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Chapter 7 DRAINAGE & WASTEWATER SYSTEM MODELING

This chapter of the Design Standards and Guidelines (DSG) describes Seattle Public Utilities (SPU) standards and guidelines for construction and use of hydrologic and hydraulic (H/H) models of drainage and wastewater collection facilities in Seattle.

Standards appear as underlined text.

The audience for this chapter is SPU modeling staff. This chapter may also have relevance to other engineers, scientists, and planners, including Seattle Department of Construction and Inspections (SDCI) and Seattle Department of Transportation (SDOT) staff and others who perform routine H/H modeling on SPU drainage and wastewater projects. Typical City of Seattle projects that require H/H modeling are combined sewer overflow (CSO) abatement design, pump station upgrades, storm drain facilities, claims investigation, and mainline capacity analysis.

7.1 KEY TERMS

The abbreviations and definitions given here follow regulatory guidance or common industry practice. Definitions for key terms are given in the section in which they first appear.

7.1.1 Abbreviations

Abbreviation	Term
CIP	Capital Improvement Program
CSO	combined sewer overflow
DSG	Design Standards and Guidelines
EPA	U.S. Environmental Protection Agency
EPA SWMM	U S. Environmental Protection Agency's Stormwater Management Model
H/H	hydrologic and hydraulic
I/I	Infiltration and inflow
KCDOA	King County Department of Assessment
QA	quality assurance
SDCI	Seattle Department of Construction and Inspections
SDOT	Seattle Department of Transportation
SPU	Seattle Public Utilities
STAZ	Statewide Traffic Analysis Zone

7.1.2 Definitions

Term	Definition
base flow	Flow during dry weather is base flow (also called dry weather flow). Base flow consists of groundwater infiltration and direct inflows during dry weather. Direct inflows can include underground springs, flow from sanitary side sewer lateral connections, and others.
block	A geographic area bounded by visible and/or invisible features (features may be visible such as a street, road, stream, shoreline, or power line; or invisible such as a county line, city limit, property line, or imaginary extension of a street or road). Generally, the boundary of a census block must include at least one addressable feature; that is, a street or road shown on a map prepared by the U.S. Census Bureau. A block is the smallest geographic entity for which the Census Bureau tabulates decennial census data.
block group	A statistical subdivision of a census tract (or, prior to Census 2000, a block numbering area). A BG (block group) consists of all tabulation blocks whose numbers begin with the same digit in a census tract. For example, for Census 2000, BG 3 within a census tract includes all blocks numbered from 3000 to 3999. (A few BGs consist of a single block.) BGs generally contain between 300 and 3,000 people, with an optimum size of 1,500 people. The BG is the lowest-level geographic entity for which the U.S. Census Bureau tabulates sample data from a decennial census.
boundary condition	Boundary condition can be most downstream discharge point of a model, most upstream point of a model, and/or adjacent point to a model. Some examples are discharge from a upstream basin, discharge from adjacent basin, outfall to a body of water (such as creek, river, stream, Lake Washington, or Elliott Bay) as well as discharge to King County wastewater system.
calibration	The process of adjusting model parameters in order to have agreement between model simulation results and flow monitoring data.
combined sewer	Public combined sewers are publicly owned and maintained sewage systems that carry stormwater and sewage to a treatment facility. Treated water is released to Puget Sound.
Combined Sewer Overflow (CSO)	Abbreviated as CSO. A combination of untreated wastewater and stormwater that can flow into a waterway when a combined sewer system reaches its capacity.
design flow rate	Flow rate used to size infrastructure such as a pipe, creek cross-section, weir, and others
Discrete Address Point (DAP)	Addresses are the common way to identify specific buildings and/or property units. Discrete Address Points are intended to provide a comprehensive geographic reference for any and all addresses. Each point in the DAP layer represents either a building or a vacant parcel, derived from the BLDG and PARCEL layers. Linkage keys back to these source GIS layers are the primary DAP element attributes.
drainage	Stormwater that collects on a site through footing or yard drains, gutters, and impervious surfaces. If there is no discharge point, discharge may infiltrate or disperse into the ground. Otherwise, stormwater is conveyed to one or a combination of natural drainage systems, ditch and culvert systems, or public storm drains.
drainage system	A system intended to collect, convey and control release of only drainage water. The system may be either publicly or privately owned or operated, and the system may serve public or private property. It includes constructed and/or natural components such as pipes, ditches, culverts, streams, creeks, or drainage control facilities
Dry-weather flow model (DWF)	Simulation of generation of sanitary sewer flow and seasonal groundwater infiltration (sGWI).
ESRI	Formerly an acronym for Environmental Systems Research Institute, the company that developed the Arc/Info geographical information system (GIS) software.
flow control	Controlling the discharge rate, flow duration, or both of drainage water from the site through means such as infiltration or detention. 22.801.070 SMC
flow monitoring	Collection of data such as flow depth and velocity at a monitoring point.
green stormwater infrastructure (GSI)	Distributed BMPs integrated into a project design that use infiltration, filtration, storage, or evapotranspiration, or provide stormwater reuse. 22.801.080 SMC
guidelines	Advice for preparing an engineering design. They document suggested minimum requirements and analysis of design elements in order to produce a coordinated set of design drawings, specifications, or lifecycle cost estimates. Design guidelines answer what, why, when and how to apply design standards and the level of quality assurance required.

Term	Definition
hydraulics	Conveyance of water through pipes, open channels, force mains, maintenance holes, weirs, orifices, hydrobrakes, pump stations, and similar infrastructure.
hydraulic conveyance system model	Model that simulates routing of wet weather and sanitary flow generated by the hydrologic and dry weather flow models of the study area. Hydraulic conveyance system model consists of link and nodes.
hydrologic (hydrology)	Transport and distribution of water (such as rainfall) based upon top surface layer (i.e. pervious or impervious) and below surface conditions (soil type).
Hydrologic (wet-weather) model	Model that generates wet weather flow based upon meteorological and hydrologic conditions.
hydrograph	A graphical representation of stage, flow, velocity, or other characteristics of water at a given point as a function of time. Hydrographs are commonly used in the design of surface water and sewer systems including combined systems.
Infiltration and inflow (I/I)	Simulation of the component of flow from the study area attributed to surface runoff (inflow) and subsurface flow (infiltration) entering into the sewer and drainage system.
level of service	Performance measure of a system over time.
natural systems	A vegetated area in its natural state prior to development (such as a forest)
natural drainage systems	A form of green stormwater infrastructure (GSI). Natural or constructed rain gardens, swales, ravines, and stream corridors. Natural drainage systems cross privately- and publicly-owned property and can flow constantly or intermittently. See also *green stormwater infrastructure*.
Operations	Generic term for SPU staff responsible for field operations.
outfall	Generally, the point of discharge from a storm drain. Can also include combined sewer flows. See also Table 8-1.
overflow control volume	Overflow volume at a NPDES outfall point for a defined performance level.
pump runtime	The amount of time a pump is on.
Rainfall Dependent Infiltration and Inflow (RD I/I)	During a storm event, the resulting increase of inflow and infiltration is commonly referenced as Rainfall Dependent Inflow and Infiltration (RD I/I) by literature. Then, I/I = RD I/I + DW I/I (sources of DW I/I are underground spring as described in *base flow* definition above and seasonal fluctuation of groundwater table). In literatures, "I/I" and "Total I/I" are synonymous.
sanitary sewer flow	Sewage produced by private residents, businesses, schools, hospitals, industrial users, and other sewer connections to the wastewater conveyance system. It is also called Base Sanitary Flow (BSF). This flow does not include drainage.
Seasonal groundwater infiltration (sGWI)	Groundwater infiltration into conveyance system due to seasonal non-storm related fluctuation of groundwater table.
service drain (or lateral)	A privately owned and maintained drainage system that conveys only stormwater runoff, surface water, subsurface drainage, and/or other unpolluted drainage water and discharges at an approved outlet as defined by the SPU Director. Service drains include, but are not limited to, conveyance pipes, catch basin connections, downspout connections, detention pipes, and subsurface drainage connections to an approved outlet. Service drains do not include subsurface drainage collection systems upstream from the point of connection to a service drain. 22.801.030 SMC. See also Table 8-1.
side sewer (or lateral)	A privately owned and maintained pipe system that is designed to convey wastewater, and/or drainage water to the public sewer system or approved outlet. This includes the pipe system up to, but not including, the tee, wye, or connection to the public main. 21.16.030 SMC. See also Table 8-1.
SIMS	Scientific Information Management System. SIMS manages scientific information and work processes for SPU
SPU engineering	Generic term for SPU staff responsible for plan review and utility system design for CIP projects.
standards	Drawings, technical or material specifications, and minimum requirements needed to design a particular improvement. A design standard is adopted by SPU and generally meets functional and operational requirements at the lowest life-cycle cost. It serves as a reference for evaluating proposals from developers and contractors. For a standard, the word must refers

Term	Definition
	to a mandatory requirement. The word should is used to denote a flexible requirement that is mandatory only under certain conditions. Standards appear as underlined text in the DSG.
stormwater	Stormwater means runoff during and following precipitation and snowmelt events, including surface runoff, drainage and interflow. 22.801.200 SMC
surcharging	Occurs when level of water in pipe (or structure) rises above the top of pipe (or structure) and therefore the pipe (structure) becomes under pressure.
tract	A small, relatively permanent statistical subdivision of a county or statistically equivalent entity, delineated for data presentation purposes by a local group of census data users or the geographic staff of a regional census center in accordance with U.S. Census Bureau guidelines. Designed to be relatively homogeneous units with respect to population characteristics, economic status, and living conditions at the time they are established. Census tracts generally contain between 1,000 and 8,000 people, with an optimum size of 4,000 people. A census tract, census area, or census district is a geographic region defined for the purpose of taking a census.
validation	The process of comparing simulated model results with flow monitoring data (not used for model calibration) and finding agreement without adjusting model parameters.
wastewater	Wastewater is a comprehensive term including industrial waste, sewage, and other polluted waters, as determined by the Director of Health or Director of SPU. 22.16.030 SMC

7.2 GENERAL INFORMATION

Hydraulic/Hydrologic (H/H) modeling is a frequent component of SPU's drainage and wastewater system planning and engineering. H/H models contain a physical description of a collection system network (e.g. a sewer collection system, stormwater drainage network, or natural flow channel). The models use mathematical equations to estimate the amount of water entering the system and simulate its movement through sewers, maintenance holes, pump stations, and other sewer system components. This information is then used to estimate the hydraulic capacity of the system and its response to specific changes (e.g. larger pipes, new pumps, or new demands).

H/H modeling results are integrated into the following SPU planning, operational, and facility design activities:

- Predicting base and peak flows
- Performing system capacity assessments and Capital Improvement Program (CIP) planning
- Setting sizing criteria for preliminary engineering, pre-design, and design projects
- Planning future annexations
- Managing assets (replacement, rehabilitation, and system optimization scenario testing)
- Forensic testing of system overflows, backups, and surface flooding problems.

7.2.1 Modeling Concepts

Models must adequately capture the physical characteristics of the system to compute the hydraulic capacity of individual structures. For non-mechanical structures (e.g. pipes or maintenance holes), this includes elevations, geometry/diameters, friction characteristics, and connections to other system components. Models for mechanical structures, such as pumps stations and gates, also require operational characteristics. Generally, the required information on physical infrastructure is available from GIS databases, record drawings (as-builts), and other resources (see section 7.5, Model Construction).

Estimating the amount of water entering a drainage or wastewater system and simulating its movement through pipes is complex. For drainage and combined sewer systems, models utilize hydrologic information of the modeled area provided by users to predict the amount of precipitation and nearby groundwater that enters the pipes. For sanitary and combined sewer systems, in addition to hydrologic information, models also utilize sanitary flow information of the modeled area provided by users to calculate the amount of sanitary flow entering into pipes. In a model, flow generally enters pipes via nodes. These nodes usually represent maintenance holes in the field. During model construction process, GIS analysis and other methods are used to allocate area tributary to these input nodes within the modeled system to mimic how laterals, curbs, drainage inlets, and possible subsurface inflow and infiltration sources could convey flow to the pipes in the field. Depending on the complexity of the modeled system hydraulics, equations ranges from Manning's flow equation to the full Saint Venant equations of Continuity and Momentum coupled with various surcharge algorithms can be used for modeling hydraulic processes.

With the appropriate hydrologic, hydrogeologic, and hydraulic information entered into the models, H/H models can generate various simulation results (e.g. water surface elevations in a portion of the network, pump operation sequence, and flow hydrographs) useful for system operation and design activities.

7.2.2 Types of Models

H/H models have differing strengths and limitations and thus vary widely in complexity and requirements (e.g. quantity of input data, user training, software licensing). The design engineer should select a modeling approach with an appropriate level of complexity to address project goals (e.g. simple spreadsheet models to more specialized H/H modeling software).

7.2.2.1 H/H Models

SPU characterizes its H/H models in the following three categories based on level of detail: skeletal models, planning models and detailed design.

A. Skeletal Model

Skeletal H/H models simulate flow in major (large diameter) sewers within a collection and conveyance system. A skeletal model is also referred to as a *trunk line model*. Typically, a skeletal model extends from a downstream outlet (e.g. a major pump station or sewer basin outlet) to the upper reaches of a sewer catchment and can include multiple sewer basins. Skeletal models can also include simplifications to eliminate complexity or to improve calculation speed. The primary benefit of a skeletal model is a quick, representative evaluation of a system's major component performance. The skeletal model is used for:

- Long-term H/H simulations for deriving performance statistics and evaluating historical events of interest
- Simulation of flows at specific locations (e.g. pump stations), where a characterization of the upstream system is not of interest

- Overall assessment of a sewer basin to gage the impact of planned development or annexation and/or compare alternatives for major changes to a sewer network
- Simulation of boundary conditions in larger sewers so that more detailed models of ancillary sewers can be developed using representative tail water conditions
- Design and testing of major CIP projects, where less detail is appropriate.

B. Planning Models

Planning models are H/H models that simulate flow in most or all portions of a collection system within a specified neighborhood. These models are used when more detailed assessment is required than can be provided in a skeletal model. Planning models can be used to identify problem areas within specific portions of wastewater or drainage systems and a range of possible solutions. The level of detail included in a planning model should balance the need for precision. For example, small-diameter pipes could be excluded from a planning model that covers a very large spatial extent, particularly in areas with no documented flooding history. A planning model typically is used for:

- Simulation of flows in areas excluded from a skeletal model
- Assessment of a known problem area where a skeletal model does not provide sufficient detail.

C. Detailed Design

Detail Design models are used for evaluating specific problem areas and detailed investigation and operations. Detailed design models are usually derived from planning models but include a greater level of hydrologic, hydrogeologic, and hydraulic detail and cover a more limited spatial extent. They are often used in evaluating proposed solutions to improve drainage and wastewater service. These models also include any downstream elements (e.g. weirs, orifice, sluice gate, or pump stations) that could be affected by infrastructure upgrades.

7.2.2.2 H/H Model Software

The standard approved H/H modeling software for SPU projects is the U. S. Environmental Protection Agency's (EPA) Stormwater Management Model (EPA SWMM) latest version software. EPA SWMM is public domain software that can run dynamic wave simulation (i.e. St. Venant Equations) coupled with the Aldrich, Roesner et al Surcharge Algorithm to compute simultaneous flow depths (or pressures) and velocities throughout any dendritic or looped conveyance system. Results generated by the software can also be post processed by third-party SWMM user-interface model processing software and shared with Environmental Systems Research Institute, Inc. (ESRI) GIS software. Examples of such third-party model processing software include PCSWMM, XPSWMM, MIKE URBAN/SWMM, InfoSWMM, among others. Currently, SPU uses PCSWMM.

However, whenever the use of EPA SWMM cannot achieve SPU project, operation, or programmatic goals (e.g. SOPA operation, Joint Operation with King County, or other interagency collaboration), other public or proprietary modeling software (e.g. HEC-RAS, DHI MIKE URBAN/MOUSE) can be used. In those cases, the use of such software must be approved by the SPU Line of Business representative and/or project manager prior to commencement of work. Please contact the SPU project manager for additional information. Currently, for Drainage and Wastewater Operations and Joint Operation projects with King County, MIKE URBAN/MOUSE software is used.

Refer to City of Seattle Stormwater Manual for additional modeling software approved for hydrologic modeling.

For GSI modeling, refer to **Appendix 7H**.

7.2.3 Codes and Regulations

For relevant codes and regulations for drainage and wastewater system modeling, see *DSG Chapter 8, Drainage and Wastewater Infrastructure*, section 8.3, General Requirements as well as City of Seattle Stormwater Manual and its Appendix F Hydrologic Analysis and Design.

7.3 BASIS OF DESIGN FOR MODELING

SPU requires a modeling plan and a technical memorandum that describes key goals of modeling. Quality Assurance (QA) milestones approved by the SPU Line of Business Representative assigned to the project must also be incorporated into the modeling plan.

7.3.1 Modeling Plan

All SPU projects with H/H modeling must have a Modeling Plan. The Modeling Plan must follow the sample outline presented in **Appendix 7A**. SPU must approve any deviations from the plan.

All projects with flow monitoring must have a Flow Monitoring Plan prepared before flow monitoring installation. The Flow Monitoring Plan must follow the sample outline in **Appendix 7A.**

7.3.2 Technical Memorandum on Key Goals

Key goals for modeling must be developed collaboratively between SPU and consultant staff (if applicable). Key goals of the project must be documented in a brief technical memorandum. The memo should follow the outline presented in **Appendix 7A**.

7.3.3 Quality Assurance Milestones

The Quality Assurance (QA) milestones that must be incorporated into each SPU project with H/H modeling are shown in Table 7 1.

Table 7-1
H/H Modeling QA Milestones

Milestone	Phase (after . . .)	Review Activity
1	Modeling plan	Project team must review. Project Manager should assign reviewers
2	Flow monitoring and precipitation plan (if necessary).	Plans must be reviewed by staff assigned by project manager
3	Precipitation and flow monitoring collection (if necessary)	Team must formalize a data QA process for weekly or biweekly review of monitoring data
4	Model development and construction	The QA check should be completed by an independent senior member of the project's modeling team
5	Model calibration	Completed by an independent senior member of the project's modeling team.
6	Long-term simulation and uncertainty analysis (if applicable)	Determines whether uncertainty in modeling results generates substantial risks to overall success of project. Key project team members must participate.
7	Alternative analysis	Reviewed by an independent senior member of the project modeling team
8	Model documentation	Reviewed by an independent senior member of the project modeling team

The following are SPU standards for H/H modeling QA:

1. The modeling plan must identify the key project milestones where model review and QA checks must be performed.
2. The model QA checks must be documented and complied as part of the overall model documentation.
3. The elements and results of each QA check must be written to make QA documentation understandable to future modelers unconnected to the original project.

For a detailed Modeling QA checklist, see **Appendix 7B**.

7.4 MODEL ARCHIVING, UPDATES, AND DOCUMENTATION

Model archiving, updating, and documentation must all be considered before an H/H model is developed. This section describes SPU standard methods for archiving, updating, and documenting H/H models of the SPU drainage and wastewater collection system. SPU collection system models are currently cataloged on the SPU server. For checking out a SPU model, refer to section 7.5.9.8.

7.4.1 Preparing Model for Archiving

SPU staff periodically access archived models to ensure that they function with the latest versions of relevant software packages owned and operable by SPU. All models 5 years or older must be compatible with the latest version of the relevant SPU owned software or they can be discarded when updating is not practicable. SPU staff or consultants working on an H/H modeling project should first check to see if an H/H model of the area of interest may be available for the study area. Refer to section 7.5.9.8 for checking out a model. If so, those models should be utilized as much as possible or as a basis for further project refinement.

7.4.1.1 New Models

New models must follow these standards to develop an archiving package:

1. The H/H model file name can only use up to a maximum of 30 characters. The file name must be a brief version of the project name. For example, Windermere CSO Reduction project's H/H basin model file name is *Windermere*.
2. Naming model scenarios: The model scenario for existing conditions must be named Existing. All other scenarios must be named sequentially (e.g. Scenario #1, Scenario #2…). A brief description for each scenario should be added to the first 3 lines of the Title block in SWMM5 input (.inp) file. An example of the Title Block of SWMM .inp file can be as follow to include the scenario information:

    [Title]

    Windermere CSO Reduction project

    Scenario #1

    (12/10/2015 – 10:20 a.m.) Replaced hydrobrake with automatic gate

    All intermediate scenarios that are not current or no longer needed must be deleted prior to submitting the model files for archiving.
3. Place input and output time series data into separate subfolders.
4. Group supporting calculations in a subfolder and provide them with the modeling files.
5. Include the modeling plan, modeling report, and documentation with the modeling files.

7.4.1.2 Archive Package

A ready-to-archive model package must be provided to SPU staff when a project is completed. The model archive package must include a one-page summary (i.e. README file) that identifies key elements of the model for those searching the archive. The summary must include the following information:

1. Brief narrative description of model purpose, study area, and results
2. Map showing model location and boundaries
3. Model quick view table that includes the following:
    a. Type of model (e.g. skeletal, planning, design)
    b. Purpose of model (e.g. planning, pump station design, CSO control)
    c. H/H model software and version number used to create the model
    d. Rainfall data sources
    e. Evaporation data sources
    f. Basin hydrologic and hydrogeologic properties data sources (e.g. percent imperviousness, soil map and properties)
    g. Infrastructure data sources (e.g. pipe properties, pump curves, real time control algorithm)

h. Boundary condition data sources (e.g. Lake Washington level, Elliott Bay level, King County system level time series)

i. Model calibration period

j. List of baseline/existing and scenarios run and names of the associated model input files

k. Type of I/I calculations used (e.g. for the Madison Valley InfoWorks model, it would be appropriate to note that HSPF was used to calculate direct inflows to area catch basins instead of using EPA SWMM I/I simulation techniques)

l. Key assumptions and work remaining

m. List of file name(s) of associated documentation/reports/TM's

4. Other interesting or unique information about the model that should be noted by modelers using the model should also be included under a Special Note heading. Final acceptance of the archived package would be reviewed by SPU.

7.4.2 Updating a Model

SPU staff must update models as new or updated information becomes available. Generally, most models are maintained and updated in response to one of two events:

- New or updated system infrastructure information and/or flow data become available
- The model can be expanded or integrated into a nearby modeling effort or integrated into SPU's system wide modeling effort.

At a minimum, updating the model must consist of the following:

1. Give the model a new name and date stamp
2. Document the sources of new information added to the model
3. Add new or revise existing infrastructure, boundary condition, and/or flow data to the model. If applicable, revise model calibration. Document the revisions within the model.
4. Document all modeling updates in a technical memorandum and update the one-page summary (README file) of the updated model with new and/or revised information.

For detailed information on a modeling plan, see DSG section 7.3.1.

7.4.3 Modeling Report

A modeling report describes the model and conclusions drawn from its use. The report provides a record to assess the model's suitability for future use such as during design, post construction monitoring, and on other projects.

SPU H/H modeling work must be documented in a modeling report. SPU must approve any deviations from the modeling plan and must be documented in the modeling report. At a minimum, the modeling report must include the following sections:

- Model development
- Model calibrations and validation
- Uncertainty Analysis (if applicable)

- Discussion of existing system performance
- Alternatives analysis (if applicable)
- Discussion of modeling results limitations
- Discussion on model future use (i.e. post construction monitoring, informing design)
- Conclusions and recommendations

For a sample outline for a modeling report, see **Appendix 7A**.

7.5 MODEL CONSTRUCTION

Model construction is the initial phase in building an H/H model. This section describes the five major elements required to construct a model for H/H modeling analyses:

- Hydraulic conveyance system model
- Sub-basin delineation and flow assignment in the study area
- Boundary condition definition and modeling
- Dry-weather flow model
- Hydrologic (wet-weather) model.

7.5.1 Data Sources and Requirements

SPU H/H models have several data sources (Table 7-2). Time series data sources include both meteorological data used to calculate extraneous flow rates into the system and base wastewater flow demand data sources.

Table 7-2
H/H Model Inputs and Data Requirements

Major Input	Required Data
System Infrastructure Data (Hydraulic conveyance system model data)	• Pipes • Maintenance holes, Catch Basins, Tee-connections • Pump Stations • Special Structures (e.g. weirs, gates, hydrobrakes)
Spatial Data (Sub-basin delineation and flow assignment data)	• Topography – contour and LIDAR data • Impervious and Pervious Areas • Soils Characteristics • Land Use and Zoning • Parcels • Lateral connections (buildings and inlets)
Precipitation and Evaporation Data (Hydrologic wet-weather model data)	• Permanent gauges • Project-specific gauges • Evaporation monitoring stations
Flow Demand Model Data	• Dry weather flow (Base sanitary flows and seasonal groundwater infiltration) • Extraneous flow (Rainfall-induced infiltration and inflow)
Boundary Conditions	• Lake, rivers, creeks, and marine outfalls

Major Input	Required Data
	• Discharge to King County system or to SPU facilities used as boundary condition (e.g. pump station wet well)

7.5.1.1 Geographic Information Systems (GIS)

SPU GIS maintains and updates the system infrastructure data inventory. At the beginning of a modeling project, SPU staff will provide system infrastructure data to the modeling team. The pipe and maintenance hole GIS records are mostly complete. However, if the modeling team discovers any missing or erroneous data that would otherwise be needed to build a model, the modeling lead should check as-built records, review available survey information, and if needed work with SPU staff to coordinate field work to fill the data gaps. SPU staff will inform SPU GIS of missing or erroneous data.

The horizontal and vertical datum of data associated with constructing a computer model must be consistent with the SPU GIS datum:

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

7.5.2 Hydraulic Conveyance System Model Data

SPU compiles drainage and wastewater system infrastructure (hydraulic conveyance) data in its GIS system. The data include information on pipes and maintenance holes. SPU's Special Structures Data Manager contains many special structures designed to regulate, divert, or otherwise control the flow of water through the conveyance system. Most common are weirs, gates, pumps, and hydrobrakes. Special Structures Data Manager includes data for weirs such as weir crest elevation, weir length, hydrobrake curve and other data. Contact SPU GIS to obtain access to Special Structures Data Manager.

A hydraulic model contains links and nodes. Nodes represent structures within the study area such as maintenance holes, storage facilities, catch basins, or tee connections. Links represent pipes, open channels, culverts, and special structures such as weirs, gates, pumps, and hydrobrakes.

7.5.2.1 Hydraulic Model Requirements

The following data standards must be used in H/H modeling of SPU drainage and wastewater system infrastructure:

1. SPU GIS data must be used to build basic hydraulic models for the SPU system.
2. The model structure must be clear, easy to understand, reflective of field condition, and follow the naming conventions for data format **(Appendix 7D**).
3. Whenever data from other sources such as King County are needed, the request must be made through SPU Line of Business Representative.
4. Whenever new GIS datasets are created, the file names and coverage data fields must follow the guidelines described on the SPU GIS website.
5. If the modeling team identifies any data gaps during model setup, they must work with SPU staff to fill data gaps (e.g. review record drawings (as-builts), review available

survey information, or if needed work with SPU staff to send survey crews to collect relevant information).

6. If discrepancies occur among GIS and other data sources such as record drawings and survey, the following data preference hierarchy must be followed:
   a. Survey data
   b. Record drawings (as-builts) – If record drawings used a datum other than NAVD 88, check with SPU Survey to obtain local conversion. For other datum conversions, refer to City of Seattle Standard Plans 001 and 001a.
   c. Field observations
   d. GIS data

7.5.2.2 GIS Point Data for Structures

Point data are GIS coverage for drainage and wastewater structures that occupy a single location in the SPU system (e.g. maintenance holes, catch basins, tee-connections). For a complete list of structure types, see SPU GIS website.

A. GIS Coverage

This coverage contains the following data fields, which are important for model development:

- Structure type (i.e. FEATYPE)
- Structure ID (i.e. S_ENDPT_ID (wastewater) or D_ENDPT_ID (drainage)
- Top elevation (i.e. rim elevation of maintenance holes)
- DEPTH (i.e. depth of maintenance holes)
- Invert elevation of connecting pipe(s)
- Location (i.e. easting and northing coordinates)

B. Modeling Point Data as Nodes

Point data are contained within the model's nodes. For modeling of nodes, the following coordinating data fields are in GIS:

- Node ID = S_ENDPT_ID (wastewater) and D_ENDPT_ID (drainage)
- Coordinates = X_COORD, Y_COORD
- Ground Elevation = CURVE_ELEV_FT
- If the model requires node bottom invert, use the minimum of ELEV1_FT, ELEV2_FT, ELEV3_FT, ELEV4_FT or CURVE_ELEV_FT – DEPTH_FT.

Note: *the node invert can also be calculated from the lowest pipe invert connected to the node.*

7.5.2.3 GIS Pipe Data

Pipe data include GIS coverage for all public sewer pipes within the city limits and some King County interceptors. The pipe database includes a field that indicates whether a pipe conveys stormwater, sanitary, or combined sewer flows.

A. GIS Coverage

For each pipe segment, the GIS coverage should include the following:

- Pipe shape (circular, oval, rectangular)
- Pipe lifecycle (connected, abandoned)
- Pipe dimensions (diameter, width, height)
- Pipe length
- Upstream and downstream pipe invert elevations
- Pipe material
- Pipe installation year
- Upstream and downstream connecting maintenance hole IDs

B. Modeling Pipe Data as Links

For modeling pipe data as links, the coordinating data fields in GIS are the following:

- Pipe ID = MAINLINE_PT_ID
- Upstream Node ID = UPS_ENDPT_ID
- Downstream Node ID = DNS_ENDPT_ID
- Upstream Invert Elevation = UPS_ELEV_FT
- Downstream Invert Elevation = DNS_ELEV_FT
- Pipe Cross-section = PIPE_SHP
- Pipe Dimensions = HEIGHT_IN and WIDTH_IN
- Pipe Length = LENGTH_FT
- Pipe Material = MATERIAL_CODE
- Pipe use = USE_PERMIT
- Pipe lifecycle = LIFECYCLE

7.5.2.4 Special (Ancillary) Structures

Special structures are often located in vital flow control areas of the drainage and wastewater system. These structures regulate flows and are designed to prevent unplanned flooding onto streets and private property. SPU special structures include:

- Pump stations
- Weirs
- Sluice gates
- Hydrobrakes
- Orifices
- Flap gates or valves
- Storage facilities

The SPU drainage and wastewater infrastructure GIS node database differentiates among various ancillary structures using the FEATYPE (structure type) attribute. However, GIS should be used only to locate ancillary structures. Layout, dimensions, and function of these devices are not defined in GIS for modeling purposes. Refer to the following subsections for more information.

Special structures such as pumps, weirs, or hydrobrakes are modeled as links. SPU GIS data should be modified to add a dummy node and a link, representing the hydraulic structure, between the actual node and the dummy node. For naming conventions, see **Appendix 7D**, Data Formats.

A. Pump Stations

GIS coverage of drainage and wastewater pump stations is limited to location, connecting maintenance hole ID, NPDES basin number, and sometimes wet-well elevation. The locations of pump stations are provided in the DWW Mainline End Points coverage wherever the FEATYPE field has a value of "PST." Accurately modeling the hydraulics of SPU pump station operations requires information beyond that available in the GIS system.

SPU staff can help the modeling team acquire the information listed below. Typical sources are record drawings, SCADA data, technical reports, and O&M documentation:

- Wet-well dimensions and elevations
- Influent pipe elevations
- Force main information (length, diameter, starting and ending elevations, material)
- Force main discharge conditions
- Pump control type: VFD or constant speed
- Pump curves
- Control setting elevations
- Real-time controls or other pump control information

Generally, SPU pump stations are modeled by entering pump curve data (i.e. head vs. flow) or fixed discharge rate and control specifications (wet-well pump on and pump off elevations).

B. Weirs

Weirs provide a method to control flow within a collection system. They are generally located in maintenance holes where flow is diverted from one section of the sewer system to another. SPU drainage and wastewater system infrastructure uses several types of weirs, including transverse, trapezoidal (Cipolletti), side overflow and leaping weirs.

The modeling team should acquire record drawings, photographs, field investigation record, and all physical dimensions for weir structures. The team should have physical dimensions field verified when possible. The DWW Mainline End Points (i.e. point) coverage indicates the location of weirs in the drainage and wastewater conveyance system with FEATYPE value of "OF" (for overflow maintenance hole). Results of hydraulic modeling simulations are usually very sensitive to weir dimensions, elevation, and orientation. All drawings and field reports provided for a weir structure should be documented in the model.

The modeling team should determine if the overflow structure has entrance losses to include in the weir modeling. Entrance losses happen when turbulence occurs upstream of the weir.

1) Common Attributes

Various software packages model the common attributes of weirs (Table 7-3). The modeler should consult the software's user manual or other hydraulic references to determine the appropriate values for discharge coefficients. If a weir can be submerged, the modeler should review the weir solution method to make sure the software can accurately simulate submerged weirs. The modeler should also review the weir solution method to determine how the software manages surcharging upstream of the weir and whether the software automatically switches to a gate equation solution when surcharging occurs.

Table 7-3
Weir Attributes for Modeling Software

Weir Attribute	Description
Weir type	Select type of weir: 1) sharp crested , 2) broad crested 3)transverse, 4)sideflow, 5)V-notch, 6)Trapezoidal (Cipolletti)
Crest	Level of the crest (or top) of the weir Software may ask for height or crest elevation
Width	Width of weir over which water spills. This can be referred to as "Length" in some software (e.g. EPA SWMM).
Height	Roof height for the weir Weir should behave like a sluice gate orifice when water level is above roof height.
Weir (Discharge) coefficient	The coefficient for the weir flow equation. This coefficient is unit and equation dependent. Modelers should confirm how the weir equation is implemented in the modeling software and use the weir coefficient appropriate for the unit and equation used.
Length	Distance across flat part of weir top measured parallel or particular to direction of flow depending on the type of weir Applies only to broad crested weirs Should not be confused with the "Width" of weir. This "Length" equals to zero for a sharp crest weir.

2) Transverse Weir

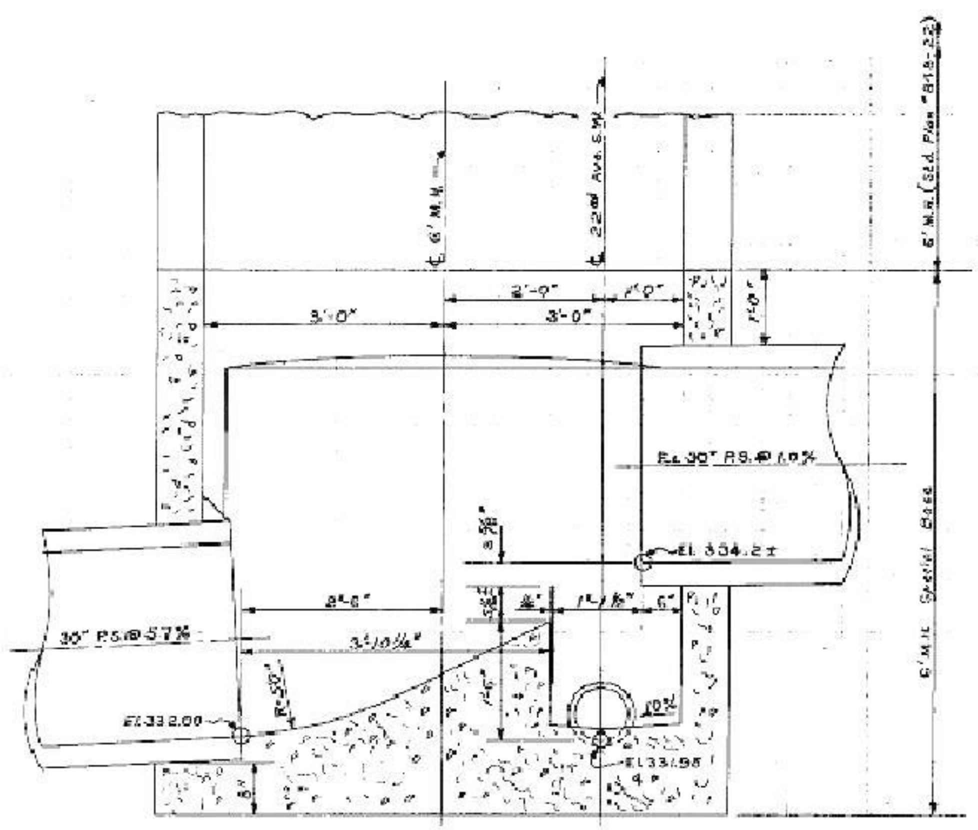
Transverse weirs are installed perpendicular to the flow direction. Transverse weir structures are frequently used near CSO outfalls to allow excessive flows to exit the system to prevent surface flooding. Flows are fully conveyed within the sewer system until water surface elevation exceeds the elevation of the weir. If the water surface elevation exceeds the weir level, flows are split between the sewer system and CSO outfall piping.

3) Side-Overflow Weir

Side-overflow weirs are installed on the side of a pipe or main channel of a structure parallel to the flow direction. Flows are fully conveyed within the sewer system until high flow conditions occur and the water surface elevation exceeds the weir elevation. Once the water surface elevation exceeds the weir elevation, flows are split between the sewer system and the outfall piping. Leaping Weirs

Leaping weirs are a special case (Figure 7-1). Leaping wears are transverse weirs incorporated into a drop maintenance hole. Under low flow conditions, water will drop into the maintenance hole trough and flow out in a direction perpendicular to the entrance flow. When flow on the upstream side of a maintenance hole is sufficiently fast, water will leap over the trough and continue to flow in the same direction as upstream flow. At intermediate or transitional velocities, the influent water will divide: part flows through the low-flow outlet and part flows over the leaping weir. Whenever possible, the modeling team should calibrate the behavior of the weir using upstream and downstream flow monitoring. After an appropriate regression relationship is established, a leaping weir could be simulated using a user-defined relationship. The modeler should consult the user's manual of the selected software to determine the most appropriate method of simulating a leaping weir.

Figure 7-1
Example of Leaping Weir



C. Sluice Gates

SPU currently has two types of sluice gates in their drainage and wastewater conveyance systems. One type is a manual operating gate to bypass flows during maintenance. They consist of a vertical slide gate that can be set in open or closed position. During normal operation, manual sluice gates are closed. Manual sluice gates must be modeled as closed unless SPU provides information that the gate has been open for normal operation. The second type is automated sluice gates used to regulate flows to the downstream system. As water levels in the conveyance system rise, flow through the gate is limited, which causes water upstream to back up into storage and/or overflow to a nearby body of water through an outfall. Using an automatic sluice gate ensures overflows occur at the designed locations instead of unplanned locations in the downstream conveyance system. For additional information on automatic sluice gate operation at a specific location, contact SPU System Operations Planning and Analysis (SOPA) section.

Table 7-4 lists common gate attributes for various modeling software packages.

Table 7-4
Gate Attributes for Modeling Software

Gate Attribute	Description
Gate type	Sluice (common for wastewater) Radial or other Some software implement sluice gates as rectangular orifices (e.g. EPA SWMM). Modelers should confirm how sluice gates are represented in selected modeling software.
Maximum gate opening Height	Height open when gate is fully withdrawn
Gate width	Width of flow channel through gate
Gate controls	Initial gate level and description of conditions that change gate level Features vary widely among modeling software packages

D. Hydrobrakes

Hydrobrakes, which are located throughout the SPU drainage and wastewater system, regulate flow. They also provide for implementing inline storage during high flow events, and can protect downstream facilities from unplanned overflows at locations other than CSO outfalls. Water flows into the device through an open channel and into the conical section. During low flows, water and air can flow into the conical section of downstream piping with minimal head losses. During high flows, water will swirl in the conical section and proceed through the orifice portion and then into the downstream system.

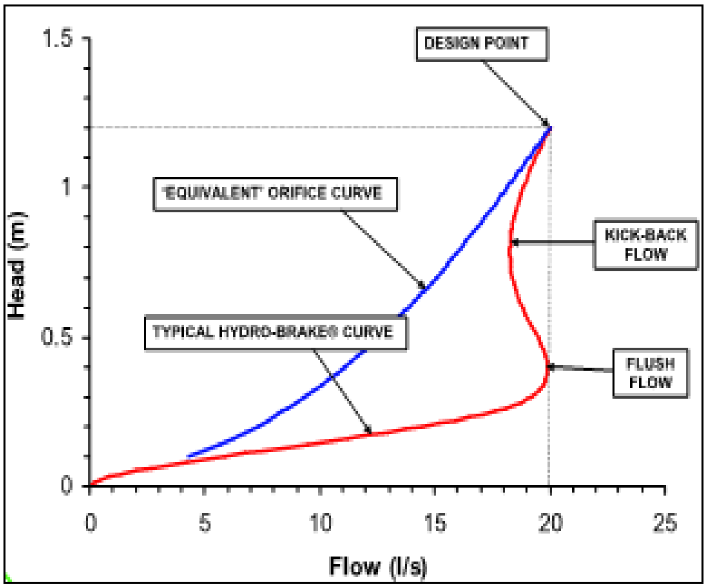
These complicated hydraulic structures can be modeled as a generic structure using a user-specified *Head versus Discharge* curve. If flow monitoring data collection is planned for a project, data should be collected up- and downstream of the hydrobrake to ensure the manufacturer's curve reflects field operation of the structure.

Figure 7-2 shows a typical head versus flow curve for a hydrobrake. During a free flow period, water will flow through the hydrobrake. As flow increases, the swirling motion of the fluid generates a forced vortex with a central air core that restricts flow through the hydrobrake.

<u>The modeling team must develop site-specific hydrobrake *Head versus Discharge* performance curves by collecting water surface elevation data on the upstream side of the hydrobrake and flow data on the downstream side</u>. The modeling team should not rely on the manufacturer's curve unless there is no other option. SPU experience has

shown that hydrobrake performance in the field may vary substantially from manufacturer's curve.

Figure 7-2
Head vs. Flow Performance Curve for a Hydrobrake



E. Orifices

Orifices are a method of regulating flow. Typical input requirements are limited to the orifice diameter and discharge coefficient. Orifices can be useful for modeling complex hydraulic conditions such as flow splitting or flow constraints. For example, when a maintenance hole includes two exit discharge sewers, some software cannot accurately predict relative division of flow between the two lines. Inserting orifices at the exits will force the software to apply energy balancing orifice equations at these locations. Orifices have been useful in SPU's Madison Valley study, which routed overland flow from catch basins to the drainage system. In that study, an orifice was inserted into each pipe between the catch basin and the drainage mainline. By varying the size of the orifice, the modeling team effectively simulated the inlet constraints on the catch basins until the drainage system flows were calibrated to match observed flows in those mainlines.

Table 7-5
Orifice Attributes for Modeling Software

Orifice Attribute	Description
Orifice type	Select type of orifice: 1) Side , 2) Bottom
Orifice Shape	Select shape of orifice: 1) Circular, 2) Rectangular (RECT_CLOSED)
Invert Elevation	Invert of the bottom of the orifice
Height	Height of orifice (diameter for circular orifice)
Width	Width of orifice (zero for circular orifice)

Orifice Attribute	Description
Discharge coefficient	The coefficient for the orifice flow equation. This coefficient is unit and equation dependent. Modelers should confirm how the orifice equation is implemented in the modeling software and use the discharge coefficient appropriate for the unit and equation used.

F. Storage Facilities

Storage facilities include any type of tank or pipe system designed to detain flows. These elements are typically modeled using a stage-area table and appropriate outflow controls. Representing the storage facility using a stage-area relationship neglects flow velocities within the structure, which is a reasonable simplification. Modelers should confirm how the modeling software uses the stage-area relationship in determining storage volume at specific depths. In some cases, the area requested is the plan area of the storage facility at a specific depth (e.g. as in MIKE URBAN/MOUSE). In other cases, it is the area backed calculated by using Trapezoidal Rule from the stage-storage curve of the facility (e.g. as in EPA SWMM).

The method of defining outlet controls will vary by software. The modeling team should include as much detail as possible to represent the outlet controls. Often outlet controls are a combination of pipe, gates, orifices, hydrobrakes, and weirs.

Table 7-6
Storage Facilities Attributes for Modeling Software

Storage Attribute	Description
Invert Elevation	Invert of the bottom of the storage facility
Ground Elevation	Ground elevation of the storage facility
Stage-Area Curve	Curve that defines the Stage-Area relationship of the storage facility. Modelers should confirm how area should be calculated for the storage facility. Depending on the software, it can be plan area at specific depth or area backed calculated from stage-storage relationship by using Trapezoidal Rule.

G. Backflow Preventers

Common backflow preventers in SPU drainage and wastewater systems are flap vales. Flap valves are commonly known as tide gates and/or flap gates. Some common uses for flap valves are at the end of some outfall pipes (especially pipes that are tidally influenced), points of discharge from storage to mainline system, and to prevent fish from swimming up pipe.

For an outfall with a tide gate at the end of it, the modeler selects *Yes* in the Tide Gate option for the outfall.

For a tide gate that is linked to real time control (RTC), an orifice of the appropriate shape (closed rectangular or circular) and size should be connected to the upstream side of the outfall to represent the gate as the Tide Gate option of an outfall cannot be controlled by control rules. When an orifice is used to represent a tide gate, the Tide Gate option of the outfall should be set to *No* since the tide gate is already represented by the upstream orifice. Control rules are then used to control the rate and conditions of the opening and closing of the gate.

For flap gates, the modeler selects *Yes* in the Flap Gate option for the conduit used to represent the gate.

7.5.2.5 Natural Channel Parameters

Even in an urban environment, natural channels are encountered and need modeling. Table 7-7Table 7-5 below lists the natural channel parameters with guidelines to follow to define each value.

Table 7-7
Natural Channel Parameters

Natural Channel Parameter	Guideline
Cross-Sectional Geometry	The minimum width is set by extending the left and right ends of the cross-section to one foot above the left and right floodplain (LRFP) elevation
Spacing of Cross-Sections	Cross-section locations should be based on sound engineering judgment. Higher density is required at tributary locations, slope changes, roughness changes, valley morphology changes, and at bridges or other structures.
Cross-Section Data Points	A minimum of seven data points is required to describe each cross-section. The maximum number of data points is limited by software constraints.
Elevation	Elevation data in the active channel must be collected with field survey and tied to SPU current datum standard. GIS 2-ft contour mapping may be used to supplement cross-section data in the floodplain (overbanks). A licensed Land Surveyor or Professional Engineer must document the accuracy of survey information at cross-sections and structures
Bank Stations	Bank stations in natural cross-sections should be placed at the geomorphic bankfull elevation.
Manning's Roughness Coefficient	Roughness values should be reflective of the natural variations in the bed materials and overbank vegetation. Manning's roughness values must be used to describe frictional energy losses. A listing and description of roughness values with photographs must be included in the documentation of the model development. Manning's roughness values must be included for the channel bed, left and right banks, and left and right floodplains.
Reach Lengths	The distance measured along the stream thalweg for the centerline reach length. Left and right overbank reach lengths must be estimated as the center of mass of the floodplain discharge.
Expansion and Contraction Coefficients	Subcritical flow contraction and expansion coefficients are used to estimate energy losses caused by abrupt changes in the flowing cross-sectional area. Where contraction and expansion losses are expected to occur, contraction coefficients can vary between 0.1 and 0.3, expansion coefficients can vary between 0.3 and 0.5.
Ineffective Flow Areas	Effective flow, in one-dimensional modeling, is the portion of the flow traveling in the downstream direction. Portions of the cross-section that are occupied by water but not flowing in the downstream direction are described as ineffective flow areas and must be specified. A definition of ineffective flow areas must be justified in the H/H report. Ineffective flow areas in urban watersheds must reflect current development.

7.5.2.6 Naming Convention for Links and Nodes

All data collected for defining nodes and links of the hydraulic conveyance model must follow the naming convention and data format defined in **Appendix 7D**.

7.5.3 Sub-basin Delineation and Flow Assignment

Sub-basin delineation determines the individual catchment physical boundaries within a collection system. Flow assignment is the correlation of the flow from a tributary area to a specific node within the system. Flow assignment nodes should be selected based on the layout of the network. The delineation should always be consistent with flow monitoring locations.

GIS tools can be very helpful for automating the delineation. For example, ArcMAP includes network tracing tools that will identify all pipes upstream of the given node. SPU also has a propriety ESRI-based network tracing tool. Overland drainage and infiltration and inflow (I/I) delineations should be based on sewer mapping and local topography.

7.5.3.1 Spatial Data

Spatial data are used in drainage and wastewater modeling projects to assist with basin mapping, and for drainage direction and flow generation calculations. Five common spatial data categories are used for H/H modeling: (1) topography, (2) parcels, (3) impervious area, (4) soils (pervious area) and (5) land use and zoning. All are available from GIS.

A. Topography

The modeling team must use either LiDAR-derived or local survey data. The team must determine whether the dataset used meets datum requirements defined in DSG section 7.5.1.1. If data conversion is necessary, the team should obtain the conversion factor from SPU's Land Survey Section.

Topography data can be used with spatial analysis tools to determine the direction of surface water drainage and to delineate the extent of surface water basins. Topographic datasets may be available as raster (e.g. digital elevation models), triangular irregular network (TIN) or contour line files. Topography data analysis is important for projects that route stormwater into catch basins. For example, in the Madison Valley modeling, drainage areas were computed upstream of each catch basin.

B. Parcels

Parcels or property data can be used for many purposes. For example, parcels can be used to map which properties drain wastewater to specific maintenance holes within a basin via the Side Sewers and Laterals GIS coverage. Delineating wastewater sub-basins at the MH level helps SPU accurately estimate tributary area and number of customers contributing flow to each maintenance hole in a model. In addition, parcels data could be combined with land use data to provide a preliminary estimate of impervious area. Parcels data can also be used to indicate the locations of various customer types (e.g. residential, industrial, commercial, or institutional) within a basin. Parcel data can also help identify critical public facilities that may require a higher level of protection against flooding.

C. Impervious Area

Impervious area data are used to help calculate the rate of surface water runoff and direct sewer inflow. Impervious area datasets are usually developed from orthophotography data, land use categories, and building outlines. If impervious area coverage is not available for a project area and surface runoff calculations are needed to calibrate a model, the modeling team should consult with SPU GIS in developing the impervious area coverage for the modeled area. For more information on impervious area, refer to section 7.5.6.1B.1) Impervious Area Submodel.

D. Soils Data (Pervious Area)

Soil characteristics are used to help calculate infiltration potential through pervious surfaces in a watershed. For drainage and wastewater modeling projects, soils data can be used to compute surface water runoff from pervious area and subsurface infiltration contributing to the conveyance system. Soils coverage could also help a project team identify potential stormwater infiltration locations. For example, soils coverage might indicate areas of higher infiltrating soils, which could be feasible locations for GSI. Refer to the DSG modeling library for City of Seattle soil characteristics. (for more info on City of Seattle soil characteristics, contact SPU_DSG@Seattle.gov)

E. Land Use and Zoning

Land-use and zoning data can be used to estimate impervious areas when other more detailed information is not available. For SPU projects, these data types are more useful for calculating wastewater loading for existing and future conditions.

7.5.3.2 Sub-catchment Delineation

After all of the necessary data are collected and sub-catchment boundaries have been delineated, each sub-catchment must be further divided into:

1. Building (BLG_) area;
2. Right-Of-Way (ROW_) area; and
3. Catchment (C_) area.

Catchment (C_) area of each sub-catchment is the rest of the sub-catchment area that is not occupied by buildings or right-of-way.

7.5.4 Boundary Conditions

A specified boundary condition is required for the most downstream model node in each basin. The boundary condition for these outlets may be modeled by supplying a downstream water surface elevation: static or time-varying. The outlet must be accurately modeled because the level at the outlet can affect water surface levels upstream due to backwater effects.

For the SPU drainage and wastewater conveyance system, downstream boundaries include:

- Outfalls (e.g. Longfellow Creek, Lake Washington, Puget Sound, Elliot Bay, or the Duwamish River). Refer to Assigning Boundary Conditions
- Discharge to King County wastewater conveyance system
- Discharge to SPU large hydraulic structures (e.g. pump station wet well)

For locations where continuous water surface elevation data are not available, the team should make a conservative assumption about the water level in the receiving pipe. For example, the modeling team could vary the elevation of the water in the receiving pipe based on I/I rates for the upstream basin. When the upstream SPU system receives high levels of I/I, the modeler can assume King County interceptor water levels are high. Alternately, the modeling team could set the water level in the receiving pipe to match recorded or inferred high water marks or simply assume the receiving pipe is continuously submerged. Coordination with King County staff can help determine normal and peak range of water levels in the receiving system.

7.5.4.1 Assigning Boundary Conditions

H/H modeling software packages commonly include a graphical interface to help define boundary conditions. Often, boundary conditions are defined by times series data.

A. Assigning Boundary Condition

When assigning a boundary condition at a discharge node in a model, the modeler should consider how a boundary fits into the physical system and how boundary conditions will affect overall model results:

- In situations where the downstream boundary is likely to affect upstream modeling results, the modeling team should use the most detailed time-varying water surface elevation available. For example, if the water level in a King County system feature could potentially backup wastewater in the SPU system, the modeler should obtain time series data for the water level in the King County system feature for time period simulating. Time series data should always be examined for outliers, data gaps and other potential sources of error before being deployed in a model run.
- For models that are relatively insensitive to downstream boundary conditions (e.g. steep pipe or supercritical flow to an outfall), the modeling team may use simplified or average values to describe the water surface variations.

B. Availability of Time Series Data for Outfall to Water Body

Historically observed and estimated water surface elevation data are available for Lake Washington and Puget Sound. However, freshwater-seawater specific weight conversion must be performed on all Elliott Bay tide level data before the data are used to form the boundary conditions of hydraulic models. The conversion accounts for the effect of the difference between the pressure head of a column of sea and fresh water of the same height has on the boundary of a hydraulic model. The hydraulic model treats all fluid (both in the system and at the boundary) as having the same specific weight. The conversion is only necessary when Elliott Bay water level data are used. Lake Washington level data do not need to be converted. The following are SPU standards:

1. <u>When the downstream boundary is close to a hydraulic structure, the structure must be modeled to mimic field operations so that the correct downstream boundary condition is determined</u>.
2. <u>SPU must be involved in the entire process of determining downstream boundary conditions and the results must be documented in the modeling report</u>.

1) Lake and Ship Canal Level Data

Refer to City of Seattle Stormwater Manual Appendix F.

2) Tidal Influence/Sea Level Rise

Refer to City of Seattle Stormwater Manual Appendix F.

C. King County or Other Agencies Time Series Data

When the downstream boundary of a study area or a sub-catchment is the King County wastewater conveyance system, the modeling team should use actual historical water surface elevation data. SPU can obtain the data from King County when data are available. When data are not available, SPU will determine with King County how boundary conditions should be defined.

Note: *Whenever data from other agencies is needed, SPU must first be consulted and SPU must make the request.*

7.5.5 Dry Weather Flow Model Data

During dry weather, sewer flow includes sanitary sewer flow and infiltration and inflow (I/I) that is not rainfall related. It is generally known as dry weather flow. Data used for computing dry weather flow include:

1. Demographic data – Parcel data, current and future population, and traffic analysis zone.
2. Dry weather flow – Flow monitoring data collected during dry weather or estimated available information.
3. Industrial flow – Flow discharged from identified industries.

All of the information above is collected and analyzed to develop dry weather flow patterns. This section describes data sources for computing dry weather flow patterns.

7.5.5.1 Demographic Data

A. SPU Data

SPU can provide the following demographic data:

- Parcel
- Current Residential Population Data
- Current Employment Population Data
- Future Residential Growth Estimates
- Future Employment Growth Estimates
- Statewide Traffic Analysis Zones (STAZs)

B. Other Agency Data

Whenever data from other agencies such as King County or Puget Sound Regional Council (PSRC) are needed, SPU must first be consulted and SPU must request the data. This direct involvement ensures that SPU is aware of the data source.

The following demographic data from other agencies may be used on SPU modeling projects:

1) Puget Sound Regional Council (PSRC)

- Current Household Population
- Current Employment Population
- Estimated future Household Population growth
- Estimated future Employment Population growth
- Census Tracts
- Traffic Analysis Zones (TAZs)

2) King County Department of Assessment (KCDOA)

3) U.S. EPA

Per capita flow estimates from Tables 3-3 to 3-6 of the U.S. EPA Onsite Wastewater Treatment Systems Manual. The EPA manual lists results from urban area across the United States, including Seattle.

7.5.5.2 Dry-Weather Flow

Dry-weather flow consists of sanitary sewer flow and dry-weather groundwater infiltration. Sanitary sewer flow is sewage produced by residential, business, schools, hospitals, and other connections to the wastewater conveyance system. These flows can be predicted based on population and employment counts and per capita unit flow rates. Groundwater infiltration results from defects in the sewer system below the water table or around portion of the vadose (unsaturated) zone with high subsurface flow activities.

For the SPU system, dry weather flow can be estimated from two sources:

- Hydrographs from existing dry weather flow data
- Population and employment forecasts and unit wastewater generation rates plus an estimate of the seasonal groundwater infiltration flow rate.

Dry weather flow should be assigned to specific flow loading maintenance holes in a model. The appropriate number and location of flow loading maintenance holes should be determined during the model schematic and sub-basin delineation phases of model development see DSG section 7.5.3.

A. Dry-Weather Flow Based on SPU's Sewer Billing

Sanitary sewer flow component of dry weather flow can be estimated by using SPU's sewer billing data, which includes Discrete Address Point ID (DAP _ID) shape files and an associated wastewater consumption database. The database includes sewer consumption volume in 100 cubic feet (CCF) for each DAP_ID and days of service (DOS). This information is used to calculate annual average sanitary sewer flow rate:

Sanitary Sewer Flow (gallon/day) = CCF * 748 / DOS

The DAP_ID shape file is used with the sewer system maintenance hole file to associate each DAP_ID with the nearest sewer maintenance hole. Once a relationship between DAP_ID and sewer maintenance hole is established, a total sanitary sewer flow for each maintenance hole can be calculated and loaded into the corresponding models. Census data can be obtained from SPU GIS or King County GIS. These data contain three levels of resolution: Tract, Block Group, and Block. To get the highest level of resolution, block data are appropriate. Using the DWF estimates from the sewer billing data and population per each modeling basin, a wastewater production rate can be summarized.

After sanitary sewer flow rate is determined, an estimate of the seasonal groundwater infiltration component of the dry weather flow is to be established. A common equation used for such estimation (e.g. Northeast Power blackout of 2003, King County I/I Program) is the **Stevens-Schutzbach equation**.

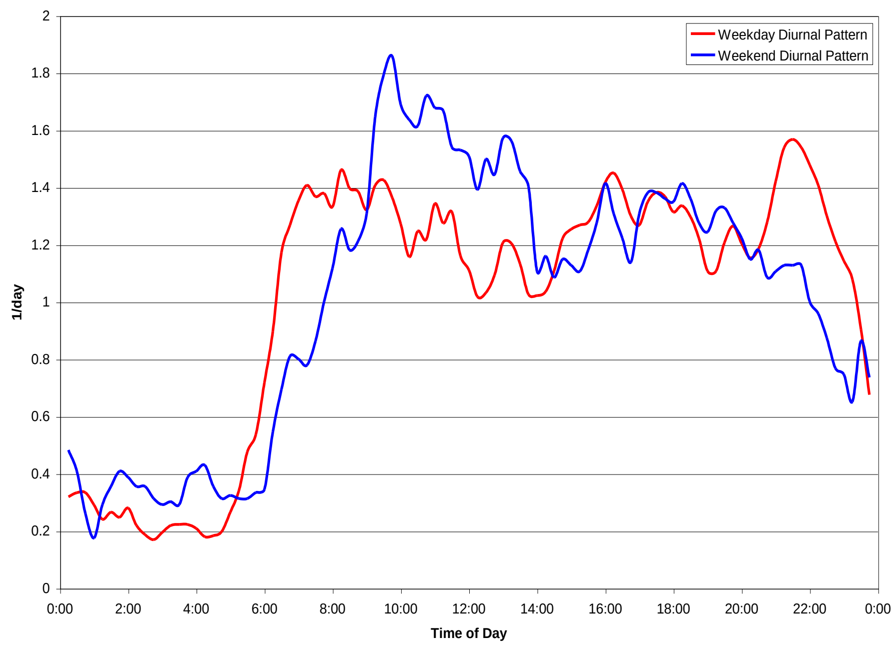
B. Dry-Weather Flow Based on Flow Monitoring Data

When flow records are available for a basin, the modeling team should examine flows for a dry-weather period (May through June or September through October) to determine the dry weather flow. When there is no rainfall, the flow data shows a simple diurnal pattern with peaks and troughs. A 7-day period of dry weather flow data must be selected for a dry-weather flow model. The 7-day period must include data from each day of the week. Using population estimates and land-use categorization, the team should then estimate the number of connections of different categories and per capita wastewater generation rate for each category. For basins with sizable contributions from several connection types, the team should attempt to compute unit contributions from each source using observed flow data.

After the 7-day dry-weather flow data are selected, an average weekday and weekend dry-weather flow hydrograph must be calculated. The average weekday dry-weather flow hydrograph must be calculated by averaging the hydrographs of Monday to Friday within the 7-day dry weather flow data. Likewise, the average weekend dry-weather flow hydrograph must be calculated by averaging the hydrographs of Saturday and Sunday within the 7-day dry-weather flow data.

Figure 7-3 shows an example of diurnal patterns generated from flow monitoring data collected in residential area adjacent to south downtown area.

Figure 7-3
Example of Base Sanitary Flow Diurnal Patterns



C. Estimating Population and Per-Capita Flow Values

The daily sanitary sewer flow (a.k.a. Base Sanitary Flow (BSF)) volume of a monitoring catchment is used with other demographic data to estimate the population distribution and per-capita flow rate of the catchment. The demographic data can be obtained from SPU's GIS or from SDCI see section 7.5.5.1. Most data are available in geospatial format (e.g. shapefile). No single data source contains all of the data needed for estimating population in a catchment. Thus, all of the data should be used together.

In addition, the boundaries of the geospatial polygons that accompany various data often do not align. The modeling team will need to interpolate among the data sources. Follow these steps to estimate population and per-capita flow for flow monitoring catchment:

1. Establish initial population density range estimates for each type of residential, and government. See Table 7 8 Population Density Range.

Table 7-8
Population Density Range

Building Type	Population Density
Multi-Family - Apartment/condo	1 to 2 person per unit
Multi-Family - Townhouse/duplex/triplex	2 to 3 person per unit
Single-Family Residence	2 to 5 person per residence
Public School	Refer to Seattleschools.org
Private School	Schooltree.org

2. Create a new set of parcel data by merging the information in SPU's parcel data with corresponding parcels in KCDOA data. New parcel data are especially useful for estimating population in multi-family, mixed use, commercial, industrial, and institutional zones. The merged data give information such as the number of apartment units and square foot of office space on a parcel. When an SPU parcel does not have a corresponding KCDOA parcel, information gathered from field survey or aerial photographs can be used to estimate characteristics and use of the parcels.
3. Intersect SPU's STAZ polygon data with the new parcel data created in step 2. After this intersection, the total residential and commercial population estimates are established for all the parcels within each STAZ polygon. The next step is to distribute this total population back to each parcel.
4. Within the estimated residential and employment population density range established in step 1, pick a value for each type of land use. Distribute the population of each STAZ polygon to its parcels within the STAZ boundary based on land-use information (e.g. apartment units, schools, hospitals, office square footage). If there are not enough or too much population to distribute to parcels, adjust the selected population density values within their ranges established in step 1 and redistribute population again. Iterate until the sum of residential and the sum of employment population from all parcels in the STAZ polygon equals the respective values of the STAZ polygon.
5. After this process is completed, a reasonable estimate of residential and employment population will be established for each parcel. Create a new parcel layer based upon work completed from steps 1 to 4.
6. Estimate population. Intersect the boundary of the flow monitoring catchment with the new population-filled parcel layer created in step 5. After the intersection, an estimate is established of the total residential and employment population within the boundary of the flow monitoring catchment.
7. Establish a per-capita flow for either the whole flow monitoring catchment or per parcel depending on the level of detail required by the model. To calculate per-capita flow at flow monitoring catchment level, simply divide the average daily BSF volume by the population estimates established for the area in step 6.

After this process is completed, reasonable population and per-capita flow estimates are established for the flow monitoring catchment. With these values, the final calculated average daily dry weather flow should add up to that calculated from flow monitoring data. If not, care should be taken to note that the dry weather flow data is not taken from summer months when demographic shift in an urban area is the greatest due to finishing of school and people going on summer vacation. Thus, dry weather flow data collected during summer month in an urban area is usually not smaller than those of the rest of the year. For these reasons, if dry weather flow data during summer months are used, either the per-capita flow or population used in the calculation would be underestimated.

SPU should review the final population and per-capita flow values developed for a flow monitoring catchment before that data is used for modeling. Population values should reasonably agree with SPU's overall population and employment figures for the area and per-capita flow values. The values should be compared against any dry weather flow data that may be available for the basin in question to determine if the modeled flows agree with observed flows for those periods.

After all the data needed for developing a dry-weather flow model are entered into the modeling software, each piece of data must be associated with a data source. See **Appendix 7C** for data flags that must be assigned to each data series. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.

7.5.5.3 Industrial Flows

Flows from industries and other non-uniform sources can be determined by two types of review:

- Flow monitoring data to identify non-residential flow patterns and volumes. These will be needed for calibration of downstream meters.
- Industrial waste treatment records from King County as appropriate.

The modeling team must develop a strategy for creating industrial flow patterns and volumes or creating time series data profile for industrial flows.

A. Develop Dry-Weather Flow Pattern for Industrial Flows Using Flow Monitoring Data

Industrial flows behave differently than normal DWF. Many times, industrial flows exhibit repeatable patterns and volumes for set time periods. The modeling team must review the flow monitoring data during dry weather to identify the portion of flow above the normal DWF. This additional flow will be used to develop DWF pattern for the industrial flows to be incorporated into the model. If the modeling team is unable to determine a repeatable pattern and time for the industrial flows, the modeling team must develop another strategy.

7.5.6 Hydrologic Model

As rain falls, a series of meteorological and hydrological processes generate wet-weather flow. During wet-weather flow, surface runoff from both pervious and impervious areas begins to drain into openings (e.g. inlets, catch basins, leaking maintenance holes) of the sewer systems along its flow paths. Such runoff forms the Rainfall Dependent Inflow (RD Inflow) into the sewer system. At the same time, as the soil in the vadose zone becomes saturated, subsurface flow consisting of a combination of Preferential flow, Matrix flow, and Interflow (RD PMI) infiltrates into the sewer systems through defects (e.g. cracks along pipes, cracks on maintenance hole barrels, defective pipe joints, defective pipe-maintenance hole barrel joints) along the system. Additional groundwater infiltration can also be generated when the groundwater table rises above its dry-weather seasonal level (sGWI) due to rainfall and causes rainfall-dependent groundwater (RD GWI) to infiltrate into the sewer system. The sum of RD PMI and RD GWI forms Rainfall Dependent Infiltration (RD Infiltration).

In cities, Base Sanitary Flow (BSF) generated by people is also considered as part of wet-weather flow see DSG section 7.5.5.

The following equations illustrate various components of wet-weather flow (WWF).

WWF = BSF + sGWI + RDI/I

RD I/I = RD Inflow + RD Infiltration

RD Inflow = RD surface runoff from impervious area + RD surface runoff from pervious area

RD Infiltration = RD PMI + RD GWI

Where:

WWF = Wet Weather Flow

BSF = Base Sanitary Flow

GWI = Groundwater Infiltration

sGWI = dry-weather seasonal level of groundwater infiltration

RD = Rainfall Dependent

RD I/I = Rainfall Dependent Inflow/Infiltration

RD PMI = Rainfall Dependent Preferential flow, Matrix flow, and Interflow

RD GWI = Rainfall Dependent Groundwater Infiltration

<u>A hydrologic model must be constructed to simulate each of the meteorological and hydrological processes. The hydrologic model development process must include three components</u>:

1. Meteorological time series refer to DSG section 7.5.6.1A
2. Surface runoff refer to DSG section 7.5.6.1B
3. Subsurface infiltration refer to DSG section 7.5.6.1C

SPU will provide and help collect the topographic, land-cover, subsurface, aerial photographs, soil, rainfall, and other spatial terrain data used for the model (see DSG sections Spatial Data 7.5.3.1 and Precipitation 7.7).

7.5.6.1 Hydrologic Model

The following are guidelines for developing each of the hydrologic model components.

A. Meteorological Time Series Model

Meteorological input into a hydrologic model primarily consists of rainfall and evapotranspiration time series. For detailed information on precipitation, see DSG section 7.7.

B. Surface Water Runoff Model

Surface water runoff modeling should be used whenever runoff directly contributes flow to a portion of the SPU drainage and wastewater collection system. Examples include site development projects and CSO projects with substantial contributions from the drainage network.

The available software, runoff generation mechanisms, and other guidelines for computing surface water runoff are described in detail in City of Seattle Stormwater Manual Appendix F.

The following standards must be used to develop SPU surface water runoff models:

1. At a minimum, a surface runoff model must contain two submodels: 1) impervious area and 2) pervious area. To determine if a drainage area is impervious or pervious, refer to Figure 7-4 Impervious vs. Pervious Area Flow Diagram.
2. SPU-provided impervious and pervious area GIS data must be used in the initial development of these submodels.
3. As the initial submodels are developed, the impervious and pervious area data must be verified with aerial photos to ensure reasonableness and accuracy of data.
4. Where GIS data is not available, information inferred from aerial photographs provided by SPU or collected from field survey must be used.
5. After the extent of impervious and pervious areas are determined, the areas must be summed and compared with the total area of the catchment to ensure no areas are neglected.
6. If there are areas in the catchment not connected to the sewer system, those areas must be flagged and documented in the modeling report.

1) Impervious Area Submodel

One or more impervious submodel must be established for the tributary area of each flow monitoring subbasin. The percent of imperviousness must initially be assumed to be 100%. Documentation should be provided for impervious areas where the percent of imperviousness is determined to be less than 97% based upon field investigation. The impervious surface can be less than 100% for areas with the following conditions:

- Pavement or concrete around maintenance hole covers exhibit excessive cracks or other defects that cause inflow and infiltration
- Miscellaneous impervious surfaces (e.g. garage roofs, decks, some sidewalks) drain to pervious surfaces
- Drainage ordinance has resulted in connection of roof tops or other impervious surfaces being directed to pervious surfaces or rock pockets.

For modeling surface runoff volume from an impervious area, the routing algorithm should be theoretically sound, use the fewest empirical coefficients, and have the appropriate complexity level. These algorithms are generally based on the unsteady continuity equation and wide channel approximation of the Manning's Equation. Such algorithms can be applied to areas of various sizes and rainfall hyetographs of various intensity, shapes, duration, and frequencies. Documentation should be provided for rationale and choice of algorithm chosen for modeling runoff routing from an impervious area.

Where calibrated models are available, the impervious submodel should use the calibrated values for impervious area. When a calibrated model or monitoring data for calibration of model inputs are not available, the effective impervious surface area must be calculated using the equation below and Table 7-9.

Effective Impervious Surface Area = Total Impervious Surface Area X SF

SF = Effective Imperviousness Scaling Factor (from Table 7-9)

Table 7-9
Estimating Effective Impervious Surface Area

Land Use	Drainage System	Effective Imperviousness Scaling Factor (SF)
Right-of Way	Informal[1]	61%
	Formal[2]	95%
Parcel (non-ROW)	Informal[3]	28%
	Formal[4]	56%

[1] ROW Informal drainage indicates lack of a designed conveyance system (e.g. runoff travels as edge of pavement flow, or through ditch and culvert system).

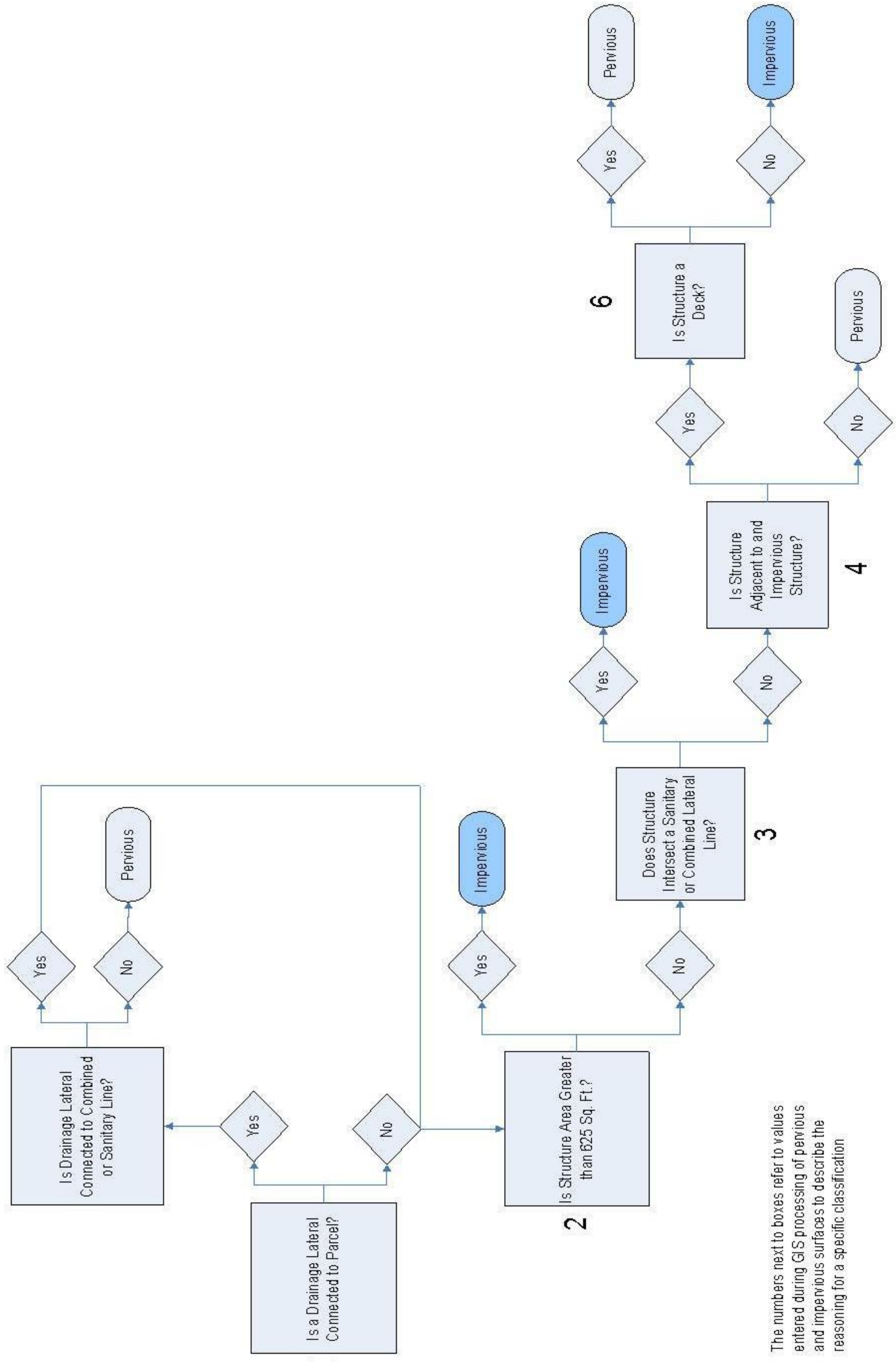
[2] ROW Formal drainage indicates a piped storm drain.

[3] Parcel Informal drainage indicates existing impervious surface discharges primarily to the private pervious surface or private drainage feature (e.g. rock pockets, large vegetated area).

[4] Parcel Formal drainage indicates existing impervious surfaces discharges directly to the public drainage system through a pipe or surface channel).

<u>After all data needed for developing an impervious area submodel are input into the model, each piece of data must be associated with a data source</u>. See **Appendix 7C** for data flags that must be assigned to each data value. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.

Figure 7-4
Impervious vs. Pervious Area High Flow Diagram



2) Pervious Area Submodel

One or more pervious submodels must be established for the tributary area of each flow monitor. For modeling surface runoff volume from a previous area, the model should be theoretically sound, use the fewest empirical coefficients, and have the appropriate complexity level (e.g. Modified Green-Ampt Equation). Soil information and characteristics needed as input into the submodel can be obtained from SPU. Documentation should be provided for rationale and choice of pervious area model chosen for modeling runoff volume from pervious area.

After all data needed for developing an pervious area submodel are input into the model, each piece of data must be associated with a data source. See **Appendix 7C** for data flags that must be assigned to each data value. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.

C. Subsurface Infiltration Model

One or more subsurface infiltration model must be established for the tributary area of each flow monitor. This model provides data on storing of rainfall dependent subsurface flow in the ground and the routing of rainfall dependent infiltration (RD Infiltration) into the sewer system. Minimum seasonal groundwater infiltration that is part of the dry-weather flow model is assumed to be constant and would not be included in this model. However, past experience in calibrating wet weather flow models in the City of Seattle have shown that it takes an average of 2 years for the groundwater table in Seattle to reset itself after a wet season. As a result, when flow monitoring data shows that seasonal groundwater infiltration varies significantly from year to year, the modeling of the additional seasonal groundwater infiltration above the minimum established from dry weather flow can be included as part of the rainfall dependent infiltration modeling.

For modeling rainfall dependent infiltration, the model should be theoretically sound, use the fewest empirical coefficients and/or time series, and have the appropriate complexity level. Soil information and characteristics needed as input into the model can be obtained from SPU. Whenever possible, the subsurface model should be limited to using a 1-reservoir model. The routing equation must have sufficient number of calibration parameters so that level pool routing can be used to model the routing of rainfall dependent infiltration into the sewer system.

For areas where groundwater table is very close to the surface, porous soil with active subsurface flow activities in the vadose (unsaturated) zone, and prolonged rainfall dependent groundwater infiltration is observed in the flow data, a 2-reservoir model (one reservoir for modeling rainfall dependent preferential, matrix, and interflow and one for rainfall dependent groundwater flow) may be used. However, SPU must first be consulted before a 2-reservoir model is applied. Documentation must be provided for rationale and choice of the subsurface model used.

After all data needed for developing subsurface infiltration submodel are input into the model, each piece of data must be associated with a data source. See **Appendix 7C** for data flags that must be assigned to each data value. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.

7.5.7 Operational and Observational Data

Operational information provides important qualitative and quantitative data about the performance of a sewer system. The primary sources for this information are interviews with operations staff (e.g. height of debris in surcharged maintenance holes), survey information from local residents, and maintenance logs. Operational criteria can be observed from the following changes in system operations: pump replacement, weir adjustments, work-around fixes, locations with frequent maintenance, and sediment depths and surcharge during installation of flow monitors.

7.5.8 Conversion of Existing Models

SPU will consider converting and adapting previously developed models for a new purpose if the model was used within the past 5 years. Some examples include updating a model to new software version, changing model to another software platform, updating an existing model with new infrastructure, and adding more detail to a planning level model for a detailed design model. Converting previously developed models can save time and effort. <u>The modeling team must first ensure the existing model contains sufficient documentation describing key assumptions and simplifications used during the model setup. The modeling team must also examine the converted model to ensure it produces simulations results consistent with previous results</u>.

The following are key steps in model conversion:

- Check to make sure pipes and nodes successfully come through the model conversion
- Examine dimensions and elevations to identify missing data, units errors, or other similar data problems
- Examine the level of conversion for other infrastructure types. If the updated version of the software contains new features for simulating other structures, the model characteristics of these elements likely will not transfer. The modeling team should examine and revise the model descriptions of these special structures, as necessary
- Determine whether the hydrologic parameters are properly converted to the updated version of the model. If calculation methods and features of the hydrologic model have changed from older to newer versions of the software, the modeling team will probably need to reenter hydrologic data and possibility recalibrate the model.
- Perform simulations that compare results of the updated and previous model versions. This activity is more straightforward if the old version of the modeling software is available. In this case, the team can run the models side-by-side and compare the results. If the older version of the software is not available, the team should run the converted model and compare the results with those contained in any report prepared using the previous model's simulations. Note: This is a QA step that helps quantify the impact of new information and identifies any erroneous data or hydraulic problems introduced to the model.

Note: *The steps described above also apply to converting an existing model to a new modeling platform--although the process may require more data review and correction. The modeling team should determine whether any routines have been developed by the manufacturer of the destination software to help manage the conversion. Some conversion routines include helpful reports that will inform the team about incomplete portions of the conversion.*

7.5.9 Quality Assurance/Quality Control

The modeling team should perform a series of quality assurance (QA) tests to identify any missing or erroneous data. Identifying and correcting data errors early on will help minimize the potential for inaccurate simulations and associated delays.

After the initial hydrologic and hydraulic model is constructed, the model must be checked for quality assurance and quality control (QA/QC) according to the following guidelines.

7.5.9.1 Data Available for QA/QC

Several sources of data are available for QA/QC. Each source varies in degree of accuracy. The following data sources in order of most to least accurate can be considered:

- Survey
- As-built
- Sewer card
- SPU GIS

For SPU's system, these data can be obtained from SPU's GIS section. For King County's system, these data must be obtained through SPU Drainage and Wastewater Line of Business Representative for the project. SPU must be the only channel through which data of the King County system are acquired.

If missing data cannot be found from any of the above sources, the modeler can either interpolate or infer from adjacent available data using best engineering judgment. All such data must be flagged/documented in the model, reported to the SPU project manager, and documented in the Modeling Report.

7.5.9.2 Hydraulic Conveyance System Model QA/QC

The hydraulic conveyance system model involves three types of QA/QC: data completeness, data connectivity, and profile data. Results from each of these processes must be documented in the Modeling Report.

The modeling team should evaluate the network infrastructure data while creating the model, identify missing or potentially incorrect data, and work with SPU staff to fill any data gaps. If any data gaps are identified, the team should work with SPU staff to verify suspect data and if necessary take corrective action. Often, missing data directly affect the project schedule.

A. Data Completeness

After sewer network data are entered into the model, QA/QC for completeness of the dataset must be conducted. Check all model links and nodes for missing data such as diameters, lengths, elevations and any other required data. All data values must have an associated data flag attached to document source Information. Data flags are defined in

Appendix 7C. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file. All missing data must be tabulated, reported, and resolved with SPU project manager.

B. Data Connectivity

After QA/QC of data completeness and resolving missing data issues, a connectivity QA/QC must be completed on the network data. This QA/QC verifies all elements are appropriately connected and each link connected to an up- and a downstream node with no nodes and/or links inadvertently disconnected from the rest of the network. This can be done by reviewing the Warning and/or Error messages from the modeling software after the first model run. The modeler can also select the *upstream trace* and/or *downstream trace* capability, if available, to complete this connectivity QA/QC. ESRI's ArcGIS software has built-in network analysis tools. SPU also has an in-house network tracing tool and software tools that can conduct such QA/QC. Any data connectivity issues revealed must be tabulated, reported, and resolved with SPU project manager.

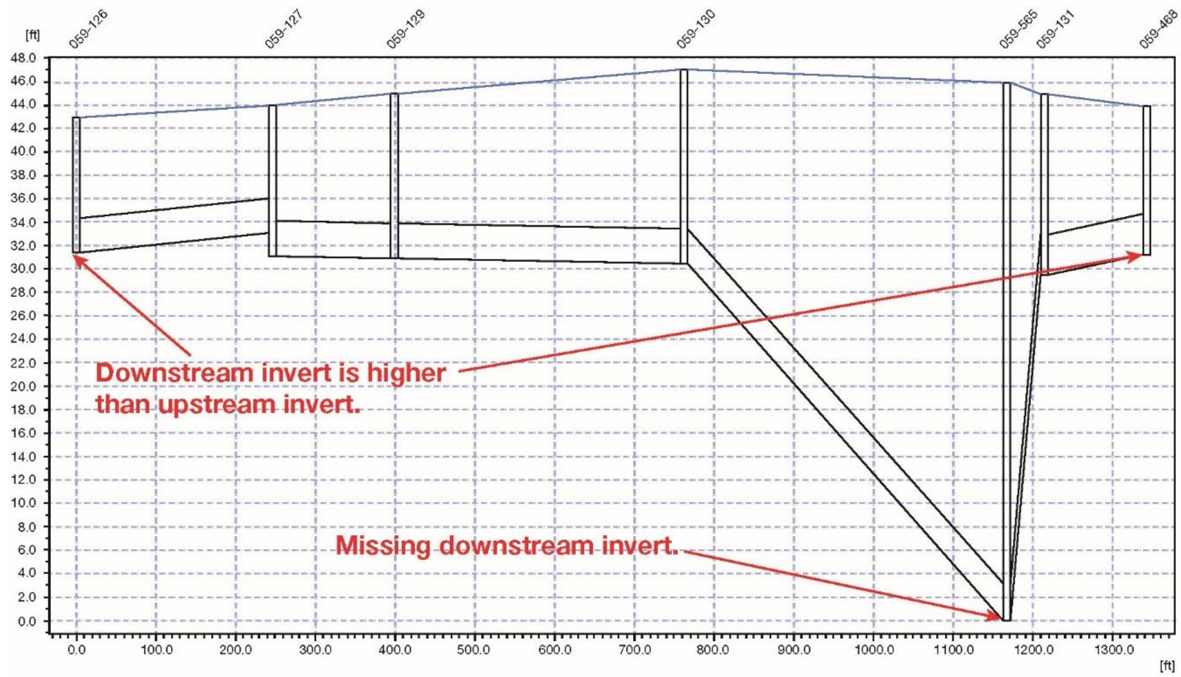
C. Profile Data

After completing a QA/QC of connectivity, the profile data for the conveyance system must be verified. The following should be verified during a profile data QA/QC.

1. In general, for a section of gravity sewer pipe, the upstream invert should be at a higher elevation than the downstream invert. Some sections of pipe in the SPU system are not gravity sewer (e.g. force mains, elevated overflow pipes, or siphons). In these areas, the sewers must be documented, flagged, and confirmed with SPU.
2. Obverts of a pipe should be below the ground elevation of the maintenance hole to which it is connected. In parts of the SPU system that is not the case (e.g. force mains or siphons). In such parts, the sewers must be documented, flagged, and confirmed with SPU.
3. Large vertical drop between inlet and outlet conduit at a deep maintenance hole should be verified and confirmed.
4. Vertical datum of the data must be verified to ensure that the correct datum is being used in the model.
5. Examine pipe profiles or network traces to identify any areas where pipe diameters and/or capacities decrease in the downstream direction. Typically, pipe diameters and capacities should increase in the downstream direction. If such sections of sewers are found in the data, they must be documented, flagged, and confirmed with SPU.

The attributes of sewers that should be flagged and confirmed with SPU during profile data QA/QC are shown in Figure 7-5. After the QA/QC is completed, any profile data issues must be tabulated, reported, and resolved with SPU's GIS department and project manager.

Figure 7-5
Sewer Attributes to Flag and Confirm during QA/QC for Profile Data



7.5.9.3 Hydraulic Structure QA/QC

For all hydraulic structures, SPU data flags (**Appendix 7C**) and data formats (**Appendix 7D**) must be followed for the various structures as data is input into the model and data sources are documented. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.

All missing data must be tabulated, reported, and resolved with SPU's GIS department and the project manager.

For hydraulic structures such as pump stations, weirs, and hydrobrakes, compare model simulation results to head discharge curves (generated from flow monitoring data, field tests, or manufacture curves) to make sure hydraulic control structures are functioning properly in the model.

If Real Time Control (e.g. Control Rule in EPA SWMM) capability of the modeling software is used to model the operation of hydraulic structures, the logic of the model rules must be field verified with the operation logics of the structures so that the model will produce the same results as that observed in the field data.

7.5.9.4 Delineation of Study Area and Sub-catchments Boundaries QA/QC

The following are QA/QC steps for delineation of study area and sub-catchments boundaries:

1. Verify that the boundary of the study area is delineated correctly within the intended area of study.

2. Verify that sub-catchments of different system types are correctly delineated by their system types and that all sub-catchment boundaries are within the study area boundary.
3. Verify that the sum of area of sub-catchments delineated within the study area boundary includes the full extent of the study area and no area is excluded.
4. Each sub-catchment is drained to one or more flow monitors at the outlet or downstream of the sub-catchment.
5. Building (BLG_) area, Right-Of-Way (ROW_) area, and Catchment (C_) area are appropriately delineated for each sub-catchment in the study area.

7.5.9.5 Boundary Conditions QA/QC

The following are QA/QC steps for boundary conditions:

1. Verify that unit used in the user specified input time series is the same as the corresponding unit used in the model.
2. Check the magnitude of inflow data to drain points to ensure values are within physically reasonable range.
3. Check that each drain point assigned to an area in the hydrologic model corresponds to a node in the hydraulic model. <u>All discrepancies between the hydrologic and hydraulic model node assignment must be reconciled</u>.
4. Check that sub-catchments and all of their associated building, right-of-way, and catchment area in a study area are drained to the appropriate type of system (sanitary, storm, or combined) in the hydraulic conveyance system model.

7.5.9.6 Dry-Weather Flow Model QA/QC

The following are QA/QC steps for a dry-weather flow model:

1. Each sub-catchment has at least one weekday diurnal pattern and one weekend diurnal pattern assigned to it.
2. The sum of residential and employment population from each sub-catchment in a study area equals that of the study area. The residential and employment population values agree with those provided by SPU for the area of interest.
3. The sum of sGWI distributed by area to sub-catchments tributary to a flow monitor equals that calculated by using **Stevens-Schutzbach equation** applied to the flow monitoring data. See DSG section 7.5.5.2.
4. Per-capita flow used for each land-use type is reasonable and within the limits established in Tables 3-3 to 3-6 of <u>EPA's Onsite Wastewater Treatment Systems Manual</u>.

7.5.9.7 Hydrologic Model QA/QC

The following are QA/QC steps for a hydrologic model:

1. Verify that there are at least 2-years of rainfall data before the start of calibration rainfall events in the input rainfall time series used for model calibration.
2. Verify that there is a continuous long-term rainfall time series of 30 years or more in the input rainfall time series for model validation.

3. Verify that all flow data used for model calibration and validation have been input into the model.
4. Verify that for each tributary area of flow monitor, at least one impervious, pervious, and subsurface infiltration model are established.
5. After hydrologic parameters are entered into the model, a QA/QC of the completeness of the dataset must be conducted. All data values must have an associated data flag attached to document source Information as shown in **Appendix 7C**. When the software does not provide for the capability of using such data flags, description of the data source must be provided in the Description fields or similar means within the model input file.
6. Verify that the sum of impervious area in each sub-catchment equals the total impervious area of the study area. Similarly, the sum of pervious area in each sub-catchment must equal the total pervious area of the study area.
7. Hydrologic parameters related to the geometric and subsurface properties of a catchment (e.g. size of area or type of soil) must be verified with GIS data.
8. Hydrologic parameters used for calibration (e.g. hydraulic conductivity of soil) must be verified for their reasonableness with available data and accepted values. Initially, modelers must establish a reasonable range for each calibration parameters based on accepted engineering and hydro-geological values. Refer to Table 7-7.
9. Perform simulations that compare results of updated and previous model versions.

   Note: *This QA step helps quantify the impact of new information and identifies any erroneous data or hydraulic problems introduced to the model.*

Table 7-10
Estimation of Green-Ampt Infiltration Parameters

USDA Soil Texture Classification	Suction Head		Hydraulic Conductivity		Porosity	Effective Porosity
	(in)	(mm)	(in/hr)	(mm/hr)		
Sand	1.95	49.5	4.64	117.8	0.437	0.417
Loamy Sand	2.42	61.3	1.18	29.9	0.437	0.401
Sandy Loam	4.34	110.1	0.43	10.9	0.453	0.412
Loam	3.50	88.9	0.13	3.4	0.463	0.434
Silt Loam	6.57	166.8	0.26	6.5	0.501	0.486
Sandy Clay Loam	8.61	218.5	0.06	1.5	0.398	0.330
Clay Loam	8.23	208.8	0.04	1.0	0.464	0.309
Silty Clay Loam	10.76	273.0	0.04	1.0	0.471	0.432
Sandy Clay	9.42	239.0	0.02	0.6	0.430	0.321
Silty Clay	11.51	292.2	0.02	0.5	0.479	0.423
Clay	12.46	316.3	0.01	0.3	0.475	0.385

Notes:

1. These values are provisional, and are offered as reasonable parameters estimates for SWMM applications where more detailed soils information is not available. There is significant variance in these values; laboratory and field testing, sensitivity analysis, and calibration may be employed to improve upon these estimates.
2. In the absence of a soil survey or more reliable information, the values listed above may be used.
3. Values are derived from Journal of Hydraulic Engineering, ASCE, volume 109, No. 1, pp 62-70.

7.5.9.8 Model Check In and Out

Engineering, Investigations & Modeling (EI&M) within Systems Assessment, Operations & Monitoring (SAO&M) of DWW LOB maintains all developed models, including calibrated and un-calibrated models. They are stored in a centralized network location for SPU's staffs and its consultants to use.

All models and associated data and documents are checked out for use and checked-in after the models are completed or updated. Contact EI&M Modeling staff for check In-Out request for modeling information. Procedures for check In-out modeling information are as follows:

1. Fill out a form and send it to EI&M Modeling staff
2. You will be notified once received and contacted if further information is needed
3. Modeling team will review and process your request and notify you about next step(s)
4. Check In-Out Request form is in **Appendix 7F**.

7.6 INITIAL MODEL TESTING

After the physical structure of the model is complete and all input data and boundary conditions defined, the modeler should perform initial tests to ensure the model functions as intended. These simple checks help identify setup problems before more detailed calibration and validation are performed.

While the information for initial testing will depend on the type of system modeled and the modeling software, the following initial checks are a guideline:

1. Does the model run to completion?
2. Does the model summary file(s) list specific errors or warning messages that indicate possible hydraulic or solution convergence problems?
3. Does the time series output database include data for all requested pipes, nodes and other structures?
4. Do the overall system inflows and outflows balance?
5. Do pump stations and other on/off or moveable structures change settings during a simulation as expected?
6. Does the model produce any overflows during low flow test simulation?
7. Does the model simulation produce any suspicious velocities (e.g. greater than 8 fps or less than 0.5 fps)? High or low velocities do not necessarily indicate an error, but the system infrastructure and hydraulics in these areas should be carefully scrutinized.

The initial model test descriptions and results should be briefly documented and saved with other model plan documentation.

7.7 PRECIPITATION

This section describes the use of precipitation data for drainage and wastewater modeling projects. Drainage and wastewater infrastructure models use precipitation data to calculate stormwater flows and infiltration and inflows to the conveyance system (i.e. rainfall-induced flows). During large storms (ones that generate CSOs), the rainfall-induced component of wastewater flow is usually much larger than the base sanitary wastewater component. Rainfall-induced flows clearly affect the level of service provided by hydraulic facilities. Modelers should use appropriate and representative precipitation data to model the SPU drainage and wastewater conveyance system.

7.7.1 Permanent Rain Gauge Network

The City of Seattle operates and maintains a network of 17 automated precipitation gauges distributed throughout the City. Many of these gauges have been operating since 1978 (Table 7 11 Permanent Rain Gauge Network Attributes). Currently, SOPA manages and maintains these rain gauge locations.

Table 7-11
Permanent Rain Gauge Network Attributes

Gauge ID	Name	Address	Period of Record	In Operation
RG 01	Haller Lake Shop (SPU)	North 128th Street & Ashworth Avenue North	1978-current	Active
RG 02	Magnuson Park	7022 Sand Point Way Northeast	1978-current	Active
RG 03	UW Hydraulics Lab	Northeast Pacific Street & 15th Avenue Northeast	1978-current	Active
RG 04	Maple Leaf Reservoir	Northeast 82nd Street & 12th Avenue Northeast	1978-current	Active
RG 05	Fauntleroy Ferry Dock	4829 Southwest Barton Street	1978-current	Active
RG 07	Whitman Middle School	9201 15th Avenue Northwest	1978-current	Active
RG 08	Ballard Locks	3015 Northwest 54th Street	1978-current	Active
RG 09	Woodland Park Zoo	5500 Phinney Avenue North	1978-current	Active
RG 10	Rainier Avenue Elementary	116500 Beacon Avenue South	1978-2008	Inactive
RG 11	Metro-KC Denny Regulator	Myrtle Edwards Park	1978-current	Active
RG 12	Catherine Blaine Middle School	2550 34th Avenue West	1978-current	Active
RG 14	Lafayette Elementary School	2635 California Avenue Southwest	1978-current	Active
RG 15	Puget Sound Clean Air Monitoring Station	4401 East Marginal Way	1978-current	Active
RG 16	Metro-KC East Marginal Way		1978-current	Active
RG 17	West Seattle Reservoir Treatment Shop	8th Avenue Southwest and Southwest Cloverdale Street	1978-current	Active
RG 18	Aki Kurose Middle School	3928 South Graham Street	1978-current	Active
RG 20	TT Minor Elementary School	1700 East Union Street	1978-2010	Inactive
RG 25	Garfield Community Center	2323 East Cherry Street	2010-current	Active
RG 30	Rainier Beach Public Library	9126 Rainier Avenue South	2009-current	Active

The precipitation gauges contain tipping buckets that record precipitation in 0.01-inch increments, with the timing of each bucket tip recorded to the nearest minute. All gauges include an onsite data logger for recording precipitation data and communication equipment to transmit data to the monitoring contractor’s computers for processing.

Precipitation data from the City of Seattle permanent gauge network. (for more info on the Precipitation data from the City of Seattle permanent gauge network, contact SPU_DSG@Seattle.gov)

For more discussion on City of Seattle rain gauge network and precipitation analysis, refer to technical memorandum prepared by MGS Engineering Services, Inc. in 2004, "Analyses of Precipitation-Frequency and Storm Characteristics for the City of Seattle."

Due to the Joint Operation and System Optimization Plan between SPU and King County resulted from each agency's Consent Decree, for study area that is closer to a King County rain gauge than any of the SPU rain gauge, King County rain gauge data are also available for use by SPU. <u>However, request for King County rain gauge data must be made through SPU SOPA</u>.

7.7.2 Selecting City of Seattle Rain Gauge

The project team should evaluate the following local conditions when selecting the appropriate rain gauge location for obtaining rainfall datasets for a modeling project:

- Size of project area. Larger project areas are more likely to experience significant rainfall variability. To accurately capture total precipitation volume, additional gauging stations could be required.
- Proximity of nearest permanent rain gauge site. Gauges located within or near to the project area are more likely to correlate with flow monitoring data collected within the basin. Gauges farther from the site could present challenges during model calibration.
- Complexity of project drainage and conveyance issues. The Modeling Plan in **Appendix 7A** describes the acceptable level of uncertainty.

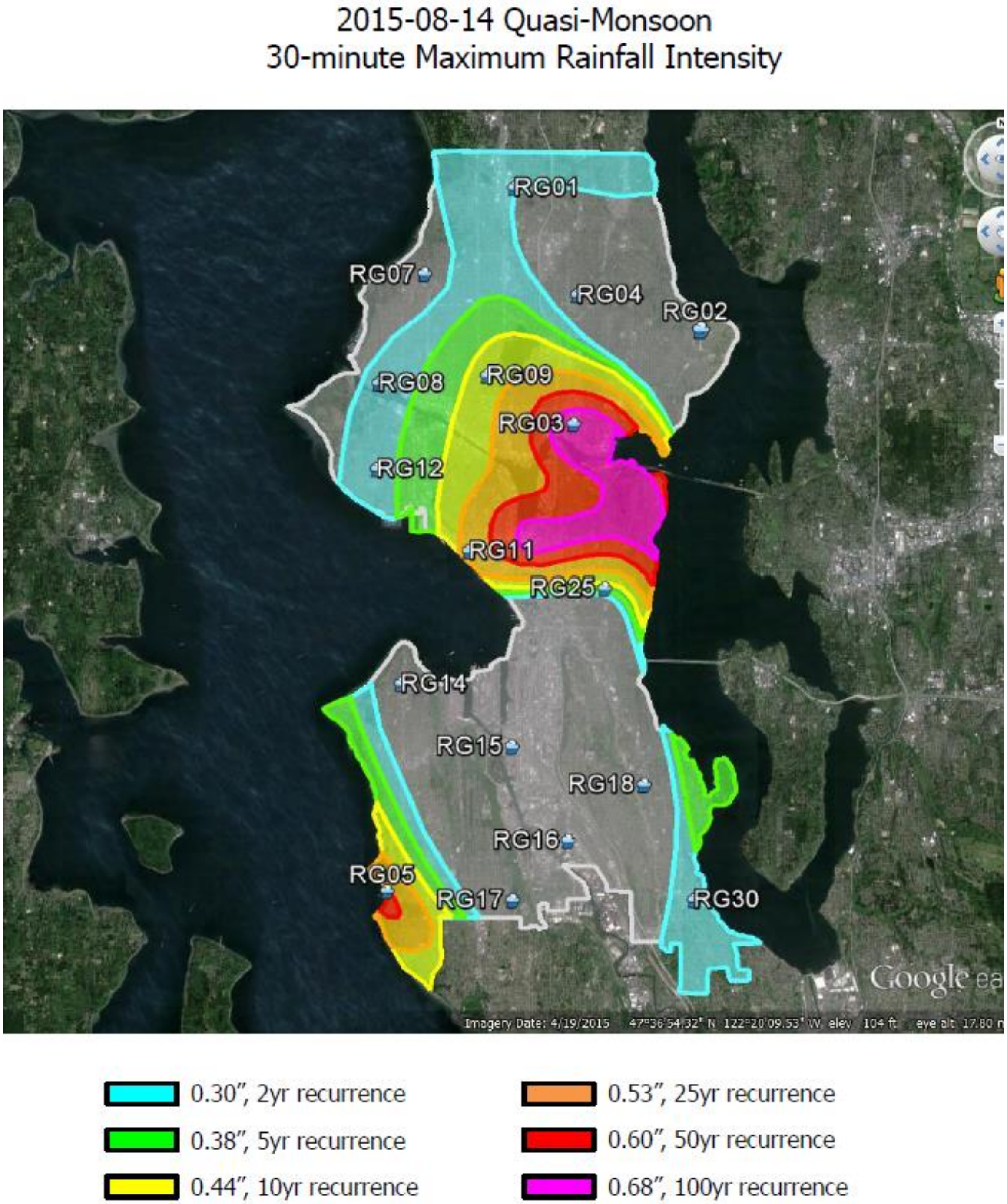
The project team should consider the issues above when determining source of rainfall data. For straightforward projects located near a permanent rain gauge, one gauge will be sufficient. For larger project areas or more complex projects, the project team should consider installing a temporary precipitation gauge to help calibrate the model.

7.7.2.1 Thiessen Method

<u>Whenever multiple rain gauges are used for drainage and wastewater system model, the Thiessen Method must be used to initially distribute rainfall data throughout a basin</u>. The Thiessen Method assumes the rainfall at a particular location is equal to the rainfall recorded at the nearest gauge. Applying the method will generate a set of polygons or sub-catchments associated with each rain gauge. ArcGIS has built-in tools for generating the Thiessen Method polygons.

For model calibration, SPU Climate Resiliency Group creates rainfall event return period maps for significant rainfall events that fell within the City boundary. When such maps are available for rainfall events selected for model calibration, information shown on those maps should be reviewed to fine tune the rainfall data and gauge(s) used for the study area. As the Thiessen Method does not take into account the path that storm cells take to move across the City, incorporating such information would help with instances when flow monitor data records show more flow than what the rain data suggests because the responsible storm cell did not pass over the Thiessen Method rain gauge but the study area. This is especially useful when no additional rainfall data (e.g. temporary rain gauge data) is available. Figure 7-6 shows an example of such map.

Figure 7-6
Example Rainfall Event Return Period Map



Maximum Rainfall Intensity by Duration																								
Duration (HH:MM)	SPU Rain Gages																		Recurrence Values					
	01	02	03	04	05	07	08	09	11	12	14	15	16	17	18	25	30		2	5	10	25	50	100
00:05	0.07	0.04	0.27	0.05	0.22	0.05	0.10	0.14	0.22	0.12	0.05	0.04	0.01	0.04	0.06	0.10			0.13	0.17	0.20	0.26	[illegible]	0.35
00:10	0.13	0.07	0.45	0.09	0.56	0.09	0.16	0.25	0.34	0.19	0.09	0.07	0.02	0.07	0.10	0.18			0.18	0.23	0.27	0.34	[illegible]	0.45
00:30	0.30	0.18	[illegible]	0.19	[illegible]	0.23	0.33	0.50	0.55	0.35	0.21	0.16	0.03	0.16	0.21	0.29			0.30	0.38	0.44	0.53	0.60	0.68
01:00	0.50	0.30	[illegible]	0.35	[illegible]	0.38	0.43	0.64	0.69	0.58	0.37	0.28	0.06	0.30	0.32	0.42			0.42	0.51	0.58	0.70	[illegible]	[illegible]
02:00	0.88	0.52	[illegible]	0.56	[illegible]	0.65	0.65	0.78	0.78	0.80	0.60	0.40	0.12	0.45	0.36	0.48			0.58	0.70	0.78	0.92	1.04	1.14
06:00	1.31	0.89	[illegible]	1.00	[illegible]	1.08	1.08	1.33	1.22	1.34	1.23	0.90	0.33	0.95	0.78	0.90			1.08	1.26	1.38	1.56	[illegible]	[illegible]
12:00	1.31	0.91	1.76	1.01	1.92	1.08	1.08	1.33	1.22	1.34	1.23	0.96	0.58	0.96	0.82	0.96			1.56	1.80	2.04	2.40	[illegible]	[illegible]
24:00	1.38	0.97	1.81	1.07	1.92	1.12	1.12	1.36	1.24	1.35	1.23	0.96	0.68	0.96	0.88	0.96			2.16	2.40	2.88	3.36	[illegible]	[illegible]

7.7.3 Temporary or Project-Specific Rain Gauges

Temporary rain gauges are occasionally installed for projects without adequate local rainfall coverage to meet project requirements. Reasons to install a project-specific gauge in an area:

- No nearby precipitation gauge.
- Spatially variable rainfall and available nearby gauges do not adequately represent basin-wide rainfall.
- Susceptible to flooding from short-duration, intense rainfall. Short, intense storms are usually more spatially variable. They capture total precipitation volume for the project area and may require a higher density of gauges.

Typically, the lead modeler will determine during the early phase of planning a project whether to install additional rain gauges. The timing of the new gauge is important. The gauge should be installed as early as possible in advance of temporary flow monitors for better model calibration. Temporary rain gauges must be documented in the flow monitoring plan and report.

7.7.3.1 Selecting Temporary Precipitation Monitoring Location

The project team may decide to install temporary rain gauges in a project area. These installations have the following design considerations:

- Design and install to the same standards as a permanent rain gauge network, as much as practical. Installation locations should allow for accurate data collection (e.g. no vertical obstructions, low-wind location), convenient access for maintenance, and good security to prevent vandalism or accidental damage.
- Locate in areas that tributary to the problem areas. This will provide greater data resolution in the areas that contribute to known problems. When combined with existing gauges in the area, temporary gauges should provide a good representation of the entire project area. SPU Climate Resiliency Group creates rainfall event return period maps for significant rainfall events that fell within the City boundary. When such maps are available for the problem area, the maps should be reviewed as they provide insights on the historical trend that storm cells take to move across the area. When correlated with locations of problem area, such information further helps in selecting suitable locations for the temporary rain gauge.
- Install before model calibration. Ideally, the temporary gauges would function throughout planning, design, construction, and up to 5-years years post-construction to allow SPU staff to verify effectiveness of facility upgrades.

7.7.4 Other Sources of Precipitation Data

City of Seattle permanent and temporary gauges should be sufficient for all drainage and wastewater modeling projects in the city. However, users may want to examine other nearby local precipitation data sources. Non-SPU gauges could be used for quality assurance, to determine the spatial extent of a particular storm, or to verify an SPU rain gauge was accurately recording information for a particular storm. Other sources of precipitation data include:

- NOAA/NCDC sites at SeaTac Airport and Sand Point
- King County precipitation sites

7.7.5 Design Storms

For the applicable use of design storms, please refer to City of Seattle Stormwater Manual Appendix F.

Design storm times data is located in the DSG modeling library. (for more info on the DSG modeling library, contact SPU_DSG@Seattle.gov)

7.7.6 Evaporation Monitoring Stations

If evaporation calculations are needed for modeling, the team should obtain a evapotranspiration (ET) time series from a nearby location, such as the WSU station at UW (Gauge 61) available at WSU's AgWeatherNet website. Please refer to DSG modeling library for evaporation time series data at UW. (for more info on the DSG modeling library, contact SPU_DSG@Seattle.gov)

The City of Seattle does not operate any long-term evaporation monitoring stations.

7.8 FLOW MONITORING

The project team should evaluate the need for flow monitoring data early in the project based on the project goals. If flow monitoring data is needed, the project team should check first with the SPU project manager to determine if flow monitoring data already exists for the project area. If no useable flow monitoring data is available, the following are guidelines for gathering flow monitoring data.

7.8.1 Flow Monitoring Plan

A flow monitoring plan must be developed for projects that require flow data collection. The Flow Monitoring Plan must follow the sample outline in **Appendix 7A**. The plan should be developed early and updated to reflect changing conditions.

The schedule outlined in the monitoring plan should be integrated with the overall project schedule, including the milestones outlined in the modeling plan (see DSG section 7.3.1).

7.8.2 Selecting Flow Monitoring Locations

Monitoring locations must be selected and prioritized to maximize data usefulness and to ensure proper calibration of subsequent modeling. Monitoring locations must be functional and practical. The following are basic steps for selecting flow monitoring locations:

1. Coordinate Monitoring Team: The project manager should coordinate with SPU staff, contractors, and consultants early in the project. Flow monitoring can be time intensive, especially when trying to capture a wide range of events or infrequent events. Flow monitoring must be initiated early to minimize impacts to project schedule.
2. Establish Objectives. Data needs should be assessed. Based on data needs, specific objectives should then be established for flow monitoring. The objectives should include types of data to be collected (e.g. flow rates, flow velocities, flow depths), temporal frequency of the data, duration of data, and precision and accuracy requirements. The

objectives should also indicate the geographic area of interest and specify locations of particular concern.

3. Identify Constraints. Constraints should be identified and quantified (if possible). The primary constraints are 1) lack of good monitoring sites at critical locations due to poor flow monitoring conditions, 2) budget, 3) staff availability for O&M of flow monitoring sites, and 4) time.
4. Select Monitoring Equipment. Equipment should be selected based on flow monitoring objectives and constraints for the project.
5. Identify preliminary locations with alternatives.
6. Field verify.
7. Finalize locations.

7.9 MODEL CALIBRATION AND VALIDATION

Model calibration consists of adjusting model input parameters to compare model simulations results with observed information (such as flow monitoring data) until the modeling team determines a reasonable agreement has been reached. Validation involves testing the model simulation against an independent set of observations that excludes calibration time period. The purpose of model calibration and validation is to replicate key H/H conditions in a project area. Model calibration and validation should give the project team a higher level of confidence in using the results to plan and design facility improvements.

7.9.1 Levels of Calibration

The modeling team should plan calibration to match project goals and available information. For example, sizing a short length of pipe may not require extensive model calibration, particularly if the project has an accelerated schedule. In this circumstance, the project team could specify a larger diameter pipe to offset any uncertainty caused by minimal calibration. By contrast, larger projects that carry significant costs and consequences of failure should receive a more thorough modeling analysis that includes calibration and validation. This may require the project team to collect additional flow monitoring data before calibration.

As part of the initial project planning, the project team should evaluate the need for model accuracy by quantifying the risks and consequences of modeling uncertainty. Would a simple, conservative approach to facility sizing suffice? Or does the project require a more thorough understanding of H/H conditions to ensure conveyance goals are adequately met?

The following types of information may be very useful for model calibration and validation.

1. **Flow monitoring data.** Continuously monitoring flow rates and depths will help the modeling team determine the physical mechanisms by which flow enters and moves through the SPU drainage and wastewater system. Continuous flow monitoring will allow the modeler to match the rising and falling limbs of the flow hydrograph and compare flow responses to storms of different lengths and intensities and antecedent conditions.

2. **Historical anecdotal information.** Flow monitoring data may be limited in the project area, particularly if the events that triggered the need for a project occurred before any flow monitoring data was available. In some cases, historical anecdotal information may be the only type available for floods of interest. Available sources of anecdotal information may include the following:
   a. Interviews with local residents
   b. Photographs and/or videos of specific storm events
   c. Debris marks indicating high water within maintenance holes or aboveground flood stage
   d. Water level measurements (i.e. measure-downs) by City of Seattle staff during floods. Anecdotal information can be particularly helpful in model validation
3. **Permanent CSO NPDES monitoring data.** Because SPU has long, continuous monitoring records for its permanent CSO NPDES sites, these locations are a useful source of operational history. Modelers should use caution, however, when using permanent CSO NPDES monitoring data for calibration. NPDES CSO sites are typically difficult to monitor. The resulting data usually have a higher level of uncertainty than flow monitoring data collected in more ideal locations in the upstream collection system. NPDES CSO site monitoring data should primarily be used to determine 1) when overflows occurred and 2) the relative magnitude of differing CSO events.
4. **Pump station runtime data.** Pump stations may offer a history of operational data in the SPU drainage and wastewater system. Pump runtime information extracted from the SPU SCADA system could be converted to flow data by using the manufacturer's pump curve data for a station or by drawdown tests done to test the actual pump performance. The modeler should use caution when using pump runtime information for calibration purposes. The computed flow rates are often less accurate than actual flow monitoring data. It is preferable to use pump station runtime data as a secondary source of operational information.

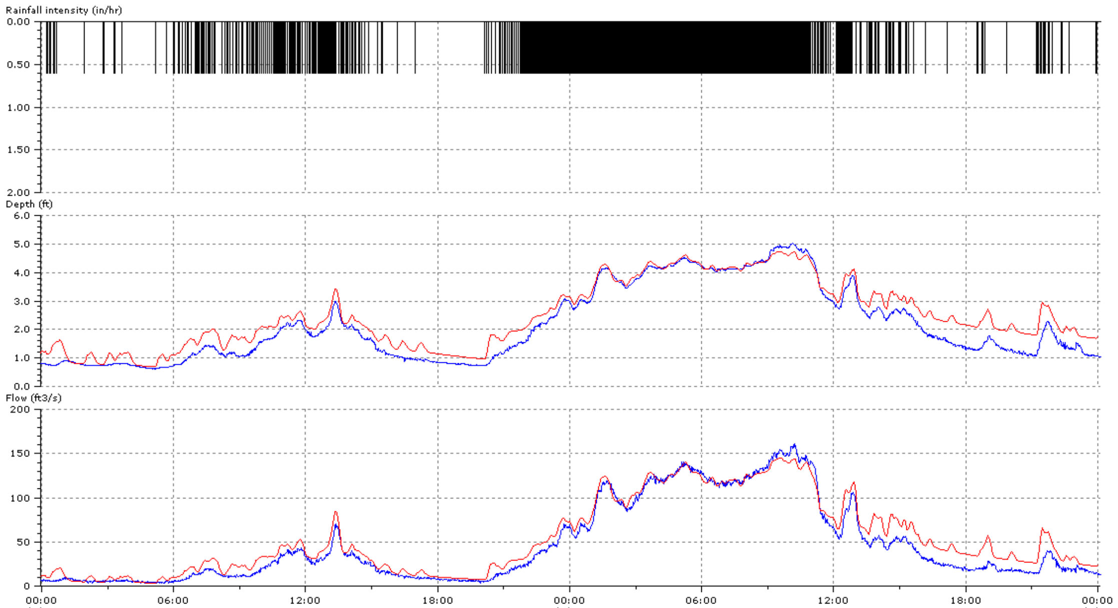
7.9.2 Calibration to Flow Monitoring Data

This section discusses methods and performance goals for calibrating to flow monitoring data. The discussion focuses primarily on sanitary and combined sewer methods. However, general goals (if not specific methodology) applies equally to drainage and creek systems.

For Seattle, a full wet season of flow data is needed for model calibration. The extent of soil moisture during winter affects the quantity of extraneous flows entering the drainage and wastewater system. October I/I flows contain much less rainfall than do February storms.

The quality of a model calibration and the iterative adjustment of model variables can be guided by both graphical and statistical methods. During the initial iterations, it is convenient to use a graphical comparison of modeled and observed flow, as shown on Figure 7-7.

Figure 7-7
Example of Calibration Comparing Simulated and Observed Flow



Graphing modeled and actual flow provides a quick analysis of model accuracy. This can be used early in calibration to identify large discrepancies and make broad adjustments to the model.

Criteria for consideration during graphical analysis are hydrograph shape, peak flow rate, and the timing of peak and low values. These criteria should be applied to both base flow and I/I.

Statistical methods provide quantitative comparisons between modeled and observed flow. Calibrated models should meet the requirements in section 7.9.2.1 for dry and wet-weather flow. The aforementioned requirements should also be applied for model validation.

7.9.2.1 Measures of Calibration Success

The ability to produce an accurate calibration is affected by several factors that may be out of the modeler's control. Calibration performance will be affected by flow monitoring accuracy, rain gauge accuracy and representativeness for the project area, the model's I/I computation algorithms, and quality of input data. While the modeling team should set calibration goals, it may need to adjust those goals during calibration phase to meet data and model limitations. The following are general guidelines for model calibration on SPU drainage and wastewater system projects.

A. Dry-Weather Flow Calibration

For dry-weather flow (i.e. base flows), the following standards should be used for calibration, in addition to matching general hydrograph shape. These standards should be met for at least 2 dry-weather days (weekday and weekend day):

- Predicted time of peaks and troughs should be within 1 hour of the observed flow
- Predicted peak flow rate should be within ± 10% of the observed flow data

- Predicted volume of flow over 24-hours should be within ± 10% of observed flow

B. Wet-Weather Flow Calibration

For wet-weather flows (base flow plus infiltration/inflow), the following standards should be used for calibration and should match the general hydrograph shape. These guidelines should be met for at least five wet-weather events of varying rainfall depth, intensity, and duration:

- Predicted time of peaks and troughs should be within 1 hour of the observed flow
- Predicted peak flow rates should be within -15% and +25% of the observed flow
- Predicted volume of the wet-weather event should be within 10% and +20% of the observed volume
- Predicted surcharge depth in maintenance holes or other structures should be within -0.3 feet and +1.5 feet of the observed depth
- Predicted water surface elevations (i.e. non-surcharge depth should be within ± 0.3 feet of the observed depth

C. Other Considerations for Calibration

Depending on the models purpose, other parameters also require examination to ensure accurate calibration. These include, but are not limited to, the following:

- Reasonable agreement between predicted and actual pumping station wet-well level and discharge
- Accurate prediction of known overflow location and volume
- Accurate prediction of duration and volume of flow equalization/storage systems
- Representative performance of flow control structures such as weirs

7.9.2.2 Automated Calibration Methods

Several software packages offer automated calibration routines that provide a quick and less labor intensive way to produce a calibrated model. Automated calibration is helpful when calibrating several different flow meters or when combined with a sensitivity analysis. Methods for automated calibration include the following:

- Minimizing the difference of squares between the model output and flow monitoring data. This method is simple but tends to optimize the fit for base flows instead of matching peak flows.
- Minimizing the difference of squares while providing additional weighting to high flow periods. This variation on the method above seeks to provide better matching to storm data.
- Neural networks methods sequentially test adjustments to model parameters. They select and build on adjustments that produce a closer match between simulated and observed data. The process continues until a specified minimum level of agreement is met.

Automated calibration techniques are helpful. However, they should be used with caution. Most I/I model applications attempt to simulate the physical processes by which water enters the pipe network. When setting up an automated calibration, the modeler should use caution in selecting calibration parameters and only allow the model calibration parameters to vary within believable limits. Automated calibration methods increase the potential to "get the right answer for the wrong reason." For modeling studies that means producing a good calibration fit without capturing the essential physical mechanisms of the system. If a method does not capture the essential physical elements of the system, the model is unlikely to perform well in "what if" scenarios that test alternative improvement, particularly I/I removal.

For CSO projects and basin plans, ACU-SWMM is available for use with EPA SWMM. ACU-SWMM has two primary functions. The first function is automated calibration of SWMM models of urbanized basins. The automated calibration function may be used with any SWMM5 basin model. Second function is it computes Control Volumes and uncertainty bounds for CSO volumes with a frequency occurrence of once per year. For more information on ACU-SWMM, refer to **Appendix 7G**.

7.9.3 Model Validation

The validation process tests that the model can rigorously reproduce a variety of H/H conditions, not only those included in the calibration period. The validation process is the final step before a model is used to plan specific drainage and wastewater improvements.

The validation process includes the following steps:

1. Determine available data for the model validation effort. Potential sources of data (e.g. historical flow monitoring, anecdotal or operational data) are described in DSG section 7.9.1
2. Prepare precipitation data and any time-varying boundary conditions for the period of time covered by the validation data
3. Run a model simulation and compare the results to the validation dataset

The validation dataset should be independent from the calibration dataset. Ideally, the validation data would be from a different wet season with different conditions from the seasons already used in the calibration period.

Methods for evaluating the quality of a model validation simulation are less prescriptive than for a model calibration. Graphical and statistical comparison methods are both valid. The modeler should expect model validation simulations to match flow observations less precisely than the calibration simulations.

The model team can set specific goals for the validation exercise, such as matching peak flows to within 20% or volume to within 10%. The modeling team should consider the model to represent the physical processes of flow entering and moving through the drainage and wastewater system. The validation criteria should be set such that when the validation results meet those criteria, the team can comfortably believe that model is sufficiently accurate to support project goals (e.g. design pump station improvements to reduce flooding).

If the model validation simulation results do not adequately match the validation dataset, the modeler should carefully examine the model input and output data. From that data, the modeler may determine the probable cause of the discrepancies (e.g. not enough direct inflow, rainfall timing does not match flood timing, or the storm cells that produce the validation flow did not pass over the rain gauge used by validation simulation run). If the modeler believes the model is not sufficiently robust, model calibration should be revisited. After adjusting the model calibration, model validation should be performed again with a new validation dataset.

7.9.4 Flow Estimation in Absence of Flow Monitoring Data

The project team can estimate the range of peak flows in a project area by using the results of nearby studies, back-of-the-envelope calculations, or general rules of thumb. There are several reasons why a team may want to first develop a quick flow estimate. Sometimes a team may want to better understand the magnitude of a drainage problem or construction project during the initial stages of project planning. Or project schedule may not allow time for flow monitoring and model calibration and validation.

The following are examples of estimating local flows using available historical flow information.

- The modeling results from a similar, nearby basin could be used to estimate flows in the project area. For example, if a previous study estimated peak I/I flows for a variety of flow recurrence intervals (peak 5-year flow, 10-year flow, 20-year flow), the modeler could convert those I/I flows into unit rates, such as gallons per acre per day (gpad) and apply those unit rates to the project area.
- Anecdotal information or historical operational data, such as those described DSG section 7.9.1 could be used to help develop a quick model calibration. This would involve calibrating to a single event.
- A project team could do statistical analysis of long-term operational data measured in a nearby portion of the drainage and wastewater system. For example, the pump station runtime data could be used to develop flow estimates over a wide range of conditions. These flow estimates could be converted into unit I/I rates and applied to the project area.
- When an upper bound on the potential flow rates is all that is needed, the project team could perform simple runoff calculations (e.g. the rational method) to determine the maximum amount of water that could enter the system.

The project team could expand or modify the examples provided above to meet the needs of a specific project. When estimating flows without benefit of local flow monitoring data, the team should consult SPU staff experienced in the project area.

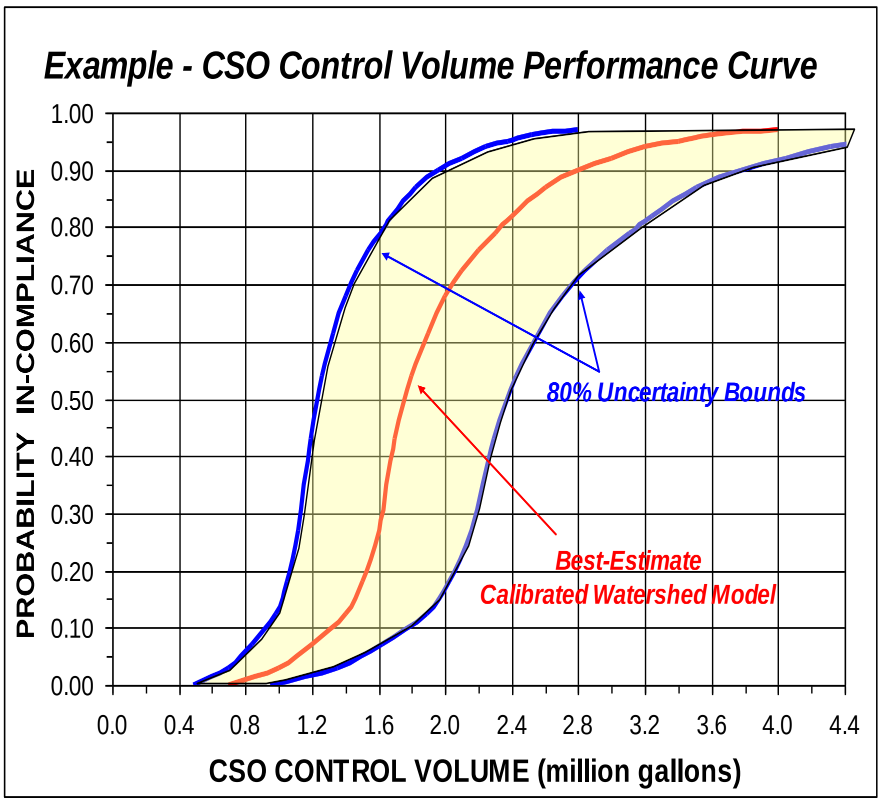
7.10 UNCERTAINTY/LEVEL OF ACCURACY

SPU has developed a risk-based approach to estimating CSO control volumes. The risk-based approach uses multiple calibrations and simulations to determine the potential spread—or level of uncertainty—associated with CSO control volume modeling. The purpose of the risk-based analysis is to provide SPU decision makers a way to assess risk and consequences when sizing CSO control facilities. The risk-based approach is designed to provide the information necessary to help balance the cost of over-performance against the risk of underperformance of CSO control facilities.

Figure 7-8 illustrates the relationship between compliance and level of confidence in modeling results. The curve shows the likelihood a specific CSO control volume would meet the NPDES permit requirement of one untreated overflow per year over a 20-year running average. The spread in the CSO control volumes indicates the level of uncertainty associated with the model outputs.

For example, Figure 7-8 shows a model where the best-estimate calibration suggests that a CSO control volume of 2 million gallons would meet the permit requirements 70% of the time. Other calibration-simulation curves show CSO control volumes higher or lower than the best-estimate calibration value. Statistical analysis of the other calibration-simulation results generates uncertainty bounds (confidence levels) for other CSO control volumes. The example shows CSO control volumes of 1.4 million gallons and 2.8 million gallons at the lower and upper range of the 80% uncertainty bounds at a 70% compliance level.

Figure 7-8
Example of Risk-Based CSO Volume Curves



Several factors should be considered when using a risk-based methodology:

- The approach has only been applied to the combined sewer system, although the basic philosophy would apply to modeling other types of systems.
- The analyses performed to date focus on CSO control volumes. These volumes do not precisely correspond to the size of CSO storage facilities required by SPU's NPDES permit. Other issues, such as allowable discharge rates to the downstream system, will affect facility sizing.

- The approach could become substantially more complex when applied to combination of CSO control strategies, such as storage, diverting flows, and demand management.

At the beginning of a project, the project team should assess the feasibility of the risk-based approach, the potential benefits, and cost and schedule impacts. Larger, more sensitive projects are more likely to benefit from this approach. Smaller, more straightforward projects would not.

For estimating CSO control volumes, see the CSO Technical Guidance Manual in **Appendix 7E**.

7.11 CAPACITY ASSESSMENT AND ALTERNATIVES ANALYSIS

This section describes approaches to conducting capacity assessments and alternatives analyses for SPU drainage and wastewater infrastructure. SPU does drainage and wastewater capacity assessments and alternatives analyses for two purposes:

1. Private development. For some large developments, SPU may require a developer to assess the project’s downstream impacts and build capacity improvements to offset them.
2. CIP planning. Capacity assessments and alternatives analyses are done when developing basin plans and planning improvements to facilities that do not meet SPU’s desired level of service.

7.11.1 Existing System Capacity Assessment Elements

Capacity assessments should involve the following calculations:

- An estimate of stormwater and/or wastewater flows in the project area. Flow projections should be computed for the SPU level of service in the area and not just for base flow or low flow conditions.
- An estimate of the capacity of each conveyance element in the project area and sufficiently far enough downstream.
- A comparison of flow projections and conveyance capacities. Whatever method of comparison (e.g. sophisticated hydraulic model; pipe-by-pipe Manning’s capacity calculation), the comparison should identify the conveyance elements with insufficient capacity.
- An alternative analysis that identifies specific facility improvements and/or flow reduction methods that eliminate the problems noted in the item above.

SPU does not have a standard for *at capacity* for its piped conveyance system. SPU will permit surcharging in deep pipes but not in shallow cover pipes due to the risk of side sewer backups and surface flooding. Please refer to *DSG Chapter 8, Drainage and Wastewater Infrastructure*.

7.11.2 Capacity Assessments for CIP Projects

Capacity assessments for SPU CIP projects will usually occur in areas with known drainage and wastewater capacity problems. These problems could include excessive maintenance hole surcharging, excessive CSO frequency, or similar problems. The goal of the capacity assessment should be to determine the location of the capacity problem, the frequency and magnitude of the problem, the underlying cause or causes of the capacity problem, and to test alternative strategies to improve drainage and wastewater service.

The methodology described in this DSG should be used to develop a D/WW system model to evaluate conditions that will generate overflows. The following lists basic steps for conducting a capacity assessment:

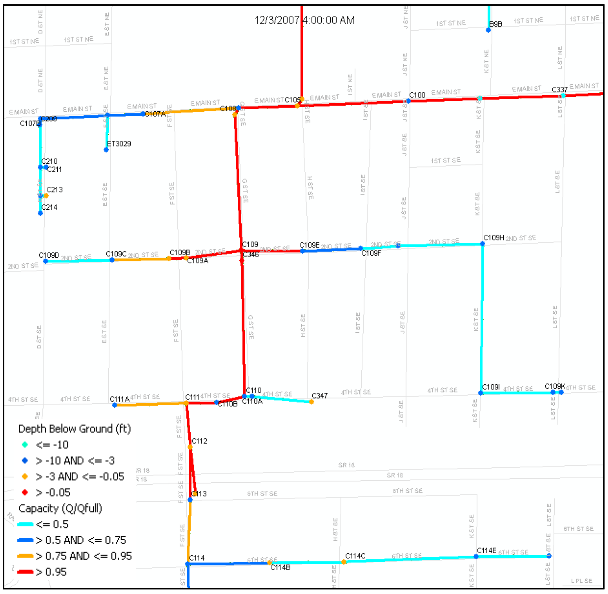
1. Complete the model. The modeling plan should outline the level of detail and accuracy that is necessary for a particular project (e.g. fully calibrated and validated model; simple and uncalibrated model).
2. Determine the level of service for the piping system, creek, or other conveyance assets in the model
3. Develop a time series of input flows to test the level of service. This time series should include flows up to exceeding the level of service design flow rate. Long time series inputs are best when they are available. Continuous simulations with inflows that are based on actual, historical precipitation data provide a more realistic range of storm types, intensities and durations. This diversity will help the modeling team evaluate model outputs to determine the actual function of the physical system.
4. Run the model and evaluate the results. The model outputs should be summarized graphically as much as possible (see next section). Plan view and profile plots are effective tools that illustrate key results to modeling staff and non-technical project staff.
5. Generate statistical summaries that characterize the frequency and magnitude of the capacity problems (e.g. frequency of side sewer backups, how often does a flood occur in a specific location; what is the 5-year overflow volume at a creek culvert/bridge) and compare with proposed alternatives that improve drainage and/or wastewater service.

7.11.2.1 Methods for Characterizing Capacity Assessment Results

The modeling team should develop graphics that summarize the locations of capacity problems and illustrate the relative severity of these capacity problems. For example, Figure 7-9 shows the simulated surcharge level in a storm drainage piping system.

In this example, the pipes and maintenance holes are color coded to illustrate the maximum water surface level during the large storm event in December 2007. The red pipes flowed more than 95% full, the yellow pipes flowed between 75 and 95% full, and the blue pipes flowed 75% full or less. Dark blue, yellow and red colored maintenance holes experienced varying levels of surcharging. Red maintenance holes show the locations of street-level overflows. This plan view summary of the capacity assessment results communicates valuable information very clearly to modelers and non-technical staff alike. Most hydraulic modeling packages include some ability to produce plan view capacity snapshots. Software packages with GIS linkages or import/export capabilities will enable the modeling team to include other types of information. These include street names and locations of critical facilities (e.g. hospitals, evacuation routes) that provide additional context for the capacity assessment results.

Figure 7-9
Plan View: Capacity Assessment Simulation Results

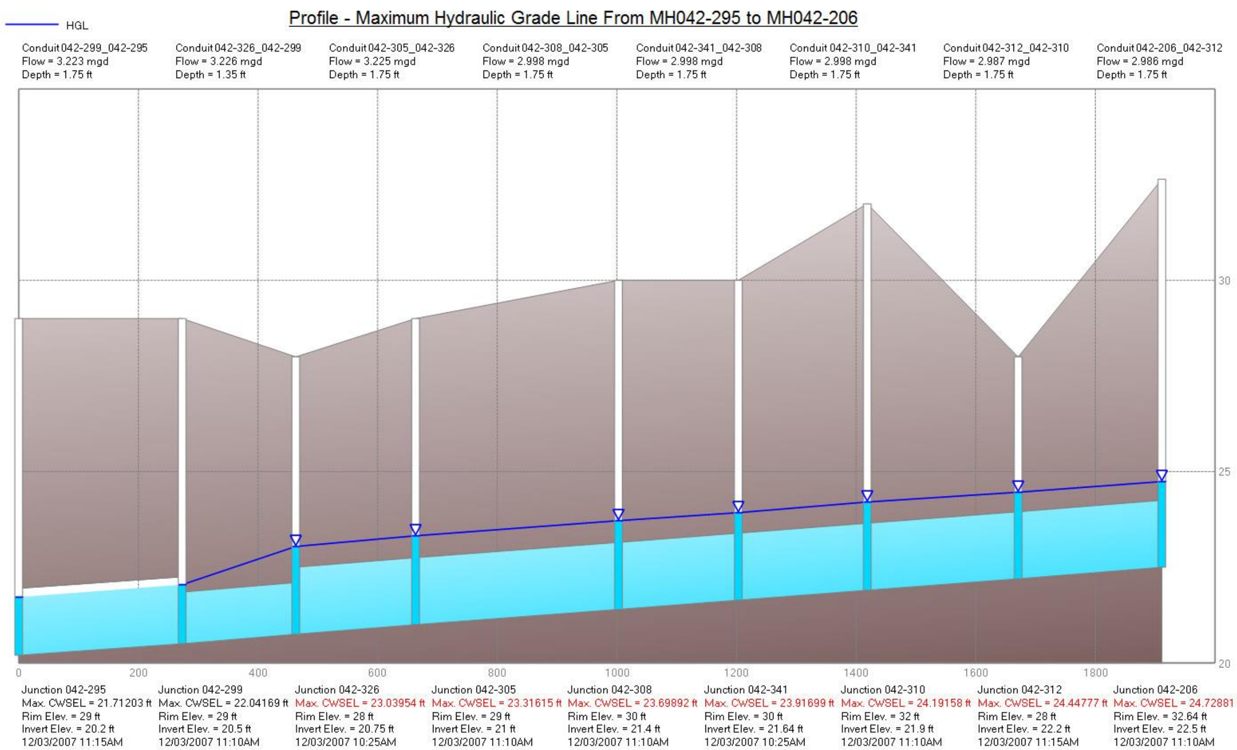


After identifying the locations of capacity problems, the modeler should produce supplemental graphics that focus on these areas to aid in determining the underlying cause of a problem. Profile plots can illustrate common causes of flooding:

- Decreasing flow capacities (e.g. smaller or flatter pipes) in the downstream piping.
- Hydraulic restrictions due to special structures, such as gates and weirs.
- Large flows joining the system without a corresponding increase in conveyance capacity.
- Local low spots that only allow for shallow bury pipes.

Figure 7-10 is a profile view showing the pipe diameters, hydraulic grade line, and ground surface elevations of a pipe network. Note that the surcharge level is modest through the pipe. Flooding occurred because the pipe runs through a localized low spot where it has little cover. A parallel bypass pipe was installed around the low spot.

Figure 7-10
Profile View: Capacity Assessment Simulation



Hydraulic software packages that are used to evaluate natural drainage systems, such as HEC-RAS, can also produce useful profile plots. Floodplain analysis tools, such as HEC-GeoRAS, can extend the water surface profile simulations across the flood plain to map the simulated areas of inundation for various storm magnitudes.

The preceding graphics show how model simulation results for large areas can be reported for a single time step or for worst-case conditions. Sometimes, it is also very useful to demonstrate hydraulic conditions or summarize facility operations for specific locations over a long time period. This approach illustrates the frequency and magnitude of capacity problems at a specific location. For example, Figure 7-11 shows all the simulated overflow events for a particular location over a 30 year simulation period. From this information, the project team can infer the size of flood controls required to meet different levels of service at this location. This type of graphic can communicate capacity assessment results effectively to both modeling team members and non-technical staff.

Figure 7-12 shows the maximum detention pond depth for each year in a 50-year continuous simulation for existing and future development levels. The type of “before and after” comparative graphics effectively and simply summarize the capacity implications of land use changes.

Figure 7-11
Overflow Example Derived From Long-Term Continuous Simulation

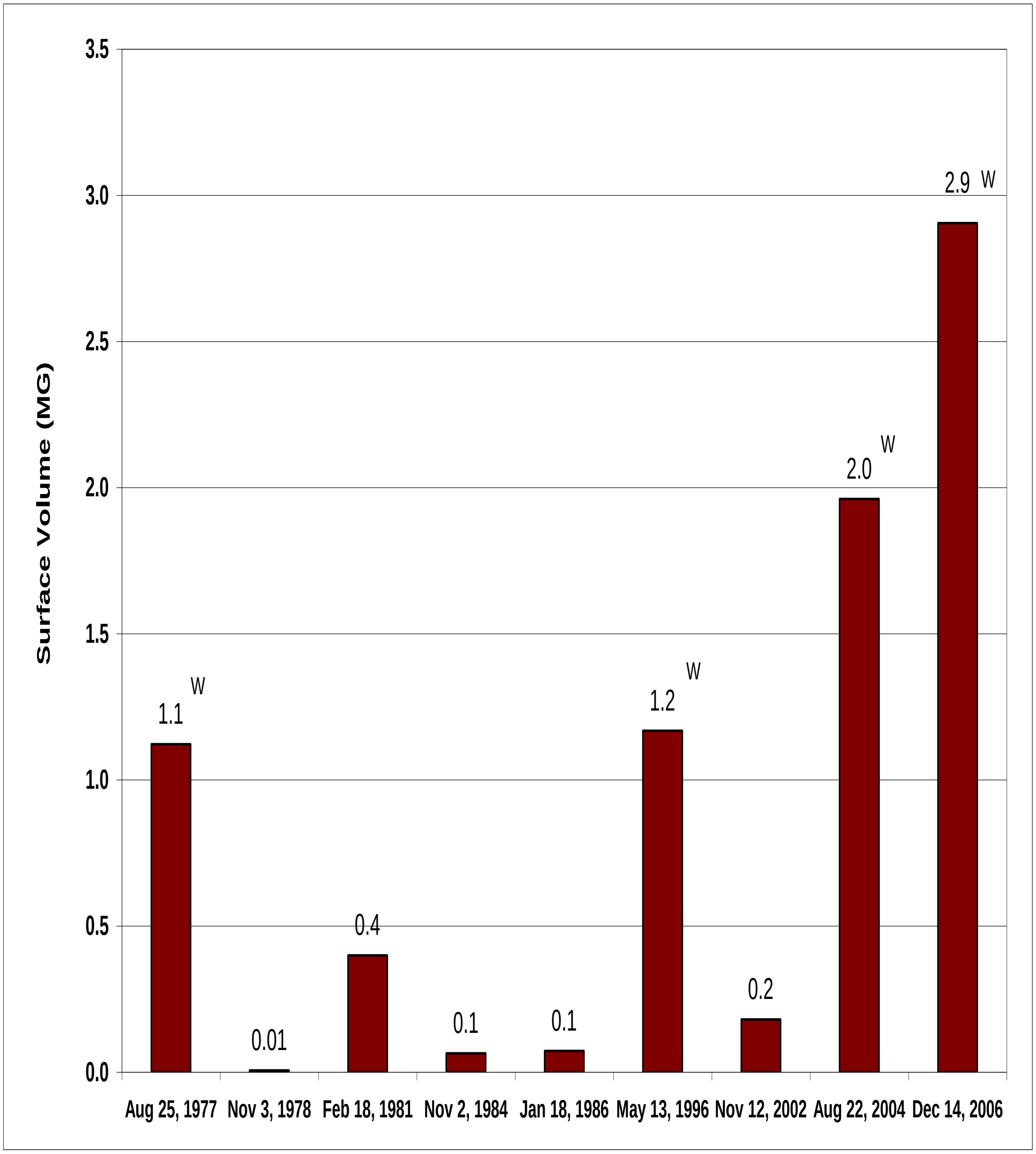
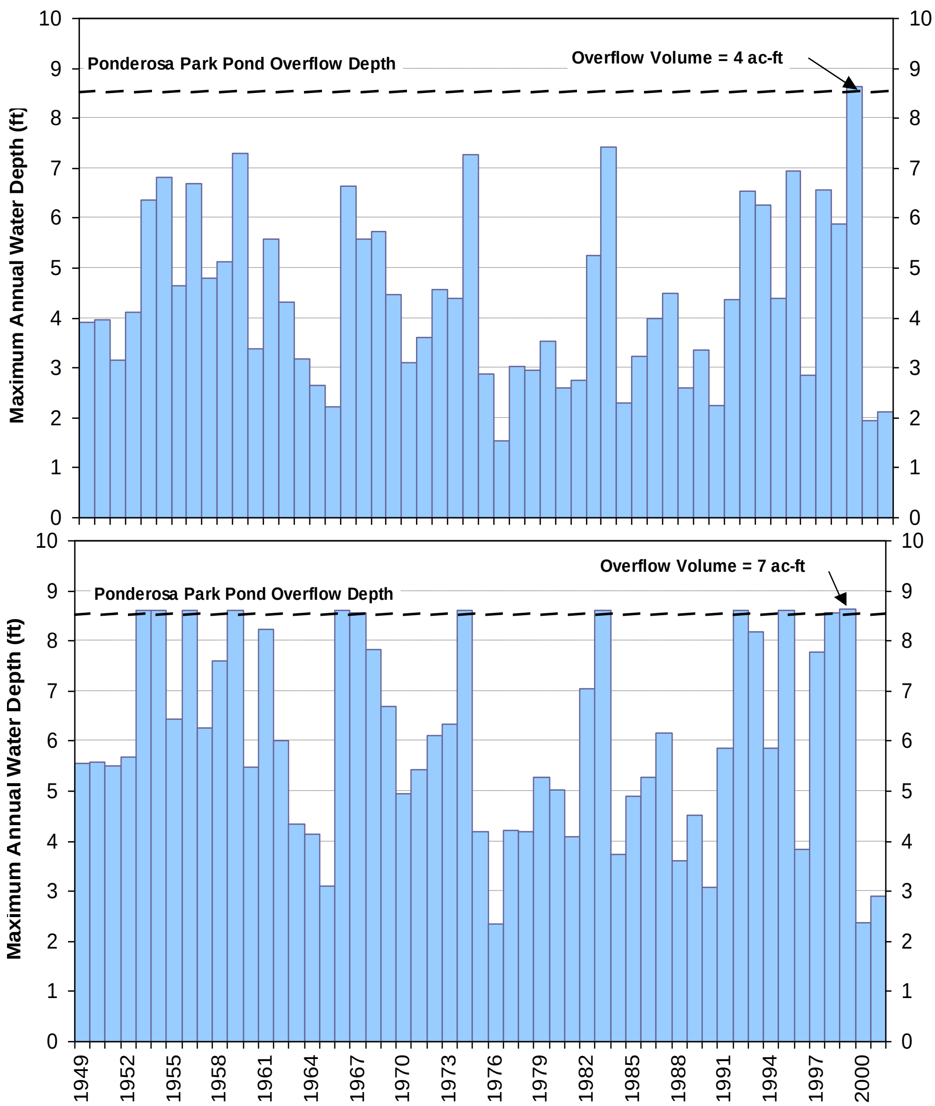
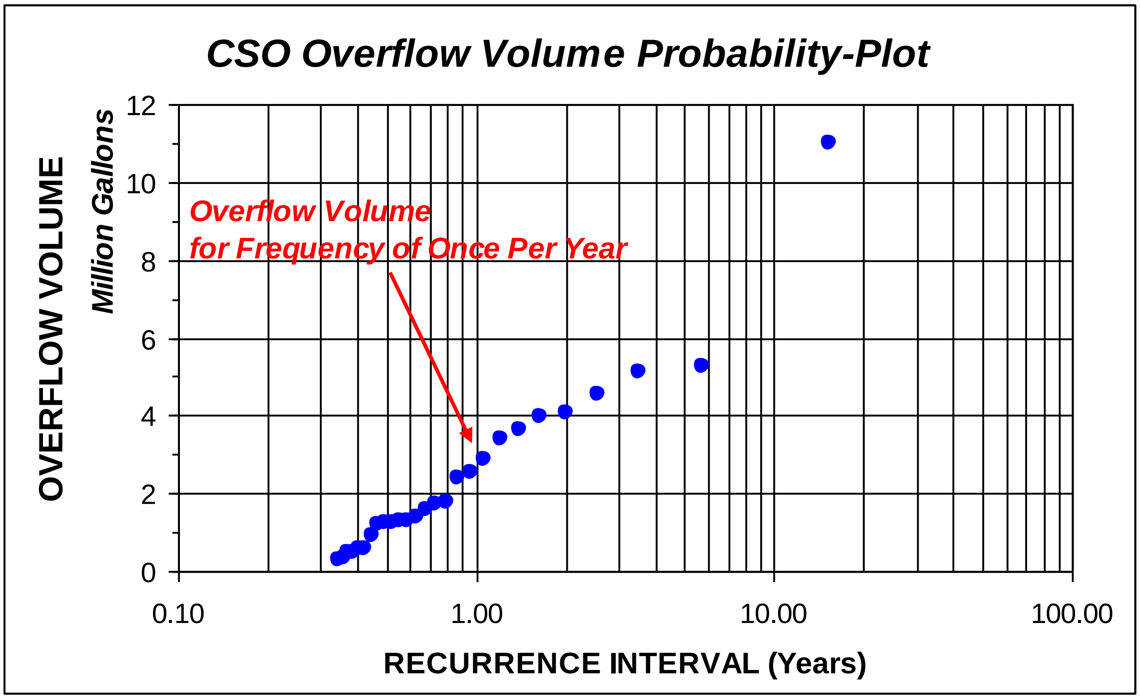


Figure 7-12
Simulated Maximum Annual Detention Pond Depth for Existing and Future Land Use



The peak flow and/or overflow volume frequency and magnitude for long-term simulations can be summarized by using statistical methods that estimate the recurrence interval for specific events in the continuous model output time series (Figure 7-13). By matching the peak flow and/or overflow volume to SPU's level of service for that element of its D/WW system, the modeling team can compute appropriate design flow or overflow control volume. Then, the project team can formulate appropriate alternatives to control problems identified in the capacity assessment.

Figure 7-13
Frequency-Volume Distribution of CSO Events



The modeling team should produce peak flow or overflow volume versus recurrence interval curves as follows:

1. Parse the long-term model simulation output time series into a group of discrete events, using either the peak annual series or the partial duration series.
2. Compute the plotting position for each event in the series. This will generate a recurrence interval for each event (e.g. largest event = 35-year recurrence; second largest event = 14-year recurrence).
3. Plot the peak flows or overflow volumes against the recurrence intervals and estimate the value that most closely matches SPU's desired level of service. Alternately, the modeling team can fit the plotting data to a theoretical distribution, such as the commonly used Log Pearson Type III or Extreme Value Type I (Gumbel) distribution.

7.11.3 Developing Upgrade Options or Alternative Analysis

The capacity assessment should identify any areas that do not meet the required level of service. After identifying the problem locations, the project team should delve more deeply into the modeling results to determine the underlying causes of the capacity constraints, if possible. The team should then develop alternative strategies to eliminate D/WW conveyance problems. Potential solutions often fall into these general categories:

1. Conveyance Improvements: Installing larger conveyance or parallel conveyance infrastructure

2. Flows Attenuation: Installing detention basins or storage tanks to skim off peak flows until the downstream system has available capacity
3. Demand Management: Flows to key facilities are reduced by installing flow diversions or by reducing the amount of runoff and/or inflow and/or infiltration

When developing a model to address the alternative strategies, alternative facilities should be represented as closely as possible within the model. Storage facilities should include explicit outlet structures and logic that determines when the tank is allowed to drain. Including an appropriate level of detail will allow the team to evaluate operational alternatives that optimize the storage system including minor adjustments to facility operations to optimize the system. For green stormwater infrastructure alternatives, refer to section 7.12 for evaluation.

Long-term simulations are helpful in evaluating complex alternatives, particular those that include flow storage. Continuous simulations of storage facilities will track the water level in the tank between storms. This is very important for simulating long-duration storms typical during a Seattle winter. If the model runtimes are very long, the modeling team should consider creating a synthetic inflow time series that condenses the long-term model inflow time series by stripping out low flow conditions. For example, a synthetic inflow file would contain all flow time series resulting from large storms (e.g. storms surpassing a 3-month threshold) and sufficient inter-storm periods (i.e. non-flood or CSO generating flows) to allow the system to reset. The modeling team must make sure critical antecedent conditions for water quality projects are maintained in the process.

7.11.4 Characterizing Future Conditions

The future performance of a D/WW system is largely related to the change in flow demands and condition of the conveyance infrastructure (or natural system) over time. Future conditions are usually evaluated over a specific horizon, such as 20 years, in connection with comprehensive planning. The following items are most likely to change over a planning period:

- **Flow Projections:** Base flows and storm flows could change over the planning horizon as a result of new development and redevelopment projects. These projects would add new wastewater customers and impervious areas that affect site runoff. The project team should get population and development forecasts. They should also consider how revisions to the City of Seattle Stormwater Manual could affect total runoff.
- **Infrastructure Condition:** Sanitary and combined sewer infrastructure generally degrades over time and allows larger quantities of I/I to enter the system. These impacts may be counteracted with an aggressive sewer inspection and rehabilitation program. Some municipalities assume a 7% increase in I/I flow per decade. Others assume no I/I increase while committing to maintain the quality of conveyance infrastructure. The change in future performance for conveyance elements in natural systems are more difficult to quantify. However, for creek systems, the project team could assess whether a stream reach is aggrading or degrading when assessing the future probability of flooding.
- **Capital Improvement Projects:** The existing conditions model should be updated to incorporate any future infrastructure upgrades. The preferred alternative model created during the alternatives analysis should include capital improvements. When evaluating the impacts of capital improvements on future conditions, the project team should be

mindful of any planned upgrades outside the immediate project area that could influence the project area (e.g. removing downstream bottlenecks to lower model boundary conditions; removing upstream bottlenecks to increase inflows to the model).

- **Programmatic Efforts:** Future flow projections should incorporate the expected results of any programmatic initiatives at SPU. The increased use of low-flow water fixtures and efforts to reduce water consumption could reduce per capita wastewater generation. Low-impact landscaping methods, downspout disconnection, infiltration galleries, permeable pavement, bioretention, rain gardens, and rain barrels have the potential to reduce the effective imperviousness of the city's watersheds.
- **Changes in Service Area:** The SPU drainage and wastewater system is largely built out. Only small pockets of unsewered area remain within the City limits. Any changes to the SPU service area are likely to occur for one of the following reasons:
  - A redevelopment project results in a change to the location of flow discharge from the project site (i.e. site flow discharges to a different pipe).
  - Annexation areas are added to the City of Seattle.

Redevelopment projects that modify the site discharge location can be easily incorporated into an existing model by adjusting the D/WW system network. Any changes in the network should also be reported to SPU GIS so that the appropriate drainage and wastewater databases are updated.

Annexation areas are more complex to evaluate. When a potential annexation is under consideration, SPU Engineering staff may be asked to assess the potential impacts of extending drainage and wastewater services into the annexation area. Providing service into a new area can potentially have dual impacts: 1) contributions from the annexation area could stress the capacity of existing infrastructure and 2) the City could be required to upgrade annexation area infrastructure to meet the City's level of service guidelines.

The contributions from the potential annexation area should be computed by using the base flow and I/I flow projection methods for sanitary flows and/or hydrologic methods for drainage flows. In many cases, a modeling team can estimate contributions from a potential annexation area without creating a detailed model of the conveyance network. Computing flows basin-by-basin is usually sufficient. These new inflow sources should be incorporated into existing City of Seattle system wide model to assess specific capacity impacts, if any.

Assessing the level of service provided by existing facilities in a potential annexation area is more complex. This effort would require compilation of a full infrastructure data inventory and any flow monitoring and/or operations records to build an H/H model. The project team would need to determine if the existing information was sufficient for model calibration, validation and for performing a capacity assessment. The process could involve additional data collection.

7.12 GSI MODELING

Green stormwater infrastructure (GSI) projects use small and distributed stormwater management practices to control flow into drainage or combined sewer systems. Initial modeling setup and calibration are anticipated to follow the procedures identified within this manual. Modeling methods and procedures for evaluating impacts of GSI BMPS within CIP project alternatives evaluation require focused procedures for GSI elements because:

- GSI projects are comprised of numerous facilities distributed across a basin rather than centralized facilities (such as storage facilities).
- Modeling approaches must be able to simulate the natural physical processes (e.g. filtration, infiltration) of GSI practices.

For information on GSI modeling, refer to Green Stormwater Infrastructure Modeling Methods guidelines in **Appendix 7H**.

7.13 CLIMATE CHANGE

The modeling team must consult with DWW LOB representative and Engineering, Investigations & Modeling (EI&M) section within Systems Assessment, Operations & Monitoring (SAO&M) of DWW LOB to plan approach for climate change.

For more information on sea level rise due to climate change, refer to City of Seattle Stormwater Manual Appendix F.

7.14 RESOURCES

Documents

- MGS Engineering Services, Inc. (2004). Description of the Seattle Public Utilities' Precipitation Measurement and Data Collection System (Technical Memorandum)
- SPU's Sewer and Drainage GIS Physical Database Design (version October 25, 2000)
- Wastewater Planning Users Group (WaPUG). Code of Practice for the Hydraulic Modeling of Sewer Systems. United Kingdom, 2002. www.wapug.org.uk
- Washington State Department of Ecology. Criteria for Sewage Works Design, 2008
- American Society of Civil Engineers. Gravity Sanitary Sewer Design and Construction. ASCE Manuals and Reports on Engineering Practice No. 60. ASCE, 1982.
- Merrill, S., Lukas, A, et al. Reducing Peak Rainfall-Derived Infiltration/Inflow Rates – Case Studies and Protocol (WERF 99-WWF-8). Water Environment Research Foundation, 1999.
- Rawls, W. J., Brakensiek, D. L., and Miller, N., Journal of Hydraulic Engineering, ASCE Volume 109, No. 1, 1983

Websites

- Seattle Public Utilities GIS
- City of Seattle Stormwater Manual
- Seattle Public Utilities CSO Program
- King County Wastewater Treatment Division
- NOAA National Weather Service Forecast Office
- WSU AgWeatherNet

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