

REPORT

**Regional Hydraulic Model and
Other Consent Order
Requirements**

Applying SSOAP and SWMM to
Determine 10-Year Peak Flows

Hampton Roads Sanitation
District

April 12, 2016



Table of Contents

1. Introduction	1-1
1.1 Introduction.....	1-1
1.2 Minimum Flow and Rainfall Data Requirements.....	1-1
1.3 EPA SSOAP Toolbox Introduction.....	1-2
1.4 EPA SWMM Program Introduction	1-3
1.5 Statistical Analysis.....	1-3
2. EPA SSOAP Toolbox Flow Analysis.....	2-1
2.1 Introduction	2-1
2.2 Creating and Opening SSOAP Databases	2-1
2.3 Adding Flow Data to SSOAP	2-2
2.3.1 Creating Flow Meter Record	2-2
2.3.2 Formatting Flow Data for Import to SSOAP	2-3
2.3.3 Creating Flow Data Converter	2-4
2.3.4 Loading Flow Data to SSOAP.....	2-5
2.3.5 Flow Data Utilities	2-5
2.3.5.1 Fill in Missing Flow Records and Data	2-5
2.3.5.2 Flow Data Scatter Plots.....	2-6
2.3.5.3 Flow Data Review.....	2-6
2.4 Adding Rainfall Data to SSOAP.....	2-6
2.4.1 Creating Rainfall Gauge Record	2-7
2.4.2 Formatting Rainfall Data for Import to SSOAP.....	2-7
2.4.3 Creating Rainfall Data Converter	2-8
2.4.4 Loading Rainfall Data to SSOAP	2-9
2.4.5 Rainfall Data Utilities.....	2-9
2.4.5.1 Convert Rainfall Data Time Step.....	2-9
2.4.5.2 Other Rainfall Processing Utilities	2-10
2.5 Defining an RDII Analysis.....	2-11
2.6 Dry Weather Flow Analysis.....	2-12
2.6.1 Automatic Dry Weather Flow Day Determination.....	2-12
2.6.2 Manual Weekday and Weekend DWF Day Review and Removal	2-14
2.6.3 Defining Holidays.....	2-16
2.6.4 Automatic DWF Adjustment Calculation	2-16
2.6.5 Other Dry Weather Flow Menus.....	2-16
2.7 Wet Weather Flow Analysis	2-16
2.7.1 Automatic RDII Event Identification.....	2-17
2.7.2 Using the RDII Graph.....	2-17
2.7.3 Navigating Through the Flow Record in the RDII Graph	2-19
2.7.4 Manual ADF Adjustment Refinement.....	2-19
2.7.5 Manual Definition of RDII Event Start and End Times.....	2-20
2.7.6 Computation of Volume-Weighted Average R-Value.....	2-21
2.8 Calibrating RTK Triangular Unit Hydrograph Parameters.....	2-23

2.8.1 RTK Triangular Unit Hydrograph Procedures..... 2-23

2.8.2 Calibrating Parameters in SSOAP 2-25

2.8.3 SSOAP Simulated vs. Observed RDII Statistics..... 2-27

3. EPA SWMM 5 Long-Term Hydrologic Simulation 3-1

3.1 Introduction 3-1

3.2 Setup and Perform Simulation 3-1

3.2.1 Creating and Documenting SWMM Input File..... 3-1

3.2.2 Setting the Flow Parameters 3-2

3.2.3 Performing the Long Term Simulation 3-4

4. Long-Term Simulation Results Analysis 4-1

4.1 Introduction 4-1

4.2 Identify Event Peak Flows from SWMM Simulation Results 4-1

4.3 Identify Event Peak Flows Using the Statistical Analysis Spreadsheet..... 4-1

5. References..... 5-1

Appendices

Appendix A HRSD Computer Tool Metadata Descriptions

List of Figures

Figure 2-1 SSOAP Toolbox Main Screen.....	2-2
Figure 2-2 SSOAP Flow Meter Data Management Menus.....	2-3
Figure 2-3 Example Flow Data Format.....	2-3
Figure 2-4 SSOAP Flow Data Converter Setup Menus.....	2-4
Figure 2-5 SSOAP Flow Data Import Menu.....	2-5
Figure 2-6 Flow Data Utilities Menus.....	2-6
Figure 2-7 SSOAP Rainfall Gauge Management Menus.....	2-7
Figure 2-8 Example Rainfall Data Format.....	2-7
Figure 2-9 SSOAP Rainfall Data Converter Setup Menus.....	2-8
Figure 2-10 SSOAP Rainfall Data Import Menu.....	2-9
Figure 2-11 Convert Rainfall Data Time Step Menus.....	2-10
Figure 2-12 Other Rainfall Processing Utilities.....	2-10
Figure 2-13 RDII Analysis Definition Menus.....	2-11
Figure 2-14 Dry Weather Flow Analysis Menus.....	2-12
Figure 2-15 Automatic Dry Weather Flow Day Determination Menu.....	2-13
Figure 2-16 Automatic Dry Weather Flow Day Determination Result Dialog Window.....	2-14
Figure 2-17 Manual DWF Day Review and Removal Graph.....	2-15
Figure 2-18 Wet Weather Flow Analysis Menus.....	2-17
Figure 2-19 RDII Graph Produce by RDII Graph Option.....	2-18
Figure 2-20 RDII Event Statistics Results.....	2-21
Figure 2-21 Triangular Unit Hydrograph Procedure.....	2-24
Figure 2-22 SSOAP .SDB Database Analysis Table with Default RTK Parameters.....	2-26
Figure 2-23 RDII Graph with Computed RDII Curves 1, 2 and 3, and Total Simulated RDII Response.....	2-26
Figure 2-24 Simulated vs. Observed RDII Summary Statistics.....	2-27
Figure 2-25 Simulated vs. Observed Peak Flow Scatter Graph.....	2-28
Figure 3-1 EPA SWMM 5 Main Screen.....	3-2
Figure 3-2 Edit Node Menu and Menu to Enter Dry Weather Flow.....	3-3
Figure 3-3 RDII Parameter Menu.....	3-3
Figure 3-4 RTK Parameter Menu.....	3-4
Figure 4-1 Statistical Report Menu.....	4-1

List of Tables

Table 1-1 Point Precipitation Frequency Estimates for Norfolk WSO Airport. Rainfall Depth in Inches for Various Durations and Rainfall Recurrence Frequency.....	1-2
Table 2-1 RDII Event Summary Spreadsheet with Computer Total R-Value for Events and Volume Weighted Total R-Value.....	2-22
Table 2-2 Example Set of RTK Parameters.....	2-27
Table 4-1 Log-Person Type III Results Table from Spreadsheet.....	4-2

This page intentionally left blank.

List of Acronyms

ADF	Average Daily Dry Weather Flow
CSV	Comma Separated Value
EPA	Environmental Protection Agency
DWF	Dry Weather Flow
HRSD	Hampton Roads Sanitation District
I/I	Infiltration / Inflow
MGD	Million Gallons per Day
NOAA	National Oceanic and Atmospheric Administration
RDII	Rainfall Dependent Inflow and Infiltration
RHM	Regional Hydraulic Model
SDB	SQLite Database
SSOAP	U.S. EPA Sanitary Sewer Overflow Analysis and Planning Toolbox
SWMM	U.S. EPA Storm Water Management Model
USGS	U.S. Geological Survey

This page intentionally left blank.

Section 1

Introduction

1.1 Introduction

This report provides guidance and procedures for estimating 10-year peak flows from flow meter and rainfall data in a manner consistent with the methodologies used and applied in the Regional Hydraulic Model and the Regional Wet Weather Management Plan. The standardized procedures include the following major steps:

1. RDII Analysis in SSOAP Toolbox - Analyze observed flow and rainfall data from using the U.S. EPA Sanitary Sewer Overflow Analysis and Planning Toolbox (SSOAP) to determine dry weather flows and RTK triangular unit hydrograph parameters that best represent observed peak flows and hydrograph shapes for observed wet weather flow events. (Section 2)
2. Long-Term Peak Flow Estimates in SWMM - Use observed average daily flow and estimated RTK values in the U.S. EPA Storm Water Management Model (SWMM) to simulate 61 years of wastewater flows from hourly rainfall data available at the Norfolk airport rainfall gauge. A base SWMM file that contains the basic setup and rainfall needed to perform this simulation was created to facilitate this analysis. (Section 3)
3. 10-Year Peak Flow Determination with Statistical Analysis - Process the simulated flow data to determine the peak flows for wet weather flow events within SWMM and perform a statistical analysis to determine the 10-year peak flow using a Log Pearson Type III statistical distribution within a supplied spreadsheet. (Section 4)

1.2 Minimum Flow and Rainfall Data Requirements

Accurate flow and rainfall data are critical to the success of the evaluations and in determining the accuracy of the results. At a minimum, observed flows from at least three events that produced a significant wet weather flow response are needed to accurately simulate the wet weather flows at a particular location. At a minimum, these three events should have 1-year or greater rainfall recurrence frequencies.

The National Weather Service National Oceanic and Atmospheric Administration publishes an online Atlas 14 that documents rainfall frequency estimates for the United States and describes how to determine the rainfall recurrence frequencies of a given wet weather event (NOAA 2006). **Table 1-1** presents the rainfall frequency for Norfolk International Airport at various durations. As an example for how to interpret this table, a rainfall depth of 1.4 inches over an hour is equaled or exceeded once every year on the average.

The rainfall frequency for any given event is determined by calculating the maximum rainfall for each duration listed in Table 1-1. This is accomplished by computing running totals over the entire event duration to identify the maximum 5-minute, 10-minute, 15-minute etc. duration

rainfall depths embedded in the observed rainfall. These values are then compared with the values in Table 1-1 to determine the rainfall recurrence for each duration. The rainfall recurrence for each duration is the recurrence where the calculated rainfall depth is greater than or equal to the rainfall depth listed for the reported frequency.

Table 1-1 Point Precipitation Frequency Estimates for Norfolk WSO Airport. Rainfall Depth in Inches for Various Durations and Rainfall Recurrence Frequency

Duration/Frequency	1-Year	2-Year	5-Year	10-Year	25-Year
5-minute	0.41	0.48	0.55	0.63	0.71
10-minute	0.65	0.77	0.88	1	1.13
15-minute	0.82	0.97	1.12	1.27	1.43
30-minute	1.12	1.34	1.59	1.84	2.12
60-minute	1.4	1.68	2.04	2.4	2.82
2-hour	1.66	1.99	2.47	2.96	3.55
3-hour	1.78	2.15	2.67	3.21	3.9
6-hour	2.17	2.6	3.24	3.9	4.77
12-hour	2.57	3.08	3.85	4.66	5.74
24-hour	2.93	3.57	4.62	5.5	6.82
48-hour	3.39	4.1	5.28	6.29	7.81

1.3 EPA SSOAP Toolbox Introduction

The EPA SSOAP Toolbox is used by HRSD to determine RDII (Rainfall Derived Inflow and Infiltration) characteristics for the Regional Hydraulic Model based on several flow monitoring periods beginning in 2008. SSOAP is a U.S. EPA program used to evaluate observed flow and rainfall data to identify the extraneous flows generated by rainfall (RDII flows) and estimate the RDII characteristics using a RTK triangular unit hydrograph approach. This approach consists of calibrating RTK parameters to simulate observed RDII flows from observed rainfall.

Detailed information on SSOAP, including the user manual, RTK triangular unit hydrograph approach, and the SSOAP Toolbox software, can be found and downloaded at the following URL:

<http://www2.epa.gov/water-research/sanitary-sewer-overflow-analysis-and-planning-ssoap-toolbox>.

The report Computer Tools for Sanitary Sewer System Capacity Analysis and Planning (US EPA, 2007) should be downloaded and reviewed for background and further information on the program and methodology. This manual provides information on the RTK triangular unit hydrograph procedure used to simulate sanitary sewer rainfall induced inflow and infiltration from rainfall. SSOAP also includes an extensive help menu system that provides guidance on the program use.

The SSOAP program stores rainfall and flow data in a Microsoft Access database (suffix is .SDB). The program itself provides menus and programs that load and manipulate the data to perform the analyses. The SSOAP .SDB file can be opened and the tables viewed and manipulated in within Microsoft Access.

Section 2 provides procedures for loading the data to SSOAP and applying the program to perform an analysis.

1.4 EPA SWMM Program Introduction

After RDII characteristics in the form of RTK parameters are determined with the SSOAP Toolbox, EPA's SWMM software is used to estimate peak flow rates based on a long-term simulation. EPA SWMM provides the means to simulate various aspects of stormwater and sanitary sewer hydrology and hydraulics. A SWMM input file named SWMM_LTS_BASE_FILE.INP is supplied with this report. This file includes the basic model setup to perform a 61-year simulation using the hourly rainfall data that is available from the Norfolk Airport since 1954 (hence 61 years). This long-term rainfall record is applied to the calibrated RTK triangular unit hydrograph parameters, from SSOAP Toolbox, and combined with dry weather flows to simulate a 61 year long synthetic record of sanitary sewer. The procedures used to setup the model parameters and perform this simulation are documented in **Section 3**.

The EPA SWMM program and manuals can be downloaded from the following URL:

<http://www.epa.gov/water-research/storm-water-management-model-swmm>

1.5 Statistical Analysis

The long-term simulation performed with the EPA SWMM program is the basis for the determination of the 10-year peak flow using a Log Pearson Type III statistical distribution analysis. The statistical analysis starts by identifying the largest peak flows produced by independent wet weather flow events. The events are sorted from largest to smallest peak flows. This step is performed from within the EPA SWMM program.

The events and their peak flows are copied from SWMM to a spreadsheet named LogPearson.xlsx that is supplied with this report. The 61 events with the largest peak flows comprise a partial-duration series used for this statistical analysis. A Log-Pearson Type III statistical distribution is fit to the partial duration series by computing the mean, standard deviation, and skew of the base 10 logs of the peak flows. The net result of this evaluation is the 10-year peak flow value as determined from the observed flow and rainfall data. This process is documented in **Section 4**.

This page intentionally left blank.

Section 2

EPA SSOAP Toolbox Flow Analysis

2.1 Introduction

Basic data required for a SSOAP Toolbox dry and wet weather flow analysis include the following:

- Flow data from a sanitary sewer meter at an appropriate time increment (typically 5, 10, or 15 minute time increments).
- Rainfall data from a rainfall gauge near the monitored catchment that include the complete duration of the flow data. Time increment of rainfall data should be same as the flow data though SSOAP provides options for converting the rainfall time step if this is not the case.
- Estimate of the sewered area upstream from the meter. The sewered area is typically estimated as a fraction of the total area served by the meter adjusted to exclude larger unsewered areas such as parkland, cemeteries, highways, water bodies, and similar unsewered areas.

The following sections provide instructions to estimate RDII characteristics in 5 major steps, they are:

1. Creating a SSOAP database (Section 2.2)
2. Loading the flow and rainfall data to the SSOAP database (Section 2.3 and 2.4)
3. Performing a dry weather flow analysis (Section 2.4)
4. Performing a wet weather flow analysis (Section 2.5)
5. Calibrating RTK unit hydrograph parameters to simulate the observed flow hydrograph from the observed rainfall (Section 2.6)

2.2 Creating and Opening SSOAP Databases

SSOAP stores the flow and rainfall and other data in a Microsoft Access database that has a .sdb suffix. This database can be opened and viewed in Microsoft Access.

The main screen that appears when SSOAP is opened is shown on **Figure 2-1**. To create a new database, use the File/New Database menu option and save the database where desired using a name that is meaningful.

To view or analyze data in an existing database, go to the File/Open Database option. The main screen also provides a simplified workflow chart showing how the tools in the SSOAP Toolbox link to each other.

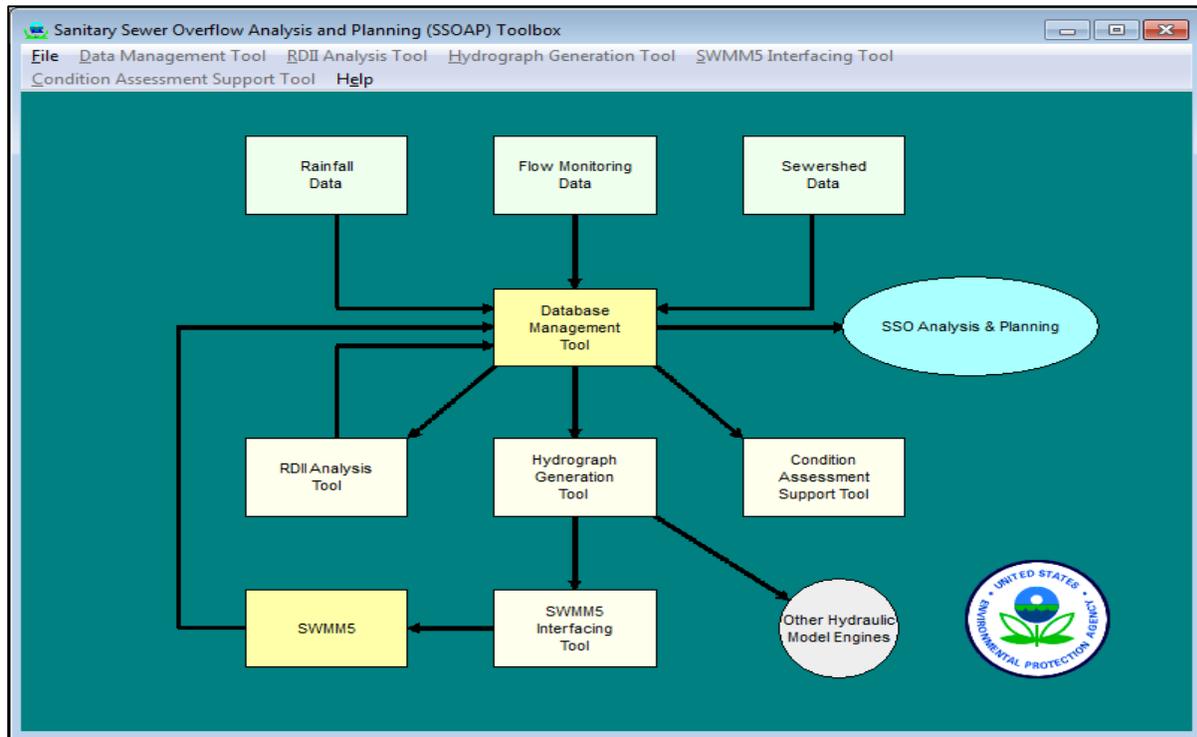


Figure 2-1
SSOAP Toolbox Main Screen

2.3 Adding Flow Data to SSOAP

Flow data are managed and entered through menus accessed by either:

- Clicking on the “Flow Monitoring Data” block on the main screen or
- Using the Data Management Tool menu and clicking on Flow Monitoring Data.

2.3.1 Creating Flow Meter Record

The first step is to create a flow meter record by clicking the Flow Data Management menu using the menus shown on **Figure 2-2**. Enter the meter name, contributory or sewer area, units to be used, and time step. Location and length of sewer data are optional and can be left blank. After adding the meter, users can go back and edit the information entered. However, the units should be set before the data are loaded.

SSOAP has the ability to store data for multiple meters, gauges, and analyses in a single .SDB file. The recommended approach is to have one meter, gauge, and analysis in each database file.

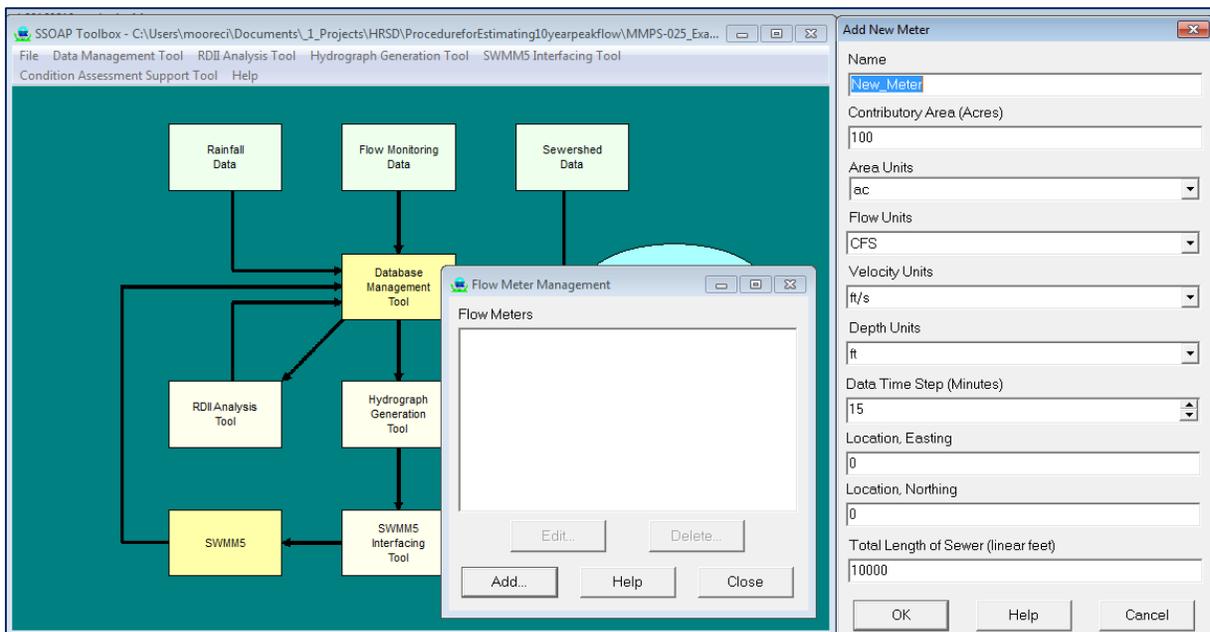


Figure 2-2
SSOAP Flow Meter Data Management Menus

2.3.2 Formatting Flow Data for Import to SSOAP

Loading data to SSOAP works best when the flow data are in Comma Separated Values format (CSV). The CSV formatted file can have multiple header lines if desired. **Figure 2-3** provides an example of the appropriate format.

	0	10	20	30	40	50	60
1	Month, Day, Year	, Hour, Minute	, Depthinches,	Flowmgd,	Velocityfps		
2	4, 30, 2009, 0, 0,	2.18, 0.136,	2.17				
3	4, 30, 2009, 0, 15,	1.94, 0.083,	1.56				
4	4, 30, 2009, 0, 30,	1.93, 0.052,	0.99				
5	4, 30, 2009, 0, 45,	2.06, 0.064,	1.1				
6	4, 30, 2009, 1, 0,	1.94, 0.064,	1.21				
7	4, 30, 2009, 1, 15,	1.91, 0.074,	1.42				
8	4, 30, 2009, 1, 30,	1.91, 0.07,	1.35				
9	4, 30, 2009, 1, 45,	1.98, 0.063,	1.15				
10	4, 30, 2009, 2, 0,	1.85, 0.036,	0.73				
11	4, 30, 2009, 2, 15,	1.74, 0.033,	0.73				
12	4, 30, 2009, 2, 30,	1.75, 0.044,	0.96				
13	4, 30, 2009, 2, 45,	1.73, 0.039,	0.85				
14	4, 30, 2009, 3, 0,	1.69, 0.043,	0.99				
15	4, 30, 2009, 3, 15,	1.85, 0.043,	0.87				
16	4, 30, 2009, 3, 30,	1.66, 0.042,	0.99				

Figure 2-3
Example Flow Data Format

The best approach for creating this file is to use Microsoft Excel to format the data and then save the data in .CSV format from within Excel. The Excel Month, Day, Year, Hour, and Minute functions can be used to extract these values from the standard Excel date format.

2.3.3 Creating Flow Data Converter

A flow data converter must be setup within SSOAP by using the Flow Monitoring Data/ Converter Setup menus shown on **Figure 2-4**. The purpose of this flow data converter is to instruct the SSOAP Toolbox about the exact data format set-up prior to the loading of the data. Enter a name for the converter, the units of the flow data, and the number of lines to skip at the start of the file for header lines (should be 1 for the example data in Figure 2-3).

Velocity and depth data are not used by SSOAP but can be loaded to the database if desired. SSOAP does include features to plot the flow vs. depth scatter graphs if these data are loaded. If velocity and depth are not available or desired, uncheck the two check boxes next to these data parameters as shown on Figure 2-4. It is recommended that the time be entered in military time where the hours go from 1 to 24. SSOAP will convert the flow data if the units in the converter differ from the units used when setting up the meter.

When CSV format is selected, inform SSOAP in which columns or in which order the month, day, year, hour, minute, flow, velocity (if used) and depth (if used) appear in the input CSV file. The column or order in SSOAP can be changed to fit the flow monitoring data format.

Once the format is set, the converter setup is saved by pressing the OK button.

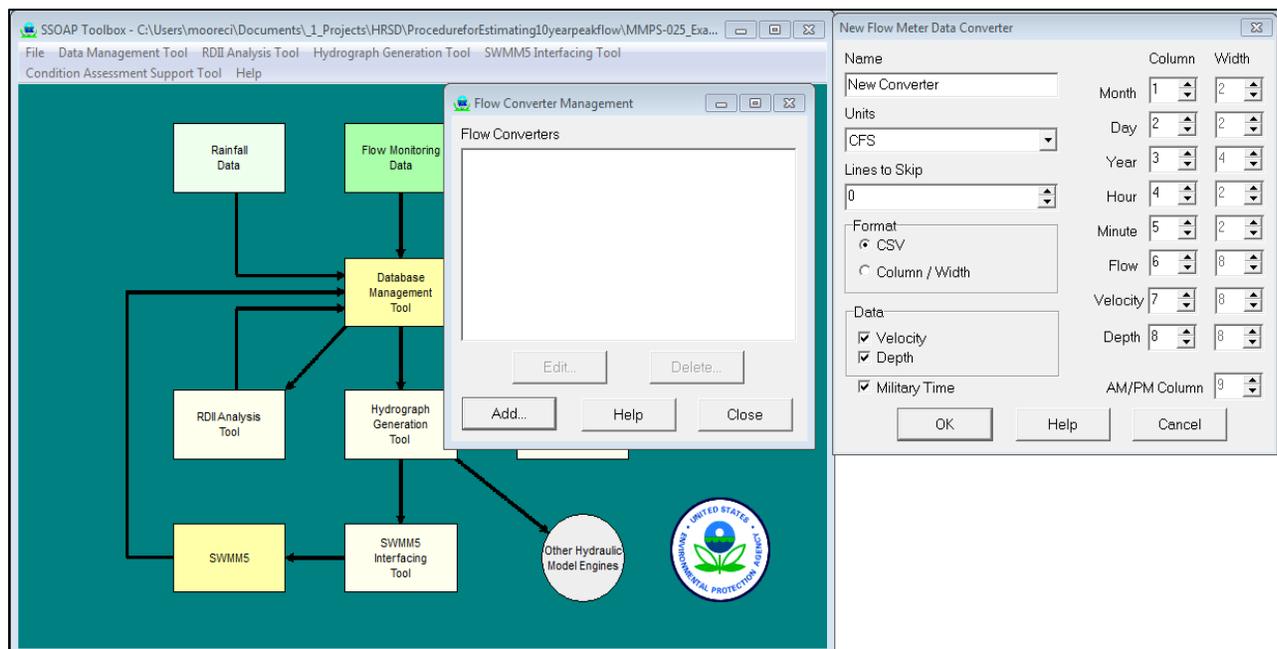


Figure 2-4
SSOAP Flow Data Converter Setup Menus

2.3.4 Loading Flow Data to SSOAP

Once the flow meter is setup, the flow data is formatted to the correct CSV format, and the Flow Data Converter is defined, the flow data can be loaded to SSOAP using the Flow Monitoring Data / Import menus as shown on **Figure 2-5**:

- Select the Flow Meter Name.
- Select the CSV file name using the Browse button.
- The default values for the various options should be used in most cases.

After pressing ok, a dialog should appear that indicates that the data are being imported. A summary dialog will appear that documents the number of records processed, first and last date read, errors encountered, number of non-zero flows, number of zero flows, date range, maximum flow and date, minimum flow and date, and the average flow. This should be reviewed to verify that the data were loaded correctly. The data on this Processing Complete menu can be saved to a file if desired.

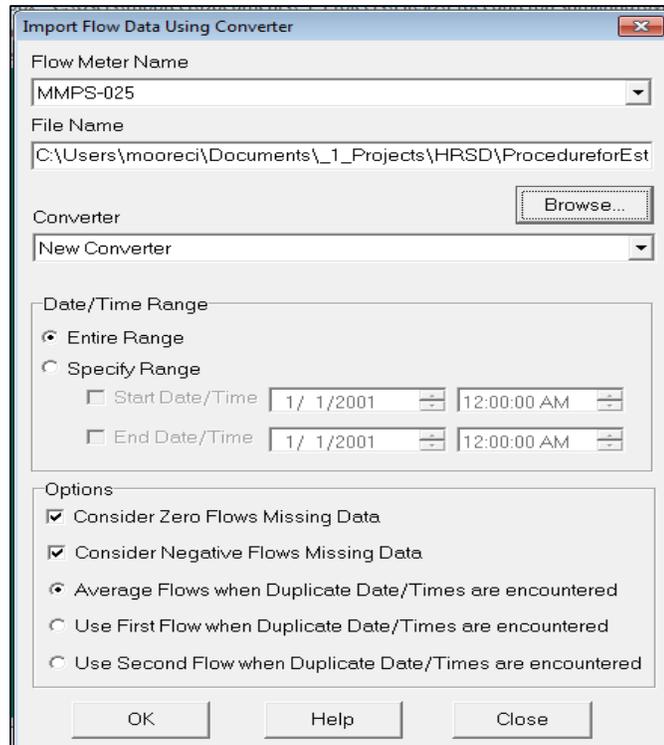


Figure 2-5
SSOAP Flow Data Import Menu

The loaded flow data can then be viewed through Access by opening the .SDB file. Frequent causes for data not being loaded included non-numeric data in the file, control characters in the file, and improper setup of the Flow Converter. ***Having the file open in Excel will also prevent the loading of the data into SSOAP.*** SSOAP recognizes if data have already been loaded for a meter and will provide options to add to the existing data or remove the existing data.

2.3.5 Flow Data Utilities

2.3.5.1 Fill in Missing Flow Records and Data

SSOAP has utilities to add missing data records and to interpolate missing or zero flow data. **Figure 2-6** presents the location of the menu that assess this feature for the flow data. Select the meter to be processed and define the maximum duration over which flows should be filled in through linear interpolation from the values before and after the missing data period.

It is typically allowable to fill in up to an hour of missing data if several hours of valid data are available before and after the missing data period.

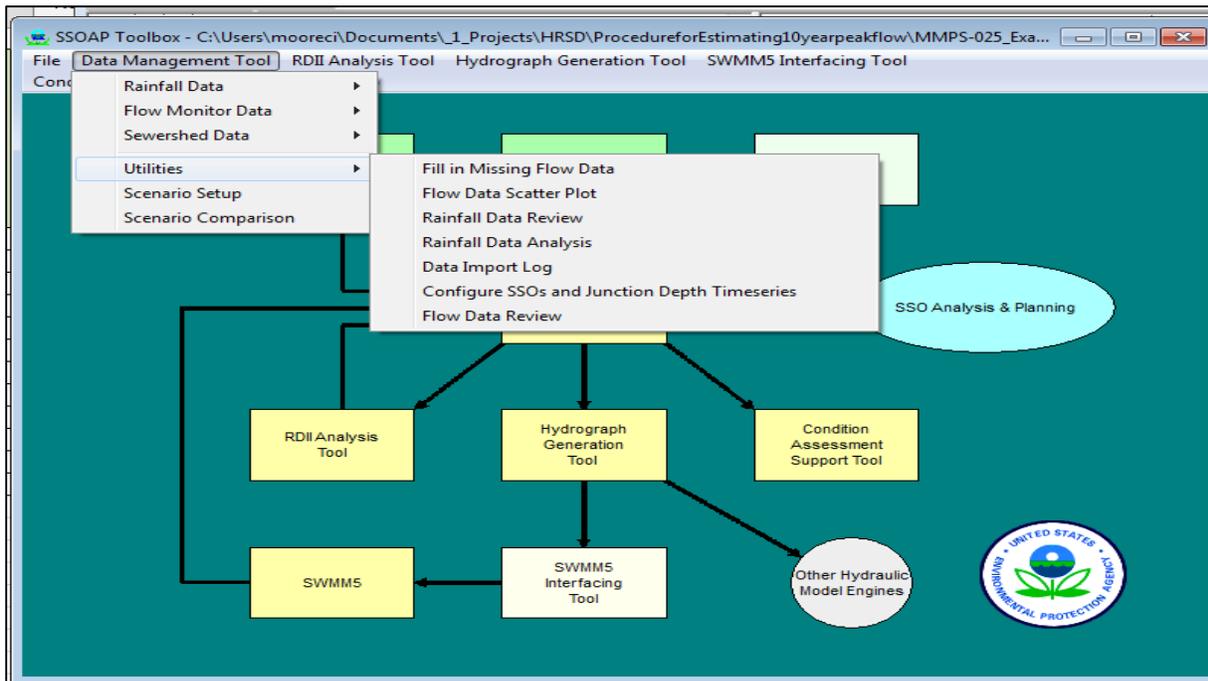


Figure 2-6
Flow Data Utilities Menu

2.3.5.2 Flow Data Scatter Plots

SSOAP provides the option to show flow vs. depth or velocity vs. depth scatter plots. Such plots are useful to evaluate whether the meter is subject to surcharging and backwater from downstream conditions that may affect the flow data accuracy or to determine if the flow data is adequate to support the RDII analysis.

2.3.5.3 Flow Data Review

SSOAP provides the option to review the imported flow data graphically through this menu option.

2.4 Adding Rainfall Data to SSOAP

Rainfall data are added to SSOAP using procedures similar to adding the flow data. Rainfall data are needed to perform the analysis of total R-values (i.e. dry-weather and wet-weather analysis) and to calibrate RTK parameters.

Rainfall data are managed and entered through menus accessed by either:

- Clicking on the “Rainfall Monitoring Data” block on the main screen or
- Using the Data Management Tool menu and clicking on Rainfall Data.

2.4.1 Creating Rainfall Gauge Record

The first step is to create a rain gauge record by clicking the Rainfall Data Management menu using the menus shown on **Figure 2-7**. Enter the rainfall gauge name, units to be used, and time step of the data contained in the file to be loaded. The input rainfall time step does not need to equal the flow time step as SSOAP includes tools that will adjust the rainfall time step. Location information is optional and can be left blank. After adding the rainfall gauge, users can go back and change the information entered though the units should be set and final before the data are loaded.

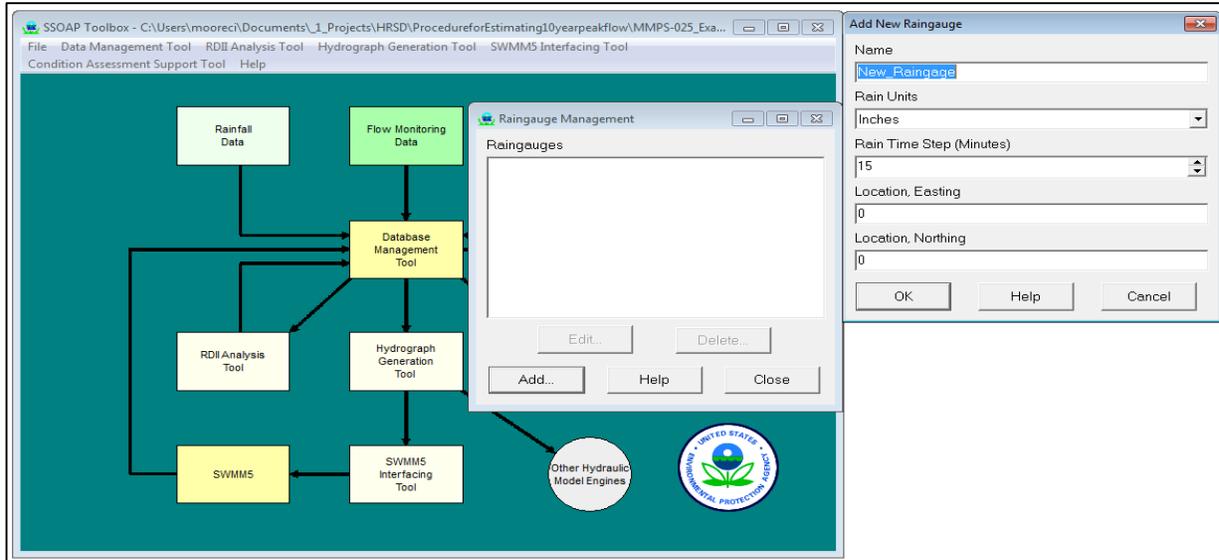


Figure 2-7
SSOAP Rainfall Gauge Management Menus

2.4.2 Formatting Rainfall Data for Import to SSOAP

Loading data to SSOAP works best when the flow data are in Comma Separated Values format (CSV). The CSV formatted file can have multiple header lines if desired. **Figure 2-8** provides an example of the appropriate format.

	0	10	20	30	40	50
1	Month, Day, Year, Hour, Minute, Raininches					
2	5, 7, 2009, 7, 0, 0.07					
3	5, 7, 2009, 7, 15, 0.08					
4	5, 7, 2009, 7, 30, 0					
5	5, 7, 2009, 12, 0, 0.01					
6	5, 7, 2009, 12, 15, 0					
7	5, 7, 2009, 15, 0, 0.03					
8	5, 7, 2009, 15, 15, 0.05					
9	5, 7, 2009, 15, 30, 0.01					
10	5, 7, 2009, 15, 45, 0					
11	5, 7, 2009, 17, 0, 0.01					
12	5, 7, 2009, 17, 15, 0					
13	5, 7, 2009, 18, 0, 0.04					
14	5, 7, 2009, 18, 15, 0.01					
15	5, 7, 2009, 18, 30, 0					
16	5, 11, 2009, 7, 45, 0.01					

Figure 2-8
Example Rainfall Data Format

The best approach is to use Microsoft Excel to format the data and then save the data in .CSV format from within Excel. The Excel Month, Day, Year, Hour, and Minute functions can be used to extract these values from the standard Excel date format.

2.4.3 Creating Rainfall Data Converter

A rainfall data converter must be setup within SSOAP by using the Rainfall Data/ Converter Setup menus shown on **Figure 2-9**. Enter a name for the converter, the units of the rainfall data, and the number of lines to skip at the start of the file for header lines (should be 1 for the example data in Figure 2-8).

It is recommended that the times be entered in military time where the hours go from 1 to 24. If the units in the converter setup differ from the units used in the rainfall gauge definition, SSOAP will convert the data to correct for the units.

When CSV format is selected, inform SSOAP in which columns or in which order the month, day, year, hour, minute, and rainfall volume appear in the input CSV file. The column or order can be changed to fit the rainfall monitoring data format.

Once the format is set, the converter setup is saved by pressing the OK button.

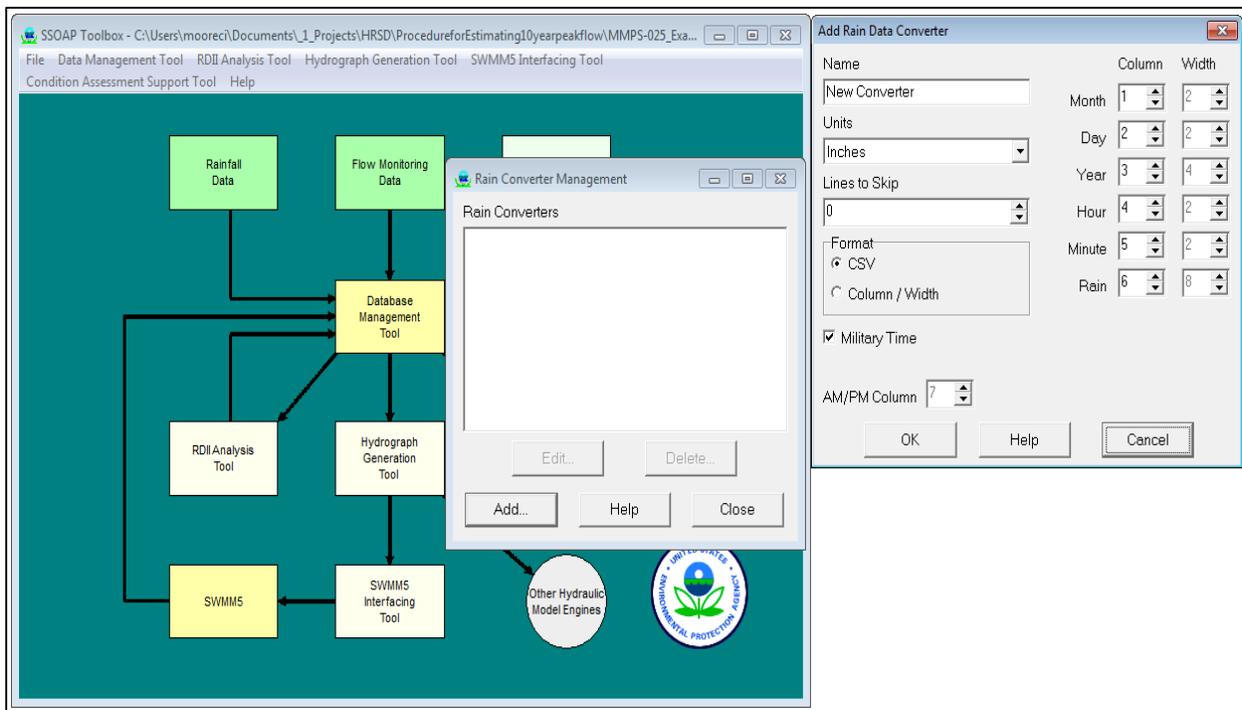


Figure 2-9
SSOAP Rainfall Data Converter Setup Menus

2.4.4 Loading Rainfall Data to SSOAP

Once the rainfall gauge is setup, the rainfall data is formatted to the correct CSV format, and the Rainfall Data Converter is defined, the rainfall data can be loaded to SSOAP using the Rainfall Data / Import menus as shown on **Figure 2-10**.

- Select the Rainfall Gauge Name.
- Select the CSV file name using the Browse button.
- The default values for the various options should be used in most cases.

After pressing ok, a dialog will appear that indicates that the data are being imported with a running date as the data are loaded. A summary dialog will appear that documents the number of records processed, starting and ending dates, total rainfall, average rainfall and the five records with the maximum rainfall. These data should be reviewed to verify that all of the data were loaded correctly. The data on this Processing Complete menu can be saved to a file if desired. The loaded rainfall data can be viewed through Access by opening the .SDB file.

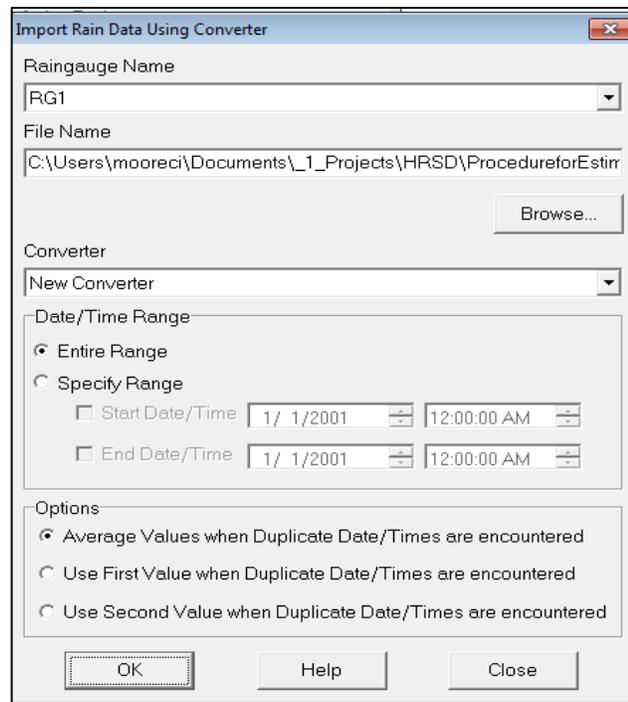


Figure 2-10
SSOAP Rainfall Data Import Menu

Frequent causes for data not being loaded included non-numeric data in the file, control characters in the file, and improper setup of the Rainfall Converter. ***Having the file open in Excel will also prevent the loading of the data into SSOAP.***

SSOAP recognizes if data have already been loaded for a rainfall gauge and will provide options to add to the existing data or remove the existing data.

2.4.5 Rainfall Data Utilities

2.4.5.1 Convert Rainfall Data Time Step

The flow data and the rainfall data need to be stored at the same time step for the SSOAP analysis. SSOAP provides a utility that will convert the rainfall from the input time step to the flow data time step. This is accessed through the Data Management, rainfall data convert time step menu as shown on **Figure 2-11**.

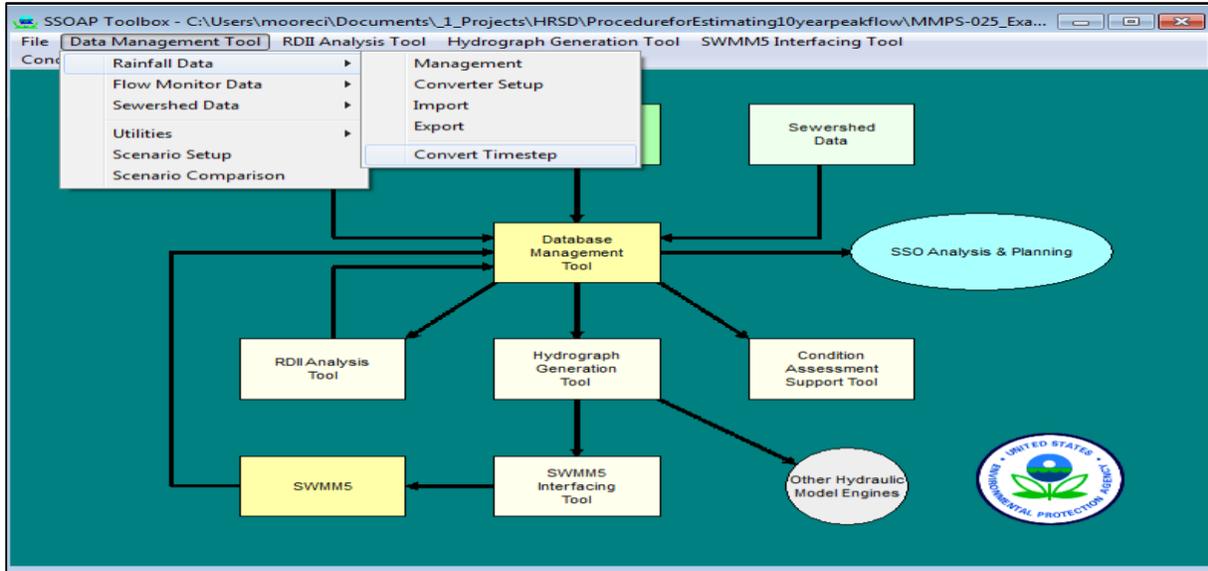


Figure 2-11
Convert Rainfall Data Time Step Menus

If the time step is reduced, the converted rainfall step must be an integer fraction of the input time step. To transform 15 minute data to 10 minute data, it is necessary to first convert to a 5 minute time step and then convert the 5 minute data to 10 minute.

2.4.5.2 Other Rainfall Processing Utilities

SSOAP provides other processing utilities for viewing and evaluating rainfall data as shown on **Figure 2-12**. The Utility Menu Rainfall Data Review menu allows the loaded rainfall to be reviewed.

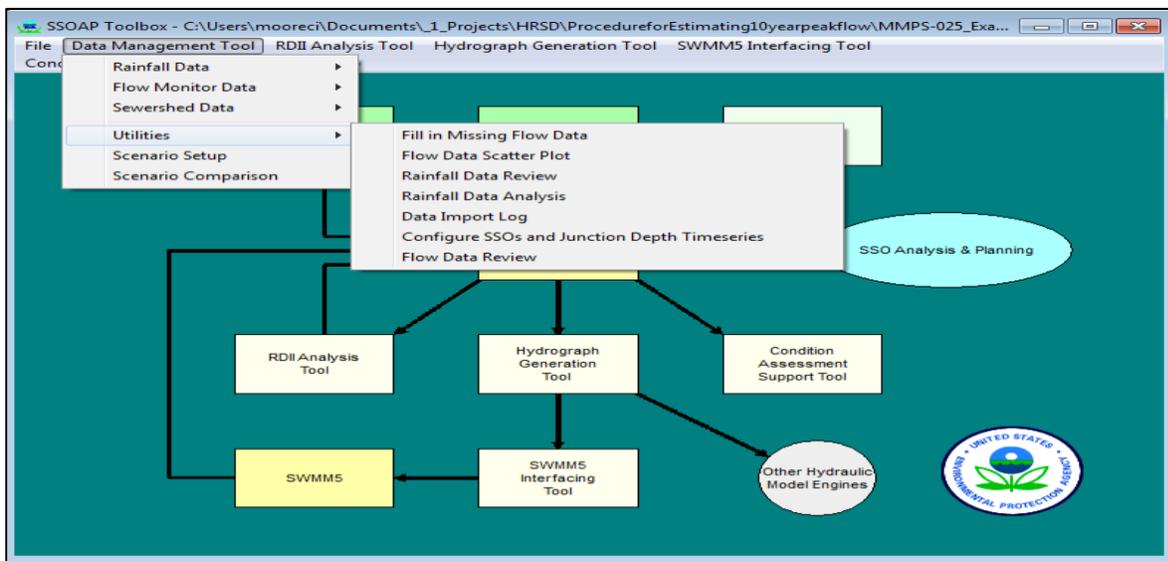


Figure 2-12
Other Rainfall Processing Utilities

The Rainfall Data Analysis menu provides a means to break the rainfall data into events by designating a minimum inter-event time in hours. Volume, duration, peak intensity and antecedent moisture condition are displayed for each event identified in the selected period of record for the selected rain gauge. This analysis is very useful and the results of this analysis should be saved for reference and used when identifying flow event start and end dates in subsequent analyses.

2.5 Defining an RDII Analysis

The first step in evaluating the loaded flow and rainfall data is to define an RDII Analysis. The RDII Analysis defines the flow meter and rainfall gauge to use for the analysis and defines other parameters associated with an analysis as shown on **Figure 2-13**. Enter an analysis name (typically the meter name), select the flow meter, and select the rainfall gauge. Parameters related to the estimated base flow rates and dry weather flow variation by day of the week are not typically used.

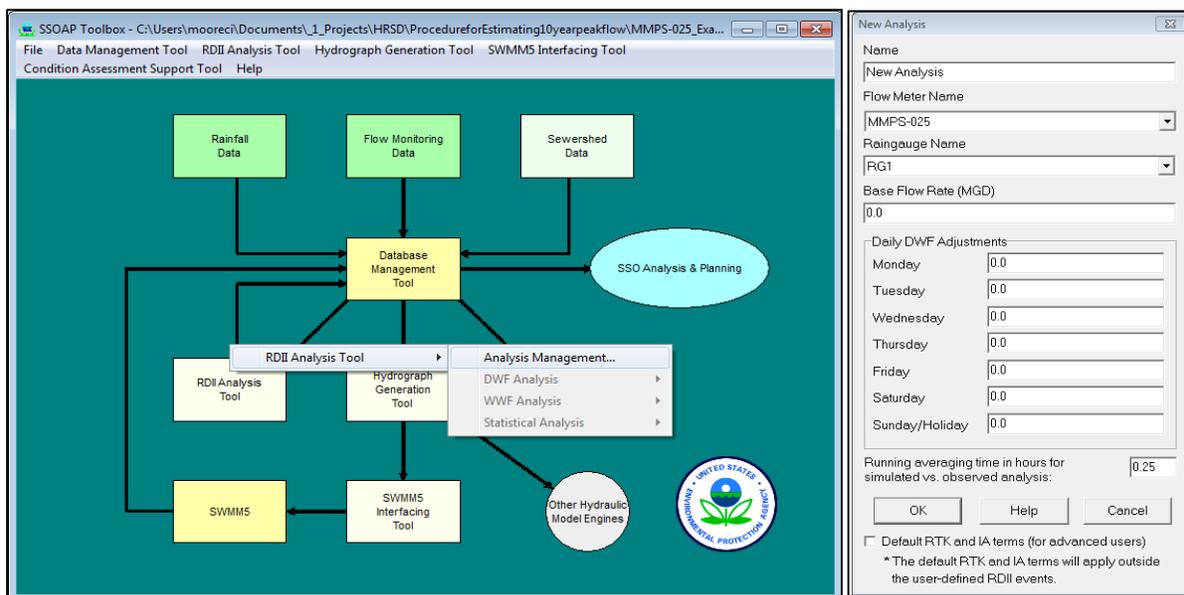


Figure 2-13
RDII Analysis Definition Menus

The parameter regarding the time to average flows controls the peak simulated and reported flow that is used when comparing simulated and observed peak flows. Flows are computed at the same time step as the observed flows. It is often useful to do a running average of 15-minute or 1-hour when documenting and comparing simulated and observed peak flows.

2.6 Dry Weather Flow Analysis

A dry weather flow analysis is first performed to define the dry weather flow rates and variation. The menus are shown on **Figure 2-14**. The dry weather flow days identified in Sections 2.6.1 and 2.6.2 serve to identify the dry weather flow pattern, determine average dry weather flow rates, and to define how dry weather flows vary over the observed flow period.

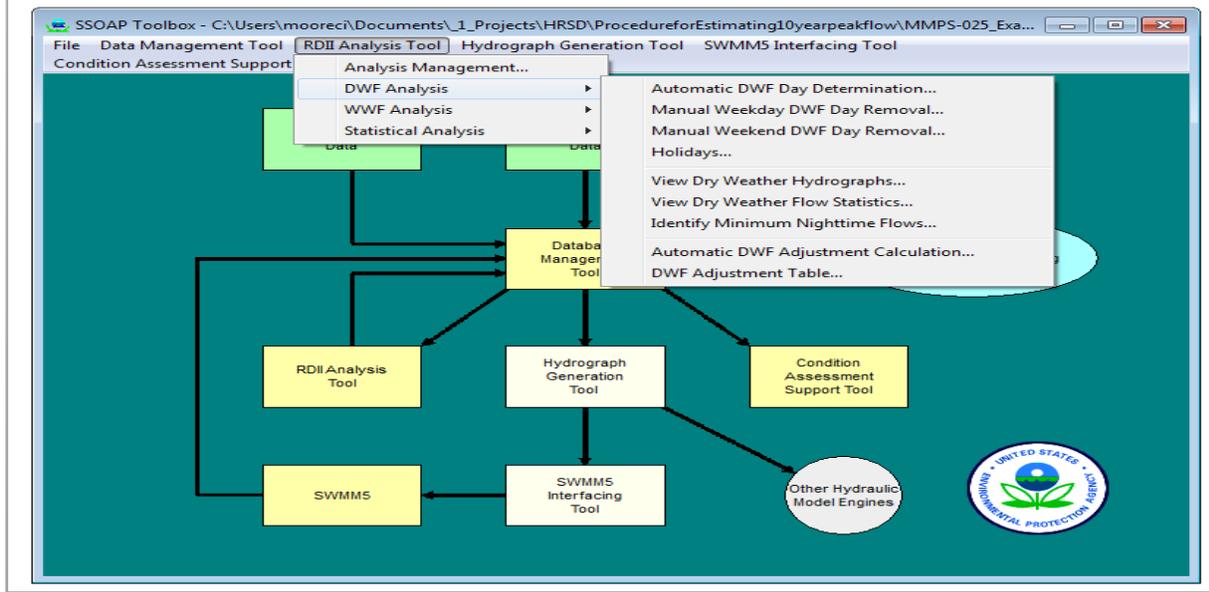


Figure 2-14
Dry Weather Flow Analysis Menus

2.6.1 Automatic Dry Weather Flow Day Determination

Dry weather flow days are first identified using this menu option which brings up the menu shown on Figure 2-15. The Automatic Dry Weather Flow Day Determination menu includes three methods to identify typical weekday and weekend dry weather days not affected by rainfall or by non-standard flows. These methods are typically used in combination:

- Remove days with missing data
- Remove days where rainfall occurred
- Remove days statistically based on the average and standard deviation

The first set of parameters will discard days that have incomplete flow data and should be set to 100 percent. This means that only days with 100 percent of the flow data will be considered.

The second portion of the menu discards days based on the rainfall that fell on the day under consideration and prior days. Typically, days with a total rainfall of 0.25 inches or less and days with less than 0.5 inches on the prior day with values for days three to seven days before the event set to larger and larger rainfall volumes as shown of Figure 2-14. The user is free to use other maximum rainfall volumes to evaluate how the dry weather day selection is affected.

Figure 2-15
Automatic Dry Weather Flow Day Determination
Menu

The final parameter to select dry weather flow days statistically is more complicated than the previous two methods. For the days that meet the flow data points and rainfall criteria, SSOAP will compute the mean and standard deviation of 1) average daily flow, 2) maximum daily flow, and 3) minimum daily flow. Days where either the average daily flow, maximum daily flow, or minimum daily flow fall outside the specified number of standard deviations are discarded. This provides a statistical procedure to eliminate days with flows that differ significantly from the average dry weather day. Increasing the number of standard deviations includes more days but some of these days will be less similar to the average. A standard deviation of 1 is typically a good starting point. The number of standard deviations can be modified to come up with a meaningful number of dry weather days but exclude outliers.

Each time the “Ok” button is pushed, the program will reselect dry weather days which allows the user to iterate with different parameters to evaluate the results. The results dialog shown on **Figure 2-16** is produced for each iteration.

The results dialog presents the results as they are computed starting with weekday followed by weekend day evaluations as presented below:

- The first part indicates that 221 weekdays of the 309 total days in the flow record met the criteria for number of data points and maximum rainfall.
- The average and standard deviations for these 221 days is presented next.
- Following the statistical analysis, 170 of the weekdays remain.
- The average and standard deviations for these days are then presented.

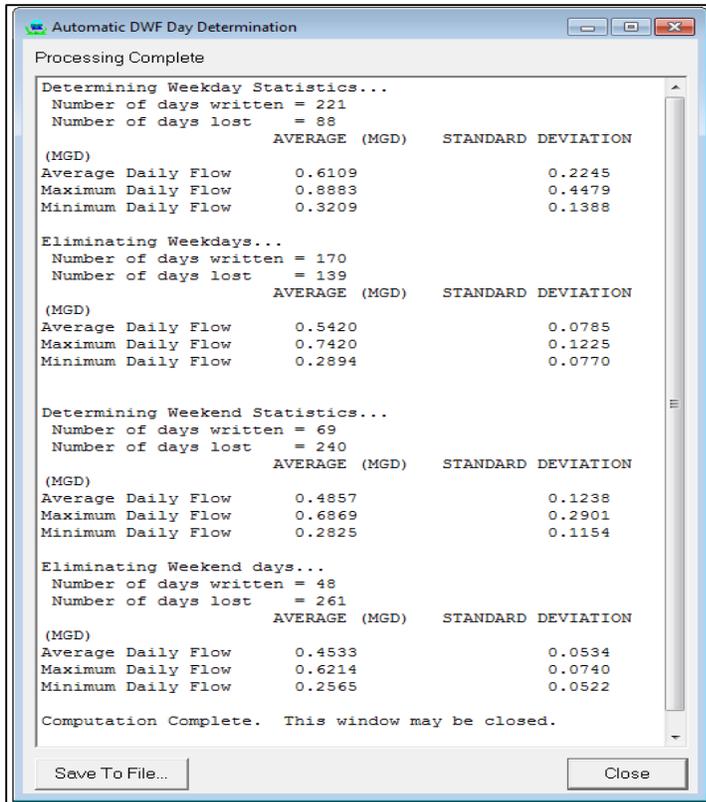


Figure 2-16
Automatic Dry Weather Flow Day Determination Result
Dialog Window

Similar results are presented for weekend days showing that after the selection there are 48 weekend days. Care should be taken such that a meaningful number of days remain for weekdays and weekend days after the analysis is complete. The standard deviation parameter may need to be increased to allow more days through the filter.

The selected days are saved in a database but are overwritten each time this automatic dry weather flow day determination is performed.

2.6.2 Manual Weekday and Weekend DWF Day Review and Removal

This menu option is used to manually review the flow hydrographs for the selected dry weather flow days and eliminate those that are not representative. Graphs similar to that shown on **Figure 2-17** are created for each of the selected dry weather days with the blue line showing the average hydrograph for all of the selected days and the red line presenting the flows for the date that appears at the top of the graph.

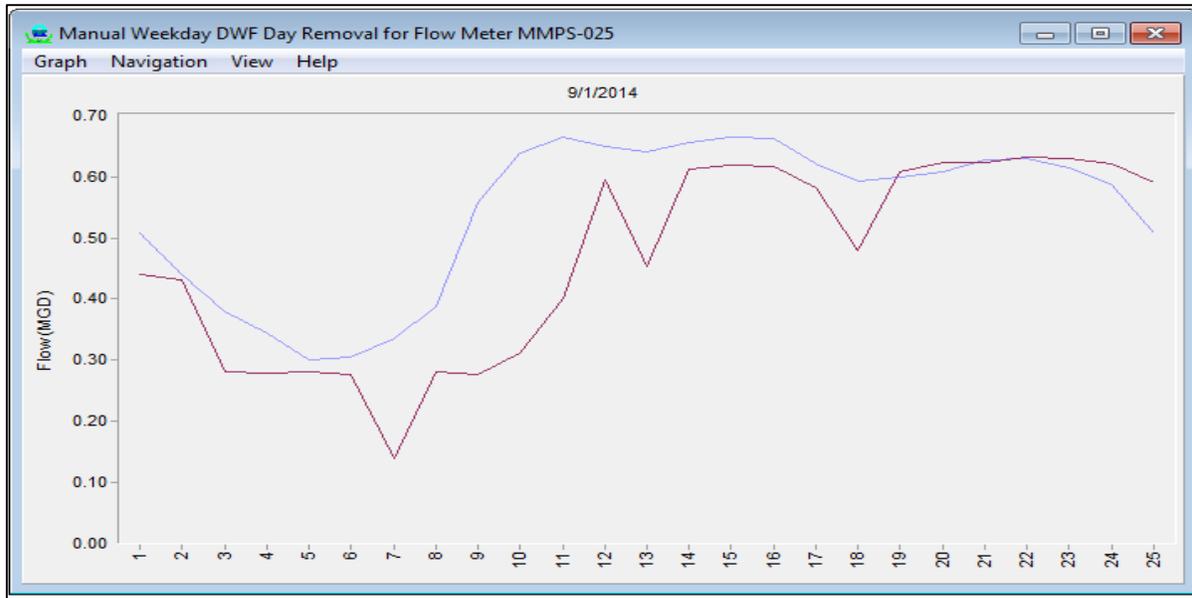


Figure 2-17
Manual DWF Day Review and Removal Graph

The SSOAP Help system provides useful tips for moving through the menus and eliminating days. The following provides some guidelines for quickly reviewing these days:

- **Control P** moves to the previous day.
- **Control N** moves to the next day.
- **Control B** goes back to the beginning of the record.
- **Control E** goes to the ending of the record.
- **Control K** will keep this day and move to the next day.
- **Control D** will delete this day and move to the next day.

Control K and Control D provides a means to quickly move through the days. The key point in this evaluation is to not be too meticulous about the days to remove or keep and to just eliminate those that obviously have non-typical flows that may have a significant effect on the average shown in blue. Two or so passes through the days should be sufficient and the number of excluded days should be small. When starting again using Control B, the days that were previously excluded will have a red X through the graph. Close the window when completed. This step of manually reviewing the selected days should be performed for both weekdays and weekend days.

The selected dry weather flow days are stored in a database table that can be viewed and manipulated.

2.6.3 Defining Holidays

If desired, the user can identify the holidays that occurred during the monitoring period. These days use the weekend dry weather flow hydrographs and should be excluded unless they show typical weekend flows

2.6.4 Automatic DWF Adjustment Calculation

This is a critical step that must be performed after dry weather flow days are identified. The purpose of this step is to normalize the difference of dry weather days, which is essential if the flow meter data is a long-term record. This process determines and saves the difference between the average dry weather flow on each day and the average dry weather flow for all dry weather days. These values are used to adjust the dry weather flows based on the observed data.

Performing the automated DWF adjustment after selecting the dry weather days is critical for the successful analysis of wet weather flows.

2.6.5 Other Dry Weather Flow Menus

Other menus allow you to view the weekday and weekend dry weather flow hydrographs and average flow statistics and to view a table listing the dry weather flow days and the adjustments from the average.

SSOAP also provides a means to identify the minimum nighttime dry weather flows. This can be used to split dry weather flows into base sanitary and ground water infiltration by assuming that some fraction of the minimum nighttime flow within the period of record is groundwater. Depending on land use, typically approximately 80 percent of the minimum nighttime dry-weather flow can be assumed to be groundwater. This rule of thumb for splitting dry weather flows into base sanitary and groundwater infiltration is valid for service areas that are mostly residential. Service areas that have commercial or industrial land use and that have discharges during nighttime hours may need different assumptions. Where water consumption data and billing information is available, this information can be used to estimate base wastewater flows. The fraction that is groundwater can then be estimated as the difference between the minimum nighttime dry weather flow and the lowest nighttime water consumption. However, this additional analysis is not critical for determining wet weather peak flow.

2.7 Wet Weather Flow Analysis

After completing the dry weather flow analysis described in Section 2.6, the next step is to perform the wet weather flow analysis. This process includes the following major steps:

- Identify wet weather flow events by their respective start and end dates.
- Review and adjust dry weather flows such that the estimated RDII flows computed as the difference between the observed flows and estimated dry weather flow is zero before and after the event.
- Compute an average total R-value which is the fraction of the rainfall over the sewershed that entered the sewer system as RDII flows.

Figure 2-18 presents the major menus available when performing the wet weather flow (WWF) analysis.

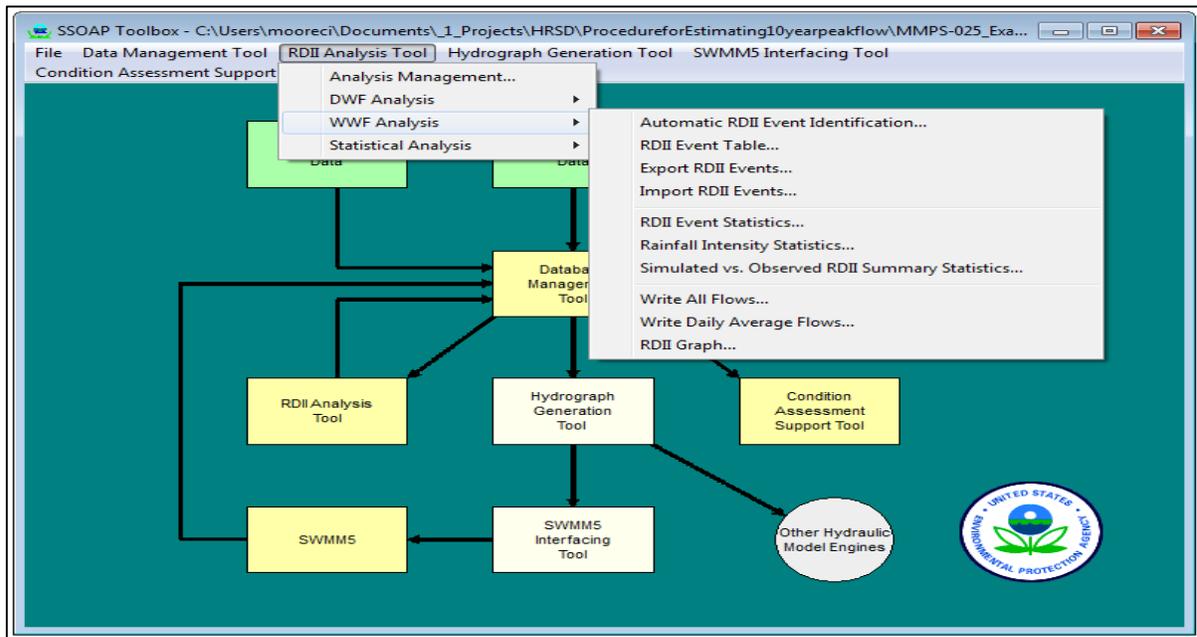


Figure 2-18
Wet Weather Flow Analysis Menus

2.7.1 Automatic RDII Event Identification

The wet weather flow analysis menu provides tool options that perform automatic identification of wet weather events. It is recommended that this option not be used and that the manual identification as described in Section 2.7.5 be used to identify wet weather events.

The automatic RDII event identification tool uses the following parameters to identify RDII event start and end times through analyzing the RDII flow hydrograph and rainfall for conditions that meet a definition of an RDII event:

- Minimum peak flow and number of time steps to average to estimate the peak.
- Minimum event duration
- Minimum rainfall volume

The program has inputs for the number of hours to add to the start and end of the event (defined by the start and end of the event rainfall) to be sure that the elevated flows from the event are included.

2.7.2 Using the RDII Graph

The RDII graph option provides a powerful visual tool to view various flow hydrographs. **Figure 2-19** shows the graph generated through this option. Features and options typically used for evaluating wet weather flows are described in this section. It is recommended that the SSOAP

user's manual and help systems be reviewed to fully understand the functionality built into the RDII graph menus.

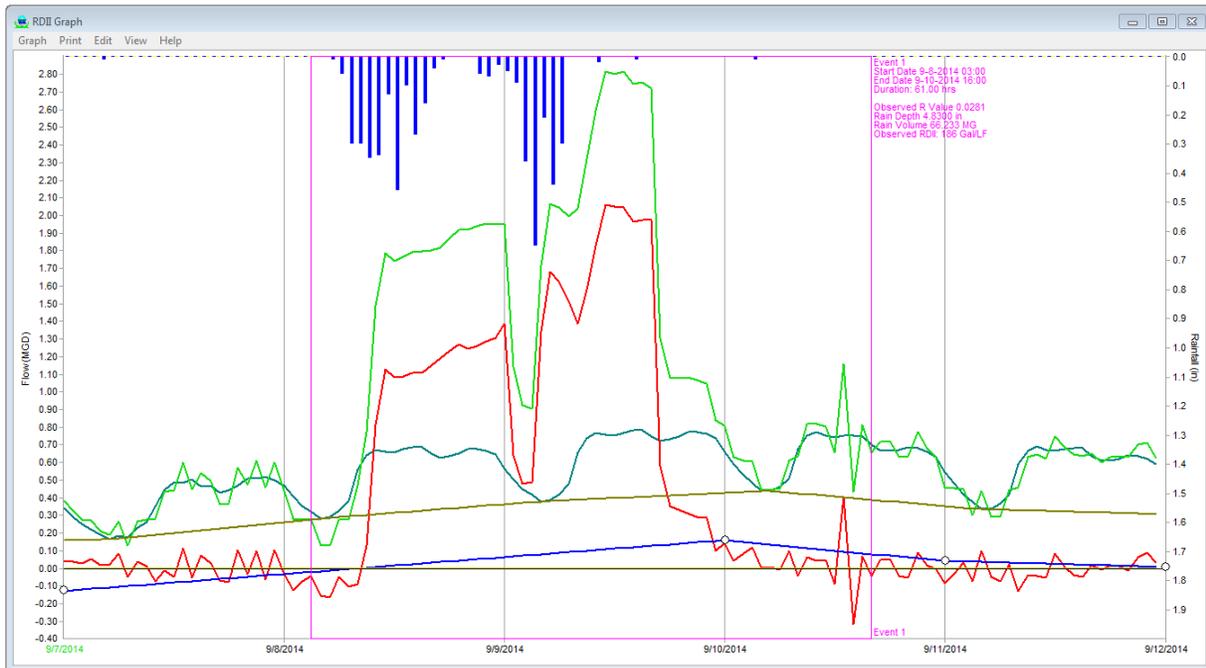


Figure 2-19
RDII Graph Produced by RDII Graph Option

The following describes the major features in the RDII graph as shown in Figure 2-19:

- The dark blue bars extending from the top of the graph is the observed rainfall.
- The light green line shows the observed flows.
- The red line shows the “observed” RDII flows computed by subtracting the estimate dry weather flows from the observed flows. Note that after proper dry weather flow adjustments the observed RDII is zero before the event and returns to zero after the RDII event.
- The blue graph is the dry weather flow (DWF) adjustment. The DWF adjustment is the difference between the ADF on this day from the average of the ADF for all selected dry weather flow days. The data points identified by the circle are the actual DWF adjustment values for the selected dry weather flow days. The DWF adjustment at any time is estimated through linear interpolation.
- The blue green line is the estimated dry weather flow. This includes the weekday and weekend diurnal curves superimposed on the DWF adjustments. This shows that the dry weather flows increase during the storm. This curve is subtracted from the observed flow to estimate the RDII flow.
- The vertical magenta lines and text define the start date and end date of RDII events.

- The green dates on the x-axis labels are weekend days and the black dates are the weekdays. The respective diurnal curves are used for these days.

2.7.3 Navigating Through the Flow Record in RDII Graph

There are numerous ways to navigate through the period of flow record to review the RDII graph including the following:

- The scroll wheel on the mouse will move through the record forward and backward day by day.
- The left and right arrow keys will also move through the record forward and backward one day.
- The PgUp and PgDn buttons will move data on the screen to the left (backward in time) or to the right (forward in time) by the number of days shown on the screen. By default, five days are shown at a time. Therefore, the PgDn button will show the next five days.
- Home and End keys will take users to the start and end of the period of flow record.
- The plus and minus keys add to or subtract from the number of days included in the graph (i.e. zoom in / out).

2.7.4 Manual ADF Adjustment Refinement

The automatic DWF adjustment described in Section 2.6.4 should be manually refined to further normalize the difference between the average dry weather flow of the dry weather flow record and the average dry weather flow before the event. The dry weather flow adjustment is the blue graph and the data points identified by a circle are the actual DWF adjustment values for the selected dry weather flow days. The data points should be adjusted to have the RDII equal zero before and after the event. This is accomplished by selecting the point and dragging up and down by pressing and holding the left mouse key. The point can be deleted by double clicking on it. A new point can be added by double clicking near the vertical line that represents the start of each day and then dragging this point up and down. Lowering the ADF adjustment raises the computed RDII. The flows for the complete record should be reviewed and the ADF adjusted as necessary to get the desired results that includes the following goals:

- The RDII flows should be zero before the event.
- The RDII flows should return to zero at some time after the rainfall ends.
- The DWF should not change rapidly. It represents the slow change in dry weather flows as groundwater levels rise and fall in response to rainfall. In Figure 2-19, the adjustment value on September 10, 2014 should be deleted to reduce the DWF change over time.

The record should be reviewed several times to obtain the desired results and it may be necessary to review the adjustments after the event start and end times have been defined.

2.7.5 Manual Definition of RDII Event Start and End Times

The event start and end times are defined by the magenta colored lines on the RDII graph. Instead of using the automatic RDII event identification tool described in Section 2.7.1, these should be added manually using the following steps:

- Place the cursor on the graph near where the event starts.
- Press and hold the right mouse button and drag the cursor to the end date. The magenta box will appear as a dashed line.
- Release the mouse where you want the event to end.
- The start and end dates and times can be adjusted by left clicking and holding the mouse button and dragging the start or end date vertical line.
- The event can be deleted by double clicking on the start or end date vertical line.

Events should be defined for all rainfall events where there is a discernable RDII flow response. It is useful to apply the Rainfall Data Analysis utility to define the rainfall events and use the rainfall intensity as a guide to review if there is a corresponding RDII flow response.

The following guidelines should be followed when defining the RDII event start and end times:

- The event should start before there is a RDII response but should not include time before the event.
- The event duration should include all of the rainfall associated with the event.
- The event should end at or shortly after the flows return to dry weather and the computed RDII is zero. The event should not include an excess amount of time after the flows return to normal after the event.
- The groundwater may react to the rainfall such that the ADF adjustment will increase over the event duration. However, the ADF adjustment should not increase too drastically. Having ADF vary rapidly results in flows that should be considered RDII being falsely included in the ADF.

The text that appears to the right of the event documents the following statistics:

- Event number and starting and ending date and time.
- Duration between the starting and ending dates.
- Observed R-Value which equals the RDII volume divided by the rainfall volume over the sewered area. This is the fraction of the rainfall that is identified as RDII for this event.
- Rainfall depth in inches and volume in million gallons over the sewered area.
- RDII volume expressed in gallons per linear foot of sewer using the length of sewer entered for the flow meter. The RDII volume is computed as the volume under the red RDII line

over the event duration. Negative volumes where the red line falls below zero are included in the total and reduce the overall volume. In most cases, the negative values result from random variations or noise in the observed data and including the negative values counters the periods where the noise cause the flows to be higher.

The user should go through the events carefully and edit the events and the ADF to accurately define the event RDII volumes and flow rates. Some special cases may make it difficult to define the average flows and to estimate the RDII flows including the following:

- Holidays and other events may affect the base wastewater flows which reduces the accuracy in separating the RDII flows from the observed flows.
- Snow and freezing precipitation as well as melting can affect the wastewater flow response. Generally, the analysis should not include these events. These will often appear as events with very high or very low R-values.
- Meters where the upstream land uses such as tourism related uses, and universities cause variable base sanitary flows are difficult to analyze.

2.7.6 Computation of Volume-Weighted Average R-Value

The next step is to determine the total R-Value for each representative event of interest. This option is accessed through the RDII Event Statistics option under the Wet Weather Flow Analysis menu. This provides summaries as shown on **Figure 2-20** documenting various statistics for each of the defined RDII event which can be paged through by clicking the up and down arrows next to the Event # textbox.

The results should be saved to a CSV file using the respective button on the bottom of the summary window. The saved file should be opened using Microsoft Excel and the event-specific R-Value in column G should be re-computed in Excel by dividing the I/I volume in column E by the Rain volume in inches in column F. This step is necessary because the current SSOAP software version reports the same Total R-Value in column G. The event-specific Total R-Value should be reviewed for very large or small outliers (e.g., values more than four and less than 0.25 times the typical

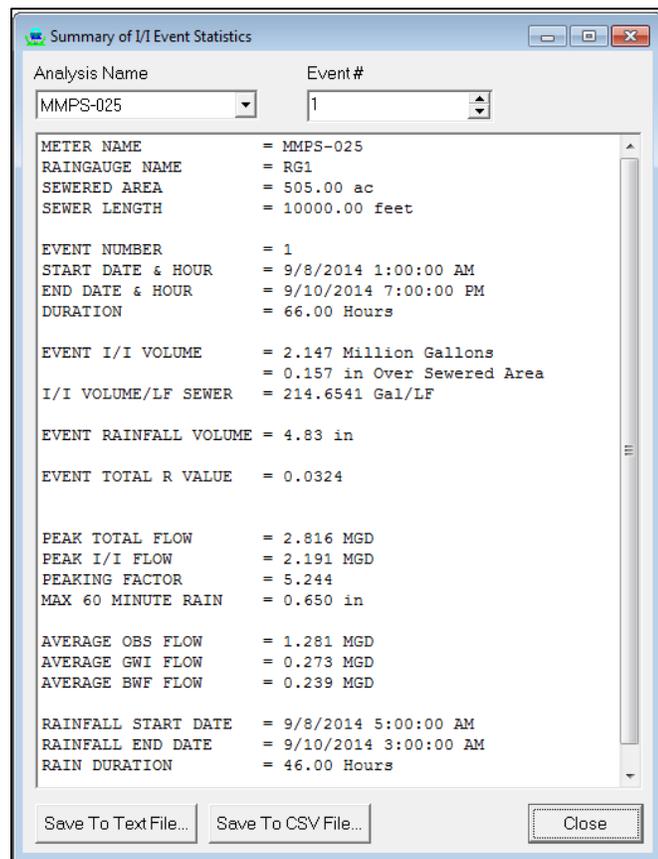


Figure 2-20
RDII Event Statistics Results

value). It may be necessary to eliminate these events which are likely caused by freezing or melting conditions or where the observed rainfall otherwise does not represent the rain that fell over the metered area for the event of interest.

A volume-weighted R-value should be computed as the sum of the I/I volume for all events by the sum of the rain volume for all events. This volume-weighted average places more emphasis on the larger rainfall and I/I volume events. **Table 2-1** presents the results for the example meter. In this case, the average R-value is 0.0363 but there is a wide range in values over the individual events. In this case, events have R-Values of 0.1375 and 0.0079 which should be considered outliers and dropped from the weighted average. Eliminating the rainfall and I/I volume of these events from the weighted average changes the average R-Value for all events to 0.0359.

The resulting final event summary spreadsheet should be saved as a .XLSX Excel Workbook file and included as part of the analysis documentation.

Table 2-1 RDII Event Summary Spreadsheet with Computed Total R-Value for Events and Volume-Weighted Total R-Value

METER NAME		MMPS-025																					
RAINGAUGE NAME		RG1																					
SEWERED AREA		505 ac																					
										←-----EVENT AVERAGE-----→													
				I/I		RAIN		PEAK I/I		PEAK TOTAL		PEAK		OBSERVEE GWI		BASE WAS		RAINFALL		RAINFALL			
EVENT		START DATE		END DATE		DURATION		VOLUME		TOTAL		FLOW		FLOW		FLOW		FLOW		STARTDATE		ENDDATE	
		Hours		in		in		R-VALUE		MGD		MGD		MGD		MGD		MGD		Hours		Hours	
1	9/8/2014 1:00	9/10/2014 19:00	66	0.157	4.83	0.0325	2.191	2.816	5.244	0.65	1.281	0.273	0.239	9/8/2014 5:00	9/10/2014 3:00	46							
2	9/24/2014 2:00	9/26/2014 15:00	61	0.055	1.64	0.0335	1.269	1.801	3.371	0.23	0.771	0.245	0.236	9/24/2014 6:00	9/26/2014 1:00	43							
3	10/3/2014 20:00	10/4/2014 21:00	25	0.004	0.23	0.0174	0.277	0.612	1.301	0.19	0.43	0.179	0.196	10/3/2014 21:00	10/4/2014 3:00	6							
4	10/10/2014 15:00	10/12/2014 12:00	45	0.01	0.45	0.0222	0.413	0.646	1.391	0.17	0.441	0.18	0.188	10/10/2014 17:00	10/11/2014 5:00	12							
5	10/15/2014 4:00	10/16/2014 12:00	32	0.006	0.32	0.0188	0.321	0.848	1.604	0.06	0.511	0.223	0.231	10/15/2014 8:00	10/15/2014 20:00	12							
6	11/6/2014 11:00	11/7/2014 19:00	32	0.021	0.84	0.0250	1.347	1.862	3.293	0.49	0.682	0.206	0.271	11/6/2014 13:00	11/7/2014 1:00	12							
7	11/23/2014 17:00	11/24/2014 19:00	26	0.01	0.38	0.0263	0.537	0.808	1.532	0.19	0.578	0.231	0.231	11/23/2014 17:00	11/24/2014 8:00	15							
8	11/25/2014 21:00	11/27/2014 14:00	41	0.083	2.11	0.0393	2.189	2.78	5.249	0.28	1.127	0.249	0.231	11/25/2014 22:00	11/27/2014 13:00	39							
9	12/6/2014 11:00	12/7/2014 7:00	20	0.007	0.47	0.0149	0.348	0.853	1.837	0.18	0.547	0.243	0.192	12/6/2014 13:00	12/6/2014 23:00	10							
10	12/16/2014 10:00	12/17/2014 10:00	24	0.005	0.39	0.0128	0.432	0.955	1.75	0.31	0.546	0.233	0.249	12/16/2014 13:00	12/16/2014 16:00	3							
11	12/22/2014 3:00	12/23/2014 12:00	33	0.007	0.45	0.0156	0.454	0.947	1.81	0.17	0.445	0.152	0.221	12/22/2014 6:00	12/23/2014 6:00	24							
12	12/23/2014 19:00	12/25/2014 23:00	52	0.09	1.78	0.0506	2.095	2.357	4.306	0.27	1.017	0.212	0.247	12/23/2014 22:00	12/25/2014 6:00	32							
13	12/29/2014 2:00	12/30/2014 8:00	30	0.012	0.61	0.0197	0.668	1.43	2.846	0.17	0.699	0.383	0.191	12/29/2014 5:00	12/30/2014 5:00	24							
14	1/12/2015 1:00	1/16/2015 1:00	96	0.063	1.28	0.0492	0.75	1.311	2.43	0.2	0.753	0.298	0.241	1/12/2015 2:00	1/15/2015 10:00	80							
15	1/18/2015 5:00	1/19/2015 12:00	31	0.037	0.98	0.0378	2.126	2.719	5.755	0.37	0.893	0.328	0.182	1/18/2015 7:00	1/18/2015 12:00	5							
16	1/23/2015 17:00	1/26/2015 9:00	64	0.065	1.05	0.0619	1.206	1.692	3.643	0.16	0.879	0.367	0.183	1/23/2015 17:00	1/24/2015 15:00	22							
17	2/21/2015 18:00	2/24/2015 3:00	57	0.033	0.79	0.0418	0.736	1.334	2.692	0.09	0.764	0.369	0.208	2/22/2015 0:00	2/22/2015 16:00	16							
18	3/1/2015 10:00	3/3/2015 13:00	51	0.038	0.98	0.0388	0.968	1.799	3.435	0.15	0.935	0.466	0.228	3/1/2015 12:00	3/3/2015 12:00	48							
19	3/3/2015 19:00	3/5/2015 1:00	30	0.033	0.24	0.1375	0.778	1.327	2.424	0.15	1.073	0.475	0.248	3/4/2015 0:00	3/4/2015 2:00	2							
20	3/5/2015 3:00	3/6/2015 20:00	41	0.066	0.95	0.0695	1.486	2.263	4.166	0.15	1.239	0.476	0.247	3/5/2015 4:00	3/6/2015 15:00	35							
21	3/11/2015 6:00	3/12/2015 20:00	38	0.019	0.46	0.0413	0.688	1.472	2.626	0.1	0.872	0.454	0.26	3/11/2015 6:00	3/11/2015 21:00	15							
22	3/13/2015 17:00	3/16/2015 13:00	68	0.059	0.8	0.0738	1.48	2.14	4.504	0.17	0.917	0.445	0.194	3/13/2015 18:00	3/14/2015 17:00	23							
23	3/19/2015 20:00	3/21/2015 15:00	43	0.017	0.53	0.0321	0.522	1.312	2.618	0.07	0.761	0.414	0.217	3/19/2015 21:00	3/20/2015 14:00	17							
24	3/25/2015 23:00	3/27/2015 22:00	47	0.038	1.17	0.0325	1.732	2.484	4.595	0.56	0.896	0.387	0.245	3/26/2015 2:00	3/27/2015 19:00	41							
25	4/9/2015 1:00	4/10/2015 6:00	29	0.007	0.57	0.0123	0.713	1.321	2.63	0.43	0.63	0.346	0.206	4/9/2015 3:00	4/9/2015 6:00	3							
26	4/14/2015 4:00	4/15/2015 11:00	31	0.01	0.65	0.0154	0.712	1.372	2.612	0.5	0.656	0.331	0.226	4/14/2015 7:00	4/15/2015 0:00	17							
27	4/19/2015 12:00	4/21/2015 17:00	53	0.074	1.69	0.0438	2.612	2.97	5.572	0.58	1.017	0.331	0.237	4/19/2015 15:00	4/20/2015 4:00	13							
28	4/25/2015 7:00	4/27/2015 1:00	42	0.015	0.63	0.0238	0.453	1.032	2.192	0.1	0.65	0.34	0.193	4/25/2015 9:00	4/26/2015 14:00	29							
29	5/10/2015 8:00	5/11/2015 23:00	39	0.012	0.77	0.0156	0.546	1.078	2.041	0.27	0.672	0.34	0.235	5/10/2015 12:00	5/11/2015 10:00	22							
30	5/17/2015 10:00	5/18/2015 8:00	22	0.009	0.9	0.0100	0.778	1.332	2.785	0.84	0.646	0.321	0.191	5/17/2015 15:00	5/17/2015 16:00	1							
31	5/21/2015 6:00	5/22/2015 15:00	33	0.017	0.84	0.0202	0.997	1.654	2.988	0.23	0.743	0.32	0.26	5/21/2015 9:00	5/21/2015 17:00	8							
32	6/1/2015 14:00	6/7/2015 17:00	147	0.216	5.51	0.0392	2.493	3.199	6.179	1.91	1.05	0.344	0.227	6/1/2015 19:00	6/6/2015 15:00	118							
33	6/8/2015 22:00	6/10/2015 18:00	44	0.044	1.06	0.0415	2.1	2.606	4.869	0.39	0.972	0.416	0.236	6/8/2015 23:00	6/9/2015 8:00	9							
34	6/17/2015 20:00	6/18/2015 16:00	20	0.003	0.38	0.0079	0.288	0.834	1.566	0.22	0.633	0.345	0.235	6/18/2015 1:00	6/18/2015 3:00	2							
35	6/20/2015 19:00	6/21/2015 9:00	14	0.004	0.33	0.0121	0.39	0.829	2.025	0.32	0.517	0.301	0.133	6/20/2015 22:00	6/20/2015 23:00	1							
Total					1.346	37.06	0.0363																
Adjusted Total					1.31	36.44	0.0359																

2.8 Calibrating RTK Triangular Unit Hydrograph Parameters

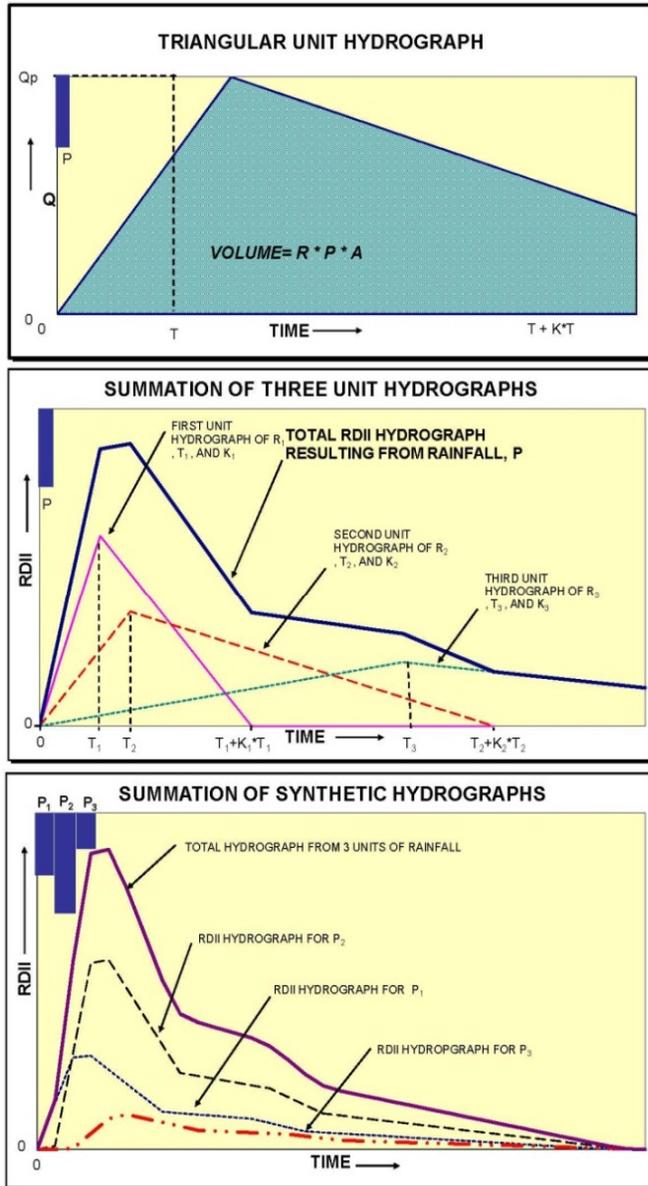
The final step to perform with the SSOAP toolbox is the determination of RTK triangular unit hydrograph parameters that best represent the RDII flow response for the observed storm events. These factors will then be applied to simulate the peak flows for a long-term simulation in SWMM to estimate the 10-year peak flow rate with statistical analysis.

2.8.1 RTK Triangular Unit Hydrograph Procedures

The RTK triangular unit hydrograph method is used to represent the RDII flow response to rainfall. The SSOAP user's manual and online help systems should be reviewed for additional information and documentation. This procedure is based on fitting three triangular unit hydrographs to an observed RDII hydrograph. The shape of each unit hydrograph is described by three parameters:

- R – Ratio of unit hydrograph volume to rainfall volume
- T – Time to peak in hours
- K – Ratio of time to decline to time to peak (aka time to decline expressed as multiple of T). The total duration of each unit hydrograph equals $(1+K) \cdot T$.

Figure 2-21 presents the RTK methodology of developing three unit hydrographs and how they combine to produce the unit hydrograph that is used to simulated RDII flows from rainfall. This procedure has nine parameters that should be adjusted to have the simulated RDII flows simulated from the observed rainfall to reproduce the observed flows. One set of parameters needs to be used for each flow meter and the values need to remain constant over all events. The parameters should be adjusted to match the peak flows, flow volumes, and the general shape of the RDII hydrograph. Higher emphasis should be placed on matching the peak flows and hydrograph shape for the larger events. However, the accuracy of observed flows during extreme events (e.g., events with recurrence intervals greater than 10-years) and events that may have exceeded the capacity of the facilities including upstream and downstream pump stations should be considered carefully when calibrating the parameters to these events.



DEFINITION OF TERMS:

- P = PRECIPITATION DEPTH OVER TIME STEP
- T = TIME TO PEAK OF THE UNIT HYDROGRAPH
- Q_p = PEAK FLOW OF THE UNIT HYDROGRAPH
- K = RECESSION COEFFICIENT
- VOLUME = AREA OF SHADED REGION
- VOLUME = VOLUME OF RDII IN UNIT HYDROGRAPH
- R = FRACTION OF RAINFALL THAT BECOMES RDII
- A = SEWERED AREA

- $T_1, T_2, \text{ \& } T_3$ = TIME TO PEAK OF THE RESPECTIVE UNIT HYDROGRAPHS
- $K_1, K_2 \text{ \& } K_3$ = RECESSION COEFFICIENTS OF THE RESPECTIVE UNIT HYDROGRAPHS
- $R_1, R_2 \text{ \& } R_3$ = R-VALUES OF THE RESPECTIVE UNIT HYDROGRAPHS
- R = FRACTION OF RAINFALL, P, THAT BECOMES RDII
- $R = R_1 + R_2 + R_3$

- $P_1, P_2, \text{ \& } P_3$ = SUCCESSIVE RAINFALL DEPTHS OVER EACH TIME STEP
- TOTAL HYDROGRAPH = SUMMATION OF SYNTHETIC HYDROGRAPHS RESULTING FROM EACH UNIT OF RAINFALL

Figure 2-21
Triangular Unit Hydrograph Procedure

The following provides steps and guidelines to use when calibrating RTK values to observed flows:

1. Define a starting set of RTK parameters. The table below provides a typical set of values that can be used for many analyses. R1, R2, and R3 should be set to approximately 33% of the total R to start the analysis. In this example R1, R2, and R3 are each set to 0.0120.

R1	T1	K1	R2	T2	K2	R3	T3	K3
0.0120	1	1	0.0120	2	3	0.0120	2	3

2. Iteratively change the parameters to best reproduce the observed data. This will take numerous iterations and requires some experience to perform quickly. The first few calibrations will take some time to complete as the user gets a feel for how to change parameters to get the desired response.
3. R1, T1, and K1 represent the fast RDII response that comprises the peak flows. T1 and K1 should generally be in the range of 0.5 to 2. R1 will typically be a smaller percentage of the Total R-Value than R2 or R3. However, R1 could be a higher percentage of the Total R-value under the cases where inflow is the dominant factor in RDII.
4. R2, T2, and K2 represent the middle of the RDII response. T2 will fall in between T1 and T3 and will typically range between 2 and 4 hours. K2 will typically range from 1 to 3.
5. R3, T3, and K3 represent the long-term RDII response that affects primarily the tail end of the event. R3 will typically be the largest. T3 typically will range from 3 – 6 hours and K3 typically ranges from 3 to 6.

2.8.2 Calibrating Parameters in SSOAP

SSOAP was originally intended to be applied by calibrating parameters individually for each event. Since a single set of parameters will be used, it is better to develop and calibrate a single global RTK parameter set for the meter that best fits all events and focusses on the larger and more important events with the best flow and most representative rainfall data.

SSOAP stores the flows and parameters in a single file with a .SDB suffix. This is simply a Microsoft Access database. This file should be opened in Access by going to the directory that contains the file and either by clicking on “all files” for the file type or typing “*.SDB” for the file name. The available .sdb files will appear and can be opened by double clicking. Being a database file, the .sdb file can be open in both Access and SSOAP simultaneously.

The analysis table includes the data related to the analysis defined in Section 2.5 including the default RTK parameters. Values can be entered directly in this table in Access and the change values will be reflected in SSOAP. Note that the columns can be dragged in the table to place them in the correct order which may facilitate pasting values from a spreadsheet in less steps. **Figure 2-22** shows a portion of this table where the order has been shifted to the order presented above and the default values have been pasted to the table.

	AnalysisID	AnalysisName	Meter	RainGaugel	R1	T1	K1	R2	T2	K2	R3	T3	K3
+	1	MMPS-025	1	1	0.012	1	1	0.012	2	3	0.012	2	3
*	(New)		0	0	0	0	0	0	0	0	0	0	0

Figure 2-22
SSOAP .SDB Database Analysis Table with Default RTK Parameters

If the SSOAP RDII Graph option is clicked and opened, the graphs for this analysis will now have additional lines as shown on **Figure 2-23**. Clicking on the Graph menu brings down a legend that defines the various lines. This menu provides options to turn on and off particular graphs to unclutter the graph. Control keys indicated in this list can also be used to toggle the various graphs on and off. When calibrating RTK parameters, it is typically useful to turn off all graphs except for the observed rainfall, the red observed RDII graph, and the four simulated lines described below to allow easier comparisons.

Once default RDII values have been defined in the database, the RDII graph includes the following additional lines:

- RDII Curve 1 – The response to rainfall from R1, T1, and K1 parameters.
- RDII Curve 2 – The response to rainfall from R2, T2, and K2 parameters.
- RDII Curve 3 – The response to rainfall from R3, T3, and K3 parameters.
- Simulated RDII – The total simulated RDII response as the sum of Curve 1, Curve 2, and Curve 3.

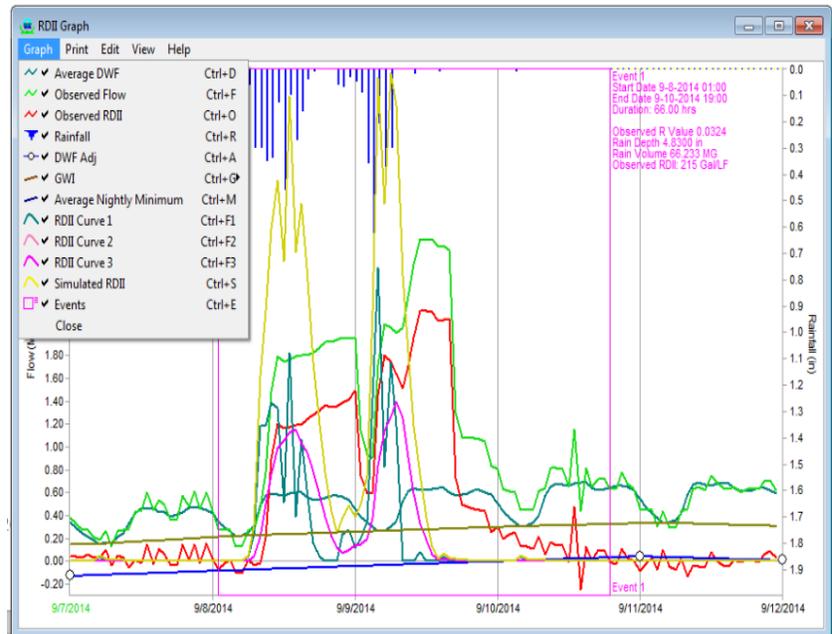


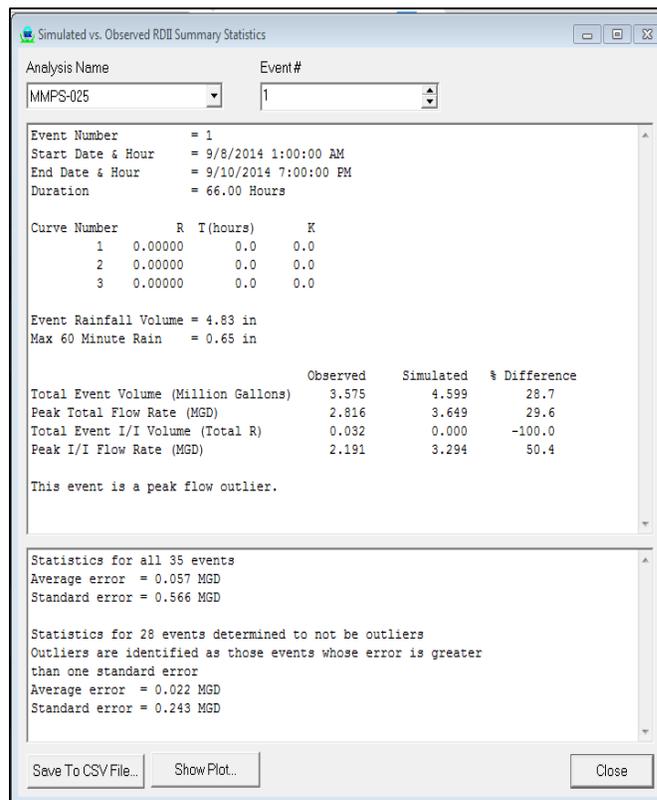
Figure 2-23
RDII Graph with Computed RDII Curves 1, 2 and 3, and Total Simulated RDII Response

Calibrating the RTK parameters involves iteratively changing the values in the Analysis table within Access and then viewing the impact of the changes on the shape of the simulated hydrograph in SSOAP. To ensure that the changes are committed to the database, it is best to click on the new record. The changes will be reflected in SSOAP only after the RDII graphs is closed and reopened. The RTK parameters calibrated for this example are presented in Table 2-2 below.

Table 2-2 Example Set of RTK Parameters

R1	T1	K1	R2	T2	K2	R3	T3	K3
0.0075	1	1.5	0.015	3.5	3.5	0.025	4.5	6

2.8.3 SSOAP Simulated vs. Observed RDII Statistics



While the primary tool for model calibration should be the RDII graph analysis, SSOAP includes an option to compare simulated and observed RDII statistics that can be used to summarize and support the validity of the graphical analysis. This option is available under the Wet Weather Flow Analysis Menus shown on Figure 2-18 and presents summaries of the simulated and observed total event volume, peak total flow rate, total I/I volume, and peak I/I flow rate as shown on **Figure 2-24**. The “Save to CSV File” option provides a tabular summary that can be formatted to be included in a report or other documentation. The “Show Plot” option produces a scatter graph of the simulated and observed peak total flows as included in **Figure 2-25**.

The following overall goals should be met at the end of a successful and defensible calibration:

Figure 2-24
Simulated vs. Observed RDII Summary Statistics

- The total RDII volumes expressed as Total R are maintained as much as possible.
- A close as possible match between the simulated and observed peak flows is achieved while focusing on larger events of interest.
- On the average, the observed peak flows are reproduced as closely as possible.
- The simulated peak flows are not consistently biased as being higher or lower than those observed.

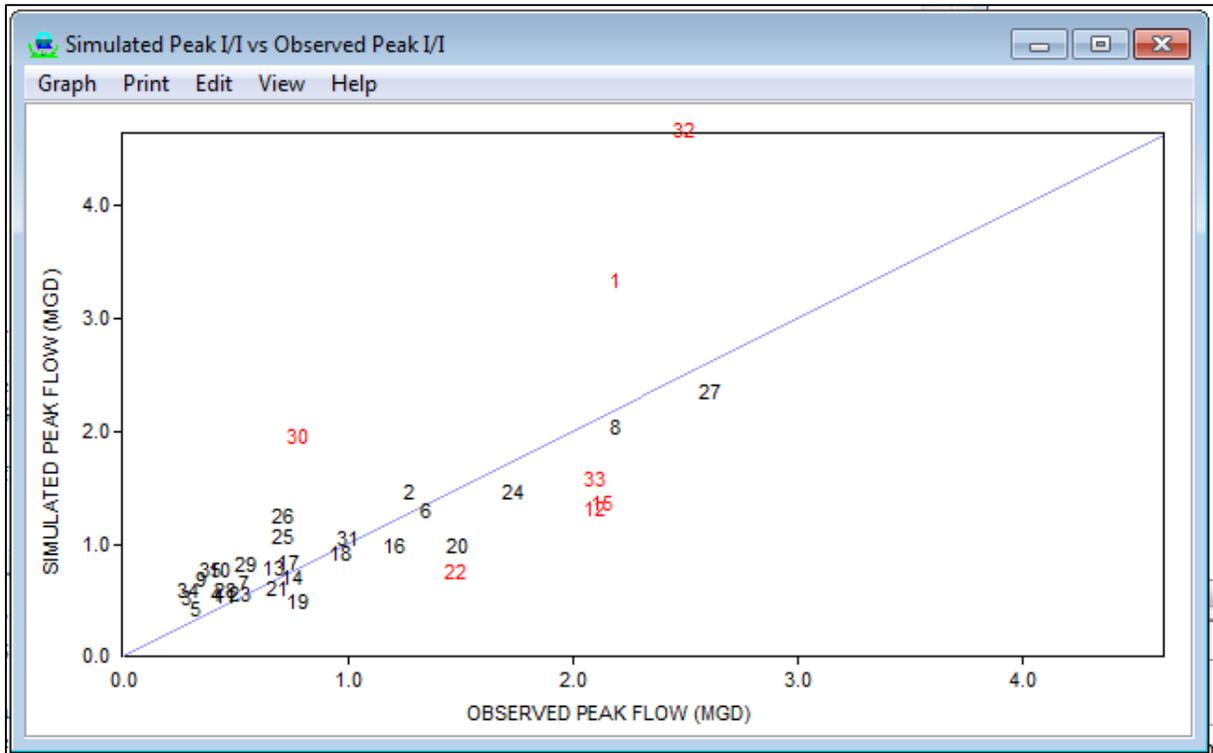


Figure 2-25
Simulated vs. Observed Peak Flow Scatter Graph

In the end, realize that having non-representative rainfall, flows that are affected by pump operation or sewer system capacity constraints, and naturally occurring variations in I/I response to rainfall will make it not possible to match all events.

Section 3

EPA SWMM 5 Long-Term Hydrologic Simulation

3.1 Introduction

If dry and wet weather flow characteristics in form of base dry weather and RTK flow parameters are known, EPA SWMM can be used to compute a long term time series of flows using the 62 years of continuous hourly rainfall data currently available from Norfolk International Airport. A base file is provided that includes the rainfall and other parameters set to facilitate simulating the flows using the average daily flow, sewered area, and RTK triangular unit hydrograph parameters obtained from the SSOAP flow analysis described in Section 2:

- SWMM_LTS_BASE_FILE.INP is a SWMM 5 input file that includes basic model setup for the required simulation. The following sections provide information for changing the average daily flows, RTK parameters, and sewered area. The steps to perform the long term simulation (LTS) and process the simulated flow results to obtain the event peak flows are also documented. The steps to determine the 10-year peak flow based on this analysis using a Log-Pearson III distribution are documented in **Section 4**.
- SWMM 5 is a free software program and the files and documentation can be downloaded from the following URL:

<https://www.epa.gov/water-research/storm-water-management-model-swmm>

This guide is not intended to document all of the features of SWMM 5 but to show the basic options needed to setup and perform the simulation and analysis to estimate the 10-year peak flow. The user should review the user's manual and help systems to become more familiar with the user interface and other features.

3.2 Setup and Perform Simulation

3.2.1 Creating and Documenting SWMM Input File

The first step would be to make a copy of SWMM_LTS_BASE_FILE.INP, giving it a name that represents the site or flow meter being simulated. The .INP suffix indicates that this is a SWMM 5 input file. Open the file in SWMM program interface and open the file you created. The SWMM screen will appear as shown in **Figure 3-1**.

When clicking on the "Title/Notes" option and then clicking on the "hand holding a pen" option above the low right menu, the user can edit the description of the file. It is recommended that this be updated for future reference.

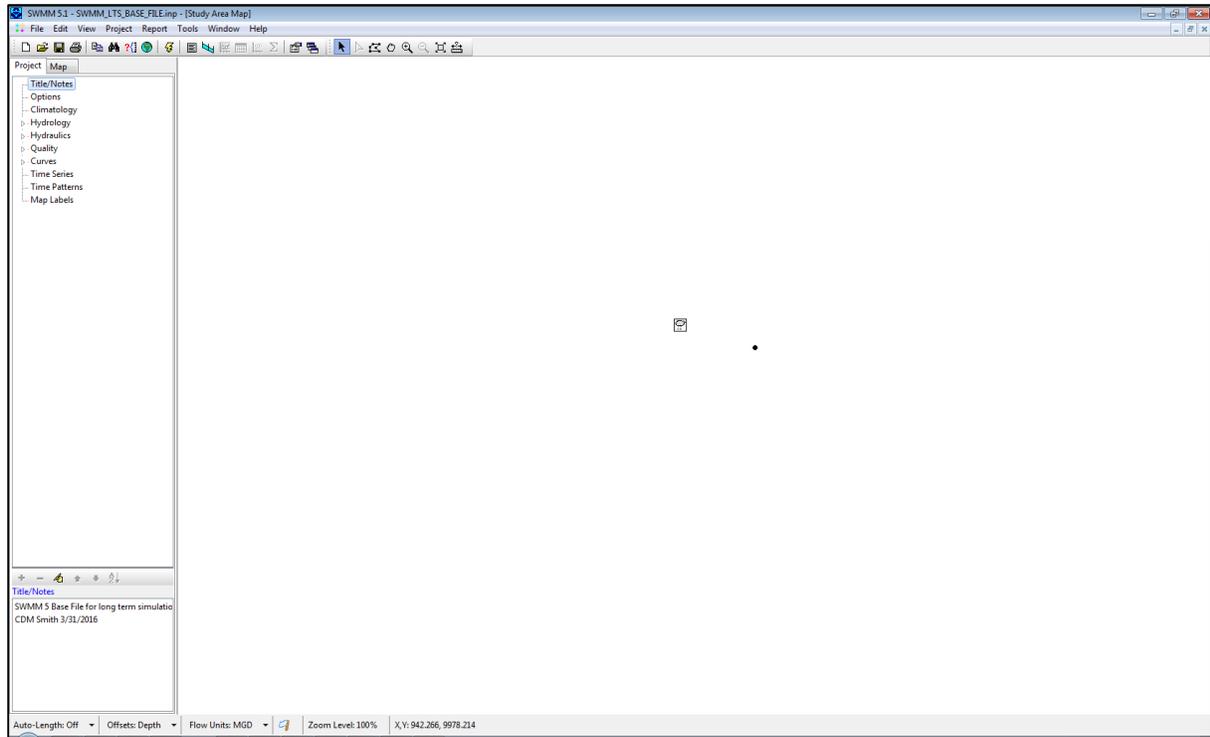


Figure 3-1
EPA SWMM 5 Main Screen

3.2.2 Setting the Flow Parameters

The following flow parameters need to be set prior to performing a long term simulation:

- Average dry weather flow (ADF) in mgd
- Sewered area in acres
- Calibrated RTK parameters

There are several ways to get to the menu to edit the data associated with a node. The simplest is to double click on the black circular dot near the center of the screen. Alternatively, the user can select the hydraulics / nodes / junctions in the menu and click on the node named “Computed Flows” in the window in the bottom left window.

Either method will bring up a menu similar to that shown on the left on **Figure 3-2**. Clicking on the area to the right of the inflows line where it says “Yes” and clicking on the button with three periods brings up another menu as shown on the right on Figure 3-2.

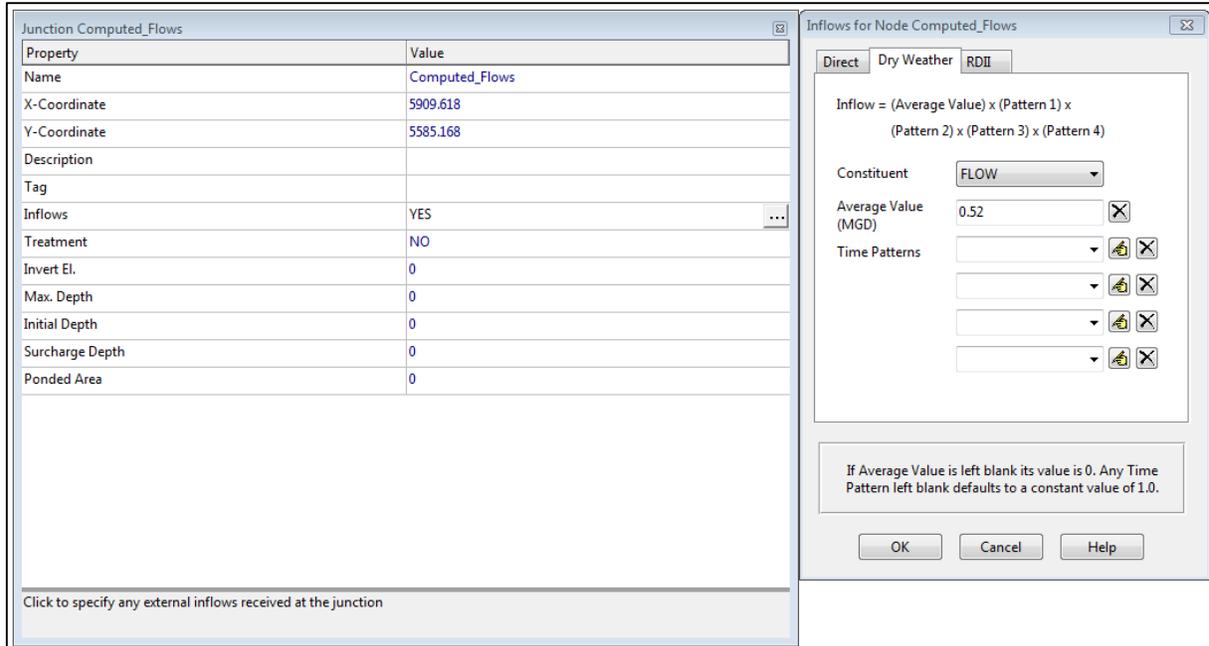


Figure 3-2
Edit Node Menu and Menu to Enter Dry Weather Flow

Average Dry Weather Flow

The user can go to the Dry Weather tab to enter the average dry weather flow in mgd. This value comes from the dry-weather flow analysis in the SSOAP analysis. For these simulations (for estimating 61-year flow), it can be assumed that the dry weather flow is constant. The SSOAP dry weather flow analysis provides an option to view the dry weather flow statistics. This provides the average week day and weekend day flows for the selected dry weather days. A weighted average can be computed by multiplying the week day value by 5 and adding the weekend value multiplied by 2 and dividing the result by 7. This flow value can be entered into the appropriate field on the Dry Weather tab as shown on the right on Figure 3-2.

Sewered Area and Calibrated RTK Parameters

The RDII tab provides a window to enter the sewered area in acres as shown on **Figure 3-3**. By clicking on the edit button (hand holding a pen), the menu shown on **Figure 3-4** appears where the calibrated RTK triangular unit hydrograph parameters can be entered. Curve 1 is considered the short-term response (R1, T1, K1), Curve 2 is the medium-term response (R2, T2, K2), and Curve 3 is the long-term response (R3, T3, K3). After entering the desired values, press the OK buttons to exit the menus.

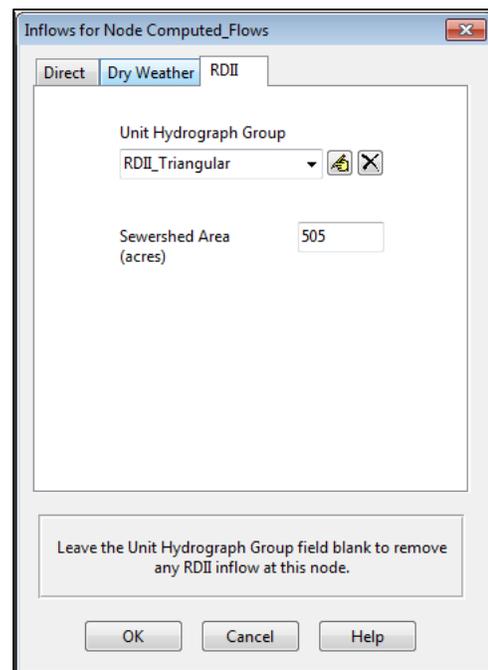


Figure 3-3
RDII Parameter Menu

3.2.3 Performing the Long Term Simulation

Once the baseline model has the parameters set to perform the long term hydrologic simulation, the simulation can be launched by pressing the lightning bolt icon at the top of the screen. Another menu will appear that documents the progress of the simulation. The simulation should be completed in a few minutes.

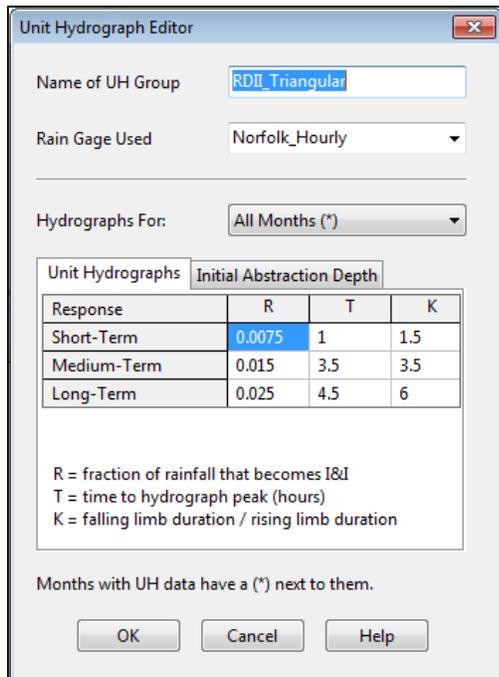


Figure 3-4
RTK Parameter Menu

The simulation options can be viewed by selecting the options menu in the top left window and then selecting the appropriate option in the bottom left window.

The flow hydrograph can be viewed and copied by clicking the graph symbol at the top and then clicking on the circular node in the map view. This will bring up a menu to allow the user to plot the total inflow to the node named Computed_Flows. The program defaults to node “depths” and the user will need to change the variable being plotted to “total inflows” to see the flows.

Section 4

Long-Term Simulation Results Analysis

4.1 Introduction

The long-term simulation performed with the EPA SWMM program is the basis for the determination of the 10-year peak flow using a Log Pearson Type III statistical distribution analysis. The analysis starts by identifying the largest peak flows produced by independent wet weather flow events within the EPA SWMM program followed by a statistical analysis that determines the 10-year peak flow using a Log Pearson Type III statistical distribution in a supplied spreadsheet.

4.2 Identify Event Peak Flows from SWMM Simulation Results

The first step is to identify individual event peak flows from the SWMM simulation results. After performing the simulation as documented in Section 3 select the Report / Statistics menu or the Σ button on the toolbar.

Enter the values shown in **Figure 4-1**. The total inflow event threshold needs to be set to a value slightly above the average dry weather flow entered as described in Section 3.2.2 or only a single event will be evaluated. Press the OK button to perform the analysis

The processed output provides a summary of the results of this analysis and event listings. Click on the Events tab which provides a list of the event peak flows sorted in order of decreasing event peak flows. The listed return periods use the Weibull plotting position formula.

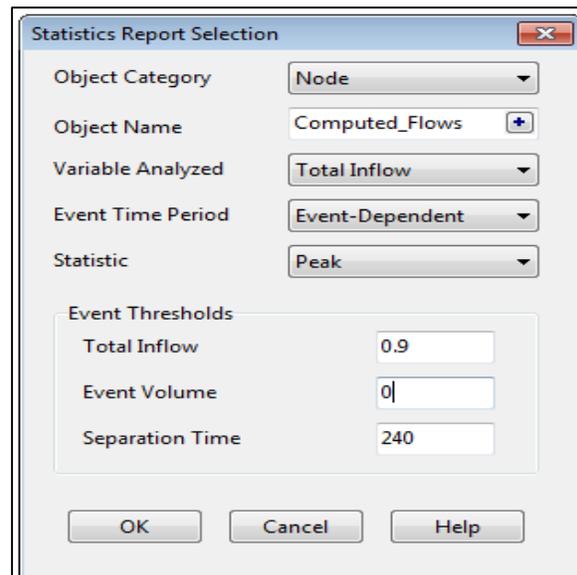


Figure 4-1
Statistical Report Menu

4.3 Identify Event Peak Flows Using the Statistical Analysis Spreadsheet

A spreadsheet named LogPearson.xlsx is provided to fit the Log-Pearson Type III distribution to the peak flow data and compute the 10-year peak flow. A copy of this should be made and renamed to identify the meter name and to provide other useful information such as the date of the analysis. The Information tab in the spreadsheet provides basic instructions and locations to further document the analysis being performed.

The event peak flows created as described in Section 4.2 need to be extracted from the SWMM 5 results list and entered to the SWMM Output tab of the spreadsheet. From the SWMM Events tab, select all events by either clicking on the top right square or using the Edit / Select All menu. Then use the Edit / Copy To / Copy To Clipboard function and press the OK button to copy the values from SWMM.

Paste the contents of the clipboard to cell A1 of the SWMM Output tab in the spreadsheet. The FlowData tab then will have a table as shown on **Table 4-1** that documents the result. In this case, the 10-year Log-Pearson Type III peak flow equals 6.5 mgd. The table provides statistical confidence bands of 6.1 to 7 mgd. The value of 6.5 should be used as the best estimate of the 10-year peak flow in this example.

Table 4-1 Log-Pearson Type III Results Table from Spreadsheet

Return period (years)	Log-Pearson Type III					
	K	Q_{LP3}	K5%	K95%	Q5%	Q95%
1.5	-0.6	4.2	-0.8	-0.3	4.0	4.4
2	-0.2	4.5	-0.5	0.0	4.3	4.8
5	0.7	5.6	0.4	0.9	5.3	6.0
10	1.3	6.5	1.0	1.6	6.1	7.0
25	2.1	7.9	1.7	2.5	7.2	8.7
50	2.8	9.2	2.3	3.2	8.2	10.3
100	3.4	10.6	2.8	3.9	9.3	12.1
200	4.0	12.3	3.3	4.6	10.5	14.3
1000	5.4	17.1	4.5	6.2	14.0	21.0

Section 5

References

NOAA Atlas 14: Precipitation-Frequency Atlas of the United States:

NOAA (2006) NOAA Atlas 14: Precipitation-Frequency Atlas of the United States Volume 2 Version 3.0 (301 pp, 7.7 MB, PDF) Library of Congress Classification No. GC 1046.C8 U6 no.14 v.2 (2006).

http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume2.pdf

Computer Tools for Sanitary Sewer System Capacity Analysis Overview:

US EPA (2007) "Computer Tools for Sanitary Sewer System Capacity Analysis and Planning." (PDF) (104 pp, 3.53 MB, About PDF) Publication No. EPA/600/R-07/111.

<http://nepis.epa.gov/Adobe/PDF/P1008BBP.pdf>

U.S. EPA 2016 SSOAP Toolbox Software Download and Reference Manual:

US EPA (2012) SSOAP Toolbox Enhancements and Case Study. (PDF) (53 pp, 2.6 MB, About PDF) Publication No. EPA/600/R-12/690.

<https://www.epa.gov/water-research/sanitary-sewer-overflow-analysis-and-planning-ssoop-toolbox#links>

U.S. EPA Storm Water Management Model Download and Reference Manual:

US EPA (2016) Storm Water Management Model Reference Manual Volume 1 - Hydrology (PDF) (235 pp, 3.8 MB) January 2016 Revised, Publication No. EPA/600/R-15/162A.

<https://www.epa.gov/water-research/storm-water-management-model-swmm>

This page intentionally left blank.

Appendix A

HRSD Computer Tool Metadata Descriptions

HRSD provides the two files with this report. The files can be used to compute a long term time series of flows as described in Section 3 and to perform a Log Pearson Type III statistical distribution analysis as described in Section 4.

SWMM 5 LTS Example Base Model File:

SWMM_LTS_BASE_FILE.INP

SWMM 5 input file that includes a basic model setup for a long term simulation.

The model was setup by Charles I. Moore, CDM Smith with 62 years of continuous hourly rainfall data from the Norfolk International Airport (from October 1953 to October 2015) and example parameters obtained from a SSOAP flow analysis. Refer to Section 3 of this report for information on how to change the average daily flows, RTK parameters, and sewer area prior to performing the long term simulation.

Statistical Analysis Spreadsheet Template with Example Data:

LogPearson.xlsx

Microsoft Excel Spreadsheet that can be used to fit the Log-Pearson Type III distribution to peak flow data from a SWMM 5 long term simulation and compute the 10-year peak flow.

The spreadsheet was developed by Mitchell Heineman, CDM Smith and contains example peak flow data from Salt Creek at Western Springs, Illinois (USGS 05531500) for the 59 year period from July 1951 to September 2010. Refer to Section 4 of this report for more information on how to apply this spreadsheet.

This page intentionally left blank.

