Supplemental Documentation Volume 4

Hydrologic and Hydraulic Modeling

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V4.1 BASELINE MODEL DEVELOPMENT

Development of the baseline model for the LTCPU was significantly important. The baseline model is the foundation from which all alternatives were built and resulting data compared against. Accurately simulating the current hydrologic conditions and hydraulic infrastructure was essential to producing valuable and reliable results. The methods and input data utilized in order to create the baseline model with respect to the hydrology, hydraulics and the calibration and validation, are discussed in the subsections following. Detailed analyses of the Water Pollution Control Plants (WPCP) for the Southeast, Northeast and the Southwest Drainage Districts (SEDD, NEDD and SWDD) were performed to determine the WPCP treatment capacities, pumping rates, WPCP piping and head works. The WPCPs exiting conditions were used for each of the baseline models. The maximum treatment rate for the SEDD WPCP (SEWPCP), NEDD WPCP (NEWPCP) and SWDD WPCP (SWWPCP) used for the baseline models were 280 mgd, 435 mgd and 480 mg respectively. Please refer to the supplemental documentation volume numbers 6, 7 and 8 for stress testing of the WPCPs.

v4.1.1 Hydrologic Model Development

The baseline model was developed using the EPA-SWMM4 software. The RUNOFF module in SWMM4 requires the input of several physical parameters to determine the rainfall-runoff response from modeled combined-sewer and separate sanitary sewer subcatchments.

- Subcatchment area
- Subcatchment width (used to determine overland flow length)
- Percent directly connected impervious area (effective impervious area)
- Subcatchment ground slope
- Manning's roughness coefficient for both pervious and impervious areas
- Depression storage for both pervious and impervious areas (initial abstraction)
- Soil infiltration parameters
- Rainfall dependent inflow and infiltration parameters
- Baseflow ranges
- Precipitation input data
- Evaporation input data

Each parameter is discussed in greater detail in the following subsections.

Subcatchment Area

Natural stormwater drainage subcatchment area can be determined by constructing drainage divides on topographic maps and is dependent upon the detail of the topographic information. Combined sewer subcatchment area is determined based on detailed sewer plans within the City and the topographic maps needed to determine surface drainage to sewer inlet locations. The delineation of sanitary sewer subcatchment area inside the City is based on detailed sewer plans. Subcatchment areas outside of the City were delineated with a tool in ArcView using USGS 30-meter DEMs to identify drainage divides. Subcatchment areas within the City were defined based on detailed sewer plats. The RUNOFF model represents all stormwater runoff subcatchments as rectangular areas defined by the subcatchment width parameter. RUNOFF simulates surface runoff from drainage areas using three "planes" of overland flow. One plane represents all impervious surfaces directly connected to the hydraulic system and include initial abstraction or surface detention storage (puddles, cracks, etc.) which do not permit immediate runoff. A second plane represents all pervious areas and impervious areas not directly connected to the hydraulic system. The third plane is defined as the fraction of the directly connected area that provides no detention storage and thus produces runoff immediately. The runoff from the drainage area is the sum of the flow off the three planes. The complete hydrologic model consists of 2098 subcatchments representing the entire PWD service area.

Subcatchment Width

The width of the subcatchment is the physical width of overland flow. Since real subcatchments are not rectangular with properties of symmetry and uniformity, it is necessary to adopt other procedures to obtain the width for more general cases. This is important because if the slope and roughness are fixed, the width can be used to alter the hydrograph shape. For the PWD combined sewer system (CSS) models, width was initially taken to be double the square root of the subcatchment's area and later treated as a calibration parameter.

Directly Connected Impervious Area (DCIA)

The percent imperviousness of a subcatchment is a parameter that can be reasonably estimated from aerial photos or land use maps. However, not all of the impervious area is directly connected to the drainage system, or is "effective" when simulating a hydrologic response from these areas. For example, if a rooftop drains onto a pervious area, this should not be included as directly connected. The total percent impervious area was used as the initial effective impervious area and then reduced during the calibration process to best simulate the observed hydrologic response over a range of precipitation events.

In generating initial estimates of gross impervious cover the following method was employed. For all areas within the City of Philadelphia, GIS coverage of impervious areas derived from 2004 orthodigital photographs was used. This coverage delineates all land use in the City into pervious or "natural surfaces," comprised of lawns, parks, marshes, golf courses, wooded areas and cemeteries, as well as several different classifications of impervious areas. Impervious land uses were broken down into the following types:

- Alleys
- Buildings
- Building Centers
- Concrete/Asphalt Slabs/Patios
- Ditches (Asphalt or Concrete)
- Driveways
- Institutions
- Lakes
- Medians
- Parking
- Pedestrian Bridges
- Parking Islands
- Pond
- Pools
- Railroad Ballast
- Railroad Bridges
- Reservoirs
- Rivers
- Sidewalks
- Shoulders
- Streams
- Tanks
- Travel Bridges
- Travelways

For each RUNOFF subcatchment, the area of these land uses was summed to generate a total impervious area. Impervious areas in each subcatchment were summed and divided by the total area in order to get the first estimate of subcatchment "effective" impervious area.

For residential land uses outside of the City for areas contributing stormwater and do not have any flow monitoring data , population densities were developed using 2000 census and block area data. Two equations, Stankowski (1974) and Manning et al (1987) that use population density as the independent variable to define percent impervious were selected for this modeling application. The equations are expressed as:

Stankowski, $I = 0.117D^{0.792 - 0.039 \log D}$

Manning, $I = 10v4.95\text{-}81.27(0.974)^{PD}$

Where I = Percent impervious
PD = Population density per acre
D = Population density per square mile

Percent impervious estimates for each census block were calculated with both equations. For population densities less than 35 persons per acre (ppa), the Stankowski and Manning equations were averaged. However, only the Manning estimate was used when the population density was greater than 35 ppa. This distinction was made because the Stankowski equation is less accurate for high density urban areas.

Each land use classification was assigned a percent impervious cover based upon regional averages and/or population density. If monitoring data was available for the shed monitoring data was used to reach upon a percent impervious number.

Slope

The subcatchment slope should reflect the average slope along the pathway of overland flow to inlet locations. For a simple geometry, the calculation is the elevation difference divided by the length of flow. Subcatchments containing highway ramps underwent a more technical slope procurement procedure in order to prevent distortion of the slopes due to the grade of the ramp.
ArcGIS was utilized in order to calculate the slopes for these subcatchments. Generally, the topographic lines representing the ramps were removed and new raster layers were created. From the new raster layers, slopes were calculated using the remaining topographic lines.

Manning's Roughness Coefficient

Manning's roughness values must be estimated for both pervious and impervious overland flow. Manning's roughness for impervious surfaces was set to 0.013 and for pervious surfaces to 0.1 or 0.05. Roughness is an empirical value and may be treated as a calibration parameter when necessary.

Depression Storage

Depression (retention) storage is the rainfall abstraction volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas. In RUNOFF, every subcatchment is divided into three subareas: Pervious area with depression storage, impervious area with zero depression storage and impervious area with depression storage. By default, the model assumes 25% of the impervious area has zero depression storage. This default value was not altered in the LTCPU model setup. In the model, water stored as depression storage on pervious areas is subject to infiltration and evaporation. Water stored in depression storage on impervious areas is depleted only by evaporation therefore replenishment of the retention storage typically takes longer when compared to pervious areas. Depression storage is an empirical value and may be treated as a calibration parameter when necessary. Following calibration, impervious depression storage was set as 0.02, 0.05, or 0.1 inches and pervious depression storage was set at 0.15 or 0.1 inches. These values were selected based on literature review and past modeling experience with the City's existing hydrologic models of combined sewer areas.

Pervious Area Infiltration Parameters

The rate of infiltration is a function of soil properties in the drainage area, ground slopes and ground cover. RUNOFF computes the rate of infiltration into the soil using either the Horton method or Green-Ampt method, as selected by the user. In each method, a set of infiltration parameters is required to represent soil properties. For the LTCPU hydrologic model, the Green-Ampt method is used to estimate infiltration rates. The Green-Ampt equation for infiltration has physically based parameters that can be estimated based on soil characteristics. The soil parameters used in this method are:

- Average Capillary Suction
- Saturated Hydraulic Conductivity
- Initial Moisture Deficit

Soil information for the Philadelphia watersheds was obtained at the beginning of the PWD CSO program in the early 1990s. Information was obtained from the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), which is responsible for collecting, storing, maintaining and distributing soil survey information for privately owned lands in the United States. Initial infiltration parameters were assigned to each subshed based on soil texture classification. Saturated hydraulic conductivity was treated as a calibration parameter.

Flow Routing

Subcatchments are divided into three subareas that represent impervious area with and without depression (detention) storage and pervious area with depression (detention) storage. Overland flow is generated from each of the three subareas by approximating them as non-linear reservoirs. When inputs to the non-linear reservoir (rainfall/snowmelt) exceed the outputs (evapotransporation & infiltration) for any of the three subareas, outflow is generated using the Manning's equation.
The kinematic wave approximation is used as the basic flow routing algorithm across the three planes of flow. This approximation assumes the friction slope is equal to the ground slope of the plane. This flow routing algorithm is applied sequentially to the impervious (with detention) plane, the pervious plane and the impervious (without detention) plane.

Hydrologic routing techniques that apply the kinematic wave approximation algorithms are used to route the overland flow through the pipe, culvert, channel and lake networks as required.

Rainfall Dependent Inflow and Infiltration (RDI/I)

Rainfall-Dependent Inflow and Infiltration (RDI/I) into sanitary sewer systems has long been recognized as a major source of operating problems, causing poor performance of many sewer systems. The three major components of wet-weather wastewater flow into a sanitary system - base wastewater flow (BWF), groundwater infiltration (GWI) and RDI/I are illustrated in Figure v4.1.1 below.

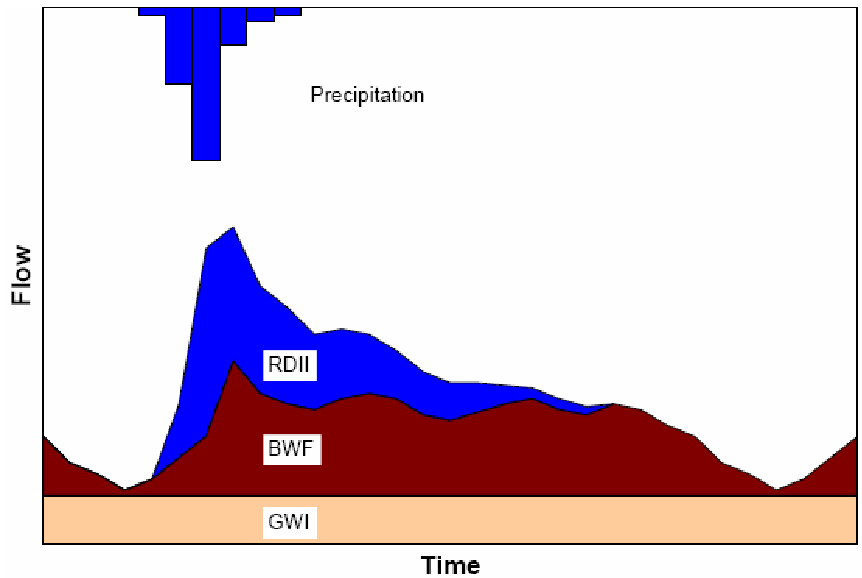


Figure v4.1.1 Three components of wet-weather wastewater flow (EPA, 2007)

The RTK hydrograph generation method to define the RDI/I response for the sanitary sewer systems has two steps. The first step is to define RTK parameters in response to one unit of rainfall over one unit of time. Three unit hydrographs are typically used because the shape of an RDI/I hydrograph is too complex to be well represented by a single unit hydrograph. The RDI/I hydrograph can be generated using less than three sets of R, T and K. However, experience indicates that it often requires three unit hydrographs to adequately represent the various ways that precipitation becomes RDI/I. The first triangle represents the most rapidly responding inflow component and has a T of one to three hours. The second triangle includes both rainfall-derived inflow and infiltration and has a longer T value. The third triangle includes infiltration that may continue long after the storm event has ended and has the longest T value. In this first step, the RTK parameters for each of the three triangles are defined for each unit rainfall over one unit time frame. The sum of the R values for each of the three unit hydrographs (i.e., R1, R2 and R3) must equal the total R value for the rainfall event. Figure v4.1.2 below depicts a summation of three unit hydrographs into a total RDI/I hydrograph in response to one unit rainfall over one unit time frame. This unit hydrograph is described by the following parameters:

- R - The fraction of rainfall volume that enters the sewer system and equals the volume under the hydrograph
- T - The time from the onset of rainfall to the peak of the unit hydrograph in hours

- K - The ratio of time to recession of the unit hydrograph to the time to peak
- A - Sewered area
- P - Rainfall depth over one unit time
- Volume - Volume of RDI/I in unit hydrograph
- Qp - Peak flow of unit hydrograph

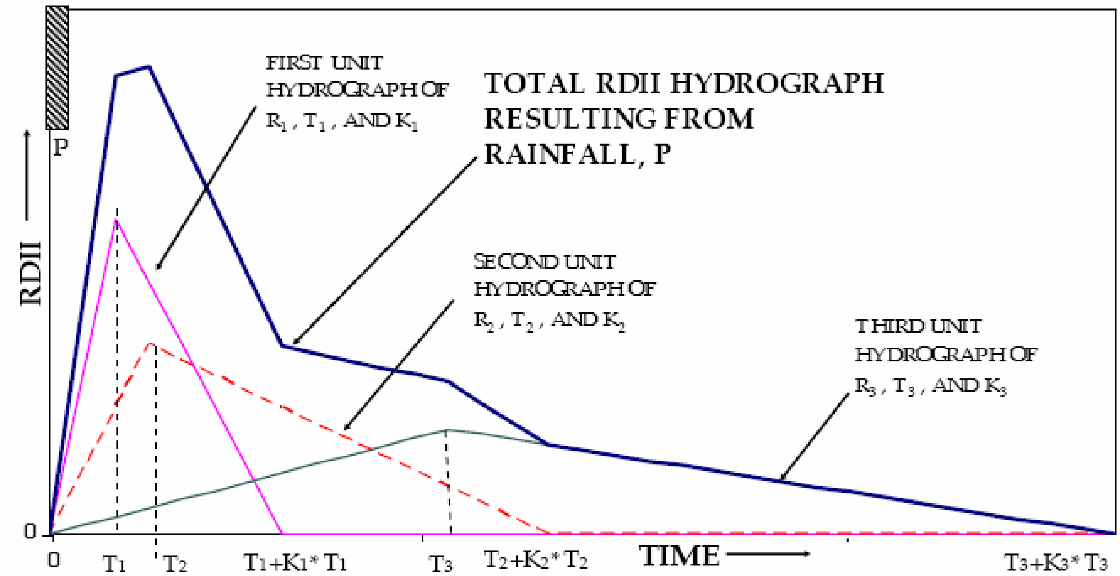


Figure v4.1.2 Summation of three unit hydrographs (EPA, 2007)

RDI/I analysis was performed on sewersheds with separate sanitary sewers contributing to the combined sewer system. This analysis was performed to more accurately account for the excess rain water entering the sanitary sewers through a combination of inflows from directly connected downspout pipes, sump pumps, foundation drains, manhole openings and large defects along streams and infiltration through saturated soils and an elevated groundwater table into small leaks in degraded sewer pipes and joints. RDI/I decrease the available sewer capacity available to convey stormwater runoff through the trunks and into the interceptor. The RUNOFF module uses three sets of unit hydrographs defined by R, T and K values to represent the shape of the RDI/I hydrograph. Please refer to the Model Calibration and Validation section for details on RDI/I parameters used in the model.

Evaporation Input Data

Evaporation data is required by the model in the form of average monthly evaporation rates, although finer time increments may be input as negative flows by creating an evaporation time series. Evaporation data usually can be obtained from the NWS or from other pan measurements.

Limited long-term daily evaporation data exists for the Philadelphia area. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. Average monthly evaporation (inches per day) are used for all SWMM4 models determined from New Castle County, Delaware recorded daily evaporation data from 1956 through 1994.

Temperature Input Data and Snowmelt

Temperature time series input data can be used to run a snowmelt routine in SWMM4. The average snowfall volume and frequency for Philadelphia, however, does not account for a significant portion of the average annual precipitation. Therefore, the snowmelt routine was not employed. Instead several snowfall events that occurred during the year 2005, which was selected as the basis for the typical year, were modified to represent snowmelt time series based on PWD non-heated raingage observations, Philadelphia International Airport observed hourly snowfall, daily snow cover and daily maximum temperatures.

The RUNOFF hydrographs are saved in binary format for input to the EXTRAN block of SWMM to perform hydraulic routing in sewer and/or open channel system networks.

v4.1.2 Hydraulic Model Development

This section describes the process by which the Hydraulic models of PWD's combined and separate sanitary sewer system has been developed. The hydraulic model was developed using the EXtended TRANsport (EXTRAN) block of the U.S. EPA's Storm Water Management Model Version 4 (SWMM4; Huber and Dickinson, 1998). The Tier 2 models were developed by refining and adding hydraulic elements to the Tier 1 EXTRAN models. The Tier 1 EXTRAN models in combination with the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM; Hydrologic Engineering Center, 1977) were used to represent the hydraulic elements and evaluate alternatives for the 1997 LTCP (for more information refer to System Hydraulic Characterization June 27 1995).

The EXTRAN module of SWMM is used to analyze and simulate flow through the combined sewer system. EXTRAN uses a link-node description of sewer and open channel systems facilitating the physical prototype and the mathematical solution of the gradually-varied unsteady flow (St.Venant) equations, which forms the mathematical basis of the model. The links transmit the flow from node to node. The primary dependant variable for the links is discharge. The primary dependant variable for the nodes is head, which is assumed to be changing in time, but constant throughout any one node. To reiterate the list of elements required by SWMM to calculate the flow in the sewers, values for the following variables are necessary:

- Pipes
- Junctions
- Orifices
- Weirs
- Pumps
- Outfalls

The information required to accurately represent these elements within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings. Individual descriptions of how these elements are modeled follow below.

Pipes

Pipes are the conveyance element in the EXTRAN models. For the EXTRAN model the following pipe information is required.

- Pipe name.
- Pipe's upstream and downstream nodes
- Initial flow in the pipe.
- Shape of the pipe (the pipes that can be modeled circular, rectangular, horseshoe, egg, basket handle, trapezoidal channel, parabolic/power function channel, irregular (natural) channel, horizontal ellipse, vertical ellipse, arch, bridge).
- Pipe dimensions (depth, width, area, side slopes, power function parameters and natural section data).
- Offsets of pipes (if the pipe does not begin or end at the invert (bottom) of the upstream or downstream node an offset value describing the difference from the bottom of the upstream and or downstream node and the pipe bottom needs was provided).
- Manning's roughness coefficient, the manning's coefficient is usually the property of the pipe's building material. The manning's coefficient may be changed in to account for additional sediment depositions and unintended restriction like rubble in the pipe.
- Minor losses (entrance, exit and additional losses).
- Sediment depth in the pipe.

Very short pipes can cause mathematical instabilities in the model. Short pipes are converted to equivalent pipes that have lengths that will satisfy the courant condition while maintaining the same head loss as the original (this is achieved the manipulating the Manning's roughness coefficient). The following procedures were followed to represent the pipes in the model. Pipes in a branch with the same shape, slope and make material may have been combined together to hydraulically represent one single equivalent pipe. If necessary, minor expansions may have been ignored if occurring between two pipes of the same diameter, slope and same material so as to combine all the section in to one longer stable section. If the need arose to combine pipes of varying capacities, slopes, shapes and make material; the diameter of the resulting section was set equal to the most constricting pipe in the series and the manning's coefficient was adjusted so as an equivalent flow was conveyed and head loss was maintained as the original section. Some of the offsets when the pipe invert is not the same as the node invert may cause mathematical instabilities; if such instabilities were seen a minimal storage was provided to remove the instability and if the problem still persisted the last resort was to change the slope of the pipe so as the pipe invert matched the water surface at the node if the problem still persists then pipe slope was changed to set pipe invert equal to the node invert (when ever the slope of the pipe is changed the manning's coefficient should be changed so that the flow and head loss would match the original section of the pipe). Broadly the pipes in the waste water collectors system can be separated in to 4 categories; trunk sewers that collect sanitary and wet weather flow from house lateral branches, street inlets etc. and bring them to the regulators, the dry weather flow pipes that take all of the dry weather sanitary and a percentage of the wet weather flow to interceptor, the interceptors that collect the flows from the dry weather flow pipes and deliver the flows to downstream interceptor system or the WPCPs, the wet weather overflow pipes that convey the flow that cannot be accommodated in either the dry weather pipes or interceptor to the receiving water.

Junctions (Nodes)

Nodes are the connection points for the pipes. The primary dependant variable for the nodes is head, which is assumed to be changing in time, but constant throughout any one node. Flow and volume continuity are calculated at nodes in the EXTRAN model. The nodes in the model can be actual manholes and places where there is pipe size and or slope and or pipe material change or there is a hydraulic control structure in the pipe network. Nodes at locations where a manhole does not exist were simulated in a manner so as they do not flood out. The following information is required to model a node in EXTRAN:

- Junction Name
- Ground elevation/Top of the node, for manholes with bolted down covers an increase in top of the node higher than the actual top may be provided to mimic the excess head built up that can be handled by the node before the mode floods.
- Invert elevation (Bottom of the junction)
- Constant inflow if any in to the junction, this can be the average dry weather flow that the junction receives from the surrounding sewer sheds (More description about the baseflow distribution can be found in the hydrology section above).
- Initial water depth in the junction above invert
- Junction location data (x,y) for spatial location.
- Junction volume calculation parameters (either default plan surface area (12.6 ft^2) or fixed plan surface area other than default value or power function defining the plan surface areas or set of depth and plan surface area pairs). The volume other than default volumes is required for junctions that mimic storage elements or non-standard manholes or chambers.

In sections where multiple pipes may be combined in to one longer section it is important to keep track of the node that has the lowest top elevation. If flooding occurs in a section of pipes, the hydraulic grade line will be controlled by the node with the lowest top elevation. In these situations the node with the lowest top elevation should be correctly represented so as to get the correct hydraulic representation. The information required to accurately represent the junctions within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Orifices

Two types of orifices are used within the LTCPU model, static and variable. Static orifice opening sizes remain constant over the length of a simulation. The variable orifices opening cross-section is controlled by either a set of time closure rules or head level in a control node (this can be any node in the model). EXTRAN internally converts the orifices to equivalent pipes of 200 feet and a manning's coefficient representing the same head loss as the orifice. Following are the parameters necessary to define an orifice in EXTRAN:

- Upstream and Downstream nodes

- Type of orifice (side outlet circular, bottom outlet circular, side outlet rectangular, bottom outlet rectangular, time-history side outlet circular orifice with gated controls, time-history bottom outlet circular orifice with gated controls, time-history side outlet rectangular orifice with gated controls, time-history bottom outlet rectangular orifice with gated controls, side outlet circular orifice with timed closure with gated controls, bottom outlet circular orifice with timed closure with gated controls, side outlet rectangular orifice with timed closure with gated controls, bottom outlet rectangular orifice with timed closure with gated controls, side outlet circular orifice with head-dependent gated control, bottom outlet circular orifice with head-dependent gated control, side outlet rectangular orifice with head-dependent gated control, bottom outlet rectangular orifice with head-dependent gated control)
- Orifice coefficient
- Orifice offset from the bottom of the junction invert.
- Dimensions of the orifice (depth, width area).
- Orifice control information (time history data for timed closure orifices, node from which the controls are based on, orifice completely open cross-sectional area, orifice completely closed cross-sectional area, rate of orifice closure and flow direction restrictions.)

If the static orifice causes mathematical instabilities then they may be modeled in the EXTRAN model as equivalent pipes that mimic the same flow characteristics and head loss as the orifice. The information required to accurately represent the orifices within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Weirs

For all EXTRAN models used in LTCPU analyses all weirs were modeled as equivalent pipes with the head loss and flow characteristics simulating those that would be produced from a weir. The information required to model a weir is:

- Upstream and downstream junctions for the weir.
- Type of weir
- Weir length and height to the crest of the weir
- Weir coefficient.

The information required to accurately represent the weirs within the model were obtained from the return plans (as-built), contract drawings and drainage plats available through the Engineering Records Viewer (ERV) developed by the City of Philadelphia. Values which did not match the drawings were modified to bring them current with plan drawings.

Pumps

Pumps in EXTRAN are modeled to lift the flows to a higher head at a pre-specified rate. Pumps can be offline pumps that pump flow based on the volume in the pumped junction. The pump curve is defined by three pump rates and three corresponding pump volumes measured at the pumped junction. The pump rates remain constant between each volume in the pumped junction. Another type of pump is the inline pump where the pump rate depends on the head level in the pumped junction. Three sets of head level and respective pump rates are provided with the pump rate remaining constant between each head level. EXTRAN allows simulation of a three-point head discharge pump. The pumping rate depends on the water level difference between the pumped junction and the discharge junction. A set of differential head and pump rate pairings is provided and the pump rate varies linearly between each head and pump rate pair. The fourth type of pump that can be modeled is the variable speed inline pump. In this type of pump the pump rate is based on the depth in the pumped junction. Pumping rate varies linearly between input depth in the pumped junction and the pump rate pairs. Lastly, a lift station type pump may be simulated. This pump type more realistically simulates the operation of a typical pump station. The pump rates are provided for each of the pumps and each one turns on at a given depth and stays on until the depth goes below the "pump-off" depth. Pump station and WPCP data, wet well depths and corresponding pumping rates were studied to determine the type of pump and curves used for the EXTRAN model. For all the models used in the LTCPU analysis the variable speed inline pump mentioned above was used. To model a pump the following information is required:

- Pump Type
- Pumped junction name
- Pump discharge junction name
- Pairs of pumped junction depth and corresponding pump rates
- Volume of wet well (for the offline pump)
- Pump on and off water levels in the pumped junction.

The information required to accurately represent the pumps within the model were obtained from either pump station monitoring data or pump manufacturer's specification sheets.

Outfalls

Outfalls are the discharge points in the EXTRAN models. The outfalls can either have a boundary condition that the head has to overcome for outflow to occur or the outfalls can be free outfalls without any boundary conditions. For most of the sections in the EXTRAN model where the outfalls are in the tidal sections of the rivers (Schuylkill and Delaware) the outfalls have boundary conditions equal to the mean tide (-4.89 ft). For the non-tidal sections in the model the outfalls do not usually have outfall boundary conditions. For special conditions like the gravity flow into the WPCPs, where the plant boundary had to be overcome to reach the WPCP, the appropriate boundary conditions are applied. Another special condition is the computer controlled outflows where the outflow only occurs once a predetermined head has been reached and the appropriate head boundary conditions are applied.

To model the outfall in EXTRAN the following information was needed:

- Name of the outfall
- Boundary condition to be applied.

Regulators

Regulators are structures in the CSS that prevent flow from going to the receiving waters in dry weather and control the flow that reaches the WPCPs in wet weather. Significant differences in design approaches and philosophies can be observed from system to system. The various types of regulators include weir diversions into side or bottom orifices, float-controlled gates, tipping-plate gates, vortex drop shafts, leaping weirs, motor-operated sluice gates and a number of other configurations. A brief description of the modeling approaches for the types of regulators used for the LTCPU analyses is mentioned below. The PWD system includes a variety of regulator types. A regulator's function is to divert all the dry weather and part of the wet weather flow (e.g. storm flow) into a dry weather outlet pipe (DWO) that feeds the interceptor pipes, delivering the flows to the WPCPs. Any excess wet weather flow that can not be accommodated in the DWO goes in the storm over flow pipe (SWO) and overflows in to the receiving water by way of an outfall. There are 5 types of common regulators simulated in the EXTRAN models:

- Slot regulators
- Sluice gate regulator
- Water hydraulic
- Computer controlled
- Brown and Brown regulators (B&B)

Other than the above listed regulators, two types of additional structures are used for storm relief:

- Dams
- Side overflow weirs
- Tide Gates

Slots

The slot-type regulators divert dry weather flow into the DWO conduit through an orifice constructed at the bottom of the combined trunk sewer. During storms, the wet weather flow can exceed the capacity of the orifice and/or the DWO and rise above the orifice and flow over a dam (where static dam are constructed to enhance the DWO capacity) to a SWO and onto the receiving water. Adjustable plates are utilized in some instances to allow for changes in the diverted flows. At a minimum, this orifice opening is sufficiently large to convey dry weather flow plus a certain percentage of the storm flow. In some locations, static dams are constructed to work in conjunction with the slot in order to enhance the capture of both dry and wet-weather flow. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow into the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the slot opening) and if the flow from the regulating chamber does not pass through tide gates, then the section representing a dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber to the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions simulate the opening above the dam).

Sluice gates regulators

Sluice gates located in the regulating chambers manage flow to the DWO by controlling the size of the opening from the trunk sewer. Typically, this type of regulator consists of a dam constructed in the invert of the trunk sewer downstream of the sluice gate opening. The dam diverts flow into the regulator chamber under dry weather conditions. During storms, the sluice gate may be lowered to a predetermined height and the tide gate (if present) on the SWO is opened. When flows return to normal dry weather conditions, the sluice gate returns to the fully opened position and the tide gate is closed. The sluice gate may be operated manually or automatically either by computer controls or based on water hydraulics. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow in to the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the sluice gate opening) if the DWO opening is static. If the flow in to the DWO passes through an automated opening that change based on levels in a control node then the opening is modeled as a variable orifice with controls mimicking the actual sluice gate controls. If the flow from the regulating chamber does not pass through tide gates, then the section representing dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber to the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Water Hydraulic Control

There were regulators in the CSS originally designed to operate under City-water hydraulic control. These systems no longer operate in that mode, but now function as static dams. The regulator gates are fixed in the full open position and the tide gates are fixed in a fully closed position. CSOs occur when the water level in the trunk exceeds the top of the tide gates. In their current operating mode, these structures create a large (or near optimum) amount of storage in the trunk sewer during wet weather. This condition minimizes overflows to the receiving waters. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and the flow into the DWO from the regulating chamber is modeled as a fixed orifice (orifice dimensions equal the sluice gate opening). Flow from the regulating chamber does not pass through tide gates, so the section leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section).

Computer controlled

Computer controlled regulators use level monitors and Programmable Logic Controllers (PLCs) to locally regulate the opening and closing of the regulator and tide gates to achieve in-system storage. This is accomplished through the monitoring of the trunk sewer water level relative to a storage set point. During wet-weather flow, the trunk sewer water level will rise above the dam elevation and flow will begin to store behind the gate. When the set point depth is reached, the PLC lowers the regulator gate and actuates the tide gate to maintain the water level at the storage set point. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and if flow into the DWO passes through an opening that changes based on water levels in a control node, the orifice is modeled as a variable orifice with controls mimicking the actual gate controls based on control node depths. If the tide gate openings leading to the SWO are also based on levels then they are also represented as variable orifice(s) to mimic the actual controlled openings.

Brown and Brown regulators (B&B)

Brown and Brown regulators B&B regulators are float operated regulators with controls on the openings into the regulator chamber and the DWO. The opening at the gate from the combined sewer trunk to the regulating chamber is variable and is controlled by a float in the chamber. For this type of regulator structure in EXTRAN, the regulator is modeled as a node with inflow from trunk(s) and if the flow into the DWO passes through an opening that changes based on water levels in a control node then the orifice is modeled as a variable orifice with controls mimicking the actual orifice gate controls. If the orifice gate is chained open and acts as a static orifice then it is modeled as a static orifice. If the flow from the regulating chamber does not pass through tide gates, the section representing the dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber into the SWO passes through a tide gate, the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Dams

The static dams utilized in the storm relief systems operate in the same manner as the static dams in the combined sewer system. In the relief system, static dams divert wet weather flows from the trunk sewer into the storm relief sewer. For this type of structure in EXTRAN the structure is modeled as a node with inflow from trunk(s) and if the flow from the regulating chamber does not pass through tide gates, then the section representing the dam leading to the SWO is modeled as a weir (weir dimensions are made to represent the dam section). If the flow from the regulating chamber into the SWO passes through a tide gate then the dam section leading to the SWO is modeled as an orifice (orifice dimensions are set to represent the opening above the dam).

Side Overflow Weirs (SOW)

SOWs operate in a similar manner to dam-type regulators except SOWs are constructed on the side of the trunk sewer, parallel to direction of flow. When the hydraulic grade line in the trunk sewer exceeds the weir crest elevation, the storm flow spills laterally over the top of the weir into the relief sewer and ultimately into the receiving water. With the weir crest constructed parallel rather than perpendicular to the direction of flow, the hydraulic capacities in the trunk are not restricted due to downstream control. In a few isolated cases, the side-discharge control function is accomplished through a conduit rather than a weir. In these cases, while the sewer may be circular, baskethandle or another standard sewer shape, the geometry of the flow to the discharge is otherwise identical to the SOW. For this type of structure in EXTRAN the structure is modeled as a node with inflow from trunk(s) and the SOW is modeled as a weir with an offset and an opening that represent the SOW dimensions and offset.

Tide gates

Tide gates are one-way gates that allow the flow to go to the receiving water but prevent the backwater from the receiving water body to enter the combined sewer system. Tide gates are installed in combined sewer systems to prevent back-flooding of the combined sewer system by high tides or high stages in the receiving waters. This back-flooding can cause flooding of regulator structures and introduce the receiving water to the interceptor system. In combined systems, tide gates are installed in the outfall sewer just beyond the regulator or between the regulator and the receiving water. Tide gates can be differentiated into two categories: (1) vertical tide gates; and (2) horizontal tide gates.

Vertical tide gates are hinged at the top and designed to permit discharge with a small differential head on the upstream side of the gate and to close tightly with a small differential head on the downstream side of the gate. Vertical tide gates can be further classified depending on the material used for their flap: (1) Cast iron; (2) pontoon; and (3) timber. Cast iron gates are comprised of solid iron while pontoon gates are fabricated of layered sheet metal which forms air cells in the gate, increasing its buoyancy. Generally, cast iron gates are used for smaller sizes and timber or pontoon gates for larger sizes. Sluice gates are also present in the PWD sewer system. These are classified as horizontal tide gates. Opening and closing of horizontal tide gates is governed by a predetermined water level in either the regulating chamber or combined trunk sewer. Sluice gates are generally comprised of cast iron. The tide gates are represented in the EXTRAN model as one-way equivalent pipes, the flow from which can only flow in the downstream direction.

v4.1.3 Model Simplification

Once all the information is compiled into the model the models are simulated and error checks performed to find mathematical and implementation problems. The models were put through a thorough Quality Assurance procedure. The EXTRAN model gets inflow information from the preceding hydrologic and or hydraulic model runs. After creating the model, it was simplified by reducing the amount of nodes and pipes within the network. The goal of the simplification process was to increase the efficiency by decreasing run-time, while keeping the integrity of the model results. A simplification process was completed to increase the computational speed of the model, effectively decreasing the model run-time. The simplification process followed the steps outlined below:

- Increase the minimum length of the pipes for all feasible situations to 1000 feet.
- Most branches shorter than 1000 feet were identified and eliminated.
- All pipes in a branch with the same shape and slope were combined.
- Expansions were ignored if occurring between two pipes of the same diameter.
- Branches having pipes of varying capacities and shapes and not having a series of similar pipe sizes to combine to a length of 1000 feet were combined regardless and the diameter was set equal to the most constricting pipe in the series.
- If slopes were changed to meet the 1000 foot pipe length requirement, the Manning's coefficient was adjusted accordingly.
- If baseflow existed at a node to be eliminated, the baseflow was transferred to the downstream node if less than 500 feet from the eliminated node, otherwise it was loaded to the upstream node.
- Equivalent pipes were avoided where possible to conserve volumes.

The resulting simplified model allowed for a larger time step (20 seconds) to be used without violating the Courant conditions and, thus, decreasing the computational burden of the model. Continuous simulations were performed using the RUNOFF and EXTRAN models and the results from the simulations were directly or indirectly used to evaluate effects of various alternatives for LTCPU.

v4.1.4 Model Calibration / Validation

Development of the SWMM model for the LTCPU was followed by a calibration and optimization of the parameters for both modules. During the calibration of any model, it should not be expected that simulated results will match perfectly the measured data, since the measured data is subjected to some degree of error, while the model is an approximation of the system hydrology and hydraulics. Therefore, the measured data must be thoroughly reviewed and any limitations must be identified before adjusting calibration parameters. Note that the model calibration is accomplished by finding the best comparison between simulated and measured runoff characteristics over a range of storm events.

Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and measured flow and volume. The variables selected to adjust or calibrate were parameters that typically cannot be measured accurately (e.g., percent impervious, soil infiltration parameters, etc) and which have the greatest affect on the accuracy of the results. The calibration parameters were prioritized according to their influence on the model results, which can vary from one drainage system to another and on several model simulations (sensitivity analysis) on the PWD LTCP.
For the hydrologic calibration, the following data was assessed:

- Precipitation Data
- CSS Trunk Monitor Data
- DCIA Calibration
- RTK Distribution

For the hydraulic validation, the following elements were considered:

- WPCP Inflow and Pumping Data
- Validation Results

Simulations were performed using different model settings and compared using a combination of quantitative and qualitative measures. These combinations are detailed in Table v4.1.1 below with the characteristics for each specific presentation outlined next to each measure.

v4.1.5 Hydrologic Model Calibration

Calibration of the hydrologic model was an iterative process by which RUNOFF module parameters were changed, within acceptable ranges based on available data, from initial estimated values to ones that quantitatively provide the best match between modeled results and observed data.

Table v4.1.1 Details and characteristics of the measures to define the "goodness-of-fit" for calibration and validation results.

Event Volume		
Measure	**Type**	**Basis**
slope of regression line, scatter plot of simulated vs. observed data	Quantitative	A slope equal to 1 represents equality between simulated and observed event volumes. transformation for use in performance spreadsheet: absolute value of (1 – slope) A lower number is better.
probability value for t-test of slope equal to 1, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: slope is not significantly different from 1 alternative hypothesis: slope is significantly different from 1 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
intercept of regression line, scatter plot of simulated vs. observed data	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
probability value for t-test of intercept equal to 0, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: intercept is not significantly different from zero alternative hypothesis: intercept is significantly different from zero Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
r-squared value about equal-fit line, scatter plot of simulated vs. observed data	Quantitative	measures scatter transformation for use in performance spreadsheet: none A higher number is better.
slope of regression line, double mass plot of cumulative simulated and observed data over time	Quantitative	A slope equal to 1 represents equality between simulated and observed event volumes. transformation for use in performance spreadsheet: absolute value of (1 - slope) A lower number is better.
intercept of regression line, double mass plot of cumulative simulated and observed data over time	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
simulated and observed cumulative frequency distributions of data, small events	Qualitative	*Small events are defined as those where rainfall volume does not exceed depression/interception storage, and no runoff takes place. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.
simulated and observed cumulative frequency distributions of data, medium events	Qualitative	*Medium events are defined as those where runoff occurs from impervious cover, but not from pervious cover. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.
simulated and observed cumulative frequency distributions of data, large events	Qualitative	*Large events are defined as those where runoff occurs from pervious cover. This distinction is left to the best judgment of the person reviewing the graph. A rating of L or H indicates that more calibration is required.* L: simulated event volumes are lower than observed event volumes M: simulated event volumes are approximately equal to observed event volumes H: simulated event volumes are higher than observed event volumes transformation for use in performance spreadsheet: L=H=1; M=2 A higher number is better.

Event Peak Flow		
Measure	**Type**	**Basis**
slope of regression line, scatter plot of simulated vs. observed data	Quantitative	A slope equal to 1 represents equality between simulated and observed peak flows. transformation for use in performance spreadsheet: absolute value of (1 - slope) A lower number is better.
probability value for t-test of slope equal to 1, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: slope is not significantly different from 1 alternative hypothesis: slope is significantly different from 1 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
intercept of regression line, scatter plot of simulated vs. observed data	Quantitative	An intercept equal to 0 is ideal. transformation for use in performance spreadsheet: absolute value of intercept A lower number is better.
probability value for t-test of intercept equal to 0, scatter plot of simulated vs. observed data	Quantitative	null hypothesis: intercept is not significantly different from 0 alternative hypothesis: intercept is significantly different from 0 Reject the null hypothesis for small p-values. transformation for use in performance spreadsheet: none A higher number is better.
r-squared value about equal-fit line, scatter plot of simulated vs. observed data	Quantitative	measures scatter transformation for use in performance spreadsheet: none A higher number is better.

Time to Peak		
Measure	**Type**	**Basis**
time when event peak flow occurs, simulated and observed event time series plots	Qualitative	*The reviewer looks at all time series plots and makes a qualitative determination whether, on balance, simulated event peaks are different from observed event peaks. A rating of E or L indicates that more calibration is required.* E: simulated event peaks occur earlier than observed event peaks M: simulated event peaks occur at approximately the same time as observed event peaks L: simulated event peaks occur later than observed event peaks transformation for use in performance spreadsheet: E=L=1; M=2 A higher number is better.
volume under the recession limb, simulated and observed event time series plots	Qualitative	*The recession limb is defined as the portion of the event after the last peak. The reviewer looks at all time series plots and makes a qualitative determination whether, on balance, simulated volumes are different from observed volumes. A rating of L or H indicates that more calibration is required.* L: simulated recession limb volumes are lower than observed event volumes M: simulated recession limb volumes are approximately equal to observed event volumes H: simulated recession limb volumes are higher than observed event volume transformations for use in performance spreadsheet: L=H=1; M=2 A higher number is better.

Precipitation data

The main goal in acquiring precipitation data was to get the most detailed and consistent (temporally and spatially) data available for the periods in which hydraulic data were available for the Philadelphia CSS service area. It was determined after extensive review and QA assessment that the PWD 24-raingage network data required bias adjustment and normalization to provide the spatial and temporal consistency necessary for the calibration process. Details of the precipitation data analyses and adjustment procedures are presented in Supplemental Documentation 5: Precipitation Analysis.

The SWMM RUNOFF module requires assignment of an input rainfall time series for each stormwater runoff or sanitary sewer RDI/I basin in the model. Inverse distance-squared weighting is used to estimate rainfall in areas between rain gauges. A one-square-kilometer grid is imposed over the PWD service area. Next, a rainfall value for every time step is assigned to each grid element by inverse distance-squared weighting of the rainfall values from three nearby surrounding gages. Finally, the gridded precipitation values are area-weighted to provide average rainfall values for each individual sewershed in the model. In this manner, the bias adjusted 15-minute accumulated rainfall data for the PWD 24-raingage network is distributed to RUNOFF model basin areas using the Inverse Distance Weighted (IDW) method. Details of this distribution procedure may be found in Supplemental Documentation 5: Precipitation Analysis.

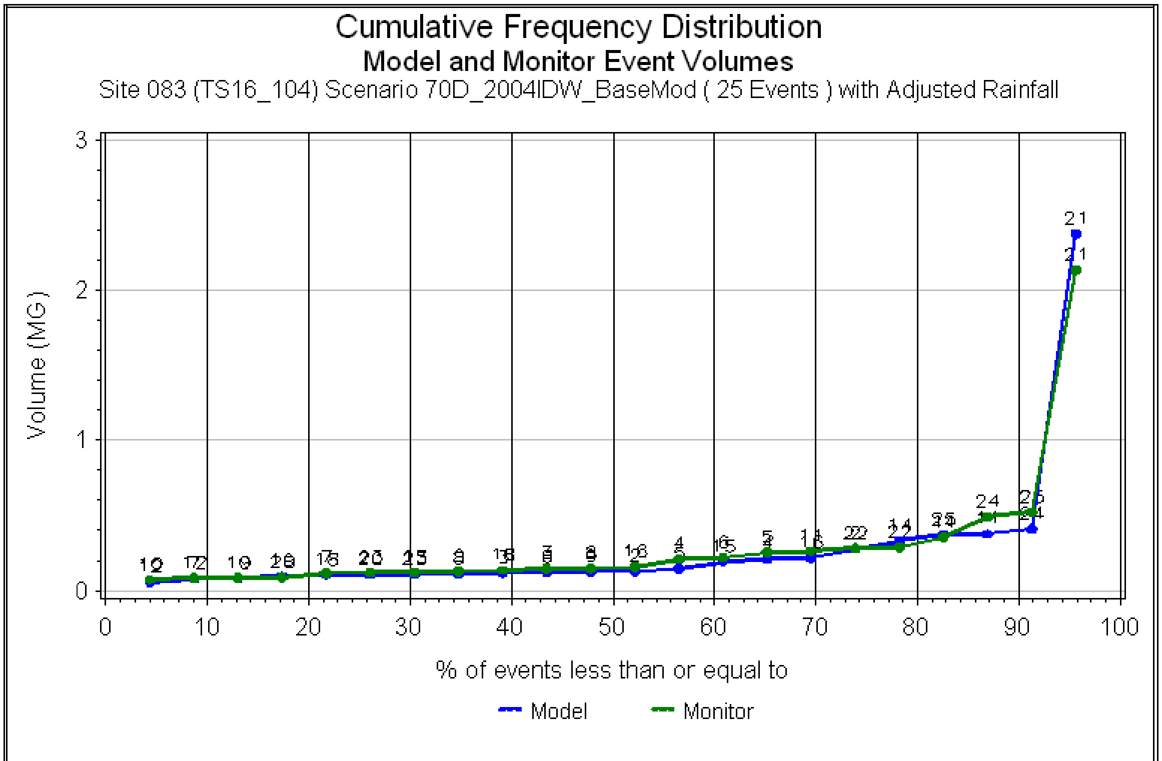
Combined Sewer System Trunk Monitor Data

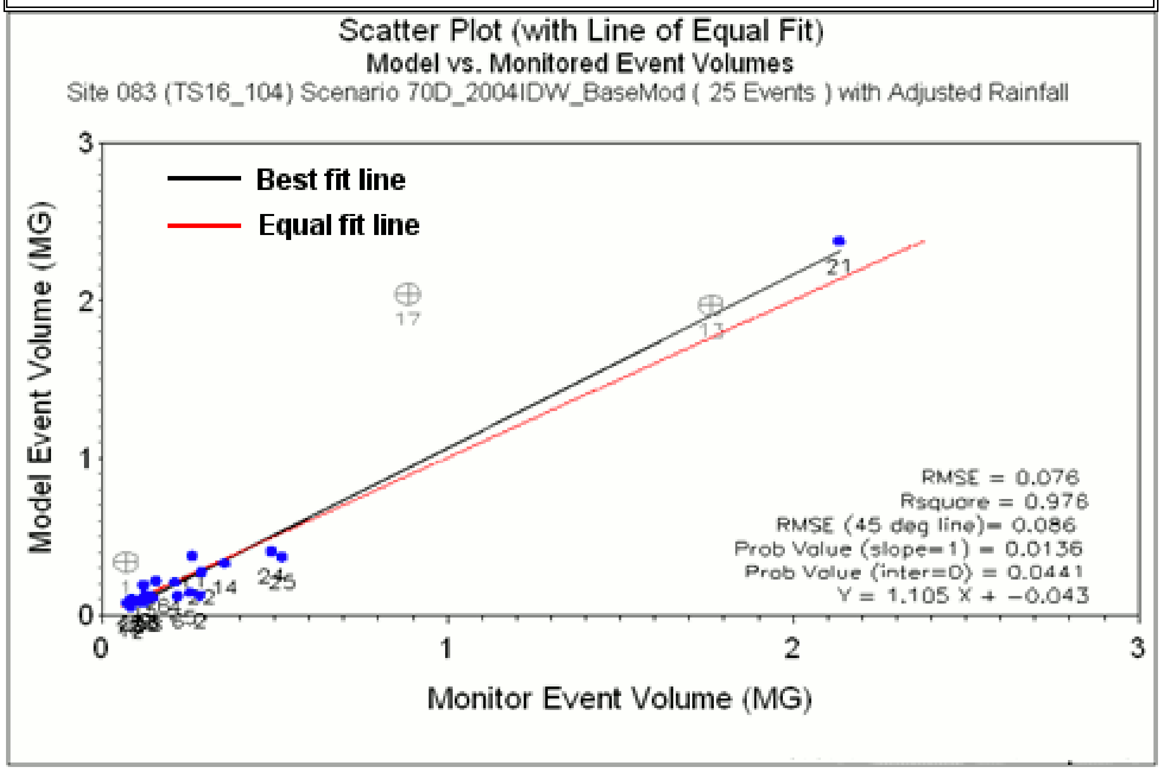
Flow data taken from flow monitors located in trunk sewers throughout the combined sewer area were analyzed and then used to adjust calibration parameters for the hydrologic models. There were six combined trunk sewer monitors having sufficient usable data to perform calibration analyses. These six flow monitors are presented in Table v4.1.2 below. Included in the table are the model pipe names of the monitor location, the area draining to the monitor, the calibration period and corresponding drainage districts.

Table v4.1.2 Trunk monitor calibration information.

Monitor	District	Pipe Name	Data Range	Drainage Area (ac)
79	SW	TS27-3308	1/1/2002-9/2/2002	4.33
83	SW	TS16-104	1/1/2004-12/31/2004	19.65
84	SW	TS13-108	1/13/2004-5/2/2006	25.11
85	SW	TC06-112	10/25/2002-7/28/2004	98.56
S42-130	SW	TR25-104	4/26/2006-9/19/06	73.05
D54-15	SE	TD54-604	5/26/2006-9/15/2006	167.19

Hydrograph decomposition was performed on the data from the above flow monitors to extract the wet weather portion. This flow was used to compare to the simulated model flow. To assess the goodness of fit of the model output to observed data a series of plots were created including scatter plots of event volumes, time to peak and peak flows, Cumulative Frequency Distributions (CFDs), Cumulative mass regression plots and timeseries plots for each event. A selection of result plots for monitor 83 is presented collectively as Figure v4.1.3 below. The r-squared, slope, intercept and the equal fit line from the scatter plots and the qualitative assessment of the timeseries plots were used to determine the level of fit for model output compared to observed data.


Cumulative Frequency Distribution
Model and Monitor Event Volumes
Site 083 (TS16_104) Scenario 70D_2004IDW_BaseMod (25 Events) with Adjusted Rainfall
Volume (MG)
% of events less than or equal to
Model
Monitor


Scatter Plot (with Line of Equal Fit)
Model vs. Monitored Event Volumes
Site 083 (TS16_104) Scenario 70D_2004IDW_BaseMod (25 Events) with Adjusted Rainfall
Best fit line
Equal fit line
Model Event Volume (MG)
Monitor Event Volume (MG)
RMSE = 0.076
Rsquare = 0.976
RMSE (45 deg line)= 0.086
Prob Value (slope=1) = 0.0136
Prob Value (inter=0) = 0.0441
Y = 1.105 X + -0.043

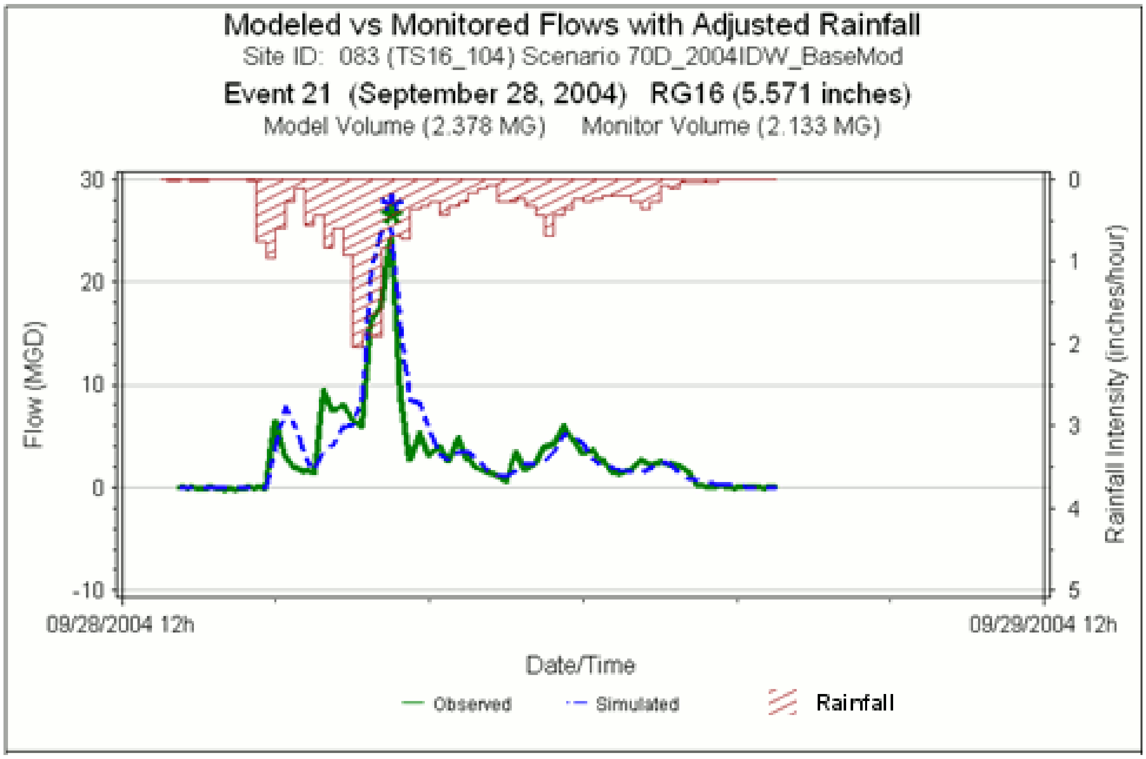


Figure v4.1.3 Result plots for Site 83 including the CFD, event volume scatter plot and the September 28, 2004 event timeseries plot.

The results for each model run were organized into a performance spreadsheet and model parameters that provided the best fit calibration scenario were chosen.

Parameters Adjusted

Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and measured flow and volume. The variables selected to adjust or calibrate were parameters that typically cannot be measured accurately (e.g., percent impervious, soil infiltration parameters, etc) and which have the greatest affect on the accuracy of the results. The calibration parameters were prioritized according to their influence on the model results, which can vary from one drainage system to another and on several model simulations (sensitivity analysis) on the PWD LTCP.

<u>Directly Connected Impervious Area (DCIA)</u>

For all sewersheds with monitored trunk sewers, directly connected impervious area (DCIA) in the best-fit model was lower than gross impervious cover derived from aerial photography. The ratio of DCIA to total gross impervious area ranged from 50% to 100%. Because the majority of sewersheds are unmonitored and the measurements themselves have uncertainty associated with them, it is reasonable to present this value as a range. Presented below are ranges associated with specific areas in the drainage district.

- 5 monitors in trunk sewers: Adjustments in the best-fit model range from 50% to 95% of gross impervious cover.

- Cobbs Creek watershed model: Adjustments were made watershed-wide based on USGS streamflow records. Adjustments were made in combined and separate areas and in areas inside and outside the City. This calibration process had a higher level of uncertainty than the trunk monitors. Adjustments ranged from 50% to 100% of total impervious cover.
- Tookany/Tacony-Frankford Creek watershed model: Adjustments were made watershed-wide based on USGS streamflow records. Adjustments were made in combined and separate areas and in areas inside and outside the City. This calibration process had a higher level of uncertainty than the trunk monitors. Adjustments ranged from 50% to 75% of total impervious cover.

Based on the histogram shown below (Figure v4.1.4), the mean and most common adjustment is 70% of DCIA. This value is used in the best-fit model, with the exception of monitored sheds. To account for the uncertainty that exists in the monitoring data a high and low range of DCIA were chosen for the LTCPU models. The high estimate for DCIA for the unmonitored shed was assumed to be 80 percent of the gross impervious and for the low estimate it was assumed as 60 percent of gross impervious. For the calibrated sheds an increment of 10 percent in calibrated DCIA was used to account for the high uncertainty estimate and a 10 percent decrease from the Calibrated DCIA was used to represent the low estimate of the uncertainty.

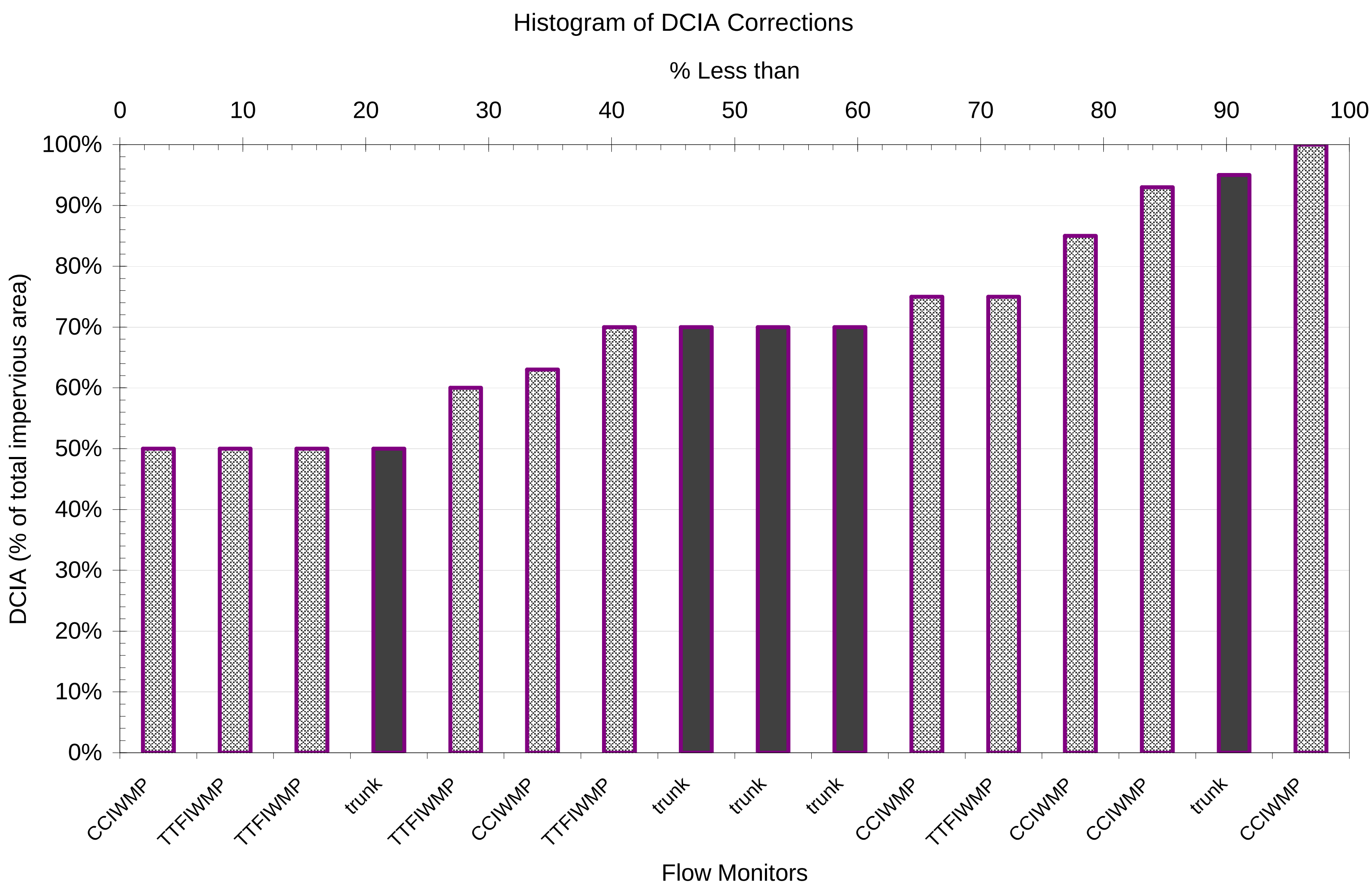


Figure v4.1.4 Histogram of resulting calibrated DCIA percentages of gross impervious area for available monitors within the drainage district.

RTK Distribution

The purpose of this task was to determine an acceptable average R-value range within the simplified SWMM model to represent rainfall dependent inflow and infiltration volumes (RDI/I) across all un-monitored separate sanitary sewer area. The existing RDI/I values from the 39 flow monitoring sites discussed previously were used in this process. The full range of R-Values showed no apparent correlation to population density, geographic location or size of monitored shed, therefore, the analysis included:

- Ranking of the 39 sites based on R-value.
- Creation of a histogram and cumulative frequency distribution plot.
- Upper (80 percentile) and lower (20 percentile) limit determination based on the central tendency about the median.

The resulting histogram is presented as Figure v4.1.5 below. The final median R-Value to represent the watershed area is 0.0401.

An in-depth RDI/I analysis was conducted for the city of Philadelphia to account for the contribution to the CSS within the LTCPU models. The first step in the process was data collection (described in section 2.1) and assessment. To define the RTK values for the city, a selection of flowmeter sites was made from the 39 sites available. Selection of the flowmeter sites was based on the quantity and quality of data existing at each site and of the 39, 13 provided a satisfactory amount of observed flow data. The selected flowmeter site ID, contributing area and the location (district) are shown below in Table v4.1.3.

Table v4.1.3 Sites chosen for full RTK analysis.

Site ID	Contributing Area (Acres)	Drainage District	Data Date Range
5	9361	NE	6/2000 to 9/2001
27	674	NE	8/1999 to 4/2000
29	656	NE	9/1999 to 10/1999
40	4557	SW	8/1999 to 9/2001
44	1986	NE	11/1999 to 4/2000
49	1784	SE	5/2000 to 8/2002
57	164	SW	6/2000 to 9/2001
70	276	NE	6/2000 to 9/2001
72	301	NE	3/2001 to 5/2005
75	179	NE	6/2001 to 7/2004
77	162	NE	9/2000 to 7/2002
95	3540	NE	6/2004 to 5/2006
96	12594	NE	6/2004 to 5/2006

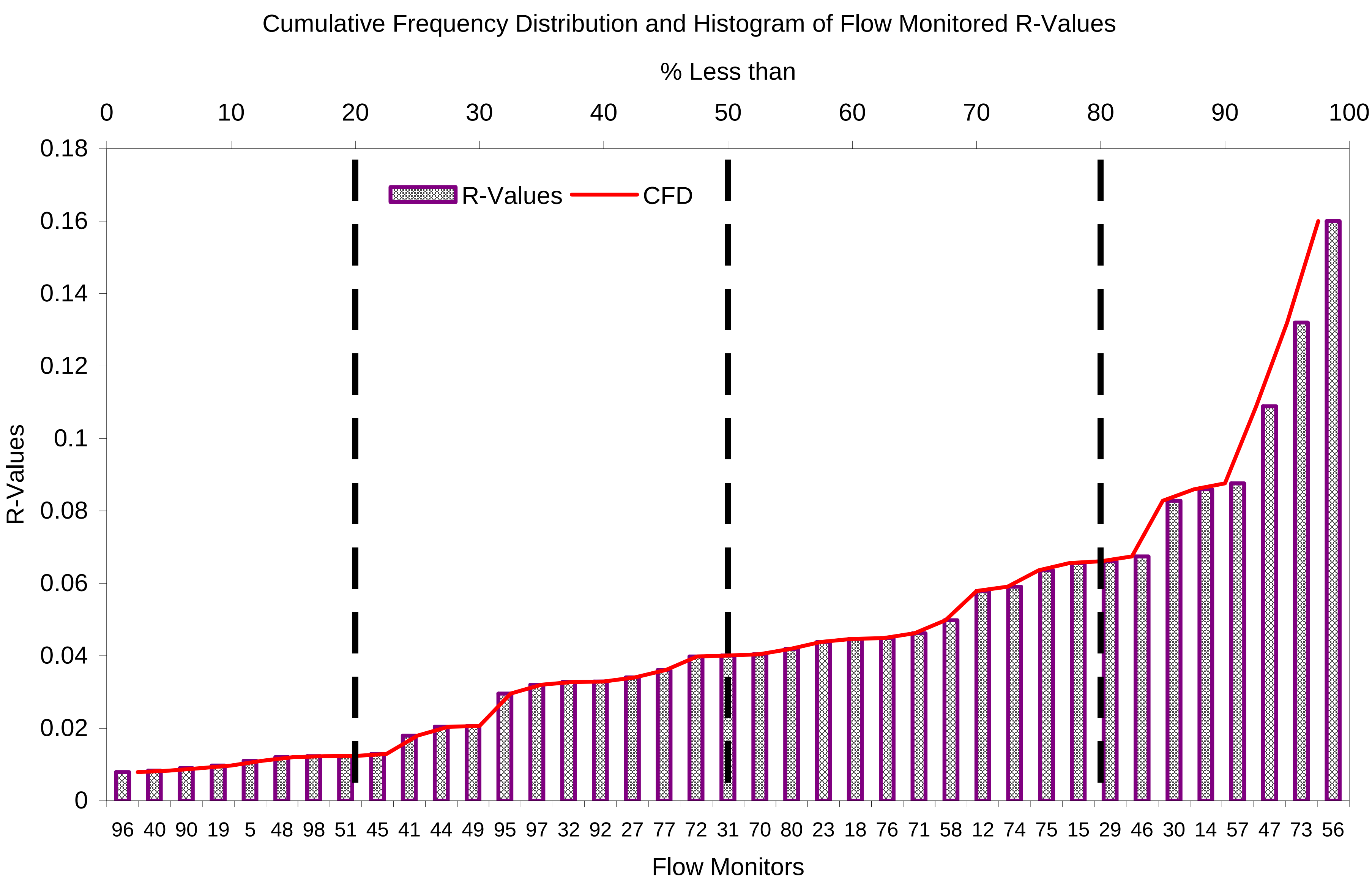


Figure v4.1.5 Histogram of resulting calibrated R-values for selected monitors within the drainage district.

1. Quality assurance procedure carried out on above selected sites. The raw flowmeter data was formatted and imported into a QA template. Data was checked for date/time inconsistencies, unusable data due to flowmeter malfunctions or missing data. Data was flagged at each timestep to identify data as good, missing, unusable or interpolated. Flags were used to help calculate statistical information on the data and to facilitate understanding of anomalous data in subsequent data processing steps (e.g., SHAPE analysis). If previous Quality checks had been done to older data sets, those data were re-evaluated and brought up to current quality standards
2. After quality assurance of the data, it was formatted and imported into CDM SHAPE software. Rain data from the Allflows.mdb database was generated specific to each flowmeter site (i.e., raingage ID and time frame). Within the SHAPE software, weekday and weekend dry-weather flow patterns were determined. Hydrograph decomposition was performed by adjusting groundwater points through the entire time frame of the data. During groundwater adjustment, wet-weather event boundaries were delineated. R-values and inflow and infiltration values for each flowmeter site were calculated and exported.
3. The exported data for all events were further assessed for anomalies (i.e., events affected by snow, holiday patterns or extreme events) that may skew analysis results. If events existed fulfilling any of these criterion, they were removed from the event list and were not included in subsequent analyses.

4. The R-Values (calculated for each event) are summarized to get average values for each month. The events are sorted based on month, year and then day. The average for each month was calculated two ways:
    i. The arithmetic average
    ii. The volume weighted average calculated using the I/I depth and rainfall depth for each event

   The method chosen to use in further analyses was determined by how well the data flowed from month to month (i.e., which showed smoother transitions)
5. Exported parameters from SHAPE and the calculated average R-values are inserted to a Microsoft EXCEL spreadsheet created to analyze the fast (RTK1), medium (RTK2) and slow (RTK3) response of rainfall dependent inflow and infiltration (RDII). The RDII volume from observed and simulated data is calculated and plotted for each event at each flowmeter site. Based on volume comparison, the R, T and K values are manipulated to produce a more closely matched comparison of volumes. Adjustment of RTK values followed these guidelines:

    i. Divide the R value exported from SHAPE analysis three ways (fast, medium and slow response R-values) for each month
    ii. For first run arbitrarily choose T and K values for one month
        a. The month with the most data was chosen
    iii. Run the program
        a. The resulting hydrograph produced by summing the three response hydrographs equals the total simulated RDII response
    iv. Adjust RTK values based on how well the simulated RDII response matches the observed RDII response
    v. Once the RTK values produce an acceptable match to the observed hydrograph, the RTK values are placed in another Microsoft EXCEL

spreadsheet to check the shape of each unit hydrograph corresponding to the fast, medium and slow responses

a. Adjustments are made (if necessary) to make transitions between the three phases smooth (i.e., without dips)

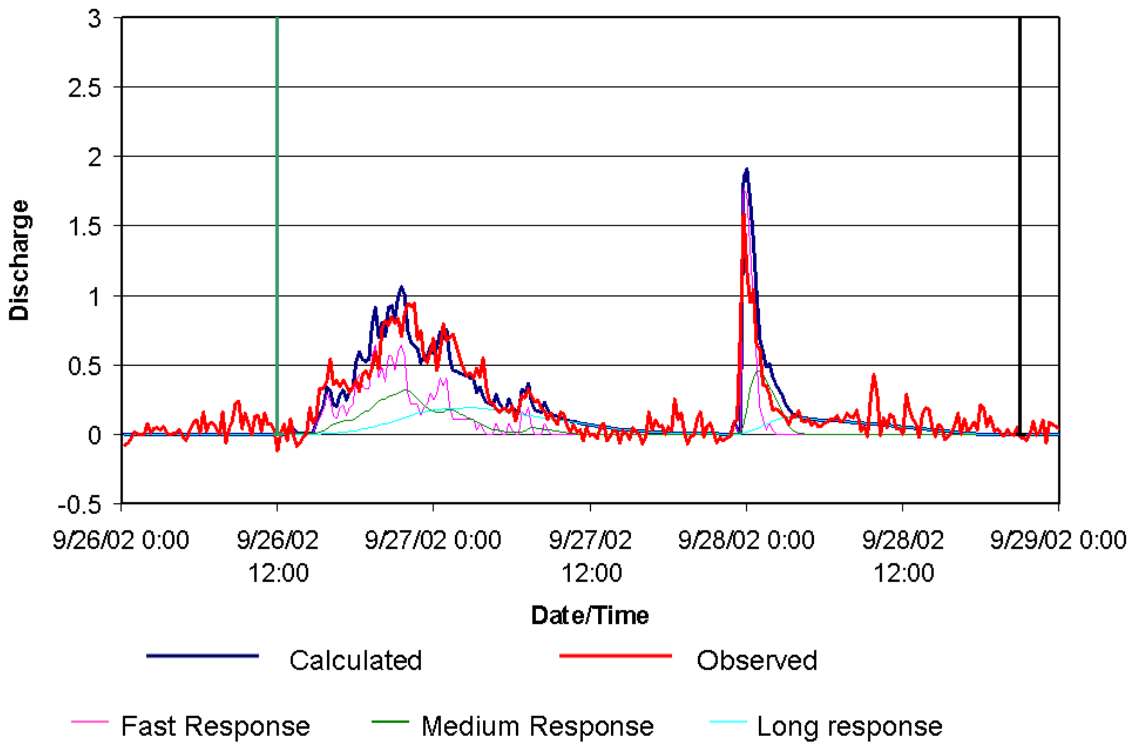
vi. Once adjusted (or fine-tuned), the TK values are applied to all other months.

vii. R-values are adjusted for each month to create matching hydrographs while the TK values remain static

Final values for RTK at each flowmeter site were distributed to all sheds contributing to that flowmeter in the simplified runoff master sheet

6. A second EXCEL spreadsheet was utilized to check the unit hydrographs resulting from the RTK values specific to each site. This was done to make certain the transitions between the response curves remained fluid, without disruption due to dips. If there are disruptions, the values are adjusted slightly and distributed to the remaining months. For the remaining months the TK values remain static, while the R-values are adjusted.
7. The R, T and K values from the last step were used for the RUNOFF simulation. Runoff results produced from SWMM were plotted with SAS for verification and observed versus simulated responses compared
   a. If hydrographs did not produce an acceptable match, refinement of the RTK parameter values was done and the data re-imported to the SWMM runoff input file
   b. The SWMM model was re-run and data plotted
   c. The process was repeated until an acceptable match was created

An example of an acceptable matching hydrograph and corresponding best-fit volume scatter plot are shown in Figure v4.1.6.



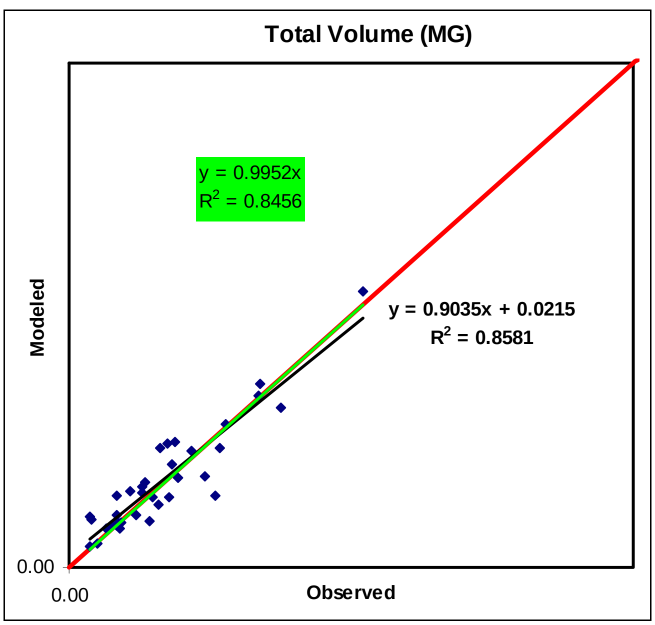


Figure v4.1.6 Examples of an Acceptable Observed to Simulated Data Hydrograph and Best-Fit Volume Scatter Plot Match from the RTK Template Analysis Spreadsheet Tool.

During this process, four sites were chosen as templates for the remaining 26 flowmeter sites and all remaining un-metered sanitary sewer shed loading points. Selection of the four sites to use as templates was based on flowmeter data consistency, accuracy and precision of observed hydrographs compared to estimated hydrographs. The size of the contributing area to the flowmeter was used as the criteria for distributing the templates to the un-metered sheds. Table v4.1.4 outlines the four sites selected as templates.

Table v4.1.4 Listing of the sites chosen as templates and the corresponding ranges of application.

Site ID	Contributing Area	Area Range to Apply
75	179	area < 300 acres
70	276	300 acres ≤ area ≤ 1000 acres
40	4557	1000 acres ≤ area ≤ 5000 acres
5	9361	area > 5000 acres

Distribution among un-metered sheds

The distribution of template RTK values to un-metered sheds was based on the contributing drainage area to each outlet node. The un-metered shed names were searched respective outlets identified. The contributing area to each outlet was totaled. Based on the total contributing area to each outlet, template IDs were assigned to each shed draining to that outlet. The template IDs associated RTK parameters to each shed. The RTK templates and boundary conditions are those outlined in Table v4.1.4 above.

Outlying Community User Input Hydrographs

The outlying community areas chosen for direct time series input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

The procedures described herein were used to create SWMM4 EXTRAN K3-line timeseries input data for selected outlying community sanitary sewer connections to the Philadelphia combined sewer system (CSS). The timeseries data are to be used to define wet weather flow response from these areas in continuous simulations performed for the 2005 representative year selected for LTCPU project evaluations. Filling missing or errant data is required in order to generate continuous timeseries over the one-year simulation period. The outlying community areas chosen for direct timeseries input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

Bucks County and Lower Southampton Township timeseries flow data source is the 2.5-minute permanent billing meter data obtained from the PWD real-time unit (RTU) database. Quality assurance and quality control (QAQC) procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then averaged to 15-minute intervals.

DELCORA flow data is obtained from hourly Southwest WPCP influent flow data measured at the plant. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then interpolated to 15-minute intervals.

Data Gap Filling Procedures

Identification and filling of data gaps are required in order to generate continuous timeseries data needed for performing the typical year model simulations for 2005 data. First, all data gaps and their durations are identified. Next, each data gap is characterized as either wet weather or dry weather flow with the corresponding procedures used for gap filling as described below.

The procedure for Dry Weather Flow is as follows. For small data gaps of less than 1 hour, linear interpolation was performed. Missing or errant data over one or more hours was filled using the nearest previous day's dry weather flow (DWF) data.

The procedure for Wet Weather Flow is as follows. For small data gaps of less than 1 hour, linear interpolation was performed. Wet weather events with missing or errant data periods of one hour duration or more were filled for the entire wet weather event boundaries as defined by the RDI/I analysis. Model simulation results using RDI/I RTK shape parameters previously calibrated for these areas were used to generate the wet weather flow by subtracting baseflow. The calculated wet weather flow for each timestep was added to the timeseries nearest previous day's DWF data.

The continuous flow timeseries generated for the year 2005 that contained diurnal and seasonal time varying baseflow patterns. In contrast, RUNOFF model generated hydrographs used for all other model areas simply have wet weather hydrograph responses added to a constant average baseflow. In order to represent the wet weather responses from the K3 line timeseries input areas more consistently with the modeled areas from the RUNOFF module, hydrograph separations were performed on the K3 timeseries data using CDM SHAPE software to extract the wet weather response hydrograph. The final timeseries was constructed by adding a constant average baseflow to the separated wet weather response K3 timeseries

High and Low Baseflow Estimates

Average monthly dry weather flow rates are determined from WPCPs hourly influent flow data based on days with complete records of average hourly flow data and for which there is no rainfall recorded at any of the PWD rain gages on that day or the previous two days. Annual average dry weather flow (baseflow) rates are determined from these monthly values. Average annual dry weather flow rates for each WPCP over the period 1999 through 2005 are presented in Figure v4.1.7. Average annual flow rates for the period 1999 through 2005 have been standardized dividing by the 7-year average in order to better compare relative changes in inter- annual baseflow rates between drainage districts and are presented by the time series plots in Figure v4.1.8. Note: the time period from 1999 through 2005 is selected because significant reductions from dry weather flow rates prior to this period are generally observed as a result of tidal inflow eliminations.

High and low average annual dry weather flow rates are used to establish upper and lower estimates of available wet weather treatment capacity (worst and best case scenarios) for LTCPU project evaluations. Cumulative frequency distribution plots of average monthly dry weather flow rates over the period 1999 through 2005 are presented for each WPCP in Figure v4.1.9. The values representing the 80^{th} and 20^{th} percentiles for each WPCP, presented in Table v4.1.5, are selected for determining high and low baseflow estimates, respectively. These low, median and high baseflow estimates are expressed as a fraction of current SWMM EXTRAN model dry weather WPCP influent flow. These baseflow multiplication factors are presented in Table v4.1.6 for each drainage district model.

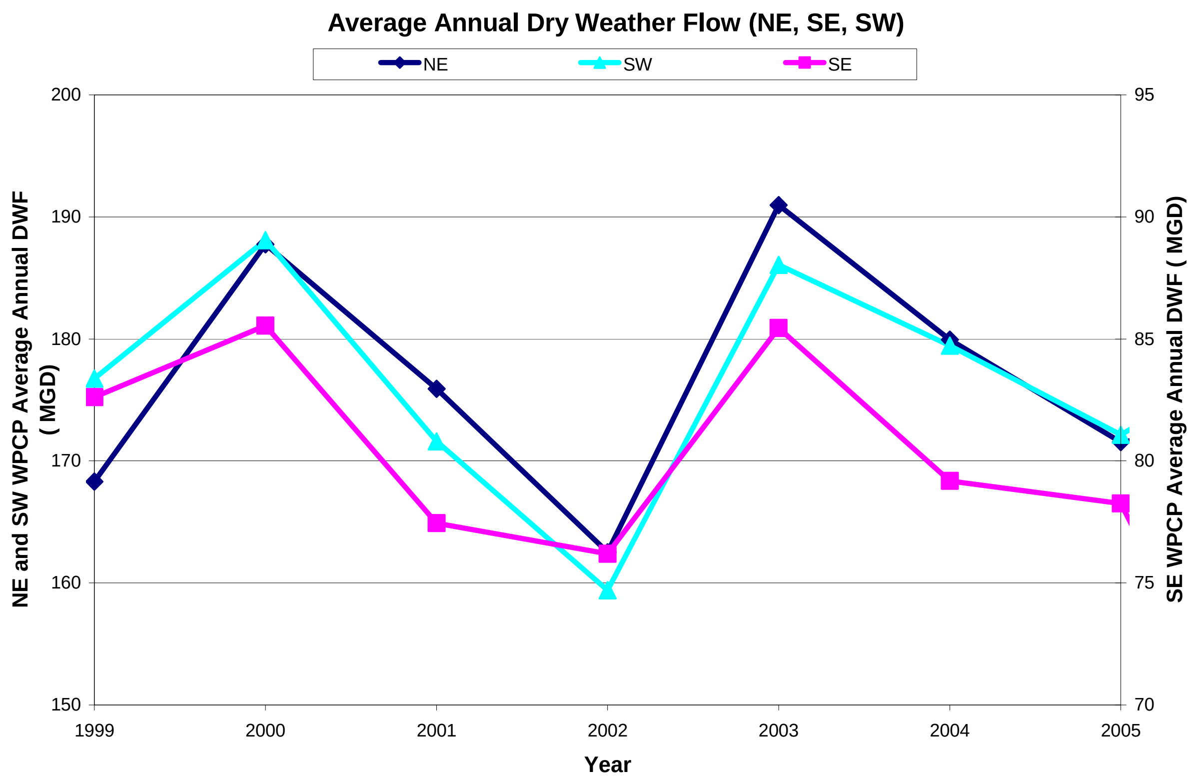


Figure v4.1.7 Average annual dry weather flow rates for each WPCP over the period 1999 through 2005.

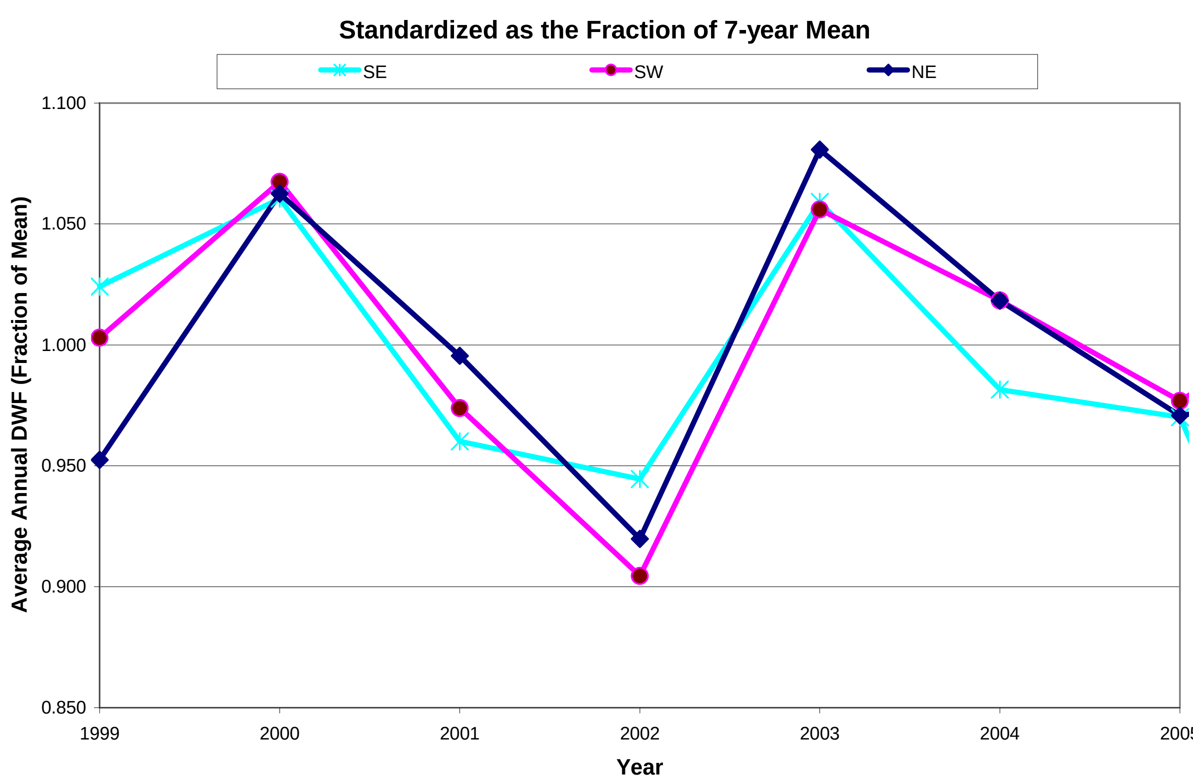


Figure v4.1.8 Standardized **a**verage annual flow rates for the period 1999 through 2005.

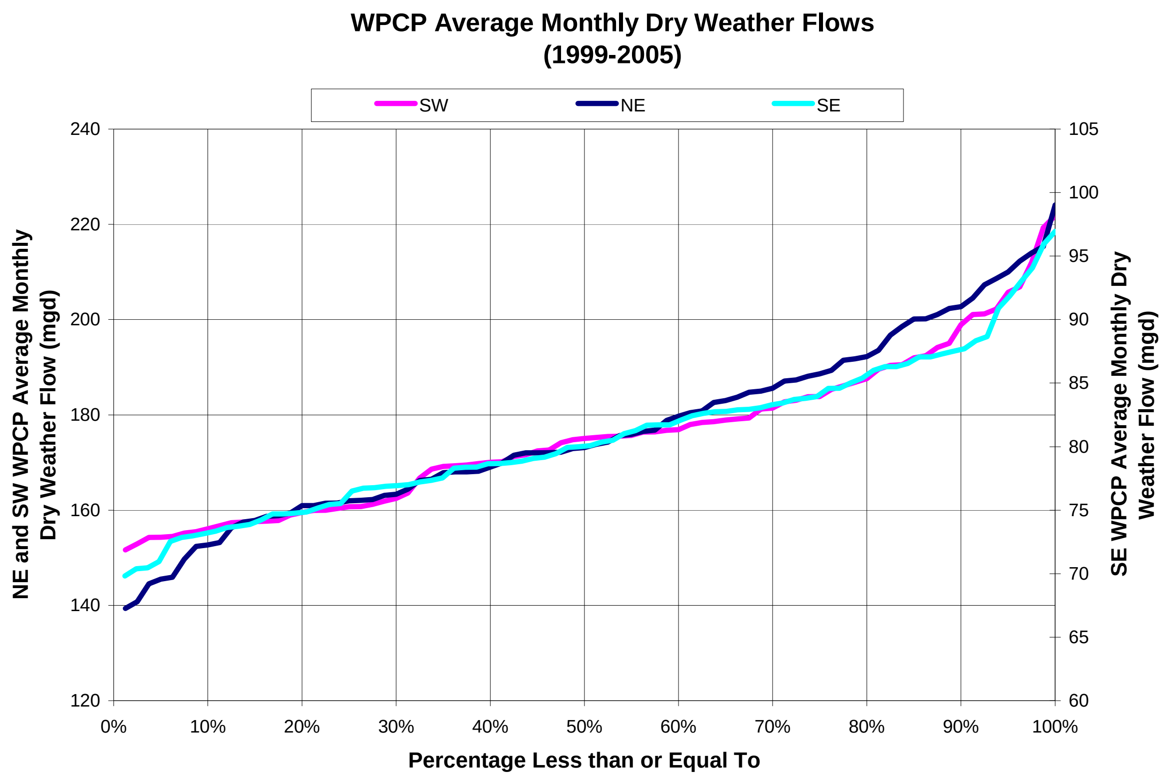


Figure v4.1.9 Cumulative frequency distribution plots of average monthly dry weather flow rates over the period 1999 through 2005.

Table v4.1.5 Average Monthly Baseflow Statistics (1999 - 2005)

WPCP	DWF Percentiles (mgd)		
	20th	50th	80th
SE	75	80	86
NE	161	173	192
SW	160	175	188

Table v4.1.6 SWMM EXTRAN Model Baseflow Multiplier Factors for Low, Median and High Flow Scenarios

WPCP	SWMM EXTRAN Baseflow Multiplier Factors		
	Low	Median	High
SE	0.938	1.003	1.073
NE	0.911	0.980	1.088
SW	0.892	0.979	1.049

v4.1.6 Hydraulic Model Validation

Once the hydrologic models have been calibrated based on combined trunk and sanitary sewer monitoring data, the system hydraulic models were validated against observed pollution control plants (WPCP) influent flow and level data for the calendar year 2005. The results for each drainage district are subsequently discussed using the quantitative and qualitative best-fit measures outlined in Table v4.1.1 as a guide for model result accuracy.

WPCP Inflow and Pumping Data

PWD monitors level and inflow at its three water pollution control plants. These flows were compared to simulated flows for a range of storm events during the calendar year 2005. WPCP influent flow and pump wet-well level data are stored in average hourly time intervals. A QA process was performed on the flow data, during which errant or missing data were removed. The observed flow time increments were interpolated to a 15-minute time interval before being imported into the SHAPE program along with the rainfall data for analysis. The data underwent hydrograph decomposition and the wet-weather portion of the flow coming to the plant was extracted.
The model parameters adjusted to best match the monitored WPCP influent flow and level data included plant head boundaries, pump curves, metering head losses and QA of regulator gate settings.

Southeast Drainage District

The results of final Southeast Drainage District (SEDD) hydraulic model validation, performed using SE WPCP influent hydrograph separated wet-weather flow data, are presented in Figures v4.1.10 through v4.1.12. Linear regression analysis is performed comparing model estimated SE WPCP influent wet weather flow volumes (y-axis) to monitored event volume (x-axis) using IDW rainfall data for the calendar year 2005. The events that have been excluded from the regression analysis based on the protocols described previously are presented in the scatter plots with different symbols and shading so they can be distinguished from those events included in the regression. Ideally the plots would reveal a one to one relationship, meaning the model simulated exactly the monitored runoff volume for each event.

Figure v4.1.10 is a scatter plot with the linear regression analysis results used to determine quantitatively how well the model simulated total event volumes treated at the SE WPCP. The red-dashed line is the 45-degree line that would indicate a perfect fit with an r-squared value of 1. Figure v4.1.11 is an overlay of model and monitored SE WPCP influent wet-weather event volume cumulative frequency distribution (CFD) plots. Figure v4.1.12 is an overlay of model and monitored hydrograph time-series plots for the October 22, 2005 storm event. The plots display a good correlation between observed and simulated event volumes over the full range of events analyzed. Any significant systematic deviation between simulated and observed data would indicate events of a certain volume range were not being adequately simulated by the model.

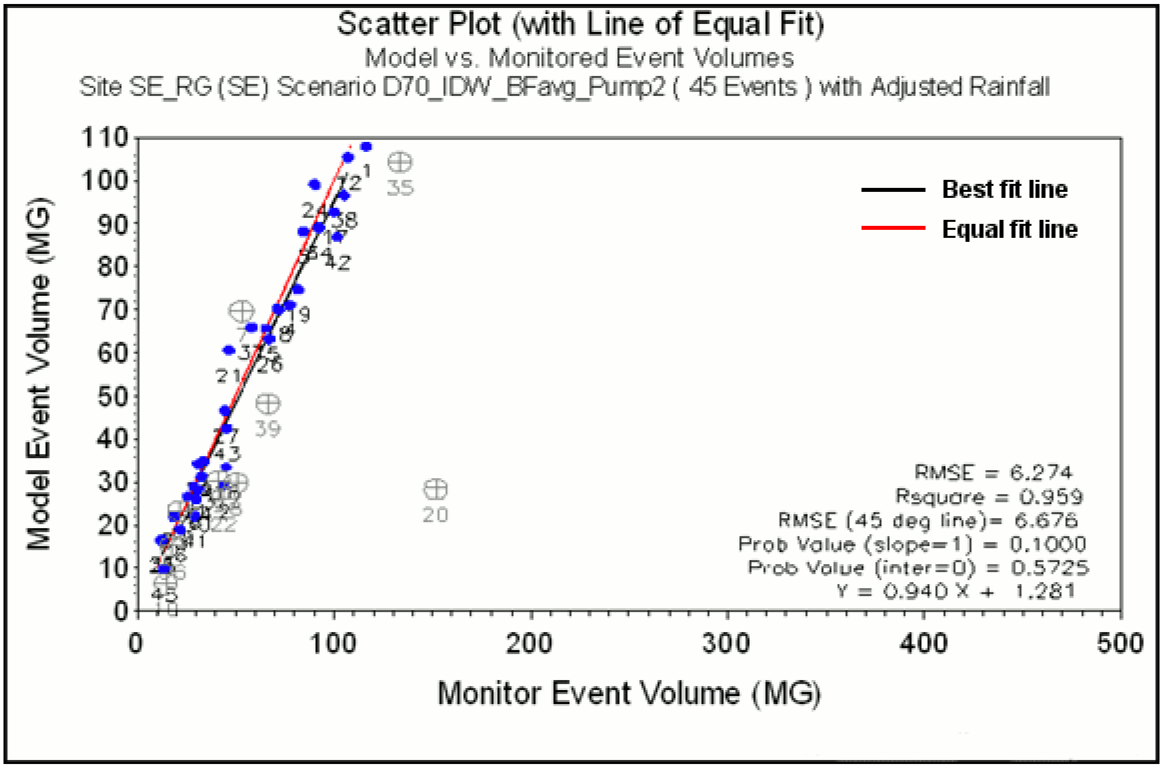


Figure v4.1.10 SE WPCP linear regression of modeled versus monitored event volumes

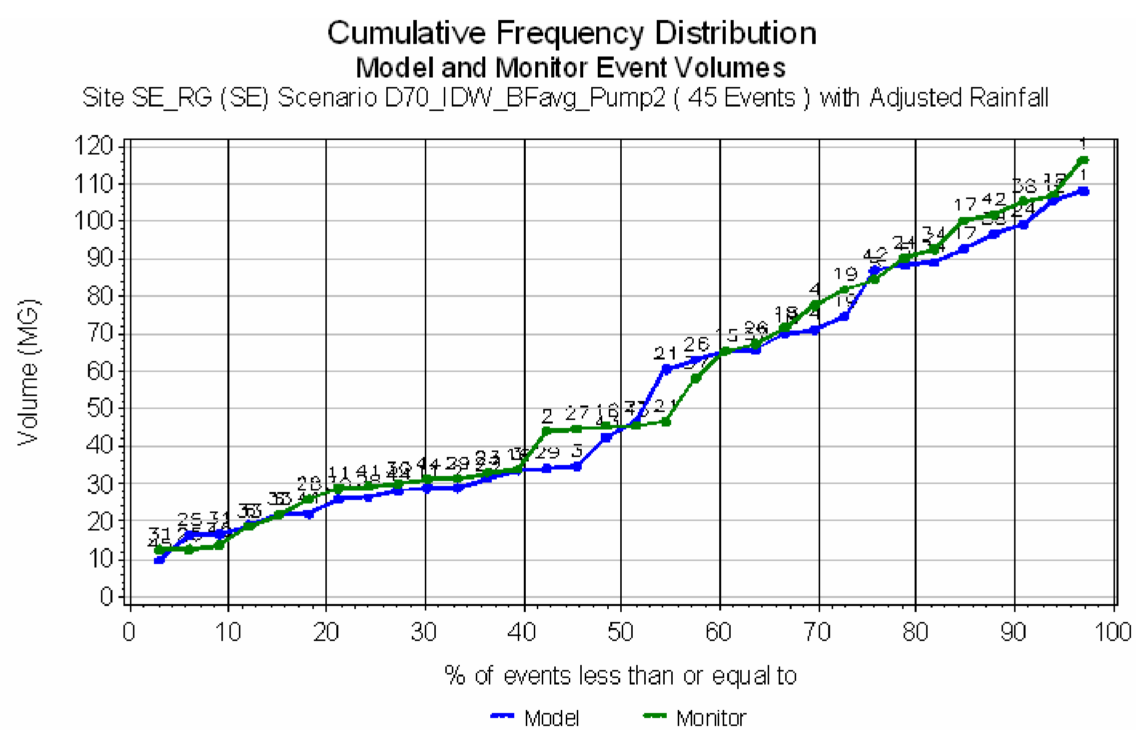


Figure v4.1.11 SE WPCP CFD plots of monitored and modeled event volumes

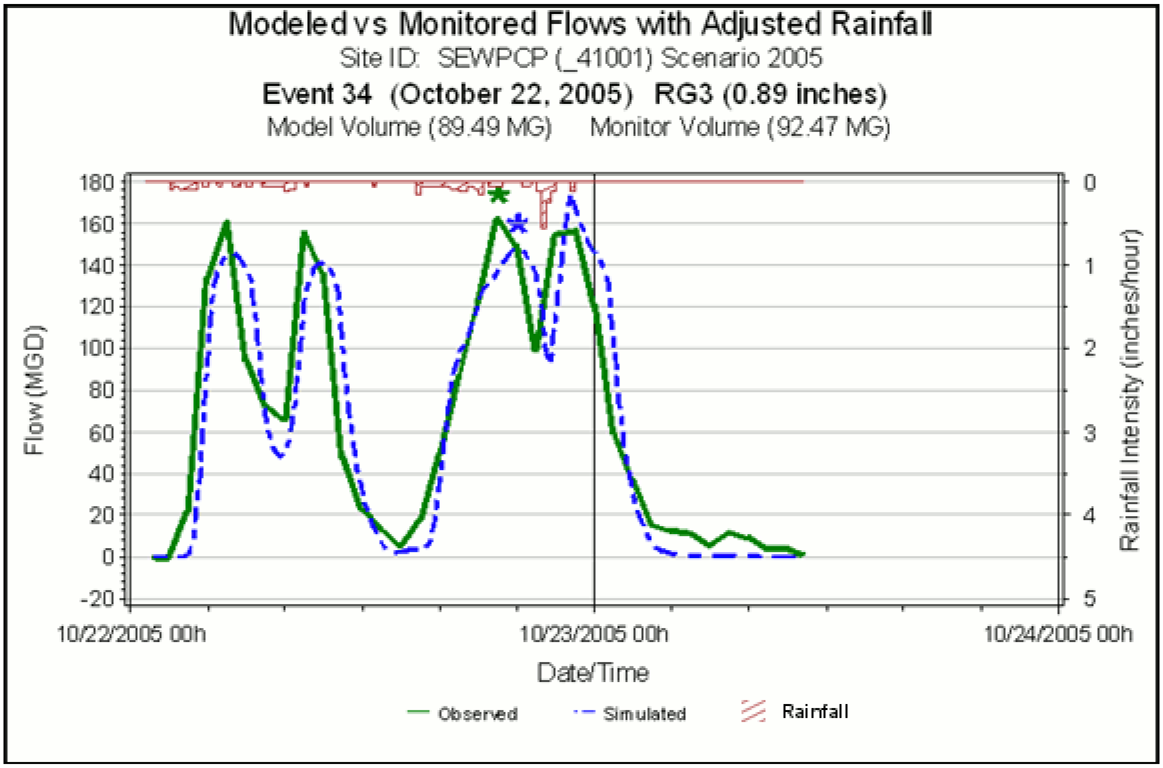


Figure v4.1.12 SE WPCP model and monitored wet-weather flow time-series plot for the October 22, 2005 event

Southwest Drainage District

Final validation plots for the Southwest drainage district (SWDD) hydraulic model are presented in Figures v4.1.13 through v4.1.16. The plots are presented separately for the two interceptor systems that feed the Southwest Water Pollution Control Plant (WPCP), the Southwest High Level (SWHL) and the Southwest Low Level (SWLL). The events that have been excluded from the calibration analyses, using the set of protocols described previously, are presented in the scatter plots with different symbols and shading so they can be distinguished from those included in the regression analyses.

Figure v4.1.13 shows the linear regression analysis used to determine quantitatively how well the SWHL simulated the wet-weather event volumes. The monitored wet-weather event volumes are on the horizontal axis and the modeled event volumes are on the vertical axis. (The red-dashed line is the 45-degree line that would indicate a perfect fit with an r-squared value of 1.0). Figure v4.1.14 shows the cumulative frequency distribution (CFD) plots of the monitored and the modeled wet-weather volume from the SWHL. This plot is used to check if the wet-weather volumes being simulated are different from the observed for various sized storms. Similarly figure v4.1.15 and v4.1.16 show the linear regression analysis and the cumulative frequency distribution plots for the SWLL interceptor system. The curves at the SW interceptors match each other reasonably well with no significant deviation for each plot.

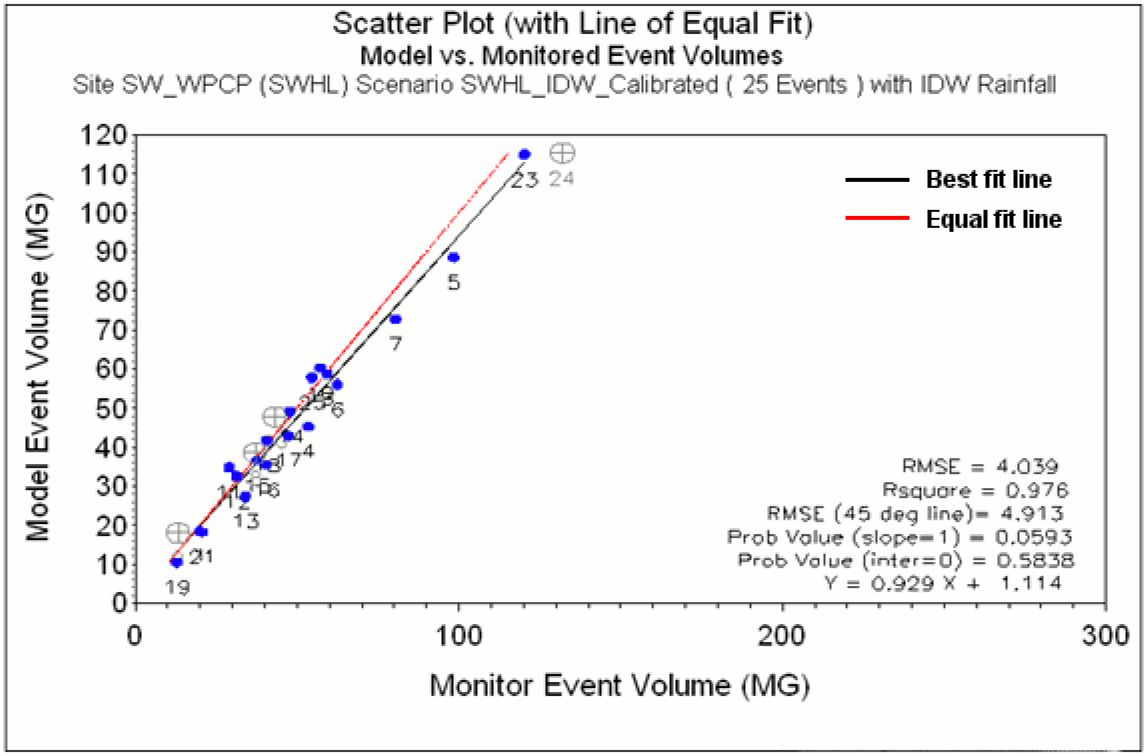


Figure v4.1.13 SWHL linear regression of modeled versus monitored event volumes

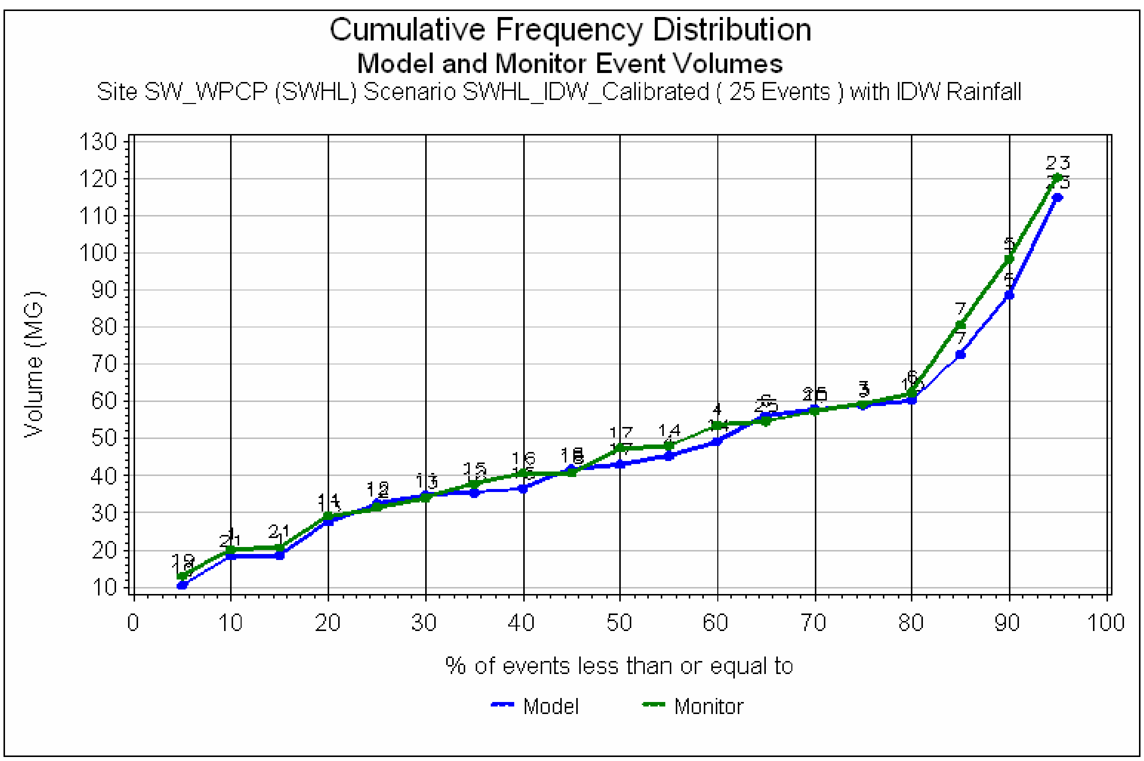


Figure v4.1.14 CFD Monitored and Modeled event volumes SWHL

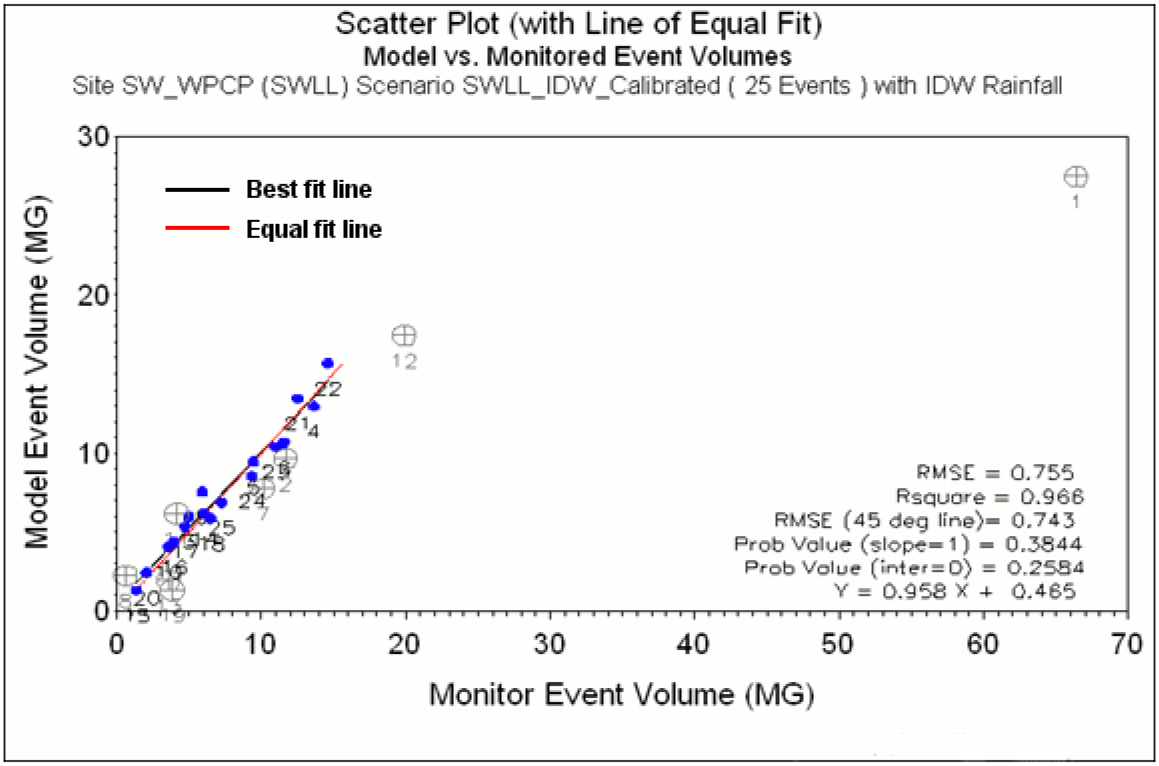


Figure v4.1.15 SWLL linear regression of modeled versus monitored event volumes

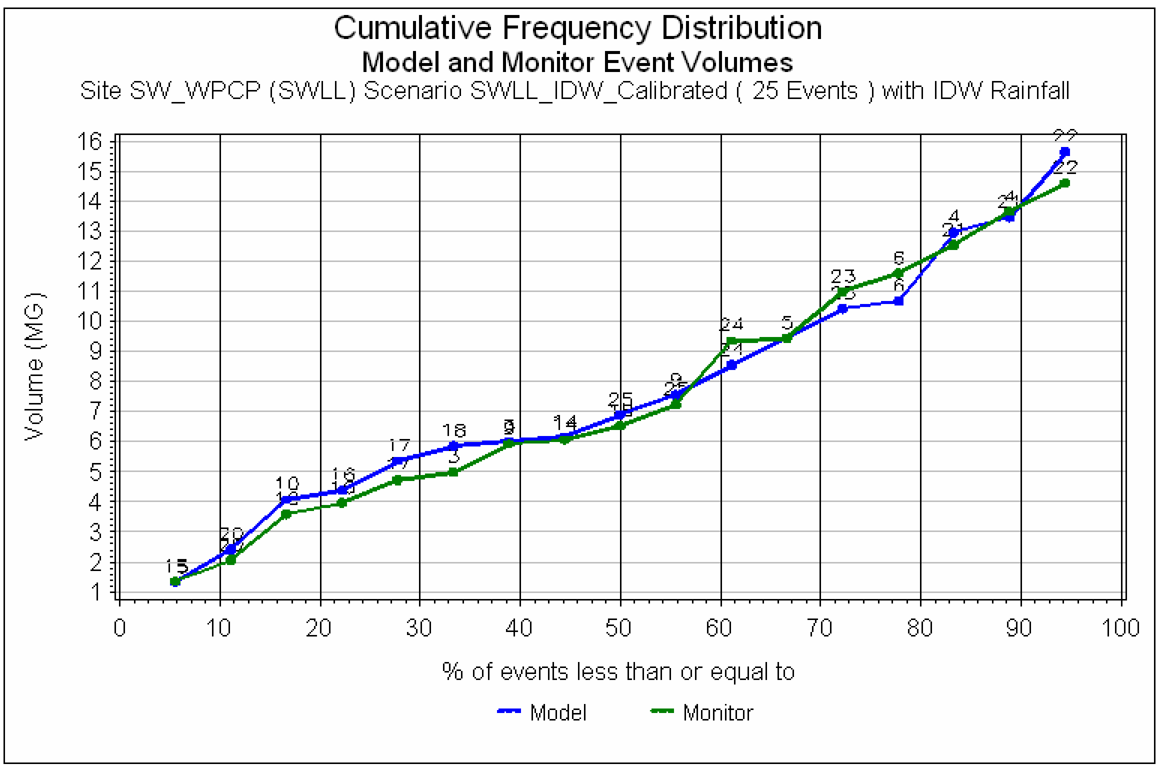


Figure v4.1.16 CFD Monitored and Modeled event volumes SWHL

Northeast Drainage District

The Northeast Water Pollution Control Plant (NE WPCP) receives combined sewer flows by gravity from the Northeast High-Level system (NEHL) and through pumping from the Northeast Low-Level system (NELL). These two drainage systems connect at the NE WPCP and can be modeled separately or as a single combined model. The NEHL system is comprised of two interceptor systems: the Frankford High Level (FHL) and the Tacony (T). The NELL system is comprised of five interceptor systems: the Somerset Low-Level (SOM), the Upper-Frankford Low-Level (UFLL), the Lower Frankford Low-Level (LFLL), the Upper Delaware Low-Level (UDLL) and the Pennypack (P).

Final validation plots for the Northeast drainage district (NEDD) model are presented in Figures v4.1.17 through v4.1.30. These plots include scatter plots of model versus monitored WPCP influent wet-weather event volumes showing linear regression analysis results, cumulative frequency distribution plots of model and monitored WPCP influent wet-weather event volumes and selected model and monitored influent wet-weather flow hygrographs. Plots are first presented for the total NE WPCP and the combined NELL. Calibration plots are also presented for each of the following three metered plant influent lines, FHL, the combined SOM and UFLL and the UDLL which also includes flow from the LFLL. The same event list is used for all analyses. Events are excluded from the calibration analyses based on the set of protocols described previously and are distinguished from those included in the regression plots by use of different symbols and shading.

The plots generally display a good correlation between observed and simulated event volumes over the full range of events analyzed. Any significant systematic deviation between simulated and observed data would indicate events of a certain volume range were not being adequately simulated by the model.

Significant systematic under-estimation of the combined SOM/UFLL influent wet-weather event volumes is indicated by the linear regression and CFD as presented in Figure v4.1.25 and Figure v4.1.26. However, inspection of individual influent wet-weather flow hygrographs for the January 7 and July 1, 2005 rainfall events presented in Figure v4.1.27 and Figure v4.1.28, respectively, reveal a very close overall correlation between modeled and monitored hydrographs. In fact, the correlation between modeled and monitored hydrographs for the combined SOM/UFLL appears to be much better than that for the UDLL, as illustrated in Figure v4.1.29 and Figure v4.1.30, which shows a higher correlation in the linear regression and CFD plots than the combined SOM/UFLL.

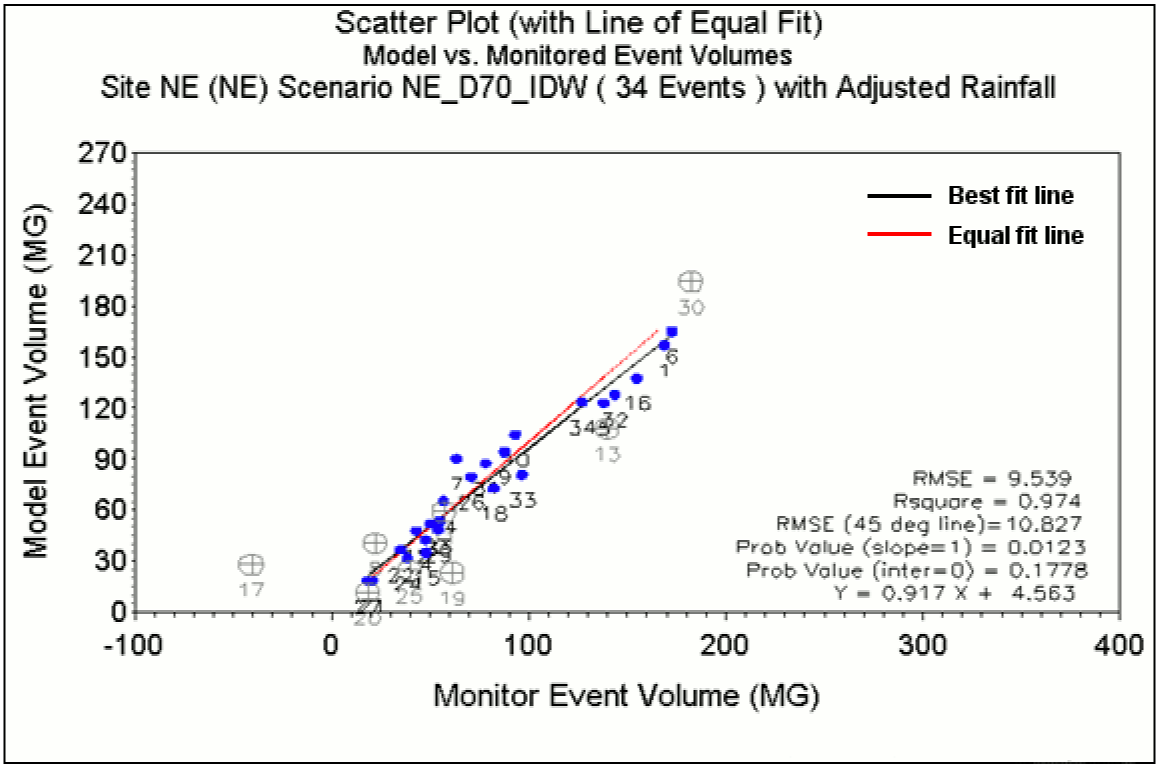


Figure v4.1.17 NE WPCP linear regression of modeled versus monitored event volumes

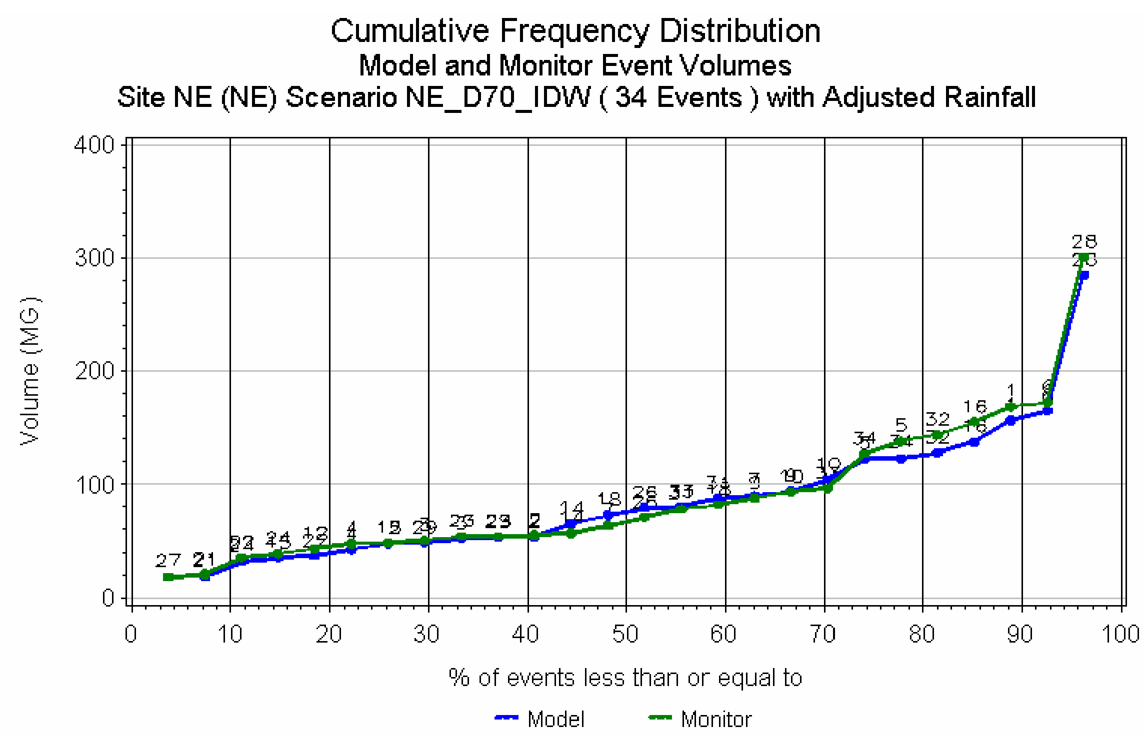


Figure v4.1.18 NE WPCP CFD of modeled and monitored event volumes

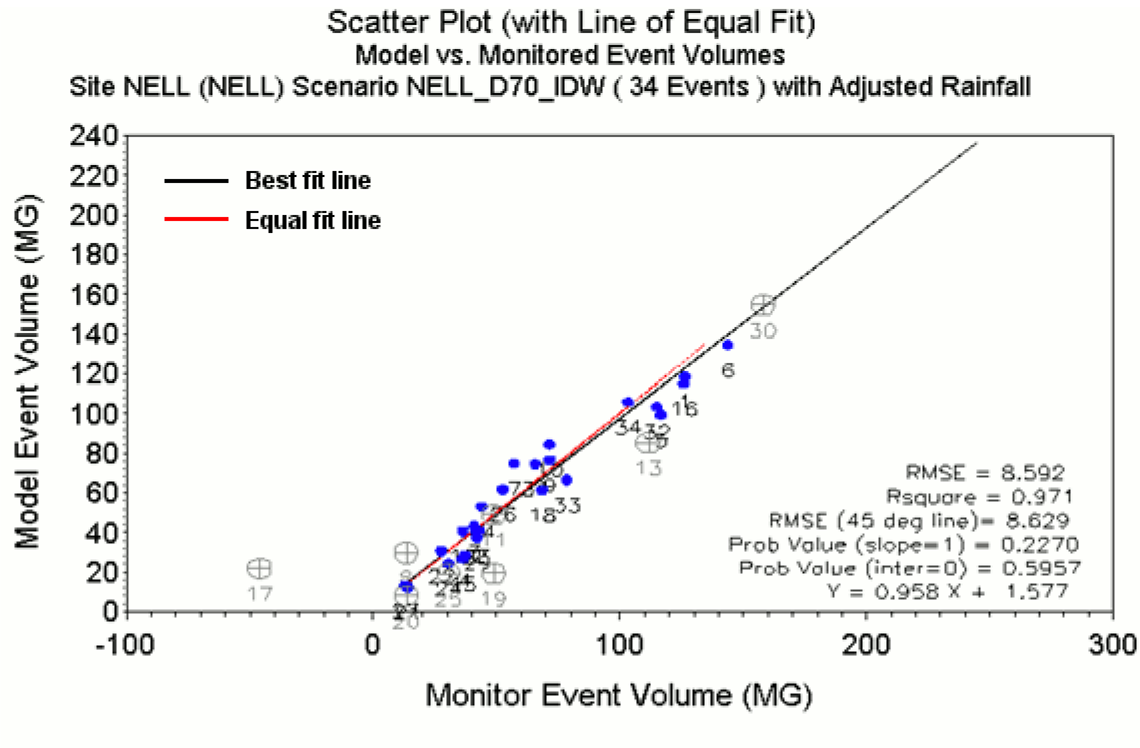


Figure v4.1.19 NELL linear regression of modeled versus monitored event volumes

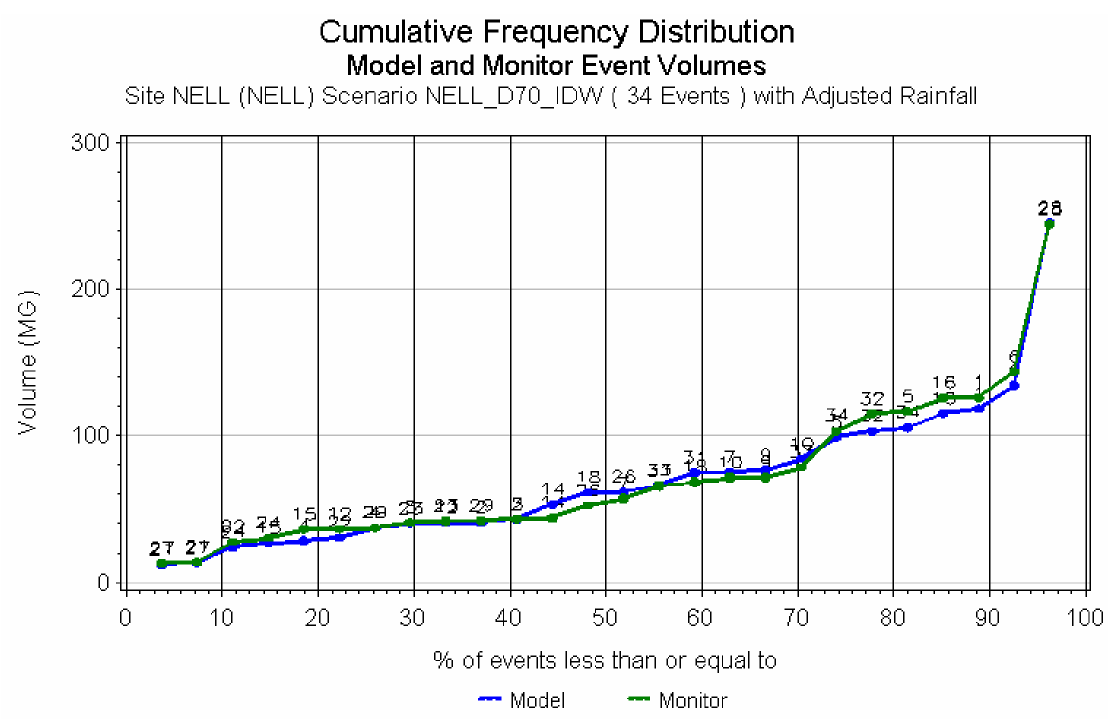


Figure v4.1.20 NELL CFD of modeled and monitored event volumes

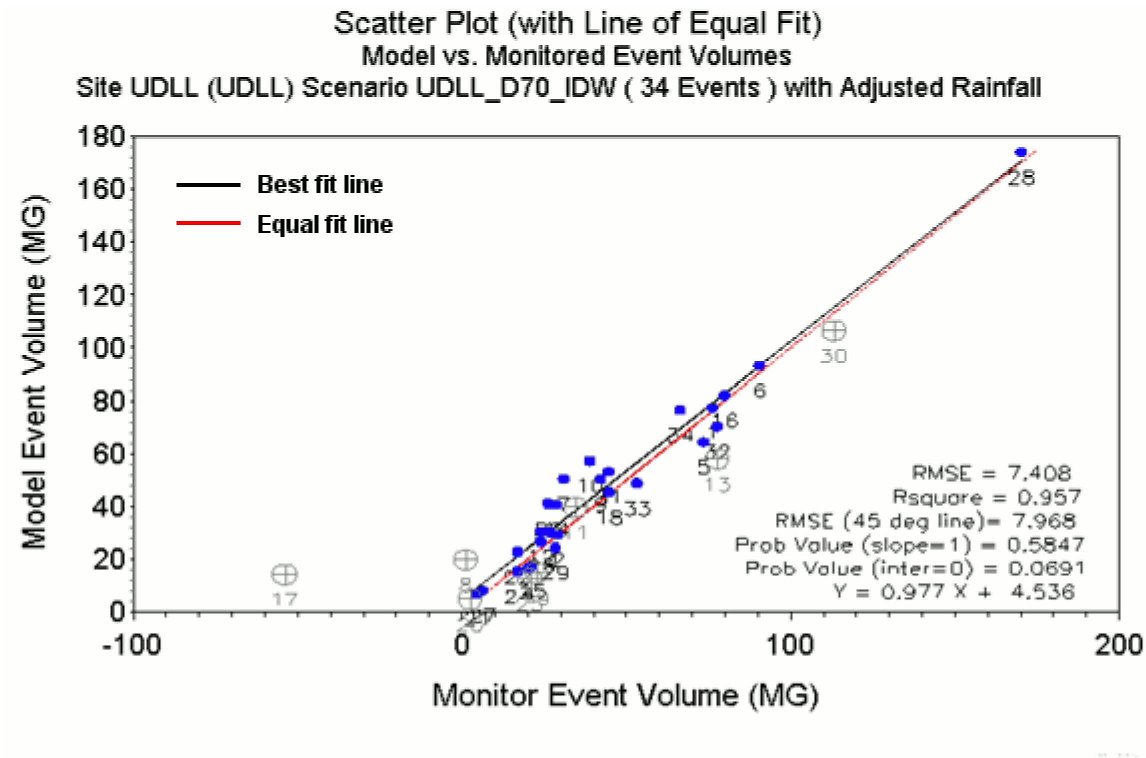


Figure v4.1.21 UDLL linear regression of modeled versus monitored event volumes

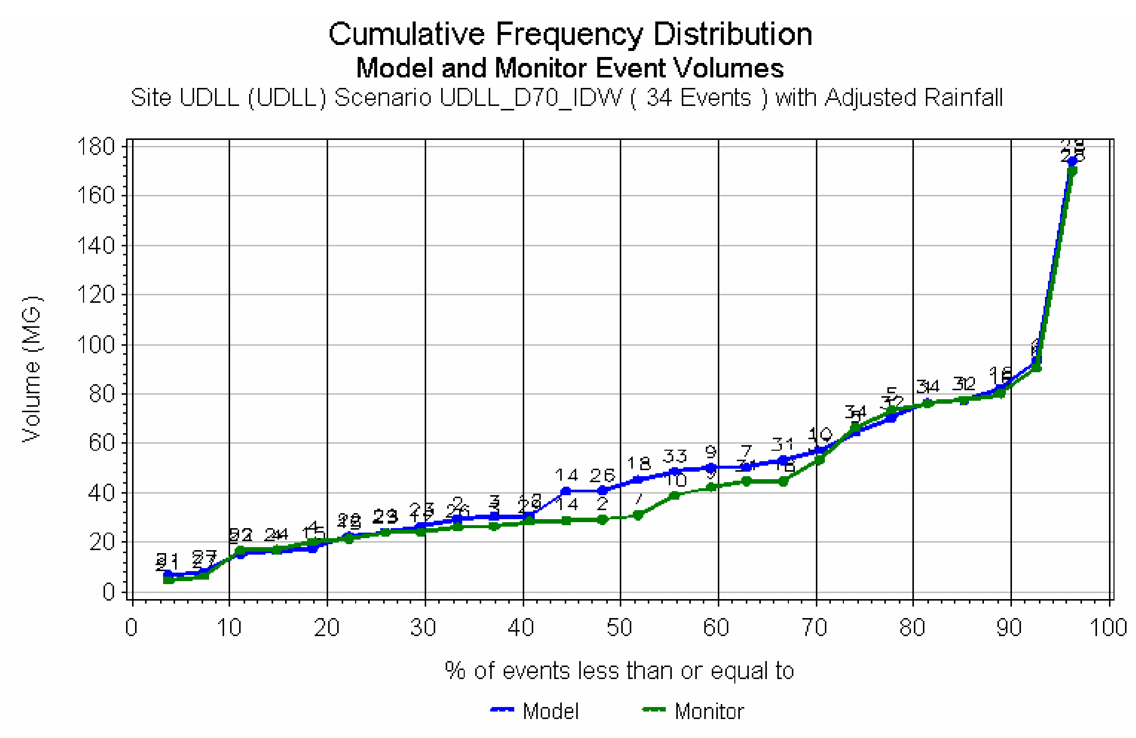


Figure v4.1.22 UDLL CFD of modeled and monitored event volumes

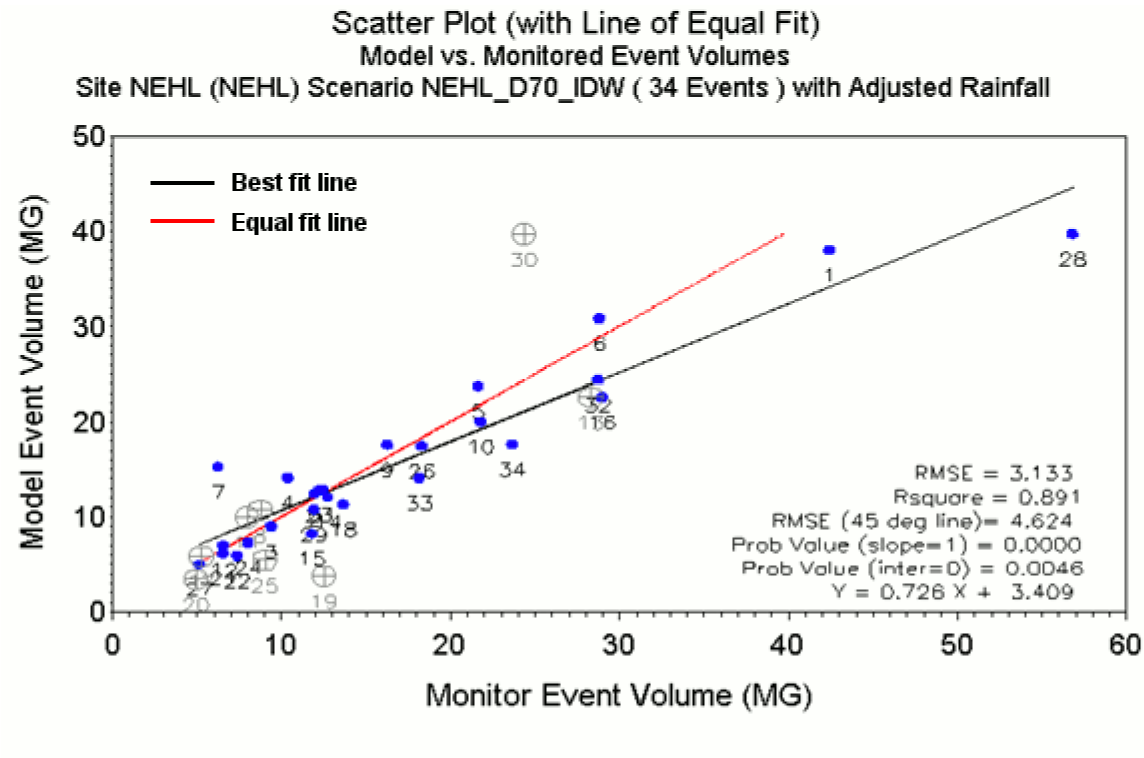


Figure v4.1.23 NEHL linear regression of modeled versus monitored event volumes

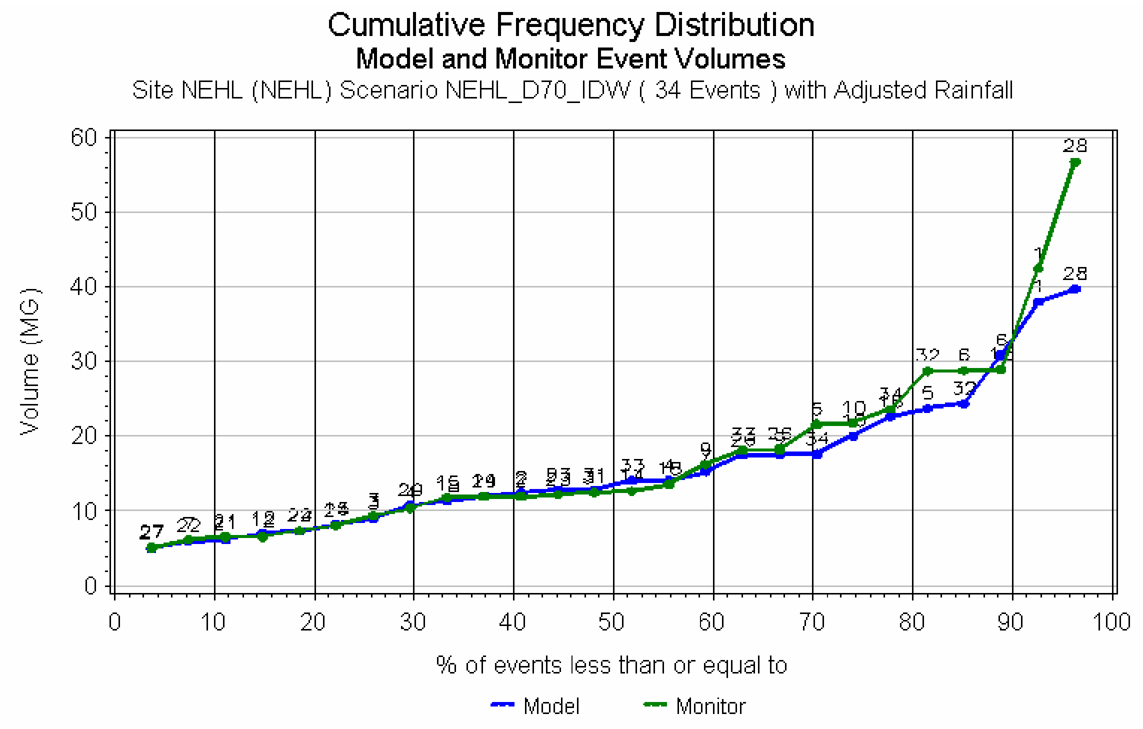


Figure v4.1.24 NEHL CFD of modeled and monitored event volumes

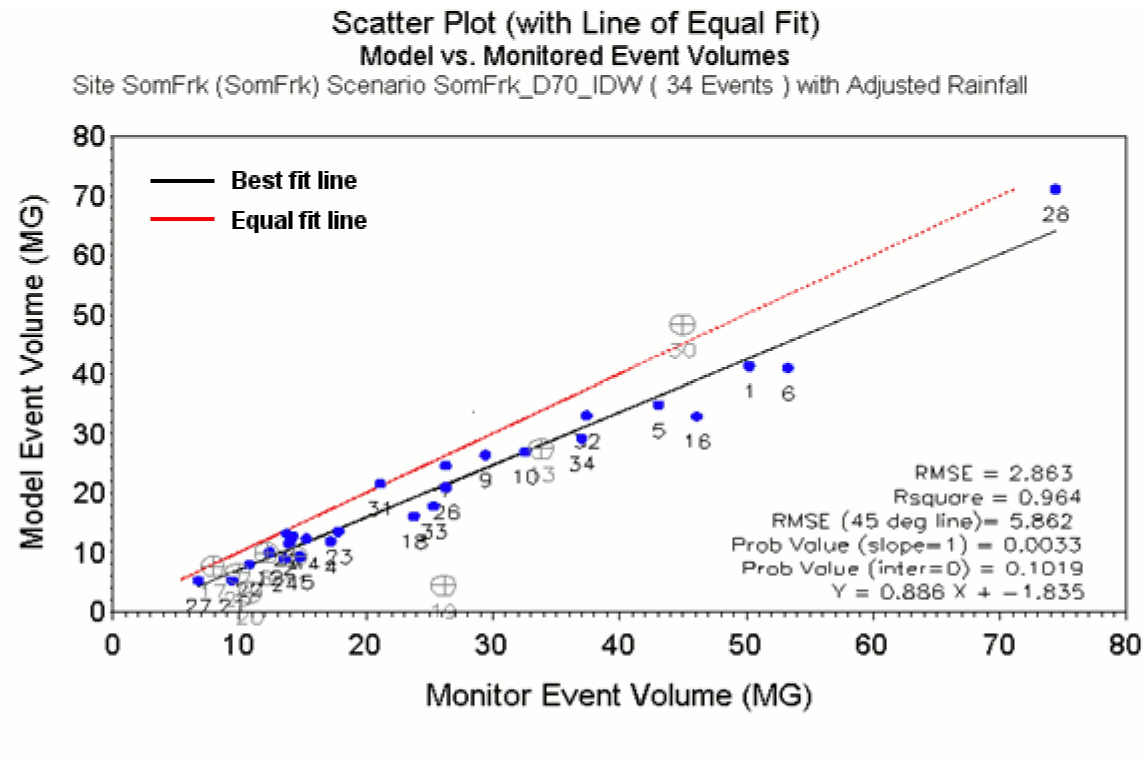


Figure v4.1.25 Som-Frk linear regression of modeled versus monitored event volumes

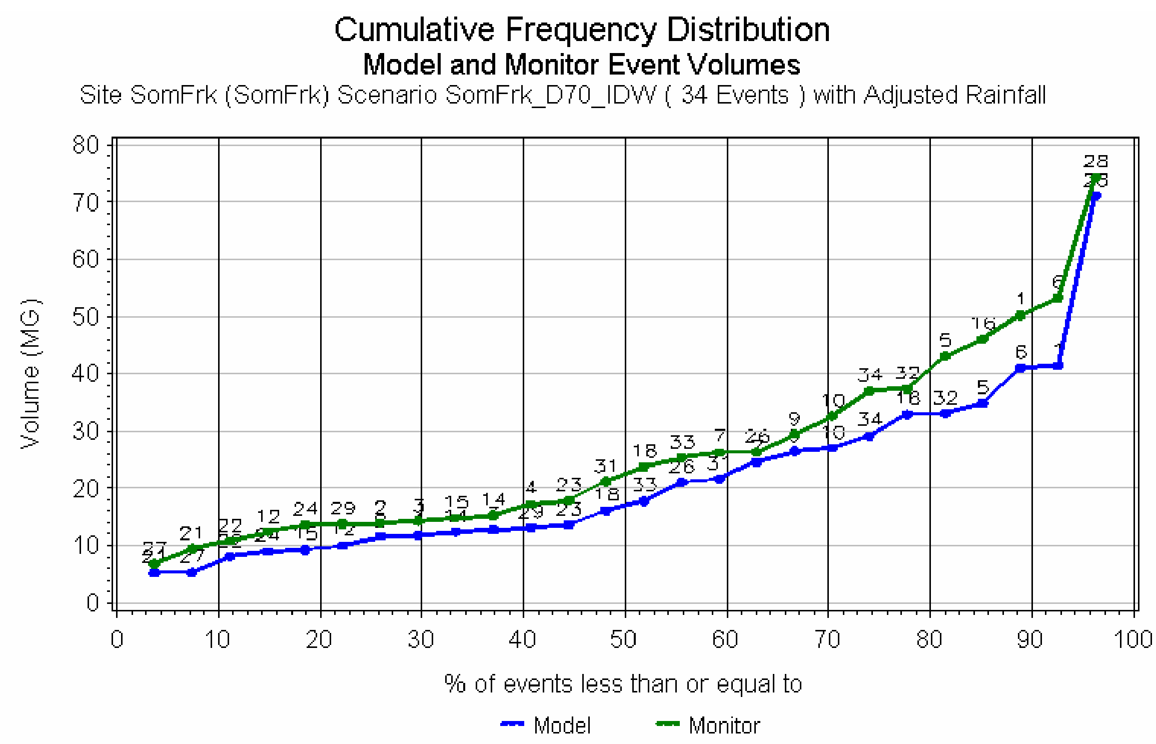


Figure v4.1.26 Som-Frk CFD of modeled and monitored event volumes

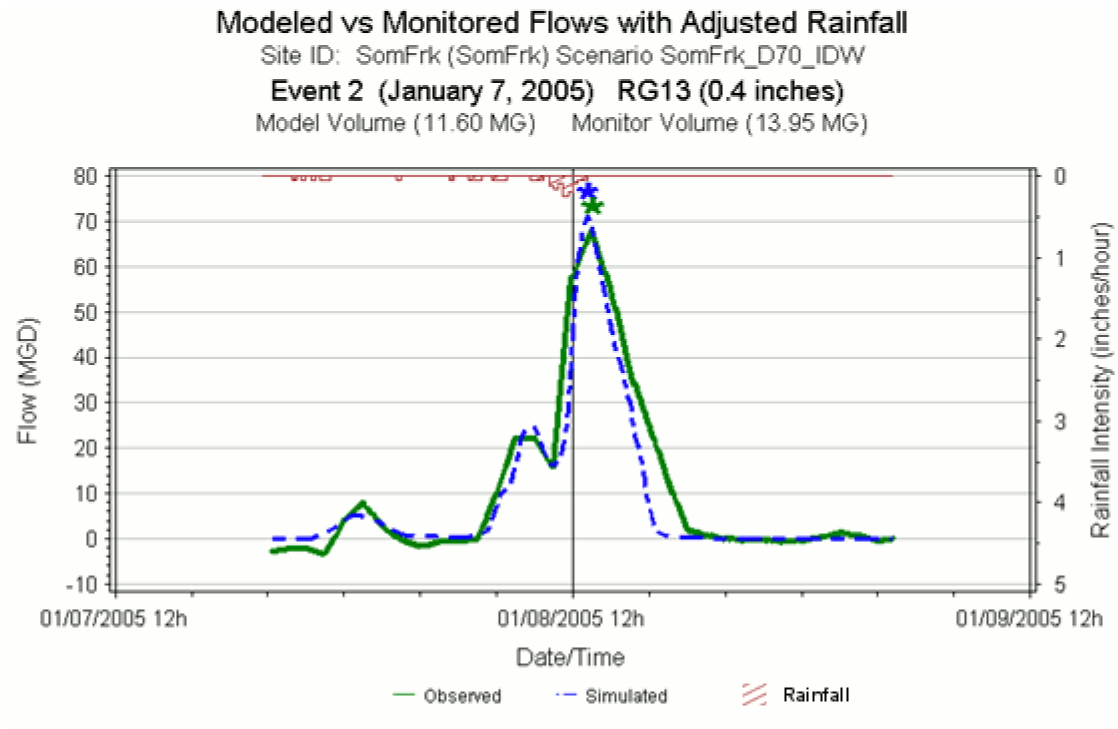


Figure v4.1.27 Som-Frk model and monitored wet-weather flow time-series plot for the January 7, 2005 event

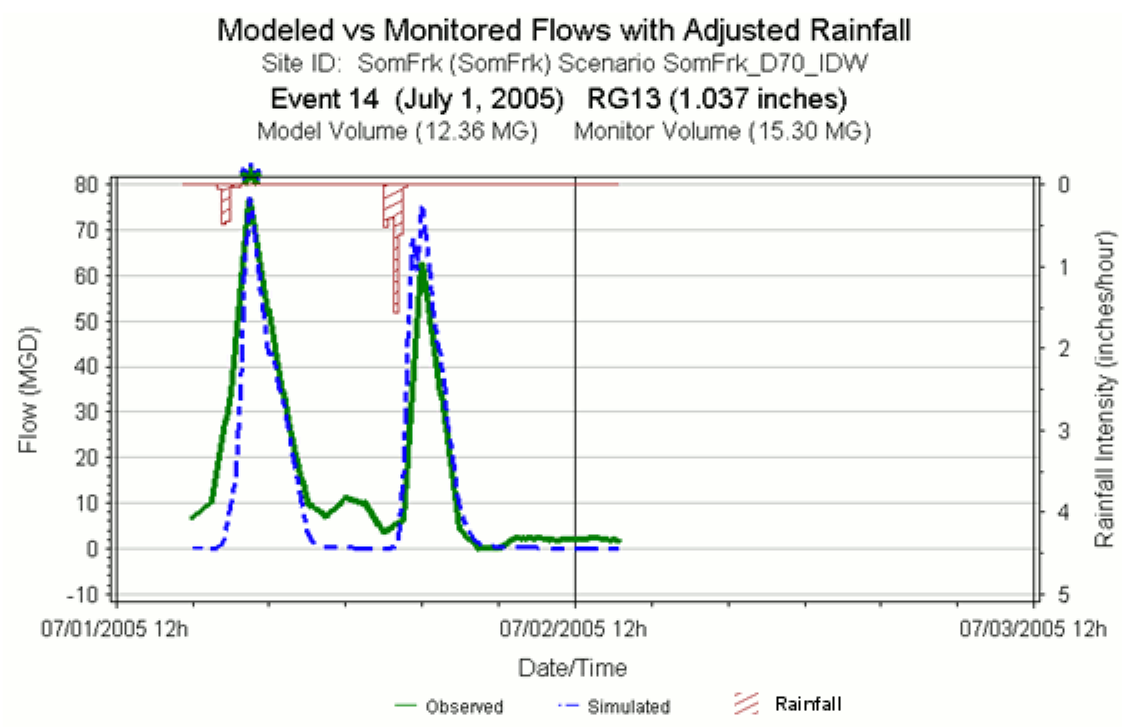


Figure v4.1.28 Som-Frk model and monitored wet-weather flow time-series plot for the July 1, 2005 event

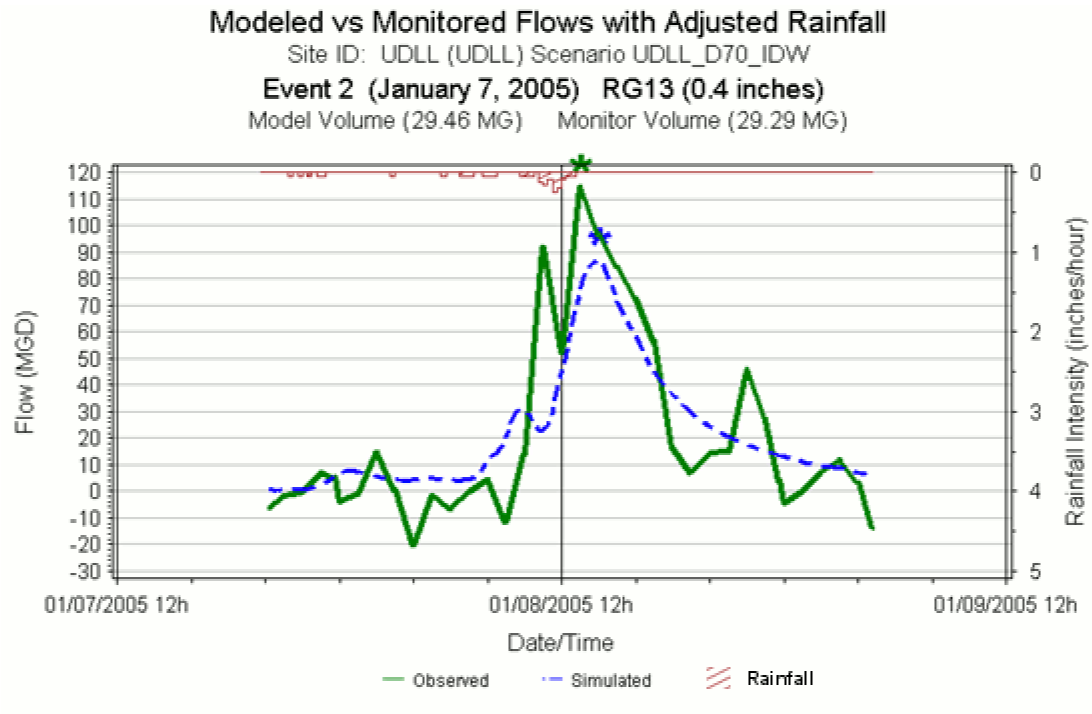


Figure v4.1.29 UDLL model and monitored wet-weather flow time-series plot for the January 7, 2005 event

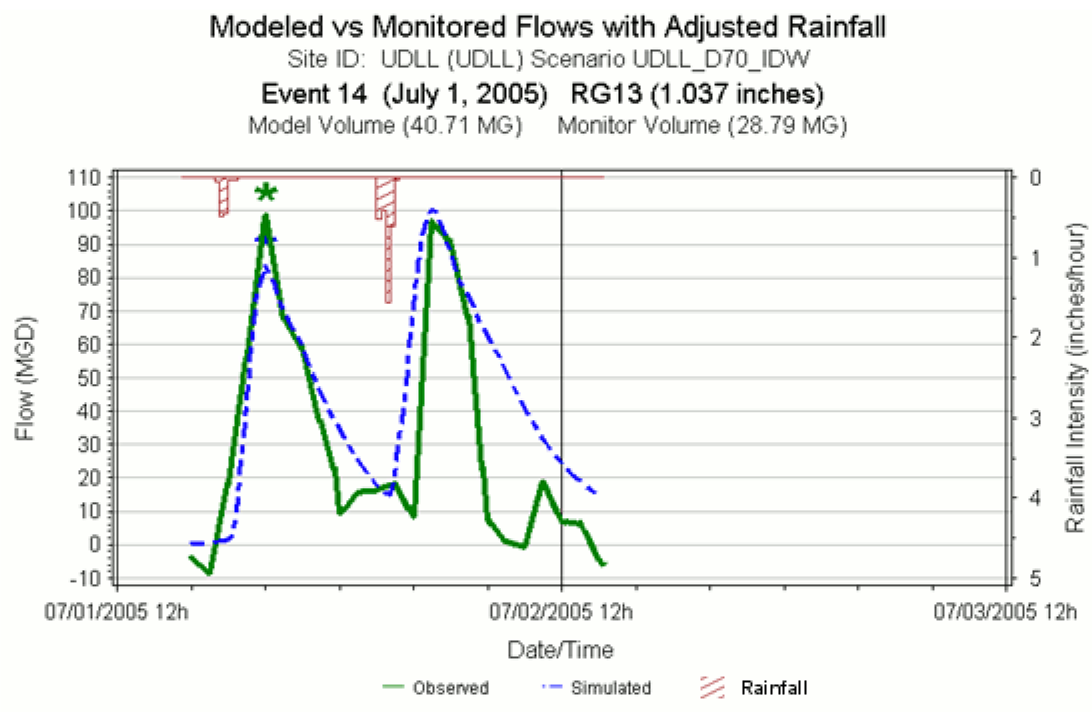


Figure v4.1.30 UDLL model and monitored wet-weather flow time-series plot for the July 1, 2005 event

4.2 CHARACTERIZATION OF BASELINE CONDITIONS – SYSTEM RESPONSE TO WET WEATHER

The response of the CSS to wet weather conditions is detailed for each WPCP drainage district through model simulations of calibrated LTCPU baseline models using typical year rainfall and the median range of estimated hydrologic parameters. Statistics for each rainfall event causing a CSO are presented for each drainage district in Table v4.2.1 through Table v4.2.3. These tables include a list and count of regulators overflowing and estimates of rainfall, runoff, and overflow volumes for each event.

Table v4.2.1 NEDD Response to Wet Weather Conditions

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/3/05 19:00	1/4/05 5:00	8	D22, R18	2	0.08	0.14	0.05	0.05	0.002	0.001	0.015	0.000
1/5/05 1:00	1/6/05 23:00	42	D02, D03, D05, D08, D12, D18, D19, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	31	0.93	1.10	0.81	0.14	0.001	0.014	0.384	0.134
1/7/05 21:00	1/8/05 20:00	17	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.52	0.62	0.40	0.30	0.001	0.008	0.204	0.109
1/11/05 15:00	1/12/05 8:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	40	0.57	0.69	0.48	0.23	0.001	0.008	0.241	0.156

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/13/05 23:00	1/14/05 21:00	15	D02, D03, D04, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	56	1.72	1.90	1.56	0.44	0.001	0.022	0.846	0.731
1/25/05 13:00	1/27/05 2:00	32	D05, D17, D18, D19, D22, D25, F04, F05, F09, F10, F11, F21, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	23	0.58	0.59	0.57	0.11	0.01	0.007	0.209	0.079
2/4/05 9:00	2/4/05 22:00	8	D05, D22, D25, F04, F05, F10, F11, F21, R18, T01, T08, T10, T14	13	0.34	0.35	0.33	0.06	0.013	0.004	0.134	0.059
2/10/05 5:00	2/10/05 12:00	3	R18	1	0.03	0.08	0.02	0.04	0.004	0.001	0.012	0.001

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
2/14/05 9:00	2/15/05 7:00	15	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	40	1.13	1.41	0.93	0.18	0.003	0.018	0.478	0.324
2/16/05 14:00	2/17/05 0:00	3	D03, D05, D12, D17, D18, D19, D22, D23, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	30	0.21	0.26	0.14	0.18	0.018	0.002	0.077	0.039
2/21/05 10:00	2/22/05 8:00	16	D03, D05, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F21, F23, R18, T01, T03, T04, T08, T10, T13, T14, T15	24	0.58	0.58	0.58	0.09	0.01	0.008	0.235	0.114
2/25/05 11:00	2/25/05 22:00	4	D05, D17, D18, D19, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14, T15	21	0.23	0.23	0.23	0.10	0.02	0.003	0.087	0.041

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/1/05 11:00	3/2/05 2:00	8	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	41	0.49	0.50	0.48	0.19	0.013	0.006	0.199	0.119
3/8/05 4:00	3/8/05 18:00	11	D03, D05, D12, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	30	0.43	0.48	0.37	0.13	0.001	0.006	0.173	0.095
3/11/05 22:00	3/12/05 6:00	7	D22	1	0.09	0.11	0.06	0.06	0.001	0.001	0.022	0.000
3/20/05 3:00	3/21/05 2:00	22	D22, D25, F04, F05, F10, F11, F21, R18, T01, T08	10	0.31	0.43	0.25	0.09	0.001	0.004	0.117	0.023

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
3/23/05 6:00	3/24/05 6:00	25	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	46	1.00	1.28	0.83	0.29	0.001	0.013	0.434	0.246
3/27/05 19:00	3/29/05 14:00	40	D02, D03, D04, D05, D07, D08, D11, D12, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	51	1.54	1.74	1.35	0.33	0.001	0.025	0.665	0.453

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/1/05 22:00	4/4/05 0:00	48	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	3.01	3.48	2.80	0.63	0.001	0.051	1.456	1.234
4/7/05 22:00	4/8/05 15:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	43	0.81	1.07	0.53	0.36	0.001	0.010	0.365	0.235

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
4/23/05 7:00	4/24/05 7:00	20	D02, D03, D04, D05, D07, D08, D11, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	49	0.57	0.88	0.33	0.47	0.001	0.006	0.241	0.172
4/27/05 2:00	4/27/05 11:00	8	R18, T01, T08, T14	4	0.08	0.17	0.04	0.09	0.002	0.001	0.018	0.005
4/30/05 4:00	5/1/05 15:00	29	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	48	1.03	1.27	0.58	0.36	0.002	0.015	0.414	0.231
5/2/05 19:00	5/3/05 1:00	2	R18, T08	2	0.04	0.06	0.01	0.05	0.002	0.001	0.007	0.000

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
5/20/05 5:00	5/20/05 23:00	17	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	35	0.93	1.04	0.85	0.14	0.001	0.010	0.396	0.254
6/3/05 6:00	6/4/05 7:00	25	D02, D03, D05, D08, D12, D17, D18, D19, D21, D22, D25, F04, F05, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T08, T10, T11, T13, T14, T15	34	0.86	1.19	0.67	0.18	0.001	0.010	0.372	0.212
6/6/05 18:00	6/7/05 7:00	11	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	59	1.02	1.34	0.73	0.96	0.002	0.012	0.505	0.461

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
6/7/05 11:00	6/7/05 17:00	1	R18, T03, T04, T05, T08, T09, T10, T13	8	0.01	0.18	0.00	0.18	0.002	0.001	0.008	0.003
6/8/05 17:00	6/8/05 21:00	2	F10, F11	2	0.04	0.14	0.01	0.10	0.009	0.000	0.004	0.000
6/10/05 11:00	6/10/05 23:00	6	D02, D03, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T12, T13, T14, T15	55	0.85	1.45	0.25	1.00	0.001	0.009	0.320	0.259
6/16/05 14:00	6/16/05 22:00	5	D05, D08, D22, D25, F04, F05, F11, F21, F24, R18, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	20	0.08	0.20	0.01	0.18	0.001	0.000	0.030	0.011
6/22/05 17:00	6/22/05 22:00	5	P02	1	0.05	0.21	0.01	0.16	0.001	0.001	0.004	0.000

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/27/05 9:00	6/28/05 11:00	26	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.87	1.15	0.65	0.32	0.001	0.009	0.384	0.207
6/29/05 22:00	6/30/05 5:00	6	D05, D12, D15, D17, D18, D19, D20, D21, D22, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, P02, R13, R14, R18, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	38	0.27	0.63	0.01	0.62	0.001	0.003	0.091	0.065

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/1/05 16:00	7/2/05 11:00	17	D02, D03, D04, D05, D06, D07, D08, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	55	0.99	1.97	0.27	0.96	0.001	0.013	0.439	0.347
7/5/05 16:00	7/6/05 9:00	12	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	44	0.33	0.68	0.17	0.39	0.001	0.003	0.138	0.074
7/6/05 23:00	7/7/05 6:00	5	D22, F04, F05, F10, F21, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	18	0.13	0.58	0.02	0.56	0.001	0.003	0.025	0.013

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/8/05 0:00	7/8/05 23:00	19	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	1.97	3.07	1.25	1.17	0.001	0.023	1.186	1.040
7/15/05 17:00	7/15/05 21:00	2	T01	1	0.04	0.54	0.00	0.53	0.003	0.000	0.001	0.000
7/16/05 16:00	7/18/05 22:00	48	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T06, T08, T09, T10, T11, T12, T13, T14, T15	58	1.92	3.14	0.52	2.30	0.001	0.022	1.010	0.837

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/25/05 3:00	7/25/05 16:00	10	D05, D22, F04, F05, F10, F11, F21, R13, R14, R18, T01, T04, T08	13	0.19	0.26	0.10	0.19	0.003	0.002	0.039	0.006
7/27/05 19:00	7/28/05 5:00	5	D17, D18, D22, D25, F04, F05, F09, F10, F11, F13, F21, R18, T01, T03, T04, T08, T10, T13, T14, T15	20	0.14	0.20	0.10	0.10	0.002	0.002	0.039	0.015
8/6/05 3:00	8/6/05 8:00	2	D05, D08, D22, D25, F03, F04, F05, F11, F21, F23, F24, R18, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	22	0.07	0.40	0.01	0.29	0.01	0.000	0.040	0.019
8/8/05 6:00	8/9/05 17:00	30	D05, D17, D18, D19, D22, D23, D24, D25, F04, F05, F09, F10, F11, F21, F24, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	26	0.40	0.73	0.20	0.38	0.001	0.004	0.112	0.043

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
8/14/05 21:00	8/15/05 10:00	13	D02, D03, D04, D05, D06, D07, D08, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	57	0.75	1.28	0.34	1.27	0.001	0.006	0.344	0.300
8/16/05 12:00	8/17/05 11:00	21	D02, D03, D05, D07, D08, D12, D15, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	46	0.57	0.87	0.37	0.34	0.001	0.005	0.256	0.143

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
8/27/05 10:00	8/28/05 16:00	31	D02, D03, D05, D08, D12, D17, D18, D19, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T13, T14, T15	42	0.55	0.78	0.30	0.41	0.001	0.006	0.189	0.112
8/29/05 17:00	8/30/05 1:00	2	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	50	0.35	0.72	0.01	0.72	0.008	0.002	0.218	0.180
8/31/05 19:00	8/31/05 22:00	1	T01	1	0.03	0.09	0.01	0.09	0.009	0.000	0.003	0.000

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/14/05 9:00	9/15/05 0:00	12	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.42	0.84	0.13	0.43	0.001	0.005	0.153	0.089
9/15/05 7:00	9/15/05 22:00	10	D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	46	0.36	0.91	0.10	0.48	0.002	0.003	0.170	0.110
9/17/05 21:00	9/18/05 4:00	7	D02, D22, D25, F04, F05, F07, P02, R18, T01, T03, T04, T05, T08, T09, T10, T11, T13, T14, T15	19	0.10	0.36	0.01	0.34	0.003	0.001	0.039	0.025
9/26/05 20:00	9/27/05 5:00	8	D05, D17, D18, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14	19	0.17	0.20	0.09	0.12	0.001	0.002	0.053	0.023
9/29/05 12:00	9/29/05 19:00	3	R18, T08	2	0.07	0.11	0.04	0.05	0.008	0.001	0.012	0.001

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
10/7/05 14:00	10/9/05 12:00	44	D02, D03, D04, D05, D06, D07, D08, D09, D11, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, F25, P01, P02, P03, P04, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T07, T08, T09, T10, T11, T12, T13, T14, T15	60	3.31	3.86	2.85	0.96	0.001	0.051	1.687	1.443
10/11/05 0:00	10/11/05 14:00	12	D12, D17, D18, D19, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, R18, T08, T11, T13, T15	23	0.18	0.33	0.07	0.20	0.002	0.001	0.055	0.011
10/11/05 18:00	10/15/05 5:00	82	D02, D03, D05, D08, D12, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	1.51	2.14	1.22	0.34	0.001	0.026	0.569	0.231

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
10/21/05 9:00	10/21/05 19:00	10	D05, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T08, T14	13	0.22	0.27	0.18	0.08	0.001	0.002	0.077	0.026
10/22/05 2:00	10/23/05 6:00	24	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	50	0.94	1.20	0.80	0.32	0.002	0.014	0.383	0.205
10/24/05 18:00	10/26/05 10:00	38	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T06, T08, T09, T10, T11, T13, T14, T15	40	1.28	1.61	1.10	0.25	0.002	0.024	0.532	0.251
11/6/05 21:00	11/7/05 3:00	2	D22, F05, F10, F11, R18, T01, T03, T04, T05, T08, T10, T13, T14	13	0.08	0.12	0.04	0.12	0.012	0.001	0.018	0.005

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/10/05 1:00	11/10/05 9:00	4	D02, D03, D05, D08, D12, D17, D18, D19, D22, D23, D25, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	39	0.21	0.31	0.15	0.27	0.002	0.002	0.064	0.032
11/16/05 17:00	11/17/05 7:00	9	D02, D03, D04, D05, D07, D08, D11, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	51	0.97	1.09	0.79	0.31	0.009	0.012	0.419	0.310

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/21/05 16:00	11/22/05 20:00	23	D02, D03, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	45	0.97	1.12	0.81	0.21	0.001	0.014	0.410	0.222
11/29/05 17:00	11/30/05 9:00	10	D02, D03, D04, D05, D06, D07, D08, D11, D12, D15, D17, D18, D19, D20, D21, D22, D23, D24, D25, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P01, P02, P03, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	54	0.98	1.39	0.74	0.36	0.001	0.013	0.407	0.316
12/4/05 12:00	12/4/05 22:00	7	D22, D25, F11, F21, R18	5	0.12	0.24	0.05	0.05	0.001	0.002	0.040	0.004
12/6/05 11:00	12/6/05 19:00	6	D22	1	0.06	0.09	0.04	0.04	0.001	0.001	0.012	0.000
12/9/05 8:00	12/9/05 21:00	10	D05, D18, D22, D25, F04, F05, F09, F10, F11, F21, R18, T01, T03, T04, T08, T10, T13, T14	18	0.21	0.34	0.07	0.11	0.001	0.002	0.083	0.025

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
12/11/05 12:00	12/11/05 22:00	8	D22, F21, R18	3	0.10	0.14	0.02	0.04	0.001	0.002	0.032	0.003
12/15/05 19:00	12/16/05 15:00	13	D02, D03, D04, D05, D07, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F12, F13, F14, F21, F23, F24, P02, P05, R13, R14, R15, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	47	1.19	1.69	1.04	0.30	0.001	0.019	0.493	0.357
12/25/05 13:00	12/26/05 11:00	20	D02, D03, D05, D08, D12, D17, D18, D19, D20, D21, D22, D23, D25, F03, F04, F05, F07, F08, F09, F10, F11, F13, F14, F21, F23, F24, P02, R13, R14, R18, T01, T03, T04, T05, T06, T08, T09, T10, T11, T13, T14, T15	42	0.61	0.71	0.55	0.18	0.001	0.008	0.240	0.131
12/29/05 7:00	12/30/05 1:00	18	D05, D12, D13, D15, D17, D18, D19, D20, D21, D22, D23, D25, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F21, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	35	0.46	1.14	0.34	0.46	0.001	0.006	0.180	0.071

Rainfall Events			CSO Regulators Overflowing		NEDD Rain Gage Rainfall Depth Statistics					Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
12/31/05 13:00	12/31/05 22:00	7	D05, D12, D22, D25, F04, F05, F09, F10, F11, F13, F21, F24, P02, R18, T01, T03, T04, T08, T10, T11, T13, T14, T15	23	0.13	0.16	0.11	0.09	0.001	0.002	0.043	0.015

Table v4.2.2 SEDD Response to Wet Weather Conditions

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/5/05 2:00	1/7/05 0:00	41	D37, D38, D39, D40, D44, D47, D51, D68, D71, D73	10	0.98	1.08	0.89	0.12	0.001	0.003	0.422	0.018
1/7/05 23:00	1/8/05 20:00	15	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D67, D68, D71, D73	17	0.46	0.56	0.40	0.17	0.001	0.001	0.164	0.038
1/11/05 16:00	1/12/05 7:00	10	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D68, D71, D73	16	0.49	0.59	0.46	0.17	0.001	0.001	0.196	0.063
1/13/05 23:00	1/14/05 22:00	15	D37, D38, D39, D40, D41, D42, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	1.69	1.78	1.56	0.44	0.001	0.004	0.811	0.621
1/25/05 13:00	1/27/05 0:00	32	D37, D38, D39, D40, D44, D47, D51, D51A, D61, D68, D71, D73	12	0.58	0.59	0.57	0.11	0.01	0.002	0.226	0.018
2/4/05 9:00	2/4/05 21:00	8	D37, D47, D51, D68	4	0.34	0.35	0.33	0.06	0.013	0.001	0.125	0.003
2/14/05 10:00	2/15/05 9:00	15	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D68, D71, D72, D73	16	1.05	1.41	0.83	0.18	0.002	0.003	0.398	0.121

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
2/16/05 15:00	2/16/05 23:00	3	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D68, D71	13	0.20	0.26	0.14	0.18	0.02	0.001	0.081	0.010
2/21/05 10:00	2/22/05 8:00	16	D37, D38, D39, D40, D41, D44, D45, D47, D51, D51A, D68, D71, D73	13	0.58	0.58	0.58	0.09	0.01	0.002	0.242	0.032
2/25/05 11:00	2/25/05 21:00	4	D37, D39, D40, D44, D47, D51, D51A, D68, D71	9	0.23	0.23	0.23	0.10	0.02	0.001	0.087	0.005
3/1/05 11:00	3/2/05 0:00	8	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D65, D66, D67, D68, D71, D73	22	0.49	0.50	0.48	0.19	0.013	0.001	0.202	0.061
3/8/05 4:00	3/8/05 18:00	7	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D66, D68, D71, D73	16	0.40	0.45	0.36	0.13	0.011	0.001	0.169	0.034
3/11/05 22:00	3/12/05 5:00	6	D47, D51, D51A	3	0.10	0.11	0.07	0.06	0.002	0.000	0.031	0.000
3/20/05 3:00	3/20/05 23:00	20	D37, D40, D47, D51, D51A	5	0.36	0.43	0.25	0.09	0.001	0.001	0.157	0.002
3/23/05 5:00	3/24/05 4:00	20	D37, D38, D39, D40, D41, D44, D45, D46, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	27	1.16	1.38	0.91	0.24	0.001	0.003	0.574	0.203

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
3/27/05 20:00	3/29/05 12:00	39	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	1.59	1.74	1.49	0.31	0.001	0.004	0.725	0.344
4/1/05 23:00	4/3/05 12:00	36	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	2.81	3.19	2.62	0.59	0.001	0.008	1.231	0.827
4/7/05 22:00	4/8/05 16:00	12	D37, D38, D39, D40, D41, D44, D45, D46, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	26	0.75	1.07	0.53	0.36	0.001	0.002	0.393	0.175

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
4/23/05 8:00	4/24/05 8:00	19	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.78	0.84	0.73	0.57	0.004	0.002	0.302	0.162
4/30/05 4:00	5/1/05 15:00	29	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	1.07	1.39	0.58	0.36	0.001	0.003	0.544	0.210
5/20/05 5:00	5/21/05 2:00	17	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D58, D61, D63, D65, D66, D67, D68, D69, D70, D71, D72, D73	23	0.95	1.02	0.89	0.19	0.001	0.002	0.409	0.176
5/21/05 17:00	5/22/05 0:00	6	D61	1	0.05	0.11	0.02	0.10	0.004	0.000	0.014	0.000
5/28/05 16:00	5/28/05 21:00	2	D51, D61, D62, D64, D71	5	0.06	0.13	0.01	0.13	0.007	0.000	0.022	0.000
6/3/05 6:00	6/4/05 7:00	25	D37, D39, D40, D44, D47, D51, D51A, D66, D68, D71, D72, D73	12	0.74	0.85	0.66	0.11	0.001	0.002	0.305	0.031

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/6/05 20:00	6/7/05 8:00	9	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.12	1.41	0.73	0.93	0.009	0.003	0.810	0.717
6/10/05 14:00	6/11/05 0:00	3	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	31	0.57	0.83	0.25	0.40	0.067	0.001	0.256	0.174
6/16/05 16:00	6/16/05 22:00	4	D39, D40, D47, D51, D51A, D61, D68, D71	8	0.11	0.16	0.09	0.16	0.001	0.000	0.048	0.002
6/22/05 17:00	6/23/05 3:00	4	D66, D67, D68, D69, D70, D71, D72, D73	8	0.08	0.21	0.01	0.18	0.002	0.000	0.071	0.052
6/27/05 9:00	6/28/05 10:00	26	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D52, D61, D62, D64, D66, D68, D71, D73	19	0.70	0.96	0.55	0.24	0.001	0.002	0.249	0.036
6/29/05 22:00	6/30/05 4:00	2	D39, D44, D47, D66, D68	5	0.11	0.63	0.03	0.62	0.001	0.000	0.021	0.004

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/1/05 16:00	7/2/05 14:00	18	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	32	0.94	1.97	0.64	0.96	0.004	0.003	0.290	0.215
7/5/05 16:00	7/6/05 8:00	11	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.52	0.75	0.26	0.50	0.003	0.001	0.288	0.172
7/8/05 0:00	7/9/05 1:00	17	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	2.11	2.75	1.80	0.85	0.005	0.005	1.020	0.759
7/15/05 17:00	7/16/05 0:00	3	D39, D44, D45, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D63, D66, D68	15	0.23	0.82	0.02	0.60	0.002	0.000	0.088	0.034

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/16/05 17:00	7/18/05 21:00	48	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.69	2.10	1.18	1.37	0.002	0.004	0.708	0.536
7/25/05 3:00	7/25/05 13:00	9	D47, D51	2	0.14	0.20	0.10	0.09	0.009	0.000	0.021	0.000
7/27/05 20:00	7/28/05 3:00	4	D37, D39, D40, D47, D51, D51A	6	0.13	0.17	0.11	0.09	0.01	0.000	0.044	0.001
8/4/05 17:00	8/4/05 20:00	3	D47, D51	2	0.02	0.09	0.01	0.09	0.001	0.000	0.006	0.000
8/8/05 16:00	8/9/05 19:00	20	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	28	0.71	1.36	0.20	0.65	0.001	0.001	0.375	0.177
8/15/05 0:00	8/15/05 13:00	2	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	1.09	1.28	0.76	1.27	0.009	0.003	0.505	0.450

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
8/16/05 13:00	8/17/05 5:00	14	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D68, D71	12	0.47	0.60	0.36	0.25	0.003	0.001	0.179	0.019
8/27/05 12:00	8/28/05 1:00	7	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D61, D62, D64, D66, D67, D68, D71, D73	19	0.40	0.70	0.27	0.36	0.013	0.001	0.133	0.033
8/29/05 17:00	8/30/05 3:00	2	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D58, D61, D63	19	0.27	0.68	0.01	0.63	0.009	0.001	0.106	0.059
9/14/05 12:00	9/15/05 2:00	10	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.55	0.95	0.03	0.55	0.009	0.001	0.311	0.146
9/15/05 8:00	9/15/05 23:00	7	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	31	0.71	1.30	0.09	0.95	0.001	0.002	0.433	0.276
9/17/05 21:00	9/18/05 2:00	2	D39	1	0.08	0.36	0.01	0.34	0.01	0.000	0.005	0.000

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/26/05 20:00	9/27/05 5:00	8	D37, D39, D40, D44, D47, D51, D51A, D68, D71	9	0.17	0.19	0.15	0.10	0.01	0.000	0.062	0.003
9/29/05 13:00	9/29/05 17:00	2	D47, D51, D51A	3	0.06	0.08	0.05	0.05	0.01	0.000	0.018	0.000
10/7/05 16:00	10/9/05 10:00	42	D37, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D51A, D52, D53, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	33	3.46	3.71	2.86	1.25	0.006	0.007	1.955	1.488
10/11/05 0:00	10/12/05 18:00	41	D37, D38, D39, D40, D41, D44, D47, D51, D51A, D61, D71	11	0.47	0.67	0.37	0.14	0.009	0.001	0.177	0.008
10/13/05 0:00	10/15/05 2:00	50	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D52, D58, D61, D62, D63, D64, D65, D66, D67, D68, D71, D73	23	0.78	1.03	0.54	0.32	0.013	0.002	0.265	0.052
10/21/05 9:00	10/21/05 16:00	6	D47, D51	2	0.22	0.23	0.20	0.08	0.009	0.000	0.082	0.001
10/22/05 2:00	10/23/05 6:00	22	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D52, D61, D62, D63, D64, D66, D67, D68, D71, D73	22	0.94	1.07	0.82	0.29	0.009	0.002	0.378	0.053

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
10/24/05 18:00	10/26/05 8:00	34	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D61, D62, D66, D67, D68, D71, D72, D73	20	1.12	1.34	0.98	0.20	0.009	0.002	0.449	0.068
11/6/05 21:00	11/7/05 1:00	2	D40, D47, D51	3	0.07	0.10	0.04	0.09	0.012	0.000	0.020	0.000
11/10/05 1:00	11/10/05 14:00	11	D37, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D62, D64, D68, D71	14	0.19	0.31	0.15	0.27	0.009	0.000	0.058	0.005
11/16/05 17:00	11/17/05 9:00	9	D37, D38, D39, D40, D41, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	0.99	1.09	0.79	0.31	0.012	0.002	0.465	0.259
11/21/05 16:00	11/22/05 20:00	22	D37, D38, D39, D40, D41, D43, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D71, D72, D73	25	0.97	1.11	0.81	0.21	0.009	0.002	0.454	0.101

Rainfall Events			SEDD CSO Regulators Overflowing		SEDD Rain Gage Rainfall Depth Statistics					SEDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
11/29/05 17:00	11/30/05 10:00	10	D37, D38, D39, D40, D41, D43, D44, D45, D46, D47, D48, D50, D51, D51A, D52, D54, D58, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73	30	0.97	1.39	0.74	0.34	0.009	0.002	0.371	0.233
12/4/05 12:00	12/4/05 22:00	8	D37, D47, D51	3	0.16	0.25	0.05	0.06	0.009	0.000	0.088	0.001
12/9/05 8:00	12/9/05 22:00	12	D37, D40, D47, D51, D51A, D68, D71, D73	8	0.25	0.41	0.13	0.11	0.013	0.001	0.120	0.004
12/15/05 18:00	12/16/05 15:00	13	D37, D38, D39, D40, D41, D44, D45, D47, D48, D51, D51A, D58, D61, D62, D63, D65, D66, D67, D68, D69, D70, D71, D72, D73	24	1.20	1.43	1.01	0.28	0.009	0.003	0.502	0.229
12/25/05 13:00	12/26/05 12:00	20	D37, D38, D39, D40, D41, D44, D47, D48, D51, D51A, D61, D62, D66, D67, D68, D71, D73	17	0.58	0.70	0.51	0.18	0.013	0.002	0.225	0.029
12/29/05 7:00	12/29/05 23:00	15	D37, D40, D47, D51, D51A, D61, D71	7	0.35	0.37	0.34	0.08	0.013	0.001	0.144	0.002
12/31/05 14:00	12/31/05 19:00	3	D40, D47, D51, D51A	4	0.12	0.13	0.10	0.08	0.009	0.000	0.038	0.000

Table v4.2.3 SWDD Response to Wet Weather Conditions

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/3/05 18:00	1/4/05 6:00	12	R01, R01A, R02, R04, R05, S04, S06, S16, S20, S33, S42A	11	0.07	0.12	0.05	0.05	0.001	0.001	0.017	0.000
1/5/2005	5:00 AM	42	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	40	0.95	1.22	0.76	0.39	0.001	0.017	0.381	0.059
1/7/2005	3:00 AM	27	C06, C09, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	52	0.44	0.57	0.35	0.18	0.001	0.007	0.164	0.053

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/11/2005	11:00 AM	11	C06, C11, C12, C14, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	42	0.46	0.59	0.36	0.17	0.001	0.007	0.176	0.062
1/13/2005	2:00 PM	15	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	77	1.70	1.85	1.56	0.46	0.001	0.035	0.798	0.587

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
1/25/2005	1:00 AM	32	C06, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S44, S50	29	0.57	0.59	0.57	0.11	0.01	0.006	0.207	0.030
2/2/2005	8:00 PM	5	R01A, R04, S04, S20, S42A	5	0.06	0.06	0.06	0.02	0.01	0.001	0.015	0.000
2/4/2005	11:00 PM	8	R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S42A, S50	17	0.33	0.35	0.33	0.06	0.013	0.004	0.133	0.018
2/9/2005	9:00 AM	10	R01A, R02, R04, R05, S04, S20, S42A	7	0.07	0.13	0.04	0.05	0.001	0.002	0.017	0.000
2/14/2005	7:00 AM	15	C06, C11, C12, C13, C14, C17, C22, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	45	1.00	1.41	0.83	0.18	0.001	0.020	0.403	0.152

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
2/16/2005	12:00 AM	3	C06, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S50	29	0.19	0.26	0.14	0.18	0.02	0.003	0.070	0.015
2/21/2005	7:00 AM	16	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	31	0.58	0.58	0.58	0.09	0.01	0.009	0.234	0.055
2/25/2005	10:00 PM	4	C06, C17, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	27	0.23	0.23	0.23	0.10	0.02	0.004	0.090	0.018
2/26/2005	5:00 PM	4	R01A, R04, R05, S04, S20, S42A	6	0.06	0.06	0.06	0.02	0.01	0.002	0.015	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/1/2005	6:00 AM	8	C06, C11, C12, C17, C28A, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	43	0.48	0.50	0.47	0.19	0.013	0.007	0.171	0.053
3/8/2005	10:00 PM	8	C06, C11, C12, C17, C29, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	38	0.40	0.45	0.36	0.16	0.001	0.008	0.158	0.045
3/11/2005	5:00 AM	6	R01, R01A, R02, R04, R05, S04, S06, S16, S20, S26, S33, S42A	12	0.09	0.11	0.07	0.06	0.002	0.001	0.028	0.001
3/20/2005	12:00 AM	20	C29, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S37, S42A, S50	19	0.34	0.43	0.25	0.09	0.001	0.004	0.121	0.007

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/23/2005	9:00 AM	27	C06, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	58	1.13	1.38	0.92	0.24	0.001	0.023	0.490	0.188

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
3/27/2005	4:00 PM	40	C04, C04A, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	70	1.55	1.74	1.34	0.31	0.001	0.036	0.663	0.325

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/1/2005	8:00 PM	69	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	83	2.82	3.19	2.54	0.59	0.001	0.078	1.232	0.825

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
4/7/2005	8:00 PM	12	C06, C09, C11, C12, C13, C14, C15, C17, C18, C19, C21, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	59	0.78	1.07	0.53	0.36	0.001	0.013	0.347	0.153

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
4/23/2005	1:00 PM	28	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	74	0.73	0.88	0.39	0.57	0.001	0.009	0.271	0.136
4/27/2005	8:00 AM	5	R01, R01A, R02, R04, R05, S04, S05, S20	8	0.09	0.17	0.03	0.09	0.001	0.001	0.019	0.000
4/27/2005	9:00 PM	5	S31, S36A, S37, S42A	4	0.04	0.16	0.01	0.09	0.001	0.000	0.005	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
4/30/2005	8:00 PM	29	C04, C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	63	1.03	1.39	0.58	0.36	0.001	0.017	0.417	0.139
5/2/2005	10:00 PM	2	R01A, R02, R04, R05	4	0.03	0.07	0.01	0.05	0.006	0.001	0.005	0.000
5/20/2005	3:00 AM	17	C06, C11, C12, C13, C14, C17, C22, C24, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	46	0.88	1.02	0.67	0.19	0.001	0.010	0.341	0.150
5/21/2005	1:00 AM	1	S16, S18, S26, S42A	4	0.03	0.10	0.01	0.10	0.005	0.000	0.005	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
5/28/2005	9:00 PM	2	R04, S10, S12, S16, S18, S23, S26, S36A, S42A	9	0.05	0.13	0.01	0.13	0.007	0.000	0.009	0.001
6/3/2005	1:00 PM	30	C06, C11, C12, C14, C17, C22, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	42	0.79	0.93	0.66	0.13	0.001	0.012	0.333	0.092

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/6/2005	9:00 PM	9	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	1.16	1.77	0.73	1.41	0.009	0.013	0.647	0.563

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/10/2005	5:00 AM	5	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	83	0.60	0.83	0.25	0.60	0.001	0.004	0.320	0.228

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/16/2005	1:00 AM	5	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, C33, C34, C35, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S50	64	0.20	0.51	0.01	0.47	0.001	0.001	0.107	0.066
6/22/2005	1:00 AM	5	C06, C17, C18, C19, C22, C25, C28A, C29, C30, R01, R01A, R02, R03, R04, R05, R06, S04, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	44	0.17	0.73	0.01	0.72	0.002	0.001	0.060	0.023

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
6/27/2005	11:00 AM	26	C06, C09, C11, C12, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	47	0.64	0.96	0.38	0.24	0.001	0.006	0.241	0.061
6/29/2005	3:00 AM	3	S05, S06, S10, S11, S12, S12A, S13, S15, S16, S17, S18, S19, S21, S23, S24, S25, S26, S31, S36A, S37, S42A	21	0.06	0.63	0.01	0.62	0.001	0.001	0.023	0.009

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/1/2005	8:00 PM	18	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	81	0.81	1.97	0.44	0.96	0.004	0.009	0.298	0.220

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
7/5/2005	9:00 AM	12	C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	73	0.58	1.02	0.26	0.80	0.003	0.008	0.258	0.146

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/7/2005	12:00 PM	18	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	87	2.01	2.75	1.38	0.85	0.005	0.029	1.038	0.758
7/12/2005	11:00 PM	2	C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, R01, R01A, R02, R03, R04, R05, R06, S20, S24, S26, S31, S32, S33, S36A, S37, S38, S42, S42A, S44, S45, S46	32	0.12	0.75	0.01	0.71	0.006	0.001	0.038	0.012

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/13/2005	8:00 PM	1	S42A	1	0.01	0.06	0.00	0.06	0.001	0.000	0.001	0.000
7/14/2005	9:00 PM	2	C06, R01A, R02, R04, R05	5	0.03	0.15	0.00	0.08	0.001	0.000	0.004	0.000
7/15/2005	8:00 PM	74	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	85	1.80	2.45	0.79	1.37	0.001	0.034	0.887	0.678
7/25/2005	1:00 PM	9	C06, R01, R01A, R02, R04, R05, S04, S05, S06, S16, S20, S26, S33, S42A	14	0.12	0.20	0.08	0.09	0.007	0.001	0.024	0.001

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
7/27/2005	6:00 AM	4	C06, C17, R01, R01A, R02, R04, R05, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	24	0.13	0.17	0.08	0.09	0.003	0.001	0.038	0.005
8/4/2005	12:00 AM	3	C11, C12, C17, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S22, S33, S50	25	0.05	0.43	0.00	0.43	0.001	0.000	0.041	0.023
8/8/2005	5:00 PM	29	C06, C11, C12, C17, C18, C22, C25, C28A, C29, C30, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	54	0.69	1.39	0.20	0.94	0.001	0.005	0.216	0.085

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
8/15/2005	5:00 PM	56	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	1.50	1.79	0.86	1.27	0.003	0.014	0.732	0.520
8/19/2005	4:00 PM	3	R01, R01A, R02, R04, R05	5	0.03	0.06	0.01	0.04	0.009	0.000	0.004	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
8/27/2005	5:00 PM	26	C01, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C19, C20, C21, C22, C24, C25, C28A, C29, C30, C31, C32, C33, C34, C35, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S32, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	75	0.70	1.09	0.30	0.61	0.002	0.007	0.300	0.189
8/29/2005	1:00 AM	2	C28A, C29, R04, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42A, S50	37	0.18	0.68	0.01	0.63	0.009	0.001	0.054	0.024

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
9/14/2005	9:00 PM	29	C01, C04, C04A, C05, C06, C07, C09, C11, C12, C13, C17, C31, C32, C33, C34, C37, R01, R01A, R02, R03, R04, R05, R06, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42, S42A, S44, S46, S50	61	0.79	2.25	0.08	0.95	0.001	0.004	0.213	0.101
9/17/2005	12:00 AM	2	C06, R01A, R02, R04, R05, S05, S16	7	0.06	0.36	0.01	0.34	0.01	0.001	0.009	0.000
9/26/2005	5:00 AM	8	C06, C09, C11, C12, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S02, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42, S42A, S45, S50	34	0.19	0.22	0.15	0.18	0.007	0.002	0.072	0.018
9/29/2005	5:00 PM	3	R01, R01A, R02, R04, R05, S04, S06, S16, S18, S20, S26, S33, S36A, S42A	14	0.07	0.08	0.05	0.05	0.002	0.001	0.015	0.001

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
10/6/2005	11:00 PM	2	C06, C09, C31, R01, R01A, R02, R04, R05	8	0.02	0.13	0.01	0.13	0.009	0.000	0.005	0.000
10/7/2005	8:00 PM	66	C01, C02, C04, C04A, C05, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28A, C29, C30, C31, C32, C33, C34, C35, C36, C37, R01, R01A, R02, R03, R04, R05, R06, R12R, R24, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S30, S31, S32, S33, S35, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50, S51	88	3.47	3.73	2.90	1.25	0.001	0.050	1.935	1.506

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
10/11/2005	3:00 AM	98	C06, C11, C12, C17, C29, C31, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S07, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S42, S42A, S44, S45, S50	48	1.19	1.54	0.94	0.32	0.003	0.013	0.402	0.074
10/21/2005	7:00 AM	40	C06, C07, C09, C10, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	57	1.18	1.35	1.02	0.29	0.007	0.014	0.465	0.115

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
10/24/2005	4:00 PM	43	C06, C17, C22, C28A, C29, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	41	1.12	1.34	0.99	0.20	0.008	0.011	0.438	0.084
11/6/2005	6:00 AM	2	C06, C17, C22, C28A, C29, R01, R01A, R02, R03, R04, R05, R06, S04, S05, S06, S10, S11, S12, S14, S16, S18, S20, S23, S24, S26, S31, S33, S36A, S37, S42A	30	0.08	0.12	0.04	0.12	0.012	0.001	0.026	0.003
11/10/2005	5:00 PM	11	C06, C09, C11, C12, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	50	0.20	0.32	0.14	0.27	0.009	0.002	0.067	0.022

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
11/16/2005	12:00 PM	16	C04, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	65	1.00	1.09	0.79	0.33	0.008	0.010	0.435	0.253
11/21/2005	10:00 PM	23	C06, C09, C11, C12, C13, C14, C17, C18, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S42, S42A, S44, S45, S50	50	0.95	1.11	0.81	0.21	0.008	0.012	0.393	0.110
11/24/2005	7:00 PM	3	S42A	1	0.02	0.05	0.01	0.05	0.009	0.000	0.002	0.000

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
11/29/2005	9:00 AM	16	C04, C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C23, C24, C25, C28A, C29, C30, C31, C32, C33, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S31, S33, S36, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	66	0.94	1.39	0.74	0.34	0.002	0.011	0.388	0.237
12/4/2005	8:00 AM	24	R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S42A, S50	17	0.20	0.34	0.05	0.09	0.002	0.002	0.082	0.006
12/6/2005	6:00 PM	6	R01, R01A, R02, R04, R05, S04, S20, S33, S42A	9	0.07	0.10	0.02	0.04	0.002	0.000	0.024	0.000
12/9/2005	10:00 PM	12	C06, C17, C29, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S26, S33, S36A, S37, S42A, S44, S50	22	0.28	0.48	0.13	0.16	0.003	0.003	0.104	0.010

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	End Time	Duration (hrs)	List	Count	Average Depth (inches)	Max Depth (inches)	Min Depth (inches)	Max Intensity (in/hr)	Min Intensity (in/hr)	RDI/I (inches)	Runoff (inches)	Overflow (inches)
12/11/2005	3:00 AM	16	R01, R01A, R02, R04, R05, S04, S05, S06, S16, S20, S26, S33, S42A	13	0.10	0.21	0.01	0.05	0.009	0.001	0.050	0.002
12/15/2005	1:00 PM	14	C06, C07, C09, C10, C11, C12, C13, C14, C15, C17, C18, C22, C24, C25, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S38, S42, S42A, S44, S45, S46, S50	57	1.21	1.43	1.01	0.28	0.009	0.020	0.499	0.259
12/25/2005	1:00 AM	34	C06, C07, C09, C10, C11, C12, C13, C17, C22, C28A, C29, C30, C31, C32, R01, R01A, R02, R03, R04, R05, R06, S01, S02, S04, S05, S06, S08, S09, S10, S11, S12, S12A, S14, S16, S18, S20, S22, S23, S24, S25, S26, S31, S33, S36A, S37, S38, S42, S42A, S44, S45, S50	51	0.62	0.73	0.52	0.25	0.003	0.007	0.250	0.075

Rainfall Events			SWDD CSO Regulators Overflowing		SWDD Rain Gage Rainfall Depth Statistics					SWDD Flow Depth Values		
Start Time	**End Time**	**Duration (hrs)**	**List**	**Count**	**Average Depth (inches)**	**Max Depth (inches)**	**Min Depth (inches)**	**Max Intensity (in/hr)**	**Min Intensity (in/hr)**	**RDI/I (inches)**	**Runoff (inches)**	**Overflow (inches)**
12/29/2005	2:00 AM	15	C17, R01, R01A, R02, R04, R05, S04, S05, S06, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	21	0.37	0.46	0.31	0.09	0.012	0.004	0.143	0.015
12/31/2005	11:00 PM	3	C06, C17, C29, R01, R01A, R02, R03, R04, R05, S04, S05, S06, S10, S11, S14, S16, S18, S20, S23, S26, S31, S33, S36A, S37, S42A, S50	26	0.11	0.13	0.10	0.10	0.009	0.001	0.037	0.004

4.3 ALTERNATIVE MODEL DEVELOPMENT

The alternative model was built using the baseline model as its foundation. Some changes were made to the baseline models to represent the projects that are in the process of being implemented. The alternative models that were developed with these changes in them form the basis of various analyses that were performed for the LTCPU.

v4.3.1 WPCP Expansion

LTCPU Section 8 Infrastructure-Based Control Measures describes the WPCPs and their expansion scenarios. More information on the stress testing of the WPCPs can be found in Supplemental Documentation Volumes 6, 7 and 8. More information on the WPCP Wet Weather Treatment Alternatives can be found in Supplemental Documentation Volumes 9, 10 and 11.
Based on these studies the WPCP capacities for each of the drainage district were chosen.

For the alternative model the WPCP treatment rates 330 mgd, 650 mgd and 540 mgd were chosen for the SEWPCP, NEWPCP and SWWPCP respectively.

For the SEDD and SWDD these treatment rates can be delivered to the respective WPCP with minor improvements. For the SEDD the treatment rate at SEWPCP can achieved by process improvements and improvements to the influent pumping at SEWPCP. For the SWDD the treatment rate at SWWPCP can achieved by improvements at the SWWPCP. For the NEDD two additional barrels would need to be built to deliver the flow from the high level interceptor system to achieve peak flow of 650 mgd at the NEWPCP.

The alternative models were developed to include the above changes so as to achieve the peak treatment flow at each of the WPCPs.

v4.3.2 Infrastructure Improvements

The following infrastructure improvements have been included in all alternatives evaluated as part of the LTCPU.

Indian Creek Daylighting In-System Storage

The project is located in the Cobbs Creek Watershed at the confluence of the East Branch Indian Creek and the West Branch Indian Creek. Currently the West Branch Indian Creek flows into a culvert within which the outfall of CSO regulator C_05 discharges before merging with the East Branch Indian Creek to form the main stem of Indian Creek. The proposed project will divert the creek out of the culvert and restore the surrounding stream channel. The approximately 700 feet of 6' x 6' culvert will now be over-sized for conveying CSO flows from regulator C_05 and will be modified to allow storage of a majority of this flow during wet weather and release to the collection system for treatment at the SW WPCP as capacity becomes available.

T14 Real-Time-Control In-System Storage

CSO outfall T14 is a very large sewer (21' by 24') that discharges into the Tacony Creek during periods of moderate to heavier rainfall. The T14 combined trunk sewer has a volume of approximately 10 million gallons upstream of the regulator chamber. To use as much of this storage as possible, a control structure is needed in the sewer. Installation of a crest gate is proposed in order to retain flow within the sewer. This gate will reduce CSO discharges to the creek by utilizing the sewer for in-system storage. This control technology provides an additional margin of protection against wet weather discharges while maintaining flood protection for upstream communities. The crest gate retains the stored flow in the sewer and a new connector pipe and control gates drain the stored flow for treatment at the NE WPCP as capacity becomes available.

Rock Run Relief Real-Time-Control In-System Storage

The Rock Run Relief Sewer provides flood relief to combined sewersheds in PWD's Northeast Drainage District (NEDD). The Rock Run Relief structure, R15, is a side overflow weir which diverts wet weather flows into the Rock Run Relief Sewer at R15 once flow levels exceed the diversion weir height. This proposed project will utilize approximately 2.3 MG of the 11 ft diameter relief sewer for storage of combined sewer flows through a control structure, inflatable dam or hydraulic gate, constructed within the outfall pipe along with a new connector pipe to the Tacony Interceptor and control gate to drain the flow for treatment at the NE WPCP as capacity becomes available.

v4.3.3 Waterfront Disconnection

Currently, stormwater runoff from the two interstate highways (I-95 and I-76) along Philadelphia's riverfronts is discharged to the combined sewer system, using wet weather capacity and increasing overflow from sewersheds along the waterfronts. The area represented by I-95 is approximately 2.1% of impervious area in the Delaware Direct watershed. Currently, the Pennyslvania Department of Transportation has plans to expand the capacity of a portion of I-95 by adding new lanes. This major construction project provides an opportunity to incorporate a stormwater management component concurrently with the transportation component. In this concept, stormwater runoff from new and existing lanes will be diverted from the combined sewer system. New separate storm sewers will be constructed from I-95 to the waterfront, with appropriate stormwater quality treatment included as appropriate. This infrastructure can be sized to accommodate not just runoff from the highway, but runoff from future redevelopment projects along the waterfront.

Interstate Highways and Waterfront Land

ArcGIS was used to identify the areas between the highway and the river. The highway area was also identified. Properties located close to the Delaware and Schuylkill waterfronts present opportunities for sewer separation, appropriate pretreatment of stormwater and direction of stormwater to public or private permitted outfalls. It is important to note the same land-based stormwater management techniques being considered for the combined sewer system can function as pretreatment for runoff entering a separate storm sewer system. This runoff would no longer be included in PWD's CSO management program but would continue to be managed through PWD's larger stormwater and watershed management programs.

Table v4.3.1 lists the "waterfront" drainage area currently draining to combined sewers. Waterfront can be defined in one of two ways. Defined as all land between interstate highways and rivers, it comprises approximately 4% of combined drainage area. This percentage is highest in the southeast drainage district at 7%. Defined more narrowly as the area between combined sewer regulator structures and the river, the waterfront area comprises approximately 2% of drainage area. There is also a long-term potential to disconnect the interstate highways themselves from the combined sewer system.

Table v4.3.1 Distribution of Waterfront Land

Land Location	Combined-Sewered Impervious Area (ac)				Combined-Sewered Impervious Area (% of total)			
	City-Wide	SED D	NED D	SWD D	City-Wide	SED D	NED D	SWD D
Non-Waterfront	43,414	8,700	20,060	14,654	95.8	91.5	98.4	94.9
Between Regulator Structures and Rivers	681	157	245	279	1.6	1.8	1.2	1.9
Between Major Highways and Rivers	1,507	578	234	695	3.5	6.6	1.2	4.7
Highway	315	165	94	56	0.7	1.9	0.5	0.4
Waterfront + Highway	1,822	743	327	752	4.2	8.5	1.6	5.1

v4.3.4 Green Stormwater Infrastructure Model Details

Philadelphia's stormwater regulations require a minimum level of performance from post-construction stormwater management structures. Rather than focusing on differences in structure between different land-based practices, we will assume that an appropriate practice or mix of practices can be designed to meet this level of performance. We will model a generic structure that meets management goals through some combination of storage, infiltration and slow release.

To improve modeling efficiency, stormwater management will be modeled separately from combined sewer system hydraulics. Outflow hydrographs from stormwater management structures will be used as inflow hydrographs for the sewer system. This section describes sizing and configuration of model elements that will approximate the requirements of the Philadelphia stormwater regulations.

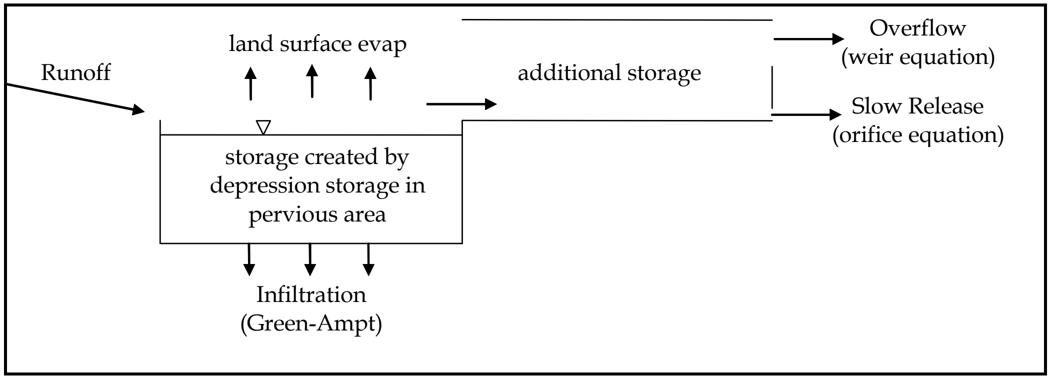


Figure v4.3.1 Conceptual Diagram of Modeling Approach

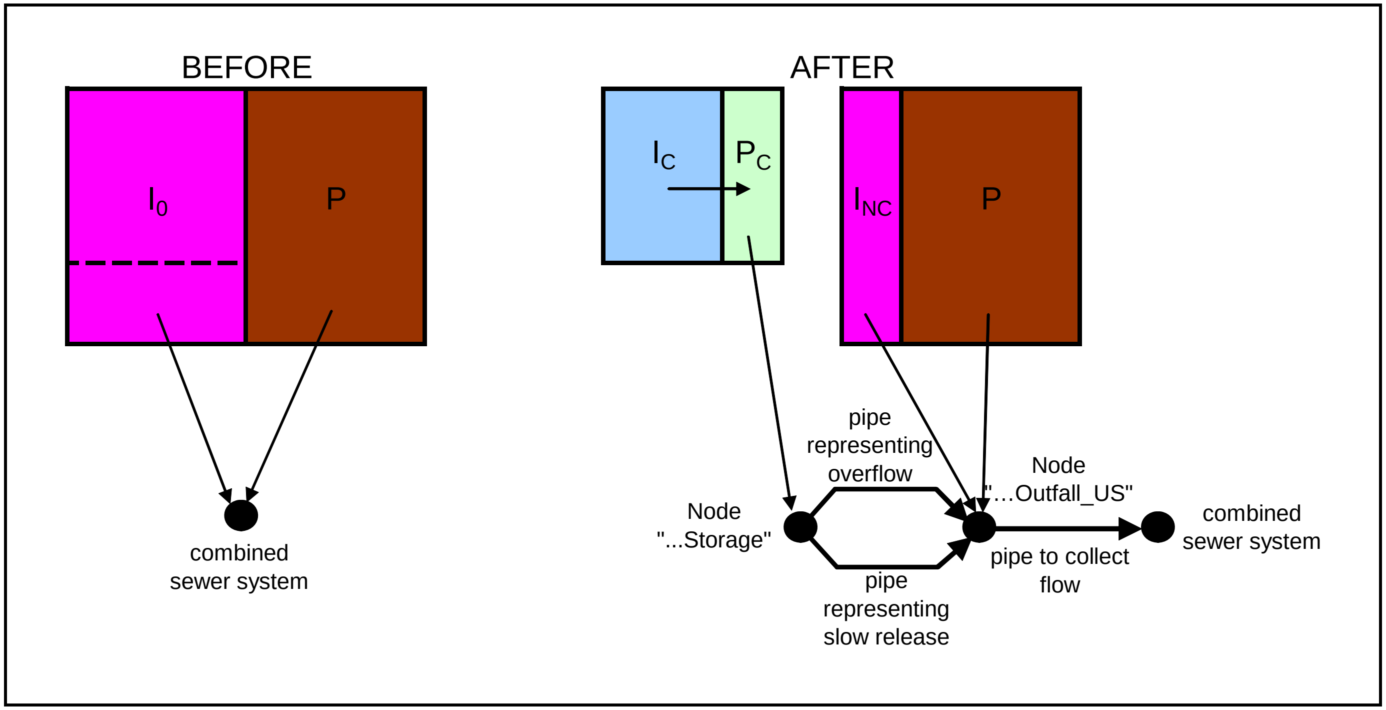


Figure v4.3.2 Schematic Diagram of Modeling Approach

Identified in the schematic diagram above, portions of the subcatchments are divided up and labeled as follows:

I_0 = impervious area of original model subshed (ac)
P = pervious area of original subshed (ac)
I_C = impervious area draining to stormwater controls (ac)
P_C = bottom area of stormwater controls (ac)
I_{NC} = impervious area not draining to controls (ac)

The portion of the impervious drainage area to be controlled is calculated. The area to be occupied by stormwater control structures is included in this area.

$$(I_C + P_C) = I_0 \text{ x } X$$

Where X = percentage of original impervious area to be controlled, designated by the user

Next, the bottom area of stormwater controls and the impervious drainage area can be calculated.

$$P_C = (I_C + P_C) / (R + 1)$$
$$I_C = R \text{ x } P_C$$

Where R = ratio of controlled impervious area to stormwater control bottom area , designated by the user

Next, the impervious area not draining to controls is calculated.

$$I_{NC} = I_0 – I_C – P_C$$

In SWMM, these numbers are entered as percent impervious and total area.

Total area (controlled) = $I_C + P_C$
Total area (not controlled) = $I_{NC} + P$
Percent impervious (controlled) = $I_C / (I_C + P_C)$
Percent impervious (not controlled) = $I_{NC} / (I_{NC} + P)$

The Philadelphia Stormwater Regulations require control of a water quality volume equal to 1.0 inch of runoff from the directly connected impervious area. This volume includes two components, an infiltration volume and a treat-and-release volume. The infiltration volume is the minimum of the water quality volume or the volume that can be infiltrated in an acceptable period.

$$V_I = \min\left[\left(V_{WQ} \text{ x } I_c \text{ x } (43{,}560\text{ ft}^2/\text{ac}) \text{ x } (1\text{ ft}/12\text{ in})\right), \left(P_C \text{ x } K_{sat} \text{ x } T \text{ x } (43{,}560\text{ ft2/ac}) \text{ x } (1\text{ ft}/12\text{ in})\right)\right]$$

Where V_I = infiltration volume (ft^3)
V_{WQ} = water quality volume = 1.0 in
K_{sat} = saturated vertical hydraulic conductivity of soil under stormwater control (in/hr)
T = allowable time for standing water to infiltrate soil, designated by user (hr)

The infiltration volume determines depression storage in the pervious area representing stormwater controls.

$$D_C = [V_I / (P_C \text{ x } 43{,}560 \text{ ft}^2/1 \text{ ac})] \text{ x } (12 \text{ in}/1 \text{ ft})$$

Where D_C = depression storage in pervious area representing stormwater controls (in)

The treat-and-release volume is the difference between the water quality volume and infiltration volume, if any. This volume is represented in the model as a storage node, with orifice and weir controls on its outflow, which will only receive runoff after depression storage is full. The weir height (difference between invert and overflow elevation) of this pipe is designated by the user and the cross-sectional area is calculated to give the required storage volume.

$$V_{TR} = (V_{WQ} \text{ x } I_C \text{ x } 43{,}560 \text{ ft}^2/\text{ac x } 1 \text{ ft}/12 \text{ in}) – V_I$$
$$A_N = V_{TR} / H_w$$

Where A_N = surface area of storage element (ft^2)
V_{TR} = treat-and-release volume (ft^3)
H_W = weir height in storage node, designated by user (ft)

A weir control is added to allow larger storms to overflow the storage element. This discharge is assumed to receive no significant detention or water quality treatment. The total height of the storage element is set at an arbitrary value greater than the weir height to allow high flows to exit the storage element unimpeded.

The stormwater regulations designate an allowable release rate for the treat-and-release volume in combined-sewered areas, based on 24-hour detention of a reference volume equal to runoff from a 1-year, 24-hour storm. The average allowable release rate is calculated as this volume released over 24 hours:

$$Q_{ave} = [(2.64 \text{ in}) / (24 \text{ hrs})] \text{ x } (1 \text{ ft}/12 \text{ in}) \text{ x } (43{,}560 \text{ ft}^2/\text{ac}) \text{ x } (1 \text{ hr}/3600 \text{ s}) = 0.11 \text{ cfs/ac}$$

Where Q_{ave} = allowable average controlled release rate per acre of impervious drainage area

It is assumed that with a submerged orifice control, the peak release rate is approximately twice the average:

$$Q_{peak} \sim 2 \text{ x } Q_{ave} = 0.22 \text{ cfs/ac}$$

Where Q_{peak} = maximum allowable controlled release rate per acre of impervious drainage area

An orifice control sufficient to provide this level of detention can be estimated by solving the submerged orifice equation.

$$D_O = (4\, A_O / \pi) \text{ ^ } (1/2)$$

Where A_{ref} = cross-sectional area of the storage node if it were required to store this volume (ft^2)
A_O = area of orifice to release reference volume in targeted time (ft^2)

C_D = submerged orifice discharge coefficient, designated by user (dimensionless)
g = gravitational constant (ft/s^2)
D_O = orifice diameter (ft)

EXTRAN converts the slow-release orifice to an equivalent pipe with a diameter equal to the orifice diameter. The model automatically lowers the invert of this pipe to approximately simulate a bottom-discharge orifice and calculates a roughness coefficient (assuming flow given by Manning's equation and slope equal to the change in head divided by the change in length) to provide approximately the same head loss that would have been provided by an orifice. To prevent backwater affects on the orifice from non-LID sheds loading to the downstream node of the storage pipe, the invert elevation of the upstream storage node is increased by 30' and an offset equal to the increase is added to the downstream node of the storage pipe to keep the slope parameters intact. Any offset existing at the upstream storage node was removed. The orifice control is modeled as a static orifice without gated controls.

The stormwater regulations require management of a channel protection volume on some sites. Management of this volume does not require storage of the entire volume and management of the water quality volume meets part of this requirement. The approach below is based on a practical interpretation of how these controls might be designed by site engineers, assuming a relatively lenient interpretation of the requirement.

Runoff during the most intense 30 minutes of a 1-yr, 24-hour NRCS Type II event will be approximately as follows:

$$Q_{runoff} = (0.306) / (0.5 \text{ hrs}) = 1.62 \text{ in/hr} = 1.63 \text{ cfs/ac}$$

The NRCS approximate method of reservoir routing (Urban Hydrology for Small Watersheds, Figure 6-1) suggests that a storage volume equal to 52% of the runoff volume will be needed to reduce the peak runoff to the allowable peak release rate. This storage volume is calculated and the water quality volume is subtracted to determine additional storage needed to meet the channel protection requirement. This volume is added to the volume in the storage element. The orifice control is not changed.

Total storage volume required = 52% x 2.64 in = 1.37 in

$$V_{ch\text{-}add} = (1.37 \text{ in} - 1.00 \text{ in}) \times (1 \text{ ft}/12 \text{ in}) \times I_C \times (43{,}560 \text{ ft}^2/1 \text{ ac}) \times I_{ch}$$

$$A_{ch\text{-}add} = V_{ch\text{-}add} / H_W$$

Where $V_{ch\text{-}add}$ = additional volume to be added to storage element (ft^3)
I_{ch} = portion of controlled impervious area subject to channel protection requirement (%)
$A_{ch\text{-}add}$ = additional cross-sectional area to be added to storage element (ft^2)

In the special case where infiltration is sufficient to manage the entire water quality volume and no additional channel protection volume is required, the surface area of the storage pipe is set arbitrarily to 50 ft^2 and the orifice diameter is set to 10 ft. These settings should be sufficient to allow effectively uncontrolled flow through the storage element.

Validation of Prototype EXTRAN Model

Single-Subshed, Constant-Inflow Case
RUNOFF and EXTRAN elements were set up for a single subshed ('47TH-ST') according to the equations in the previous section, with 50% of impervious cover served by LID. Based on impervious cover (1.15 ac), the peak allowable slow release flow was calculated (0.22 cfs/ac x 1.15 ac = 0.253 cfs). A constant flow of 0.300 cfs was introduced to the storage element. Once the storage element reached equilibrium under this condition, flow in the controlled release orifice was 0.253 cfs. Overflow reached a constant value of 0.047 cfs (0.300 cfs – 0.253 cfs) as expected.

Single-Subshed, Single-Event Comparison to Spreadsheet Solution
A hydrologic model and the same hydraulic model from the single-subshed, constant-inflow case was run with 25-yr, 24-hour NRCS Type III rainfall distribution. This distribution was chosen to test the model response to a variety of runoff intensities. At lower intensities, runoff intensity does not exceed slow release orifice capacity. When runoff intensity exceeds slow release capacity, storage begins to fill. When depth in the storage element exceeds the overflow elevation, flow occurs in the pipe representing an overflow weir.

The table below shows the SWMM RUNOFF water balance before and after application of stormwater BMPs serving all impervious cover in a subshed. As expected, infiltration increases and surface runoff decreases by approximately the same amount.

Table v4.3.2 RUNOFF Water Balance

	pre-LID		post-LID	
	cu.ft.	in	cu.ft.	in
Total Precipitation (Rain plus Snow)	117,990.00	6.501	117,990.00	6.501
Total Infiltration	40,035.60	2.206	50,269.60	2.770
Total Evaporation	357.05	0.020	388.67	0.021
Total Surface Runoff from Watersheds	77,622.50	4.277	67,347.50	3.711
Impervious Area Runoff from Watersheds......	58,654.30	6.463	0.00	0.000
Pervious Area Runoff from Watersheds........	18,968.00	2.090	18,968.00	1.941
Impervious to Pervious Area Runoff..........	0.00	0.000	54,077.40	2.979
Infiltration over the Pervious Area...	40,035.60	4.412	50,269.60	5.144

A time series of runoff was input to a spreadsheet model of a stormwater control structure that performs a mass balance of storage volume, controlled release and overflow on a one-minute time step. The algorithm followed for each time step was as follows:

1. Controlled runoff is taken from SWMM RUNOFF output.
2. Storage volume = storage volume (from previous time step) + runoff – slow release volume (from previous time step).
3. Overflow volume is the difference between storage volume and the volume of the storage element. If storage does not exceed volume of the storage element, overflow volume = 0.
4. Storage volume = storage volume (from step 2) – overflow volume.
5. Depth = storage volume (from step 4) divided by storage element cross-sectional area.
6. Slow release is calculated using the orifice diameter and submerged orifice equations discussed in the previous section.

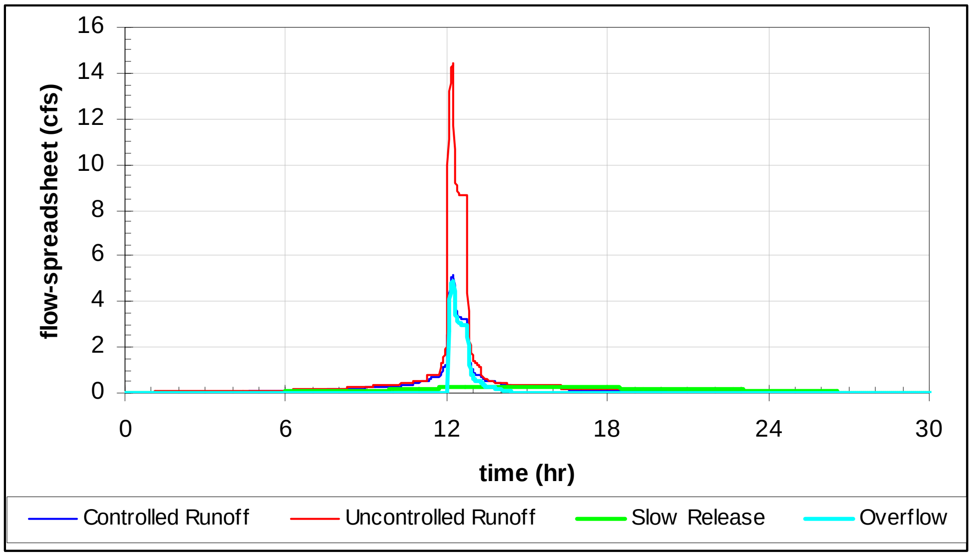


Figure v4.3.3 Spreadsheet Solution

An EXTRAN model was constructed with the same dimensions, same hydrologic input and same time step as the spreadsheet model. For the purpose of validating the SWMM model, the spreadsheet solution was assumed to be exact. In other words, the SWMM model is considered valid if it matches the spreadsheet model within a reasonable tolerance. The figure and table below compare results of the two models. Volumes and peak flows match within 1% or less, an acceptable margin of error for the application.

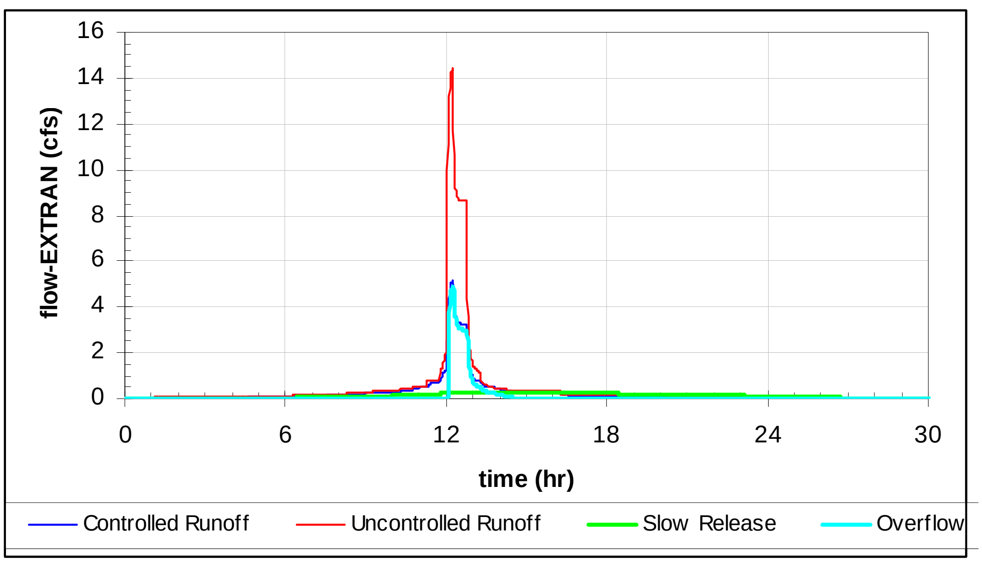


Figure v4.3.4 EXTRAN Solution

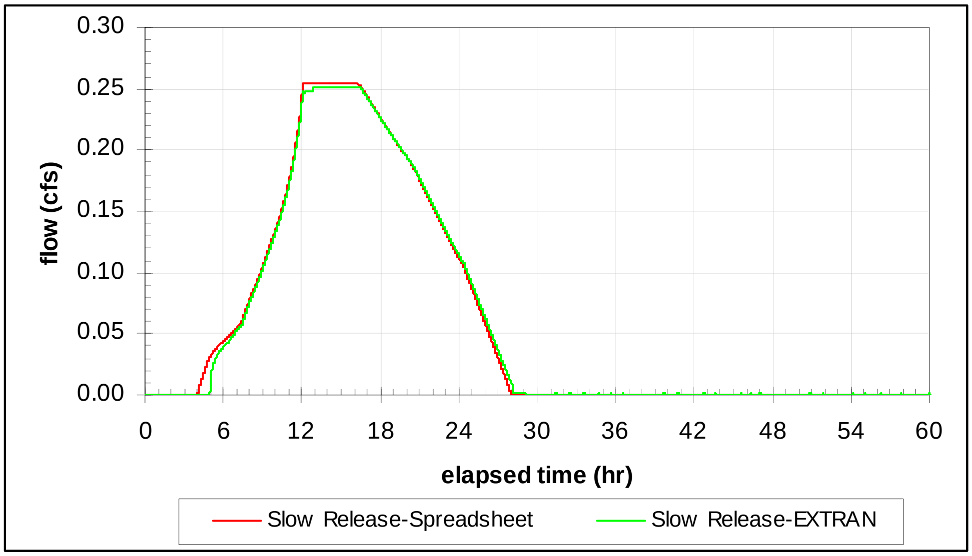


Figure v4.3.5 Comparison of Slow Release

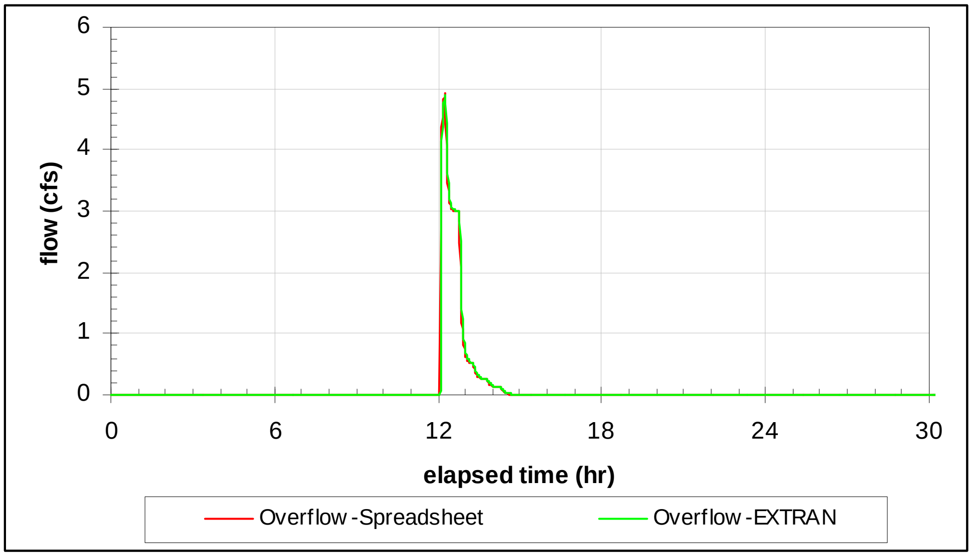


Figure v4.3.6 Comparison of Overflow

Table v4.3.3 Comparison of Volumes and Peak Flows

	spreadsheet	EXTRAN	Difference
Slow release volume (cu.ft.)	12,629	12,557	-0.57%
Overflow volume (cu.ft.)	11,565	11,587	0.19%
Peak slow release (cfs)	0.254	0.252	-0.80%
Peak slow release (cfs/ac)	0.203	0.201	-0.80%
Peak slow release (cfs/ac imperv.)	0.221	0.219	-0.80%
Peak overflow (cfs)	4.91	4.90	-0.32%
Peak overflow+slow release (cfs)	5.17	5.14	-0.44%

v4.3.5 LID Model Runs

Scenarios

- A: storage/infiltration/treatment = 1" over all impervious area not excluded
- B: storage/infiltration/treatment = 1" over all impervious area not excluded, plus 20% DCIA reduction for parcels over 1 ac and not classified as "direct drainage" as defined by stormwater program
- C: storage/infiltration/treatment = 1" over all impervious area not excluded, plus channel protection requirement for parcels over 1 ac and not classified as "direct drainage" as defined by stormwater program
- sensitivity runs
  - D: infiltrate 1" or maximum that can be infiltrated in 24 hours, whichever is less
  - E: store and slow release 1" everywhere, no infiltration
  - F: increase infiltration/water quality volume to 1.5"
  - H: partial failure – reduce infiltration rates by 50%, remove 50% of slow release orifices

Combinations

[(A, B, C = 3) x (# of runs needed to define a curve ~ 10)] + (D, E, F, H) ~ 34

Interpretation of Results

- Determine an area (or range) to be affected by the stormwater ordinance over the planning horizon.
- Adjust acreage affected by ordinance for practices that may provide a lower level of performance than the ordinance (green roofs and trees). (i.e., perform an analysis to estimate X ac served by bioretention provides the same function as Y ac covered by a green roof).
- Determine an area (or range) to be affected by incentives for private land not subject the ordinance.
- Determine an area (or range) of public land to be targeted for stormwater management.
- Evaluate results of sensitivity runs.
- Choose a single run (or set of runs) to represent source controls and produce a baseline model to be used for infrastructure evaluation projects.

v4.3.6 Deep Tunnels

For a tunnel storage alternative, CSO flows in excess of the interceptor capacity are diverted via a modified or new diversion structure to a series of secondary tunnel structures that convey flow into the storage tunnel. The approach to model the tunnels for all three districts was to simulate the tunnels as storage nodes. To model the tunnels as a storage node, the length of the tunnel to be modeled is obtained by doing a preliminary tunnel alignment. Once the length is determined models are set up for varying tunnel diameters. The tunnel is assumed to be circular.

The diameters range from 15 to 35 feet and are increased by an interval of 2.5 feet for each simulation. Using the tunnel length and the diameter a volume is calculated. Using eighty percent (80%) of the calculated volume, a storage node 20 feet deep with constant surface area is simulated.

The storage section representing the tunnel volume itself has a plan surface area that will satisfy the tunnel volume requirements. The maximum tunnel drain down rate was set so that the tunnel would drain down in 24 hours when the capacity of the WPCP is available. All the outfalls that will contribute to the tunnel are connected to the storage node. Figure v4.3.7 shows a visual representation of the tunnel in the models.

The following steps were followed to setup the models.

1. The tunnel model is built on top of the model that has all the alternatives in the LTCPU.
2. Any flow that goes over the dam in a regulator connected to the tunnel is assumed to go in the tunnel. The only exceptions are the regulators that have the computer controlled overflow gates; in these cases the flows that currently go to the receiving water are assumed to go to the tunnel.
3. All the overflows from the regulator are conveyed to the tunnel using additional conveyance conduits. The conveyance conduits were sized to not cause any backwater conditions at the regulators.
4. The bottom of the tunnel storage junction is a 10 feet high section with small plan surface area so that the tunnel volume can be drained with out causing long tails towards the end of the drain down.
5. The storage section representing the tunnel volume itself is 20 feet deep and has a plan surface area that will satisfy the tunnel volume requirements
6. There is an overflow pipe just above the storage section representing the tunnel volume (Figure v4.3.7).
7. The tunnel drain down pipe is rated to only allow a maximum flow. This maximum flow is set so that the tunnel can be drain down in 24 hours, at this rate.
8. The tunnel drain down pipe is connected to another downstream pipe that conveys the flow from the tunnel drain down and the interceptors that convey flow to the WPCP in the given drainage district. The pipe that combines both these flows is rated to deliver a maximum flow to which each of the WPCPs will be expended to. This final pipe is also setup in a way that the flow from the interceptors is given priority over the tunnel drain down.
9. The tunnel will only drain down when there is capacity left over at the WPCP after the flows from the existing interceptors are treated.

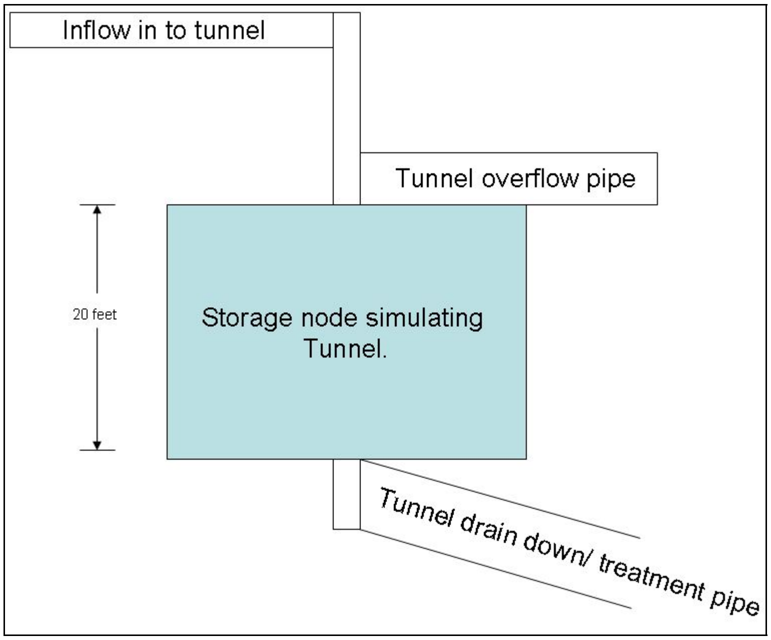


Figure v4.3.7 Storage depicting the tunnel

The volume captured by the tunnel over the course of a one-year simulation was calculated as the difference between the overflow produced from the simulated tunnel scenario and the corresponding baseline scenario. There are two baseline scenarios, each representing the upper and lower boundary of an uncertainty range for DCIA, baseflow and RDI/I watershed characteristics. Each baseline scenario has the interceptors draining to the plant with pumping boundary conditions limiting the high level interceptors' inflow into the WPCP. The baseline plant capacities for the SEDD, NEDD and SWDD are 280, 435 and 480 MGD, respectively.

SEDD Tunnel

The SEWPCP was assumed to be expanded to treat 330 MGD. The total length of the tunnel, excluding the drain down section, is 5.9 miles. The inflow into the tunnel model is the total flow produced from each regulator's outfall. Table 4.3.4 presents the tunnel length and corresponding volume of the storage node for the SEDD tunnel. The volumes shown in the first row represent the total tunnel volume and the second row shows the 80% tunnel volume that was used for the simulations.

Table v4.3.4 Length Volume and Drain down Data for the SEDD Tunnel Model

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	41.4	56.4	73.7	93.2	115.1	139.3	165.8	194.6	225.6
Volume used For simulation	33.2	45.1	58.9	74.6	92.1	111.4	132.6	155.6	180.5
Peak Tunnel Drain Down rate (MGD)	33.2	45.1	58.9	74.6	92.1	111.4	132.6	155.6	180.5

NEDD tunnel

It was assumed the NEWPCP will be expanded to treat 650 MGD. The total NEDD tunnel length is estimated to be 10 miles. The tunnel length along the Delaware was estimated as 5.3 miles and along Tacony as 4.7 miles. The tunnel for the NEDD was simulated as one storage node as it is also assumed that the tunnel along the Tacony and Delaware in the NEDD are interconnected. Table v4.3.5 presents the tunnel length and corresponding volume of the storage node. The volumes shown in the first row are the total volumes of the tunnel and the 80% volume used for simulations is presented in the second row.

Table v4.3.5 Length Volume and Drain down Data for the NEDD Tunnel Model.

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	70.1	95.4	124.6	157.7	194.7	235.6	280.3	329	381.6
Volume used For simulation	56.1	76.3	99.7	126.2	155.7	188.5	224.3	263.2	305.3
Peak Tunnel Drain Down rate (MGD)	56.1	76.3	99.7	126.2	155.7	188.5	224.3	263.2	305.3

The NEDD also includes all regulators draining to the Upper Frankford Low Level (UFLL), Lower Frankford Low Level (LFLL) and the Pennypack (PP) interceptor systems in addition to the regulators draining to the UDLL, SOM and TAC interceptor systems. The overflow from the regulators along these interceptor systems were conveyed to the tunnel.

SWDD tunnel

It is assumed the SWWPCP will be expanded to treat 540 MGD. The total SWDD tunnel length is estimated to be 13.7 miles. The tunnel length along the Schuylkill was estimated as 6.4 miles and along Cobbs Creek as 7.3 miles. The tunnel for the SWDD was simulated as one storage node; it is also assumed that the tunnel along the Cobbs Creek and Schuylkill River in the SWDD are interconnected. Table v4.3.6 presents the tunnel length and corresponding volume of the storage node. The volumes shown in the first row are the total volumes of the tunnel and the 80% volume used for simulations is presented in the second row.

Table v4.3.6 Length Volume and Drain down data for SWDD Tunnel.

	Tunnel Diameter (ft)								
	15	17.5	20	22.5	25	27.5	30	32.5	35
	Tunnel volume (Million Gallons)								
Tunnel Volume	95.9	130.5	170.4	215.7	266.3	322.2	383.4	450	521.9
Volume used For simulation	76.7	104.4	136.3	172.5	213	257.8	306.7	360	417.5
Peak Tunnel Drain Down rate (MGD)	76.7	104.4	136.3	172.5	213	257.8	306.7	360	417.5

The SWDD includes all regulators draining to the Central Schuylkill East Side (CSES), Central Schuylkill West Side (CSWS), Lower Schuylkill West Side (LSWS), Southwest Main Gravity (SWMG), Cobbs Creek High Level (CCHL) and the Cobbs Creek Low Level (CCLL). The overflow from the regulators along these interceptor systems were conveyed to the tunnel.

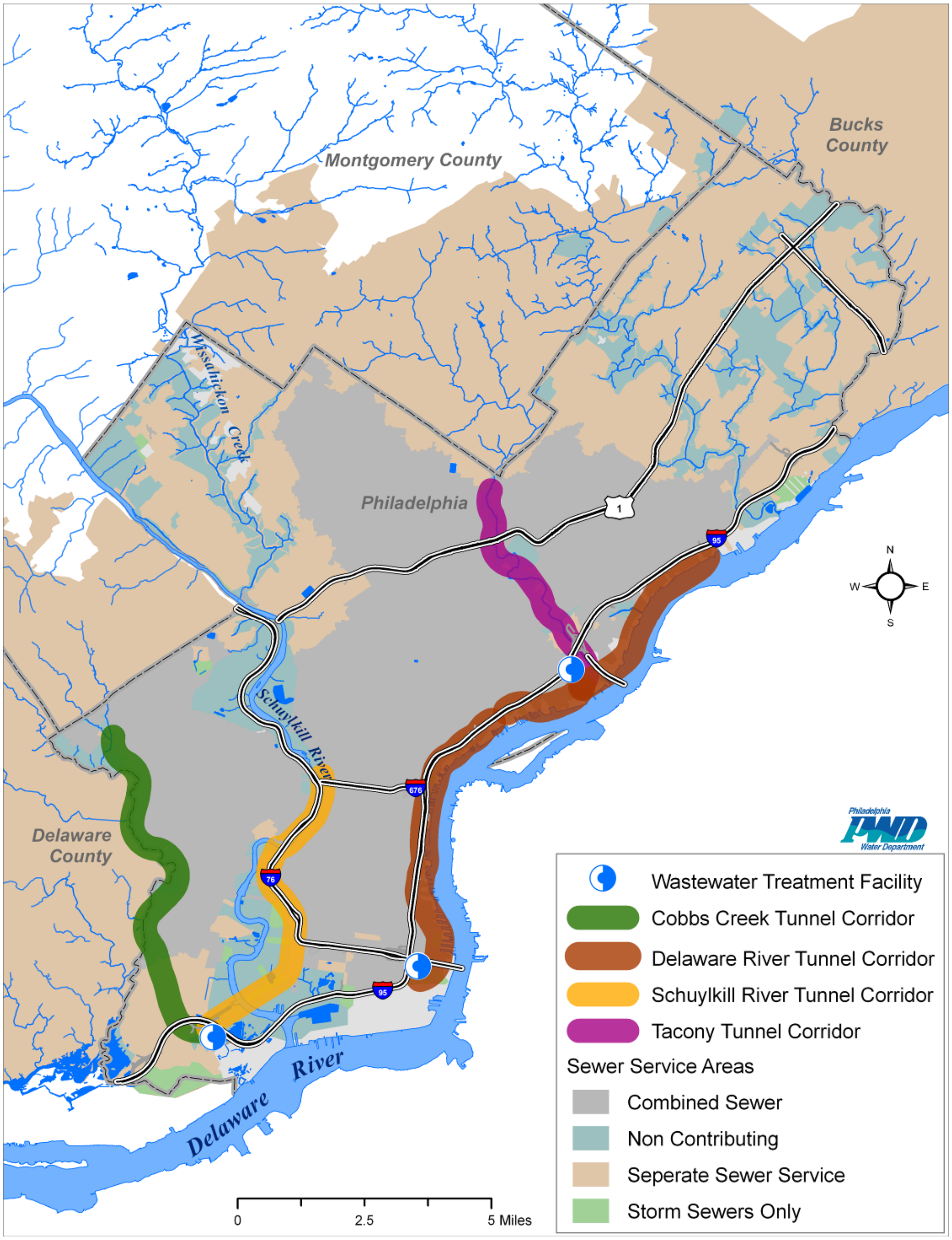


Figure v4.3.8 Potential Tunnel Alignment.

v4.3.7 Spreadsheet Analysis Procedure for the "All Transmission" and Satellite Treatment Unit Alternatives

Prior to building a model representing parallel interceptor systems and satellite treatment facilities, spreadsheet tools were created to align a parallel conveyance system to capture and convey flow to the respective WPCP of the existing interceptor system being paralleled. In this section, parallel transmission and treatment alternatives are referred to as "all transmission". Output from a SAS processing tool served as input to the spreadsheets. The SAS tool identifies a peak flow value and overflow volume for each overflow goal at every regulator in the system having an outfall. The spreadsheet analyzes each regulator producing an overflow for each green stormwater infrastructure implementation scenario for all overflow goals 1 through 25 events per year.

All Transmission Alternative and Satellite Treatment Alternative Descriptions

Building a conveyance sewer to capture and deliver overflow from the regulators in the existing interceptor system is the foundation from which these alternatives have been created. Using the estimated peak overflow numbers produced from the SAS program – discussed in further detail below – as input to the preliminary spreadsheets provides a preview into the effectiveness of building a parallel interceptor system. The spreadsheets are designed to size parallel interceptors using a targeted overflow frequency and corresponding overflow rate with the sizing limited to an assumed constructability limit (12 ft x 12 ft box sewer). Once the constructability limit has been reached or exceeded, either another parallel system is required to continue conveying flow to the WPCP or a satellite treatment unit must be built.

In the case of building a satellite treatment unit, another spreadsheet tool was developed to appropriately size and place the unit. The input to this particular spreadsheet is the same as the all transmission spreadsheet. The satellite treatment spreadsheet is automated to place units at regulators where half the total interceptor system overflow rate to convey to the WPCP or the constructability limit has been reached or exceeded. For some watersheds and interceptor systems, the location of a satellite treatment unit has been predetermined based on availability of land. In these situations, the automated process is manually overridden and pipe dimensions are calculated based on the predetermined location.

The processes and details of each spreadsheet and an overview of the SAS program algorithm used to generate the overflow numbers used as input to the spreadsheets are presented below.

Conveyance Logistics

The loading priority within both spreadsheets for parallel interceptor conveyance to the plant is based on spatial logistics. The assumption was made that the amount of flow delivered by the existing interceptor systems modeled under free outfall (no restrictions at the plant) conditions is the maximum flow that can be treated at the plant. For the Northeast drainage district the plant capacity is 650 MGD, for the Southeast drainage district the plant capacity is 330 MGD and the Southwest drainage district is 540 MGD. Any flow delivered by the parallel interceptor conveyance pipes to the WPCP that exceeds the capacities above would have to be treated using high-rate treatment trains, which would be located at the WPCP.

It is important to understand that each parallel interceptor system is analyzed independently of the others within the same watershed. For instance, the Schuylkill watershed contains regulators along five (5) interceptor systems and regulators in each interceptor system was sized and underwent satellite treatment unit analysis without being affected by analyses done on the regulators in the other interceptor systems. This is mainly due to the possibility that building the parallel interceptor and/or satellite treatment placement alternatives may not be feasible for all – or any – of the interceptor systems within a watershed and therefore, these systems should be analyzed as independent operations to determine which interceptor systems show the most benefit from the parallel system. This also allows for flexibility in choosing the best "package" of options to create the most appropriate alternative to mitigate the overflows in any particular watershed. This analysis process is applied to all systems throughout the city until the overflow target has been met and delivered to the plant or the constructability limit for a single open cut conveyance sewer has been reached in order to determine which interceptor systems are best suited for the all transmission and/or satellite treatment unit alternative.

SAS Tool Description

The inputs to the SAS program are the capture dataset for each regulator (described in section v4.3.12), land-based control model simulation output and an outfall list. The program uses these three inputs to determine the corresponding peak event overflow treatment rate required to satisfy targeted overflow frequencies between 1 and 25 overflows per year.

The SAS program analyzes the treatment rates required at each of the outfalls in the Combined Sewer System (CSS) so that a targeted overflow frequency is achieved. For instance, if an outfall overflows fifty (50) times a year and the treatment capacity exists to treat the third largest overflow among the fifty (50), then there will be only two (2) storm events that will cause an overflow. The rest of the 48 events can be treated. This is the premise under which the program was written. The steps outlined below were followed in order to calculate targeted overflow numbers for each regulator:

1. The overflow data from the EXTRAN model for each regulator having an outfall is loaded into the SAS program. The input data is in 15-minute average wet weather flow data.
2. One of the options in the program is averaging of the 15-minute input flow data to 30 minutes or 1 hour flow.
    a. For the purposes of the all transmission and satellite treatment spreadsheet analyses the 15-minute flow data was averaged over the hour.
3. SAS uses the regulators' generated event lists contained in the capture input data file to retain only events that produced overflows.
4. The type of processed flow data – raw 15 minute or averaged 30 minute or 1 hour flow data – is selected and merged with the overflow event list from step 3. For each regulator, the peak overflow rate for each of the events is extracted and then ranked in descending order.
5. The program steps through each ranked regulator dataset and determines the number of events overflowing, the respective total overflow rate, untreated volumes and treated volumes.
    a. For example, for a given regulator, the second peak overflow treatment rate produced from a given event in the sorted list from step 4 is set equal to the available treatment capacity. Referring to Table v4.3.7 below, this value equals 14 cfs.

b. All overflow events that have peak overflows equal to or less than this value are considered treated – or captured as labeled in Table v4.3.7.
c. The number of events with peak overflow values greater than the available treatment capacity value is determined, which for this example is equal to 1 as there is only one event that is ranked as having a greater peak overflow rate. This overflow frequency number represents one of the targeted overflow goals that will be analyzed within the all transmission and satellite treatment analysis spreadsheets.
d. The regulator's untreated volume for the respective overflow frequency is calculated by summing the residual overflow rate and converting it to a volume.
e. The treated volume – or captured volume – is the difference between the total ranked overflow volume for all events and the untreated volume as calculated in the previous step.
f. The SAS program steps through each ranked event comparing and calculating the overflow numbers as described above for target overflow frequencies 1 through 25.

All Transmission and Satellite Treatment Spreadsheet Descriptions

Of the two spreadsheets, the all transmission spreadsheet is the more straightforward and least complex as it essentially follows the alignment and slopes of the existing interceptor without exception. Implementing the algorithm to place the satellite treatment units made the second spreadsheet inherently more difficult to build and maintain. Additional factors that came into consideration as the satellite treatment spreadsheet was being built included the calculation of reverse grade interceptor conveyance pipes to deliver flow upstream to the satellite treatment units and manual overrides to the automated selection of satellite treatment unit locations because of predetermined land availability. As a result, the satellite treatment unit spreadsheet was built to only analyze 1, 4, 10 and 25 overflows per year for each green stormwater infrastructure implementation level, as opposed to the all transmission spreadsheet which calculates pipe dimensions for all targeted overflows from 1 through 25 for each green stormwater infrastructure implementation level.

All Transmission Analysis Methodology

The spreadsheet analysis for the all transmission alternative is developed to exactly mimic the existing parallel systems. The slope and segment length is taken to be that of the existing interceptor segment it is paralleling. The spreadsheet also provides the depth of cover in order to estimate the amount of excavation necessary for each pipe segment.

The dimensions of the conveyance pipes are estimated using the existing interceptor pipe segment slope and the cumulative overflow rate captured at the nearest upstream regulator outfall, prior to any loading from the nearest contributing downstream regulator's outfall. These numbers are used within the Manning equation – representing full flow conditions – to determine the box sewer dimensions.

The parallel interceptor collects and conveys overflow by moving upstream from the plant through interceptor systems until the sum of target peak overflow rates exceed the assumed constructability limit for open cut conveyance sewers – set to be a 12 ft x 12 ft box sewer. The spreadsheet also summarizes the total system wide untreated overflow volume and total peak overflow rates for each scenario.

Satellite Treatment Location Analysis Methodology

Generally, the satellite treatment location spreadsheet is setup to calculate the total overflow rate for all regulator outfalls contributing overflows to the system and at the regulator where half of that flow is reached or exceeded, the spreadsheet places a satellite treatment unit. Manual overrides were necessary for some interceptor systems where locations were known to have sufficient land available to build a treatment unit.

Because the algorithm places the satellite treatment unit at the regulator where half the total overflow of the interceptor system is reached or exceeded, at least part of the parallel system will have to be built at reverse grade as compared to the corresponding existing interceptor system segments. Due to the potentially high variability of satellite treatment locations for interceptor systems where predetermined locations do not exist – e.g. the interceptor systems within the Schuylkill watershed – the reverse grade pipe segment dimensions, slopes and depth to cover calculations were extensive and had to be done for each scenario and each interceptor system independently. Also, depending on the target overflow rate, the size of the satellite treatment units varied. All these numbers are summarized within the satellite treatment analysis spreadsheets.

Table v4.3.7 The example below assumes the second event's peak treatment rate – 14 cfs – set as the available treatment capacity. The residual overflow rates, used to calculate the overflow untreated and treated volumes are included and the resulting overflow event number.

<table>
<tr><th>Time</th><th>Event Overflow Rate (cfs)</th><th>Total Event Overflow Volume (cu.ft)</th><th>Ranked Overflow Event Number</th><th>Event Peak Overflow (cfs)</th><th>Total Overflow Volume for All Ranked Events (cu.ft)</th><th>Total Available Treatment Rate (cfs)</th><th>Event Residual Overflow (cfs)</th><th>New Overflow Event Number</th><th>Overflow Volume After Treatment (cu.ft)</th><th>Treated Volume (cu.ft)</th></tr>
<tr><td>1/1/2005 18:15</td><td>1</td><td rowspan="8">93600</td><td rowspan="8">1</td><td rowspan="8">25</td><td rowspan="19">142200</td><td rowspan="19">14</td><td>0</td><td rowspan="8">1</td><td rowspan="8">25200</td><td rowspan="8">68400</td></tr>
<tr><td>1/1/2005 18:30</td><td>2</td><td>0</td></tr>
<tr><td>1/1/2005 18:45</td><td>25</td><td>11</td></tr>
<tr><td>1/1/2005 19:00</td><td>24</td><td>10</td></tr>
<tr><td>1/1/2005 19:15</td><td>20</td><td>6</td></tr>
<tr><td>1/1/2005 19:30</td><td>15</td><td>1</td></tr>
<tr><td>1/1/2005 19:45</td><td>14</td><td>0</td></tr>
<tr><td>1/1/2005 20:00</td><td>3</td><td>0</td></tr>
<tr><td>1/1/2005 8:15</td><td>2</td><td rowspan="6">36900</td><td rowspan="6">2</td><td rowspan="6">14</td><td>0</td><td rowspan="6">Captured</td><td rowspan="6">0</td><td rowspan="6">36900</td></tr>
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<tr><td>1/1/2005 8:45</td><td>14</td><td>0</td></tr>
<tr><td>1/1/2005 9:00</td><td>5</td><td>0</td></tr>
<tr><td>1/1/2005 9:15</td><td>6</td><td>0</td></tr>
<tr><td>1/1/2005 9:30</td><td>1</td><td>0</td></tr>
<tr><td>1/1/2005 0:15</td><td>1</td><td rowspan="5">11700</td><td rowspan="5">3</td><td rowspan="5">4</td><td>0</td><td rowspan="5">Captured</td><td rowspan="5">0</td><td rowspan="5">11700</td></tr>
<tr><td>1/1/2005 0:30</td><td>2</td><td>0</td></tr>
<tr><td>1/1/2005 0:45</td><td>3</td><td>0</td></tr>
<tr><td>1/1/2005 1:00</td><td>4</td><td>0</td></tr>
<tr><td>1/1/2005 1:15</td><td>3</td><td>0</td></tr>
</table>

v4.3.8 Street Trees

Concepts

Street trees are desirable, but by themselves provide a level of control lower than the level defined by Philadelphia's stormwater regulations. Therefore, an "equivalency ratio" was determined defining the relative benefits of these measures and other stormwater management measures. For example, "1.0 ac of impervious surface covered by tree canopy results in the same runoff volume reduction as 0.X ac of impervious surface draining to an infiltration bed meeting the level of performance defined by PWD's stormwater regulations."

Under PWD's regulations and demonstration programs, trees are often used in combination with other practices such as bioretention and tree trenches under sidewalks. We can assume the level of performance for these facilities will meet the regulations. This section is only applicable to trees functioning as a green stormwater interception mechanism independently.

For the purposes of this study, it was assumed that pervious surfaces do not need to be managed. This approach applies only to street trees over impervious surfaces, typically street trees. As the city becomes greener in the future, street trees by themselves could be viewed as a temporary solution that can be implemented relatively quickly on a large scale, while more comprehensive street greening solutions such as tree trenches and infiltration inlets will take longer to implement. If a more pessimistic (but still green) view is taken, it can still be thought that in some areas, street trees can be seen as being the only desirable controls.

Ideal Model

In forestry research, trees and soils are being modeled as the complex three-dimensional systems they are. This is beyond the scope and appropriate level of detail for the LTCPU, but it is worth examining the processes to determine which can be simplified.

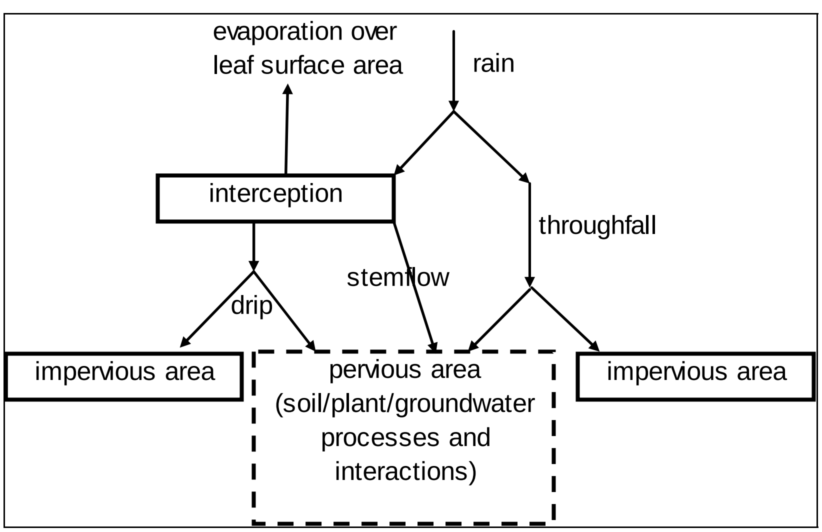

Figure v4.3.9 Conceptual model of tree canopy interception, storage and stemflow.

- Throughfall: Rain falls directly through the tree either because there is no leaf in its path or because it strikes hard enough to move the leaves out of its way. Throughfall may fall on a pervious surface (tree well) or impervious surface (pavement). This can happen at any time during the storm.
- Interception: Rain either ponds on curved leaf surfaces, or "sticks" to leaves through surface tension. Together, these two phenomena comprise canopy storage. When canopy storage is exceeded, water either drips off the tree or flows down the stem.
- Stemflow: For a street tree or other tree planted in impervious cover, all stemflow flows to the pervious area or tree well. A portion of drip falls on pervious cover and a portion on impervious cover, since part of the tree canopy covers both types of surfaces.
- Canopy evaporation: Water stored in the canopy is exposed to the air over the entire leaf surface, not just over the ground projection ("footprint") of the tree.
- Infiltration/Evaporation/Transpiration from soil: Once water reaches the soil, it can continue downward by gravity to recharge groundwater, evaporate through contact with air in soil pores, or be taken up by tree roots and transpired into the atmosphere.

Typical Model

Many modeling studies model trees simply as a storage value, or "initial abstraction". Once this storage is exceeded, any excess stormwater flows immediately to a sewer inlet or receiving water.

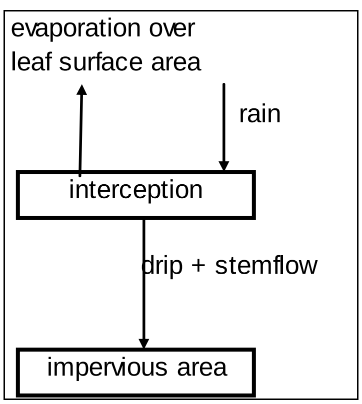

Figure v4.3.10 Typical simplistic model setup to represent tree canopy interception

Compromise Model

The model developed for this study is a good compromise between the ideal and typical models and can be implemented in SWMM. A strong basis for distinguishing between throughfall, drip and stemflow cannot be built without a lot more research. Therefore, a simplifying assumption was made that when canopy storage over pervious cover is exceeded, the excess will drip to pervious cover and vice versa. The dynamics of the unsaturated soil zone are not simulated for the LTCPU.

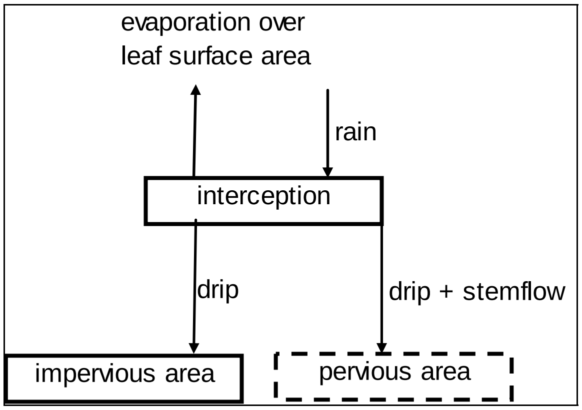

Figure v4.3.11 Visualization of the model setup for the LTCPU to represent tree canopy dynamics.

Model Assumptions and Setup

- Model a hypothetical acre of impervious cover equal to the leaf area.
- Canopy storage = 0.10 inches. This value is conservative compared to the Vanaskie and Xiao (2002) studies and roughly equivalent to the Xiao (2000) study. The CaseyTrees/Limno-Tech value of 0.032 inches seems overly conservative (see additional discussion below).
- Divide into 5 subsheds. Use SWMM 4 subshed routing options to route flows as shown in the diagram.
    - Two impervious sheds representing the leaf area and canopy storage (change SWMM default of 25% area with no depression storage); shed area = leaf area (tree canopy area times mean leaf area index (LAI) from Vanaskie study); divide rainfall and canopy storage (0.10 inches) by LAI; one drains to the impervious shed and one drains to the pervious shed
    - one shed representing pervious area under trees; no rainfall
    - one shed representing impervious area under trees; no rainfall
- Calculate and use the median and mode of the soil properties over the entire CSO area for the pervious area soil shed properties.
- Assuming mean crown diameter from the Vanaskie study, determine how many trees can be planted on the hypothetical acre if all canopies are touching.
- Assume each tree has a 16 sq.ft. (4 ft x 4 ft) tree well.
- A leaf on period of April 1 to October 31 is proposed. During the leaf off period, no canopy storage will be simulated.

Interpreting model results:

- Determine an equivalent acreage of green stormwater infrastructure that will result in the same reduction of uncontrolled runoff volume as the acre of trees. For example, "1.0 ac of impervious cover covered by street trees results in the same runoff volume reduction as 0.X ac draining to an infiltration bed meeting the level of performance defined by PWD's stormwater regulations."
- This approach assumes tree canopy covers all impervious cover on the site.

- With street trees, an added complication is that a fair level of implementation already exists; The resulting ratio will be adjusted based on an estimate of existing tree canopy and available area to implement new tree canopy.

Research/Previous Studies of Leaf Area and Canopy Storage

The CaseyTrees/LimnoTech Green Buildout study assumed a canopy storage volume of 0.032 inches over the ground projection. They conducted a literature review of twelve sources. CDM reviewed some of these sources and the results of an unpublished internal study by Matt Vanaskie. All storage depths are expressed over the tree's ground projection ("crown projection", "footprint"), not over the leaf area. Key results are summarized below:

Table v4.3.8 Literature review summary table for urban tree canopy research

Source	Study	Storage Min (in)	Storage Max (in)	Reviewed?	Urban/Open Grown	Deciduous	Species in Philadelphia "Top 30"?
Agricultural Runoff Manual, 1978	Casey Trees	0.138	0.197	No	No	?	?
Aston, 1979	Casey Trees	0.008	0.031	Yes	No	No	No
Blyth, 2002	Casey Trees	0.027	0.027	No	?	?	?
Crockford and Richardson, 1990	Casey Trees	0.067	0.079	No	?	No	No
Keim, 2006	Casey Trees	0.038	0.038	No	No	No	No
Link et al., 2004	Casey Trees	0.140	0.140	No	?	?	?
Pypker, 2005	Casey Trees	0.055	0.131	No	No	No	No
Schellekens, 1999	Casey Trees	0.045	0.045	No	?	?	?
Liu, 1998	Casey Trees	0.017	0.037	No	No	No	No
Wang, 2006	Casey Trees	0.027	0.027	No	?	?	?
Xiao, 2002	Casey Trees	0.340	0.563	Yes	Yes	Yes	Yes
Xiao, 2000	Casey Trees	0.106	0.106	Yes	Yes	Yes	Yes (similar)
Nowak/Von Hoyningen-Huene/USDA	Vanaskie	0.070	0.348	Yes	Yes	Yes	Yes

Green – results should apply to Philadelphia street trees
Yellow – unknown/not reviewed by CDM
Red – results do not apply to Philadelphia street trees

- Summary statistics on range of canopy storage in CaseyTrees literature review:
  - range: 0.008-0.563 in
  - median: 0.042 in
  - mean: 0.089 in
  - 95% confidence interval: (0.035, 0.143)

- CaseyTrees chose to simulate canopy storage at 0.032 inches. They arrived at this value based on assumptions in USDA's UFORE model, referenced in Wang 2006 above. According to CaseyTrees, UFORE assumes a value of 0.2 mm (0.0079 inches) over the leaf area. Using a leaf area index of 4.10 for District of Columbia street trees, this value works out to 0.032 inches over the ground projection.
- Many of CaseyTrees' sources are based on evergreen species, which are not commonly used as street trees on the east coast.
- Studies of interception in forest canopy may be useful, but the two recent studies by Xiao specifically consider urban, open grown, deciduous trees. These studies also report some of the highest values in the literature review.
- The unpublished Vanaskie study uses data from USDA specifically on trees in Philadelphia. It estimates leaf area and storage depths using regression approaches in the literature.
    - The USDA Forest Service provides data on species, sizes, condition and age of trees in Philadelphia (some documentation on data set in USDA Forest Service, 2007). Of the 31 most common types of trees, Matt found sufficient information to estimate storage for 14 of them.
    - Matt applied a regression approach reported by Nowak (1996) to estimate leaf area for species specific to Philadelphia. Leaf area is related to diameter at breast height and to shading factor. Nowak's study was specifically for urban, open grown, deciduous trees with species and sizes similar to Philadelphia street trees.
    - Matt applied a regression approach reported by Von Hoyningen-Huene (1981, reported in Schulze and George 1987, original reference available only in German). Storage is related to leaf area index. This equation is also applied by USDA's UFORE model and was used by Casey Trees.
    - After applying this regression approach to species and size data specific to Philadelphia, trees in the Vanaskie study had a mean LAI of 11.29 and a storage volume of 0.23 inches. Mean crown diameter was 24.5 ft.
    - Estimated LAIs were higher in the Vanaskie study than the mean found by Casey Trees of 4.10. Applying the Von Hoyningen-Huene regression with an LAI of 4.10 yields canopy storage of 0.113 inches.

Table v4.3.9 Summary of Unpublished Vanaskie Study Results

Common name	Genus	Species	% Population (% of trees)	Height (ft)	Crown Diameter (ft)	Shading factor	Ground Projection (ft^2)	Leaf Area (ft^2)	Leaf Area Index	Canopy Storage (in)
Crabapple	*Malus*	*species*	7.5	16.5	16.0	0.85	201	926	4.61	0.122
Red Maple	*Acer*	*rubrum*	6.6	43.3	22.5	0.83	396	4,880	12.31	0.244
Boxelder	*Acer*	*negundo*	5.6	21.6	12.6	0.86	125	870	6.98	0.163
White Ash	*Fraxinus*	*americana*	5.1	43.4	18.6	0.82	271	3,957	14.60	0.275
Norway Maple	*Acer*	*plantanoides*	2.6	31.3	19.8	0.88	307	3,338	10.86	0.223
Red Oak	*Quercus*	*rubra*	2.2	63.0	29.7	0.81	695	8,101	11.66	0.235
London Planetree	*Plantanus*	*x acerifolia*	1.5	63.2	46.4	0.86	1,691	2,954	1.75	0.070
American Beech	*Fagus*	*grandifolia*	1.4	58.7	32.1	0.88	811	9,913	12.22	0.243
Silver Maple	*Acer*	*saccharinum*	1.3	42.4	28.7	0.83	648	5,352	8.26	0.183
Siberian Elm	*Ulmus*	*pumila*	1.3	29.0	20.4	0.85	327	2,642	8.08	0.180
Eastern Cottonwood	*Populus*	*deltoides*	1.2	58.9	24.9	0.85	488	10,217	20.92	0.348
Black Walnut	*Juglans*	*nigra*	1.1	45.8	24.6	0.91	477	8,972	18.82	0.326
Green Ash	*Fraxinus*	*pennsylvanica*	0.9	32.3	15.4	0.83	187	1,880	10.06	0.211
American Sycamore	*Plantanus*	*occidentalis*	0.9	59.9	30.9	0.91	752	12,702	16.89	0.303
Total			39.2							
Minimum				16.5	12.6	0.81	125	870	1.75	0.070
Median				43.4	23.6	0.85	437	4,419	11.26	0.229
Mean				43.5	24.5	0.85	527	5,479	11.29	0.223
Max				63.2	46.4	0.91	1,691	12,702	20.92	0.348
St. Dev.				15.7	8.8	0.03	401	3,823	5.33	0.077
95% C.I. Lower Bound				35.3	19.9	0.84	317	3,476	8.49	0.183
95% C.I. Upper Bound				51.7	29.1	0.87	737	7,481	14.08	0.264
Leaf Area-Weighted Ave.										0.260

v4.3.9 Tree Canopy Coverage Adjustment Methodology

Street Tree Planting Research

A short literature review of Philadelphia and other cities' documents addressing street tree planting provided an outline of important restrictions for tree placement. A summarized outline of these documents is included in this memorandum following the results section. A list of specific considerations produced from this literature review affecting the city-wide tree canopy analysis is below.

- Distance from intersection to tree centerlines
- Distance between tree centerlines
- Distance from street lighting
- Distance from curb edge
- Distance from buildings

Other factors listed in the attachment were assumed to have minimal if any significance on calculating the amount of possible tree canopy coverage. For example, distances from parking meters or fire hydrants were assumed to have no affect on tree canopy coverage because 1) the objects do not impair tree canopy size and 2) the required distance from the tree is less than the mean tree canopy radius and does not limit the available area.

Distances from intersections, however, do limit available tree canopy area because the required distance may be greater than the mean tree canopy radius. The distance in this particular situation is the limiting factor, not the tree canopy (as in the parking meter and hydrant scenario). Figures v4.3.12 and v4.3.13 below are visual representations of these concepts. These figures also show a comparison of tree centerlines and the edge of tree canopy, which is a significant point for calculations that follow. Distance requirements (Table v4.3.10) are measured from the tree centerline and not the edge of tree canopy. When distance calculations are being performed, however, the edge of tree canopy is taken into account and therefore having an understanding of the distinction between the two is necessary.

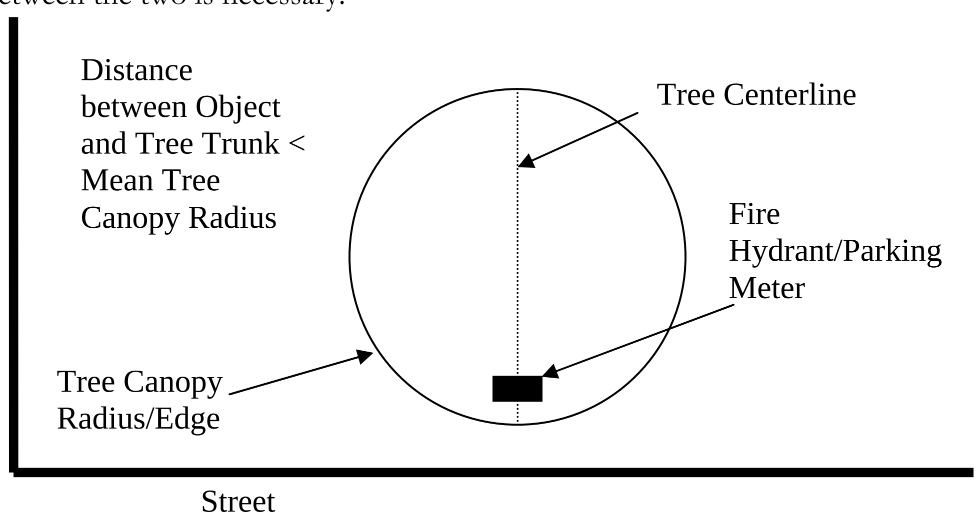

Figure v4.3.12 Visualization of the physical placement of an object with a required distance less than the mean tree canopy radius that does not obstruct the tree canopy area coverage.

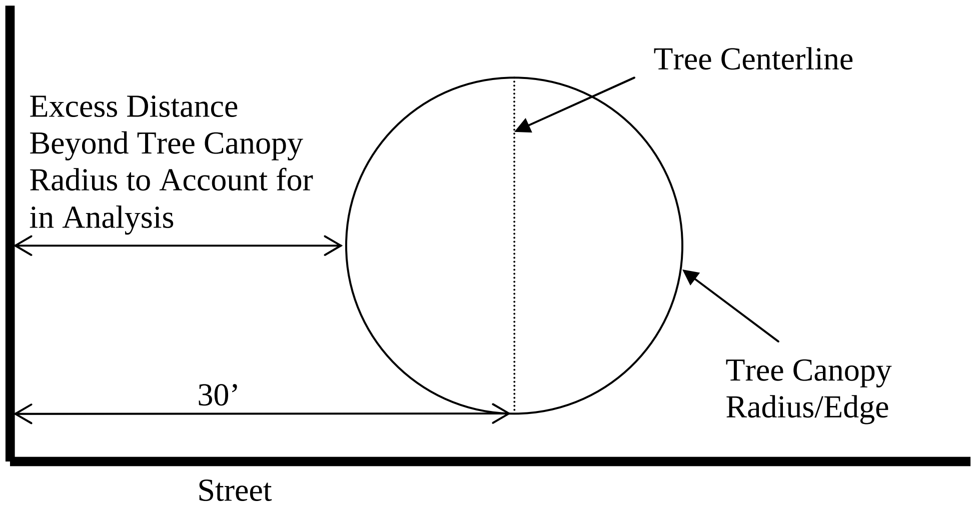

Figure v4.3.13 Excess distance to subtract from available tree canopy coverage area to fulfill distance requirements for tree center to the intersection.

In Figure v4.3.13, the area beyond the mean tree canopy perimeter needs to be subtracted from the available area for street tree canopy coverage. Based on the required distance from the tree center and height of the object, any distance less than the mean tree canopy radius will not affect the coverage of the tree canopy. Table v4.3.10 summarizes the final distance ranges found during the literature review used to calculate an adjusted equivalency ratio for the Philadelphia LTCPU.

Table v4.3.10 Distance Ranges for Specific Urban Elements Measured from Tree Center Line Based on Literature Review.

Distance from Intersection to Tree Center (ft)	30
Distance from Street Lighting (ft)	25
Distance between Tree Centerlines (ft)	30
Distance from Building Face to Edge of Canopy (ft)	5
Distance from Curb Face to Tree Center (ft)	1
Distance between Street Lights (ft)	150

Derivation of Available Coverage Area

It is inappropriate to extrapolate the unadjusted runoff reduction equivalency ratio to the entire city because it assumes an unrestricted availability of area for tree canopy coverage. Street tree canopy is limited by distance requirements due to such things as street lighting, buildings and intersections, as described previously. An adjustment based on these limitations is necessary. A ratio of the allowable area of tree canopy within the city versus the total city-wide sidewalk and street area is calculated and then adjusted to account for the limitations listed above. This value is multiplied with the preliminary equivalency ratio to determine the relative city-wide runoff benefit of street trees as compared to the runoff reduction from the model representing the city meeting the stormwater regulations.

Assumptions and Input Data

Assumptions were required in order to calculate an estimate of available urban area for tree canopy coverage. The main assumptions are as follows:

- Mean Tree Canopy Area = 527 square feet
- Total City-Wide Sidewalk and Street Area = 10,774.34 acres
- Required Distances affecting Available Area (found in Table v4.3.10)

These and other input data were produced from the literature review discussed in the previous section, the impervious cover master table spreadsheet (ImperviousAnalysis_071107_SKR.xls) and the tree canopy simulation results table and database (Parameter_adjmts_071102_SKR.xls, TREE_CANOPY_DATA_071119_932.mdb).
GIS sidewalk data provided by the Impervious_Surfaces_PHILA_2004 shapefile was used to estimate the total sidewalk area for the city. This data contained the area and perimeter length of sidewalk per square block and was the foundation from which all subsequent calculations were created. For the purposes of this analysis and the duration of this memo, the definition of a square block encompasses the length of sidewalk existing on all four sides of a block and does not include street length or width.

Calculations

The data from the Impervious_Surfaces_PHILA_2004 shapefile was imported into a database where all length, width and area calculations were performed. Within the database, each record represents a square block. The perimeter length of each square block was reduced by half to estimate the total sidewalk length. The given sidewalk area for each square block was divided by its respective calculated total sidewalk length to determine a width. The data was filtered to include only sidewalk widths greater than or equal to 6 feet (d_{smin}). Sidewalk widths less than 6 feet do not offer enough space to fulfill the building and curb edge distance requirements (required distances are listed in Table v4.3.10).

For the remaining data records, the distance between street lights was divided into the total square block length to determine the number of street lights per square block. Because the intersection distance requirement will compensate for street lighting at the corners of each square block, the total number of street lights per square block (n_{SL}) was reduced by 4. The length to remove to account for street lighting (L_{SL}) was determined using the equation below with the calculated number of lights per square block ($n_{SL} - 4$). Basically, the length to subtract for street lighting consists of the excess sidewalk area existing between the street light and the mean tree canopy perimeter. Each light will have two occurrences of this situation, assuming a tree exists on either side of the light and then it must be multiplied by the calculated number of street lights minus the occurrences on the corners ($n_{SL} - 4$).

$$L_{SL} = 2(d_{SL} - r)(n_{SL} - 4)$$

The sidewalk length to remove to fulfill the distance from an intersection requirement (d_I) was calculated as 240 feet. This was based on the required distance from an intersection (30 feet) and the number of instances (2 lengths per corner) of subtraction for a square block.

If the total calculated sidewalk length for a square block was less than the total length to subtract calculated from summing the excess street light (L_{SI}) and intersection (d_I) distance, the total distance to remove was set equal to the total sidewalk length for that square block. In these situations, the square block does not have enough space to allow for street tree coverage. Otherwise, the total distance to subtract was equal to the sum of the two calculated lengths (L_{SL} and d_I). The preliminary available length of sidewalk ($L_{Available}$) for tree canopy coverage was calculated by subtracting the summed distance requirement lengths (L_{SL} and d_I) from the total calculatedsidewalk length per square block.

Oftentimes, the tree canopy is obstructed by building interfaces. Therefore, only a portion of the tree canopy is active in intercepting rainfall. For each square block, the amount of tree canopy affected by the building interface was calculated using the equations that follow. The equations were taken from the Equv-pipes-RR-GM (version 3c) spreadsheet.

$$d_s = (Width + r) - d_{curb}$$
$$\text{Width of Active Tree Canopy } (W_{ATC}) = diameter - d_s$$
$$\text{Angle Subtended} = 2(Acos(r - W_{ATC})) / r$$
$$\text{Active Tree canopy Area per Tree} = (1/8(\text{Angle Subtended} - Sin(\text{Angle Subtended})))* diameter^2$$

Where *diameter* = The Diameter of the Tree Canopy (feet)
r = The Radius of the Tree Canopy (feet)
d_s = The Length of Tree Canopy Unobstructed by Objects (feet)
d_{curb} = The Distance Required to the Curb Edge Measured from Tree Center Point (feet)

For larger sidewalk widths that do not impede the tree canopy the average tree canopy area of 527 square feet was applied.

The number of trees feasible per square block (n_B) was calculated by dividing the eligible length of sidewalk ($L_{Available}$) by the distance between tree center points requirement. For each square block the number of trees was multiplied by the active tree canopy area per tree to determine the estimated total tree canopy area available for each square block. The values for each square block were summed to determine the eligible city-wide tree canopy area. The ratio of calculated tree canopy area to total city-wide street and sidewalk area was calculated and then applied to the preliminary tree canopy total runoff reduction equivalency ratio of 0.875.

Results

A final runoff reduction equivalency ratio was developed based on required distances found in Table v4.3.10. Tables v4.3.11 and v4.3.12 contain all input parameters, assumptions and calculated values. The final ratio may be found in Table 3 and represents the percent city-wide tree canopy total runoff reduction as compared to the total runoff reduction produced from the model meeting the required stormwater regulations requirements. Ultimately, the ratio states that 1 acre of impervious surface covered by tree canopy results in the same total runoff volume reduction as approximately 0.287 acres of impervious surface draining to an infiltration bed meeting the stormwater regulations requirements.

Table v4.3.11 Static Input Variables used in Calculating Adjusted Tree Canopy Equivalency Ratios.

Variable Description	Values	Units
Total Combined Shed Area	43414.05	acres
Mean Tree Canopy Ground Projection Area	527	sq.ft
Percent of Combined Area without Trees	85%	
Runoff Reduction Equivalency Ratio	87.5%	
Diameter of Mean Tree Canopy Ground Projection Area	25.90	ft
Radius of Mean Tree Canopy Ground Projection Area	12.95	ft

Table v4.3.12 Varying Calculated Inputs and Outputs Used to Determine the Adjusted Equivalency Ratio.

Variable Description	Values	Units
Required Distance from Tree Center point to Building Face	5	ft
Required Distance from Tree Center point to Curb Edge	1	ft
Distance from Intersection to Tree Center (from curb to tree center)	30	ft
Distance Between Tree Centerlines	30	ft
Distance from Street Lighting	150	ft
Minimum Sidewalk Width where Tree Canopy is not Affected by Building Face	13.95	ft
Total Street/Sidewalk Area	4.69E+08	sq.ft
Total Area of Available Tree Canopy Coverage	1.54E+08	sq.ft
Adjusted Total Area of Available Tree Canopy Coverage	1.31E+08	sq.ft
Percent of City Area Available for Tree Canopy	32.78%	
New Tree Canopy Equivalency Ratio	**28.68%**	

v4.3.10 Outlying Community Flow Timeseries Analysis

Background

The procedures described herein were used to create SWMM4 EXTRAN K3-line timeseries input data for selected outlying community sanitary sewer connections to the Philadelphia combined sewer system (CSS). The timeseries data are used to define wet weather flow response from these areas in continuous simulations performed for the 2005 representative year selected for LTCP project evaluations. Filling missing or errant data is required in order to generate continuous timeseries over the one-year simulation period. The outlying community areas chosen for direct timeseries input are DELCORA, Bucks County (MB-1) and Lower Southampton Township (MSH-1). These areas were selected based on the magnitude of the contributing flows and the availability of acceptable quality data for the period of interest.

Data Sources

Bucks County and Lower Southampton Township timeseries flow data source is the 2.5-minute permanent billing meter data obtained from the PWD real-time unit (RTU) database. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then averaged to 15-minute intervals.

DELCORA flow data is obtained from hourly Southwest WPCP influent flow data measured at the plant. Quality assurance and quality control procedures including inspection of monthly timeseries plots were used to flag errant or missing data. The accepted data is then interpolated to 15-minute intervals.

Data Gap Filling Procedures

Identification and filling of data gaps are required in order to generate continuous timeseries data needed for performing the one-year (2005) model simulations. First, all data gaps and their durations are identified. Next, each data gap is characterized as either wet weather or dry weather flow with the corresponding procedures used for gap filling as described below:

<u>Dry Weather Flow</u>
For small data gaps (< 1 hour), linear interpolation was performed. Missing or errant data over one or more hours was filled using the nearest previous day's dry weather flow (DWF) data.

<u>Wet Weather Flow</u>
For small data gaps (< 1 hour), linear interpolation was performed. Wet weather events with missing or errant data periods of one or more hour duration were filled for the entire wet weather event with model simulation results using RDII RTK shape parameters previously calibrated for these areas. The model generated wet weather flow, obtained by subtracting the constant model baseflow from the simulated response, is added to the nearest previous day's DWF data.

Wet Weather Flow Separation

The continuous flow timeseries generated for the year 2005, as described above, contain diurnal and seasonal time varying baseflow patterns. In contrast, RUNOFF model generated hydrographs used for all other model areas simply have wet weather hydrograph responses added to a constant average baseflow. In order to represent the wet weather responses from the timeseries input areas more consistently with the Runoff modeled areas, hydrograph separations were performed on the timeseries data using CDM SHAPE software to extract the wet weather response hydrograph. The final timeseries was constructed by adding a constant average baseflow to the separated wet weather response timeseries.

v4.3.11 Capture Methodology

Capture calculations are performed in two steps. In the baseline condition, captured volume is the volume of combined sewer flow that is sent to the WPCPs during wet weather. In the LTCPU baseline wet weather is defined as when the flow in the dry weather pipe, connecting the regulator to the interceptor, increases more than 5 percent of the dry weather baseflow. In alternatives with CSO controls in place captured volume includes volume sent to the WPCPs and the volume prevented from reaching the CSS by source controls. Percent capture is calculated as the ratio of the captured volume to the sum of captured volume and volume overflowed to receiving waters.

The capture calculations are performed at each regulator. Each of the regulators is assigned to an interceptor system and the capture results from each regulator can be aggregated for that interceptor system. These results from the interceptors can be further aggregated by WPCP drainage district and by watershed

Capture calculation steps

For the Baseline capture calculations the following approach is used.

Requirements to calculate capture.

1. The capture formula is "Percentage Capture at a given regulator = 100 * [Total Volume through the dry weather pipe at the regulator / (Total Volume through the dry weather pipe at the regulator + Total volume that overflows to receiving water from the regulator)]".
2. For each regulator in the CSS, the dry weather flow pipe (DWO) and wet weather overflow pipe (SWO) is identified.
3. Flow for all the pipes identified in the last step is generated from the SWMM models. Another set of flow for the same pipes as above are generated for the same period as the wet weather simulation except using 0 (zero) precipitation. The zero precipitation simulation is performed to obtain the dry weather flows for the period of interest.
4. Using each of the regulators' DWO and SWO pipe flows calculations are performed.
    a. A tolerance is set for the baseflow for all the regulators which when exceeded indicates the regulator is in wet weather conditions (This tolerance is set at 5% for the LTCPU, when flow in the DWO pipe exceeds above 5% of baseflow, regulator is assumed to be in wet weather). Based on the baseflow tolerance the wet weather events are identified for the regulator. Capture calculations are performed for the wet weather events (using formula in step 1).
    b. If overflows from one regulator (Regulator "A") are re-regulated at another regulator (Regulator "B"), the overflow from A will be ignored when the capture result is aggregated to interceptor system.
    c. If a regulator (Regulator "C") re-regulates flow from upstream regulator's DWO (Regulator "D", Regulator "E"), all the DWO flows from D and E are ignored and only DWO flow from C is used when capture result is aggregated to the interceptor system.
    d. Negative flow through DWO (flow being relieved) pipes is subtracted when the capture calculation is performed. This accounts for regulators relieving other regulators.
5. The result from the CAPTURE program is summarized for yearly totals and aggregated by interceptor systems.

v4.3.12 Alternative Capture Calculation Methodology: Green Stormwater Infrastructure, Traditional Infrastructure and Large Scale Centralized Storage

Capture calculations for the alternatives that have been analyzed in the LTCPU – Green Stormwater Infrastructure, Traditional Infrastructure (Transmission to the WPCP) and Large Scale Centralized Storage (Tunnel) – are performed using the baseline model capture values as the foundation. The approach described below assumes that the overflow volume reduction, as compared to the baseline values, due to implementation of the alternatives is captured.

Steps included in alternative capture calculation

1. The overflow volume (SWO_0) to the receiving waters and treated volume (DWO_0) from the baseline models are obtained. This may be aggregated to the interceptor level or further aggregated to the WPCP drainage district level or the watershed level depending on the alternative for which effective capture calculations need to be performed.
2. The alternative scenario's overflow volume (SWO_1) aggregated to the interceptor level or further aggregated to the WPCP drainage district level or the watershed level depending on the alternative (representing Green Stormwater Infrastructure, Traditional Infrastructure or Large Scale Centralized Storage) are obtained.
3. The treated flow that accounts for reduction in volume that overflows to the receiving water due to implementation of the alternatives when compared to the baseline is inferred by the water balance to be: $[(SWO_0 + DWO_0) - (SWO_1)]$
4. The alternative capture formula is: $100*[(SWO_0 + DWO_0) - (SWO_1)] / (SWO_0 + DWO_0)$

v4.3.13 References

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