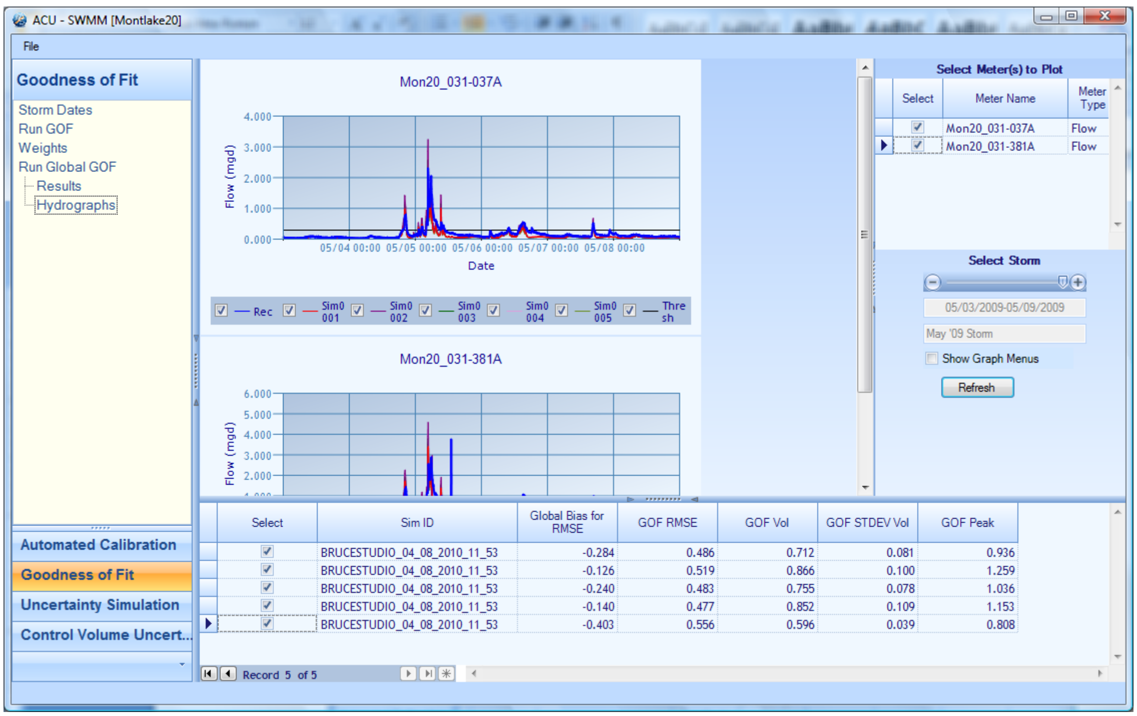
ACU-SWMM
USERS MANUAL

Automated Calibration and Uncertainty (ACU) Analysis for Storm Water Management Model (SWMM)



Seattle Public Utilities
Combined Sewer Overflow Reduction Program

July 19, 2010

ACU-SWMM
Table of Contents

ACU-SWMM
Table of Contents - Continued

ACU-SWMM

Automated Calibration and Uncertainty (ACU) Analysis for Storm Water Management Model (SWMM)

OVERVIEW

ACU-SWMM is a software package designed for use with the EPA Storm Water Management Model (SWMM). It was designed primarily for use with combined sewer systems where uncertainties from multiple sources can make model calibration difficult and severely impact the reliability of sewer flow predictions. ACU-SWMM has two primary functions. First, it is intended for automated calibration of SWMM models of urbanized basins. Second, it computes Control Volumes and uncertainty bounds for combined sewer overflow (CSO) volumes with a once-per-year frequency of occurrence. The automated calibration features are not specific to combined sewer systems and may be used with any SWMM basin model.

ACU-SWMM has four major modules. Two modules are for automated calibration and two modules are for conducting an uncertainty analysis for estimating the CSO control volume. Detailed descriptions of the computational procedures for automated calibration and uncertainty analysis will not be presented here. The reader is referred to Chapters 5 and 6 of the *CSO Technical Guidance Manual* for a detailed description of the computational procedures. The functions of the four modules are briefly described below.

Module 1 – Automated Calibration

Module 1 of automated calibration includes all of the tasks for project description, file management, data management, identifying flow and depth meters used for calibration, identifying model parameters used for calibration, setting sampling ranges of parameter values and conducting numerous simulations by executing the SWMM basin model in a batch mode.

Module 2 – Goodness-of-Fit Measures

Module 2 of the automated calibration process includes computation of the numerical goodness-of-fit (GOF) measures for comparison of recorded and computer simulated hydrographs, weighting the relative importance of specific flow and depth meters and specific storm events for use in computing global GOF measures, computation of global GOF measures reflecting the combined importance of the various meters and storms, sorting SWMM model parameter sets in order of global GOF measures and viewing of comparisons of recorded and simulated hydrographs for selection of the best-fit model parameter set.

Module 3 – Uncertainty Simulation

Module 3 is the first component of the uncertainty analysis which includes conducting long-term simulations. Precipitation scaling factors are computed that are used to scale the long-term 30-year precipitation time-series which is used to mimic the variability in sewer flow predictions arising from four sources of uncertainty. The four sources of uncertainty for sewer flow predictions are:

- representativeness of prior 30-year precipitation time-series relative to future precipitation
- possible effects of climate change on future precipitation time-series
- model uncertainty in the SWMM computer model
- residual uncertainties, aggregation of uncertainties from multiple sources.

Module 4 – Control Volume Uncertainty
Module 4 is the second component of the uncertainty analysis and is used for computing the best-estimate control volume and uncertainty bounds for the overflow volume with a once-per-year frequency of occurrence.

Operation of each of these four modules is described in the following sections.

OPERATION OF ACU-SWMM
ACU-SWMM is started by either Clicking on the ACU-SWMM icon shown on the list of programs displayed after Clicking the MS Windows *Start* button or by double-Clicking on the ACU-SWMM icon on the desktop. When the program starts up, an initial blank blue screen is displayed as shown in Screen-Shot 1. Clicking on *File* initiates the drop-down menu with the options of creating a new project, opening an existing project or exiting the program (Screen-Shot 1).

Screen-Shot 1 – Initial Screen Displayed Upon Program Start-Up

Creating a New ACU-SWMM Project
To create a new project, Click on *NewProject* which brings up the data entry screen for setting the project folder and for identifying the data management file (Screen-Shot 2).

Important Note: All of the project files should be kept in a project folder to minimize pathing problems. Before starting ACU-SWMM, create a project folder on your hard drive. Put the SWMM template (.INP) file along with the meter (.CSV) files in the project folder. ACU-SWMM will store the project database and results database files in the project folder along with the SWMM input files from each simulation.

The data entry prompts shown on Screen-Shot 2 are defined as follows:

Project Name – will be the filename for the *MS Access* database file that stores project data

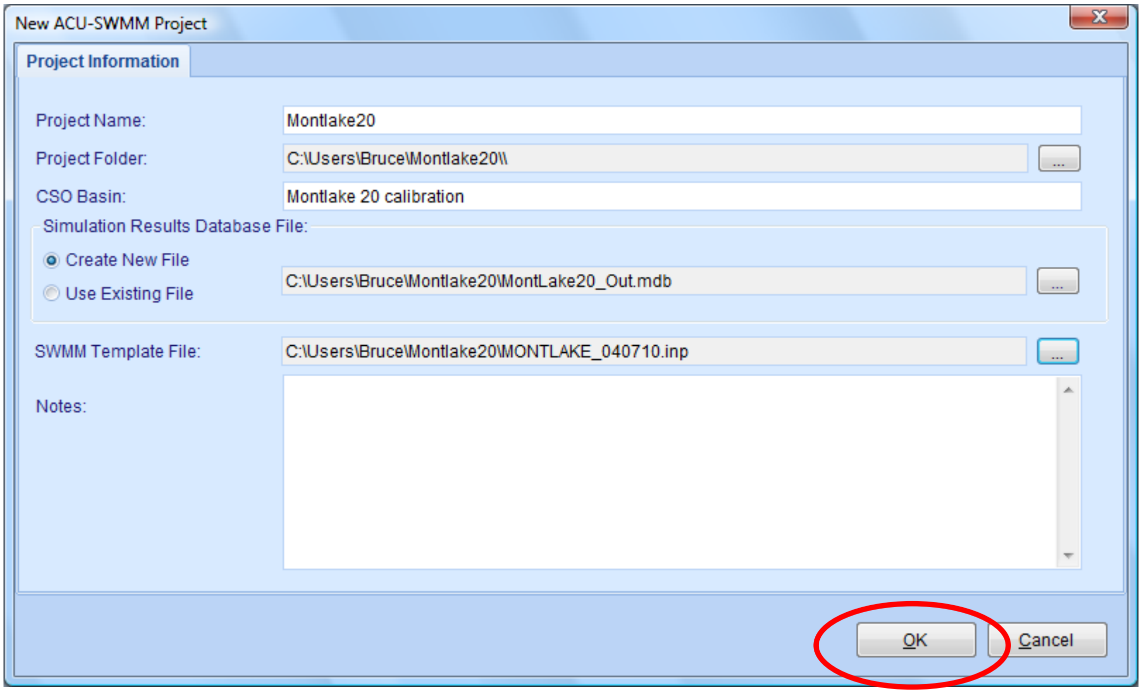
Project Folder – is the name of the folder created to store the SWMM template (.INP) file, meter (.CSV) files, the project database, simulation results database, and all other project files

CSO Basin – is a text field that is used in project reporting

Simulation Results Database File – is the *MS Access* database file used to store the sampled model parameter values and goodness-of-fit results. This must be a different filename than the project name above and recommend adding “ _Out” to the project name file to differentiate it from the project database file

SWMM Template File – is the SWMM template (.INP) file used by ACU-SWMM to create input files for each simulation

Notes – is a text field used for user convenience and displayed in project reports

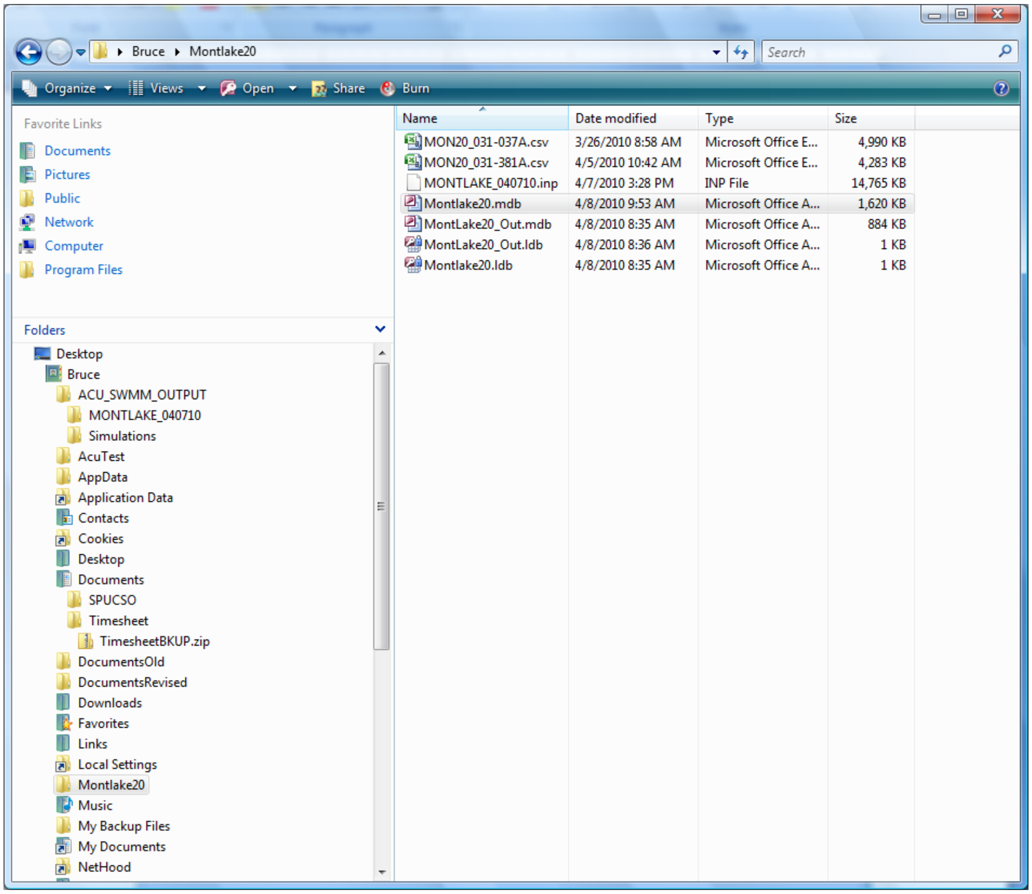


Screen-Shot 2 – Data Entry Screen for New Project

When data entry is complete, Click *OK* and the relevant database files are created or connected, and the SWMM template (.INP) file is read by the program. In this case, *Montlake20.mdb* holds the simulation settings (sampling parameters, meter information, etc) and *Montlake20_Out.mdb* will hold the sampled parameters and goodness-of-fit results from each simulation. ACU-SWMM will then display the standard screen format (Screen-Shot 4a) where the left panel provides connection to the four modules and the options for a given module. The panels on the right are the working area where current operations are active.

Opening an Existing ACU-SWMM Project

To open an existing project, start ACU-SWMM and then Click *File> Open*. Navigate to the project folder and select the project file to open (*MS Access* .mdb file). In this example, the project file would be *Montlake20.mdb* (Screen-Shot 3). The project database and results database files will be connected automatically and ACU-SWMM will display the standard screen which consists of a navigation panel on the left and data entry screens on the right (Screen-Shot 4a).



Screen-Shot 3 – Listing of Files in Project Folder for Opening an Existing Project

MODULE 1 – AUTOMATED CALIBRATION

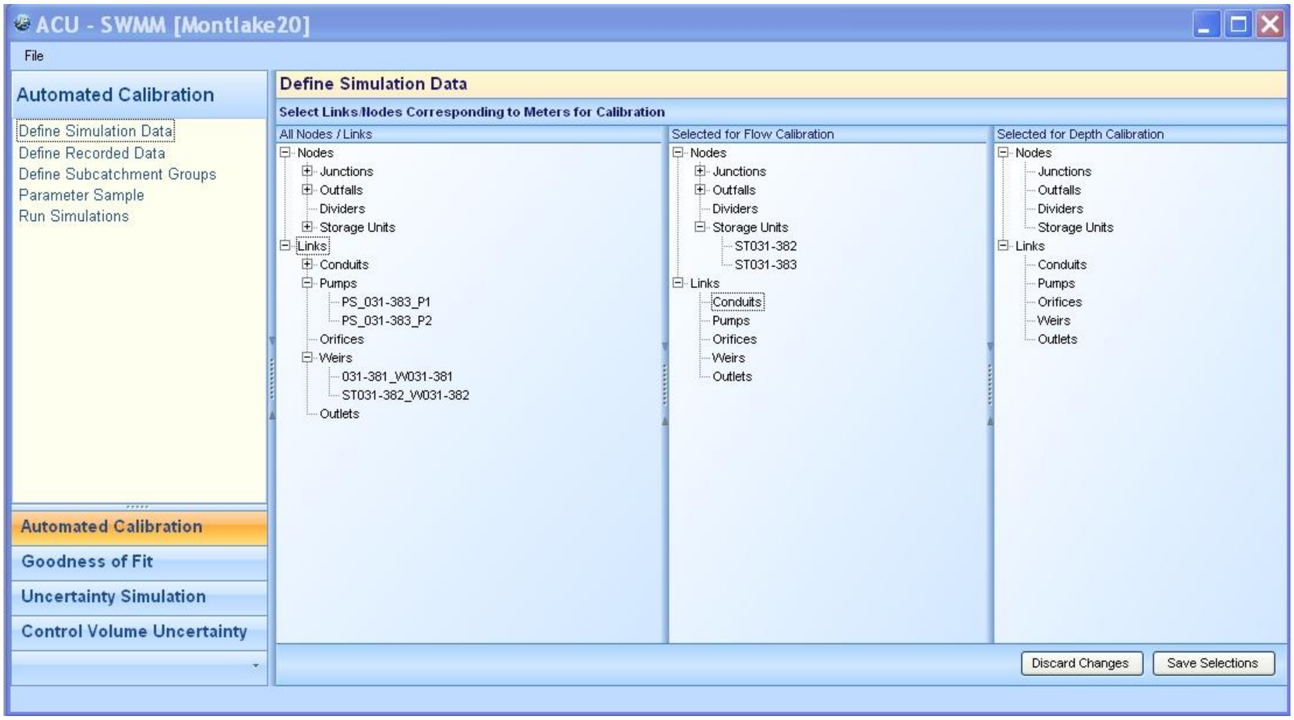
The Automated Calibration module has 5 components which are used to provide all of the data and information necessary for conducting simulations of the SWMM basin model. These 5 components are listed in the upper left corner of the left panel (Screen-Shot 4a) and are selected by a click of the mouse. The functionality of each of the five components is described below.

Define Simulation Data

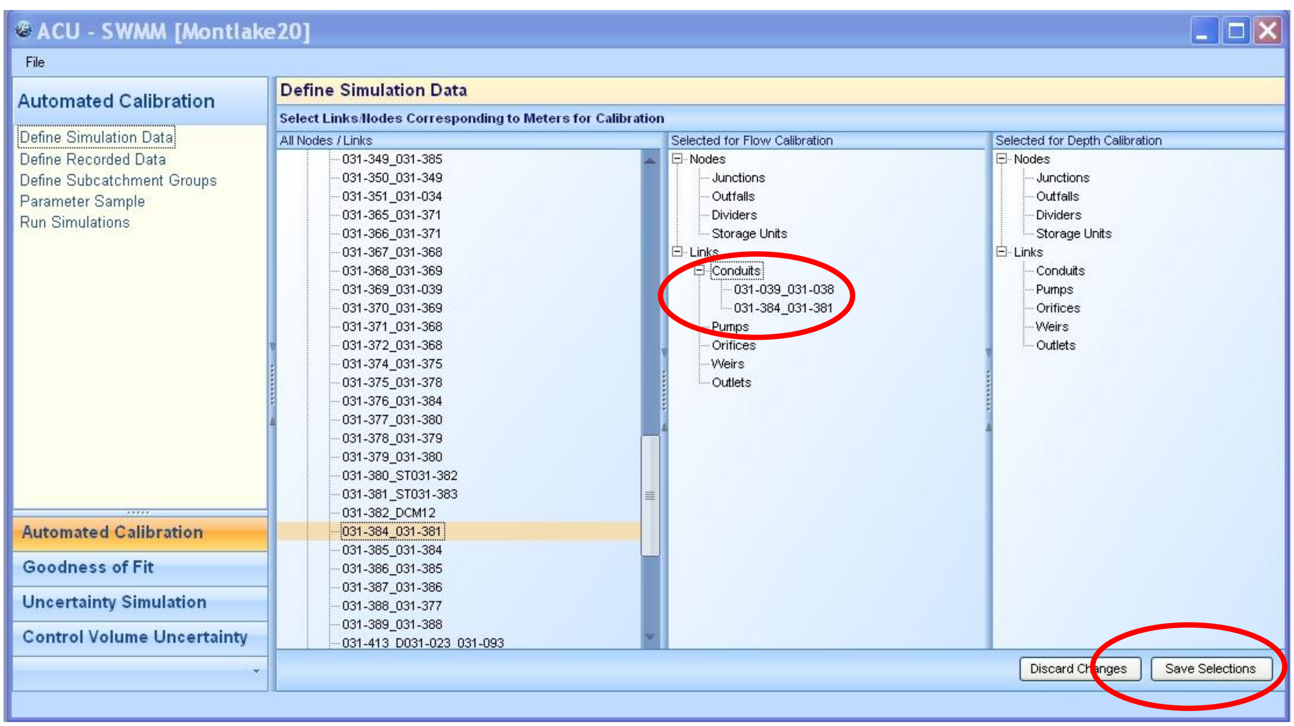
The *Define Simulation Data* component provides the ability to identify where the flow and depth meters are located in the sewer system for use in model calibration. The links and nodes where flow and depth meters may be located are listed in a tree structure in the center-left panel (Screen-Shot 4a). Flow meters are typically located within conduits (links). Depth measurements may be part of the flow meter assembly and located in a conduit or may be part of depth-only meters which are often located at access holes, weirs, storage tanks (nodes). The tree structure is created automatically by reading the SWMM input (.INP) template file and may be expanded or collapsed with the + or – button.

Define meter locations by Dragging the element where the meter is located on the center-left panel to either the Flow Calibration Panel or Depth Calibration Panel on the right (Screen-Shot 4b). The element will automatically attach to the appropriate node or link.
In Screen-Shot 4b, flow meters for model calibration are seen to be located in SWMM conduits

03-039_031-038 and 031-384_031-381. To remove a selected element, right Click on the element and Select *Remove*. When complete, Click *Save Selections* to save them to the project file.



Screen-Shot 4a – Standard Screen Format and Working Panel for Automated Calibration Options



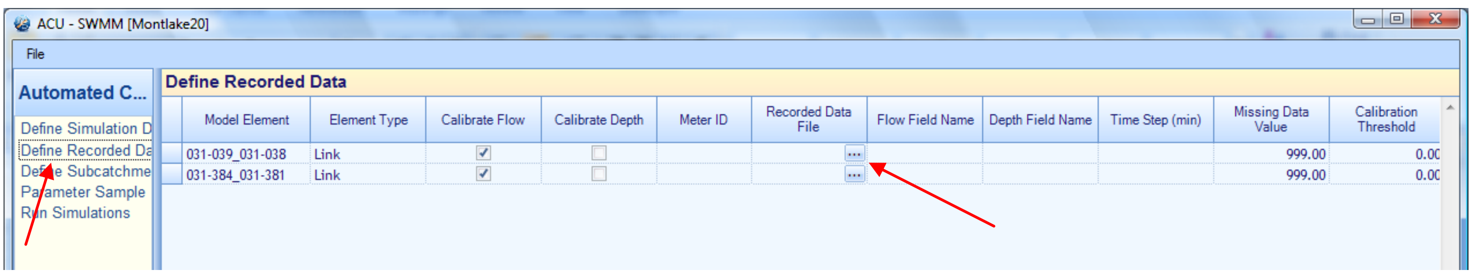
Screen-Shot 4b – Defining Elements Where Flow Meters and Depth Meters are Located

Define Recorded Data

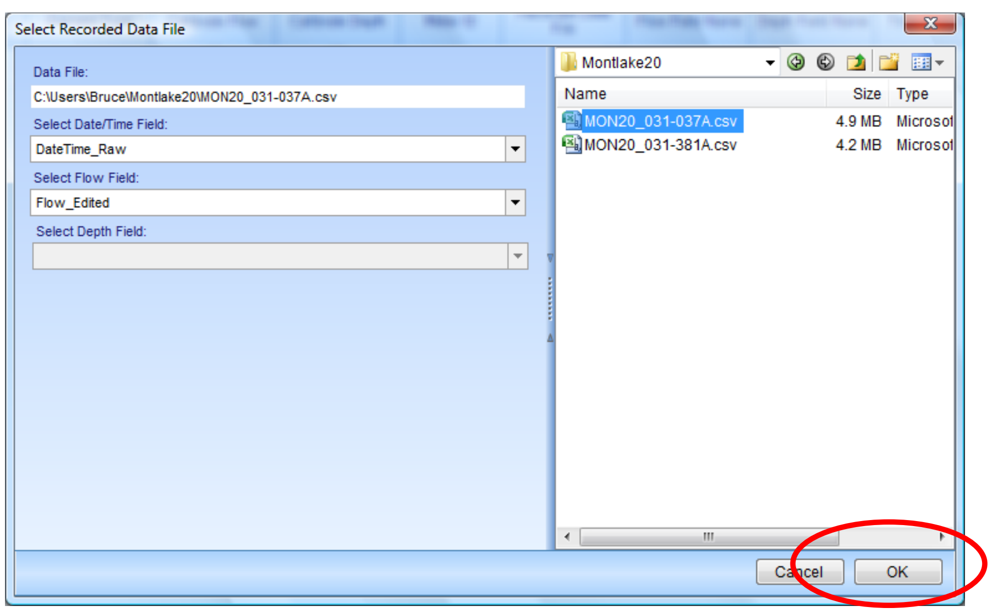
The *Define RecordedData* component provides the ability to connect the meter data file and to set meter characteristics. Clicking on the *Define RecordedData* label opens the data entry screen for defining the recorded meter data (Screen-Shot 5a).

Click the *Recorded Data File Button* in the center-top of the screen to open the screen for selecting the data files (Screen-Shot 5b). Use this data entry screen to define the recorded data file for the selected model element. Navigate to the project folder and Drag the .CSV file from the project folder window on right (Screen-Shot 5b) to the *Data File* field at left. The headers in the .CSV file will automatically loaded into the list date/time and data field boxes. Make sure to choose the correct field for the date/time and data fields before selecting OK.

Repeat this process for the other meter(s) in the project.



Screen-Shot 5a – Defining Elements Where Flow Meters and Depth Meters are Located



Screen-Shot 5b – Defining Elements Where Flow Meters and Depth Meters are Located

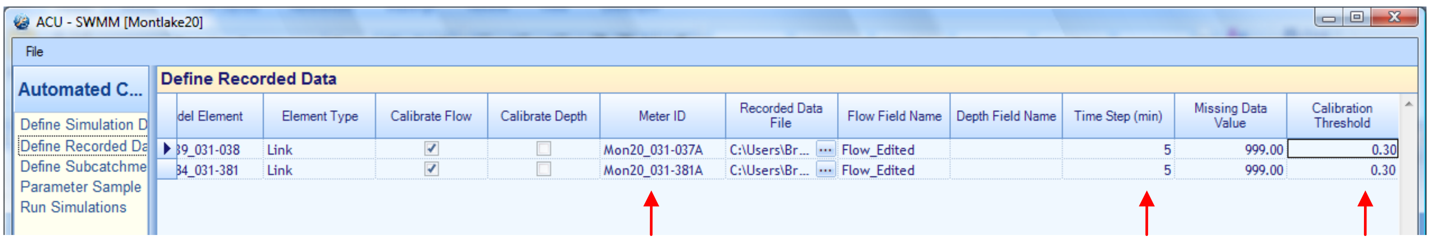
After defining the recorded data files, the following meter characteristics fields (Screen-Shot 5c) are entered:

<u>*Meter ID*</u> – The Meter ID appears on subsequent screens to identify the meter

<u>*Time Step*</u> – Time step (minutes) of the recorded data

<u>*Calibration Threshold*</u> – The calibration threshold defines the minimum flow rate or minimum depth to be used in computing goodness-of-fit (GOF) measures for model calibration. Only values above the threshold are used in the GOF computations. The measurement units for the calibration threshold are the same units as the recorded data – mgd for flow and feet for depth.

Click *Save Changes* when finished entering meter complete.



Screen-Shot 5c – Data Entry of Fields for Recorded Meter Data Characteristics

Define Subcatchment Groups

Calibration Parameters are applied on a subcatchment level. It is common that the same calibration parameter values are to be assigned to multiple subcatchments. Assigning of calibration parameter values to subcatchments is accomplished by defining *Subcatchment Groups* and including multiple subcatchments to each group.

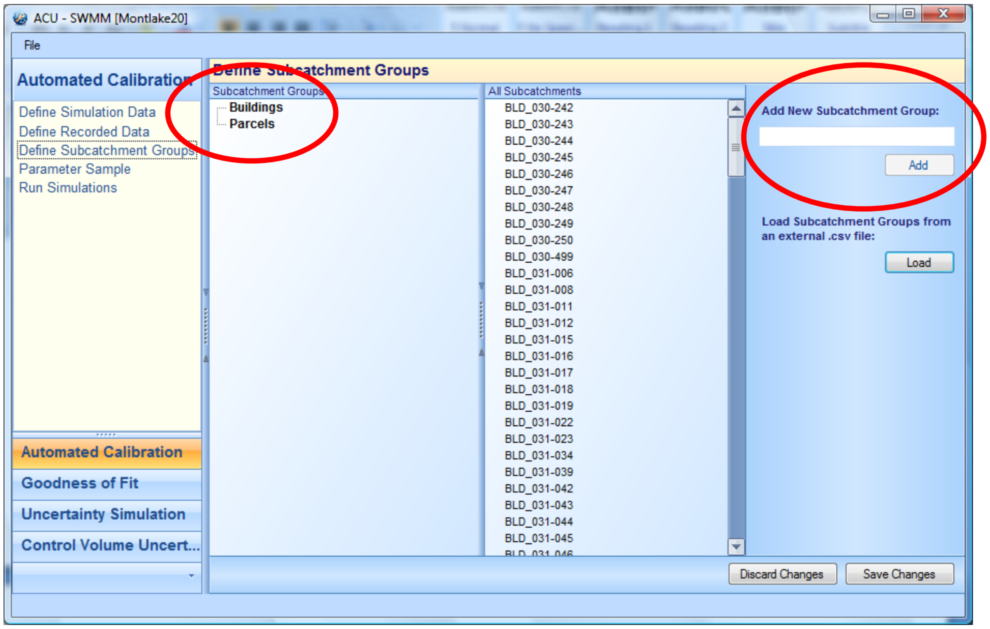
<u>Manual Method of Defining Subcatchment Groups</u>

Subcatchment Group Names are created by entering the subcatchment group name into the *Add Subcatchment GroupName* text box and Clicking *Add*. Screen-Shot 6a shows where the subcatchment group names of *Buildings* and *Parcels* were created and are now listed in the center-left panel.

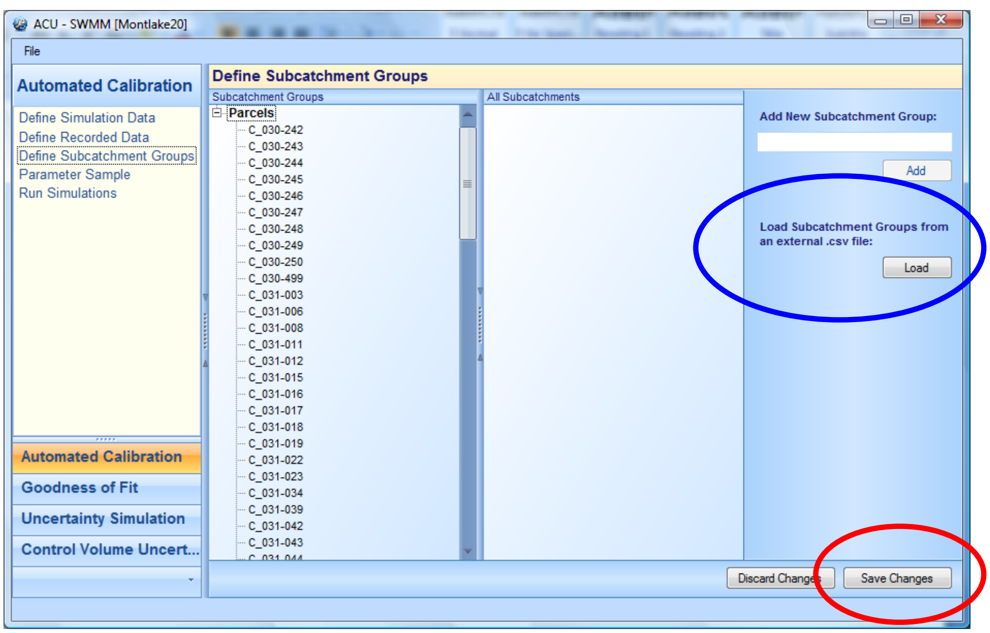
Subcatchments are then assigned to Subcatchment Groups by selecting multiple subcatchments in the center-right panel and Dragging them into the appropriate Subcatchment Group in the center-left panel as seen in Screen-Shot 6b. Click *Save Changes* when finished.

<u>Pre-Defined Subcatchment Groups</u>

Subcatchments may also be assigned to *Subcatchment Groups* using a pre-defined list created during the construction of the SWMM basin model. The pre-defined subcatchment groups and associated subcatchments are loaded from a .CSV file located within the project folder. This is accomplished by Clicking on the *Load* button which brings up the files located in the project folder. Selecting the .CSV file of group names and Clicking on Open will load the subcatchments and subcatchment groups into the center-left panel. Click *Save Changes* when finished.



Screen-Shot 6a – Example of Defining Subcatchment Group Names
Available Subcatchments are Listed in Center-Right Panel



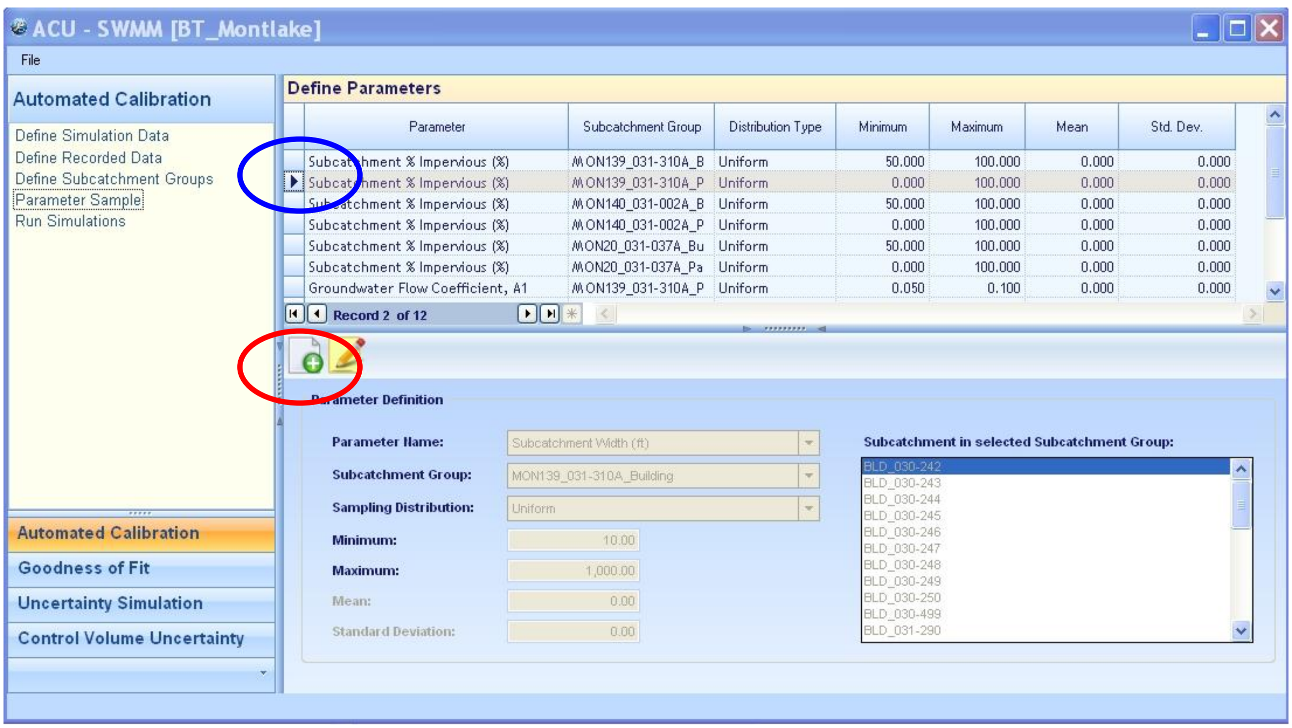
Screen-Shot 6b – Assignment of Subcatchments to Subcatchment Groups is Complete

Parameter Sample

The automated calibration procedure utilizes a Monte Carlo sampling approach similar to that used in the Generalized Likelihood Uncertainty Estimation (GLUE) approach initially developed by Bevin and Binely[1]. Additional information on this approach is described in the CSO Technical Guidance Manual[2]. The *Parameter Sample* component is used to identify the probability distribution, and minimum and maximum values of the model parameters that will be used in automated calibration. As discussed in the prior section, the model parameters used for calibration are associated with Subcatchment Groups and those groups are identified here.

<u>Adding Model Parameters for Calibration</u>

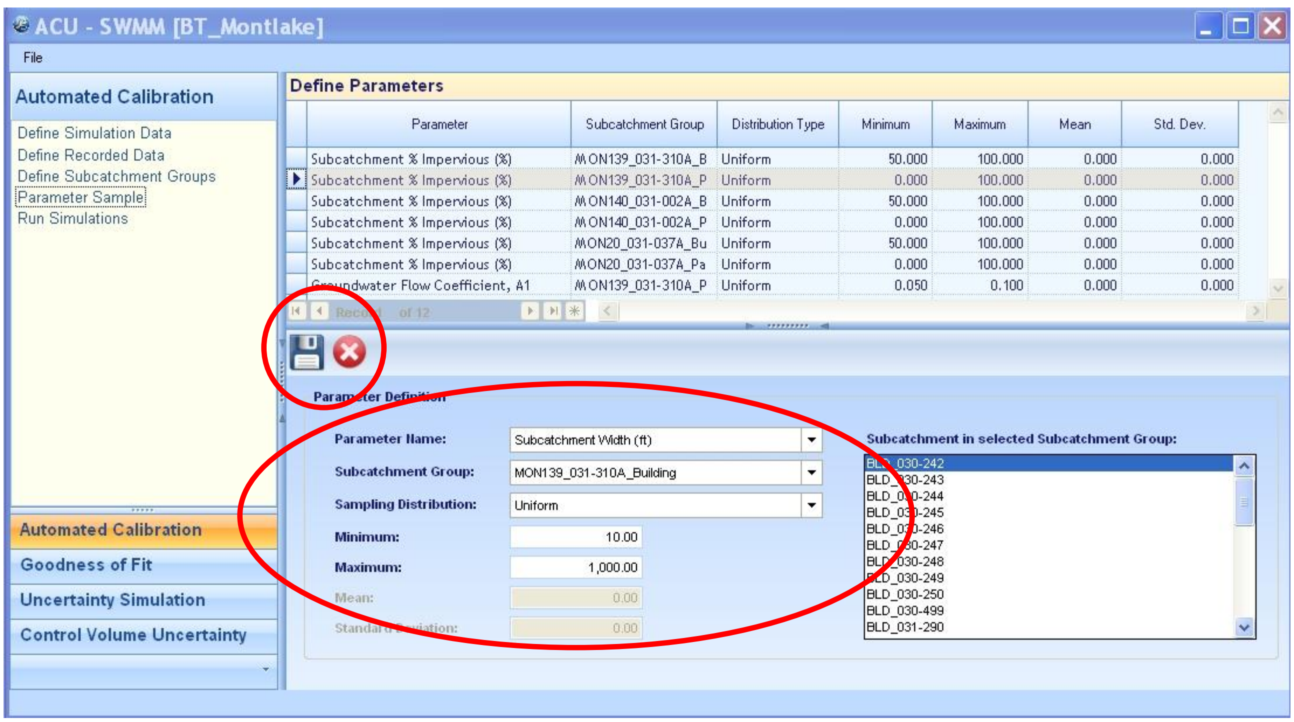
The Calibration Model Parameters and Sampling Characteristics are defined by first *Clicking* the green plus sign icon (Screen-Shot 7a). Select the desired model parameter from the list box, and identify a subcatchment group (Screen-Shot 7b). Select the probability distribution for sampling and that selection will cause the correct sampling property text entry boxes to activate (minimum and maximum or mean and standard deviation). Use the keyboard to enter the desired values in the sampling property fields. The *Red X* icon remains illuminated until the selections are saved. After all of the data fields are deemed satisfactory, Click the *Floppy Disc* icon to save the data which will be displayed in the upper panel (Screen-Shot 7b). This process is repeated for each combination of model parameter and subcatchment group.



Screen-Shot 7a – Screen for Setting Model Parameters
and Sampling Characteristics for Automated Calibration

Deleting Previously Selected Model Parameters for Calibration
Removal of any of the previously selected model parameters is accomplished by first marking the model parameter to be edited. This is done by Clicking on the index button to the left of the parameter (upper panel) which marks the record with a black pointer. Right clicking provides a selection to remove the parameter. Removal of multiple parameters is accomplished by first highlighting the records to be removed and then right Clicking and confirming deletion of the records.

Editing Model Parameters for Calibration
Editing of the any of the model parameters is accomplished by first marking the model parameter to be edited. This is done by Clicking on the index button to the left of the parameter (upper panel) which marks the record with a black pointer. Clicking on the yellow *Pad and Pencil* icon then allows access to editing the parameter sampling characteristics as the boxes in the lower panel are activated. After changes are made, click on the *Floppy Disc* icon to save the changes.



Screen-Shot 7b – Screen for Adding or Editing Model Parameters and Sampling Characteristics

Run Simulations

The *Run Simulations* component provides the ability to sample the model parameters and to view the sample values. It also provides the ability to sample the model parameters and to execute the EPA SWMM model in a batch mode. This allows numerous simulations to be conducted without interaction from the analyst.

A number of inputs must be provided before sampling of modeling parameters or executing simulations for automated calibration. The inputs for conducting simulations include.

Simulation Name – Computer generated name produced when the *Sample and Run* button is

Clicked. The name consists of the Computer ID and the date and time when the simulation was started, e.g. SEA31040742_04_07_2010_15_30_58

Random Number Seed – Value used to start the random number generator. If you use the same seed, you'll get the same sequence of pseudo random numbers each time. Change this number to get a different sequence. A 9-digit integer value is recommended.

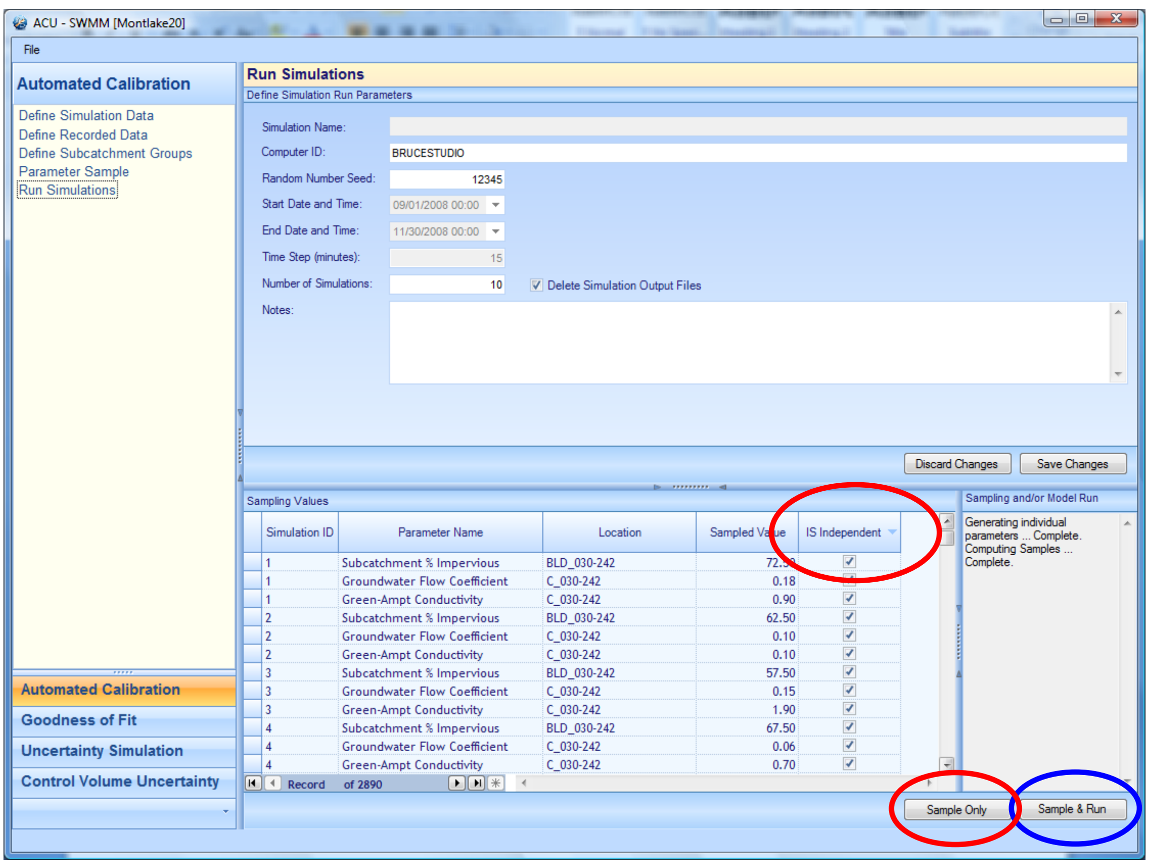
Start/End Date Time – The simulation start and end dates as defined in the SWMM template file. To change this, you must edit the template file using a text editor or through the SWMM program interface

Time Step – Model time step which is read from the SWMM file

Number of Simulations – Number of parameter samples to compute, and the number of calibration simulations to perform.

Delete Simulation Output Files – SWMM will create a binary output file for each simulation. These files can be quite large. Checking this feature will delete this binary file after the flows and depths at the calibration locations are exported to CSV files. The input files are saved for later use.

Notes – A text field is provided for notes.



Simulation ID	Parameter Name	Location	Sampled Value	IS Independent
1	Subcatchment % Impervious	BLD_030-242	72.50	✓
1	Groundwater Flow Coefficient	C_030-242	0.18	✓
1	Green-Ampt Conductivity	C_030-242	0.90	✓
2	Subcatchment % Impervious	BLD_030-242	62.50	✓
2	Groundwater Flow Coefficient	C_030-242	0.10	✓
2	Green-Ampt Conductivity	C_030-242	0.10	✓
3	Subcatchment % Impervious	BLD_030-242	57.50	✓
3	Groundwater Flow Coefficient	C_030-242	0.15	✓
3	Green-Ampt Conductivity	C_030-242	1.90	✓
4	Subcatchment % Impervious	BLD_030-242	67.50	✓
4	Groundwater Flow Coefficient	C_030-242	0.06	✓
4	Green-Ampt Conductivity	C_030-242	0.70	✓

Screen-Shot 8 – Screen for Sampling Model Parameter Values and Executing Simulations

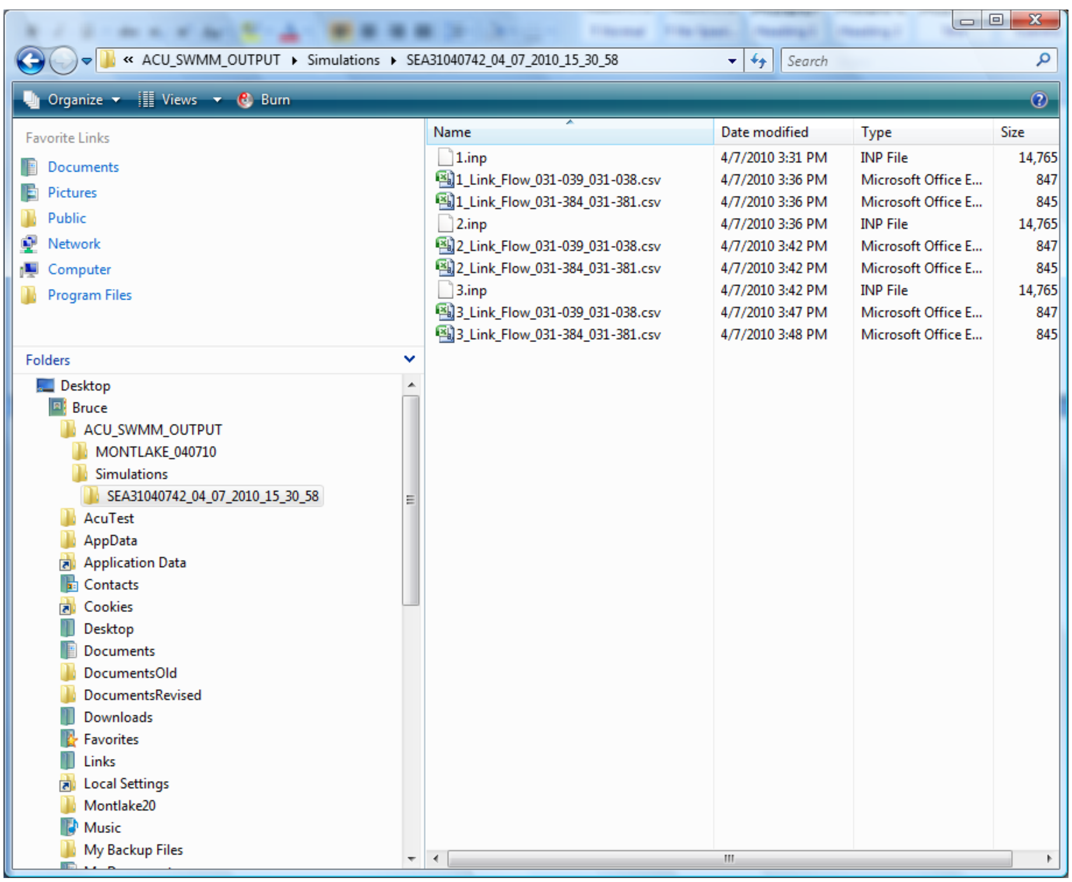
Sampling Model Parameter Values

Sampling of model parameters without running the SWMM model, is done by *Clicking* on the *Sample Only* button at the lower right corner of the bottom panel (Screen-Shot 8). The lower left panel shows the sampled model parameters. If you click the *Is Independent* column heading, the independent samples will sort to the top so you can quickly view the samples for each parameter.

Conducting Simulations with Sampled Model Parameter Values

Clicking on the *Sample & Run* button samples the model parameters and then executes the SWMM model in batch mode for the number of simulations and time period specified in the upper panel. The simulation results are stored in a folder called *Simulations* in the project folder. Each simulation is stored in a separate folder with the simulation name. Each simulation is numbered sequentially and the simulated data are exported from the model for each meter.

After the SWMM simulations have completed, the next step is to compute goodness of fit statistics for the simulation results and to view comparisons of sewer hydrographs. Click the Goodness of Fit tab in the left navigation panel.



Screen-Shot 9 – Example of Contents of One Simulation
Stored in the Simulations Folder within the Project Folder

MODULE 2 – GOODNESS-OF-FIT

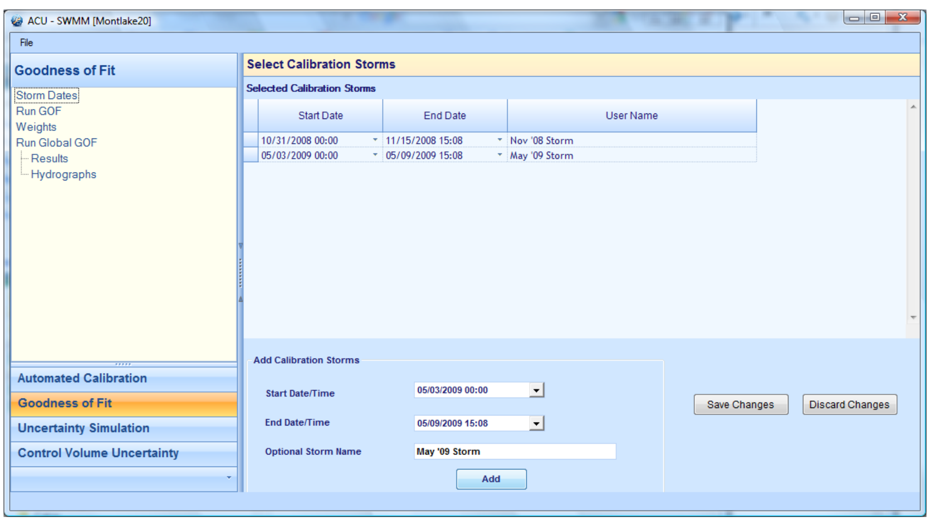
The Goodness-of-Fit module has 4 components which are used to provide all of the data and information necessary for computing global goodness-of-fit measures and for graphically presenting comparisons of recorded and simulated sewer flow and depth hydrographs. These 4 components are listed in the upper left corner of the left navigation panel (Screen-Shot 10) and are selected by a click of the mouse. The functionality of each of the four components is described below.

Storm Dates

The *Storm Dates* component is used to specify the time periods to be used for conducting automated model calibration. These time periods correspond to the dates when storms produced noteworthy sewer flows in the combined sewer system.

<u>Specifying Storm Dates</u>

Enter the storm dates using the controls in the lower panel. A text field is provided to allow use of a more recognizable name for a given storm. Click *Add* which stores the dates in the upper panel. To edit the storm dates or the user name (optional storm name), make changes in the table in the lower panel and then Click *Save Changes*. To delete a storm, click the row header and then press the delete key on the keyboard.



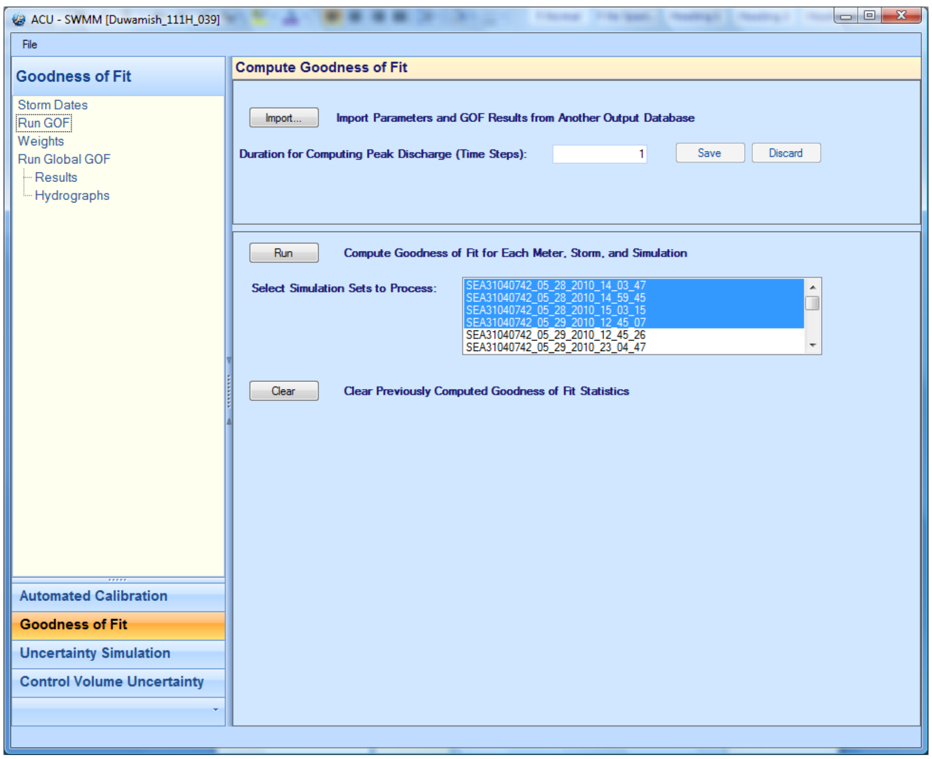
Screen-Shot 10 – Screen for Entering Storm Dates (Time Periods) for Use in Model Calibration

Run GOF

The *Run GOF* component is used to compute goodness-of-fit (GOF) measures for each sewer flow and depth hydrographs for each meter site. In addition, simulations performed on other computers may be imported to the current project.

Compute Goodness-of-Fit Measures

To compute GOF measures, first select the simulation sets that are to be processed by highlighting them in the window in the center of the panel (Screen-Shot 11). Only simulation sets that have not been previously processed will be displayed in the window. Next specify the *Duration for Computing Peak Discharge* that is to be used to average the peak discharge over a number of time steps to filter out fluctuations that may be present in the recorded data. If no smoothing is desired, then use a value of 1 should be used (instantaneous peak for one time-step) should be used. Clicking the *Run* button will compute GOF statistics for each storm date at each meter for the each simulation in the simulation set.



Screen-Shot 11 – Screen for Computing Goodness of Fit for Each Simulation Set

Importing Simulation Results From Other Computers

The Import button at the top of the screen can be used to import simulation results computed from other ACU-SWMM sessions, either on a separate or the same computer. Information on performing model calibration with multiple ACU-SWMM sessions is described in the section *Running Calibration Simulations On Multiple Computers*.

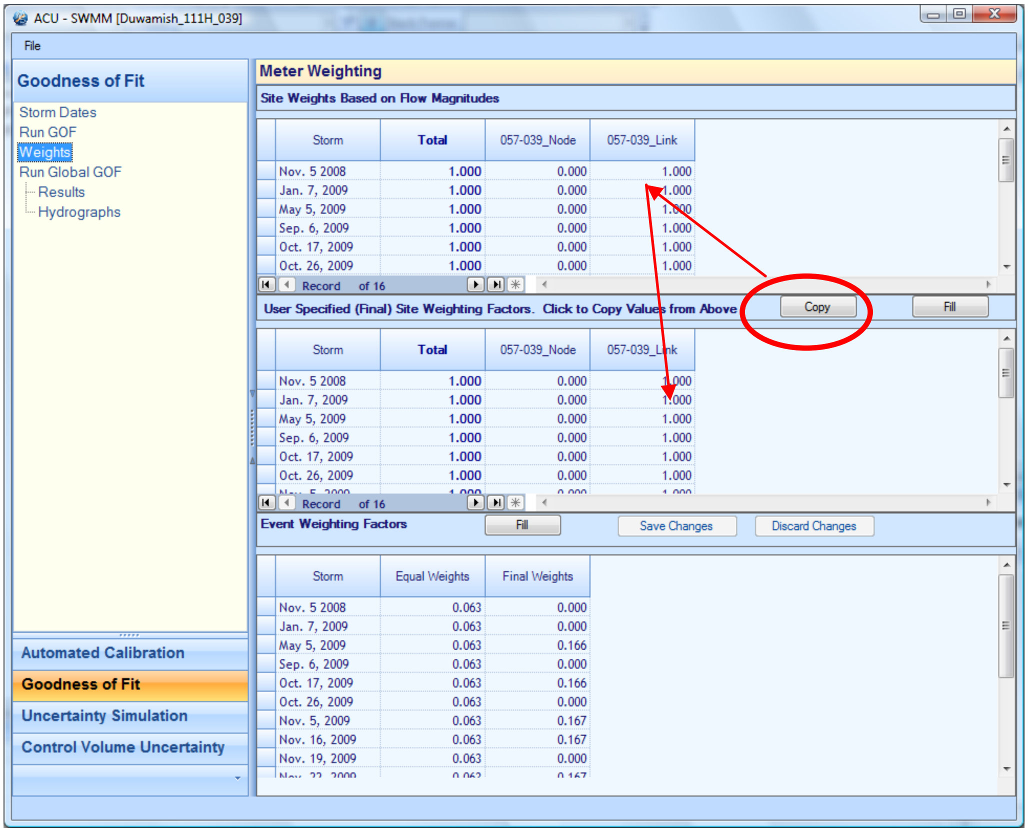
Weights
The *Weights* component is used for assigning weights to meters and storm dates. These weighting factors reflect the importance of a given hydrograph at a meter, relative to the hydrographs at other meters for a specified storm date. Weights are used to reflect the importance of a given storm used in model calibration relative to the group of storm and always sum to 1.

The upper panel of the *Meter Weighting* screen automatically displays preliminary site (meter) weights that were computed based on the relative magnitude of sewer flows at the various flow meters (Screen-Shot 12a). These weightings are advisory only and are not used in the GOF computations. Weightings are not provided for depth hydrographs.

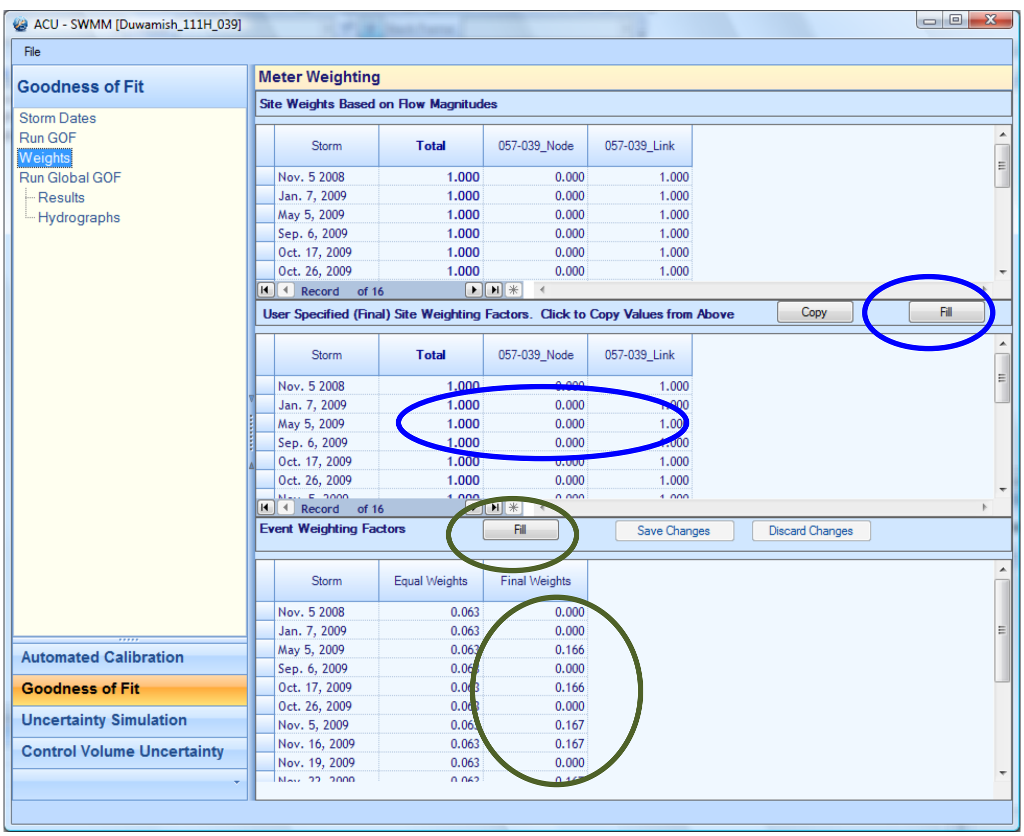
<u>User Specified Site Weighting Factors (Meters)</u>
The middle panel is used to specify weighting factors for the meters that are to be used for computing global GOF measures for each storm date. The date entry fields are initially populated with the weights listed in the upper panel which were computed based on sewer flow magnitudes. However, these weights can be edited to give higher or lower weight to individual meters. Entry of a value of zero removes the hydrograph at that meter/storm date from the global GOF computation.

Clicking on the *Copy* button will transfer the preliminary weights from the upper panel to the User Specified table, thus resetting it (Screen-Shot 12a).

Clicking on the *Fill* button can be used to fill in rows on the User Specified table so that the total weights sum to 1 (Screen-Shot 12b). Enter the weights for the desired meters and storms. Next, enter a weight of 999 in the remaining fields. Clicking the Fill button will total up the non 999 weights, and replace the 999 values with a value such that the total will be 1.



Screen-Shot 12a – Screen for Entering Weighting Factors for Meters and Storm Events



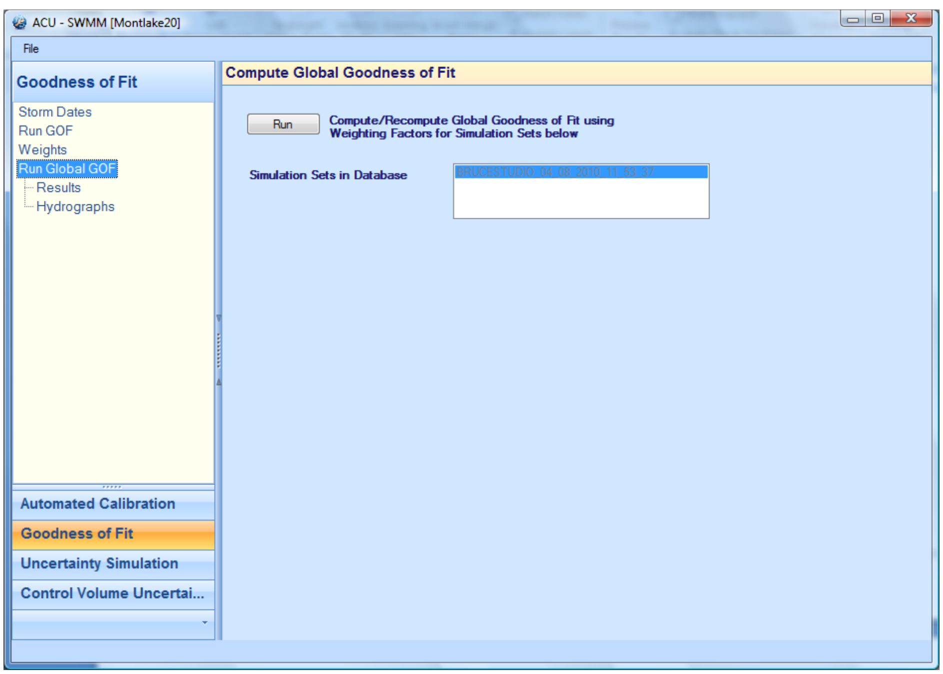
Screen-Shot 12b – Screen for Entering Weighting Factors for Meters and Storm Events

User Specified Site Weighting Factors (Meters)
The bottom panel is used to specify the weighting factors for each storm. The program initially populates the column marked *Equal Weights* for convenience of the analyst. The column marked *Final Weights* is used in the global GOF computations and must be specified by the analyst (Screen-Shot 12b).

Clicking on the *Fill* button can be used to fill in values in the *Final Weights* column so that the total weights sum to 1 (Screen-Shot 12b). Enter the weights for the desired meters. Next, enter a weight of 999 in the remaining fields. Clicking the *Fill* button will total up the non-999 weights, and replace the 999 values with a value such that the total will be 1. Click the *Save* button when all the weights have been specified.

Run Global GOF

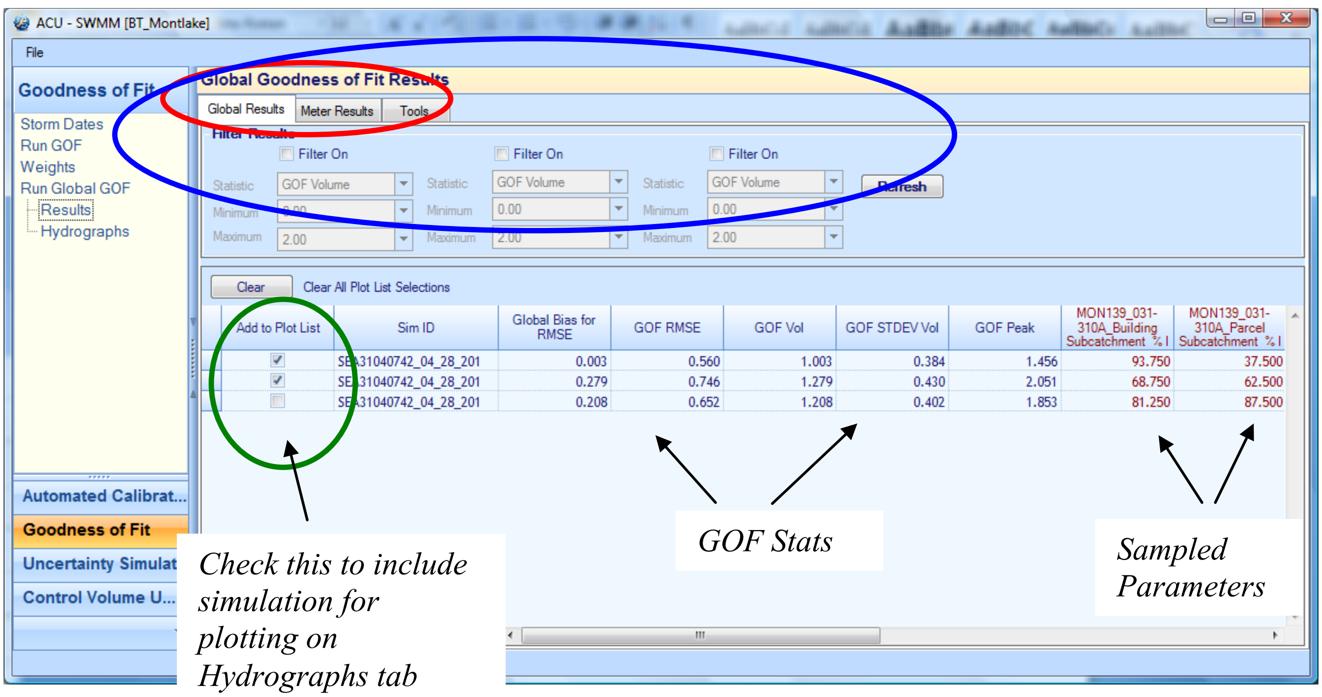
The *Run Global GOF* component is used to execute the routine that computes the global GOF measures as a weighted-average using the weights for the meters and storm dates specified on the *Weights* screen. Global GOF measures for all simulations will be computed using the same weighting factors. Clicking the *Run* button executes the global GOF measures for all simulation sets listed in the viewing window (Screen-Shot 13).



Screen-Shot 13 – Screen for Computing Global Goodness-of-Fit Measures
Using Previously Assigned Weights

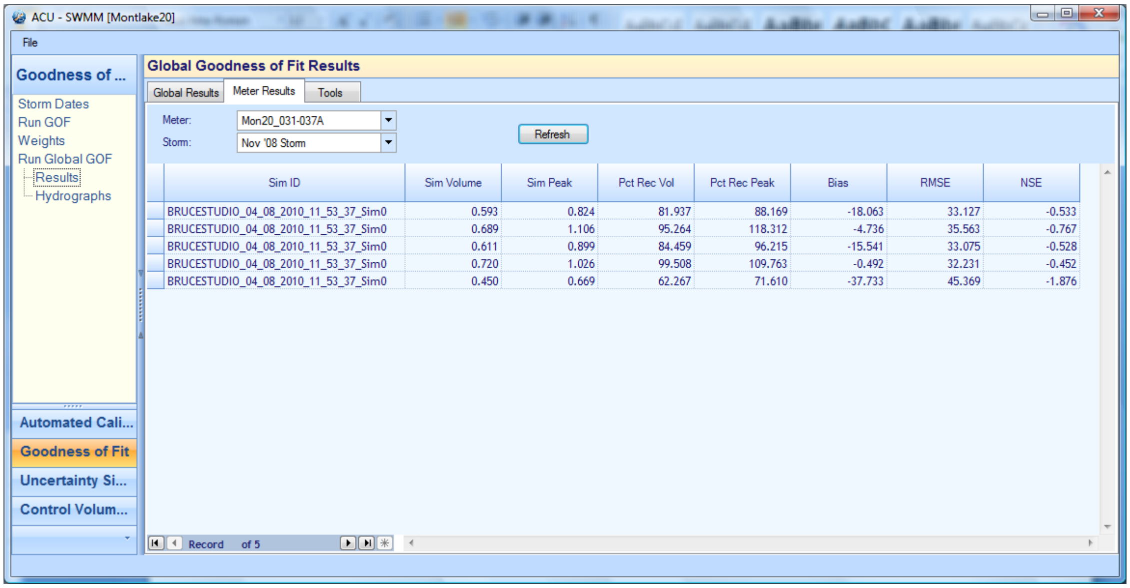
Run Global GOF – Results
Clicking the *Results* tab on the navigation panel provides access to the *Global Results*, *Meter Results*, and *Tools* sub-tabs (Screen-Shot 14).

Global Results Sub-Tab – The *Global Results* sub-tab displays the global goodness-of-fit statistics and the associated sampled model parameters. The various goodness-of-fit measures may be filtered by selecting the GOF statistic and the range for filtering using the drop-down menus in the upper-left portion of the working panel (Screen-Shot 14). The filters are activated and de-activated with the check-box to the right of the filter boxes. Each set of filter boxes uses an "and" condition to further refine the filter. Clicking the column headings sorts the data based on that column. Check the box in the first column to add the simulation to be available on the graphs list on the *Hydrographs* tab.



Screen-Shot 14 – Screen for Displaying Global Goodness-of-Fit Measures

Meter Results Sub-Tab – The *Meter Results* sub-tab (Screen-Shot 15) provides viewing of the individual goodness-of-fit statistics for each meter and storm. The goodness of fit statistics from each meter/storm combination is used along with the user-assigned weights to compute the global goodness-of-fit measure for the simulation.

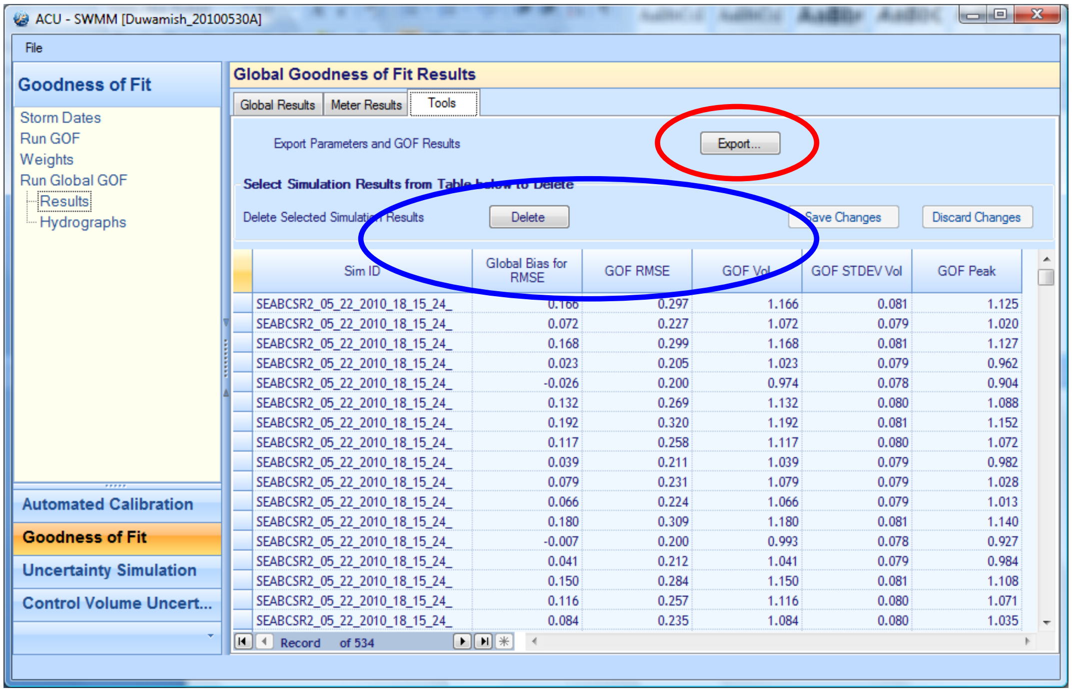


Screen-Shot 15 – Screen for Displaying Individual Goodness-of-Fit Measures
for a Selected Meter and Storm Event

<u>Tools Sub-Tab</u> – The *Tools* sub-tab is used to perform two functions.

- Exports the global GOF measures along with the sampled model parameters to a .CSV file. The .CSV file can then be imported into Excel and scatter-plots generated to examine the sensitivity of the global GOF measures to a particular model parameter used for model calibration. This is accomplished by clicking on the Export button which will bring up a standards Windows file-viewing window for naming and saving the .CSV file with the exported data.

- Deleting results from the database. To delete simulation results from the results database, click the row of the simulation you want to delete in the working panel and then click the *Delete* button. The simulation results won't be permanently deleted until you click the *Save Changes* button. Only the values in the ACU-SWMM results database are deleted, the SWMM data files will remain on the hard drive. The *Discard Changes* button restores the "deleted" simulations, provided the *Save Changes* button has not been previously clicked and the results removed from the database.



Screen-Shot 16 – Tools Screen for Exporting and Importing of Files

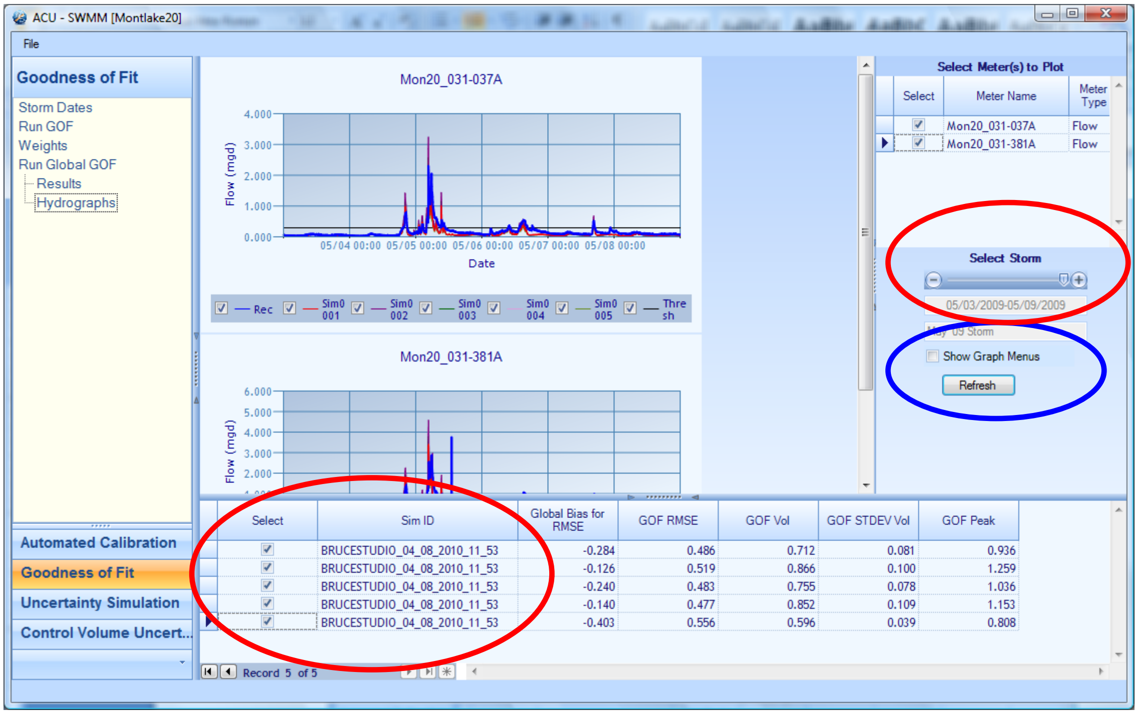
Run Global GOF – Hydrographs

Clicking the *Hydrographs* tab on the navigation panel provides access to the functions for viewing of hydrographs for comparing simulated and recorded sewer flow and depth hydrographs (Screen-Shot 17a).

Selecting Specific Simulations for Viewing Hydrographs – Simulations of interest are identified by Checking the *Add to Plot List* boxes in the table on the *Global Goodness-of-Fit Results* tab (Screen-Shot 14). All hydrographs for the various meters and storm events are available for viewing. The simulations available for viewing are listed in the lower panel on the *Hydrographs* tab. The column may need to be widened to see the full simulation ID number.

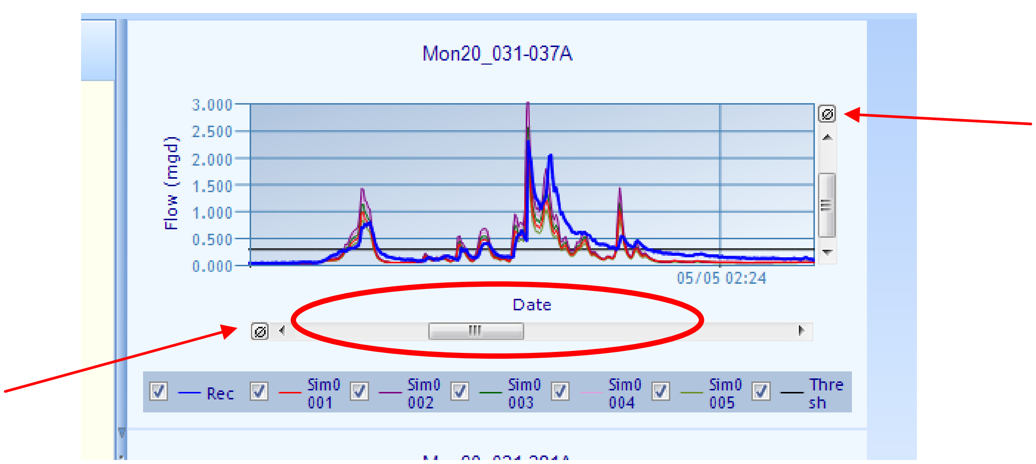
Selecting Hydrographs for Plotting – To select a particular simulation for viewing, Check the check-box in the *Select* column next to the desired simulation ID number in the lower panel. Next, select the meter(s) to be plotted using the check-boxes from the panel at the upper-right of the screen. Click *Refresh* to generate the selected plots. The value of the calibration threshold for the chosen meter is also plotted. A separate hydrograph is plotted for each meter for each of the selected simulations.

To view another storm, click the *Select Storm* slider in the upper right panel to move forward or backward through the storms.



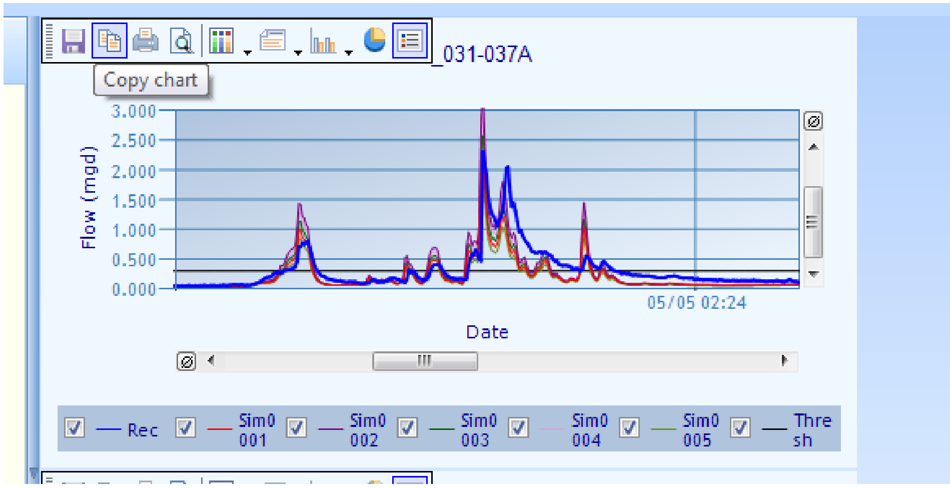
Screen-Shot 17a – Screen for Viewing of Hydrograph Comparisons

Zooming – To zoom in on a particular plot, click and drag a rectangle in the desired area of the graph. To zoom back out, click the button(s) on the horizontal and vertical sliders as shown below (Screen-Shot 17b). You can turn the plotted line for an individual simulation on or off by Clicking the check box on the graph legend for the desired simulation. When the graph is zoomed, slider bars appear along each axes allowing you to scroll to areas of the graph not on the screen.



Screen-Shot 17b – Example of Zooming Features for Plotting

Chart Toolbar – The graphs have a chart toolbar that can be displayed by clicking the *Show Graph Menus* check-box in the upper-right panel on the right side of the screen. The toolbar allows charts to be coped, printed, or saved to disk (Screen-Shot 17c).



Screen-Shot 17c – Example of Graphics Toolbar

RUNNING CALIBRATION SIMULATIONS ON MULTIPLE COMPUTERS

The relatively long run-times of SWMM simulations will often require that simulations be conducted in parallel on multiple computers or multiple ACU-SWMM sessions on the same computer. This situation requires a means of combining all of the simulation results into one location.

The procedure for combining simulation results from different computers or separate sessions of ACU-SWMM on the same computer is described below.

1. Install ACU-SWMM on each computer. To run multiple sessions of ACU-SWMM on the same computer, separate copies of the ACU-SWMM database files and SWMM inputs are needed for each session. Start ACU-SWMM for each session by clicking the ACU-SWMM icon from the start menu once for each session desired. Open a different input ACU-SWMM input database file for each session.

2. When running ACU-SWMM on multiple computers or multiple sessions on the same computer, set the random number seeds to <u>different values</u> and keep track of the seeds. Perform multiple simulations using the procedures described within this manual.

3. After the simulations are complete, copy the output *MS Access* database files (Screen-Shot 18a) and the simulation results folders (Screen-Shot 18b) from each computer to the Master Computer where you want to aggregate all of the simulation results.

4. On the Master Computer, start ACU-SWMM and open the Master project file where all results will be stored.

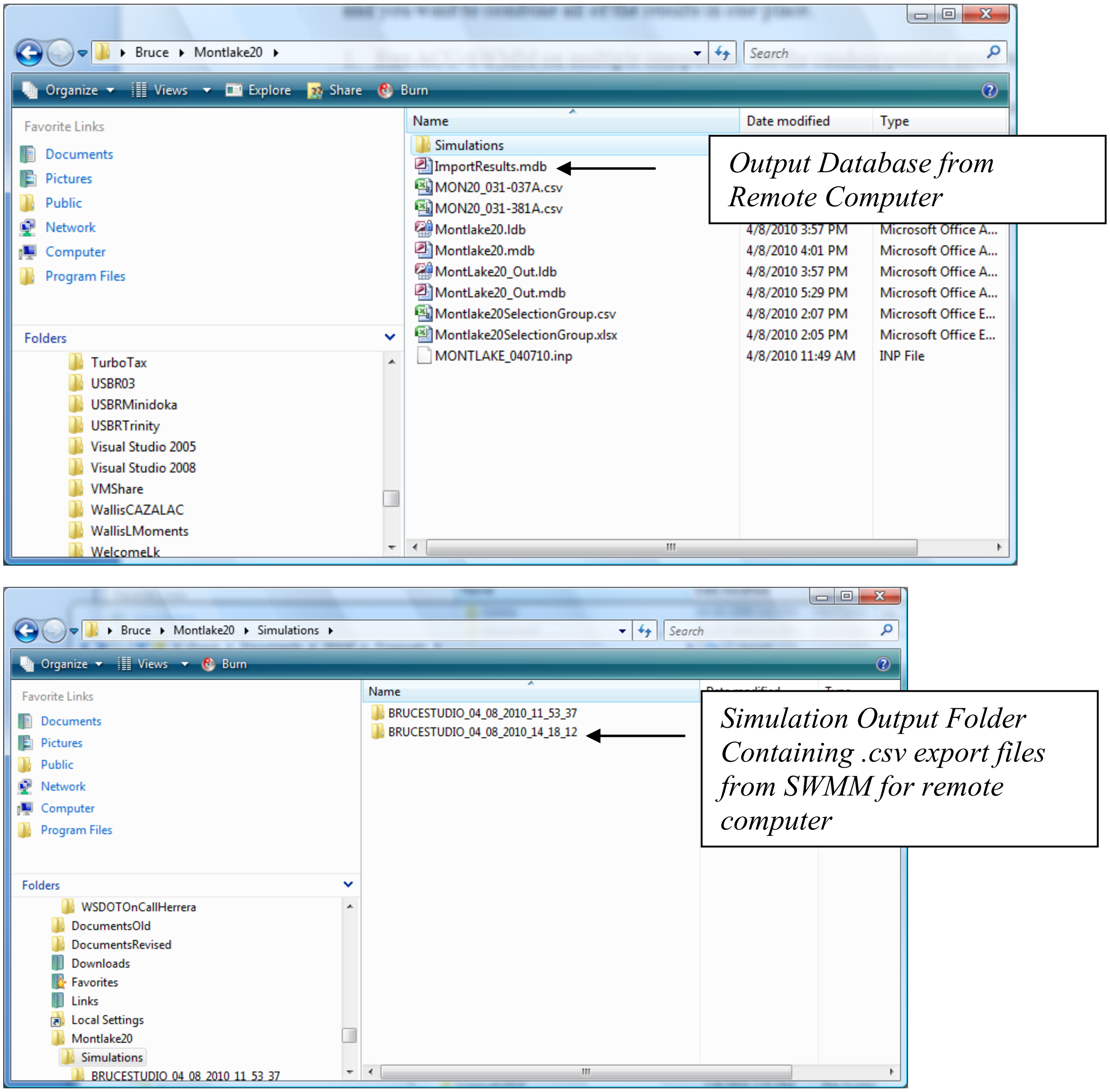
5. Navigate to the *Run GOF* screen by clicking on the *Global Goodness-of-Fit* tab in the navigation panel and then clicking on the *Run GOF* tab. Click the *Import* button and then navigate to the <u>output database</u> you want to load into the master project file (Screen-Shot 19). Click the *Open* button to import the simulation information to the central database file.

6. After the import is complete, the simulation names will be listed in the *Select Simulation Names to Process* field of the *Run GOF* screen. Click on the *Run GOF* button to compute goodness of fit statistics for each simulation.

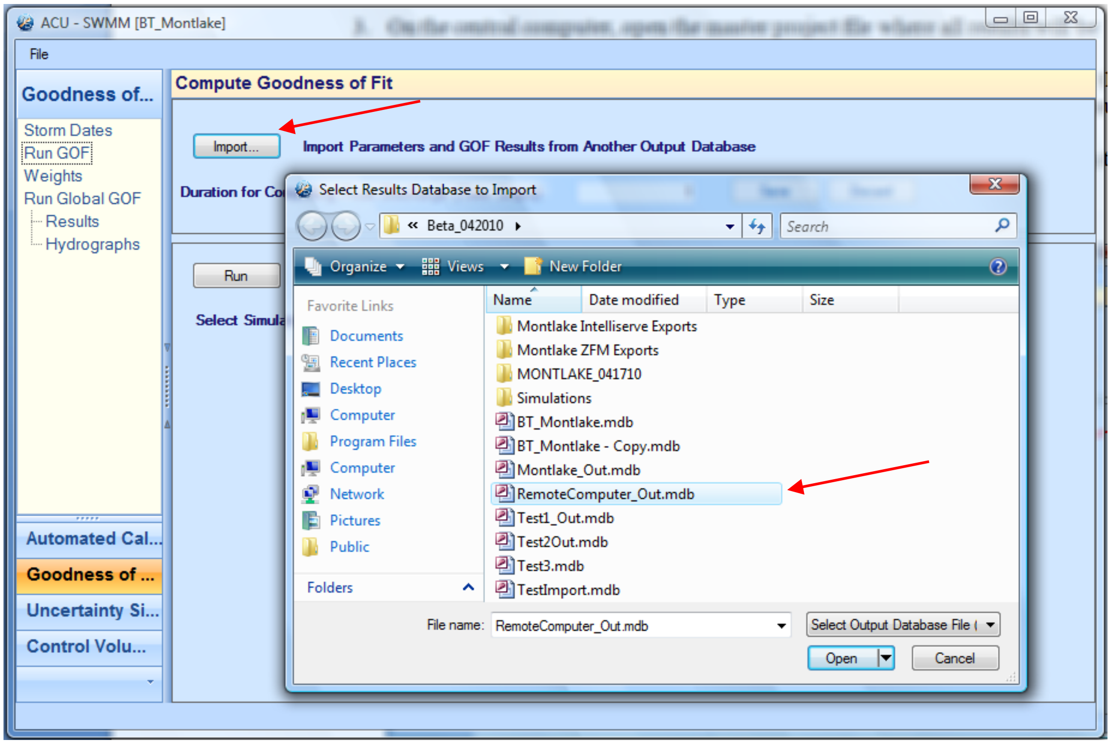
7. Click the *Weights* tab to display the Weights screen. Set the weights for each calibration meter and storm as described earlier in this document.

8. Click the *Run Global Goodness of Fit* tab. Compute the global goodness of fit statistics by clicking the *Run* button as described in this document.

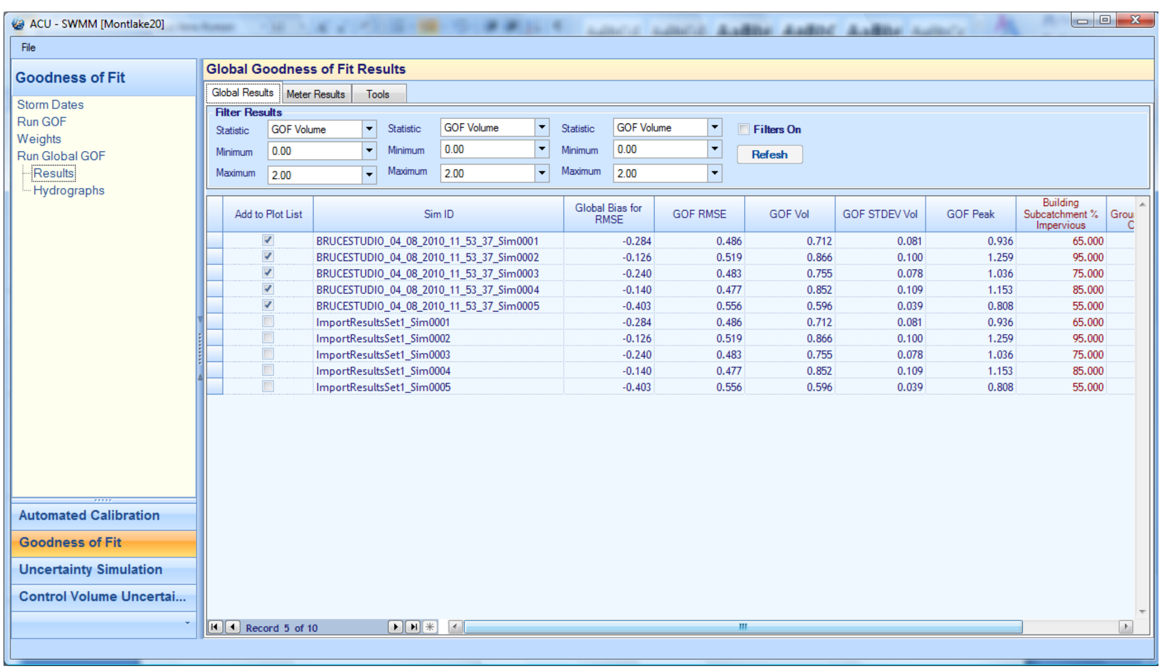
9. The goodness of fit results and sampled parameters for each simulation set will now appear on the *Results* tab as shown in Screen-Shot 20. The hydrographs from these simulations can be viewed from the *Hydrographs* tab provided that the simulated file folder is present in the ACU-SWMM Master project simulation folder for each simulation set.



Screen-Shots 18a,b – Examples of Project Folder (18a) and Simulation Results Folder (18b) Showing files that were Copied from Remote Computers/Cores



Screen-Shot 19 – Import Parameters and Simulation Information from Another ACU-SWMM Output File. (Used to Combine Calibration Simulations Performed on Separate Computers or Separate ACU-SWMM Sessions on the Same Computer)



Screen-Shot 20 – Listing of Goodness-of-Fit Results from Multiple Computers

MODULE 3 - UNCERTAINTY SIMULATION

The *Uncertainty Simulation* module is used to perform long-term simulations for determining the CSO Control Volume and associated uncertainty bounds. This step is performed after the model is calibrated and the parameters have been set (locked in) in the SWMM template file.

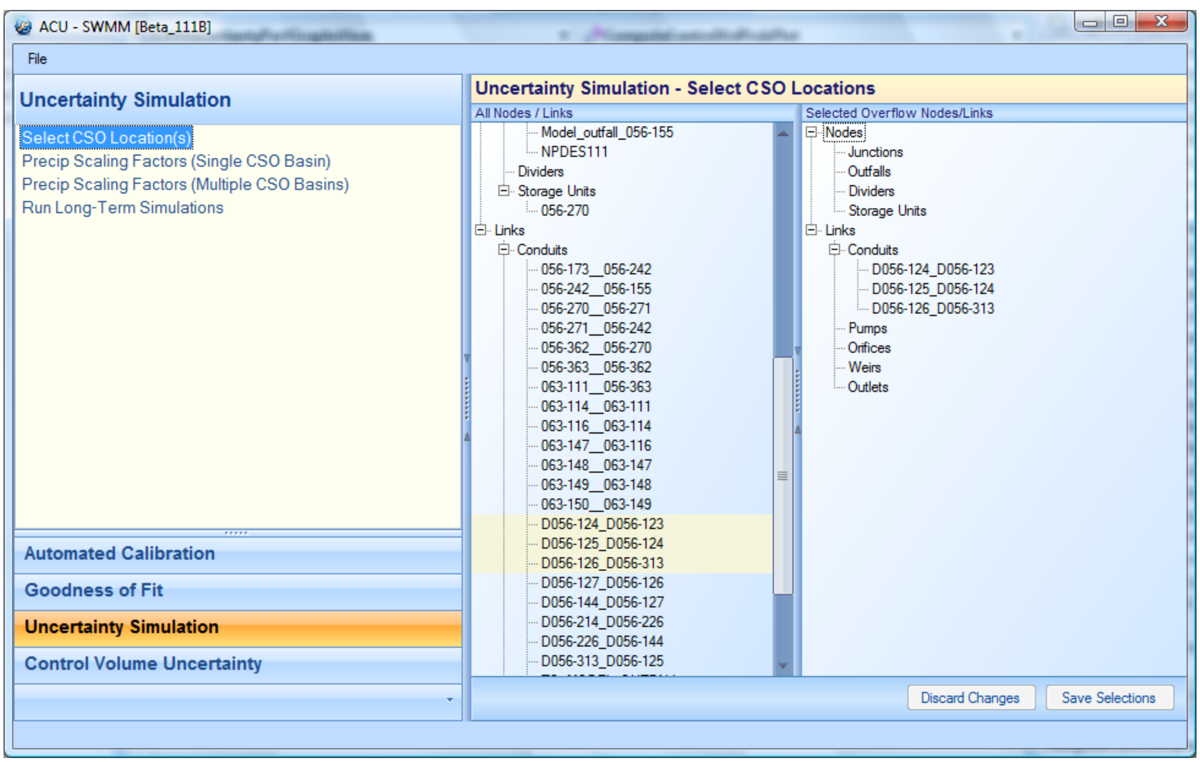
First the CSO locations are defined. Next, precipitation scaling factors are computed that represent the uncertainty due to four sources:

- representativeness of the past 30-year precipitation record for describing future precipitation;
- potential effects of climate change;
- SWMM model uncertainty; and
- residual uncertainty, a catch-all that accounts for a variety of uncertainties.

Last, long-term SWMM simulations are performed (one for each precipitation scale factor) and the discharge hydrograph at each overflow structure are saved. Statistical analyses of the simulated overflows are then performed in Module 4 to compute the best-estimate of the control volume and uncertainty bounds.

Select CSO Location(s)

The *Select CSO Location(s)* component is used to define the locations (nodes/links) where combined sewer overflows occur. This is done by selecting the nodes/links from the center-left panel and dragging them onto the center-right panel (Screen-Shot 21). The selected nodes/links will be displayed on the tree structure in the center-right panel. Selections in the right panel may be removed by right clicking on the selected element and clicking *Remove* from the pop-up menu. The nodes/links in the left panel are read from the SWMM template file connected to the project. For the uncertainty simulations, the template file should be configured with the best-fit calibration parameters developed in the calibration phase.



Screen-Shot 21 – Screen for Selecting Nodes/Links Where Sewer Overflows are Located

Precip Scaling Factors (Single Basin)

The *Precip Scaling Factors (Single Basin)* component has two functions. First, it is used for specifying the statistical characteristics of the four sources of uncertainty. Second, it is used to execute the routines for computing the precipitation scaling factors to be used in the long-term simulations.

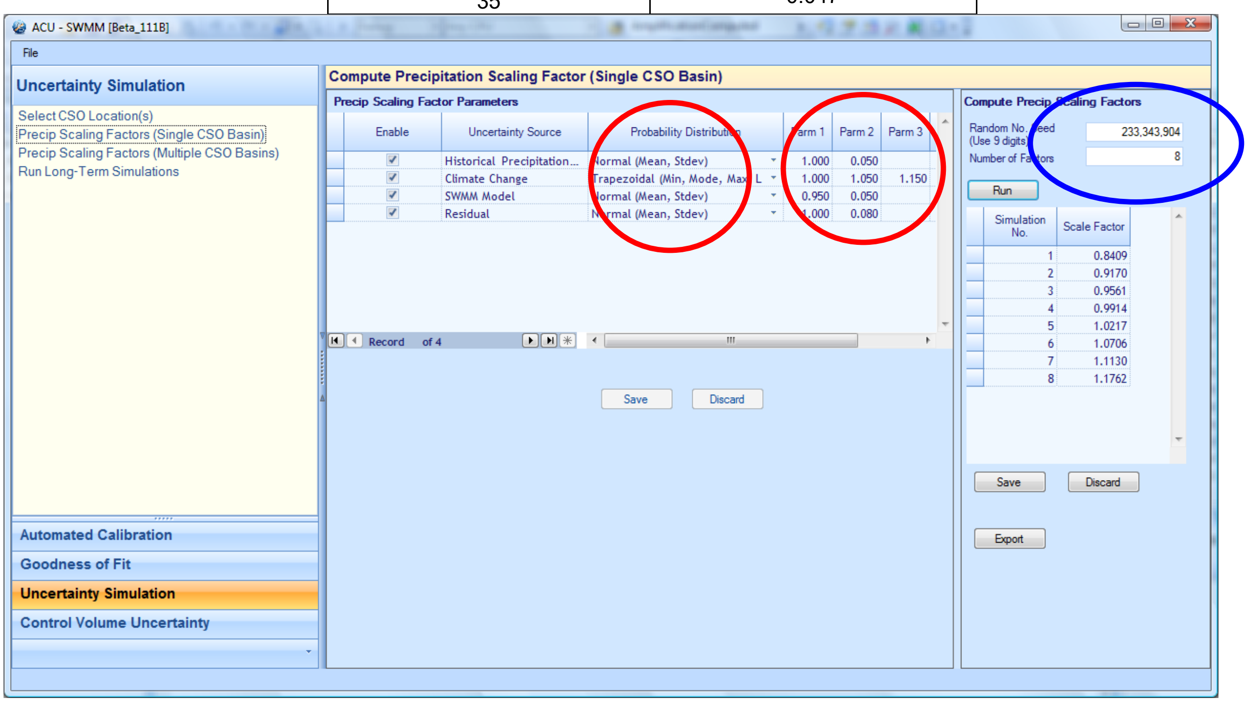
<u>Setting Statistical Characteristics of the Four Sources of Uncertainty</u>

The first step is to identify which of the four sources of uncertainty are to be included in the uncertainty analysis. This is done by checking the check-box to the left of the source of uncertainty in the *Enable* column in the upper left-corner of the upper panel (Screen-Shot 22). The statistical characteristics for the chosen sources of uncertainty are set by selecting a probability distribution from the drop-down menus in the upper panel. The distribution parameters are then set based on the probability distribution that was chosen. The required distribution parameters are listed on the data entry screen. Clicking the *Save* button saves the selected distributions and parameters associated with each source of uncertainty. Clicking the *Discard* button clears any changes to the selected parameters.

The standard deviation for the Historical Precipitation Representativeness uncertainty is a function of long-term precipitation record length. Table 1a lists appropriate values of the standard deviation for precipitation in the Seattle area. The default parameter values for describing the uncertainty characteristics for climate change are listed in Table 1b.

Table 1a – Standard Deviation for Representativeness of Future Precipitation

Precipitation Time-Series Record Length (Years)	Standard Deviation for Precipitation Scaling Factor
20	0.063
25	0.056
30	0.051
35	0.047



Screen-Shot 22 – Screen for Computing Precipitation Scaling Factors for Sources of Analysis Uncertainty for a Single CSO Basin

Table 1b – Probability Distribution Parameter Values for Uncertainties Due to Climate Change

Precipitation Scaling Factor Values			Likelihood Values		
Minimum	Mode	Maximum	Precipitation Scaling Minimum	Precipitation Scaling Mode	Precipitation Scaling Maximum
1.00	1.05	1.15	0.50	1.00	0.00

<u>Computing Precipitation Scaling Factors for Uncertainty Analysis</u>
The next step is to provide a 9-digit integer in the *Random Number Seed* field in the upper right corner of the right panel. This is used to seed the random number generator. If this number is not changed, the program will produce the same precipitation scaling factors.

Next, enter the desired sample-size of precipitation scaling factors in the *Number of Factors* field. An odd number is recommended and equals the number of long-term simulations to be performed. Click the *Run* button in the upper right-corner to execute the precipitation scaling factor routine and display the results in the table in the panel on the right. Click the save button to save the computed scaling factors to the database file. The scale factors can be edited if the user has a particular scaling factor they wish to run.

Clicking the *Export* button saves the precipitation scale factors to a CSV file. The export feature is useful for tracking the scaling factors used at each CSO basin. The saved precipitation factors can be loaded into an Excel Workbook for this purpose.

Precip Scaling Factors (Multiple Basins)

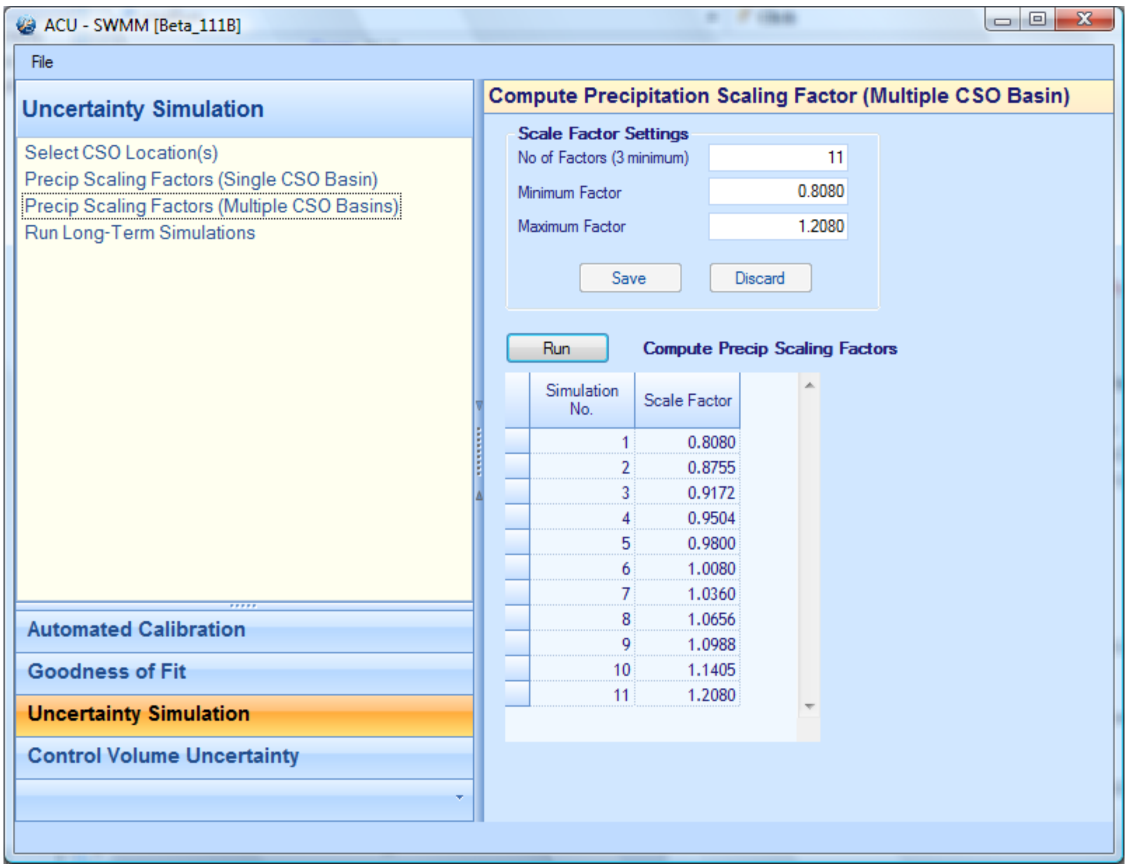
The *Precip Scaling Factors (Multiple Basins)* component is used to compute precipitation scaling factors for a CSO project where there are multiple CSO basins and each basin has a different set of precipitation scaling factors. In this case, the minimum and maximum precipitation scaling factor is determined from the group of basins (computed above) and entered in the *Scale Factor Settings* fields (Screen-Shot 23).

Click the *Run* button to execute the routine for generating the precipitation scaling factors from a Normal Distribution for the specified number of factors and display the results in the table.

<u>*Example*</u>: a watershed with two CSO overflows has precipitation scaling factors computed using the *Precip Scaling Factors (Single Basin)* component shown in Table 2. The overall minimum and maximum precipitation scaling factors are 0.808 and 1.208, respectively. These would be the minimum and maximum values entered in the *Minimum and Maximum Factor* fields.

Table 2 – Example Precipitation Scale Factors Computed for a Watershed with Two CSO's These Values were Computed using the *Precip Scaling Factors (Single Basin)* component

Scaling Factor Number	CSO Basin 1 Precipitation Scaling Factors	CSO Basin 2 Precipitation Scaling Factors
1	**0.808**	0.812
2	0.885	0.882
3	0.926	0.928
4	0.953	0.953
5	0.976	0.979
6	1.010	1.004
7	1.038	1.039
8	1.066	1.068
9	1.099	1.094
10	1.138	1.135
11	1.199	**1.208**



Screen-Shot 23 – Screen for Computing Precipitation Scaling Factors for Sources of Analysis Uncertainty for Project with Multiple CSO Basins

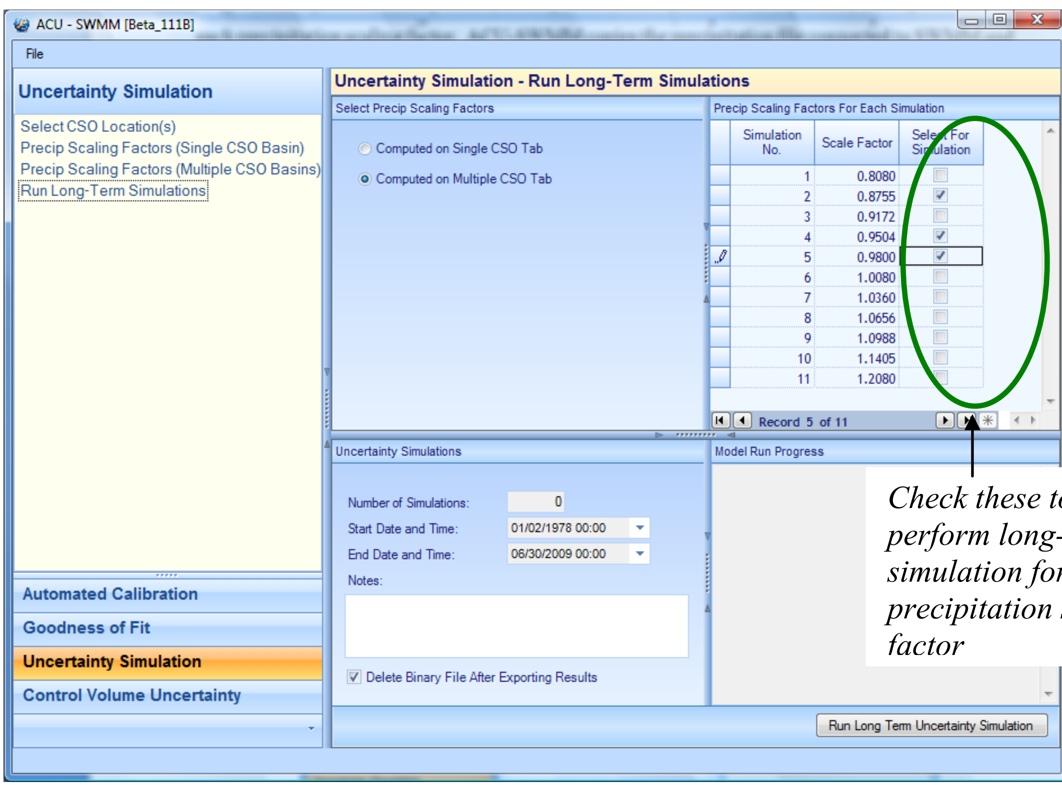
Run Long-Term Simulations

The *Run Simulations* component is used for executing the long-term simulations for the SWMM basin model. The SWMM model should be configured with the long-term precipitation stored in an external file. When the long-term simulations are executed, a separate simulation is performed for each precipitation scaling factor. ACU-SWMM copies the precipitation file connected to SWMM and scales it by the precipitation scaling factor. The SWMM model is then executed by ACU-SWMM, and the overflow discharge at each CSO location is saved to a separate CSV file following the simulation.

Conducting Long-Term Simulations

A long-term simulation is conducted by first selecting the precipitation scale factors to use for the simulation by clicking the option button in the upper center panel. The precipitation scaling factors computed from either the *Single CSO Basin* component or the *Multiple CSO Basin* component will be displayed in the table at the upper right depending on the option selected and will be used to scale the precipitation for the long-term simulations.

Next, select which scale factors to use in the simulation(s) by checking the box next to the precipitation scale factor in the table. This feature is useful for distributing the simulations across multiple ACU-SWMM sessions on a single computer or multiple computers. In Screen Shot 24, three long-term simulations will be performed with precipitation scaling factors of 0.8755, 0.9504, and 0.9800 used.



Screen-Shot 24 – Screen for Selecting Precipitation Scale Factors and Executing Long Term Simulations

The start and end dates for the simulation shown in the lower left window are defined by changing the start and end dates in the SWMM file. This defines the start-0end dates for output of the overflow hydrographs. The actual start date for the simulations may begin earlier to allow spin-up for the soil moisture and groundwater components.

The *Notes* field is for user-defined information regarding the simulations. The *Delete Binary File After Exporting Results* box causes ACU-SWMM to delete the SWMM binary file after exporting the results. It is recommended that this box be checked to reduce the amount of disk space usage. To run the long-term simulations for each precipitation factor that is checked, click the *Run Long Term Uncertainty Simulation* button.

Before performing a long-term simulation, it is recommended that a short test simulation be performed to ensure that the model files are correctly configured and that the CSO elements are correctly specified in ACU-SWMM. Set the start and end dates in the SWMM file for a one-year simulation. Run the long term uncertainty simulation in ACU-SWMM from the *Run Long-Term Simulations* component with one of the precipitation scaling factors checked. After the simulation has completed, open the CSV file containing the exported overflow data for each CSO for the 1 year simulated. The data will be stored in a folder called *LongTermSimulations* in the project folder. Check that there are overflows occurring during storms where overflows are known to have occurred in the past.

An overflow discharge threshold is required to alert ACU-SWMM to compute an overflow volume. Review the simulated overflow hydrographs to determine the minimum non-zero value indicating that an overflow is on-going. This information will be input in the next module.

The CSV export file format has the following parts:

D056-126_D056-313_1.1000.csv

Where: D056-126_D056-313 is the SWMM model element name and
1.1000 is the precipitation scaling factor for the run.

Similarly, the scaled precipitation data for each simulation are stored in files with the following naming convention:

RG181_2_1978to7_1_2009_1_1000.dat

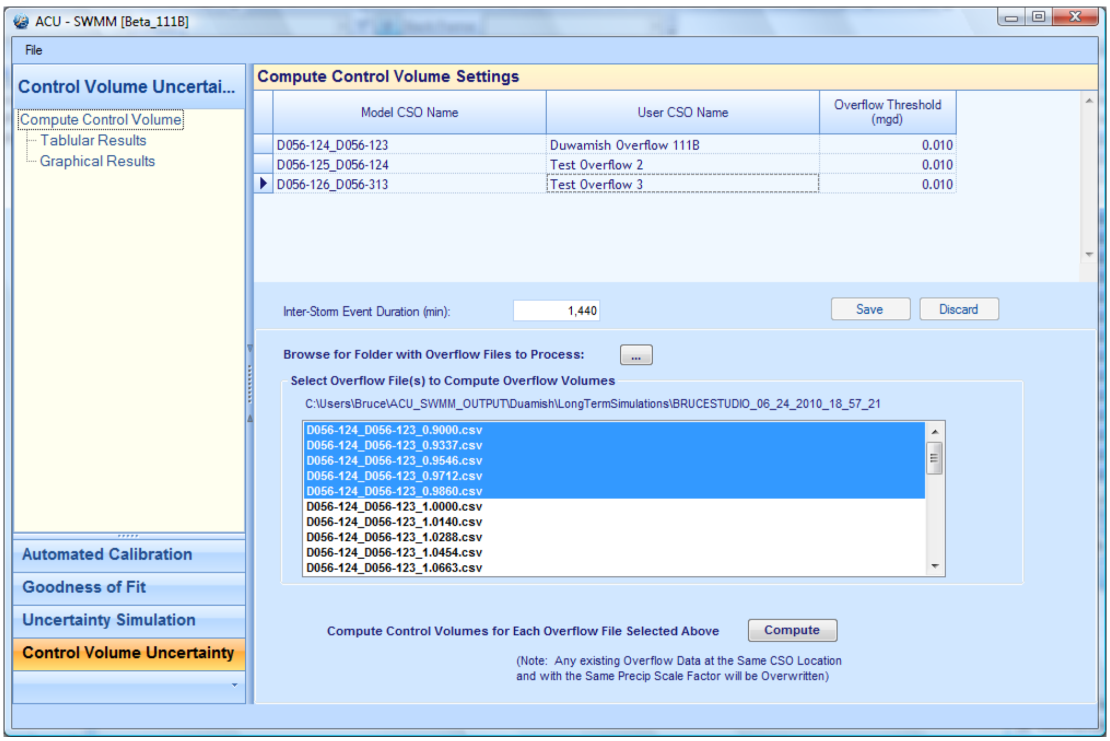
Where: RG181_2_1978to7_1_2009 is the file name of precipitation file connected to the SWMM template file and
1_1000 is the precipitation scaling factor for the run. Note that the decimal was replaced by "_", which was required so that the SWMM model could open the file.

MODULE 4 - CONTROL VOLUME UNCERTAINTY

The *Control Volume Uncertainty* module has three components. These components are used to compute overflow volumes from the long-term simulations and to compute the CSO Control Volume. The Control Volume is defined as the average overflow volume for the once-per-year frequency of occurrence. They are also used to display the results in both a tabular and graphical format.

Compute Control Volume

The model elements (links or nodes) defined on the *Select CSO Locations* component of the *Uncertainty Simulation Module* are listed in the table at the top along with a user-specified name for the CSO (Screen-Shot 25). The *Overflow Threshold* is the minimum discharge through the overflow structure that will be considered as an overflow event. The reason this value may not be zero is because the SWMM model will often times show a very small discharge rate through the overflow structure during times of non-overflow due to numerical rounding in the routing routine. Setting the threshold to a value greater than zero eliminates these non-overflow events from consideration by ACU-SWMM. The *Inter-Storm Event Duration* defines the amount of time that must elapse after the flow drops below the overflow threshold before the next overflow is considered a separate event. Twenty-four hours (1440-minutes) is the default value based on Department of Ecology criteria.



Screen-Shot 25 – Screen for Computing the Duration and Volume of Overflows and the Control Volume for each Long-Term Simulation

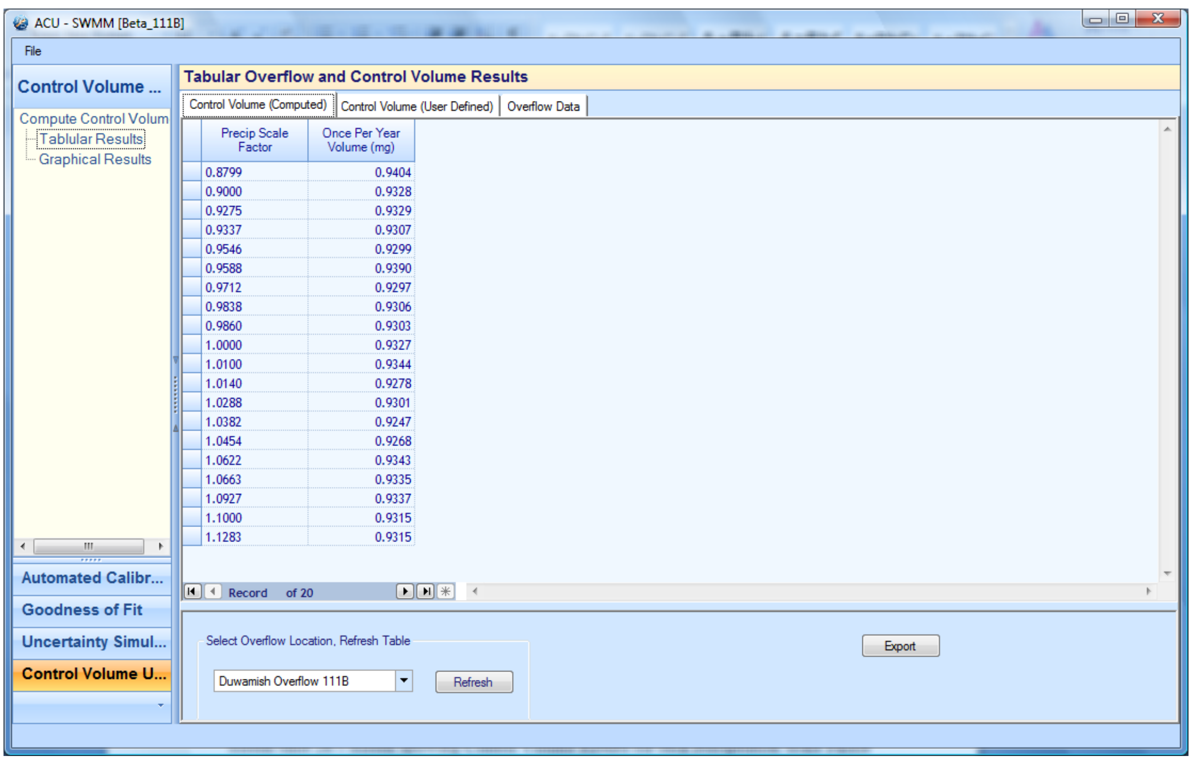
ACU-SWMM reads each CSV file containing the simulated overflows exported during the long-term simulations and computes the volume and duration of each overflow event. The collection of overflows are ranked from largest to smallest and the once-per-year control volume for the given long-term simulation is computed as the N-largest overflow volume in N-years. If there are fewer than N-overflows in N-years, then the control volume for that long-term simulation is set to zero.

If the long-term simulations were performed on separate computers, copy the output CSV files to a central computer before computing the control volumes. Click the *Browse* Button and select the folder that contains the overflow files from the long-term simulation(s). Select the files to process in the *Select Overflow Files* window. Click the *Compute* button to scan each overflow file, compute the volume and duration of each overflow event, and the control volume for each simulation.

Tabular Results

Control Volume (Computed)

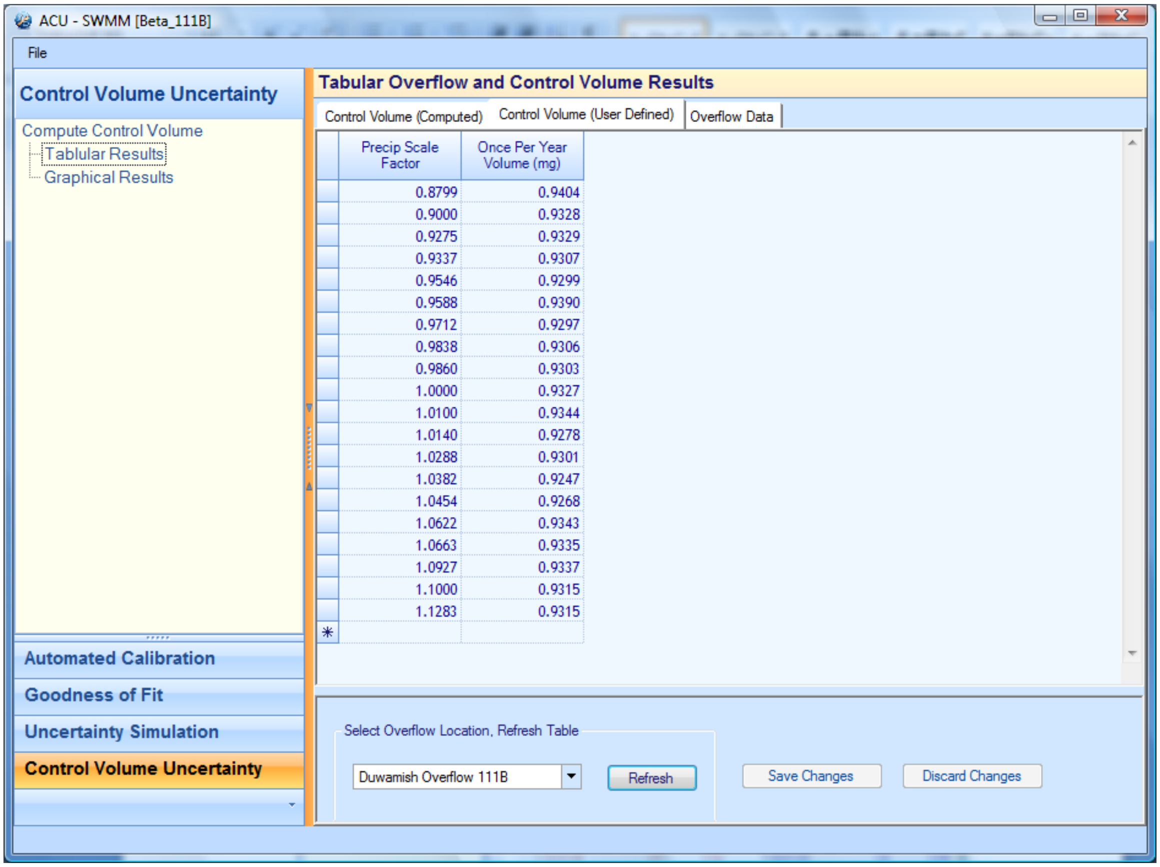
The *Control Volume (Computed)* tab of the *Tabular Results* component displays the precipitation scaling factor and control volume results for each long term simulation. If more than one overflow structure is present in the SWMM project, results from other overflow structures may be viewed by selecting the desired CSO from the list box at the bottom of the screen and then clicking the *Refresh* button. The *Export* button saves the control volume results to a CSV file. The data in the table may also be copied by selecting rows of interest and then right clicking to display the *Copy* pop-up menu.



Screen-Shot 26 – Screen Showing Control Volume Results for each Precipitation Scale Factor

Control Volume (User Defined)

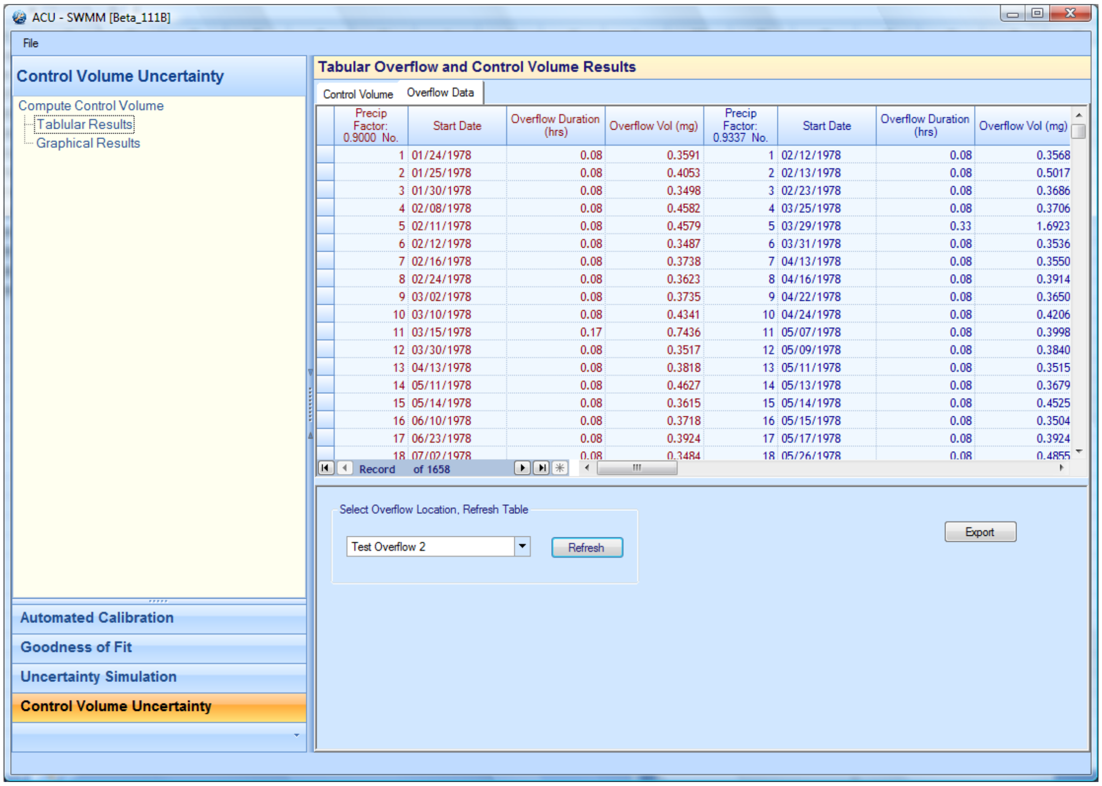
The *Control Volume (User Defined)* tab of the *Tabular Results* component allows the user to manually input the precipitation scaling factor and control volume. This feature is useful for basins with multiple overflow structures where the once per year volume is determined using regression/interpolation functions external to ACU-SWMM. The precipitation scaling factor and once-per year volume can be entered on this tab and then the control volume uncertainty statistics displayed on the *Graphical Results* screen.



Screen-Shot 27 – Screen Showing Screen for Manually Entering Control Volume Results for each Precipitation Scale Factor

Overflow Data

The *Overflow Data* tab of the *Tabular Results* component displays the overflow volume and duration for each overflow event and each precipitation scaling factor. If more than one overflow structure is present in the SWMM project, results from other overflow structures may be viewed by selecting the desired CSO from the list box at the bottom of the screen and then clicking the *Refresh* button. The *Export* button saves the overflow results to a CSV file. The data in the table may also be copied by selecting rows of interest and then right clicking to display the *Copy* pop-up menu.

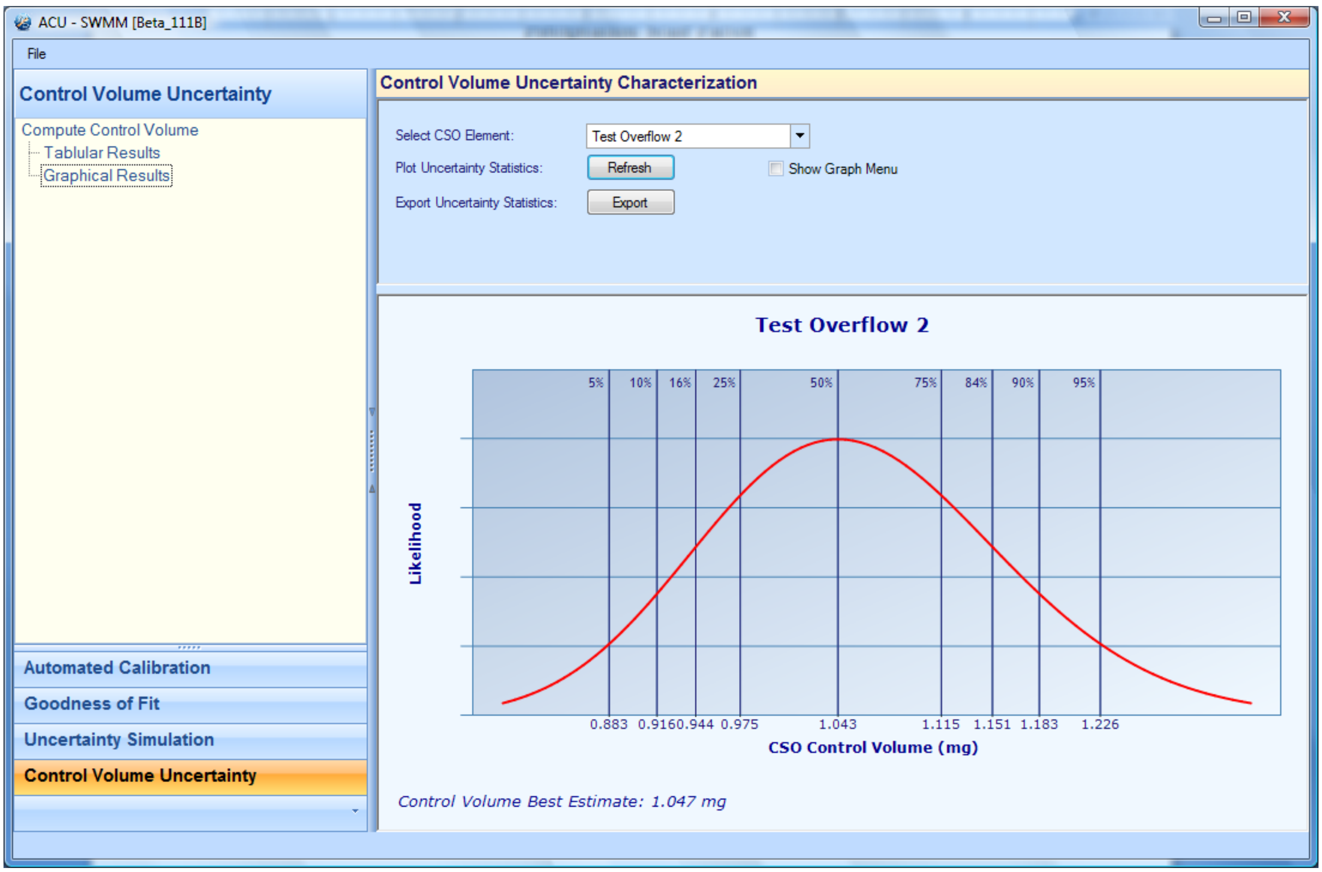


Screen-Shot 28 – Screen Showing Simulated Overflow Data for each Overflow Event and Each Precipitation Scale Factor

Graphical Results

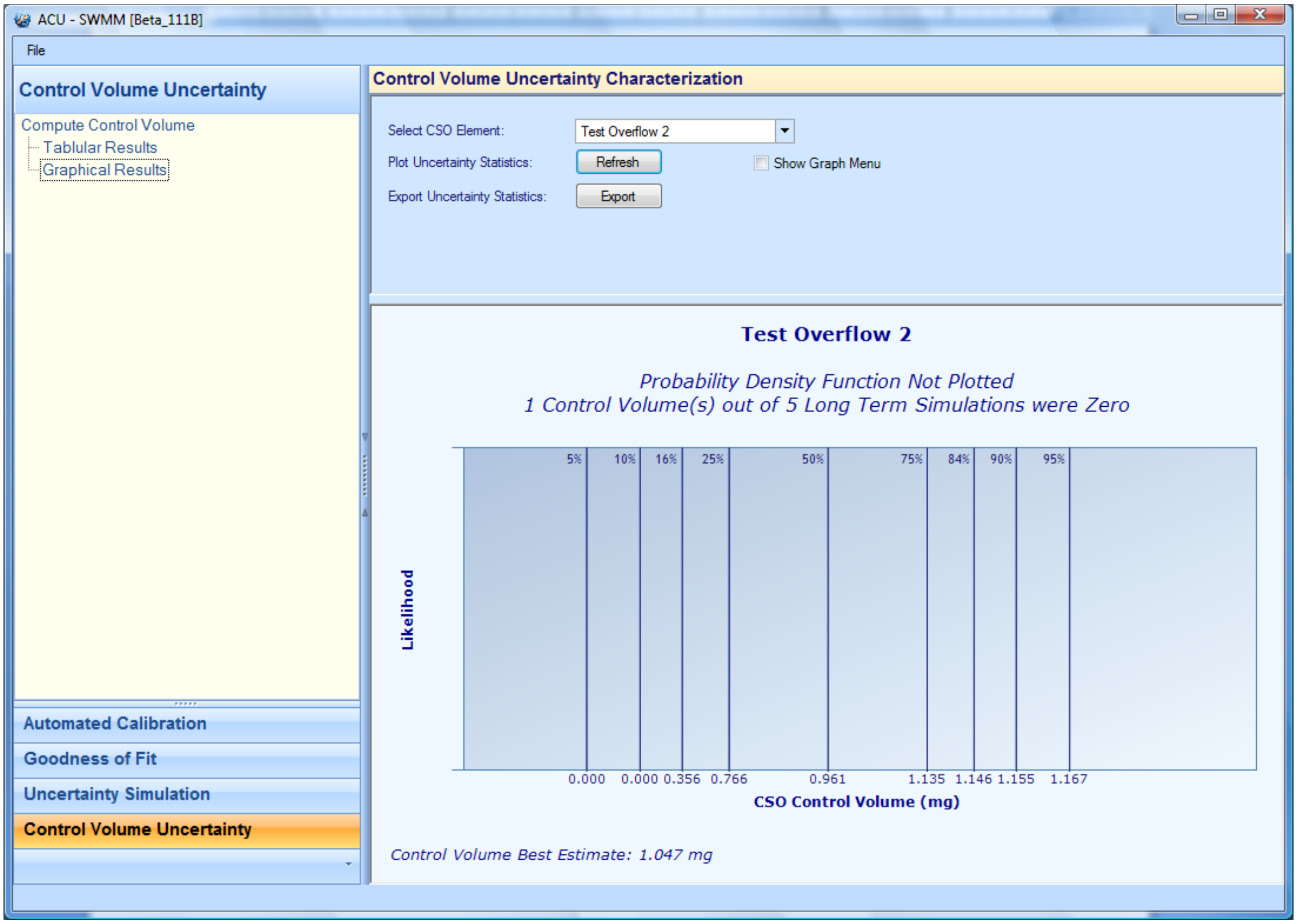
Control volume uncertainty statistics are displayed on the *Graphical Results* component (Screen-Shot 29). The line on the graph represents the probability density function of the Gamma Distribution[3] fit to the computed control volumes for the selected overflow structure. The figure shows the relationship between control volume and non-exceedance probability and can be used to determine the likelihood that a particular control volume would be equaled or exceeded. For example in Screen-Shot 29, there is a 90% chance that the control volume will be less than or equal to 1.183 million gallons (10% chance of being exceeded). The "best estimate" control volume is also displayed at the bottom of the figure and represents the mean of all of the control volume values, in this case 1.047 million gallons. Tabular values of control volume non-exceedance probability values can be exported to a CSV file by clicking the *Export* button.

Definition - The best-estimate control volume is a statistical term that simply equates to the average of the estimated control volumes from the collection of long-term simulations. Each long-term simulation produces a plausible future that considers the four sources of uncertainties described earlier.



Screen-Shot 29 – Screen Showing Control Volume Uncertainty Characterization

If some of the long-term simulations result in less than N-overflows in N-years, the once-per-year control volume will be zero for that specific long-term simulation. If the control volume for one or more of the long-term simulations is zero, then the program does not fit a probability distribution to the simulated data, but uses a non-parametric plotting position approach[3] instead. For these situations, the probability density function is not plotted, but the statistics are still shown on the graph (Screen-Shot 30).



Screen-Shot 30 – Screen Shot Showing the Control Volume Uncertainty Characterization Where one or more Control Volumes were Zero

REFERENCES

1. Beven KJ and Binley A, The Future of Distributed Models: Model Calibration and Uncertainty Prediction, Hydrological Processes, Volume 6, pp272-298, 1992.
2. CSO Technical Guidance Manual Chapters 5 and 6, prepared for Seattle Public Utilities by MGS Engineering Consultants Inc, March 2010.
3. Hirsch RM, Helsel DR, Cohn TA and Gilroy EJ, Statistical Analysis of Hydrologic Data, Chapter 17, *Handbook of Hydrology*, McGraw Hill, 1992.