Combined Sewer Overflow Program

Long-Term Control Plan

Volume 1
Flow Monitoring Summary Report

2008–2010

RESTORE OUR WATERS
SEATTLE PUBLIC UTILITIES
COMBINED SEWER OVERFLOW REDUCTION

December 2010

Seattle Public Utilities

SEATTLE PUBLIC UTILITIES
LONG-TERM CONTROL PLAN

VOLUME 1

FLOW MONITORING SUMMARY REPORT
2008–2010

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Seattle, Washington

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This report has been prepared under the direction of a registered professional engineer.

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LIST OF ABBREVIATIONS

BMP	best management practice
City	City of Seattle
CSO	combined sewer overflow
CSS	combined sewer system
CWA	Clean Water Act
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GSI	Green Stormwater Infrastructure
LTCP	Long-Term Control Plan
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
POTW	publicly owned treatment works
QAPP	Quality Assurance Project Plan
RG	rain gauge
SCADA	supervisory control and data acquisition
SPU	Seattle Public Utilities
WQS	water quality standards

LONG-TERM CONTROL PLAN FLOW MONITORING SUMMARY REPORT

Introduction

The City of Seattle (City) owns and operates a combined sewer system that overflows at designed relief points during heavy rain events. These relief points and the combined sewer overflows (CSOs) they produce help the City avoid more serious operational, environmental, and public-safety concerns, such as sewage flooding into the streets or backing up into basements. Nevertheless, these CSOs discharge untreated wastewater and its inherent pollutants (e.g., bacteria, metals) to our local water bodies, potentially impacting their quality and beneficial uses. The City is working to reduce these discharges.

Over the last 30 years, the City has built new facilities and instituted operational and flow-reduction strategies to decrease the number of CSO events at 24 of the City's 90 outfalls, significantly reducing pollutant loads discharged to Lake Washington, Lake Union, the Lake Washington Ship Canal, the Duwamish River, Longfellow Creek, and Puget Sound. But more work needs to be done.

For the next 15 years, through Seattle Public Utilities (SPU) the City will work in concert with King County and regulators to create the optimal blend of capital and operational investments to control remaining CSOs. To comply with the City's National Pollutant Discharge Elimination System (NPDES) CSO Permit, it will need to limit the number of untreated CSO events to a long-term average of no more than one per year at each outfall. To ensure that this process stays on track, SPU is preparing a Long-Term Control Plan (LTCP) that will guide the planning and implementation of the CSO control program beyond 2015 by addressing technical, environmental, financial, and regulatory elements of CSO control.

A key element of the effort to reduce CSOs across Seattle is SPU's LTCP Flow Monitoring project, which is documented in this report. This project, a comprehensive effort to characterize flows and operational conditions in the City's combined sewer system, was divided into three phases comprising 2 years of data collection. Phase 1 (10/1/2008–5/31/2009) was the wet season of the first year of monitoring. Phase 2 (6/1/2009–9/30/2009) and Phase 3 (10/1/2009–5/31/2010) were the dry and wet seasons, respectively, of the second year of monitoring.

The project strategically targeted 12 uncontrolled CSO basins—Ballard, Delridge/Longfellow, Duwamish, Fremont/Wallingford, Interbay, Leschi, Madison Park/Union Bay, Magnolia, Montlake, North Union Bay, Portage Bay/Lake Union and West Seattle—which are subdivided into 38 smaller NPDES basins. Each NPDES basin represents 1 outfall, so the LTCP Flow Monitoring project targeted about 43 percent of the city's total outfalls. In addition, rainfall data were collected from rain gauges installed citywide. During Phases 2–3, monitoring was also conducted at 53 system-wide monitoring locations across the city. Together, these data will be used to calibrate a system-wide hydraulic model and provide the foundation for the CSO control strategies to be implemented through the LTCP.

Data were collected from every area of the city where needed; constant review of data quality and project needs led to adjustment or removal and replacement of meters at locations where high-quality data could not be collected. Overall, data quality at 80 percent of the monitoring sites was classified as "Excellent" or "Good." Data quality at another 16 percent of the sites was classified as "Some Limitations," meaning that significant portions of the data are suitable for model calibration (for example, dry weather flow data may be suspect due to the configuration of the sewer but peak wet weather flows are consistently excellent). Thus, data at 96 percent of the monitoring sites are considered suitable for model calibration. Sites where the quality was classified as "Poor" were generally removed—for example, LTCP sites shown as "Poor" in Figure 12–Figure 26 were removed as they were found to receive repeated "Poor" rankings. For sites classified as "Poor," either alternative sites or means were typically found to acquire the needed data. However, in some instances, they were left in the system, where needed for specific purposes such as provision of depth data or guidance on system response to rainfall. Generally, the "Poor" classification signals to the model developer that care must be taken in selecting which portions of the data to use. Thus, data usable for model calibration were acquired at all sites.

In summary, the LTCP Flow Monitoring project collected reliable, representative data in the 12 CSO basins, at the system-wide flow monitoring locations, and from the City's rainfall gauges. These data will provide a solid foundation for hydrologic and hydraulic model calibration and will support the City's efforts to continue to strategically reduce CSOs in compliance with its NPDES permit in the most cost-effective manner.

The LTCP Flow Monitoring Report consists of the following five volumes:

> **Volume 1** is this summary report. The remainder of this report summarizes the project drivers, the strategic methods used to identify and evaluate potential monitoring locations, the execution of the Flow Monitoring project, and the monitoring results. This information is presented in greater detail in Volumes 2–5.
>
> **Volume 2 and Volume 3** are the Quality Assurance Project Plans (QAPPs), also known as the Flow Monitoring Plans, for the first year (Phase 1) and the second year (Phases 2–3) of the project, respectively. These volumes describe the project's goals and objectives, success criteria, and site selection methodology.
>
> **Volume 4** summarizes the data collected during Phase 1 (10/1/2008–5/31/2009). This volume also describes the suitability of the flow monitoring data for meeting SPU's goals and objectives, suitability of rainfall data, and at-a-glance summaries of each monitoring site.
>
> **Volume 5** summarizes the data collected during Phases 2–3 (6/1/2009–5/31/2010) in a manner similar to Volume 4. This volume also summarizes the flow monitoring data collected during Phases 2–3 to support SPU's system-wide model development effort.

Background

The LTCP Flow Monitoring project was the latest step in the City's ongoing effort to reduce citywide CSOs in compliance with federal NPDES and Clean Water Act (CWA) requirements. The following section provides a snapshot of key developments and objectives in this process.

NPDES CSO Permit

The City's NPDES CSO Permit is the regulatory mechanism through which the U.S. Environmental Protection Agency (EPA) controls water pollution discharged to water bodies through point sources in Seattle. The Department of Ecology (Ecology), as the federally designated water pollution control agency in Washington State, sets compliance requirements by issuing and renewing NPDES Permits every 5 years. This report was prepared and submitted to meet the requirements of the 2005 NPDES Permit No. WA-003168-2, effective 12/1/2005, which requires monitoring and planning for CSO reduction at three CSO basins in Seattle: Duwamish, Ballard, and Fremont/Wallingford. These were 3 of the 12 CSO basins studied for this LTCP Flow Monitoring project. In addition, three CSO basins (Windermere, Genesee, and Henderson) underwent separate flow monitoring efforts. These basins are on a separate CSO implementation schedule (described below in the discussion of the CSO Reduction Plan) and were not included in this LTCP Flow Monitoring project.

The City's next NPDES Permit No. WA-003168-2, issued by Ecology 11/27/2010, becomes effective 12/1/2010. The next NPDES Permit is based on the 2010 CSO Reduction Plan submitted by the City on May 2010.

Figure 1. Green stormwater infrastructure

CSO Reduction Plan

One of the tools Ecology uses to administer NPDES permits for CSO outfalls is the CSO Reduction Plan (Washington Administrative Code 173-245). In May 2010, the City submitted its 2010 CSO Reduction Plan Amendment, which focuses on reducing CSOs at the City's most critical and sensitive sites through a cost-effective blend of traditional solutions and green stormwater infrastructure (GSI) (Figure 1). Its aim is to limit the number of untreated overflows at each CSO outfall to a long-term average of no more than one per year. According to the 2010 CSO Reduction Plan Amendment, Seattle has successfully reduced CSO events over the last 30 years from 2,800 CSO events in 1980, totaling 400 million gallons, to an annual average of approximately 200 CSO events in 2008–2009, totaling less than 100 million gallons.

The 2010 CSO Reduction Plan Amendment presents an aggressive schedule for constructing CSO reduction projects in the Windermere, Genesee, and Henderson Basins—GSI in Ballard, North Union Bay, and Interbay—and construction of CSO retrofit projects throughout the city to improve CSO control over the next 5 years.

The 5-year program will significantly reduce the City's CSOs into its most sensitive receiving water—Lake Washington. Lake Washington (Figure 2) is one of the region's greatest natural resources. As the largest freshwater lake in King County, it provides habitat for numerous aquatic species and recreational areas for the region's residents and visitors. Due to the importance of this water body, the City has placed the reduction of CSOs into Lake Washington as its highest priority through 2015.

One of the goals of the 2010 CSO Reduction Plan Amendment was to also provide interim direction for the remaining basins not covered in the 2005 update. For these basins it provides a high-level analysis of the types of projects to be constructed along with budget and schedule forecasts. The intent of the 2015 LTCP project is to build on this information and use the flow monitoring and modeling to finalize project recommendations for these 12 CSO basins.

Figure 2. Lake Washington

CSO Control Policy

In response to water pollution caused by CSOs across the U.S., the EPA developed its CSO Control Policy, published in the Federal Register in 1994 (59 Federal Register 18688). The CSO Control Policy was issued to provide guidance to permittees, ensure coordination among appropriate parties, and ensure public involvement. The CSO Control Policy articulates the requirement for CSO communities to develop LTCPs that incorporate the following nine elements:

- characterization, monitoring, and hydrologic and hydraulic modeling activities to select and design effective CSO controls
- a process that involves the public in selecting long-term CSO controls
- consideration of sensitive areas as the highest priority for controlling overflows
- evaluation of alternatives that will enable the City to select CSO controls that meet CWA requirements
- cost/performance considerations to demonstrate the relationships among alternatives
- operational plan revisions to include agreed-upon long-term CSO controls
- maximization of treatment at the existing POTW treatment plant for wet weather flows
- an implementation schedule for CSO controls
- a compliance monitoring program to verify CWA compliance and CSO control effectiveness.

Seattle's LTCP will document the overall program to limit the number of untreated overflows at each CSO outfall to a long-term average of no more than one per year by 2025. In meeting the nine EPA-required elements, the comprehensive LTCP will accomplish the following objectives:

- gather sufficient flow monitoring information to characterize the hydrology and hydraulics of all uncontrolled City CSO basins (Figure 3) and the overall King County system to calibrate the City's CSO basin models and the King County system model—the primary objective of the LTCP Flow Monitoring project documented in this report.
- develop and calibrate the City CSO basin models and the King County system-wide model to represent City/County boundary conditions, evaluate independent and collaborative CSO project opportunities, and size CSO control volumes
- establish clear boundary conditions between the City's and County's systems for each CSO reduction project to ensure continued compliance and proper project sizing
- for each uncontrolled City CSO basin, identify and evaluate alternatives (i.e., triple-bottom-line analysis) that cost-effectively reduce CSOs down to regulatory targets
- recommend preferred alternatives and develop projects to a "facility plan" level to ensure feasibility for design
- develop an implementation plan for all preferred alternatives
- execute a programmatic National Environmental Policy Act (NEPA) environmental review process.

Figure 3. Combined sewer overflow monitoring location

The LTCP Flow Monitoring project was an essential first step in meeting the LTCP objectives. Existing data were insufficient to establish dry and wet weather baseline conditions, so a monitoring program was necessary to adequately characterize conditions and provide the calibration and verification data necessary for system modeling. Reliable modeling requires reliable, representative data; thus the primary objective of this project was to gather sufficient suitable data for modeling the City's combined sewers.

Project Approach

Data needed to be collected over two wet seasons in order to gather sufficient rainfall, flow (depth, level, velocity), and operational data (pump on-off data, run times, overflow structure behavior, etc.) to allow accurate representation of conditions in the City's sewers. These data will be used to characterize the hydrologic and hydraulic performance of the combined sewer system and support development of the LTCP.

Figure 4. Flow monitoring project crew

To ensure that the LTCP Flow Monitoring project achieved its objectives, the City developed two LTCP Flow Monitoring Plans for Phase 1 and Phases 2–3. The LTCP Flow Monitoring Plans were consistent with two EPA guidance manuals: *Combined Sewer Overflows: Guidance for Long-Term Control Plan* (Publication No. 832-B-95-002, September 1995) and Combined Sewer Overflows: Guidance for Monitoring and Modeling (Publication No. 832-B-99-002, January 1999). Key elements of EPA's requirements are covered in Volumes 2–5 of this report.

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

- Adequately and accurately characterize the hydrologic and hydraulic performance of the combined sewers by collecting rainfall depth, level, velocity, and operational data.
    - Hydrologic performance is defined as the response of a subcatchment to rainfall.
    - Hydraulic performance is defined as the operating characteristics of structures and facilities in the combined sewer system, including in-line and offline storage, HydroBrakes, gates, weirs, diversions, regulators, and pump stations.
- Capture data before, during, and after a wide range of storm events with a range of antecedent moisture conditions. In terms of recurrence intervals this objective can be defined as a minimum of three storm events of recurrence interval between 6 months and 1 year at any duration, and a minimum of two storm events of recurrence interval between 1 and 10 years at any duration spaced throughout the wet season.
- Recommend storm events for model calibration and future flow monitoring in the event that the desired storms do not occur during the project monitoring period.

Data Quality Assurance

QAPPs were prepared for Phase 1 and Phases 2–3, titled "Quality Assurance Project Plan: SPU CSO Reduction Program, CSO Long-Term Control Plan, Flow Monitoring Plan." The QAPPs, provided as Volumes 2 and 3 of this report, describe the quality assurance process for flow monitoring of the sewer system owned and operated by the City. The flow monitoring and data assessment procedure is shown in Figure 5. The information in the plans, including monitoring locations, was specific to the phases. The Flow Monitoring documents were developed with guidance from the Ecology Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (Ecology 2004).

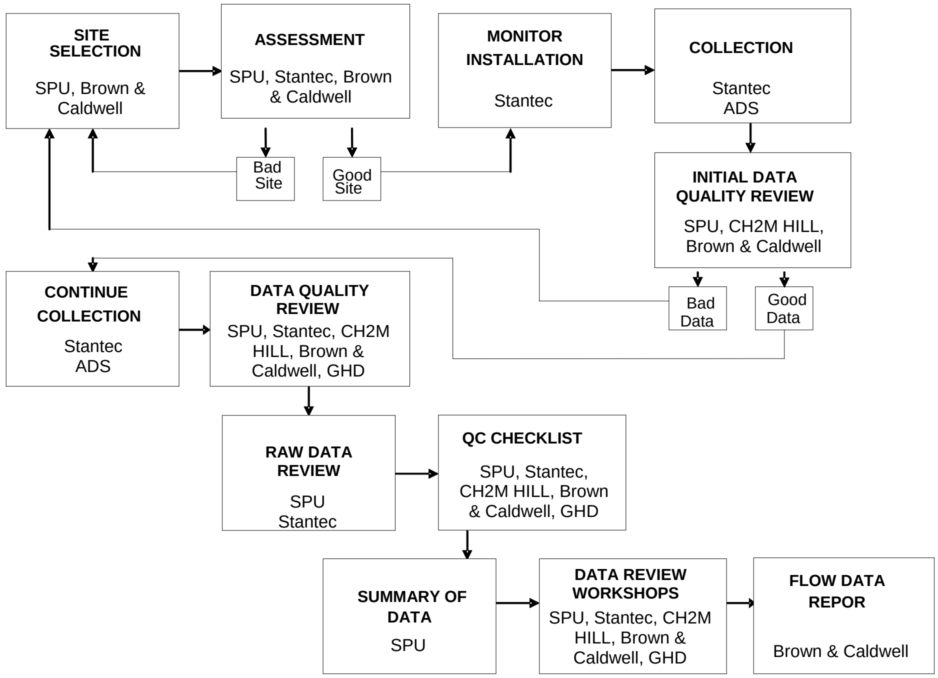

Figure 5. Flow monitoring and data assessment procedure

The roles and contact information of key individuals involved in the Flow Monitoring project are provided in Table 1.

Table 1. Flow Monitoring Study Team Contact Information

Company/organization	Contact/project role	Address	Phone/e-mail
CH2M HILL	Bill Mori, Project Manager	1601 Fifth Avenue, Suite 1100 Seattle, WA 98101-3603	206-470-2273 Bill.Mori@CH2M.com
Seattle Public Utilities	Ed Mirabella, LTCP Manager Ben Marré, Flow Monitoring Study Project Manager	700 Fifth Avenue, Suite 4900 Seattle, WA 98124	206-684-5959 J.Edward.Mirabella@seattle.gov Ben.Marre@seattle.gov
Brown and Caldwell	Steve Merrill, Modeling Manager Tony Dubin, Lead Project Engineer	701 Pike Street, Suite 1200 Seattle, WA 98101	206-624-0100 SMerrill@brwncald.com TDubin@brwncald.com
GHD	Dave Jacobs, Project Engineer	1201 Third Avenue, Suite 1500 Seattle, WA 98101	206-441-9385 David.Jacobs@ghd.com
Stantec Consulting	Roger Jacobsen, Project Manager	1500 Lake Shore Drive, Suite 100 Columbus, OH 43204	614-486-4383 Roger.Jacobsen@stantec.com
ADS Environmental Services	Mike Pina, Project Manager	309 S. Cloverdale Street, Suite D-38 Seattle, WA 98108	206-762-5070 MPina@idexcorp.com

An overall data quality rating system was also described in the QAPPs, which showed how the data obtained from each of the monitoring locations were classified for their suitability for use in model calibration. This rating system is shown in Table 2 below.

Table 2. Data Quality Usability Assessment Applied to Flow Monitoring Data

Quality rating	General description	Criteria
Excellent	Data are reliable for modeling with no critical exceptions.	▪ No data gaps during significant rainfall periods. ▪ Meter shows consistent response to snowmelt, if applicable. ▪ Scattergraph is narrow without many outliers in both dry and wet weather periods. ▪ Scattergraph deviations from a Manning's relationship are repeatable and explainable. ▪ Site signature does not significantly change over the monitoring period. ▪ Response of flow to rainfall is consistent across the entire monitoring period. ▪ Diurnal pattern is clear and repeatable (if the site is intended to be used for dry weather flow calibration). ▪ Where applicable, flow balancing shows that the meter is within the right range.
Good	Data are reliable for modeling with noted exceptions, noted edits, slight degree of error, or some missing data.	▪ No data gaps during significant rainfall periods. ▪ Meter has captured all or most of the significant rainfall events. ▪ Wet weather scattergraph is narrow. ▪ Scattergraph deviations from a Manning's relationship are repeatable and explainable. ▪ Diurnal pattern is clear and repeatable (if the site is intended to be used for dry weather flow calibration). ▪ Where applicable, flow balancing shows that the meter is within the right range.
Some limitations	Modeler must take into account the limitations of the data when calibrating, however some important aspects of the data are still suitable for model calibration.	▪ Meter may have not recorded all significant events. ▪ Periods of suitable data exist, particularly during wet weather events. ▪ Meter had to be replaced. ▪ Dry weather flow data may not show clear pattern due to site hydraulics. ▪ Wet weather scattergraph is narrow. ▪ Scattergraph may be thick with scatter except in peak wet weather events. ▪ Scattergraph deviations from a Manning's relationship are repeatable and explainable. ▪ Dry weather scattergraph may exhibit significant scatter due to change in site hydraulics or meter intelligence (locking on to multiple velocities or ramping at low flows). ▪ Where applicable flow balancing shows that the meter is in the right range in wet weather events. ▪ Meter exhibited sensor failure or debris fouling.
Poor	Data may provide some useful modeling information, but should be used with caution for calibration. Sites with a persistent poor rating will be removed and alternative sites considered or alternative methods to provide relevant data will be explored.	▪ Significant data gaps during wet weather. ▪ Site hydraulics may preclude collection of trust worthy data. ▪ Dry weather flow data does not show clear pattern (if the site is intended to be used for dry weather calibration). ▪ Wet weather flow data does not show clear pattern. ▪ No clear diurnal pattern (if site is intended to be used for dry weather calibration). ▪ Scattergraph is thick with scatter. ▪ Scattergraph is unusual with no clear pattern (i.e. horizontal line). ▪ Where applicable, flow balancing shows that the meter may be over or under estimating.

Data Collection

The 12 combined CSO basins included in the LTCP Flow Monitoring project are approximately 5,538 acres (8.65 square miles) in size and comprise 182 miles of sewers. Phase 1 of the LTCP Flow Monitoring project focused on 12 CSO basins—Ballard, Delridge/Longfellow, Duwamish, Fremont/Wallingford, Interbay, Leschi, Madison Park/Union Bay, Magnolia, Montlake, North Union Bay, Portage Bay/Lake Union, and West Seattle (Figure 6). Phases 2–3 of the LTCP Flow Monitoring Plan focused on 10 of the original 12 CSO basins and excluded the Magnolia and West Seattle Basins, for which sufficient data had been collected at the conclusion of Phase 1 monitoring.

Approximately 240 meters were in place throughout Phases 1–3 monitoring. Of these, 89 were new monitoring locations installed during Phases 2–3. These new sites are categorized as follows:

- 53 meters installed in the City and County system for purposes of providing calibration data for a system-wide model and for supporting the City's GSI efforts and capacity assessment
- 6 meters installed in the storm drainage system for purposes of characterizing stormwater flows in NPDES basins.
- 30 meters installed in NPDES basins where additional data were required for system characterization.

Additional data were also obtained from the following sources:

- SPU-maintained permanent flow meters installed at NPDES outfalls
- supervisory control and data acquisition (SCADA) data from SPU pump stations associated with the CSO basins
- SCADA data collected from CSO Facilities 2 and 3
- precipitation data from SPU's rain gauges (RGs) 01, 02, 03, 05, 07, 08, 09, 11, 12, 14, 15, 16, 17, 18, and 20 (Figure 7)
- SCADA data from King County monitoring locations as necessary to provide boundary conditions for the CSO basin models.

A combination of ultrasonic and pressure sensors were used to measure depth in pipes, hydraulic control structures, and detention tanks.

Figure 6. Long-Term Control Plan CSO basin map

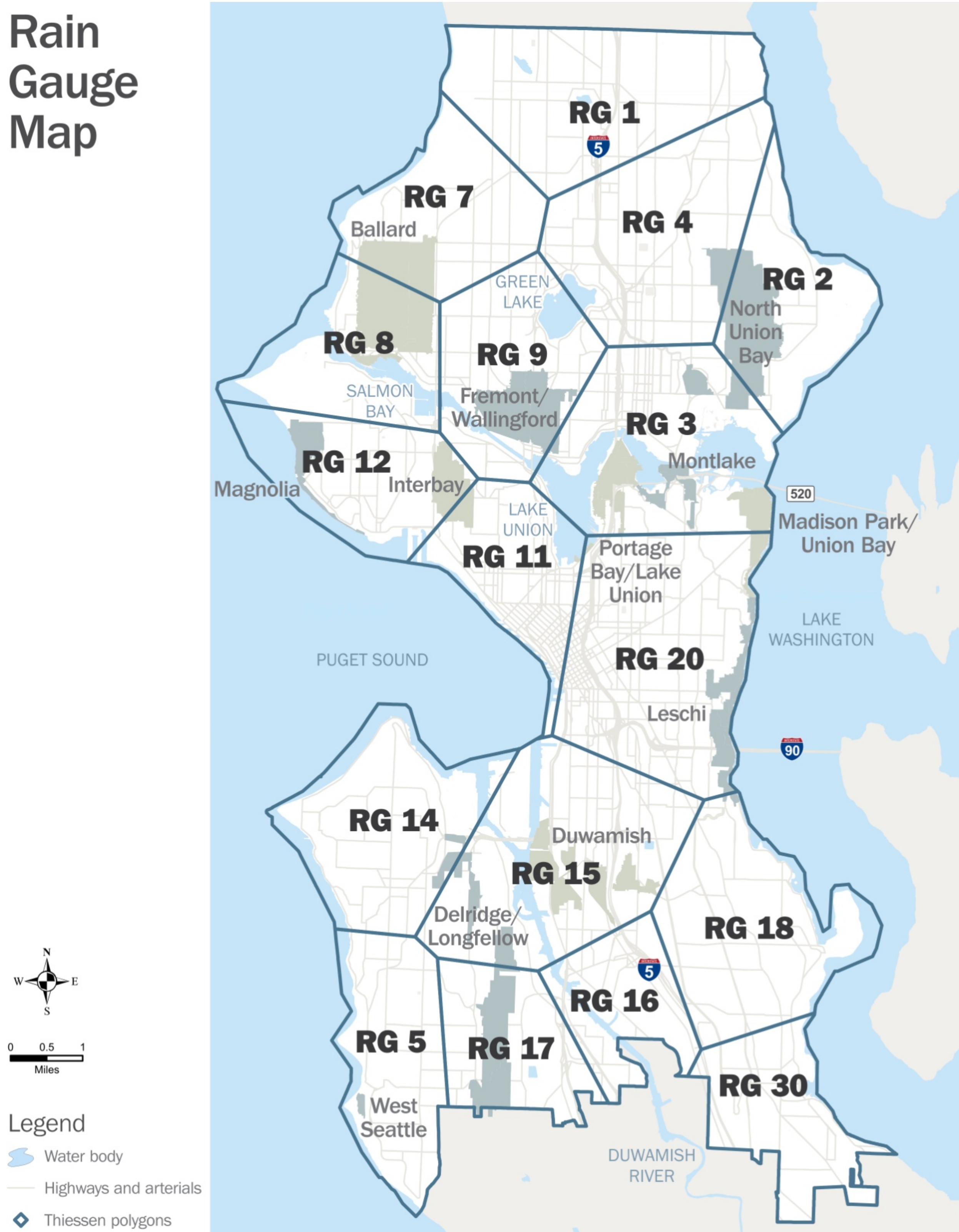

Figure 7. Thiessen polygons for each of the SPU rain gauges

Data Screening

To ensure the highest possible data quality, meter data were screened on a weekly basis during the wet weather season. The screening focused on consistency and completeness of meter response. Data screeners noted anomalies, if any, which were then reviewed and resulted in action items for attention by the metering contractor if appropriate. In addition, five wet-season workshops were conducted to review the data for hydrologic and hydraulic modeling suitability. These meetings focused on review of consistency of upstream and downstream meters (flow balance), flow response to rainfall, and the quality of the data for modeling purposes. These reviews resulted in removal and replacement of meters where suitable data could not be captured, and the identification of suitable and unsuitable portions of the data in locations where meter performance was challenged. Where data were still in question, detailed analysis of the monitoring site and meter response were conducted including installation of alternative flow meter technology when warranted.

Additional details on the screening activities and outcomes are contained in the monitoring plan and workshop presentations available on the SPU LTCP file transfer protocol (FTP) site. Overall, these screening activities resulted in the collection of data that can confidently be used in hydrologic and hydraulic model calibration.

Summary of Monitoring Results

During Phase 1, 12 CSO basins comprising 38 smaller NPDES basins were monitored. Based on the results of Phase 1 monitoring, it was determined that 2 basins (Magnolia and West Seattle) did not need to be monitored for Phases 2–3; consequently, only 10 CSO basins were monitored during Phases 2–3. In addition, data were collected from 53 system-wide monitoring locations during Phases 2–3. The following section presents a summary of rainfall data collected and the results for flow monitoring at the 12 CSO basins and the system-wide monitoring locations during the 2-year LTCP Flow Monitoring project.

Rainfall Monitoring

As stated in the QAPP 2009–2010 (Volume 4 of this report), the objectives for LTCP Flow Monitoring project rainfall monitoring were as follows:

- Capture data before, during, and after a wide range of storm events with a range of antecedent moisture conditions. In terms of recurrence intervals this objective is achieved by meeting both of the following criteria:
  - A minimum of three storm events of recurrence interval between 6 months and 1 year at any duration
  - A minimum of two storm events of recurrence interval between 1 year and 10 years at any duration spaced throughout the wet season.
- Recommend storm events for model calibration and future flow monitoring in the event that the desired storms do not occur during the project monitoring period.

Rainfall data were collected for the LTCP through the City's rain gauge network. Data from 9 of the 17 gauges were applicable to the CSO basins included in the LTCP. Each of these nine gauges was assigned to a CSO basin for review of flow monitoring results.

Figure 8 shows the monthly long-term Sea-Tac average rainfall together with the observed rainfall at RG 03, RG 05, and RG 09. In general, the rainfall recorded at the monitoring gauges during Phase 1 was below average, but above average during Phase 3. Few events occurred in the Phase 1 monitoring period that are suitable for model calibration. In contrast, the Phase 3 wet season provided several significant storms that provide a solid foundation for reliable model calibration.

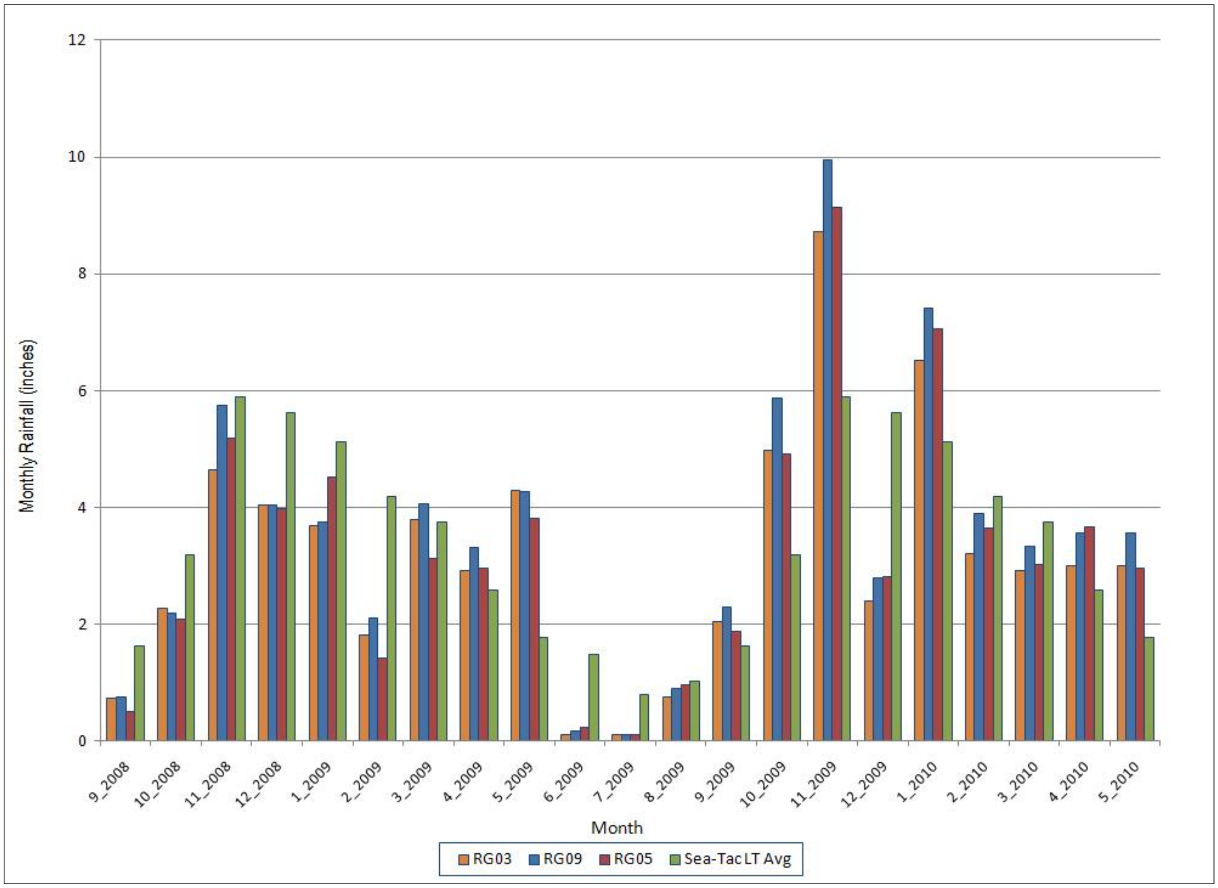

Figure 8. Monthly average precipitation at three SPU gauges compared to the long-term average at Sea-Tac Airport

Figure 9 and Figure 10 provide examples of four depth-duration-frequency storms at two of the rain gauges used in this study: RG 09, located in the north of the city, and RG 15, located in the south of the city. These storm events, compared against the 6-month, 1-year, 10-year, and 100-year depth-duration-frequency curves for Seattle, met the criteria listed in the QAPP. The QAPP states that storms recommended to be used for calibration need to fall within 6-month to 1-year recurrence intervals and from 1-year to 10-year recurrence intervals. Table 3 lists for each rain gauge the maximum recurrence intervals of significant storm events for any duration. The events listed indicate that the QAPP criteria were exceeded over the two seasons of monitoring, and no further monitoring is required to meet these criteria. In addition, the characteristics of the rainfall that occurred provide excellent opportunities to calibrate both the impervious runoff and groundwater flows in the models. Storms listed in Table 3 are recommended for calibration.

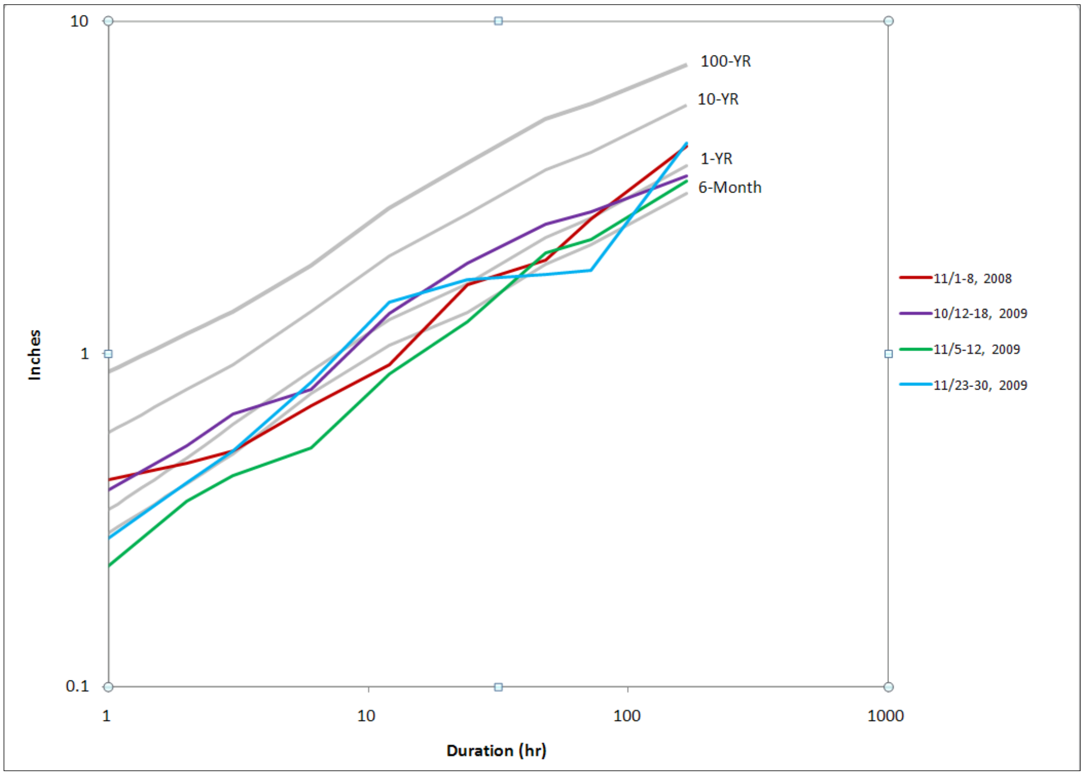

Figure 9. Example depth-duration-frequency curves, RG 09

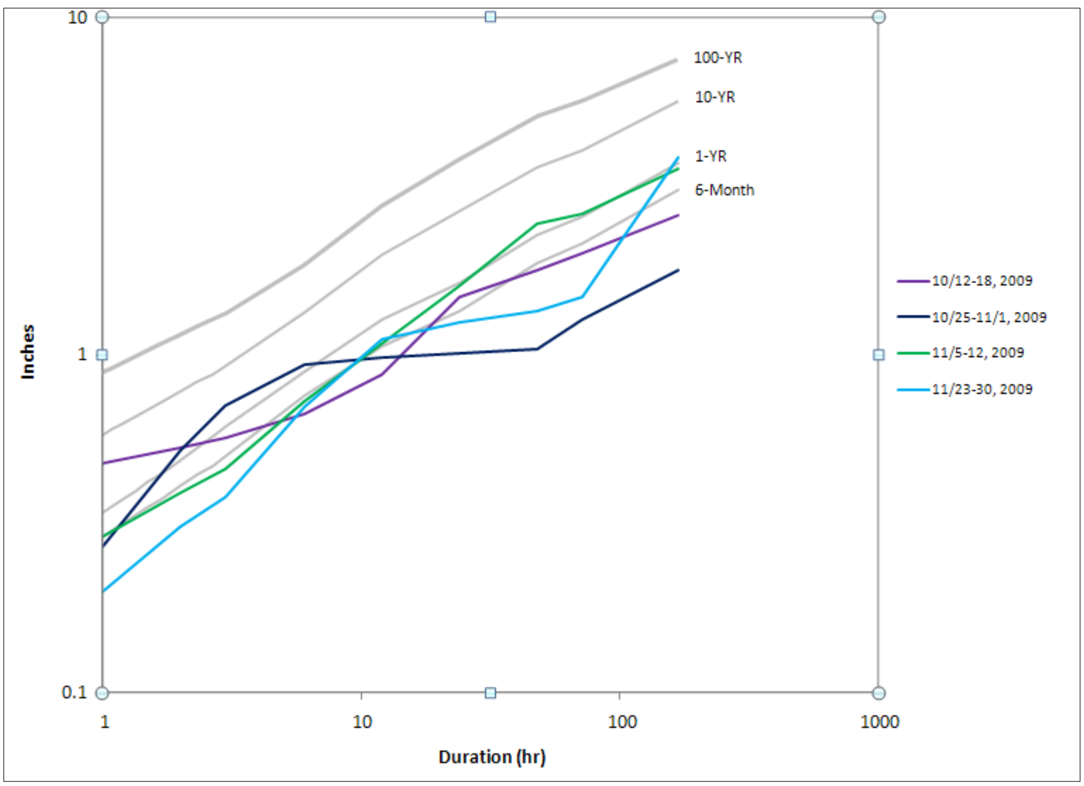

Figure 10. Example depth-duration-frequency curves, RG 15

Table 3. Maximum Recurrence Intervals for Storm Events by Rain Gauge: any Duration from 5 min to 7 days

Selected events			Rain gauge number and maximum return period [a]								
Event #	Start date	End date	RG 02	RG 03	RG 05	RG 08	RG 09	RG 12	RG 15	RG 17	RG 20
1	11/1/2008	11/7/2008	6 mo	< 1 yr	2 yr	~ 2 yr	~ 3 yr	1 yr	1 yr	~ 3 yr	1 yr
2	1/1/2009	1/7/2009	~ 1 yr	1 yr	2 yr	~ 4 yr	~ 3 yr	< 3 yr	1 yr	20 yr	~ 2 yr
3	5/1/2009	5/7/2009	1 yr	1 yr	3 yr	6 mo	1 yr	1 yr	~ 1 yr	1 yr	< 2 yr
4	5/13/2009	5/19/2009	8 yr	20 yr	~ 1 yr	2 yr	1 yr	3 yr	1 yr	1 yr	~ 2 yr
5	9/1/2009	9/8/2009	1 yr	6 mo	2 yr	4 yr	1 yr	6 mo	2 yr	2 yr	1 yr
6	10/12/2009	10/19/2009	4 yr	2 yr	1 yr	1 yr	2 yr	3 yr	4 yr	6 yr	3 yr
7	10/25/2009	11/1/2009	6 mo	< 6 mo	1 yr	6 mo	~ 1 yr	6 mo	2 yr	2 yr	~ 1 yr
8	11/5/2009	11/12/2009	< 6 mo	6 mo	3 yr	2 yr	< 1 yr	2 yr	6 mo	6 mo	~ 1 yr
9	11/14/2009	11/20/2009	< 6 mo	6 mo	5 yr	~ 1 yr	~ 1 yr	6 mo	6 mo	6 mo	6 mo
10	11/21/2009	11/27/2009	1 yr	1 yr	6 mo	< 2 yr	2 yr	1 yr	1 yr	1 yr	1 yr
11	1/8/2010	1/15/2010	1 yr	6 mo	6 mo	< 1 yr	< 2 yr	1 yr	< 1 yr	< 6 mo	< 6 mo
12	5/18/2010	5/25/2010	6 mo	6 mo	2 yr	6 yr	< 6 mo	1 yr	< 6 mo	< 6 mo	< 6 mo

[a] *Indicates approximately; < indicates frequency is between that indicated and the next lower value.*

Flow Monitoring

Overall, the data collected in the 12 CSO basins and system-wide monitoring locations are reliable and representative and provide a solid foundation for hydrologic and hydraulic model calibration. For the 12 basins and the system-wide monitoring locations for which monitoring was conducted during the LTCP Flow Monitoring project, the quality of 96 percent of monitoring data was classified as either “Excellent,” “Good,” or “Some Limitations,” meaning that they are valuable in varying degrees to calibrate and verify hydraulic models. Figure 11 shows the final overall flow monitoring data quality classifications for the 12 uncontrolled CSO basins and the system-wide meters that were monitored during the LTCP Flow Monitoring project.

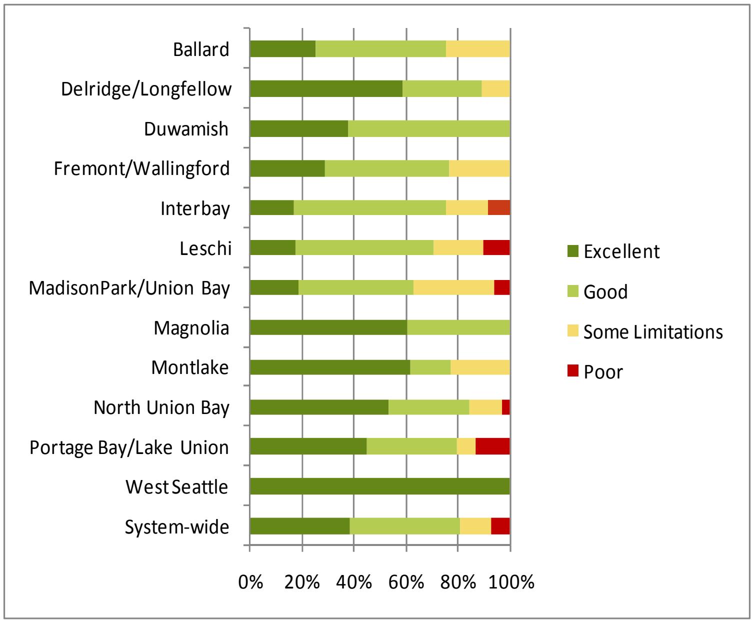

Figure 11. Overall flow monitoring data quality classifications

Ballard Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Ballard Basin were classified overall as shown in Table 4.

Table 4. Overall Flow Monitoring Data Quality, Ballard Basin

Data classification	Meters	Percentage
Excellent	6	25%
Good	12	50%
Some limitations	6	25%
Poor	-	-

Figure 12 shows the overall data quality by individual meter for the Ballard Basin.

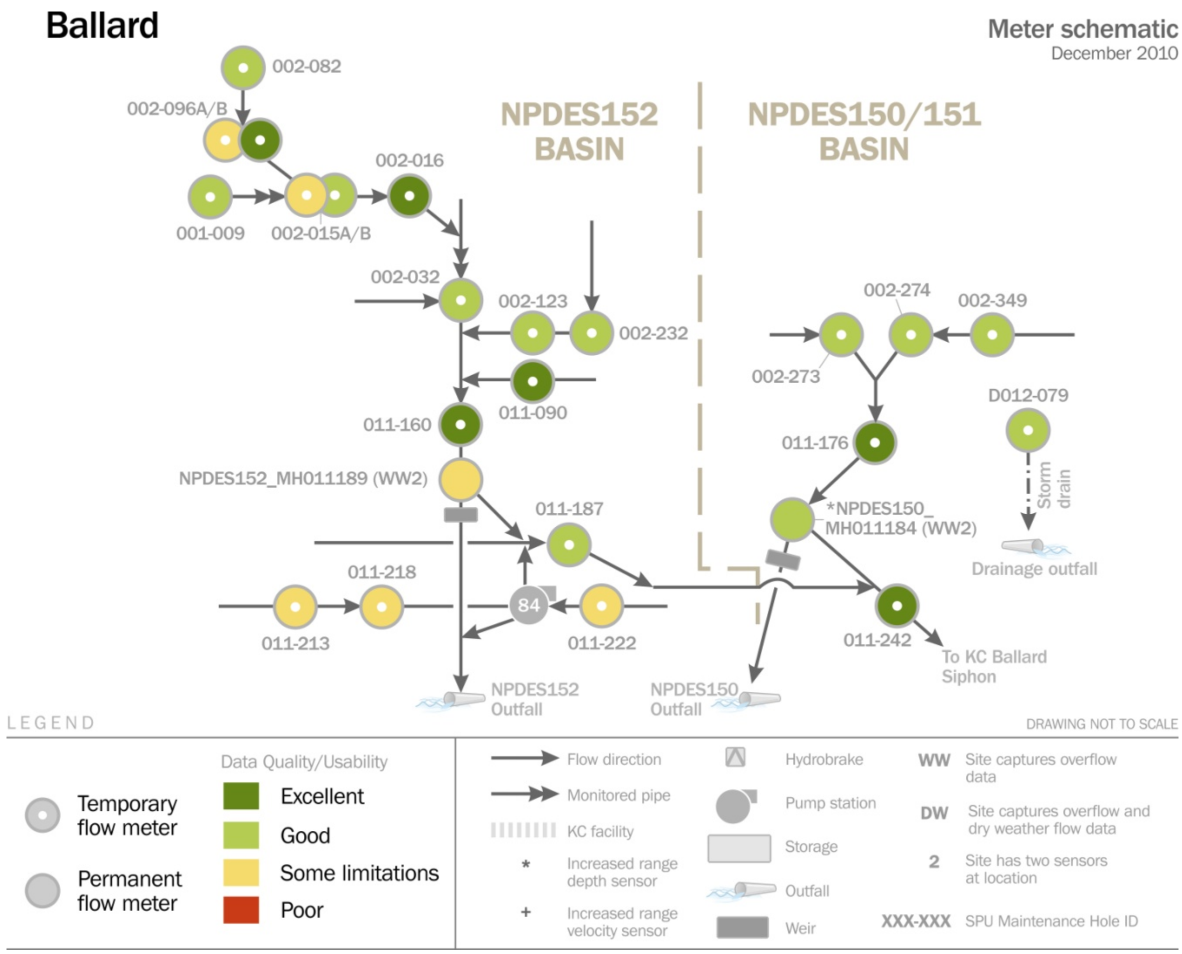

Figure 12. Overall monitoring data quality by meter, Ballard Basin

At the conclusion of the LTCP Flow Monitoring project, the Ballard Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and 15 of the 22 temporary meters were removed. Seven temporary meters remained to continue collecting data for the GSI pilot studies and CSO retrofit project. The permanent meters will continue to be screened for data quality in the future.

Delridge/Longfellow Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Delridge/Longfellow Basin were classified overall as shown in Table 5.

Table 5. Overall Flow Monitoring Data Quality, Delridge/Longfellow Basin		
Data classification	Meters	Percentage
Excellent	21	58%
Good	11	31%
Some limitations	4	11%
Poor	-	-

Figure 13 and Figure 14 show the overall data quality by individual meter for the Delridge/Longfellow Basin.

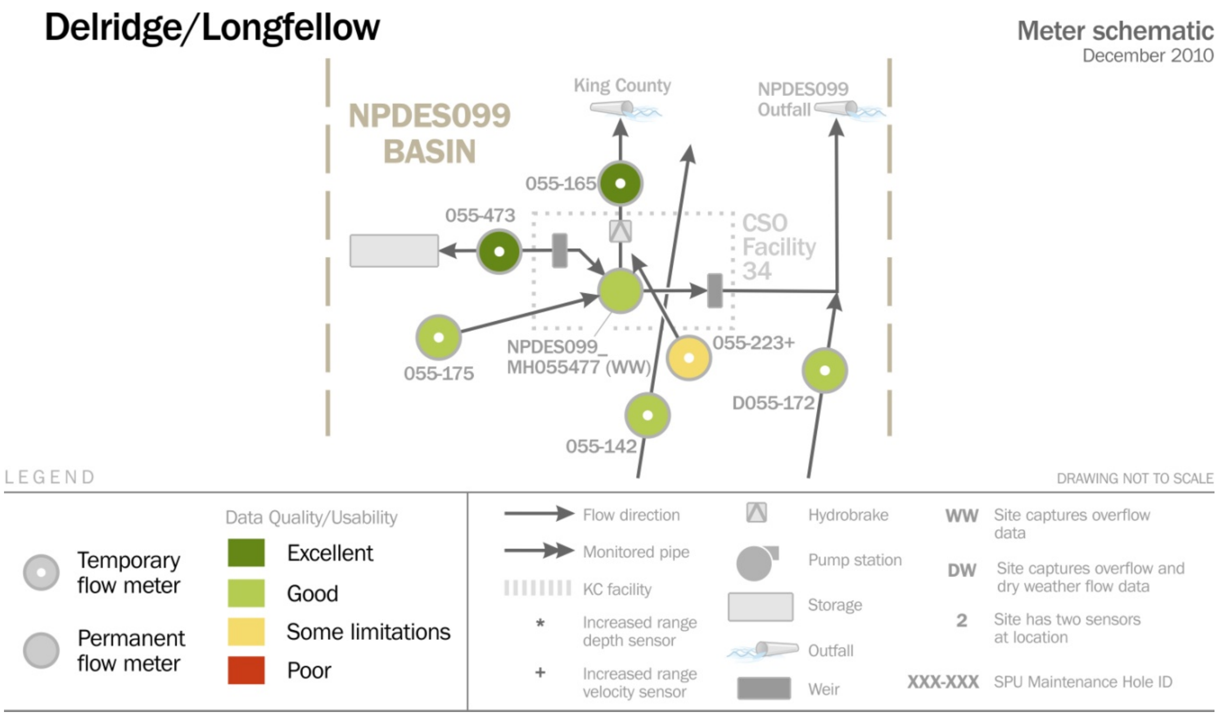

Figure 13. Overall monitoring data quality by meter, Delridge/Longfellow Basin NPDES099

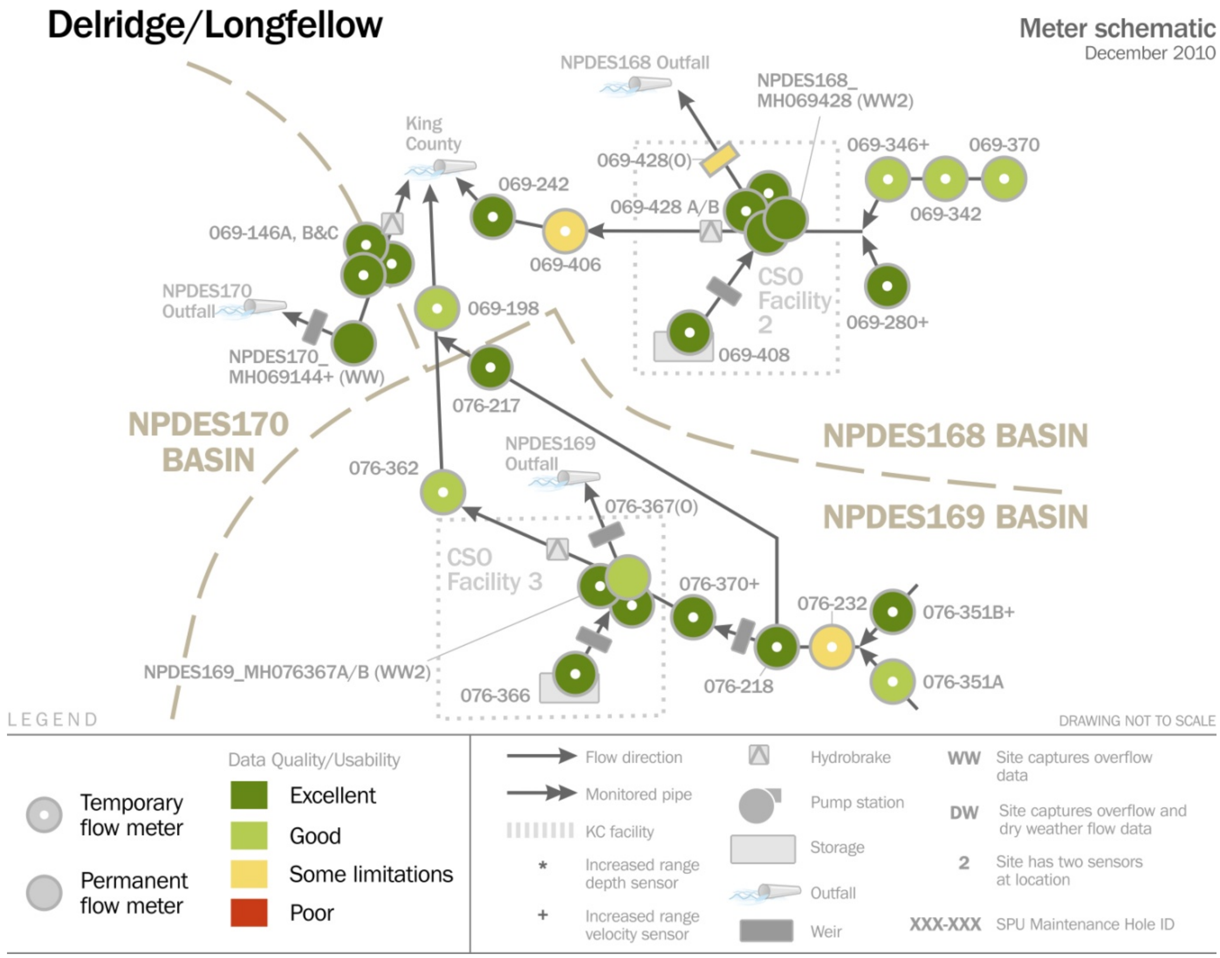

Figure 14. Overall monitoring data quality by meter, Delridge/Longfellow Basin NPDES168–NPDES170

At the conclusion of the LTCP Flow Monitoring project, the Delridge/Longfellow Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and most temporary meters were removed. Four temporary meters remained installed—three recommended for removal shortly after the conclusion of Phase 3 monitoring and one (DEL168_069-406) that will continue to collect data for the CSO retrofit project. The permanent meters will continue to be screened for data quality in the future.

Duwamish Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Duwamish Basin were classified overall as shown in Table 6.

Table 6. Overall Flow Monitoring Data Quality, Duwamish Basin

Data classification	Meters	Percentage
Excellent	6	38%
Good	10	62%
Some limitations	-	-
Poor	-	-

Figure 15 shows the overall data quality by individual meter for the Duwamish Basin.

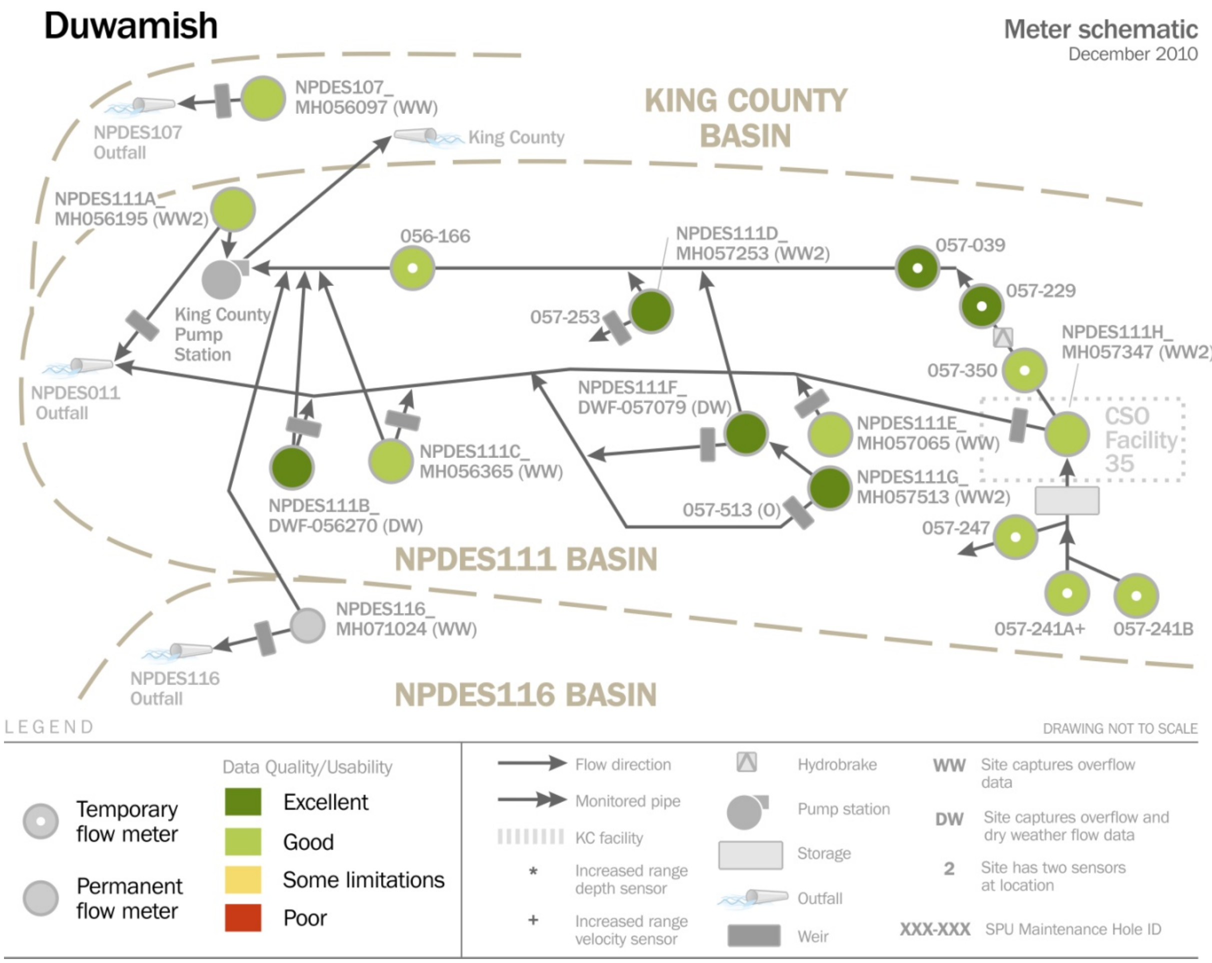

Figure 15. Overall monitoring data quality by meter, Duwamish Basin

At the conclusion of the LTCP Flow Monitoring project, the Duwamish Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all seven temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

Fremont/Wallingford Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Fremont/ Wallingford Basin were classified overall as shown in Table 7.

Table 7. Overall Flow Monitoring Data Quality, Fremont/Wallingford Basin

Data classification	Meters	Percentage
Excellent	6	29%
Good	10	48%
Some limitations	5	23%
Poor	-	-

Figure 16 shows the overall data quality by individual meter for the Fremont/Wallingford Basin.

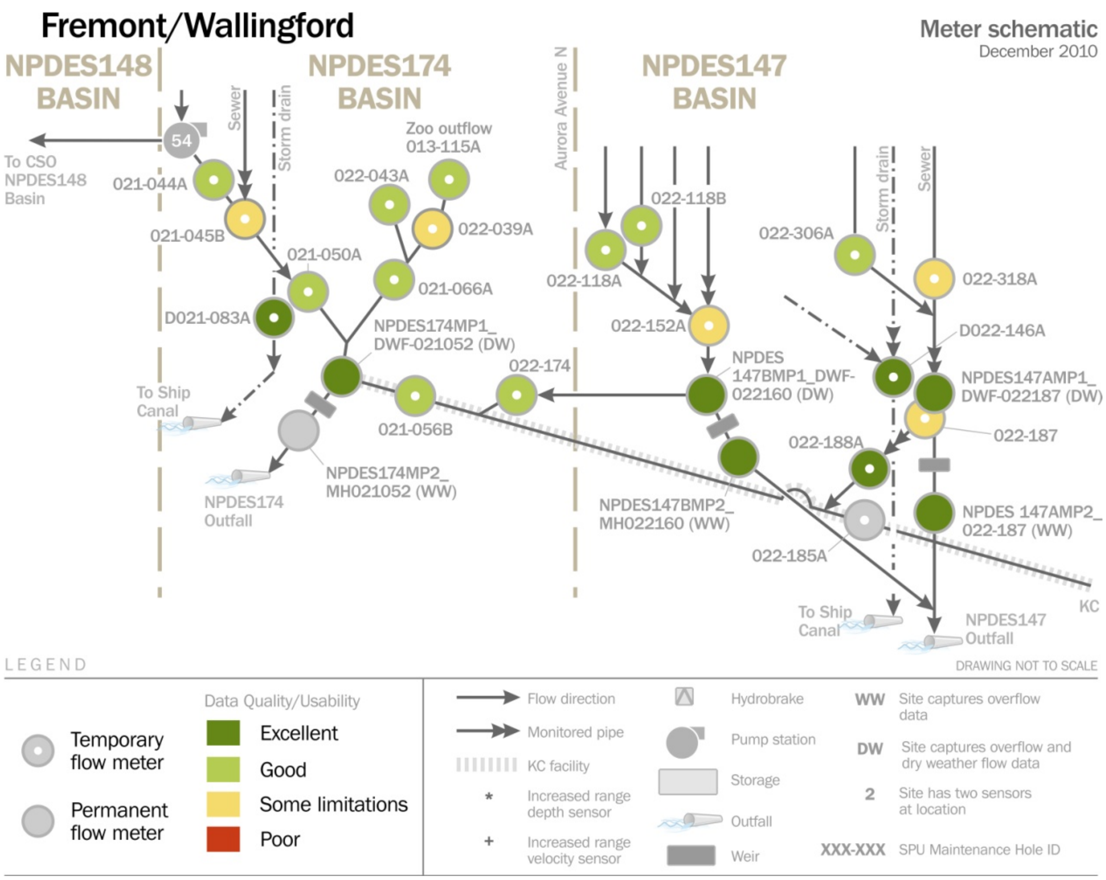

Figure 16. Overall monitoring data quality by meter, Fremont/Wallingford Basin

At the conclusion of the LTCP Flow Monitoring project, the Fremont/Wallingford Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all 18 temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

Interbay Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Interbay Basin were classified overall as shown in Table 8.

Table 8. Overall Flow Monitoring Data Quality, Interbay Basin

Data classification	Meters	Percentage
Excellent	2	17%
Good	7	58%
Some limitations	2	17%
Poor	1	8%

Figure 17 shows the overall data quality by individual meter for the Interbay Basin.

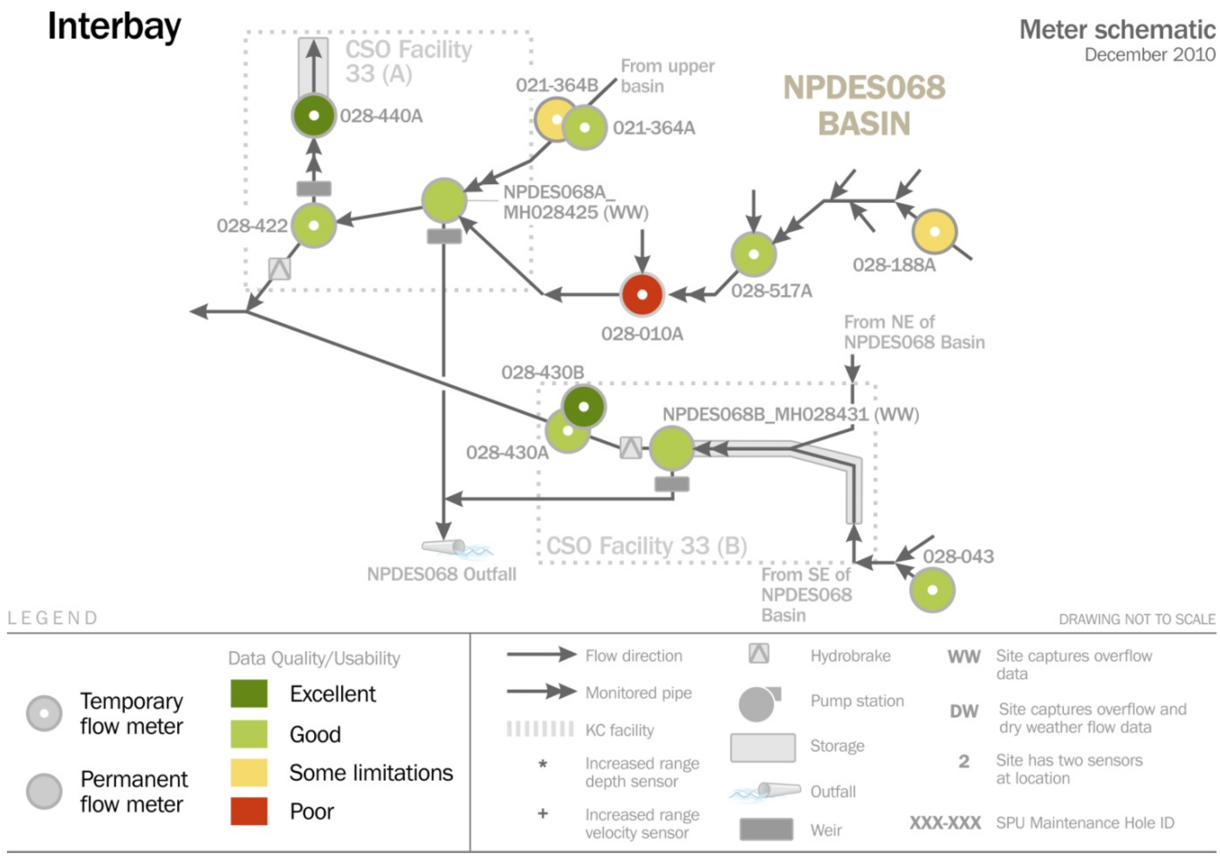

Figure 17. Overall monitoring data quality by meter, Interbay Basin

At the conclusion of the LTCP Flow Monitoring project, the Interbay Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. Most of the temporary meters in the Interbay Basin remained installed at the conclusion of Phase 3 but no additional data were required and all meters were recommended for removal. The permanent meters will continue to be screened for data quality in the future.

Leschi Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Leschi Basin were classified overall as shown in Table 9.

Table 9. Overall Flow Monitoring Data Quality, Leschi Basin		
Data classification	Meters	Percentage
Excellent	10	18%
Good	30	53%
Some limitations	11	19%
Poor	6	10%

Figure 18, Figure 19, and Figure 20 show the overall data quality by individual meter for the Leschi Basin.

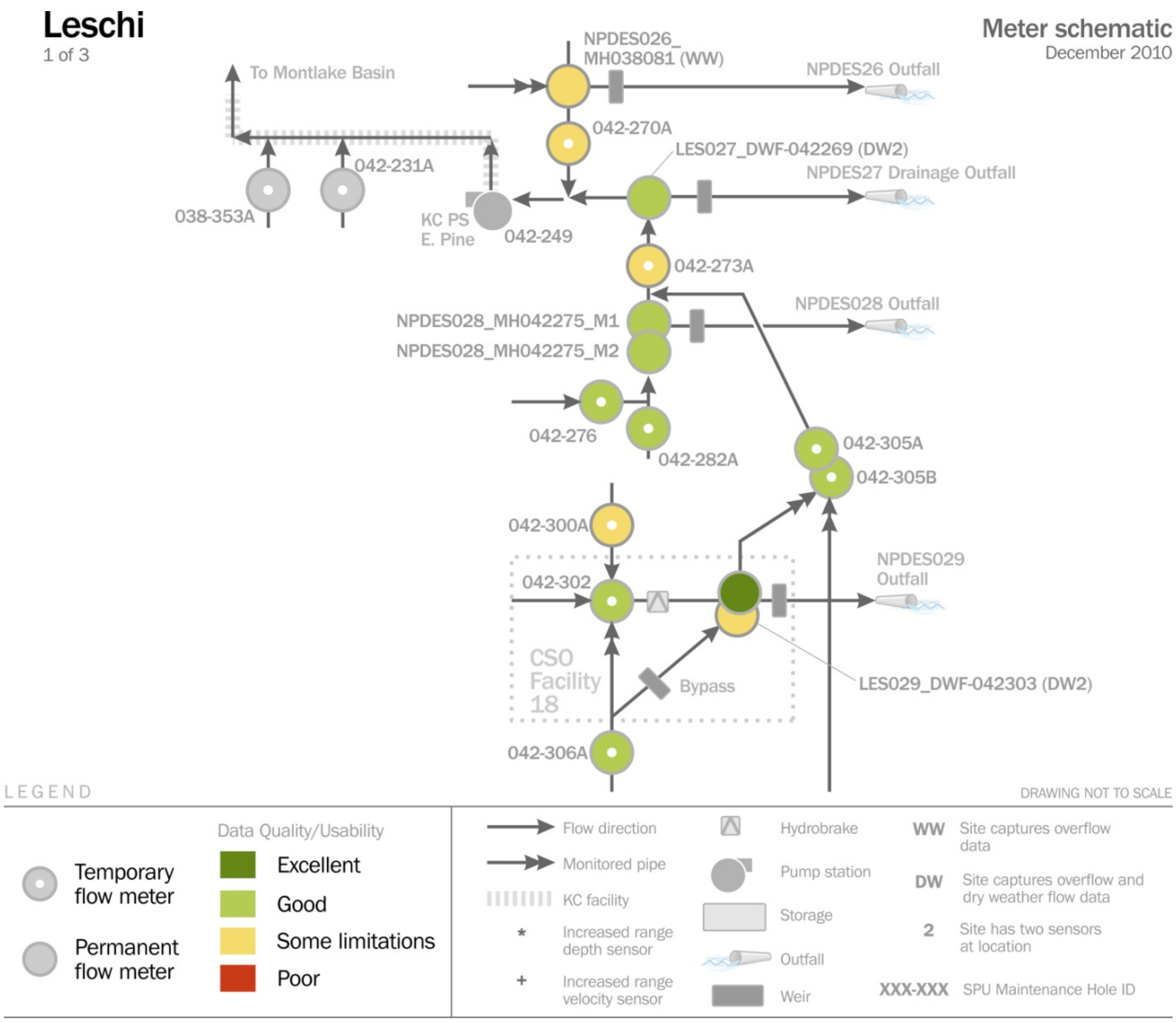

Figure 18. Overall monitoring data quality by meter, Leschi Basins NPDES026–NPDES029

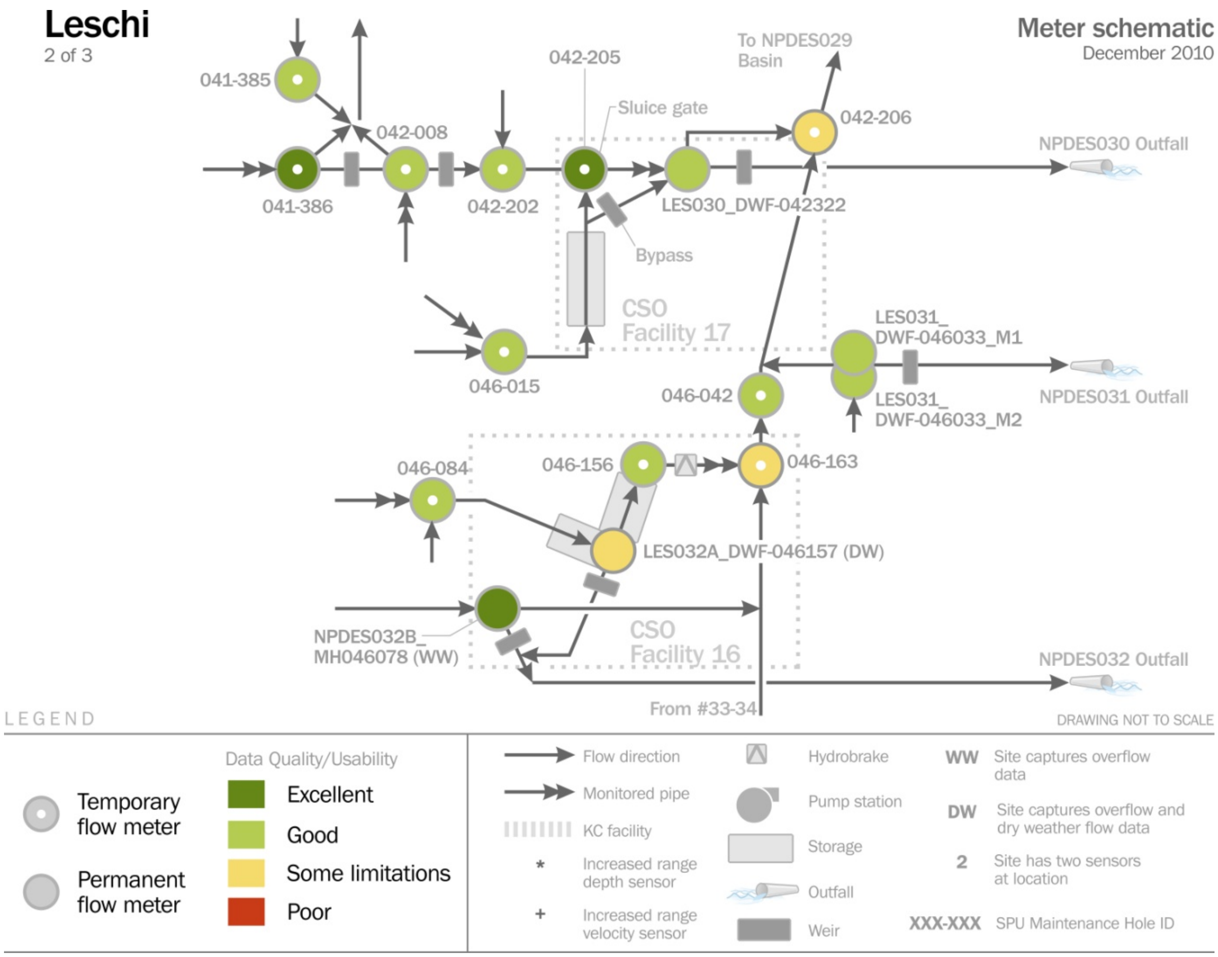

Figure 19. Overall monitoring data quality by meter, Leschi Basins NPDES030–NPDES032

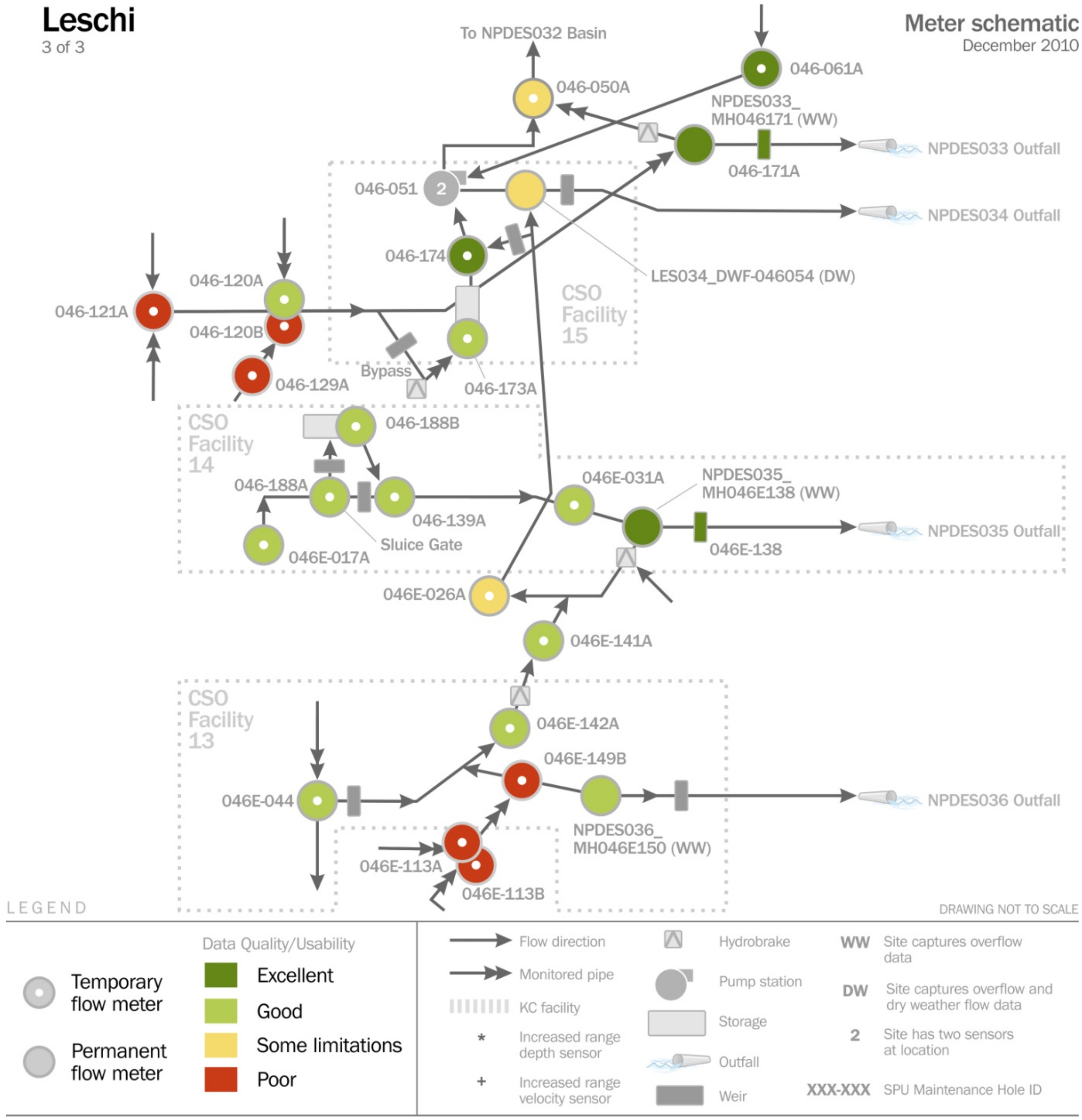

Figure 20. Overall monitoring data quality by meter, Leschi Basins NPDES033–NPDES036

At the conclusion of the LTCP Flow Monitoring project, the Leschi Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. At the conclusion of Phase 3 only five temporary meters remained installed but no additional data were required and all meters were recommended for removal. The permanent meters will continue to be screened for data quality in the future.

Madison Park/Union Bay Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Madison Park/Union Bay Basin were classified overall as shown in Table 10.

Table 10. Overall Flow Monitoring Data Quality, Madison Park/Union Bay Basin

Data classification	Meters	Percentage
Excellent	3	19%
Good	7	44%
Some limitations	5	31%
Poor	1	6%

Figure 21 shows the overall data quality by individual meter for the Madison Park/Union Bay Basin.

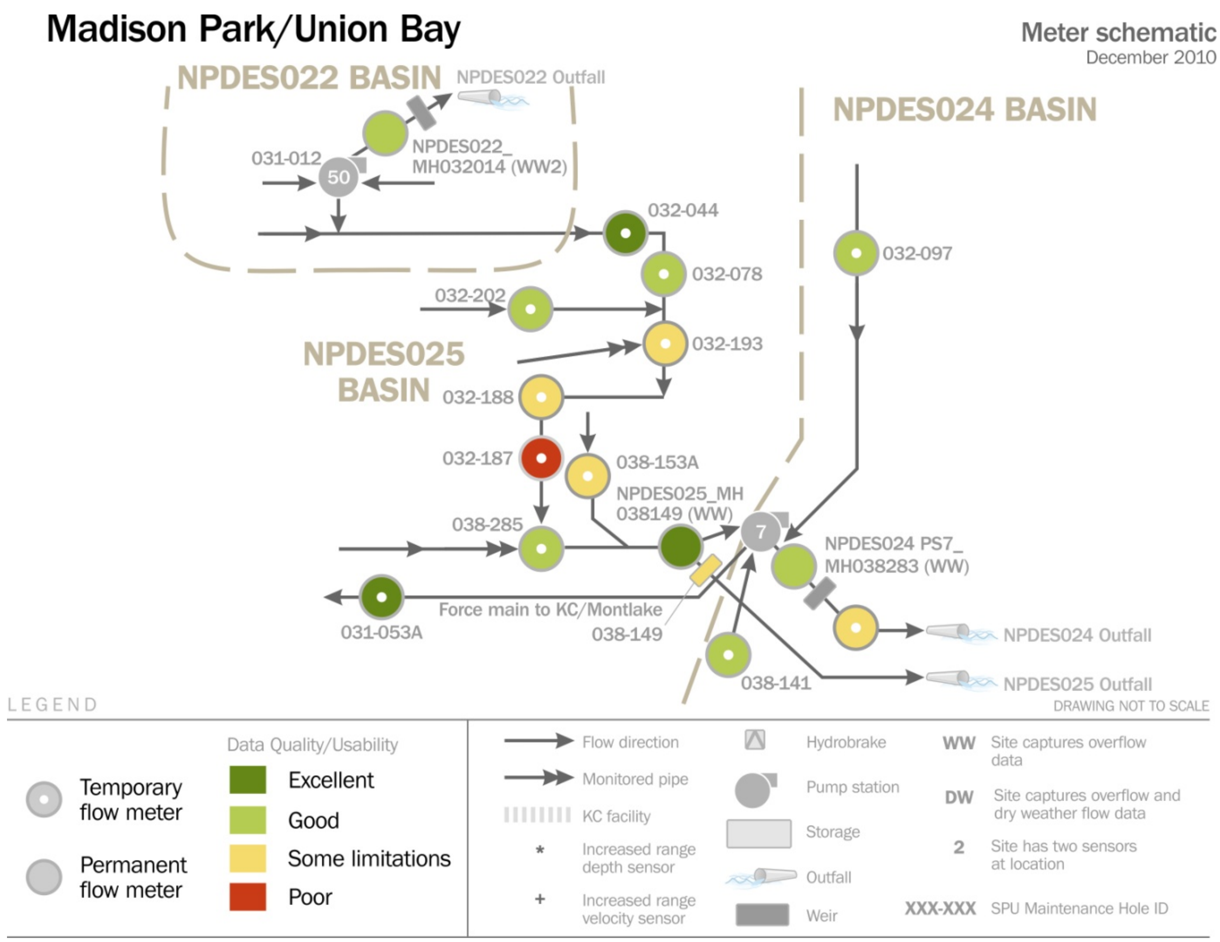

Figure 21. Overall monitoring data quality by meter, Madison Park/Union Bay Basin

At the conclusion of the LTCP Flow Monitoring project, the Madison Park/Union Bay Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all 14 temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

Magnolia Basin

During Phase 1 of the LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Magnolia Basin were classified overall as shown in Table 11. All temporary meters were removed at the conclusion of Phase 1.

Table 11. Overall Flow Monitoring Data Quality, Magnolia Basin

Data classification	Meters	Percentage
Excellent	6	60%
Good	4	40%
Some limitations	-	-
Poor	-	-

Figure 22 shows the overall data quality by individual meter for the Magnolia Basin.

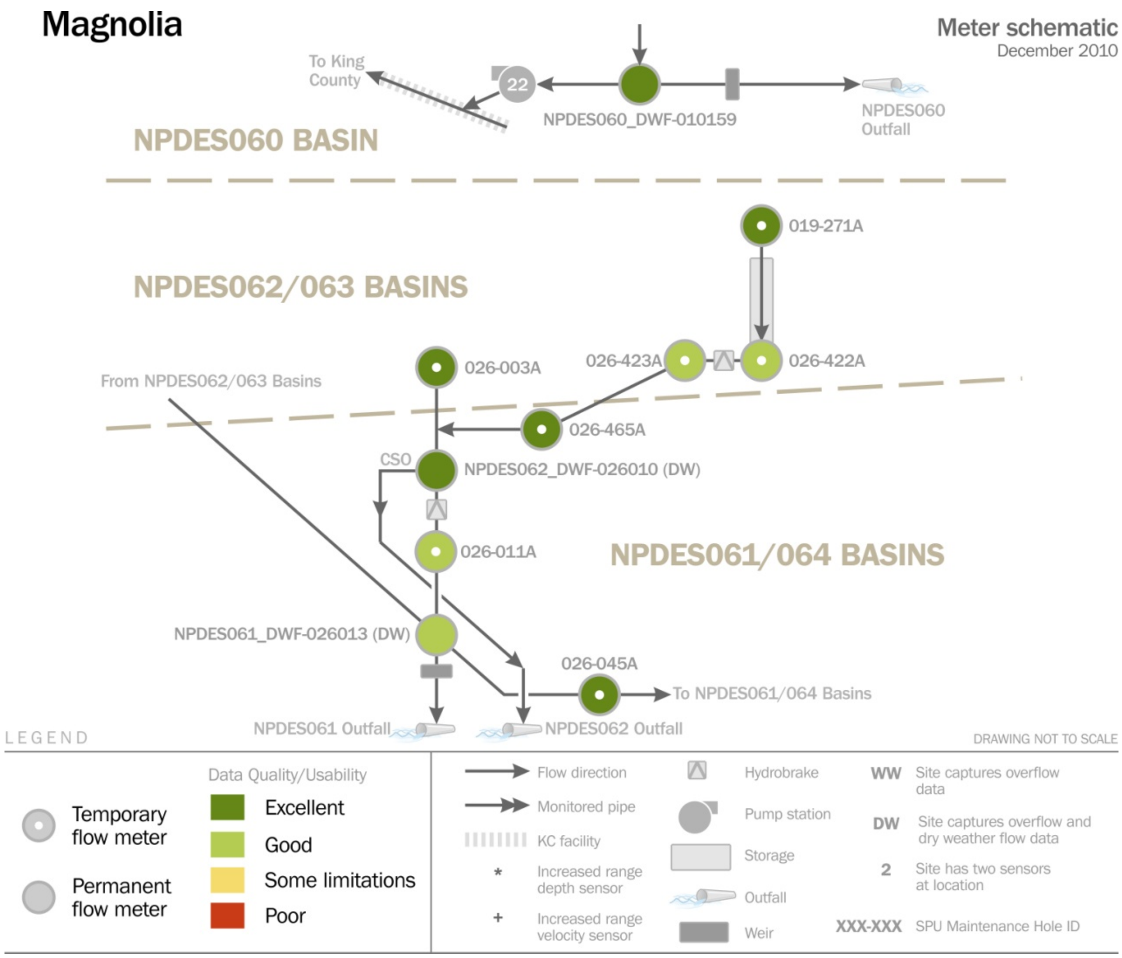

Figure 22. Overall monitoring data quality by meter, Magnolia Basin

At the conclusion of the LTCP Flow Monitoring project, the Magnolia Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all temporary meters were recommended for removal at the conclusion of Phase 1. The permanent meters will continue to be screened for data quality in the future.

Montlake Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Montlake Basin were classified overall as shown in Table 12.

Table 12. Overall Flow Monitoring Data Quality, Montlake Basin		
Data classification	Meters	Percentage
Excellent	8	62%
Good	2	15%
Some limitations	3	23%
Poor	-	-

Figure 23 shows the overall data quality by individual meter for the Montlake Basin.

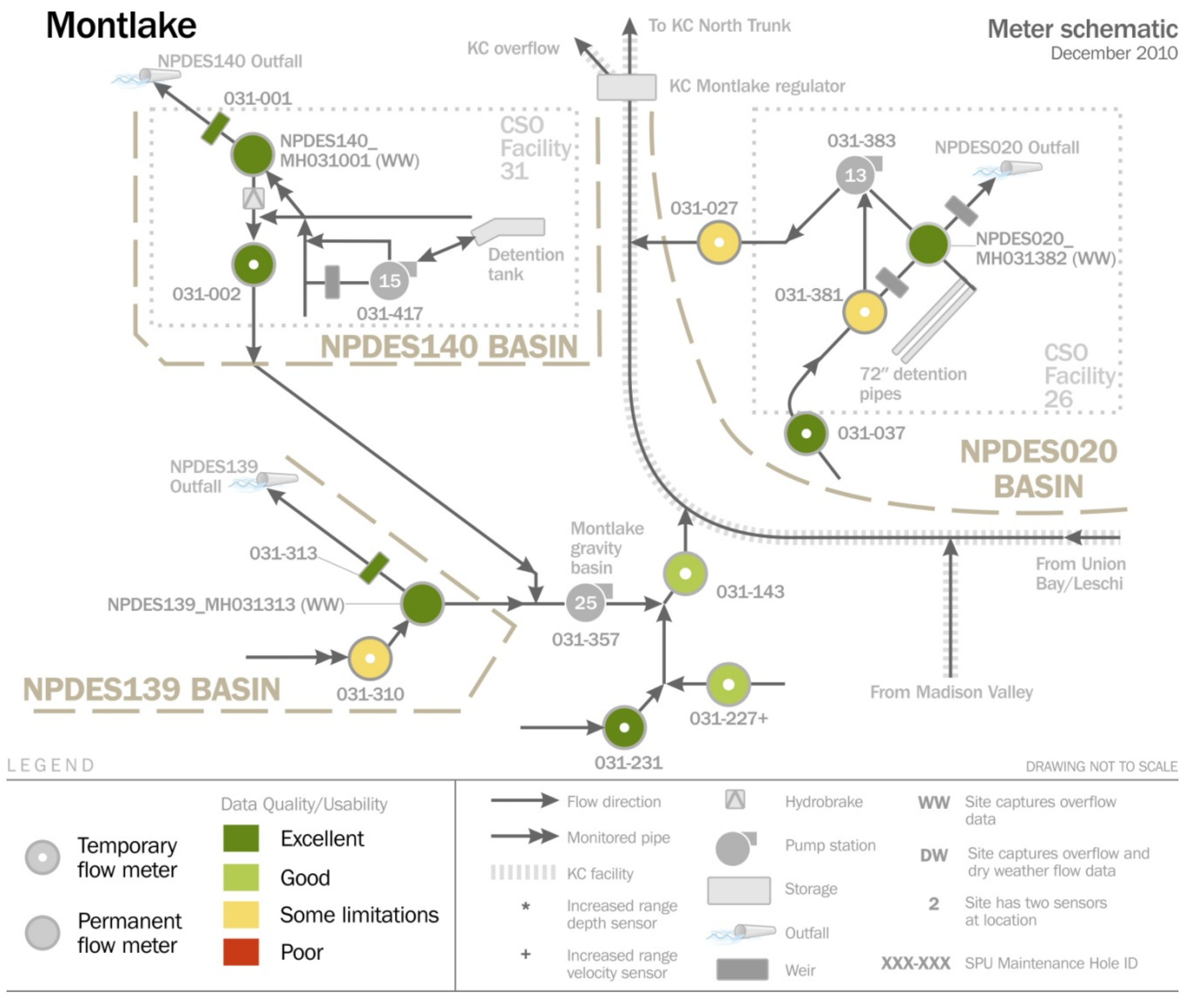

Figure 23. Overall monitoring data quality by meter, Montlake Basin

At the conclusion of the LTCP Flow Monitoring project, the Montlake Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all 10 temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

North Union Bay Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the North Union Bay Basin were classified overall as shown in Table 13.

Table 13. Overall Flow Monitoring Data Quality, North Union Bay Basin

Data classification	Meters	Percentage
Excellent	17	53%
Good	10	31%
Some limitations	4	13%
Poor	1	3%

Figure 24 shows the overall data quality by individual meter for the North Union Bay Basin.

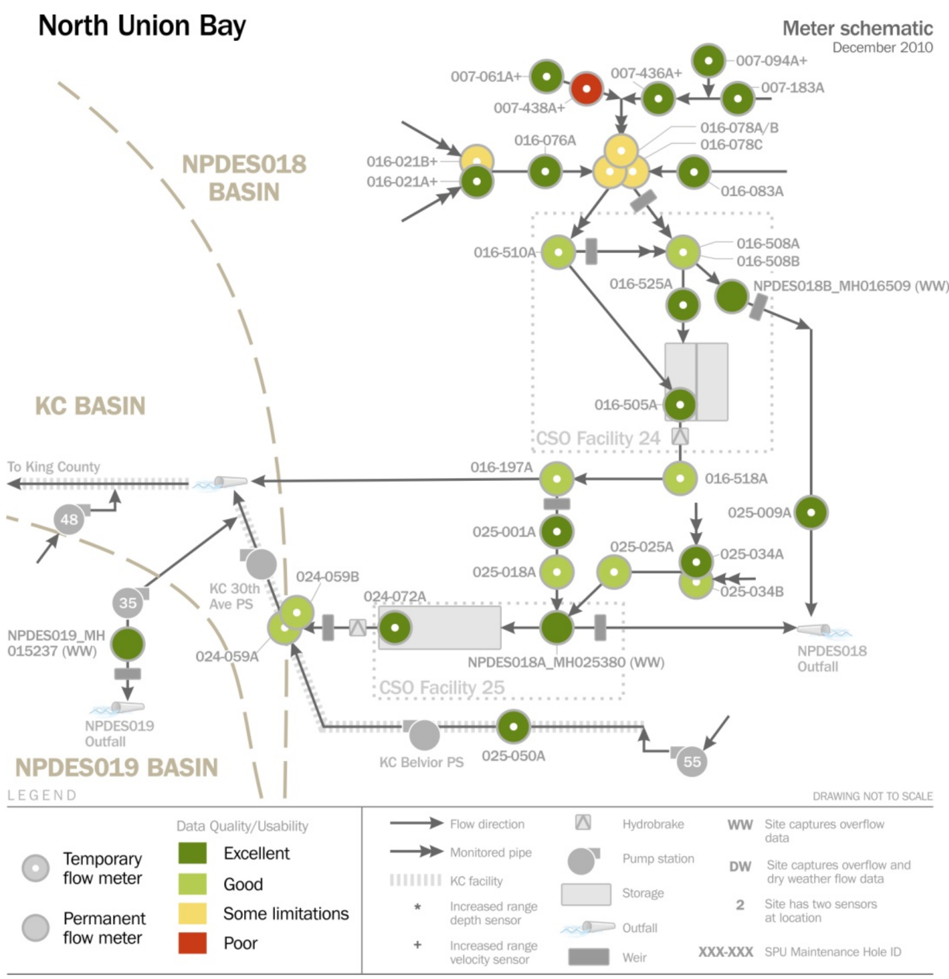

Figure 24. Overall monitoring data quality by meter, North Union Bay Basin

At the conclusion of the LTCP Flow Monitoring project, the North Union Bay Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all 26 temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

Portage Bay/Lake Union Basin

Over the 2-year LTCP Flow Monitoring project, the monitoring data yielded by the meters in the Portage Bay/Lake Union Basin were classified overall as shown in Table 14.

Table 14. Overall Flow Monitoring Data Quality, Portage Bay/Lake Union Basin

Data classification	Meters	Percentage
Excellent	13	45%
Good	10	34%
Some limitations	2	7%
Poor	4	14%

Figure 25 shows the overall data quality by individual meter for the Portage Bay/Lake Union Basin.

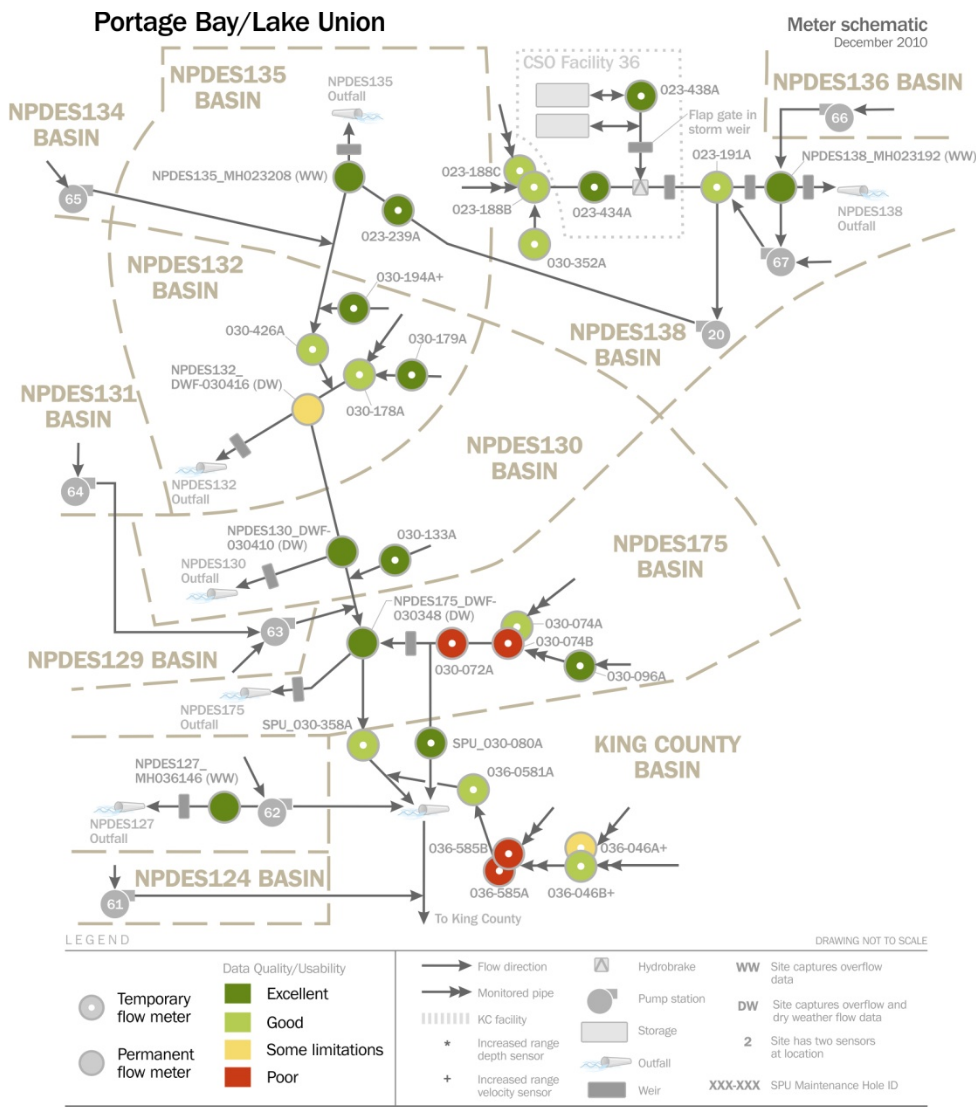

Figure 25. Overall monitoring data quality by meter, Portage Bay/Lake Union Basin

At the conclusion of the LTCP Flow Monitoring project, the Portage Bay/Lake Union Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all 23 temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

West Seattle Basin

During Phase 1 of the LTCP Flow Monitoring project, the monitoring data yielded by the meters in the West Seattle Basin were classified overall as shown in Table 15. All temporary meters were removed at the conclusion of Phase 1.

Table 15. Overall Flow Monitoring Data Quality, West Seattle Basin

Data classification	Meters	Percentage
Excellent	4	100%
Good	-	-
Some limitations	-	-
Poor	-	-

Figure 26 shows the overall data quality by individual meter for the West Seattle Basin.

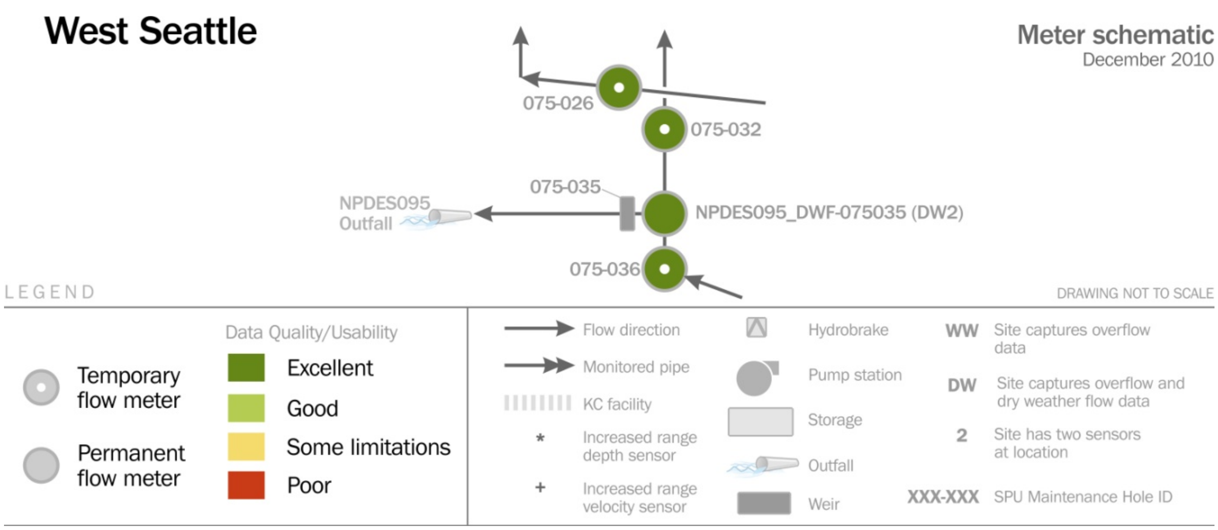

Figure 26. Overall monitoring data quality by meter, West Seattle Basin

At the conclusion of the LTCP Flow Monitoring project, the West Seattle Basin produced reliable, representative flow monitoring data that can be used to calibrate and verify hydraulic models. No additional data needed to be collected and all temporary three temporary meters were removed. The permanent meters will continue to be screened for data quality in the future.

System-Wide Meters

Over the 2-year LTCP Flow Monitoring project, the dry weather flow and wet weather flow monitoring data yielded by the system-wide meters located across the city were classified overall as shown in Table 16.

Table 16. Overall Flow Monitoring Data Quality, System-Wide Meters

Data classification	Meters	Percentage
Excellent	20	38%
Good	22	42%
Some limitations	6	12%
Poor	4	8%

Figure 27 shows the overall data quality by individual meter for the North Seattle area system-wide meters.

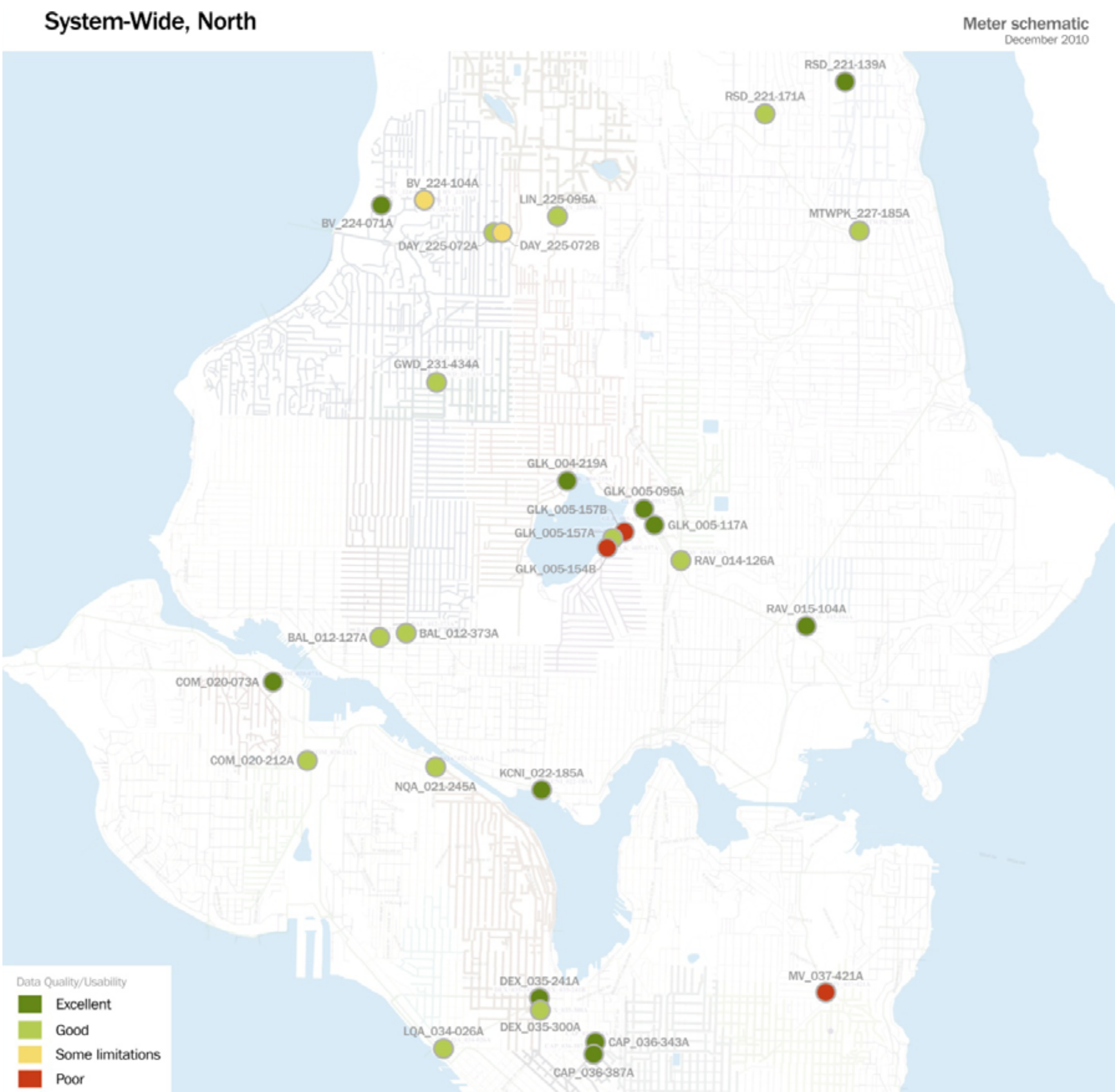

Figure 27. Overall monitoring data quality by meter, system-wide meters, North Seattle

Figure 28 shows the overall data quality by individual meter for the South Seattle area system-wide meters.

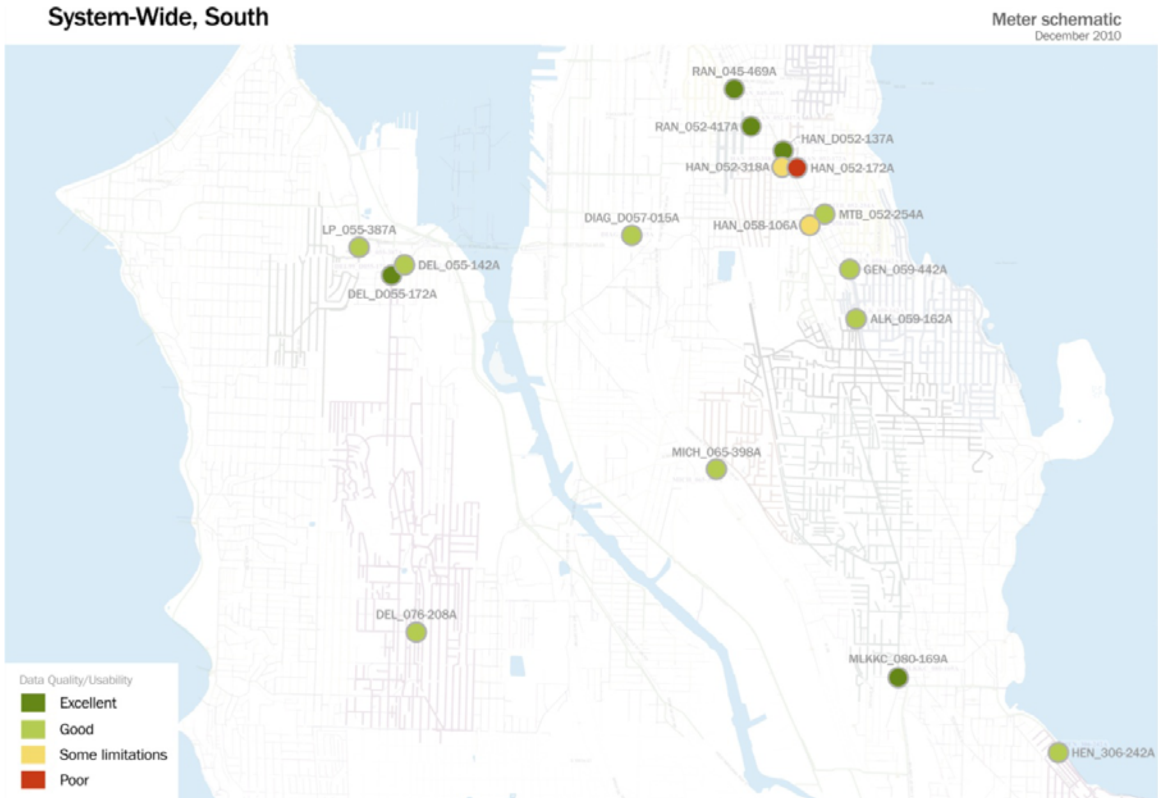

Figure 28. Overall monitoring data quality by meter, system-wide meters, South Seattle

At the conclusion of the LTCP Flow Monitoring project in all 12 CSO basins on 5/31/2010, no additional data needed to be collected and most meters were removed. The permanent meters should continue to be screened for data quality in the future. Of the 50 temporary meters installed in strategic locations to collect system-wide flow data, 17 were left in place at the conclusion of the LTCP Flow Monitoring project to continue collecting data for the system-wide model calibration.

Conclusion

The 2-year LTCP Flow Monitoring project successfully collected reliable, representative rainfall, flow monitoring, and operational data from across the city, and achieved its key objectives:

- It adequately and accurately characterized the hydrologic and hydraulic performance of the combined sewers by collecting rainfall depth, level, velocity, and system operational data. A total of 96 percent of the flow monitoring data collected were classified as "Excellent," "Good," or "Some Limitations," meaning that they are considered suitable for model calibration. It captured data before, during, and after a wide range of storm events with a range of antecedent moisture conditions, meeting the recurrence-interval criteria defined in the QAPP.
- It captured storm events that are recommended for model calibration. In addition, the characteristics of the rainfall that occurred provide excellent opportunities to calibrate both the impervious runoff and groundwater flows in the models. No further monitoring is required to support calibration of hydrologic and hydraulic models in the basins covered by this project.

In summary, the data collected from the 12 CSO basins and the system-wide flow monitoring locations, combined with the rainfall data also collected, provide a solid foundation for hydrologic and hydraulic model calibration and subsequent development of CSO reduction strategies.

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Quality Assurance Project Plan: SPU CSO Reduction Program, CSO Long-Term Control Plan, Flow Monitoring Plan—Phase 1 (October 1, 2008 through May 31, 2009), Revision R1D0, Seattle Public Utilities, December 18, 2009.

Quality Assurance Project Plan: SPU CSO Reduction Program, CSO Long-Term Control Plan, Flow Monitoring Plan—Phases 2 and 3 (October 1, 2009 through May 31, 2010), Revision R1D0, Seattle Public Utilities, December 14, 2009.

2010 CSO Reduction Plan Amendment, Seattle Public Utilities, May 2010.