicted Overflow Volumes for Basins

Basin 41 had the highest frequency of overflows, with 17 percent of the significant storm events causing overflows. Sixteen percent of the significant storm events caused overflows in Basin 43, 13 percent in Basin 40, and less than 3 percent in basins 165, 38, and 42. As expected, basins 41, 43, and 40 have the lowest threshold for rainfall causing overflow events. Although overflows at Basin 165 are less frequent than in basins 41, 43, and 40, the threshold for rainfall causing overflow events is just as low as for the three more active basins.

6.3 Performance of CSO Control Facilities

The performance of CSO control facilities was evaluated by correlating overflow events with CSO storage utilization. Storage utilization was defined as the ratio of peak event depth to maximum allowable storage depth ("usable storage depth") determined by the CSO overflow weir. Depending on the storage overflow configuration, the usable storage depth may be less than the total storage height. Figures 4-4 and 4-5 provide a description and diagram of usable storage depth in the four CSO control facilities in the Genesee Area. Usable storage utilization ratios in excess of 100 percent indicate surcharging above the storage control structure and full utilization of the available usable storage.



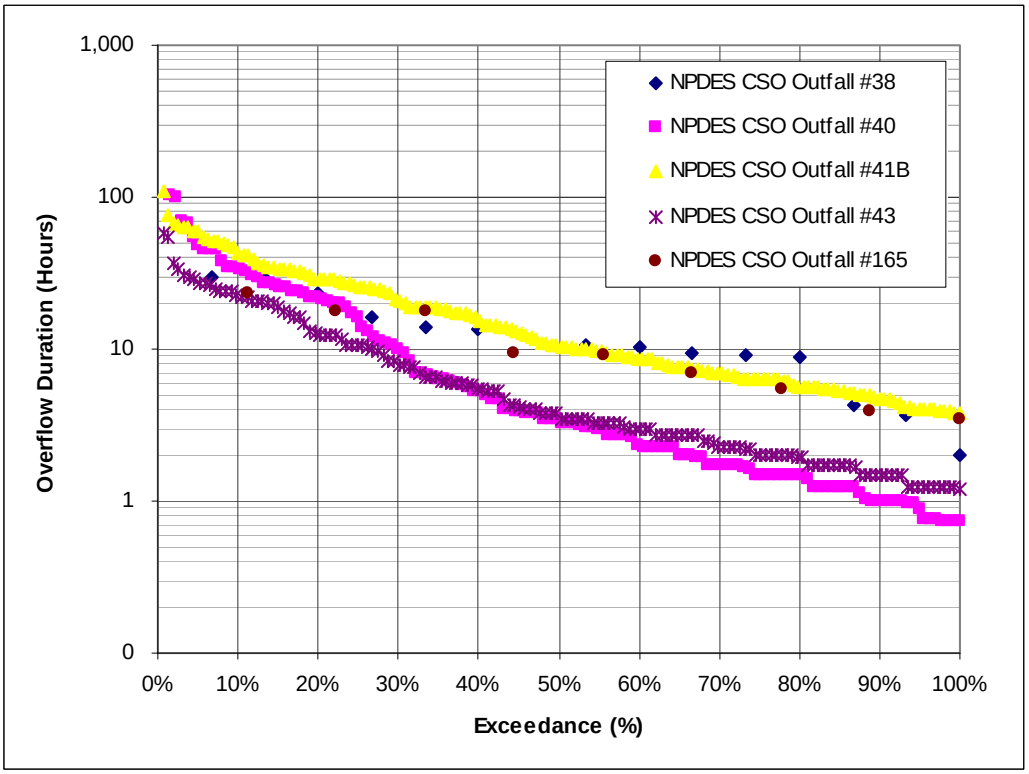


FIGURE 6-3. Predicted Overflow Volume and Duration Exceedance

TABLE 6-2
Rainfall Events Triggering Overflows (inches)

Event Duration	6-hour	12-hour	24-hour
NPDES CSO Outfall 37	-	-	-
NPDES CSO Outfall 38	1.6	1.8	2.1
NPDES CSO Outfall 40	0.5	0.6	0.9
NPDES CSO Outfall 41	0.4	0.5	0.8
NPDES CSO Outfall 42	1.7	1.8	2.1
NPDES CSO Outfall 43	0.4	0.5	0.7
NPDES CSO Outfall 165	0.4	0.5	0.8

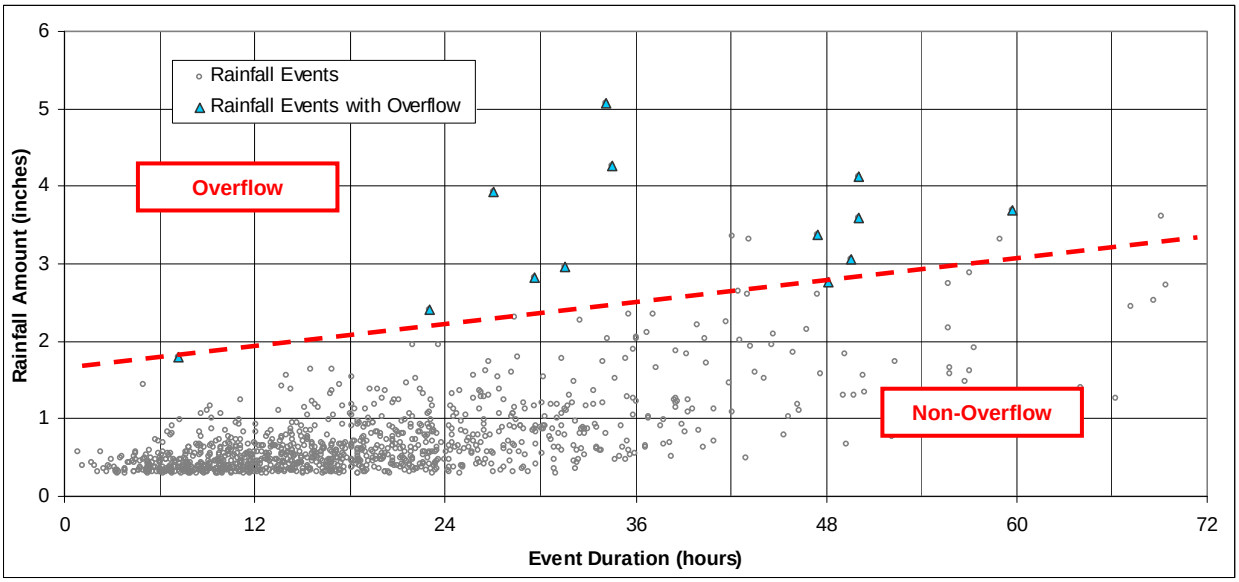


FIGURE 6-4. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 38

Figures 6-10 through 6-13 show overflow volumes and the corresponding usable storage utilization at each of the four CSO control facilities for the 31-year, long-term simulation. Of the basins with CSO control facilities, basins 43 and 40 have the highest frequency of overflows. Basins 38 and 42 both have an average of less than one overflow event per year over the 31-year record. All CSO control facilities have an usable storage depth near or above 100 percent, which is to be expected given the overflow conditions.

6.4 Performance of Pump Stations

Each of the three pumps in the Genesee CSO model shares an outfall with a specific basin. Overflows at these locations may be due to a variety of reasons, including the inability of the pump station to convey contributing flows from the basin. SPU's Pump Station 6 pumps flows from Basin 165 and shares that basin's outfall. SPU's Pump Station 5 pumps flows from a portion of Basin 38 and all of basins 40, 41, 42, 43, and 165. Overflows from Pump

Station 5 are released from the NPDES 38 CSO Outfall. King County's Rainier Avenue Pump Station pumps flows from the entire Genesee Area.

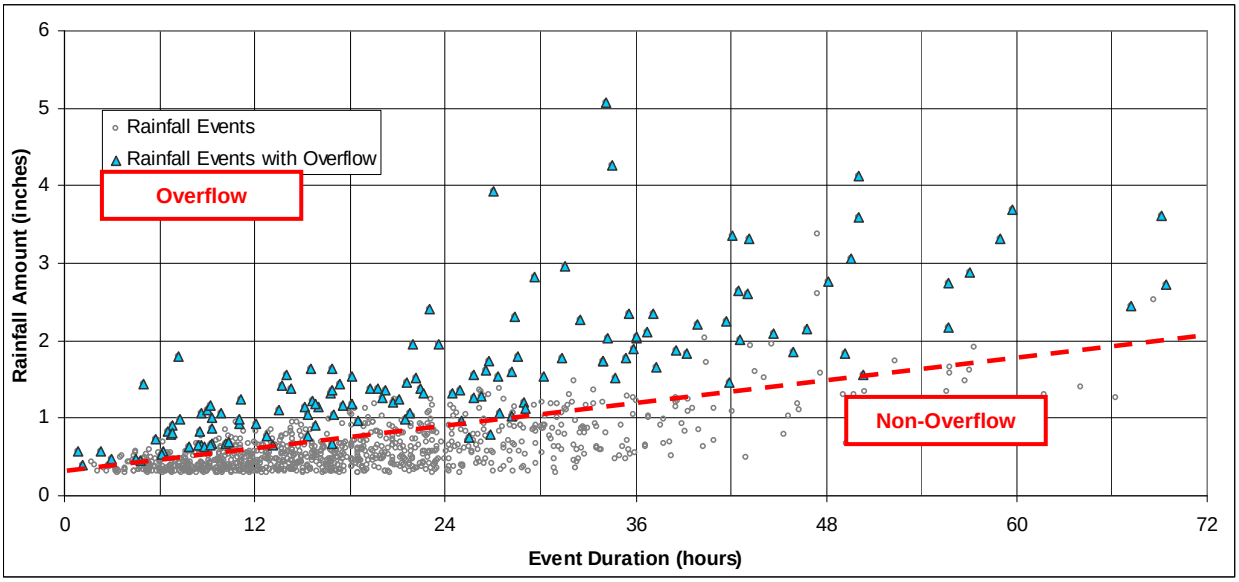


FIGURE 6-5. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 40

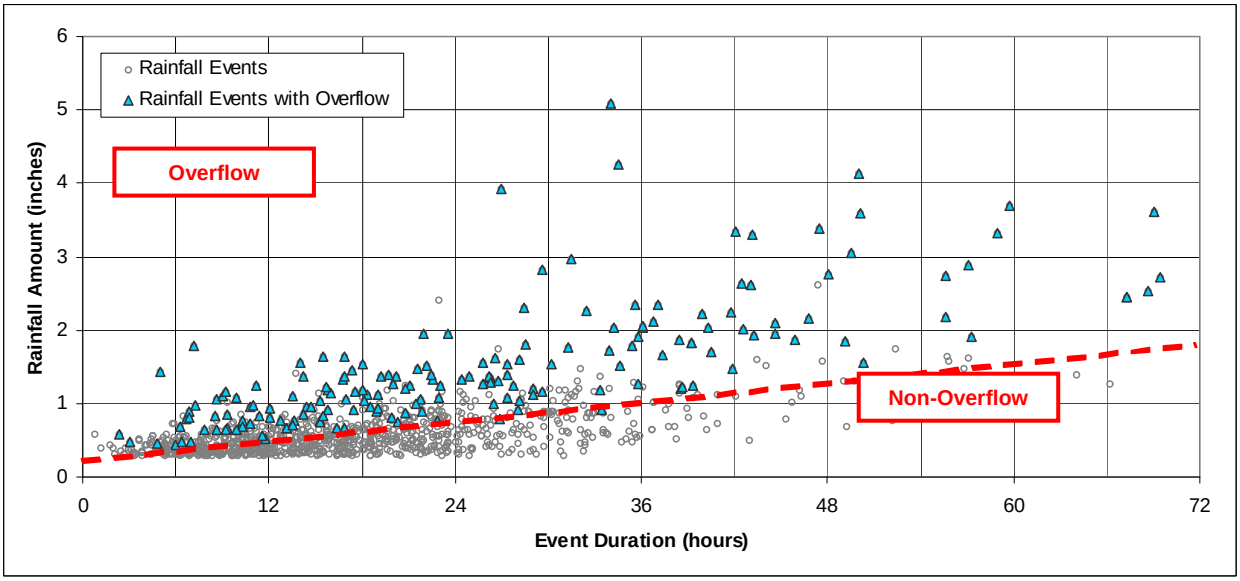


FIGURE 6-6. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 41

Figures 6-14 and 6-15 show the ranked overflow volumes from the two basins associated with pump station overflows, along with the maximum modeled pump rate during each overflow event. Figure 6-14 shows Pump Station 6 operating at a peak pump rate between 0.66 and 0.75 MGD during all overflow events at Basin 165. Figure 6-15 shows Pump Station 5 operating at a peak of 2.92 MGD during all overflows at Basin 38. Figure 6-16 shows the ranked cumulative Genesee Area system overflows compared to the Rainier Avenue Pump Station peak pumping rate. This peak rate is approximately constant at 9.1 MGD for the

largest 30 of the system overflows. The peak rate at this variable-speed station decreases to as low as 5.7 MGD during the smaller overflow events.

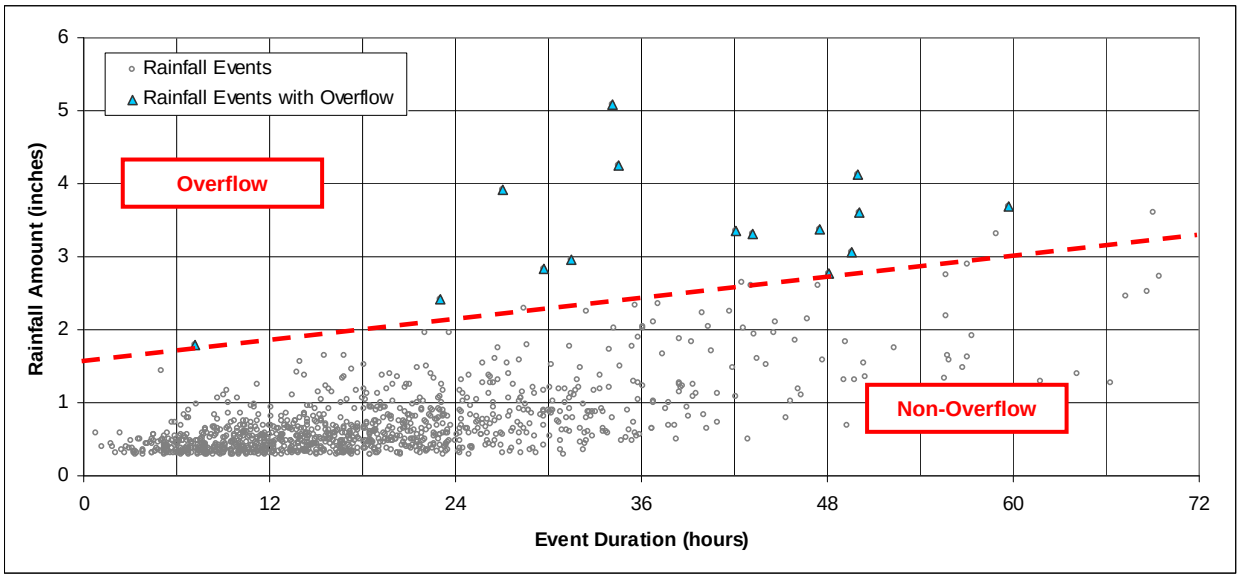


FIGURE 6-7. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 42

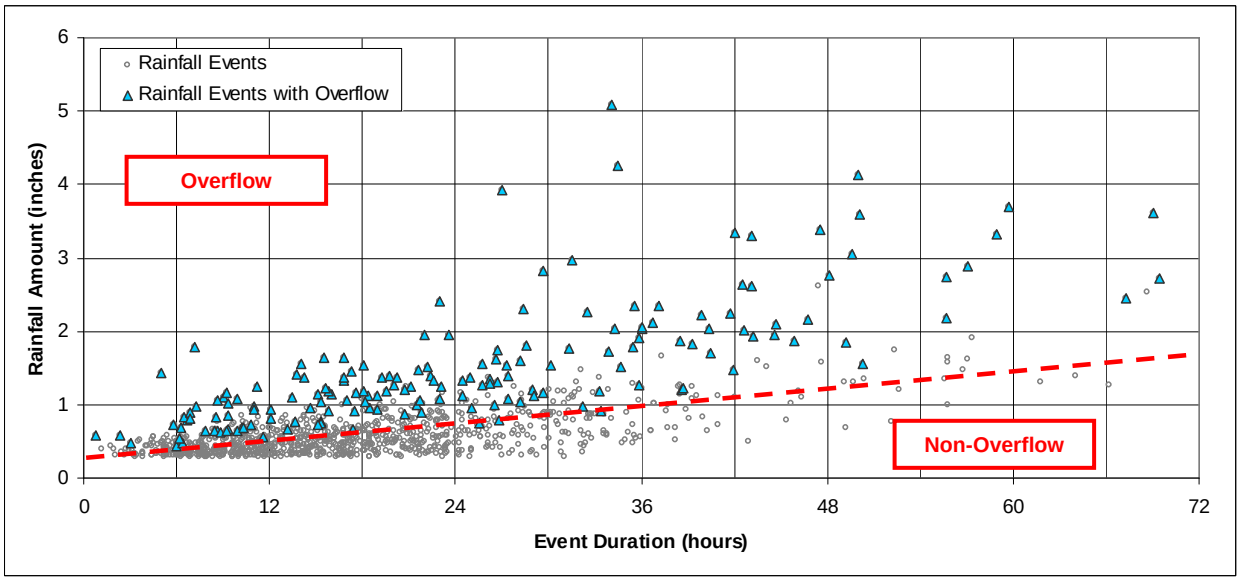


FIGURE 6-8. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 43

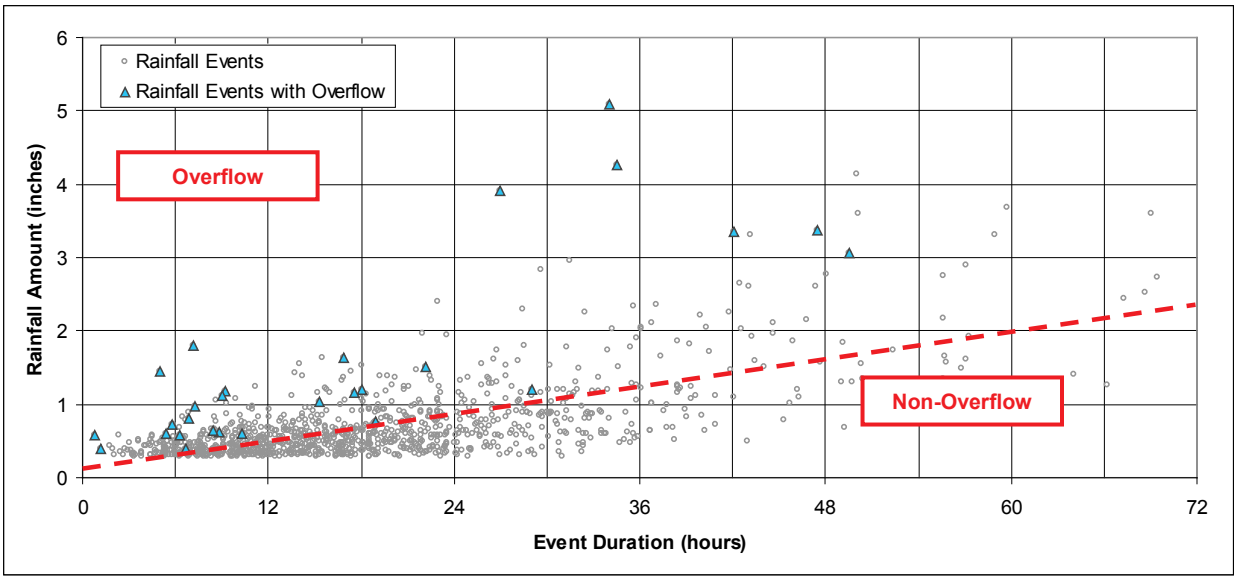


FIGURE 6-9. Rainfall Events Generating Combined Sewer Overflows at NPDES CSO Outfall 165

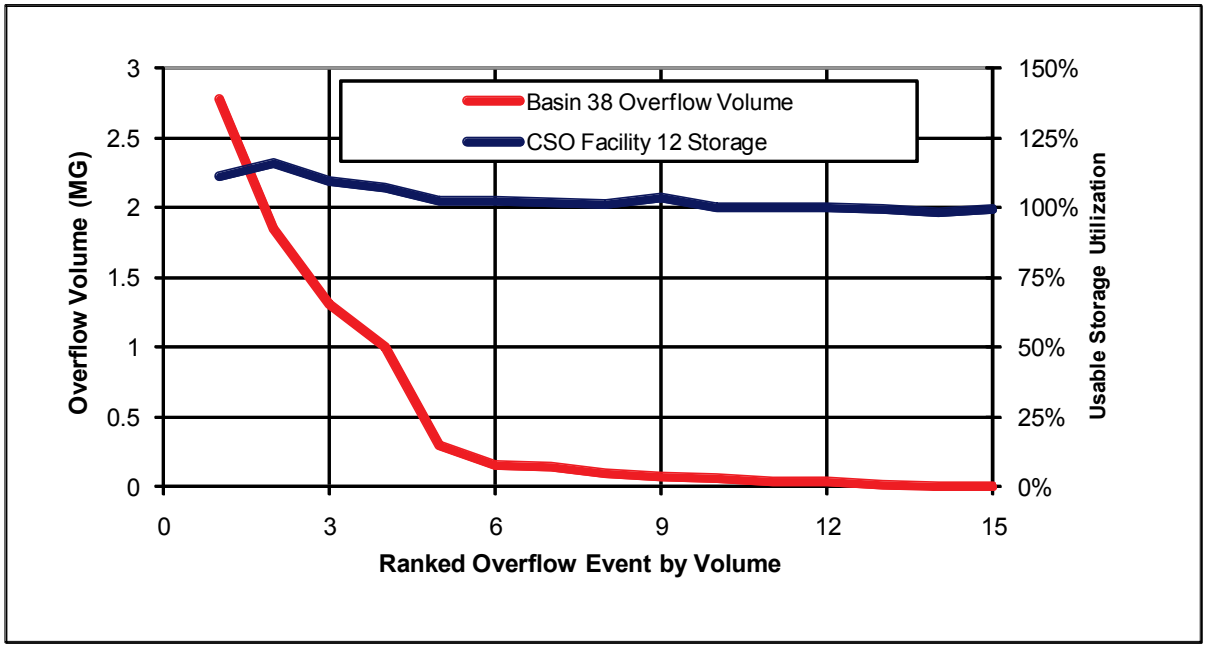


FIGURE 6-10. Basin 38 Ranked Overflow Volumes with Storage Utilization

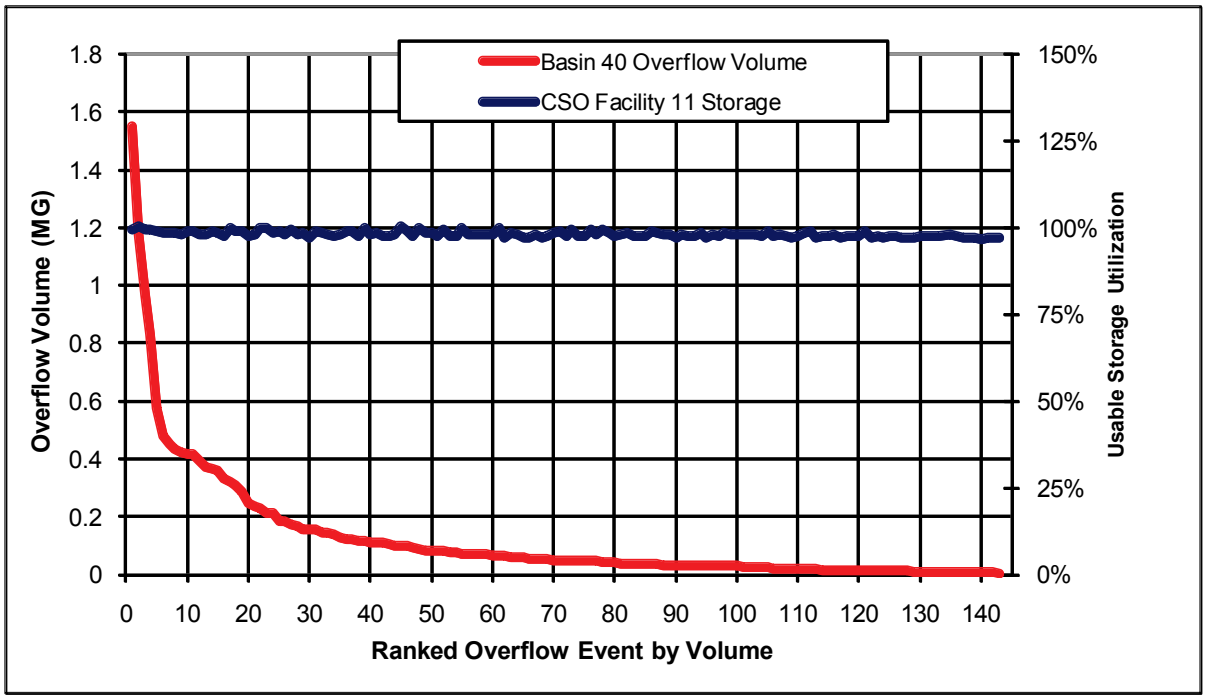


FIGURE 6-11. Basin 40 Ranked Overflow Volumes with Storage Utilization

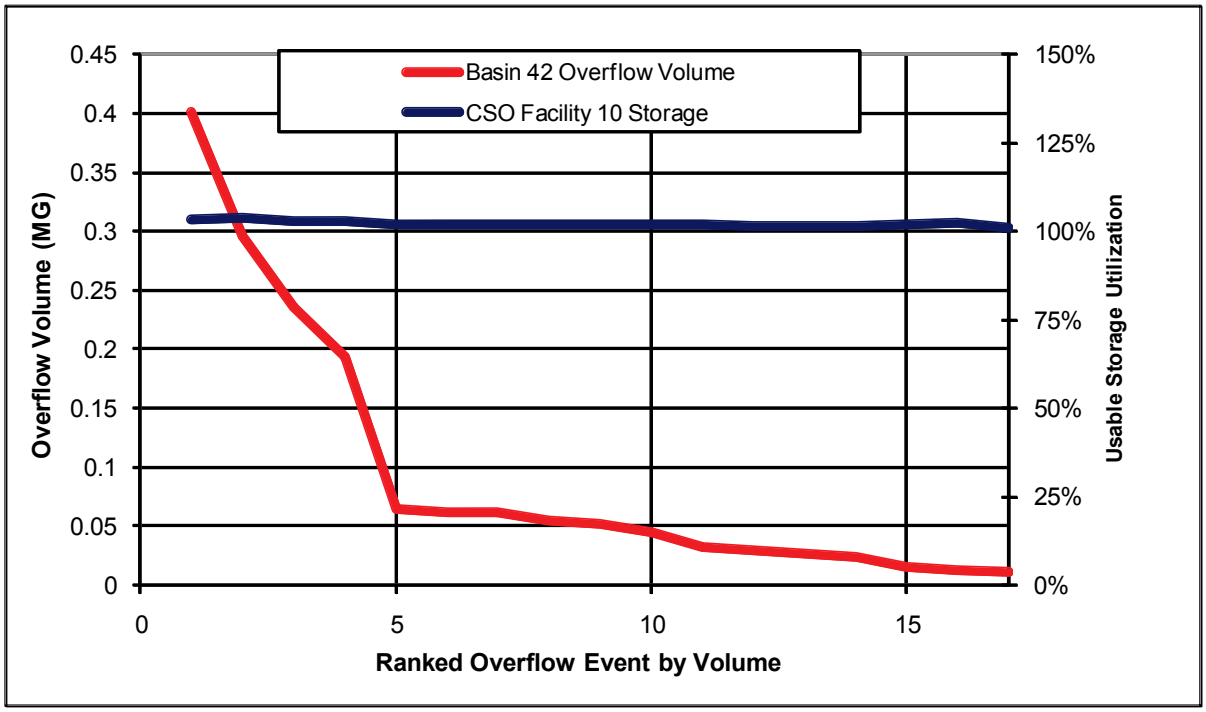


FIGURE 6-12. Basin 42 Ranked Overflow Volumes with Storage Utilization

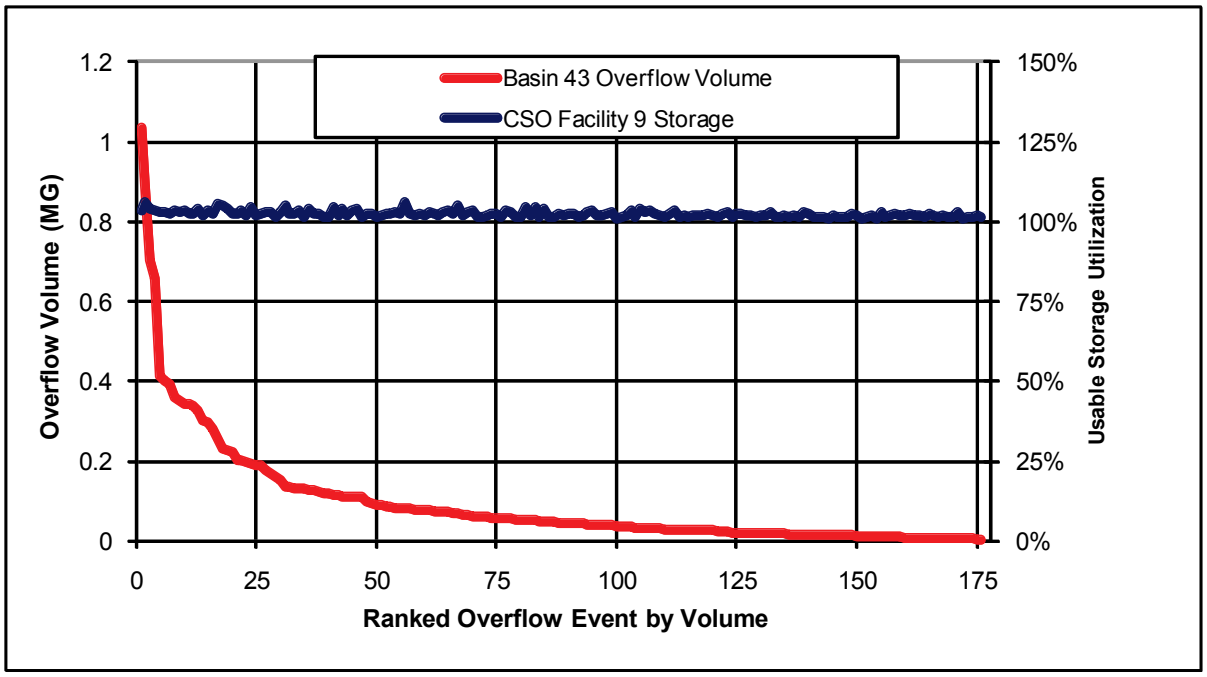


FIGURE 6-13. Basin 43 Ranked Overflow Volumes with Storage Utilization

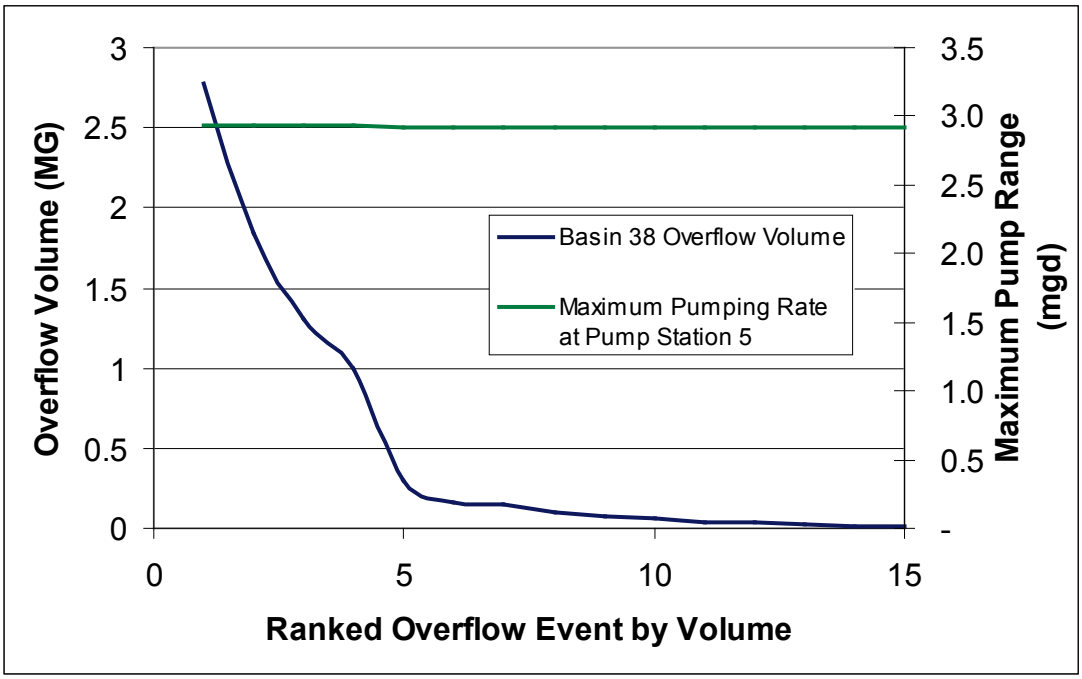


FIGURE 6-14. Basin 165 Ranked Overflow Volumes and Pump Station 6 Event Peak Pumping Rate

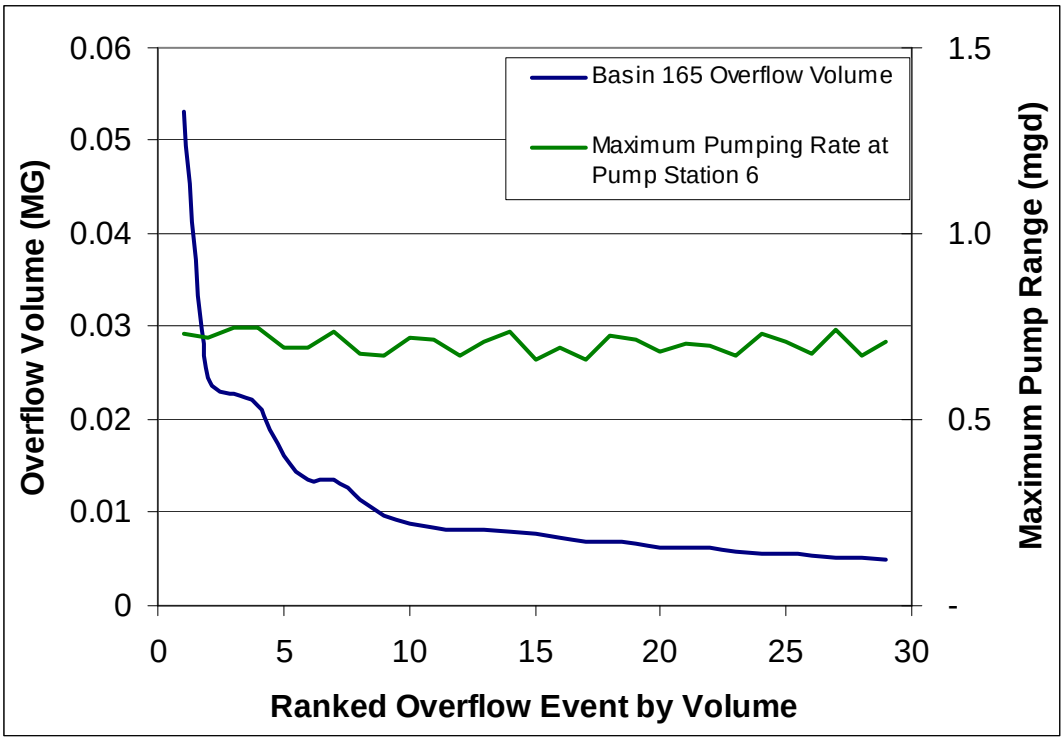


FIGURE 6-15. Basin 38 Ranked Overflow Volumes and Pump Station 5 Event Peak Pumping Rate

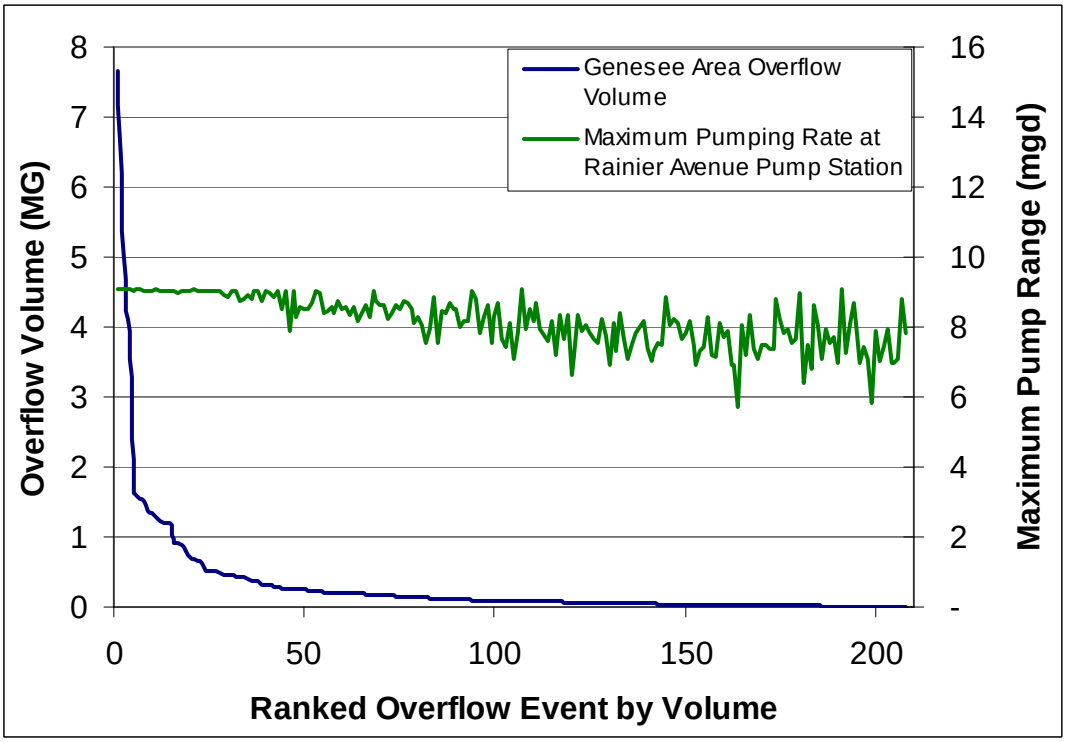


FIGURE 6-16. Cumulative Genesee Area Ranked Overflow Volumes and King County Rainier Avenue Pump Station Peak Pumping Rate

6.5 Capacity Limitations and Surface Flooding in the Combined Sewer System

Capacity limitations in the combined sewer system were assessed for the December 13, 2001, rainfall event. This event, ranked 32nd at Basin 40, was used to develop the estimate of the CSO control volume. Chapter 7 of this report presents the methods used and results of the selection of a CSO control volume. The three surcharge conditions the model reported were used to evaluate system capacity:

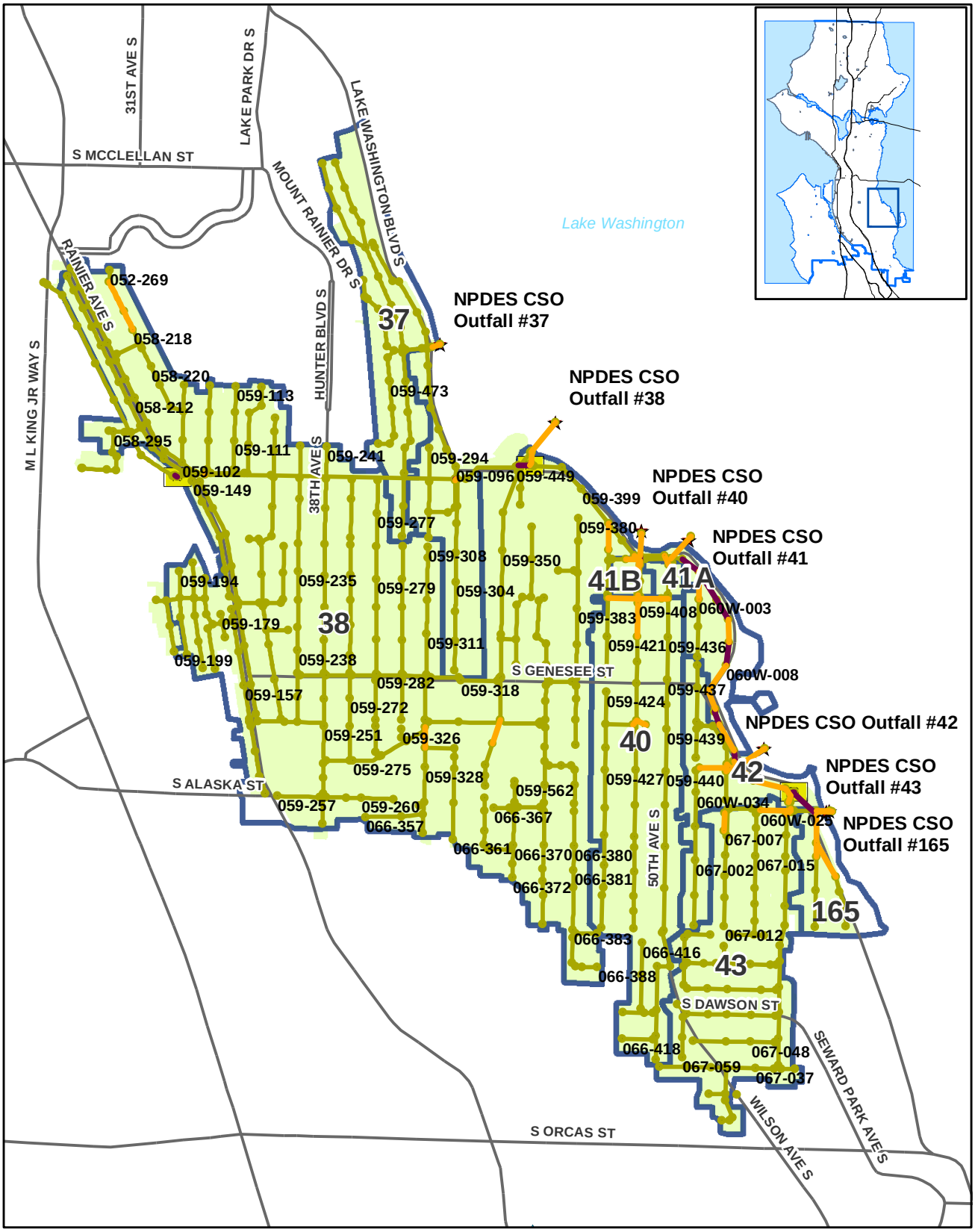
- **Under Capacity.** The water level is above the crown of the pipe, and the hydraulic grade line is greater than the pipe slope. This situation indicates that the pipe capacity cannot convey the peak flow, which may be due to low slopes and small pipe sizes. This under-capacity condition occurs at multiple locations along the lake line, upstream of the point where Basin 41 discharges into the line.
- **Backwater.** The water level is above the crown of the pipe, and the hydraulic grade line is equal to or less than the pipe slope. This situation indicates a slowing of flow due to downstream conditions, which occurs behind HydroBrakes and weirs by design. As expected, backwater also occurs in CSO outfall pipes due to the level of Lake Washington inside the pipe. This backwater situation also occurs at multiple locations along the lake line where downstream pipes are under capacity.
- **No Surcharge.** The water surface is below the crown of the pipe and indicates free-flowing conditions.

Figure 6-17 shows all of the modeled pipes; those that are surcharged during the peak of the December 13, 2001, rainfall event are highlighted. The figure shows the under-capacity and backwatered lake line, as well as backwater caused by the HydroBrakes in CSO control facilities and weirs at control structures. Table 6-3 identifies specific pipe segments and the cause of their under-capacity.

Surface flooding was not apparent during the simulation of the December 13, 2001, rainfall event, indicating that surcharged water levels did not exceed the ground elevation.

TABLE 6-3
Pipe Capacity Limitations

Location	Cause of Restriction
Lake line, upstream of Basin 41:	
MH 059-404 to 060W-006	Undersized pipe
MH 060W-007 to 060W-008	Undersized pipe
MH 060W-010 to 060W-012	Flat pipe gradient
MH 060W-013 to 060W-014	Undersized pipe
Lake line, upstream of Overflow Structure 165:	
MH 060W-021 to 067-078	Flat pipe gradient



Under Capacity
Surcharged where the hydraulic gradient is greater than the pipe gradient

Backwater
Surcharged where the hydraulic gradient is less than or equal to the pipe gradient

No Surcharge

0 500 1,000
Feet

N

FIGURE 6-17
Surcharge State and Volume Lost due to Flooding during Design Event (12/13/01)
Modeling Report
SPU Genesee Area

CH2MHILL

\\SIMBA\PROJ\SEATTLEPUBLICUTILCSO\373008WA1GENMODEL\GIS\LAYOUT\H&HREPORT\SURCHARGESTATE_FIG6-17.MXD MWU 4/14/2010

7.0 Long-Term System Performance

Following calibration of the model and an evaluation of the existing system conditions using that model, a long-term simulation was performed in order to account for uncertainties in the model calibration and uncertainties in future conditions. Because input precipitation is the driver for output model response, an adjustment to the long-term precipitation record (also known as a *precipitation scaling* factor) was used as a conservative assumption to account for potential future uncertainties to inform the selection of control volumes for each of the uncontrolled CSO basins: Basin 40, Basin 41, and Basin 43. The process used to develop this uncertainty analysis is based on MGS Engineering Consultants, Inc. (2009).

7.1 Existing Conditions

Long-term performance and CSO control volumes under existing conditions were evaluated using the calibrated Genesee Model and the unadjusted long-term rainfall record (1978 to 2008). This performance is analyzed in Chapter 6.

The CSO control volume is defined in terms of the volume of water that must be withheld (that is, stored, treated, or otherwise managed) in order to reach the one overflow per site per year long-term average. This study assumed that the volume of the 32nd-ranked overflow event within the 31-year data represents the existing conditions control volume. Table 7-1 shows the resulting CSO existing conditions control volume for each outfall.

Reported CSO events (from approximately August 2007 through June 2009) were also compared to model results for a simulation with a scaling factor of 1.0 to evaluate the effectiveness of the model to simulate existing overflow conditions. In general, historically reported CSO volumes (i.e., volumes based on overflow monitoring) are considered less accurate than the modeled overflows because of difficulties in collecting accurate flow monitoring data at the overflow points. However, with the exception of poor metering or errors in alarm elevations for overflows, the simulation of CSO event frequency compares relatively well to reported data. This comparison is summarized in Tables 7-2 through 7-8.

7.2 Future Conditions

Population and land use in the Genesee Area are not expected to change significantly in the future from the current condition. No zoning changes are planned for the basin, but infill and redevelopment will likely occur. Redevelopment could increase impervious area, but the effects will reduce wet weather inflows to the combined system. Future improvements will follow the current stormwater codes, which do not allow new connections to the combined system where there is an existing storm drain system. As discussed in Section 2.5, large-scale conversion from single-family to multi-family housing is not expected in the Genesee Area, so population density will be relatively

unchanged. For these reasons, the future-conditions long-term performance is assumed to be the same as the long-term performance of existing conditions.

TABLE 7-1
Existing Conditions CSO Control Volume

Outfall	2007-2009 Average Annual Reported Overflow Frequency	2007-2009 Annual Simulated Overflow Frequency	CSO Control Volume (MG)
Basin 37	0	0	0
Basin 38	1	0.5	0
Basin 40	2	5	0.146
Basin 41	8	7	0.135
Basin 42	1	0.5	0
Basin 43	4.5	4.5	0.138
Basin 165	1.5	3	0.004[a]

[a]Retrofits after the reporting period result in Basin 165 being a controlled basin.

TABLE 7-2
Genesee Basin 37 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration	Volume (MG)
No Overflow	--	--	No Overflow	--	--

TABLE 7-3
Genesee Basin 38 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration	Volume (MG)
12/3/07 23:10	22:15	6.741	12/3/2007	29.74	2.78
1/8/09 4:00	7:25	0.365	No Overflow	--	--

TABLE 7-4
Genesee Basin 40 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
12/4/07 0:00	24:30	2.117	12/2/2007 12:30	67.68	1.553
11/7/08 0:00	3:40	0.507	11/6/2008 8:00	23.91	0.157
1/8/09 8:15	13:45	2.000	1/7/2009 18:15	6.44	0.182
4/2/09 20:45	0:20	0.003	4/2/2009 18:40	2.00	0.024
			Additional Simulation Overflows		
			8/25/2008 17:20	1.250	0.049
			12/24/2008 15:15	1.138	0.009
			1/5/2009 3:45	1.750	0.061
			4/12/2009 16:25	0.750	0.010
			5/5/2009 6:40	0.500	0.012
			5/19/2009 21:05	0.750	0.015

TABLE 7-5
Genesee Basin 41 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
9/4/07 10:10	1:40	0.046	9/4/2007 8:30	2.36	0.004
11/16/07 3:30	5:10	0.254	11/15/2007 22:30	4.82	0.011
11/17/07 14:10	1:30	0.036	11/17/2007 12:45	2.44	0.005
12/4/07 11:25	51:40	2.098	12/2/2007 11:15	59.26	1.667
1/10/08 21:40	21:30	0.017	No Overflow	--	--
3/1/08 18:35	0:55	0.010	No Overflow	--	--
3/23/08 16:15	2:35	0.138	3/23/2008 13:56	2.19	0.002
3/29/08 23:50	4:00	0.150	No Overflow	--	--
8/24/08 18:55	0:55	0.002	8/24/2008 18:05	26.35	0.019
11/4/08 8:25	2:55	0.007	11/4/2008 5:25	5.59	0.014
11/7/08 12:05	20:25	0.835	11/6/2008 17:10	20.38	0.378
12/29/08 11:40	50:45	0.647	No Overflow	--	--
1/8/09 13:50	38:05	1.024	1/7/2009 17:00	12.77	0.113
4/3/09 6:30	12:15	0.098	4/2/2009 18:10	4.77	0.024

TABLE 7-5
Genesee Basin 41 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
4/12/09 19:05	2:45	0.030	4/12/2009 16:11	20.32	0.015
5/6/09 18:15	37:10	0.099	5/6/2009 16:40	1.44	0.009
			Additional Simulation Overflows		
			6/6/2008 16:50	1.24	0.004
			12/24/2008 14:45	3.84	0.012
			1/5/2009 3:30	4.97	0.029

TABLE 7-6
Genesee Basin 42 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
12/4/07 0:20	24:20	1.865	12/3/2007 3:00	28.50	0.401
1/8/09 1:30	4:45	0.006	No Overflow	--	--

TABLE 7-7
Genesee Basin 43 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
11/16/07 0:05	00:10	0.001	11/16/2007 0:30	1.00	0.018
12/4/07 0:00	36:55	6.593	12/2/2007 12:00	36.50	1.033
11/6/08 22:00	2:45	0.976	11/6/2008 17:55	12.24	0.139
12/27/08 16:40	4:00	0.272	No Overflow	--	--
12/28/08 18:10	0:50	0.019	No Overflow	--	--
1/8/09 5:35	11:45	0.252	1/7/2009 18:00	6.50	0.192
4/2/09 20:30	0:55	0.004	4/2/2009 18:25	2.25	0.048
4/12/09 17:00	0:25	0.006	4/12/2009 16:25	2.12	0.019
6/10/09 9:35	0:05	0.004	No Overflow	--	--
			Additional Simulation Overflows		
			8/25/2008 17:20	1.25	0.041
			12/24/2008 14:45	1.98	0.027
			1/5/2009 3:30	2.25	0.086

TABLE 7-8
Genesee Basin 165 Comparison of Simulated to Reported Overflows

Reported Overflow	Duration	Volume (MG)	Model Prediction	Duration (hours)	Volume (MG)
12/3/07 12:50	9:50	0.027	12/3/2007 2:15	9.50	0.366
3/1/08 17:15	0:05	0.000	No Overflow	--	--
1/8/09 0:25	3:45	0.005	No Overflow	--	--
			Additional Simulation Overflows		
			8/25/2008 17:05	0.75	0.006
			10/13/2008 18:55	0.50	0.005
			1/5/2009 3:30	1.00	0.001
			4/12/2009 16:10	0.50	0.002
			5/19/2009 20:35	0.50	0.003

7.3 Long-Term System Performance

A long-term simulation of 31 years was performed with the calibrated InfoWorks model to reflect possible long-term system performance. To account for uncertainties in sewer flow predictions from the InfoWorks model, a precipitation scaling factor of 1.088 was included in the long-term simulation. This scaling factor was based on a conservative estimate of potential future uncertainties in precipitation associated with global climate change, model accuracy, and other potential sources of uncertainty. This scaling factor will be used for alternatives analysis and design.

Control volumes were estimated by applying the precipitation scaling factor over all the Genesee Area, and are listed in Table 7-9. Alternatives to reduce CSOs are being developed that may be implemented in, or may affect, one or more basins within the Genesee Area.

TABLE 7-9
Genesee Area Control Volumes

Basin	Control Volume (gallons)
Basin 43	187,000
Basin 41	188,000
Basin 40	203,000

7.4 Surface Flooding Losses

To check if flow was lost out of the system from a non-CSO outfall location, a sensitivity analysis was conducted by varying the precipitation scaling factor and reviewing the nodes for flooding. A simulation of the April 23, 1996, storm—a storm that ranked 15th

based on CSO volume in Basin 40—with a large precipitation scaling factor of 1.316 was used to determine if surface flooding affects the control volume estimates. This scaling factor was selected to account for larger future uncertainties in precipitation due to global climate change, model accuracy, and other potential sources of uncertainty. This event and precipitation scaling factor, more intense and larger than those used for the existing conditions capacity limitations, were used to check for the potential of system flooding during a moderate to large storm event. Seven maintenance holes were identified where flow left the system through the top of the maintenance hole. The smallest volume was 303 gallons at the Rainier Avenue Pump Station wet well. All other overflowing maintenance holes, with the exception of 060W-017, are in the vicinity of Pump Station 5 in the controlled Basin 38. MH 060W-017 had a total volume lost of 11,430 gallons due to the restriction placed in the model at Basin 42 CSO storage facility, or approximately 3 percent of the 0.37-MG CSO volume from Basin 40 during the storm. This restriction has since been removed by SPU pipe maintenance, and the maintenance hole does not flood in simulations of future conditions.

8.0 QA/QC Review Process

This chapter documents the quality assurance/quality control (QA/QC) process implemented by the project team so that the combined sewer system model of the Genesee Area provides meaningful and reliable results.

Quality assurance (QA) refers to independent review of work products to verify that modeling standards are properly incorporated into the model. A QA review was performed at two points during the model development and calibration process: first after model construction and dry weather flow loading, and again after wet weather calibration. The second QA review, after the wet weather calibration, was performed dynamically during working meetings with the independent reviewer and modeling team.

Quality control (QC) refers to actions taken during all phases of model development and implementation to ensure that the model supports the project goals and objectives. QC was performed throughout the model development and calibration through a series of informal and formal checks. A QC checklist provided by SPU for model development and calibration was used as a guide for QC procedures and is included in Appendix I.

SPU contracted a third party to provide independent QA/QC review at multiple stages during the model development and calibration process. This firm was not directly involved in any of the processes described in the previous paragraphs but instead provided impartial and independent review of the construction of the model and of the calibration of the model. Appendix J includes the product of this review, a completed QA/QC checklist.

The independent third-party review of the construction of the Genesee model was divided into five parts: 1) General, 2) Network Development, 3) Subcatchment Development, 4) Sanitary/Dry Weather Flow Components, and 5) Other Data Groups. This review did not find any major gaps or issues in the model. Several minor issues were identified. Appendix J contains the complete review spreadsheet.

The independent third party review of the calibration of the Genesee model was divided into two parts (numbered 6 and 7 to follow the five model refinement parts above): 6) Dry Weather Flow Calibration and 7) Wet Weather Flow Calibration. The complete review is included in Appendix J. Review of Wet Weather Calibration, (Part 7) was performed throughout the calibration process as a series of weekly working meetings where model results were compared to monitoring results and field observations. The independent reviewer was present to perform QA checks during many of the weekly and post-calibration meetings.

9.0 Summary and Conclusions

A comprehensive, calibrated model was developed for the Genesee Area combined sewer system. The level of detail and extensive calibration make the model well suited for analysis and design of the new and existing CSO control facilities in the area. The refined model encompasses more area and provides a higher level of detail and accuracy than provided by previous modeling efforts.

The model is highly detailed in the areas of the basin tributary to the City's NPDES CSO outfalls. Every data point in the model was reviewed for accuracy during the model refinement process and updated using the best available information. The refined model includes all CSO control facilities, pump stations, CSO outfalls, and pipes 8 inches or larger in diameter. Model inputs for all system components were reviewed and updated based on the best available information. Subcatchments were delineated based on detailed lateral house connections on a parcel basis, and all runoff surfaces were directly computed from the GIS.

The model was calibrated at 29 locations for seven rainfall events from the 2008/2009 monitoring period. The model is able to predict peak flow and volume for wet weather events in the range of the one-year rainfall event, which makes it well suited to analyze overflow conditions associated with the once-per-year overflow events.

Calibration using the GLUE process determined a best-fit parameter set for each of the calibration basins. It calculated standardized bias, volume, and peak to quantify the goodness-of-fit between simulated and observed hydrographs. The final model is well calibrated, with about 96.7 percent of all flow values within the target range. Calibration at CSO facilities was problematic due to hydraulic instability and HydroBrake operations, which resulted in some calibration events failing to meet project criteria. At the most downstream monitoring site (059-443), the calibrated model estimated flow 5 percent higher than the measured volume recorded by the monitor site.

A performance analysis confirmed that NPDES CSO outfalls 40, 41, and 43 are not meeting SPU's long-term performance targets. The analysis also showed that NPDES CSO Outfall 165 is uncontrolled, but the control volume is less than 5,000 gallons, which is viewed as within the accuracy of the model. Additionally, recent retrofits (slip-lining and raising the overflow weir in Overflow Structure 165) will likely decrease the overflow frequency. The performance analysis also showed that storage at CSO facilities is fully utilized during overflow events.

The calibrated InfoWorks model and an adjusted rainfall record were used to evaluate the long-term performance of the Genesee system to develop an estimate of the CSO control volume. This adjusted rainfall record does not include climate change. The CSO control volume represents the volume of overflow associated with the once-per-year overflows, which for this study was assumed to correspond to the 32nd-ranked overflow event. The CSO control volume for each NPDES CSO outfall for the existing condition is as follows:

- NPDES CSO Outfall 40: 187,000 gallons

- NPDES CSO Outfall 41: 188,000 gallons
- NPDES CSO Outfall 43: 203,000 gallons

The analysis of the long-term system performance showed that the combination of the flow data, accurate model refinements, and rigorous calibration effectively reduced the estimate of the CSO control volumes at basins 40, 41, and 43.

Quality assurance and quality control processes ensured that the InfoWorks model of the Genesee Area yielded meaningful and reliable results. An independent QA/QC review was performed by an expert in collection systems modeling not directly associated with developing the Genesee InfoWorks model. QA/QC review was performed after the model refinement, calibration, and uncertainty analysis phases of the project were completed.

The final calibrated model is sufficient for the modeling of alternatives to bring the uncontrolled basins into control. Appendix K documents some of the potential modeling approaches to hydraulically model various types of conceptual CSO control alternatives. These approaches will be used during alternatives analysis to modify the calibrated model to allow for simulation of potential alternatives.

10.0 References

Beven, K.J., and A. Binley. 1992. The Future of Distributed Models: Model Calibration and Uncertainty Prediction. *Hydrological Processes,* Volume 6.

Black and Veatch. 2006. *City of Seattle Impervious Surface Data*. GIS data. Prepared for Seattle Public Utilities. Based on Aerial Imagery flown March 2005. Shipped March 10, 2006.

City of Seattle. 2001. Combined Sewer Overflow Reduction Plan Amendment. December 2001.

CH2M HILL. 2007. Meeting minutes, SPU South Genesee CSO Project model development meeting. Meeting held August 28,2007, at Seattle Public Utilities, Seattle, Washington.

CH2M HILL. 2008a. *Quality Assurance Project Plan: Genesee Basin Flow Monitoring Study.* Prepared for Seattle Public Utilities.

CH2M HILL. 2008b. *South Genesee Combined Sewer Overflow Reduction Plan Project: Genesee Modeling Plan*. Prepared for Seattle Public Utilities. September 2008.

CH2M HILL. 2009a. *Genesee CSO Reduction Project Flow Monitoring Report: January 2008 through May 2009*. Prepared for Seattle Public Utilities. November 2009.

CH2M HILL. 2009b. *Technical Memorandum: Genesee Weir Elevations for use in Infoworks CSO Model.* Prepared for Seattle Public Utilities. December 9, 2008. Updated March 10, 2009.

Earth Tech, Inc. 2001. *Sewerage System Modeling and Assessment Project.* Prepared for Seattle Public Utilities.

Earth Tech, Inc. 2006. *Genesee Project Development-Level Model: Model Development Report (NPDES Basins 39, 40, 41a, 41b, 42, 43, and 165).* Prepared for Seattle Public Utilities. December 2006.

HDR. 2008. *South Henderson Combined Sewer Overflow (CSO) Reduction Project: Initial Estimation of CSO Control Volumes for Henderson/Genesee Basins.* July 9, 2008.

Herrera Environmental Consultants. 2006. *Outfall Evaluation Report: NPDES Permit Documentation*. Prepared for Seattle Public Utilities. August 2006.

Herrera Environmental Consultants. 2007. *Evaluation of Methods for Reducing Combined Sewer Overflows to South Lake Washington: Lakewood RainCatchers, Seattle, Washington.* Prepared for Seattle Public Utilities. June 19, 2007 draft.

King County. 1993. *Offsite Facilities and Miscellaneous Structures Manual, Volume 2, West Division*. Revision B, 2993.

King County. 2008. Email conversation between Dan O'Leary of CH2M HILL and Bruce Crawford of King County Wastewater Treatment Division. 3/31/2008.

MGS Engineering Consultants, Inc. 2003. *Analysis of Precipitation-Frequency and Storm Characteristics for the City of Seattle.* December 2003.

MGS Engineering Consultants, Inc. 2008. *CSO Technical Guidance Manual*.

MGS Engineering Consultants, Inc. 2009. *Methods for Estimating Control Volumes for CSO Reduction: Technical Guidance Manual*. Prepared for Seattle Public Utilities. February 2009.

Puget Sound Regional Council. 2007. Census Block 2000 (king00blk.shp). Available at: http://psrc.org/data/gis/shapefiles.

Rawls, W. J., D. Giménez, and R. Grossman. 1998. Use of soil texture, bulk density, and the slope of the water retention curve to predict saturated hydraulic conductivity. *Transactions American Society of Agricultural Engineers* 41(4):983-988.

Seattle Public Utilities (SPU). 2008. *CSO InfoWorks Modeling Quality Assurance/Quality Control (QA/QC) Checklist*. November 14, 2008.

Seattle Public Utilities - Information Technology. 2007. *GeoGuide- Guide to Digital Geographic Data within the City of Seattle Geographic Information System (GIS)*. Electronic help file provided by the City of Seattle.

Street, R.L., G.Z. Watters, and J.K. Vennard. 1996. *Elementary Fluid Mechanics*. Seventh Edition. John Wiley and Sons.

United States Army Corps of Engineers (USACE). 2008. *Datum Planes Vicinity of Lake Washington*. July 11, 2008. Available at: http://www.nws.usace.army.mil/PublicMenu/documents/TOPOSURVEY/Datum_Planes_Lk_WA08.pdf.