City of Memphis

Stormwater Drainage Study Surveying, Mapping, and Modeling Protocols for Stormwater Masterplan Studies

City of Memphis Division of Engineering

For

City Stormwater Masterplan Study Program

ACKNOWLEDGMENT

The purpose of this protocol is to provide the guidelines for selected masterplan Study Consultants in performing the necessary analysis to fulfill the assigned drainage study. The objective is to set forth to achieve consistency and facilitate the comparison of results among recommendations across numerous drainage studies in the City of Memphis. The results allow the City's decision makers to compare and prioritize projects among the studied drainage basins. Additionally, aconsistent process will allow the models to become "living entities," making them usable for a several years. Once the analysis has been completed, the results will be sent to the City of Memphis' Stormwater Program Management (MSQ2) and used to implement the future Capital Improvement Plan (CIP).

We would like to acknowledge the following individuals who dedicated the knowledge and review for this protocol, including Mr. Evan Boulanger, P.E. from the City of Memphis, Mr. Jacob Wiley from Allworld Project Management, P.E., and Mr. Fred Ernst, P.E. from ABES Engineering.

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Chapter I – Introduction to Stormwater Masterplan Study Protocols

1.1 Purpose of the Protocol

The purpose of this protocol is to provide guidance for selected Masterplan Study Consultants in performing the required scope of work to fulfill the assigned drainage study. This includes conducting:

a. Public outreach programs.
b. Mapping and surveying.
c. Hydrologic and hydraulic (H&H) modeling and analysis.
d. Assessment of alternative solutions.
e. Final report submission.

This protocol follows the Memphis/Shelby County Stormwater Manual, along with applicable standards, rules, and regulations. The objective is to ensure consistency and facilitate comparison of results across multiple drainage studies conducted throughout the City of Memphis. These results enable City decision-makers to compare and prioritize improvement projects among the studied drainage basins.

A consistent methodology also ensures that the models serve as "living entities," remaining usable for several years. Upon completion of the drainage study, the results will be submitted to the City of Memphis Stormwater Management Team—MSQ2—for consideration in future Capital Improvement Plan (CIP) implementations.

The protocol presents a generalized outline of expectations for any project scope related to a Stormwater Masterplan Study contract issued as a result of an RFQ. However, it may not include all potential scope items or cover every topic. Therefore, each selected entity is responsible for making a good-faith effort to develop a practical, study-specific scope of work, subject to City Staff approval.

1.2 Definitions

This protocol uses the following terms, acronyms, abbreviations, and definitions:

a. **CAESER** – Center for Applied Earth Science and Engineering Research, University of Memphis.
b. **City** – City of Memphis Government.

c. **City Staff**, **City Engineering Staff**, **City Communications Staff**, etc. – Any full-time employee of the City of Memphis, including staff from the Division of Engineering and potentially other divisions.
d. **EPA SWMM / PCSWMM –** Environmental Protection Agency Storm Water Management Model, version 5.0 or higher, used for hydrologic and hydraulic analysis.
e. **H&H –** Hydrologic and Hydraulic (modeling).
f. **Memphis SWMM 3.0** – Third Edition of the **Memphis/Shelby County Stormwater Management Manual**.
g. **MSQ2 –** Consultant team managing the City's Stormwater Program (currently Allworld Project Management, LLC), including associated subconsultants and employees.
h. **Protocol –** Surveying, Mapping, and Modeling Protocols for Stormwater Masterplan Studies.
i. **QA/QC Reviewer –** Individual(s) or organizations responsible for quality assurance/quality control of the City's Stormwater Masterplan Studies (currently the Surface Water Institute at Christian Brothers University).
j. **RFQ –** Request for Qualifications for the City of Memphis Stormwater Masterplan Study Program.
k. **Stormwater Masterplan Study Program** – Initiative launched in 2014 by the City of Memphis Division of Engineering to perform drainage studies; also referred to as "drainage studies," "the program," or "the study."
l. **Study Area –** Geographic region evaluated by a Study Consultant, consisting of one or more watershed boundaries as defined in the City's GIS database.
m. **Study Consultant –** Individual firm or team of firms contracted to complete a drainage study project under the RFQ.
n. **SWI –** Surface Water Institute at Christian Brothers University.

1.3 Stormwater Masterplan Study Schedule

The City of Memphis publicly announces and issues RFQs to select qualified consultant teams to study hydrologic and hydraulic conditions within designated drainage basins. Once selected, a Study Consultant enters into a service contract with the City to perform the assigned study.

The Study Consultants will meet regularly with City Staff to review the scope of work and address inquiries throughout the study duration.

Each study is ideally completed within 24 to 30 months following the issuance of a Notice to Proceed**.** However, extensions may be granted due to fieldwork challenges, complex modeling, or other unforeseen circumstances. Consultants are encouraged to maintain open communication with the City and formally request additional time when needed.

Table 1 outlines the general project milestone schedule, and **Table 2** provides a tentative schedule for completing the drainage studies. City preapproval is required for extending any task beyond the listed timelines.

Table 1 City of Memphis Drainage Studies Tentative Program Schedule

Program Year	Study District	Study Area
2006	05	Lick Creek
2014	01	Raleigh
	02	Walnut Grove Lake
	03	Whitehaven
	04	Cane Creek
	05	Cypress Creek
	06	South Cypress Creek
	07	Todd Creek
2015	01	Windermere
	02	Sweetbriar
	03	Days Creek
	04	Black Bayou
	05	White Station
	06	Southland
2016	01	Allen
	02	Ridgeway
	03	Hurricane Creek
	04	Cherry Bayou
	05	Harrison
	06	Mallory
	07	Gayoso Bayou

Program Year	Study District	Study Area
2025	03	Ten Mile Bayou
	07	Point Church

Table 2 Suggested Study Schedule

Task	To be completed by:
Notice and kick-off meeting	Month 1
Initial public meetings	Month 2-3
Data collection & field surveys	Month 4-10
Meeting to review existing condition model and calibration results and to discuss solutions with City Staff	Month 11-18
Workshop meeting to review Recommended Solutions with City Staff	Month 19-24
Submission and presentation of final report and model delivery	Month 25-30
Final public meeting (If necessary)	Per request

Chapter 2 – Drainage Study Operational Plan

2.0 Introduction

After the contract is executed, the Study Consultant must prepare an operational plan. This plan should include the following key activities:

2.1 Project Kick-Off Meeting

The first activity is to schedule and conduct a kick-off meeting. During this meeting, the Study Consultant shall present the following key project components to the City:

a. A contact list of individuals responsible for the project, identifying both primary and secondary points of contact. The list should include the duties and responsibilities of each team member and detail their specific tasks throughout the study period.
b. A project schedule aligned with the defined scope of work. Any changes to the schedule must be approved by the City.
c. A schedule of invoices and payments.
d. A list of special considerations or data needs from the City, as referenced in Chapters 4 and 5 of this protocol.

2.2 Initial Public Meeting

The initial public meeting is intended to communicate the project to the community and should occur after the kick-off meeting. Unless otherwise directed by City Staff before contract execution, it is assumed that only one public meeting will be held per drainage study. The meeting should ideally take place within the study area.

The Study Consultant is responsible for:

a. Proposing and securing an appropriate meeting location.
b. Coordinating with City Staff and MSQ2 to arrange logistics and schedule the meeting.
c. Preparing the meeting agenda and presentation materials, subject to City Staff review.
d. Assisting with public notifications and advertisements.
e. Supplying necessary equipment (e.g., computers, easels, projectors).
f. Collecting attendee information (e.g., name, address, contact details).
g. Facilitating public discussion during the meeting.
h. Providing sufficient staff to engage with attendees.
i. Enabling the public to submit digital or hard copy photos/videos.
j. Providing and collecting public survey forms and compiling the data.

k. Preparing meeting minutes in written, audio, or video format.

City support may include:

a. Providing prior flood data, hot spot maps, and anecdotal flooding history.
b. Assessing meeting space suitability (e.g., size, tables, sound system).
c. Suggesting venues such as community centers, libraries, schools, or churches.
d. Assisting with directional signage and community notifications.
e. Contacting Executive and Legislative divisions for potential City official attendance.
f. Ensuring at least one City Staff member is present to answer questions outside the Consultant's scope.
g. Hosting a dedicated webpage for each drainage study. The Consultant shall provide content for this page. A link to an external site may be included with prior City approval and at no additional cost.

The Consultant must submit a PowerPoint presentation to City Staff at least **14 days** before the meeting for review. The presentation should be accessible to the general public, avoiding overly technical or engineering terminology. Where such terms are used, clear explanations should be provided.

The presentation should cover:

a. An overview of the drainage program and study objectives.
b. The boundaries of the study area.
c. Study procedures and methods.
d. Opportunities for public involvement, including a tentative study schedule and the collection of local flood experience.

The public should also be informed that study personnel may need to access private property. Additional outreach methods—such as signage, announcements in places of worship, community leader meetings, or earned/paid media—are encouraged. The Consultant is responsible for securing any necessary permissions for signs placed in the study area.

Meeting dates must be pre-approved by the City. Avoid scheduling conflicts with City Council meetings, holidays, school events, elections, and religious services. Meetings should be scheduled after 6 p.m. to maximize community attendance.

Minimum public notification methods:

a. Posting the meeting on the City of Memphis drainage study webpage.
b. Adding the event to the City of Memphis public calendar at www.memphistn.gov, with City Staff approval.
c. Advertising via City social media (Facebook, Twitter, Instagram, Nextdoor), coordinated with City Communications.
d. Notifying the local City Council member's office.
e. Reaching out to registered homeowner associations (HOAs).

2.3 Public Outreach

Following the initial public meeting, the Study Consultant must implement a Public Outreach Program. This program allows for direct, ongoing interaction with community members. Outreach is essential for:

a. Familiarizing residents with the study team and scope.
b. Gathering on-the-ground insights into drainage problems.
c. Helping the City identify unknown problem areas.
d. Validating and refining modeling assumptions.
e. Engaging the community in the evaluation and selection of potential solutions.

The information collected will inform both current modeling and future maintenance strategies. Later in the study, the Consultant and City will present proposed solutions and collect feedback, allowing residents to be active stakeholders in shaping outcomes.

2.4 Final Public Meeting

Unlike previous studies, the City currently does not require a final public meeting by default. Post-study outreach is primarily the responsibility of City Staff and MSQ2, although the Study Consultant may be asked to assist with technical input or public engagement.

If the City determines that a final meeting is necessary, the Consultant will be informed before contract execution. The meeting's purpose is to present:

a. A summary of the study findings.
b. Viable solutions that may be considered for future Capital Improvement Projects (CIPs).
c. Realistic expectations about project timelines.

The Consultant's responsibilities will mirror those of the initial public meeting, including venue planning, material preparation, and stakeholder coordination.

A final public meeting may be waived if controversial issues arise during the study. In such cases, the Consultant must consult with City Staff to decide whether the meeting should proceed.

Chapter 3 – Data Collection, Survey, and Mapping Requirements

3.0 Introduction

The data used for conducting the drainage study shall be obtained from multiple sources. The following sections outline the procedures and standards for data collection, field surveys, and mapping interpolation.

3.1 City Data

The City of Memphis Division of Engineering has collected drainage infrastructure data for several years. The Study Consultant shall acquire the following from the City:

a. Drainage basin boundaries.
b. GIS data of the City's storm drain and open channel systems. **All Study Consultants must check the City's storm drain and open channel systems** to cooperate their future drain network modeling efforts.
c. Flood complaint maps, heat maps, and databases.
d. Memphis SWMM protocol.
e. Stormwater plans in digital format (paper copies available upon request).
f. Structural designs of the drainage system.
g. Previous drainage studies (including older studies and those from the Stormwater Masterplan Study program).

While the City maintains substantial project data—such as historical plans, GIS maps, and design documents—completeness is not guaranteed for every study area. Additional data sources include:

a. CAESER (University of Memphis): Maintains stormwater infrastructure geodatabases.
b. SWI (Christian Brothers University Surface Water Institute): Serves as QA/QC reviewer and contributed to the Stormwater Management Manual (Third Edition).
c. Shelby County ReGIS: Manages the latest LiDAR data, typically in 1-foot contours.
d. Shelby County**:** Maintains zoning and land use data.

The Study Consultant must coordinate with City Staff to assemble data in a consistent format from CAESER, SWI, and City sources.

3.2 Field Survey

Although the City has extensive data, some of it may be outdated or unverified. Additional field surveys may be required. All field survey work shall utilize the field survey codes included in

Appendix A. The Study Consultant shall work with the City, CAESER, and MSQ2 to perform accurate field surveys, including:

a. Drainage structures (manholes, inlets, etc.)
b. Channel cross-sections.
c. Road crossings.
d. Finished Floor Elevations (FFEs), required before model construction.

Prior to entering into an agreement with the City, the Study Consultant shall:

a. Review provided files and conduct site visits to estimate required survey work.
b. Use these estimates to determine the cost of surveys.
c. Additional survey tasks may be negotiated as extra work, subject to City approval.

The Study Consultant shall notify City Staff when field surveys have commenced. The notification includes to:

a. Notify City Staff before beginning fieldwork.
b. Report any fieldwork issues promptly.
c. Obtain and carry a property access notification letter signed by the City Engineer as shown in **Appendix B**.
d. Ensure field personnel carry photo ID.

The surveying efforts shall meet or exceed the following requirements:

a. Horizontal datum: NAD83, TN Zone 4100, as derived from the NGS National Spatial Reference System (NSRS). Horizontal survey data collection shall comply with "SECOND ORDER" standard, as defined in Table A-4 of the current TDOT Survey Manual.
b. Vertical datum: City of Memphis Benchmark Network, which is the North American Vertical Datum 1988, (NAVD88). Vertical survey data collection shall comply with "THIRD ORDER" standard, as defined in Table A-5 of the current TDOT Survey Manual.
c. All channel and pipe sections shall be surveyed, including discrete points to define the top and invert elevations of each drainage structure (inlet, headwall, manhole, etc.). All channel sections shall be surveyed from top left bank to top right bank.
d. The distance between channel cross-sections will be variable, depending on channel geography and vertical and horizontal transitions.

- In irregular channels, the maximum distance between cross sections is five hundred feet.
- In prismatic channels (i.e., concrete-lined channels), cross sections are required at any change in geometry, such as horizontal curves, changes in vertical longitudinal grade, or changes in channel cross section. These cross sections shall be taken upstream and downstream of each change in geometry.
- Cross sections are required at all points of concentrated stormwater discharge and any bridge crossing, regardless of channel type.

e. All field survey work shall utilize the field survey codes included in **Appendix A**. In the event the provided list does not cover all the necessary survey codes, a list of additional codes used, and their accompanying descriptions shall be provided to the City.

f. The following features shall be included in the surveying effort as a minimum requirement:

- All open channels.
- All pipes twenty-four" and larger in the tributary drainage network.
- All pipes downstream from an identified flooding concern.
- All structures (headwalls, bridges, weirs, offices, inlets, etc.) along drainage features meeting the above criteria.

g. All surveyed road crossings and outfalls shall be photographed. Photographs shall be georeferenced in a manner to be determined by the Study Consultant and submitted as a GIS layer. Structures crossing an open channel shall have photographs from the upstream and downstream vantage points. Structures discharging into the channel shall be photographed from the channel. Photographs should be located close to the subject matter, but are not expected to have survey-grade accuracy.

h. Coordination with MSQ2 and CAESER shall be made, as a condition assessment effort is being performed of the entire City drainage system. Some of the above-referenced data may already be in existence. If newer photographs or more detailed survey data exist, this data shall be updated to the latest version/condition.

3.3 Drainage Study Boundaries and Boundary Limitations

Watersheds and drainage structures may cross municipal, county, or state boundaries, as well as on properties owned by entities with higher security concerns. If infrastructure exists in these areas, the following procedures shall be followed:

a. Digital elevation models define drainage boundaries but may not capture pipes crossing ridgelines. These crossings shall be included in the study and surveyed.
b. Surveying outside Memphis city limits is not required unless flooding concerns justify a more detailed model. In such cases:
    1) Seek City Staff approval.
    2) Unapproved external surveys are at the Consultant's expense.
    3) Coordinate drainage modeling at city boundaries with City Staff.

c. Infrastructure on high-security or restricted-access properties (e.g., airports, railroads, military facilities) requires coordination. The facility includes:
    1) Memphis/Shelby County Airport Authority (including Memphis International Airport or FedEx).
    2) St. Jude Children's Research Hospital.
    3) Memphis Defense Depot.
    4) Valero Refinery.
    5) Any railroad right-of-way (Burlington, Northern and Santa Fe; CSX; Canadian National; Norfolk Southern, Union Pacific).

3.4 Stream and Rainfall Data

The Study Consultant is able to contract a qualified service to install two rain gauges and two stream gauges per site to collect precipitation and flow discharge data. Data is used to calibrate/validate the H&H model. During the data collection and gauge monitor period, the Study Consultant's responsibility is to:

a. Collaborate on gauge site selection.
b. Collect/monitor data biweekly for ~6 months.
c. Ensure at least one major wet season (April/November) is captured.
d. If no storms occur, contact the City a month before gauge removal to request extensions.
e. Notify the service contractor to remove gauges after the project is completed.

The collection of precipitation and stream gage measurement shall meet the following requirements:

a. **Rainfall:** 5-minute intervals, inches or inches/hour.
b. **Stream:** Depth via pressure transducer, in feet.
c. **Optional:** Convert depth to discharge using verified rating curves (City approval required).

3.5 Other Data Collection Considerations

Project safety is the responsibility of the Study Consultant. All Study Consultants and their subconsultants are expected to follow applicable local, state, and federal safety guidelines. The following items are provided for information only. It does not serve as a substitute for an appropriate safety protocols. The considerations include:

a. Certain areas of the City have a high rate of crime. The City is not responsible for obtaining or providing security or escorts for the Study Consultant staff or for their equipment. If there are specific areas where the Study Consultant has security concerns, they may coordinate with the City for police escorts. The basin consultant should discuss these concerns at the kick-off meeting. Any such assistance shall be provided at the discretion of the City of Memphis.

b. Certain drainage ditches fill very quickly and become hazardous during extreme rain events. It is the responsibility of the surveyors and other field personnel to take the necessary safety precautions.

c. Various drainage areas may be infested with snakes, ticks, spiders, dogs, and other wildlife. During the installation and operation period, the Study Consultant should take extra precautions on this matter when they are working through the data collection phase in the field.

d. The Study Consultant will always conduct its fieldwork to assure the least possible obstruction to traffic. Appropriate safety gear shall always be worn, and appropriate roadway hazard markings shall be used. Any data collection activities performed on Tennessee Department of Transportation (TDOT) roads will be performed in accordance with all TDOT regulations and protocols. In addition, the Study Consultant can contact TDOT's Help Truck at (901) 537-2988 for assistance. A list of state-maintained roadways shall be provided by the City and/or TDOT at the Study Consultant's request.

e. It is the Study Consultant's responsibility to ensure that the survey crews abide by proper Occupational Safety and Health Administration (OSHA) and Tennessee Occupational Safety and Health Administration (TOSHA) requirements. No survey crew shall enter a confined space without proper confined space entry training.

f. If traffic control is needed to perform the survey of a particular structure, this traffic control shall comply with the 11th Edition of the Manual on Uniform Traffic Control Devices (MUTCD). If the survey of a structure necessitates a significant road closure (i.e., multiple lanes, one direction of traffic for a long duration, etc.), it is the responsibility of the Study Consultant to submit a traffic control plan to the City of Memphis Division of Engineering, Traffic Engineering Office for prior approval.

Chapter 4 Identification of Drainage Systems

4.0 Introduction

This section summarizes the general protocols to determine the identification names of the stormwater network. Through these standardizing protocols, the City can identify each individual model that will be developed using the same base assumptions. It can also enhance future Storm Water Management Teams to continue the drainage efforts in the City of Memphis.

Stormwater asset network contains points (manholes/junctions), polylines (conduits or open channels/transits), and polygons (storages or ponds) displaying infrastructure that collects, conveys and/or manages stormwater runoff and/or conveys watercourses. The sources of the data displayed include digitization of construction plans, field collection of assets, and/or GIS data being directly converted into ArcMap or ArcGIS pro, which is compatible to various modeling software.

Memphis Stormwater Quality and Quantity Program (MSQ2) has defined a network of project asset ID as:

a. Buried Manhole: This is a manhole that has been located but found to be paved over, buried, or otherwise inaccessible.
b. Digitized Data: This is an asset that has been digitized and entered GIS but has not been field inspected or had a survey conducted on it.
c. FacilityID (FID) – This is the asset identification number; all FIDs must be unique.
d. Field Verified: This is an asset that has been successfully field verified and accepted by GIS. A line that has any part verified (even if partial verification due to blockage) will be classified as Field Verified.
e. Unable to Complete (UTC) – This is used for both line and point assets that cannot be completed due to issues like unable to access pipe due to a buried manhole, unable to enter pipe due a welded manhole cover, unable to reach line due to a location (private property, too much vegetation, etc.)
f. Unable to Locate (UTL) – This is used solely for manholes that cannot be located either by above ground searching or unable to reach the manhole from the pipe due to obstructions.
g. Pipe Transition Node – This is a point asset used to connect pipes, ditches, culverts, which connect directly from line to line without first connecting to a point asset such as a: manhole, inlet, or headwall. Pipe transition nodes should only

be used when there is no point asset and the line that is transitioning is changing size, material, etc.

Detailed descriptions of each component of assets are listed in the following sections:

4.1 Identification Names of Project

Once the Study Consultant starts developing the model, the model file(s) associated with supporting data and documentation will be named appropriately according to the City assigned Study Area Code File names. The project name shall be followed the format below:

[Study District] [Study Area Code] _ [Study Area Name] _ [User Description]

where:

Study District: The City assigned code for the Study District where the basin is located.

Study Area Code: The City assigned codes for each study area.

Study Area Name: The name of the study area modeled.

User Description: The user can add a text description of the information included in the file.

The City assigned Study District and Study Area Codes are shown in **Table 3**. For example, if the study basin is on the Lick Creek Basin, then the project name should be designated as 05_LC_FieldData file.

This section will describe a systematic approach to labeling/coding these stormwater components. This schema shall assist the City as well as MSQ2 in managing stormwater infrastructure and help with future condition assessments.

Table 3 Drainage Basin Codes in City of Memphis

Program Year	Study District	Study Area
2006	LC	Lick Creek
2014	RL	Raleigh
	WG	Walnut Grove Lake
	WHV	Whitehaven
	CC	Cane Creek
	CY	Cypress Creek
	SC	South Cypress Creek
	TDC	Todd Creek
2015	WI	Windermere
	SB	Sweetbriar
	DC	Days Creek
	BB	Black Bayou
	WS	White Station
	SD	Southland
	AL	Allen
2016	RW	Ridgeway
	HR	Hurricane Creek
	CB	Cherry Bayou
	HS	Harrison
	ML	Mallory
	GY	Gayoso Bayou

Program Year	Study District	Study Area
	FL	Forrest Lake
	KB	Kirby
	TMB	Ten Mile Bayou
	PC	Point Church
	CA	Campbell
	WKH	Workhouse
	GI	Gayoso Interceptor
	MH	Madison Heights
	HT	Harrington
	CT	Cotton
	JC	John's Creek
	HI	Huling Interceptor
	ML	Marble
	FL	Fletcher
	HL	Horn Lake

4.2 Identification Names of Drainage Systems

A sequential number shall be assigned to each manhole. The initial sequence numbers should have sufficient gaps to allow for future expansion of the model. Manholes should be assigned a Model ID as follows:

[Study District] [Basin Code] _ [Structure ID] *where:*

Study District + Structure ID: A combination of the City assigned codes for each basin as shown in **Table 4.1**. For example,

LC0011102

Drainage Basin Structure ID Newly Located Addendum ID

A manhole is located between manhole 0011102 in Lick Creek Basin where is receiving flows on drain line 0011102 to manhole 0011101. The line with the higher number will always flow to a line with a lower number, the line will always have the same ID as the upstream asset.

This protocol suggests using the stream order approach to lay out the storm drain system. **Figure 1** shows the example of storm drain layout with GIS data. The detailed description is listed below:

Pipes and channels should be assigned a Model ID that consists of a combination of the upstream and downstream Manhole Model IDs. The Model ID should follow thefollowing format:

[Study Area Code] _ [Upstream Manhole ID]- [Downstream Manhole ID] + [Structure]

where:

Study District + Study Area Code: A combination of the City assigned codes for eachbasin as shown in **Table 3**.

Upstream Model ID: The upstream manhole ID.

Downstream Model ID: The downstream manhole sequence.

If a line would run from manhole LC0011101.001 to manhole LC0011101. Drain lines will always flow from a higher number to a lower number. As the line reaches its final discharge point, it will be at its lowest number. The drainpipe should be labeled as:

Figure 1 Layout of Storm Drain System

LC0011101.001P

Drainage Basin Structure ID Newly Located Addendum ID

A concrete channel, open ditch, or transit would run from a node LC0011101.001 to a node LC0011101. Drain lines always run flows from a higher number to a lower number. As the line reaches its final discharge point, it will be at its lowest number. The following label shows the ID should be used in the model:

LC0011101.001D

Drainage Basin Structure ID Newly Located Addendum ID

For hydraulic structures, such as weir, culvert, orifice, and spillway, the letters of W, C, O, and S can be added after the Located Addendum ID. For example, the culvert can be expressed as:

LC0011101.001C

Drainage Basin Structure ID Newly Located Addendum ID

This culvert would run from a node LC0011101.001 to a node LC0011101. Culverts will always flow from a higher number to a lower number. As the line reaches its final discharge point, it will be at its lowest number.

LC0011101.001

Drainage Basin Structure ID Newly Located Addendum ID

The above example would be the AssetID of an inlet, junction box, manhole, headwall. This asset would be the first asset from LC001101 on line LC001101.001S, if there is an additional asset it will be give the .002 suffix. If two inlets are the same distance from the downstream manhole, then choose one as .001 and one as .002.

Multiple Downstream Connections:

LC0011101.001P-1

Drainage Basin Structure ID Newly Located Addendum ID

There are rare cases where a single manhole will break into two downstream lines. Normally the downstream line will always have the same FID as the upstream manhole with addition of the P pipe suffix but as there are two downstream pipes this will not work. In cases such as these, the downstream pipes will have a further suffix of P-1 and P-2 to indicate both downstream pipes.

Chapter 5 Hydrologic and Hydraulic Model Development

5.0 Introduction

The development of Hydrologic and Hydraulic Models (H&H models) is a key component of the Stormwater Masterplan Study program, and are intended to be "living and breathing" models, updated as conditions with the stormwater drainage system change. A few notes:

a. The H&H model(s) shall be validated to the extent most practical, based on available information and/or observations.

b. All modelling efforts shall be completed using sound engineering judgement and modeling practices (both in this protocol and via other accepted practices).

c. The projects proposed shall be modeled using 1D hydrologic and hydraulic modeling, which relies on traditional 1D model mechanics to characterize flow throughout the underground drainage network, channels, and overland flow areas. It is possible that within certain areas of the City of Memphis, a 2D modeling approach is required to better simulate flooding. This approach shall be approved by City Staff prior to the commencement of said modeling effort in order to be considered for compensation.

The City of Memphis has adopted the Environmental Protection Agency's Storm Water Management Model (EPA-SWMM) software, version 5.0 or later as the modeling engine for the basin studies. The software to be used for all basin modeling efforts shall be PCSWMM. It is the Study Consultant's responsibility to obtain a license for this software at no cost to the City. The City shall not provide a license for the modeling software (unlike for past studies). Examples of appropriate software to use are PCSWMM.

Several limitations need to be considered when running the model:

a. SWMM can only apply a triangular-shaped unit hydrograph. When non-triangular unit hydrographs apply to the model, some approximation is required.

b. Infiltration losses should be considered before the model is built.

c. SWMM's Rainfall Dependent Inflow and Infiltration (RDII) procedure does not account for soil infiltration.

d. For single-event and continuation simulations, no information will be obtained if the upstream surcharges or re-routes from overland overflow.

5.1 SWMM Model Setup

The following sections describe the default protocols of the SWMM model for the City drainage study using PCSWMM software, including SWMM setup, H&H model setup, input parameter selections, determination of the basic model, etc. The Study Consultant should discuss with the City and the Storm Water Management Team prior to clarifying the methodology during the modeling development period that can make the future drainage improvement plan easier to maintain. **Figure 2** shows the layout of this modeling approach.

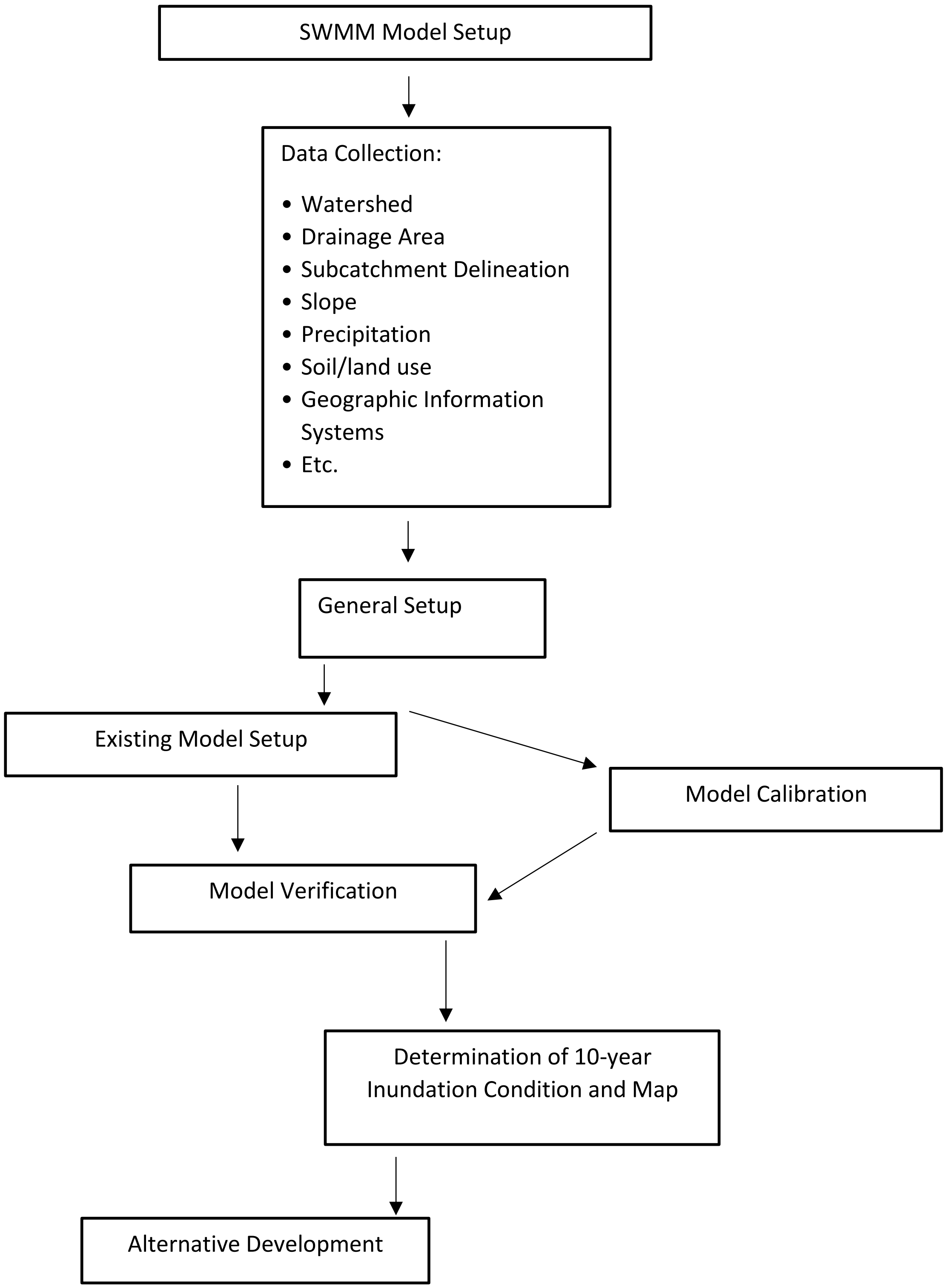


Figure 2 Model Development Procedure

The general SWMM setup includes the following tabs. The description of those tabs is listed below:

a. General tab

Figure 3 shows the recommended default settings on the General tab in the Simulation Options. All flow units will be reported in cubic feet per second (cfs). Infiltration method shall use Green-Ampt infiltration and the EPA SWMM/Non-linear Reservoir runoff models. For low rainfall intensities, the modified Green-Ampt may be applied. The model engine must use the dynamic wave routing model, which will allow the model to produce the most accurate results and account for channel storage, backwater, entrance/exit losses, flow reversal, and pressurized flow.

At a minimum scenario, the following Process Models shall be used in the model:

- Rainfall/Runoff.
- Flow Routing.
- RDII (rainfall-derived infiltration and inflow).

Model instabilities during simulations may occur due to the existence of short conduits and/or conduits with exceedingly small slopes. If the instabilities occur, the following action can be taken place:

To provide a minimum slope value that may help address the issue of conduits with small slopes. Otherwise, it should use the default value- “0” to conduct the model computation.

- To address short conduit lengths, conduit lengthening can be initiated by entering a value for this parameter. This value is a time step in seconds that is used to initiate a process to artificially lengthen short conduits. Conduit lengthening will be applied in conduits where the travel time through the conduit is smaller than the specified conduit lengthening time step. A value of 0 indicates that no conduits will be lengthened.

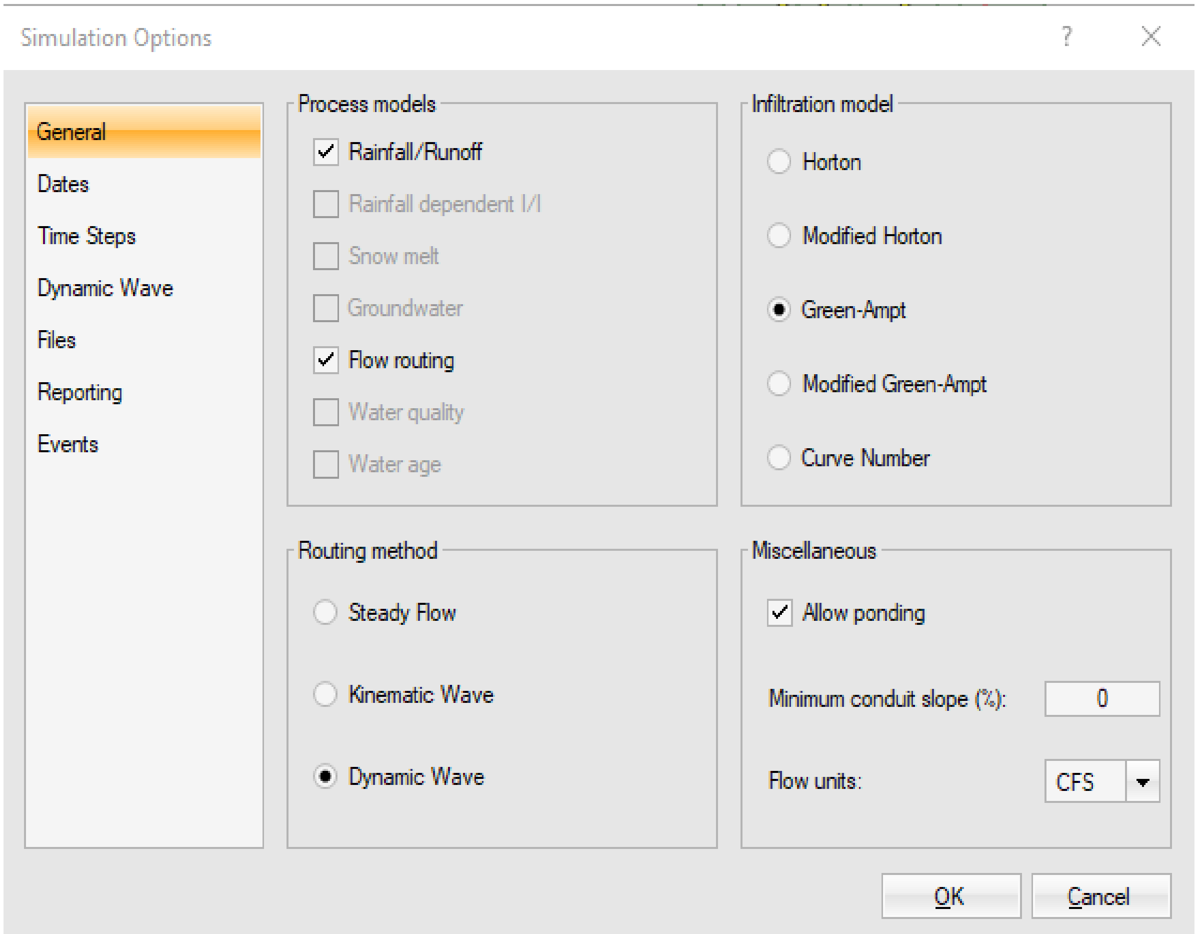


Figure 3 Simulation Options -General Tab

Other Process Models may be used to represent the basin, as necessary. If desired, ponding can be tracked at nodes. Tracking ponding at nodes will allow excess water to be collected at the top node/junction and be reintroduced into the system as conditions permitted. If this option is selected, a value for Ponded Area must be entered at each node where ponding is anticipated.

The conduit lengthening process will artificially lower the roughness value and adjust the slope of the conduit so that the same velocity and flow are maintained after lengthening.

b. Dates

Figure 4 shows an example of a simulation period. The frequency flow analysis will be based on a 24-hour duration. The dates should start at any date as selected. The simulations will end after a period of 24-36 hours that can extend the falling hydrograph to zero. During the real-time continuous simulations, the analysis period should be based on the period of recording rainfall and stage flow data. The modeler also needs to look at the tail of the hydrograph to justify the proper simulation period.

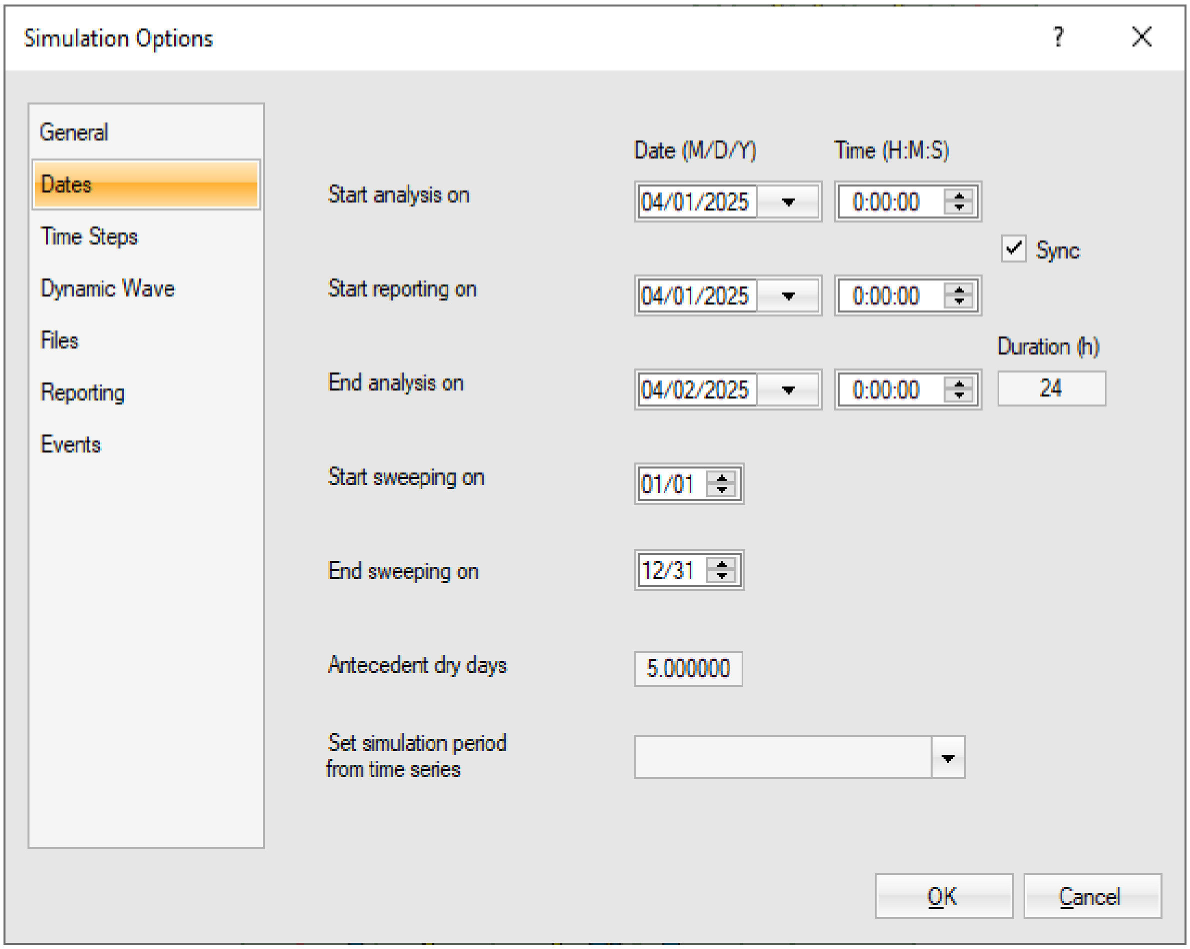


Figure 4 Simulation Options - Dates Tab

c. Time Steps

In **Figure 5**, there are four types of time step that can be defined in SWMM. The runoff time steps include dry weather and wet weather. The regular time steps include reporting time step and routing time steps. They can be setup as described below:

- Dry Weather Time Step: The time step used for computations during periods when there is no rainfall and no ponded water. This must be greater or equal to the Wet Weather Time Step. The default value for this time step is 1 hour.

- Wet Weather Time Step: The time step used to compute runoff from sub-catchments during periods of rainfall or when ponded water remains on the surface. This time step should be consistent with the time step for the rain event being evaluated.

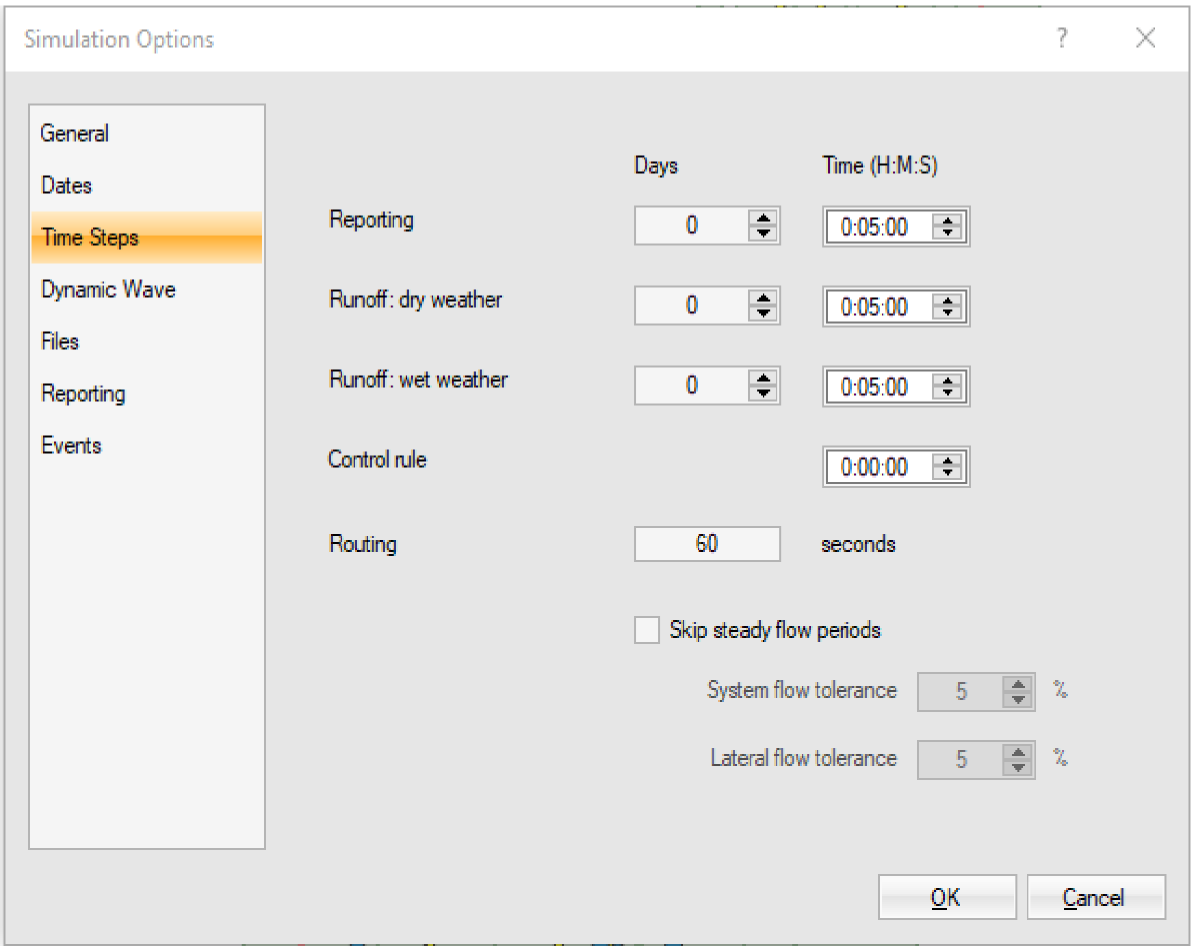


Figure 5 Simulation Options – Time Step Tab

- Reporting Time Step: The time step used for tabular reports of computed results. This should be the same or longer as the routing time step. Reported values are instantaneous values at the reporting time step and not averaged values. Because of this, if the reporting time step is longer than the routing time step minimums and maximums may be missed in SWMM's standard reports.

Statistical summary reports generated by SWMM, however, will report computed minimums and maximums based on the routing time step. The more reporting time steps saved for a simulation, the greater the file size. This value should be set to meet the needs of the modeler.

- Routing Time Step: The time step (in seconds) used for routing flows and water quality constituents through the conveyance system. The suggested starting value for this timestep is 60 seconds. This value may need to be adjusted if instabilities in the model are encountered.

The default setting for the Maximum Total Report Steps is 2500. The appropriate value for this setting will depend on the selected Reporting Time Step and may be changed if more report steps are needed. (*NOTE – since initiation of the program and preparation of this manual, the current version of the model no longer includes a Maximum Total Report Steps field*.)

d. Dynamic Wave

Dynamic wave consists of the continuity and momentum equation for conduits and volume calculations at modes for routing computation. In the SWMM model, the dynamic wave tab contains routing information for stormwater runoff. The following information in **Table 4 and Figure 6** shows the recommended default settings. However, water surface slope less than conduit slope may be considered as the normal depth criteria is used in the simulation. The modeler should check the Froude Number for the subcritical, critical, and supercritical conditions. If the basin has both supercritical and subcritical flows in conduit system, the “Both” should be used for the Normal Flow Criteria. The Hazen-William equation is preferred to use for the Force Main Equations during routing computation. The surcharge method should use the – EXTRAN option.

Table 4 Dynamic Wave Recommended Settings

Parameter	Recommended Setting
Inertial Terms	Keep
Variable Time Steps	Checked
Safety Factor	75%
Conduit Lengthening	0
Minimum Surface Area	0
Use Normal Flow Limit	Both
Force Main Equation	Hazen-Williams
Picard Iterations: Maximum Number	4
Stopping Tolerance	0.005

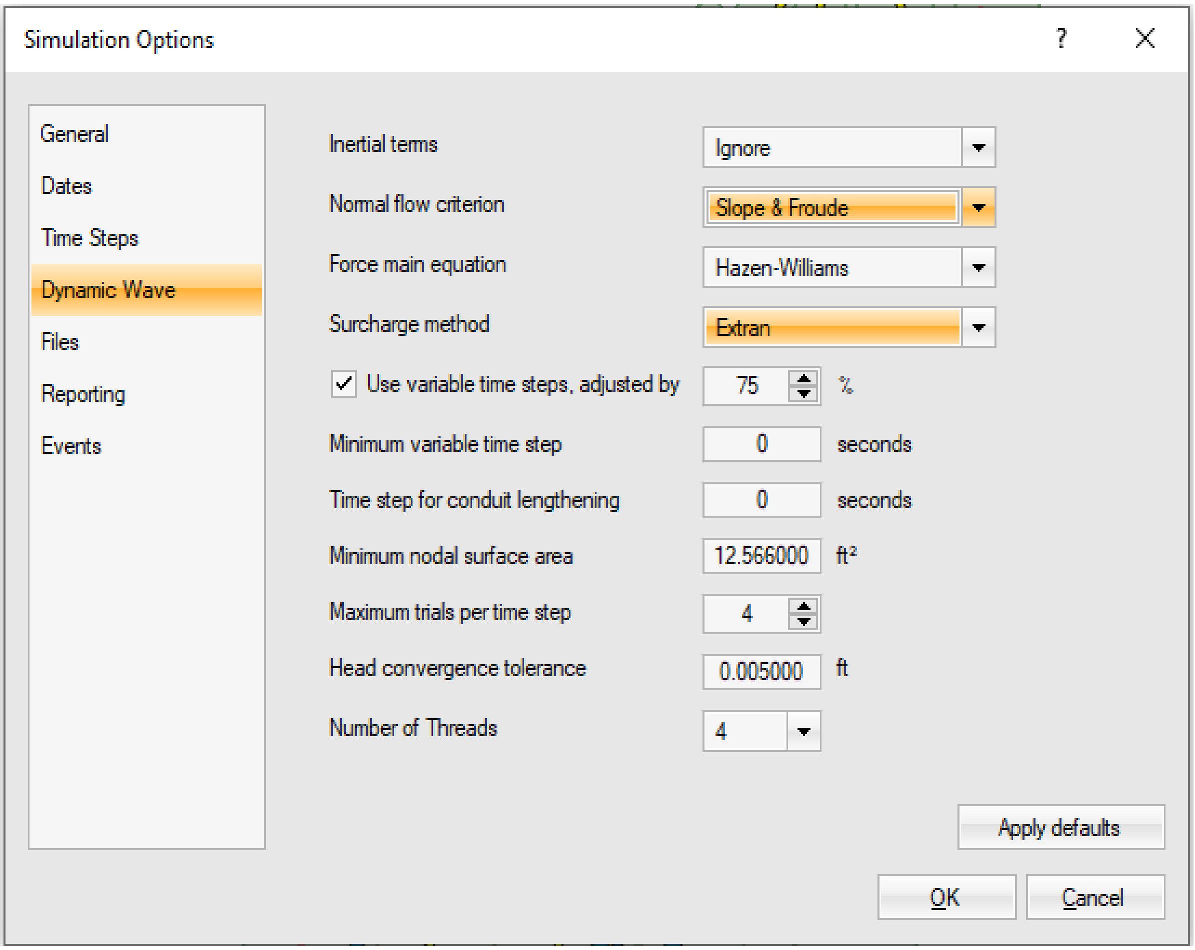


Figure 6 Simulation Options – Dynamic Wave Tab

e. Other Operation Settings

Other project preferences as shown in **Figure 7** can be configured through the Project Preferences dialog box:

(SWMM -> Tools -> Project Reporting 

There are a few options on the Operation Settings tab of this dialog box that should be the same for all projects.

- The Auto Length and Auto Area calculations should be turned off (unchecked).
- The Store Absolute Conduit Invert and Store Absolute Junction Rim options should be activated (checked) so that the actual invert and rim elevations can be stored in the model.

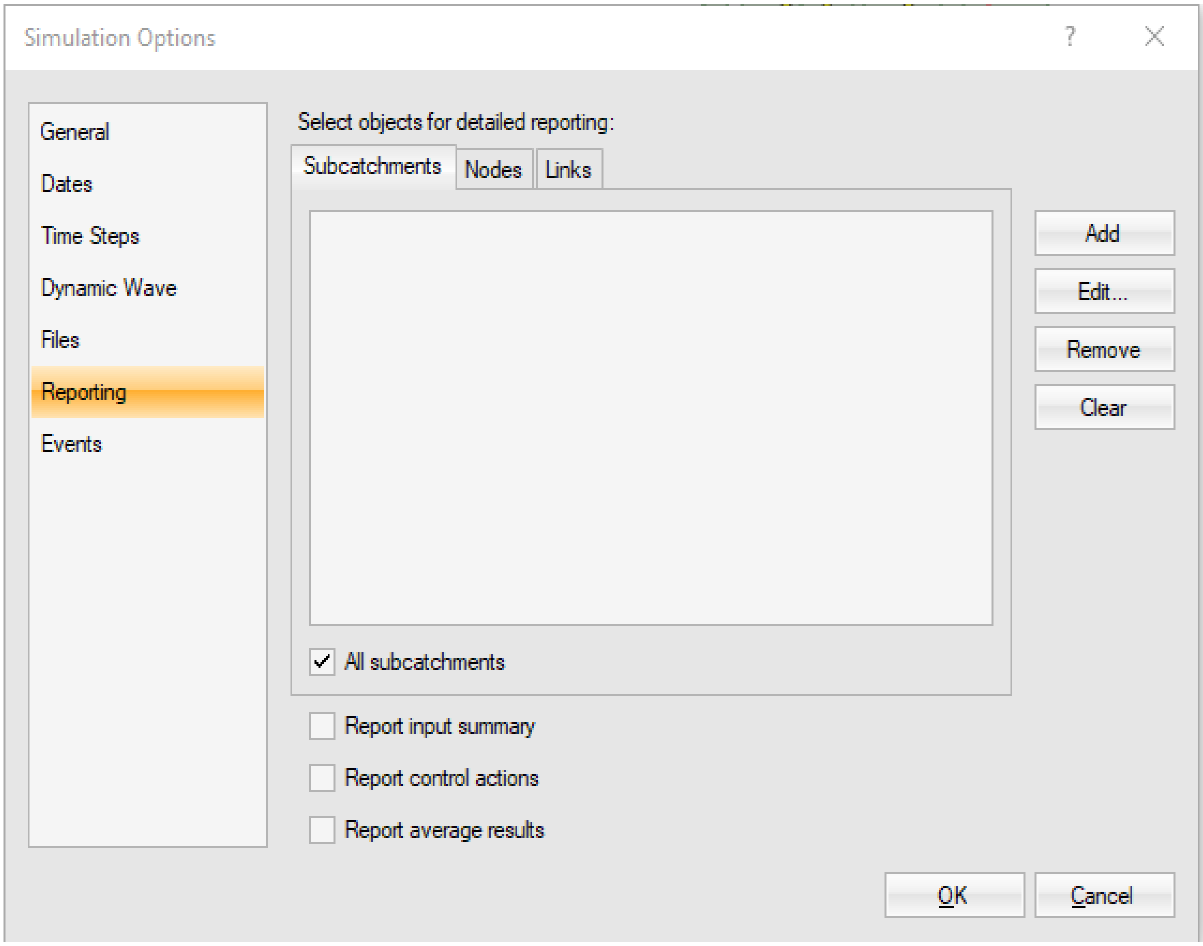


Figure 7 Project Reporting – Options Tab

5.2 Model Data Collection

The modeler should check the USEPA SWMM manual - EPA SWMM v 5.1 User's Manual (pdf) (September 2015, EPA/600/R-14/413b), which is the proper references to its modelling efforts. The following sections are going to provide the basic guidelines to collect hydrologic parameters and input information for the SWMM model. The Study Consultant may apply other methods to generate those parameters, however it is highly recommended that the Study Consultant discuss different approaches with City Staff and the Storm Water Management Team on different approaches.

a. Drainage Area and Watershed Delineation

The watershed area is one of the major hydrologic parameters in storm drainage design, defined as the runoff from the design area that flows into the outlet or a discharge point. To determine the drainage area within a watershed, the designer may use United States Geological Survey (USGS) 7.5-minute quadrangle maps or U.S. Army Corps of Engineers (USACE) topographic maps to assist with catchment delineation. HUC-8 (8-digit Hydrologic Cataloging Units), HUC-10, or HUC-12 watershed hydrologic unit maps from USGS can assist further delineation to the sub-drainage area. The National Hydrography Dataset (NHD) watershed is an ArcGIS extension tool which allows a designer to delineate a watershed from any place on the NHD system. The designer can also use the Arc Hydro toolbox from ArcGIS or Autodesk Civil 3D to delineate the watershed. The Civil Design Office of the City of Memphis will provide the drainage basin, watershed, and sub-watershed information. The Study Consultant should check the delineation of the basin before modelling.

b. Topography, Drainage Slope, and Grade

To obtain topography and slope for a design area, USGS 7.5-minute quadrangle maps, USACE topographic maps, USGS digital elevation model (DEM), or USGS digital terrain model (DTM) can be used. Because USGS has moved its 3D Elevation Program of Digital Elevation Models to Cloud Optimized GeoTIFF (COG) system, all USGS topographic information can be found in the National Geospatial Program (NGP). The City of Memphis and Shelby County have developed and updated its DEM's topography. The updated and latest version of DEM is highly recommended. Topography or survey information from a certified surveyor or professional survey company is acceptable and approved by the City of Memphis or Shelby County.

The ground slope in the watershed or design area is used to compute the average grade in the drainage area. The general method uses a USGS quadrangle map or a 2-ft contour map to obtain the slope in the design area. Another approach using the weighted slope (S_w) by Jewell, Mangarella, DiGiano, and Adrian (1976) can also be applied when a composite drainage area is designed. For most urban projects in the City of Memphis and Shelby County, ArcGIS, Autodesk Civil 3D, and USGS Digital Elevation Model (DEM) are also suitable tools to develop the slope.

c. Precipitation

A typical monthly rainfall distribution in Memphis area is listed in **Table 5**. For SWMM modeling purposes, NOAA Atlas 14 Point Precipitation Frequency Estimates, NRCS

TP-40, NRCS Type II rainfall distribution curve, and NOAA Intensity Duration and Frequency curve (IDF Curve) shall be used to develop rainfall distributions and runoff computations. The design rainfall distribution in the Hydro-35 Paper can be found in **Figure 8**.

Table 5 Average Monthly Precipitation in Memphis

Month	Average Rainfall (in)
January	3.9
February	4.09
March	4.34
April	3.89
May	3.81
June	3.55
July	4.26
August	2.75
September	2.20
October	3.73
November	4.71
December	5.13
Total	48.36

For the minor drainage system, the design storm should apply the Intensity-Duration-Frequency (IDF) curve from NOAA Technical Paper 40- Rainfall frequency Atlas to obtain the rainfall intensity from different durations for the Rational Method (https://www.weather.gov/gyx/TP40s.htm).

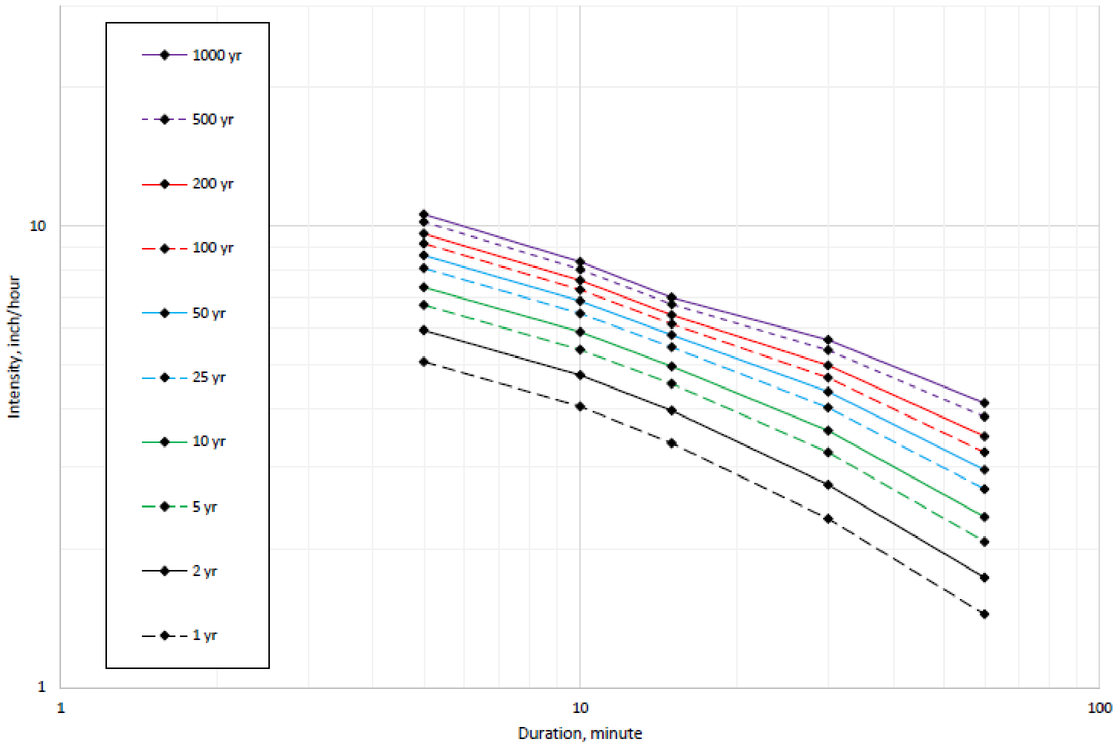


Figure 8 Duration and Frequency of Precipitation in Memphis

d. Soil Classification

Soil data is used to study the infiltration rate and support the LID design. Two soil classification systems are recommended to use: the first is a two-letter Unified Soil Classification System (USCS) to describe the soil's texture and grain size distribution. **Table 6** shows the USCS chart, a two-letter symbol where the first letter is the primary component of the soil's texture, and the second letter describes the grain size distribution or plasticity characteristics. Any interested area can be found and downloaded from the NRCS soil survey's website: (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm).

The second soil classification used in drainage design is the NRCS Curve Number (CN) for Hydrologic Soil Classification. Under this system, the soil is assigned to one of four hydrologic soil groups (HSGs): A, B, C, or D. Each soil group is determined by the water transmitting soil layers with saturated hydraulic conductivity and moisture (water) depth. Most soils in Memphis and Shelby County are loam and silt or can be found on CN Table in B or C category.

Table 6 Unified Soil Classification System (USCS) – Soil Classification

First Letter		Definition	Second Letter	Definition
G		Gravel	P	Poor graded
S		Sand	W	Well graded
M		Silt	H	High plasticity
C		Clay	L	Low plasticity
O		Organic		

e. Land Use and Impervious Area

The U.S. Geological Survey (USGS) has created the National Land Cover Database (NLCD, 2016) for the United States. NLCD 2016 contains twenty-eight different land cover products characterizing: land cover and land cover changes across seven epochs from 2001-2016, urban imperviousness and urban imperviousness changes across 4 epochs from 2001-2016, tree canopy and tree canopy change across 2 epochs from 2011-2016, and western U.S. shrub and grassland areas for 2016. The data for the City of Memphis and Shelby County can be downloaded from the following website: (https://www.mrlc.gov/data/nlcd-2016-land-cover-conus).

Impervious surface areas can be classified as total impervious areas (TIA) and effective impervious areas (EIA). The effective impervious area is the area where the impervious area is directly connected to an urban drainage system. The discharge runoff and pollutants from the effective impervious area will be directly discharged into the city drain system or the receiving waters. Impervious area information can also be found in the NLCD, 2016 under the Multi-Resolution Land Characteristics Consortium (MRLC), which can be downloaded from the following website: (https://www.mrlc.gov/).

f. Sheet Flow and Channel Flow

It was recommended by the first edition and the second edition of the City Storm Water Management Manuals that the Kinematic Wave Equation shall be used for the overland sheet flow calculation based on the following assumptions:

- Depth of flow does not exceed 0.1 feet.
- Maximum flow length should not exceed three hundred feet.

For the shallow flow, the assumptions include:

- Shallow flow is assumed not to have a well-defined channel and has a flow depth of 0.1 to 0. 5 feet.
- Shallow concentrated flow can be represented by one of seven flow types with an estimation of velocity listed in the NRCS National Engineering Handbook Part 630.

The following assumptions should be considered for channel flow:

- Bank flow velocities and channel lengths are the representative values to use in computing travel time.
- The slope of the water surface is equal to the channel slope under steady and uniform flow conditions.
- Storm drains manage a small portion of a large rainfall event. The rest of the flow may travel from streets, lawns, or yards to the outlet.

Channel flow is the last part to attribute to the time of concentration. Manning's velocity formula as shown is used to calculate the travel time and channel velocity.

$$\mathrm{V} = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{5-1}$$

5.3 Model Assembly

Several hydrologic and hydraulic parameters need to be selected to compute the discharge peak flow and flood control using the SWMM model. The following criteria and procedures for those parameter selections are recommended:

a. Catchment and Sub-catchment

A catchment is the entire drainage design area where it can be divided into several sub-catchments. The delineation of catchments and sub-catchments should follow the watershed delineation procedure described in USGS procedures. However, the sub-catchment for the delineation standpoint could be different. In the City of Memphis and Shelby County, the minimum storm drain system is a 15-inch diameter and a 24-inch diameter of this drainage study, which can deliver runoff from at least a 5-acre drainage area. It is suggested that the sub-catchment be greater than 5-acre.

b. Impervious Area

Total impervious areas (TIA) are areas where the ground surface would not allow water to percolate into the ground and, as a result, will generate significant runoff from rainfall events. The directly connected impervious area (DCIA) or effective impervious area (EIA) refers to an impervious area that is directly connected to a drainage system without flowing over a pervious area to the outlet discharge point. The total impervious area information should be obtainable from USGS National Land Cover Database (NLCD). A recommended percentage of impervious area based on the land use is listed in **Table 7**.

Typically, roofs in a single-family home comprise only 10% of the total area. Rooftop areas are considered as ineffective impervious surfaces because less than one-quarter of a roof discharges its runoff into the storm drainage system. In one special case of DCIA in SWMM computation, rooftops drain onto adjacent pervious lawn areas. They should not be treated as hydraulically effective impervious areas. It is suggested to use as a guideline 50% of rooftops as DCIA and 50% as non-DCIA in the modeling or computing of the runoff using the SWMM model.

The relationship between EIA and TIA is shown in **Equation 5-2**.

$$EIA = a * TIA^b \tag{5-2}$$

where:

EIA = Effective impervious area, %

TIA = Total impervious area, %

a & b =Constants

Table 7 Impervious Area as Percentage of Land Use

Land Use	Percent Impervious Area (%)
Commercial	56
Industrial	76
High-Density Residential	51
Medium Density Residential	38
Low-Density Residential	19
Institutional	34
Agricultural	2
Forest	1.9
Open Urban Land	11

c. Catchment Width

Catchment width is a physical parameter and an assumption value in the SWMM model. The width of the catchment is the physical width of overland flow, which leaves the sub-catchment surface and enters the main drainage conduit. If the catchment is symmetrical, the total width is twice the length of the drainage channel. Two methods for calculating the catchment width are recommended in this protocol: skew factor method and the Guo and Urbonas method.

The skew factor method recommended by the SWMM model is computed using **Equations 5-2** and **5-3** to determine the width of the catchment.

$$Zs = Am/A \qquad (5\text{-}2)$$

where:

Z_s = Skew factor, $0.5 \leq Z_s \leq 1$,

Am = Larger of the two areas on each side of the channel, ac

A = Total area, ac

If L is the length of the main drainage channel, then the width L_w is the weighted sum between the two limits of L and 2L. The width of the catchment can be expressed in **Equation 5-3** as follows:

$$L_w = L + 2L\,(1 - Zs) \tag{5-3}$$

Another method for estimating the catchment width can be calculated from the Guo and Urbonas (2009) method using the following procedure below:

- Determine the designed sub-catchment area (A).
- Measure the hydraulic path (L).
- Determine the area skewness coefficient Z_s= Am /A from **Figure 9** or **Equation 5-4.**
- Calculate the shape coefficient X= A/L^2.
- Use the general formula in **Equation 5-4** to calculate Y or L_w/L value, when K is equal to 4 as the default value.
- Find catchment width, L_w.

$$Y = \frac{L_w}{L} = (1.5 - Z)[\frac{2}{1-2K}(\mathrm{X})^2 - (\frac{4K}{1-2k})(\mathrm{X})\ ] \tag{5-4}$$

where:

Y = Ratio between catchment width and hydraulic path

L_w = Catchment width, ft

L = Hydraulic path, ft

A = Catchment area, ac

K = Constant equal to 4

X = Shape coefficient, dimensionless

Z = Skewness coefficient (in **Figure 10**)

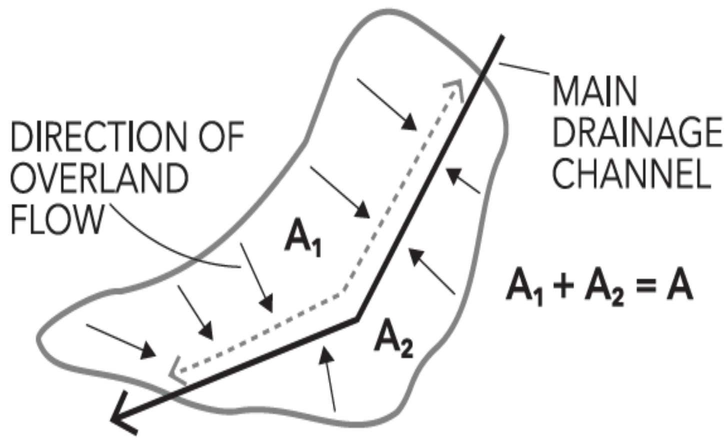


Figure 9 Determination of the Skewness Parameters

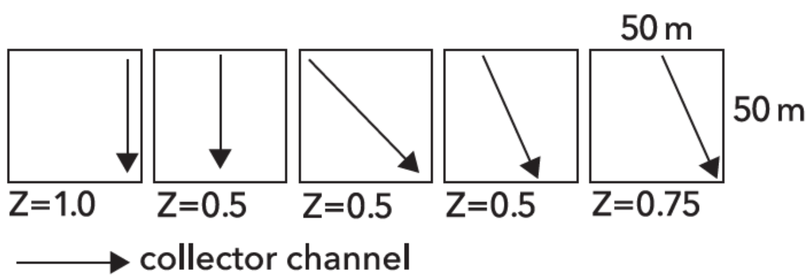


Figure 10 Determination of Z in Guo's Equation using Equation 5-4

Both methods can be quickly used to determine the width of the catchment. The final catchment width will be determined through the model calibration processes.

d. Slope

The catchment slope is the average slope along the pathway of overland flow to the outlets. It can be simplified to retrieve data from DEM or survey by taking the elevation difference of overland flow divided by the length of overland flow. Another approach using the weighted slope (S_w) by Jewell, Mangarella, DiGiano, and Adrian (1976) can be applied as shown in **Figure 11**. **Equations 5-5** and **5-6** will be used to calculate the composite slope in the study area.

e. Manning's Roughness Coefficient, n, Value

This Manning's roughness coefficient, n, value is counted for the friction roughness of overland flow and channel flow because both have considerable features included in the runoff computations. A list of Manning's roughness coefficients suggested by the SWMM model in **Table 8** is recommended to use.

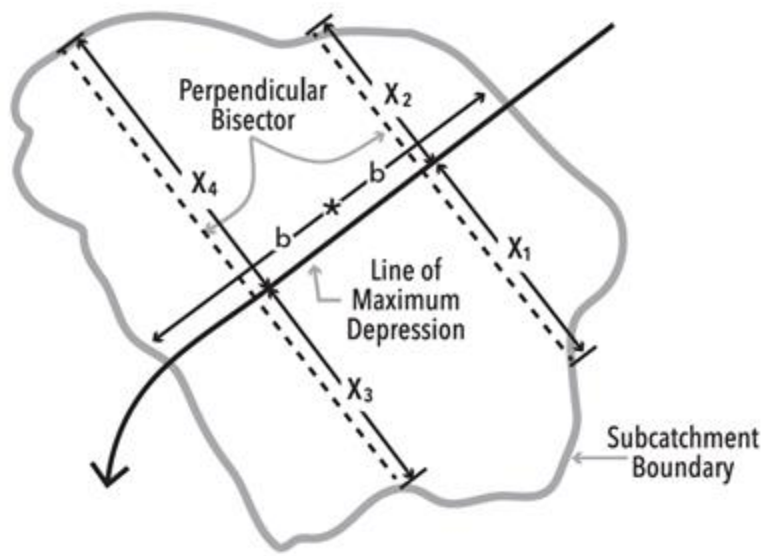


Figure 11 Determination of Basin Slope

$$\Delta Z_i = X_i S_i \tag{5-5}$$

$$S_w = \frac{\sum_{i=1}^{n} \Delta Z_i}{\sum_{i=1}^{n} X_i} \tag{5-6}$$

where:

ΔZ_i = Elevation drop, ft

X_i = Distance between elevation drop, ft

S_i = Individual slope, ft/ft

S_w = Composite slope, ft/ft

Table 8 Estimates of Manning's Roughness Coefficient for Overland Flow

Source	Ground Cover	n Value	Range
Crawford and Linsley (1966)	Smooth asphalt	0.01	
	Asphalt of concrete paving	0.01	
	Packed clay	0.03	
	Light turf	0.20	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.40	
Engman (1986)	Concrete or asphalt	0.01	0.010-0.013
	Bare sand	0.01	0.01-0.016
	Graveled surface	0.02	0.012-0.03
	Bare clay-loam /eroded)	0.02	0.012-0.033
	Range (natural)	0.13	0.01-0.32
	Bluegrass sod	0.45	0.39-0.63
	Short grass prairie	0.15	0.10-0.20
	Bermuda grass	0.41	0.30-0.48
Yen (2001)	Smooth asphalt pavement	0.01	0.010-0.015
	Smooth impervious surface	0.01	0.011 -0.015
	Tar and sand pavement	0.01	0.012-0.016
	Concrete pavement	0.02	0.014-0.020
	Rough impervious surface	0.02	0.015 -0.023
	Smooth bare packed soil	0.02	0.017-0.025
	Moderate bare packed soil	0.03	0.025-0.035
	Rough bare packed soil	0.04	0.032-0.045
	Gravel soil	0.03	0.025-0.045
	Mowed poor grass	0.04	0.030-0.045
	Average grass, closely clipped sod	0.05	0.040-0.060
	pasture	0.06	0.040 -0.070
	Timberland	0.09	0.060-0.120
	Dense grass	0.09	0.060-0.120
	Shrubs and bushes	0.12	0.080-0.180
	Business land use	0.02	0.014-0.035
	Semi-business land use	0.04	0.022-0.050
	Industrial land use	0.04	0.020-0.050
	Dense residential land use.	0.04	0.025-0.060
	Suburban residential land use.	0.06	0.030-0.080
	Parks and lawns	0.08	0.040-0.120

f. Depression Storage

Depression storage may be derived from rainfall-runoff data for impervious areas by plotting runoff volume *V* (depth) as the ordinate against rainfall volume *P* as the abscissa for several storms. The rainfall intercept at zero runoff is the depth of depression storage *ds*, i.e., a regression of the form is shown in **Equation 5-7**:

$$V = C\,(P - d_s) \qquad (5\text{-}7)$$

where *C* is a coefficient.

This kind of analysis tends to work better for longer averaging periods than individual storm events, but will work better for small, more impervious catchments than for larger mixed catchments for individual storm events. The reason is that even for small rainfall amounts, impervious surfaces (DCIA) will generate some runoff (one reason for the *% Zero-Imperv* parameter). Hence, a depression storage value found as the intercept may be appropriate for a longer-term water balance than for simulation of hydrographs.

Depression storage (ds) is the volume of runoff which fills into pervious and impervious areas. In the SWMM model, water stored in depression storage on impervious areas is depleted only by evaporation; therefore, it takes much longer to restore such storage to its full capacity. The depression storage equation developed by Viessman, Knapp, and Lewis (1977) is recommended to use and is shown in **Equation 5-8**.

$$ds = 0.303\, S_L^{\,0.49} \qquad (5\text{-}8)$$

where:

ds = Depression storage, in

S_L = Average slope in catchment, ft/ft

g. Infiltration

Infiltration is a major process of water movement into the soil under gravity and capillarity forces. It is the largest portion of rainfall losses during the hydrologic processes. The method used to define and determine the number of rainfall losses highly depends on the type and condition of soil studied. There are several infiltration methods used for the SWMM model. However, the Green-Ampt method and the NRCS Curve Number Method are two recommended infiltration methods for SWMM application in the City of Memphis and Shelby County. The Green-Ampt method theory and calculation can be found in the SWMM reference manual version 5.1 – Section 4.4 and by clicking on the following link:

(https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P2NY.PDF?Dockey=P100P2NY.PDF).

For a long-time simulation, the Green-Ampt infiltration procedures for the available rainfall exceedance shall be computed using the follow steps:

- Select the design storm or rainfall intensity data.
- Obtain the initial and saturated soil moisture content in **Table 9.**
- Select or measure the soil hydraulic conductivity and suction head.
- Determine the infiltration rate, Fs (in/hr.), and calculate the ponding time (ts).
- Develop the infiltration rate based on the various times.
- Determine the runoff when the runoff intensity or volume exceeds the infiltration rate; otherwise, the runoff is equal to 0.

h. Minor Head Losses

Despite the friction head losses in the closed conduit system, the minor head losses depend on pipe configuration, entrance, and exit angles, bends, expansion, and contraction at the manholes or junctions. The modeler should use better estimations and approaches to project junction and minor head losses in the close conduit system with free surface flow and without pressure flow conditions. As defined by the minor head losses, HL can express it = K ($\frac{V^2}{2g}$), where K is a loss constant, V is the velocity in the conduit, and g is the gravity constant. The recommended loss constants are listed below:

- Entrance

  Entrance loss coefficient is based on the shape of the entrance pipe or the condition of storm drain and manhole. A free-flowing stream entering a pipe is the most common condition. The entrance loss constant for a sharp-edged entrance is 0.5 and the slight round entrance is 0.25. Other conditions should check the reference of hydraulic handbooks.

Table 9 Green-Ampt Parameters for Different Soil Classes (Rawls et al., 1983)

Soil Class	Porosity, ϕ	Effective Porosity, ϕe	Wetting Front Suction Head, ϕs (in)	Saturated Hydraulic Conductivity, Ks (in/hr)
Sand	0.437 (0.374-0.500)	0.417 (0.354-0.480)	1.95 (0.38-9.98)	4.74
Loamy Sand	0.437 (0.363-0.506)	0.401 (0.329-0.473)	2.41 (0.53-11.00)	1.18
Sandy Loam	0.453 (0.351-0.555)	0.412 (0.283-0.541)	4.33 (1.05-17.90)	0.43
Loam	0.463 (0.375-0.551)	0.434 (0.334-0.534)	3.50 (0.52-23.38)	0.13
Silt Loam	0.501 (0.420-0.582)	0.486 (0.394-0.578)	6.57 (1.15-37.56)	0.26
Sandy Clay Loam	0.398 (0.332-0.464)	0.330 (0.235-0.425)	8.60 (1.74-42.52)	0.06
Clay Loam	0.464 (0.409-0.519)	0.309 (0.279-0.501)	8.22 (1.89-35.87)	0.04
Silty Clay Loam	0.471 (0.418-0.524)	0.432 (0.347-0.517)	10.75 (2.23-51.77)	0.04
Sandy Clay	0.430 (0.370-0.490)	0.321 (0.207-0.435)	9.41 (1.61-55.20)	0.02
Silty clay	0.479 (0.425-0.533)	0.423 (0.334-0.512)	11.50 (2.41-54.88)	0.02
Clay	0.475 (0.427-0.523)	0.385 (0.269-0.501)	12.45 (2.52-61.61)	0.01

- Exit

  Exit loss occurs as the conduit flow discharges into a free water body or another hydraulic structure. The loss constant is 1.0 applied to the velocity of the upstream pipe.

- Expansion and Contraction

  Loss constants for the expansion and contraction in open channel or between the conduit and open channel were developed by Chow (1959) and vary depending on the shape of the transition structure. **Table 10** shows the loss constants of different transitions for a rectangular open channel system. Other methods can be used depending on the condition. It is strongly recommended that the study team provide the references and discuss it with City Staff.

Table 10 Expansion and Contraction Loss Constants (Chow, 1959)

Type of Transition	Inlet	Outlet
Warped	0.1	0.2
Cylinder-Quadrant	0.15	0.25
Simplified Straight Line	0.20	0.30
Straight Line	0.30	0.50
Square-Ended	0.3+	0.75

Marsalek (1985) conducted experiments for loss constants in pressure flow and free flow conditions. The losses can be determined by the ratio of manhole width (W) and diameter of connected conduit (d) using the minor head loss equation based on the downstream velocity head. The results are shown in **Table 11**.

Table 11 Head Loss Coefficients of Bending and Benching (Marsalek, 1985)

W/d	No Shaping	Half Benching	Full Benching
2.3	0.29		0.12
2.0	0.22	0.16	
1.6	0.16		
1.3	0.13		
1.0	0.12		

i. Ponding Area

Normally in flow routing, when the flow into a junction exceeds the capacity of the system to transport it further downstream, the excess volume overflows the system and is lost. An option in the SWMM model allows extra flow to be stored at the top of the junction, instead of being lost from the system. The stored flow can go back to the system when it has capacity. Under the Kinematic Wave flow routing, the ponded water is stored simply as an excess volume. For Dynamic Wave routing, which is influenced by the water depths maintained at nodes, the excess volume is assumed to pond over the node with a constant surface area. This amount of surface area is an input parameter supplied for the junction.

The most popular and effortless way to manage the ponding area and to code the volume into the junction is described below:

- Assume a ponded area.
- Run the model and find out the maximum ponded volume.
- Iterate by using the maximum ponded volume and an assumed maximum ponded depth to find the good estimation of the ponded area.
- As the ponding volumes merge or close to each run, the ponded area is the final value put into the model.

j. Boundary Condition

The City's drainage basins may discharge an outfall with a downstream condition. The model will determine the water surface level at the outfall. The approach for each of these boundaries during system analysis is described below:

For modeled basins that discharge into another basin downstream the boundary condition should be carefully considered. In the model, the "Type" of outfall assigned determines the stage against which the outfall is evaluated. The most usedoutfall types are:

- **Free –** The outfall stage is determined by the minimum of the critical flow depth andthe normal depth of flow in the model element.
- **Normal –** The outfall stage is based on the normal flow depth of the receiving stream atthe discharge location.
- **Fixed –** The outfall stage is determined by a fixed valued input by the modeler.

- **Time Series –** The outfall stage is provided from a time series of elevations. The modeler should select the most appropriate outfall type that reflects the stage condition for the downstream discharge location.

a. Backwater Effect

Locally, stormwater is discharged to one of four major rivers: the Mississippi River, the Loosahatchie River, the Wolf River, and the Nonconnah Creek. In addition to these rivers, basins may discharge into smaller creeks, upstream of these rivers as well as directly into the Mississippi River. Of these water bodies, the smaller creeks and the Nonconnah Creek tend to be more responsive to the rainfall (i.e., levels tend to respond much quicker during rain events) than the Mississippi, Loosahatchie, or Wolf Rivers.

The appropriate boundary condition will vary from basin to basin and may also vary by the design storm being evaluated. It is up to the modeler to determine the appropriate boundary condition to use for each individual basin and storm being evaluated. The following should be taken into consideration when selecting the boundary condition for any basin:

- The design storm being evaluated.
- The sensitivity of the receiving water to rainfall.
- Observed high water marks or flooding at the outfall location.
- The availability of historical stage data from the USGS or FEMA for the receiving water body.
- The distance from the basin outfall to available stage gauge data.

The risk tolerance for a given area should be taken into consideration when identifying the appropriate boundary condition. For example, if an area is particularly sensitive to flooding a more conservative boundary condition may be selected for a basin. During the calibration process the selection of the boundary condition should be evaluated. The reasoning for the selection of the boundary condition(s) should be documented.

5.4 Existing Model System Setup

The hydrologic model estimates the runoff characteristics in each subcatchment. The input of data shall follow the standards outlined in the USEPA SWMM model user manual. The hydraulic model is used to analyze the performance of conveyance and drainage patterns of conduits and open channels in the model. The existing model incorporates storm drains, open channels, and hydraulic structures to determine the quantity of runoff generated in each basin.

As all hydrologic and hydraulic parameters, including rain gages, junctions, storages, subcatchments, conduits, pumps, orifices, weirs, and outlet data enter the SWMM model as shown in **Figure 12** for the existing model, the preliminary runoff from each basin and at each junction will be obtained.

5.5 Model Calibration and Verification

Model calibration is a procedure to justify the model parameters as the model results compare to the data collected from the field. This process involves comparing the modeled results to actual measured values in the field. It is a tedious and trial-and-error process. The fundamental concept of calibration is to optimize and adjust the modeling parameters. According to the EPASWMM parameter sensitivity study, the sensitivity of runoff volume and peak flow to surface runoff parameters are listed in **Table 12**.

5.6 Calibration and Validation Criteria

The Study Consultant needs to carefully investigate the preliminary hydrograph and the sensitivity of hydrologic parameters once the SWMM model is built. The hydrologic and hydraulic parameters need to be justified one-by-one for the model calibration. The parameters include:

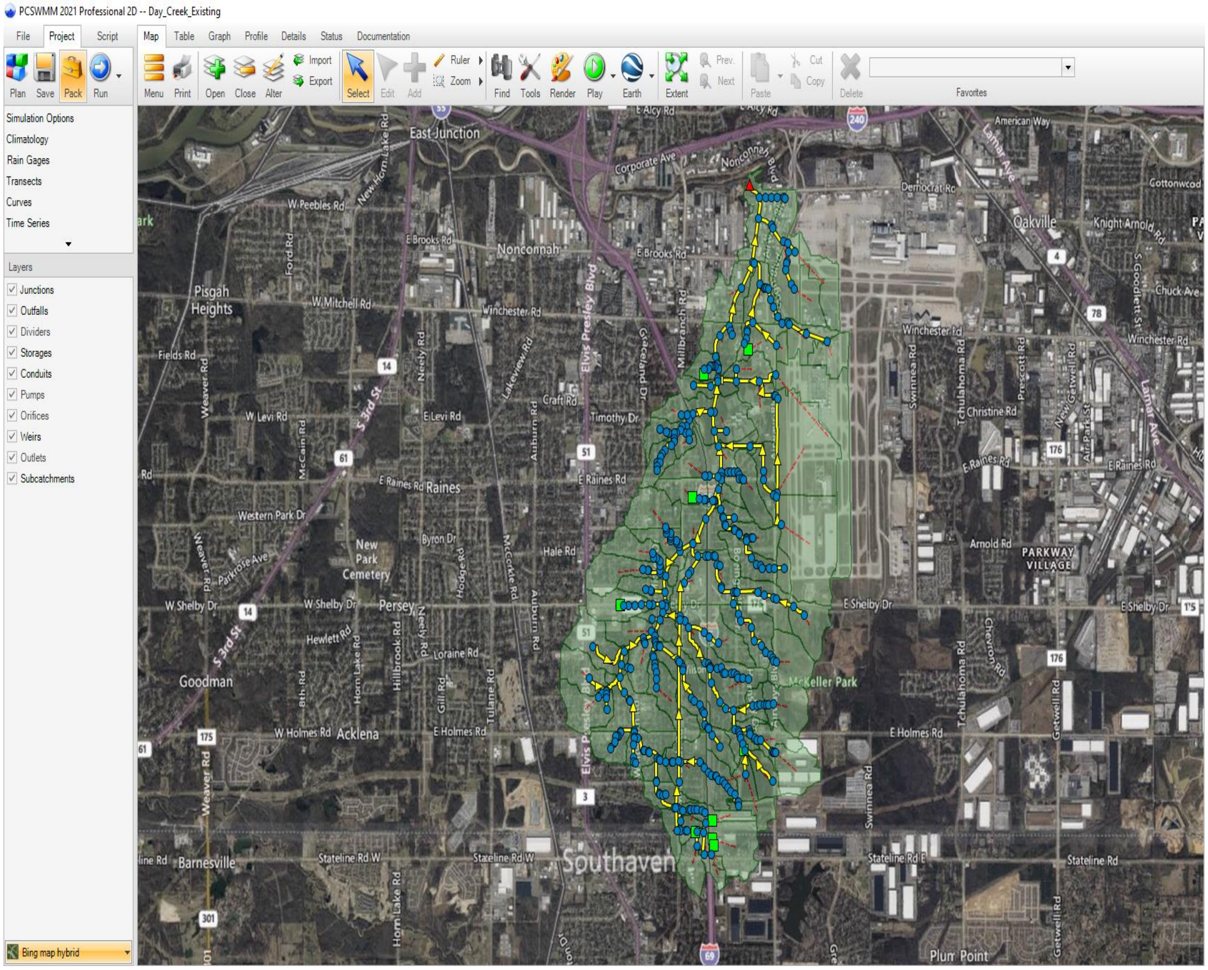


Figure 12 Example of PCSWMM Existing Model

Table 12 Sensitivity of Runoff Volume and Peak Flow to SWMM Parameters (USEPA, 1985)

Parameters	Typical Effect of Hydrograph	Effect of Increase Runoff Volume	Effect of Increase Runoff Peak
Area	Significant	Increase	Increase
Imperviousness	Significant	Increase	Increase
Width	Affects shape	Decrease	Increase
Slope	Affects shape	Decrease	Increase
Roughness	Affects shape	Increase	Decrease
Depression Storage	Moderate	Decrease	Decrease

a. Basin geometry – basin width and/or slope.

b. Basin characteristics – runoff roughness coefficients, basin impervious area, depression storage, and infiltration parameters in Green-Ampt Equation.

c. Other hydraulic parameters – inlet width, junction elevation, ponding area, and outlet elevation.

Three basic criteria should be applied for the model calibration: (1) minimizing the values of the peak flows; (2) minimizing the total flow volume; and (3) maintaining the similar shape of the hydrograph. Utilization of comparison to real-time field data as the base, the deviation between the raw model and calibrated model needs to be plotted as shown in **Figure 13**.

Each model should be calibrated using at least one rainfall event and validated using the rest of the rainfall events. Charts and tables showing the final results of the calibrated models as compared with the observed storm data should be provided in the final documents.

The scenario manager in SWMM should be used to organize different models for calibration and validation. The final calibration model and validation model should be clearly labeled and documented for the modelling QA/QC processes. The following file names and labels are recommended:

[Study District] [Study Area Code]- [Scenario]-[Rainfall]- [User Defined]

where:

Study District + Study Area Code: A combination of the City assigned codes for each Study Area as shown in **Table 3**. For example, each element in the Lick Creek study area wouldbe identified as LC.

Scenario manager: The files of calibration and validation that is being labeled:

- Existing system (mm/day/year) --> LCEX08312023,
- Calibration storm (mm/day/year) --> LCCL09012023,
- Validation system (mm/day/year) -- > LCVAL09182023,

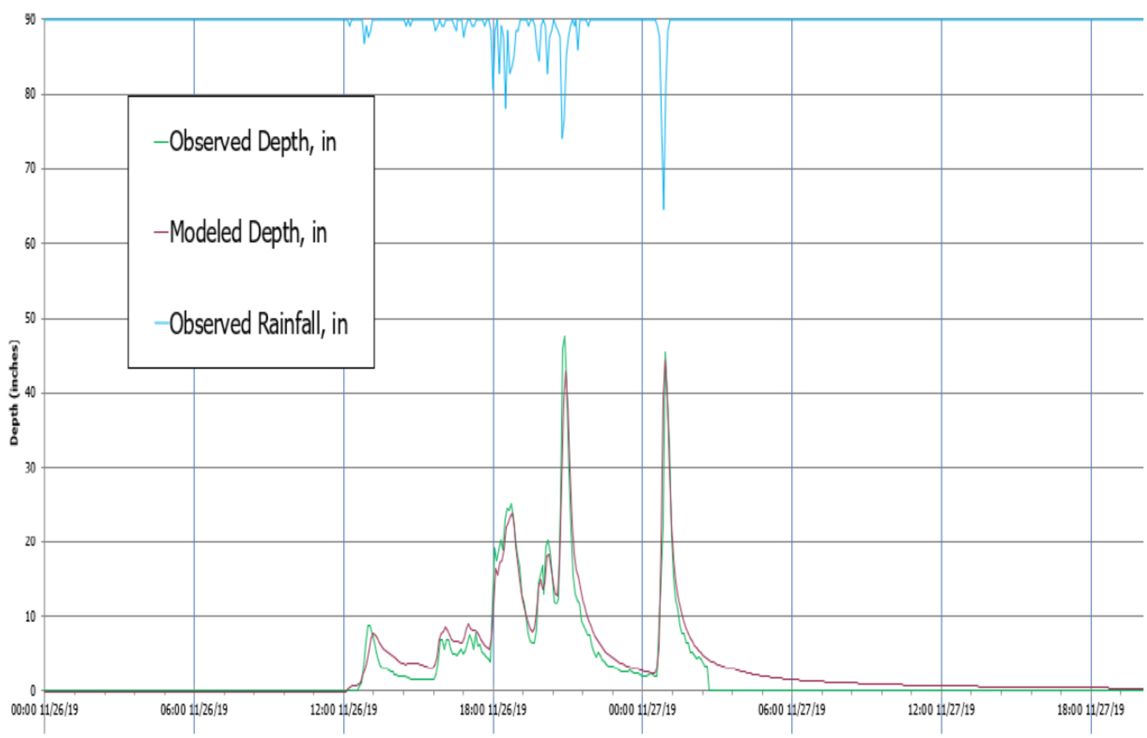


Figure 13 Comparison between SWMM Model and Gage Data During Calibration Processes

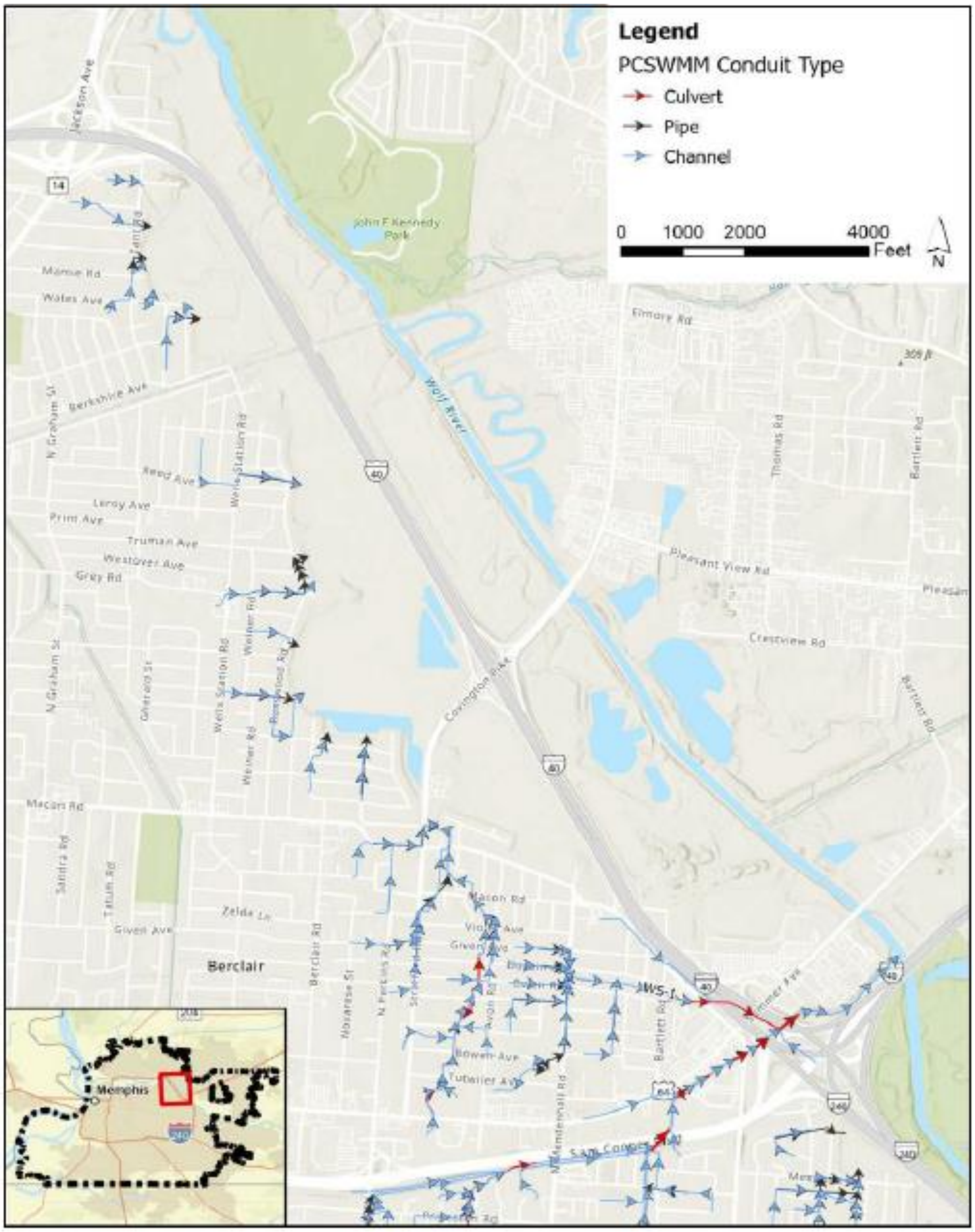


Figure 14 Drain Network Using PCSWMM

Chapter 6 Flood Analysis and Alternative Selection

6.0 Introduction

The H&H model assembled with GIS layers and survey data is shown in **Figure 14**. The model shall be run the existing flood analysis. In addition, the model shall be calibrated with real-time flow discharge and flow depth data. Once model calibration is completed, the next step is to utilize the model to analyze flooding during various design storms, called the existing conditions. The Study Consultant evaluates potential scenarios. Several alternative solutions to relief flood shall be proposed. The QA/QC reviewer and MSQ2 team will join each stage presentation. The results of both the existing conditions and proposed alternatives, along with cost estimates of said alternatives shall be presented to City Staff, MSQ2, and evaluated by the QA/QC reviewer for concurrence prior to proceeding to each next step. The procedures for each step are documented below.

6.1 Existing Conditions Analysis and Flood Mapping

The Study Consultant shall prepare inundation maps for the following storm events under existing conditions:

a. 2-year.
b. 5-year.
c. 10-year.
d. 25-year.
e. 50-year.
f. 100-year.

These maps are to be created within the SWMM model; however, at a minimum the 10-year and 100-year inundation maps shall be included in the final report. One example of the 10-year flood analysis and inundation map is shown in **Figure 15**. Optionally, the Study Consultant may include all storm events within the report at their own discretion and expense. The model results shall summarize water surface elevations throughout the study area to identify flooding locations. The maps shall delineate affected properties showing whether flooding will impact roads, yards, ancillary structures, and/or homes. The Study Consultant shall vet these results with service requests and drainage investigations provided by the City. The Study Consultant shall submit this data to City Staff, MSQ2, and the QA/QC reviewer for concurrence before proceeding to the selection of alternatives. A meeting may be required if there are any questions.

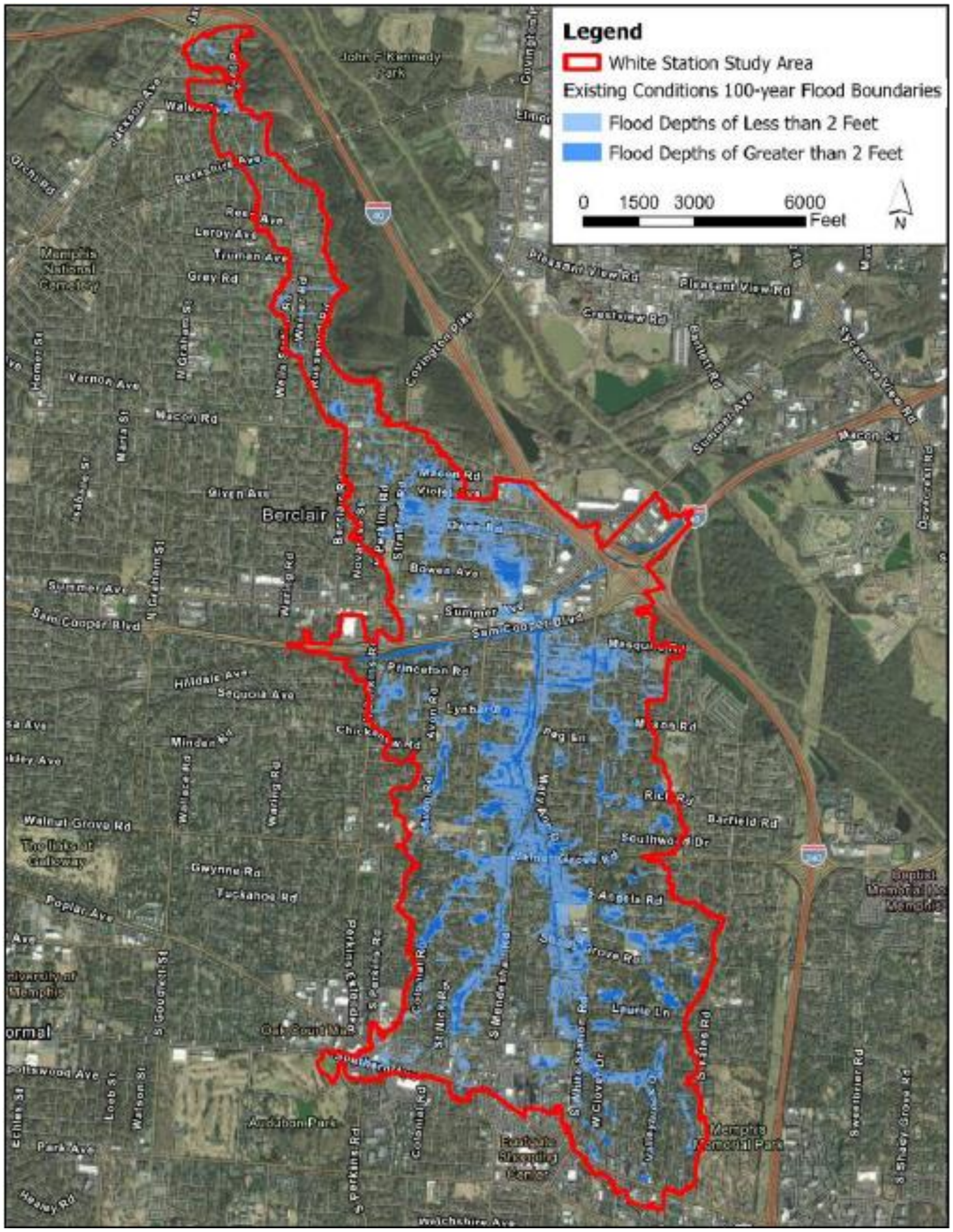


Figure 15 Flood Analysis and Inundation Map

6.2 Alternative Selection and Mapping

Based on input from City Staff and the H&H models after the review of the existing conditions model, the Study Consultant shall evaluate the impacts of potential areas of inundation. The alternative solutions for flood relief plans shall be developed and presented to City Staff. The objectives of the alternative plan are to:

a. Prevent in-structure, living space flooding (especially repetitive and documented flooding) at the 10-year or less design storm.
b. Maintain flood stages below this design storm.
c. Keep runoff below the six" curb elevation.

Note that adjustments may be made by City Staff as well as in accordance with MSQ2's Risk Integrated Project Prioritization (RIPP) scoring process. Reasonable improvement alternatives will be modeled and presented in the SWMM model.

Each improvement plan (called an alternative model) must be built within the calibrated model and evaluated under each design storm event listed in 6.1. A modified water surface elevation for each alternative shall be calculated so that the effect of each alternative may be compared to other alternatives and other studies. The Study Consultant shall identify solutions that may work well together to offer reduction of flooding across the entire study area. It is encouraged that the Study Consultant evaluate alternatives individually; the City may only have the ability to construct a portion of an alternative at one time due to funding or inability to acquire property. In the event multiple alternatives in an area need to be proposed, the Study Consultant shall consider the priority/sequencing in which the solutions are to be constructed, as to avoid a worsening of flooding impacts. Consultation with City Staff should be considered at this event.

Potential solutions that may be considered are:

a. Conveyance Upgrades: upsizing of pipes, culverts, open channels.
b. Above or Below Ground Detention Facilities.
c. Expanded Floodplains.
d. Green Infrastructure.
e. Pumped System.

Alternatives shall be avoided under the following circumstances:

a. Alternative involves crossing a railroad or major highway (example: do not propose upsizing a culvert under Interstate 240 or the BNSF Intermodal Yard.
b. Construction of an alternative which involves the acquisition of occupied parcels (homes, businesses, etc. unless they are a tax sale).
c. Installation of culverts or a new concrete-lined channel within a natural conveyance due to permitting issues.

The following criteria is preferred when proposing new alternatives:

a. Private ownership of improvements (specifically detention/retention ponds, green infrastructure) is preferred over public ownership.

b. Above-ground detention facilities are preferred to underground detention facilities.

c. Gravity flow is preferred to pumped flow.

In the event there is no other feasible solution besides these mentioned above, the proposed condition shall be presented to the City for approval. Such approval may need to be approved by the City Engineer and/or City Public Works Director. Final determination shall be documented in the final report.

Note: as stated, the minimum design standard is for a 10-year storm or less. However, an alternative may be proposed if the cost for the higher design is not increased or the benefit is increased for the minimal cost increase. Engineering judgement shall be utilized in making this decision and demonstrated in the final report and to City Staff.

6.3 Model Organization

The scenario manager in SWMM should be used to organize different model for frequency/recurrence flows. The final model should be clearly labeled and documented based on the following labelling procedures:

[Study District][Study Area Code]- [Scenario]-[Rainfall]-[User Defined]
where:

Study District + Study Area Code: A combination of the City assigned codes for each Study Area as shown in **Table 4.1**. For example, each element in the Lick Creek study area wouldbe identified as LC.

Scenario manager: The files of calibration and validation that is being labeled:
Frequency system (FQ: year) --> LCFQ02YEAR

6.4 Cost Estimation Procedures

The consultant is required to prepare cost estimates and the cost for each solution from the alternative models. Cost estimates will be prepared in tabular format using EXCEL worksheets or workbook. Eachtable shall include the following items:

a. Description of the task.

b. Item number (following City of Memphis specification format. If none exists, leave columnblank).
c. Pay unit (how this item is paid: lump sum, each, or specific quantity. Keep this consistentwith City of Memphis Specifications.).
d. Quantity (associated with the pay unit).
e. Unit Price (Use City of Memphis specified amounts, where given. Provide source of anyunspecified unit costs by footnote.).
f. Price per item (the extension by multiplying quantity by price per unit).

A benefit-to-cost (B/C) ratio analysis of each alternative should be submitted and presented in the way for the final selection. It is advised that this analysis should be compliant with FEMA requirements.

6.5 Summary of City Coordination

To summarize when City Staff concurrence is needed, the potential meetings and submittals are discussed below. Required steps are in bold and potential interactions are in regular text. Note that this is a general guideline and further meetings may be needed.

a. Review of Calibrated Model and discussion of potential alternatives (Meeting with City Staff, MSQ2, QA/QC Reviewer).
b. Submittal to QA/QC Reviewer for approval (via email).
c. Follow up meeting with City Staff and QA/QC Reviewer.
d. Meeting to discuss proposed alternatives if there issues.
e. Review of Final Alternatives and Model (Meeting with City Staff, MSQ2, QA/QC Reviewer).
f. Submittal of final model to QA/QC Reviewer for approval (via email).
g. Any follow up meeting with City Staff and QA/QC Reviewer).

Chapter 7 Final Project Report Submission

7.0 Introduction

Once the drainage study is completed, the Study Consultant needs to prepare a final submission to the City, including final reports, survey data, GIS data, photos, public meeting records, and the H&H models. The final report consists of two volumes; the first volume (or Volume 1) includes general information of the drainage study, primarily utilized by Senior City Staff and/or City Administration and the second volume (Volume 2) provides a more comprehensive and in-depth discussion of the drainage study, primarily used by internal City Staff engineers as well as MSQ2The following items must be submitted to the City (a summary of the file structure is included in **Appendix E**):

7.1 Survey Data

Detailed survey coordination, structure type, and photographs shall be included with the final submission. A point file of the surveyed elements shall be submitted in AutoCAD. The version of AutoCAD should be compatible with that in use by the City at the time of the project award. This file is for the City's use to improve its records of the existing drainage infrastructure. This is not intended to be a "worked-up" AutoCAD file, but simply the points and basic automation. A summary coding table with detailed descriptions of each point should be presented and included in **Appendix A**.

7.2 Geographic Information Systems

The GIS data should use version 10.8.1 or higher version of ArcGIS. To ensure those compatible to the CAESER Center format, all feature layers in the provided geodatabase shall have the same coordinate system. Typically, the NAVD88 datum or the NAD_1983 Tennessee State Plan Coordinates- FIPs 4100 is required. Deliverable materials will also be included the packaged PCSWMM digital model including all results and GIS background layers. As a part of the model network, GIS layers depict flooded areas under each modeled storm event for existing conditions and the recommended alternatives shall be prepared for electronic submission. The flood inundation maps may be interpreted either using 2D PCSWMM extension or flood inundation analysis to show the floods. The 10-year inundation map and the 100-year inundation maps generated from PCSWMM and DEM flood analysis. Other flood inundation methods need to receive the approval from the City. The final submission of all GIS data will be transferred to MSQ2 and (CAESER. If there is an inactive GIS layers used the models, the Study Consultant should explain and demonstrate the layers which are not included in the submission. A typical

GIS mapping is shown in **Appendix C**. Another GIS schema format is listed in **Appendix D**.

7.3 Final Report

Two (2) printed, bound, full-color copies of the final report should be submitted to the City and the Storm Water Management Team. The following sample report outline is a general approach intended to standardize the final reports received by the City to maximize the usability of the final products throughout the applicable City operational divisions. Each final report shall be tailored to the individual study, although it is expected that any major deviations from the report outline, defined below, be approved prior to the submission of the final report.

The Volume 1 report is a summarized report, which provides general information about the project. The final report shall include the following items:

a. An Executive Summary, no more than five pages in length, highlighting the modeling. effort, recommended improvements, and estimated costs.
b. Background information for the project and a synopsis of known issues.
c. Summary/Results from the existing conditions analyses.
d. Summary/Results from the alternatives analyses.
e. Planning-level cost analysis for each of the recommended improvements.
f. A FEMA-compliant Benefit-Cost Analysis.
g. Color exhibits (1:200 scale, max) illustrating the modeled flooding extent for the existing and improved conditions.
h. Incorporation of pertinent City comments.

The Volume 2 report contains more detailed information than Volume I. The materials and contents should be more comprehensive and detailed. The following items should be included:

a. Executive Summary

   The executive summary is intended to summarize the project in a short and meaningful way for senior City Staff and leadership. It should be limited to five pages and include a description of the problems, study efforts, recommendations, and associated costs.
b. Table of Contents
c. List of Tables (refer to following pages for examples)
d. List of Figures
a. List of Exhibits (refer to following pages for examples)
b. Chapter 1: Project Introduction and Background

   This section is intended to provide an overview of the project area, which would include known problem areas and an exhibit of the study area illustrating the drainage basin and known issues covered in aerial photography.

c. Chapter 2: Review of Previous Studies and Available Data

This section is intended to include a review of any applicable studies, if any, and other pertinent data available from the City or other reliable sources.

d. Chapter 3: Modeling Preparation and Results

This section is intended for the discussion of specific modeling exercises, analysis of existing conditions, development and testing of improvement alternatives, and cost estimating. If the overall study area includes smaller sub-basins that warrant individual discussion, each sub-basin should be included in its own section. This section shall contain a listing of all assumptions and parameters used by the modeling team to develop the models and a rationale for the decisions made.

- Review of Hydrologic and Hydraulic Modeling Approach

  This section is intended to include an overview of the overall modeling approach and process used, as well as details of the model validation efforts.

- Existing Conditions Analysis and Review

  This section should include a review of the modeling results for the features which could aggravate flooding conditions, and applicable exhibits and profiles to illustrate the modeling results.

- Development and Modeling of Potential Solutions

  This section should include a review of the modeling results for the various alternatives analyzed; including details of flooding areas, elevations, features which could aggravate flooding conditions, and applicable exhibits and profiles to illustrate the modeling results.

- Cost Estimates

  This section should include a cost estimate for the construction of each recommended improvement. Cost analyses should include the cost to purchase land to construct any improvements.

e. Chapter 5: Final Recommendations

This section should contain an overall summary of all the recommended improvements, sequence of proposed improvements, estimated construction costs, and a benefit-cost analysis for the recommended course of action in the basin.

f. Chapter 6: Benefit-Cost Analysis

This section shall include a Benefit-Cost Analysis consistent with FEMA standards for each individual project that comprises the final recommendation and the entirety of the final recommendation. Refer to FEMA's website: (http://www.fema.gov/benefit-cost-analysis) for additional details, methodology, and software tools.

g. Standard Exhibits

This section shall include the following items:

- Summary Tables for Scenario Result.
- Overall Study Area Map (11" x 17", Scale Unrestricted).
- Sub-Basin Delineation Map (11" x 17", Scale Unrestricted).
- Existing Conditions Plan and Floodplain (11" x 17", 1" = 200' MAX Scale).
- Improved Conditions Plan and Floodplain (11" x 17", 1" = 200' MAX Scale).

7.4 Model Transfer

The Study Consultant is expected to transfer ownership and operation of the project models to the City. This service shall include, at a minimum, the following:

a. Provision of competed models on write-protected digital media for installation on the City servers. The folder/file naming convention and organizational structure shall be provided.

b. A presentation to selected City Staff to review the completed model, including all non-standard aspects.

c. The consultant's lead modeling engineer shall attend two separate 4-hour sessions at City Hall to ensure the model is running correctly on City computers and the results are consistent with those presented in the Final Report.

A point file of the surveyed elements shall be submitted in AutoCAD format. The version of AutoCAD should be compatible with that in use by the City at the time of the project award. This file is for the City's use to improve its records of the existing drainage infrastructure. This is not intended to be a "worked-up" AutoCAD file, but simply the points and basic automation.

Only surveyed features that are included in the drainage model and all photographs will be incorporated into the GIS deliverable. It may not be necessary for the Study Consultant to incorporate all surveyed data into the drainage model. Engineering judgment will be used to dictate the specific elements that are incorporated into the model. The GIS deliverable will also include the drainage model network. As a part of the modelnetwork, GIS layers depict flooded areas under each modeled storm event for existing conditions and the recommended improvements shall be prepared for electronic submission. An updated Metadata file documenting the Study Consultant's work will be prepared for electronic submission.

Other survey data that include comma-separated file of all surveyed features will be submitted. Files will be named appropriately to include the Study District Number and the Study Area Code in the file name. File names shall be in the following format:

[Study District] [Study Area Code] _ [Study Area Name] _ [Survey Feature or GIS file] _[User Description]

where:

Study District: The City assigned code for the Study District where the basin is located.
Study Area Code: The City assigned code for each study area.

Study Area Name: The name of the area under study

Survey Feature: The assigned feature nomenclature

The following maps will be prepared as final project deliverables on paper and as PDF files. All deliverables will be prepared for presentation on 11"x17" paper and will be in color. All maps are to be oriented with north or east at the top of the page. A north arrow is to be included.

An electronic version of the title block will be furnished to the Study Consultant during the study. All graphics will be titled as follows:

[Study District] [Study Area Code] _ [Study Area Name] _ [Exhibit No X] _ [Map Title]

a. Overall Study Area Map - unrestricted scale, fit to one page. All streams, channels and primary roads shall be depicted.
b. Sub-Basin Delineation Map – unrestricted scale, fit to one page. The model network, streams, channels, and primary roads shall be depicted. The graphic shall be oriented with north or east at the top of the page.
c. Existing Conditions Plan and Floodplain – maximum scale at 1 inch = 200 feet, use multiple sheets, as necessary. Odd size scaling shall not be used. Include a

sheet/key index on each plan page. Acceptable scaling includes: 1 inch = 100 feet, 1 inch = 50 feet. Include both text and graphic scale on the page. Include 2-foot contours as furnished by the City and modified at the channels. The graphic is to highlight areas expected to be flooded by the 10-year storm and the additional areas expected to be flooded by the 100-year storm. The maps should differentiate pictorially whether a house will be flooded during the 10- and 100-year storm events based on its finished floor elevation.

d. Improved Conditions Plan - maximum scale at 1 inch = 200 feet, use multiple sheets, as necessary. Include a sheet/key index on each plan page. Match the scale and tiling of the Existing Conditions Plan and Floodplain Map. Include both text and graphic scale on the page. The plan should call out and schematically depict all recommended improvements to the drainage network. Contours should only be presented where changes are necessary as a part of the system improvements, such as the addition of a storage area.

e. Improved Conditions Plan and Floodplain - maximum scale at 1 inch = 200 feet, use multiple sheets, as necessary. Match the scale and tiling of the Existing Conditions Plan and Floodplain Map. Include both text and graphic scale on the page. Graphic to show area and expected to be flooded by the 10-year storm and area expected to be flooded by the 100- year storm after all improvements have been implemented. The maps should differentiate pictorially whether a house will be flooded during the 10- and 100-year storm events based on its finished floor elevation.

7.5 Public Survey Data and Database

Although much can be learned through survey, modeling, and analysis, public input brings an aspect of true experience – actual vs. theoretical conditions. Public observations and experiences can assist the Study Consultant in determining where to focus the investigations and in calibrating the model.

To capture pertinent information from the public regarding their experiences with flooding, the Study Consultant shall use the survey form provided in Appendix 2.0. The form shall also be made available on the Study Consultant's drainage basin website for electronic upload. A basic Adobe file of the document will be provided by the City for the Study Consultant's use and customization.

The collected survey data shall be incorporated into a Geodatabase which will be turned over to the City of Memphis Division of Engineering at the completion of the project.

Some surveys received may be for a property outside of the Study Consultant's assigned boundary. These surveys will be included in the database and will be entered with the appropriate study district and study area identification numbers (ID) as listed in **Table 1**.

7.6 Study and Result Website

The Study Consultant shall assist City Staff to create and maintain a study area specific website. The website will be posted on-line after the first public meeting is completed. The website will be maintained by the Study Consultant for six (6) months after project completion. At that time, the City will either take ownership or discontinue the website.

The website will be linked to a City-hosted webpage dedicated to the City's Stormwater Management Program. The consultant's website will follow a ".net" framework to facilitate inclusion in the City's hosted webpage. The content of the Study Consultant's website shall be professional in appearance and contain, at a minimum, the following items:

a. Information related to any upcoming public outreach events.
b. A link returning to the City's drainage master webpage (when available).
c. City of Memphis' Non-Emergency Support Center Number 311 for residents to report drainage issues.
d. A study area e-mail address, as established by the Study Consultant, to collect data and comments from citizens.
e. A project schedule specific to the basin being studied.
f. A survey form that may be completed during the meeting or submitted via the website for collection of existing condition data from the public.

All content related to the initiation of the website and public outreach efforts is subject to review and approval by City Staff prior to posting.

APPENDIX-A STANDARD SURVEY CODES

The survey data and associated CAD file provided to the City of Memphis as part of these projects shall conform to the following survey codes. The decision is left to the selected entity to decide whether to utilize these codes during field survey work or to “find and replace” codes using a computer and the survey log file. However, if different codes are used during the field work, a list of original and modified survey codes shall be provided in addition to the other requirements.

ID	CODE	DESCRIPTION
1	INL3X3	3x3 Inlet (Shoot 4 Corners on Top)
2	INL4X4	4x4 Inlet (Shoot 4 Corners on Top)
3	6-72L	6-72 inlet Left Corner @ Face of Curb
4	6-72R	6-72 inlet Right Corner @ Face of Curb
5	ANGPT	Angle Point
6	ABUT	Bridge Abutment
7	ACPAD	Air Conditioner (Shoot 4 Corners)
8	AHEADW	Word, Ahead (Shoot 4 Corners) Word written on Asphalt
9	APPSLAB	Bridge Approach Slab
10	ARROWL	Left Turn Arrow (3 Shots, 2 at the bottom, 1 at the point)
11	ARROWR	Right Turn Arrow
12	ARROWS	Straight Ahead Arrow
13	ASP	Asphalt Surface
14	ASPCURB	Top of Asphalt Curb
15	AWNING	Awning
16	AXLEFND	Axle Fnd
17	BC	Back of Curb
18	BSW	Back of Sidewalk
19	BSWMP	Back Walk @ Mid Point
20	BARR	Barricade
21	BBGOAL	Basketball Goal
22	BBP(*)	Billboard Pier (#= Pole Diameter in Feet)
23	BENCH(*)	Bench (*= Wood, Metal, etc.)
24	BIRDHSE	Bird House

ID	CODE	DESCRIPTION
25	BL	Base Line
26	BLDGCOR	Building Corner
27	BLDGFACE	Building Face
28	BM	Bench Mark
29	BOTTOM	Creek or River Bottom
30	BOXELEC	Electrical, not defined by code list
31	BOXTS	Traffic Signal, mounted flush in s/w with cover (Shoot 4 Corners)
32	BOXMLGW	Traffic Signal, mounted flush in s/w with MLGW cover (Shoot 4 Corners)
33	BRIDGEEND	Bridge End
34	BRIDGERAIL	Bridge Railing
35	BFFE	Basement Finish Floor Elevation
36	BUSSHELT	Bus Shelter
37	BUSH	Bush
38	CARM	Control Arm (access to parking lot)
39	CFT(*)	Crow Foot (*= FND or SET)
40	CARPORT	Carport
41	CONCSLAB	Concrete Slab
42	CONCSPILL	Concrete Spillway
43	CPS(*)	Cotton Picker Spindle (*= FND or SET)
44	CSPLIT	Curb Split
45	CONCSWALE	Concrete Swale
46	CTVPED	Cable TV Pedestal
47	CCL(*)	Concrete Channel Lining (*= TOP, TOE, FL, etc.)
48	CHIMNEY	Chimney (describe material in a note)
49	CL	Center Line
50	CLPOST	Clothes Line Post
51	CLSTRC	Centerline of Structure
52	COLUM(*)	Column (*= Wood, Brick, CONCrete etc.)

ID	CODE	DESCRIPTION
53	CONCCOR	Concrete Corner
54	CONCENC	Concrete Encasement
55	COPWALL	Coping Wall
56	CUL(*)	Culvert (*= TOP,TOE, INVert, FL, etc.)
57	DBYL	Double Broken Yellow Line
58	DMH	Drain Man Hole
59	(*)DOCK	(* = Loading, Boat, Etc.) Dock
60	DOGHSE	Dog House
61	DOGRUN	Dog Run
62	DSBYL	Double Solid & Broken Yellow Line
63	DSYL	Double Solid Yellow Line
64	DW(*)	Driveway (*= ASPhalt, CONCrete, GRVL)
65	DWLB	Driveway apron (left back corner, facing street)
66	DWLF	Driveway apron (left front corner, facing street)
67	DWRB	Driveway apron (right back corner, facing street)
68	DWRF	Driveway apron (right front corner, facing street)
69	ELECLINE	Electric Line
70	ELECVALUT	Electric Vault
71	EM	Electrical Meter
72	EMH	Electrical Man Hole
73	E(*)	Edge of (*= Pavement, Water, GRVL, Brick)
74	ER	End Radius
75	FH	Fire Hydrant
76	FPUMP	Fuel Pump, at Service Stations
77	FSW	Front of Side Walk
78	FB	Flower Bed
79	FC	Face of Curb
80	FCAPT	Face Curb Angle Pt

ID	CODE	DESCRIPTION
81	FCER	Face of Curb @ End Radius
82	FFE	Finished Floor Elevation
83	FIRECB	Fire Call Box
84	FLDI	Flow Line Ditch
85	FLGUT	Flow Line Gutter
86	FLP(*)	Flowline Pipe (*= Pipe Dia. in Inches)
87	FLAGP	Flag Pole
88	FNC(*)	Fence (*= Height in Feet)
89	FNCCOR	Fence Corner
90	FNCEND	Fence Terminates
91	FOC	Fiber Optic Cable
92	FOLL	Following
93	FTBRIDGE	Foot Bridge
94	GLINE	Gas Line
95	GM	Gas Meter
96	GRAIL	Guard Rail
97	GARAGE	Garage
98	GARDEN	Garden
99	GATE(*)	Fence Gate (*= Metal, Wood, etc.)
100	GMH	Gas Manhole
101	GND	Ground
102	GRATE	Grate That Does Not Have Abbreviation (Give Corner Shots)
103	GRDSTK	Guard Stake
104	GRVL	Gravel
105	GUYP	Guy Pole
106	GUYW	Guy Wire
107	GV	Gas Valve
108	HWL	Head Wall (Left End Face)

ID	CODE	DESCRIPTION
109	HWR	Head Wall (Right End Face)
110	HROW	Hedgerow (Shoot at Face or Corners)
111	HSTONE	Headstone (Grave)
112	HUB (*)	Point Location (*= FND or SET)
113	INL10	No. 10 Inlet (Shoot 4 Corners)
114	INL11	No. 11 Inlet (Shoot 4 Corners)
115	INL12	No. 12 Inlet (Shoot 4 Corners)
116	IP(*)	Iron Pin (*= FND or SET)
117	JCTBOX	Junction Box
118	LIFTSTA	Lift Station
119	LIP(*)	Man Hole Lip (*= Sewer, Drain, Electrical, Etc.)
120	LP(*)	Light Pole (*= Metal, Wood, etc.)
121	LS	Last Shot
122	MCOVER	Metal Cover for unknown utilities
123	MAILBOX	Mailbox
124	MED	Median
125	METP(*)	Metal Pole (*= Pole Diameter in Inches)
126	MHCOR	Mobile Home Corner
127	MON(*)	Monument (*= FND OR SET)
128	NAIL	Nail (other than P-K)
129	NS	Next Shot
130	ONLYW	Word, Only (Shoot 4 Corners) Word written on Asphalt
131	PROPSMH	Proposed Sewer Man Hole
132	PARWALL	Parapet Wall
133	CTVPB	Pull Box - Cable TV
134	ELECPB	Pull Box - Electrical
135	TSPB	Pull Box - Traffic Signal
136	PC	Point of Curvature

ID	CODE	DESCRIPTION
137	PCC	Point of Compound Curvature
138	PEDBUT	Pedestrian Push Button Control
139	PEDLGT	Pedestrian Head Signal (Walk, Don't Walk)
140	PHONEB	Phone Booth (Shoot 4 Corners)
141	PHONEP	Phone, Pay (Shoot on O/S)
142	PI	Point of Intersection
143	PIER(*)	Pier (*= Diameter in Ft.)
144	PILE	Piling
145	PILECAP	Pile Cap
146	PK(*)	PK Nail (*=FND or SET)
147	PLAYEQP	Playground Equipment
148	PM	Parking Meter
149	PMT	Pad Mounted Transformer (Shoot 4 Corners)
150	POC	Point on Curve
151	POOLHSE	Pool House
152	PORCH(*)	Porch (*= Wood, Brick, CONCrete etc.)
153	POT	Point on Tangent
154	PP(*)	Power Pole (*= CONCrete, Wood, Metal, Diameter in inches)
155	PRC	Point of Reverse Curvature
156	PSL	Parking Stall Line
157	PT	Point of Tangency
158	PROTANK	Propane Tank (Shoot 4 Corners)
159	PUMP	Pump
160	RETWALL	Retaining Wall
161	RIPRAP	Rip Rap / Revetment
162	ROW	Right of Way
163	RRCL	Center Line of RR Tracks
164	RRMM	RR Mile Marker

ID	CODE	DESCRIPTION
165	RRTRK	Rail Road Track
166	RRSPIKE	Rail Road Spike
167	RRTRW	Rail Road Tie Retaining Wall
168	RWM	Rectangular Water Meter (Shoot 4 Corners)
169	INLS11	S-11 Inlet (With Side Openings Shoot 4 Corners)
170	SBWL	Single Broken White Line
171	SCDRAIN	Scupper Drain (On Bridges)
172	SCO	Sewer Clean Out
173	SDWL	Single Dotted White Line
174	SHRUB	Shrub
175	SLIDE(*)	Slide (*= Wood, Metal, etc.)
176	SMH	Sewer Man Hole
177	SPOILBK	Spoil Bank
178	SPRINK	Sprinkler Head
179	SSPILE	Steel Sheet Piling
180	SSWL	Single Solid White Line
181	SSYL	Single Solid Yellow Line
182	STSIGN	Street Sign
183	STANCH	Stanchion
184	STEP	Step (Shoot 2 Front Corners on Top of Step)
185	STOPBAR	Traffic Stop Bar
186	STOPW	Word, Stop (Shoot 4 Corners) Word written on Asphalt
187	STOSHED	Storage Shed
188	SWDRAIN	Sidewallk Drain (Shoot 4 Corners)
189	SWIMPOOL	Swimming Pool
190	SWNGSET	Swingset
191	SWRLINE	Sewer Line
192	TP(*)	Telephone Pole(* = Wood, Metal, ETC..)

ID	CODE	DESCRIPTION
193	TPED	Telephone Pedestal
194	TTB	Telephone Terminal Box
195	TLINE	Telephone Line
196	TB	Top of Bank
197	TBM	Temporary Bench Mark
198	TC(*)	Top of Curb (*= ER, MP, END Etc.)
199	TCSIGN	Traffic Control Sign
200	THRT	Throat of Inlet
201	TMH	Telephone Man Hole
202	TOEGUT	Toe of Gutter (Shot on Concrete)
203	TOE	Toe of Slope / Toe of Fill
204	TREE(*)	Tree (*= Diameter in Inches)
205	TREED(*)	Double, 2 trees from common root (* =Dia. In Inches)
206	TREEL	Tree Line
207	TREEQ(*)	Quad, 4 trees from common root (* =Dia. In Inches)
208	TREET(*)	Triple, 3 trees from common root (* = Dia. In Inches)
209	TS	Traffic Signal Light
210	TSAW	Traffic Signal Anchor Wire (Shoot Where Attached to Pole)
211	TSCAB	Traffic Signal Control Cabinet
212	TSL	Traffic Signal Loop (Cut in Asphalt)
213	TSP(*)	Traffic Signal Pole (*= Metal, Wood)
214	TVAP(*)	TVA Post, Metal (* = Dia.In Ft.)
215	TVATWR	TVA Tower (Enter # in note)
216	VAULT	VAULT
217	VENTP(*)	Vent Pipe over underground pipes (*= Sewer, etc.)
218	WSPIG	Water Spigot
219	WALL(*)	Wall (*= Brick, CONCrete., Wood, etc.)
220	WCR	Wheel Chair Ramp (Shoot 4 Corners)
ID	**CODE**	**DESCRIPTION**

221	TESTWELL	Test Well
222	WLINE	Water Line
223	WM	Water Meter
224	WV	Water Valve
225	WW	Wing Wall
226	XWALK	Pedestrian Crosswalk
227	XCUT(*)	X-CUT (*= FND or SET)

APPENDIX-B CITY'S AUTHORIZATION LETTER

City of Memphis
TENNESSEE

Jim Strickland - Mayor
Doug McGowen - Chief Operating Officer

PUBLIC WORKS DIVISION
Robert Knecht-Director

January 24, 2019

RE: CITY OF MEMPHIS SANITARY SEWER INSPECTIONS (CONTRACT 35398)

To whom it may concern:

You have been identified as a property owner on or adjacent to the City of Memphis (City) sanitary sewer system right-of-way as shown on the attached map. As part of the City's efforts to ensure that its sanitary sewer system is properly maintained and operating as efficiently as possible, the City has contracted with the Surface Water Institute (SWI) at Christian Brothers University (CBU) to perform sanitary sewer system access and environmental evaluations.

You are being notified that employees of the City of Memphis, the CBU SWI, Malasri Engineering, Thomas Lawrence Engineering and/or Allworld Project Management may be accessing the sanitary sewer system right-of-way on or adjacent to your property to perform the sanitary sewer system evaluation. The access will involve the observation of current conditions and the collection of photos and videos of site conditions along the right-of-way. More than one visit to a location may be necessary. The field work will occur from the date of this letter through approximately December 2019.

Each employee of the listed companies will appropriately identify himself and will observe proper protocols. Please notify Dr. Lin at the number listed below as soon as possible if there are access restrictions of which we need to be made aware or if you have specific site access requirements. I appreciate your cooperation in the completion of this important sanitary sewer system evaluation.

Please feel free to contact me with any questions at gary.vaden@memphistn.gov or 901-636-7123 or you may contact the CBU SWI Program Director, Dr. "Louie" L. Yu Lin at 901-321-3403.

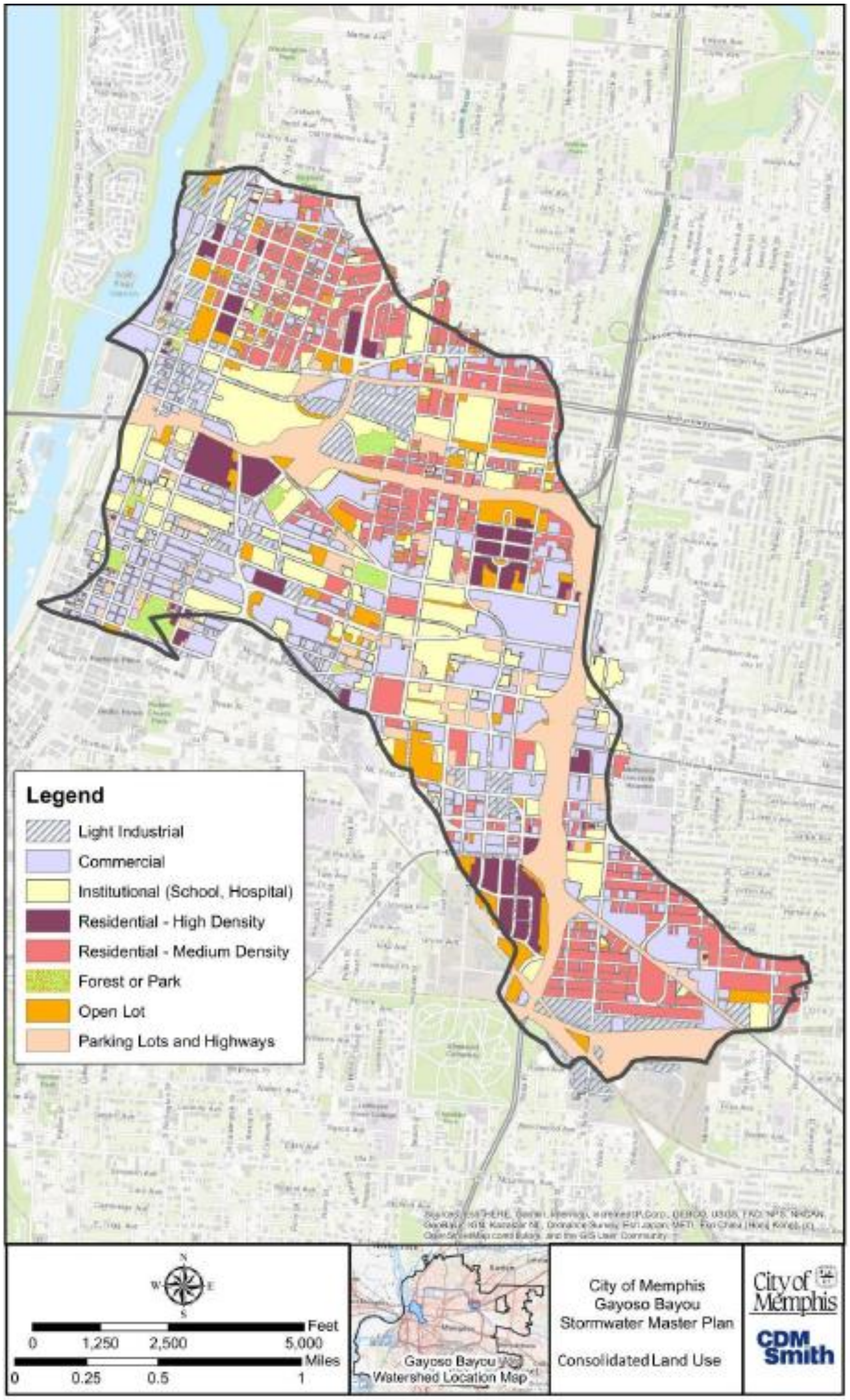
Sincerely Yours,

Gary W. Vaden, P. E.
Administrator of Environmental Construction

attachment

cc: Scott Morgan, Senior Environmental Administrator
Dr. Louie L. Yu Lin, Ph.D, P.E., CBU SWI

APPENDIX-C SWMM GIS EXAMPLE


Legend
Light Industrial
Commercial
Institutional (School, Hospital)
Residential - High Density
Residential - Medium Density
Forest or Park
Open Lot
Parking Lots and Highways
Feet
0 1,250 2,500 5,000
Miles
0 0.25 0.5 1
Gayoso Bayou Watershed Location Map
City of Memphis
Gayoso Bayou
Stormwater Master Plan
Consolidated Land Use
City of Memphis
CDM Smith

APPENDIX-D GIS SCHEMA

Field Name	Alias	Data Type	Allow Null	Default Value	Length
STATION	Station	Text	TRUE		50
STRUCTURE	Structure	Long	TRUE	4	
DESCRIP	Descrip	Text	TRUE		50
DESCRIP_2	Descrip 2	Text	TRUE		50
ELEV_RIM	Elev Rim	Double	TRUE		
ELEV_N	Elev N	Double	TRUE		
ELEV_S	Elev S	Double	TRUE		
ELEV_E	Elev E	Double	TRUE		
ELEV_W	Elev W	Double	TRUE		
SIZE_N	Size N	Double	TRUE		
SIZE_S	Size S	Double	TRUE		
SIZE_E	Size E	Double	TRUE		
SIZE_W	Size W	Double	TRUE		
QD	QD	Double	TRUE		
QC	QC	Double	TRUE		
QINTERCEPT	Q Intercept	Double	TRUE		
QBYPASS	Q Bypass	Double	TRUE		
AS_BUILT	As Built	Text	TRUE		4
DRAIN_AREA	Drain Area	Double	TRUE		
PAVED_AREA	Paved Area	Double	TRUE		
GRASS_AREA	Grass Area	Double	TRUE		
STORAGE	Storage	Double	TRUE		
OFFSET	Offset	Text	TRUE		25
SOURCE	Source	Text	TRUE		254
SOURCE_2	Source 2	Text	TRUE		254
CODE	Code	Text	TRUE		15
SYMBOLOGY	Symbology	Text	TRUE		4
AZIMUTH	Azimuth	Double	TRUE		
NOTE	Note	Text	TRUE		254
COMMENT_	Comment	Text	TRUE		254
EDITORNAME	Editor Name	Text	TRUE		100
LASTUPDATE	Last Update	Date	TRUE		
VERSIONNAME	Version Name	Text	TRUE		100
ELEV_5	Elev 5	Double	TRUE		
ELEV_6	Elev 6	Double	TRUE		
SIZE_5	Size 5	Double	TRUE		
SIZE_6	Size 6	Double	TRUE		
SOURCE_LINK	Source Link	Text	TRUE		500

ABANDON	Abandon	Text	TRUE		50
GlobalID	Global ID	Global ID	FALSE		
ENGNR_NOTE	Engineer Note	Text	TRUE		254
METRIC_SOURCE	Metric Source	Text	TRUE		254
DEPTH	Depth	Double	TRUE		
STRUCT_COMM	Struct Comment	Text	TRUE		254
CPGIS_COMM	CAESER Comment	Text	TRUE		254
QAQC	QAQC	Text	TRUE		15
LOC_SOURCE	Loc Source	Short	TRUE		
S1_YEAR	S1 Year	Short	TRUE		
PERM_ID	Perm ID	Double	TRUE		
created_user	Created By	Text	TRUE		255
created_date	Created Date	Date	TRUE		
last_edited_user	Last Edited User	Text	TRUE		255
last_edited_date	Last Edited Date	Date	TRUE		
SOURCE_3	Source 3	Text	TRUE		254
GPS_DATE	GPS Date	Date	TRUE		
Shape	Shape	Geometry	TRUE		
Size_NE	Size NE	Double	TRUE		
Size_NW	Size NW	Double	TRUE		
Size_SE	Size SE	Double	TRUE		
Size_SW	Size SW	Double	TRUE		
Cond_Assess_Status	Condition Assessment Status	Text	TRUE	Not Attempted	255
ESRIGNSS_POSITIONSOURCETYPE	Position source type	Short	TRUE		
ESRIGNSS_RECEIVER	Receiver Name	Text	TRUE		50
ESRIGNSS_LATITUDE	Latitude	Double	TRUE		
ESRIGNSS_LONGITUDE	Longitude	Double	TRUE		
ESRIGNSS_ALTITUDE	Altitude	Double	TRUE		
ESRIGNSS_H_RMS	Horizontal Accuracy (m)	Double	TRUE		
ESRIGNSS_V_RMS	Vertical Accuracy (m)	Double	TRUE		
ESRIGNSS_FIXDATETIME	Fix Time	Date	TRUE		
ESRIGNSS_FIXTYPE	Fix Type	Short	TRUE		

ESRIGNSS_CORRECTIONAGE	Correction Age	Double	TRUE		
ESRIGNSS_STATIONID	Station ID	Short	TRUE		
ESRIGNSS_NUMSATS	Number of Satellites	Short	TRUE		
ESRIGNSS_PDOP	PDOP	Double	TRUE		
ESRIGNSS_HDOP	HDOP	Double	TRUE		
ESRIGNSS_VDOP	VDOP	Double	TRUE		
ESRIGNSS_DIRECTION	Direction of travel (°)	Double	TRUE		
ESRIGNSS_SPEED	Speed (km/h)	Double	TRUE		
ESRISNSR_AZIMUTH	Compass reading (°)	Double	TRUE		
ESRIGNSS_AVG_H_RMS	Average Horizontal Accuracy (m)	Double	TRUE		
ESRIGNSS_AVG_V_RMS	Average Vertical Accuracy (m)	Double	TRUE		
ESRIGNSS_AVG_POSITIONS	Averaged Positions	Short	TRUE		
ESRIGNSS_H_STDDEV	Standard Deviation (m)	Double	TRUE		
STATE_PLANE_LATITUDE	State Plane Latitude	Double	TRUE		
STATE_PLANE_LONGITUDE	State Plane Longitude	Double	TRUE		
SOURCE_FIELD	Source Reported By Field Staff	Text	TRUE		255
PUBLIC_PRIVATE	Public or Private	Text	TRUE	Public	255
FACILITYID	Facility ID	Text	TRUE		20
ORTHOHEIGHT	Ortho Height	Double	TRUE		
PROPOSED_STATUS	Proposed Status	Text	TRUE		50
MSQ2_PP_Assessment	MSQ2 Public or Private	Text	TRUE		255
MSQ2_PP_Notes	MSQ2 Public or Private Notes	Text	TRUE		500
MSQ2_PP_Assessed_By	MSQ2 Public or Private Assessed By	Text	TRUE		255
TDOT_Maintenance	TDOT Maintenance?	Text	TRUE		255

Public_Private_Notes	Public or Private Notes	Text	TRUE		500
Public_Private_Link	Public or Private Link	Text	TRUE		500
Public_Private_Assessed_By	Public or Private Assessed By	Text	TRUE		255
MSQ2_PP_Plans_Link	MSQ2 Public or Private Plans Link	Text	TRUE		500

Field Name	Alias	Data Type	Allow Null	Default Value	Length
OBJECTID	OBJECTID	Object ID	FALSE		
MATERIAL	Type	Text	TRUE		50
LENGTH	Length	Double	TRUE		
DIAMETER	Diameter	Double	TRUE		
SLOPE	Slope	Double	TRUE		
FROM_ELE	From Ele	Double	TRUE		
TO_ELE	To Ele	Double	TRUE		
FROM_CODE	From Code	Text	TRUE		50
TO_CODE	To Code	Text	TRUE		50
QD	QD	Double	TRUE		
QC	QC	Double	TRUE		
VD	VD	Double	TRUE		
VC	VC	Double	TRUE		
AS_BUILT	As Built	Text	TRUE		4
D_AREA	D Area	Double	TRUE		
PAVE_AREA	Pave Area	Double	TRUE		
GRASS_AREA	Grass Area	Double	TRUE		
SYMBOLOGY	Symbology	Text	TRUE		4
SOURCE	Source	Text	TRUE		254
SOURCE_2	Source 2	Text	TRUE		254
COMMENT_	Comment	Text	TRUE		254
EDITORNAME	Editor Name	Text	TRUE		100
VERSIONNAME	Version Name	Text	TRUE		100
LASTUPDATE	Last Update	Date	TRUE		
PIPE_SHP	Pipe Shape	Text	TRUE		12
SOURCE_LINK	Source Link	Text	TRUE		500
OFFSET	Offset	Text	TRUE		25
NOTE	Note	Text	TRUE		255
ABANDON	Abandon	Text	TRUE		50
GlobalID	Global ID	Global ID	FALSE		
ENGNR_NOTE	Engineer Note	Text	TRUE		254
METRIC_SOURCE	Metric Source	Text	TRUE		254
DEPTH	Depth	Double	TRUE		
STRUCT_COMM	Struct Comm	Text	TRUE		254
CPGIS_COMM	CAESER Comm	Text	TRUE		254
QAQC	QAQC	Text	TRUE		15
LOC_SOURCE	Loc Source	Short	TRUE		
S1_YEAR	S1 Year	Short	TRUE		

PERM_ID	PermID	Double	TRUE		
created_user	Created By	Text	TRUE		255
created_date	Created Date	Date	TRUE		
last_edited_user	Last Editor	Text	TRUE		255
last_edited_date	Last Edit Date	Date	TRUE		
SOURCE_3	Source 3	Text	TRUE		254
Length_Feet	Length Feet	Double	TRUE		
Shape	Shape	Geometry	TRUE		
SOURCE_FIELD	Source Reported By Field Staff	Text	TRUE		255
PUBLIC_PRIVATE	Public or Private	Text	TRUE	Public	255
FACILITYID	Facility ID	Text	TRUE		20
SegmentID	Segment ID	Text	TRUE		25
PROPOSED_STATUS	Proposed Status	Text	TRUE		50
PROPOSED_SIZE	Proposed Size	Double	TRUE		
Shape.STLength()	Shape.STLength()	Double	TRUE		

Field Name	Alias	Data Type	Allow Null	Default Value	Length
OBJECTID	OBJECTID	Object ID	FALSE		
InspectionID	Inspection ID	Long	TRUE		
Surveyor1	Surveyed By (1)	Text	TRUE		50
Surveyor2	Surveyed By (2)	Text	TRUE		50
DateSurveyed	Survey Date	Date	TRUE		
Weather	Weather	Text	TRUE		255
Location_Details	Location Details	Text	TRUE		500
StructureType	Structure Type	Text	TRUE		255
RimInvert	Rim to Invert (ft)	Double	TRUE		
RimGrade	Rim to Grade (ft)	Double	TRUE	0	
ExtStructCond	Exterior Structural Condition	Short	TRUE	0	
ExtGroundCond	Exterior Ground Condition	Short	TRUE	0	
IntWallCond	Interior Wall Condition	Short	TRUE	0	
IntBenchCond	Interior Bench and Channel Condition	Short	TRUE	0	
Sediment	Sediment	Short	TRUE		
DebrisInternal	Debris Interior	Short	TRUE		
DebrisExternal	Debris Exterior	Short	TRUE		
WaterLevel	Water Level	Short	TRUE		
Scour	Scour	Short	TRUE		
Comment	Comment	Text	TRUE		500
created_user	created_user	Text	TRUE		255
created_date	created_date	Date	TRUE		
last_edited_user	last_edited_user	Text	TRUE		255
last_edited_date	last_edited_date	Date	TRUE		
PermID	Perm ID	Double	TRUE		
GlobalID	GlobalID	Global ID	FALSE		
Cond_Assess_NotCompleted	Couldn't Complete Assessment	Text	TRUE		255
ParentStructure_GlobalID	Parent Structure GlobalID	Guid	TRUE		
Assess_WorstRating	Assess Worst Rating	Text	TRUE		25

Field Name	Alias	Data Type	Allow Null	Default Value	Length
OBJECTID	OBJECTID	Object ID	FALSE		
ConnectionID	Connection ID	Long	TRUE		
InspectionID	Inspection ID	Long	TRUE		
PipeNumber	Pipe Number	Short	TRUE		
Direction	Direction	Text	TRUE		50
FlowDirection	Flow Direction	Text	TRUE		50
RimInvert	Rim to Invert (ft)	Double	TRUE		
Material	Material	Text	TRUE		255
ConnectionShape	Shape	Text	TRUE		100
Height	Height	Short	TRUE		
Width	Width	Short	TRUE		
ConnectionCond	Condition	Short	TRUE	0	
Comment	Comment	Text	TRUE		500
created_user	created_user	Text	TRUE		255
created_date	created_date	Date	TRUE		
last_edited_user	last_edited_user	Text	TRUE		255
last_edited_date	last_edited_date	Date	TRUE		
GlobalID	GlobalID	Global ID	FALSE		
ParentAssessment_GlobalID	Parent Assessment GlobalID	Guid	TRUE		