METROPOLITAN
SEWER DISTRICT
OF GREATER CINCINNATI

MSDGC MODELING GUIDELINES

Revision 5.1 – Final

Prepared by: MSDGC Compliance Services
November 2O23
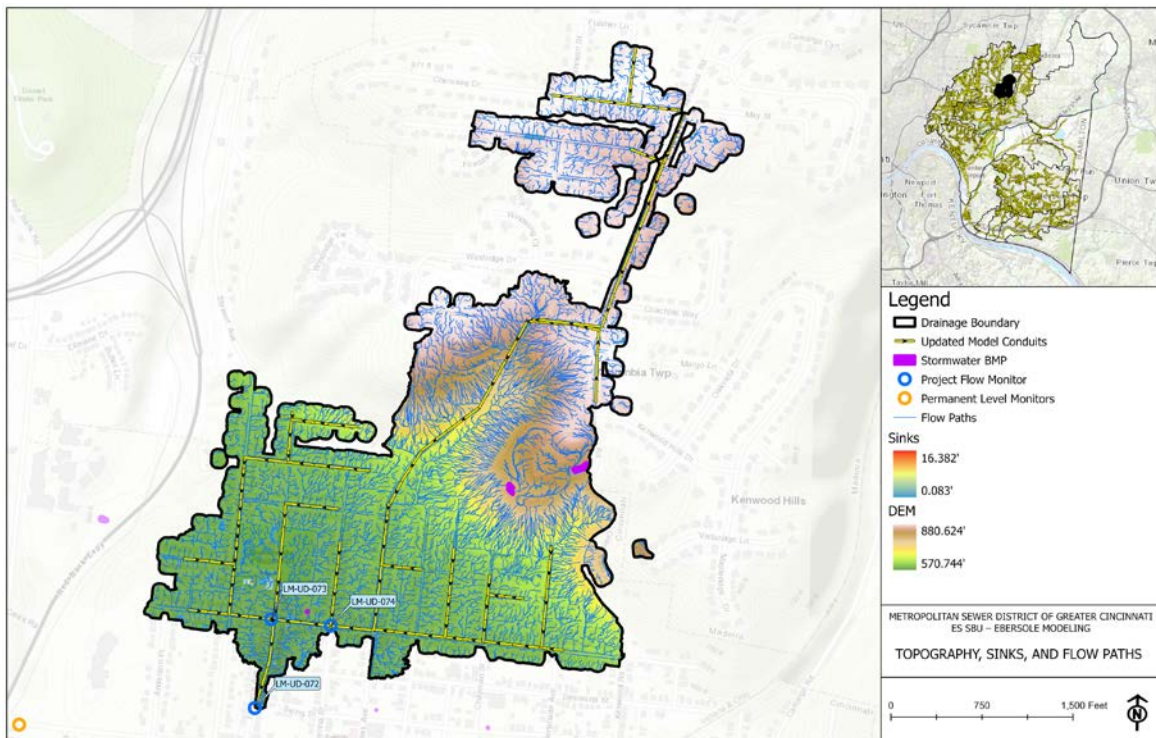
Record of Revisions

Revision No.	Date	Description of Revision
0	July 2011	Initial release
1	April 2012	Included responses to reviewer's comments
2	June 2012	Included validation and calibration templates
3	February 2013	Minor updates to figures and tables
4.7.3	September 2021	Update (Includes new calibration metric)
5.0	June 2023	Update (Includes Depth Metric, Meter Type, FlowFinity Submittals)
5.1	September 2023	Added Change Log, minor comment on maximum Manning's n

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Departmental Approval: _____

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MSD Wastewater Engineering

CHANGE LOG OF KEY UPDATES

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
All	Minor	References to Flowfinity	**Added** references to Flowfinity. All model management (acquiring a model, model steps submittals, and final model submittal) is now routed through Flowfinity.
Volume I Section 4.1 Volume II Section 2.2	Minor	Project Notes	**Changed** maintaining records of changes was expanded/updated to require "Project Notes" to be submitted within Flowfinity.
Volume I Section 4.2.2	Minor	Design Storm Setup	**Added** additional text and Figure 4-1 to explain the design storm setup. Text was also added to explain the design 15-minute timestep is required to maintain consistency with the development approach of the WWIP.
Volume I Section 4.3.1	Medium	Subcatchment Nomenclature	**Updated** the subcatchment nomenclature which applies to all new or split subcatchments.
Volume I Section 4.3.2 Volume I Section 4.4.1	Major	MSD Delineation Process	**Updated** the description of the delineation process. MSDGC will now provide the subcatchment and sewershed delineations for each calibration effort;
Volume I Section 4.3.3	Medium	Runoff Parameter Table	**Updated** the table of typical values and ranges for hydrology runoff parameters.
Volume I Section 4.4.1	Major	Redefinition of Sanitary Basins	**Updated** the process for sewershed delineation. R-value guidance was updated accordingly.
Volume I Section 4.4.1	Major	RTK standards	**Updated** RTK standards for T: - Short-term T typical range was updated to 0.083-2. - For combined sewer areas, the T value is required to be 0.25 hours to prevent a double peak. - Recommended ranges for Dmax and Drec were added.
Volume I Section 4.4.2	Minor	Aquifer Module	**Updated** the Aquifer Module discussion.
Volume I Section 4.4.2	Medium	RTK as Groundwater	**Added** instructions on adding Groundwater Unit Hydrograph based on the Delineation approach.
Volume I Section 4.5	Minor	Unused SWMM Features	**Added** section to detail the features in SWMM that are prohibited from use in MSDGC models.
Volume I Section 4.6.1	Minor	Blind Manholes	**Updated** the Nomenclature for blind manholes was to be a "BL" suffix.
Volume I Section 4.7.5	Minor	Detention Pond Sizes	**Updated** guidance on detention pond inclusion based on the size of the tributary area.

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
Volume I Section 4.8	Major	New Development Modeling	**Added** guidelines for modeling new developments.
Volume I Section 4.9	Medium	Submodels for Calibration	**Added** the requirement that if submodels are used during calibration, the submodels must be loaded back into the model (full project area or SWM) as it was provided by MSDGC to determine the final calibration, impacts, and results. All submittal items (models and all items generated from them, such as statistics and figures) must come from the full model as provided by MSDGC.
Volume I Section 4.10.2	Medium	Splitting Existing Subcatchments	**Added** the procedure for splitting a subcatchment into two subcatchments before "separation" is applied, to model sewer separation for only part of the original subcatchment.
Volume I Appendix B	Minor	Removed Pipe Shapes	**Removed** the Pipe Shapes of Appendix B.
Volume II Section 1.2 Volume II Section 1.4	Major	Flow Charts and Model Process Overview	**Updated** the Flow Charts and Model Process Overview Section based on the current MSD processes, including Flowfinity processes.
Volume II Section 1.3	Medium	Flow chart model names	**Updated** flow chart model names for several model types. More definitions were added.
Volume II Section 1.4			**Added** instructions on the "Archiving" of models.
Volume II Section 2.0	Medium	"Other" Model Definition	**Added** the statement that any models that do not apply to any of the listed model types will be considered "Other" when submitted to the *Model Archive* app of Flowfinity.
Volume II Section 2.0	Medium	Model Check-Out	**Updated** the model check-out and check-in procedures.
Volume II Section 3.10.2	Medium	Hydrology Mass Balance	**Added** a section detailing the requirements for hydrology mass balance when more than one hydrology method is utilized in the same area (i.e. Runoff + RTK unit hydrograph).
Volume II Section 4.3.1	Minor	Monitor Types	**Added** section defining the different monitor types: Calibration, Apportioning, Hydraulic, Regulatory Reported Overflow, and Non-Calibration.
Volume II Section 4.3.2	Minor	Data Review	**Added** detailed data review information to this section; this information was removed from the Appendix
Volume II Section 4.3.2	Minor	Data Review Rainfall vs Runoff	**Updated** the text to recommend that the 15- or 30-minute peaks be compared rather than the 5-min peak.

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
Volume II Section 4.3.2	Minor	Flow Balance Check	**Added** a flow balance check between monitors to the data review steps.
Volume II Section 4.3.3	Minor	Removed Short-Term Monitor Section	**Removed** the previous section 4.3.3 "Use of Short-Term Monitoring for Distribution of Upstream Parameters". Such monitors are now referred to as "Apportioning monitors" and are referenced in other parts of the Guidelines.
Section 6.0	Minor	Approach Clarification	**Updated** text to clarify that Concordance Correlation Coefficient is used, not WaPUG standards; and a statement about depth calibration was added.
Volume II Section 6.2.1	Medium	Event Definitions	**Updated** event definitions to simplify and create more consistent definitions.
Volume II Section 6.2.2	Medium	Event Selection	**Updated** event selection guidance to simplify and provide more consistent selections.
Volume II Section 6.2.4	Minor	Phase Definition	**Added** a section to describe the various phases of each event to be used to assist in the calibration evaluation.
Volume II Section 6.2.5	Minor	Event File Format	**Added** a section to describe the required event file format.
Volume II Section 6.3 Volume II Section 6.3.1 Volume II Section 6.3.3	Major	Base Flow	**Updated** the base flow calibration approach to adhere to the current approach utilized by MSDGC. Added a detailed list of which model parameters were allowed to be used in the representation of the base flow. Text was updated to clarify the three acceptable approaches for representing the base flow during calibration.
Volume II Section 6.3.2	Major	Base Flow Compliance	**Added** information about utilizing the Model Application Tools toolbox to evaluate the base flow calibration.
Volume II Section 6.5 Volume II Section 6.5.1-4	Major	Calibration Approach for Different Monitor Types	**Added** guidance on the calibration approaches for each of the defined monitor types.
Volume II Section 6.5.5	Minor	Inflow vs. Underflow Monitors	**Added** guidance to the calibration approach when monitors are located on the inflow and underflow of a CSO. If a flow imbalance is present between the two monitors, the Base Flow (BF) and long-term RTK response should be calibrated to the monitor on the underflow.

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
Volume II Section 6.6	Major	Hydrology Parameter Distribution	**Updated** this section to provide further guidance on the parameter distribution between monitoring areas. Four common situations are described in detail: project areas with multiple monitors, apportioning monitors, project areas with historical monitors, and project areas where the downstream monitor does not cover the entire area.
Volume II Section 6.7	Medium	Seasonal Variation Normal Trend	**Updated** the normal seasonal trends to define RTK unit hydrograph parameters for both the growing/non-growing and 4 season approaches.
Volume II Section 6.7	Medium	Seasonal Definitions	**Updated** April to be grouped with the non-growing season for the seasonal definition of growing/non-growing.
Volume II Section 6.7	Medium	Seasonally Varied Parameters	**Added** a note to seasonally varied R values "R1 typically varies less than R2 or R3 …"
Volume II Section 7.0	Major	Calibration Compliance for Each Monitor Type	**Updated** to discuss the compliance requirements for the different meter types. The previous guidance applied primarily to the Calibration (erstwhile hydrology) monitors, which is mostly unchanged.
Volume II Section 7.1.1	Minor	Storm Hydrograph Shape	**Added** In some cases, MSDGC may require adjustments to the model to better represent the observed data for specific storms that are larger or considered more significant, even if the metrics are reduced slightly in the process.
Volume II Section 7.1.4	Minor	Peak Fit for Largest Observed Storms (Con15)	**Added** a section to explain the calculation process and importance of the Con 15% metric.
Volume II Section 7.1.6	Major	Depth Calibration Compliance	**Added** guidance on the draft depth calibration approach. The depth calibration is assessed by the MSDGC Calibration Application Tool based on the velocity versus depth scattergraph.
Volume II Section 7.1.7	Major	Baseflow Compliance	**Added** a section on base flow compliance. The modeled base flow should match the average of the base flow for a given month (if using monthly variation) or the year (if using a fixed rate). Monthly patterns should follow a normal seasonal trend.

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
Volume II Section 7.1.8	Minor	RTK and Initial Abstraction Seasonal Trends	**Updated** the requirement to provide graphs based on a set of model runs to evaluate the RTK unit hydrographs to be simpler. The MSDGC Calibration Application Tool – RTK Shape Analysis creates a series of graphs to review the RTK unit hydrographs shapes and parameter seasonal trends. Those graphs should be reviewed and submitted to the 6 – Calibration app in FlowFinity, no model runs are required.
Volume II Section 7.2	Major	Apportioning Monitors Compliance Requirements	**Added** Section 7.2 to detail the compliance requirements for Apportioning Monitors.
Volume II Section 7.3	Major	Hydraulics Monitor Compliance Requirements	**Added** Section 7.3 to detail the compliance requirements for Hydraulic Monitors. For Hydraulic Monitors, calibration compliance does not need to adhere to set numerical requirements; rather the calibration uses the monitor data to establish key hydraulic parameters.
Volume II Section 7.4	Major	Regulatory Reported Overflow Monitors	**Added** Section 7.4 to provide details on how to assess and document the calibration of an overflow, CSO, SSO, NEO, and PSO, based on level sensor data and regulatory reporting.
Volume II Section 7.5	Major	Non-Calibration Monitor Compliance Requirements	**Updated** section to detail that for project monitors to be deemed "non-calibration", it must be approved as such by MSDGC. The model and observed data shall be submitted and any useful results of the monitor shall be listed and demonstrated.
Volume II Section 10.3	Minor	Baseline Conditions Evaluation	**Added** some guidance for the different types of system evaluations: CSO, SSO, and Capacity.
Volume II Section 10.3.3	Major	Capacity Evaluation	**Added** requirements for a capacity evaluation. The evaluation requires 100-foot surcharge depth added at each modeled manhole. The evaluation is based on sewer surcharge as well as sewer capacity (max/full value).
Volume II Section 11.4 Volume II Section 11.5	Major	Alternative Model Submittals	**Added** guidance for which models are to be submitted to MSDGC and the requirement that a detailed list of changes be provided.

Location	Significance	Title	Description
Changes from Version 4.7.3 to Version 5.0			
Volume II Section 11.5	Major	Alternative Model Review	**Added** three points of emphasis for alternative modeling reviews: the list of changes was provided, the changes are as listed and related to the Alternative, and there are no errors in the modeling.
Volume II Section 11.5	Medium	Handling Multiple Alternative Submittals as Record Models	**Added** details on handling multiple alternative submittals as record models for complex systems.
Volume II Appendices	Major	Removal of Forms	**Removed** Appendices A-I. FlowFinity submittals have replaced the forms.
Volume II Appendix A1	Minor	Calibration Report Template	**Updated** the Calibration Report Template to simplify the report. Items documented in Flowfinity were removed from the report.

Location	Significance	Title	Description
Changes from Version 5.0 to Version 5.1			
Intro	Medium	Change Log	**Added** Change Logs for Version 4.7.3 to 5.0 and from Version 5.0 to 5.1
Volume II Table 3.1	Minor	Clarification of allowable Manning's n	**Updated** maximum value

MSDGC Modeling Guidance

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LIST OF ACRONYMS AND TERMS

ALT	Alternative Model
AMC	Antecedent Moisture Conditions
BF	Base flow
BSL	Baseline Model
CAGIS	Cincinnati Area Geographic Information System
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamics
CFS	Cubic Feet Per Second
CIP	Capital Improvement Project
CSO	Combined Sewer Overflow – Flow from combined sewer in excess of interceptor capacity that is discharged to an open channel or stream
D-PC	Proposed Conditions Detailed Model
D-SVC	Storm Volume Calibration New Detailed Model
DCIA	Directly Connected Impervious Area
DUC	Dynamic Underflow Control – System of sensors and gates to automatically maximize flow to the interceptor and minimize overflows
DWF	Dry Weather Flow – Low flow of sanitary discharge and base groundwater infiltration without stormwater or rainfall derived inflow and infiltration
EC-Q_n	Existing Conditions Original Standard Model
EC-Q_{n+1}	Existing Conditions New Standard Model
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ESRI	Environmental Research Systems Institute
FII	Flow Instability Index
FTP	File Transfer Protocol
GARR	Gauge Adjusted Radar Rainfall
GIS	Geographic Information System (includes generic mapping and CAGIS)
HGL	Hydraulic Grade Line
HRT	High Rate Treatment – Primary sewage treatment system for treating wet weather flows before discharge to receiving stream
LID	Low Impact Development – Structures and techniques for reducing water quantity and water quality impacts of development compared to standard construction
MBF	Modeled Base Flow
MBF-A	Modeled Base Flow - Average
MBF-HP	Modeled Base Flow - Hourly Pattern

MBF-MP	Modeled Base Flow - Monthly Pattern
MBF-WP	Modeled Base Flow - Weekday/Weekend Pattern
MDWF	Modeled Dry Weather Flow
MDWF-DP	Modeled Dry Weather Flow – Daily Pattern
MGIF	Modeled Groundwater Infiltration Flow
MGIF-MP	Modeled Groundwater Infiltration Flow – Monthly Pattern
ML	Modeled Level
MSDGC	Metropolitan Sewer District of Greater Cincinnati
MSF	Modeled Storm Flow
MTF	Modeled Total Flow
MTF-MP	Modeled Total Flow Monthly Pattern
MV	Modeled Velocity
OBF	Observed Base Flow
OBF-A	Average Observed Base Flow
OBF-DP	Observed Base Flow Diurnal Pattern
OBF-MP	Observed Base Flow Monthly Pattern
ODOT	Ohio Department of Transportation
ODWF	Observed Dry Weather Flow
ODWF-A	Observed Dry Weather Flow - Average
ODWF-MP	Observed Dry Weather Flow – Monthly Pattern
OL	Observed Level
OSF	Observed Storm Flow
OTF	Observed Total Flow
OV	Observed Velocity
PCS	Proposed Conditions Standard Model
PID	Proportional Integral Derivative
PM	Project Manager
PSO	Pump Station Overflow
QA/QC	Quality Assurance/Quality Control
RDII	Rainfall Derived Inflow and Infiltration – Rainwater directly or indirectly flowing into a sewer
REU	Residential Equivalent Units
ROW	Right of Way
ROV	Remaining Overflow Volume

RTC	Real Time Control – System of gates, moveable dams, and sensors that automatically operates to maximize storage in combined sewers, maximize volume of flow to interceptor, and minimize overflows
RTK	RDII modeling method using R as fraction of rain entering sewer, T as time to peak inflow, and K as duration of recession limb relative to time to peak
SA	Storm Volume Analysis Model
SBU	Sewer Backup
SCADA	Supervisory Control and Data Acquisition
SF	Storm Flow
SMDA	Sabre Mass Data Appraisal
SML	Site Maintenance Log
SOP	Standard Operating Procedures
SSO	Sanitary Sewer Overflow – Flow from sanitary sewer in excess of underflow capacity that is discharged to an open channel or stream
SSOAP	Sanitary Sewer Overflow Analysis and Planning
SVC	Storm Volume Calibration Model
SWM	System Wide Model – Model input file of basin sewer system
SWMM	Storm Water Management Model – US EPA's hydrology and hydraulic modeling software.
TF	Total Flow
TM	Technical Memorandum
TSF	Time Series File
TY	Typical Year
USGS	United States Geological Survey
WIB	Water-in-Basement
WS_MIXED	Final edited GARR rainfall with final calibrated low intensity rainfall
WWF	Wet Weather Flow
WWIP	Wet Weather Improvement Plan – Merged plan for upgrading both sanitary and combined sewers
WWTP	Wastewater Treatment Plant

INTRODUCTION

The Metropolitan Sewer District of Greater Cincinnati (MSDGC) maintains hydraulic models of its collection system to study, plan, and design solutions. These models represent the tributary flows to each of MSDGC's seven wastewater treatment plants. For the purposes of this document, the System Wide Model (SWM) encompasses all collection system models and uses the US Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) engine.

This document has been organized into two volumes that provide guidance on different aspects of the modeling process:

- **Volume I General Modeling** – preferred approach to updating/developing model inputs; applied to all modeling aspects throughout the modeling process.
- **Volume II Modeling Process** – steps to follow for a modeling project.

This document provides guidelines and rules for MSDGC's sewer system model development, calibration, and documentation. The primary purpose of this document is to:

- Provide technical support and guidance to those involved with developing, using, or reviewing aspects or activities related to hydrology and hydraulic modeling for MSDGC.
- Produce accurate and reliable models.
- Ensure consistency in modeling and reporting.

This is Revision 5.0 of the Modeling Guidelines. MSDGC regards this as a dynamic and "living" document, with continual updates and reviews occurring as needed. Future changes may require an update of techniques or the addition of different sections as new or updated software features or modeling techniques become available. Proposed changes to the Modeling Guidelines should be submitted to the MSDGC Modeling Group for review and possible inclusion in future versions of this document. Additional details are provided as procedures in MSDGC's Flowfinity application titled **Procedures_and_Forms**. The procedures provided in this application provide numerous types of guidance and clarity and represent specific approaches to meet the compliance requirements herein.

VOLUME I. GENERAL MODELING

1.0 HOW TO USE THIS DOCUMENT

These guidelines are structured to support the modeling process as illustrated in the flow charts and explained in detail in **Volume II Section 1.0.** The flow charts provide modelers with a well-defined process to complete a modeling project. The flow charts reference sections throughout these guidelines, as well as submissions that should be filled out after each modeling task milestone.

Therefore, modelers are expected to follow the process outlined in the flow charts, while referring to the appropriate sections and submissions throughout this report as they advance through the modeling project. The flow charts provide a project path to follow, with built-in checkpoints throughout the project that are submitted to "FlowFinity," which is the central database used by MSDGC to track and manage projects throughout the modeling process.

2.0   FLOW CHARTS AND SUBMITTAL

At first glance, the flow charts and FlowFinity applications (refer to **Volume II Section 1.0** for details) may appear to add complexity and significant effort to a modeling project. However, the flow charts were developed to reduce guesswork on modeling work requirements, and the FlowFinity applications facilitate proper review, documentation, and feedback at the appropriate times. While this approach requires more work up front, it is intended to reduce the need for correcting errors or changing inputs in later stages of the project when rework has a much more significant impact on the overall effort of a modeling project.

In layman's terms, the flow charts and FlowFinity applications are intended to force an investment of time in performing the modeling work correctly the first time, rather than speeding through the process, and then subsequently repeating it multiple times to correct mistakes and/or address additional scenarios that could have been initially accounted for with proper forethought.

That said, MSDGC understands that modeling is an iterative process, and that changing assumptions and project needs will never be completely avoidable.

3.0 SYSTEMIC NOMENCLATURE

A system of nomenclature was developed for describing modeling terms to prevent any one term from being used to describe more than one item or concept. For example, "Total Volume" may be used to describe the total volume of flow from the beginning of an event to the end. However, it can also refer to a portion of the hydrograph, without the start and end times of the event – i.e., the volume of the entire hydrograph, as opposed to the base flow volume, only. Further, "Total Volume" does not make the distinction between whether it is observed or modeled.

A unique name will be generated for every modeling term or concept that is encountered throughout a modeling project:

- **Root Terms**
  - **Source** = [Observed, Modeled] … *blank* is used when it is a generic reference not specifically tied to Modeled or Observed
  - **Descriptor** = [Total Flow, Storm Flow, Base Flow, Dry Weather Flow, Groundwater Infiltration, Level, Velocity]
- **Appended Terms**
  - **Value** = [Average, Maximum, Minimum, Sum, or *blank*] … *blank* is used when it is not a value
  - **Repeating** = [Daily, Monthly, or *blank*] … *blank* is used when it is not a pattern

Volume I Appendix A explains each variable that will provide a fundamental understanding of each concept. From there, each term is only a variation of these variables, which are summarized in **Volume I Table 3-1**. These terms are used consistently throughout these guidelines and are required when reporting output. Therefore, **Volume I Table 3-1** should be used as a guide for understanding these terms.

This system may generate modeling terms that vary from industry-standard nomenclature. However, this is the intent of the system. For example, the definition of dry weather flow may include groundwater infiltration for one modeler, but not for another. Therefore, this system attempts to eliminate ambiguity in terms, which may ultimately cause the definitions to vary from industry standards.

Table 3-1. Nomenclature Table

Type	Name	Acronym	Common Parlance (if different)	Source Observed (O)	Source Modeled (M)	Total Flow (TF)	Storm Flow (SF)	Base Flow (BF)	Dry Weather Flow (Water Usage) (DWF)	Groundwater Infiltration (GI)	Level (L)	Velocity (V)	Average (-A)	Daily Pattern (-DP)	Monthly Pattern (-MP)	Hourly Pattern (-HP)	Weekday/ Weekend Pattern (-WK)	N/A
Time Series	Modeled Dry Weather Flow	MDWF			●				●									●
	Modeled Groundwater Infiltration Flow	MGIF	Aquifer, GWI		●					●								●
	Modeled Base Flow	MBF	Groundwater + DWF		●			●										●
	Modeled Storm Flow	MSF			●		●											●
	Modeled Level	ML			●						●							●
	Modeled Velocity	MV			●							●						●
	Modeled Total Flow	MTF			●	●												●
	Observed Dry Weather Flow	ODWF		●					●									●
	Observed Base Flow	OBF		●				●										●
	Observed Storm Flow	OSF	WWF Response, Runoff	●			●											●
	Observed Total Flow	OTF		●		●												●
	Observed Level	OL		●							●							●
	Observed Velocity	OV		●								●						●
Descriptive Parameters	Modeled Dry Weather Flow-Daily Pattern	MDWF-DP	Diurnal		●				●					●				
	Modeled Base Flow-Hourly Pattern	MBF-HP			●			●								●		
	Modeled Base Flow-Weekend Pattern	MBF-WP			●			●									●	
	Modeled Base Flow-Average	MBF-A	Average Base Flow		●			●					●					
	Modeled Groundwater Infiltration Flow-Monthly Pattern	MGIF-MP			●					●					●			
	Observed Dry Weather Flow-Monthly Pattern	ODWF-MP	Monthly DWF Multiplier	●					●						●			
	Observed Dry Weather Flow-Average	ODWF-A	ADWF Value	●					●				●					

Volume I Table 3-1 does not provide a comprehensive list of every time series or descriptive parameter type that may be encountered in this document or required for a calibration project. Instead, the primary purpose of **Volume I Table 3-1** – along with the explanation provided in **Volume I Appendix A** – is to illustrate the process by which terms will be developed and documented. The terms listed in **Volume I Table 3-1** are the most common set but may be extrapolated upon when necessary.

4.0   MODELING REQUIREMENTS AND METHODS

This section contains MSDGC's requirements and preferred methods for modeling that should be followed unless satisfactory justification can be provided. Any variance must be approved by the MSDGC Modeling Group.

All final modeling simulations used for official results must be conducted with the latest version of the EPA-SWMM engine unless directed otherwise by MSDGC. When using a commercial SWMM software interface (e.g., PCSWMM), MSDGC's required version of the EPA SWMM engine must be selected. Since conversion of a model from SWMM v5.0 to SWMM v5.1 can affect the application of weekend and weekly patterns, switching between versions should be acknowledged and accounted for by the modeler. At the time of publication of this document, EPASWMM version 5.2.3 has just recently been included in PCSWMM. It is expected that all models will be tested and then converted to this version in the near future.

4.1   NOTES AND DOCUMENTATION WITHIN THE MODELS
Project Notes
A model will also have a "Project Notes" field within the model file. This will contain the "significant" upgrades and changes, as well as a brief summary of the purpose of such changes. A "significant" upgrade is defined as any major change to the model that directly affects results such as a change in CSO estimation (e.g., recalibration of a CSO or basin, updating regulator representations, etc.).

The following notation should be used to maintain a consistent format:
> **([Project Identification Number], [Scenario] - [Date]: [Notes]. <> [Date]: [Notes].)**

Explanation:
- **[Project Identification Number]** = a unique number identifying under which project the upgrades were performed, e.g., MSDGC capital improvement project (CIP) number
- **[Scenario]** - refer to **Volume II Section 2.32.2** for explanation.
- **[Date]** = date the notes were entered
- **[Notes]** = description of a significant upgrade
- **<>** = separates notes added on different dates, but within the same project, allowing reviewers to cycle through notes when using the ctrl+f "<>" function within the model input text file

Example:
(10171641, v4.2-2017 - 11/1/2018: Recalibrated CSO 214 to updated modeling standards using historical flow data collected from March 2011 through December 2011. <> 3/19/19: Updated CSO 214 regulator chamber representation to match new survey data.)

The information within the "Project Notes" field used to track the progression and updates to a model when it is returned to MSD through the *7 – Model* or *Model Archive* App of FlowFinity. This process is outlined in **Volume II Section 2.2**.

Element Notes

Because each model element's Description field is character-limited and changes due to calibration are documented in the Calibration TM's Model Changes Log, model element notes should be limited. In general, any time the physical geometry of a model element is altered, a note should be added explaining why this was done including the data source and its date. If the Description field of an element reaches its character limit, the modeler must either condense past notes to shorthand, and/or delete them if they are no longer relevant.

Notes at specific model elements must be added for the following reasons:

- Hydraulic equivalencies – e.g., sewer siphons, CFD outlet rating curve at regulator chamber, irregular shaped pipe to simulate a restriction, etc.
- Adding additional minor losses
- Any changes made to fix or reduce model instability.

Model element notes must provide the following information:

- The Project Identification Number under which the note was entered, as this will relate each single element note back to the corresponding Project Notes – usually the MSDGC CIP number.
- Date the change was made.
- Name and organization of modeler who made the change.
- Brief description and justification for the change

The following notation should be used to maintain a consistent format:

> **([Project Identification Number] - [Date], [Modeler Name], [Organization of Modeler], [Notes].)**

Example:

(10171641 - 3/19/19, H. Williams, ABC Engineering, Exit loss added based on calibration to observed data at monitor LM-DC-003).

4.2   SWMM SIMULATION SET UP

The SWMM simulation requirements ensure consistency among modelers and reported results. Refer to **Volume I Table 4-1** through **Table 4-3** for guidance. Any variance must be approved by the MSDGC PM.

Table 4-1. Simulation Settings - Dates

Setting	Requirement	Purpose
Start Analysis	The time it would take to establish base flow throughout the model, or 2 full dry days before any rain events – whichever is greater	To stabilize flows, water levels, etc. before the model begins saving the run data
Start Reporting	At least 2 full dry days must be reported before the first rain event, plus any additional time such that the simulation begins at midnight	Allows review of the hydrograph starting at base conditions
End Analysis	72 hours after returning to base flow as a minimum or end of flow monitoring dates (Prefer to end at midnight)	Allows review of the hydrograph shape as it returns to base conditions including draining of storages

While it is possible to develop a daily evaporation time series using temperature data, MSDGC requires the use of the Monthly Pan Evaporation values shown in **Volume I Table 4-2**. This is done to maintain consistent hydrology assumptions between the SVC/D-SVC Models and the EC-Q_{n+1} Model. The definitions of these model types are discussed in **Volume II Section 1.0**. Calibrating SVC/D-SVC hydrology values with a daily evaporation time series, and then running the EC-Q_{n+1} with a different set of evaporation values would effectively alter the model's calibrated runoff characteristics.

Table 4-2. Monthly Pan Evaporation for Hamilton County, OH

Month	Monthly Total (inch)
January	0.84
February	1
March	1.9
April	3.15
May	4.4
June	5.1
July	5.08
August	4.73
September	3.55
October	2.54
November	1.38
December	0.92
Total	**34.6**

Table 4-3. Simulation Settings - Options Tab	
General Options	
Infiltration	Horton's method
Ponding at Nodes	No Ponding[1]
Dynamic Wave	
Inertial Terms	Dampen
Normal Flow Criterion	Slope and Froude number
Force Main Equation	Hazen-Williams
Surcharge Method	Extran[2]
Variable Time Steps	On
Conduit Lengthening	10 seconds
Minimum Surface Area	Default (12.556 ft^2)
Geographic Coordinates	NAD_1983_StatePlane_Ohio_South_FIPS_3402_Feet
Climatology	
Evaporation	Check "Evaporate Only During Dry Periods" option of the Evaporation tab of the Climatology window

(1) Refer to **Volume I Section 4.10.5** for further guidance on manhole flooding.

(2) Slot method is currently being evaluated but is not yet approved for use in MSDGC models.

4.2.1 Typical Year Simulation Setup

CSO overflow results are based on the impact of the Typical Year of rainfall for 1970. The WWIP Typical Year simulation should follow the specified parameters in **Volume I Table 4-4**. MSDGC will provide the rainfall input series to the modeler for use.

Note that a 1-hour reporting time step must be used for annual simulations to remain consistent with the time step used for developing the Consent Decree.

Table 4-4. Typical Year Simulation Settings	
Parameter	**Setting**
Start Analysis Date	12/30/1969
Start Reporting Date	1/1/1970
End Analysis Date	1/1/1971
Reporting Time Step	1:00:00
Runoff: dry weather	1:00:00
Runoff: wet weather	1:00:00
Routing	30 seconds

4.2.2 Design Storm Setup

Special consideration should be given to seasonal variation and antecedent moisture conditions within the model when selecting simulation run dates and times. A design storm may produce differing results in the spring versus the summer, which will impact the ultimate design. July has a large number of high recurrence interval storms and occurs during the critical months, the importance of which is discussed in **Volume II Section 7.1.5**. As can be seen from the analysis of 50 years of historical hourly data from CVG Airport shown in **Volume I Figure 4-1**, July has a high frequency of high recurrence interval storms during the 50-year period analyzed. As a result, design storm simulations should be modeled in July when evaluating alternatives, unless otherwise noted by the MSDGC PM.

Figure 4-1. High Recurrence Interval Storms

NUMBER OF EVENTS EXCEEDING 10-YEAR DEPTH FOR ALL DURATIONS

LimnoTech (2021, August 31). *MSDGC Rainfall Analysis Update* [PowerPoint slides].

Design Storm hyetographs will be saved in the Time Series Editor within the model input file by MSDGC with the simulation settings listed in **Volume I Table 4-5**. However, if the Design Storm hyetographs are missing from the Time Series Editor, the hyetographs are provided in **Volume II Appendix C**. All Design Storms use the SCS Type II distribution, with Bulletin 71 rainfall depths and a 24-hour duration. The design 15-minute timestep is required to maintain consistency with the development approach of the WWIP.

Table 4-5. Design Storm Simulation Settings	
Parameter	**Setting**
Analysis Dates	Perform simulation in July
Reporting Time Step	0:15:00
Runoff: dry weather	0:15:00
Runoff: wet weather	0:15:00
Routing	30 seconds

4.2.3 Historical Storm Setup

When running historical storm scenarios, modelers must use the settings shown in **Volume I Table 4-6**.

Table 4-6. Historical Storm Simulation Settings	
Parameter	**Setting**
Analysis Dates	Project-dependent
Reporting Time Step	0:05:00
Runoff: dry weather	0:05:00
Runoff: wet weather	0:05:00
Routing	30 seconds

4.2.4 Rain Gauge Assignment

When assigning rainfall to a subcatchment or unit hydrograph, the "Rain Gauge" input must always remain assigned to its sewershed ID rain gauge. The rainfall time series should be assigned to the rain gauges. There should never be any additional rain gauges created beyond the sewershed ID rain gauges, and the "Rain Gauge" input should never be altered (unless a subcatchment/sewershed delineation is changed that would require this).

For example, when selecting an arbitrary subcatchment in the Little Miami SWM, Rain Gauge 150 is assigned to subcatchment LMDCCAT01S.

If running a Typical Year simulation:
- Correct approach: Assign the "TypicalYear" *Time Series* to Rain Gauge 150.
- Incorrect approach (mistake most often made): Generate a TypicalYear Rain Gauge, and then assign that Rain Gauge directly to LMDCCAT01S.

The same approach would be used if switching back to a design storm – assign the appropriate *Time Series* to the Rain Gauge. The Rain Gauge assignments should not be changed.

4.3 HYDROLOGY – SUBCATCHMENTS

For project modeling, the Existing Conditions subcatchments may be adjusted to improve accuracy, better represent flow paths, or include updated infrastructure. Refer to **Volume II Section 5.0** and **Volume II Section 9.0** for guidance on the appropriate level of detail that should be maintained when updating models.

Model depiction of subcatchments that are visibly wrong or missing (default pentagon shape) should be corrected to the best available information. This correction will help users of the Existing Conditions Model understand subcatchment delineation, parameter selection, and discharge node. Refer to the mapping requirements provided with the *6 – Calibration* app in FlowFinity for guidance.

4.3.1 Naming Convention and Subcatchment Adjustment

When splitting and/or adding subcatchments, modelers must follow MSDGC's naming convention rather than using SWMM's default name or short-hand descriptions. If needed, additional notes may be added in the Description field per the format provided in **Volume I Section 4.1**. The subcatchment naming convention is presented in **Volume I Figure 4-2**. Information on naming conventions for revisions to subcatchment IDs for specific situations is provided in **Volume I Table 4-7**.

When splitting subcatchments, the original and updated subcatchments must have nearly the same runoff response to preserve the calibration developed for the original Existing Conditions model.

Figure 4-2. Subcatchment Naming Convention Example

Table 4-7. Subcatchment Specific Situation Naming Convention

Situation	Naming Convention	Naming Formula	Example
Split Subcatchment	When existing subcatchments are subdivided, the subsequent subcatchments should be named from the original subcatchment name only if the loading remains the same. The MSDGC method is to add a letter "A", "B", etc. to the end of the original subcatchment name. If the loading of one of the split subcatchment changes, it is to follow the naming based off the new load point.	Subcatchment Name and ID + Letter	MC40612017A
Subcatchments loading to the same node	Subcatchments that are directly loaded onto the same manhole should be based on the loaded manhole. The MSDGC method is to add a letter "A", "B", etc. to the end of the original subcatchment name.	Subcatchment Name and ID + Letter	MC40612017A
New Subcatchment	For new subcatchments, the name should be based on the name of the first subcatchment connecting to the sewer downstream of the new subcatchment. Generally, SWM subcatchment names begin with an abbreviation and end in a four-digit number. The new subcatchment name should use the same characters to the left of the four digits plus a new four-digit number. The first of the four digits should be increased by one and the other three digits set to zero. Subsequent new subcatchments should be numbered sequentially moving upstream. Note that new subcatchment names must be checked against the full SWM to prevent duplication.	Subcatchment Name + New 4 Digits	MC40611000
Sewer Separation	Sewer separation should be modeled as splitting the base subcatchment into two separate subcatchments – a stormwater subcatchment representing the area of runoff that was effectively separated, and a combined sewer subcatchment representing the area of runoff that was not effectively separated and that will still be tributary to the combined sewer system. The MSDGC practice is to maintain the total subcatchment area within the Existing Conditions Model input files to verify the conservation of total runoff results and allow future efforts such as installation of sustainable infrastructure, sizing of stormwater system, etc. Stormwater runoff subcatchments should be duplicated and renamed with the "S_" prepended for storm designation.	S_ + Subcatchment Name and ID	S_MC40612017

Table 4-7. Subcatchment Specific Situation Naming Convention			
Situation	**Naming Convention**	**Naming Formula**	**Example**
Duplicate Subcatchment	Duplicated subcatchments are usually reserved for Detailed Model projects and are not typically used. A duplicated subcatchment would have the same boundaries and area as the original subcatchment. Duplicated subcatchments should be renamed with "D_" prepended to the original subcatchment name.	D_ + Subcatchment Name and ID	D_MC40612017

4.3.2 Subcatchment Delineation

MSDGC provides the subcatchment delineations for each calibration effort. Before calibration, the modeler should receive a new subcatchment delineation through the *3 – Delineation* app within Flowfinity. See FlowFinity *Procedures_and_Forms* app Reference ID **#R-0372** for specific details on MSDGC's delineation process and requirements. Modelers should perform a check of the provided subcatchment delineations to look for major errors. Any necessary edits should be discussed with MSDGC, and information provided in the *6 – Calibration* app within Flowfinity.

In some instances, delineation of a project area may substantially affect the boundaries of adjacent basins. As little as a 5% change in tributary area for a neighboring historical metershed, CSO, SSO, or another subarea would be considered substantial. The MSDGC Modeling Group should be consulted on the best course of action. Potential options are presented below.

- Ideally, additional flow monitors would be placed on the adjacent area to evaluate the impacts of the changes. Even with new data, historical monitoring data should be evaluated if available.
- If additional flow monitoring of the adjacent area is not possible due to time or budget, the previous calibration must be maintained (even under prior versions of the MSDGC Modeling Guidelines),.
  - The historic monitoring data should be used to evaluate the impact of the model change. If available, the previous calibration event definitions, tools, etc., should be utilized to expedite the process.
  - If the monitoring data are unavailable, the model timeseries from the meter location (before delineation updates) can be used as the confirmation (calibration) point, bycomparing the model results for the Typical Year and 10-yr, 24-hr rainfall before and after the redelineation.

Further considerations are required when redelineated subcatchments encroach on upstream or downstream historical calibrations. **Volume II Section 6.6.3** provides guidance on what to do in these cases. In most cases this adjacent basin recalibration will be performed independent of and subsequent to the calibration of target basin.

4.3.3 Typical Hydrology Runoff Parameters

Volume I Table 4-8 provides typical values and ranges for hydrology runoff parameters that are used within MSDGC's SWMs. The values are based on the area soils, land uses, topography, model refinement, and historical calibration experience. Some values are prohibited from adjustment to limit parameter adjustments and maintain more consistent SWMs. Parameter consistency also prevents an imbalance of flow between upstream and downstream monitoring locations within the same project area. **Volume I Table 4-8** also acts as the acceptable ranges for MSDGC Audit Criteria.

In special cases, the values may deviate from the allowable ranges when justified by sufficient evidence. MSDGC must be consulted for permission to deviate from these ranges, and additional documentation is required to justify the values during the submittal process, which is discussed in **Volume II Section 7.5**.

Table 4-8. Typical Values and Value Ranges for Runoff Parameters			
	Parameter Range		
Parameter	**Typical**	**Min**	**Max**
Do not deviate from Typical Value			
Slope (%)	**Actual Slope**		
N Imperv	**0.015**		
Zero Imperv (%)	**25**		
Max Volume	**0**		
Subarea Routing	**OUTLET or PERVIOUS**		
Imperv (%) – PERVIOUS routing method	**Actual Imperviousness**		
Infrequently deviates from Typical Value			
D-Stor Imperv (in)	**0.05**	0.01	0.1
D-Stor Perv (in)	**0.25**	0.1	0.25
N Perv	**0.25**	0.1	0.8
Dry Time (days)	**7**	5	10
Sometimes deviates from Typical Value			
Flow Path Length for </= 10 ac subcatchment (ft)	**150**	50	400
Flow Path Length for </= 30 ac subcatchment (ft)	**300**	150	600
Flow Path Length for </= 100 ac subcatchment (ft)	**600**	150	1200
Decay Constant (1/hr)	**2.016**	1.5	4
Max. Infil. Rate (in/hr)	**3**	1	3
Normally deviates from Typical Value			
Imperv (%) – OUTLET routing method	**DCIA = 50-100% of total Imperviousness**		
Percent Routed (%)	**25**	0	50
Min. Infil. Rate (in/hr)	**0.25**	0.1	0.5

The requirements for calculating subcatchment parameters, which represent hydrology runoff within the SWM, are outlined in **Volume I Table 4-9.** Existing values should be adjusted if updating existing subcatchments. Variance from these values derived through the calibration process is expected, however, justification and explanation must be provided for significant variances. **Volume I Table 4-9** through **Volume I Table 4-12** provide additional guidance on runoff parameters.

Table 4-9. Subcatchment Element Parameters	
Parameter	**How to Calculate**
Area	In combined sewer areas this is the only subcatchment parameter that MSDGC does not allow changes to (unless the modeler is certain the Existing Conditions Model is incorrect or if the area was altered by a construction project) is the total area of the subcatchment. Subcatchments may be subdivided, joined, or added, but the total area of the watershed must be correct and accounted for in the SWM. If the subcatchment area is changed, the width must also be changed to maintain the flow path length calculated from the area and width values. The change in width is proportional to the change in area (i.e., a 10% increase in subcatchment area is matched by a 10% increase in width). In separated sewer areas this value must be less than or equal to the basin area. Areas that flow away from the sewer to a stream, creek or other drainageway are generally excluded.
Overland Flow Length	In SWMM, **flow length is the average flow path length** (not max). Using GIS, measure the length of the flow path from the farthest drainage point of the subcatchment to the point where the flow enters a pipe, stream, gutter, or other conveyance for several parts of the subcatchment. Then average the values. MSDGC models contain relatively small subcatchments with relatively short lengths of non-modeled sewers. Therefore, modeled/calibrated flow path lengths are typically close to the measured overflow flow path. Large deviations from the measured overland flow path length are not common. If there are unmodeled sewers or drainage ways, the Overland flow length can be significantly smaller than might be initially considered from the appearance of the gross dimensions of the subcatchment.
Width	Divide the subcatchment area by overland flow length. This will generally have some variation for very large sub-basins.
Slope	Estimate average percent slope values by dividing the elevation difference along the subcatchment's flow path by the overland flow length. Consideration must be given to larger basins with unmodeled collection points and drainage ways.
Subarea Routing	Set to Outlet or Pervious.
% Impervious	Estimated from land use, CAGIS, or calibrated value. Refer to **Volume I Table 4-10** for typical values. Note that the Hamilton County impervious surface shapefile can be used as an initial estimate if no other data are available.

Table 4-9. Subcatchment Element Parameters

Parameter	How to Calculate
Surface Roughness	Refer to **Volume I Table 4-11** for typical values.
Depression Storage	Refer to **Volume I Table 4-12** for typical values.
Infiltration Parameters	Refer to **Volume I Table 4-13** for typical values.

Table 4-10. Percent Impervious by Land Use [1]

Land Use	Typical Percent Impervious
Commercial/Industrial	90
Institutional	90
Parking	95
Multi-unit Residential	75
Residential	
0.25 acres per house	35
0.5 acres per house	25
1.0 acre per house	20
2.0 acres per house	10
Open Land	5
Forest	5

Table 4-11. Typical Manning's Roughness Values

Surface	n	Acceptable Range per MSDGC Audit Criteria
Smooth Asphalt	0.011	
Smooth Concrete	0.012	
Ordinary Concrete Lining	0.013	
Good Wood	0.014	Impervious Surfaces: 0.01-0.05
Brick with Cement Mortar	0.014	(For large pipes n should not be adjusted outside the normal range to account for the
Vitrified Clay	0.015	effect of debris on the depth of normal flow.
Cast Iron	0.015	n values should always reflect the conditions
Corrugated Metal Pipes	0.024	of the mostly full or surcharged pipe not low
Cement Rubble Surface	0.024	flow.)
Fallow Soils (no residue)	0.05	
Cultivated Soils		Pervious Surfaces: 0.1 – 0.8

Table 4-11. Typical Manning's Roughness Values		
Surface	**n**	**Acceptable Range per MSDGC Audit Criteria**
Residue Cover < 20%	0.06	
Residue Cover > 20%	0.17	
Range (natural)	0.13	
Grass		
Short, Prairie	0.15	
Dense	0.24	
Bermuda Grass	0.41	
Woods		
Light Underbrush	0.4	
Dense Underbrush	0.8	

Source: (McCuen, R., et al, 1996)

Table 4-12. Typical Depression Storage Values		
Surface	**Depth of Storage (inches)**	**Acceptable Range per MSDGC Audit Criteria**
Impervious Surfaces	0.075	0.01 – 0.1
Lawns	0.15	
Pasture	0.2	0.1 – 0.25
Forest Litter	0.3	

Source: (ASCE, 1992)

MSDGC uses the Horton's Equation method to calculate infiltration. **Volume I Table 4-13** lists the expected range of values for Hamilton County.

Table 4-13. Typical Horton Infiltration Parameter Values [2]				
Infiltration Parameter	**Units**	**Description**	**Typical Range**	**Acceptable Range per MSDGC Audit Criteria**
Maximum Infiltration Rate	In/hr	Fully dried soil	1 – 3	1 – 3
Minimum Infiltration Rate	In/hr	Fully saturated soil	0.1 – 0.25	0.1 – 0.5
Decay Rate	Hr^{-1}	Transition from Max to Min infiltration rate	2 – 4	1.5 – 4

Table 4-13. Typical Horton Infiltration Parameter Values [2]

Infiltration Parameter	Units	Description	Typical Range	Acceptable Range per MSDGC Audit Criteria
Drying Time	Days	Time to return to Max infiltration rate	5 – 10	5 – 10
Maximum Infiltration Volume	Inches	Optional capacity of soil, no infiltration once reached	Do not Use	Do not Use

4.4 HYDROLOGY – RDII AND GROUNDWATER

RDII and groundwater infiltration enter the sewer system differently than surface runoff, and as such, they are represented differently within the SWMM software.

4.4.1 RDII – RTK

Acceptable use of the RTK method as RDII representation varies depending on the sewer system type. Sanitary sewer systems require the use of RTK unit hydrographs to represent RDII flows. Combined sewer systems may be supplemented with RTK unit hydrographs when supported by observed data.

The RTK unit hydrograph should be a smooth curve with a single peak. If the data clearly demonstrates a delayed second peak, the upstream subbasin should be subdivided with different RTKs rather than using the Not Acceptable form shown in **Volume I Figure 4-3** below. Examples are shown in **Volume I Figure 4-3**, and **Volume II Table 6-2** provides further information on acceptable flow component representation. For combined sewer areas, the shortest T value should be 0.25 hours to prevent a second peak.

Figure 4-3. Example of Properly and Improperly Shaped RTK Hydrographs
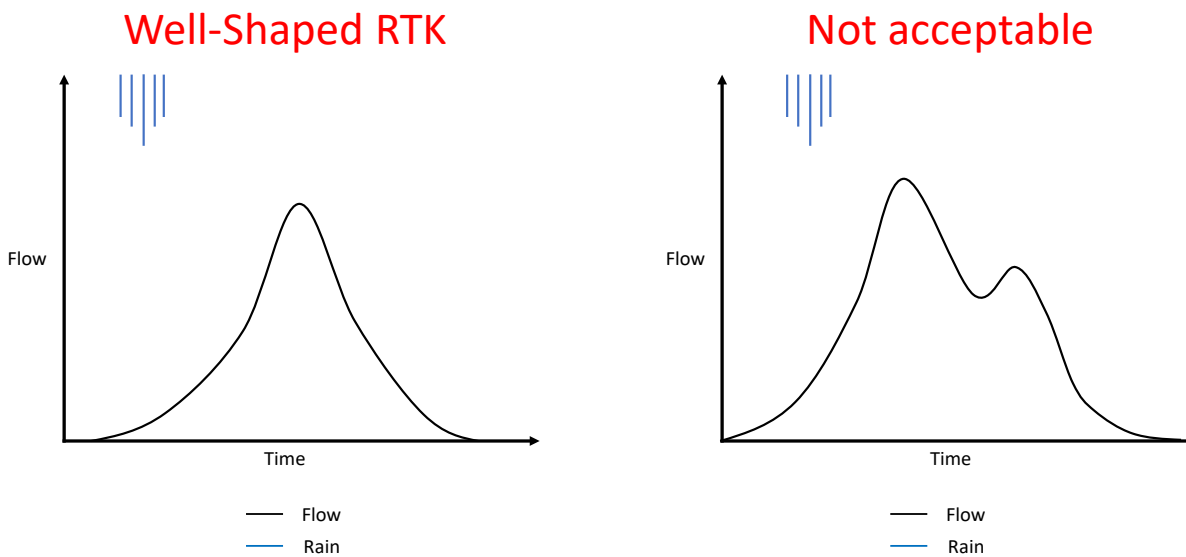
Approach

Application of RTK parameters varies between sanitary and combined sewer system representations. Sanitary systems may utilize all three hydrograph triangles to calibrate to short, medium, and long-term observed flow responses. Combined system may utilize the medium and long-term responses, starting with the long-term response. The short-term RTK parameters are not used in combined sewer areas as these responses are represented by subcatchment surface runoff, as shown in **Volume I Table 4-14.**

Table 4-14. Use of RTK for different system types		
	Combined Sewer Systems	**Sanitary Sewer Systems**
Short-Term Response	Represented by Subcatchment Surface Runoff	Represented by RTK Triangles
Medium-Term Response	May be represented by RTK Triangles	Represented by RTK Triangles
Long-Term Response	May be represented by RTK Triangles	Represented by RTK Triangles

Additional considerations in RTK modeling include:

- Initial abstraction – Used as a combination of maximum storage depth (Dmax) and subsequent storage depth recovery rate (Drec), these parameters represent wetting of the soil matrix so that initial infiltration is not available for system inflow. They are used in combination with RTK unit hydrographs to model the delay more accurately in the start of infiltration and the total volume infiltrated. MSDGC allows the use of initial abstraction as warranted by the available flow monitoring data. Note that initial starting depth (D_0) should

not be used. See **Volume II Section 6.5** for details on how to appropriately use these parameters during calibration.

- Seasonal variation – Represents changing conditions such as frozen ground and vegetation uptake of soil moisture. MSDGC requires the use of seasonal RTK factors. For the MSDGC service area, the highest R factors are expected in the spring, with lower values in the summer and fall. Refer to **Volume II, Section 6.7** for further information on modeling seasonal variation for calibration.

RTK Sewershed Area and Delineation

MSDGC will provide the sewershed delineations for the model. The modeler should request the delineation from the MSDGC Modeling Group. Sewershed areas for RTK are delineated by creating a non-overlapping, 50-foot buffer around dwelling units and sewer pipes. Buffers on the laterals are not included. The area is then assigned to the nearest modeled manhole. **Volume I Figure 4-4** shows an example of a properly delineated sewershed area for RTK. See FlowFinity *Procedures_and_Forms* app Reference ID **#R-0372** for specific details on MSDGC's delineation process and requirements.

Figure 4-4. Example of Delineated RTK Sewershed Area
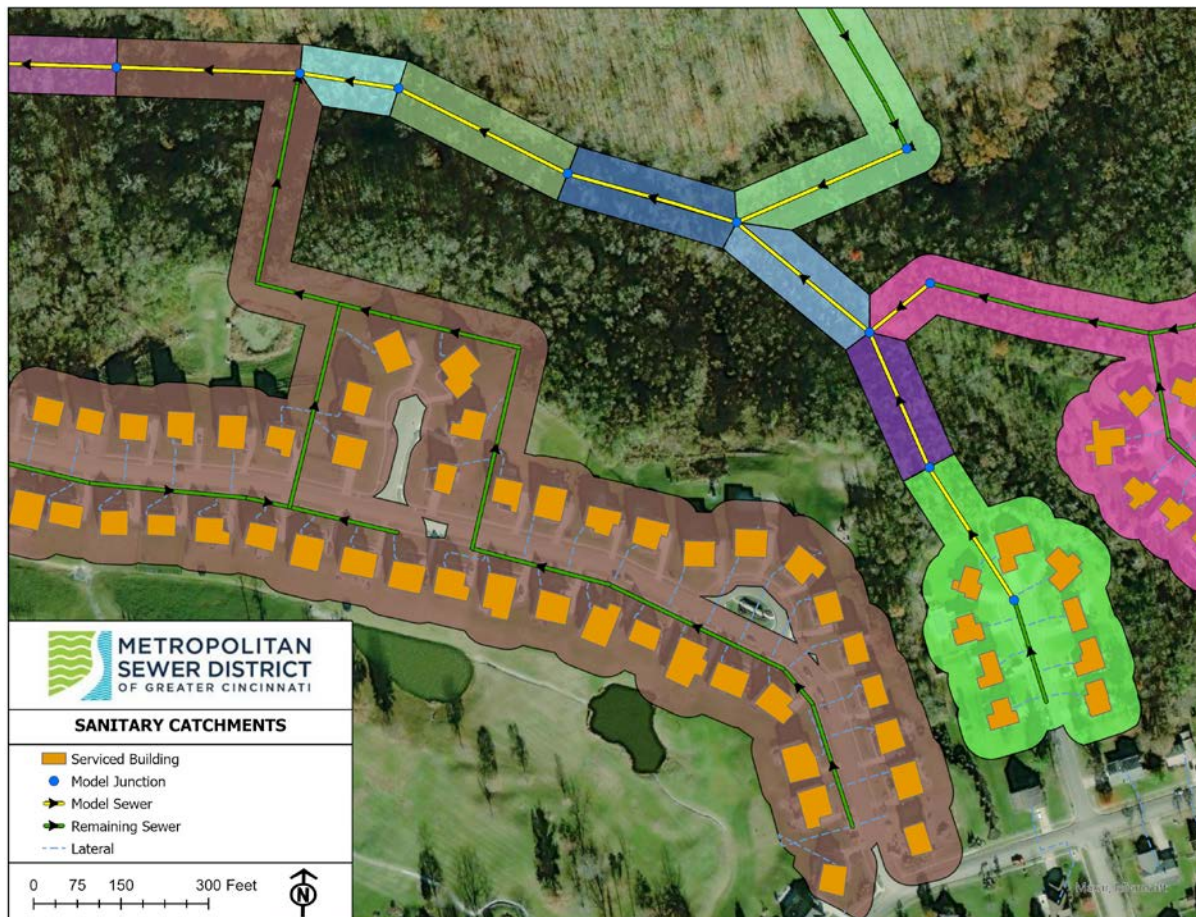
RTK Sewershed Area Values

The following guidance can be used as a starting point in establishing RTK parameters as needed by the modeler. Values provided are only general guidelines from which calibration may vary. However, the calibrated response should typically exhibit a similar relationship between the three types of flow responses. Significant variance or uncharacteristic values should be supported by observed data.

The following general guidelines and **Volume I Table 4-15** should be used by the modeler when selecting R, T, and K parameters. Any deviations from these guidelines will require justification and approval from the MSDGC Modeling Group prior to implementing.

- $T_1 < T_2 < T_3$
- $1 <= K_1 < K_2 < K_3$
- $T_1 + T_1K_1 < T_2 + T_2K_2 < T_3 + T_3K_3$

- $R_1+R_2+R_3 < 1.0*$
- $T_2 < T_1 + 0.5\ T_1K_1$
- $T_3 < T_2 + 0.5\ T_2K_2$

*The 50' buffer will result in higher-than-normal R-values. In some cases, the R-values may need to exceed 1.0, such as low-lying areas with large groundwater impacts or leaky sanitary areas where the system behaves more like a combined sewer due to direct connections. If that is the case, the MSDGC Modeling Group should be consulted to decide the best course of action. In low lying areas, the 50' buffer may need to be expanded to account for the potentially larger tributary area.

Table 4-15. Unit Hydrograph T&K Typical Values For Sanitary Sewer Basins					
	Unit Hydrographs				
Response	**#**	**T (hrs)**	**K**	**Dmax (in)**	**Drec[1] equivalent (days)**
Short-Term	1	0.083-2	1-2	0-0.1	0.25-1
Medium-Term	2	0.25-5	2-3	0.25-0.75	1-3
Long-Term	3	0.5-10	3-7	0.5-2.5	3-10

(1) *Drec units are in inches/day. Guidance is for total days to recover. Covert to Drec by dividing Dmax by recovery days.*

4.4.2 Groundwater

During the storm volume calibration process there are several acceptable approaches for modeling the base flow: such as adding the base flow as time series, using the aquifer module, or monthly base flow rates using SWMM model parameters. Whichever approach is used during storm volume calibration, monthly base flow rates using SWMM model parameters must be used for the final model submittal. MSDGC does not all use of the Aquifer module in a final submitted model. It may be used for the base flow during the storm volume calibration, but must be replaced by monthly values for submittal of the final model.

Monthly Base Flow Variation as Groundwater

The Monthly Base Flow Variation approach can be used for either combined or sanitary sewer systems. Refer to **Volume II Section 8.0** for detail on calibration and updating typical inputs. Note that the MGIF value should be input to SWMM's "Baseline" inflows field and the "Baseline Pattern" used to vary the flows monthly. This is the only acceptable approach in the final model submittal with typical inputs.

RTK as Groundwater for Areas already using RTK for Storm Volumes

RTK may be used to represent groundwater in a model using the following technique:

- Create a second RTK unit hydrograph to represent the groundwater. The groundwater RTK unit hydrograph should be assigned the same name as the original RTK unit hydrograph for that area with "_groundwater" appended to the end of the name.
- Combine the representative sewershed areas of two adjacent nodes and apply the total to both nodes. For example, if nodes A and B are adjacent, and A has a sewershed of 2 acres and B has a sewershed of 3 acres, sum these together and apply the total area of 5 acres to both. See **Volume I Figure 4-5** and **Volume I Figure 4-6** for schematic and pictorial examples, respectively.
- Apply the normal RTK unit hydrograph to the upstream node and the groundwater RTK unit hydrograph to the downstream node. Add notations to both nodes per **Volume I Section 4.1** to document these changes.
- Calibrate the groundwater RTK unit hydrograph utilizing only the long-term response (T3, K3, R3). The result should be similar to **Volume I Figure 4-7**.

If this approach is used, flow balance for the total wet weather flow must be checked as described in **Volume II Section 3.10.2**.

Figure 4-5. Groundwater Represented with RTK Hydrograph when RTK is already used for the Storm Volumes
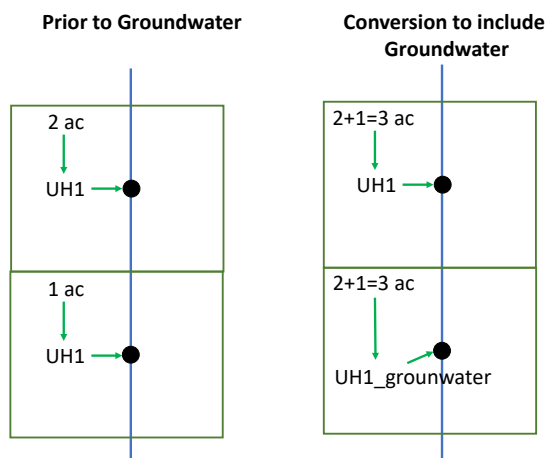
Figure 4-6. Model Configuration for Groundwater Represented with RTK Unit Hydrograph
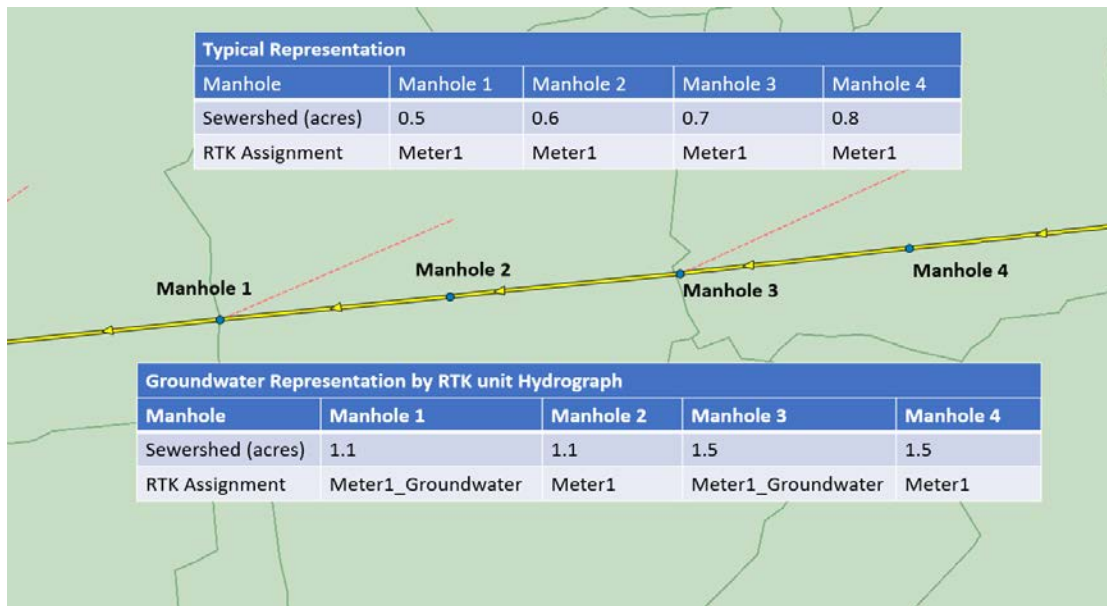
Figure 4-7. Groundwater Represented with RTK Unit Hydrograph
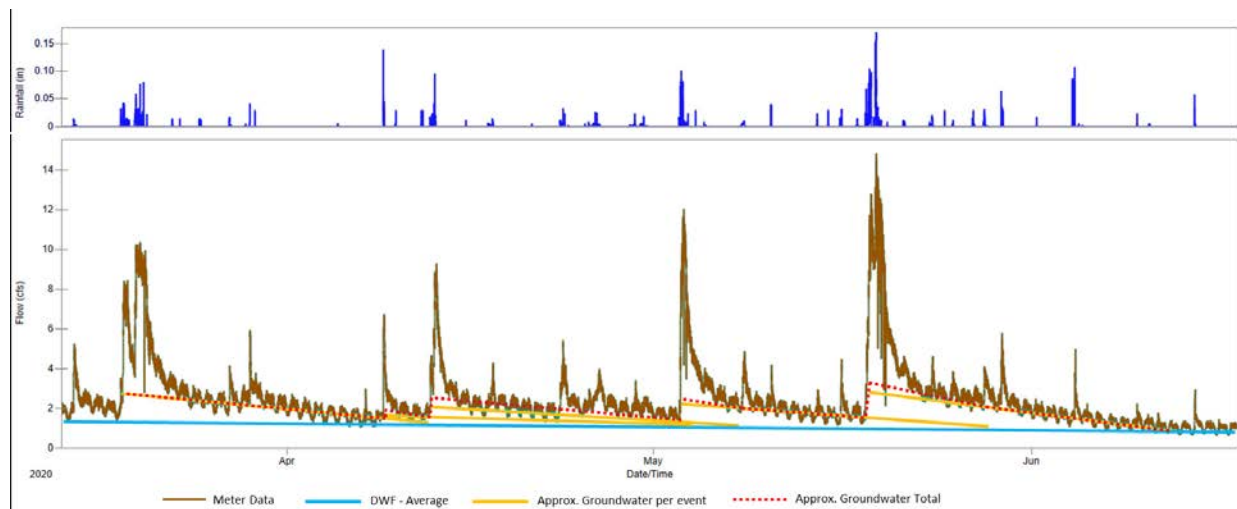
Aquifer Module

Use of the Aquifer module is not allowed in the final model submittal. It may be used during storm volume calibration. Flow monitoring for only one year provides only the groundwater rise and fall due to the specific rainfall patterns and seasonal temperatures during the calibration period. It may not be representative of normal groundwater for other years. Thus if the Aquifer module used during calibration it must be removed during final model submittal when the typical inputs are added.

4.5   UNUSED SWMM FEATURES

Some current features are prohibited from use in MSDGC models, listed below. This list should NOT be considered comprehensive, and therefore, exclusion from this list does not necessarily indicate the feature is acceptable. EPA-SWMM adds new features with each new update of the program. Commercial versions of SWMM (PCSWMM, StormNet, etc.) may have tools and features not included in EPA-SWMM. Such features (new EPA-SWMM or commercial), while valuable, are prohibited from use in MSDGC models until approved by the MSDGC Modeling Group.

- Temperature data
- Wind speed
- Snow melt
- Aerial depletion
- Monthly adjustments ("Adjustments" tab) of temperature, rainfall, or soil conductivity
- "Radar Rainfall" tab under "Rain Gages"
- Groundwater, Aquifers, etc.
- SnowPacks
- Priessman slot
- Divider elements
- Storage evaporation factor
- Conduit Seepage rate
- Conduit Flow limit
- Weir coefficient table
- For Subcatchments, the following features are prohibited:
    - Max Volume
    - Curb length
    - N-perv pattern.
    - D-store Pattern
    - Infiltration pattern
    - SnowPack
    - LID control
    - Erosion
    - Groundwater

4.6   HYDRAULICS

The SWM hydraulic network is periodically compared against CAGIS, record drawings, and other data sources to verify that the parameters are reasonable and represent the physical reality. Any anomalies or additions for the project, should be identified and brought to MSD's attention. Refer to **Volume II Section 3.0** for further guidance on checking the model's hydraulics.

4.6.1 Naming Convention

When splitting and/or adding hydraulic elements, modelers must follow the MSDGC's naming convention rather than using SWMM's default name or short-hand descriptions. If needed, additional notes may be added in the Description field per the format provided in **Volume I Section 4.1**. The naming convention of hydraulic elements is outlined in **Volume I Table 4-16**.

Table 4-16. Hydraulic Elements Naming Convention				
Model Element	**Type**	**Naming Convention**	**Naming Formula**	**Example**
Node	Manhole number in GIS or as-built drawing	Same name as GIS or as-built	Node ID	28402032
	Manhole number not available	Use nearest available manhole number and add letter "A" to the end. If the name has been taken use the following letter "C," "D," "E," etc. until there is a unique manhole ID, skipping the letter "B".	Node ID+Letter	28402032A
	Blind Manhole	Use nearest available manhole number and add letters "BL" to the end.	Node ID+BL	28402032BL
	Open Channel or Creek Connection	The connection location will use a shortened name or acronym for the stream/channel/creek followed by a location identifier, usually a numerical value.	CrkNmLocation Identifier	LckRn1
Link	Conduit	The upstream node ID followed by the downstream node ID, separated by a dash	Upstream Node ID-Downstream Node ID	28407035-28402032
	Orifice, Weir, or Pump	In addition to the upstream and downstream node IDs these element IDs begin with link type followed by location identifier. The location identifier should be the name of the location, but a unique number may be used if needed.	Link Type+Location Identifier@Upstream Node ID-Downstream Node ID	Pump7@31016027-31006020
	Open Channel, Creek	The upstream connection ID followed by the downstream ID, separated by a hyphen.	Upstream Connection ID-Downstream Connection ID	LckRn1-LckRn2

Table 4-16. Hydraulic Elements Naming Convention

Model Element	Type	Naming Convention	Naming Formula	Example
	Overland Flow or Manhole Overflow	Use "Ovrlnd" for overland flow followed by upstream node ID followed by downstream node ID, separated by dash.	Ovrlnd@Upstream Node ID-Downstream Node ID	Ovrlnd@ 28407035-28402032

4.6.2 Nodes

Volume I Table 4-17 provides guidance on using the proper node element. Note that any blind nodes added in the model should maintain a surcharge depth of 999 feet to prevent flooding from the manhole.

Table 4-17. Node Elements

Node Type	When to Use
Junction	For most manholes in the system. Note that when representing blind manholes, modelers should set the rim elevation equal to the existing topography, as opposed to using the average elevation of the upstream and downstream manhole. For blind and bolted manholes, the surcharge depth must be set to 999 feet.
Storage Node	For representations of regulator structures, inlet-controlled catch basins (to represent ponding above the inlet), pump station wet wells, storage tanks, or detention ponds; or for unstable locations in the model.
Divider	MSDGC's practice is to not use dividers.
Outfalls	Free: Represents no governing downstream conditions, can be used in specific situations.
	Normal: Represents the normal depth of flow at the downstream end of the discharging pipe. MSDGC's practice is to use normal depth outfalls.
	Fixed: Constant depth or stage boundary can only be used in specific situations such as an outfall with an invert elevation below the Ohio River's normal pool elevation. This should only be done for the Storm Volume Calibration model. No stage boundaries are included in the Existing, Baseline, or Proposed Conditions Model.
	Tidal: MSDGC does not use Tidal outfalls.
	Time Series: A user-defined series that represents the stage of the boundary condition for a certain day and time. Use when boundary information is available and required to accurately model impacts from downstream. Note this will only apply for certain models, most likely calibration and/or alternatives models. These should not be included with models that are to become, or incorporated back into, master models.

4.6.3 Links

Volume I Table 4-18 provides guidance on using the proper link element. Note that energy losses in the hydraulic system are calculated as occurring in the conduit. Any losses that would occur in the field due to the manhole itself (e.g., a bend within the manhole) should be represented as an entrance loss at that manhole's outflow pipe. Refer to **Volume I Table 4-19** and **Volume I Figure 4-8** for more information on losses. Modelers should check with the MSDGC Modeling Group before making changes to loss coefficients. Roughness values (Manning's n) should not be arbitrarily increased. In general meeting observed depth values should be by adding a silt level or reducing the effective size of the conduit.

Table 4-18. Link Elements		
Link Type	**When to Use**	**Notes**
Conduit	To represent pipes or channels.	**Volume I Table 4-19** provides Conduit Losses.
Orifice	To model outlet and diversion structures, such as openings in the wall of a manhole, storage facility, or control gate.	The orifice coefficient value will vary between 0.65 to 0.85 depending on which part of a structure is being modeled. Refer to **Volume I Section 4.7.1** for further guidance. The orifice coefficient may be adjusted during calibration by observed data.
Weir	To model outlet and diversion structures. SWMM has four types of weirs: transverse, side flow, V-notch, and trapezoidal.	For weir coefficients use: • Sharp crested weirs = 3.0 • Inflatable dams = 2.5 Inflatable dam weir coefficients should be adjusted during calibration to observed data. V-notch weirs should be used in unstable situations using low side slopes.
Outlet	To control outflows from storage units or other junctions where outlet flow is based on the head difference between the upstream and downstream nodes.	

Table 4-19. Conduit Losses	
Cause of Loss	**When to Use**
Straight Line Alignment	Ignore small energy losses at manhole between straight line aligned pipes.
Significant Bends	Turbulence caused by significant bends (22.5 degrees or larger) in alignment causes energy losses that must be accounted for in the modeling. Bends at manhole – losses assigned as entrance loss of the outflow pipe. Bends in pipe alignment – losses assigned to Avg Loss Coeffs parameter. Refer to **Volume I Figure 4-8** to calculate losses.

Table 4-19. Conduit Losses	
Cause of Loss	**When to Use**
Drop Manhole	Assign an entrance loss of 1.0 to the outflowing pipe if the invert of the inflowing pipe is above the crown of the outflowing pipe.
Minor Losses	Minor losses can be added to conduits where altering the pipe roughness coefficients in the area within the permissible range is insufficient to match the flow depths in the meter pipe. If minor losses are added, proper notation must be added to the conduits to mark the inclusion of such losses. See **Volume I Section 4.1** for details. Minor losses should only be considered when other methods are insufficient on their own.

Figure 4-8. Losses at Bends

DRAINAGE CRITERIA MANUAL (V. 1)   STREETS/INLETS/STORM SEWERS
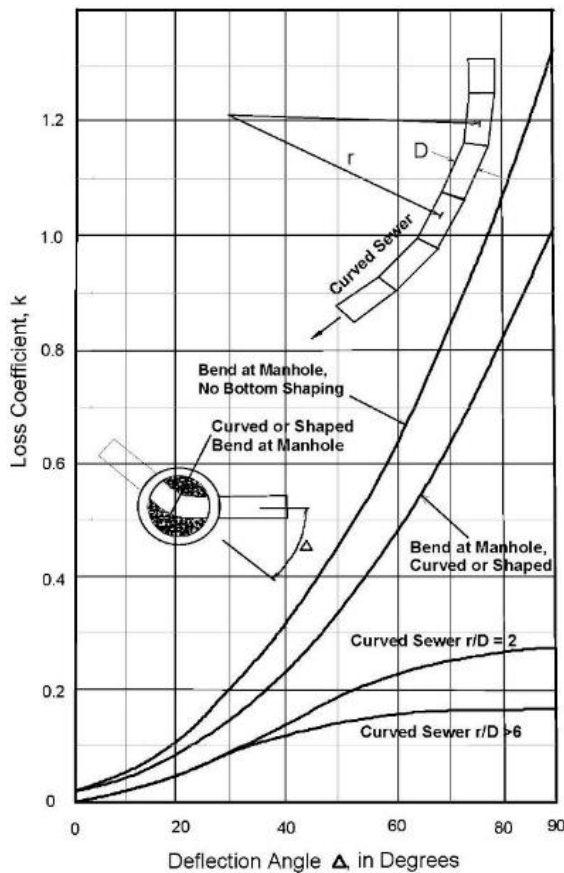
Figure ST-8—Bend Loss Coefficients

Rev. 06/2002
Urban Drainage and Flood Control District   ST-43

Source: (Urban Drainage and Flood Control District, 2002)

4.6.4   Non-Circular Sewers

Although circular is the most common shape in MSDGC's collection system (as well as the default in EPA SWMM), EPA SWMM offers additional shapes including rectangular, trapezoidal, and triangular among many others. The user can also define a custom shape for parts of the collection system that have irregular pipe segments. The EPA SWMM shapes for Semi-Elliptical and Semi-Circular, among others, have fixed proportions of depth to width. **These fixed proportions may not be the same proportions as the MSDGC constructed shapes** and must be reviewed against field measurements or available drawings. Refer to **Volume I Appendix B** for irregular pipe shapes that are most common within MSDGC's collection system, and the corresponding coordinates for inputting them as a custom shape representation in EPA SWMM. MSDGC has models constructed for all non-circular pipes, and the consultant will be responsible for changing or providing the representation of such pipes only in the event of a new pipe or noted error.

4.6.5   Pumps and Force Mains

Pumps

Model the pump wet well as a storage node with dimensions accurate to as-built or as-planned conditions. Whenever possible, the pump element in the Existing Conditions Model represents only the actual pump. Downstream force mains and gravity sewers should be represented at the modeler's best estimate of detail, as shown in **Volume I Figure 4-9**.

Figure 4-9. Pump Modeling Schematic
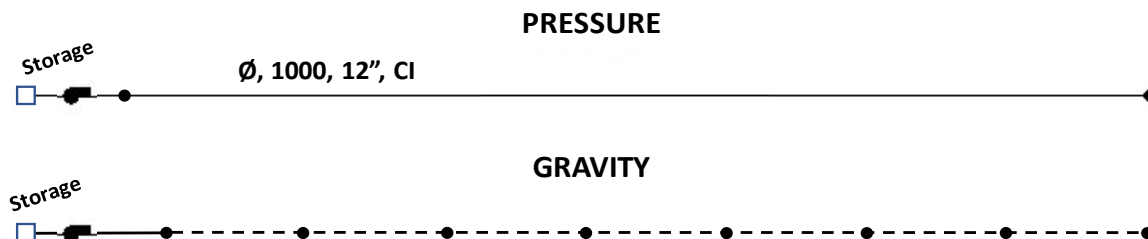
Force Main

MSDGC prefers to have an explicit representation of the components of their collection system. Because of this, model force mains using the conventional sewer elements and adding elevated surcharge depths (e.g., 999 feet), where appropriate, to avoid flooding to grade, rather than Force Main elements. Modelers may use the Force Main option with Hazen-Williams under special circumstances, or if approved by MSDGC.

4.6.6 Siphons

Represent siphons using conventional sewer elements and adding elevated surcharge depths (e.g., 999 feet), where appropriate, to avoid flooding to grade. Using the total headloss expected through each siphon, each siphon representation within the SWM should be adjusted such that the hydraulic elements would induce the same amount of headloss as was calculated. Any additional losses added to the elements should be documented within the model per the format provided in **Volume I Section 4.1**.

4.6.7 Sediment and Debris

Assume no sedimentation, unless data are available that support the assumption that stable sediment exists within a pipe segment. Stable sediment, such as accumulated cobbles or concrete that is too heavy for the expected velocities to mobilize, is unlikely to change. **Volume I Table 4-20** summarizes the recommended approach for modeling sediment or debris. If sedimentation is included in pipes within the model provided by MSDGC, the modeler should assume that the sediment representation was based on a prior model update and should not be removed unless supported by new data such as CCTV.

Table 4-20. Sediment and Debris Modeling	
Deposition Type	**Modeled**
Stable Sediment	Two methods: 1) Filled circular pipe – Preferred approach for modeling sediment is that the depth of sediment assumed is shown in the model parameters. 2) Edited cross-section – Unfortunately, the sediment feature is only available in the filled circular pipe. Editing the pipe cross section may be used for other pipe shapes but must be documented per the format provided in **Volume I Section 4.1**.
Moving Sediment	Sediment in EPA SWMM is fixed for the duration of the model run. Therefore do not model moving sediment.
Debris	With sufficient data, an approximation of entrance losses or orifice coefficients can be made for locations that are regularly blocked by debris. The modeler can develop a control curve for operating an orifice like a gate to represent the blinding by debris. Note that this would only be used in the SVC, D-SVC, or SA models. Representation of debris must be removed when updating the EC-Q_{n+1} model.

4.6.8 Flap Gates

Incorporate flap gates as model elements only where one exists or is proposed to be implemented. Flap gates may be added to unstable locations such as weirs within HRTs with permission of MSDGC Modeling Group.

4.7 FACILITIES MODELING

Model elements must often be combined to represent facilities within MSDGC's system. Guidance on how to properly represent typical MSDGC facilities is provided in the following subsections, while

information on each individual model element type (subcatchments, nodes, links, etc.) is covered in **Volume I Section 4.6**.

4.7.1 Regulator Representation

Representation of CSOs was standardized in 2017 for all SWM scenarios. MSDGC field surveyed and updated all regulator representations within their SWMs. Note that all float and gate systems were removed from MSDGC regulator structures, both in the field and in the SWMs. Generally, the structure is modeled by an inflow pipe (possibly with outlet offset), an underflow orifice, and an overflow weir. Coefficients were set by engineering judgement from a brief literature review. These values may be superseded by extended literature search, flow monitoring based calibration, or three-dimensional computational fluid dynamics (CFD) modeling. Further, if a regulator representation is exhibiting unstable behavior, minor adjustments to the regulator representation are allowed, provided the changes are discussed with the MSDGC Modeling Group.

Underflow Orifice

For the underflow, the orifice is connected to a duplicate node to start the underflow pipe. The duplicate node is normally named after the CSO node with a suffix of A added (MH 12345678A). The underflow orifice is modeled three ways; side opening, drop opening, and drop box side opening. The side opening is normally constructed in the field just upstream of the overflow weir. The modeled orifice is set to the invert of the inflow and outflow pipe. (In some cases, the orifice is set in a shaped pipe invert so the orifice is below the invert at the pipe centerline. In this case the orifice invert is the node invert and the inflow pipe has an outlet offset.) With the overflow weir directing flow to the orifice and the orifice set at the pipe invert, the orifice coefficient is set to 0.85 by engineering judgement. In some cases, the orifice is set in a shaped pipe invert so the orifice is below the invert at the pipe centerline. In this case the orifice invert is the node invert and the inflow pipe has an outlet offset.

The drop opening is normally built in the field as a larger vertical pipe to a smaller pipe elbow starting the underflow pipe. The duplicate node starting the underflow pipe has an invert set to the bottom of pipe elbow. The bottom orifice coefficient is set to 0.65.

The drop box side opening is built as a box below the inflow pipe invert with the underflow pipe starting as a side opening at the invert of the box. The inflow and overflow weir are modeled as vertically offset from the invert of the drop box. Based on the constriction of flow to the underflow pipe, the orifice coefficient is set to 0.85.

For CSOs that once had float-gate regulators, the gate chamber is modeled as a storage node having an orifice connection from the mainline sewer and a second orifice as entrance to the underflow pipe. As these orifices have directed flow to the orifice, the coefficient is set to 0.85.

Overflow Weir

The overflow weir is connected to a duplicate node to start the overflow pipe. The duplicate node is normally named after the CSO node with a suffix, usually E, added (MH 12345678E).

Most overflow weirs are modeled as weirs with weir coefficient set to 3.0 and the width set to approximate the flow width. Weir height (space above weir) is an engineering judgment to approximate shape of open pipe or other space above weir.

MSDGC recognizes that the SWMM weir is generally not the best representation of the hydraulics for CSO weirs. Other options may be better for the following situations:
- Large inflow and overflow pipes with minimal weir (high velocity over weir).
- Overflow pipes with interior weirs that create non-rectangular shapes.
- Weirs in vaults where the overflow is three dimensional into overflow pipe.

The weir may be replaced with a custom pipe with permission of the MSDGC Modeling Group and the use of observed data. The shape of the custom pipe will be the shape of the opening above the weir with the invert offset to the same elevation as the weir crest. The minimum length of the custom pipe is 10 feet for model stability with a roughness of 0.01. Entrance loss should be adjusted to match observed data. Weirs modeled as an orifice are discouraged due to the lack of control over parameters when acting as a weir. Weirs should only be converted to an orifice when the upstream water level is expected to exceed the crest of the overflow pipe for most storms. This conversion requires permission from the MSDGC Modeling Group.

Exceptions

Since the original float-gate mechanisms are modeled in the 2007 Baseline Conditions Models, the 2007 Baseline Conditions scenarios will continue to have the float-gate systems in the Control Rules.

Hydraulic brake regulators have been used at three CSOs. CSO 532 Daly Road Vortex had one on the underflow bypassing the vortex and one on the vortex underflow from 1998 construction to May 2017. CSO 438 and CSO 667 have each had one since 1998. These regulators should be modeled as conduit with fixed flow limits based on the regulator capacity except CSO 667 due to lack of information on regulator capacity.

4.7.2 HRT Systems

High Rate Treatment (HRT) systems are intended to remove solids and disinfect wet weather flows that would otherwise overflow untreated to receiving streams. The HRT described in this section is an approximation and can be modeled in greater detail.

Level of Detail in Modeling

During the Planning Phase of a project, representations of HRT facilities should typically be simplified in EPA SWMM as a system of pumps and storage nodes, with increasing detail added throughout the design process. Significant detail should be added to the model representation after the facility is built. **Volume I Figure 4-10.** shows an example schematic of an HRT setup in SWMM for use as a planning-level model. Note this is only an example of a typical HRT setup, and the HRT should be modeled as close to the proposed design as practical.

In this case, an HRT was modeled as an alternative at an existing CSO. A storage node should be placed between the regulator and the overflow. Once flow enters the storage facility, it can be pumped by the HRT or sludge pump, or it can overflow.

Figure 4-10. Typical HRT Set-up
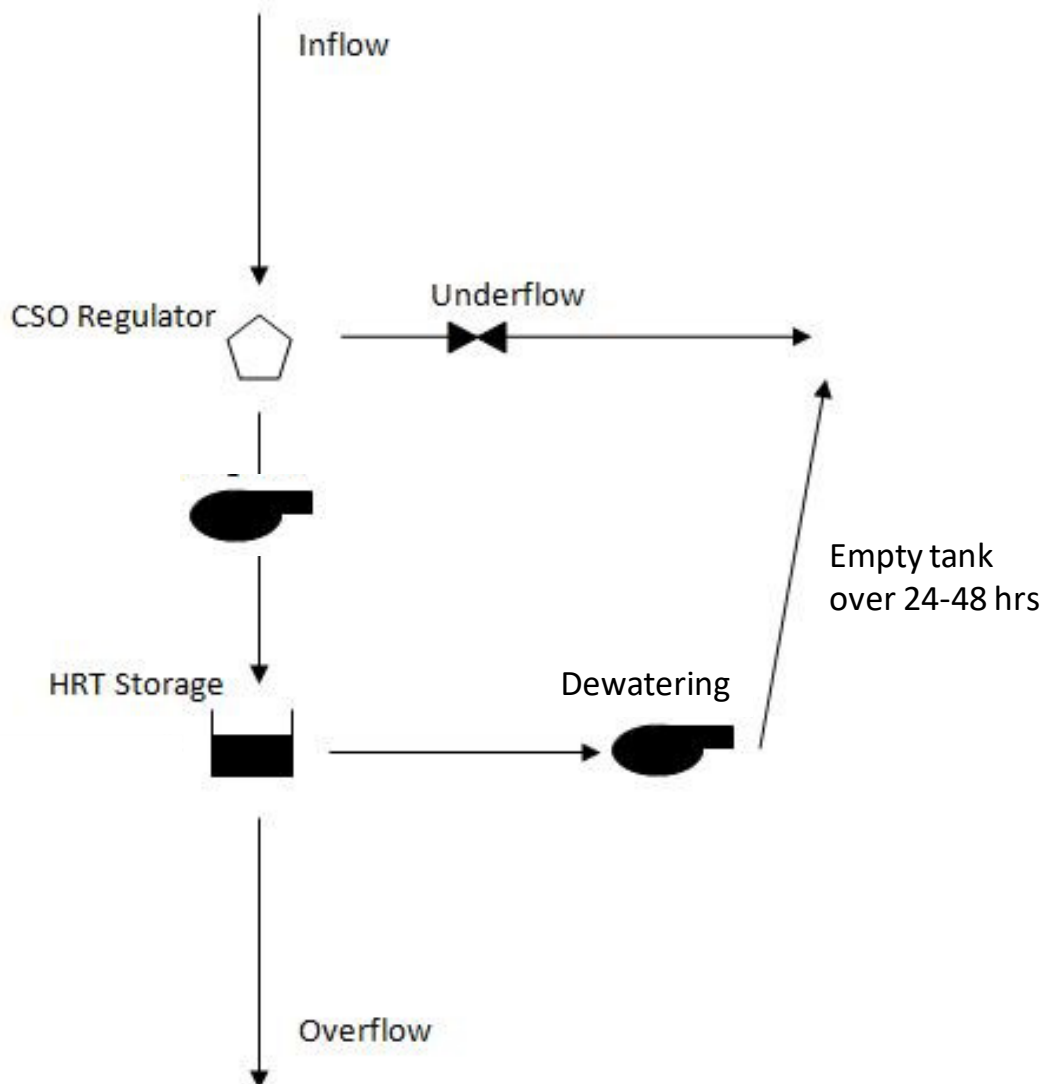
Considerations
Storage

The storage node should only represent the volume of the holding tanks. When a defined storage volume is not available, the modeler should evaluate a range of sizes in the alternatives analysis to determine an appropriate storage volume.

Pumping

The flow being pumped by the HRT pump is assumed to receive primary treatment and is pumped to an outfall (i.e., a receiving stream). For wet weather events in excess of the HRT's capacity, excess volume will overflow from the storage node and should be counted as overflow volume. The HRT pump will initially be set to turn on when water enters the storage node.

Possible Variations

HRT facility representation can vary by modeling the HRT as a storage facility or modeling to account for the activation of HRT trains. As a storage facility, the HRT and sludge pumps turn on when the volume in the HRT storage node reaches the volume in the HRT tanks. For this variation, a third pump to drain the HRT storage node after small events should be used to empty the storage when the HRT is not triggered. The drain pump will discharge to the interceptor. To account for the activation of HRT trains, the HRT pump and sludge pump rates should add to the total HRT capacity at each point in the capacity curve.

4.7.3 Storage Tanks

Storage tanks operate by capturing overflow up to a specific tank volume. After the tank is filled, no additional flow or pollutant load can be captured. After the storm, the storage tank is eventually dewatered back to the interceptor when capacity is available for treatment at the WWTP.

Inflow to a storage tank can be by gravity or pump. Gravity inflow should be represented by a conduit, weir, or orifice element and pump inflow should be represented by a pump element. Outflow from a storage tank could also be by gravity or pump. While the pump outflow would be represented with a pump element, gravity outflow should be represented by an orifice element. RTC elements and control rules may be needed to determine when dewatering is allowed based on downstream capacity. Also note that a sloped floor versus a flat floor can have a considerable effect on the dewatering of the facility. As such, the modeler should account for this type of detail when inputting the facility's storage curve.

4.7.4 Tunnels

EPA SWMM does not fully model transients in tunnels. Other specialized software should be used for modeling of tunnel operations and potential implications. EPA SWMM should be used for modeling the general operation of the tunnel in coordination with the rest of the collection system to determine overflow volumes.

If the tunnel has a circular cross-sectional area, the EPA SWMM representation should be a circular conduit. Irregularly shaped tunnels may be represented by conduits with a custom shape or a circular shape of equivalent cross-sectional area. Use of an equivalent circular area requires prior approval from the MSDGC Project Manager and must be documented in the Existing Conditions Model per the format provided in **Volume I Section 4.1**.

Tunnels normally have junctions at large distances (thousands of feet). These large distances may lead to instabilities during model runs. Intermediary junctions should be included every 300 feet for model stability.

Modelers should review HGL impacts for surcharge amounts sufficient to cause backwater from the tunnel into the sewer network.

4.7.5 Detention Ponds

Detention ponds are constructed during development and are generally small and not explicitly modeled. Runoff from an existing site may be redirected into a detention basin, and then drained back into the system at a slower controlled rate to reduce peak inflows at the downstream CSO regulator. If explicitly modeled, runoff from a redeveloped site may be routed through a detention pond to demonstrate the peak runoff contribution to the existing site's receiving stream has been maintained or reduced. Coordinate with staff from the MSDGC Modeling Group, as information on specific detention ponds may be available from Development Services.

Site detention, whether surface or underground, may be included in the model if the site will have a notable impact of system flows. Adding site detention representation can provide important detail to the model in some cases, however used excessively increases the model run time and adds potential of model instabilities. For most areas, site detention should only be represented if the tributary area of the detention is greater than 5 acres. For small CSO areas (less than 40 acres), the site detention can be represented if the tributary area of the detention is more than 1/8 of the total CSO tributary area.

The pond itself should be modeled as a storage node with a stage-storage curve assigned to represent size and shape of the pond. Outlet structures used to dewater detention ponds are unique to the individual projects and as such, modeling will be specific to the project. Outlet structures can vary in complexity, and careful consideration should be given for representing an outlet structure that consists of many different hydraulic components. The example provided in **Volume I Figure 4-11** illustrates that for complex outlet structures, the appropriate hydraulic element should be used to represent each phase along the structure's stage-discharge curve, rather than attempting to use a simplified representation, unless there are issues with model stability. Note that for each hydraulic element, documentation must be included in the Existing Conditions Model per the format provided in **Volume I Section 4.1**.

Figure 4-11. Outlet Structure Model Representation Example

Outlet Structure   **Model Representation**

Structure
Component   Model Element
1 = Circular orifice of diameter a
2 = Circular orifice with inlet offset b
3 = Rectangular orifice with inlet offset c
4 = Weir with inlet offset d
Weir Length = 2L+2W

Note that some adjustment may be
required to account for interaction of
flows from within the structure, and/or
backwater impacts. In some cases,
control rules may be needed for
switching between weir flow and orifice
flow, as needed.

Calculations should be performed to estimate the discharge capacity of the outlet from each opening
over the entire depth of the structure. The calculated stage-discharge curve should be compared to the
modeled stage-discharge curve as a validation of the Existing Conditions Model representation.
Volume I Figure 4-12 provides an example of a well matching stage-discharge curve.

Figure 4-12. Stage-Discharge Curve Example
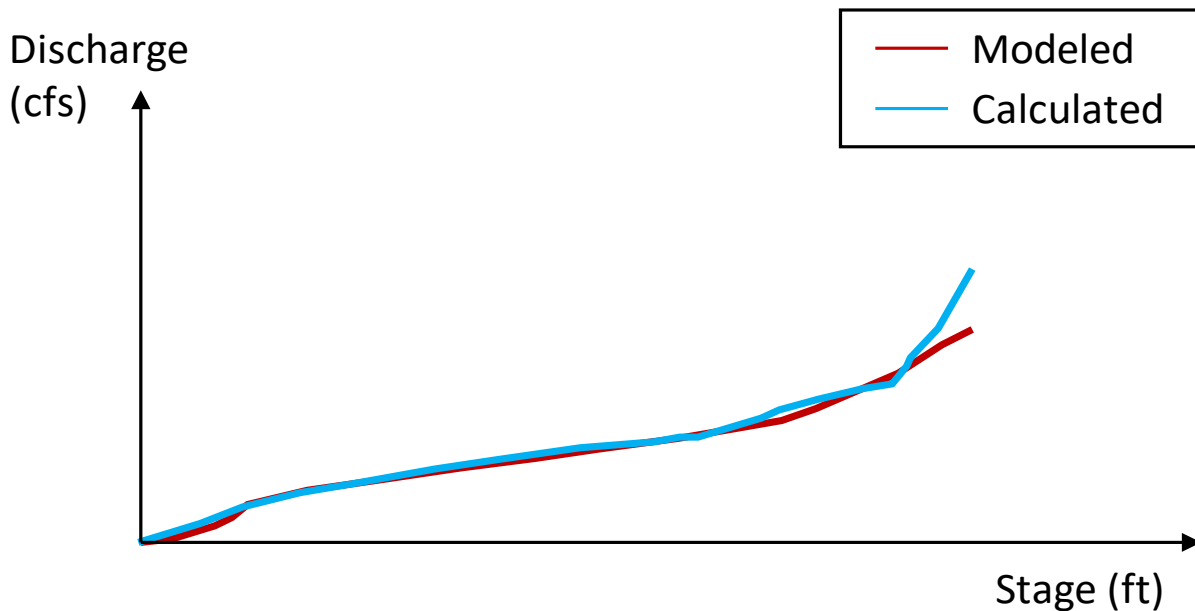
4.8   NEW DEVELOPMENT MODELING

If new development is proposed in a project area, the potential base flow and I&I should be accounted for in the model. The following outlines the requirements for new development areas.

For small new developments, the associated area and base flow should be applied to the first modeled manhole downstream of the assumed connection point. If the new connection point is unknown, the nearest manhole may be assumed. For larger developments, it may be appropriate to add some conduit and manhole elements to represent the new development.

For base flow, *MSD Rules and regulations, Article VI, Design of Sanitary Sewers* requires that new developments estimate the average flow of sanitary sewage shall be computed on the basis of 100 gallons per capita per day. The following requirements of the model representation were developed by MSDGC for representation of new developments in the model.

- Average value (flow): Calculate average flow rate based on the assumed population times 100 gallons per capita per day.

- Time Pattern 1: Appy the diurnal pattern shown in **Volume I Table 4-21** as an HOURLY type. No weekend or daily patterns should be applied.

Table 4-21. Diurnal Pattern for New Development			
Hour	**Ratio**	**Hour**	**Ratio**
12:00 AM	0.95	12:00 PM	1.21
1:00 AM	0.57	1:00 PM	1.15
2:00 AM	0.26	2:00 PM	1.06
3:00 AM	0.11	3:00 PM	0.99
4:00 AM	0.05	4:00 PM	0.97
5:00 AM	0.04	5:00 PM	0.95
6:00 AM	0.21	6:00 PM	1.02
7:00 AM	1.03	7:00 PM	1.22
8:00 AM	1.92	8:00 PM	1.4
9:00 AM	1.86	9:00 PM	1.51
10:00 AM	1.49	10:00 PM	1.46
11:00 AM	1.33	11:00 PM	1.24

For I&I, *MSD Rules and regulations, Article VI, Design of Sanitary Sewers* requires that new developments estimate an allowable of 1,000 gallons per acre per day (or 0.0166 CFS/acre). This value is assumed to account for the 10-yr, 24-hr peak flow. Therefore, the value must be applied to an assumed unit hydrograph. The following unit hydrograph was assumed for new development, which creates a peak of 1,000 gallons per acre per day for the 10-yr, 24-hr event. The following are the requirements of the model representation.

- Sewershed Area: Develop the sewershed area based on the approach described in **Volume I, Section 4.4.1**.
- Apply the unit hydrograph shown in **Volume I Table 4-22**.

Table 4-22. Unit Hydrograph for New Development					
Response	**Unit Hydrographs**				
	R	**T (hrs)**	**K**	**Dmax (in)**	**Drec (in/day)**
Short-Term	0.0027	0.083	4	0.1	0.05
Medium-Term	0.0048	0.33	5	0.25	0.125
Long-Term	0.0200	1.75	16	1.36	0.97

4.9   CREATING SUBMODELS

The MSDGC Modeling Group will provide the modeler with either the basin SWM or a submodel of the SWM, that is appropriate for the extent of the project. This will occur within the *Model Archive* app in FlowFinity. If the submodel of the SWM was provided to the modeler, the submodel is to be incorporated back into the SWM at the conclusion of the project. However, it is understood that the modeler may also desire to further subdivide the model throughout the modeling project for various reasons (e.g., isolate a CSO sewershed, decrease model simulation run time, etc.), which MSDGC allows. The submodel output should be compared to the overall SWM for peak flow and volume and for use in establishing appropriate boundary conditions. However, at the end of the modeling evaluation, the submodel must be loaded back into the model (full project area or SWM) as it was provided by MSDGC to determine the final calibration, impacts, and results. When going through the submittal process outlined in **Volume II Section 7.5**, all submittal items (models and all items generated from them, such as statistics and figures) must come from the full model as provided by MSDGC, not from a submodel. **Volume I Figure 4-13** illustrates the process for creating a submodel with boundary conditions as follows:

1. Identify cut points for submodel – meter site being calibrated **cannot** be a cut point (C ≠ B).
2. Load upstream and downstream time series.
3. Compare output; flow and depth hydrographs should match at the cut points.
4. Load updated submodel back into larger SWM before submitting final results.
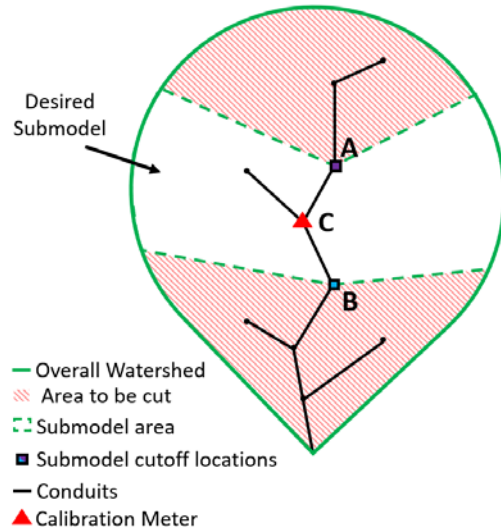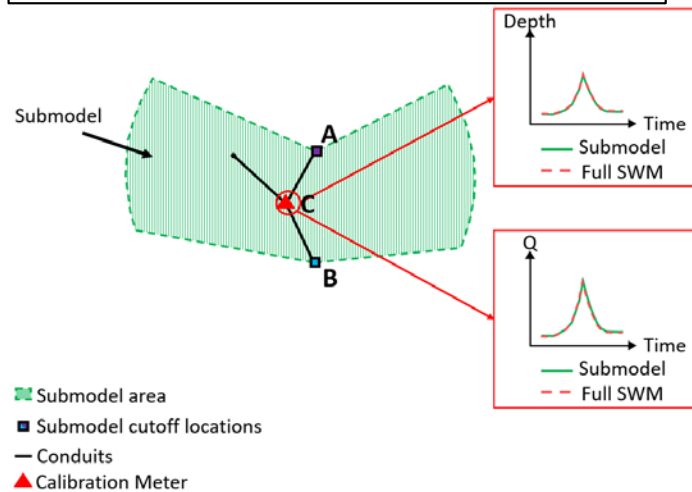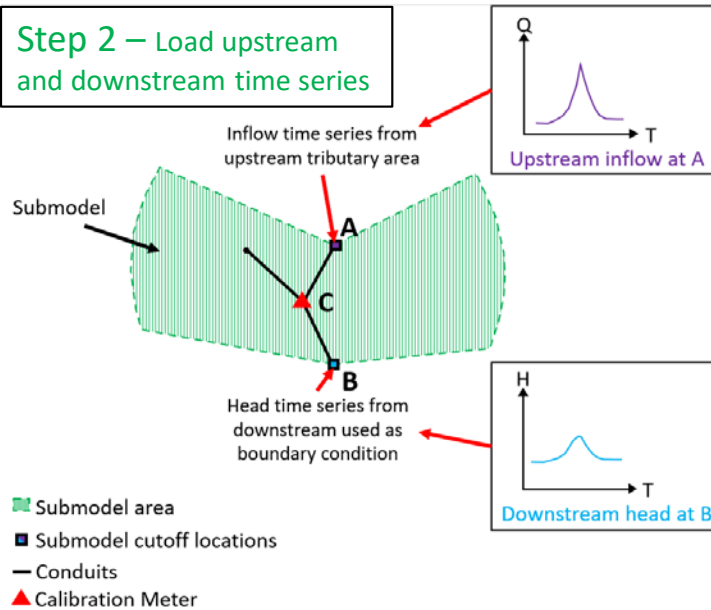
Figure 4-13. Entire SWM Before Model Cutdown
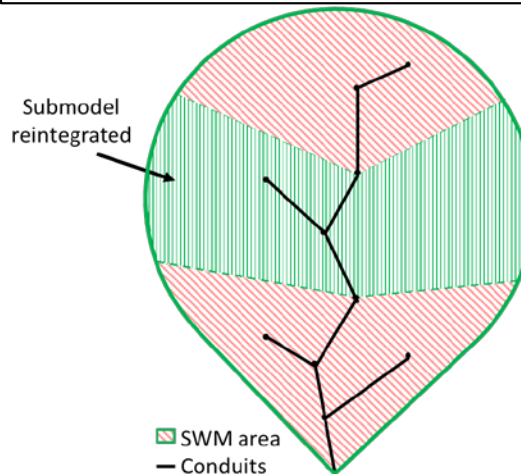
4.10 SPECIAL APPLICATIONS

The modeling methodology guidelines have been developed to ensure consistency in MSDGC SWM practice for common modeling procedures. This section outlines preferred approaches on less common applications, outside the model parameters that a modeler may encounter. If the modeler encounters a situation not covered by these guidelines, contact the MSDGC Modeling Group for further direction.

4.10.1 Low Impact Development (LID)/Green Technologies

EPA SWMM 5.0.023 and later versions have controls built into the software to explicitly simulate different LID controls. The LID controls can be added into Existing Conditions Models to replicate field conditions that reduce the amount of runoff within a watershed by the combination of infiltration, detention, and evapotranspiration. These controls are modeled as changes to the hydrology of the subcatchments. The modeler should use judgment in determining which parameters can be changed and how much to change them. Whenever possible, site data should be used over literature values.

LID structures have impacts beyond the attenuation of peak flows and removal of water from the sewer systems. LID changes the water quality (nutrients, temperature, dissolved oxygen, sediment, etc.) leaving a subcatchment. Water quality modeling, however, is beyond the scope of this document.

Soil Characteristics

For LID techniques that involve placing soil and fill, the available storage volume in the soil has an impact on the Existing Conditions Model results. Two common measures of the volume of water remaining in the soil are used: wilting point and field capacity. As shown in **Volume I Table 4-23**, the porosity of various soil textures is approximately the same. However, as the soil texture becomes finer, the pore sizes and soil particles become smaller. These two changes lead to water trapped in small pores (capillary effect) and adhering to particles. The result is that the fraction of pore space available for water storage (water that can be drained by gravity and evapotranspiration) is reduced as shown in the last column. For gravels, the field capacity and wilting point are small compared to the uncertainty in porosity and are considered negligible.

Table 4-23. Soil Classification and Porosity

Soil Texture Class	Fraction of Total Volume			Porosity Less Field Capacity
	Porosity	Field Capacity	Wilting Point	
Sand	0.437	0.062	0.024	0.375
Loamy Sand	0.437	0.105	0.047	0.332
Sandy Loam	0.453	0.19	0.085	0.263
Loam	0.463	0.232	0.116	0.231
Silt Loam	0.501	0.284	0.135	0.217
Sandy Clay Loam	0.398	0.244	0.136	0.154
Clay Loam	0.464	0.31	0.187	0.154
Silty Clay Loam	0.471	0.342	0.21	0.129
Sandy Clay	0.43	0.321	0.221	0.109
Silty Clay	0.479	0.371	0.251	0.108
Clay	0.475	0.378	0.265	0.097

Source: (Huff, F.A. & Angel, J.R., 1992)

Volume I Table 4-24 shows hydraulic conductivity, suction head, porosity, field capacity, and wilting point for various soil classifications, which can be referred to when inputting values to SWMM's LID Control Editor.

Table 4-24. Characteristics of Various Soils

Soil Texture Class	Ksat	Ψ	ϕ	FC	WP
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.4	0.437	0.105	0.047
Sandy Loam	0.43	4.33	0.453	0.19	0.085
Loam	0.13	3.5	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.31	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.21
Sandy Clay	0.02	9.45	0.43	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.6	0.475	0.378	0.265

Ksat = saturated hydraulic conductivity, in/hr
Ψ = suction head, in.   **FC** = field capacity, fraction
ϕ = porosity, fraction   **WP** = wilting point, fraction

Source: (Huff, F.A. & Angel, J.R., 1992)

The percolation decay constant (HCO) should be estimated as the slope of a best fit line through a plot of Log(K) versus moisture content. Refer to the EPA SWMM Manual to address this software detail more thoroughly. **Volume I Table 4-25** shows typical values for different soil types.

Table 4-25. HCO by Soil Type	
Soil Type	**HCO**
Sand	5
Loamy Sand	5.7
Sandy Loam	7.5
Loam	10.6
Silt Loam	10.8
Sandy Clay Loam	6.8
Clay Loam	10.1
Silty Clay Loam	12.8
Sandy Clay	9
Silty Clay	14.5
Clay	12.6

LID Within Subcatchments

For each subcatchment, several LID Controls can be added, provided the impervious area treated is 100% or less of the subcatchment impervious area. Each named LID Control can be added to the subcatchment as several identical controls. Identical in this case means that each line in the table of controls assigned to the subcatchment refers to controls that:

- Have the same layers as described by the control name in the LID Control menu.
- Have identical footprints.
- Receive flow from the same sized areas of the impervious area.
- Have an identical width of surface flow (porous pavement and vegetative swale).
- Have an identical initial saturation (soil layer for Bio-Retention Cells, storage layer for others).
- All either do or do not flow onto pervious areas.

If the controls differ in any of the listed factors, additional lines of controls are added to the subcatchment's table of controls. The modeler should verify that all the LID Controls combined treat 100% or less of the impervious area.

LID as Subcatchments

The modeler may want to use an LID Control as the entire subcatchment when modeling a green roof or regional water quality basin. In the case of a green roof, the runoff characteristics are very different from the rest of the subcatchment, so the situation is better represented as a new subcatchment. For the regional water quality basin, the basin can accept the runoff from several subcatchments as run-on.

4.10.2 Sewer Separation

For sustainable infrastructure modeling, the presumption is that a new stormwater system will be developed during sewer separation and that a separate outlet to a surface waterway will convey the majority of the stormwater. While there may be scenarios where inclusion of a stormwater system in the SWM is not warranted, stormwater systems should be included for the following scenarios, at a minimum:

- When verification of effectiveness of separation is needed to document credit on overflow reductions for Consent Decree compliance.
- If the receiving stream is already included in the model and is known to impact CSO or SSO volumes (e.g., Westfork Channel, Upper Duck Creek).
- Areas with reported or possible issues with open channels (flooding, erosion, debris), especially when projects will alter flow in channel.

The separation of stormwater from the combined system will be incomplete, as some stormwater runoff will still find its way into the existing combined sewer system. As a general rule of thumb, the values provided in **Volume I Table 4-26** can be used as a conservative estimate of how effective a complete separation project will be in the absence of other information (RDII studies, field investigations, research, etc.). A complete separation project includes all downspouts, area drains, catch basins, sump pumps and other direct sources of inflow. Projects that only address some of the inflow sources (e.g. street load separation) would have lower Separation Effectiveness values.   Note that the percentages provided in **Volume I Table 4-26** should be applied to the area of separation. For example, if 20 acres of residential area was proposed to be separated, 10 acres would remain connected to the combined sewer system in the model. All Separation Effectiveness values used in the model must be pre-approved by MSDGC.

Table 4-26. Stormwater Separation Effectiveness Base Assumptions		
Land Use	**Separation Effectiveness**	**Assumption**
Residential and commercial	50%	Many stormwater connections not found, or not removed.
Open grass areas, parks, and ravines	75%	Stormwater inflow due to damaged pipes and/or manholes.
New development, parking lots, and freeways	90%	Normal infiltration through joints.

Sewer Separation Procedure

Sewer separation should be modeled as splitting the base combined sewer runoff catchment into a combined sewer runoff catchment and a stormwater runoff catchment proportional to the Separation Effectiveness to maintain the total runoff catchment area within the model input files. This practice allows verification of the conservation of total runoff results and allows future efforts such as installation of sustainable infrastructure, sizing of stormwater system, etc.

The new storm sewer system should be modeled after the design drawings if it has been designed, or as-builts if it has already been constructed. However, if the storm sewer system is only in the planning stages, application of the following is recommended:

1. As a starting point in developing the stormwater system, the existing combined system will be mirrored by:
   a. Using the input files as a source of data tables to copy all nodes and links within the project areas.
   b. Renaming the nodes and links by ending the names with "S" for stormwater.
   c. Relocating the stormwater nodes and links by offsetting the X and Y coordinates of the nodes by a fixed distance (in the input file as [COORDINATES]). Suggested distances are 100 feet for both the X and Y coordinates.
2. Runoff catchments are duplicated and renamed with the "S" for storm designation.
   a. Outlet node names must also be edited for the stormwater catchments.
   b. Offset the X and Y coordinates of the stormwater catchments by the same distances as the nodes (in the input file as [POLYGONs]).
3. Adjust runoff parameters based on estimated effectiveness of separation.
   a. Area and percent impervious based on areas separated.
   b. Width determined from flow path length of areas separated or based on original catchment parameters.
      - Adjusted width = Original width / Original area x Adjusted area
   c. Other parameters may change for specific situations.
4. Assign last node in stormwater system as outfall or connect to other modeled stormwater systems as the situation merits.
5. Model runs should be performed to verify that the total runoff volume remains the same before and after development of the separated catchments. Information reviewed includes runoff volume, infiltration volume, evaporation volume, and peak runoff rates.
6. It is also recommended to simulate a large design storm to evaluate if out-of-system flooding occurs and determine if flow will be transferred between the proposed storm sewer and existing combined sewer systems. Depending on the goals of the project, the design of the proposed storm sewer separation may need to incorporate measures for mitigation of that flow transfer.

If the project uses new sanitary sewers, the design will be based on current MSDGC guidance. All sanitary flows will be transferred from the existing modeled sewer to the new modeled sanitary sewer. As a conservative assumption, all storm and/or RDII inflows will remain in the existing system. The RDII to the new system will be based on current MSDGC guidance.

Subcatchment Refinement Procedure

Some separation may be targeted, such as just front lawns and streets. For those, the subcatchments in the existing conditions model must be refined before they are split for the separation scenario.

When refining subcatchments to isolate select areas for sewer separation, the following rules apply:
- The original subcatchment should be split in existing conditions to isolate the area to be separated.
- All parameters except % Imperviousness from the original subcatchment to the new split subcatchments (maintaining FPL not Width).
- The impervious area (not percentage) of the original subcatchment should match the total impervious area of the two new subcatchments.
- The DCIA (calibrated impervious area) versus total impervious area should be proportional between the original subcatchment and all new subcatchments.

When refining subcatchments to isolate select areas for sewer separation, the following procedure should be followed.
- In the existing conditions model, split subcatchment area to isolate the area to be separated under the alternative.
- Apply all parameters from the original subcatchment to the new split subcatchments (maintaining FPL not Width).
- Calculate the total impervious area of the original subcatchment and the new subcatchments. Note: [original subcatchment impervious area] = the sum of [new subcatchment impervious areas]
- Calculate new subcatchment percent imperviousness (DCIA); see **Volume I Figure 4-13.**
- Outlet of the new subcatchment may differ from the original.
- Validate the model:
  - Validate the new vs original subcatchment runoff for the following design events to verify the combined hydrograph from all changed subcatchments recreates the original hydrograph– 2-month 24 hour, 6-month 24 hour, 1-year 24 hour, and 5-year 24 hr.
  - If available, validate against the historical monitoring data at the first downstream calibration monitor.
  - If the outlet of the new subcatchments is significantly different than the original, the model must be validated against historical monitoring data.

- In the **alternatives model**, "separate" the appropriate subcatchments per MSDGC Guidelines. The Separation effectiveness will be determined per **Volume I Table 4-26**.

Varying other subcatchment parameter is strongly discouraged. If any other parameters area varied MSDGC must be consulted, and the approach explicitly approved. The new model must be validated against the monitoring data from the original model calibration.

Figure 4-13. Refined Subcatchment Impervious Calculations
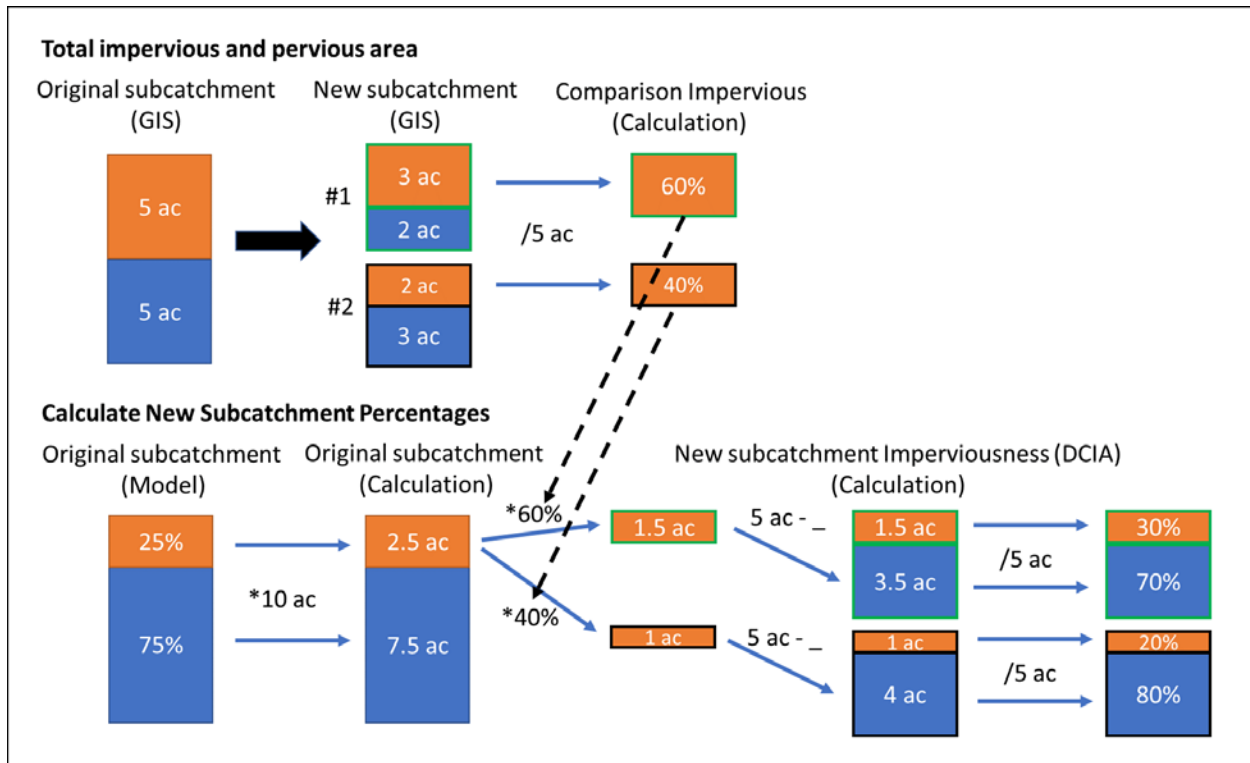
4.10.3 Control Rules

Control Rules are used to adjust links, pumps, weirs, and regulators in a conveyance system during a simulation. Control Rules allow the adjustment of model parameters in reaction to modeled or time series values. Examples include:

- Adjusting gates to control water levels upstream or downstream of the gate.
- Limiting flow through a pipe to control downstream flows.
- Turning pumps on or off separate from the pump curve settings.

A Control Rule is a statement comprised of a label, condition clause, action clause, and a priority value that are edited in the Control Rules Editor. When testing a new or modified rule, the recommended method is to use only a portion of the Existing Conditions Model with boundary condition time series as needed. Artificial time series with extreme values and period of values just above & below triggers may be used to verify the proper response for the full range of possible values.

The control rules during calibration (SVC, SA, D-SVC) are expected to be appropriate for the actual operations during the calibration period. Actual operations may include observed data referenced in the calibration control rules. They are replaced with control rules commensurate with SOPs for use in subsequent models (EC-Q_{n+1}, BSL, ALT, D-PC, PCS).

Control Curves

The Control Curve determines how the control setting of a pump or flow regulator varies as a function of some control variable, such as depth or flow. A Control Curve can be used in applications where continuous control in a simulation is required.

The Control Curve is created in the Curve Editor and referenced in an action clause as the setting parameter. The range of values in the control curve should extend above and below any possible modeled input values. The modeler should understand the impacts of extreme values on the controlled value. For example, when controlling for the gate opening (an actual fraction of full open flow) based on the depth in a manhole, the range of depth should go from zero feet to the full depth of the manhole (including added surcharge depth). This range of depths allows the modeler to know the gate settings for unexpected events including model instability.

4.10.4 Real Time Control

Real Time Control (RTC) features have been implemented in recent projects completed by MSDGC. RTC facilities are designed to optimize the amount of combined sewage reaching the treatment plant while minimizing overflows from the CSO regulators. This is accomplished by storing wet weather flows until the interceptor has capacity. Using level sensors, water levels at several locations are constantly monitored. When levels reach a programmed target point, a predetermined action occurs, such as a sluice gate opening/closing or an inflatable dam increasing/decreasing its internal pressure. The RTC response to specific levels can come as one of three types: Full, Direct, and Proportional Integral Derivative (PID).

Other systems, using sensors and control systems to adjust sewer system operation in real time, may be used by MSDGC but will be named using other terms.

Full Real Time Control

The Full Real Time Control method is a basic method for simulating RTC that utilizes Control Rules to regulate flow by completely opening or closing gates when triggered.

Direct Real Time Control

The Direct Real Time Control method references a Control Curve to apply a continuous degree of control to a pump or flow regulator as a function of a control variable, such as depth, flow, or time.

Observed data or known operational strategies of an RTC, such as an inflatable dam or sluice gate, are used to create a Control Curve. This Control Curve is referenced in a Control Rule to simulate the RTC function.

PID

A PID is a generic, closed-loop control scheme that tries to maintain a desired set-point on some process variable by computing and applying a corrective action that adjusts the process accordingly. MSDGC Project Manager approval is required before implementing PID controls. Use actual on/off, close/open, and/or percent closed values from supervisory control and data acquisition (SCADA) on historic records in the Storm Volume Calibration model. Replace the actual values with control rules in subsequent models (EC-Q_{n+1}, BSL, ALT, D-PC, PCS).

4.10.5 Manhole Flooding

Manhole flooding can cause significant errors in calibration and the application of design storms. Any manhole flooding in the model during the calibration period must be specifically identified during the submission process. All manhole flooding during any application of the model, typically during the application of design storms, must be explicitly reviewed. It must be either ponded, recaptured or clearly be identified as leaving the system as appropriate.

 While **No Ponding** is the usual setting **(Volume I Table 4-3)**, allowing ponding can be used on a case-by-case basis when evaluating flooding and/or recapture of flooding is of particular importance for the project. Depending on the level of accuracy of modeling required, how far the manhole overflow travels before re-entering the sewer, and whether the overflow returns to the same sewer line, these situations may be modeled in two ways:

- Where the overflowing manhole and receiving manhole are in close proximity and on the same sewer line, the ponding and return is modeled at the overflowing manhole.
- For flows that travel a significant distance before returning to the system, it might be deemed necessary to route overflows. To model this situation, add the street (use a special shape in the cross-section editor), natural channel, etc., to the model. Add the estimated depth of flow to the overflow and return manhole depths. The conveyance is modeled to carry the overflow to the return manhole. 2D modeling may be necessary in certain cases. However, this is not the preferred approach unless absolutely necessary. The need for 2D modeling should be confirmed with the MSDGC PM, since this could potentially require a significant increase in the level of effort.

4.10.6 Lining Sewers

Sewer lining is an effective way to prevent leaks in old pipes and/or increase the velocity through a rough section of pipe. Typically, liners range in size from 6-mm thick for an 8-inch pipe to 27-mm thick for a 30-inch pipe. This translates to a loss of 6-7% of pipe diameter, which is well within all the other sources of potential error in the Existing Conditions Model.

Structural linings to support failing pipes may be significantly thicker (up to 6 inches). For these cases, the liner thickness and final roughness must be modeled by changing pipe size/shape and roughness.

Where sewer lining is reported, the user should change either the roughness and diameter, or make the determination that no change is needed in the Existing Conditions Model. This must be noted within the model element's Description field per the format provided in **Volume I Section 4.1**.

4.10.7 Development and Use of Pollutographs

Effective management of a sewer collection system considers not only reducing the volume of uncontrolled discharges, such as CSOs, but also limiting the release of pollutant loads and the corresponding severity of their impact on water quality in local waterways. The pollutant strength of CSOs varies not only from location to location, but also temporarily at a given location. Because of this, MSDGC prefers the development and use of pollutographs, rather than the use of event mean concentration (EMC) to assess water quality where the SWM is used to develop mass loadings to the waterways from sewer overflows. Refer to **Volume I Appendix C** for guidance on this process.

4.10.8 Situation That Does Not Require an Existing Conditions Model Update

Addition of New Dry-Weather Flow

Adding new dry-weather flow area most likely does not require a full-scale modeling effort. Currently, model results are reported in cubic feet per second (cfs) to one decimal place. If the additional dry-weather flow is less than 0.1 cfs, model adjustments are not required as the Existing Conditions Model results will not be impacted significantly.

4.10.9 Situations That Does Not Require Recalibration

Changes in Horizontal Layout, Manning's Value, Planned Pipe Slope

Hydraulic changes to horizontal layout can generally be updated in the Existing Conditions Model without needing to be recalibrated. Hydraulic change such as changes in the pipe length, pipe slope, or number of turns with energy losses do not generally require recaibration. Estimates of hydraulic coefficients is acceptable.

4.10.10 Topics Outside MSDGC System Wide Model

The topics outlined below are considered outside the MSDGC SWM effort. The level of effort involved in developing and adding the required data to the model are greater than the presumed level of accuracy added to model.

High Receiving Water Levels

The SWM generally does not consider receiving stream water levels. For major streams, such as the Ohio River, Little Miami River, and Mill Creek, the scale of the effort in developing river models is beyond MSDGC's purview. Specific smaller streams, such as Duck Creek and West Fork, have been

modeled where the receiving stream water levels have a direct impact on combined sewer overflow (CSO) performance, water level data are available, and the modeling effort is manageable. Receiving stream water level data should be used for calibration. River level data is available from the MSDGC Wet-weather SCADA system as a time series for all CSOs to be used in developing the SVC, SA, and D-SVC models. It is eliminated from the subsequent models (EC-Q$_{n+1}$, BSL, ALT, D-PC, PCS) which use the Typical Year. Refer to **Volume II Section 4.5.1** for guidance on water level data collection.

Surface water intrusion affects the MSDGC sewer system during floods. Sometimes the Ohio River, Mill Creek, etc., will rise and water will enter the MSDGC collection system either through infiltration by raising groundwater levels or by direct inflow through an open CSO flap gate, damaged manhole, etc. Estimation of this inflow is uncertain and, in general, storms that show evidence of high river intrusion should be rejected from the calibration.

During calibration, set a boundary condition on all CSO overflows equal to the river stage of the receiving stream. Level monitoring at CSOs, SSOs, and other structures may be used to indicate likely high receiving water levels due to depth vs. flow for the site, high levels during low sewer flow periods, etc.

Snowmelt
Snowmelt is not accounted for in the SWM. Storm events with snow, evidence of snowpack melt, or frozen ground should be identified and not be used in the calibration process.

Modeling of Wastewater Treatment Plants
MSDGC has developed hydraulic models for each of the seven major wastewater treatment plants (WWTPs) in separate software outside of SWMM. Therefore, SWMM should only be used for modeling the general operation of the influent pumping in coordination with the rest of the SWM.

5.0 VOLUME I REFERENCES

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LIST OF APPENDICES

Appendix A – Nomenclature

Appendix B – Pipe Shapes

Appendix C – Development and Use of Pollutographs

APPENDIX A – NOMENCLATURE

The purpose of this Appendix is to establish a fundamental definition of the different parts of a flow hydrograph (modeled or observed). As was discussed in **Volume I Section 3.0**, this is done as an attempt to eliminate ambiguity in common parlance when referring to different parts of a hydrograph (e.g., the definition of "dry weather flow" may include groundwater infiltration for one modeler, but not for another).

Figures A-1 through **A-4** illustrate the different parts of a flow hydrograph, with each figure building on the previous figure by introducing and adding flow components starting from the bottom of the flow hydrograph up to the peak. Note that in the examples provided, "modeled" flow hydrographs are used. This is only for illustrative purposes. The same concept would be applied to observed flow hydrographs.

Note that the process to identify and develop each of the flow components discussed in this Appendix is covered in **Volume II Section 6.0**.

Figure A-1. Dry Weather Flow (DWF)
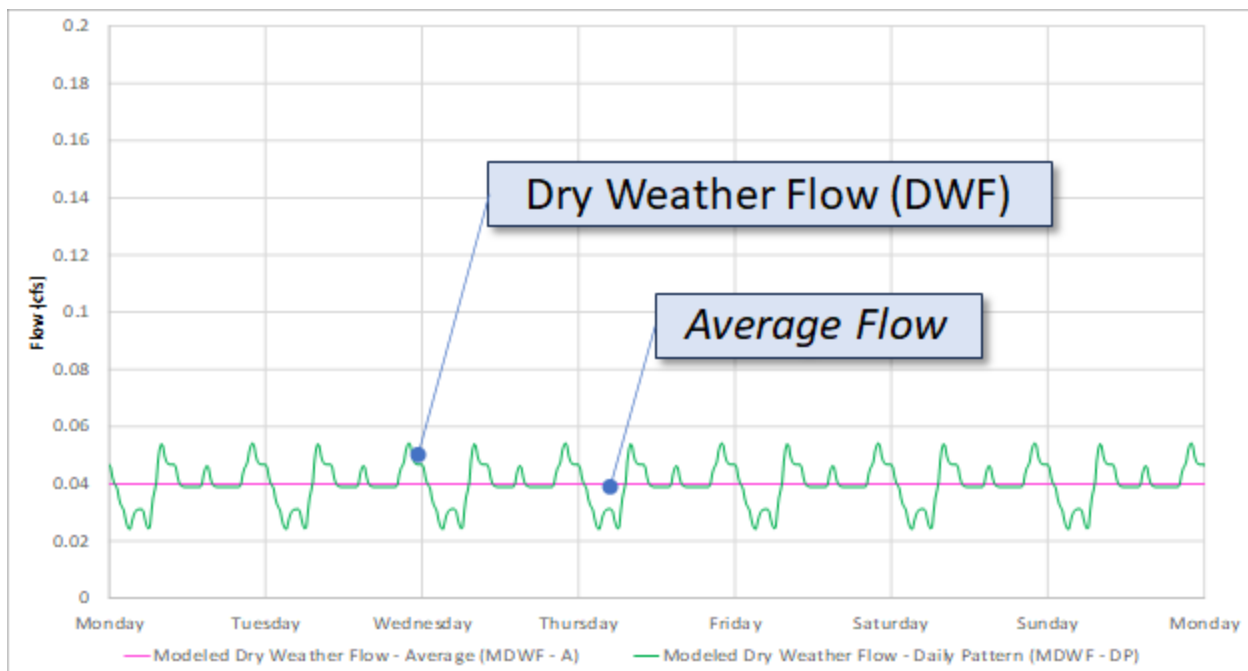
Figure A-1 illustrates the following:

- Dry Weather Flow (DWF) = Dry weather flow-daily pattern (the diurnal pattern resulting from *Time Pattern 1*: HOURLY the Hourly Pattern applied to *Average Value*.
- *Average Value* = Dry weather flow-average: sanitary contribution, and low flow period groundwater.
- *Time Pattern 1* - HOURLY = Dry weather flow-daily pattern (the diurnal pattern).

Figure A-3. Base Flow (BF)
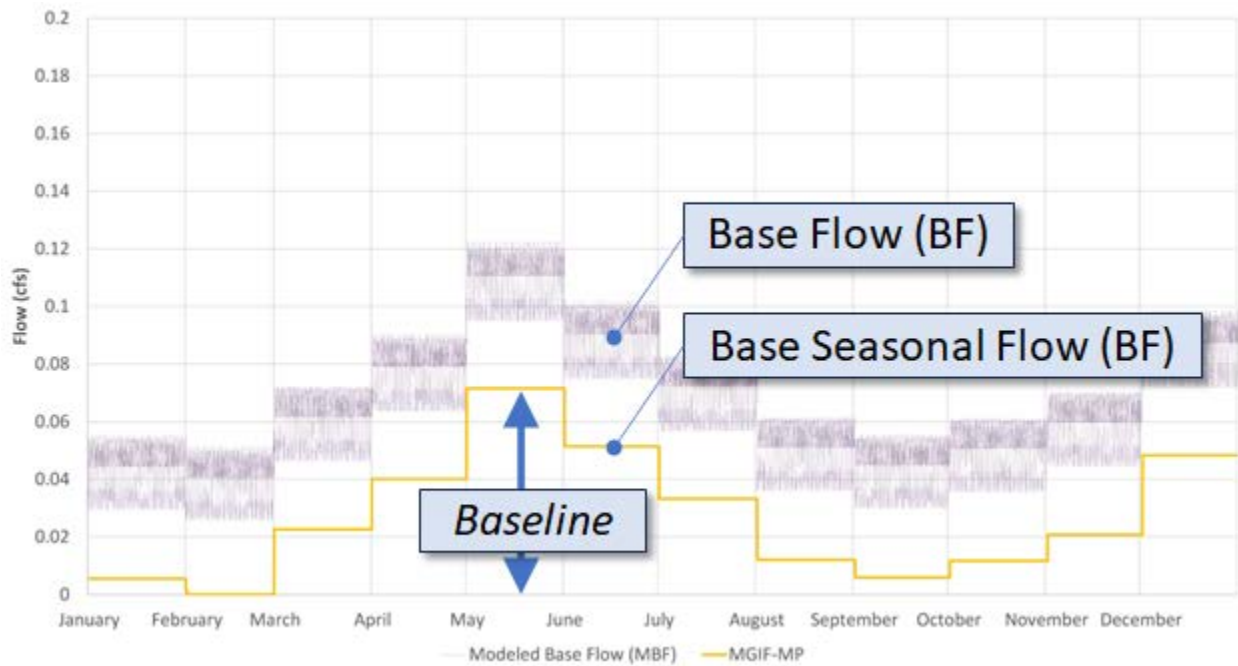
Figure A-3 illustrates the following:
- *Baseline* is the difference between the BF for the highest and lowest month
- *Baseline Pattern*: *MONTHLY* is a factor from zero to one applied to *Baseline*.
- Baseline Seasonal Flow (BSF) = *Baseline*   x   *Baseline Pattern: MONTHLY*
- BF = DWF + BSF

Figure A-4. Total Flow
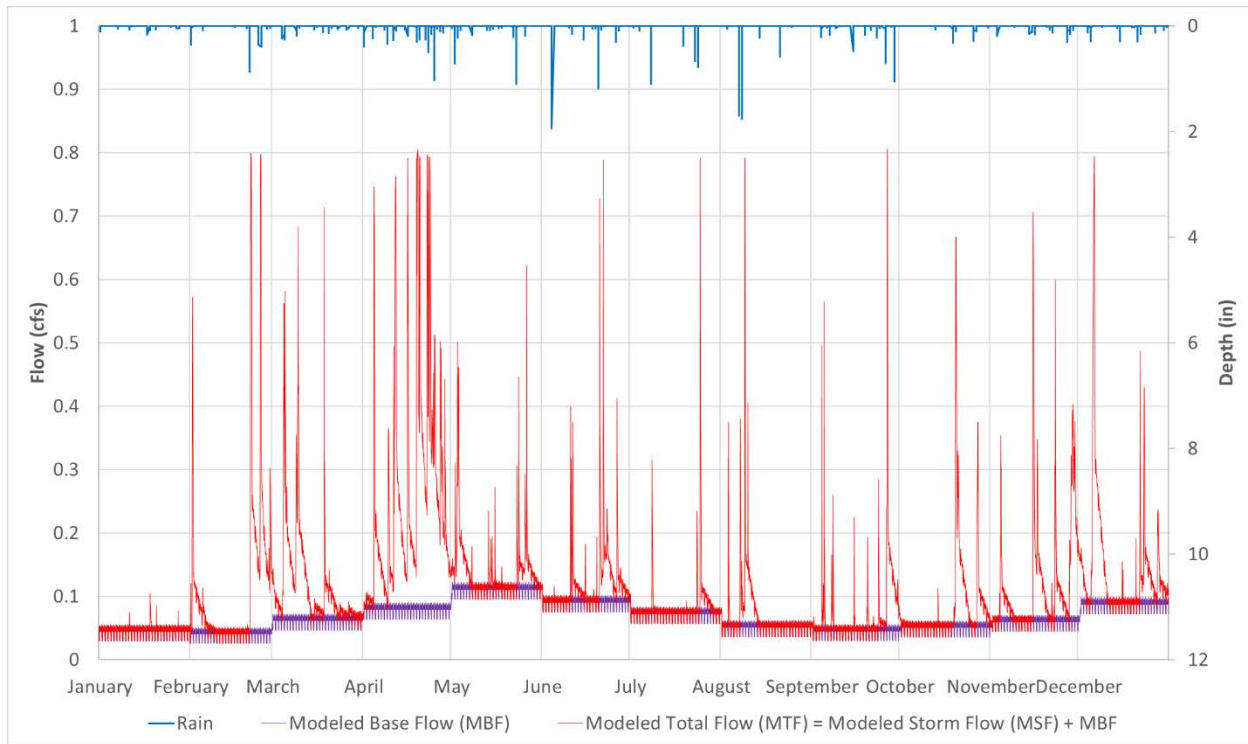
Figure A-4 illustrates the following:

- Storm Flow (SF) = the part of the hydrograph that is the result of RDII and/or surface stormwater runoff, only; does not include Base Flow
- Total Flow (TF) = Base Flow (BF) + Storm Flow (SF)

Understanding MSDGC's definition of the different parts of a flow hydrograph, as they have been defined in **Figures A-1** through **A-4**, will provide modelers with a foundational understanding of the flow components, which can then be extrapolated to include many different variations, as shown in **Volume I Table 3-1**.

APPENDIX B – DEVELOPMENT AND USE OF POLLUTOGRAPHS

The objective of this modeling method is to estimate the temporal variability in the severity of sanitary sewage in CSO discharge by implementing a mass tracer in the collection system model that corresponds to the sanitary sewage contribution.

Analysis Method

This section describes the methods developed to simulate the water quality sanitary sewage severity in a CSO discharge. The general steps of this analysis are:

1. Estimate the daily sanitary sewage contribution within a CSO basin as a function of the basin characteristics.
2. Implement a mass tracer in the collection system model (EPA's Storm Water Management Model [SWMM] that corresponds to the sanitary sewage contribution.
3. Apply the collection system model for the desired period (e.g., Typical Year).
4. Evaluate the model output.

Each step is described in more detail below. Since Step 4 depends on the user's specific interests, it is less prescriptive than the other steps.

Estimate Sanitary Sewage Contribution

Purpose: Estimate residential equivalent units (REUs) using GIS-based analysis for one or more CSO basins. The process is described for one CSO basin, but the procedure can be scaled for multiple CSO basins.

Data Inputs:

Obtain the following GIS datasets from MSDGC, Cincinnati Water Works, and CAGIS, respectively:

- CSO basin polygons (CSO_Areas.shp) – contributing areas to each CSO outfall.
- Cincinnati WaterWorks Premises (cww_premises.shp) – buildings using water and, thus, generating wastewater.
- Sabre Mass Data Appraisal (SMDA) Buildings (smda_bld.shp) – buildings that are not single family residential (e.g., multi-family, commercial, industrial, etc.)

If the WaterWorks Premises layer is not available in the area of interest, this dataset from CAGIS can be substituted:

- SMDA dwellings (smda_dwl.shp) – single-family residences

Overview:

The Cincinnati WaterWorks Premises layer has information about the type of building on each property (e.g., apartment, industrial, government, etc.). For buildings that are listed as residential (e.g., single family residential), the calculation of REU is straightforward; each building with a WaterWorks connection has a REU of 1.

For buildings that are not single-family residential, the process is more complicated. Information about multi-family residences, such as apartments and condos, require information about the number of units (e.g., number of apartments, etc.). Each unit is assumed to represent 1 REU.

For businesses and government, the REU calculation requires information about the square footage of the building (larger buildings get a higher REU because they have more bathrooms). The information needed to calculate the REUs for buildings other than single-family residential can be found in the SMDA Buildings layer for most of the buildings.

The procedure below describes how to link these datasets (WaterWorks Premises and SMDA Buildings), as well as capture the information about the CSO basin each property is in.

Procedure: For a given CSO basin,

1. Set up GIS data:

   1.1 Set up a .mxd containing all of the datasets listed above. It is helpful to have a background showing the buildings and roads, such as the ESRI topographic Base Map.

   1.2 Inspect the map to determine if WaterWorks Premises data are available throughout the CSO basin of interest. If not, the SMDA Dwelling layer can be used to fill the gap.

   1.3 Set up a Spatial Join between the CSO basin layer and the WaterWorks Premises layer. Export the attribute table as a text file.

   1.4 Set up a Spatial Join between the CSO basin layer and the SMDA Buildings layer. Export the attribute table as a text file.

   1.5 If the WaterWorks Premises layer is incomplete in the CSO basin of interest, then set up a Spatial Join between the SMDA_Dwellings layers with the CSO basin polygon. Export the attribute table as a text file.

   Note: Depending on the area being analyzed, it may be beneficial to limit the Export action in steps 1.3, 1.4, and 1.5 (if needed) to the points within the CSO basin. A selection query that restricts the points to the set where the "CSO" field is 'X' (where X = CSO basin of interest) can be used to select the subset of relevant points.

2. Process the spatial data in Excel to calculate REUs for the CSO basin(s)

   2.1 Import each of the text file exports from Steps 1.3 – 1.5 into an Excel file in separate worksheets.

   2.2 For each connection in the WaterWorks Premises layer that is not single-family residential, information from the SMDA Buildings layer is needed to calculate the REU for that connection. This set of steps compiles this information:

      2.2.1 Make a pivot table of the SMDA Buildings layer as follows:

- o Row fields = "PARCELID" and "CARD_NUMBER".
- o Value fields = "CARD_NUMBER" as Count, "BASE_AREA" as Max, "NUM_STORIE" as MAX, and "NUM_UNITS" as Max.
- o In the Design ribbon, set the report layout by selecting 'Show in Tabular Form' and 'Repeat All Item Labels'
- o For the Row fields, set the Field Settings for each field so that Subtotals are set to "None".

Notes on SMDA Building layer:

- o The PARCELID is an identifier of the property (parcel). This identifier is also included in the WaterWorks Premises layer.
- o Each CARD_NUMBER associated with a PARCELID appears to indicate a different building on the property. It is probable that each building has a separate WaterWorks Premises connection but there is no common identifier in the two datasets that can be used to link the buildings.
- o For commercial, industrial, and public properties, the REU is calculated as a function of building square footage, so the area of each building on a parcel needs to be computed, which is why the Base Area ("BASE_AREA") and Number of Stores ("NUM_STORIE") are used.
- o All area fields are assumed to have units of square feet.
- o For multi-family residences, such as apartments and condos, the REU is calculated as a function of the number of units, which is given in the "NUM_UNITS" field.

2.2.2 Depending on the version of Excel being used, it may be helpful to copy and paste the Pivot table as values so that the information is more easily retrieved via Excel formulas and updates can be made to the data where warranted.

2.2.3 Inspect the table for easily identified errors, such as non-numeric values. If the error has an obvious fix, adjust the value. Otherwise, leave the field as is.

2.2.4 Add a new field at the end of the pivot table column labeled "BLDG_AREA".

2.2.5 For each row in the table, populate the BLDG_AREA column with a formula that calculates the product of the corresponding BASE_AREA and NUM_STORIE fields:

BLDG_AREA = [BASE_AREA] X [NUM_STORIE]

Note that some values may be zero.

2.1 Link the SMDA Buildings information from the pivot table with the corresponding parcel connection information on the WaterWorks Premises worksheet.

2.3.1 Make a pivot table of the WaterWorks Premises layer as follows:

- o Row fields = "CSO", "GRPPCLID", "PARCELID" and "DWTP".

- o Column field = "RAZED"
- o Value fields = "PARCELID" as Count
- o In the Design ribbon, set the report layout by selecting 'Show in Tabular Form' and 'Repeat All Item Labels'
- o For the Row fields, set the Field Settings for each field so that Subtotals are set to "None".
- o For the Column field, set the "RAZED" selection to not display values of "Y" (values of "N" or blank should be included in the REU calculation).

Notes on WaterWorks Premises layer:

- o The "GRPPCLID" and "PARCELID" fields both appear to be identifiers of the property (parcel), though they do not always have the same value for a given property. Both can be used to link to the "PARCELID" field in the SMDA_Buildings layer, though the "GRPPCLID" seems to have more matches with the SMDA Buildings "PARCELID" field value.
- o The "RAZED" field indicates whether the property has a building structure. A value of "N" (No) indicates the building is still standing while a value of "Y" (Yes) means there is no building structure on the property. For these properties, the assumption is that although WaterWorks is providing water service, no water is being discharged into the sewer system, so the REU is 0. For the purpose of this analysis, a blank value is assumed to have a structure.
- o The "DWTP" field is the dwelling type. This information will be used to determine the information needed from the SMDA Buildings layer to calculate REUs (for buildings other than single-family residences). The values used in this field are defined below.

2.3.2   On the WaterWorks Premises pivot table worksheet, add four new fields at the end of the pivot table columns:

- o Number of Units
- o Base Area (ft^2)
- o Number of Stories
- o Building Area (ft^2)

2.3.3   Set up a SUMIF formula in Excel to look up the GRPPCLID value in the SMDA Buildings layer pivot table column with the PARCELID and return the result for Number of Units (sum the NUM_UNITS column), Base Area (sum the BASE_AREA column), Number of Stories (sum the NUM_STORIES column) and Building Area (sum the BLDG_AREA column).

2.3.4   Repeat step 2.3.3 using the PARCELID field from the WaterWorks Premises layer instead of the GRPPCLID field.

2.3.5   Keep the maximum of the values returned from steps 2.3.3. and 2.3.4.

Note: There are multiple WaterWorks points for some properties with multiple SMDA Building layer points. Although this method is intended to limit duplicate information for a given property, they may still occur. Duplicate values can be identified by the GRPPCLID field, typically when a GRPPCLID has more than one PARCELID. However, the SMDA Building layer may match the PARCELID rather than the GRPPCLID, so both are needed for the initial data linkage. Inspect the results and remove any duplicates.

3. Calculate REUs

3.1   For each parcel in the WaterWorks Premises pivot table, use the guidance below to estimate the REU(s).

Table C-1. Residential Equivalence Unit Table

#"DWTP" Identifier	Description		Number of REUs[1]	Notes
APART	Apartment		1.00	Per unit
CONDO	Condominium		4.00	Assume each condo has 4 units
GENBUS	General business		0.55	Per 1,000 sq. ft. of building area
GOLFCL	Golf club		0.55	Per 1,000 sq. ft. of building area
GOVERN	Government building		0.15	Per 1,000 sq. ft. of building area
GRNHSE	Greenhouse		2.00	Assumes five employees per shift
INDUST	Industrial		0.55	Per 1,000 sq. ft. of building area
MEDHOS	Medical hospital		1.09	Per 2,500 sq. ft. of building area[2]
MNFTRG	Manufacturing facility		0.55	Per 1,000 sq. ft. of building area
MULTFM	Multifamily		1.00 4.00	Per unit

[1]https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&ved=2ahUKEwi38ovy-PlAhUGUK0KHQG2CysQFjADegQIABAC&url=https%3A%2F%2Fwww.genoa.org%2Fcontentfiledata%2Fdownload%2F1769&usg+AOvVaw0WKeP7f6FMiexy013Q9u10

[2] https://www.healthcaredesignmagazine.com/trends/research-theory/8-considerations-benchmarking/

#"DWTP" Identifier	Description		Number of REUs[1]	Notes
				Assumed when number of units is not available
RESDNT	Residential		1.00	Per dwelling
SCHOOL	School		0.80	Per 2,200 sq. ft. of building area
SWIMCL	Swim club		3.00	Per 1,000 sq. ft. of building area
WHOLE	Wholesale		0	These are wholesale water customers who appear to then distribute the water within their jurisdictional boundaries. If this dwelling type is identified in the CSO basin, it's likely that the SMDA datasets will need to be used.

3.2   If there are commercial, industrial, or other non-residential properties in the WaterWorks Premises layer that do not have area or number of story information from the SMDA building layer, there are two options:

3.2.1   Inspect the property individually in GIS and Google Street View to approximate the information. Google Street View will provide information on the number of stories while in GIS, the measure tool can be applied with the Environmental Systems Research Institute (ESRI) topographic base map to estimate the building base area.

3.2.2   Approximate the REU as the average value of the property's dwelling type.

3.3   For areas where the WaterWorks Premises data are not available, then both the SMDA Building and SMDA Dwellings layers will be used to estimate the REUs as follows:

3.3.1   For the SMDA Buildings layer, calculate the building area for each building as described in step 2.2.5 and calculate the REU as 0.55 per 1,000 square feet of building area.

3.3.2   For the SMDA Dwellings layer, each dwelling is assigned 1 REU. Limit the use of the SMDA dwellings layer to only those points that do not have a WaterWorks Premises point.

3.4   Sum all REUs in the CSO basin.

Note that these REU methods may be refined in the future.

Output: Spreadsheet with individual building and total estimated REUs in the CSO basin.

Implementing a Mass Tracer in SWMM

Model Inputs and Setup

- Calculate sanitary flow in CSO basin as REU x 2.5 persons/REU x 150 gallons/person/day (gpcd) and convert to flow units in SWMM model.

- Divide sanitary flow by a suitably large factor, such as 1,000. This adds a negligibly small volume of additional flow so that the overall model behavior does not change.

- Determine an appropriate hourly pattern to apply to the sanitary tracer flow. This may involve some adjustment where observed hourly flow factors are significantly attenuated by dry weather infiltration, which is explained in more detail below.

- Identify junctions in the model where the sanitary tracer will be added. In small basins, it may be sufficient to add all the tracer to a single junction in an upper portion of the basin. For larger basins, the tracer could be distributed proportionally among multiple junctions. In any case, there should be some dry weather flow upstream of the tracer addition to avoid potential mass routing issues.

- Add a pollutant to the model with an unambiguous name such as "SanitaryTracer". For each junction where sanitary tracer flow has been added, set the concentration of "SanitaryTracer" to 100 times the factor used to divide the calculated sanitary flow in the previous step; for example, if the calculated flow was divided by 1,000, set the concentration of "SanitaryTracer" to 100,000 mg/L. In this way, the concentration of the tracer in the CSO will directly correspond to the percentage of sanitary sewage. As SWMM limits the number of decimal places in its output, the larger number helps retain some precision in the results.

- The above procedure is intended to impose a specific sanitary load regardless of how dry weather flow has been specified in a particular SWMM model. The REU-based sanitary flow should be compared against the dry weather flow in the model, which is expected to be based on flow measurements to the extent possible. The following steps depend on 1) the approach used to model dry weather flows in the model, and 2) the magnitude of the REU-based sanitary flow relative to the total dry weather flow in the SWMM model.

  o If the REU-based sanitary flow is less than 90% of the SWMM dry weather flow, it can be assumed that the difference is attributable to dry weather infiltration, which has the effect of attenuating diurnal variations in flow. An hourly pattern should be applied to the REU-based sanitary tracer flow that has been adjusted to account for this attenuation using the formula:

$$\alpha_i = 1 - \frac{Q_{DWF}}{Q_{SAN}}(1 - \theta_I)$$

- where:
- α_i =   adjusted sanitary tracer flow multiplier for hour I
- Q_{DWF} =   dry weather flow in SWMM model
- Q_{SAN} =   REU-based sanitary flow
- θ_I =   original model flow multiplier for hour i

o   If the REU-based sanitary flow is greater than 90% of the SWMM dry weather flow, use the hourly pattern in the model without adjustment. This may at times result in an apparent sanitary sewage fraction greater than 100%, but this would occur only during dry weather and is not expected to result in unrealistic fractions during overflow conditions.

Model Application

- Run the SWMM model for the desired simulation period.
- Extract the tracer concentration and CSO flow output at the node corresponding to the CSO outfall (note: other nodes of interests (e.g., DUC, etc.) could also be extracted). If the tracer is input properly, the output concentration should represent the % of flow that is sanitary sewage.
- Calculate a sanitary sewage overflow time series by multiplying the total CSO flow by the tracer concentration; divide by 100 assuming the above procedure for scaling has been followed.

Evaluate the Model Output

Processing of the results will be based on user interests. For example, to calculate the volume of sanitary sewage captured in a Typical Year for a specific storage volume, follow these steps:

- Use time series of CSO flow and sanitary tracer concentration to derive time series of sanitary sewage volume.
- Define overflow events.
- For each overflow event, calculate time series of both cumulative total overflow volume and cumulative sanitary sewage volume.
- For a specific storage volume, calculate sanitary volume captured as either:
  o   Entire volume for events < storage volume
  o   Corresponding point on cumulative sanitary volume curve where cumulative total CSO volume = storage volume
  o   Sum over all events

The last two steps can be repeated for other storage volumes to develop a curve that shows the volume of sanitary sewage captured for increasing storage volume. Development of these curves for multiple CSO locations may demonstrate increased benefit at certain locations; specifically, that a given volume of storage will capture a larger volume of sanitary sewage at some locations compared to others.

Assessment of capture in terms of actual pollutant mass requires assumptions for pollutant concentrations in sanitary sewage at a minimum, and, if a comparison is to be made with EMC approaches, for the other constituents of the overflow as well. It may be adequate to simply assume that the balance of the overflow (total minus the sanitary portion) is runoff, with an assumed

concentration assigned to it. For SWMM models that explicitly consider groundwater contributions, it is suggested to add tracers to both runoff and groundwater so that their individual contributions can be quantified. Runoff and groundwater tracers can be defined in the same way as the sanitary tracer (as a specific pollutant in SWMM), and the concentration can be set to 100 mg/L in the pollutant editor dialog box, using the entries for "Rain Concen.", and "GW Concen.", respectively. If the model includes rainfall-dependent infiltration/inflow modeled with the TRK unit hydrograph method, a tracer can also be added for this source, and the concentration set using the "I&I Concen." entry in the pollutant editor dialog.

VOLUME II. MODELING PROCESS

1.0 MODELING PROCESS OVERVIEW

This section provides a general overview of the modeling process established by MSDGC's Modeling Group. Each modeler will specify the type of project and steps involved in completing the work *before* beginning any modeling work.

1.1 FLOWFINITY

Throughout this document, there are frequent references to "FlowFinity", the central SQL based workflow tool used by MSDGC to track and manage workflow through the modeling process. It is broken up into various applications "apps", each of which contain different submittal items, information, or references that consultants may need during work with an MSDGC model. Use of FlowFinity and its apps require a login, and requests for credentials can be made to the MSDGC Modeling Group.

1.2 PROJECT DEFINITION AND FLOW CHART SELECTION

While every modeling project will have its own unique set of circumstances and scope that may vary from the process provided herein, work associated with an MSDGC modeling project can generally be categorized into two different phases: Model Update and Planning. This concept is illustrated in **Volume II Figure 1-1**.

The Model Update phase generally involves the calibration and updates to MSDGC's SWM models using the rainfall and other inputs of a specified historic time period or single event. The Planning phase involves developing a Baseline Model and Alternative Models to determine possible solutions for a specific objective or hydraulic issue based on a Typical Year or design storm.

Figure 1-1. Model Project Phases
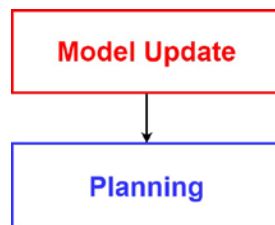
Focusing first on the Model Update phase, this will typically consist of two types of projects: Calibration, and Storm Analysis, as shown in **Volume I Figure 1-2.** Calibration Projects involve updating Existing Condition models based on a defined flow monitoring period. Storm Analysis projects are appropriate when analyzing a single (*normally extreme*) storm event or conducting a study for MSDGC that is limited in scope. For example, the model may need to be evaluated and adjusted based on flooding observed during a recent large storm event.

Figure 1-2. Modeling Update Project Types
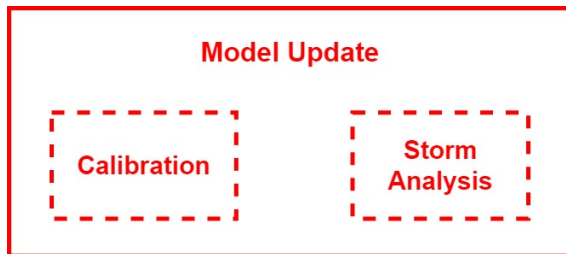
Taking this generalized process one step further, Model Updates can be broken out into two types of projects: Standard Models and Detailed Models. This is shown in **Volume II Figure 1-3.**

Figure 1-3. Details of Project Types
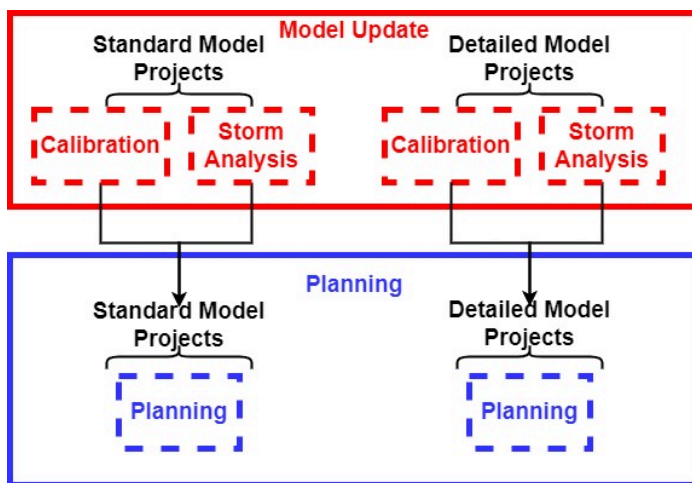
Standard Models have a level of detail necessary to provide accurate hydraulic analysis of the system. They do not contain details of the drainage within individual parcels or include basement storage.   For Standard Models, the MSDGC Modeling Group will provide the subcatchment delineations as explained in **Volume I Section 4.3.2**.

Detailed Models include additional information that will be removed or averaged prior to incorporation into the MSDGC vaulting process. These models often add smaller pipes, private lines, subdivide parcels and include basements.   Consultants may develop Detailed Models when the constraints of the project require it as described in **Volume II Section 5.0**. Once the project is completed any calibrations must be converted back to the level of detail of MSDGC's Standard Models after approval in order that the calibration performed can be captured in the vaulted model. Detailed Models will be submitted for all stages of review. In addition, the Detailed Model will be submitted for comparison with the initial model to document a "Library of Changes," such that the Detailed Model could be recreated if/when needed. For a Detailed Model project, the subcatchment delineation will be performed by the consultant and approved by the MSDGC Modeling Group.

As shown in **Figure 1-1** and **Figure 1-4**, if the Planning portion of a project is required by MSDGC, it will either be performed from a model from the MSDGC model vault or follow the Model Update. Vaulted Models and Standard Model updates will lead into Standard Planning projects; Detailed Model updates will lead into Detailed Planning projects.

Figure 1-4. Project Types and Planning Models
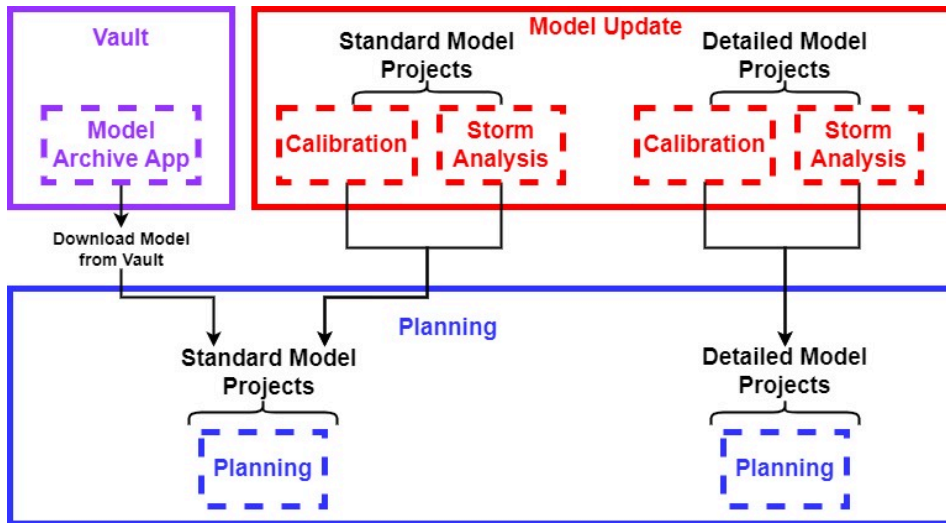
Last are the project steps for a Miscellaneous Model update, which is shown in **Volume II Figure 1-12**. As shown in **Volume II Figure 1-5,** Miscellaneous Model updates are not part of the Model Update phase nor the Planning Phase progression; these are standalone updates which feed into the vaulting process as discussed in **Volume II Section 2.1.** Miscellaneous Model updates are generally intended for new field information or adjustments to the model representation of various hydraulic elements. An example could be an adjustment of a weir height based on a field measurement.

Figure 1-5. Summary of All Model Types
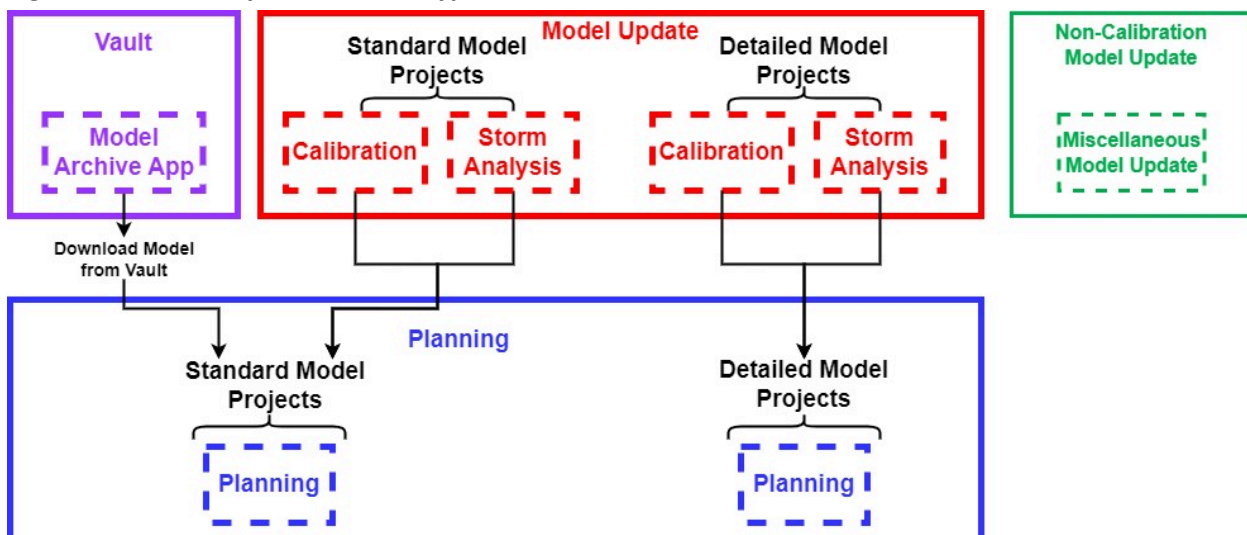
Before discussing the specific steps in the processes identified above, it will be helpful to provide the model abvreviations that will be used.

1.3 MODEL DEFINITIONS

The model definitions provided in **Volume II Table 1-1** coincide with the models shown in **Volume II Figure 1-6** through **Figure 1-12.**

Table 1-1 Model Definition Summary			
Model			**Brief Summary**
Model Number	Designation	Name	
1	EC-Q_n	Existing Conditions	Most recent version of Existing Conditions model from the model vault for the basin containing the project. *****
2	SVC	Storm Volume Calibration	The specific project area extracted from the EC-Q_n. This is the base project model for a Standard Model calibration effort. *****
3	D-SVC	Detailed Model Storm Volume Calibration	The same as an SVC model, but with additional details added by the consultant. *****
4	SA	Storm Analysis	The specific project area extracted from the EC-Qn. This is the base project model for a Storm Analysis adjustment to calibration. *****
5	D-SA	Detailed Model Storm Analysis	This is the same as an SA model, but with additional details added by the consultant. *****
6	SVC-Cal	Storm Volume - Calibrated	SVC updated with the calibration of storm volumes to a period of observed data. ******
7	D-SVC-Cal	Detailed Model Storm Volume - Calibrated	D-SVC updated with the calibration of storm volumes to a period of observed data. ******
8	SA-Cal	Storm Analysis - Calibrated	SA model updated with the calibration to a single (*usually extreme*) storm event. ******
9	D-SA-Cal	Detailed Model Storm Analysis - Calibrated	D-SA model updated with the calibration to a single (*usually extreme*) storm event. ******
10	EC-Q_n-Cal	Existing Conditions - Calibrated	SVC-Cal or SA-Cal incorporated back into the EC-Q_n with Typical Inputs. *****
11	Pre-BSL	Pre-Baseline Model	EC-Q_n, SVC-Cal or SA-Cal with Typical Inputs for alternative modelling. *****

Model			Brief Summary
Model Number	Designation	Name	
12	D-Pre-BSL	Detailed Pre-Baseline Model	D-SVC-Cal or D-SA-Cal with Typical Inputs for alternative modelling. *****
13	BSL	Baseline Model	Pre-BSL with the addition of appropriate boundaries and various projects constructed or will be constructed. The BSL may require the use of full SWM to account for all projects. *****
14	D-BSL	Detailed Baseline Model	D-Pre-BSL with the addition of appropriate boundaries and various projects constructed or will be constructed. The D-BSL may require the use of full SWM to account for all projects. *****
15	ALT	Alternative Model	Models of the individual alternatives under consideration, created from the BSL. Typically, multiple alternatives will be evaluated so multiple model ALT models will be created. *****
16	D-ALT	Detailed Alternative Model	Models of the individual alternatives under consideration, created from the D-BSL. Typically, multiple alternatives will be evaluated so multiple models will be created. *****
17	PC	Proposed Conditions	The selected alternative (PC) will match one of the ALT models, and is the final recommended project proposed for implementation. *****
18	D-PC	Detailed Proposed Conditions	The selected alternative (D-PC) will match one of the ALT models, and is the final recommended project proposed for implementation. *****
19	PC-Q_n	Proposed Conditions - Full Model	The PC incorporated into the EC-Q_n for the model archive process. *****
20	EC-Q_n-R	Revised Existing Condition	Exclusive to Miscellaneous Model Updates, this is the revised Existing Conditions Model after an update to the Model. *****
21	EC-Q_{n+1}	Existing Conditions - New	EC-Q_n-Cal incorporated back into the Master Model. In the case of a Miscellaneous Model Updates, this represents the final, vaulted model after the update. *****

*These models use the Standard Operating Procedures (SOP) governing valve, pump, gate, and real time control (RTC) operations.

**These models MAY use SOP settings OR may use the actual operations for the specific simulation period. The actual operations may be necessary when actual operations are not accurately simulated by a single set of rules, and timing errors obfuscate the accuracy of the hydraulic and hydrology calibration.

1.4   STEPS FOR MODEL PROJECTS

The steps in the progression of a model from Existing Conditions to Proposed Conditions involves multiple intermediate models. As shown in the flowcharts in **Volume II Figure 1-6** through **Figure 1-12**, between the transition from one model condition to the next, actions are performed by modelers to facilitate that transition, followed by the documentation and review process to validate and record each model in FlowFinity for review, approval and archiving.

These flowcharts follow the paths and relations of the "archive model", the model that is submitted and tracked within the MSDGC Database. The progression of the "archive model" is shown through the "Archiving" column of the flowcharts, usually occurring within the *Model Archive* app in FlowFinity.

In addition, these Flowcharts follow the paths and relations of the "project model", the model that is updated by a consultant over the course of a project. The progression of the "project model" is detailed through the "Consultant Model Versions" column of the flowcharts.

Modelers must document the steps taken from the time of acceptance of the SWM from MSDGC to completion of their modeling improvements and analysis. The documentation serves the purpose of model management and future reference. MSDGC manages changes to the SWM by reviewing and accepting changes to the model in phases. Using phases instead of reviewing and accepting a final product reduces the possibility incorrect changes to the SWM.

To facilitate this type of model management, MSDGC developed a system of checks and documentation for each step throughout the modeling process. As shown in **Volume II Figure 1-6** through **Figure 1-12**, specific project instructions have been established to help guide modeling efforts in a consistent direction. The process includes model check-out/check-in procedure, submittal of information at various milestones, and steps for MSDGC to review and comment on the progress of the modeling work.

The steps provided in **Volume II Figure 1-6** through **Figure 1-12** should be adhered to for all MSDGC modeling projects, with the understanding that there will be exceptions. In all instances, the MSDGC Modeling Group must be consulted prior to beginning any modeling project to confirm the correct course of action and identify which project flow chart and appropriate steps should be followed. For this reason, **Volume II Figure 1-6** through **Figure 1-12** should be used as both a starting point for all modeling projects, as well as a reference guide for the remainder of these Modeling Guidelines.

Figure 1-6. Standard Model Calibration Project Steps
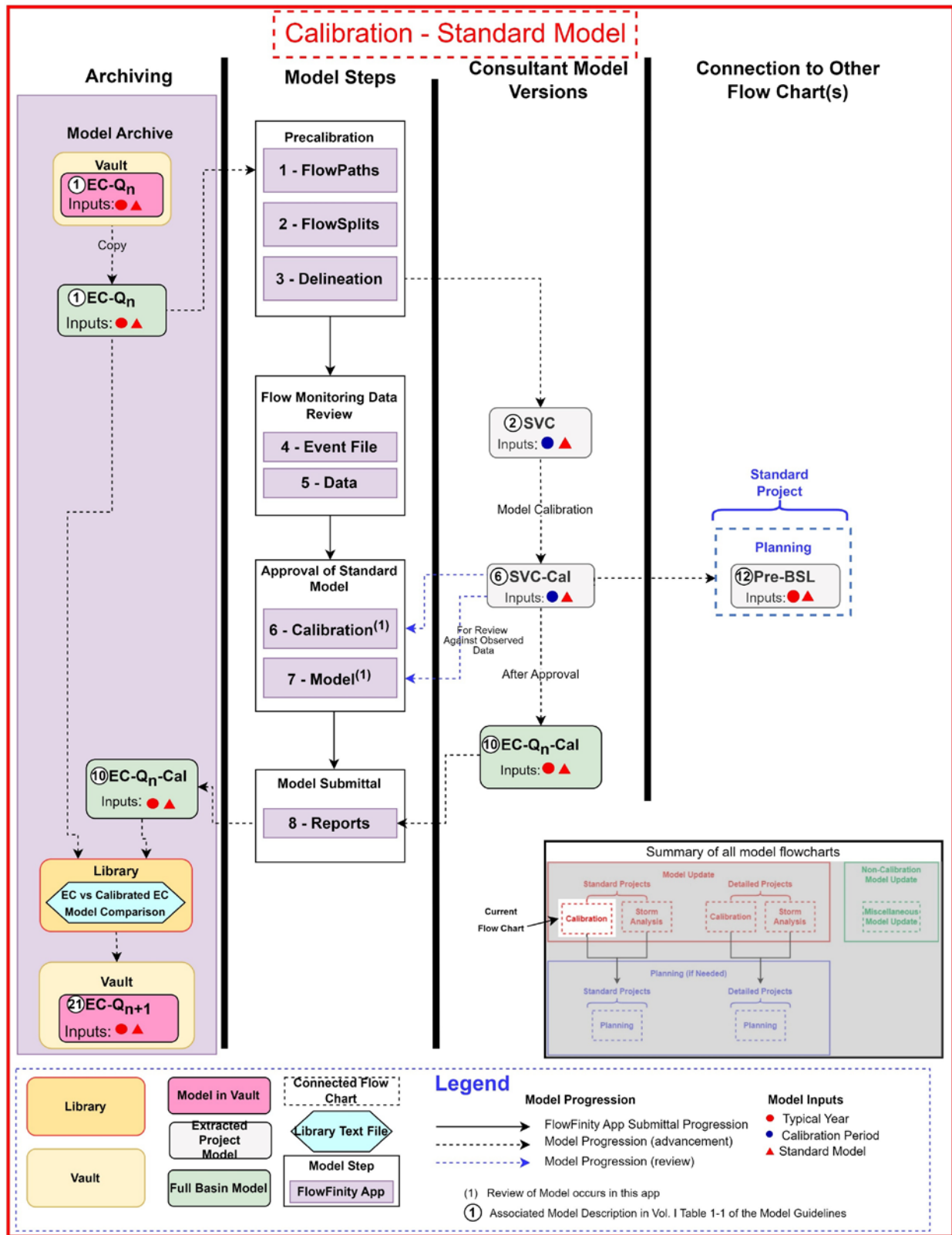
Figure 1-7. Detailed Model Calibration Project Steps
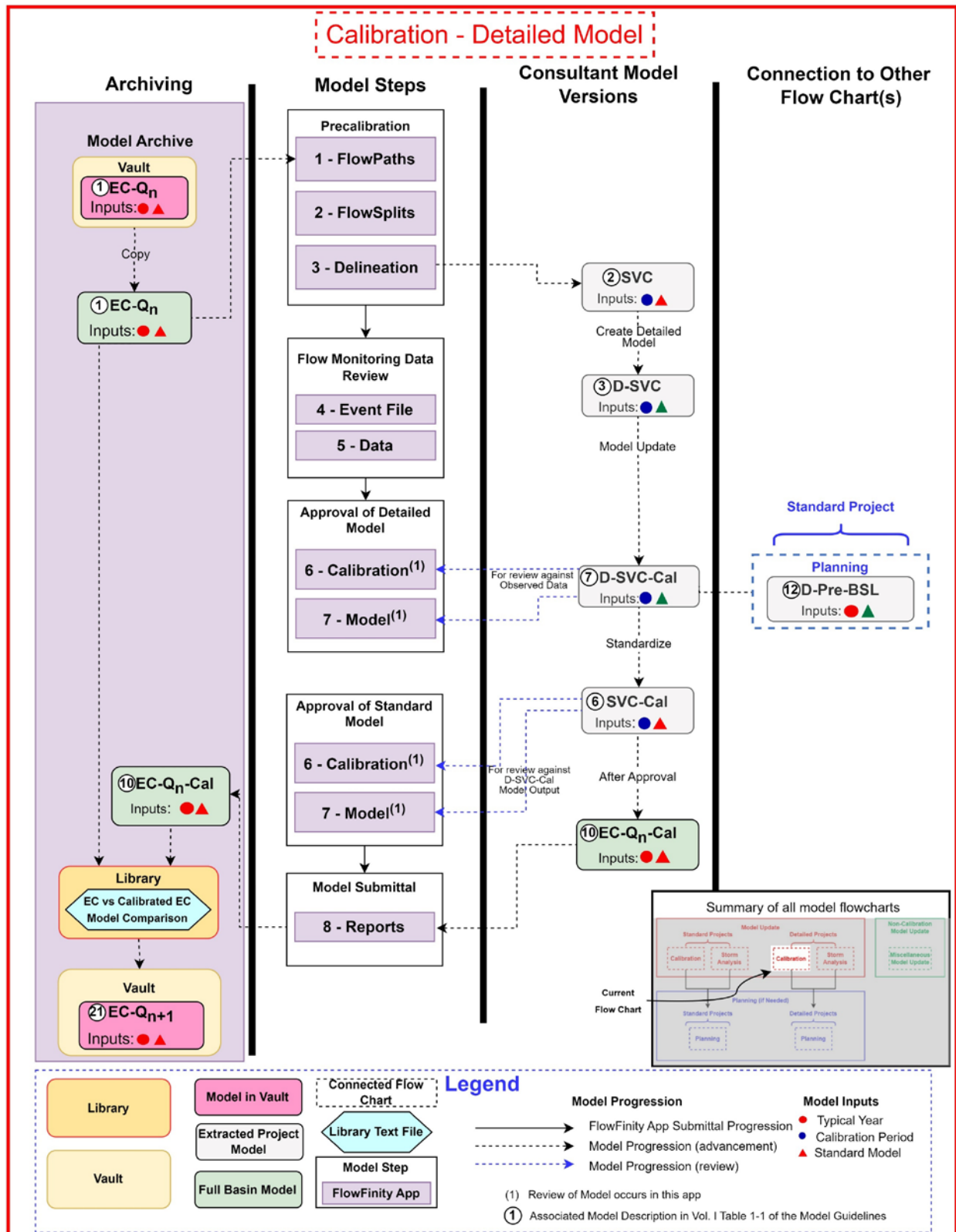
Figure 1-8. Standard Model Planning Project Steps

Figure 1-9. Detailed Model Planning Project Steps
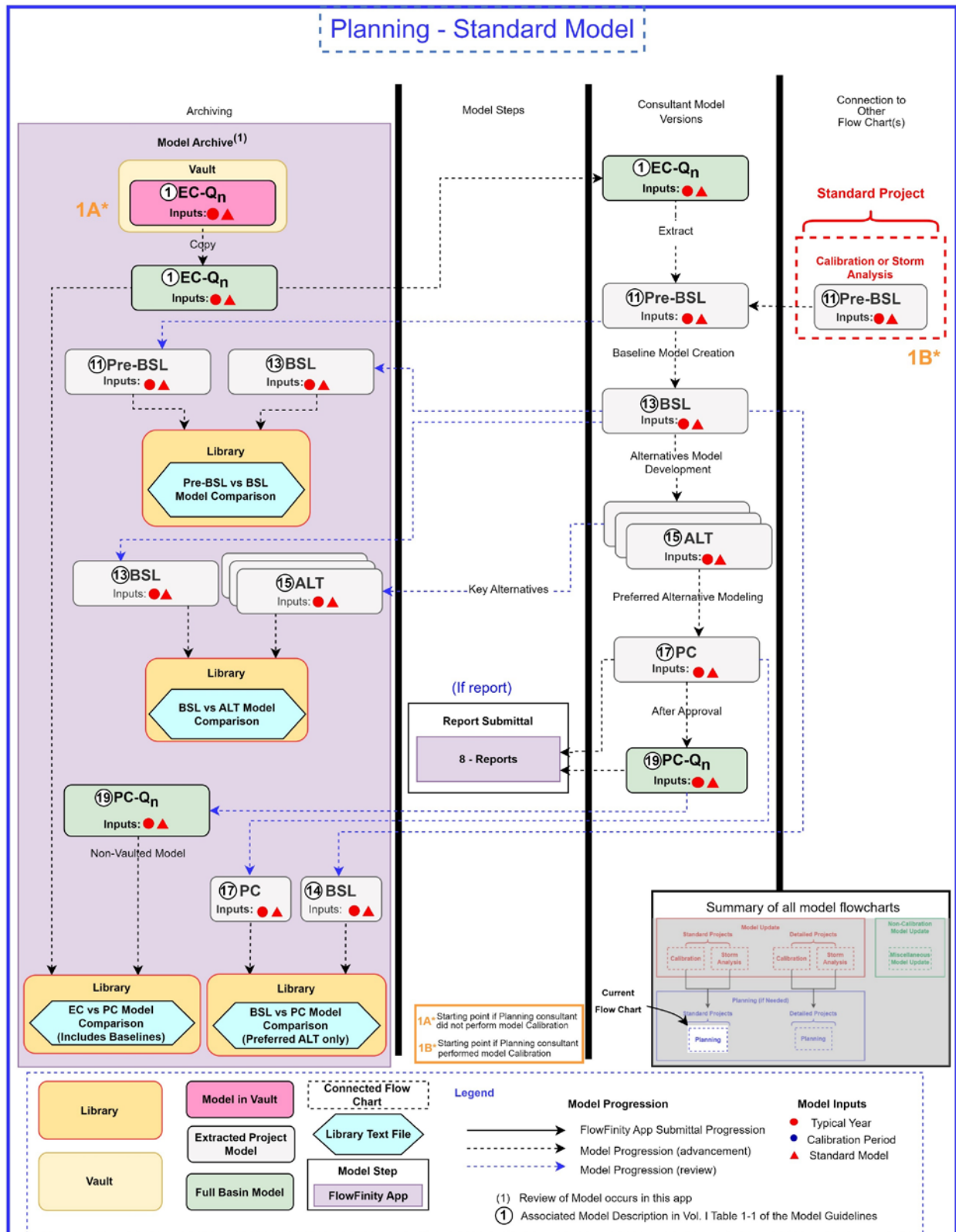
Figure 1-9. Detailed Model Planning Project Steps
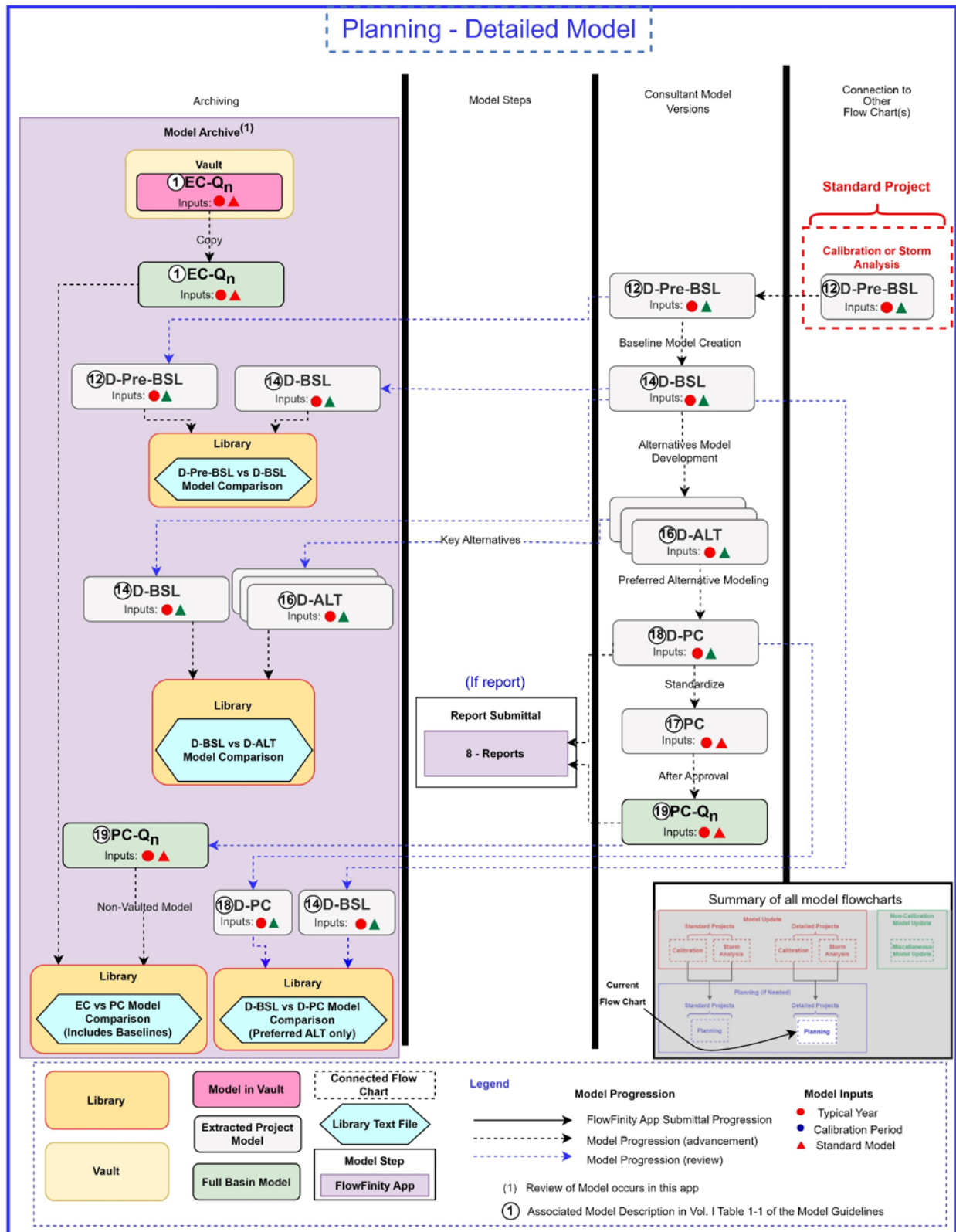
Figure 1-10. Standard Model Storm Analysis Calibration Project Steps
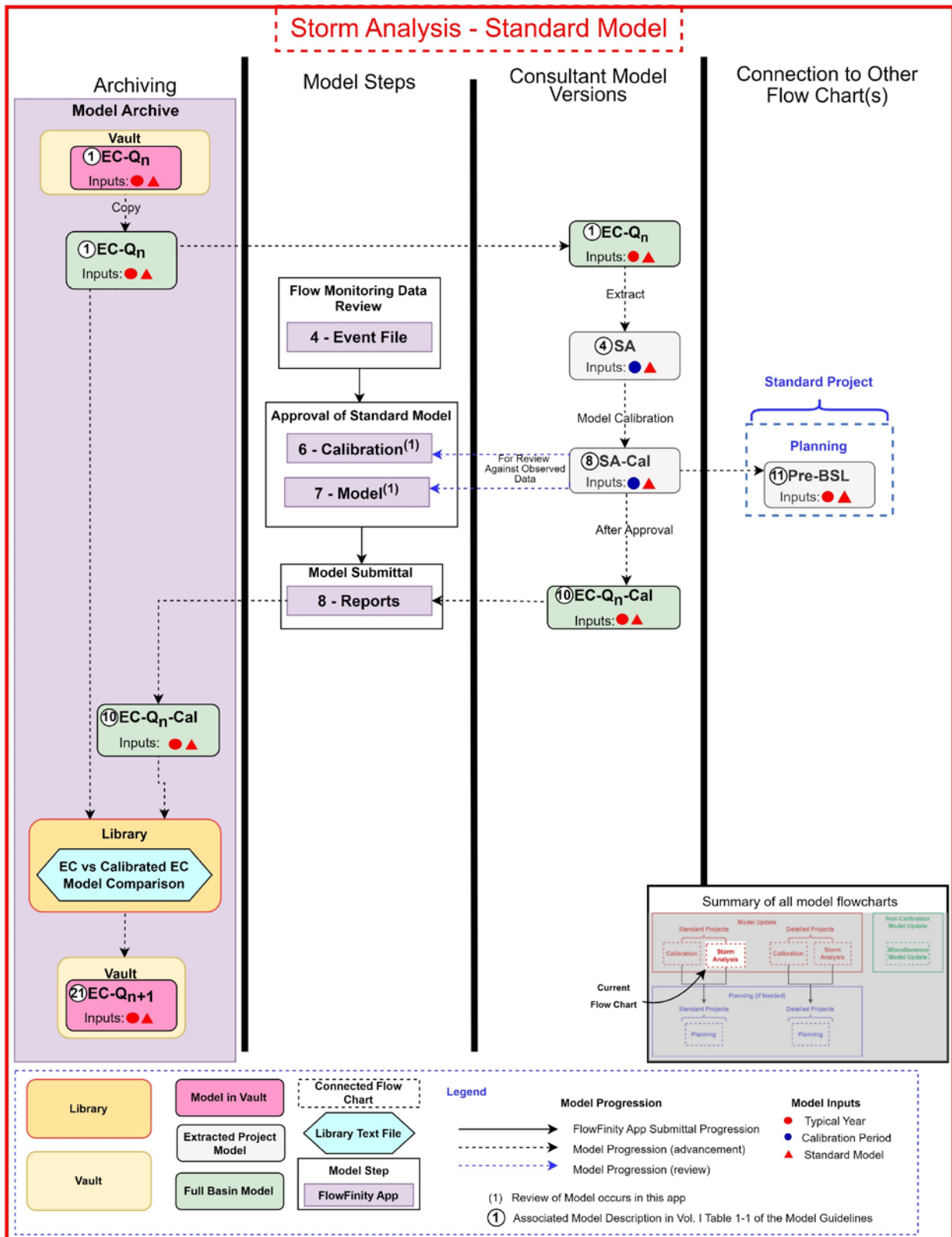
Figure 1-11. Detailed Model Storm Analysis Calibration Project Steps
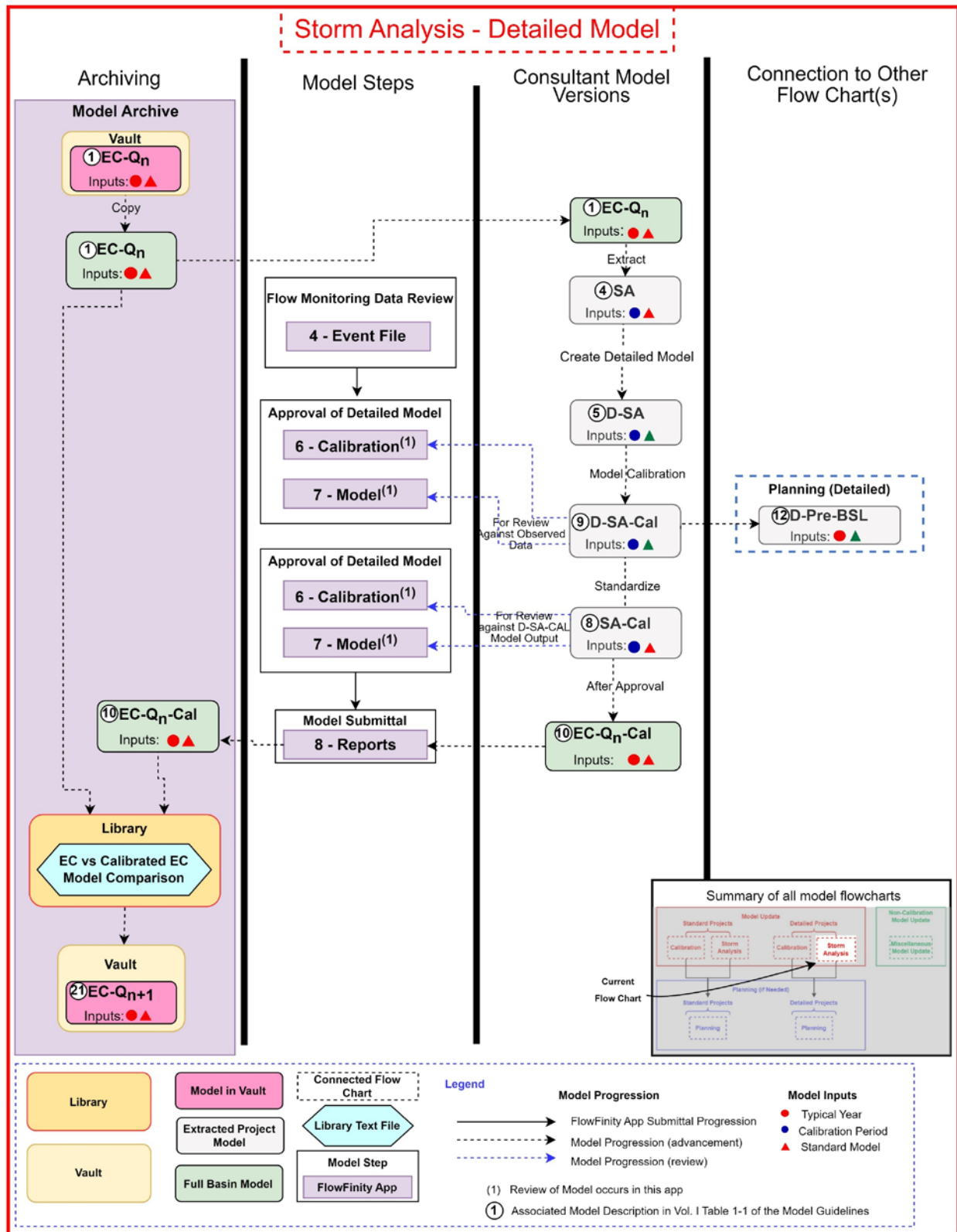
Figure 1-12. Miscellaneous Model Updates Steps
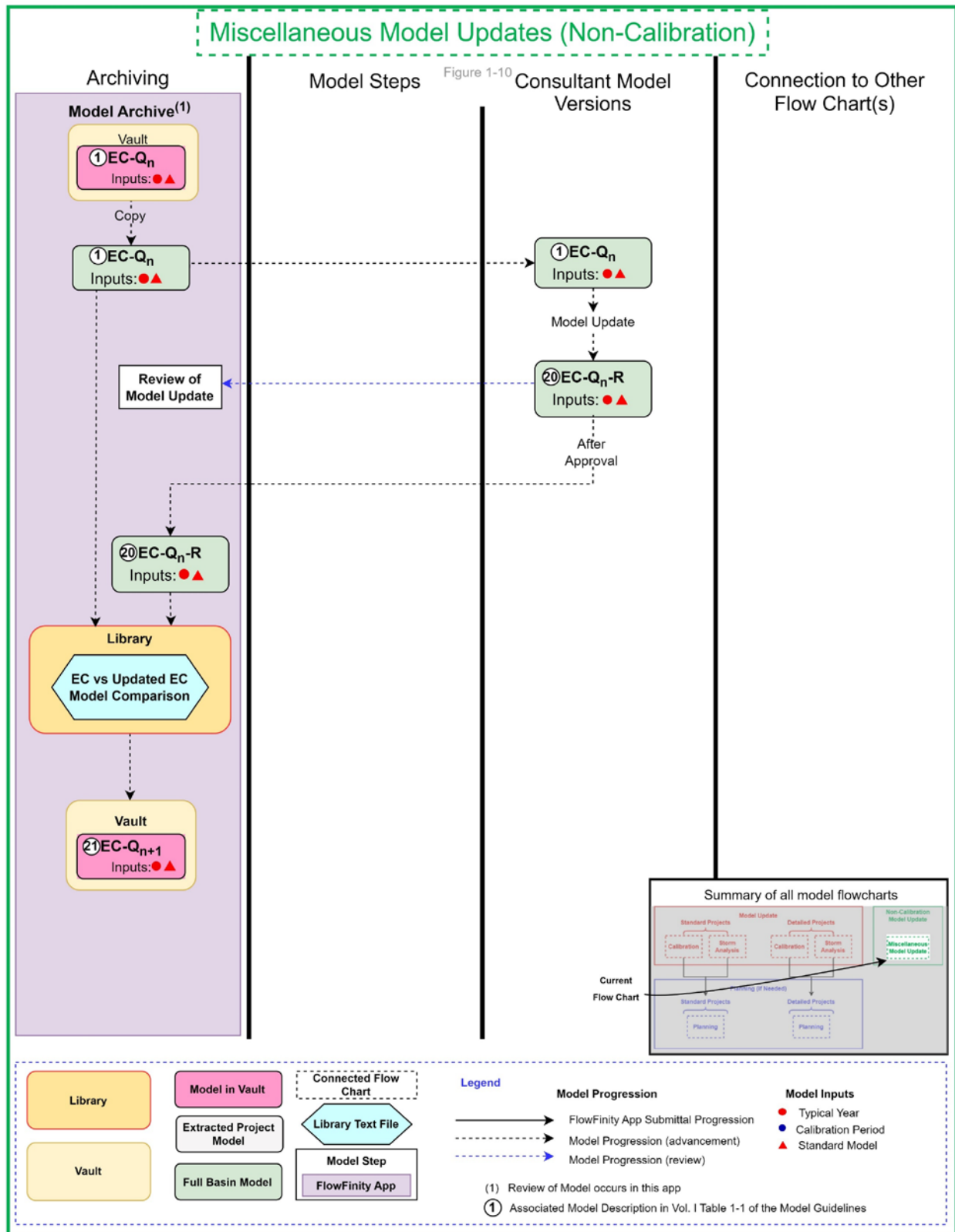
2.0 MODEL CHECK-OUT AND CHECK-IN

Prior to beginning any modeling project, the modeler must first review and understand in its entirety the modeling process that is outlined in **Volume II Section 1.0.**

Check-out and check-in of a model will occur at different locations throughout FlowFinity depending on the project type:

- Model Check-Out:
  - For Calibration projects, check-out will occur within the *3 – Delineation* app of FlowFinity.
  - For Alternatives and Storm Analysis projects, check-out will occur within the *Model Archive* app in FlowFinity, listed as *Vaulted Models – ROV.* The *Vaulted Models – ROV* listing contains links to all necessary basin models, which can be selected and downloaded when necessary.
- Model Check-In:
  - Calibration Model check-in will occur within the *8 – Report* app of FlowFinity.
  - Non-calibration model check-in will occur within the NVM or PM track of the *Model Archive* app of FlowFinity. When uploading a model to the *Model Archive* app, the "Model Type" will be selected based on how the uploaded models apply to **Volume II Table 3-1** and the Flowcharts listed in **Volume II Figure 1-6** through **Figure 1-12**. Any models that do not apply to any of the listed model types will be considered "Other" for this submission.

Note that model check-out and check-in will coincide with MSDGC's ongoing Model Vaulting Process (**Volume II Section 2.1**), and will make use of MSDGC's model file naming convention (**Volume II Section 2.3**).

2.1 MODEL VAULTING PROCESS

Model vaulting is the process of updating the System Wide Model (SWM) to include the latest information for that basin at the date of publication. Model calibration changes to parameters, updates from field data & CAGIS reviews, and changes to operations are typical changes for including in vaulting. Alternatives not moving to construction and Detailed Models of local project models are not included in vaulting.

At any given time, multiple copies of MSDGC's Existing Conditions SWM basin models are receiving updates in various project areas from many different teams of modelers. Because of this, MSDGC has developed a process that will compare and reconcile those differences as the multiple copies of the same Existing Conditions SWM basin models are received, post update. Note the following important points regarding this process:

1. Updating a model involves checking out the entire SWM basin model and giving the entire SWM basin model back to MSDGC, post update.
2. Others will still be updating that same model, simultaneously.
3. MSDGC has a process by which all models will be compared to each other using the "Library Tool" when the model is checked back in.
4. This process will be performed quarterly.
5. This process will produce one single model update with changes reconciled from all models.

The process reviews and updates the Version Control document, which lists the sources of changes in the model in three categories; changes made, pending changes, changes that will never be included. The changes made are listed by the calendar quarter in which the change was added to the vaulted model. The pending changes lists currently on-going projects that are expected to be included such as calibration projects and current construction. For the Baseline Models (BSL), proposed projects that were determined as "definitely to be constructed" are included. Under changes not to be included are projects in areas with pipes below the SWM size threshold, thin-walled pipe lining, and projects within WWTP that don't impact flow capacity. These projects are included so later users will know which projects are in or not in the model.

Once all changes for the Existing Conditions SWM basin model updates are reconciled, a single Existing Conditions Model update will be "vaulted" as the official model of record for that quarter. **Volume II Figure 2-1** provides a conceptual schematic of the model vaulting process.

Figure 2-1. Conceptual Schematic of Model Vaulting Process
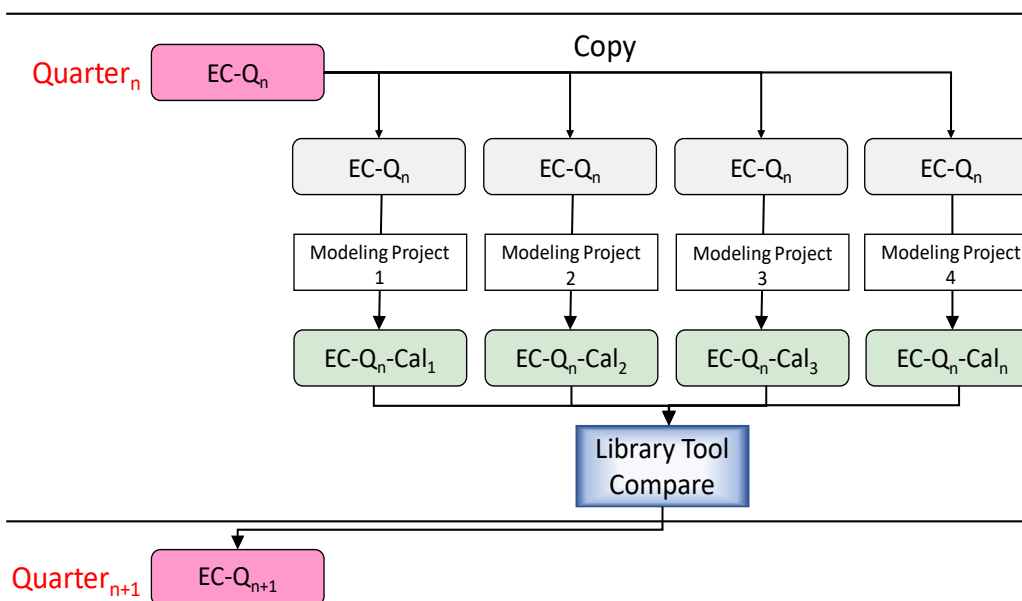
2.2   MAINTAINING RECORD OF CHANGES

A model's Project Notes are used to record updates to a model throughout various projects and are continuously tracked when models are submitted to MSDGC. When models are updated and submitted to the *7 – Model* app in FlowFinity, any remaining information in the model's "Project Notes" field is to be removed from the model file and copied to the "Project Notes Text" field in the *7 – Model* app*.* This will be moved to a record within FlowFinity's *Version Control* app after submission, where the overall list of changes to the model is tracked.

A general description of any work performed must also be added to the "Project Notes Text" field within the *7 – Model* app. The "Project Notes Text" will be used by MSDGC to track previous changes to the model in the *Version Control* app of FlowFinity*.* The format for this description and necessary level of detail is described in **Volume I Section 4.1**.

A similar process will be applied to models submitted in the *Model Archive* app. The extensive list of updates included in the model is to be removed from the model and uploaded to the "Post-Model Notes" field in FlowFinity, and the general description and summary of the work is to be included within the "Post-Model Notes Summary" field.

2.3   MODEL FILE NAMING CONVENTION

As discussed in **Volume II Section 2.1**, modelers will receive the entire SWM basin model upon check-out and will submit the entire SWM basin model upon check-in to facilitate the Model Vaulting Process. Further, all vaulted models submitted to MSDGC that are to be vaulted will be Typical Year models.

As such, the following notation should be used for all model input files to maintain a consistent naming convention:
- **Vaulted Models: [SWM Basin]_[Scenario][YYYYQX]_[Rainfall]**
  - Vault models are watershed models that are either distributed directly from MSDGC or submitted to MSDGC after Calibration is complete.
- **Project Models: [SWM Basin]_[Scenario][YYYYQX]_[Rainfall]_[DDMmmYYYY]**
  - Project models refer to any project-area models that are extracted from a Vault model and worked on over the course of a project. Project models include submissions for the required libraries and non-vaulted models.

Both vaulted models and project models are submitted throughout different stages of a project, as outlined in the flow charts in **Volume II Section 1.2**. The final product will be determined to be vaulted or non-vaulted at the outset of the project, which will determine the proper naming convention. If it is unclear whether a project is to be vaulted or not, consult the MSDGC PM.

[SWM Basin]

- **[IC]** = Indian Creek
- **[LM]** = Little Miami
- **[MC]** = Mill Creek
- **[MU]** = Muddy Creek
- **[PR]** = Polk Run
- **[SC]** = Sycamore Creek
- **[TC]** = Taylor Creek
- **[FS]** = Fort Scott
- **[MF]** = Mayflower

[Scenario]

- Vault Models
  - Existing Conditions-Original Standard/New Standard (EC-Q_n/ EC-Q_{n+1})
    - **[2007Baseline]** = 2007 Baseline Conditions
    - **[Exist]** = Existing Conditions
  - Proposed Conditions Standard (PCS)
    - **[Phase1]** = End of Phase 1
    - **[Bridge]** = End of Bridge Phase (end of 2021)
    - **[Phase2ABaseline] = Beginning of Phase 2A**
    - **[Phase2A]** = End of Phase 2A
    - **[Phase2X]** = End of Phase 2 (Completion of Consent Decree)
- Project Models
  - **[SVC]/[D-SVC]** = Storm Volume Calibration/ Storm Volume Calibration-New Detailed
  - **[SA20XXQX]** = Storm Analysis for conditions representative of year 20XX, Quarter X
  - **[Exist20XXQX-ND]** = Existing Conditions-New Detailed as of year 20XX, Quarter X
  - **[BSL20XXQX]** = Baseline for conditions representative of year 20XX, Quarter X
  - **[ALTX-20XXQX]** = Alternative X for conditions representative of year 20XX, Quarter X
  - Proposed Conditions Detailed Model (D-PC)
    - **[Phase1-D]** = End of Phase 1, Detailed Model representation
    - **[Bridge-D]** = End of Bridge Phase (end of 2021), Detailed Model representation
    - **[Phase2A-D]** = End of Phase 2A, Detailed Model representation
    - **[Phase2-D]** = End of Phase 2 (Completion of Consent Decree), Detailed Model representation

[YYYYQX]

- Quarterly date stamp of the most recently updated input file

[Rainfall]

- E.g.,
    - **[TY]** = Typical Year; continuous annual simulation
    - **[5yr24hrSCSII]** = design storm; includes frequency, duration, and distribution
    - **[7-4-TYevt]** = single event during the TY; date corresponds to start of rainfall
    - **[6-20-20evt]** = single event; date corresponds to start of rainfall
    - **[2018-01thru2018-12-Calib]** = flow monitoring by which the model is being calibrated

[DDMMYYYY]

- Date stamp of when the model input file was last updated.

Examples:

- Vault Models
    - MC_Exist2020Q4_TY
    - LM_Bridge2020Q4_TY
    - MU_Phase2ABaseline2023Q1_TY
- Project Models
    - MU_D-SVC_2021Q4_2019-01thru2021-02-Calib_06Sep2021
    - MC_BSL2022Q3_2021Q1_7-4-TYevt_07Jan2022
    - LM_SA2019Q3_2020Q1_8-13-19evt_22Feb2021
    - MC_Phase1-D_2020Q3_TY_14Dec2020

3.0 GENERAL MODEL QC REVIEW

Each modeler should conduct work in a thorough, organized, and well-documented manner. Small adjustments to the SWM can result in significant changes to proposed projects and regulatory compliance. All modeling work should apply appropriate quality assurance/quality control (QA/QC) measures to verify that the model yields meaningful, accurate, and reliable results that are of a consistent quality.   There are many required submittals via FlowFinity. But these should not be considered the only reviews to be performed.

The following general checks should be performed to ensure that the overall "health" of the model is adequate. In following the procedures provided in this section, the guidance may recommend changes be made to the model to fix errors. However, general QA/QC updates to any model that result in a change of 5% or greater in the Typical Year ROV values at the CSO and SSO locations should not be made unless defendable and supported with flow monitoring data. Instead, the model error(s) when identified in the performance of the QC review items as outlined in the following sections. should be noted and reported to the MSDGC Modeling Group. Guidance for documenting and reporting these differences will be covered in the *7 – Model* app in FlowFinity.

3.1 MODEL AUDITS

The MSDGC Modeling Group recommends that all input data conform to the values and ranges specified in **Volume I Table 3-1**, where possible. Note that these values and ranges have been incorporated into a "Validation Set" that can be imported into PCSWMM's "Auditing" function to perform an efficient and accurate audit of a model. The PCSWMM "Validation Set" can be requested from MSDGC's Modeling Group.

The following audits should be performed:
- Orphan Detection: Identify disconnected link, node, and subcatchment entities.
- Conduit Slope Screening: Identify conduits with negative or invalid (too large) slope.
- Attribute Validation: Identify out of range model input parameters.

Note that audit flags do not necessarily indicate model flaws but may instead indicate that the system element is of unusual nature. Because of this, the reviewer must review, summarize, and categorize audit flags as being either "real" or a "non-issue." "real" issues should be resolved. For "non-issue" audit flags, an explanation must be added in the model element's "Description" attribute using the proper documentation format as described in **Volume I Section 4.1**.

Attribute Name	Units	Lower Limit	Upper Limit
Subcatchments			
Area	ac	0.001	10000
Overland Flow Length	ft	50	400
Slope	%	0.001	37
Imperv.	%	0	100
N Imperv		0.0125	0.0175
N Perv		0.1	0.8
Dstore Imperv	in	0.01	0.1
Dstore Perv	in	0.1	0.25
Zero Imperv	%	25	50
Percent Routed	%	0	50
Curb Length		0	1000000
Max. Infil. Rate	in/hr	1	3
Min. Infil. Rate	in/hr	0.1	0.5
Decay Constant	1/hr	1.5	4
Drying Time	days	5	10
Max. Volume (not used)	in	0	0
Junctions			
Invert Elev.	ft	400	900
Depth	ft	0.5	100
Initial Depth	ft	0	20
Surcharge Depth	ft	0	999
Ponded Area	ft²	0	436000
Outfalls			
Invert El.	ft	400	900
Flow Frequency	%	0	50
Dividers – NOT USED BY MSDGC			
Invert El.	ft	0	0
Depth	ft	0	0
Initial Depth	ft	0	0
Surcharge Depth	ft	0	0
Ponded Area	ft²	0	0
Storages			
Invert El.	ft	400	900
Depth	ft	0	70
Initial Depth	ft	0	50
Ponded Area	ft²	0	436000
Evap. Factor	fraction	0	1

Attribute Name	Units	Lower Limit	Upper Limit
Conduits			
Length	ft	3	10000
Roughness		0.007	0.02
Inlet Offset	ft	0	35
Outlet Offset	ft	0	50
Initial Flow	CFS	0	100
Flow Limit	CFS	0	.1
Entry Loss Coeff.		0	1.3
Exit Loss Coeff.		0	1
Avg. Loss Coeff.		0	1
Geom1	ft	0.5	20
Geom2	ft	0	20
Geom3		0	100
Geom4		0	100
Barrels		0	3
Pumps			
Startup Depth	ft	0	25
Shutoff Depth	ft	0	1
Orifices			
Height	ft	0	5
Width	ft	0	16
Inlet Offset	ft	0	15
Discharge Coeff.		0.5	1.01
Time to Open/Close	h	0	0.25
Weirs			
Height	ft	0	10
Length	ft	0	20
Side Slope	ft/ft	0	100
Inlet Offset	ft	0	30
Discharge Coeff.	CFS	0.5	4
End Contractions		0	3
End Coeff.	CFS	0	1
Outlets			
Inlet Offset	ft	0	20
Coefficient	ft	0	1
Exponent	ft	0	1

Table 3-1. MSDGC Attribute Validation Criteria

3.1.1 Hydraulic Profile Review

In addition to performing the model audit prior to calibration, modelers should review the hydraulic profiles of their system to ensure that invert errors and undercapacity pipes do not exist. In most cases MSD will update the model extents/details in the area of the project to ensure that flow splits and areas with SBUs are adequately represented (but not calibrated). Only a limited review of these additions are performed at the time they are added; the modeler should, therefore, review the hydraulic profiles. **Volume II Figure 3-1** shows schematic examples of common invert errors. Note that not all apparent invert errors are wrong. E.g., a "descending node" may represent a grit pit, or a "suspect invert" may represent an overflow, etc. It is the modeler's responsibility to flag any suspect inverts and resolve them.

Figure 3-1. Schematic Example of Common Invert Errors
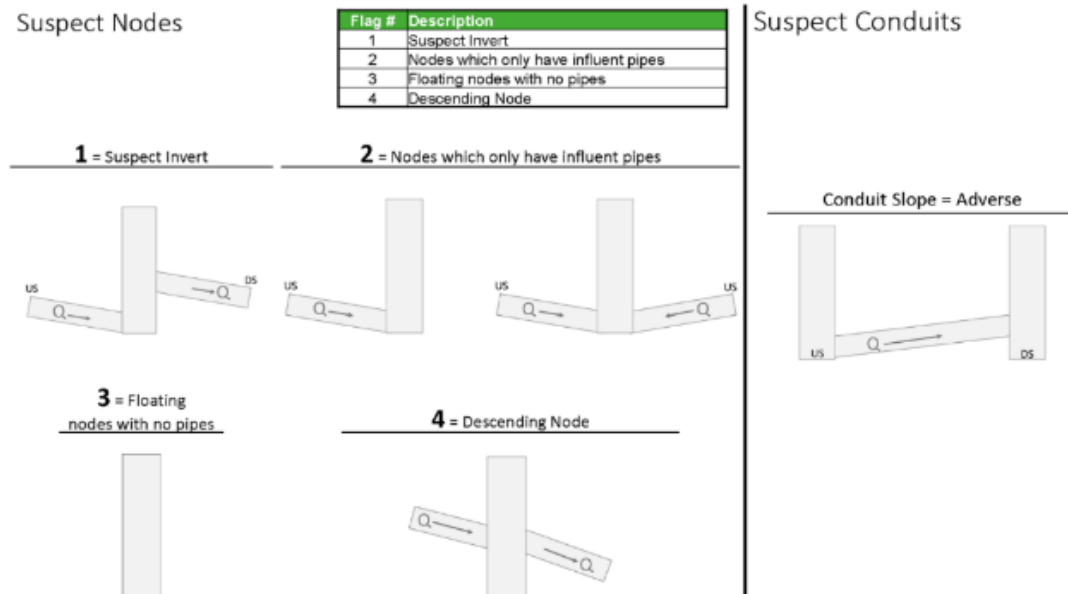
3.1.2 Subcatchment Connectivity

Unless MSDGC indicates otherwise, subcatchment connectivity is reviewed in detail prior to the model being provided to the consultant. If directed by MSDGC, modelers should explicitly check and map the area tributary to each flow monitor district. The approach with which to perform this check is left to the discretion of the modeler. However, using PCSWMM's option to select all tributary elements upstream of a specific location may be useful. An example of this is provided in **Volume II Figure 3-2**.

Once this check has been completed and the modeler has confirmed there are no misconnected basins, appropriate mapping of each flow monitor district will be submitted as part of the $7 - Model$ app in FlowFinity. The size and number of maps required will vary by project, but mapping must be provided so

the reviewer has an adequate understanding of the tributary area to confirm there are no misconnected basins. **Volume II Figure 3-3** provides an example of proper tributary area mapping.
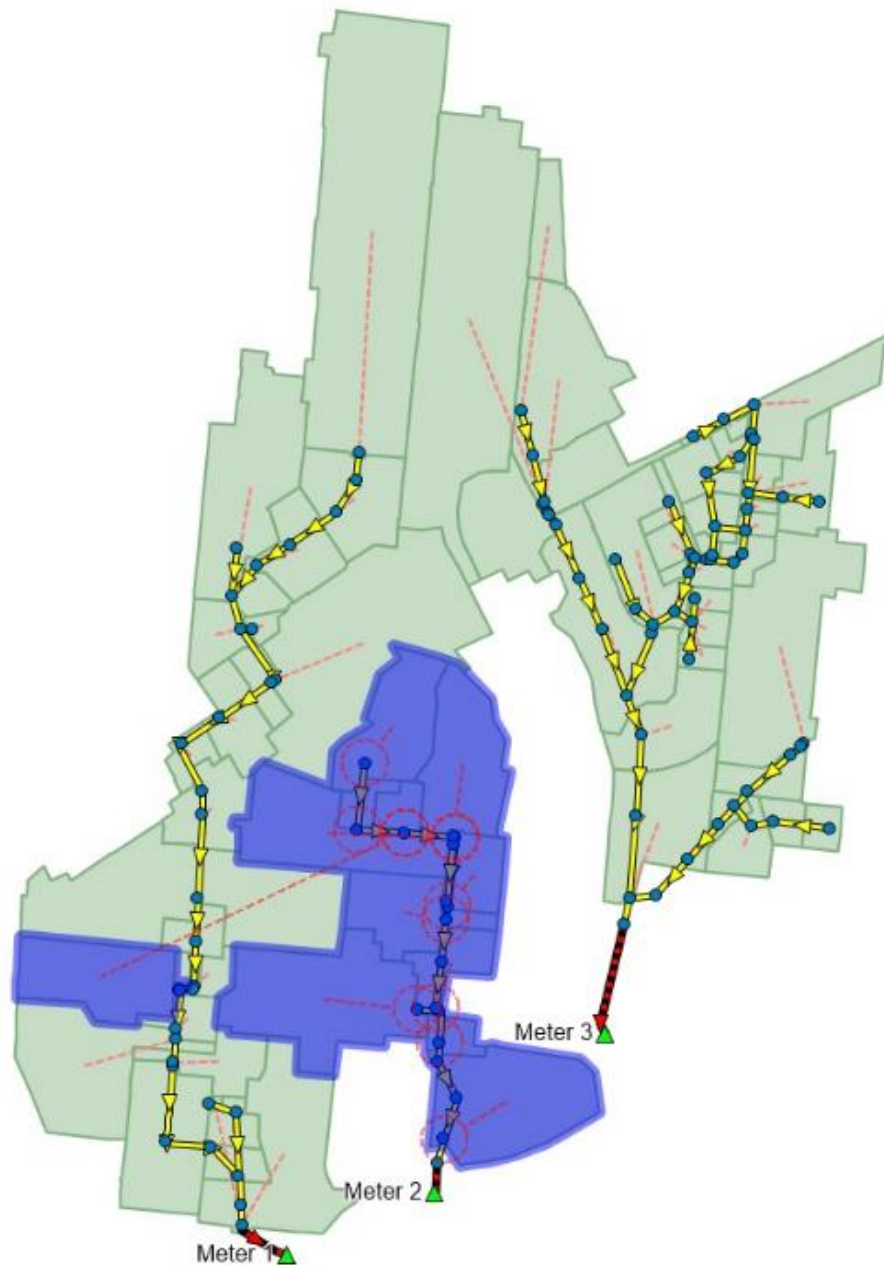
Figure 3-2. Example of Checking for Misconnected Basins using PCSWMM's "Select Upstream" Tool (Upstream of Meter 2 Tested)

Figure 3-3. Example of Proper Tributary Area Mapping
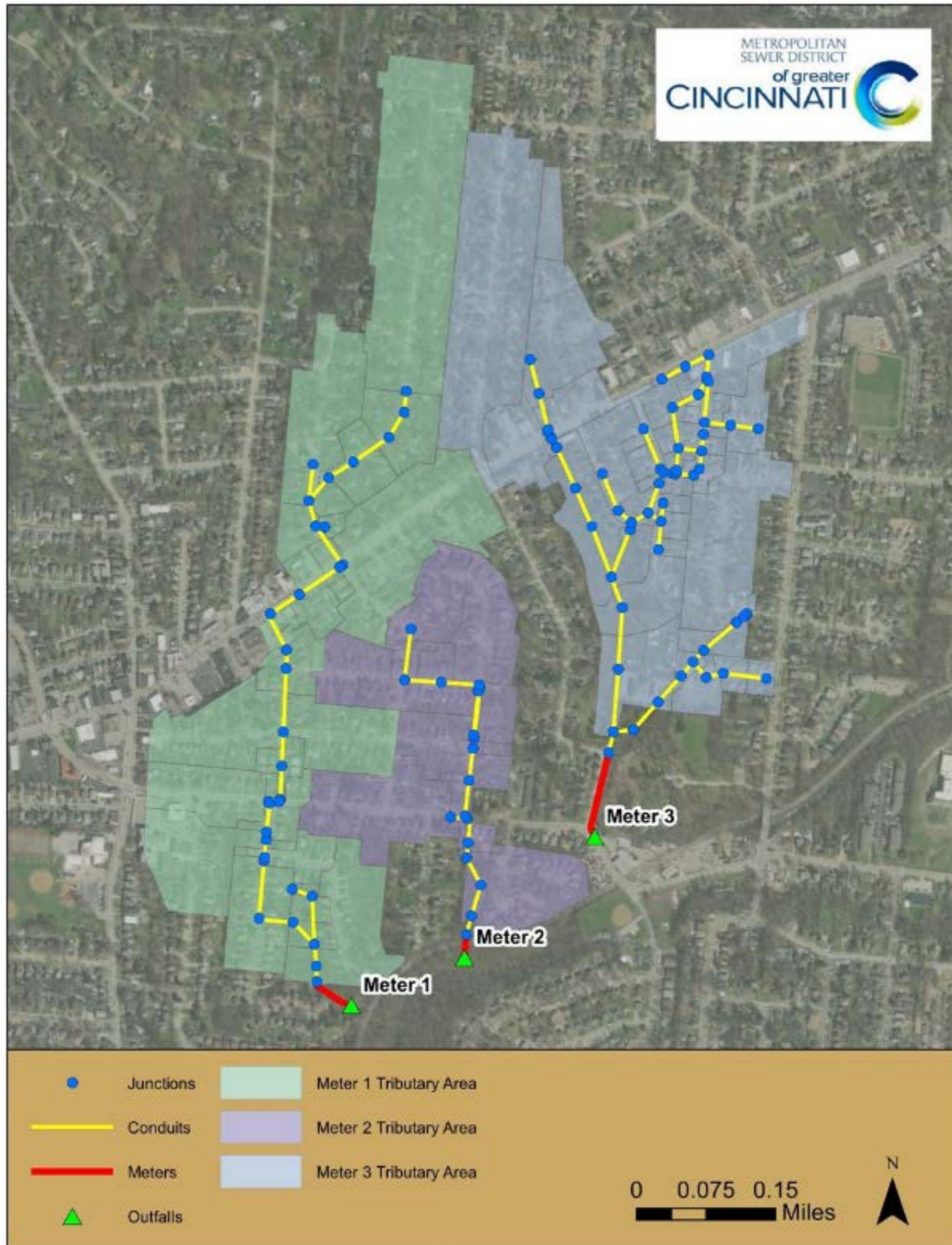
3.2 UNDERSTANDING INTERCONNECTION OF THE SYSTEM

A schematic of the system should be developed to demonstrate an understanding of how the system is interconnected. The schematic should include any regulator structures, flow monitor locations, cross-connections between basins, downstream boundary conditions, and any other important hydraulic and hydrology components within the system. It is left to the modeler's discretion for how best to develop the schematic. An example is provided below as **Volume II Figure 3-4.** The schematic will be included when the model is submitted via the *7 – Model* app of FlowFinity.

Figure 3-4. CSO-469 and Related CSOs Flow Monitor Connection Schematic
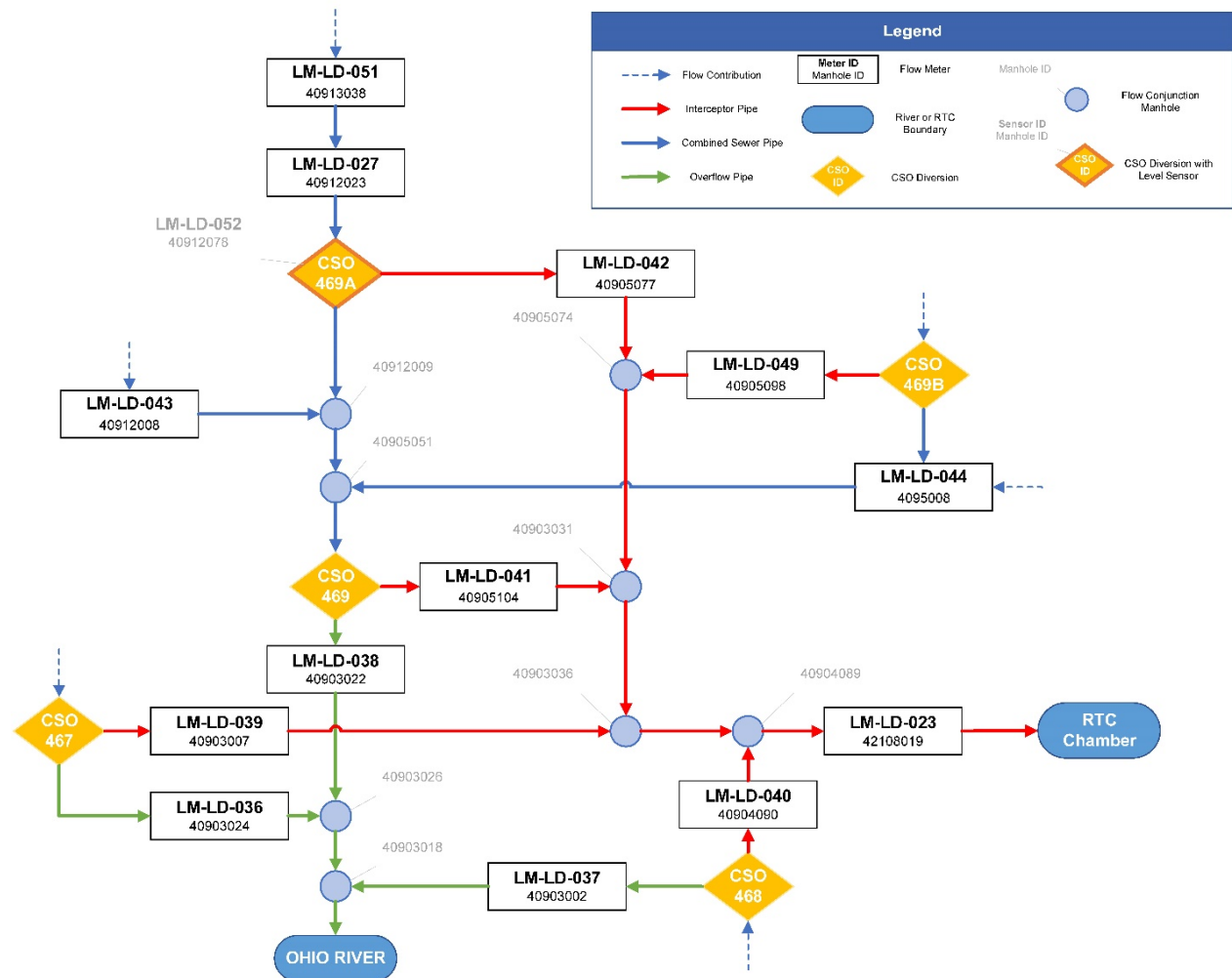
Source: (Jacobs, CSO 469 and Related CSOs Final Report, 2020)

NOTE: Flow monitor installation manhole assumes the probe is installed in the upstream pipe segment, unless otherwise noted.

3.3   DRY CONDUITS

Dry conduits should be identified by reviewing the "Flow Classification Summary" of the model output file after running a sufficiently large event such as the peak Typical Year storm that occurred on July 9, 1970 or the largest storm during the calibration period. Once identified, the dry conduits should be reviewed to determine if they can be removed from the model based on the following conditions:

- No flow loaded upstream.
- Not a cross-connection between two separate sewer lines
- Not an SSO/CSO outfall
- Not a relief sewer or cross connection for design storm flows (e.g., 100-Year)

However, dry pipes should be removed with caution. Some dry pipes may have been added due to the sewer system extension in a new development and should be kept in the model for the planned future use.

3.4   "WARNING" MESSAGES

After each run, review the output for "Warning" messages and refer to **Volume II Table 3-2** for guidance on the appropriate course of action. Note that the user is responsible for categorizing the warning messages as "Significant", "Negligible", or "Unresolved". Refer to the Storm Water Management Model User's Manual for typical warning issues.

Table 3-2. Guidance on Resolving "Warning" Messages		
"Warning" Message Categorization	**Description**	**Required Action**
Significant	Represents true issue (e.g. pipe crown is greater than rim elevation because the conduit height was input in inches instead of feet)	Fix model; resolve warning
Negligible	Does not represent true issue, e.g., irregular shapes	Add explanation in model element's "Description" attribute; refer to **Volume I Section 4.1** for proper documentation format
Unresolved	Unsure if a true issue is present and/or do not have adequate data to resolve the issue	Add explanation in model element's "Description" attribute; refer to **Volume I Section 4.1** for proper documentation format

3.5   TOTAL PRECIPITATION VOLUME CHECK

The total area-weighted average rainfall depth for the duration of the simulation from each rain gauge assignment that is input to the model should be calculated and compared to the total precipitation depth that is recorded in the model output report. **Volume II Table 3-3** provides an example of this comparison.

Table 3-3. Example Comparison for Checking Rainfall Continuity		
Radar Rainfall/Rain Gauge Basin(s)	**Rainfall Basin Area (acres)**	**Total Rainfall Depth Input (in)**
LM-DC-018	158.6	2.86
LM-DC-025	43.9	3.99
Area Weighted Average Rainfall Input (in):		*3.105*
Rainfall Output (in):		*3.105*
Difference (in):		0

The Rainfall Output should be obtained from the "Runoff Quantity Continuity" Section of the model output report. If the difference between rainfall input and rainfall output does not equal zero, then resolve the issue before doing any additional modeling. This step confirms rainfall data has been input correctly to the model input file.

3.6   CONTINUITY

Volume II Table 3-4 provides guidance on ensuring that the model runoff, groundwater, and flow routing continuity error are within permissible tolerances. If error is too high, unstable model elements should be corrected to resolve high continuity error and/or reduce simulation run time. Individual element continuity error is at the modeler's discretion to determine what is considered significant. Model adjustments should be made to minimize these errors.

Table 3-4. Guidance on Checking Model Continuity			
Model Output Continuity	**% Error**		**Action if Reported Exceeds Allowable**
	Reported	**Allowable**	
Runoff Quantity	Obtain from "Runoff Quantity Continuity" of model output report.	±1%	Go to "Subcatchment Runoff Summary" of model output report to determine subcatchments with the highest instability.
Groundwater	Obtain from "Groundwater Continuity" of model output report.	±1%	Go to "Groundwater Summary" of model output report to determine subcatchments with the highest instability.
Flow Routing	Obtain from "Flow Routing Continuity" of model output report.	±3%	Refer to the "Highest Continuity Error" and "Time-Step Critical Element" sections of the model output report.

Hydrology instabilities may be the result of

- Percent Impervious values that are greater than 100%,
- Slopes of 0%, or

- model simulations without sufficient run time following precipitation.

Model elements with hydraulic instabilities may be the result of
- abnormal weir or orifice coefficients or dimensions,
- systems changing from surcharged to non-surcharged state,
- node flooding,
- many pipes influent to a single junction,
- backwater on orifices, weirs, or dry pipes, or
- Issues with Control Rules when parameters are too high for conditions to return to base flow conditions.

Minor model updates or changes to structure representations should be considered to minimize the instability. Cases where no reasonable update can be found to fix a hydraulic instability should be discussed with the MSDGC Modeling Group.

3.7 FLOW INSTABILITY

Unstable link elements that result from unstable flow are listed in the "Highest Flow Instability Indexes" section of the model output report of SWMM and include links having the five highest Flow Instability Index (FII) values. Note that in some cases, flow instability is caused by unsteady and fluctuating flows which cannot be easily addressed, or which are actual occurrences as opposed to calculation limitations in SWMM. Minor model updates or changes to structure representations should be considered to minimize the instability. Any changes to the element representation must be documented within the model in accordance with **Volume I Section 4.1** and reported within the *7 – Model* app in FlowFinity. These modifications will also be included in the calibration report at the culmination of the project**.** Cases where no reasonable update can be found to fix a hydraulic instability should be discussed with the MSDGC Modeling Group.

3.8 NODE FLOODING

The model should be reviewed to identify the nodes with high flood volumes and durations. High flood volumes may be caused by imbalanced flow loadings, which may require a finer delineation and redistribution of flow inputs. Long flooding durations may indicate a hydraulic problem such as an improper pipe diameter, major model instability, or a malfunctioning Control Rule. Very small flood durations are likely the result of small model instabilities, especially when large, fast peaks occur. These instabilities may be reduced or eliminated by minor changes to the hydraulic network, such as small changes to energy losses or the addition of a small amount of storage, to help stabilize the model calculations.

Also note that for specific cases where there are new detention facilities being modeled, the model should be reviewed to confirm that all likely overflow points are not lost to out-of-system flooding. The model will likely be used to evaluate extreme events. Therefore, this flow **must not** be lost from the system during those subsequent applications of the model.

3.9   OUTFALL LOADING

The Outfall Loading table in the report file is to be reviewed for excessive flow frequency. Any outfall with a frequency over 50% should be examined for instabilities and hydraulic network errors.

3.10 MODEL MASS BALANCE

3.10.1 Hydraulics Mass Balance

To reduce the potential for introducing error when conducting model updates, total volume comparisons must be made at specific points of interest before and after the update is performed. It is up to the discretion of the modeling team to decide which design storms are most appropriate for conducting the comparisons. However, it is recommended that at least a smaller design storm (e.g., 2-Year, 24-Hour) and a larger design storm (e.g., 10-Year, 24-Hour) be used to assess system behavior under varying conditions. Depending on the type of project and the model's intended use, it may also be warranted to quantify the comparisons for the Typical Year, as well. Note that this check will be required within the *7 – Model* app in FlowFinity.

Total volume comparisons should be made at key locations such as:
- CSOs and SSOs
- WWTP influent
- Major interceptor points
- Facilities

And for the following:
- Total node flooding
- Total surface runoff
- Total groundwater flow
- Total RDII flow
- Total outflow

Significant differences should be consistent with the model update that was made and supported by data. If significant changes occur and are not expected, additional investigation should be conducted to identify the cause of the change, and fixed if it is determined that the change was the result of an error.

3.10.2 Hydrology Mass Balance

If multiple hydrology methods are used in the same area, the model may produce more than 100% WWF (that is, inflow volume will exceed rainfall volume). For example, an area that utilizes runoff and RTK unit hydrograph with 80% impervious area assigned and 0.4 R-total (40%) can generate approximately 120% system inflow. Excessive flow generation typically indicates that either flow data is inaccurate, or the calibration is poor. The model should be reviewed to ensure the flows are in balance.

The model should be run for the 10-year, 24-hour design event under "wet" conditions to ensure that greater than 100% inflow will not be created even under extreme conditions. The approach is as follows:

1. Model setup
   a. Remove base flow parameters: Baseline and Average Value (testing runoff only)
   b. Set Starting Depth (D_0) based on the assumed 24-hour antecedent condition.
      i. D_0 = Dmax – Drec*1 day
      ii. Example: Dmax of 2.0 inches and Drec of 0.25 inches/day results in D_0 of 1.75 inches.
   c. Set up the model to run:
      i. Start at the beginning of rainfall, 0 hours before rainfall.
      ii. End time should be 48 hours past the end of rainfall (this will account for most simulated RDII, even if long-term triangle extends past that time).
      iii. Generally, the model should be run for 72 hours.
2. Run the model for runoff only.
   a. Pull subcatchment "Runoff Depth" per subcatchment
3. Run the model for RDII only.
   a. Calculate the RTK depth; complete per unit hydrograph area.
      i. Add all the "sewershed area" and "Total Lat. Inflow."
      ii. Divide the summed "Total Lat. Inflow" by "sewershed area" to calculate the RTK wet weather flow depth (in) over the RTK area.
4. Add subcatchment runoff and RTK depth to determine total WWF depth. This approach works because the sewershed area should be close to the subcatchment area.
5. Compare rainfall depth to WWF depth (**Volume II Table 3-5** shows an example comparison) per subcatchment and metershed. Then, per metershed:
   a. If average metershed WWF is >100% of rainfall, then it is NOT acceptable.
   b. If >10% of subcatchments have >100% WWF depth, then it is NOT acceptable.
   c. If <10% of subcatchments have >100% WWF depth AND
      i. If <5 subcatchments produce >100% WWF depth, then it is acceptable.
      ii. If >5 subcatchments produce >100% WWF depth, then review the subcatchments locations (**Volume II Figure 3-5** illustrates examples of the items below). In most areas imperviousness varies. Some subcatchments may have 85% impervious, while others 30%. When RTK is applied, it is distributed evenly. This may result in higher impervious areas have >100% flow generation. On the left, Therefore, the capacity evaluation of the sewers downstream of those subcatchments should be valid.
         1. Several sporadic subcatchments with >100% runoff is acceptable. In such cases, the subcatchments surrounding the high flow subcatchments have lower flow generation which will likely average out to <100%.
         2. Large area grouping is NOT acceptable. In such areas, the sewers will have unrealistically high flows, causing the capacity evaluations to be inaccurate.

In select cases, a flow imbalance may be acceptable, such as an area that is low lying with significant groundwater moving into it. Explicit approval must be provided by MSDGC and the reviewer to allow the flow imbalance to remain. In most cases, a flow imbalance is caused by meter data issues or poor-quality calibration.

Table 3-5. Flow Balance Example Table					
Name	Precipitation (in)	Runoff Depth (in)	RTK Depth (in)	Total WWF Depth (in)	Rainfall Generation Percentage
EOMC002C0016	3.99	1.56	0.25	1.81	45%
EOMC002C0017	3.99	1.88	0.25	2.13	53%
EOMC002C0018	3.99	2.23	0.25	2.48	62%
EOMC002C0019	3.99	2.24	0.25	2.49	62%
EOMC002C0020	3.99	1.67	0.25	1.92	48%
EOMC002C0021	3.99	2.38	0.25	2.63	66%
EOMC002C0022_3	3.99	3.36	0.25	3.61	90%
EOMC002C0026	3.99	2.71	0.25	2.96	74%
EOMC002C0026a	3.99	2.62	0.25	2.87	72%
EOMC002C0027	3.99	1.77	0.25	2.02	51%
EOMC002C0028	3.99	2.91	0.25	3.16	79%
EOMC002C0029	3.99	2.34	0.25	2.59	65%
EOMC002C0031	3.99	2.51	0.25	2.76	69%
EOMC002C0032	3.99	2.62	0.25	2.87	72%

Notes:
Total Lat Inflow from RDII Only Run = 0.136 MG
Total Sewershed Area = 20 acres
RTK Depth = 0.136 MG / 20 acres = 0.25 inches

Figure 3-5. Flow Balance Examples
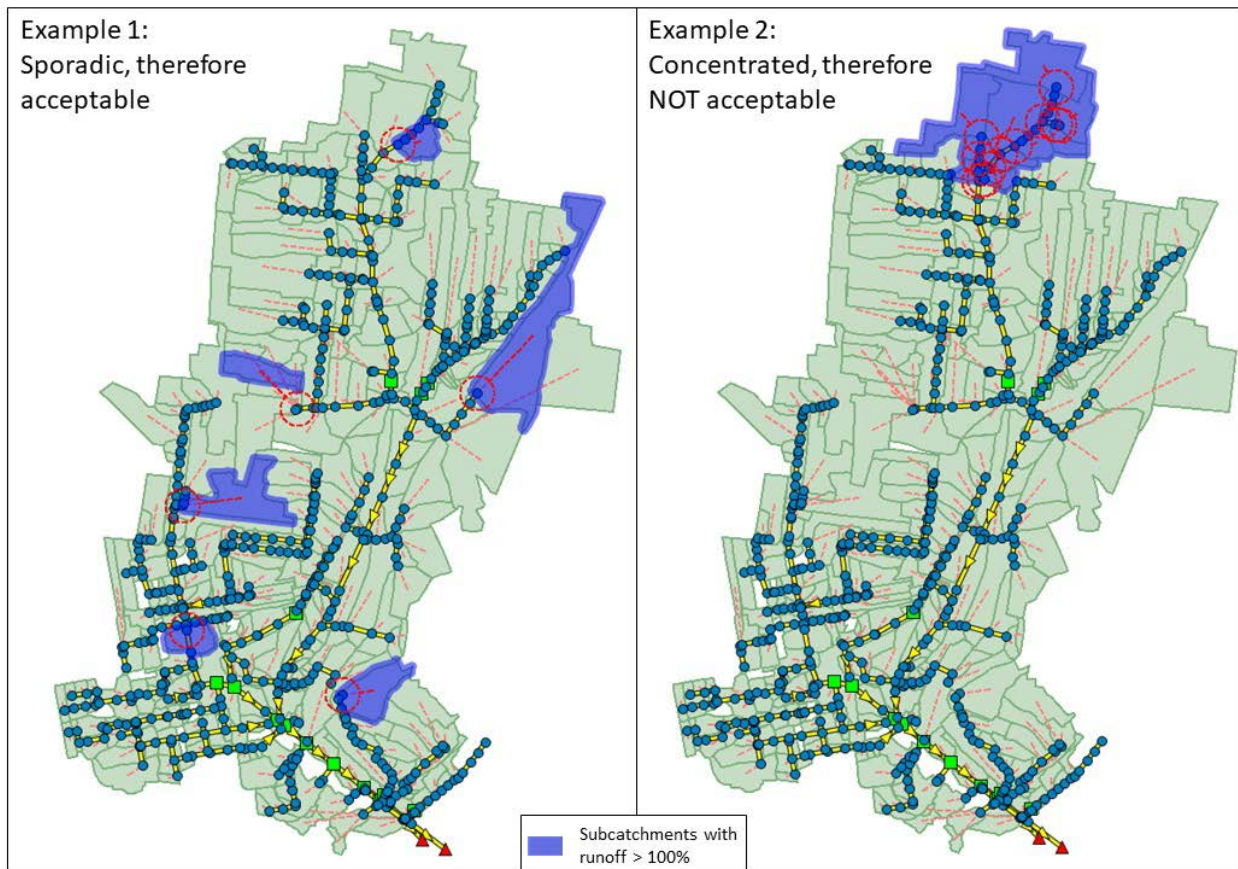
4.0   DATA COLLECTION AND REVIEW

Modelers should collect and review data used in model development and refinement, including the data sources describing the physical network (i.e., geographic information system (GIS) data, surveys, as-built drawings, field inspection) as well as the flow monitoring and operational data (rain, flow, level, velocity, pump records, gate operations, etc.).

Note that MSDGC attempts to collect all flow monitoring and rainfall data in eastern standard time. If it is discovered that data are not in eastern standard time (EST), the modeler should convert the data to eastern standard time (EST) and submit as part of the review in the *5 – Data* app in FlowFinity.

4.1   CAGIS DATA

MSDGC uses a "living database" of information on the collection system within a GIS format. This Cincinnati Area Geographic Information System (CAGIS) database is kept up to date as new information is collected and represents the best understanding of the collection system at any given time. CAGIS information typically most relevant to modeling work include the following elements:

- MSDGC sewer lines
- MSDGC manholes
- Combined Sewer Overflow (CSO)/ Sanitary Sewer Overflow (SSO) locations
- 2-foot contour data
- Land use
- Buildings

- Flow meter locations
- Pump stations
- Parcels
- Storm sewer lines
- Storm manholes
- MSDGC complaints on Water-in-Basements (WIB) and Sewer Backups (SBU)
- Pavement
- Wastewater Treatment Plant (WWTP)
- Right-of-way

Note that this is not a comprehensive list, and additional shapefiles are available upon request from MSDGC. In cases where CAGIS data are incomplete, discrepancies should be resolved through information requests to MSDGC. Record drawings can be accessed through the CAGIS MSDGC sewer line shapefile via the "IMAGE_PATH" attribute.

4.2   RAINFALL DATA

Observed rainfall is available for the MSDGC service area in the form of radar rainfall basins and point rain gauge data. In general, it is good to have at least 1 year of storm data to categorize seasonal changes.

4.2.1 Radar Rainfall

The MSDGC Modeling Group maintains multiple radar rainfall datasets for different historical time periods and ongoing data collection. Because of this, the MSDGC Modeling Group should always be consulted when requesting radar rainfall data, as the source of the rainfall data may vary. WS_Mixed data (provided by MSDGC) is the preferred radar rainfall dataset. However, in the absence of WS_Mixed data, Gauge Adjusted Radar Rainfall (GARR) data are available. The rainfall data is in EST.

GARR data are processed and available from MSDGC. GARR data are supplemented with monthly reports that contain event statistics and a list of events per month classified as non-detect, non-qualified, or qualified. These events are defined as follows:

- Non-detect: Periods with no rainfall detected by radar throughout the MSDGC service area.
- Non-qualified: Periods which record rainfall but do not meet the storm definition requirements identified as being qualified for GARR analysis (note that these are not necessarily excluded from modeling.)
- Qualified: Periods which for any given hour, at least 50% of all working gauges have an accumulation of at least 0.05 inches

In reviewing rainfall data and compiling an event list, non-qualified and non-detect periods should not be considered for model comparisons or calibration activities. Refer to **Volume II Section 4.3.2** for more guidance on rainfall data review.

4.2.2 Point Rain Gauge

Point rain gauge data are collected from individual rain gauges and used in the ground truthing of radar rainfall data. Point rain gauge data can be used to supplement missing radar rainfall data. However, because rainfall is spatial in nature, not all radar sub-basins or rain gauges will experience the same rainfall volumes and intensities through the course of a storm event.

4.3 MONITOR DATA

Reliable monitoring data are necessary for the development of an accurate hydraulic model. Flow, depth, velocity, and level data are processed and available online for download through the BLU-X database. Contact MSDGC to gain access to BLU-X.   Any questions should be directed to the MSD Flow Monitoring group.

In general, it is recommended to have at least 1 year of flow data for a typical calibration project. However, it is understood that there may be instances where a full-year dataset is not available, and in some cases, may not be necessary for the purposes of the project. The adequacy of the flow monitoring record is something that will be addressed as part of the *5 – Data* app in FlowFinity and can be discussed on a case-by-case basis with the MSDGC PM, if/when necessary.

The modeler should review the available data to identify acceptable periods for use with calibration efforts. The extent of the data review required will be determined during the project modeling scope negotiations.

4.3.1 Flow Monitor Types

MSDGC used five types of flow monitors: Hydrology, Apportioning, Hydraulic, Regulatory Reported Overflow, and Non-Calibration. Hydrology Monitors are also referred to as Calibration Monitors.

1. Hydrology Monitors (Calibration Monitors) are used for runoff parameter calibration and have a full year of data unless otherwise explicitly authorized my MSDGC. Hydrology monitors are typically distributed throughout a project area. A Hydrology Monitor is intended to accurately determine the volume and timing of flow across the seasons.

2. Apportioning Monitors are used to assess flow distribution upstream of a Hydrology Monitor. Apportioning Monitors are installed for less than a full year.

    a. The monitors are typically micromonitors or short-term monitors located in sanitary sewer areas but can be located in combined sewer areas in some situations.

    b. Apportioning monitors require a minimum of two to three storm events and a downstream Hydrology Monitor.

    c. Apportioning Monitors can be used to adjust limited parameters within the metershed, depending on the duration of the monitoring period.

    d. If a monitor is installed for one year but large portions of the data are unreliable, the monitor may be considered an Apportioning Monitor as well.

3. Hydraulic Monitors (short or long term) are located at hydraulicly critical locations. Hydraulic Monitors are used to establish hydraulic parameters and require a minimum of 3 months of data. Hydraulic Monitors can include:

    a. Level only sensors
    b. Underflow monitors
    c. Bypass or relief line monitors
    d. Pump runtime
    e. Pump flow rate
    f. Pump station wet well levels
    g. RTC gates and levels

4. Regulatory Reported Overflow Monitors are used to assess the CSO, SSO, PSO, or NEO overflow frequency. The monitors are typically the permanent level monitors installed at each overflow. They will be assessed against records reported to meet regulatory requirements. The process for reporting overflows at regulatory reported overflow monitors is described in **Volume II Section 7.4**.

5. Non-Calibration Monitors provide useful information about the system, but do not qualify as one of the types above due to the location, quality, and/or quantity for the data. For a project monitor to be deemed "non-calibration", it must be approved as such by MSDGC. Examples are monitors with:

   a. Varying amounts of silt at or downstream of the monitor (*A silt monitor could provide useful flow rates during some storms*)
   b. Poor data quality

The calibration and submittal requirements vary for each monitor type and are discussed in **Volume II Section 6.5** and located in the FlowFinity *6 – Calibration* app. Refer to **Volume II Section 4.3.2** for guidance on reviewing flow monitor data, and steps to take if additional short-term flow monitoring is needed.

4.3.2 Flow, Depth, and Velocity Review

Observed data should be reviewed to ensure that the data quality is adequate for use in calibration. The data should be reviewed over extended periods and individual storm events. The flow, depth, velocity, and rainfall timeseries should be reviewed and compared to ensure that the data is reasonable. Additionally, the data review should include (but is not limited to) the following steps as described in the following sections.

- Pipe Size/Shape Confirmation
- Observed Depth vs. Velocity Data
- Rainfall vs. Runoff
- Flow Balance Between Monitors
- Monitor Maintenance Log

When reviewing data, identify any instances of the following:

- Extreme changes in depth, velocity, and/or flow
- Extreme values of depth, velocity, and/or flow
- Depth or velocity measurements outside range of instrument
- Periods of supercritical flow and hydraulic jumps
- Periods of receiving water intrusion (check against USGS stream gauge data, if possible; **Volume II Section 4.5.1**)
- Rainfall time series not representative of actual rainfall
- Snow melt
- Facility operational failure or change
- Change in minimum flow and minimum depth over time

Rainfall events must also be defined. Refer to **Volume II Section 6.2** for guidance on defining events and example rainfall event templates. All rainfall data records must correctly account for time shifts due to daylight savings. Likewise, all data should be in Eastern Standard time.

Periods or events containing suspect data should not be used in model development or analysis. Suspect or insufficient data may include:

- Periods of data with large or frequent gaps (poor data quality), so peak flows or water levels are missed, or volume calculations may not be complete.
- Poor hydraulic conditions at the meter site leading to unstable and/or unreliable data for an extended period.
- Flow imbalance issues between upstream and downstream meters. In such situations, justification for choosing the "reliable" vs. "unreliable" meter should be provided. If multiple meters are available, illustrate that all meters but one balance well. If only two meters are balanced, then the meter data quality issue should be identified (i.e., poor velocity data, poor site hydraulics, depth sensor drift).
- Periods of unusually wet or dry conditions with abnormal rainfall-to-runoff characteristics.
- Periods with only small storms (if calibrated only to small storms, the model may poorly simulate larger storms), which could be especially detrimental if using monthly RTK values.
- Periods before major system changes (major change in land use, sewer separation, RTC, etc.) such that the flows do not correspond to the modeled collection system. However, note that a dataset such as this could still be used for updating the Calibration Model, so long as the Existing Conditions Model and Storm Volume Model are correctly managed to reflect the major system change.

If flow monitoring data are not available or are insufficient to support the project, identify the need for flow monitoring along with potential locations and submit this recommendation to MSDGC. The MSDGC PM will need to determine the extent of flow monitoring and modeling needed with respect to budget, schedule, and project risk.

Note that with proper justification (e.g., poor data) and approval from the MSDGC Modeling Group, a flow monitor can also be changed to "non-calibration," as discussed in **Volume II Section 7.4.**

Pipe Size/Shape Confirmation

Reported pipe cross sectional areas should be compared to manually calculated cross sectional areas to ensure the correct pipe size/shape were used to calculate flow. This check ensures that the field dimensions match the dimensions used by the flow monitor. The graph comparing the Reported and Theoretical pipe cross sectional area versus depth is utilized for a visual comparison. The following must be included in the graph:

- Observed Area of Flow – Reported cross sectional area vs. reported depth for every observed data point. Divide observed flows by observed velocities (Q/V) to calculate the reported cross-sectional area.

- Theoretical Area of Flow – Calculated cross sectional area vs. depth of the pipe. Calculate the cross-sectional area at various flow depths for the monitored pipe based on its physical diameter.
- Pipe Diameter

Refer to **Volume II Figure 4-1** for an example comparison.

Figure 4-1. Pipe Size/Shape Confirmation Example
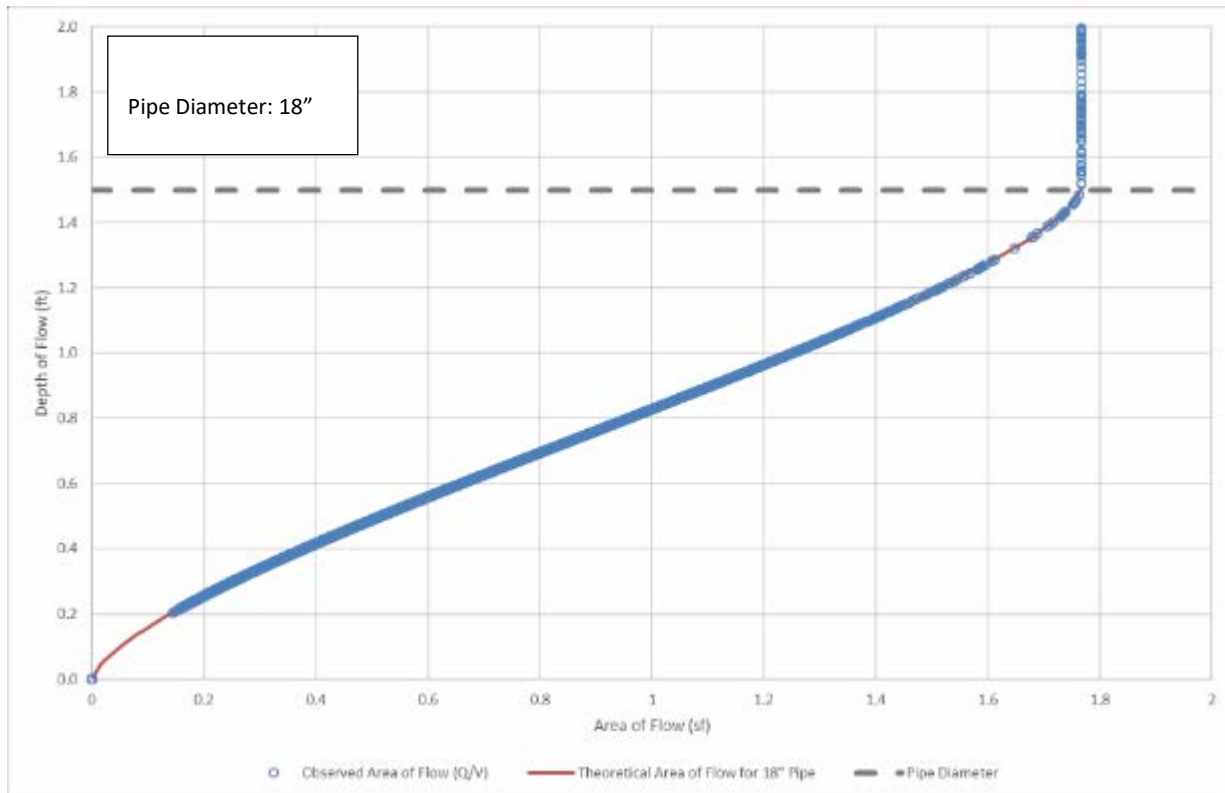
Observed Depth vs. Velocity for Complete Period of Record Scattergraph

Plotting the scattergraphs of individual events can be utilized to evaluate suspect or outlier events. Generally, the scatterplots should be consistent throughout the monitoring period.

- Differences in scatterplot shapes between events may indicate that the outlier data is unreliable.

- Differences in scatterplot shapes for large periods of data may indicate data drift and/or sensor depth adjustments.

  o If the depth or velocity data was shifted, a portion of the data may be unreliable. The shifts are most evident when one reading (velocity or depth) shifts and the other remains consistent.

o   Data shifts can also occur due to sediment or debris buildup or washout, which is indicated when one reading shifts up and the other down. In some cases, the data is still reliable, while in other cases, the buildup results in measurement errors.

Volume II Figure 6-14 shows an example of a shift in data identified during low flows which may suggest a drifting velocity sensor. Note that calibration depth guidance and compliance metrics are discussed in **Volume II Section 7.1.6.**

Figure 4-2. Velocity vs. Depth Scattergraph on an Event Basis
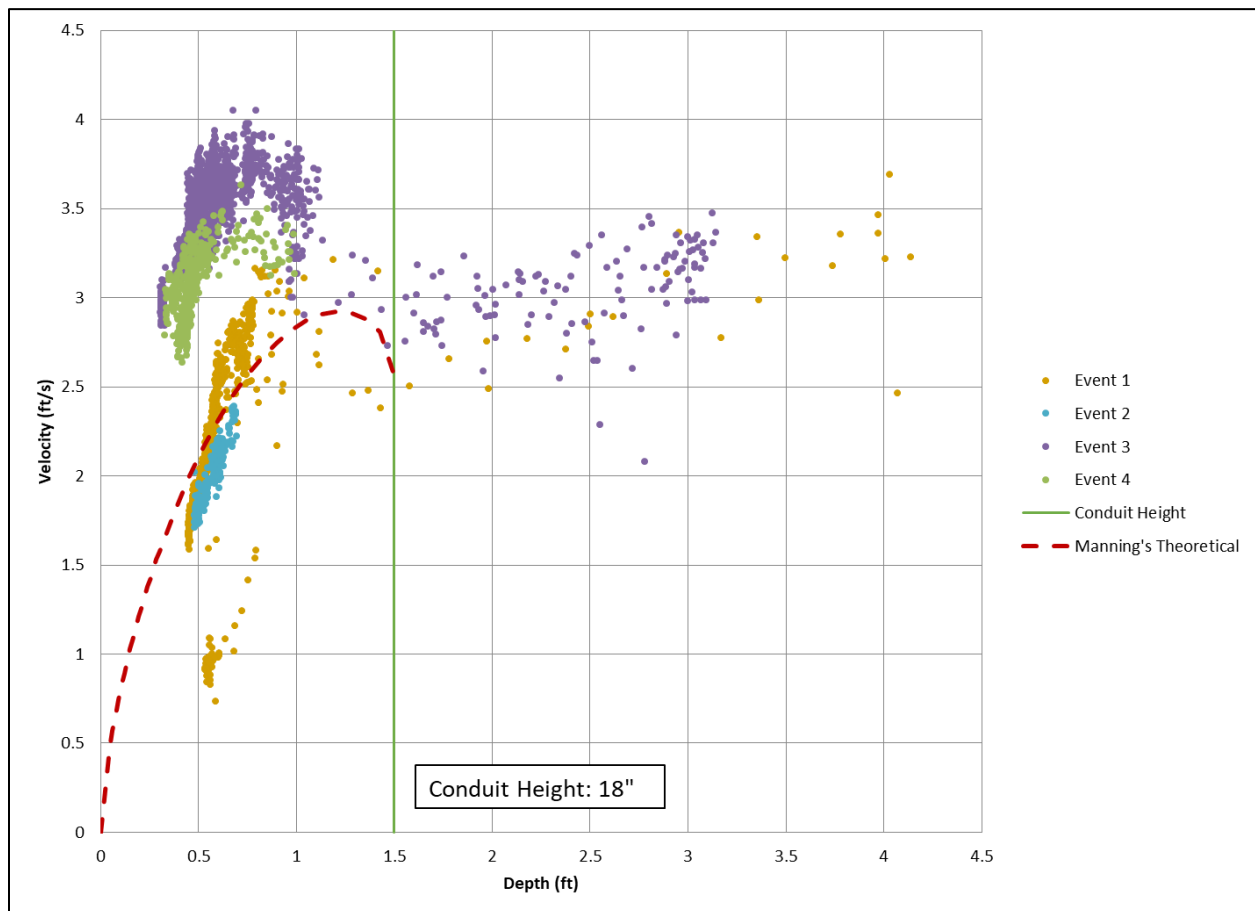
Rain vs. Runoff by Event

Observed peak flows and volumes should be compared to 15- or 30- minute peak rainfall intensities and depths per event to demonstrate typical flow responses and identify possible outlier events, as shown in the examples in **Volume II Figure 4-3** and **Volume II Figure 4-4**. Events outside the normal trend should be flagged and reviewed further to determine if the data is relibale. A data error could be caused by poor flow monitor data or rainfall data. The differences can also be caused by rainfall distribution (e.g. back-to-back rainfall events, or local thundercells missing the gauge or part of the basin) and therefore should not be used as the sole reason to identify the data as unreliable. **Volume II Figure 4-3** and **Figure**

4-4 are generated by the MSDGC Calibration Tool under the Report tab at the top of the screen as Figures C2-4 and C2-5.

Figure 4-3. Peak Rainfall vs. Peak Flow by Event
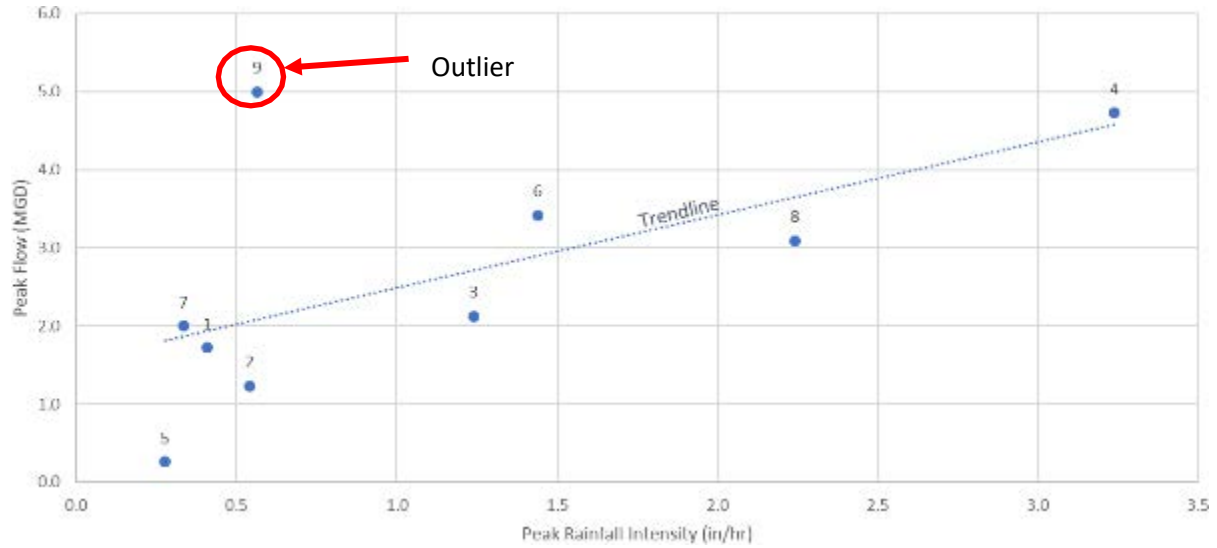
Figure 4-4. Total Rainfall vs. Flow Volume
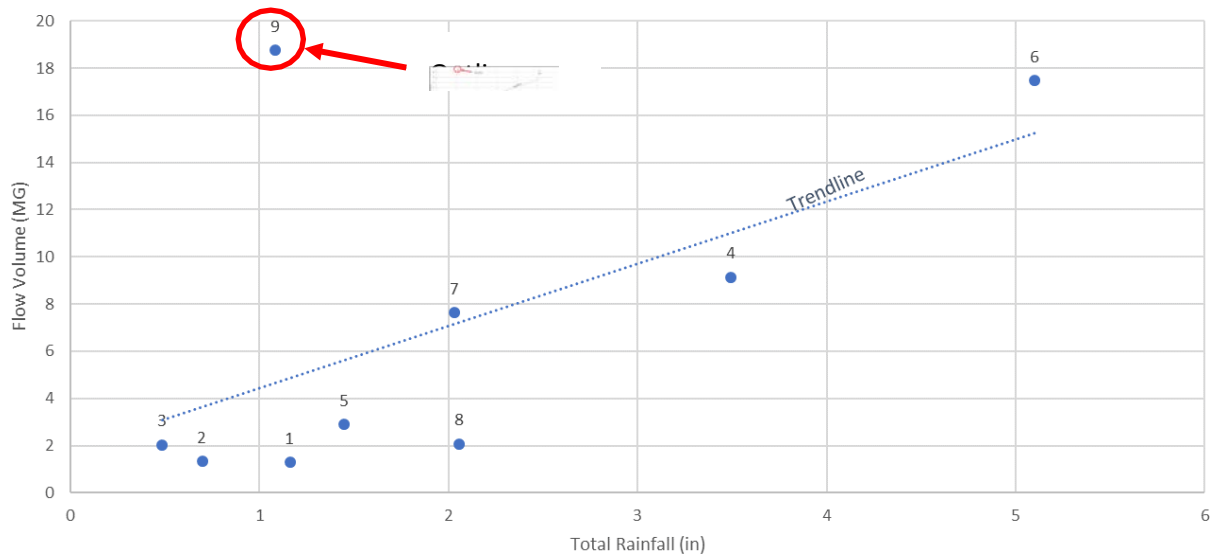
Flow Balance Between Monitors

Flow volumes should balance such that downstream flows are greater than or equal to upstream flows, unless there is a known diversion, overflow, or flow loss between monitors. The ratio of flow volume from an upstream monitor(s) over a downstream monitor should not exceed 1. In addition, the ratio should be related though not strictly proportional to the amount of area uniquely tributary to the upstream meter divided by the total area tributary to the downstream meter. The flow balance should

be checked by comparing the flow hydrographs per event. If two upstream monitors are tributary to one downstream monitor, the two upstream monitor flows should be added together, then compared as well. The flow should balance for all parts of the event, not just the total event volume.   Flow Balance can be used to identify level adjustments in flow monitors, and to exclude storm events from calibration and analysis.

Monitor Maintenance Log Summary Table

Monitor site maintenance logs should be reviewed for periods identified as questionable flow data or data dropouts. The logs should be used to confirm data issues discovered through prior review measures, such as drifting sensors or debris on a sensor. The maintenance log is available in the *Flow Monitoring* tab, *FM_Maintenance* app on FlowFinity.

4.3.3 Overflow Activation Review

Level sensors are installed at all MSDGC CSO, SSO, and pump station overflow (PSO) locations to determine if an overflow has occurred from the outfall. Level sensor depth should not be used to estimate overflow volume to calibrate a model.

Review of the level sensor data should include identifying instances of suspect data, such as extreme changes in depth, measurements outside the range of the instrument, or sensor drift. Level sensor data should also be reviewed in conjunction with flow monitor data and the record of reported discharge. Reviewing level sensor and flow monitor data together provides a check of the level sensor data quality and insight on diversion hydraulics. This comparison can assist with supporting the number of overflow activations as measured by the level sensor. **Volume II Figure 4-5** provides an example of when the timing of wet weather flow responses matches well between the upstream depth meter and the downstream activation level sensor. This comparison suggests that each meter is responding to rain events, however, it does not confirm that the model correctly correlates with observed overflows.

The level sensor data should also be reviewed for possible high receiving stream levels. The degree and duration of high receiving stream levels may change the project modeling procedures, storms used for calibration, or extend project modeling to include the receiving stream. A daily list of overflow activations for a time period will be submitted per the guidance in **Volume II Section 7.4.**

Figure 4-5. Level Sensor vs. Upstream Depth Meter Comparison
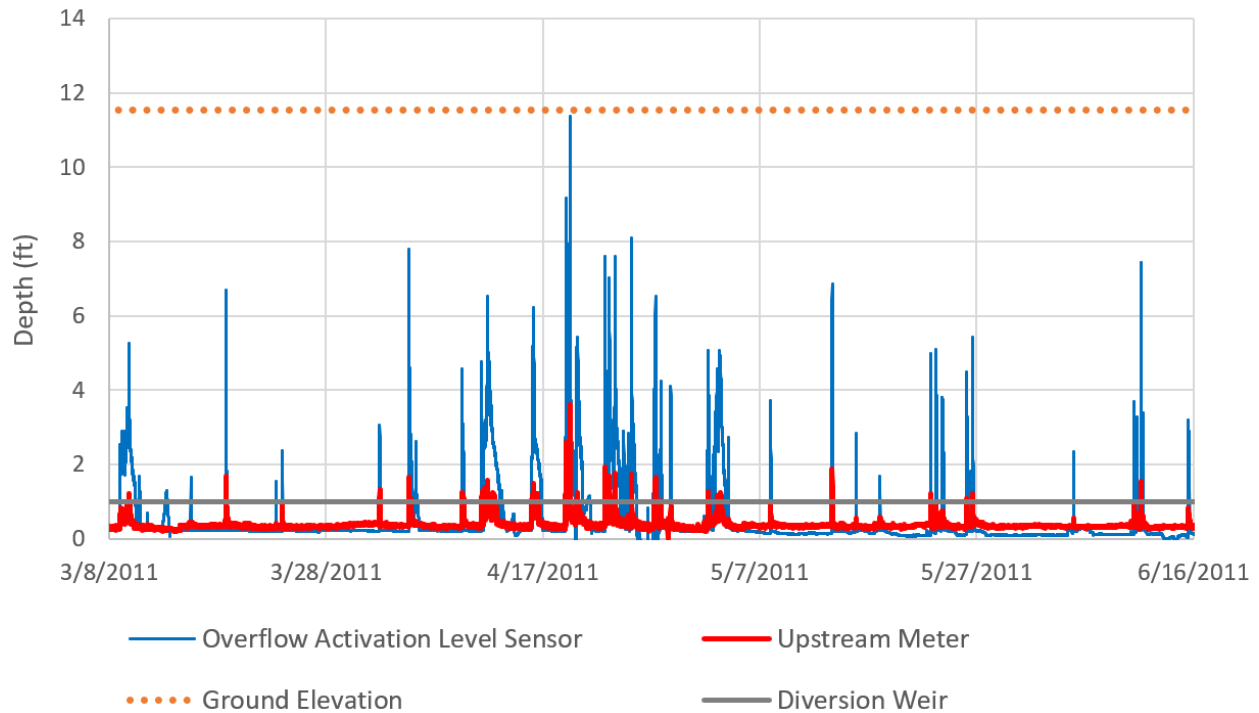
4.4   OTHER HISTORICAL DATA

MSDGC maintains a historical database of information and records from past projects that includes:

- Closed-circuit television (CCTV) and Sewer Condition Reports
- Manhole camera inspections
- CSO and SSO Reports
- Ohio Department of Transportation (ODOT) Right-of-Way (ROW) files
- Record drawings
- Reports and Technical Memorandums

Historical data are available from MSDGC upon request.

4.5   SUPPLEMENTAL DATA SOURCES

4.5.1   United States Geological Survey (USGS) Stream Gauge Data

Depending on the location in the system, and the magnitude of the storm event, collection system hydraulics may be influenced by backwater or flooding in receiving streams. MSDGC logs in the SCADA system estimated river and stream elevations at all regulated discharge points. These time series are generated from a combination of USGS gauges and MSD level sensors. Time series will be provided to the consultant for all outfalls during the calibration period.

It may be beneficial to review USGS stream gauge data to check this possibility. USGS stream gauge data are available at http://waterdata.usgs.gov/nwis. Gauges that may be of interest are shown in **Volume II Figure 4-6**.

Use of USGS stream gauge data should include a review of the following:
- Extreme changes in values of depth
- Measurements outside the range of the instrument
- Hydrograph shape and timing makes sense when compared to nearby project monitors.
- Confirmation that data has been converted to the correct elevation (i.e., modeler should understand the datum and coordinate system)
- Check flow monitor data against stream stages during large storms to identify potential river intrusion.

Note that the Ohio River, as well as the main receiving stream, may be influenced independently by storm events located outside of Cincinnati or the immediate project area.

MSDGC maintains level sensors in portions of the Muddy Creek, Mill Creek, and Little Miami River, as shown in **Volume II Figure 4-6**.

4.5.2 Site Inspection

MSDGC has access to field crews for inspections and measurement of manholes and other structures. Survey crews are also available for surveying elevations of manhole rims and other reference points. The time required for the inspection or survey is variable and may take too long for use in a particular project. All manholes within a project that have more than one outlet pipe will have key data available within the *2 – FlowSplits* app in FlowFinity.

4.5.3 Other Sources of Data

Depending on the project, supplemental data from sources outside of MSDGC may provide additional insight to model development. However, note that the use of data from external sources must be approved for the project by the MSDGC Modeling Group.

Figure 4-6. Stream Gauges in the Cincinnati Area (2019)

Map ID	Location	USGS Station	MSD Station
	USGS & MSD Gauges of Interest around the Cincinnati Area		
1	Mill Creek at Carthage	3259000	-
2	Mill Creek at Reading	3255500	-
3	Mill Creek at Evendale	3255420	-
4	Mill Creek at E. Sharon Rd at Sharonville	3255349	-
5	Sharon Creek at Sharonville	3255390	-
6	Mill Creek at Kemper Rd at Sharonville	3255300	-
7	Little Miami River at Milford	3245500	-
8	Great Miami River at Miamitown	3274615	-
9	Ohio River at Cincinnati	3255000	-
10	Little Miami River (Lower Duck Creek)	-	LMRIV-01
11	Little Miami River (Clough)	-	LMRIV-02
12	Mill Creek (Denham)	-	MC-DN-007
13	Mill Creek (RM - 1.574)	-	MILLCR-00
14	Mill Creek (RM - 1.720)	-	MILLCR-01
15	Mill Creek (RM - 3.466)	-	MILLCR-02
16	Mill Creek (RM - 5.471)	-	MILLCR-03
17	Mill Creek (RM - 7.816)	-	MILLCR-04
18	Mill Creek (RM - 13.691)	-	MILLCR-05
19	Muddy Creek	-	MUDCR-01
20	Muddy Creek	-	MUDCR-03
21	Muddy Creek	-	MUDCR-04

4.6 DATA COLLECTION AND REVIEW DOCUMENTATION

Though not required to be submitted, the modeler must follow the review process outlined in **Volume II Section 4.3.2** to vet the data properly. Once review and application of the observed data have concluded, the next step in a typical calibration project should involve either beginning calibration, or development of a Detailed Model depending on which Model Flow Chart the project is following. Note that no submittals are required before moving on to the next step. During the event selection phase, the result of the data review will be used to identify events that may need excluded from the calibration. The data review results should be presented with the event selection documentation to justify the excluded events. Referring to **Volume II Figure 1-6** through **Figure 1-12**, the modeler will proceed one of the following sections:

- **Section 5.0 Detailed Model Development**

- **Section 6.0 Calibration Procedure**

5.0 MODEL COMPLEXITY

Adding model complexity to simulate individual components in the model areas can introduce considerable computational overhead when the model is subsequently used for basin-wide decisions. Thus, MSDGC prefers not adding excessive complexity unless required to meets the goals of the project. For a typical project, forethought will be needed to identify which potential alternatives will be evaluated in the Planning phase, as this may dictate if specific additional detail, such as small tributary areas, basement storage, or sump pumps, should be added to the model. This should be done prior to calibration so that the effects of the additional model complexities are carried through the project and provide a consistent basis from which to make relative comparisons once the Planning phase commences.

When warranted, the modeler will add detail to the SVC model extracted from the EC-Q_n model to accomplish the project goals. This new Detailed Model (D-SVC) will be calibrated to the observed data. Once calibrated, the model (D-SVC-Cal) will be subsequently used in the Planning phase. When a D-SVC-Cal model is prepared, the additional level of detail will subsequently be reduced when a Standard Model (SVC-Cal) is prepared in later steps for integration back into the Model Archive. This process of model standardization is covered in **Volume II Section 9.0**.

Given the vast number of variables involved with updating complex model representations, assigning exact quantitative limits on complexity is not possible. Instead, this section provides a general qualitative basis from which to gauge the appropriate level of detail, with the understanding that defining a level of detail for model updates is subjective, and exceptions and variations will occur.

In addition to the guidance provided in this section, modelers should also review **Volume I Section 4.3** and **Volume I Section 4.5** for a review of typical ranges for hydrology/hydraulic inputs.

5.1 DECIDING IF A DETAILED MODEL IS NEEDED

Given the highly subjective nature of modeling, it is not possible to account for and itemize every instance in which a Detailed Model will, or will not, be necessary. However, more common and generic examples of when a more Detailed Model could be necessary, or conversely would not be necessary, are provided in the following subsections. These basic examples are not exhaustive and are only intended to facilitate and shape the decision-making process, which ultimately must be agreed upon by the MSDGC Modeling Group.

5.1.1 Examples of When a Detailed Model is Needed

RDII Mitigation through Rehabilitation

There may be situations where small sanitary sewersheds consisting of a few streets of residential housing are being evaluated for private downspout, yard drain, area drain, and sump pump disconnection; lateral and tap rehabilitation; and/or rain barrel installation for the purposes of RDII

mitigation. It may be such that the entire area would typically be lumped together as one representative flow. However, this area would likely need a much higher-level precision and would require that each yard and lateral be represented explicitly to evaluate the anticipated alternatives.

Basement Flooding Evaluation

When basement flooding needs to be evaluated as part of the alternatives, the model should be updated with storage and any additional detail that would be required for adequate representation of the basements being evaluated. This could include adding in the laterals if each basement should be represented individually, or it could mean grouping basements into a single storage node at critical points depending on the level of detail required for the alternatives analysis.

Overland Flow Evaluation

MSDGC's standard practice of losing surface flooding from the system is adequate for most projects when identifying the location of surface flooding is sufficient. However, when significant surface flooding and overland flow occurs during large rain events, additional investigation of that area may be necessary. This may involve adding open channel conduits at the overflowing node's surface elevation to represent the characteristics of the overland flow, and thus aid in the alternatives analysis of how to mitigate the flooding.

5.1.2 Examples of When a Detailed Model is *Not* Needed

Typical Updates Based on Field Data

Model updates that reflect standard changes to the watershed/sewershed and hydraulic system since a previous calibration should be considered standard. Examples of this could include (but are not limited to):

- Adding new pipes and subcatchments due to new subdivision developments or green infrastructure project
- Subdividing existing subcatchments and updating pipe sizes and alignments due to redevelopment
- Adding new facilities or conveyance that have been constructed (e.g., relief sewers, storage, treatment, etc.)

Standard Alternative Solutions

While some projects may require establishing a Detailed Model before calibration to support the Planning Phase, most projects will not need this since the anticipated alternatives analyses will consist of more standard solutions. Examples of this could include (but are not limited to):

- Adding facilities – storage, high-rate treatment, relief sewers
- Evaluating stormwater separation – subcatchments can be subdivided as needed as long as the runoff is conserved.
- Facilities representations (e.g., CSO/SSO regulators, high-rate treatment (HRT), WWTPs, detention ponds, BMPs, storage tanks, etc.) should primarily be viewed as a means by which to assess the volumetric distribution of flow into and out of the facility. They can also

be used to provide a general assessment of impacts to the system upstream and downstream of the facility. An intricate and detailed representation of the internal hydraulics of a facility is not necessary in most situations, and further may not be appropriate given the limitations of the EPA SWMM engine. Complex facility hydraulics will likely be better evaluated through other means, especially when supporting detailed design decisions. Consult the MSDGC Modeling Group if unsure.

- Site detention (whether surface or underground) should only be represented if the tributary area of the detention is greater than 5 acres in most cases. For small CSO areas (less than 40 acres), the site detention can be represented if the tributary area of the detention is more than 1/8 of the total CSO tributary area.

5.2   ADDITIONAL CONSIDERATIONS

In some cases, the level of detail required for the project may exceed the limitations of the SWMM engine. A generic example of this could be when analyses of turbulent flow through a complex CSO regulator structure or proposed facility are needed to evaluate the impacts on the upstream system. In such cases, it may be necessary to perform computational fluid dynamics (CFD) modeling or extensive flow and level monitoring to generate a rating curve representation which can be used in the SWM. It is the modeler's responsibility to always consider the limitations of the SWMM engine, and to consult with the MSDGC Modeling Group when the complexities of the analysis are thought to have exceeded the capabilities of SWMM.

6.0 CALIBRATION PROCEDURE

This section provides guidance on the approach that should be used for calibrating the SVC, SA, or D-SVC models, in addition to the compliance criteria that should be used to assess model calibration quality. Written approval from the MSDGC Modeling Group is required for deviations from the approach outlined in these guidelines.

Note that the approach varies from what has historically been considered the "typical" approach to model calibration, in the following ways:

- Rather than comparing the total flow during a storm event, this approach isolates the storm contribution to the flow (aka "WWF Response" or "Runoff") in both the <u>observed</u> and modeled data for comparison. In simple terms, independently calculate and subtract the base flow (balanced prior to each storm) in both the observed and modeled data, then compare the event storm contributions.
- The observed and modeled event storm contributions are compared using a modified Concordance Correlation Coefficient to determine compliance. WaPUG standards of peak and total volume are not used.
- Depths are compared using the velocity-depth scatterplot. WaPUG peak event depth is not used.

Calibration converts the extracted SVC model to a model calibrated for storm response (SVC-Cal, SA-Cal, D-SVC-Cal). The only difference in procedure for the three models is that SA is for a single event and thus some of the graphs will appear differently.

The calibration process is shown schematically in **Volume II Figure 1-6** and **Figure 1-7**, with further detail provided in subsections that follow.

Figure 6-1. Process of Calibrating for Storm Response
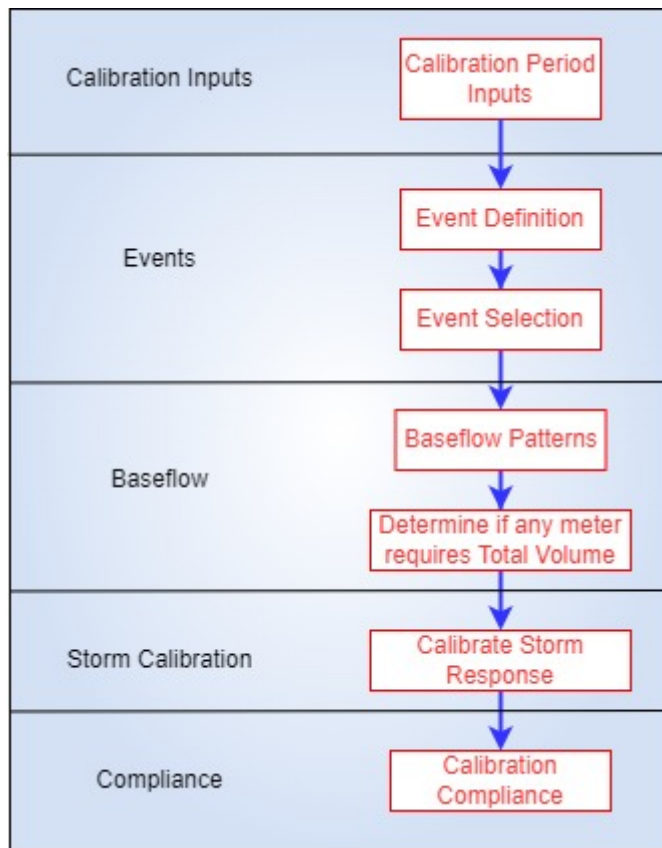
6.1   CALIBRATION INPUTS

In the calibration process the consultant will receive a model from MSD. For the Storm Volume Calibrations (SVC and D-SVC), MSD will extract the model from the vaulted Existing Conditions Model (EC-Q_n) and redelineate itprior to providing it to the calibration consultant.   For a Storm Volume Analysis (SA), this is the vaulted Existing Conditions Model (EC-Q_n) without any redelineation.   In both cases the provided model will be representative of the Typical Year. The calibration model (SVC, D-SVC or SA) must be updated to represent the calibration flow monitoring period being evaluated. This includes the calibration specific data

- Inflow Time Series (If used for Base Flow, see **Volume II Section 6.3** below)
- Rainfall time series
- River levels
- Boundary conditions
- Physical changes to hydrology or hydraulics necessary to represent the conditions that existed during the calibration/event period.
- Calibration period specific system operations (see below)

Related to the "calibration period specific system operations", the provided model will contain idealized representations of the system's operational protocols. However, during the calibration/event time period, it is possible that

- a protocol was overridden by an operator, that
- the system didn't operate as intended, or
- that the timing of operations is out of syn between observed data and modeled runs. This has been specifically observed for diversions to storage/treatment systems.

To prevent what appears to be hydrology calibration errors, but are really just operational timings, these changes to the operational protocol should be manually input to remove that source of error from the process of calibrating the hydrology of the storm flow. As discussed in **VOLUME II Section 3.0**, these manual inputs will be removed at the conclusion of the calibration effort.

For Storm Analysis (SA) MSD does not perform a review of the model before providing it the the consultant; therefore, it is strongly recommended that modelers perform a check on the provided model before beginning any work. This can potentially enhance and increase the efficiency with which the modeling work is performed, as the model would be remedied of computationally intensive errors, while highlighting problem areas in the model to be monitored throughout the project. This would likely also reduce the effort needed when performing the same model error checks in later steps. Refer to **Volume II Section 3.0** for guidance on performing these checks.

6.2   EVENTS

6.2.1   Global Event Definition – Wet Weather Flow (WWF)

One of the first tasks modelers will complete for a new calibration project is the event definition process. Modelers will define global WWF flow events for the entire monitoring period and the same definitions for all calibration meters in the project area. Exceptions to this include:

- Meters downstream of storage units that drain back to sewer (RTC, HRT, stormwater detention, low impact development (LID))
- Storm that is local in extent and travels slowly
- Upstream basins with a substantially shorter storm response (the difference will be more marked in the summer)

The recommended process for Global Event definition is to use either the *Auto-Select Events* feature in PCSWMM, or the analogous *Generate Storm Events* feature in the *Observed vs. Model Flow* tool of the *Model Application Tools* software. Since both programs have a similar interface for this feature, the general process is as follows. The global events will be defined by a 4-hour interevent period for most areas. For large tributary areas, the interevent period may need to be increased, which is at the discretion of the modeler. The appropriate input values for the generation of global events are shown in **Volume II Figure 6-2.**

Figure 6-2. Inputs for Global Event Definition

The modeler should then adjust the extent of each event. See **Volume II Figure 6-3** for examples. Discretion should be used to adjust the event durations as follows:

- The events should extend halfway between the end of rainfall and the return of the system to base flow.
- If the next event occurs before the criteria above is met, the event should end at the beginning of the subsequent event.
- Events should not extend more than 36 hours after the end of rainfall.
- For non-RDII projects, the event extent does not need to be defined to a great level of detail, rather they should be defined broadly. Refining the post rainfall extend from 12 to 6 hours may be warranted but refining an event from 12 to 11.5 or 12.5 hours would be more detailed than necessary. However, for RDII calibrations, if the basins are small, it will be necessary to very specifically define the start and end of event duration to match the flow response and prevent flow signal prevent noise from distorting the volume calculations.

The modeler should also review the timeseries to identify the top 10 flow peaks. The top 10 peaks should be compared to the event definitions. If an event contains more than one of the top 10 peak and the peaks have some meaningful separation, the event should be split into two separate events that should be considered global events with event numbers adjusted accordingly.

Figure 6-3. Appropriate Global Event Definitions
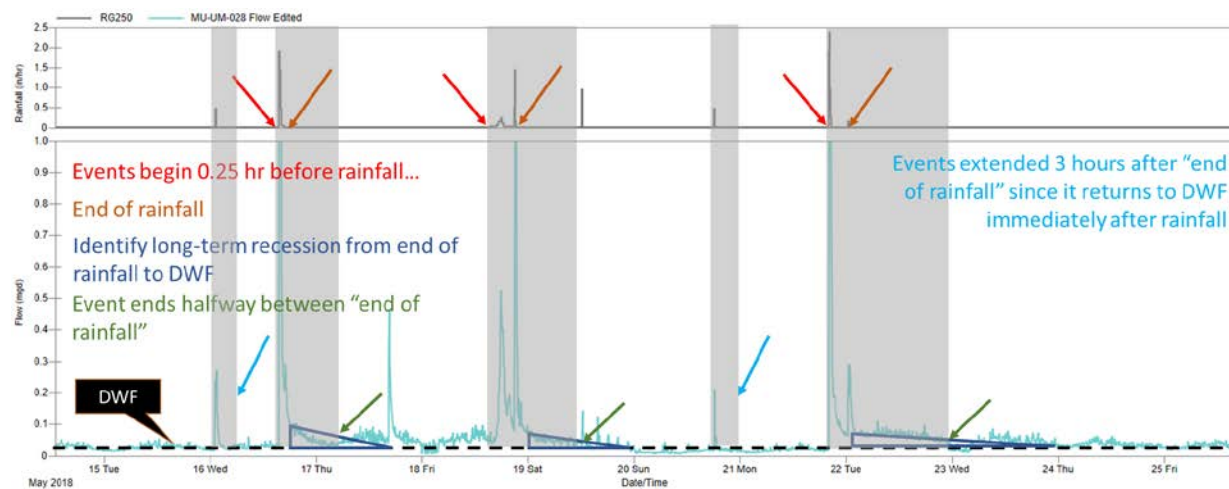
The event start and end times can vary for monitors within a project. For upstream basins with a substantially shorter storm response, the event end time should be shorter than the downstream basins. For example, if an upstream basin is an upland tributary area of 20 acres and the downstream basin has a tributary area of 2,000 acres, the recession limb of the two meters will be significantly different; event durations will likely need to be shorter for the upstream basin. But if the upstream tributary area is 100 acres and the downstream total tributary area is 400 acres, the recession limbs could likely have negligible differences; the event durations could be the same.

If a data dropout data or other data issue occurs during a recorded rainfall event, the event should still be defined. This is because the event definition will still be used globally across other flow monitors, which likely would still have flow responses recorded for the rainfall event. Note that for the flow monitor which experienced a data issues, the event can and should be excluded from the calibration.

6.2.2 Global Event Selection

After the events are defined, they will be reviewed to select which ones will be used for the calibration. The following screening criteria should be applied to automatically exclude events:

- All events with less than 0.25 inches of rainfall. When submitting event file reviews to the *4 – Event File* app in FlowFinity, these "small rainfall" events do not need to be included within event exclusion lists.
- Events that were NOT processed during the generation of the GARR. With the exception, thunder stromss which can drop significant amounts of rain locally, but not tip the required half of the rain gauges in the County to be included as a GARR storm. If these storms impacted the project area, they generally should be included as calibration events. But if they are not used, no explanation is needed.
- Any events influenced by snowfall, freezing conditions, or rainfall on snowpack. Historical temperature and snowfall data is available on the FlowFinity *Model Misc* tab, *Snowfall Snowmelt*

app. An event should be excluded if it occurs within 3 days of snowfall, freezing temperatures or if there was snowpack on the ground during the event.

Additional events may be excluded based on the finding of the flow data review process, see **Volume II Section 4.3.2** for more details. These must be submitted for review in the *4 – Event File* app within FlowFinity. The remaining events should still provide a range of modeling conditions.

6.2.3 Zone Definition

MSDGC's model calibration approach focuses on specific durations (zones) within wet weather events that will most impact the resulting model predictions (e.g., remaining overflow volume (ROV) and peak rate). The approach uses multiple zones in lieu of the more typical approach of calibrating to just peak flow rate and total event volume. Each calibration event is sub-divided into three (zones) and calibration metrics are calculated from the volumes within each zone. **Volume II Figure 6-4** provides a graphical example of the zones for a single wet-weather event.

Figure 6-4. Example Zones Duration Definition
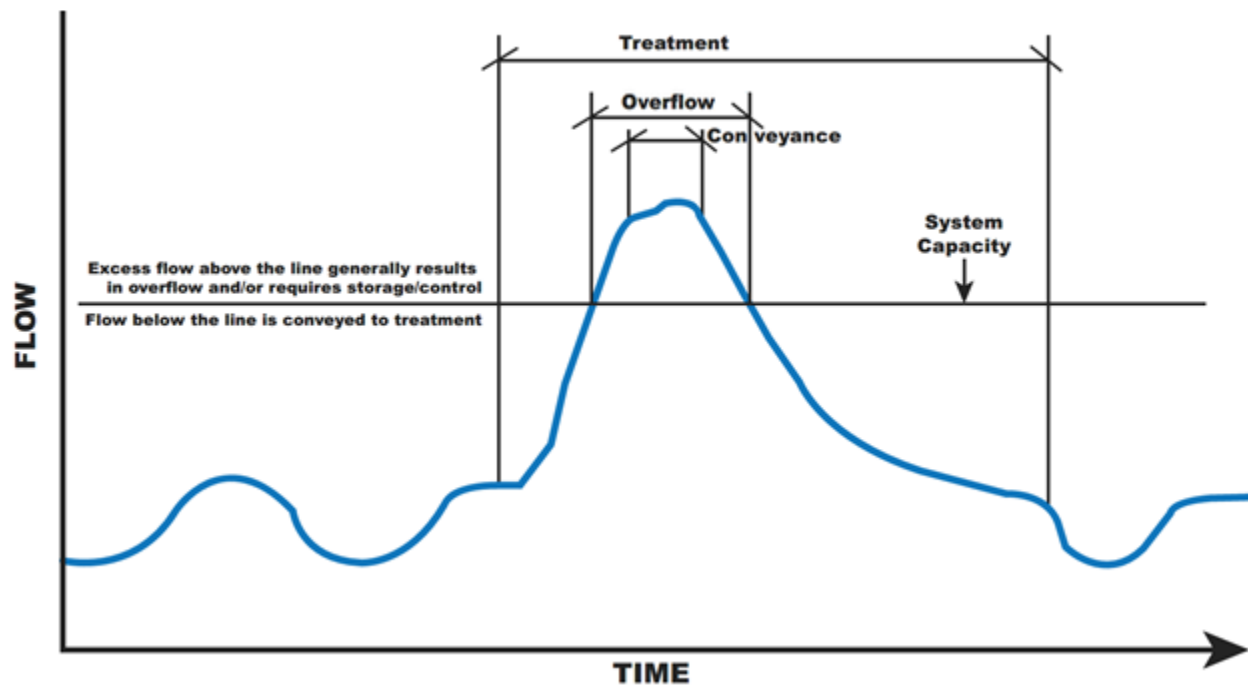
Each zone duration and its purpose in model calibration is described as follows. The definitions may be changed with approval from the MSD modeling group if appropriate to a specific project.

- **Conveyance -** The shortest zone duration defines the peak flow conditions for an event. This period of the event represents the time when sewer capacities are most stressed. Calibrating to this portion of the hydrograph increases the accuracy of evaluating system capacities and/or sizing conveyance infrastructure. Conveyance is defined as 1/24 of the

event, with a minimum duration of three data points (15 minutes) and a maximum
duration of 30 minutes.

> Conveyance: (15 minutes < 1/24 of Event < 30 minutes)

- **Overflow -** The overflow zone duration defines the period when system capacity has been
  exceeded and overflows may be occurring. It is the critical feature of MSDGC's calibration
  approach and fundamentally enforces a proper shape to the resulting unit hydrograph.
  Calibrating to this portion of the hydrograph increases the accuracy of predicting ROV
  and/or sizing storage-type infrastructure. Overflow is defined as 1/4 of the event, with a
  minimum duration of four data points (20 minutes) and a maximum duration of 4 hours.

> Overflow: (20 minutes < 1/4 of Event < 240 minutes)

- **Treatment -** The zone duration is equal to 75% of the event duration. Calibrating to the
  treatment zone improves the accuracy of total volume conveyed to wastewater treatment.
  It has a minimum duration of 30 minutes.

> Treatment: (30 minutes < 0.75 x Event)

The zone duration is based on the event duration, with a longer event having longer zone durations.
Volume II Table 6-1 provides the variable zone durations based on event duration (left-hand column).

Table 6-1. Zone Durations for Varying Event Durations			
Event Duration (Hours)	**Conveyance Zone (Minutes)**	**Overflow Zone (Minutes)**	**Treatment Zone (Minutes)**
0.5	15	20	30
1	15	20	45
2	15	30	90
4	15	60	180
8	20	120	360
24	30	240	1,080

For each zone, the maximum volume is determined based on the maximum flow in the given duration,
not based on set start and end times. Therefore, the maximum volumes for the observed data and
model results do not need to occur during the same time block as shown in **Volume II Figure 6-5**. (Note
that the aforementioned figure shows a Conveyance zone of an hour. Although, durations longer than
those specified in **Volume II Table 6-1** are allowed, a maximum of 30 minutes should be used for
Conveyance unless otherwise approved for basins with a long, slow response.) Shifting the event block
to find the maximums independently will account for any time shift in the data due to simplified model
networks and/or unsynchronized clocks in the meter and rain gauge equipment. Defined time shifts

resulting from Daylight Saving Time errors should be corrected in the beginning when the data is analyzed.

MSDGC will consider alternative definitions for the zones, particularly if the zone definitions above do not enforce proper shapes to the hydrographs. Alternative definitions must be reviewed with MSDGC prior to use.

Figure 6-5. Non-Concurrent Times Shown for Zones
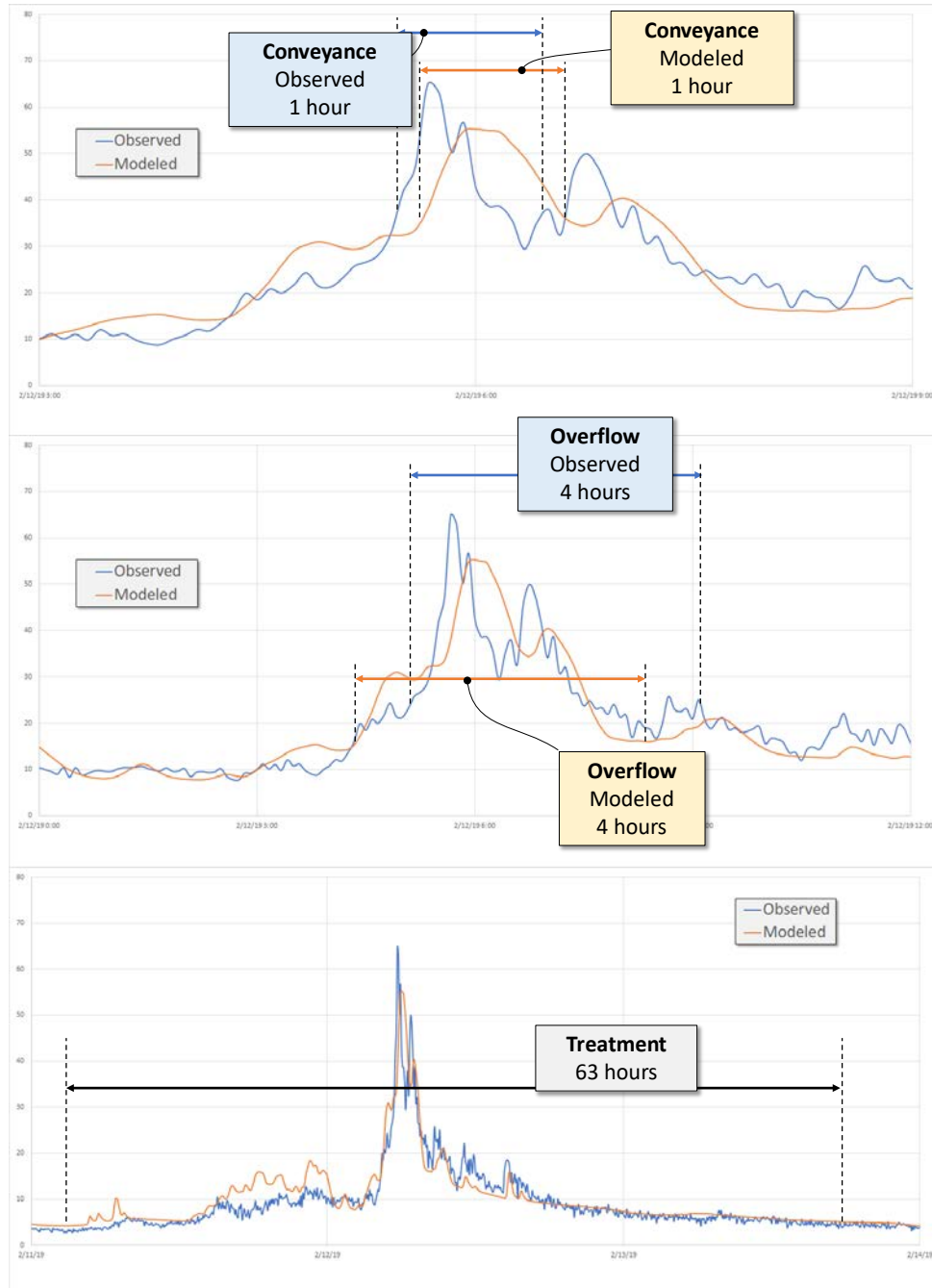
As a note, Conveyance has been shortened to a maximum value of 30 minutes.

6.2.4 Phase Definition

In addition to the zones, the model will be evaluated based on the different phases of the event. The *Observed vs. Model Flow* tool within the *Model Application Tools* software will break up each imported event into three additional phases of flow: the Pre-Conveyance Phase, Conveyance Zone (already defined), and the Post-Conveyance phase.

- The Pre-Conveyance phase is the period from the event start until the Conveyance zone.
- The Post-Conveyance phase is the period after the Conveyance zone until the event end.

Both the Pre-Conveyance and Post-Conveyance phases of flow should be used as guidance by the modeler for review. **Volume II Figure 6-6** illustrates the three phases. Flow can be broken down in this manner in the Model Toolbox as an aide for the review of initial abstractions and unit hydrograph recession.

Figure 6-6. Example Phases Duration Definition
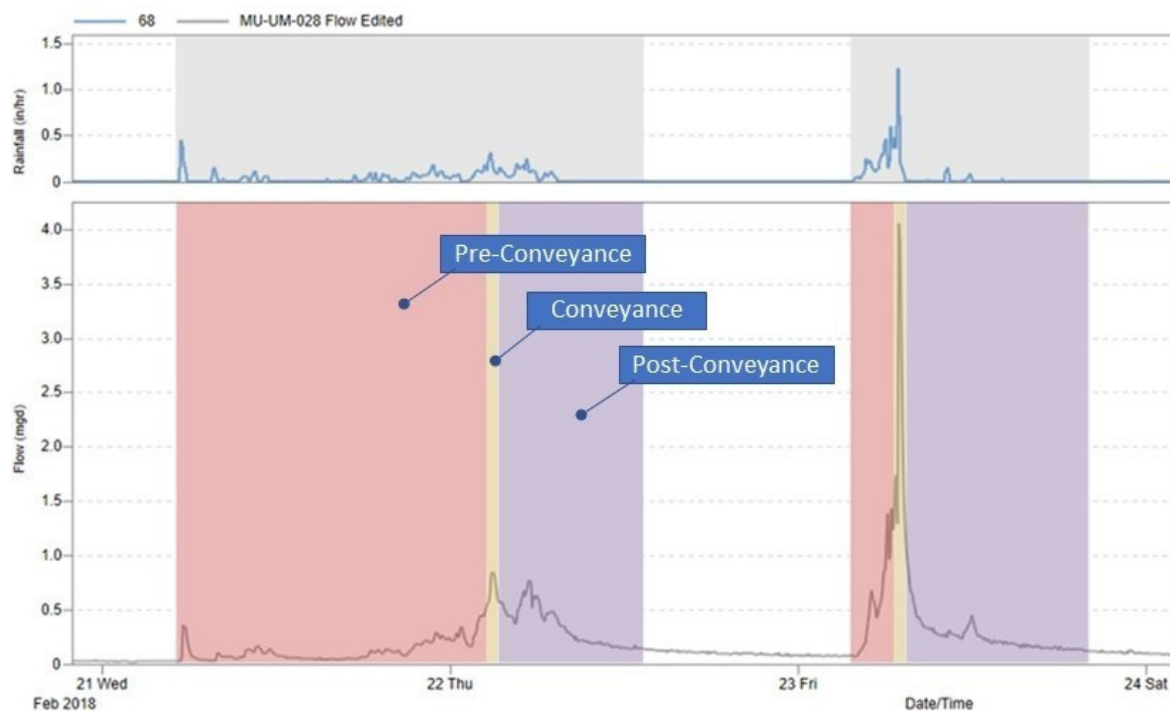
6.2.5 Event File Format

As shown in **Volume II Figure 6-7**, each global event will be defined in numerical order, represented as a three-digit number. This will go in the "Group" column. For example, the chronologically 13th global event within the flow monitoring period would be marked as **"013".**

During the process of event exclusion, events that are excluded will be prepended with an **"X"** to allow filtering of excluded events.

Figure 6-7. Event File Setup

Event	Group	Date	Duration (h)	Maximum Flow (mgd)	Minimum Flow (mgd)	Mean Flow (mgd)
1	001	Apr 20,2021 4:00 PM	13	1.108	0.127	0.2829
2	X002	Apr 21,2021 3:30 PM	2	0.372	0.179	0.2355
3	003	Apr 24,2021 1:10 PM	13.17	0.568	0.087	0.2408
4	004	Apr 28,2021 3:50 PM			0.129	0.4926
5	X005	Apr 29,2021 4:00 AM			0.247	1.509
6	006	Apr 29,2021 7:40 AM	2.5	2.378	0.494	1.045
7	007	Apr 29,2021 12:20 PM	3.67	5.455	0.284	1.353
8	X008	May 02,2021 11:45 PM	6.83	0.926	0.12	0.2641
9	X009	May 03,2021 6:45 AM	1.83	0.705	0.213	0.3767

Group = Global Event #

Events excluded from calibration

6.3   BASE FLOW (BF)

Base flow (BF) is the approximation of the low flow period between storm events. During the compliance check of the storm volumes the Base Flows (OBF and MBF) of the observed data and modeled data are independently calculated and subtracted from the observed and modeled data respectively to give the storm flow for each event. Because the model baseflow (MBF) is adjusted as part of these calculations, there is flexibility in how it is included in the model during the calibration process. However, the final model must have parameters useful for modeling design storms and typical year storms. Thus, base flow has three categories distinct categories:

- Base flow for the model input file during Storm Volume calibration,
- Base flow for Storm Volume compliance calculations (Observed and Modeled), and
- Base flows for the Typical Inputs in the model.

6.3.1   Base Flow for the Model Input File during Storm Volume Calibration

There are three approaches for how to incorporate the base flow into the models

1. Model Parameter Approach: Model parameters to replicate the observed base flow response.
2. Inflow Timeseries Approach: Directly input timeseries for base flow.
3. Aquifer Module: Not recommended.

Model Parameter Approach

In the Model Parameter Approach the Base Flow (BF) is defined as the Dry Weather Flow (DWF) plus an adjustment called the Baseline Seasonal Flow (BSF).

    Base flow (BF) = Dry Weather Flow (DWF) + Baseline Seasonal Flow (BSF)

The following summarizes key requirements for the Base Flow (BF) in the Model Parameter Approach:

- Dry Weather Flow (DWF): (*Average Value* x *Time Pattern 1*)
    - *Average Value*: The average of the base flow (BF) during the month with the lowest flow.
    - *Time Pattern 1*: HOURLY: The hourly pattern is a set of 24 multipliers that adjust the *Average Value* to the variation normally seen in low flow. The 24 multipliers must average to 1.0 to maintain the average flow.
    - *Time Pattern 2*: DAILY: Not Used: The daily pattern in the model which multiplies the *Average Value* by a weight for each calendar day should not be used.
    - *Time Pattern 3*: WEEKEND: Not Used: The pattern for weekday/weekend pattern should not be used.
    - *Time Pattern 4*: MONTHLY: Not Used: Monthly values should not be used to establish seasonal variation of the diurnal pattern as they will distort the shape of the diurnal flow pattern.
- Baseline Seasonal Flow (BSF): (*Baseline* x *Baseline Pattern*)
    - *Baseline*: The amount of flow (additional GWI) added to the Dry Weather Flow (DWF) to match the base flow of the month with the highest base flow.
    - *Baseline Pattern*: MONTHLY: Monthly values are used to establish seasonal variation of the *Baseline*. The value will be zero (0.0) for the low flow month from which the DWF was calculated (low flow) and one (1.0) for the month from which the *Baseline* value was calculated (high flow). All other months should be between zero and one.

Dry Weather Flow (DWF)

Referring to **Volume II Figure 6-8** as an example, the spring has significantly greater groundwater infiltration into the sewer system. Therefore, the late summer and early fall time periods should be used to develop the Dry Weather Flow (DWF), both the *Average Value* and *Time Pattern 1* which is HOURLY.

Figure 6-8. Example of Seasonal Change in Base Flow (BF)
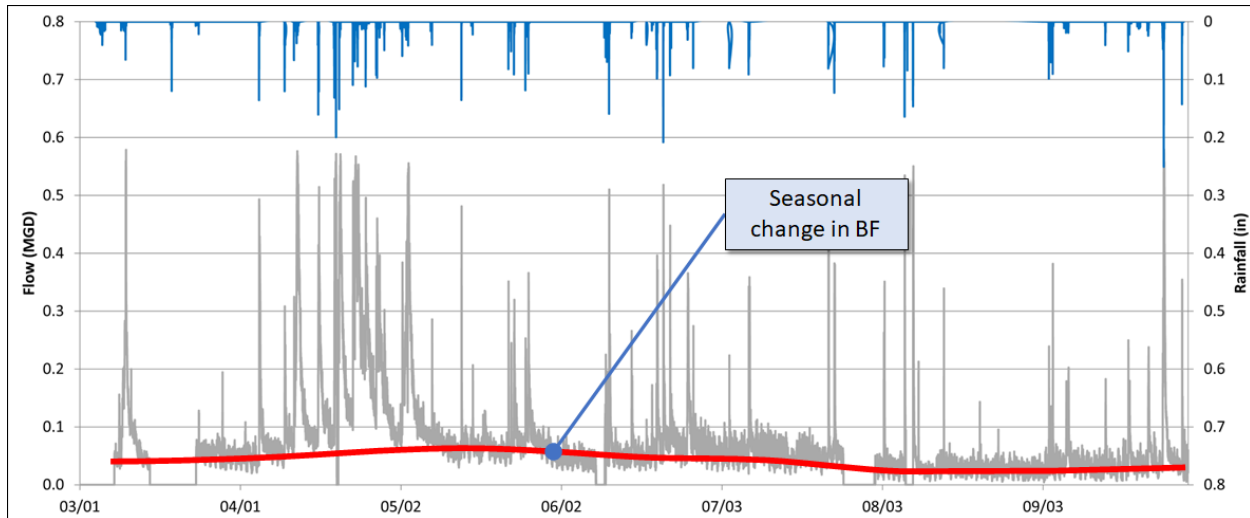
Volume II Figure 6-9 shows an example of the resulting Dry Weather Flow (DWF), which represents the typical diurnal time-varied magnitude of the Baseflow (BF) between storm events during the selected low flow period.

Figure 6-9. Example of Dry Weather Flow (DWF
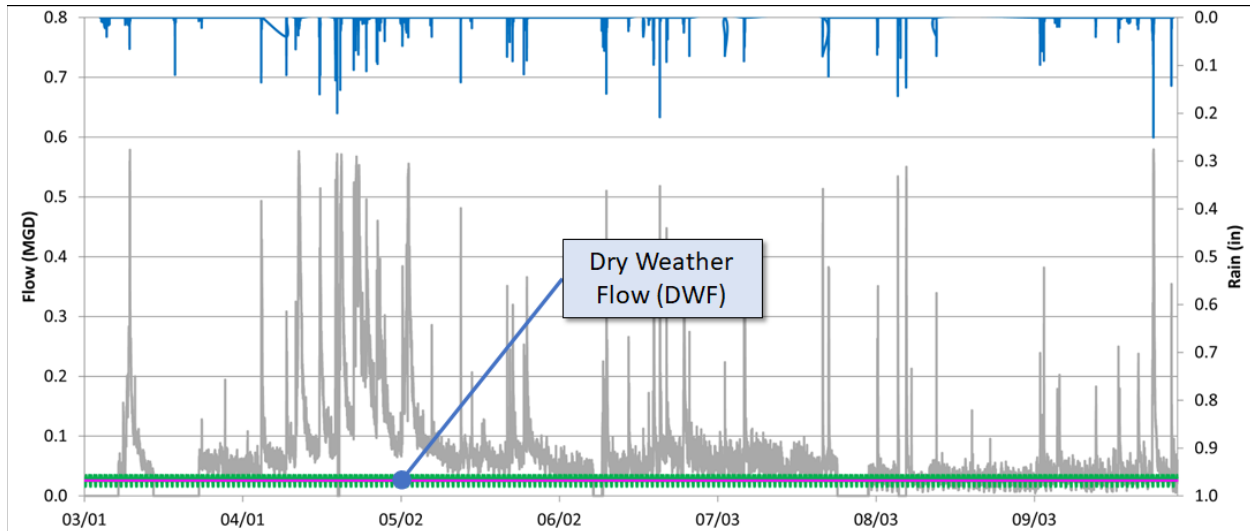
Adding Dry Weather Flow (DWF) to the Model:

1. Determine the isolated Dry Weather Flow (DWF) per flow monitor by subtracting any contributions from upstream monitors.
2. Distribute the *Average Value* to the model based on the subcatchment area and land use.
3. *Time Pattern 1*

With the Model Parameter Approach, the base flow in the model is represented using the SWMM parameters. The determination of the number of patterns to make available for *Time Pattern 1* depends on the available monitoring sites and the size of the project area. Separate patterns should not be created for each monitoring site, as it may lead to less consistent and accurate models.

- Monitoring base flow commonly has instabilities and inconsistencies, especially in small tributary areas.
- The base flows are typically low and therefore have little impact on the overall system response.

Most project areas should aggregate 300-500 acre basins for the development of unique *Time Pattern 1*'s patterns. The project area should only use additional patterns if upstream monitors are located at sites which split the areas relatively evenly. In Example #1, a project area with 1,500 acres total tributary area and includes two upstream meters with 450 acres tributary each (resulting in 600 acres directly tributary) would be an appropriate split of base flow areas. In Example #2, if a project area is 1,500 acres and includes two upstream monitors with 100 acres tributary each, the additional upstream monitors would not provide a significant refinement by having a unique pattern. Monitoring data quality should also be considered; if a flow monitor does not have reliable base flow data, then a pattern should not be developed from that data regardless of the location.

Baseline Seasonal Flow (BSF)

After the Dry Weather Flow (DWF) has been established, two factors are needed to represent the amount of additional monthly groundwater needs to be added to the Dry Weather Flow (DWF) so that the modeled Base Flow (BF) matches the observed data during each month. This additional flow is the Baseline Seasonal Flow (BSF) which is the product of *Baseline* times *Baseline Pattern* as shown in **Volume II Figure 6-10**.

Figure 6-10. Base Flow (BF) Components
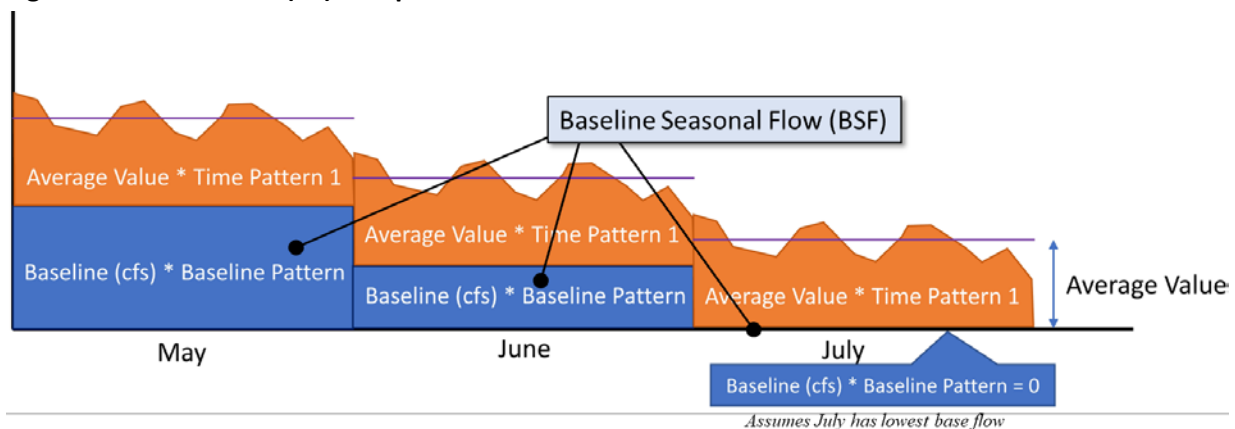
Figure 6-11. Example of Base Flow (BF) from Model Parameter Approach
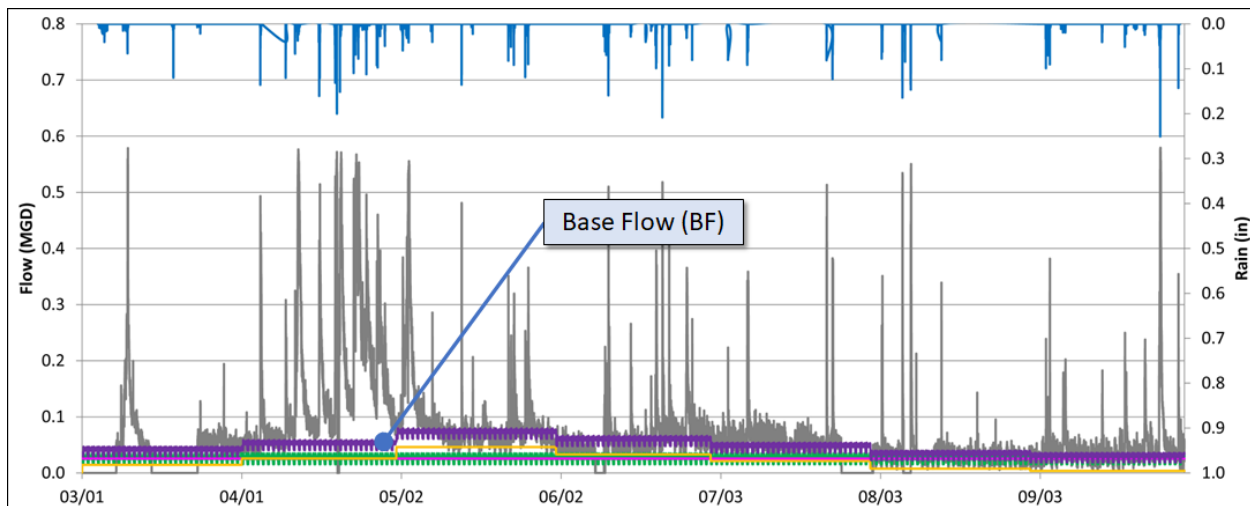
Inflow Timeseries Approach

An inflow timeseries may be applied to the model to represent the variation in the Base Flow (BF) during calibration. The timeseries should be developed for each monitor with any appropriate program (e.g.., SSOAP) and then applied to the manhole(s) upstream of the monitoring site. In some cases, it may be necessary to distribute the timeseries throughout the tributary area (i.e., the tributary area contains flow splits, or SSO).

Aquifer Module Approach

MSDGC does not prohibit the use of the Aquifer module as a representation of Base Flow (BF), but recommends against using it. If used for calibration of Base Flow (BF), it is subject to three conditions

1. It can only be used for long term base flow simulation. There cannot be a significant direct inflow or infiltration response that should modeled as part of the Storm Volume calibration.
2. Similar to the Inflow Time Series Approach, the Aquifer Module will be removed during the conversion to Typical Inputs
3. Specific requirements are in place for the calibration submittal in the *7 - Model* app of FlowFinity.
    a. Annual Total Flow Change
    b. Mass Balance Table
    c. Rainfall Mass Balance Table
    d. Percent Change in Peak Flow

6.3.2 Base flows for Storm Volume Compliance Calculations

For the calculation of Storm Volume in **Volume II Section 6.4.1**, base flows are generated by the Model Applications Tools toolbox. The toolbox calculates a time series of the Base Flow (BF) independently for the observed data (OBF) and the modeled output (MBF).   The general process used in the toolbox is as follows.

The flow measurements of non-rain days are sorted into time-of-week groups and the median flow for each time of week is calculated. The pattern of the median flows are smoothed to produce an hourly pattern of daily flows for the week, each day having its own pattern as shown in **Volume II Figure 6-12.** Each flow pattern is normalized to the observed base flow-average flow (OBF-A) to produce a pattern of ratios for hourly DWF to daily average DWF.   Again, this is performed independently for the observed data and modeled data to give the OBF and MBF respectively.   These base flow patterns should generally match between the modeled and observed. This can be tested in the MSDGC Model Tools toolbox as shown in **Volume II** Fi**gure 6-13** .

Figure 6-12. Example Schematic Diurnal Pattern (OBF-DP)
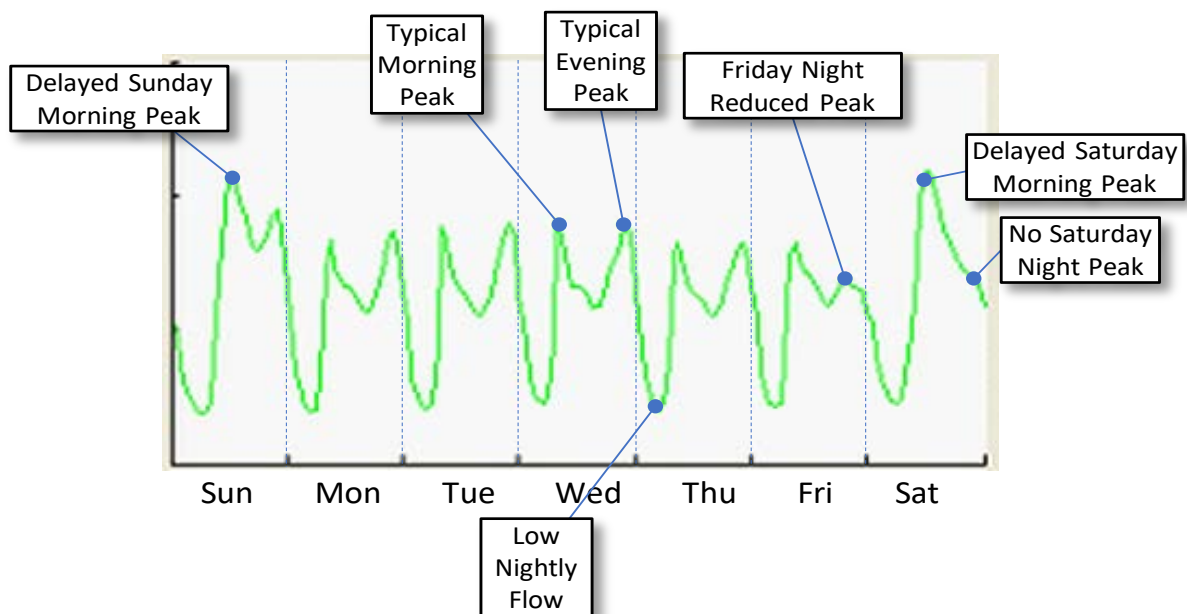
Figure 6-13. MSDGC modeling Tools Toolbox Review of Baseflow
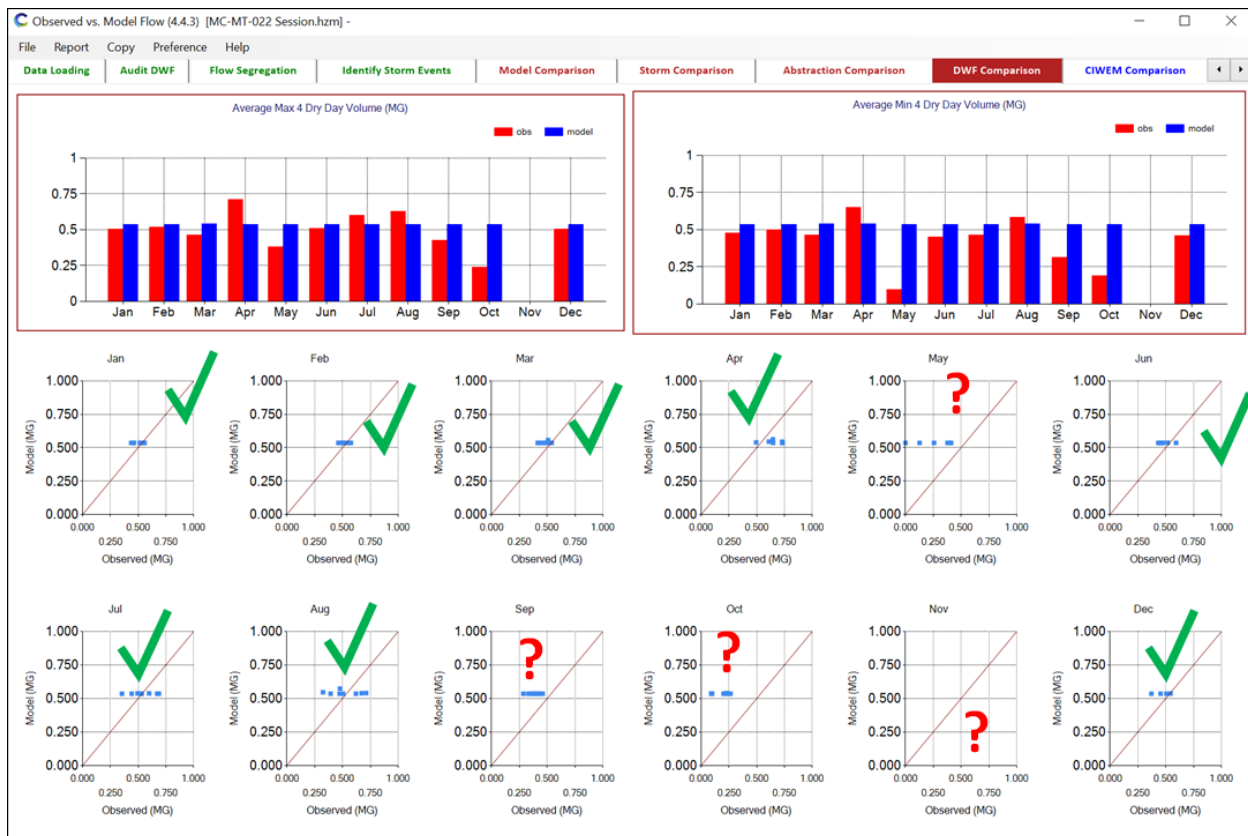
6.3.3 Base Flows for the Typical Inputs in the Model.

Since the model will eventually be used for more than just the calibration period (e.g., design storms, Typical Year), Typical Inputs are used in the model for model applications after the calibration process is completed. After Storm Volume calibration is completed and approved by MSDGC, any Base flow Time Series (BF) or Aquifer model flow must be converted to model base flow parameters. This Typical Inputs model will be included with the submitted model in the $8 - Reports$ app This process is conducted when the Typical Inputs replace the Calibration Inputs as required in **Volume II Section 8.1**.

6.4 CALIBRATION VOLUME APPROACHES

The subtraction of an event adjusted base flow from the total flow provides the storm flow. It is essential that base flows for **BOTH** the modeled data (MBF) and the observed data (OBF) be:

- Calculated as separate time series
- adjusted differently for each event,
- adjusted to the time period just prior to the event, and
- then subtracted from the event.

Each wet-weather event response should have an average flow of zero prior to the event. The difference between the event adjusted base flow and the total flow is termed "**Storm Volume**". Total observed flow and total modeled flow should NOT be directly compared, except under the conditions defined in **Volume II Section 6.4.2**.

- **Storm Volume (Volume II Section 6.4.1):** The base flows (OBF, MBF) are adjusted prior to <u>each</u> storm event to match the total flows (OTF, MTF). This provides the wet-weather response (OSF, MSF) on a storm-by-storm basis.
- **Total Volume (Volume II Section 6.4.2):** Observed base flow (OBF) and modeled base flow (MBF) are not created. Total flows (OTF, MTF) are used in the calibration.

6.4.1 Storm Volume

Storm volume requires subtraction of adjusted base flows as shown in **Volume II Figure 6-15** from both the observed total flow (OTF) and modeled total flow (MTF) on an event-by-event basis. **Volume II Figure 6-14** shows two examples where the observed base flow (OBF) does not match the observed total flow (OTF) prior to an event and must be adjusted to match prior to the event before subtraction from the OTF to get the .

Required:
- Good quality observed base flow (OBF)
- An observed base flow (OBF) with a different correction factor for each storm event for the difference between the observed base flow (OBF) and the observed total flow (OTF) for the 24 hours prior to each storm event
- A modeled base flow (MBF) with a correction factor for each storm event for the difference between the modeled base flow (MBF) and the modeled total flow (MTF) for the 24 hours prior to each storm event

Not Required:
- A significant storm response
- An exact match between either of the observed (OBF) or modeled base flow (MBF) to their respective data sets (OTF, MTF)
- An exact match of the observed base flow (OBF) to the modeled base flow (MBF)

Figure 6-14. Observed Base Flow (OBF) Not Matching Observed Total Flow (OTF) Prior to an Event
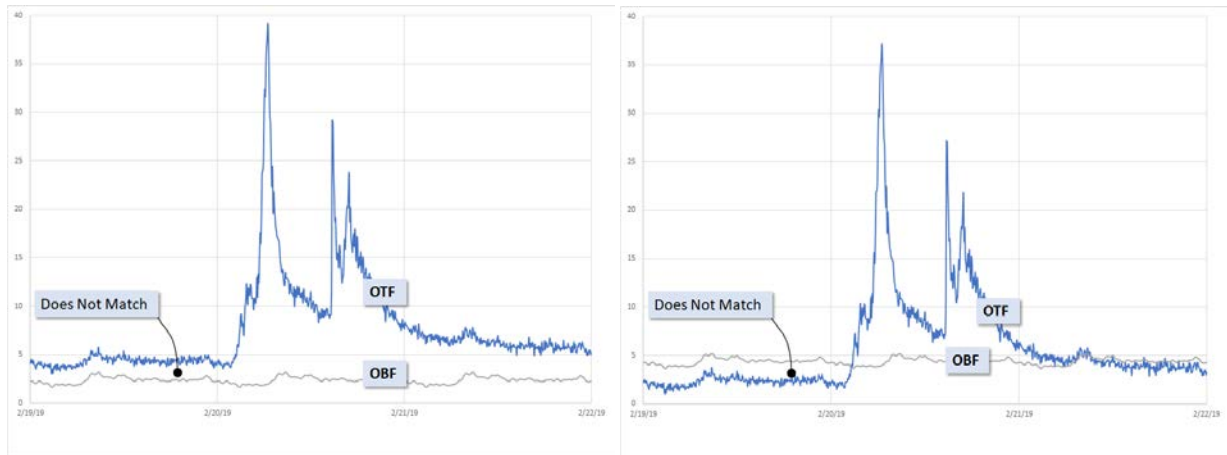
Figure 6-15. Calculation of Storm Volume Requires a Storm-by-Storm Base Flow Adjustment; Shown Here for the Observed Data
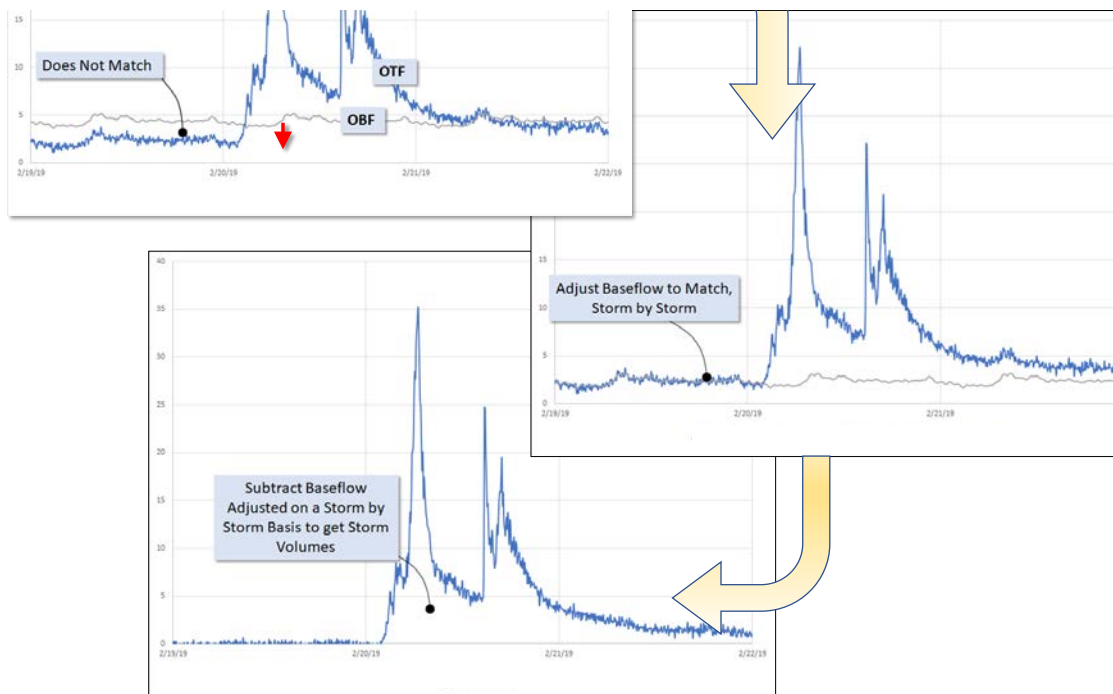
There should be no effect of rainfall on the modeled base flow. Thus, the modeled base flow (MBF) can be calculated by running the model with the rainfall turned off. Between storm events the modeled base flow (MBF) should exactly match the modeled total flow (MTF) as shown in **Volume II Figure 6-16**.

Figure 6-16. Modeled Base Flow (MBF) matches the Modeled Total Flow (MTF) Prior to each Event
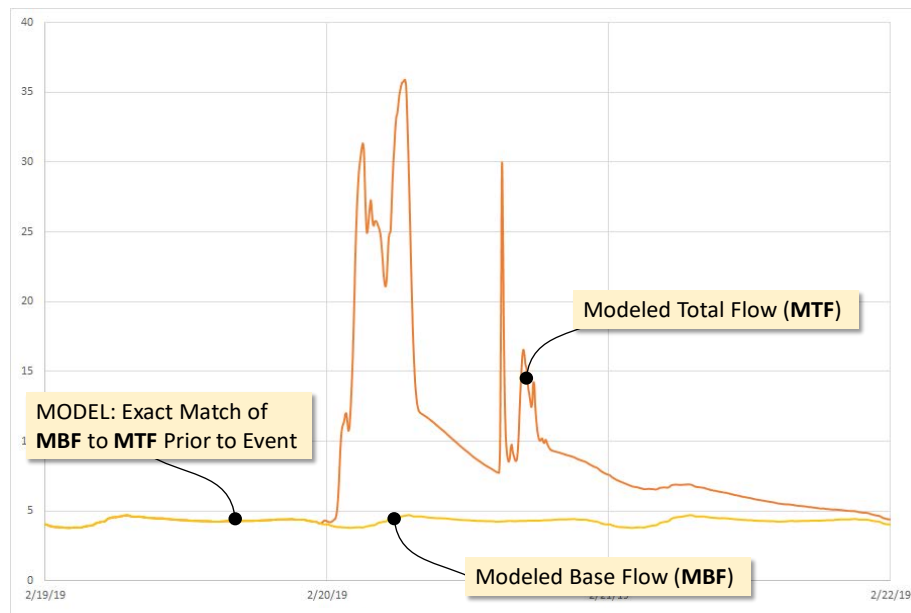
The modeled base flow (MBF) can be calculated from the modeled total flow (MTF) in a manner analogous to the calculation of the OBF from the OTF as described in **Volume II Section 6.4.1**.

6.4.2 Total Volume Approach (poor data quality)

Total volume should be used for a monitor site when the observed total flow (OTF) between storm events is very poor quality. In general, the majority of the storms should have a peak flow rate 10 times or greater than the average base flow (or the point where the data quality deteriorates).

Required:

- Good quality observed total flow (OTF) during the storm events.
- Significant storm responses of good quality.
- An estimation of the modeled base flow parameters (MDF-A, MDF-DP, MDF-MP) based on best engineering judgement. This may include parameters from similar basins, expected values, estimation of base flow from the end of storm events etc.

Not Required:

- Good quality observed base flow data
- Creation of an observed base flow time series
- Creation of a modeled base flow time series

This would be equivalent to the volume calculated by PCSWMM for an event.

Having determined that the base flow data quality is poor, the pattern to be input in the model should be copied from a proximate basin of similar scale, topography, and land use and adjusted for population differences. Best professional judgement should be used to develop this pattern and check the shape of

the base flow pattern against the pattern in the tail of storm events before the observed data quality deteriorates.

Examples of observed data with poor quality base flow, but usable storm flow, are shown in **Volume II Figure 6-17**. In both examples, the modeler should **Estimate Inputs for Modeled Base Flow Pattern** (MBF-A, MBF-HP, MBF-MP) and calculate goodness of fit of the model to observed using the **Total Flow Volume** method.

Figure 6-17. Sites with Good Observed Data Quality During Storm Events but Poor Quality Between Events
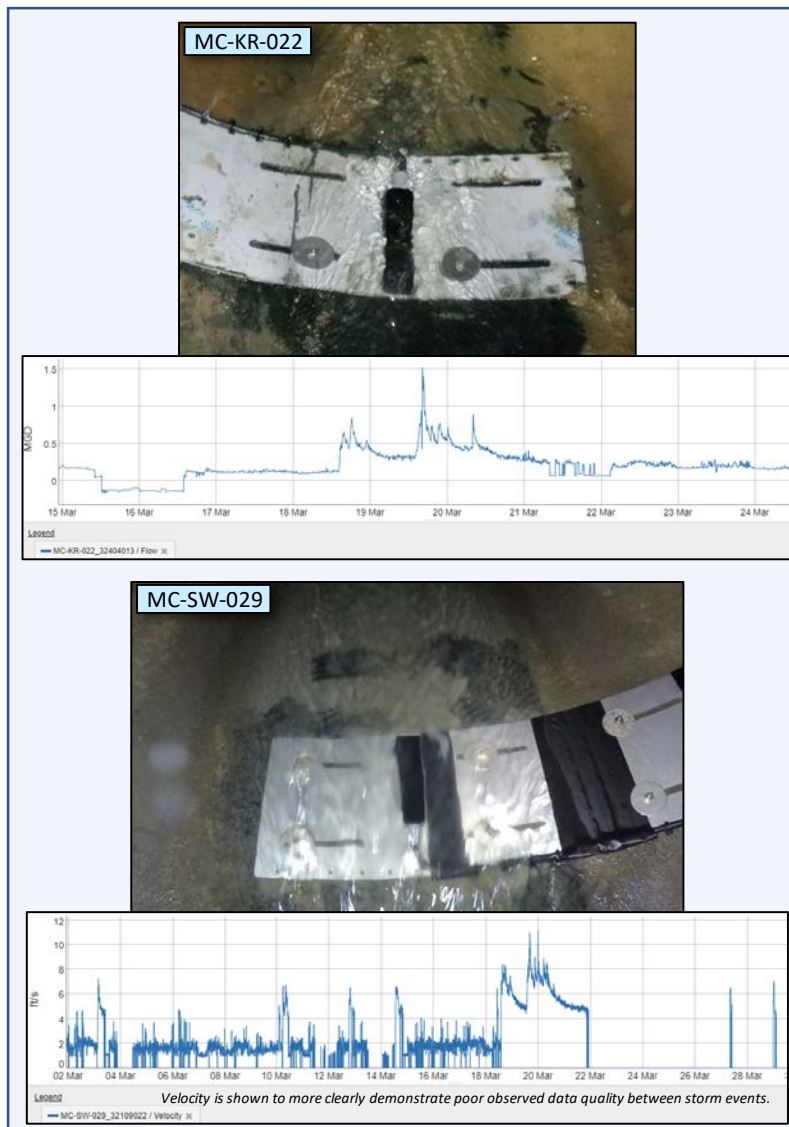
6.5   CALIBRATION APPROACH FOR DIFFERENT MONITOR TYPES

6.5.1   Hydrology Monitors

Hydrology Monitors (calibration monitors) are used for runoff parameter calibration and will require one full year of data unless otherwise explicitly authorized my MSDGC. The monitor can be used to calibrate the full range of hydrology parameters as outlined in **Volume I Section 4.3.3**.

The general steps in establishing storm calibration parameters are summarized below and assume that the observed data have been reviewed per the guidance provided in **Volume II Section 4.0** and qualified calibration events have been selected per the guidance provided in **Volume II Section 6.2.2.**

1. Understand the hydrology approach per sewer system type – Refer to **Volume II Table 6-2** for approved methods.
2. Establish initial hydrology values – Refer to **Volume I Section 4.3.3** for details on subcatchment parameters and **Volume I Section 4.4** for details on RDII and groundwater parameters.
3. Combined System
   o Adjust the directly connected impervious area (DCIA) percentage to match the small to medium storms. Adjust the flow path length in tandem with DCIA to capture the timing and shape of WWF response, concentrating on high intensity events.
   o Add long-term response triangle to match the long-term system response (if needed). Refer to **Volume I Section 4.4.1** for detailed explanation on RDII methodology.
   o Adjust infiltration parameters to match large volume events. Depression storage and pervious Manning's n can also be adjusted to affect the volume and timing of the runoff hydrograph from subcatchments. However, significant changes to depression storage and pervious Manning's Roughness would suggest other parameters should be adjusted.
   o If needed, add a medium-term response triangle to bridge the gap between runoff and long-term triangle response.
4. Sanitary System
   o Adjust the short-term response triangle and initial abstraction of the RTK unit hydrograph to match the small to medium storms and capture the magnitude, timing, and shape of WWF response.
   o Adjust medium- and long-term response triangles and initial abstraction of the RTK unit hydrograph to match the medium and large storms and capture the magnitude, timing, and shape of WWF response.
5. Use excessively wet or dry periods during the critical months with caution, as this could result in over or undersized solutions, respectively.
6. Account for Seasonal Variation – Refer to **Volume II Section 6.7** for further information on establishing seasonal variation parameters.
7. Calibrate Hydraulic Parameters – Pipe roughness and head loss can be adjusted to calibrate the model depths to monitor values. Hydraulic changes should be supported by observed data evidence. Refer to **Volume I Section 4.6** for more information on hydraulic modeling.

8. For projects with multiple flow monitors, the hydrology parameters should be normalized against each other to achieve consistent parameters between metersheds. See **Volume II Section 6.6.1** for more detailed guidance.

Hydrology Monitors are assessed through the compliancy approach discussed in **Volume II Section 7.1**.

Table 6-2. Standard Flow Component Representations			
Sewer Service Type	RDII	Horton's	Groundwater
Sanitary	R	X	✓
Combined	✓	R	✓

R = Required

✓ = Only in specific cases when supported by observed data

X = Not Used

6.5.2 Apportioning Monitors

Apportioning Monitors are used to assess flow distribution upstream of a Hydrology Monitor and are installed for less than one full year, typically only a month. Apportioning Monitors can be used to adjust limited parameters within the metershed, depending on the duration of the monitoring period. The approach for adjusting parameters for Apportioning Monitors is discussed in **Volume II Section 6.6.2** and the monitors are assessed through the compliancy approach discussed in **Volume II Section 7.2**.

6.5.3 Hydraulic Monitors

Hydraulic Monitors are located at hydraulicly critical locations. Hydraulic Monitors are used to make hydraulic parameter changes and require a minimum of 3 months of data. Hydraulic Monitors are used to calibrate CSO underflow capacity, flow splits, pump capacity, RTC levels, etc. The calibration compliance does not need to adhere to set statistical requirements; rather the calibration is qualitative, utilizing the monitor data to establish the hydraulic values. For example, at CSO underflows, flow splits, and pump stations, the data can provide the appropriate target flow rate for a variety of inflow rates. For pump stations, the data may indicate the pump capacities of multiple pumps in the pump station or merely the total pump station capacity, depending on the quality and quantity of data. Level data at RTC facilities can be used to illustrate that the model closely matches the timing and shape of levels in one or more areas of the facility and adjust the RTC model representation if needed.

6.5.4 Regulatory Reported Overflow Monitors

Regulatory Reported Overflow Monitors are used to assess the CSO, SSO, NEO, and PSO overflow frequency and duration. The monitors are typically the permanent level monitors installed at each CSO. The CSO or SSO regulator representations may be adjusted to better match the overflow frequency and duration. The overflow frequency should match well per event, not merely a total overflow frequency

count. The overflow duration for each event should also match closely, to ensure that the modeled overflow volumes are accurate.

6.5.5 Inflow vs. Underflow Monitors

The installation of a hydrology monitor at a CSO inflow and a hydraulic monitor on the CSO underflow is common for many projects to fully quantify the CSO overflow volume. A flow imbalance between the inflow and underflow monitors is common. During lower flows, the depth in the combined sewers is frequently too low to adequately cover the velocity probe, which results in less accurate velocity and depth measurements. Additionally, at low flows, the probe blocks a significant portion of the cross-sectional area of the flow, which is not accounted for in flow calculations (this area becomes insignificant during higher flows). The underflow monitor typically records more accurate data since the sewers are smaller and therefore have a higher depth and better probe coverage during lower flows. Therefore, it is common for the inflow monitor to record higher flows than the underflow monitor. The underflow monitor is considered more accurate. For such situations, the Base Flow (BF) and long-term RTK response should be calibrated to the monitor on the underflow. For the inflow monitor, the modeled treatment volume should trend slightly higher than the observed data and the Lin score may be slightly outside the target range.

In the case of very poor quality underflow monitor data , the underflow pipe hydraulic parameters can still be estimated from the peak flow rates (Hydraulic Monitor).

6.6 HYDROLOGY PARAMETER DISTRIBUTION AND MODIFICATION

6.6.1 Project Area Calibration (Multiple monitors)

For project areas with multiple flow monitors, the parameters between similar metersheds should match closely. This is more likely the case in combined areas than sanitary. For parameters that vary between subcatchments (percent impervious, slope, flow path length, etc.), the calibration adjustments from theoretic or calculated values should be similar **where project areas (metersheds) are similar in** land use, soil type, slopes, building construction types, downspout routing, age of buildings, curb style and design, etc. Consistent parameters for similar areas builds confidence in the model accuracy and can help account for any monitor inaccuracies.

Inconsistent parameters between similar metersheds causes multiple issues during calibration.
- For upstream meters, lower depths can lead to less accurate monitors and increase the chance of monitor error during WWF.
- Inconsistent parameters can also occur when datasets are inconsistent between monitors, whether the monitoring periods are different or just a few large events are unusable for one meter.
- Downstream meters have only a portion of their tributary area which is not included in upstream calibrations and thus have a risk of parameters being excessively adjusted to

overcompensate for upstream model inaccuracies or data issues. The parameters may also be excessively adjusted since negative impacts of hydrographs would be less pronounced. An example of potential error is described below.

  o A project area has two monitors, one upstream of the other.
  o Upstream monitor has a tributary area of 200 acres.
  o Downstream monitor has a total tributary area of 300 acres (100 acres directly tributary).
  o Upstream monitor is calibrated and tends to overpredict flows by 25%.
  o Downstream monitor is calibrated and tends to underpredict by 25%.
  o When considering the directly tributary area, the directly tributary area is now underpredicted by 75% since the parameters were adjusted to overcompensate for the overpredicted upstream area; likely DCIA being too low.
  o Even if the downstream monitor was calibrated to match the data, the directly tributary area would still be underpredicted by 50% and have a low DCIA.

During the calibration process, calibrated parameters between similar metersheds should be compared and sensitivity analysis completed to evaluate if more consistent parameters can be used. Slight reduction in Lin scores is acceptable if it is due to more consistent parameters between similar metersheds. Most parameters or parameter adjustments are expected to be consistent between similar metersheds. Parameters expected to be consistent:

  • Flow Path Length
  • Slope
  • N-Impervious
  • N-Pervious
  • Dstore Impervious
  • Dstore Pervious
  • Dry Time
  • Time-to-Peak (T)
  • K-value (K)
  • Max Depth (Dmax)
  • Recovery Rate (Drec)

Parameters that vary should still be relatively consistent. For example, a percent routed of 50% in one area versus 60% in another is reasonable; a percent routed of 25% in one area versus 75% in another is not expected for similar areas. In some cases, none or only some will vary. The following parameters frequently vary:

  • Precent Impervious (relative to total imperviousness)
  • Percent Routed
  • Max infiltration Rate
  • Min Infiltration Rate

- Decay Constant – possible, but unlikely
- R-value (R)

However, it should be noted that where project areas differ significantly particularly in, age of buildings and sewers the parameters chosen should not be expected to be consistent.

6.6.2 Apportioning Monitors

Apportioning Monitors have short periods of data and are upstream of a hydrology meter (which has the requisite one year of data). The Apportioning Monitor can either be intentionally monitored for less than a year or could be a monitor for which large portions of data are missing or unreliable. An Apportioning Monitor is not directly calibrated. Apportioning Monitors are used to adjust the distribution of flow in a basin calibrated from the Hydrology Monitor as shown in **Volume 2 Figure 6-18**

Figure 6-18. Apportioning Monitor upstream of Hydrology Monitor
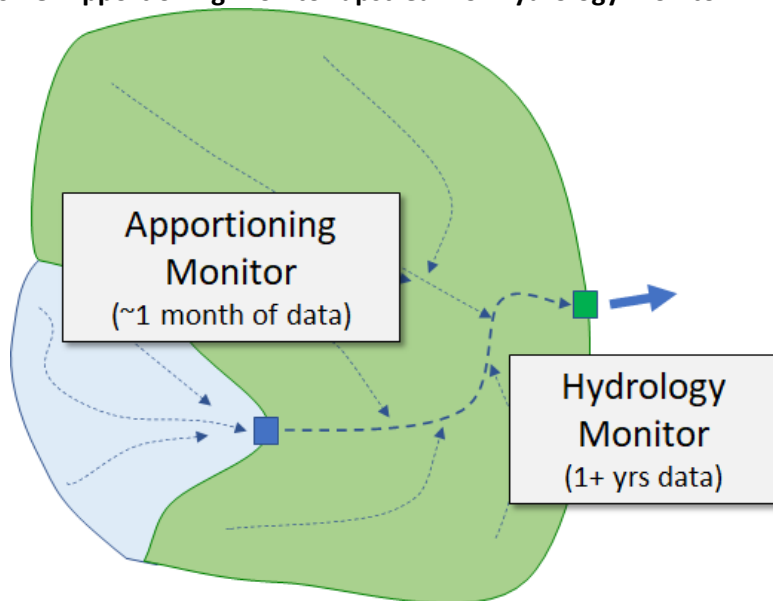
The Apportioning Monitor's tributary area should initially be calibrated to a downstream Hydrology Monitor. Then the parameters of the directly tributary area to the Apportioning Monitor are adjusted, with corresponding adjustments to the downstream areas (directly tributary to the Hydrology Monitor) to maintain the downstream calibration. Suggestions for the adjustments to the Apportioning Monitor are included in **Volume II Table 6-3** depending on the duration of data available.

Table 6-3. Apportioning Monitor Parameter List				
Parameter	**# Events**	**Months of Data**		
	2-3	**3**	**6**	**9**
Combined Basins				
% Impervious		x	x	x
% Routed		x	x	x
Flow Path Length				x
Slope				
N-Impervious				
N-Pervious				
Dstore Impervious				x
Dstore Previous			x	x
Max Infiltration Rate			x	x
Min Infiltration Rate			x	x
Decay Constant				x
Drying Time				x
R	x	x	x	x
T				
K				
Dmax			x	x
Drec			x	x
Sanitary Basins				
R	x	x	x	x
T				
K				
Dmax			x	x
Drec			x	x

Hydrograph comparisons, Lin scoring, and regression plots should be similar between the Apportioning and Calibration Monitors. If Event #1 is overpredicted by the model for the Calibration Monitor, the Apportioning Monitor should be similarly overpredicted by the model. If long-term response is underpredicted for Event #2 at the calibration meter, the Apportioning Monitor should be the same.

RTK and base flow seasonal variation is different in that the Apportioning Monitor may have missing periods of data to make adjustments. Those periods are assumed to have a similar proportion to the Apportioning-Calibration Monitor ratios. If the seasonal proportions change, then the unmonitored months should be adjusted based on the more comparable season (winter and spring are more similar; summer and fall are more similar).

- If R1 for summer and spring are reduced by 30%, the R1 for fall and winter should also be reduced by 30%.

- If R2 for spring is reduced by 30% and summer is reduced by 50%, then winter should be adjusted by 30% and fall by 50%.
- If base flow parameters should always be adjusted proportionally across the monitored period, since the monitor will typically be in smaller areas with poor base flow data or have a small directly tributary area making distinguishing the difference with the upstream and downstream monitors unreliable.

In some cases, a monitor intended to be a Hydrology Monitor may have large portions of data issues, but no downstream data is available. If no downstream meter is available, the parameters can be established by using parameters from a neighboring area. The parameter adjustments will be handled much in the same way, except the other area will not need additional adjustments. This applies only to monitors that were intended to be a Hydrology Monitor, but the reliable dataset was too small. For example, if an area had an upstream and downstream Hydrology Monitor installed, but half of the dataset of the downstream monitor was unreliable, then the upstream monitor can be fully calibrated, then apply the values to the downstream area. The downstream Apportioning Monitor could then be used to refine those values based on the available dataset.

In some cases, a monitor intended to be a Hydrology Monitor may have large portions of data issues not no downstream or adjacent data is available. In such cases, calibration may still be acceptable, but should make sure to follow normal seasonal trends for the periods with no data. If the data is not robust enough to establish certain parameters (like infiltration parameters if there are no large events), then standard values should be applied for those parameters.

6.6.3 Project Area Calibration with Historical Calibration

If historical calibration has been performed, in the absence of other information the previous distribution of flows should be maintained. If possible, the historical data should be included in the calibration process to enhance both the historical and project calibrations. The two scenarios are: the project area has historical calibration upstream of the project meters OR the project area has historical calibration downstream of the project meters.

In some cases, the project area will have historical calibration upstream of the project meters as shown in **Volume II Figure 6-19**. The upstream area should be maintained (if possible) and parameter adjustments should be limited to the area downstream of the historical sites but upstream of the project meter. The parameters established for the project calibration should be reasonably consistent with the historical calibration upstream. If reasonable parameters cannot achieve an acceptable calibration, then the historical calibration should be re-evaluated. The project data may shed new light on the historical data, allowing for consistent parameters to be established.

Figure 6-19. Historical Upstream Calibration Example
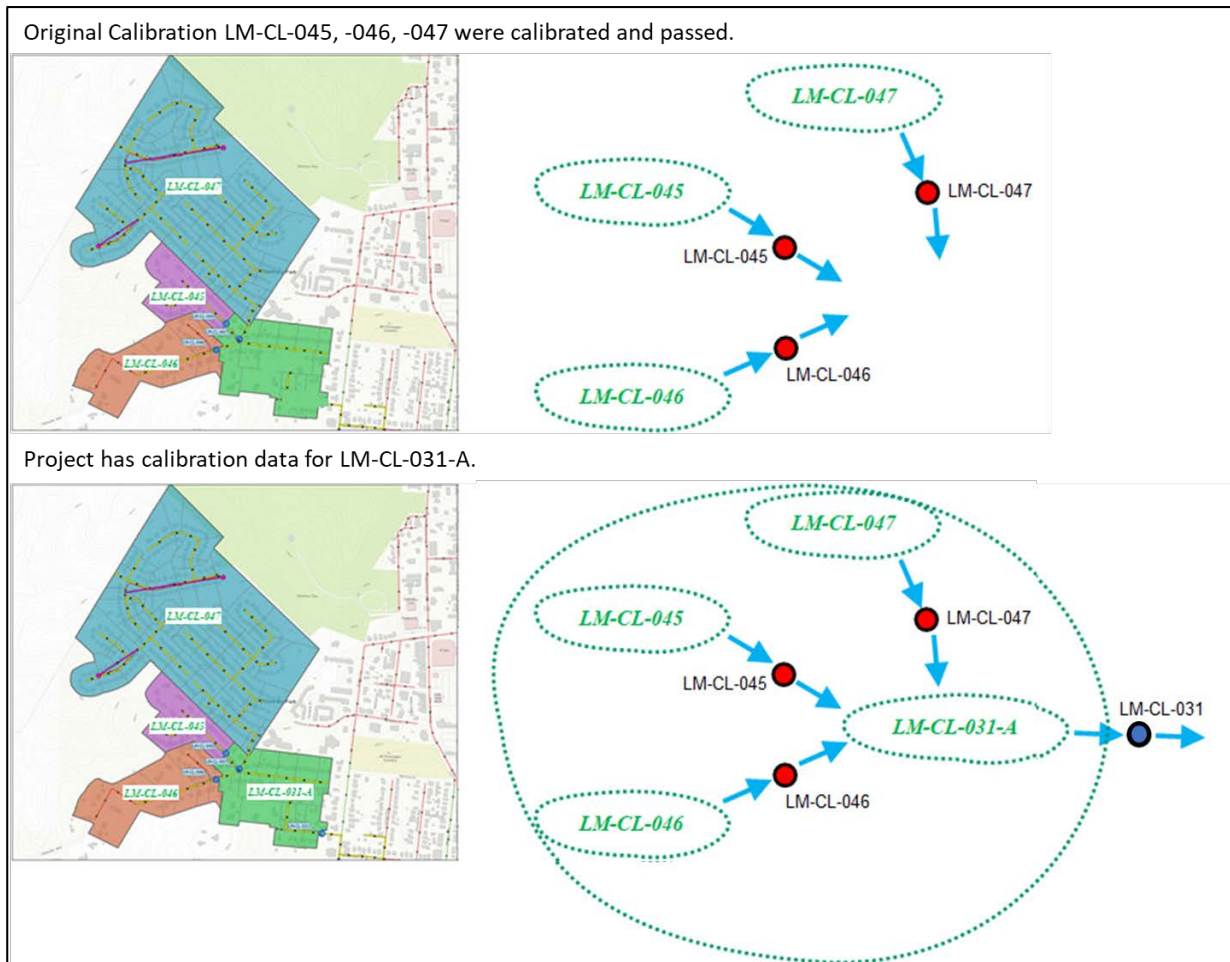
In other cases, the project area may have historical calibration downstream of the project meters as shown in **Volume II Figure 6-20**. The historical monitoring data should be used in the project calibration effort. If the historical data is not available, the model timeseries from the meter location (before updates) can be used as the "calibration data" but should be used cautiously.

Figure 6-20. Historical Upstream Calibration Example
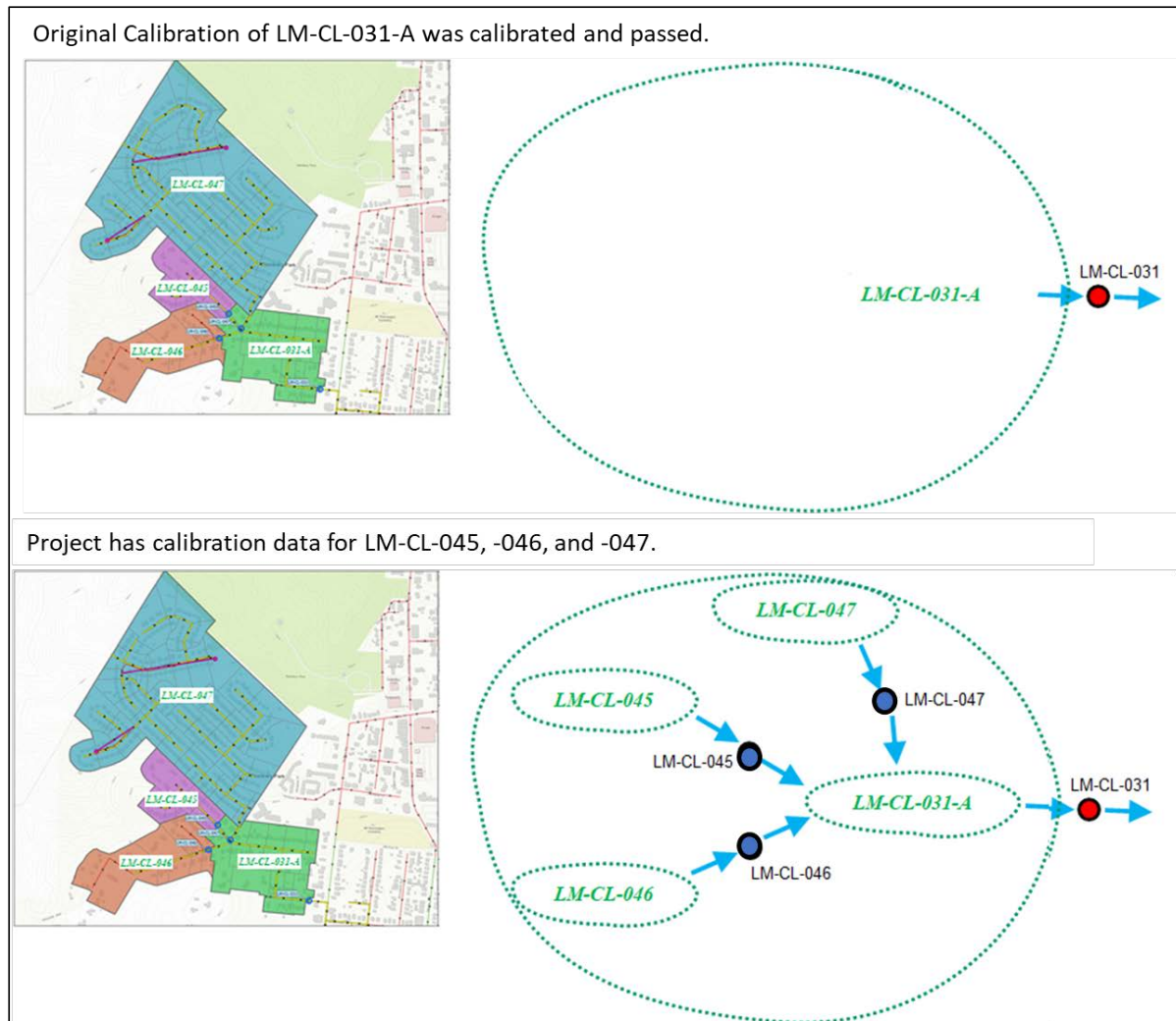
6.6.4 Downstream or Adjacent Area Adjustments

In many project areas, the furthest downstream flow monitor does not cover the entire project area. In such locations, the area downstream of the monitor should be adjusted the same/proportionally with the downstream monitor area. The area should be handled the same as the directly tributary area. Two common situations in which this occurs include:

- Near CSO regulator structures. Siting monitors at CSO structures can be difficult or not hydraulically desirable. Hydrology Monitors are frequently installed several manholes upstream of the regulator to achieve better hydraulics for monitoring. The monitors may miss a small portion of area tributary to the CSO but downstream or adjacent to the monitor.

- Near main trunks. Tributary sewers to a main trunk can be impacted by backwater from the main trunk. The backwater can cause errors in the monitor data. Therefore, the monitors are frequently installed a few manholes upstream of the main trunk to avoid the backwater.

Volume II Figure 6-21 illustrates these situations.

Figure 6-21. Downstream and Adjacent Areas Example
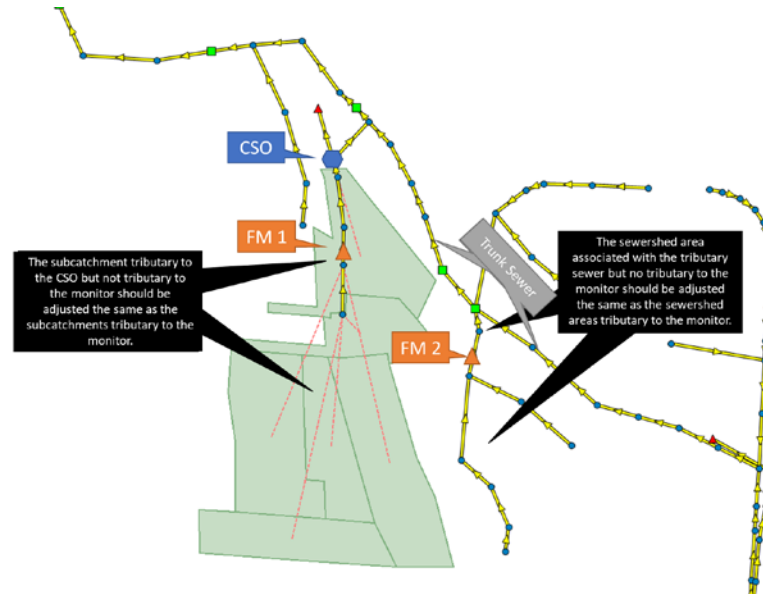
6.7 SEASONAL VARIATION

A typical seasonal variation pattern consists of higher base flows, infiltration, and pervious runoff volumes in spring since spring typically has wetter moisture conditions which contribute to reduced soil abstraction and increased sewer infiltration. There should be no variance from the typical seasonal variation pattern (wetter spring) without justification and approval by MSDGC.

Monthly varying base flow multipliers (MBF-MP) and/or seasonally varying RTK parameters may be used to represent seasonal variation when supported by observed flow data. Groundwater can be represented through different approaches. Refer to **Volume I Section 4.2.2** for guidance on groundwater modeling.

Although SWMM provides numerous opportunities with which to vary many parameters, the goal of any calibration should always be to use the simplest means possible to achieve a properly calibrated model that is sufficient for its intended purpose (parsimony). Therefore, modelers should always try to vary as few parameters as possible while still achieving an adequate calibration. As shown in **Volume II Table 6-4,** parameters should be varied for as few months as possible, and as shown in **Volume II Table 6-5**, RTK parameters should only be varied as necessary to represent sewershed conditions.

For seasonal variation, the parameters should follow a normal season trend:
- Growing/Non-Growing

- o   R-values: Growing < Non-growing.
- o   Dmax: Growing > Non-growing.
- o   Drec: Growing > Non-growing.
- 4 Season
  - o   R-values: Winter>=Spring>=Fall>=Summer
  - o   Dmax: Winter<=Spring<=Fall<=Summer
  - o   Drec: Winter<=Spring<=Fall<=Summer

Table 6-4. Recommended Seasonal Definitions		
Approach	Growing/Non-growing (preferred)	4 Seasons
Months	Growing = May through September Non-growing = October through April	Winter = November through February/March Spring = March/April through May Summer = June through August Fall = September through October

Table 6-5. Recommended RTK Parameters to be Varied			
RDII Components	Parameters	Okay to Vary	Do not Vary
Initial Abstraction[1]	D_{max}	✓	
	D_{rec}	✓	
Unit Hydrographs	$R^{[2]}$	✓	
	T		✓
	K		✓

(1) Note that the D_o parameter is not used and should be set to zero.

(2) R1 typically varies less than R2 or R3, however it depends on whether the triangles were constructed with significant overlap, or were mostly independent.

6.8   INTERPOLATION OF CALIBRATED VALUES

When flow monitor data is insufficient, it is permissible to interpolate the calibrated values discussed in **Volume II Section 6.7** from late summer through winter. However, interpolation of calibrated values from April through July is not recommended, as these are the critical months when evaluating Typical Year overflow.

7.0   CALIBRATION COMPLIANCE

A calibrated model will undergo the following reviews to determine compliance, each of which are discussed further in the sections that follow:

- Calibration Review
    - o The *6 – Calibration* app in FlowFinity
    - o Qualitative and numerical review consisting of comparing the modeled timeseries to the observed timeseries to ensure that they fall within specified tolerances for the storm volumes and
    - o Seasonal parameter review to confirm no distortion to improve fit
    - o Parameter review to ensure that the model inputs are physically based and within expected ranges.
- Model Review
    - o The *7 – Model* app in FlowFinity
    - o Review to ensure the model settings are correct and the model does not contain egregious errors.
- Typical Inputs Review
    - o The *8 – Report* app in FlowFinity
    - o Review to ensure the calibration specific elements of the model were correctly replaced with Typical Year conditions and that all calibration specific items were removed.

7.1   HYDROLOGY MONITOR

For hydrology monitors tolerances summarized in the following sections must be met to allow a model to achieve full compliance with MSDGC standards. Note that the compliance criteria are subject to change at MSDGC's discretion. As such, the MSDGC Modeling Group should always be consulted prior to beginning any calibration.

A model passes or fails calibration based on the following metrics taken from all non-excluded storms. A Model Application Tools[1] toolbox, as shown in **Volume II Figure 7-1**, will be provided to modelers to evaluate the model's compliance with the following criteria. Background on how each criterion is calculated in the Model Application Tools[1] toolbox is provided in the subsections that follow.

Passing calibration (if all are true)
- Concordance Correlation Coefficient (r_c)
    - o Lin conveyance (r_{cc}) ≥ 0.9
    - o Lin overflow (r_{co}) ≥ 0.9
    - o Lin treatment (r_{ct}) ≥ 0.9
- Critical Flow Volume ($Q_{critical}$) within +/- 10%
- Peak Fit for Largest Observed Storms (Con_{15}) within +/-10%

Failed calibration (if either is true)

- $Q_{critical}$ outside +/- 20%
- Con_{15} outside +/- 20%

Conditional "pass" calibration

- All other conditions, with adequate explanation

Figure 7-1. Model Application Tools "Observed vs Model Flow" Screenshot

7.1.1 Storm Hydrograph Shape

Model calibration produces a model which can usefully predict flows for applications in the design and operations of hydraulic infrastructure (e.g. pipes, rtcs). It is therefore important that the model match the storm component of the hydrograph in shape and magnitude. The MSDGC metrics, described in **Volume II 7.1.2** through **Volume II Section 7.1.3** below, provide a statistical evaluation intended to support the hydrograph shape calibration.   In general, the statistics below compel a good average shape across a wide range of storm types and sizes. However, in some cases MSDGC may require adjustments to the model to better represent the observed data for specific storms that are larger or considered more significant.

7.1.2 Concordance Correlation Coefficient (r_c)

Model performance can be assessed through a few metrics that determine which model is more useful for the intended purpose. A comparison between observed and modeled results can be shown in a one-to-one plot in which the x-axis shows the observed data (x) and the y-axis shows the model results (y). If

the model results are the same as the observed data ("perfect agreement"), the result would be a 45-degree diagonal line (1:1 line). There is no perfect match in the real world. However, closer to the 1:1 line indicates better match of the model to the observed data . This correlation to the 1:1 line is expressed numerically by the Concordance Correlation Coefficient (r_c), originally proposed by Lin (1989) The range is -1 to 1. r_c is 1 when all data matches on the 45-degree line.

Equation 7-1

$$r_c = rC_b$$

Equation 7-2

$$C_b = \frac{2}{v + 1/v + u^2} = \frac{2s_x s_y}{s_x^2 + s_y^2 + (\bar{x} - \bar{y})^2}$$

> where r_c is the Concordance Correlation Coefficient between the n pairs of data (x_i, y_i). $\bar{x}$ and $\bar{y}$ are the sample means of x; and y; and C_b is the bias correction factor. Here, v is a scale shift (= s_y/s_x) and u is a location shift relative to scale (= $(\bar{y} - \bar{x})/(s_x s_y)^{0.5}$.

Equation 7-3

$$s_x^2 = \sum_i^n (x_i - \bar{x})^2 / n$$

Equation 7-4

$$s_y^2 = \sum_i^n (y_i - \bar{y})^2 / n$$

Equation 7-5

$$r = \frac{\sum_i^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i^n (x_i - \bar{x})^2 (y_i - \bar{y})^2}}$$

> where r is the Pearson correlation coefficient between the n pairs of data (x_i, y_i),

References

Lawrence Lin (1989), A Concordance Correlation Coefficient to Evaluate Reproducibility, Biometrics, 45(1), pp. 255-268

Tetra Tech (2019), Analysis of ROV under WAPUG and Shape Fitting, Technical Memorandum

Concordance Correlation Coefficient Example Calculation

Prior to applying this approach, refer to **Volume II Section 6.2.1** and **Volume II Section 6.2.3** for guidance on defining total events and calibration zones.

Five events were selected from the technical memo (Tetra Tech, 2019) and analyzed. Volumes were calculated from the five events for the zones. **Volume II Table 7-1** compared the measured volume and modeled volume for the selected storm events. Five sets of measurement data (x) and model simulation results (y) are plotted separately at three zones (**Volume II Figure 7-2**).

	Conveyance		Overflow/Storage		Treatment	
Event No.	**Meter Volume (x)**	**Model Volume (y)**	**Meter Volume (x)**	**Model Volume (y)**	**Meter Volume (x)**	**Model Volume (y)**
1	0.0130	0.0174	0.0219	0.0278	0.0777	0.2744
2	0.0282	0.0297	0.0453	0.0414	0.1498	0.2933
3	0.1072	0.1013	0.1564	0.1583	0.4239	0.9606
4	0.0608	0.0565	0.0802	0.0752	0.3659	0.5429
5	0.0541	0.0542	0.0908	0.0966	0.5667	1.2334

Table 7-1. Comparison of Measured Volume and Modeled Volume for Storm Events at Each Zone

Figure 7-2. Example of One-To-One Plot for Zones (A) Conveyance Zone, (B) Overflow/Storage Zone, and (C) Treatment Zone
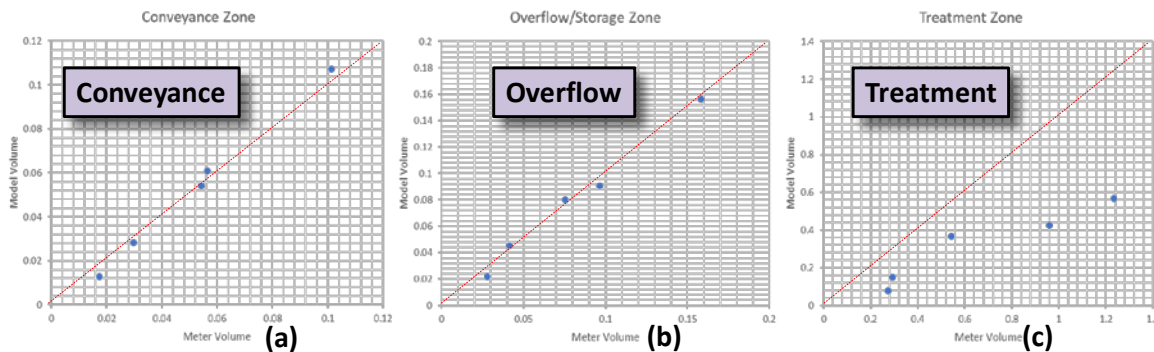
Results of Lin r_c calculation

- Conveyance zone: r_{cc} = 0.9919
- Overflow/storage zone: r_{co} = 0.9947
- Treatment zone: r_{ct} = 0.4398

The model pass-fail criteria include all three Lin scores above. Taking the average of the three scores provides a useful metric which can be used as an objective function in model optimization. This metric is termed the **Cinci Score**.

Equation 7-6

$$Cinci\ Score = r_{c_{ave}} = \frac{r_{cc} + r_{co} + r_{ct}}{3}$$

- ***Cinci Score*** = Average $r_{c\,ave}$ = (0.9919 + 0.9947+0.4398)/3 = 0.8088

7.1.3 Critical Flow Volume (Q_{critical})

Since the volume of overflow from a CSO is the target of regulatory compliance, it is extremely important that the model and observed data have similar volumes above a specified peak underflow rate. This also extends to monitors further away from CSOs as error in this metric is directly related to a commensurate error in sizing storage facilities to handle excess flows. The procedure outlined in the following paragraphs is specifically designed to demonstrate when the model has bias that will either impact modeled annual overflow volumes from a CSO or the size of storage facilities.

For each flow monitor, the total modeled and observed flow volume for all flow rates greater than defined System Capacity (Qcritical) is summed and compared. The volume does not have "Excluded" storms. **Volume II Figure 7-3** illustrates conceptually how this value would be calculated for a single storm of the observed data. The total flow above each Qcritical line from all storm events is summed for the observed total flow (OTF) and modeled total flow (MTF). **Volume II Table 7-2** provides guidance on establishing Qcritical values. Following this assessment, a table comparing the results will be provided in the *6 – Calibration* app of FlowFinity**.**

Table 7-2. Qcritical Setting			
Calibration Volume Approach			
Total Volume		**Storm Volume**	
Combined Sewer System	**Sanitary Sewer System**	**Combined Sewer System**	**Sanitary Sewer System**
{2.5} * {ODWF-A}	{1.5} * {ODWF-A}	{1.5} * {ODWF-A}	{0.5} * {ODWF-A}

Figure 7-3. Critical Flow Volume Calculation, Observed Total Flow (OTF)
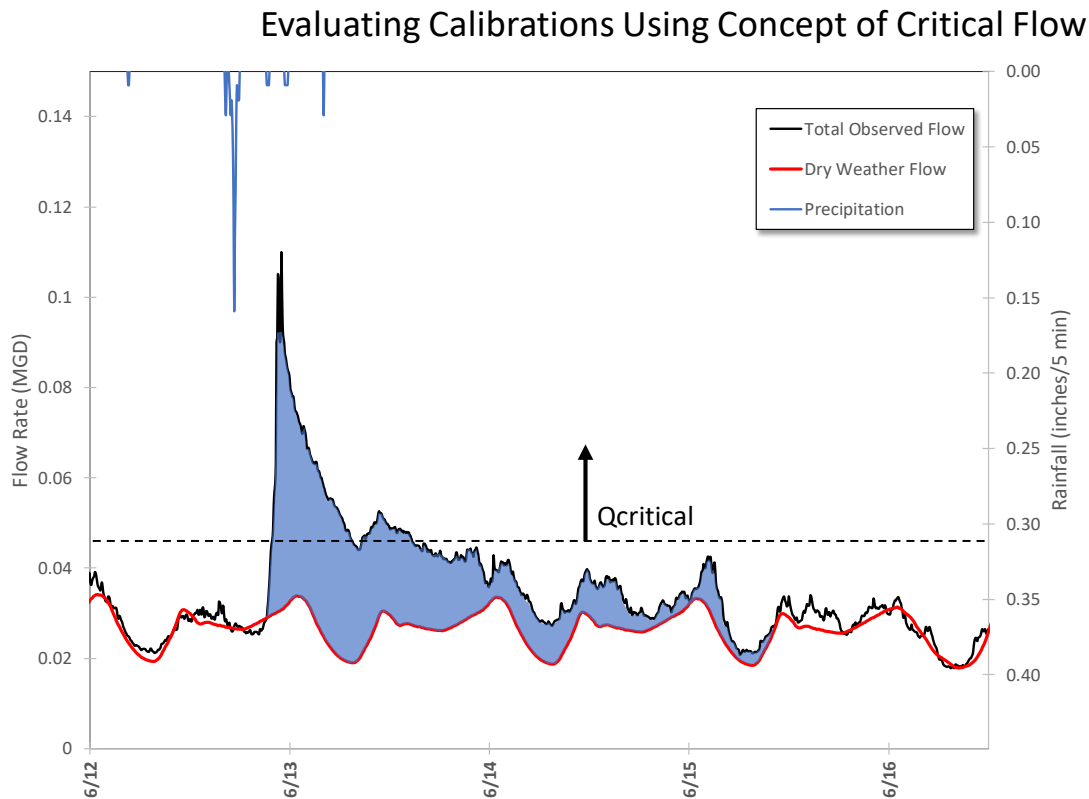
7.1.4 Peak Fit for Largest Observed Storms (Con$_{15}$)

The model is often used to size proposed infrastructure to convey peak flows during design storms; therefore, it is extremely important that the model accurately predict the peak flow of the largest observed storms. Most modelers would recognize that even though a high percentage of storms meet a given model criteria, the model can be severely flawed if the larger storms show a noticeable trend away from a close match between the observed and modeled volumes. As shown in the example in **Volume II Figure 7-4**, even though a majority of storms (82%) fit within some defined tolerances, the model is not usable for sizing conveyance infrastructure due to the significant bias towards underestimation in the larger, more important storms. The Con$_{15}$ metric is specifically designed to demonstrate when the model contains a bias which will impact the ability of the model to predict the peak flows from large events.

Figure 7-4. A Model with Good Fit for 82% of the Storms, but which Underestimates Large Events
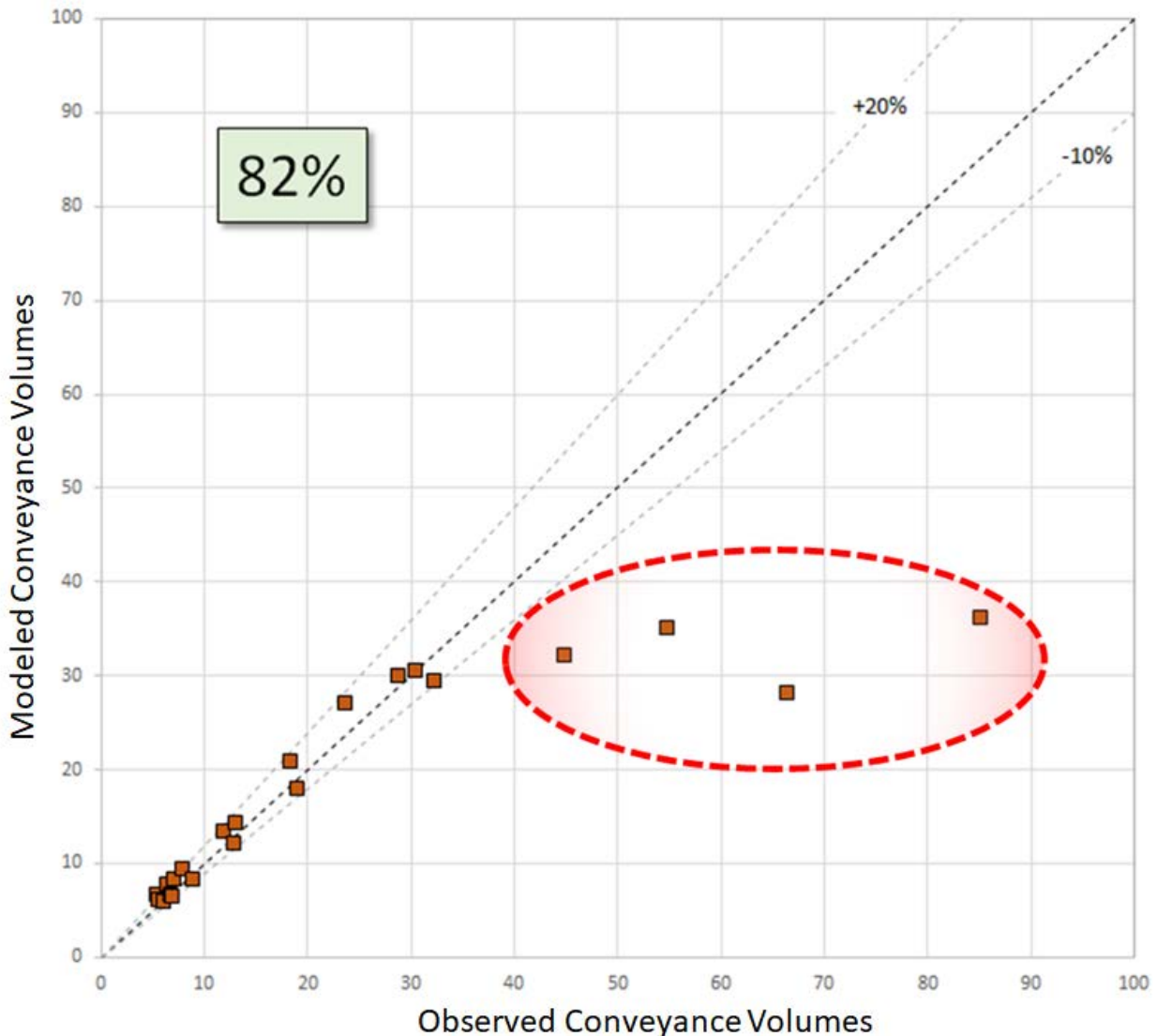
The fit of the model to the peak flows from the largest 15 percent of storms is Con_{15}, specifically, the slope of the best fit line through the origin to the conveyance graph of those storms. **Volume II Figure 7-5** shows the Conveyance graph on the left for a model to observed fit for all non-excluded storms. The graph on the right is the largest 15 percent of the storms (3 storms are on the Con_{15} graph because there are just less than 20 non-excluded storms). The slope of the zero-intercept, best fit line througth the three Con_{15} storms is 0.92. As that value exceeds 0.9 and is less than 1.1, this model would considered acceptable with respect to that metric.

Figure 7-5. Comparison of Conveyance Graph for ALL Non-excluded Storms (left) and the Largest 15% (right) which is Con_{15}
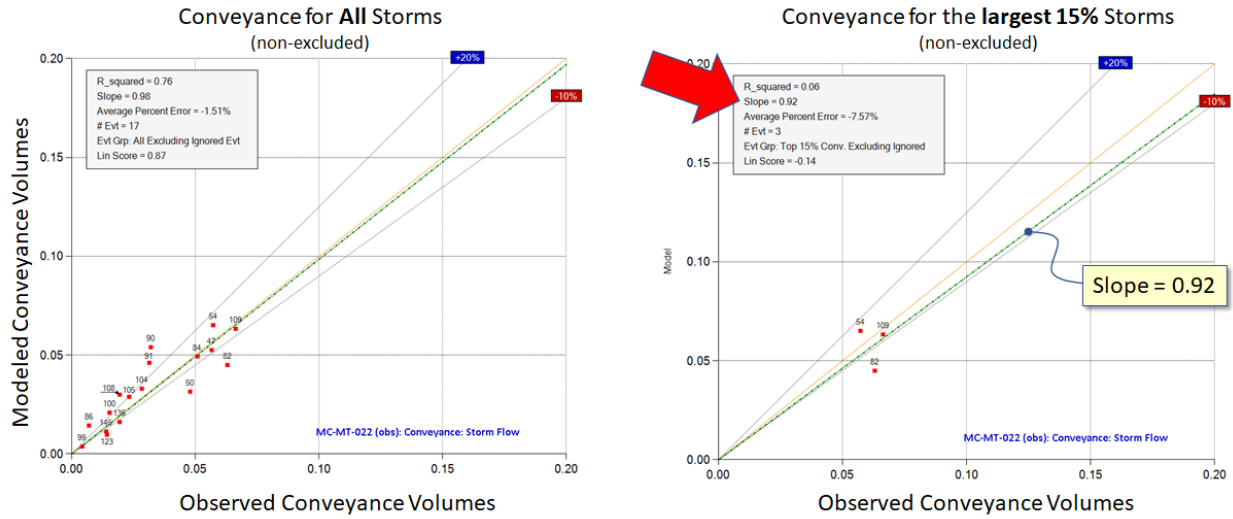
7.1.5 Seasonal Compliance

The majority of the Typical Year overflow volume (62%) from MSDGC CSOs occurs in April, June, and July as shown in **Volume II Figure 7-6**; thus, errors of calibration in these months can distort the results contributing to design decisions that oversize or undersize required facilities.

Figure 7-6. Model Decisions Distorted by Calibration Errors
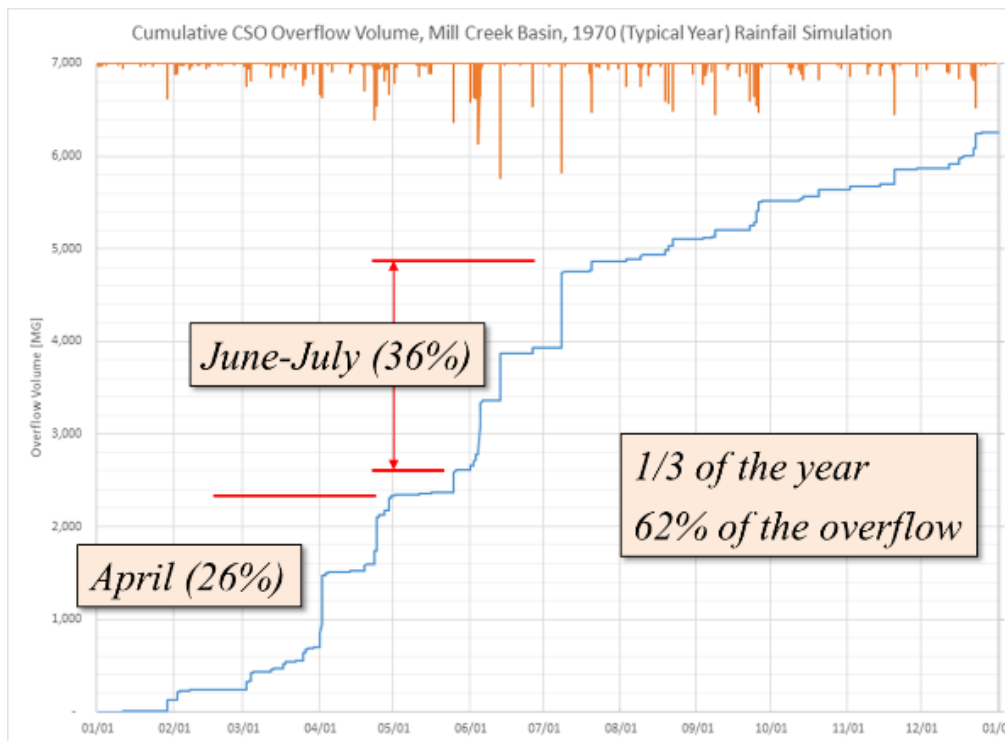
Reporting of the Concordance Correlation Coefficient within the *8 – Reports* app requires that critical months (April, May, June, and July) be plotted in a separate color and reported individually as shown in **Volume II Table 7-3**.

Table 7-3. Concordance Correlation Coefficient Summary Table										
	Conveyance			Overflow/Storage			Treatment			
Flow Monitor	**Critical Months**	**Non-Critical Months**	**All Months**	**Critical Months**	**Non-Critical Months**	**All Months**	**Critical Months**	**Non-Critical Months**	**All Months**	$r_{c\ ave}$
1	0.98	0.95	0.97	0.99	0.98	0.99	0.88	0.96	0.92	0.96
2	0.95	0.96	0.96	0.96	0.93	0.95	0.94	0.9	0.92	0.95
3	0.9	0.92	0.91	0.89	0.95	0.92	0.95	0.99	0.97	0.92
4	0.85	0.92	0.89	0.92	0.98	0.95	0.97	0.92	0.95	0.93
n										

7.1.6 Depth Compliance

Depth Compliance is primarily a check on a few hydraulic items. As any number of a multitude of changes could have the same resulting impact on the depth, adjustments should only be made when absolutely necessary.   A direct comparison of peak modeled depth to peak observed depth during storm events is not recommended, mainly as small errors in flow compound the level error identification.   Rather the scatterplot is the primary determination of this portion of the hydraulic calibration. The modeled velocity vs. depth should be compared to the observed data velocity vs. depth on a scatterplot.

Depth Calibration Guidance

The model data should generally match the observed data when depths exceed half the pipe diameter. Conditions less than half pipe diameter are misleading and unimportant; the lower depths are heavily impacted by sewer transitions, the sensor band, and internal manhole hydraulics and are not representative of model predicted depths during surcharge. The conditions and actions are summarized in **Volume II Table 7-4**.

Table 7-4. Depth Calibration Conditions	
Condition	**Action**
If model AND observed depths are LESS than 0.5*Diameter	None
If model OR observed depths are GREATER than 0.5*Diameter	Match observed depth[1]

(1) If neither model nor observed data shows surcharges, adjustment should be limited and parameters reasonable. If either one is surcharged, depth calibration should be reviewed.

The following issues can complicate the depth calibration and result in a poor match in the scatterplots:

- Downstream hydraulic structures (CSOs, RTCs, control gates, diversions)
- Hysteresis
- Sites with significant variation storm to storm
- Silt or debris deposition at or downstream of the monitoring point
- Roots or grease deposits
- Pump stations (upstream or just downstream)

The observed vs. modeled scatterplot should be submitted in the *6 – Calibration* app in FlowFinity (with modeled timeseries on top) for all models, even if surcharge conditions were not observed or modeled.

Depth Calibration Metric

The depth calibration metric described below is available in the MSDGC Model Tools toolbox. Depth (Hydraulic) calibration is assessed based on the velocity versus depth scattergraph. The scattergraph is evaluated based on the conveyance zones of the top 15 percent of conveyance events (Con_{15} storms). The compliance is evaluated as follows:

1. The scatterplot is divided into 10 bins evenly spaced between the smallest and largest depth values of the modeled and monitored data (from the Conveyance zone of the Con_{15} storms).

2. The upper and lower bounds of the model data is identified for each bin.

3. For each bin, the following counts are determined:

   a. Total observed data points

   b. Observed data points above the lower bound

   c. Observed data points below the upper bound

   d. Percent of data points above the lower bound

   e. Percent of data points below the upper bound

4. The average percent of observed points above the lower bound and the average Percent below the upper bound are calculated. Both percentages must be greater than 25% to be within compliance.

   a. Bins with less than 3 of either observed or modeled data points should be ignored.

Volume II Figure 7-7 and **Figure 7-8** illustrate the scatterplot metric calculations.

Figure 7-7. Scatterplot Metrics Example #1 – Failed Depth Calibration Review

Bin	1	2	3	4	5	6	7	8	9	10	
Number of Data Points											
Total	19	14	8	10	7	5	4	5	5	6	
Above Lower	19	11	0	6	7	4	3	1	2	6	**OK**
Below Upper	1	4	8	10	4	3	3	4	5	2	
Percent of Data Points											**Average**
Above Lower	100	79	0	60	100	80	75	20	20	100	**63%**
Below Upper	5	29	100	100	57	60	75	80	100	33	**64%**

Level
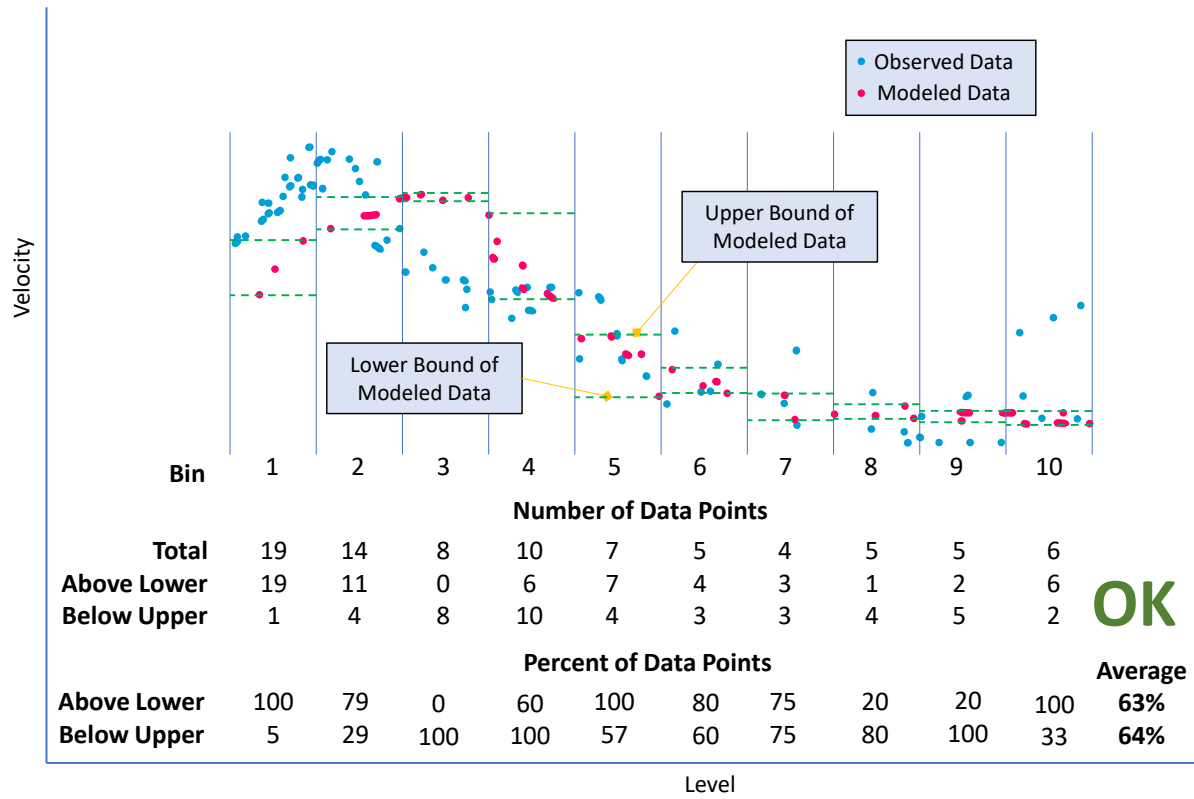
Figure 7-8. Scatterplot Metrics Example #2 - Passed Depth Calibration Review

Bin	1	2	3	4	5	6	7	8	9	10	
Number of Data Points											
Total	21	14	8	10	6	6	4	5	5	7	
Above Lower	21	10	0	0	1	0	0	0	0	3	**NG**
Below Upper	8	7	8	10	5	4	3	5	5	4	
Percent of Data Points											**Average**
Above Lower	100	71	0	0	17	0	0	0	0	43	**23%**
Below Upper	38	50	100	100	83	67	75	100	100	57	**77%**
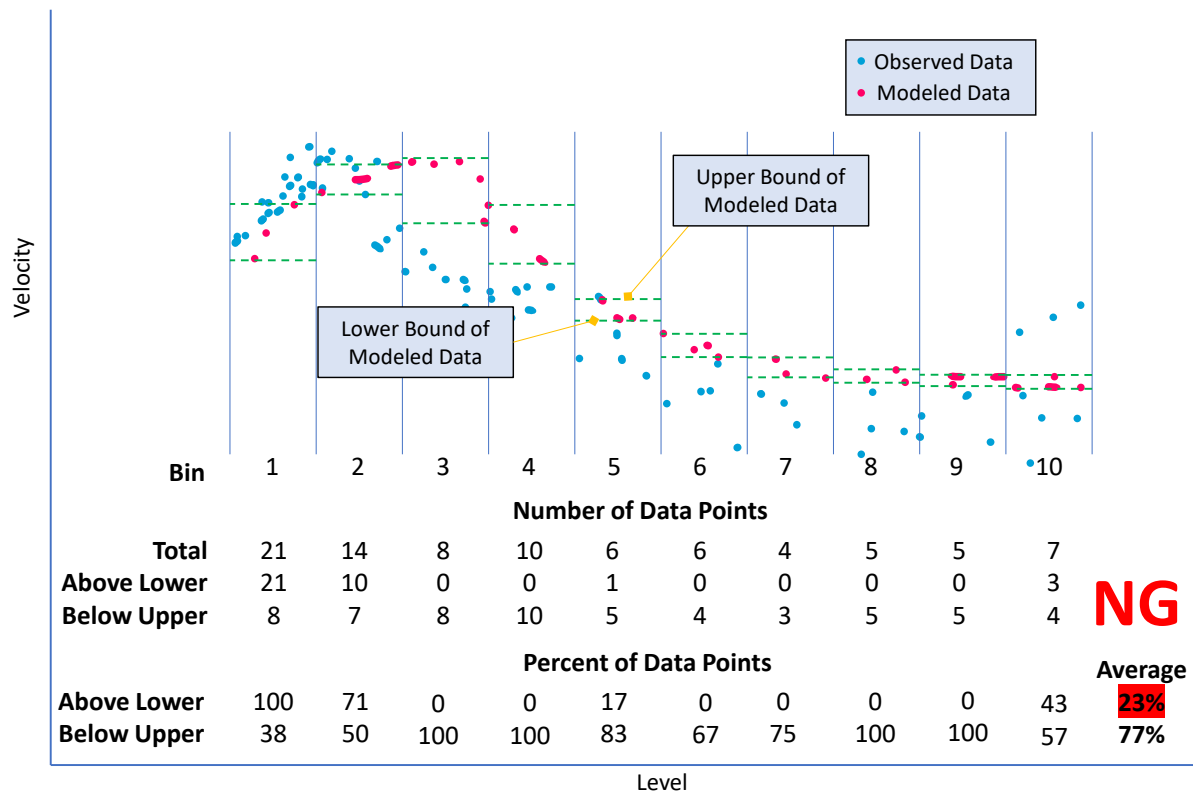
7.1.7 Base Flow

Base flow compliance is determined when the Typical Inputs are added to the model for submittal to the *8 – Report* app as described in **Volume II Section 8.1**. It is only given a cursory review during the review of the storm volumes (in *6 – Calibration* app) to confirm it is not grossly in error and contributing to erroneous surcharges.

Because the observed base flow can vary significantly over the course of a month and the monitoring data frequently has poor quality data during low flows (especially the case in combined areas and small tributaries), the following items should be considered when evaluating the base flow entered during for the Typical Inputs.

1. The modeled base flow should match the average of the base flow for a given month (if using monthly variation) or the year (if using a fixed rate).

2. Monthly patterns should follow a normal seasonal trend. The trend should not deviate to force matches when the observed data does not follow a normal seasonal trend. Therefore, some specific months may match poorly; this is acceptable.

3. The base flow calibration will be evaluated based on the overall monthly trends as well as the DWF statistics on the DWF Comparison tab of the Model Application Tools[1].

Graph and model result comparisons related to the base flow calibration will be submitted in the *8 – Report* app in FlowFinity. If the Inflow Timeseries method is used during wet weather calibration, the submitted information in the *8 - Report* should be based on the model and model runs with the model converted to Model Parameters.

7.1.8 Parameter Review

As part of the Final Review process (*6 – Calibration* app in FlowFinity), the model inputs will be evaluated to ensure that calibration did not lead to distorted parameters (atypical seasonality, poorly shaped RTK values, non-physically based Horton runoff values, etc.). The following checks will be performed by the modeler prior to completion of the *6 – Calibration* app in FlowFinity to prevent hidden parameters from being distorted to help the calibration fit.

RTK and Initial Abstraction Seasonal Trends

The MSDGC Calibration Application Tool – RTK Shape Analysis creates a series of graphs to review the RTK unit hydrographs shapes and parameter seasonal trends. The graphs should be reviewed and submitted to the *6 – Calibration* app in FlowFinity.

Parameter Uncertainty

The modeler provides a description and data as necessary to ensure that subbasins with a high percentage of total flow from upstream of the basin do not have unreasonable parameters. Refer to the *7 – Model* app in FlowFinity.

Parameter Distortion

The modeler must submit information to demonstrate that all catchments tributary to a given flow monitor have consistent parameters or that any variances are documented and related to topography, sewer age or other relevant differences. This is to prevent a single catchment from being distorted as a substitute for adjusting all catchments relatively. Refer to the *7 – Model* app in FlowFinity.

Preservation of Previous Flow Distribution

When a single flow monitor is used to recalibrate an area previously calibrated by multiple flow monitors, the prior general distribution of flow from the earlier calibration must be preserved. To help check this, a map will be provided (FlowFinity *Procedures_and_Forms* app Reference ID **#R-0331**) that shows the percent increase in flow rates for each pipe after the model update**.** This will help to illuminate any areas with a significant change in flow from the previous calibration. Further checks will be provided per the *7 – Model* app in FlowFinity**.**

7.2   APPORTIONING MONITOR

Compliance is demonstrated by providing graphs that show that the relationship of the model for the calibrated Hydrology monitor is the same in the time period when the Apportioning monitor was installed (Concurrent) and the duration when only the Hydrology monitor was installed (Hydrology

Only). For example if the hydrology monitor was installed for all of 2022, and the apportioning monitor was installed in just February, then the relationship of the two models during February (Concurrent) must be the same as the relationship during the remainder of 2022 (Hydrology Only).

Figure 7-9. Apportioning Monitor Upstream of Hydrology Monitor
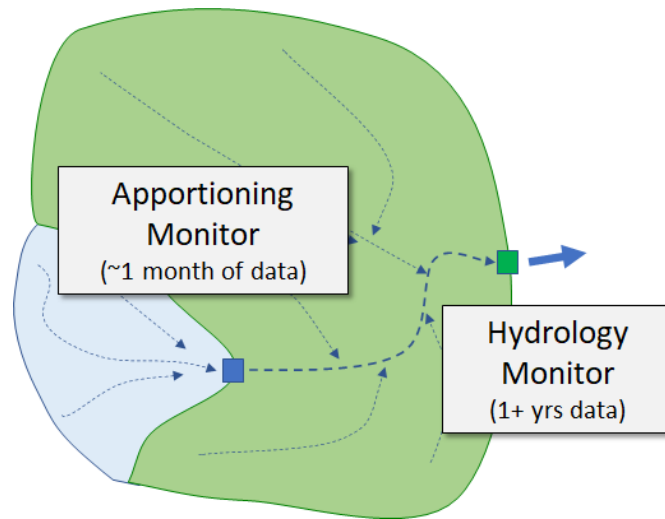
In the example below shown in **Volume II Figure 7-10** the Apportioning Monitor would not be approved because the relationship of the Conveyance values from the two models is different in the Concurrent time period from the Hydrology Monitor Only time period. The Hydrology Monitor and Apportioning Monitor must both be submitted and approved, although the criteria is quite different. The *Procedures_and_Forms* app (P-0386) can be consulted for additional detail and instructions on how to make the graphs from the Model Applications Tools.

Figure 7-10. Failed Apportioning Monitor: There is a Different Model to Model Relationship During the Concurrent Monitoring Time Period and the Time Period when only the Hydrology Monitor was Installed.
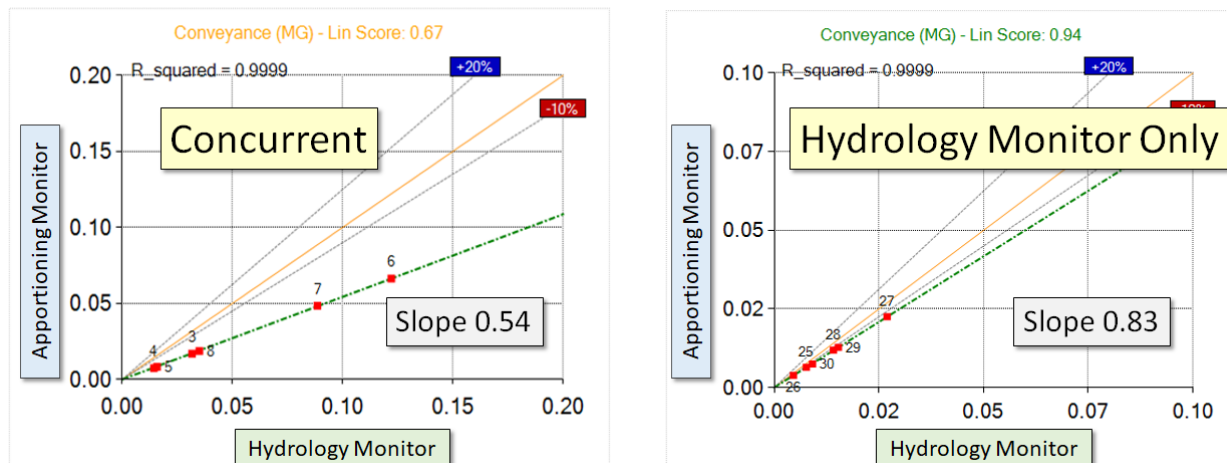
7.3   HYDRAULIC MONITOR

For Hydraulic Monitors, calibration compliance does not need to adhere to set numerical requirements; rather the calibration is qualitative, utilizing the monitor data to establish key hydraulic parameters. Generally, the hydrographs and time series of level and velocity should demonstrate that the model replicates the observed system reactions based on the purpose of the monitor. The model should replicate the observed system reaction for most events. If not, the modeler should detail the reason for matching less of the data. For example, if a CSO underflow experiences frequent grate clogging, the model may not match most events and the larger flow rates only should be matched. In this case, the modeler should include an explanation of the reasoning in the submittal process.

7.4   REGULATORY REPORTED OVERFLOW MONITORS

Regulatory Reported Overflow Monitors are used to assess the CSO, SSO, NEO, and PSO overflow frequency and duration. Reported activations are defined as having occurred if the level sensor records a depth that exceeds the head of the weir AND depth of the downstream receiving stream (Mill Creek, Ohio River, etc.). Modeled activations are defined as having occurred if the modeled HGL exceeds the modeled weir elevation.

Assessment Process

- The reported activations have been carefully reviewed and vetted. The modeler does not need to independently confirm the activation.
  - The evaluation should be completed with the full SWM model using the appropriate interceptor and river time series from the SCADA system. Interceptor impacts should be discussed with the MSDGC Modeling Group to determine the best course of action.
- Overflow frequency is the compliance criteria.
  - The model vs. monitored overflow frequency should be compared on a daily reporting interval for consistency with required EPA reporting.
  - If an overflow event occurs near midnight and the overflow is active during both days, both days are recorded with an activation.

Documentation

- Note that example tables can be found in the FlowFinity *Procedures_and_Forms* app Reference ID **#R-0376**.
- **Table 1**: A table of the daily modeled and monitored activation status should be provided for each overflow location. The table should also indicate the days reported as "site unavailable".
- **Table 2**: The following summary statistics should be provided for each Regulatory Reporting Overflow Monitor in the *6 – Calibration* app of FlowFinity:
  - # of Days with Monitoring Data: The total number of days in the observed data period. The total includes days with "site unavailable."

- o # of Days with Reported Activations: Total number of days with reported overflow activations
- o # of Days with Modeled Activations: Total number of days with modeled overflow activations
- o # of Days with Reported and Modeled Activations
- o # of Days with Modeled Activations but with "site unavailable"
- o # of Days with Reported Activations but without Modeled Activations
- o # of Days with Modeled Activations but without Reported Activations
- o # of Days without Reported or Modeled Activations
- o # of Days reported as "site unavailable"

The following issues could arise during the overflow analysis.
- If any activations occur during base flow (outside a storm event), the modeler should alert MSDGC to the issue and discuss the appropriate course of action.
- The number of observed overflows may be greater than the number of modeled overflows due to debris buildup on the underflow grate. If debris on the underflow grate is an issue, the modeler must provide detailed evidence that this is the case.

7.5   NON-CALIBRATION MONITOR

For a project monitor to be deemed "non-calibration", it must be approved as such by MSDGC. The model and observed data shall be submitted and any useful results of the monitor shall be listed and demonstrated. No specific calibration requirements apply unless directed by MSDGC for that submittal.

7.6   DOCUMENTATION

Once the storm volume calibration of the SVC, D-SVC, or SA model has concluded, the submittal and feedback process begins between the modeler and the MSDGC Modeling Group through FlowFinity. Referring to **Volume II Figure 1-6** through **Figure 1-12**, this process will include:
- Standard/Detailed/ Storm Analysis Calibration Project Submittal
  - o Model submitted through the *6 – Calibration* app in FlowFinity.
  - o Detailed Check for Modeling Errors submitted through the *7 – Model* app in FlowFinity.

After the model evaluation of the submodel is complete, the submodel will be uploaded back into the full model. Typical inputs will replace the calibration inputs. Refer to **Volume I Section 4.9** for submodel and subsumption guidance. The full SWM model will be uploaded to the *8 – Report* app in FlowFinity for review.

The MSDGC Modeling Group will provide feedback to the modeler after each submittal. Upon resolution of the MSDGC issues, calibration of the model will have concluded. The final documentation includes:
- Standard/Detailed Calibration Project Report Submission

- o **Volume II Appendix A1**– Calibration Report Template, where the report will be uploaded to FlowFinity through the *8 – Report* app.
- o Review of the Draft and Final Calibration Reports, uploaded to FlowFinity through the *8 – Report* app.

Or,

- Storm Analysis Task Memo Submission
  - o **Volume II Appendix A2**– Storm Analysis Task Memo Template
  - o Review of the Draft and Final Storm Analysis Task Memos, uploaded to FlowFinity through the *8 – Report* app.

8.0   TYPICAL INPUTS

The SVC, SA, or D-SVC model used for calibration contains several inputs specific to the calibration period which must be changed for the alternatives analysis. These include:

- Typical Year Base Flow
  - Model Parameters, or
  - Inflow Timeseries - switched to Model Parameters (**see Volume II Section 8.1**) –
  - Aquifer Model - removal
- Rainfall time series switched to Typical Year (or Design Storm) time series
- Typical Year Operations (see **Volume II Section 8.2**) including control rules representative of SOPs for
  - Plant Operations
  - RTC Operations
  - Pump Station Operations
- River Level Boundaries eliminated (see **Volume II Section 8.3**)
- If the model was an extract from the overall model and boundary conditions were used for the modeling period, the boundary conditions should be removed (in rare cases updated).

The *8 – Report* app in FlowFinity includes checklists for the changes.

8.1   TYPICAL YEAR BASE FLOW

The Base Flow needs to have monthly values, and not have dependencies on the historic calibration period or the time of year of the model run. The approach depends on how the base flow was specified in the model input file.

8.1.1   Model Parameters

Review the model parameters for base flow and confirm that all monthly values are used.   If the calibration was only for a portion of the year, the monthly values must be estimated and provided for months not in the calibration.

8.1.2   Inflow Timeseries

The Inflow Timeseries in the model must be replaced with Model Parameters. This was described in **Volume II Section 6.3.3.** Equivalency must be demonstrated and will be required in the *8 – Report* app in FlowFinity.

8.1.3   Aquifer Module

The use of the Aquifer module is not recommended. In those cases where it is approved for base flow during calibration or is a legacy or earlier modeling, the Aquifer Module must be removed and replaced with Model Parameters as outlined in **Volume II Section 6.3.3**. Equivalency must be demonstrated and will be required in the *8 – Report* app in FlowFinity.

8.2   TYPICAL YEAR OPERATIONS

Actual operations which occurred during the calibration period should have been explicitly included in the calibration model. These control rules must be replaced with current standard operating procedures (SOP) applicable to the Typical Year.

8.3   RIVER LEVEL BOUNDARIES

Wet Weather Improvement Plan (WWIP) compliance is predicated on "Normal" outfall boundary conditions at the major rivers and streams. This does not include West Fork and Duck Creek which are included in the model. All boundary conditions for the rivers and streams need to be removed to maintain validity of comparisons with the WIPP.

8.4   NEW EXISTING CONDITIONS DOCUMENTATION

Once the EC-Q_{n+1} models have been updated with the Typical Year inputs, the next step in a typical calibration project will involve another submittal and feedback exchange between the modeler and the MSDGC Modeling Group. Referring to **Volume II Figure 1-6** through **Figure 1-12**, this process will include:

- EC-Q_{n+1} Model Submission
  - Submittal of the EC-Q_{n+1} model will be through the *8 – Report* app in FlowFinity.

Following completion of this submission, refer back to **Volume II Figure 1-6** through **Figure 1-12** for guidance on the next step in the calibration project.

9.0 DETAILED MODEL STANDARDIZATION

In general, MSDGC models are intended to be used for high-level, basin-wide planning. MSDGC models are used by many, often for making relative comparisons when evaluating system performance and making important design decisions. Because of this, standardization of model complexity is necessary to reduce computational overhead and maintain a consistent representation and level of model complexity throughout all SWM basins.

If a D-SVC-Cal model was produced as described in **Volume II Section 5.0**, an SVC-Cal model must be prepared and also submitted. This SVC-Cal model will capture the calibration of the D-SVC-Cal model but without the model complexity.   The hydraulic/hydrology equivalent representation will be within MSDGC's Standard Model's level of complexity before incorporation back into the overall SWM.

9.1   PERFORMING THE STANDARDIZATION

As previously mentioned, it may not be possible to provide exact quantitative guidelines for model standardization given the great deal of variability and subjectivity associated with defining a Standard Model's level of detail. Instead, this section provides qualitative guidance.

In general, standardization will most likely consist of consolidating inputs such that the number of model elements and detail is reduced, while hydrology and hydraulic equivalency with the more detailed version of the model is reasonably maintained. While these guidelines will not attempt to list every possible scenario where this would be carried out, this process is illustrated conceptually through the schematic example provided in **Volume II Figure 9-1**. It is expected that a similar approach would be applied to the various other scenarios.

Figure 9-1. Conceptual Illustration of Model Standardization Process
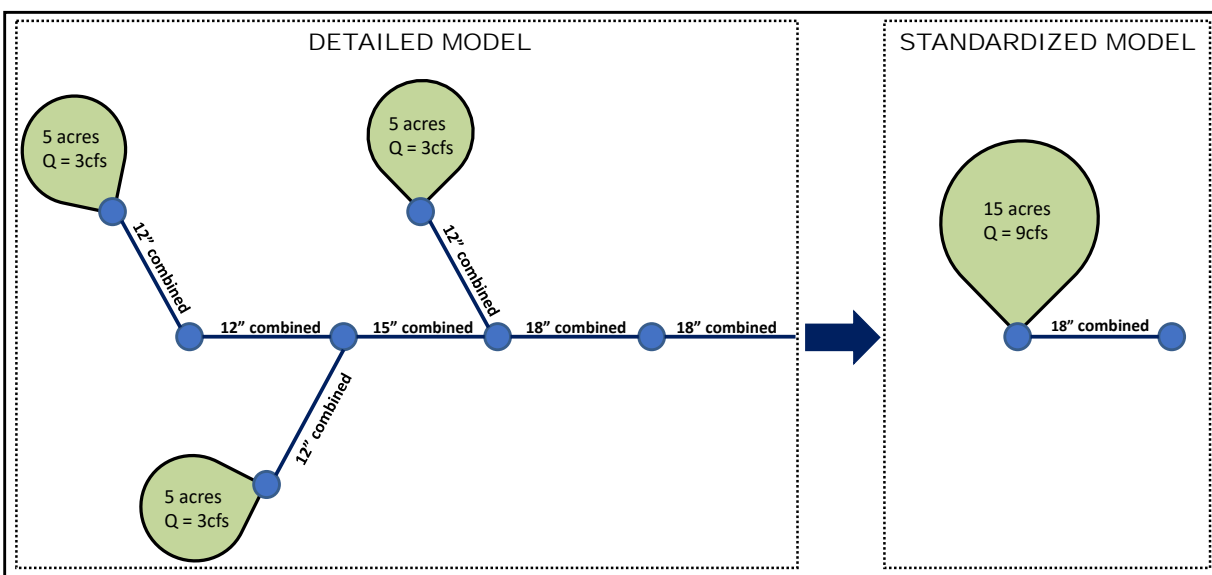
9.2   STANDARDIZATION DOCUMENTATION

For a typical Detailed Calibration project, the standardization process may need to be performed on two separate occasions. Depending on where the modeler is in the modeling project will determine what steps are next. Referring to **Volume II Figure 1-6** through **Figure 1-12**, the next steps will include:

- Steps following D-SVC-Cal Standardization
  - o SVC-Cal Model Submittal
    - Submittal of the SVC-Cal after standardization will be completed through the *6 – Calibration* and *7 – Model* apps of FlowFinity.
- Steps following D-PC Standardization
  - o PCS Model Submittal
    - Submittal of the PCS will be completed through the *8 - Report* app in FlowFinity with the Alternatives Modeling Report.

10.0 BASELINE MODEL DEVELOPMENT

When beginning the Planning phase, a Baseline model (BSL) must be established consistent with conditions just prior to the proposed project. The purpose of the BSL is to consider the effects that the proposed alternative would have on the system after other committed projects are constructed. An example would be: A pump station will be replaced and upgraded in two years.   A CSO modification is being proposed for 5 years in the future.   The alternatives for the CSO modification must have the proposed pump station in the model to reach meaningful conclusions. Therefore, the BSL should include the pump station and the alternatives would all add the modifications to that.

The modeler will be provided a model from MSDGC (Pre-BSL) which will be updated to the Baseline Model (BSL). This will be submitted via the *Model Archive* app along with a summary list of the changes. The details of this process are below. A description of how to make the submittals are included in the *Procedures_and_Forms* FlowFinity application #P-0385.

10.1 MODEL TO BE USED TO CREATE THE BASLINE MODEL (PRE-BSL)

The Pre-BSL is the model MSDGC provided for the Planning phase. In general, the Pre-BSL model will be one of the following:

1. the SVC-Cal or D-SVC-Cal from the calibration, or
2. the EC-Qn directly from the vault.

10.2 BASELINE MODEL (BSL)

10.2.1 Establish the Model Boundaries

If the EC-Qn model is provided as the Pre-BSL, it may be necessary to cut down the model to a more suitable model to ensure that all of the appropriate future projects that are planned for construction up to the Baseline Year are identified, the extent of the project's potential influence must be established. If the SVC-Cal or D-SVC-Cal is provided as the pre-BSL model, the model boundaries should have already been identified during the calibration phase and should not need to be changed.

10.2.2 Determine Baseline Projects

As part of the submittal in the *Model Archive* app in FlowFinity, provide the MSDGC Modeling Group with the extent of the sewer service area that is to be evaluated for compiling the Baseline Projects List. Also provide background on the current modeling project, potential alternatives to be evaluated (if known at the time), and the basis for which the potential Baseline Project Influence Extent was defined. The MSDGC Modeling Group will review all of the information and provide the Baseline Projects List that is to be incorporated into the model.   MSDGC will also identify whether models of the Baseline Projects exist or not, and provide any existing models

10.2.3 Incorporate Projects

Add the Baseline Projects into the model while maintaining the appropriate level of detail (**Volume II Section 9.0**) and following the guidance provided in of **Volume I Section 4.0** where appropriate. Once the projects have been added to the model, the BSL will be submitted for review.   Keep a summary list of all changes and projects added to the Pre-BSL to create the BSL. This summary will be included in the review submittal.

10.2.4 BSL Submittal

Once the BSL model has been developed it is submitted via the Model Archive app as a non-vaulted Model (NVM). This submittal procedure is described in the *Procedures_and_Forms* app of FlowFinity as R-0385. The following key items are required as part of the submittal.

- Pre-BSL model
- BSL model
- Summary List of Changes
- Library of Changes (use the *Request Library* app in FlowFinity to generate the required file)

It is important that all model corrections or adjustments made be included in the Summary List of Changes. Other items will be submitted via FlowFinity to review for various model errors.

10.3 BASELINE CONDITION EVALUATION

10.3.1 CSO Evaluation

See **Volume I Section 4.2.1** for information on how to set up and run the Typical Year storm to evaluate the ROV. Modelers should check with MSDGC to determine if any further reporting metrics are required.

10.3.2 SSO Evaluation

See **Volume I Section 4.2.2** for information on how to set up and run design storms. Modelers should check with the MSDGC project manager to determine which design storm is appropriate for their modeling project and what statistics resulting from the run will be reported.

10.3.3 Capacity Evaluation

For some projects, the capacity of the sewer system may need to be evaluated for all existing flows that could potentially reach a given sewer. To evaluate this, add 100 feet of surcharge level to the model junction and storage elements upstream to prevent losses from flooded manholes, then run the model for each design event.

1. Pipes are "undercapacity" if:

    a. Pipe is surcharged and max/full is >1.

    b. Pipe is surcharged and the max/full is <1, but the sewer stretch upstream and downstream meet the criteria above, see **Volume II Figure 10-1.**

2. Pipes have capacity if:

    a. Pipe is not surcharged.

    b. Pipe is surcharged and the max/full is <1, but the sewer stretch upstream does not meet criteria 1a above, see **Volume II Figure 10-2.**

Figure 10-1. Capacity Evaluation Example 1
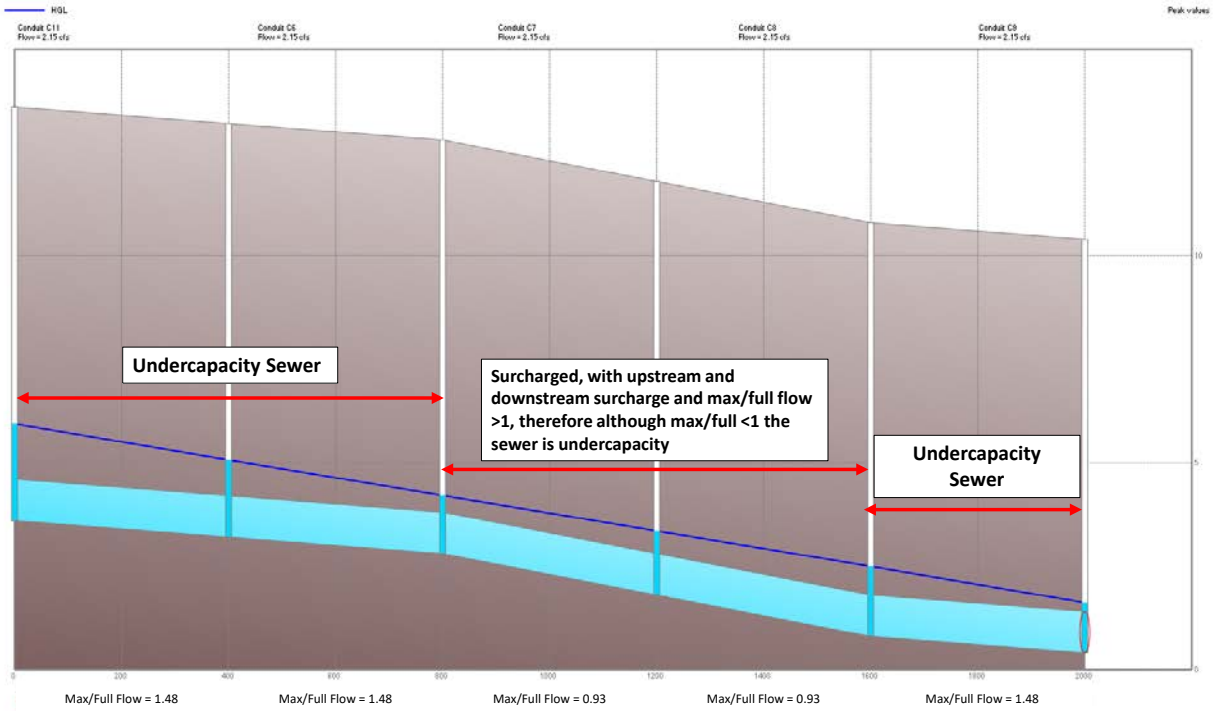
Figure 10-2. Capacity Evaluation Example 2
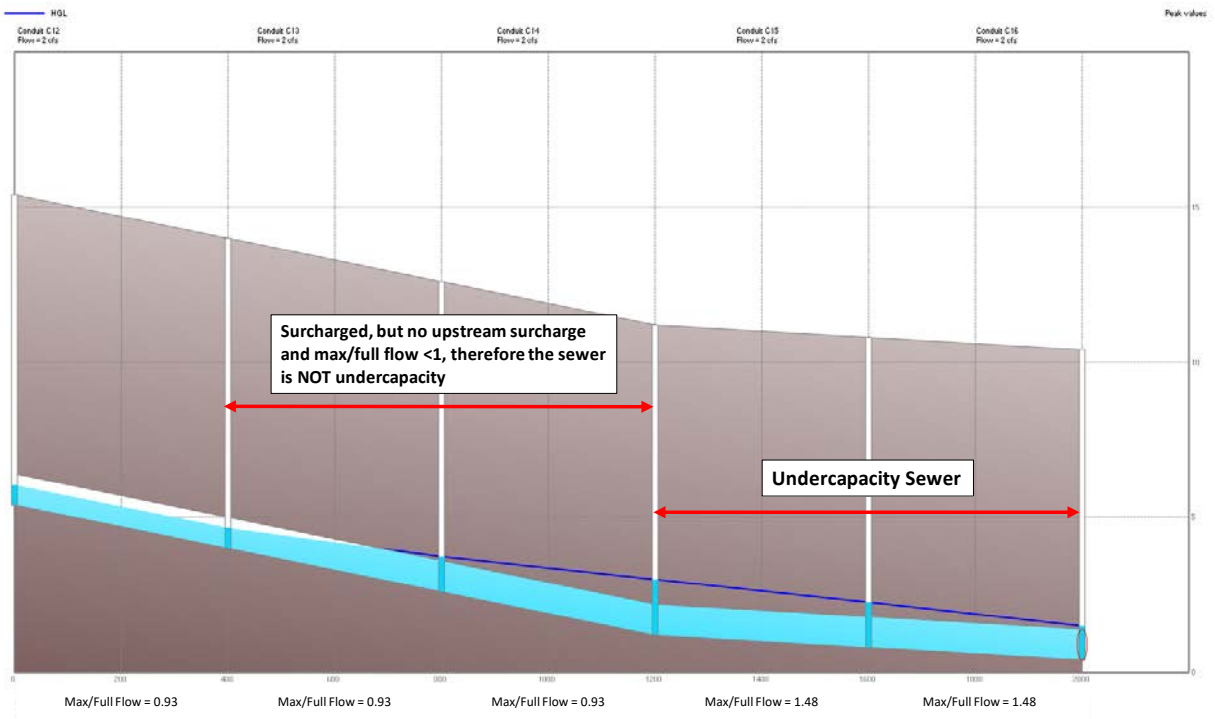
11.0 ALTERNATIVES MODELING

For modeling projects, alternatives modeling will begin with the BSL Model, developed per **Volume II Section 10.0** guidance. In general, each alternatives described in the Business case Evaluation (BCE) must have a separate submittal in the *Model Archive* app in FlowFinity. In some cases multiple submittals will be necessary to document each step in an Alternatives tree. It is imperative that no alternative be submitted without an accurate list of all changes between the pre and post models submitted (typically the BSL and ALT).

11.1 PROJECT OBJECTIVES

Before performing alternatives modeling, the project should have a clear objective and desired level of control documented in FlowFinity in order to aid in the review of the alternative by the MSDGC Modeling Group. For example, one project objective may be to reduce CSO to a certain ROV per the Typical Year. Another objective might relate to minimizing flooding across multiple design storms. The objective or level of control will determine what simulations are necessary and must be documented with the MSDGC PM prior to beginning the alternatives evaluations.

11.2 MODEL SETUP

11.2.1 Project Model Boundaries

Project model boundaries were determined when preparing the BSL model and should not be subsequently changed in the ALT model.

11.2.2 Incorporate Projects

Alternatives modeling often requires the representation and manipulation of several different types of modeling elements in combination with each other. For example, representing a combined sewer separation project may involve adding pipe elements, splitting subcatchments, and adjusting subcatchment parameters. To maintain a consistent approach to representing each element, modelers should refer to the guidance provided in **Volume I Section 4.0**, which covers each topic and modeling element individually. It is the modeler's responsibility to follow the established MSDGC guidance to achieve proper representation of the overall project alternative. Anytime modeling diverges from the general guidance in **Volume I Section 4.0**, the methods should be discussed with the MSDGC Modeling Group.

11.2.3 Simulations

Alternatives analysis will often require running design storm simulations of varying recurrence intervals for the purposes of evaluating different aspects of the proposed alternatives. Which recurrence interval to be run will vary based on the requirements of the project, which will be determined by the MSDGC PM in collaboration with the design team. Regardless of recurrence interval, all design storms should utilize the SCS Type II distribution, and rainfall depths should be taken from Bulletin 71 Rainfall Frequency Atlas of the Midwest. These design storms should be saved in the Time Series Editor within

the model input file provided by MSDGC and are also provided in **Volume II Appendix B**. Note that the "Design Storm Creator" in PCSWMM can be used to generate the rainfall time series. See **Volume I Section 4.2.2** for specifics on design storm setup for simulations.

System Impacts Evaluation

Each proposed alternative will have an impact on the existing upstream and downstream systems. Comparing system behavior (peak hydraulic grade lines (HGLs), max flow rates, total volumes, etc.) between the ALTs and BSL model for varying sized design storms is typically the approach used for gauging these impacts. Note that the reporting timestep should be used when comparing output between models. The modeler should confirm with the MSDGC Modeling Group which design storms are appropriate and refer to **Volume I Section 4.2** for guidance on setting up the simulations.

WWIP Performance Modeling

MSDGC is subject to regulatory requirements that are identified in the WWIP. Any alternatives that impact overflows must be reviewed by MSDGC for approval. The Typical Year and the 2-Year, 24-Hour SCS Type II design storms are typically used for evaluating CSO and SSO overflow volumes, respectively. The modeler should confirm with the MSDGC Modeling Group that these are appropriate and refer to **Volume I Section 4.2** for guidance on setting up the simulations.

Conveyance improvements should be sized for the 10-yr, 24-hour, SCS Type II design storm. The improvements should include any contiguous upstream or downstream pipes that cannot convey the 2-yr, 24-hour, SCS Type II storm. When pursuing pipes upstream or downstream to meet this requirement, the modeler should clearly note any pipes that are included for which there was no actual relevant flow monitoring performed. This may be on side lines or further upstream of significant pipe divides. MSDGC must be made aware of locations that are being expanded purely based on a modeler's assignment of the distribution of flows within the model, and not based on relevant observed data.

11.3 ALTERNATIVES SPECIFIC QA/QC

Alternatives modeling is expected to undergo the general model quality assurance/quality control (QA/QC) measures outlined in **Volume II Section 3.0** and include additional measures specific to alternatives analysis which can be found in the *Model Archive* app in FlowFinity. A priority in alternatives modeling is to account for the possible unintended impacts of an alternative that changes flows throughout the system, such as a new Dynamic Underflow Control (DUC) that impacts other proximate overflows. Alternatives-specific QA/QC includes evaluating flooding manholes, surcharged hydraulic grade lines, and overflow volumes to ensure there are no negative impacts on the greater MSDGC system.

11.3.1 Flooding Manholes

Node flooding is a review item in the general model QA/QC measures outlined in **Volume II Section 3.8**. However, for alternatives modeling, emphasis is placed on ensuring the proposed work does not

increase the number of flooded nodes or the volume of flooding. Compile a list of all flooding nodes before and after each alternative simulation. Confirm that no upstream node flooding is leaving the system, but should have been accounted for in the alternative design.   A table illustrating that the number of flooding nodes and amount of flooding from each node has not increased should be documented within the Alternatives Modeling Report, a template of which is available in **Volume II Appendix A3.**

11.3.2 Hydraulic Grade Line Impacts

An increased hydraulic grade line can be an area of concern indicative of a potential greater risk of surcharging, basement flooding, or ground flooding. Proposed Conditions project alternatives should not increase the level of surcharging in the system (relative to existing surcharge) and should reduce HGLs where possible. This can be evaluated by comparing the peak HGL at nodes within the project area before and after each alternative simulation. If there is a rise in peak HGLs, determine the cause of rise. Documentation (**Volume II Appendix A3)** should state that this check was performed and report any instances of increased HGLs.

11.3.3 CSOs and SSOs

Verify that the overall overflow volume of CSO or occurrences of SSO have not increased. Refer to **Volume II Section 11.0** for further guidance. This will be documented in **Volume II Appendix A3.**

11.4 IDENTIFY KEY ALTERNATIVES

The number of alternatives will vary by project – some projects may have a few, while others with optimizations may have hundreds of thousands. However, there will typically be a few Key Alternatives that are identified through the alternatives analysis process. The criteria for evaluating the alternatives, and the basis for selecting Key Alternatives will need to be done in concert with the MSDGC PM and Modeling Group. These should identify the best from each different class of solutions, not just minor tweaks on the same theme. Once identified, the Key Alternatives models should be submitted to the MSDGC Modeling Group, as is specified in the flow chart steps that follow the ALT Model development (**Volume II Section 11.0**). Any additional alternatives models beyond the Key Alternatives will not need to be submitted to the MSDGC Modeling Group. All models discussed in the BCE are considered as Key Alternatives.

11.5 DOCUMENTATION OF KEY ALTERNATIVES

Once the ALT model(s) has been developed, the next step in a modeling project will involve another submittal and feedback exchange between the modeler and the MSDGC Modeling Group. The submittal of the ALT model(s) must include the list of changes made to the distributed model and those changes **must** be related to the project. The ALT model(s) must be submitted through the *Model Archive* app for review and approval, including the list of the changes made between the associated BSL model and the submitted ALT model. The most relevant information is.

- BSL model

- ALT model
- Summary List of Changes
- Library of Changes (use the *Request Library* app in FlowFinity to generate the required file)

The review confirms the following items:

- The list of changes to the BSL was provided and is of sufficient detail to generate a cost estimate of the submitted Alternative modeled in the ALT.
- The changes made to the ALT are related to the project described.
- There are no errors in modeling. Examples of errors that would cause this audit to fail include:
  - New flooded manholes not being surface routed.
  - Disconnected pipes.
  - Adverse effects to the upstream and downstream system at critical points.
  - Unjustified increases in HGLs, peak flows or flooding volumes beyond what is acceptable per the project boundaries.

For a complex system or tree for the development of the alternatives, the modeler will submit a flowchart to detail the parent-child relationship between each ALT model and mode used to develop each alternative. This can involve multiple submittals, one for each step in the process. Each one submitted with the specific changes. **Volume II Figure 11-1** shows an example of a submitted flowchart and associated relation chart requiring eight (8) separate submittals.

Referring to **Volume II Figure 1-6** through **Figure 1-12**, this process will include:

- ALT Submission
  - Submission of ALT will occur in the *Model Archive* app of FlowFinity.
  - Submission of Proposed ALT models will also occur within the *8 – Report* app of FlowFinity.

Figure 11-1: Multiple Alternative Submittal Flowchart and Relation Chart
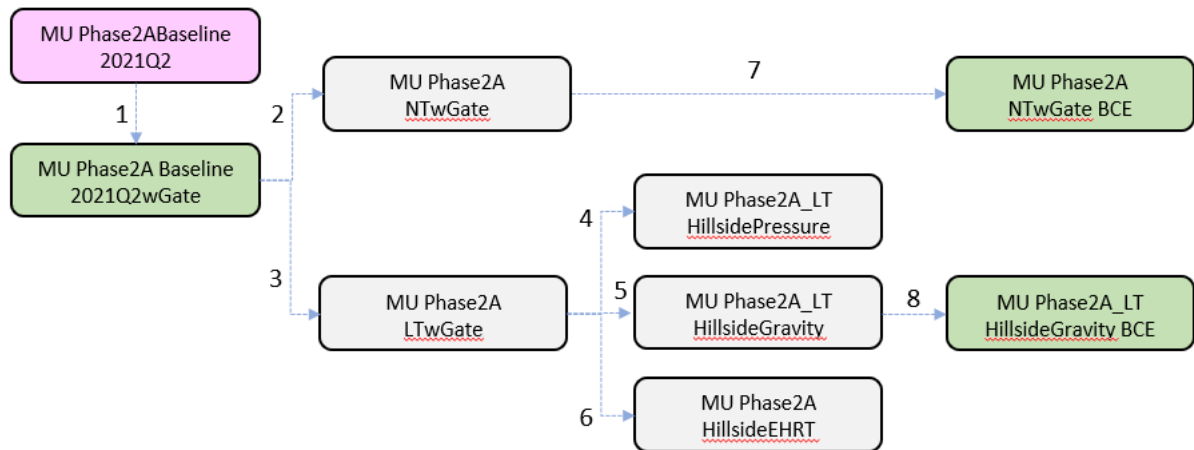
Step	Model Type	Pre-Model		Post-Model	
		Model Type	File Name	Model Type	File Name
1	PM	EC-Q2	MU_Phase2ABaseline2021Q2	EC-Q2	MU_Phase2ABaseline2021Q2wGate
2	NVM	EC-Q2	MU_Phase2ABaseline2021Q2wGate	BSL	MU_Phase2A_NTwGate
3	NVM	EC-Q2	MU_Phase2ABaseline2021Q2wGate	BSL	MU_Phase2A_LTwGate
4	NVM	BSL	MU_Phase2A_LTwGate	ALT	MU_Phase2A_LT_HillsidePressure
5	NVM	BSL	MU_Phase2A_LTwGate	ALT	MU_Phase2A_LT_HillsideGravity
6	NVM	BSL	MU_Phase2A_LTwGate	ALT	MU_Phase2A_HillsideEHRT
7	NVM	BSL	MU_Phase2A_NTwGate	ALT	MU_Phase2A_NTwGate_BCE
8	NVM	ALT	MU_Phase2A_LT_HillsideGravity	ALT	MU_Phase2A_LT_HillsideGravity_BCE

12.0 PROPOSED ALTERNATIVE MODEL

The Key Alternatives (**Volume II Section 11.0**) go through a selection process with criteria that are established through feedback and discussion with MSDGC Engineering and are not the subject of this document. This process, and the criteria by which it is established, will typically be specific and unique to the individual project.

Once the preferred alternative is selected, additional simulations and evaluations may be necessary as specified by MSDGC, but the output and metrics from the preferred alternative will have largely been established and defined from the previous step (**Volume II Section 11.0**). As such, the preferred alternative will be advanced to represent the Proposed Conditions Model.

12.1 PROPOSED ALTERNATIVE MODEL DOCUMENTATION

The route to be taken for advancing the preferred alternative to the PCS (or D-PC) Model for a modeling project will vary for the different types of modeling projects. Referring to **Volume II Figure 1-6** through **Figure 1-12**, both routes are described in the following subsections:

12.1.1 Standard Planning Modeling Project

A Standard Planning Modeling Project will involve first submitting the Alternatives Report, followed by submitting the PCS Model.

- Alternatives Report submission
  - **Volume II Appendix A3**- Alternatives Report Template
  - Submission of the Alternatives Report will occur within the $8 - Report$ app of FlowFinity.
- PCS Model Submission
  - The Detailed Check for Modeling Errors will occur within the *Model Archive* app of FlowFinity.

12.1.2 Detailed Planning Modeling Project

A Detailed Planning Modeling Project will involve submitting the Alternatives Report, submitting the D-PC, standardizing the D-PC to the PCS, and then submitting the PCS.

- Alternatives Report submission
  - **Volume II Appendix A3**- Alternatives Report Template
  - Submission of the Alternatives Report will occur within the $8 - Report$ app of FlowFinity.
- D-PC Model Submittal
  - Submission of the D-PC model will occur within the *Model Archive* app of FlowFinity.
- D-PC Standardization to PCS
  - **Volume II Section 9.0**- Model Standardization
- PCS Model Submission
- The Detailed Check for Modeling Errors will occur within the *Model Archive* app of FlowFinity.

13.0 VOLUME II REFERENCES

ASCE. (1992). Design & Construction of Urban Stormwater Management Systems. New York, NY.

Huff, Floyd A., and James R. Angel. Rainfall Frequency Atlas of the Midwest. Illinois State Water Survey, Champaign, Bulletin 71, 1992.

Jacobs. (n.d.). *11140010 SSO 700 IWAP.* Collection System Model Flow Diagram .

Jacobs. (2020, June). CSO 469 and Related CSOs Final Report.

Lin, Lawrence (1989), A Concordance Correlation Coefficient to Evaluate Reproducibility, Biometrics, 45(1), pp. 255-268

McCuen, R., et al. (1996). Hydrology. *FHWA-SA-96-067.* Washington, DC: Federal Highway
        Administration.

Rawls, W.J. et al. (1992). *Rainfall Frequenct Atlas of the Midwest.*

Tetra Tech (2019), Analysis of ROV under WAPUG and Shape Fitting, Technical Memorandum

Urban Drainage and Flood Control District. (2002). *Drainage Criteria Manual Volume 1.* Denver, CO.

Vallabhaneni and Burgess . (2007). *Computer Tools for Sanitary Sewer System Capacity Analysis and
        Planning.* Washington, DC: EPA.

CIWEM. (2017). Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (Ver 01 Nov 11, 2017)

LIST OF APPENDICES

TEMPLATES

A1 – CALIBRATION REPORT TEMPLATE

MODEL CALIBRATION REPORT
\<PROJECT NAME\>
\<BASIN NAME\>
\<SEWERSHED NAME\>

CIP # \< \>
\<TASK ORDER/MSA/PSA #\>

PREPARED FOR:

**METROPOLITAN SEWER DISTRICT OF
GREATER CINCINNATI
1600 GEST STREET
CINCINNATI, OH 45204**

PREPARED BY:

\<COMPANY NAME, ADDRESS, PHONE, AND POINT OF CONTACT\>

\<DATE\>

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Appendix A1-A: FlowFinity Records

Appendix A1-B: RTK Changes Log

EXECUTIVE SUMMARY

The following information shall be presented in this section:

- Brief project description
- MSDGC point-of-contact
- State that the MSDGC Guidelines were followed and when deviations occurred (if applicable) permission was given to deviate by the MSDGC Modeling Group.
- Calibration assessment. State if the calibration guidelines were met. If not, indicate the reason(s). State if model is acceptable for use for the specific project or recommend efforts to bring within acceptability.

This section shall not exceed one page.

(**NOTE** that all alpha-numeric numbering for all section headings, appendices, and tables and figures contained within this report template are preceded by either "A1-" or "A1" solely for the purposes of providing a unique location identifier within the larger context of these Model Guidelines. These prefixes would obviously not be included in an actual report submittal.)

A1-1.0 INTRODUCTION AND BACKGROUND

- Project area description

- Location within MSDGC service area

- CSOs, SSOs, receiving stream/interceptor/WWTP, etc.

- Map showing the modeled project area in relation to the surrounding area. Refer to **Volume II Figure A1-1** as an example.

- Purpose of the project; WWIP requirements

- Relevant history of the project and model development – previous calibration efforts, model updates, changes in modeling guidelines, etc.

- Current project implications – recalibration to new guidelines, design support, additional analysis, etc.

Figure A1-1. <Project Title> Area Overview
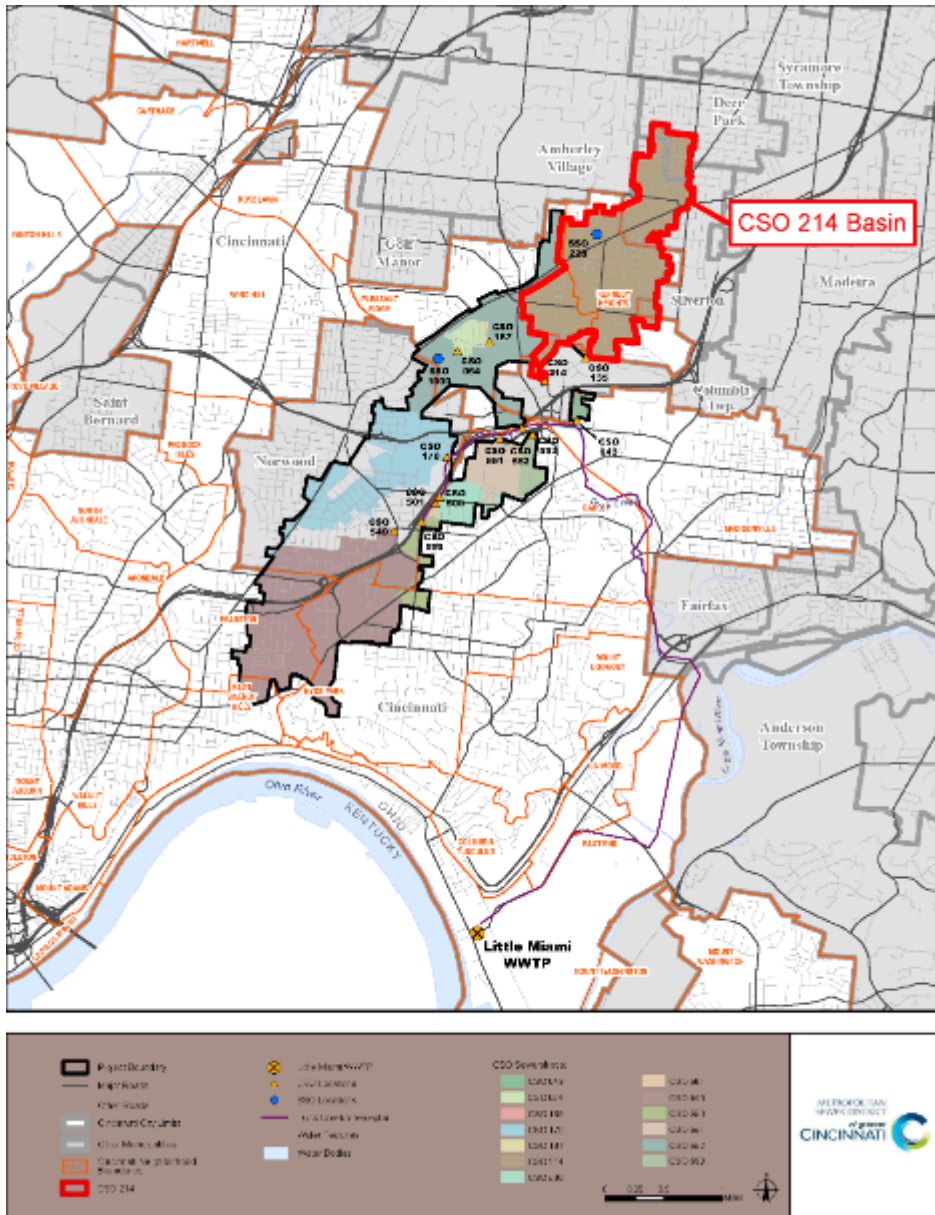
*A1-*2.0 OBSERVED DATA REVIEW

*A1-*2.1 Observed Rainfall Data

- Map showing the location of the rainfall inputs (radar rainfall basin and/or rain gauge) relative to the modeled project area. Refer to **Volume II Figure A1-2** as an example.
- Table of total depth, recurrence interval, and quality of data. Refer to **Volume II Table A1-1** as an example.

Table A1-1. Rainfall Event Identification for <Project Title>							
Storm Number	Start Date/Time	Total Depth of Rain (in)	Recurrence (1 hr)	Recurrence (6 hr)	Data Quality	Excluded	Reason

Table should contain all storms greater than 0.25 inches in 4 hrs at any gauge in the project.

Storm Number: Storms should be numbered the same across all flow monitors for the project.

Data Quality: Good, Poor, Rejected - Rain mismatch, Rejected - Flow Monitor Data Quality, etc.

Figure A1-2. <Project Title> Rainfall Input Overview
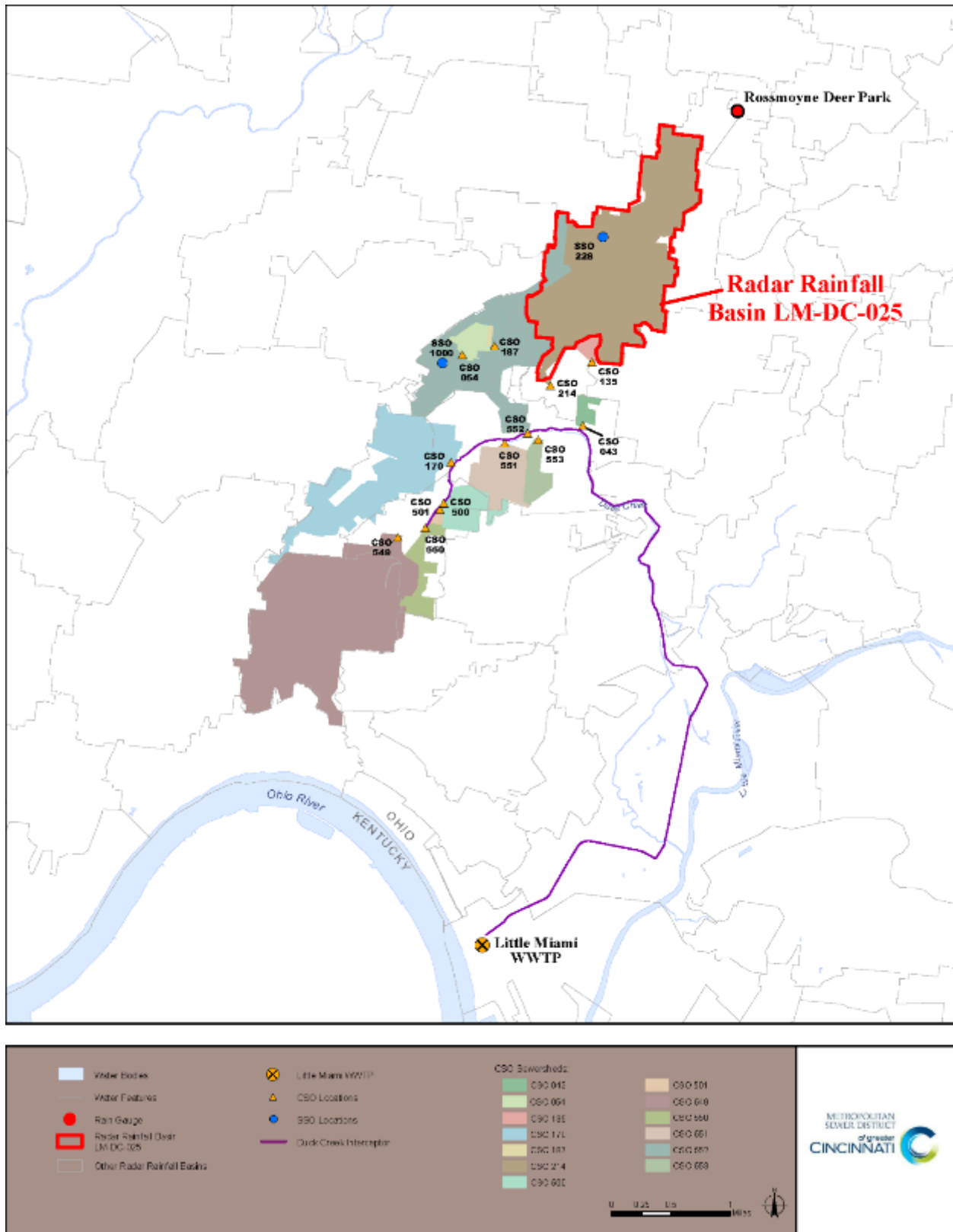
Table A1-2. Monthly Rainfall Comparison			
	Total Rainfall (in)		
Month	**1970**	**Flow monitor period (for applicable months)**	**Difference**
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
Total			

A1-2.2 Observed Flow Data

- Map showing the project flow monitor locations and tributary areas relative to the existing system. Refer to **Volume II Figure A1-3** and FlowFinity *Procedures_and_Forms* app Reference ID **#R-0320** as an example.
- Table containing each flow monitor with system type, tributary area, installation pipe size, and brief description. Refer to **Volume II Table A1-3** as an example.
- Schematic showing interconnection of flow monitors and key facilities. Refer to **Volume II Figure A1-4** as an example.
- Any additional information, plots, or figures that reveal suspect and/or outlier data.

Brief summary of any trends noticed among excluded events (i.e., storms of similar magnitude, seasonal, etc.)

Table A1-3. Overview of Flow Monitors used for Calibration				
	Tributary Metershed		**Installation**	
Flow Monitor	**Type**	**Acres**	**Pipe Size (in)**	**Location Description**

Figure A1-3. <Project Title> Flow Monitor Location Overview
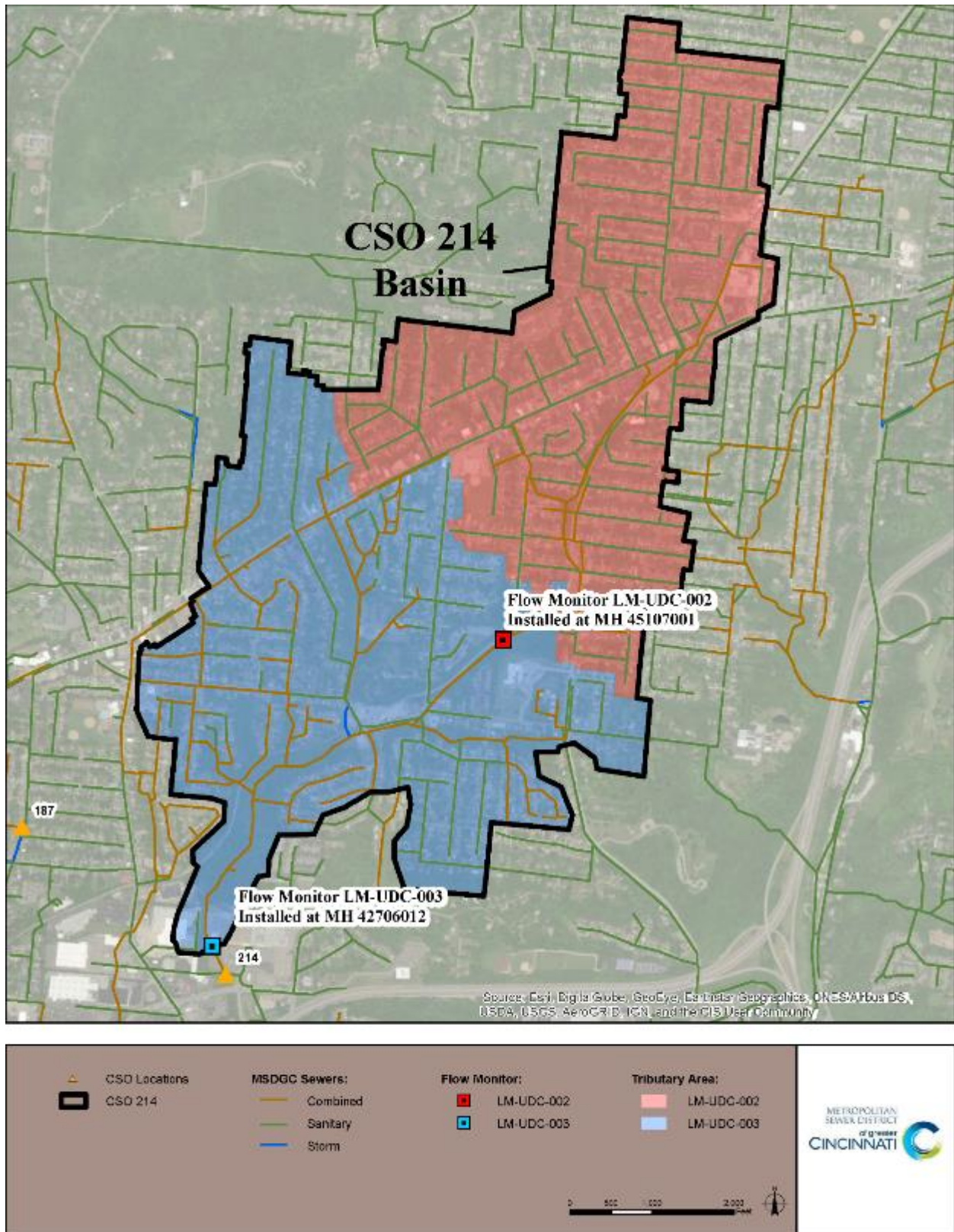
Figure A1-4. <Project Title> Flow Monitor Connection Schematic
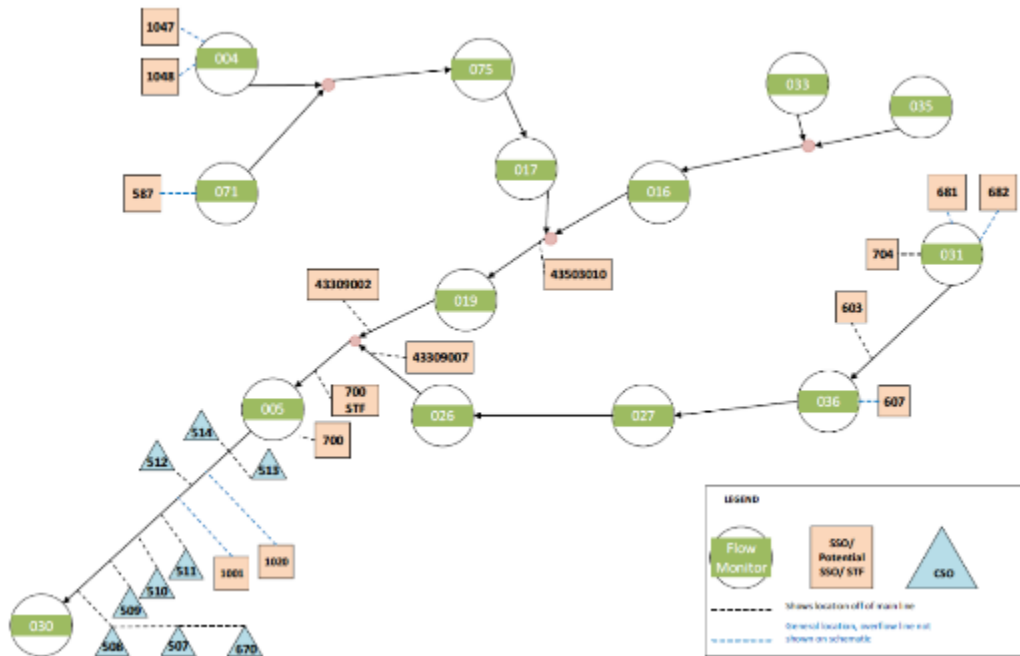
(Jacobs, 11140010 SSO 700 IWAP)

A1-3.0 MODEL SOURCE AND DATE RECEIVED

- Indicate the name of the MSDGC Modeling Group employee who provided the model and the date it was provided.
- Information on the model received:
  - Input filename
  - SWMM version
  - SWM Basin
- Communication from the MSDGC Modeling Group as to the last time the model was updated.

A1-4.0 MODEL UPDATES

A1-4.1 Calibration Inputs

- Summarize any inputs that were updated specifically for the purposes of providing explicit representation of any atypical conditions that were observed and/or existed during the calibration time period (**Volume II Section 6.1**), and which were later removed following the calibration process (**Volume II Section 8.0**).

A1-4.2 Hydrology

- General summary of changes in text.
- Map showing changes in flow rates for 2-month 24-hour Bulletin 71 Storm of 1.28 inches with SCS Type II distribution. Refer to **Volume II Figure A1-5** as an example. Note that **Volume II Figure A1-5** will have already been generated for the *7 – Model* app in FlowFinity.
- Explanation of the subcatchment delineation.
- Table providing a comparison of subcatchment hydrology parameters per flow monitor calibrated tributary area. Refer to **Volume II Table Table A1-4** as an example.
- Table providing an explanation of calibrated hydrology parameters which are outside the recommended range. Refer to **Volume II Table A1-5** for an example. Note that **Volume II Table A1-5** will have already been generated for the *7 – Model* app in FlowFinity.

Figure A1-5. Percent Change in Peak Flow for 2-month 24-hour Bulletin 71 Storm of 1.28 inches with SCS Type II distribution for <Project Title>
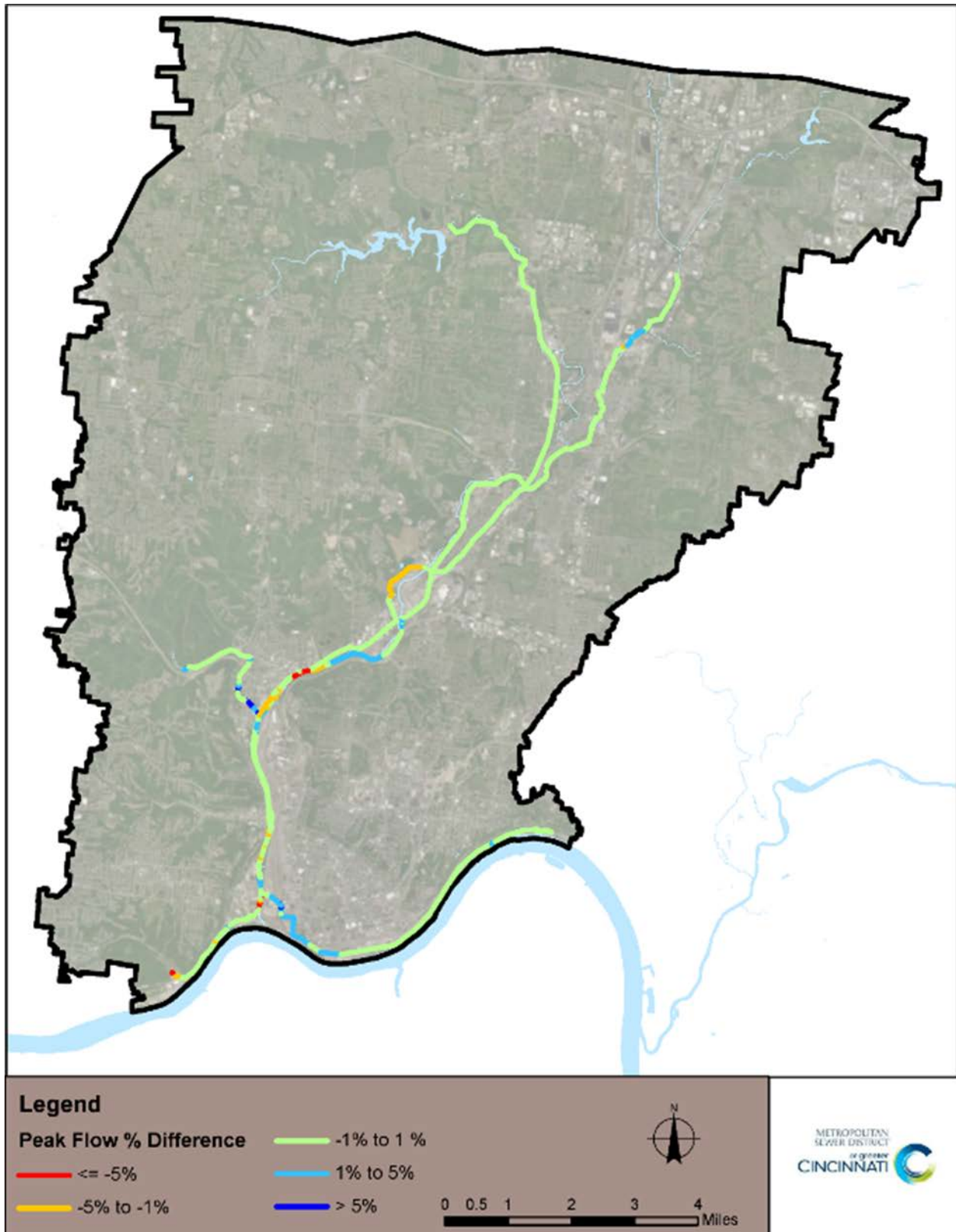
| Table A1-4. <Project Title> Calibrate Hydrology Parameters* | | | | | | | | | | | | | |
Monitor	Scenario	Total Area (acres)	Area-weighted Flow Length (ft)	Slope (%)	% DCIA	N Imperv	N Perv	Dstore Imperv (in)	Dstore Perv (in)	Area-weighted max infil rate (in/hr)	Area-weighted min infil rate (in/hr)	Area-weighted decay constant (1/day)	Drying Time (days)
<Flow Monitor Title>	Before												
	After												

*Parameters that vary should be area-weighted for an overall average comparison.

Table A1-5. Calibrated Hydrology Parameters Outside MSDGC Recommended Range				
Element ID	Parameter	Value	MSDGC Recommended Range	Comment

A1-4.3 Hydraulic

- Changes made to the model
- General summary of changes in text
- Table and schematic summarizing any changes made to CSO/SSO regulators. Refer to **Volume II Table A1-6** and **Volume II Figure A1-6** for examples.
- If applicable, map showing any significant updates to the tributary collection system. Refer to **Volume II Figure A1-6** for an example.
- Explanation of calibrated hydraulic parameters that are outside the recommended range, as listed in the *7 – Model* app in FlowFinity.

Figure A1-6. Significant Hydraulic Updates to <Project Title>
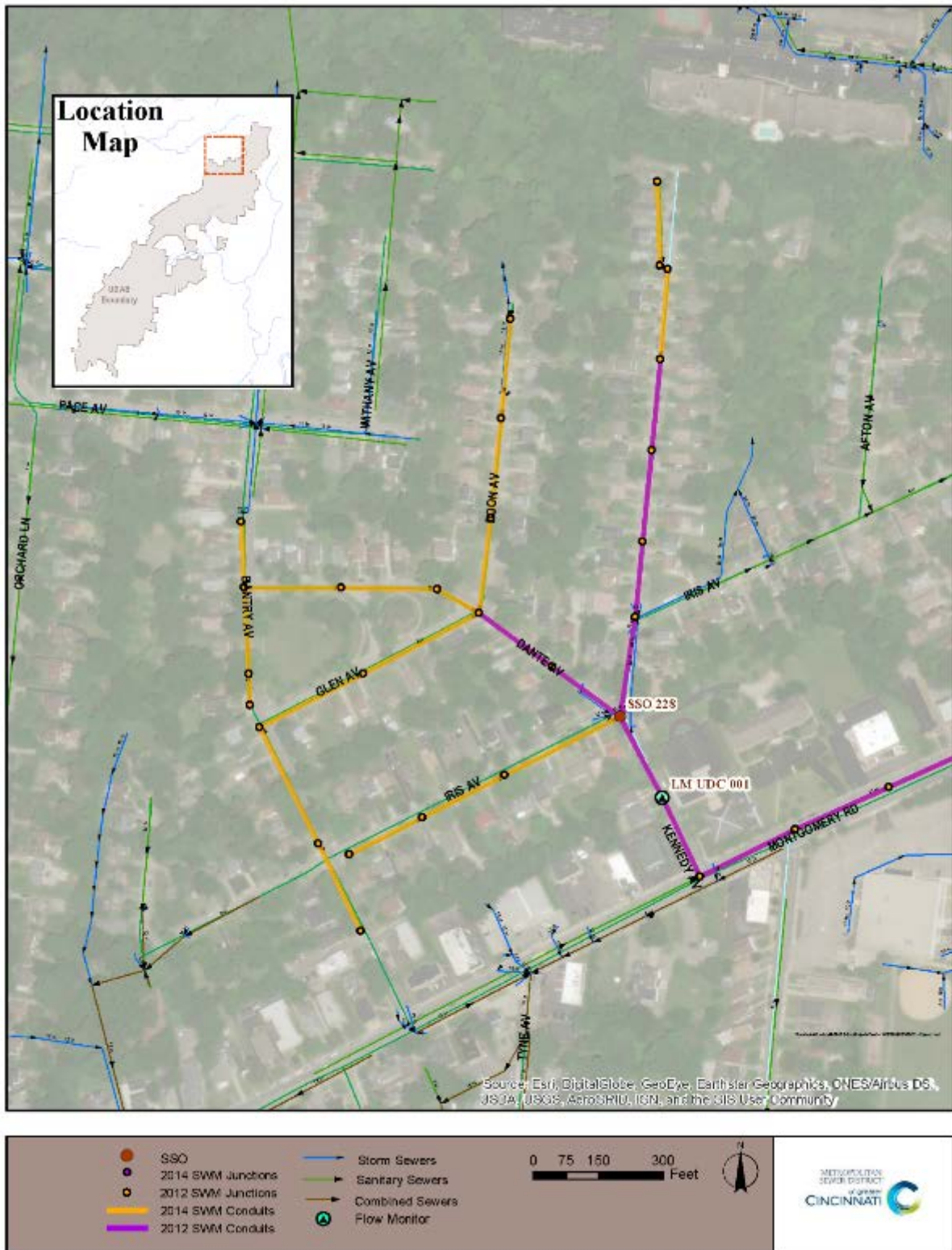
Table A1-6. CSO/SSO Regulator Discharge Coefficients Changes			
Model Element	MSDGC Acceptable Range	MSDGC Standard Value	Calibrated Value
Orifice			
Weir			

Figure A1-7. CSO/SSO Regulator Schematic
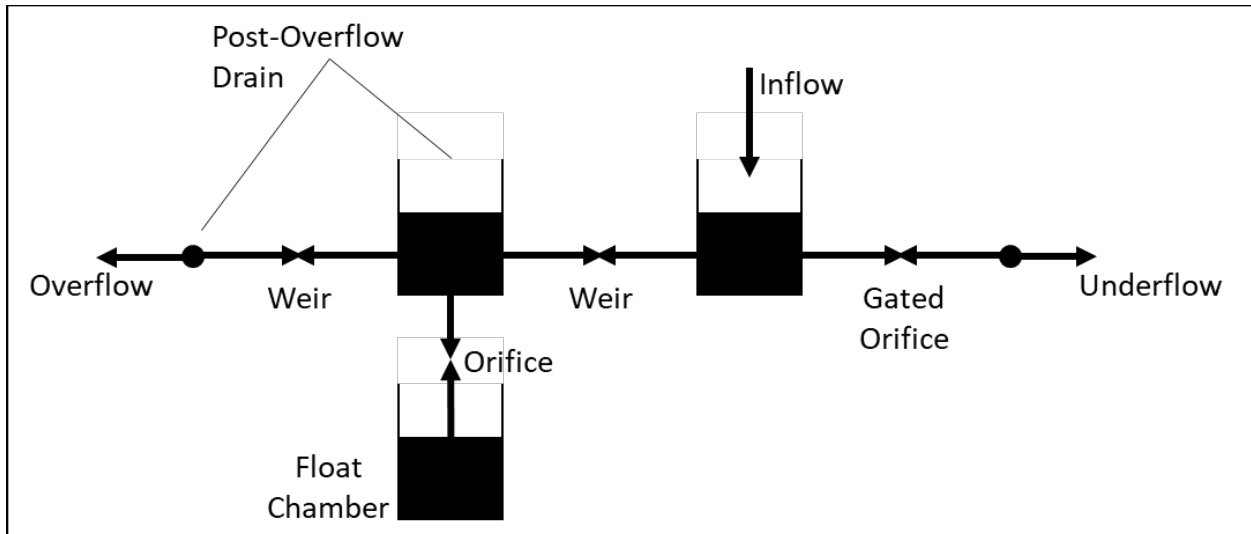
A1-5.0 CALIBRATION REQUIREMENTS

- Include a description of the calibration requirements at the time of the project. Refer to **Volume II Section 7.0** of the *Modeling Guidelines*.

*A1-*6.0 CALIBRATION RESULTS

*A1-*6.1 Base Flow Calibration

- Refer to **Volume II Section 6.3** for guidance on base flow calibration.
- Briefly describe the base flow Calibration and refer to the proper FlowFinity tab for DWF screenshots.

*A1-*6.2 Wet Weather Flow Calibration

- Refer to **Volume II Section 6.0** for guidance on calibration.
- Refer to **Volume II Section 7.0** for guidance on calibration compliance.
- Note that most, if not all, of the tables in this section will have been generated as part of the *6 – Calibration* app of FlowFinity.

Table A1-7. Concordance Correlation Coefficient Summary Table

Flow Monitor	Conveyance			Overflow/Storage			Treatment			Qcritical	Notes	6 - Calibration Record ID	7 - Model Record ID
	Critical Months	Non-Critical Months	All Months	Critical Months	Non-Critical Months	All Months	Critical Months	Non-Critical Months	All Months				
1	0.85	0.82	0.94	0.95	0.93	0.87	0.96	0.82	0.88	6%		00315461	Opt000431346
2	0.95	0.89	0.82	0.87	0.93	0.92	0.83	0.82	0.88	2%		00731541	Opt000431373
3	0.87	0.96	0.83	0.82	0.9	0.88	0.91	0.94	0.86	5%		00732137	Opt000431383
4	0.94	0.9	0.94	0.82	0.91	0.93	0.96	0.88	0.97	-10%		00135713	Opt000431641

Table A1-8. Overall Average for All Flow Meters

Months	Conveyance	Overflow/ Storage	Treatment	Overall Avg
Critical	0.92	0.94	0.94	0.93
Non-Critical	0.94	0.96	0.94	0.95
All	0.93	0.95	0.94	0.94*

*average all zones *and* months

A1-6.3 Overflow Activation Calibration

- Overflow activation comparison table. Refer to **Volume II Table A1-9** for an example.
- List the following statistics about Overflow Activations as outlined in **Volume II Section 7.4.**

Table A1-9. Overflow Activation Comparison for <CSO/SSO>							
Regulator	Days with Reported Activations	Days with Modeled Activations	Days with Reported and Modeled Activations	Days with Modeled Activations and Site Unavailable	Days with Reported Activations but without Modeled Activations	Days with Modeled Activations but without Reported Activations	Days without Reported and Modeled Activations	Days without Reliable Monitoring Data
CSO-XX1								
CSO-XX2								
CSO-XX3								
CSO-XX4								

A1-7.0 CONCLUSIONS

- Indication that the model was calibrated within MSDGC's Modeling Guidelines. If there were deviations from it indicate that and document that permission to deviate was given by the MSDGC Modeling Group.
- Issues/concerns (if any) about the data used and/or the results.
- State if the model is good enough for its intended purpose. Provide recommendations (if any) for further work (e.g., more flow monitoring).

Appendix *A1*-A
FlowFinity Records

A1-A FLOWFINITY RECORDS

- Provide a table detailing the location of any tables, figures, or files within FlowFinity and its associated apps. A sample of this table can be found in **Table A1-10**. The following information should be included:
  - A summary of Site Maintenance Logs
  - Relevant Base flow Calibration screenshots
  - Events Summary
  - Concordance Correlation Coefficients charts per event
  - Velocity vs Depth Scatterplot
  - DWF Hydrographs
  - Storm event Hydrographs
  - Mass Balance Tables
  - The full list of Model Changes
  - RTK Graphs
  - Audit Results Table
  - Parameter Results Table
- Provide a table detailing the record ID of each Flow Monitor within each of the FlowFinity apps. A sample of this table can be found in **Table A1-11.**

Table A1-10: Information Locations within FlowFInity		
Information	**FlowFinity App**	**Field Name**
Lin Scores - Conveyance	6 - Calibration	Lin-Conv
Velocity v Depth Scatterplot	6 - Calibration	Scatterplot
Mass Balance Table	7 - Model	Mass Balance Table

Table A1-11: Flow Monitor FlowFinity Record IDs		
Flow Monitor	**FlowFinity App**	**Record ID**
MC-MT-029	4 - Event File	Opt000568516
MC-BR-002	6 - Calibration	000453627
MC-BR-003	6 - Calibration	000454152

Appendix *A1*-B
Model RTK Changes

Table A1-12. RTK Changes Log																					
		Short-Term						Medium-Term						Long-Term							
Time Period	Name	R	T	K	Initial abstraction (in)	Drying Time (in/day)	Starting Depth (in)	R	T	K	Initial abstraction (in)	Drying Time (in/day)	Starting Depth (in)	R	T	K	Initial abstraction (in)	Drying Time (in/day)	Starting Depth (in)		
All Months	CSO-015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
April - July	CSO-015	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

TEMPLATES

A2 – STORM ANALYSIS TASK MEMO TEMPLATE

STORM ANALYSIS MODELING REPORT

<PROJECT NAME>

<BASIN NAME>

<SEWERSHED NAME>

CIP # < >
<TASK ORDER/MSA/PSA #>

PREPARED FOR:

METROPOLITAN SEWER DISTRICT OF

GREATER CINCINNATI

1600 GEST STREET

CINCINNATI, OH 45204

PREPARED BY:

<COMPANY NAME, ADDRESS, PHONE, AND POINT OF CONTACT>

<DATE>

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LIST OF TABLES

EXECUTIVE SUMMARY

The following information should be presented in this section:

- Brief project description
- MSDGC point-of-contact
- State that the MSDGC Guidelines were followed and when deviations occurred (if applicable) permission was given to deviate by the MSDGC Modeling Group

This section should not exceed one page.

NOTE: as the purpose and nature of alternative analyses can vary greatly between different types of projects, the template provided herein is only one specific example for consultants to be viewed as a general guide. It is understood that the alternatives reporting requirements will also vary with each project, and therefore, explicitly following this template's format may not be required. Modelers should confirm with the project's MSDGC Project Manager what alternatives analysis reporting is required.

A2-1.0 INTRODUCTION & BACKGROUND

The following information should be presented in this section:

- Project description
- Location within MSDGC service area
- Map showing the project area with identification of key locations and facilities. Refer to **Volume II Figure A2-1** as an example.
- Purpose of the project
- WWIP requirements (if applicable)
- Relevant history of the project and model development

Figure A2-1. Project Area Overview Example Figure
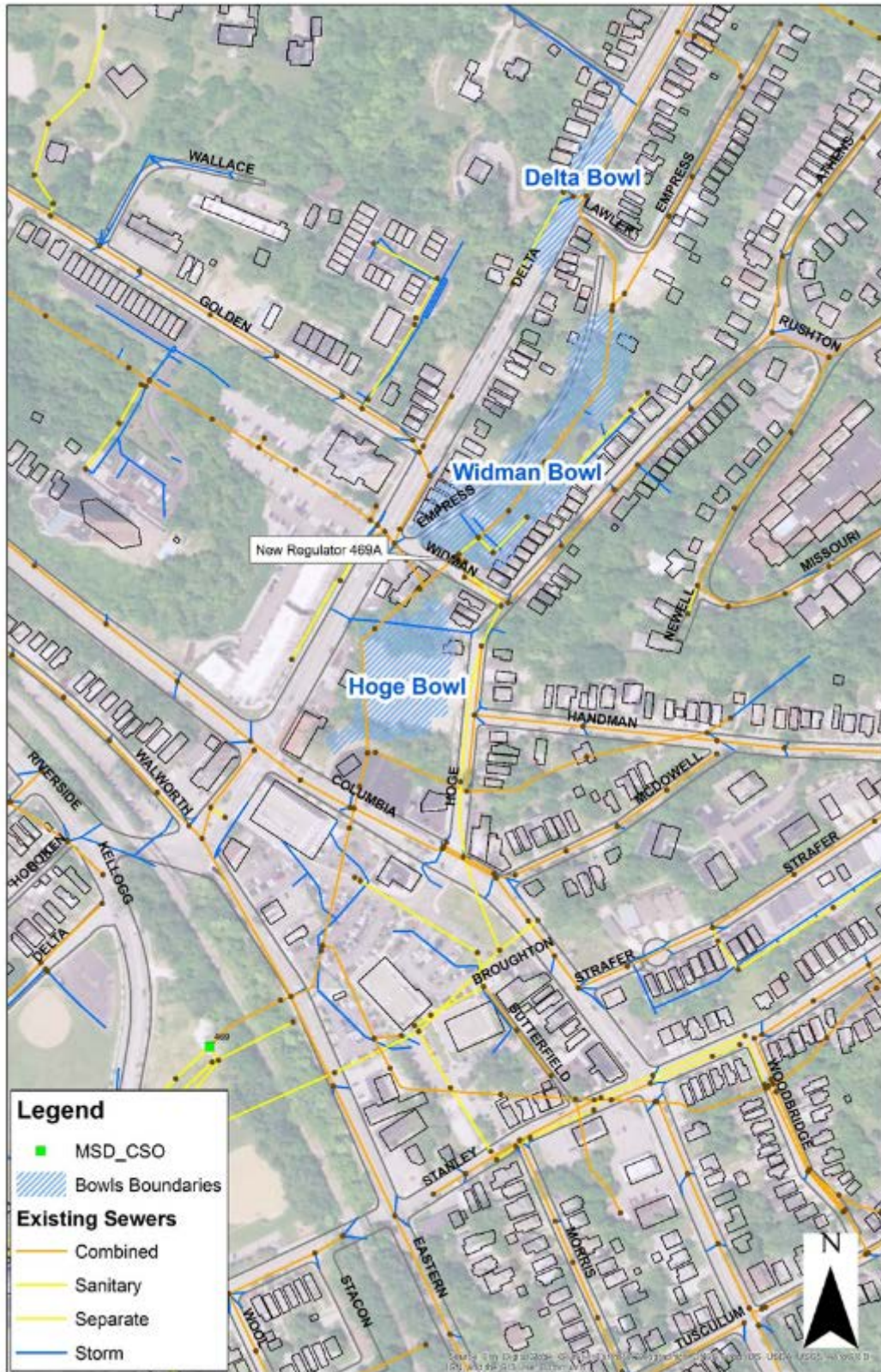
*A2-*2.0 DATA REVIEW

Summary of available information and data that were reviewed to examine the storm. Include any visuals or figures that illustrates relevant impacts from the storm. Refer to **Volume II Figure A2-2** as an example.

Figure A2-2. Example Storm Impacts Overview Figure

A2-3.0 MODEL UPDATES

This section should include information pertaining to any hydrology and/or hydraulic updates made to the model. Figures should be provided when possible. Refer to **Volume II Figure A2-3** and **Volume II Figure A2-4** as examples.

Figure A2-3. Example of Hydrology Updates Figure
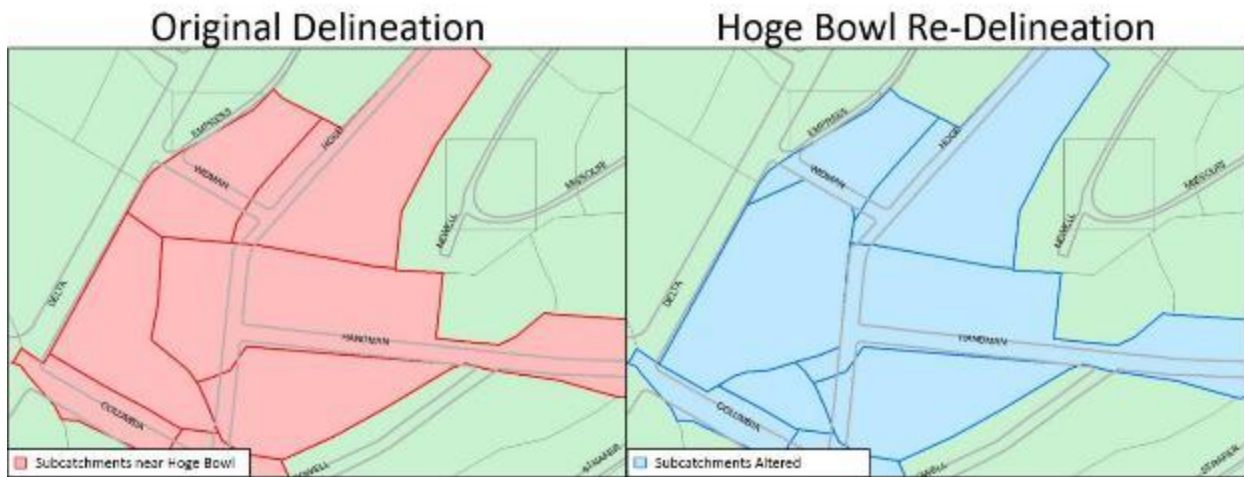
Figure A2-4. Example of Hydraulic Updates Figure
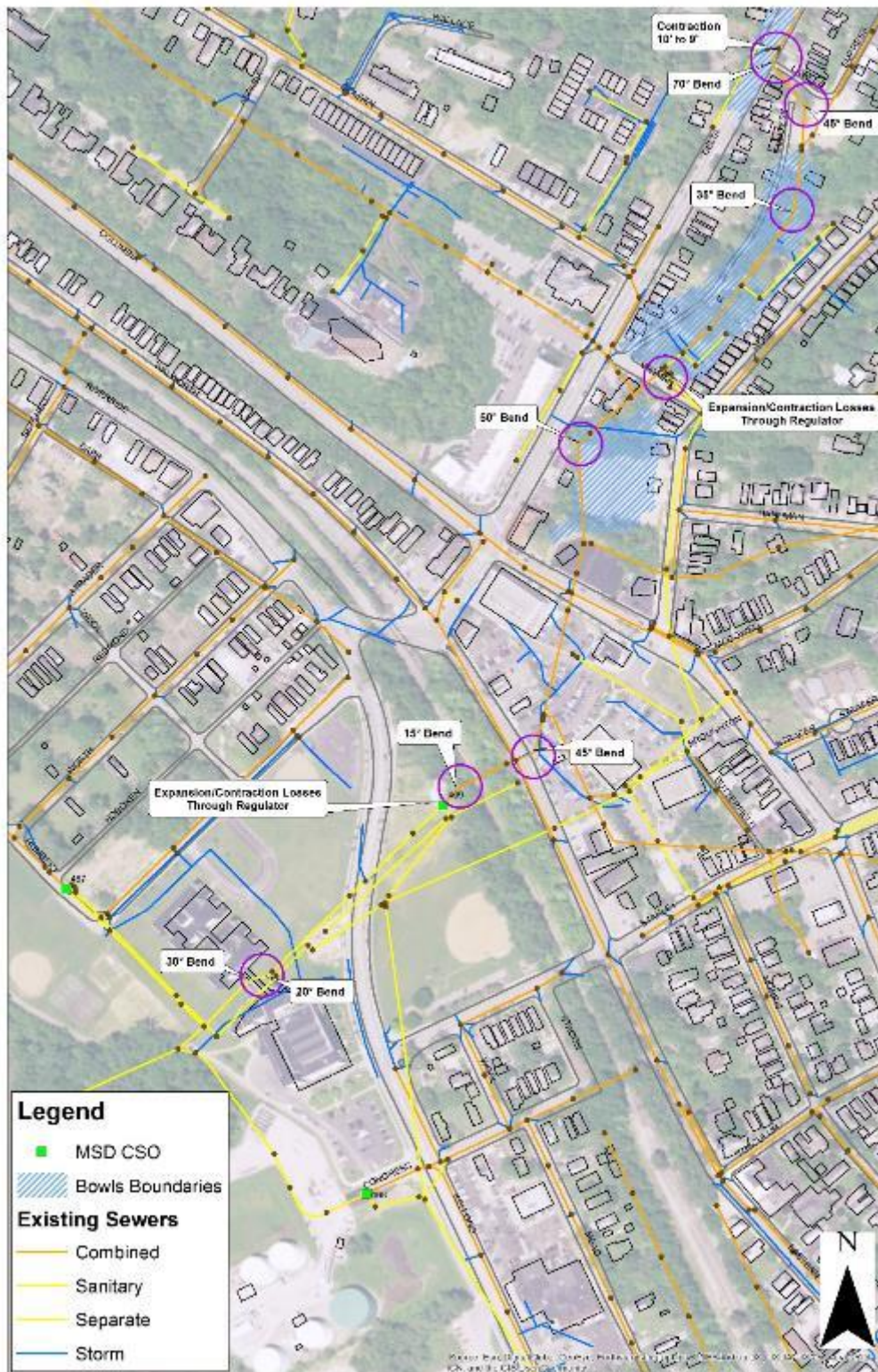
Table A2-1. Example of Hydraulic Updates Summary Table

Loss Type	Modeled Conduit	Entry Loss Coef.	Exist Loss Coef.	Avg. Loss Coef.
Contraction from 10' to 9' diameter	40913029-40912040	0.095		
70° Bend				0.25
45° Bend				0.16
35° Bend	40912024-40912055			0.11
CSO 469A Structure	40912079-40912078		0.308	
	40912078-40912078A	0.296		
50° Bend	40912010-40905041	0.19		
45° Bend	40905064-40905005			0.16
15° Bend	40905004-40906041C			0.03
CSO 469 Structure*	40905105-40906041	0.32		
20° Bend	40903020-40903026	0.05		
30° Bend		0.09		

Note: *CSO 469 structure included twin orifices to represent backwater gates. The orifice coefficients were adjusted as part of the minor loss equivalency.

*A2-*4.0 STORM ANALYSIS

This section should include discussion and proof that the model provides adequate replication of the impacts observed during the storm event. Figures should be provided when possible. Refer to **Volume II Figure A2-5** as an example.

Figure A2-5. Example Model versus Observed Storm Impacts Figure

A2-5.0 CONCLUSIONS

- Indication that the model was updated per MSDGC's preferred practices as outlined in the Modeling Guidelines. If there were deviations from it indicate that and document that permission to deviate was given by the MSDGC Modeling Group.
- Issues/concerns (if any) about the data used and/or the results.
- State if the model is good enough for its intended purpose. Provide recommendations (if any) for further work.

TEMPLATES

A3 – ALTERNATIVES REPORT TEMPLATE

ALTERNATIVES MODELING REPORT

<PROJECT NAME>

<BASIN NAME>

<SEWERSHED NAME>

CIP # < >
<TASK ORDER/MSA/PSA #>

PREPARED FOR:

METROPOLITAN SEWER DISTRICT OF

GREATER CINCINNATI

1600 GEST STREET

CINCINNATI, OH 45204

PREPARED BY:

<COMPANY NAME, ADDRESS, PHONE, AND POINT OF CONTACT>

<DATE>

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TABLE OF CONTENTS

LIST OF EXHIBITS

LIST OF TABLES

EXECUTIVE SUMMARY

The following information should be presented in this section:
- Brief project description
- MSDGC point-of-contact
- State that the MSDGC Guidelines were followed and when deviations occurred (if applicable) permission was given to deviate by the MSDGC Modeling Group

This section should not exceed one page.

NOTE: as the purpose and nature of alternative analyses can vary greatly between different types of projects, the template provided herein is only one specific example for consultants to be viewed as a general guide. It is understood that the alternatives reporting requirements will also vary with each project, and therefore, explicitly following this template's format may not be required. Modelers should confirm with the project's MSDGC Project Manager what alternatives analysis reporting is required.

A3-1.0 INTRODUCTION & BACKGROUND

The following information should be presented in this section:

- Project description
- Location within MSDGC service area
- Map showing the project area with identification of key locations and facilities. Refer to **Volume II Figure A3-1** and FlowFinity *Procedures_and_Forms* app Reference ID **#R-0340** as an example.
- Purpose of the project
- WWIP requirements (if applicable)
- Relevant history of the project and model development

Figure A3-1. <project title> Area Overview
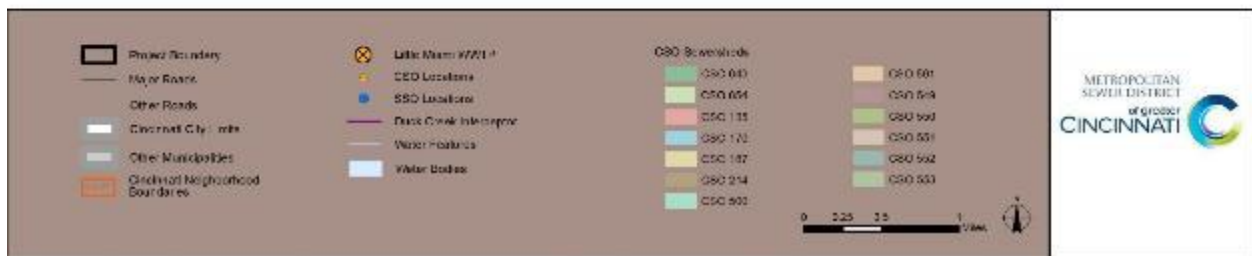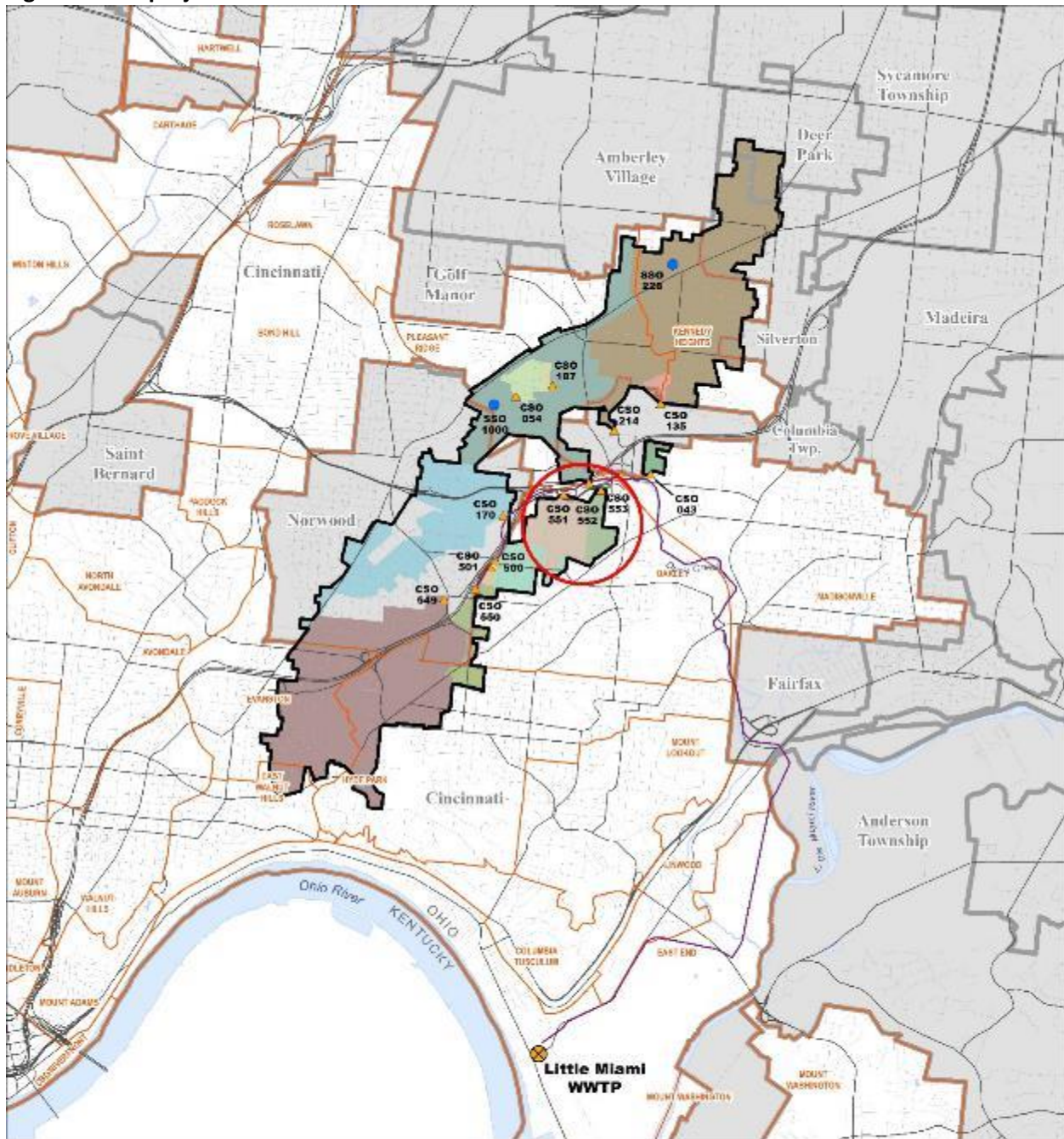
A3-2.0 ALTERNATIVE MODEL CONSIDERATIONS

The following information should be presented in this section:

- Model condition(s) chosen for alternatives modeling and the reasoning.
- Other projects included within the alternatives model (if applicable)
- Project model boundaries
- Project model simulation information
  - Storm events
  - Season

A3-3.0 SYSTEM ANALYSIS

The following information should be presented in this section:

- Table of alternatives including description and key information. Refer to **Table A3-1** as an example.
- Figure illustrating the alternatives. Refer to **Volume II Figure B3-2** as an example.
- Description of modeling methodology unique to the alternative process
- Impact of alternatives toward the project goal
- Impact of alternatives on areas outside of the project area (HGLs, peak flows, etc.)
- WWIP performance (if applicable). Refer to **Table A3-2** and FlowFinity *Procedures_and_Forms* Reference ID **#R-0341** for a comparison table template.

Table A3-1. Alternatives Table 1

Scenario Description	Separation Area	CSO 551 TY Overflow (MG)	Incremental Overflow Reduction per TY (MG)
Pre Oakley Station Development (w/ regulator)	None	61	-
Existing Conditions (w/ regulator)	Oakley Station	20.0	41.0
Existing Conditions (w/o regulator)	Oakley Station	16.9	3.1
Existing Conditions (w/o regulator) + Separation	Oakley Station + A	16.4	0.5
Existing Conditions (w/o regulator) + Separation	Oakley Station + A + B	15.2	1.1
Existing Conditions (w/o regulator) + Separation	Oakley Station + A + B + C	14.3	1.0
Existing Conditions (w/o regulator) + Separation	Oakley Station + A + B + C + D	12.8	1.5

Table A3-2. WWIP CSO ROV Comparison 1

CSO ID	Month Year _____ Conditions Model		_____ Conditions Project Model		Targeted Level of Control Per Consent Decree
	Volume (MG)	# of Overflows	Volume (MG)	# of Overflows	
Total Overflow (MG)					

Figure A3-2. Alternatives Map
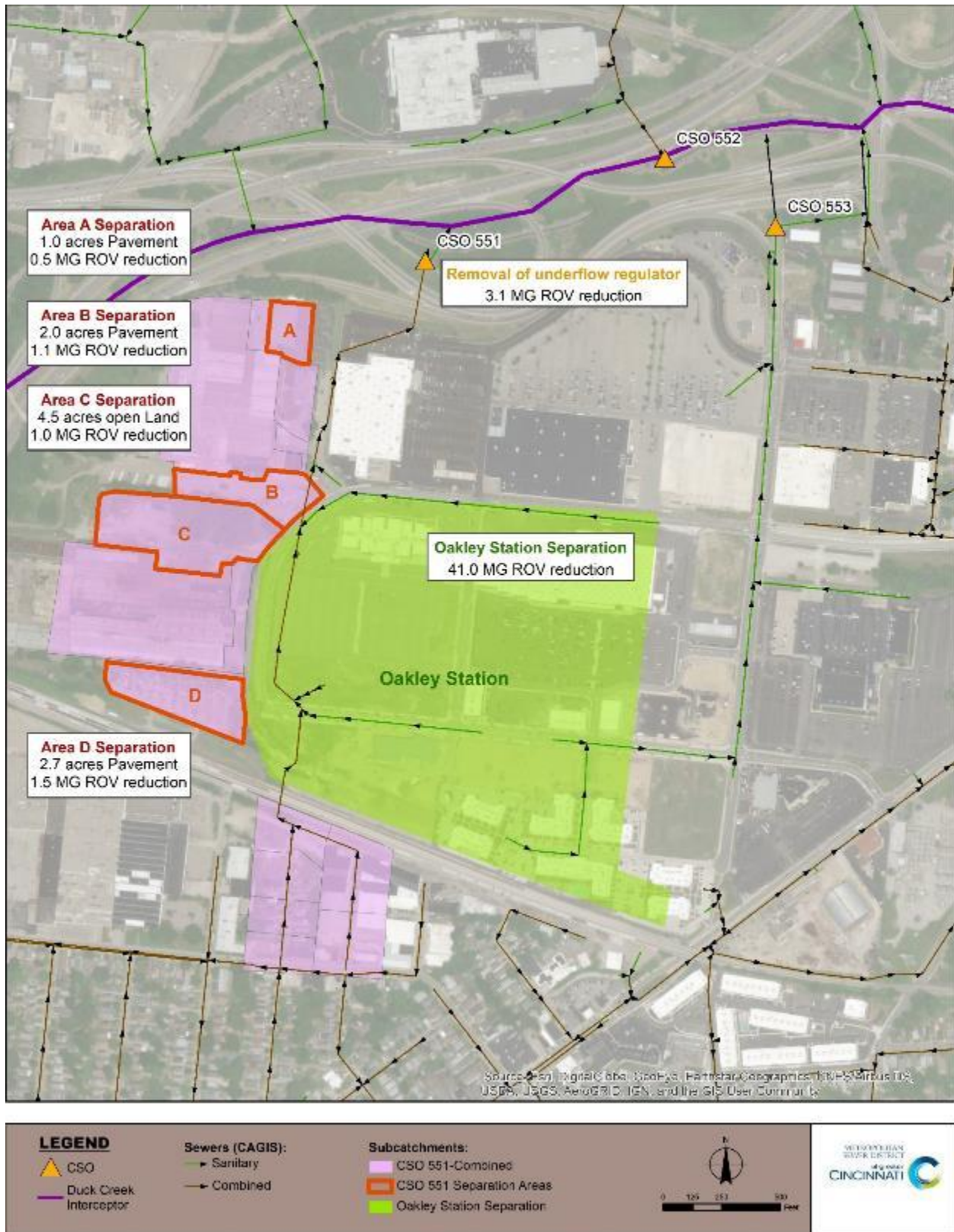
A3-4.0 FINDINGS & RECOMMENDATIONS

The following information should be presented in this section:

- Description of the preferred alternative and the reason it was selected.
    - Any recommendations on related future work or additional improvements

APPENDIX B. DESIGN STORM AND TYPICAL YEAR TIME SERIES

Figure B1-1: Bulletin 71 Design Storms

Table 8. Continued

Rainfall (inches) for given recurrence interval

Section	Duration	2-month	3-month	4-month	6-month	9-month	1-year	2-year	5-year	10-year	25-year	50-year	100-year
07	10-day	1.71	2.06	2.37	2.79	3.21	3.49	4.33	5.37	6.10	7.03	7.77	8.48
07	5-day	1.40	1.67	1.89	2.19	2.52	2.74	3.32	4.11	4.72	5.55	6.26	6.99
07	72-hr	1.28	1.51	1.70	1.98	2.27	2.47	2.98	3.64	4.15	4.94	5.63	6.39
07	48-hr	1.19	1.39	1.55	1.79	2.06	2.24	2.73	3.33	3.81	4.53	5.15	5.81
07	24-hr	1.12	1.30	1.42	1.64	1.87	2.03	2.50	3.02	3.42	3.94	4.41	4.92
07	18-hr	1.05	1.22	1.34	1.55	1.76	1.91	2.35	2.84	3.21	3.70	4.15	4.62
07	12-hr	0.97	1.13	1.24	1.43	1.63	1.77	2.17	2.63	2.98	3.43	3.84	4.28
07	6-hr	0.84	0.97	1.06	1.23	1.40	1.52	1.88	2.26	2.57	2.95	3.31	3.69
07	3-hr	0.71	0.83	0.91	1.05	1.20	1.30	1.60	1.93	2.19	2.52	2.82	3.15
07	2-hr	0.65	0.76	0.83	0.96	1.09	1.18	1.45	1.75	1.98	2.29	2.56	2.85
07	1-hr	0.52	0.61	0.66	0.77	0.87	0.95	1.17	1.42	1.61	1.85	2.07	2.31
07	30-min	0.41	0.48	0.52	0.61	0.69	0.75	0.93	1.12	1.27	1.46	1.63	1.82
07	15-min	0.30	0.35	0.38	0.45	0.51	0.55	0.68	0.82	0.92	1.06	1.19	1.33
07	10-min	0.24	0.28	0.30	0.35	0.40	0.43	0.52	0.63	0.72	0.83	0.93	1.03
07	5-min	0.13	0.15	0.17	0.19	0.22	0.24	0.30	0.36	0.41	0.47	0.53	0.59
08	10-day	1.96	2.35	2.71	3.19	3.67	3.99	4.97	6.15	7.02	8.09	8.89	9.71
08	5-day	1.59	1.90	2.15	2.49	2.86	3.11	3.92	4.94	5.66	6.58	7.32	8.05
08	72-hr	1.45	1.70	1.92	2.22	2.56	2.78	3.43	4.22	4.83	5.70	6.47	7.29
08	48-hr	1.35	1.58	1.76	2.04	2.35	2.55	3.15	3.87	4.44	5.26	5.98	6.77
08	24-hr	1.28	1.49	1.63	1.89	2.14	2.33	2.86	3.49	3.99	4.70	5.32	6.04
08	18-hr	1.20	1.40	1.53	1.77	2.01	2.19	2.69	3.28	3.75	4.42	5.00	5.68

Source: (Huff, F.A. & Angel, J.R., 1992)

Table B1-1: 24-hour design storms					Source: MSDGC
Time	1-Year	2-year	5-year	10-year	25-year	100-year
0:00	0.001866	0.00229	0.002795	0.00321	0.0037635	0.00483647
0:05	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:10	0.001866	0.00229	0.002795	0.00321	0.0037635	0.00483647
0:15	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:20	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:25	0.001866	0.00229	0.002795	0.00321	0.0037635	0.00483647
0:30	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:35	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:40	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:45	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:50	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
0:55	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:00	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:05	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:10	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:15	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:20	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:25	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:30	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:35	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:40	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
1:45	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:50	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
1:55	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:00	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:05	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:10	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:15	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
2:20	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:25	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182

Time	1-Year	2-year	5-year	10-year	25-year	100-year
Table B1-1: 24-hour design storms						Source: MSDGC
2:30	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
2:35	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:40	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
2:45	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
2:50	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
2:55	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:00	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:05	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:10	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:15	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:20	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:25	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:30	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
3:35	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:40	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:45	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
3:50	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
3:55	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:00	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:05	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:10	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:15	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:20	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:25	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
4:30	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
4:35	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
4:40	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
4:45	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
4:50	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
4:55	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985

Time	1-Year	2-year	5-year	10-year	25-year	100-year
Table B1-1: 24-hour design storms						Source: MSDGC
5:00	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
5:05	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:10	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:15	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
5:20	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:25	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:30	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
5:35	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:40	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
5:45	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
5:50	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
5:55	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
6:00	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
6:05	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
6:10	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:15	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
6:20	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:25	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
6:30	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:35	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
6:40	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:45	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:50	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
6:55	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:00	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:05	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:10	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:15	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:20	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:25	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829

Table B1-1: 24-hour design storms					Source: MSDGC
Time	1-Year	2-year	5-year	10-year	25-year	100-year
7:30	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
7:35	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
7:40	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
7:45	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
7:50	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
7:55	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
8:00	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
8:05	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
8:10	0.004661	0.005722	0.006982	0.00802	0.0094028	0.01208365
8:15	0.004894	0.006007	0.00733	0.00842	0.0098718	0.01268632
8:20	0.004894	0.006007	0.00733	0.00842	0.0098718	0.01268632
8:25	0.005126	0.006292	0.007679	0.00882	0.0103408	0.013289
8:30	0.005359	0.006578	0.008027	0.00922	0.0108097	0.01389167
8:35	0.005591	0.006863	0.008375	0.00962	0.0112787	0.01449435
8:40	0.005591	0.006863	0.008375	0.00962	0.0112787	0.01449435
8:45	0.005812	0.007134	0.008706	0.01	0.0117242	0.01506689
8:50	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
8:55	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
9:00	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
9:05	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
9:10	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
9:15	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
9:20	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
9:25	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
9:30	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
9:35	0.006742	0.008276	0.010099	0.0116	0.0136001	0.01747759
9:40	0.006742	0.008276	0.010099	0.0116	0.0136001	0.01747759
9:45	0.007207	0.008847	0.010795	0.0124	0.0145381	0.01868294
9:50	0.007207	0.008847	0.010795	0.0124	0.0145381	0.01868294
9:55	0.007672	0.009417	0.011492	0.0132	0.015476	0.0198883

Table B1-1: 24-hour design storms					Source: MSDGC
Time	1-Year	2-year	5-year	10-year	25-year	100-year
10:00	0.007905	0.009703	0.01184	0.0136	0.015945	0.02049097
10:05	0.00837	0.010273	0.012536	0.0144	0.0168829	0.02169632
10:10	0.008835	0.010844	0.013233	0.0152	0.0178208	0.02290167
10:15	0.009067	0.01113	0.013581	0.0156	0.0182898	0.02350435
10:20	0.009532	0.0117	0.014278	0.0164	0.0192277	0.0247097
10:25	0.009765	0.011986	0.014626	0.0168	0.0196967	0.02531238
10:30	0.010462	0.012842	0.015671	0.018	0.0211036	0.0271204
10:35	0.011159	0.013698	0.016715	0.0192	0.0225105	0.02892843
10:40	0.011624	0.014269	0.017412	0.02	0.0234485	0.03013378
10:45	0.01238	0.015196	0.018544	0.0213	0.0249726	0.03209248
10:50	0.013078	0.016052	0.019588	0.0225	0.0263795	0.0339005
10:55	0.013542	0.016623	0.020285	0.0233	0.0273175	0.03510585
11:00	0.014937	0.018335	0.022374	0.0257	0.0301313	0.03872191
11:05	0.016332	0.020047	0.024463	0.0281	0.0329451	0.04233796
11:10	0.01796	0.022045	0.026901	0.0309	0.0362279	0.04655669
11:15	0.019355	0.023757	0.028991	0.0333	0.0390417	0.05017275
11:20	0.020982	0.025755	0.031428	0.0361	0.0423245	0.05439147
11:25	0.022377	0.027467	0.033518	0.0385	0.0451383	0.05800753
11:30	0.046382	0.056932	0.069473	0.0798	0.0935594	0.12023379
11:35	0.083115	0.102021	0.124494	0.143	0.1676566	0.21545653
11:40	0.126125	0.154815	0.188917	0.217	0.2544159	0.32695152
11:45	0.195291	0.239713	0.292517	0.336	0.3939343	0.50624752
11:50	0.249926	0.306776	0.374352	0.43	0.5041421	0.64787629
11:55	0.184829	0.226871	0.276847	0.318	0.3728307	0.47912712
12:00	0.03685	0.045232	0.055195	0.0634	0.0743317	0.09552409
12:05	0.033304	0.04088	0.049885	0.0573	0.0671799	0.08633328
12:10	0.029584	0.036314	0.044313	0.0509	0.0596764	0.07669047
12:15	0.026329	0.032318	0.039438	0.0453	0.0531108	0.06825301
12:20	0.02261	0.027753	0.033866	0.0389	0.0456073	0.0586102
12:25	0.019122	0.023472	0.028642	0.0329	0.0385727	0.04957007

Table B1-1: 24-hour design storms					Source: MSDGC
Time	1-Year	2-year	5-year	10-year	25-year	100-year
12:30	0.016332	0.020047	0.024463	0.0281	0.0329451	0.04233796
12:35	0.015635	0.019191	0.023419	0.0269	0.0315382	0.04052994
12:40	0.014937	0.018335	0.022374	0.0257	0.0301313	0.03872191
12:45	0.013775	0.016908	0.020633	0.0237	0.0277864	0.03570853
12:50	0.01331	0.016338	0.019936	0.0229	0.0268485	0.03450318
12:55	0.01238	0.015196	0.018544	0.0213	0.0249726	0.03209248
13:00	0.011624	0.014269	0.017412	0.02	0.0234485	0.03013378
13:05	0.011159	0.013698	0.016715	0.0192	0.0225105	0.02892843
13:10	0.010462	0.012842	0.015671	0.018	0.0211036	0.0271204
13:15	0.010462	0.012842	0.015671	0.018	0.0211036	0.0271204
13:20	0.009765	0.011986	0.014626	0.0168	0.0196967	0.02531238
13:25	0.0093	0.011415	0.013929	0.016	0.0187588	0.02410702
13:30	0.008835	0.010844	0.013233	0.0152	0.0178208	0.02290167
13:35	0.008602	0.010559	0.012885	0.0148	0.0173519	0.022299
13:40	0.00837	0.010273	0.012536	0.0144	0.0168829	0.02169632
13:45	0.007905	0.009703	0.01184	0.0136	0.015945	0.02049097
13:50	0.007672	0.009417	0.011492	0.0132	0.015476	0.0198883
13:55	0.00744	0.009132	0.011144	0.0128	0.015007	0.01928562
14:00	0.007207	0.008847	0.010795	0.0124	0.0145381	0.01868294
14:05	0.006975	0.008561	0.010447	0.012	0.0140691	0.01808027
14:10	0.006742	0.008276	0.010099	0.0116	0.0136001	0.01747759
14:15	0.006742	0.008276	0.010099	0.0116	0.0136001	0.01747759
14:20	0.006742	0.008276	0.010099	0.0116	0.0136001	0.01747759
14:25	0.00651	0.00799	0.009751	0.0112	0.0131311	0.01687492
14:30	0.00651	0.00799	0.009751	0.0112	0.0131311	0.01687492
14:35	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
14:40	0.006277	0.007705	0.009402	0.0108	0.0126622	0.01627224
14:45	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
14:50	0.006045	0.00742	0.009054	0.0104	0.0121932	0.01566957
14:55	0.005812	0.007134	0.008706	0.01	0.0117242	0.01506689

Time	1-Year	2-year	5-year	10-year	25-year	100-year
Table B1-1: 24-hour design storms						Source: MSDGC
15:00	0.005812	0.007134	0.008706	0.01	0.0117242	0.01506689
15:05	0.005591	0.006863	0.008375	0.00962	0.0112787	0.01449435
15:10	0.005591	0.006863	0.008375	0.00962	0.0112787	0.01449435
15:15	0.005359	0.006578	0.008027	0.00922	0.0108097	0.01389167
15:20	0.005359	0.006578	0.008027	0.00922	0.0108097	0.01389167
15:25	0.005126	0.006292	0.007679	0.00882	0.0103408	0.013289
15:30	0.005126	0.006292	0.007679	0.00882	0.0103408	0.013289
15:35	0.004894	0.006007	0.00733	0.00842	0.0098718	0.01268632
15:40	0.004894	0.006007	0.00733	0.00842	0.0098718	0.01268632
15:45	0.004894	0.006007	0.00733	0.00842	0.0098718	0.01268632
15:50	0.004661	0.005722	0.006982	0.00802	0.0094028	0.01208365
15:55	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
16:00	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
16:05	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
16:10	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
16:15	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
16:20	0.004429	0.005436	0.006634	0.00762	0.0089339	0.01148097
16:25	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
16:30	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
16:35	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
16:40	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
16:45	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
16:50	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
16:55	0.004196	0.005151	0.006286	0.00722	0.0084649	0.01087829
17:00	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
17:05	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
17:10	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
17:15	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
17:20	0.003964	0.004866	0.005937	0.00682	0.0079959	0.01027562
17:25	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294

Table B1-1: 24-hour design storms					Source: MSDGC
Time	1-Year	2-year	5-year	10-year	25-year	100-year
17:30	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
17:35	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
17:40	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
17:45	0.003731	0.00458	0.005589	0.00642	0.007527	0.00967294
17:50	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
17:55	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
18:00	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
18:05	0.003493	0.004288	0.005232	0.00601	0.0070463	0.0090552
18:10	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:15	0.003499	0.004295	0.005241	0.00602	0.007058	0.00907027
18:20	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:25	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:30	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:35	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
18:40	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:45	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
18:50	0.003261	0.004002	0.004884	0.00561	0.0065773	0.00845253
18:55	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:00	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
19:05	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
19:10	0.003028	0.003717	0.004536	0.00521	0.0061083	0.00784985
19:15	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:20	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:25	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:30	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:35	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
19:40	0.002796	0.003432	0.004188	0.00481	0.0056394	0.00724717
19:45	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
19:50	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
19:55	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445

Time	1-Year	2-year	5-year	10-year	25-year	100-year
Table B1-1: 24-hour design storms						Source: MSDGC
20:00	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:05	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:10	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
20:15	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:20	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:25	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
20:30	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:35	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:40	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
20:45	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
20:50	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
20:55	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:00	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
21:05	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:10	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
21:15	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:20	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:25	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:30	0.002563	0.003146	0.003839	0.00441	0.0051704	0.0066445
21:35	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:40	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:45	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:50	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
21:55	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:00	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:05	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:10	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:15	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:20	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:25	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915

Table B1-1: 24-hour design storms					Source: MSDGC	
Time	1-Year	2-year	5-year	10-year	25-year	100-year
22:30	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:35	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:40	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:45	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
22:50	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
22:55	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:00	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
23:05	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
23:10	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:15	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
23:20	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:25	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:30	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
23:35	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:40	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:45	0.002331	0.002861	0.003491	0.00401	0.0047014	0.00604182
23:50	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915
23:55	0.002098	0.002575	0.003143	0.00361	0.0042324	0.00543915

Note: All null rainfall timestep values are omitted from this table. When copying this table into PCSWMM to create a rain file, zeroes will automatically be added for any null time periods.

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
1/1/1970	5:00	0.01
1/1/1970	6:00	0.02
1/1/1970	7:00	0.01
1/1/1970	8:00	0.01
1/1/1970	10:00	0.02
1/1/1970	11:00	0.01
1/1/1970	14:00	0.01
1/2/1970	6:00	0.01
1/2/1970	9:00	0.01
1/2/1970	10:00	0.01
1/2/1970	11:00	0.01
1/2/1970	12:00	0.01
1/2/1970	17:00	0.02
1/3/1970	5:00	0.01
1/3/1970	6:00	0.01
1/4/1970	5:00	0.01
1/9/1970	2:00	0.01
1/9/1970	7:00	0.01
1/11/1970	8:00	0.01
1/11/1970	9:00	0.03
1/11/1970	10:00	0.03
1/11/1970	11:00	0.04
1/11/1970	12:00	0.02
1/11/1970	13:00	0.01
1/11/1970	16:00	0.01
1/18/1970	4:00	0.02
1/18/1970	5:00	0.01
1/18/1970	6:00	0.01

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
1/20/1970	9:00	0.01
1/20/1970	10:00	0.01
1/20/1970	11:00	0.01
1/20/1970	12:00	0.01
1/23/1970	2:00	0.02
1/23/1970	3:00	0.01
1/23/1970	5:00	0.01
1/23/1970	6:00	0.02
1/23/1970	7:00	0.01
1/23/1970	10:00	0.01
1/29/1970	3:00	0.37
1/29/1970	4:00	0.28
1/29/1970	5:00	0.05
1/29/1970	6:00	0.05
2/1/1970	23:00	0.03
2/2/1970	0:00	0.12
2/2/1970	1:00	0.1
2/2/1970	2:00	0.02
2/2/1970	3:00	0.08
2/2/1970	4:00	0.03
2/2/1970	5:00	0.07
2/2/1970	6:00	0.06
2/2/1970	7:00	0.03
2/2/1970	8:00	0.02
2/2/1970	9:00	0.01
2/2/1970	10:00	0.01
2/2/1970	11:00	0.02
2/2/1970	12:00	0.04

Table B1-2: Typical Year Time Series	Source: MSDGC	
Date	Time	Rainfall
2/2/1970	13:00	0.08
2/2/1970	14:00	0.03
2/2/1970	15:00	0.04
2/2/1970	16:00	0.08
2/2/1970	17:00	0.02
2/2/1970	18:00	0.02
2/2/1970	19:00	0.01
2/2/1970	23:00	0.01
2/3/1970	0:00	0.01
2/3/1970	2:00	0.01
2/3/1970	3:00	0.01
2/3/1970	8:00	0.01
2/5/1970	0:00	0.02
2/5/1970	2:00	0.01
2/5/1970	8:00	0.01
2/5/1970	10:00	0.01
2/5/1970	11:00	0.01
2/7/1970	13:00	0.05
2/7/1970	14:00	0.06
2/7/1970	15:00	0.05
2/7/1970	16:00	0.05
2/7/1970	17:00	0.03
2/7/1970	18:00	0.02
2/7/1970	19:00	0.01
2/7/1970	20:00	0.01
2/7/1970	21:00	0.01
2/8/1970	11:00	0.02
2/8/1970	12:00	0.01
2/8/1970	16:00	0.01
2/8/1970	17:00	0.02

Table B1-2: Typical Year Time Series	Source: MSDGC	
Date	Time	Rainfall
2/8/1970	18:00	0.01
2/10/1970	8:00	0.01
2/11/1970	20:00	0.01
2/11/1970	21:00	0.01
2/14/1970	6:00	0.02
2/14/1970	7:00	0.04
2/14/1970	8:00	0.01
2/14/1970	17:00	0.03
2/14/1970	18:00	0.02
2/14/1970	19:00	0.04
2/14/1970	20:00	0.02
2/15/1970	0:00	0.01
2/15/1970	1:00	0.01
2/15/1970	4:00	0.02
2/19/1970	10:00	0.01
2/20/1970	4:00	0.01
2/25/1970	5:00	0.01
2/25/1970	13:00	0.01
3/1/1970	22:00	0.02
3/2/1970	8:00	0.14
3/2/1970	9:00	0.24
3/2/1970	10:00	0.04
3/2/1970	11:00	0.02
3/2/1970	12:00	0.06
3/2/1970	13:00	0.07
3/2/1970	14:00	0.09
3/2/1970	19:00	0.04
3/2/1970	21:00	0.14
3/2/1970	22:00	0.02
3/3/1970	21:00	0.03

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
3/3/1970	22:00	0.02
3/3/1970	23:00	0.05
3/4/1970	0:00	0.05
3/4/1970	1:00	0.01
3/4/1970	3:00	0.01
3/4/1970	4:00	0.08
3/4/1970	5:00	0.1
3/4/1970	6:00	0.06
3/4/1970	7:00	0.05
3/4/1970	8:00	0.04
3/4/1970	9:00	0.08
3/4/1970	10:00	0.01
3/4/1970	17:00	0.1
3/4/1970	18:00	0.18
3/4/1970	19:00	0.02
3/10/1970	9:00	0.01
3/12/1970	5:00	0.01
3/12/1970	6:00	0.01
3/12/1970	12:00	0.01
3/12/1970	13:00	0.01
3/12/1970	14:00	0.04
3/12/1970	15:00	0.14
3/12/1970	16:00	0.11
3/12/1970	17:00	0.02
3/12/1970	18:00	0.01
3/12/1970	19:00	0.01
3/12/1970	20:00	0.04
3/12/1970	21:00	0.03
3/12/1970	22:00	0.02
3/12/1970	23:00	0.03

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
3/13/1970	0:00	0.02
3/13/1970	1:00	0.01
3/14/1970	3:00	0.01
3/15/1970	1:00	0.01
3/15/1970	9:00	0.02
3/15/1970	10:00	0.02
3/15/1970	11:00	0.01
3/17/1970	17:00	0.02
3/17/1970	18:00	0.04
3/17/1970	19:00	0.1
3/17/1970	20:00	0.12
3/17/1970	21:00	0.14
3/17/1970	22:00	0.12
3/17/1970	23:00	0.07
3/18/1970	0:00	0.01
3/18/1970	1:00	0.04
3/18/1970	2:00	0.03
3/18/1970	3:00	0.02
3/18/1970	4:00	0.01
3/20/1970	2:00	0.01
3/20/1970	3:00	0.01
3/20/1970	4:00	0.01
3/22/1970	3:00	0.02
3/22/1970	4:00	0.02
3/22/1970	5:00	0.03
3/22/1970	6:00	0.03
3/22/1970	7:00	0.03
3/22/1970	8:00	0.03
3/22/1970	9:00	0.01
3/22/1970	14:00	0.01

Table B1-2: Typical Year Time Series	Source: MSDGC	
Date	**Time**	**Rainfall**
3/22/1970	15:00	0.05
3/22/1970	16:00	0.01
3/22/1970	17:00	0.01
3/25/1970	12:00	0.05
3/25/1970	13:00	0.14
3/25/1970	14:00	0.17
3/25/1970	15:00	0.23
3/25/1970	16:00	0.07
3/25/1970	17:00	0.01
3/25/1970	18:00	0.02
3/26/1970	2:00	0.05
3/26/1970	3:00	0.15
3/26/1970	4:00	0.1
3/26/1970	6:00	0.05
3/29/1970	2:00	0.05
3/29/1970	3:00	0.04
3/29/1970	4:00	0.1
3/29/1970	5:00	0.05
3/29/1970	6:00	0.02
3/29/1970	7:00	0.02
3/29/1970	9:00	0.02
4/1/1970	15:00	0.02
4/1/1970	16:00	0.14
4/1/1970	17:00	0.15
4/1/1970	18:00	0.03
4/1/1970	19:00	0.03
4/1/1970	20:00	0.2
4/1/1970	21:00	0.11
4/1/1970	22:00	0.29
4/1/1970	23:00	0.23

Table B1-2: Typical Year Time Series	Source: MSDGC	
Date	**Time**	**Rainfall**
4/2/1970	0:00	0.33
4/2/1970	1:00	0.27
4/2/1970	2:00	0.36
4/2/1970	3:00	0.19
4/2/1970	4:00	0.03
4/2/1970	6:00	0.01
4/4/1970	9:00	0.01
4/4/1970	10:00	0.01
4/6/1970	8:00	0.05
4/6/1970	9:00	0.08
4/13/1970	6:00	0.08
4/13/1970	7:00	0.09
4/13/1970	8:00	0.04
4/14/1970	4:00	0.01
4/14/1970	5:00	0.03
4/18/1970	22:00	0.01
4/19/1970	5:00	0.04
4/19/1970	6:00	0.29
4/19/1970	7:00	0.11
4/19/1970	8:00	0.01
4/19/1970	18:00	0.01
4/19/1970	19:00	0.04
4/19/1970	21:00	0.02
4/19/1970	22:00	0.14
4/19/1970	23:00	0.15
4/20/1970	1:00	0.01
4/21/1970	1:00	0.01
4/23/1970	1:00	0.08
4/23/1970	2:00	0.03
4/23/1970	4:00	0.6

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
4/23/1970	5:00	0.01
4/23/1970	7:00	0.02
4/23/1970	12:00	0.01
4/23/1970	13:00	0.01
4/23/1970	20:00	0.02
4/23/1970	21:00	0.03
4/23/1970	23:00	0.08
4/24/1970	0:00	0.02
4/24/1970	1:00	0.45
4/24/1970	3:00	0.2
4/24/1970	4:00	0.17
4/24/1970	5:00	0.1
4/24/1970	6:00	0.18
4/24/1970	7:00	0.08
4/24/1970	10:00	0.01
4/24/1970	11:00	0.02
4/24/1970	12:00	0.05
4/25/1970	22:00	0.03
4/25/1970	23:00	0.05
4/26/1970	0:00	0.05
4/26/1970	1:00	0.02
4/27/1970	16:00	0.15
4/27/1970	17:00	0.18
4/27/1970	18:00	0.07
4/28/1970	6:00	0.05
4/29/1970	18:00	0.14
4/29/1970	19:00	0.27
4/29/1970	20:00	0.01
4/29/1970	21:00	0.32
4/29/1970	22:00	0.05

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
5/1/1970	16:00	0.2
5/1/1970	22:00	0.01
5/1/1970	23:00	0.02
5/2/1970	1:00	0.01
5/2/1970	2:00	0.01
5/2/1970	5:00	0.01
5/2/1970	6:00	0.02
5/2/1970	7:00	0.01
5/2/1970	8:00	0.03
5/2/1970	9:00	0.01
5/10/1970	12:00	0.01
5/11/1970	20:00	0.13
5/11/1970	21:00	0.03
5/12/1970	20:00	0.01
5/13/1970	13:00	0.01
5/13/1970	15:00	0.01
5/14/1970	22:00	0.02
5/16/1970	0:00	0.1
5/16/1970	1:00	0.1
5/16/1970	13:00	0.01
5/16/1970	20:00	0.01
5/16/1970	21:00	0.07
5/16/1970	22:00	0.01
5/25/1970	16:00	0.02
5/25/1970	18:00	0.38
5/25/1970	19:00	0.01
5/25/1970	20:00	0.62
6/1/1970	17:00	0.41
6/2/1970	17:00	0.05
6/2/1970	21:00	0.05

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
6/2/1970	22:00	0.36
6/2/1970	23:00	0.12
6/3/1970	0:00	0.01
6/3/1970	12:00	0.04
6/3/1970	13:00	0.37
6/3/1970	14:00	0.03
6/3/1970	17:00	0.01
6/3/1970	18:00	0.01
6/3/1970	20:00	0.01
6/3/1970	21:00	0.02
6/3/1970	22:00	0.02
6/3/1970	23:00	0.03
6/4/1970	0:00	0.02
6/4/1970	1:00	0.01
6/4/1970	2:00	0.03
6/4/1970	3:00	0.01
6/4/1970	4:00	0.05
6/4/1970	5:00	0.08
6/4/1970	6:00	0.04
6/4/1970	23:00	0.38
6/5/1970	0:00	0.87
6/5/1970	1:00	0.13
6/5/1970	2:00	0.01
6/5/1970	21:00	0.33
6/5/1970	22:00	0.01
6/5/1970	23:00	0.04
6/6/1970	0:00	0.08
6/6/1970	6:00	0.01
6/13/1970	7:00	0.02
6/13/1970	8:00	0.28

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
6/13/1970	9:00	1.23
6/15/1970	2:00	0.01
6/15/1970	3:00	0.01
6/21/1970	6:00	0.01
6/26/1970	16:00	0.06
6/26/1970	17:00	0.45
6/26/1970	22:00	0.02
7/3/1970	10:00	0.02
7/3/1970	11:00	0.01
7/8/1970	15:00	0.59
7/8/1970	16:00	0.05
7/8/1970	17:00	1.17
7/8/1970	18:00	0.39
7/8/1970	23:00	0.05
7/9/1970	17:00	0.02
7/19/1970	17:00	0.02
7/19/1970	20:00	0.02
7/19/1970	21:00	0.09
7/19/1970	22:00	0.04
7/20/1970	1:00	0.23
7/20/1970	6:00	0.01
7/20/1970	7:00	0.51
7/22/1970	23:00	0.01
7/23/1970	0:00	0.03
7/23/1970	2:00	0.02
7/23/1970	3:00	0.03
7/23/1970	4:00	0.01
7/23/1970	5:00	0.01
7/23/1970	6:00	0.01
7/23/1970	7:00	0.01

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
7/27/1970	18:00	0.05
7/31/1970	3:00	0.01
7/31/1970	4:00	0.01
7/31/1970	6:00	0.01
7/31/1970	7:00	0.04
8/3/1970	10:00	0.01
8/3/1970	11:00	0.1
8/3/1970	12:00	0.01
8/3/1970	14:00	0.24
8/8/1970	19:00	0.01
8/8/1970	20:00	0.02
8/8/1970	21:00	0.01
8/9/1970	3:00	0.01
8/9/1970	4:00	0.24
8/9/1970	5:00	0.12
8/9/1970	7:00	0.01
8/9/1970	9:00	0.08
8/9/1970	10:00	0.01
8/9/1970	11:00	0.01
8/9/1970	14:00	0.03
8/9/1970	16:00	0.06
8/9/1970	21:00	0.01
8/9/1970	22:00	0.04
8/9/1970	23:00	0.14
8/10/1970	0:00	0.07
8/10/1970	1:00	0.01
8/12/1970	12:00	0.02
8/12/1970	16:00	0.12
8/12/1970	17:00	0.02
8/13/1970	15:00	0.02

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
8/17/1970	8:00	0.02
8/19/1970	14:00	0.4
8/19/1970	15:00	0.02
8/20/1970	19:00	0.01
8/20/1970	20:00	0.42
8/22/1970	16:00	0.05
8/22/1970	17:00	0.5
8/30/1970	13:00	0.1
8/30/1970	14:00	0.02
9/3/1970	9:00	0.01
9/3/1970	18:00	0.05
9/3/1970	19:00	0.21
9/3/1970	21:00	0.03
9/4/1970	23:00	0.01
9/5/1970	0:00	0.13
9/5/1970	1:00	0.01
9/7/1970	7:00	0.01
9/7/1970	8:00	0.08
9/7/1970	9:00	0.02
9/8/1970	17:00	0.54
9/13/1970	22:00	0.05
9/14/1970	18:00	0.01
9/14/1970	19:00	0.01
9/18/1970	10:00	0.13
9/18/1970	11:00	0.05
9/21/1970	16:00	0.09
9/22/1970	21:00	0.4
9/22/1970	22:00	0.01
9/23/1970	0:00	0.01
9/24/1970	17:00	0.13

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
9/24/1970	18:00	0.34
9/25/1970	7:00	0.44
9/25/1970	8:00	0.19
9/25/1970	9:00	0.09
9/26/1970	15:00	0.52
9/26/1970	16:00	0.04
9/26/1970	17:00	0.02
9/26/1970	18:00	0.01
9/26/1970	20:00	0.01
9/26/1970	21:00	0.04
9/26/1970	22:00	0.05
9/26/1970	23:00	0.03
9/27/1970	0:00	0.02
9/27/1970	2:00	0.03
9/27/1970	3:00	0.03
9/27/1970	4:00	0.02
10/8/1970	18:00	0.03
10/8/1970	21:00	0.01
10/9/1970	21:00	0.04
10/9/1970	22:00	0.06
10/9/1970	23:00	0.1
10/10/1970	0:00	0.04
10/10/1970	1:00	0.04
10/10/1970	2:00	0.02
10/12/1970	10:00	0.02
10/12/1970	11:00	0.03
10/12/1970	13:00	0.03
10/12/1970	14:00	0.01
10/12/1970	18:00	0.01
10/12/1970	19:00	0.02

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	**Time**	**Rainfall**
10/12/1970	20:00	0.04
10/12/1970	21:00	0.05
10/12/1970	22:00	0.04
10/12/1970	23:00	0.01
10/13/1970	0:00	0.01
10/13/1970	1:00	0.09
10/13/1970	2:00	0.1
10/13/1970	3:00	0.02
10/14/1970	2:00	0.02
10/14/1970	3:00	0.1
10/14/1970	4:00	0.16
10/14/1970	5:00	0.1
10/14/1970	6:00	0.05
10/14/1970	18:00	0.04
10/14/1970	20:00	0.01
10/15/1970	13:00	0.01
10/20/1970	2:00	0.02
10/20/1970	3:00	0.05
10/20/1970	4:00	0.07
10/20/1970	5:00	0.11
10/20/1970	6:00	0.17
10/20/1970	7:00	0.13
10/20/1970	8:00	0.02
10/20/1970	11:00	0.02
10/20/1970	12:00	0.02
10/20/1970	13:00	0.07
10/20/1970	14:00	0.01
10/20/1970	15:00	0.02
10/20/1970	16:00	0.07
10/20/1970	17:00	0.04

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
10/20/1970	18:00	0.03
10/20/1970	19:00	0.04
10/20/1970	21:00	0.01
10/20/1970	22:00	0.06
10/28/1970	17:00	0.01
10/28/1970	18:00	0.01
10/29/1970	3:00	0.01
10/29/1970	5:00	0.01
10/29/1970	6:00	0.02
10/29/1970	7:00	0.01
10/29/1970	8:00	0.02
10/29/1970	11:00	0.01
10/29/1970	12:00	0.01
10/29/1970	14:00	0.02
10/29/1970	15:00	0.04
11/2/1970	5:00	0.02
11/2/1970	6:00	0.13
11/2/1970	7:00	0.01
11/2/1970	8:00	0.01
11/2/1970	9:00	0.08
11/2/1970	10:00	0.1
11/2/1970	11:00	0.1
11/2/1970	12:00	0.03
11/2/1970	14:00	0.01
11/9/1970	17:00	0.02
11/9/1970	18:00	0.07
11/9/1970	19:00	0.1
11/9/1970	20:00	0.01
11/10/1970	2:00	0.01
11/10/1970	3:00	0.02

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
11/14/1970	4:00	0.01
11/14/1970	8:00	0.01
11/14/1970	9:00	0.05
11/14/1970	10:00	0.06
11/14/1970	11:00	0.12
11/14/1970	12:00	0.06
11/14/1970	13:00	0.04
11/14/1970	14:00	0.02
11/14/1970	15:00	0.02
11/14/1970	16:00	0.02
11/14/1970	17:00	0.01
11/14/1970	19:00	0.02
11/14/1970	21:00	0.01
11/14/1970	22:00	0.01
11/14/1970	23:00	0.01
11/15/1970	0:00	0.01
11/15/1970	1:00	0.02
11/15/1970	10:00	0.01
11/19/1970	23:00	0.04
11/20/1970	1:00	0.15
11/20/1970	2:00	0.54
11/20/1970	3:00	0.15
11/20/1970	4:00	0.01
11/20/1970	8:00	0.03
11/22/1970	10:00	0.01
11/29/1970	17:00	0.13
12/3/1970	8:00	0.01
12/3/1970	22:00	0.05
12/11/1970	14:00	0.08
12/11/1970	16:00	0.01

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
12/11/1970	17:00	0.03
12/11/1970	18:00	0.03
12/11/1970	19:00	0.07
12/11/1970	20:00	0.01
12/12/1970	1:00	0.06
12/12/1970	2:00	0.08
12/12/1970	3:00	0.09
12/12/1970	4:00	0.09
12/12/1970	5:00	0.08
12/12/1970	6:00	0.07
12/12/1970	16:00	0.01
12/16/1970	5:00	0.03
12/16/1970	6:00	0.06
12/16/1970	7:00	0.11
12/16/1970	8:00	0.06
12/16/1970	10:00	0.04
12/16/1970	11:00	0.15
12/16/1970	12:00	0.03
12/16/1970	13:00	0.07
12/16/1970	19:00	0.02
12/16/1970	20:00	0.1
12/16/1970	21:00	0.03
12/16/1970	22:00	0.09
12/16/1970	23:00	0.06
12/21/1970	6:00	0.04
12/21/1970	7:00	0.05
12/21/1970	8:00	0.02
12/21/1970	9:00	0.05
12/21/1970	10:00	0.06
12/21/1970	17:00	0.01

Table B1-2: Typical Year Time Series Source: MSDGC		
Date	Time	Rainfall
12/21/1970	19:00	0.01
12/21/1970	22:00	0.1
12/21/1970	23:00	0.05
12/22/1970	0:00	0.12
12/22/1970	1:00	0.18
12/22/1970	2:00	0.05
12/22/1970	3:00	0.08
12/22/1970	4:00	0.08
12/22/1970	5:00	0.02
12/23/1970	3:00	0.47
12/23/1970	4:00	0.09
12/23/1970	5:00	0.16
12/23/1970	6:00	0.02
12/25/1970	17:00	0.01
12/25/1970	18:00	0.01
12/27/1970	11:00	0.01
12/27/1970	12:00	0.01