Modeling Plan

Henderson Combined Sewer Overflow Reduction Plan Project

Henderson Modeling Plan

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For

Seattle Public Utilities

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Contents

Appendix

Acronyms

AD	above datum, as in elevation in feet above datum
ADS	ADS Environmental
BSF	base sanitary flow
CSO	combined sewer overflow
CSS	combined sewer system (equivalent to the 'PS' designation within SPU)
DWF	dry-weather flow
GIS	geographic information system
GLUE	Generalized Likelihood Uncertainty Estimation
gpcd	gallons per capita per day
gpm	gallons per minute
H&H	hydraulics and hydrology
HGL	hydraulic grade line
KC	King County
LS	lift station
MH	maintenance hole
MLK	Martin Luther King
MLLW	mean lower low water
NAVD88	North American Vertical Datum established in 1988
NMC	Nine Minimum Control
NPDES	National Pollutant Discharge Elimination System
PF	peaking factor
QA/QC	quality assurance/quality control
RDI/I	rainfall dependent inflow/infiltration
SCADA	supervisory control and data acquisition
SPU	Seattle Public Utilities
USACE	U.S. Army Corps of Engineers

Introduction

This document summarizes Seattle Public Utilities' (SPU's) needs and goals for the hydraulic model of its combined sewer system (CSS) and the essential attributes of the model. The CSS conveys both domestic and stormwater flows. Within SPU, '*PS*' is often used to differentiate the *public combined system* and is equivalent to the CSS reference in this modeling plan.

1.0 Project Background

The Washington State Department of Ecology (Ecology) administers the City of Seattle's (the City's) National Pollutant Discharge Elimination System (NPDES) permit for combined sewer overflow (CSO) outfalls. The City developed the Combined Sewer Overflow Reduction Plan Amendment in December 2001 and subsequently issued an amendment update in 2005, which outlines plans to comply with permit conditions. The City is required to abide with a compliance schedule designed to achieve the greatest reasonable reduction of CSOs at the earliest possible date. The City's goal is to reduce CSOs to the Washington State Regulation of an average of one untreated CSO per year per outfall by the year 2020. A review of Water Quality Standards is being performed by SPU's Water Quality Business Unit, which will provide input on how to meet Water Quality Standards.

The 2001 Plan describes a series of projects intended to comply with regulatory requirements through a mix of best management practices, off-line storage, and structural modifications to existing facilities. The Henderson Basin was identified as one of the project areas and comprises seven sub-basins corresponding to CSO outfalls designated by NPDES Numbers 44, 45, 46, 47, 48, 49, and 171.

Recent CSO reporting to Ecology and a review of historical CSO volumes from 1998 to 2007 indicate that CSO sub-basins 46 and 48 are controlled and sub-basins 44, 45, 47, 49, and 171 are not controlled to Ecology standards. Controlled basins are defined as those that meet the limit of one untreated CSO per year per outfall based on a rolling 5-year average. The 2005 Plan Amendment indicated an anticipated construction completion date of 2015 for the South Henderson CSO Storage Project. (See Figure 2 in Section 2.0, Modeling Goals and Objectives, for a map of the Henderson Basin.)

1.1 Problem

Based on historical overflow data, CSOs currently exceed one untreated discharge per year on average in Henderson sub-basins 44, 45, 47, 49, and 171.

1.2 Project Goal

The goal of SPU's South Henderson Combined Sewer Overflow Reduction Plan Project is to develop and evaluate alternatives that support the project objectives (see Section 1.3, Project Objectives) and reduce CSOs to the Washington State Regulation of an average of one untreated CSO per year per outfall by 2020.

1.3 Project Objectives

The project objectives include the following:

1. Submit a CSO reduction plan (engineering report) to Ecology by December 31, 2010.
2. Develop a plan that is technically feasible and financially responsible.
3. Coordinate the CSO project with King County's (KC's) wastewater system.
4. Coordinate with affected communities and neighborhood groups.
5. Control odors to meet Puget Sound Clean Air Agency Standards.
6. Comply with Nine Minimum Control (NMC) CSO requirements for solid and floatable materials.
7. Implement a post-construction monitoring program to measure the effectiveness of the CSO controls and demonstrate the attainment of water quality standards.

To assist SPU in developing the CSO reduction strategies and facilities, the existing hydraulic model must be updated to reflect monitoring data collected from January 2008 through approximately June 2009 and refined to support the alternatives analysis for the seven Henderson sub-basins (that is, 44, 45, 46, 47, 48, 49, and 171). The updated comprehensive InfoWorks hydraulic model will to be used to characterize the Henderson combined sewer system and CSO activity, aid in development of a long-term CSO control plan, and identify and prioritize capital improvements.

2.0 Modeling Goals and Objectives

2.1 Characterize Existing System (Hydraulic and Hydrologic Performance)

The model will be used to evaluate hydraulic grade lines (water levels), velocities, and flow rates throughout the Henderson Basin under varying conditions based on historical precipitation and known boundary conditions. The model must address the following objectives:

- Characterize the performance of the existing Henderson CSO diversion structures, outfall structures, storage facilities, conveyance pipes, and hydrobrakes
- Simulate SPU Lift Stations 9, 10, and 80 and KC South Henderson Street Lift Station
- Characterize the hydrologic performance of the basin
- Identify hydraulic capacity deficiencies within the basin
- Predict long-term simulation CSO frequency, volumes, and flow rates
- Provide for the evaluation of CSO reduction alternatives

SPU recognizes that a risk-based approach is needed to provide information to SPU decision-makers for evaluating options for sizing of control facilities to meet compliance targets with CSO reduction variability. As a result, the hydraulic model developed as part of the Henderson project will undergo several refinements, as summarized in Figure 1, (derived from MGS Engineering Consultants Inc., Figure 1.1). The final hydraulic model will be used to apply probabilistic and risk-based methods for estimating the control volumes needed for reducing the frequency of CSOs.

2.2 Impacts on Downstream System

2.2.1 Boundary of Model and Downstream Boundary Condition

As seen in Figure 2, all flow from Henderson Basin discharges into the KC Metro system through the Henderson trunk sewer. Flow into the trunk sewer is from the following sources:

- KC Henderson lift station (LS)
- Flow from NPDES Basin 47 from both the north and the south along Henderson Street
- Flow from KC system through maintenance hole (MH) 080-368

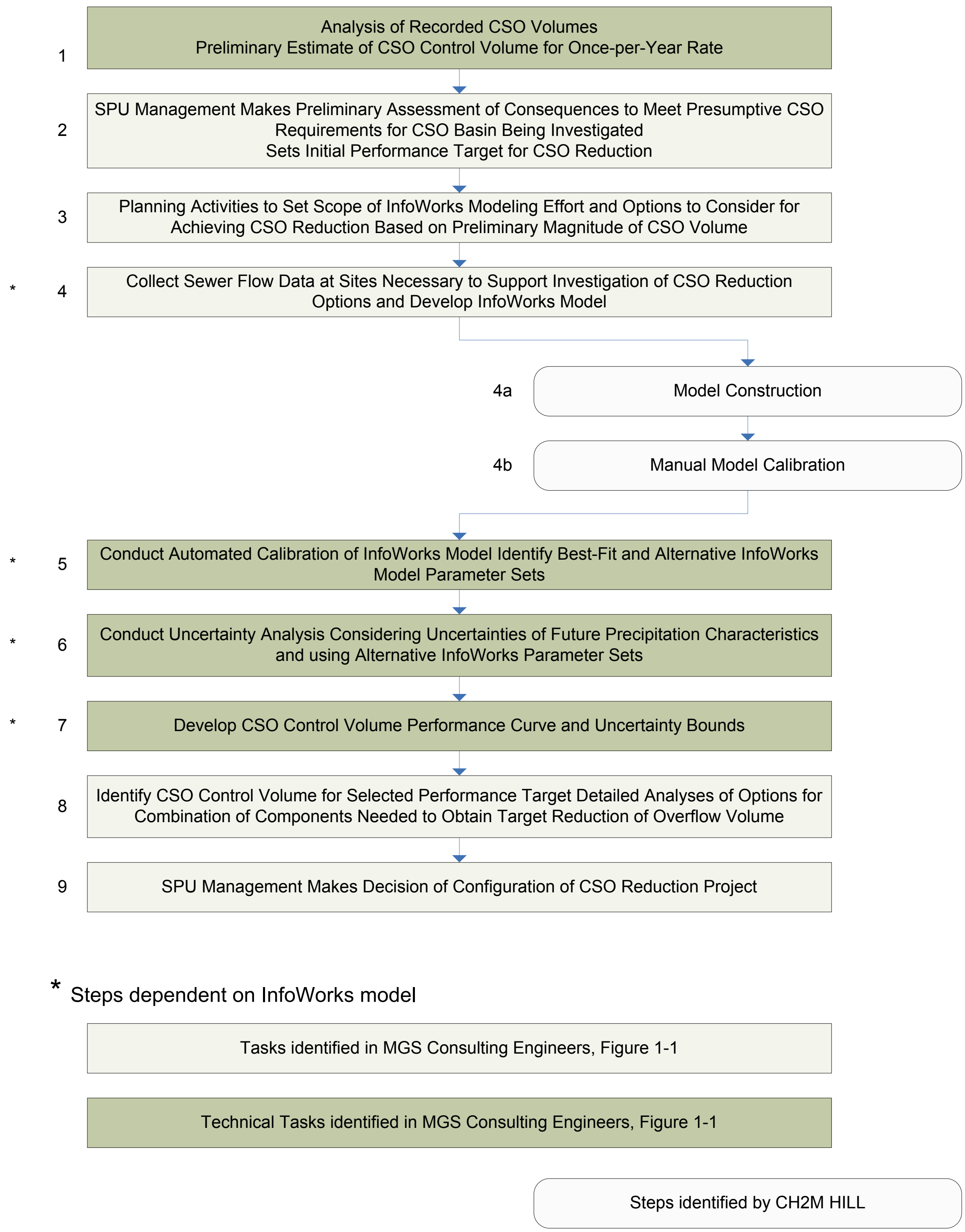

FIGURE 1. **HENDERSON COMBINED SEWER OVERFLOW REDUCTION PROJECT PROCESS RELYING ON INFOWORKS MODEL**

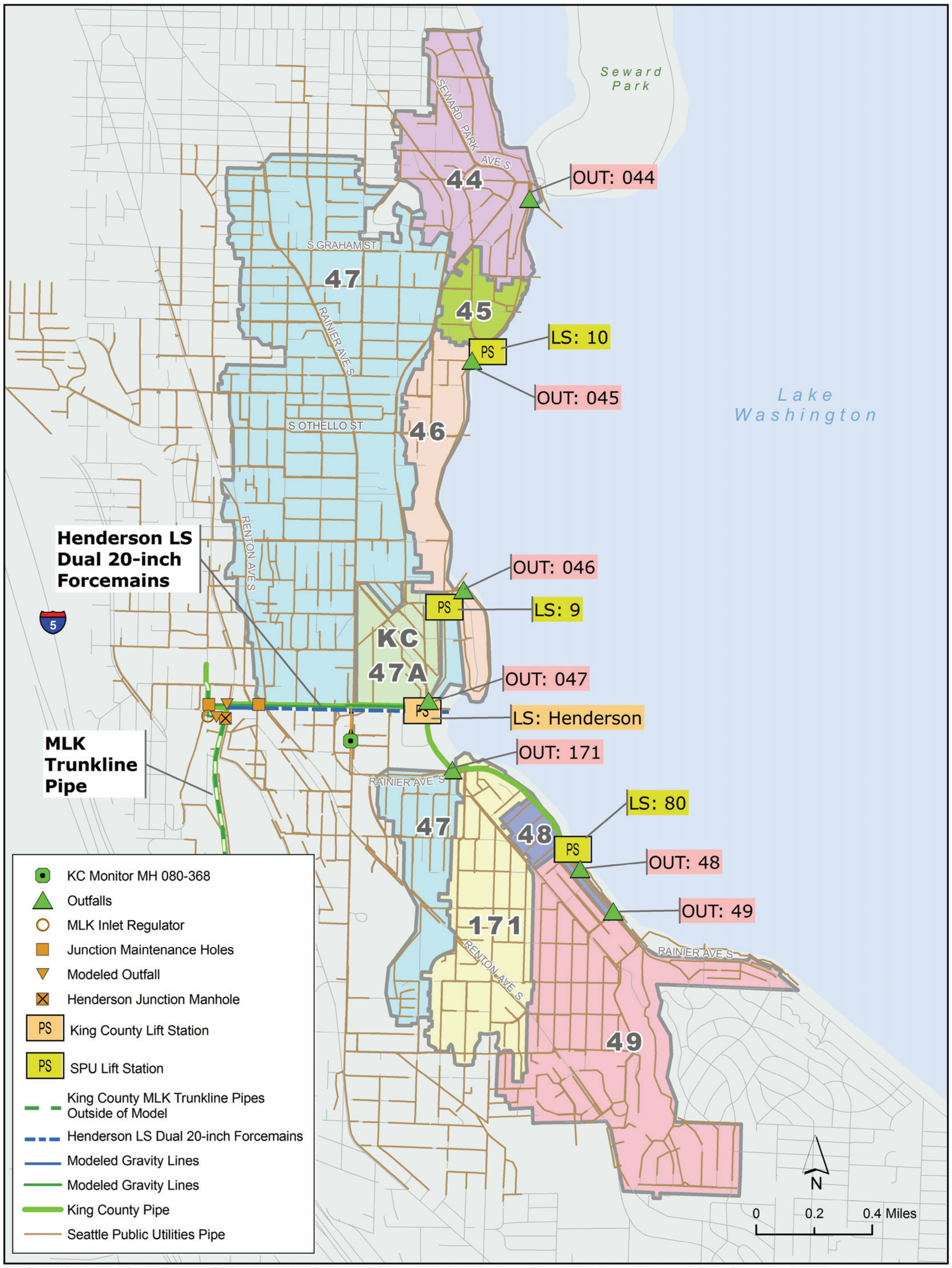

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FIGURE 2. HENDERSON BASIN AND KING COUNTY FACILITIES

Flow is conveyed west then south along the Henderson trunk where discharge to the KC Henderson tunnel may occur. Discharges to the KC Henderson tunnel occur during high flow events based on a complex control system based on KC system capacity at various points in the KC system. Because of the hydraulic connection with the KC system, the model and alternatives analysis must account for both the impacts by the KC system on the Henderson system and vice versa.

Developing accurate flow hydrographs from the KC Henderson Street Lift Station, all the NDPES basins including NPDES 47, and CSO outfall discharges will be critical objectives of the model and used to estimate the impact on the downstream KC Metro system and receiving waters.

2.2.2. Downstream Boundary Constraints

Flow from the Rainier Beach community in the Henderson Basin is conveyed through the Henderson List Station discharging through dual 20-inch-diameter force mains into the 42-inch Henderson trunkline. Additional flow is contributed from Basin 47 from both the south and north as well as from the KC Martin Luther King (MLK) trunk. During typical operation, flow is conveyed through the Henderson Junction MH continuing into the Henderson Trunk; however during periods of heavy precipitation flow is diverted from the trunk into the 14-foot-diameter Henderson/MLK tunnel at 42nd Avenue South and South Fairbanks Street. As the flows are drained from the tunnel, they are conveyed west in 72-inch pipelines under Interstate 5 and rail lines to Airport Way South. From there, flows can be sent to either the King County West Point Treatment Plant in the City's Magnolia area or the King County South Treatment Plant in Renton.

The downstream conditions in the KC system may affect the hydraulic performance in the Henderson Basin and must be incorporated into the model. Coordination with KC to identify the downstream conditions will be included in the model.

2.3 Identification of Alternatives to Reduce CSOs

2.3.1 Presumptive Approach

Ecology's requirement is up to one untreated discharge event per year per CSO outfall, on average. It has been presumed that satisfying the Ecology untreated CSO discharge frequency will meet the water quality standards.

2.3.2 Types of Alternatives to be Evaluated

Table 1 summarizes the types of alternatives that may be evaluated for the project. The list will be finalized as the model is calibrated and the uncertainty analysis process is completed.

TABLE 1. HENDERSON CSO CONTROL CONCEPTUAL OPTIONS

CSO Control Options	Specific Conceptual CSO Control Option
Conveyance System	I/I removal
	Passive or active controls (that is, real time control)
	Increased maintenance cycles
	Increased conveyance capacity
	Sewer Separation
	Inter-basin and intra-basin (SPU) flow transfer
Demand Management	Diversion of stormwater away from combined sewer within public right-of-way, including low impact development practices
	Diversion of stormwater away from combined sewer on private property, including low impact development practices
Storage	In-line storage
	Off-line storage
KC CSO Treatment	CSO flow transfer to KC sewer system
	CSO flow transfer directly to KC CSO Treatment Plant
SPU CSO Treatment	CSO Treatment (CSO discharges only)
	Joint CSO/Stormwater Treatment

Throughout the project phases (calibration, uncertainty analysis, and alternatives evaluation), opportunities for retrofit will be targeted and communicated to the project team for consideration.

3.0 Data and Documentation

3.1 Sources of Information

The Henderson hydraulic model requires the compilation of data from multiple data sources from multiple agencies. In general, SPU's geographic information system (GIS), as-builts, and record drawings, supplemented with survey and field investigations, will be used to develop the system information in the hydraulic model. Flow monitoring and supervisory control and data acquisition (SCADA) data will be used for flow inputs, and lake level information will be used for boundary conditions. Precipitation data will be obtained from the network of rain gauges maintained by SPU. Table 2 lists the general data needed for the Henderson model and the sources of the data.

TABLE 2. GENERAL DATA NEEDS OF THE HENDERSON MODEL

Data	GIS	Flow Monitoring	As-builts/ Record Drawings	Field Observation/ Measurement
Sewer flows	X	X		X
Pumps				X
Weir dimensions			X	X
Hydrobrakes		X		
Boundary conditions (Lake Washington, KC system)				X
Invert elevations of sewer pipes	X		X	
Ground elevations	X		X	
Connectivity, size, and length of sewers	X		X	
Sewer types (material and shape)	X		X	
Precipitation				X
Condition of sewers				X

3.2 Metadata

The Henderson model will be developed from a wide variety of sources. Metadata is information about the data and usually includes information such as the data source, field names and data codes, and horizontal and vertical projections. Below are sources of metadata that CH2M HILL anticipates will be used in the project.

- http://www.ci.seattle.wa.us/GIS/docs/availdata.htm#property (Source: City of Seattle GIS listing available datasets)
- "Geoguide" (Source: City of Seattle for detailed metadata for each feature provided by SPU/City of Seattle)

The final list of metadata used will be presented in the project's final Hydraulics and Hydrology (H&H) Report.

Anticipated data sources include SPU's GIS, aerials, topographic/contour, as-builts, field surveys, sewer cards, publicly available information (Web sites), previous studies and models, and engineering and operations and maintenance personnel. Much of the data used in the model will be derived from a combination of multiple sources (for example, per capita flow loading will be derived from flow monitoring and population data). Table 3 is a proposed list of user-defined flags that denote sources of data. As the project progresses, the user-defined flags will be adjusted and the final list will be presented in the project's final H&H Report.

TABLE 3. INITIAL USER-DEFINED FLAGS IN 2008 HENDERSON MODEL

Name	Description
G	GIS
IN	Interpolated
S	Survey
AB	As-built
RD	Record Drawing
SC	Sewer Card
AS	Assumed
KC	King County
FO	Field observation
DM	Developed for Model

Figure 3 shows the defined flags in the 2001 Henderson Model. CH2M HILL will use a similar method to document the various sources and pertinent information.

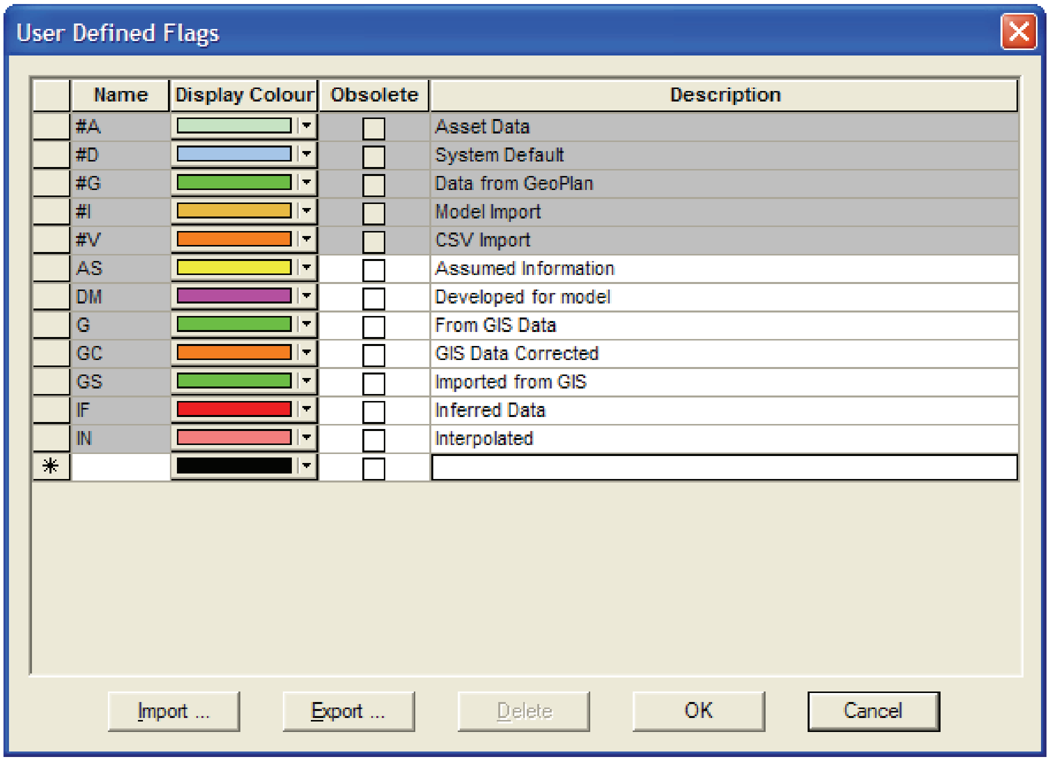

FIGURE 3. USER-DEFINED FLAGS USED IN THE 2006 INFOWORKS HENDERSON MODEL

3.3 Model Documentation

As the model is developed, model documentation will be a critical aspect of the project. The objective of model documentation will be to record the assumptions made in developing the model. To meet this objective, CH2M HILL will keep a log book to document data sources, assumptions, methodology, and decisions. As each phase of the model development (for example, calibration) is completed, a draft chapter documenting the work will be prepared and reviewed with SPU. At each monthly review meeting, or more frequently, as appropriate, decisions needed for the project will be reviewed and documented.

In addition, the '*Notes* tab' available in the model properties information window will be used to document site-specific adjustments, assumptions, and so forth.

Also, the project's final H&H Report will document the model development. The following chapters are anticipated:

- Introduction
- Model Construction
- Calibration/Validation
- Existing Conditions Assessment (Uncertainty)
- Performance Curves
- Modeling Approaches for CSO Alternatives (Appendix)

4.0 Review of Past Modeling and Monitoring and Gap Analysis

4.1 Previous Modeling

In 2001, Earth Tech, Inc., released the "Sewerage System Modeling and Assessment Project – Basin Group A Model Development Report," which 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 models and the documented simulation results. The report focused on the modeling of sub-basins 44, 45, 46, 47, 49, and 171 within the Henderson Basin. The model was calibrated from flow monitoring data collected November 1999 to May 2000.

Since 1998, there has been permanent monitoring at the basin outfalls, consisting primarily of depth measurements. These data were used to provide information regarding CSO frequency.

SPU has maintained a network of rain gages since 1978. Two of these existing gages, rain gages 10 and 18, will be used to provide the needed precipitation data for the Henderson CSO Reduction Project. Rain gage 10 was relocated and precipitation data temporarily unavailable from June 25th through mid-December 2008. During this period, precipitation data from King County SKY1 rain gage will be used for model development.

Recognizing the significant influence the KC Henderson Street Lift Station and Henderson Street Trunkline have on the Henderson Basin, the project team concluded the existing InfoWorks model should be expanded to include these facilities downstream to the Henderson Tunnel junction maintenance hole.

4.2 Gap Analysis Results

To determine the extent of information needed to develop the updated model and to evaluate CSO control alternatives, a review of the existing model and available data was completed and is summarized as follows:

- The physical connectivity (pipes and nodes) in the existing model of basins 44, 45, 46, 47, 48, 49, and 171 generally correlate to the GIS and is generally sufficient to meet the project objectives. There were discrepancies (pipe diameter, connectivity, pipe reroute of 60 inch) in the vicinity of the Henderson Street Trunkline and Henderson Street Lift Station due to system changes resulting from a King County improvement project. The model will be updated to reflect the as-built locations based on aerial and project data.
- The GIS contains adequate data to expand the model without the need of extensive surveying. Data gaps can be filled through interpolation (to be documented in the model as "interpolated" using data flags).
- Updated data for SPU's lift stations 9, 10, 80, and the Henderson Street lift station were needed. Drawdown tests were conducted at the SPU lift stations 9 and 10 in August 2008 to verify capacity. LS 80 was investigated in the field for drawdown testing; however, it was concluded that a test at this facility could not be conducted due to the pump type—the station is an ejector-type pump with a sealed tank, and therefore inaccessible for testing. LS 80 serves a small area and pump curve information will be used in the model. For the KC Henderson Street Lift Station, the SCADA data will be the basis for lift station capacity.
- SPU SCADA data are available. Flow monitors exist upstream and downstream of the lift stations, and in combination with the 2008 drawdown tests, sufficient data exist to model the lift stations.
- The flow and rainfall data previously collected in the basin between 2005 and 2007 were reviewed by HDR and described in the *Initial Review of Flow and Rainfall Monitoring Data Technical Report No. 1.* The report's conclusion was flow monitoring data to characterize the general hydrology or structures (hydrobrakes, weirs) of the basin was insufficient to meet the objectives of South Henderson CSO Reduction Project. From January 2008 through approximately June 2009, 21 temporary monitors will be installed and maintained to obtain water level and velocity information at sites that support simulating the hydrobrakes, detention facilities, and hydraulic loading upstream in the Henderson Basin. Two additional monitors were installed in stormwater drainage lines. These monitors complement the 11 permanent monitors installed for NPDES reporting.
- Data from rain gages 18 and 10 will be used for model development for the period from January through June 25, 2008. Data from gage 10 was temporarily unavailable from June 26 through mid-December 2008 while SPU coordinated the relocation of the gage. During this period, data from King County SKY1 rain gage will be used.

- Model catchments and loadpoints will need to be adjusted to reflect the flow monitoring data collected from January 2008 to approximately June 2009. This will result in adjusted impervious and pervious areas for each catchment. GIS sewer system, drainage system catchment areas, digital terrain model, and landuse shapefiles will be the basis for delineating the new sewer catchments.
- The CSO diversion structure configurations need to be updated. ADS Environmental (ADS) performed site assessments during the installation of permanent monitors in 2007, and their measurements will be the basis for data needed to model the overflow weirs. Additional surveys are needed at other diversion structures within the Henderson Basin.
- In reviewing the previous monitoring data, it is difficult to confirm the reported CSO overflow volumes due to questionable data sets and incorrect empirical weir formulas. After correcting the weir equations, there is still uncertainty in the current calculations being 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.
- KC SCADA data are available at the Henderson Street Lift Station. These data will be compared to available drawdown tests, but information from KC indicates that the "Total Flow" tagged data are the best source of flow data through the station.

As model development occurs, additional gap analyses will be conducted and summarized in the final H&H Report.

5.0 Flow Monitoring

5.1 Monitoring Program

As noted in the Gap Analysis, a review of the available flow monitoring data resulted in the need to install additional monitors in the Henderson Basin. In December 2007 and January 2008, 21 temporary monitors were installed in the Henderson system to supplement flow monitoring data from permanent monitors installed at the Henderson CSO outfalls. In addition, three KC flow monitor installed in the vicinity of the Henderson Street Trunk will be used to characterize the basin hydrology. Each of the above monitors will be used in the model development. An additional two monitors were installed in February 2008 in the stormwater drainage system at MHs D081-131 and D081-069 in the Henderson Basin. These monitors were installed to characterize flow from an area adjacent to a CSO outfall to support developing possible CSO and storm water treatment alternatives.

The temporary meters will be in place through approximately June 2009. The objective of the flow monitoring program is to adequately and accurately characterize the performance of the combined sewer system and existing facilities before, during, and after storm events. The monitors were located to characterize the hydrologic response and to develop sanitary flow loading within individual monitoring sub-basins, as well as the operation and performance of significant facilities (for example, hydrobrakes, in-line and off-line storage, CSO regulator structures). There will be inherent error in the flow monitoring data due to the complexity of monitoring an urban collection system, meter inaccuracy and drift, and so forth. However, these errors are acknowledged and will be incorporated into the uncertainty analysis.

In addition, SPU improved the monitoring at each of the Henderson CSO outfalls in mid 2008. Additional information is available in the S. Henderson Flow Monitoring Quality Assurance Project Plan.

5.2 Monitoring Basin Delineation

Each monitor is located in the most downstream manhole within a *flow monitoring basin*. The delineation of the flow monitoring basins was completed as part of the monitoring program in early 2008. Delineation of the flow monitoring basins was based on topology and CSS pipe network configuration and will be used to determine per capita flows and loading in the model. Figure 4 shows the delineation of the flow monitoring basins and monitor installation locations.

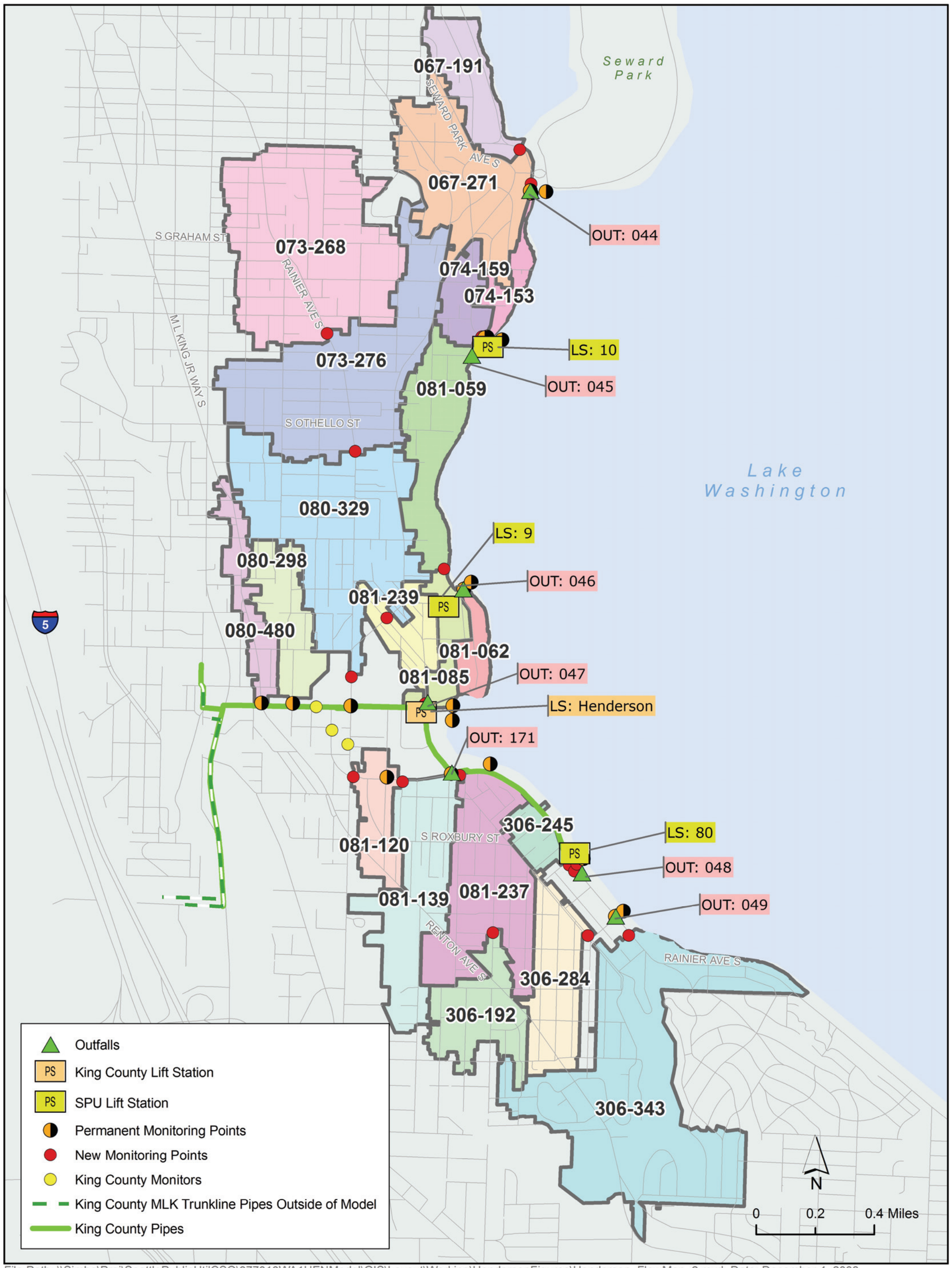

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FIGURE 4. MONITORING BASINS AND MONITOR LOCATIONS

6.0 Model Development

This section details the models, data requirements and sources, and boundary conditions.

6.1 Modeling Platform

The modeling platform of the Henderson model is InfoWorks CS version 9.5—the current standard H&H modeling platform for CSO planning projects for SPU.

6.2 Horizontal and Vertical Datums

6.2.1 Horizontal and Vertical Datums

The datums of the hydraulic model are consistent with SPU's GIS:

- Horizontal: NAD_1983_HARN_StatePlane_Washington_North_FIPS_4601_Feet
- Vertical: NAVD88-North American Vertical Datum of 1988

Many of the as-built drawings used in the model development are based on City of Seattle Vertical Datum. To convert to the NAVD88 used in the model, the general conversion number of 9.7 feet will be added to each elevation referenced in the drawings, unless otherwise specified on the drawing.

6.3 Data Sources and Data Filling

6.3.1 Hierarchy of Data Sources

There are multiple data sources that will be compiled for the Henderson model, each with varying degrees of accuracy. The following is the hierarchy of data accuracy used for the system information in the Henderson model:

1. Survey
2. As-built
3. GIS
4. Sewer card
5. Interpolated
6. Inferred/assumed

6.3.2 Data Filling and Documentation

The model will be developed primarily from the GIS, but superceded by survey and as-built information. After the extent of the model is established, initial reviews of the available system data will be incorporated into the model and pipe profiles will be reviewed. GIS will generally contain the necessary information; however, in some instances missing data will be identified. In most instances, interpolation will fill the data gaps. As the model is developed and areas requiring greater accuracy are identified, data for these areas will be obtained through field surveys.

As discussed in the Model Documentation section, user-defined flags will be used to denote data sources, including those data fields populated through interpolation. Figure 5 shows an example of where CH2M HILL will apply the 'assumed' and 'interpolated' flags.

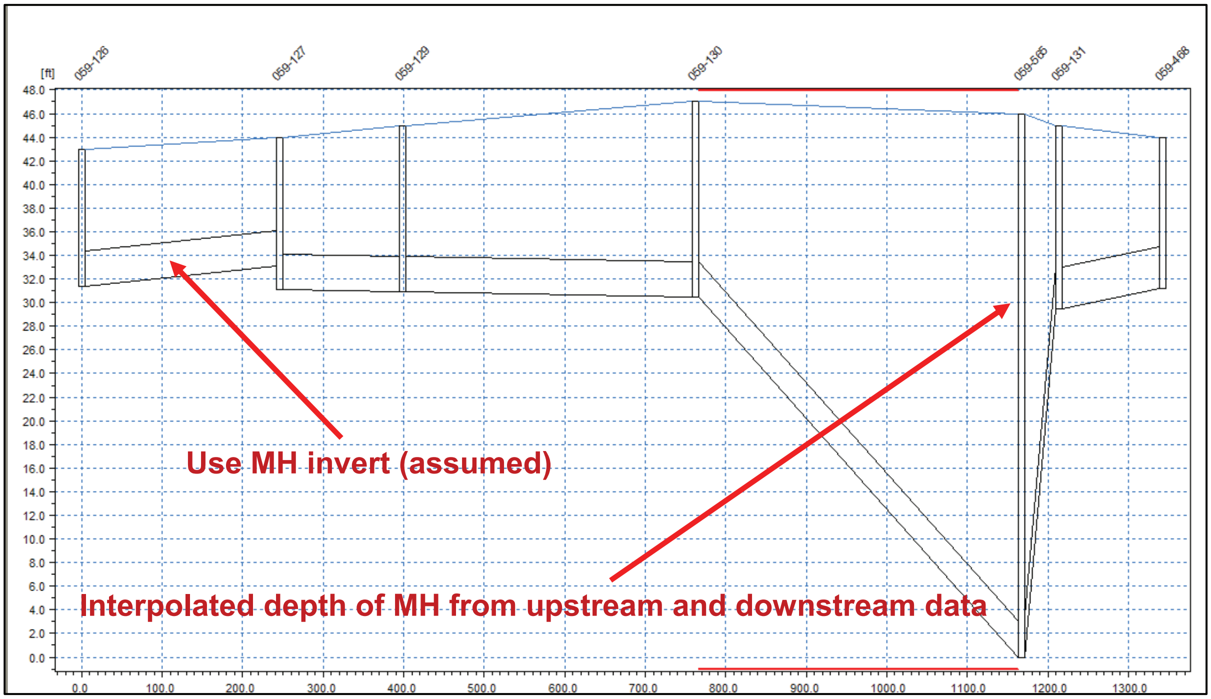

FIGURE 5. EXAMPLE OF DATA FLAGS TO DOCUMENT SYSTEM REVIEW

6.4 Boundary Conditions

6.4.1 Lake Level

Lake Washington lake levels will be a boundary condition in the node affecting the hydraulics at each of the Henderson Basin CSO outfalls. Lake Washington lake levels fluctuate on a yearly cycle controlled by the U.S. Army Corps of Engineers (USACE) at the Chittenden Locks. Lake levels are available from the USACE Seattle District of the Water Management Section based on the mean lower low water (MLLW) USACE Locks Datum, which is 3.25 feet below the NAVD 88 (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 (needed for the uncertainty analysis).

6.4.2 Model Outfalls

In addition to the NPDES CSO outfalls, the Henderson model will have two outfalls where flow is discharged. One will be located just upstream of the Henderson Junction structure in the 60-inch gravity sewer.   Henderson Junction structure and the Fairbanks Tunnel, which enters the structure from the west and discharges from the MLK Inlet Regulator, will not be included in the model. The outfall boundary condition for this "Henderson Junction outfall" will be set equal to the control level established by KC for restricting flow away from the Henderson trunk sewer and the MLK regulator.

The second outfall will be downstream of the Henderson Lift Station and the two 20-inch diameter force mains discharging from the station. The force mains initially discharge to a discharge structure (identified as the "Forcemain Discharge Structure" in the profiles of vault drawings 235-6 and 235-7) where flow enters a 42-inch gravity sewer. The 42-inch gravity sewer then flows to a 60-inch gravity sewer at the "Transition MH", which is where the second outfall will be located. The outfall boundary condition for this "Henderson LS outfall" will be set as a "free discharge"—downstream water level set below the invert of the pipe. Figure 6 details the model outfalls in the vicinity of the Henderson trunk sewer.

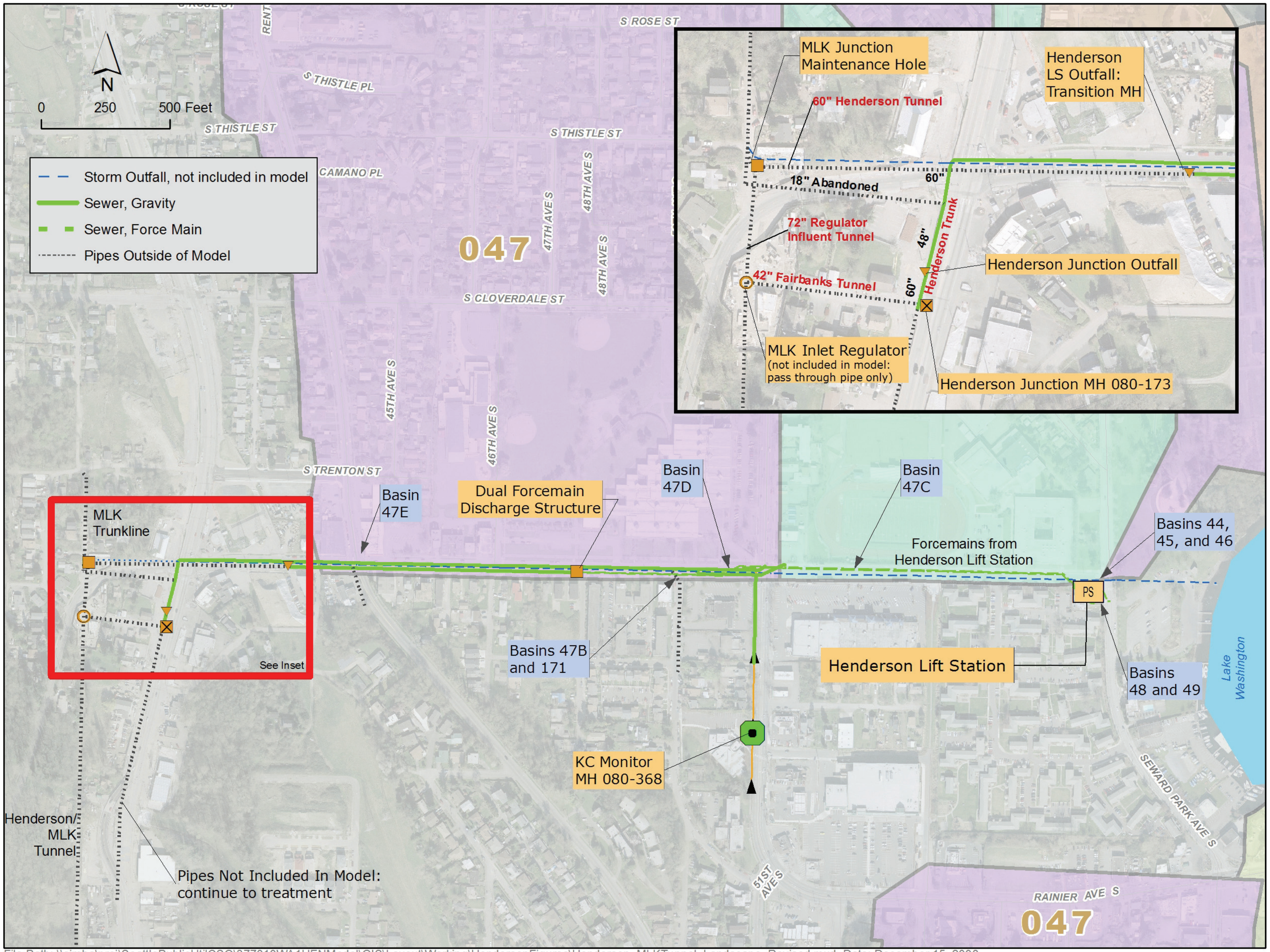

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FIGURE 6. **HENDERSON MODEL OUTFALLS**

6.5 Models

The Henderson model includes combined and partially separated sewer systems. The comprehensive model is organized into three model types as described below:

- A 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.

Each model type is discussed below.

6.5.1 Model Hydraulics

6.5.1.1 Extent of Modeled Pipes

The project team anticipates the sewer system model consisting of all pipes in combined or separated areas that convey wastewater—all pipes 8-inches and greater (this criterion excludes the service laterals to each parcel from being in the model). The model will not be a "skeletonized" or other macro-scale model. To determine the extent of the modeled system, CH2M HILL will use the GIS as the primary source of information. Pipe information (in particular, probable flow, permitted flow, system type, nodes, building footprints, and topography) will be referenced. Figure 7 shows the extent of the Henderson hydraulic model.

As model development of the combined sewer system occurs, the project team may elect to delineate catchments for hydraulic loading to the stormwater drainage network and to connect catchment loads to the appropriate inlet or catchbasin. Delineating catchments and associated loadpoints for both the sewer system and stormwater drainage system will optimize use of the data. Although not part of the Henderson CSO project, this approach compiles the data needed for future modeling of the storm water drainage system.

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FIGURE 7. EXTENT OF HENDERSON HYDRAULIC MODEL

6.5.1.2 System Information

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, lift 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

6.5.1.2.1 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 (for example, circular, egg, or square) or user-defined shapes for irregular pipes, but for the Henderson model each pipe will be assumed to be circular, based on GIS data. Link locations are defined by their upstream and downstream node names. Links in the model are selected based on connectivity to the sewer system. Table 4 presents the types of data required to define links in InfoWorks.

TABLE 4. INFOWORKS DATA REQUIREMENTS FOR LINKS

Description	Units	Sample Data	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 feet	feet	325.0	GIS
(Pipe) Shape		CIRC	GIS
(Pipe) Width	inch	8.0	GIS
(Pipe) Height	inch	8.0	GIS
(Pipe) Roughness		0.013	Field observation
Upstream Invert Level	feet AD[1]	87.800	GIS
Downstream Invert Level	feet AD[1]	86.600	GIS

[1] feet AD = feet above datum (*NAVD88-North American Vertical Datum of 1988)*

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 will be inserted to model the special structure. Coordination will be required between the model and SPU's GIS for the unique link ID.

The project includes soliciting input from SPU operations and maintenance personnel to incorporate anecdotal information, including areas of sedimentation, heavy root intrusion, misaligned pipe, or other conditions that will greatly affect the hydraulic capacity of the system. In such instances, the approach will be to increase the roughness coefficient and, if warranted, specific cross sections will be developed that reflect the reduced pipe capacity due to significant sediment. The default roughness coefficient Manning's *n* of 0.013 will be used for each pipe without specific condition data, but possibly adjusted to calibrate to measured water levels. The same value will be used for the bottom and top roughness for each pipe.

6.5.1.2.2 Nodes

Nodes are structural elements like maintenance holes, blind connections, outfalls, or user-defined structures (pump station wet wells). They 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 Henderson model, each node defined as a maintenance hole in the GIS will be included in the model. Tees or cleanouts will be included in the model to maintain spatial reference, but these will be "sealed" and the ground level set equal to the top of the pipe. Nodes defined as "plugs" (usually at the terminus end) will not generally be included. Table 5 presents the types of data required to define nodes in InfoWorks.

TABLE 5. INFOWORKS DATA REQUIREMENTS FOR NODES

Description	Units	Sample Data	Data Source
Node ID		059-398	GIS
Node Type		Maintenance hole	GIS
System Type		Combined	GIS
X-coordinate feet		1282611.9	GIS
Y-coordinate feet		213245.8	GIS
Ground Level	feet AD1	96.000	GIS
Flood Level	feet AD1	96.000	GIS
Chamber Floor Level *(maintenance holes only)*	feet AD1	87.800	
Chamber Roof Level *(maintenance holes only*	feet AD1	88.467	
Chamber Plan Area	square feet	7.9	Default set to 28.3 (equivalent to 6 feet in diameter). Survey and as-builts for significantly different hydraulic structures

TABLE 5. INFOWORKS DATA REQUIREMENTS FOR NODES

Description	Units	Sample Data	Data Source
Shaft Plan Area	square feet	7.9	Default set to 12.6 (equivalent to 4 feet in diameter). Survey and as-builts for significantly different hydraulic structures
Flood Type (*maintenance* holes only)		Stored	
Level (storage nodes only)		324	
Plan Area (storage nodes only)	square feet	34.5	

1 feet AD = feet above *NAVD88-North American Vertical Datum of 1988* datum

6.5.1.2.3 Pumps

Pumps connect two nodes together and pass flow between them according to established rules that simulate the operation of the pumps. There are four pump stations in the Henderson model—SPU lift stations 9, 10, and 80, and the KC Henderson Street Lift Station. They are defined at a node in the hydraulic model, transferring flow to another node according to the relationships specified in the model.

Available options to model pumps in the Henderson Basin are to: (1) use a pump curve (flow versus a differential head relationship between the upstream node and the downstream node)—QdH; or (2) to set the pump based on the water level in wetwell—a QH relationship.

Because of the availability of data (drawdown tests and SCADA), CH2M HILL will model SPU lift stations 9 and 10 as a *screw* pump type—pump increases with an increase in wetwell level set equal to the measured drawdown flow rate. Drawdown tests could not be conducted at Lift Station 80 and therefore, pump curves will be used. The KC Henderson Street Lift Station is a variable speed station and will be modeled based on the SCADA *Total Flow* data. This station will be modeled as a *variable speed* pump type—it has controls permitting variations in speed to maintain a consistent wetwell level.

6.5.1.2.3.1 Drawdown Tests

Drawdown tests were performed at each of the SPU lift stations 9 and 10 in August 2008 to obtain average pump capacity across the pumping range. Drawdown tests consisted of measuring the time required to draw and fill the wetwell. After calculating the area of the wetwell, the lift station's pump rate could be calculated.

6.5.1.2.3.2 Submerged Wetwell Effects

The drawdown tests were conducted across the pumping range (below the lowest influent pipe to just above the sump in the wetwell). No indications of excessive water levels were evident during the test; however, to account for the increased pumping rates during submerged wetwell conditions, the QH curve developed from the drawdown test will be increased to account for the decrease in total dynamic head. The effect of approximately 2 to

3 feet of increased water level above the drawdown pump range is not expected to be significant.

6.5.1.2.3.3 Start/Stop Elevations

For all lift stations, field observations (local SCADA displays) and facility drawings will be used to provide the start and stop elevation data. Table 6 presents the types of data required to define pumps in InfoWorks.

TABLE 6. INFOWORKS DATA REQUIREMENTS FOR PUMPS

Description	Units	Sample Data	Data Source
Upstream Node ID		059-453	GIS
Downstream Node ID		059-453Dummy	
Link Type (Pump type)		FIXPMP	Field observation
System Type		Combined	GIS
Switch On Level	feet AD	16.57	Field measurement
Switch Off Level	feet AD	11.7	Field measurement
Head Discharge Table	gpm-feet	LS5	Field measurement

feet AD = feet above *NAVD88-North American Vertical Datum of 1988* datum

gpm = gallons per minute

6.5.1.2.4 Weirs

Weirs connect two nodes together and pass flow between them according to mathematical equations that simulate flow over a weir. There are 13 weirs in the Henderson hydraulic model located primarily at seven CSO outfalls. Information regarding the existing weirs will be developed from the site installation sheets developed by ADS during monitor installation. These sheets documented the items needed for the model: type, crest elevation, length, and crest length (applicable for broad-crested weirs). Table 7 lists the items required to define weirs in InfoWorks.

TABLE 7. INFOWORKS DATA REQUIREMENTS FOR WEIRS

Description	Units	Sample Data	Data Source
Upstream Node Name		059-456	GIS
Downstream Node Name		059-456Dummy	
Link Type		BRWeir (broad crested weir)	Field measurement
System Type		Combined	GIS
Crest Elevation	feet AD[1]	18.8	Field measurement
Weir Width	feet	4	Field measurement
(Roof) Height (sharp-crested weirs only) feet	feet	3	Field measurement

TABLE 7. INFOWORKS DATA REQUIREMENTS FOR WEIRS

Description	Units	Sample Data	Data Source
(Crest) Length (broad-crested weirs only)	feet	0.67	Field measurement

1 feet AD = feet above *NAVD88-North American Vertical Datum of 1988* datum

The *roof height* is a modeling parameter that indicates the height of the chamber roof above the weir crest and is applicable. For the Henderson CSO diversion structures, this parameter is needed for the CSO diversion structures and weirs. When the water level is above the roof elevation, the weir behaves like a sluice gate. Note that this parameter is given as a height, not an elevation referenced to a datum.

6.5.1.2.5 Detention Systems

The Henderson Basin has detention systems (off-line and in-line storage facilities) to retain runoff volume during periods of wet weather. Flows into these structures are controlled through hydrobrakes and weirs. The detention systems will be modeled as links.

6.5.1.2.6 Hydrobrakes

There are five hydrobrakes in the Henderson Basin and all are included in the hydraulic model. 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 regarded as a vortex control type structure and is represented in the model as a link of zero length, forming a discharge-head (Q-H) relationship between two nodes. The vortex invert level determines when the control first comes into operation. The Q-H relationship will be developed from the flow monitoring conducted between January 2008 and June 2009. If monitored flows are insufficient to activate the hydrobrake across their performance range, operation points may be determined by extrapolation.

6.5.1.2.7 Valves

There are three flap valves in the Henderson Basin that will be included in the model, based on the 2001 model version. The gates in MH 081-231, MH 067-272, and MH 306-428 control flow into CSO facilities 5, 8, and 4, respectively.

6.5.2 Hydrologic Model

In a hydrologic model, physical parameters describing urban catchments—the basic area unit required by a hydrologic model—are used to determine the magnitude of stormwater runoff. The runoff is introduced into the hydraulic model of SPU's combined sewer system at locations specified for each catchment, after which the hydraulic model routes it through the sewers to the KC system or to the CSO outfalls.

The catchments are primarily described in terms of land area and contributing area, percent impervious, surface slope, and catchment width. The data requirements that define catchments are presented in Table 8.

TABLE 8. INFOWORKS DATA REQUIREMENTS FOR CATCHMENTS

Description	Units	Sample Data	Data Source	Comment
Catchment ID		059-398		Unique identifier
System Type		Combined		
(Inlet) Node ID		059-398		Maintenance hole where flow from catchment is loaded into model.
Total Area	Acres	4.3	GIS	Used for information only.
Contributing Area	Acres	3.5	GIS	Sum of the absolute areas from runoff surfaces.
(Catchment Center) X-coordinate	feet	1284379.9	GIS	
(Catchment Center) Y-coordinate	feet	211185.1	GIS	
Landuse ID		1	GIS. A single landuse ID per flow basin will be used to describe a combination of runoff surfaces in each catchment. Every catchment will have areas specified for each of the seven runoff surfaces (sometimes zero).	Available soil information will be used to distinguish between varying infiltration characteristics.
Population	Residential dwelling unit	100	GIS—landuse and available data sources (KC block census, Puget Sound Regional Council census data)	Population per catchment will be multiplied by a flow per capita rate to determine sanitary flow contribution.
Wastewater Profile		1	Flow monitoring	A weekend and a weekday profile will be developed from each monitor.
Rainfall Profile		1	Historical precipitation (Rain gages 18 and 10)	
Area Measurement Type		Absolute		
(Catchment) Slope	Percent	8.2	GIS	Based initially on topography, but may be adjusted in calibration.
Dimension (Catchment Width)	feet	244	GIS	May be adjusted during calibration.

TABLE 8. INFOWORKS DATA REQUIREMENTS FOR CATCHMENTS

Description	Units	Sample Data	Data Source	Comment
Runoff Area 1 (to 12 as needed): Impervious Surfaces: 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– Runoff Area 6	Acres	0.2	GIS	Absolute areas of pervious and impervious runoff surfaces within each catchment

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

6.5.2.1 Catchment Delineation

The Henderson Basin will be divided into approximately 356 drainage catchments with an average size of just under 5 acres. A catchment 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.

The catchments can contain multiple land uses. They can be a combination of pervious and impervious areas that are largely defined by the type of land use 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, depending on the type of soil. There is a limit to the infiltration rate, after which additional precipitation results in surface runoff from pervious lands. Impervious lands include 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 can be collected by the sewer system.

In the Henderson Basin, two different types of systems exist. There are portions of the basin that meet the traditional definition of combined areas, as well as other areas considered partially separated (to be referred to herein as “separated”). Roof leaders and yard drains are assumed to be connected to the combined system; however, this assumption will need to be verified through some field observations and adjusted accordingly. Catchments will be delineated based on topography from the GIS and then refined as needed according to the layout of the combined sewer network.

In combined areas, the contributing area will consist of impervious and pervious surfaces. All areas can be considered to contribute runoff to the combined system.

In the separated area, the hydrology model will be limited to the areas of roofs and yard drains. As in the combined system discussed above, this assumption will need to be verified in the field and adjusted accordingly. A nominal area will be needed to allow for the contribution of rainfall dependent inflow/infiltration (RDI/I) in the sewer system. Although these areas are separated, RDI/I is generally present and is expected in the Henderson Basin. The sum of these areas will be the contributing area. For separated areas, it will be assumed no impervious area contributes to the combined system.

For each catchment there is one loadpoint—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).

If the project team elects to determine the contributing areas to the storm water drainage system, another layer of subcatchments will be added to the hydraulic model (identified as storm water drainage) and connected to an inlet or catchbasin in the storm water system.

6.5.2.2 Wet-Weather Hydrology

6.5.2.2.1 Impervious Area Delineation/Definition/Subcatchment Resolution

Within each catchment, impervious and pervious surfaces will be delineated. To support the CSO alternatives analysis, the following impervious surfaces will be defined per catchment:

Impervious Surfaces:

- 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 Surfaces

- Runoff Area 6

Within each delineated catchment, the above runoff surfaces are used to generate a runoff volume that is routed through the system. There are a variety of data sources that will be used to quantify the contributing areas for each runoff surface, including the following:

- Aerial images
- Shapefiles:
  - Building
  - Sidewalk
  - Street—edge of pavement
  - Parcel/landuse
  - Black and Veatch runoff surfaces
  - Pipes (storm, sewer, small diameter laterals)

- Maintenance holes and catchbasins/inlets
- Storm water pipes and smaller diameter lateral information

A description of the approach to quantify the runoff surfaces will be presented in the project's final H&H Report.

The GIS will be the primary source of information to quantify the contributing areas. The project team recognizes that the data in the GIS are not absolute (for example, not all roof leaders and yard drains are connected in the combined system) and some field verification may be necessary. The need to perform a more extensive assessment of connectivity in the system will be determined during model development and initial calibration simulations. Figure 8 describes the process used to determine impervious and pervious surfaces for structures and parcel areas using a series of GIS spatial and attribute queries.

6.5.2.2.2 Pervious Area Delineation/Definition

All surfaces that drain to the combined sewer system that are not classified as one of the above-identified impervious surfaces will be classified as a pervious surface. Figure 8 describes the process of pervious surface delineation.

6.5.2.2.3 Runoff Generation and Routing Methodology

6.5.2.2.3.1 Runoff Volume Model

It is necessary to define how much precipitation falling on each runoff surface type (such as buildings, roads, and driveways, as listed above) will be converted to runoff that will enter the combined sewer system. The impervious surface types will be set to use the Fixed Runoff Volume model with 100 percent runoff. For the pervious surface type, the Green-Ampt Infiltration model will be used with values that are typical for loam soil, which is appropriate for the Henderson Basin.

6.5.2.2.3.2 Runoff Routing Model

InfoWorks provides five different models for routing stormwater runoff. The model that InfoWorks refers to as *SWMM* was selected for the Henderson 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.

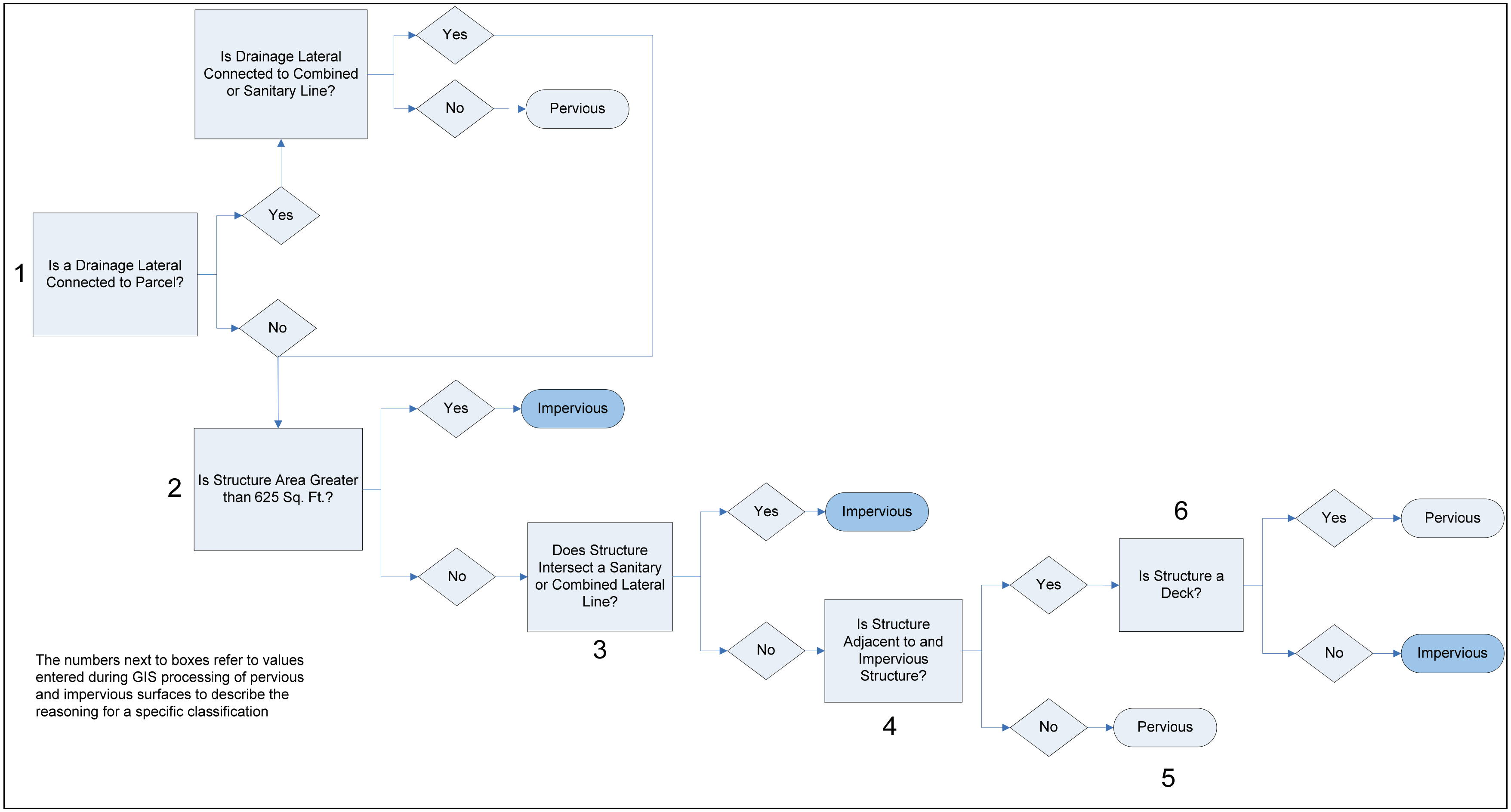

FIGURE 8. DECISION TREE FOR IMPERVIOUS/PERVIOUS SURFACE DELINEATION

6.5.2.2.4 Areas Routed to Combined Sewer vs. Storm Sewer

One of the first steps in catchment delineation is the delineation of *System Type* boundaries. For Henderson Basins, there is a combination of two types of systems: *Separated* and *Combined. Separated* areas are those areas where storm water drainage systems exist that collect and route storm water. In the case of the South Henderson Basin, 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 storm water pipes include streets, sidewalks, and large pervious surfaces found in parks. Flows from these surfaces are routed to their own drainage outfalls and are not connected to the CSS.

In *Combined* areas, storm water drainage pipes do not exist and surface flows from streets, parking lots, and so forth, are routed into the CSS. Because street runoff surfaces are characterized separately between the two types of systems, catchment boundaries must also follow system type boundaries. The presence of storm water pipes and laterals from contributing parcels will be used to differentiate the two systems. In addition, *PRBLE_FLOW* and *USE_PERMIT* fields in the pipe shapefiles may also be used, but primarily as a reference. These GIS fields provide information regarding the general purpose of the pipe.

6.5.2.2.5 Modeling Parameters

Modeling parameters refine the amount of modeled flow entering the CSS system. Although some of these parameters are defined globally, others may be used as calibration parameters and are adjusted to align modeled flows with measured flows. Modeling parameters used for wet-weather hydrology include the following:

- Catchment widths
- Initial abstractions
- Catchment connectivity
- Contributing area of runoff impervious surfaces and pervious surfaces
- Percolation coefficient

6.5.3 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 and is typically at a constant rate, but varies seasonally. In the Henderson CSS model, these two flow components will be addressed simultaneously as a combined base sanitary flow-groundwater infiltration estimate referred to as dry-weather flow (DWF).

The InfoWorks model computes DWF from three parameters:

1. The average rate of sanitary waste generated per person per day
2. The catchment population
3. The hourly variation in the sanitary flow pattern, given as a set of peaking factors (PF)

InfoWorks computes DWF using the following equation:

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

where:

$WW_{cap\ avg}$ = average per-capita wastewater generation rate, including groundwater infiltration (gallons/capita/day, or gpcd)

Pop = population (for an individual catchment)

PF = diurnal peaking factors

To calculate $WW_{cap\ avg}$, the following will be performed:

1. Total population will be compiled for each monitoring basin by overlaying the Puget Sound Regional Council census and land use data with the monitoring basin delineation.
2. The net (upstream basin flows will be removed) average DWF will be calculated for each monitoring basin.
3. Dividing the average DWF by the population in the catchment yields $WW_{cap\ avg}$.

InfoWorks has the functionality to add specific industrial discharges into the system. Data from the hydrographs will be reviewed to determine if industrial discharges are evident and need to be addressed. During model development, significant industrial discharges may be added; however, it is expected to be on a limited basis. Any industrial discharge average will be subtracted from the net average flows calculated for each flow monitoring basin.

6.5.3.1 Net Average Flow

To calculate the DWF contributed within each catchment, a wastewater generation rate (flow per capita) is needed in the model. The net average flow is calculated by subtracting the upstream DWF contribution.

6.5.3.2 Diurnal Pattern

The diurnal pattern is the predictable flow pattern evident in the system on a typical dry-weather day. A distinct diurnal PF pattern will be developed for both weekdays and weekends for each monitoring basin (a diurnal pattern is not applicable to the outfall monitors). The final processing will yield an hourly ratio of the peak flow to the average flow for each monitoring site.

6.5.3.3 Population-based Distribution

The Henderson model will rely on a network of temporary and permanent flow monitors to provide DWF loading into the model. To further distribute the net DWF upstream of each monitoring location for each catchment, CH2M HILL will use population.

7.0 Calibration/Verification (QA/QC Procedures)

The primary purpose of calibrating and validating a model with measured data is to assure that the model will provide a realistic simulation within the level of accuracy needed for its ultimate goal. For the Henderson model, the model will be compared to the 13 permanent flow monitors needed to monitor the 7 CSO outfalls and 18 temporary flow monitors. The temporary monitors will be installed and maintained in the interior of the basin from January 2008 to approximately June 2009. Both traditional calibration techniques and automatic calibration technologies will be used.

7.1 Manual Calibration

Calibration refers to the process of making changes to certain model parameters so that model output matches flow monitoring data. Once the model is calibrated, an independent storm that was not used in the calibration effort was simulated to verify that the model can reproduce the storm's impact on the sewer system. The calibration of the Henderson Model falls into three distinct elements:

1. Preliminary assignment of Hydrobrake stage-discharge curves
2. Calibration of the hydrologic and hydraulic characteristics of the overall basin dry-weather flows
3. Calibration of the hydrologic and hydraulic characteristics to the overall basin wet-weather flows, and adjustment of hydraulic structure behavior (hydrobrake stage-discharge curves, lift station start/stop elevations, weir configuration, and so forth.)

Each of these steps requires different types of flow monitoring data and different calibration methodology.

7.1.1 Hydrobrake Calibration

One data objective of the flow monitoring program is the development of a stage-discharge curve for each of the five hydrobrakes in the Henderson Basin. Because it is likely that the hydrobrakes do not behave as suggested by the manufacturer's stage-discharge curves flow data are being collected from January 2008 through approximately June 2009 to generate a best-fit stage-discharge curve, as shown in Figure 9. These best-fit curves will be loaded into the model to assign hydraulic behavior characteristics to the hydrobrakes. Monitoring data is required from the upstream and downstream monitors to each hydrobrake shown in Table 9. For the model to replicate hydraulic behavior at the hydrobrakes for a wide range of hydraulic conditions, it will be necessary to have data from low (dry-weather), medium, and high (wet-weather) flows to create an adequate best-fit stage discharge curve. An absence of high flows will require some approximation and extrapolation.

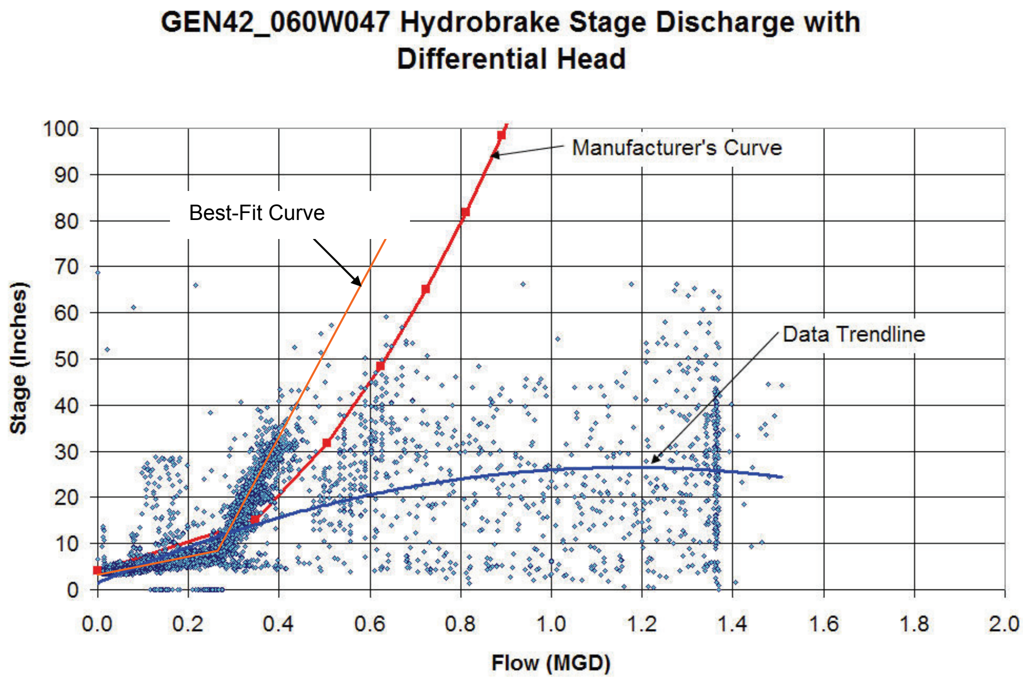

FIGURE 9. EXAMPLE OF HYDROBRAKE MANUFACTURER'S STAGE-DISCHARGE CURVE COMPARED WITH BEST-FIT STAGE-DISCHARGE CURVE

TABLE 9. MONITORS USED FOR DETERMINING HYDROBRAKE PERFORMANCE

Hydrobrake (MH ID)	Description
067-272	Basin 44 – Lake Washington Blvd. S. in Seward Park.
074-159	Basin 45 –57th Ave. S. & S. Holly St.
081-239	Basin 47 – Seward Park Ave. S & S. Henderson St.
081-231	Basin 47B/171 – Rainier Ave. S. & Seward Park Ave. S.
306-428	Basin 49 – Rainier Ave. S. & S. Perry St.

7.1.2 Dry-Weather Calibration

The second element focuses on calibrating dry-weather flows. For this element, data from each of the flow monitors assigned directly to a flow-monitoring basin are used. This includes all of the permanent and temporary flow monitors (Table 10), except those that are directly downstream of a hydrobrake.

TABLE 10. **MONITORS USED FOR MEASURING BASIN HYDRAULIC AND HYDROLOGIC RESPONSE**

NPDES #	MH ID	Location	Purpose	Temporary (T) or Permanent (P)
44	067-274	NPDES #44 Outfall. CSO Basin 44A. In 30-inch pipe downstream of weir diversion to storage.	Characterize basin flow and measure CSO events. Measures depth in storage & estimates flow over weir to outfall.	P
44	067-261	NPDES #44 Outfall CSO Basin 44B. In 15-inch pipe upstream of weir diversion & downstream of HydroBrake	Characterize basin flow and measure CSO events. Depth & flow will be used to develop rating curve for HydroBrake located upstream.	P
44	067-191	N. of Seward Park on Lake Washington Blvd. S.	Characterize basins flow	T
44	067-271	Seward Park Rd. east of Lake Washington Blvd. S. in 24-inch pipe upstream of HydroBrake.	Meter relocated from 067-269. Depth will be used to develop rating curve for Hydrobrake located in next downstream maintenance hole	T
44	067-275	NPDES #44 Outfall. Downstream of diversions 44A and 44B. One sensor in 30-inch pipe from north & one sensor in 15-inch pipe from west.	Characterize flow in overflow structure.	T
45	074-153	NPDES #45 Outfall. 57th Ave. S. CSO Basin 45A	Characterize basin flow and measure CSO events	P
45	074-167	NPDES #45 Outfall. CSO Basin 44B	Characterize basin flow and measure CSO events	P
45	074-159	Martha Washington Park 57th Ave. S. In 15-inch pipe upstream of HydroBrake.	Depth will be used to develop rating curve for HydroBrake	T
46	081-062	NPDES #46 Outfall. Island Dr. S. CSO Basin 46	Characterize basin flow (Prichard Island).	P
46	081-059	East of Seward Park Ave. S. between S. Kenyon St. & S. Budd Ct. In 21-inch pipe upstream of Pump Station #9.	Characterize basin flow	T
47	081-224	NPDES #47 Outfall. CSO Basin 47B.	Characterize basin flow and measure CSO events	P
47	081-330	NPDES #47 Outfall. CSO Basin 47C	Measure CSO events	P
47	080-298	NPDES #47 Outfall. 46th Ave. S. & S. Henderson St.CSO Basin 47D	Characterize basin flow and measure CSO events	P
47	080-480	NPDES #47. Renton Ave. S. & S. Henderson St. CSO Basin 47E	Characterize basin flow and measure CSO events	P
47	073-268	South of S. Holly St. on Rainier Ave	Characterize basin flow	T
47	073-276	S. Fontanelle. St. & Rainier Ave. S.	Characterize basin flow	T
47	080-329	North of S. Henderson St. on Rainier Ave. S	Characterize basin flow	T

TABLE 10. **MONITORS USED FOR MEASURING BASIN HYDRAULIC AND HYDROLOGIC RESPONSE**

NPDES #	MH ID	Location	Purpose	Temporary (T) or Permanent (P)
47	081-085	Seward Park Ave. S. & S. Henderson St	Measure flow from previously unmetered part of basin to characterize basin flow	T
47	081-139	Rainier Ave. S. & 53rd Ave. S	Characterize basin flow	T
47	081-120	Rainier Ave. S. & 51st Ave. S	Characterize basin flow	T
171	081-231	NPDES #171 Outfall. CSO Basin 171	Characterize basin flow and measure CSO events.	P
171	306-192	S. Gazelle St. & 59th Ave. S	Characterize basin flow	T
171	081-237	Rainier Ave. S. west of 57th Ave.	Characterize basin flow	T
48	306-250	NPDES #48 Outfall. Pump Station overflow	Measure CSO Events. Pump Station records	P
49	306-437	NPDES #49 Outfall. CSO Basin 49	Measure CSO events	P
49	306-284	In roadway in front of 9926 Waters Ave S, in northwest side of road.	Characterize basin flow	T
49	306-343	Rainier Ave. S. between S. Cooper St. & S. Thayer St	Characterize basin flow	T
49	306-245	Rainier Ave. S. just south of S. Pilgrim St	Captures flow from northern portion of CSO Basin 49	T
49	306-275	Rainier Ave. S. just south of S. Pilgrim S	Captures dry-weather flow for CSO Basin 49	T
49	306-428	Rainier Ave. S. near Pump Station 80 (CSO Basin 48)	Measures depth in storage and develop rating curve for hydrobrake	T

Observed data and model results for dry-weather periods are compared to ensure that base DWF is accurately simulated. A well-calibrated DWF model can help pinpoint troublesome spots in the sewer system and provides a basis for calibrating the model to wet-weather conditions. To calibrate the DWF model, a dry period with average flows and detailed meter data from the monitoring program is selected. The model is then run for the selected period (a week). An iterative approach of identifying issues, seeking solutions, and rerunning the model is then taken until an appropriate level of calibration is achieved. Parameters that may be adjusted for dry-weather calibration are the following:

- Per capita flow load factor
- $WW_{cap\ avg}$ in units of gpcd
- Adjustment to the loadpoint locations

Slight adjustments may also be necessary to the Manning's n to align measured water levels with simulated HGL.

7.1.3 Wet-Weather Calibration

After the model is calibrated to dry-weather conditions, precipitation that was measured during the flow monitoring period is used in a hydrologic model and routed through the hydraulic model. CSOs occur as a result of a sewer system becoming overloaded during wet-weather and being relieved through regulating structures. The wet-weather model is used for estimating the volume, frequency, and duration of CSOs, which can then be used to estimate pollutant loadings to receiving waters or to evaluate CSO reduction alternatives. As in the dry-weather calibration, data from all of the flow monitors (except those directly downstream of a hydrobrake) are used for calibration. To calibrate the model, observed data and model results for a range of wet-weather events are compared to ensure that the system's wet-weather characteristics are realistically simulated in the model. The process used to calibrate the model for wet-weather simulations is the same as that followed for dry weather: Realistic values are applied, the model is run, differences between the model and monitors are noted, reasons for the discrepancies are sought, and the model is adjusted based on the findings. The parameters that may be adjusted during wet-weather calibration include the following:

- Catchment widths
- Initial abstractions
- Catchment connectivity
- Contributing area or runoff surfaces
- Percolation coefficient
- Hydrobrake Q-H curves

7.1.4 Model Validation of Initial Calibration

Several iterations of this process are used to refine the model. The wet-weather calibration will be achieved by using a small number of storms selected from the initial monitoring program that represents a range of storm volumes and intensities. Monitoring data from the 2008 to 2009 seasons will be used after the traditional calibration to refine hydrologic and hydraulic response of the model to storms. A single storm from the monitoring period will be excluded from the data used for calibration so that these storm data can be used for independent model verification following the traditional calibration procedure.

7.2 Automatic Calibration

The calibration process discussed above is the traditional industry-accepted approach of calibrating a hydraulic model to support facility planning and alternatives analysis. In addition to this traditional calibration process, an automated model calibration and validation process developed specifically for SPU will be used. Using this process, Generalized Likelihood Uncertainty Estimation and Validation (GLUE) developed by MGS Engineering Consultants for SPU, modeling parameters, and the corresponding upper and lower bounds of these parameters will be identified. A Monte Carlo type repetitive simulation will be used to determine multiple alternative hydrologic parameter sets from a randomized sample. This process is discussed in more depth in *Guidance Manual: Technical Methods for Estimating Control Volumes for CSO Reduction- Draft 1* (CH2M HILL, 2008). The GLUE approach applies primarily to the dry and wet-weather calibration.

The GLUE process depends on an external controlling program that operates InfoWorks in a batch mode. The external controlling program runs the model multiple times (sometimes even hundreds of runs are executed), each time using a different set of model parameters. Each set of model parameters is randomly generated from among the range of acceptable parameters (set by the user). Instead of a relative few parameter sets being investigated, as in the traditional calibration, this process ensures a more thorough evaluation of possible parameter sets. The results from each model run are recorded and compared with measured flows using the Goodness-of-Fit measures of percent of total volume and percent of peak flow rate. The top 10 parameter sets whose results best match the measured flow data are selected as “behavioral” parameter sets and are used for model validation and uncertainty analysis.

The goal is to calibrate to three storms of varying magnitude. The period of precipitation and flow monitoring data selected for automatic calibration will consist of storms representing the widest range of events experienced during the monitoring period. Because of the large computational time commitment needed for the GLUE process, automatic calibration will only commence after the extended monitoring period (2008 through 2009 season) is complete. The period for one selected storm will be excluded from the calibration data in order that these data be used for independent model validation. After this is completed, personnel familiar with the operation and performance of the system will be consulted to verify the model’s accuracy. These comparisons are often qualitative, but usually result in greater confidence in the accuracy of the model.

7.3 Calibration Criteria

7.3.1 Target Criterion

The following criteria will be used as a guideline for the evaluation of GLUE calibration for wet-weather events:

- Predicted peak flows between 20 percent above and 15 percent below metered flow for the highest peak of each rain event
- Predicted flow volume between 20 percent above and 15 percent below metered flow volume for each rain event
- Predicted peak flow depth between 1 foot above and 0.5 foot below measured flow depth for each rain event
- Predicted flow event hydrograph should follow meter hydrograph in magnitude and shape until the flow has substantially returned to the dry-weather flow rates.

7.3.2 Water Level

Simulated hydraulic grade lines will be compared to measured levels from the flow monitors and observed water levels in the field. The water levels at the CSO diversion structures will be specifically targeted for review.

7.4 Uncertainty Analysis

7.4.1 Uncertainty Analysis Approach

SPU has recognized the high variability with regard to number, magnitude, and temporal characteristics of storms used to evaluate CSO reduction alternatives. In addition, there are sizable uncertainties associated with the various analyses, data reliability, and computer modeling of combined sewer systems. In considering these factors, a risk-based approach was developed to provide information to SPU decision-makers for evaluating options for sizing of control volumes for meeting compliance targets for CSO reduction. A risk-based approach is particularly well-suited to the CSO reduction problem because many of the factors to consider have elements of chance and uncertainty, and there can be significant environmental, economic, and social consequences for not complying with state and federal water quality regulations.

The Uncertainty Process, as developed by MGS Engineering Consultants under contract by SPU, is briefly discussed below. As with the automated calibration process, a more detailed discussion of the uncertainty analysis can be found in *Guidance Manual: Technical Methods for Estimating Control Volumes for CSO Reduction- Draft 1* (CH2M HILL, 2008).

For the uncertainty analysis, precipitation scaling factors representing uncertainty in the model input parameters are assigned to each of the 10 selected "behavioral" parameter sets from the GLUE calibration. These factors will eventually be applied to the entire period-of-record precipitation dataset for SPU gages (1978-2008), thus driving uncertainty analysis. Unique precipitation scaling factors are applied to represent the following sources of uncertainty:

- Representativeness of the 1978 through 2008 period of precipitation data for use in predicating future precipitation (assuming stationary climate)
- Effects of climate change
- Accuracy of flow measurements used for calibration and validation
- Ability of model to accurately predict flows given a set of parameters

The above uncertainties are each quantified using a probabilistic scaling function. From this function, a scaling factor is randomly chosen for each of the 10 selected "behavioral" parameter sets. Scaling factors for each source of uncertainty are multiplied, resulting in a Total Precipitation Scaling Factor. A unique Total Precipitation Scaling factor is applied to model runs for the entire period of rainfall record (1978 to 2008) for each of the 10 selected parameter sets. The results from these 10 long-term model simulations are then evaluated by graphing Probability In-Compliance against CSO Control Volume (also known as a Control Volume Performance Curve). The Control Volume Performance Curve, along with percent uncertainty bounds, will allow the SPU management to select a CSO Control Volume that meets acceptable performance and risk objectives.

7.4.2 Existing Conditions Assessment

The purpose of the uncertainty analysis is to determine the effects of uncertainties on the sewer flows and overflow volumes predicted by the computer model. Sufficient simulations are performed to yield the following:

- Most probable performance curve presented as a probability versus peak overflow rate
- Most probable performance curve presented as a probability versus volume
- 80 percent uncertainty bounds for each curve
- 90 percent uncertainty bounds for each curve

7.4.3 Selection of Performance Curves

The performance curves are reviewed for the alternative future and the performance curve that best meets the performance target is selected and recommended to SPU as the basis for CSO alternative analysis.

7.5 General Quality Assurance/Quality Control Procedures

The Henderson Basin model development requires the compilation and analysis of multiple data from a wide variety of sources with information of varying accuracy, resolution, and formats. Implementing quality assurance and quality control (QA/QC) procedures continuously throughout model development is critical in developing a model that meets the objectives of the project. Procedures to be implemented include the following:

- Specified SPU personnel tasked with review and assisting in compiling the most accurate, pertinent information available
- Ongoing review meetings among project team members to clarify issues, document decisions, and anticipate/obtain additional data or resource needs
- Project team to consult senior hydraulic engineers and software vendor technical resources verifying the modeling approach, construction and analysis
- Redundant and independent review of model inputs, use, and analysis throughout the model development process

To enhance the QA/QC reviews, the project team has compiled a checklist to guide critical reviews. The checklist, provided in Appendix A, guides reviewers to target specific items throughout the various development and analysis tasks: network and catchment development, sanitary/dry weather flow components, and dry and wet weather calibration, as well as other general issues and data groups.

8.0 Modeling of Alternatives

After the model is calibrated using GLUE and refined during the uncertainty analysis, it will be used to evaluate CSO reduction alternatives. An appendix in the final H&H Report will be the proposed methodology to model the selected alternatives.

9.0 Implementation

9.1 Roles and Responsibilities

In general, ADS is responsible for installing and maintaining the flow monitors that will be the basis for the flow loading in the model. CH2M HILL is responsible for developing and calibrating the InfoWorks hydraulic model and model documentation. These roles are described in greater detail in Table 11, which is derived from *Work Assignment Form Attachment 1: Scope of Service for the Henderson CSO Model Development Project.*

TABLE 11. ROLES AND RESPONSIBILITIES

Role	Entity Responsible
Flow monitor installation and maintenance	ADS
Providing the GIS, SCADA, and lift station configuration data needed to develop model	SPU
Model development and initial calibration	CH2M HILL
GLUE Calibration Tool	MGS
Automated model calibration GLUE – Generalized Likelihood Uncertainty Estimation) and Validation	CH2M HILL
Uncertainty Analysis Tool Module	MGS
Performance Curve selection	SPU
Hydrological and Hydraulic Modeling Report	CH2M HILL
Henderson Street lift station capacity and configuration	KC
Monitoring data on S. Charleston Trunk	KC
Develop alternatives modeling approach	CH2M HILL
Alternative screening methodology approval	SPU
Coordinate the CSO project with KC's wastewater system	SPU

9.2 Project Deliverables

Project deliverables for Henderson CSO Flow Monitoring are listed in Table 12. The proposed chapters of the Henderson Model Report are listed in the Model Documentation section.

TABLE 12. PROJECT DELIVERABLES

Project Element
Final Modeling Plan submittal to Ecology
Final H&H report

9.3 Timeline and Project Schedule

The permanent flow monitors were installed in the summer of 2007. The temporary flow monitors were installed in January 2008 and expected to be maintained through approximately June 2009. Following flow monitoring, the model will be calibrated and alternatives developed to proceed with the Project Development Plan. The anticipated duration of the project is expected to be approximately 2 years. Table 13 details the major activities as described in the Scope of Services for the S. Henderson Combined Sewer Overflow Reduction Project.

TABLE 13. PROJECT SCHEDULE

Project Element	Schedule
Flow Monitoring	January 2008 through June 2009
Final H&H report	October 2009
CSO reduction plan (engineering report) to the Department of Ecology	December 31, 2010

10.0 References

CH2M HILL *TM#7 – Model Development and Calibration*. Prepared for the City of Omaha: Omaha, NE 2004.

CH2M HILL, Inc**.,** *Flow Monitoring Plan Draft.* Prepared for Seattle Public Utilities: Seattle, WA 2008.

CH2M HILL, Brown and Caldwell, et al., *Comprehensive Modeling and Real Time Control Strategies Strategy Development for Sewer Conveyance Hydraulic Models***.** Prepared for the Milwaukee Metropolitan Sewerage District: Milwaukee, WI 2002.

CH2M HILL, Brown and Caldwell., et al., *Comprehensive Modeling and Real Time Control Strategies Strategy Development for Sewer Flow (Hydrology) Models*. Prepared for the Milwaukee Metropolitan Sewerage District: Milwaukee, WI 2002.

HDR, *South Henderson Combined Sewer Overflow (CSO) Reduction Project Initial Estimation of CSO Control Volumes for Henderson/Genesee Basins,* Prepared for Seattle Public Utilities: Seattle, WA 2008.

Earthtech, *Sewerage System Modeling and Assessment Project.* Prepared for Seattle Public Utilities: Seattle, WA 2001.

MGS Engineering Consultants, Inc**.,** *Guidance Manual: Technical Methods for Estimating Control Volumes for CSO Reduction- Draft 1*. Prepared for Seattle Public Utilities: Seattle, WA 2008.

HDR, *Initial Review of Flow and Rainfall Monitoring Data Technical Report No. 1*. Prepared for Seattle Public Utilities: Seattle, WA 2008.

Wallingford InfoWorks CS Help

http://www.epa.gov/

http://www.wallingfordsoftware.com/

http://www.ecy.wa.gov/

http://dnr.metrokc.gov/

APPENDIX A

CSO InfoWorks Modeling QA/QC Checklist - Model Development and Calibration

CSO InfoWorks Modeling QA/QC Checklist - Model Development and Calibration

Project Henderson CSO Reduction Project
Reviewer
Date 12/4/2008
Model File

This checklist is considered a minimum for QA/QC review, and should be expanded to meet the needs of the project being reviewed.

Part 1 - General

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
1	The performance requirements of the model are clearly defined through the project performance requirements and the modeling plan. These requirements include the boundary condition(s), the sewered area to be modeled, the types of alternatives that will evaluated, how the performance of alternatives will be evaluated, and any other requirements external to the project that may impact the model (e.g., SPU Standards & Guidelines, systems modeling program).						
2	The design and level of detail of the model meet the performance requirements						
3	Catchment group organized and labeled in a consistent and clear manner. Catchment group contains the following minimum data groups: Network, Rainfall, Level, Wastewater, Inflow, Flow Survey, Run, Graph Template, and Ground Infiltration.						
4	Current version of network flagged "Current"						
5	Model passes Engineering Validation with no errors or warnings						
6	Each element and attribute in the model has a user defined data flag, with the exception of #D (default). Elements and attributes that are assumed, calculated, or otherwise modified from the SPU GIS or drawings should include additional description in the comment fields to indicate how the value was calculated (e.g., "invert elevations calculated from average slope of 0.002 between node 006-488 and node 006-188")						
7	NAVD88 datum used for all elevations. Converstion factors documented and verified (9.7 feet for both Henderson and Genesee unless otherwise stated).						
8	Other general items that warrant QA/QC review given the project goals, objectives and performance requirements						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
Part 2 - Network Development							
1	Boundary conditions defined by project team are applied correctly in the model. Downstream boundary condition, typically an interface point (regulator or pump station) within King County's combined sewer system, modeled as described in design documentation. Any deviations from design documentation are described. Downstream boundary condition designed so as to achieve the performance requirements described in the boundary condition performance requirements.						
2	Outfall boundary conditions defined as time versus stage relationships at each outfall location. Time versus stage information for Lake Washington and Puget Sound based on historical level information collected by the U.S. Army Corps of Engineers. Salt water density differential, if applicable, accounted for through adjustment of time versus stage relationship.						
3	Extents of modeled network defined (e.g., minimum pipe diameter) and deviations explained						
4	Node and link names follow SPU naming conventions. Nodes - SIMSID; Links - InfoWorks naming convention; Dummy nodes associated with special structures - SIMSID[StructureCode] (StructureCodes - Hydrobrake = H, Weir = W, Sluice Gate = S, Flap Gate = F, Pump Station = P). Predominant hydraulic element takes precedence.						
5	Link attribute data (i.e., length, diameter, invert elevations, system type) matches SPU GIS system, any differences are explained in comment fields						
6	Node attribute data (i.e.,MH ID, rim elevation, system type) matches SPU GIS system or best available information. Any differences are explained in comment fields						
7	Asbuilts, survey data, or best available information reviewed for critical nodes and links, and attributes						
8	Pipe profiles reviewed and no anomalies are noted						
9	Head loss coefficients that aren't default are explained in comment fields						
10	Default Manning's n of 0.013 applied, other n values explained in comment fields						
11	Sediment levels included where information is available (e.g., measurements from flow monitoring) and explained in comment fields						
12	Flood types applied (e.g., sealed for force mains, stored, lost) - Lost is default, unless in an area where surface discharges are known to re-enter the system						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
13	Additional node storage applied where node does not represent an ordinary maintenance hole (e.g., maintenance hole used as a wet well for a pump station)						
14	Hydraulic control elements that divert flow out of or into the basin are included in the model, and characteristics checked against asbuilts or best available information, differences noted						
15	Hydraulic control elements that divert flow within the basin are included in the model, and characteristics checked against asbuilts or best available information, differences noted						
16	Configuration of pump stations checked against asbuilts or best available information and differences noted - minimum pump station information should be pump curves or operating points, off/on elevations, wet well dimensions, wet well depth, relief point characteristics (e.g., weir and outfall), and minor losses of pump fittings (unless calibrated against measured data)						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
17	Pump curves or operating points adjusted based on flow monitoring data, and changes from design information described in the comment field						
18	Configuration of CSO control structures checked against asbuilts or best available information, differences noted. Overflow weir elevations match survey data. Field visit by modeler to confirm hydraulic characteristics of CSO control structures.						
19	Hydrobrake curves adjusted based on flow monitoring data, and changes from design information described in the comment field						
20	Weir coefficients or rating curves adjusted based on flow monitoring data, and changes from design information described in the comment field. Source of coefficients for weirs without measured data is documented.						
21	Configuration of other structures, including storage, checked against asbuilts or best available information, differences noted						
22	Review configuration of key facilities in the CSO basin: diversion structures, pump stations, NPDES Permitted CSOs						
23	Other items related to network development that warrant QA/QC review						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
Part 3 - Subcatchment Development							
1	Resolution of subcatchments is sufficient for the needs of the project						
2	Methodology for delineating subcatchment boundaries and final subcatchment boundaries reviewed						
3	Methodology for determining subcatchment physical parameters (e.g., all drainage and sewered area tributary to boundary condition accounted for in model subcatchments, drain node id, slope, hydraulic width, percent imperviousness) reviewed and final physical parameters reviewed.						
4	Latest available information from Puget Sound Regional Council utilized for determining subcatchment population. Adjustments for commercial and industrial populations reviewed and documented. Methodology for dissolving population values from TAZ zones reviewed and final population values totals reviewed.						
5	Runoff area measurement type correctly assigned (percent or absolute), and total runoff areas corresponds with contributing area						
6	Rain gage assignments verified						
7	If land use table is used, verify values						
8	Runoff volume and routing models appropriate for geographic area and project needs. Review subcatchment size limitations for selected runoff method.						
9	Runoff volume and routing model parameters within reasonable range according to literature						
10	Ground infiltration module or Ground Infiltration Events utilized and parameters within reasonable range according to literature						
11	Determination of land use and application of developed/undeveloped areas						
12	Other items related to subcatchment development that warrant QA/QC review						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
Part 4 - Sanitary/Dry Weather Flow Components							
1	Key monitoring locations to be used for dry weather flow derivation identified, reasons for not selecting locations for dry weather flow derivation documented						
2	Documentation for derivation of wastewater profiles and per capita flow rates reviewed (included separately from model)						
3	Weekday and weekend wastewater profiles defined						
4	Correct wastewater profiles and population assigned to each subcatchment						
5	Significant flow from unmodeled and modeled areas (large users) applied						
6	Sanitary & dry weather flow balances using a flow meter schematic - dry weather flows used in the model should hold continuity prior to being allocated						
7	Other items related to dry weather flow components that warrant QA/QC review						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
Part 5 - Other Data Groups							
1	Level groups created and populated with measured level data, assigned to outfalls in network						
2	Flow survey group created and populated with data from flow monitoring period, survey points match node names in network						
3	Rainfall group created and contains gages needed for the modeled area, contains observed event data for 30 years of record for calibration and long term simulation purposes						
4	Rainfall group contains the adjusted rainfall time series that will be required for long term simulations that include climate change (climate change only applies if uncertainty analysis is being applied)						
5	Real time control scenarios defined and working, match operational procedures or measured data, utilize the most appropriate incremental or PID controllers to match real world performance						
6	Groundwater group contains infiltration event profile for each subcatchment if a time-varying profile is being used, parameters being used are reasonable range according to literature and best available information about groundwater levels						
7	Other items related to data groups that warrant QA/QC review						
Part 6 - Dry Weather Calibration							
1	Key monitoring locations to be included or excluded for dry weather calibration are identified and reasons for inclusions or exclusion are documented, selected locations should be the same for dry weather flow and wet weather flow						
2	Model is stable during dry weather runs						
3	Flow and volume balances across key monitoring locations and outfalls						
4	Modeled hydrographs during dry weather flow periods match monitored hydrographs at key monitoring locations, in volume, peak, and shape (standard error within 5%) on weekday and weekend days						
5	Other items related to dry weather calibration that warrant QA/QC review						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Acti	Modeler Response	Final Resolution
Part 7 - Wet Weather Calibration							
1	Key monitoring locations to be included or excluded for wet weather calibration identified and reasons for inclusions or exclusion are documented. Selected locations should be the same for dry weather flow and wet weather flow. Key monitoring locations should contain storms that meet the criteria for calibration.						
2	Review weighting for key monitoring locations, and methodology that was used to determine weighting factors						
3	Flow survey and rainfall data being used for calibration is final data, not raw or preliminary. Final data has been finalized by a flow monitoring consultant, and the scattergraph for the data matches the theoretical curve for the monitoring location.						
4	Following model shakedown/initial calibration, performance of significant hydraulic structures reviewed to confirm proper operation within the model and consistency with what is known about actual performance. Qualitative assessment made to identify which structures have a significant role in determining CSO control volume. If required, field visit conducted to these significant hydraulic structures for which there are sizeable uncertainties in hydraulic characteristics and/or actual performance, and modifications made to reduce uncertainties.						
5	Calibration period utilized includes 6 - 10 key storm events that range between those that do not cause overflows to those that do, typically events between 2-month recurrence interval and 10-year recurrence interval						
6	Model parameter set selected for automated calibration excludes physically based parameters that can be directly measured in GIS (e.g., subcatchment area, contributing area, impervious area) that could potentially be adjusted during analysis of green infrastructure alternatives (e.g., downspout disconnects)						
7	Minimum and maximum values established for each parameter in the model parameter set are reasonable given the physical limits of each parameter, characteristics of the subcatchment, and literature values						
8	Model parameter space thoroughly evaluated (I.e., enough runs completed) to identify behavioral parameter sets						
9	Review flow thresholds used for computing goodness-of-fit measures at key monitoring locations						

Item	Description	Reviewer	Date	Review Comments	Reviewer Recommended Actio	Modeler Response	Final Resolution
10	Modeled hydrographs match monitored hydrographs at key monitoring locations, in volume (+/- 15%), peak (+/- 20%), and shape (standard error within 10%), for the 6 - 10 key storm events selected for model calibration						
11	Comparison of modeled CSO frequency for the 1998-2008 period to measured CSO frequency yields expected results						
12	Surface flooding predicted by the model is comparable with reported flooding during monitoring period - flooding should be generally reproduced by the model both in terms of location, severity and frequency						
13	Model is stable during calibration model runs, volume into the model matches volume discharged						
14	Outfall hydrographs reviewed to ensure that flows are being discharged						
15	Other items related to wet weather calibration that warrant QA/QC review						