STORMWATER MODELING, MAPPING & ANALYSIS

CANE CREEK STUDY AREA

VOLUME I OF II

PREPARED BY:

Pickering

Service and Good Work, Our Foundation, Our Future.

PREPARED FOR:

CITY OF MEMPHIS

DIVISION OF ENGINEERING

REVISED DECEMBER, 2020

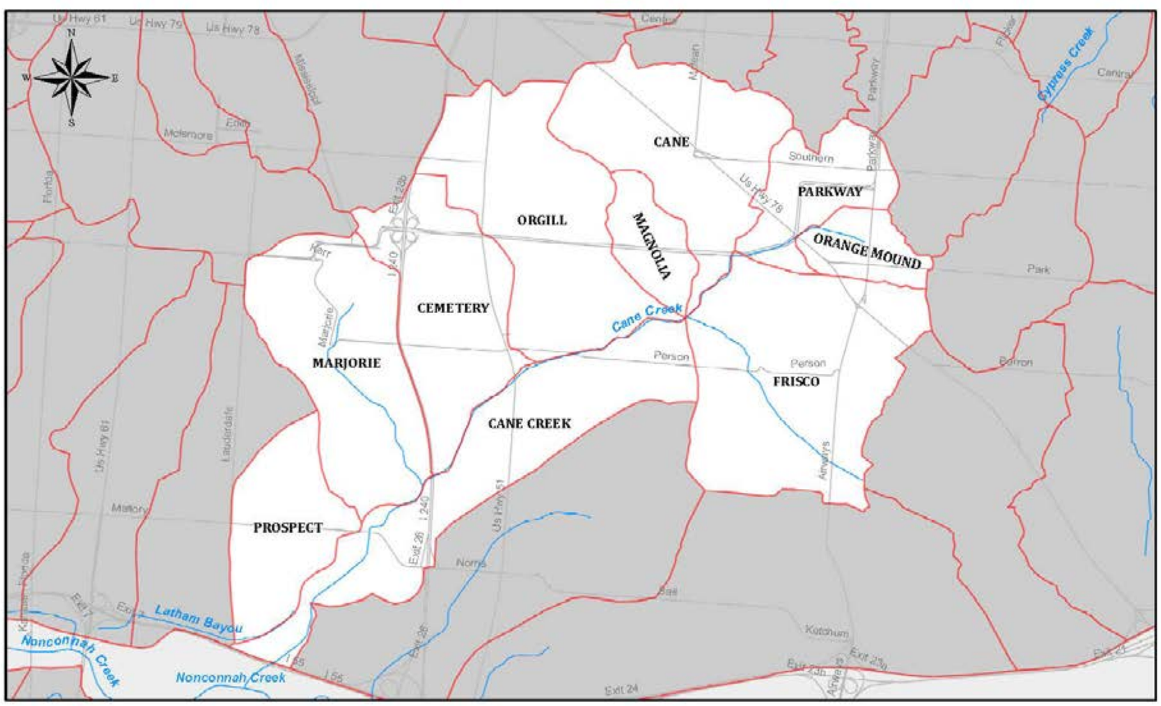
i. Executive Summary

Project Background:

In 2013, the City of Memphis, Division of Engineering began a systematic approach to study each major stormwater drainage basin or watershed within the City. The initial phase included the hydrologic and hydraulic analysis of seven (7) stormwater drainage basins located within the City's seven major study districts. The goal of each study was to prepare an updated stormwater system map, develop a stormwater model to predict the performance of existing infrastructure, and analyze potential system improvements to mitigate flooding in the watershed.

Cane Creek Watershed Overview:

The Cane Creek Watershed is approximately 5,110 acres in the central portion of the City generally located south of the CSX Railroad and Nelson Avenue, north of the CN Railroad and the former Memphis Defense Depot, west of East Parkway / Airways Boulevard, and east of South Lauderdale Street as shown below.



FY 2014 / FY 2015 Stormwater Modeling, Mapping, & Analysis
Cane Creek Study Area

Land use in the Cane Creek Watershed is varied and includes single-family residential, multi-family residential (i.e. apartments), commercial, industrial, institutional, parks/recreational, and cemetery.

The main stem of Cane Creek begins at its downstream confluence with Nonconnah Creek approximately 1 mile west of the I-55 / I-240 interchange. From this downstream terminus, the channel alignment is routed upstream in a northeasterly direction generally parallel to and west of the CN Railroad to a crossing at South Parkway where it turns to the northwest before crossing through Glenview Park and neighborhoods to the north. The main stem of Cane Creek is approximately 4.5 miles long and consists of natural channel sections, concrete lined channel sections, and concrete box culverts, with multiple bridge crossings along the way.

Within the overall Cane Creek drainage basin, there are ten (10) primary sub-basins as illustrated on the study area map. These sub-basins range in size from 135 acres to over 825 acres (+/-) and contain lined and unlined open channels, box culverts, and an extensive network of large and small diameter culverts that provide stormwater collection for each service area.

<u>Study Scope and Goals:</u>

The Cane Creek Watershed study achieves three (3) primary purposes:

- Drainage System Mapping – updated / as-built mapping of the City's major drainage infrastructure (pipes 24-inches in diameter and larger) within the watershed
- Stormwater System Modeling – a computer model to accurately reflect the hydrologic and hydraulic characteristics of the study area for various storm intensities
- Stormwater System Analysis – an assessment of the stormwater infrastructure in the Cane Creek study area and recommendations for critical infrastructure improvements to mitigate flooding or potential flooding

A summary of these three study components for the Cane Creek Watershed is provided below.

Mapping – A significant element of the Cane Creek Watershed study was a detailed field survey of the existing stormwater infrastructure. This survey was conducted to establish as-built information for the system layout, drain structure sizes, geometric shapes, invert elevations, and general condition for open channels, box culverts, pipes, bridge crossings, and major inlet structures. The survey goal was to create a comprehensive map of the stormwater infrastructure for all pipes and conveyance structures with a 24-inch diameter and larger.

The Cane Creek survey effort was unique in that field data was collected with Global Positioning System (GPS) data collection equipment and processed for direct input into the City's existing GIS system. This was significant given that the stormwater modeling software selected by the City, InfoSWMM, operates within a GIS framework.

Overall the field survey efforts collected information for the following stormwater infrastructure in the Cane Creek Watershed:

Natural and concrete lined open channel sections –	67,262 feet
Box culverts –	30,437 feet
Pipe (> 48-inch diameter) –	16,577 feet
Pipe (24 to 48-inch diameter) –	86,368 feet
Bridge crossings –	165 crossings
Manholes, Junctions, and Inlets –	742 structures

Stormwater System Modeling – The City selected InfoSWMM as the stormwater modeling software to be used for each study area. InfoSWMM offers a powerful tool for utilizing the City's existing GIS data supplemented with data acquired in the mapping exercise described above and other sources of GIS data to model the stormwater system. Modeling of the Cane Creek Watershed consisted of developing hydrologic and hydraulic parameters and calibration of the model to observed or recorded conditions.

Hydrologic Parameters: The hydrologic (i.e. flow) component of the InfoSWMM model for the Cane Creek Watershed was developed using the GIS data described above to establish the model input parameters such as sub-basin areas, impervious percentages based on land use, topographic characteristics, storage areas, and soil infiltration parameters.

Hydraulic parameters: The hydraulic capacity of the Cane Creek stormwater infrastructure was based on the modeling of pipes 24-inches in diameter and larger and other major components such as open channels and box culverts. GIS data for existing infrastructure obtained during the field survey phase and the City's existing 2-foot contour mapping were used as the primary input data for InfoSWMM.

Model Calibration: Calibration of the Cane Creek Watershed model was based on three sources of information: 1) information from the public, 2) historical records from the City, and 3) recorded rainfall and flow data.

Public input – During the field survey phase of the project, three meetings were held to solicit information from community leaders, property owners, and residents related to flooding or known drainage system problems. This information was requested to assist with validation of model results. Attendance at these meetings was very low (less than 5 attendees at each meeting) and the limited amount of information obtained had no direct benefit to model validation or calibration.

Historical records – Over the years, the City has commissioned small area drainage studies for many locations across the City. A file search was conducted for any such studies that may have occurred in the Cane Creek Watershed. No information was available from previous studies and there were no known records of historical flooding in the Cane Creek Watershed.

Recorded rainfall and flow data – During the field survey phase of the study, the City commissioned the installation of two rainfall gauges and two stream gauges within the Cane Creek Watershed. From early July to early October of 2014 rainfall data was recorded along with corresponding stream depth measurements at each of these gauge locations. This data served as the primary tool for model calibration as hydrologic and hydraulic input parameters were adjusted so that model results closely matched observed and recorded conditions for specific rainfall events in the watershed.

Stormwater System Analysis – The InfoSWMM model was used to predict the performance of infrastructure in the Cane Creek Watershed for various storm events (i.e. rainfall intensities). Model results were developed for the 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year rainfall events.

Flooding analysis was conducted specifically for the 10-year and 100-year events as design criteria in the City of Memphis / Shelby County Storm Water Management Manual (2007) focuses on these storm events for new construction. These events were considered to be the most relevant when considering potential Capital Improvement Program (CIP) projects in the Cane Creek Watershed.

The model revealed approximately 12 areas where flooding may occur in the Cane Creek Watershed during a 10-year rainfall event. It is estimated that the floodplain boundary for this event could affect over 140 homes and businesses. Model results indicate that the impact of a 100-year rainfall event would be more extensive with over 200 homes and businesses potentially affected.

Based on this information, the six areas with the greatest threat for potential flooding were targeted for an alternatives analysis to investigate opportunities to reduce flood potential. These areas and the recommended CIP project to alleviate flooding are described below:

- Kellogg Avenue and Castalia Street – 5 to 10 homes and businesses near this intersection are potentially impacted by the 10-year event. A proposed stormwater detention basin located along the south side of Frisco Avenue south of the Kellogg manufacturing facility will mitigate flooding potential on these properties.

- Wabash Avenue east of Castalia Street – Approximate 20 homes and small businesses are susceptible to flooding in this area. A detention pond adjacent to the open channel in this area is proposed along the south side of Wabash Avenue east of Castalia Street to mitigate flooding in this area.

- Ragan Street north of Cane Creek / south of Ethlyn Avenue – The 10-year rainfall event will potentially impact 5 homes and businesses in this area. A detention facility is proposed near the southeast corner of Ragan Street and Gold Avenue to reduce or remove this flooding threat.

- Southeast of Glenview Park between Netherwood Avenue and Kendale Avenue – A detention basin is proposed in Glenview Park to mitigate flooding potential to approximately 7 to 10 homes in this area.

- Wilson Street north and south of East McLemore Avenue – Two storm water storage facilities are proposed in this area, one located east of the Lehman-Roberts facility on Wilson Street and the other located along the south side of East McLemore Avenue west of Wilson Street. These basins will reduce flooding potential for 5 homes and businesses in this area and more than 40 homes in the area described below.

- Residential area east of Jesse Turner Park and Hamilton Elementary/Middle School campus – The two stormwater detention facilities identified above will help to eliminate or reduce flooding potential for over 40 homes in this area during the 10-year storm event.

Benefit-Cost Summary:

The Federal Emergency Management Agency (FEMA) benefit-cost analysis (BCA) version 5.1.0 was used to estimate the cost effectiveness of recommended improvements. The preliminary opinion of probable construction cost for recommended storm water detention facilities described above is approximately $300,000. The FEMA methodology for estimating benefits resulting from flood mitigation resulted in an estimated benefit of approximately $4,280,000. The overall B/C ratio was estimated at 14.25 indicating that these recommended CIP projects would be extremely cost effective.

ii. Table of Contents **Page**

Volume I

iii. List of Tables

Volume II

iv. List of Exhibits

v. Appendices

1. Project Introduction

a. Project Background

In 2013, the City of Memphis, Division of Engineering began a systematic approach to study each major stormwater drainage basin or watershed within the City. The initial phase included the hydrologic and hydraulic analysis of seven (7) stormwater drainage basins located within the seven major study districts shown on Exhibit 1a.

The purpose of this report is to present the results of stormwater mapping, modeling, and analysis of the Cane Creek Watershed.

b. Cane Creek Watershed Overview

The Cane Creek Watershed is approximately 5,110 acres in the central portion of the City generally located south of the CSX Railroad and Nelson Avenue, north of the CN Railroad and the former Memphis Defense Depot, west of East Parkway / Airways Boulevard, and east of South Lauderdale Street as shown on Exhibit 1b. Major roadway corridors traversing the study area include South Parkway, Southern Avenue / East McLemore Avenue, and East Person Avenue (east-west) and I-240, Lamar Avenue, Elvis Presley Boulevard / South Bellevue Boulevard (north-south). Three Class I rail lines also cross through portions of the watershed: Norfolk-Southern Railroad, BNSF Railroad, and CN Railroad.

Land use in the Cane Creek Watershed is varied and includes single-family residential, multi-family residential (i.e. apartments), commercial, industrial, institutional, parks/recreational, and cemetery. Due to this widely varied land use, the corresponding pervious and impervious characteristics of the study area range from large tracts of open areas with grasses and trees to paved and highly developed areas of heavy industrial facilities, distribution centers, and rail yards. See Exhibit 2a for an aerial view of the watershed and Exhibit 2b for a land use map of the study area.

The main stem of Cane Creek begins at its downstream confluence with Nonconnah Creek approximately 1 mile west of the I-55 / I-240 interchange. From this downstream terminus, the channel alignment is routed upstream in a northeasterly direction generally parallel to and west of the CN Railroad to a crossing at South Parkway where it turns to the northwest before crossing through Glenview Park and neighborhoods to the north. The main stem of Cane Creek is approximately 4.5 miles long and consists of natural channel sections, concrete lined channel sections, and concrete box culverts, with multiple bridge crossings along the way.

Within the overall Cane Creek drainage basin, there are ten (10) primary sub-basins as illustrated on Exhibit 1b. These sub-basins range in size from 135 acres to over 825 acres (+/-) and contain lined and unlined open channels, box culverts, and an extensive network of large and small diameter culverts to provide stormwater collection for each service area.

c. Study Scope and Goals

As stated previously, the City's Engineering Division plans on conducting a study of each major stormwater drainage basin throughout the City over the next several years. There are three (3) primary purposes of each study, as follows:

- Drainage System Mapping – provide updated, as-built mapping of the City's major drainage infrastructure (pipes 24-inches in diameter and larger)
- Stormwater System Modeling – develop a computer model to accurately reflect the hydrologic and hydraulic characteristics of each study area for various storm intensities
- Stormwater System Analysis – provide an assessment of the stormwater infrastructure in each study area relative to its conveyance capacity for various storm intensities and make recommendations for critical infrastructure improvements to mitigate flooding or flooding potential

A summary of these three study components for the Cane Creek Watershed is provided below:

2. Data Gathering

a. Drainage System Mapping

Stormwater infrastructure maps and drainage system information for large portions of the City consists of old paper maps from original design drawings which are on file with the City. In recent years this information was incorporated into the City's Geographic Information System (GIS), however a very small percentage of mapping data entered into the GIS was obtained from as-built or as-constructed drawings. There are also significant gaps in the GIS mapping due to the absence of original design drawings or missing paper copies on file with the City. In addition, GIS mapping often does not include system modifications or re-construction by the City's Public Works crews, the Tennessee Department of Transportation, railroad companies, or other agencies which may have occurred over many years.

Due to the factors described above, a significant element of the Cane Creek Watershed Study was a detailed field survey of the existing stormwater infrastructure. This survey was conducted to establish as-built information for the system layout, drain structure sizes, geometric shapes, invert elevations, and general condition for open channels, box culverts, pipes, bridge crossings, and major inlet structures. The survey goal was to map create a comprehensive map of the stormwater infrastructure for all pipes and conveyance structures with a 24-inch diameter and larger.

The Cane Creek survey effort was unique in that field data was collected and processed for direct input into the City's GIS system. Unlike traditional survey data collection where data is collected and processed into a CAD format and then modified for GIS input, the Cane Creek Watershed survey was conducted with Global Positioning System (GPS) data collection equipment and the field data was entered directly into data fields matching the City's existing GIS protocol. This was significant given that the stormwater modeling software, InfoSWMM (discussed below), operates within a GIS framework. Survey crews also collected photographs and other assessments of key infrastructure to input as additional attributes to the base GIS mapping.

Overall the field survey efforts collected information for the following stormwater infrastructure in the Cane Creek Watershed:

Natural and concrete lined open channel sections –	67,262 feet
Box culverts –	30,437 feet
Pipe (> 48-inch diameter) –	16,577 feet
Pipe (24 to 48-inch diameter) –	86,368 feet
Bridge crossings –	165 crossings
Manholes, Junctions, and Inlets –	742 structures

b. Public Input

During the field survey phase of the project, three meetings were held to solicit information from community leaders, property owners, and residents related to flooding or known drainage system problems. The initial meeting was conducted with community leaders and representatives of various associations in the watershed to give them information related to the project and to request help in getting the word out to their constituents. Two public meetings were held to allow citizens opportunity to give specific information on flooding that may have impacted streets, houses, businesses, or properties in their neighborhoods. This information could help to validate model results if enough specific information were available such as date of flooding, water depth or high-water information, etc. The attendance at these meetings was very low (less than 5 attendees per meeting) and the limited amount of information obtained did not have any direct benefits to model validation or calibration. The presentation materials used at the public meetings is provided in Appendix A.

c. Historical Records

Over the years, the City has commissioned small area drainage studies in many locations across the City. A file search was conducted for any such studies that may have occurred in the Cane Creek Watershed. No information was available from previous studies and there were no known records of historical flooding in the Cane Creek Watershed.

d. Recorded Rainfall and Flow Data

During the field survey phase of the study, the City commissioned the installation of two rainfall gauges and two stream gauges within the Cane Creek Watershed. From early July to early October of 2014 rainfall data was recorded along with corresponding stream depth measurements at each of these gauge locations. This data served as the primary tool for model calibration as hydrologic and hydraulic input parameters were adjusted so that model results reasonably matched observed and recorded conditions for specific rainfall events in the watershed.

3. Results and Details for Major Sub-Basins

InfoSWMM was used to simulate hydrologic and hydraulic conditions in the Cane Creek Watershed. The InfoSWMM software is integrated with ArcGIS to simulate existing conditions and predict future conditions based on a variety of land use inputs. The Cane Creek InfoSWMM model described below provides a powerful tool to evaluate and manage urban stormwater runoff and conveyance for both existing and proposed conditions after improvements. The results of the model are used to identify locations of existing flooding and to identify appropriate Capital Improvement Projects (CIPs) for the City to consider in order to address these flooding problems.

a. Hydrologic and Hydraulic Modeling Approach

Hydrologic Model Development:

To simulate stormwater runoff quantity InfoSWMM requires the delineation of individual subcatchment or sub-basin areas and input data for each area including imperviousness, slope, width (a subcatchment shape factor), and infiltration parameters.

The Cane Creek Watershed has a total drainage area of approximately 5,110 acres. For the hydrologic component of the modeling, Cane Creek Watershed was divided in to 297 sub-basins using a Digital Elevation Model (DEM) from 2012 Shelby County, Tennessee LiDAR (Light Detection And Ranging) data. The sub-basins were verified by comparison with other topographic data, aerials, and available as-built information.

The hydrologic model was initially developed using Curve Numbers as the method for modeling infiltration and runoff. A single Curve Number (CN) was assigned to each sub-basin in accordance with a variety of sub-basin characteristics including land use, impervious area, soil types, and antecedent moisture conditions. However, assigning a single value CN to account for a variety of runoff parameters resulted in broad generalizations and difficulties in calibrating the model. Model calibration was attempted by adjusting the CN values, but in order to detect significant changes in flows and volumes, large increases to the CN values were required. The CN method did not appear to respond realistically to locally collected rainfall data during the initial calibration process.

As a result, the Green-Ampt method was used to estimate runoff and infiltration. This method produced more realistic results when compared to measured values and was therefore used in lieu of the CN method. Modeling results using the Green-Ampt method more closely followed the observed trends from rainfall and stream gage data, and thus was determined to be the better method for simulating infiltration and runoff of stormwater for the Cane Creek Watershed.

Hydrologic Parameters

The hydrologic input data for the InfoSWMM Model was taken from the GIS data provided by the City. The following user-defined hydrologic parameters were specified for each sub-basin in the InfoSWMM model:

- Sub-basin name or number
- Area (acres)
- Impervious percentage (percent)
- Width of sub-basin (feet)
- Average ground slope (%)
- Manning’s roughness coefficient for impervious areas
- Manning’s roughness coefficient for pervious areas
- Depression storage for pervious areas (inches)
- Green-Ampt soil infiltration parameters: initial moisture deficit of soil, hydraulic conductivity of soil, and suction head at the wetting front.

A summary is provided below for each user-defined hydrologic parameter entered into the InfoSWMM model.

Sub-basin Name/Number
Most sub-basins were named in accordance with default number ID generated when delineating sub-basins with prefix “BASIN”.

Sub-basin Area (acres)
Initially, sub-basins were delineated with minimum size of 100 acres. These sub-basins were further subdivided in accordance with as-built survey information for the stormwater network to create a more detailed model. Current sub-basins areas range from minimum area of 0.051 acres to maximum area of 98 acres with an average area of approximately 17 acres. See Exhibit 3.

Sub-basin Impervious Percentage (%)
Table 1 was used to assign a percent impervious to each land use type. Using GIS, a weighted average of the percent impervious was calculated for each sub-basin, reflective of the sub-basin’s overall land use. Existing condition land use coverage and associated percent impervious values were determined using aerial photos to document undeveloped areas.

TABLE 1 – LAND USE IMPERVIOUS PERCENTAGES

LAND USE	IMPERVIOUS AREA (%)
Agriculture	5
Industrial	85
Open Space	5
Vacant	5
Commercial	80
Residential	35
Multi Family Residential	55

Sub-basin Width (feet)

Width for each subcatchment was calculated using following formula:

W = k*SQRT(Area)

W=sub-basin width
k=0.4

Average Ground Slope (%)

The slope for each subcatchment was calculated using the Digital Elevation Model (DEM) from the 2012 Shelby County, Tennessee LiDAR (Light Detection and Ranging) data.

Manning's Roughness Coefficient for Impervious Areas

The Manning's "n" for impervious areas used in the InfoSWMM Model was set at 0.02 for all impervious surfaces. Ref: Manning, R. (1891). "On the flow of water in open channels and pipes". *Transaction of the Institution of Civil Engineers of Ireland*. 20: 161-207.

Manning's Roughness Coefficient for Pervious Areas

The Manning's "n" for pervious areas used in the InfoSWMM Model was set at 0.3 for all pervious surfaces. See reference above.

Depression Storage for Pervious Areas

The depression storage is the maximum surface storage provided by ponding, surface wetting, etc. that is filled prior to runoff occurring. The value for depression storage for all pervious areas was set at 0.4 inches.

Green-Ampt Infiltration Parameters (units vary)

The Green-Ampt method was used to estimate runoff and infiltration. The Green-Ampt method calculates infiltration of stormwater into soils, by taking into account antecedent moisture conditions, suction head, and hydraulic conductivity of the soil. The values of these three parameters were based on soil types in the Cane Creek Watershed. Specific soils types and their associated distribution within each watershed were determined using GIS files from the Natural Resources Conservation Service (NRCS). Using GIS, the area-weighted averages were calculated on a sub-basin basis, using information in Table 2, and entered into the InfoSWMM model for each sub-basin. See Exhibit 2c for Soil Types throughout the study area.

TABLE 2 – GREEN-AMPT INFILTRATION PARAMETERS*

Soil Texture	Capillary Tension (in)	Capillary Tension (mm)	Saturated Hydr. Conductivity (in/hr)	Saturated Hydr. Conductivity (mm/hr)	(cm/s)	Porosity wet clim.	Porosity dry clim.
Sand	1.95	49.5	9.27	235.6	6.54E-03	0.346	0.404
Loamy Sand	2.41	61.3	2.35	59.8	1.66E-03	0.312	0.382
Sandy Loam	4.33	110.1	0.86	21.8	6.06E-04	0.246	0.358
Loam	3.50	88.9	0.52	13.2	3.67E-04	0.193	0.346
Silt Loam	6.57	166.8	0.27	6.8	1.89E-04	0.171	0.368
Sandy Clay Loam	8.60	218.5	0.12	3.0	8.33E-05	0.143	0.250
Clay Loam	8.22	208.8	0.08	2.0	5.56E-05	0.146	0.267
Silty Clay Loam	10.75	273.0	0.08	2.0	5.56E-05	0.105	0.263
Sandy Clay	9.41	239.0	0.05	1.2	3.33E-05	0.091	0.191
Silty Clay	11.50	292.2	0.04	1.0	2.78E-05	0.092	0.229
Clay	12.45	316.3	0.02	0.6	1.67E-05	0.079	0.203

Ref: Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993.

*Note: All standard parameters, including Initial Moisture Deficit, for the Green-Ampt method used in the hydrologic calculations were built into the InfoSWMM model and auto-selected by the model.

Hydraulic Model Development:

Due to limited resources including budget and schedule, only the major components of the stormwater system were modeled. Modeling included pipes that are, in general, 24-inch in diameter and greater, although there were a few exceptions. In addition, as with most public stormwater systems, the locations and functions of existing facilities are not well documented, particularly older systems installed prior to current documentation and stormwater management requirements. Thus, modeling was limited to major systems including interceptors that provide for the primary drainage for each basin. Simplification of the modeled drainage system minimized overall model run time. The existing modeled system was presented, adjusted based on City staff comments, and approved by the staff stakeholder team.

Hydraulic Parameters

The hydraulic portion of the InfoSWMM Model is primarily comprised of conduits (pipes, open channels, and box culverts) and nodes (junctions, outfalls, and storage nodes). The majority of the hydraulic input data was taken from the field survey data, with remaining input gathered from GIS data provided by the City of Memphis. Input parameters required for each component of the hydraulic system are described below.

Conduits

Conduits connect all points within the hydraulic system (manholes, flow control devices, ponds, etc.) and transport stormwater through the system. For the Cane Creek Watershed model, conduits were either pipes, open channels, or box culverts. Associated input parameters are as follows:

Conduit Length
Conduit length specifies the distance a conduit spans between two points.

Manning's roughness coefficient (n)
Manning's "n" values for conduits were based on pipe material, and taken from the GIS data supplied by the City. Typical values were used based on pipe materials:
n = 0.011 for PVC
n = 0.013 for RCP
n = 0.024 for CMP
Pipes with unknown materials were assigned the manning's "n" for concrete, 0.012. Natural open channels were assumed to have a Manning's "n" of 0.045.

Upstream and Downstream Invert Elevations (feet)
Upstream and downstream invert elevations taken from the survey data were input into the model, in order for the model to calculate the slope of each conduit.

Cross-Sectional Geometry (feet)
For round pipes, the pipe diameter was used. For arch-shaped conduits, both the width (feet) and height (feet) were specified. All open channels were surveyed and channel cross-section shape specified with depths equal to the depth of upstream and downstream conduits.

Nodes

Nodes are used to describe points in the conveyance system. The three main types of nodes used in the InfoSWMM model are junctions, outfalls, and storage nodes. Junction nodes can receive runoff from a sub-basin, or connect links in the system conveying flow. Outfall nodes can receive flow from a sub-basin or a system link, and define the downstream boundary of the system. Storage nodes represent detention facilities, designed to collect runoff, store it, and release it at a slower rate. The discharge from the storage nodes is typically described by a stage-discharge data table. Input parameters associated with nodes are as follows:

Invert Elevation (feet)
Describes the inside bottom elevation of the node.

Maximum Depth (feet)
Represent the distance from the ground surface to the invert elevation of a node. These values were calculated from the survey data or estimations based on 2-foot contour DEM provided by the City of Memphis.

Ponded Area (square feet)
Describes the area around a node that is allowed to pond at the junction, and subsequently drain back into the junction.

Storage Curves
Tabular storage curves, representing a depth vs. surface area relationship were used to define the available storage volume.

Rainfall Data

Precipitation frequency (PF), obtained from NOAA Atlas 14, volume 2, Version 3 for Memphis, TN (Latitude: 35.0564°, Longitude: -89.9864°), listed in Table 3 for the 24-hour duration storm and SCS Type II rainfall distribution were used to develop rainfall intensity curves, listed in Appendix B*, for 2-Year, 5-Year, 10-Year, 25-Year, 50-Year, and 100-Year rainfall return intervals.

*Note: Parameters and methods to develop SCS dimensionless curve were based on conversion from a cumulative rainfall curve [for an example, see City of Memphis / Shelby County " STORM WATER MANAGEMENT MANUAL" Volume 2: Drainage Manual; developed by City of Memphis Division of Public Works and Division of Engineering]. The fluctuation in intensity is due to the rounding of the cumulative rainfall curve to the nearest 0.1% of the total. When converting this cumulative rainfall curve to incremental rainfall, the incremental rainfall is not consistently rising/falling (e.g: for the two year storm, between hour 5.25 and 5.5, the incremental rainfall is 0.02 inches, but between 5.5 and 5.75, the incremental rainfall is 0.01 inches). This effect is small, and does not impact the peak of the storm.

TABLE 3 – 24-HOUR PRECIPITATION

Recurrence Interval (Yr)	24-Hour Precipitation (inches)
2	4.01
5	4.88
10	5.58
25	6.51
50	7.26
100	8.02

Hyrdologic Model Calibration

Calibration is a technical term that refers to the adjustment of model parameters to match observed conditions. A full calibration process requires multiple independent data sets, each with good geographic coverage within the model area. One of the data sets can be used to adjust model parameters, with at least one additional independent data set to verify that the calibrated model can simulate actual data. Due to the limited available data, there was no full calibration performed for the Cane Creek model as described above. The available data was used to the extent possible to calibrate the model and validate that the model predictions are reasonable.

This model validation was performed in two steps, one step using rain gage data, and a second step using rainfall derived from the National Weather Service's NEXRAD system. Both of these compare available stream gage information to the model results.

Two rainfall gages and two stream depth gages were located within the Cane Creek Watershed during the model development period. These four gages were the primary sources of data used to confirm that the model appropriately represented the infiltration, runoff, and routing conditions for Cane Creek. The available rainfall and stream gage data span the time frame between July 8, 2014 and October 6, 2014, which included 12 small to moderate rainfall events, with the largest event being on September 11, 2014. Near the watershed, there are five other rainfall gages that were used to confirm general rainfall patterns. Figure 1 shows the locations of the rainfall and stream gages within the watershed. Figure 2 shows the location of rainfall gages inside the Cane Creek Watershed along with the neighboring external rain gages. Table 4 describes the 12 rainfall events as measured by the two rainfall gages.

FIGURE-1: Rainfall & Stream Gage Locations

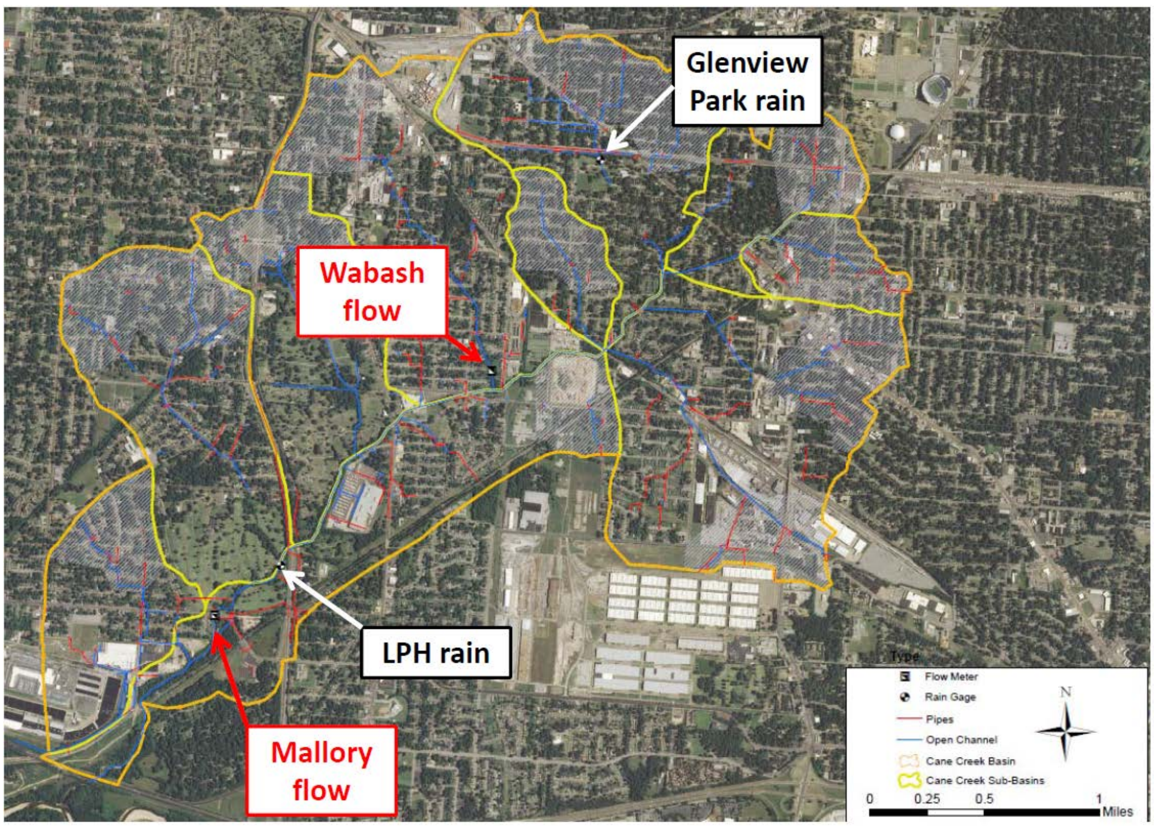


FIGURE-2: Rainfall Gages Inside Cane Creek Watershed & External Gage Locations

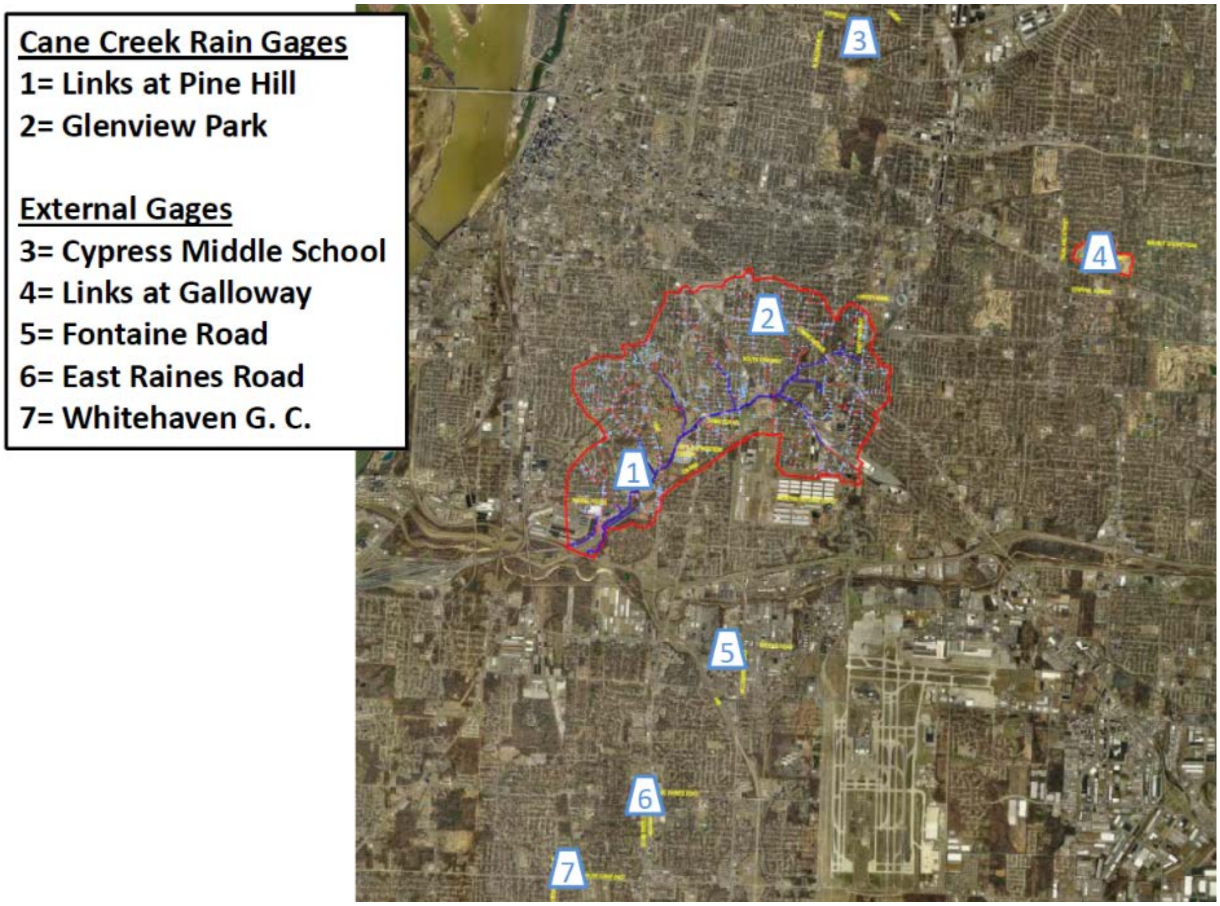


TABLE 4 – CANE CREEK WATERSHED RAINFALL MEASUREMENTS

Glenview Park Rain Gage					Rainfall Intensity (in/hr)			Prior Rainfall Totals (in)		
Event No.	Rainfall Event Start	Rainfall Event End	Duration (hr)	Rainfall Total (in)	15-min	30-min	60-min	1-day	3-day	7-day
1	8-Jul-2014	9-Jul-2014	10.5	0.81	1.5	0.8	0.5	0	0	0.02
2	14-Jul-2014	14-Jul-2014	6.3	0.54	0.7	0.4	0.2	0	0.01	0.81
3	17-Jul-2014	18-Jul-2014	13.3	0.37	0.1	0.1	0.1	0	0.02	0.55
4	23-Jul-2014	23-Jul-2014	0.7	0.34	0.8	0.6	0.3	0	0	0.39
5	7-Aug-2014	7-Aug-2014	2.0	0.47	1.1	0.8	0.4	0	0	0.01
6	8-Aug-2014	8-Aug-2014	1.0	0.16	0.3	0.2	0.2	0.47	0.47	0.47
7	9-Aug-2014	9-Aug-2014	9.0	0.13	0.2	0.1	0.1	0.16	0.63	0.63
8	30-Aug-2014	31-Aug-2014	27.8	1.67	1.3	1.1	0.8	0	0	0
9	6-Sep-2014	6-Sep-2014	2.7	0.88	0.9	0.6	0.5	0	0.09	0.13
10	11-Sep-2014	11-Sep-2014	11.7	4.07	2.9	2.2	1.6	0	0	0.96
11	2-Oct-2014	3-Oct-2014	8.5	1.03	1.3	1.2	0.7	0	0	0
12	6-Oct-2014	6-Oct-2014	1.5	0.42	0.5	0.5	0.3	0	0	1.03

Links at Pine Hill Rain Gage					Rainfall Intensity (in/hr)			Prior Rainfall Totals (in)		
Event No.	Rainfall Event Start	Rainfall Event End	Duration (hr)	Rainfall Total (in)	15-min	30-min	60-min	1-day	3-day	7-day
1	8-Jul-2014	9-Jul-2014	5.7	1.19	3.0	1.9	1.0	0	0	0.01
2	14-Jul-2014	14-Jul-2014	6.7	1.07	1.2	0.8	0.5	0	0	1.19
3	17-Jul-2014	18-Jul-2014	13.8	0.39	0.1	0.1	0.1	0	0.04	1.07
4	23-Jul-2014	23-Jul-2014	0.8	0.12	0.3	0.2	0.1	0	0	0.42
5	7-Aug-2014	7-Aug-2014	2.0	0.37	1.3	0.7	0.4	0	0	0.01
6	8-Aug-2014	8-Aug-2014	2.7	0.32	0.8	0.4	0.2	0.37	0.37	0.37
7	9-Aug-2014	9-Aug-2014	8.5	0.18	0.4	0.2	0.1	0.32	0.69	0.69
8	30-Aug-2014	31-Aug-2014	27.0	0.93	0.5	0.4	0.3	0.01	0.01	0.01
9	(no measurable rain recorded at this station)							0	0	0.06
10	(no measurable rain recorded at this station)							0	0	0.01
11	2-Oct-2014	2-Oct-2014	0.3	0.01	0.0	0.0	0.0	0	0	0.01
12	6-Oct-2014	6-Oct-2014	0.3	0.01	0.0	0.0	0.0	0	0	0.01

Note: Rain gage at the Links at Pine Hill location malfunctioned during events 9 and 10

The two rainfall gages within the watershed are at Glenview Park and the Links at Pine Hill (LAPH) golf course. One of these gages, LAPH, reported no rainfall for the two events in September and October, 2014. Because the Glenview Park rainfall gage is the closest adjacent gage, Glenview Park rainfall data was used for the entire watershed during September and October 2014.

The two stream gages are located at Malory and Wabash. These gages were surveyed in December 2014, and have datum elevations of 219.60 and 259.63 ft, respectively. The two gages show clear responses to the 12 storm events that occurred during the calibration time period, with maximum depths of about 4.5 and 6.5 ft during the September 11, 2014 event that is, by nature of being the largest event available, the primary focus of the model validation. The Malory stream gage is just upstream of a set of culverts, and is best represented by the conditions at model node CANE-24. The Wabash stream gage is best represented by the conditions at model node CHANNEL-1.

The Wabash gage consistently reports negative depth values of about 0.14 feet during the period between storms (Figure 3). Although it is unclear why this is happening, for this validation analysis the depth was added to the surveyed vertical datum of the gage, and compared to the head reported in the model (Figure 4).

FIGURE 3 – Wabash stream gage showing negative values

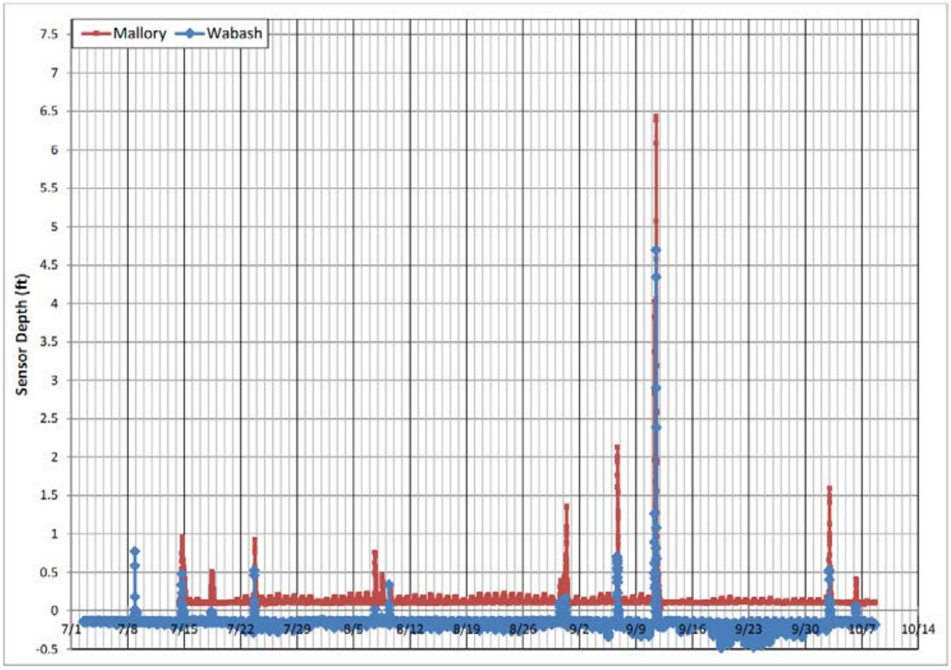
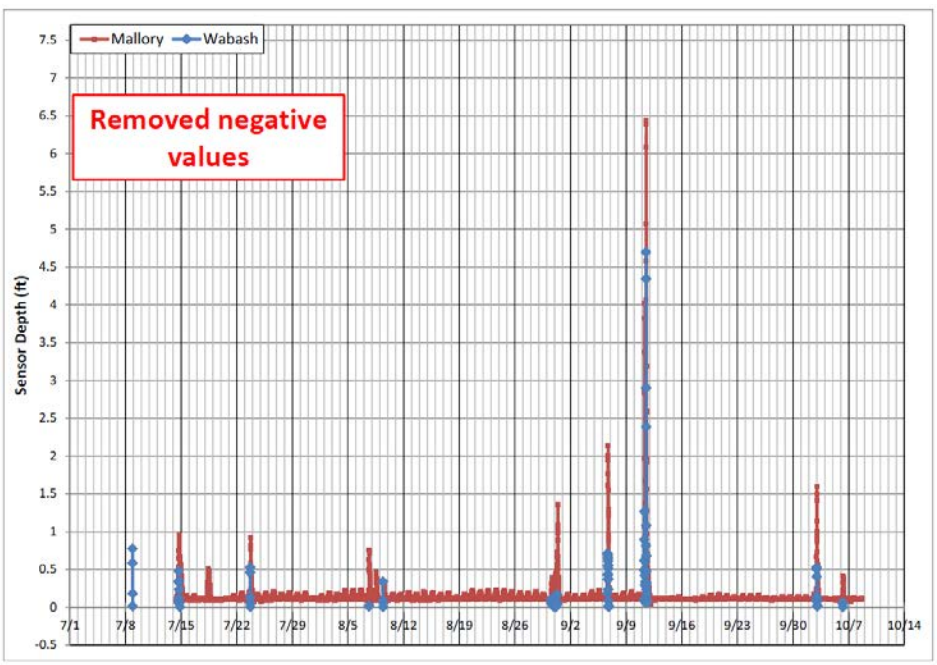


FIGURE-4-Negative values removed from Wabash stream gage



Calibration focused on matching the general shape of the modeled and observed runoff hydrographs, as well as matching peak measured flows. In an effort to prevent the model from overestimating or underestimating flows, several hydrologic input parameters in the model were adjusted to simulate flows that meet measured flows. Several model runs were conducted to evaluate the model's sensitivity to changes in certain hydrologic input parameters, specifically subcatchment slope, and Manning N for pervious and impervious areas. Modeled peak flows changed significantly with varying changes to the subcatchment's slope while varying Manning N for pervious and impervious areas provided very little changes to peak flows. The hydrologic model adjustment that resulted in the best match of peak modeled flow rates and peak observed flow rates was assigning 25% of the impervious area with no depression storage to all sub-basins.

Each sub-basin was assigned to one of the two rainfall gages, depending on the proximity of the sub-basin centroid to the rainfall gage. A continuous simulation was performed using the rain gage data. Figures 5a, 5b, 5c and 5d show the results for the two stream gages.

Figure 5a-Comparison of Malory Gage (*Current*/Model Value) v/s Observed/Field Measurement Depth at Model Junction CANE-24

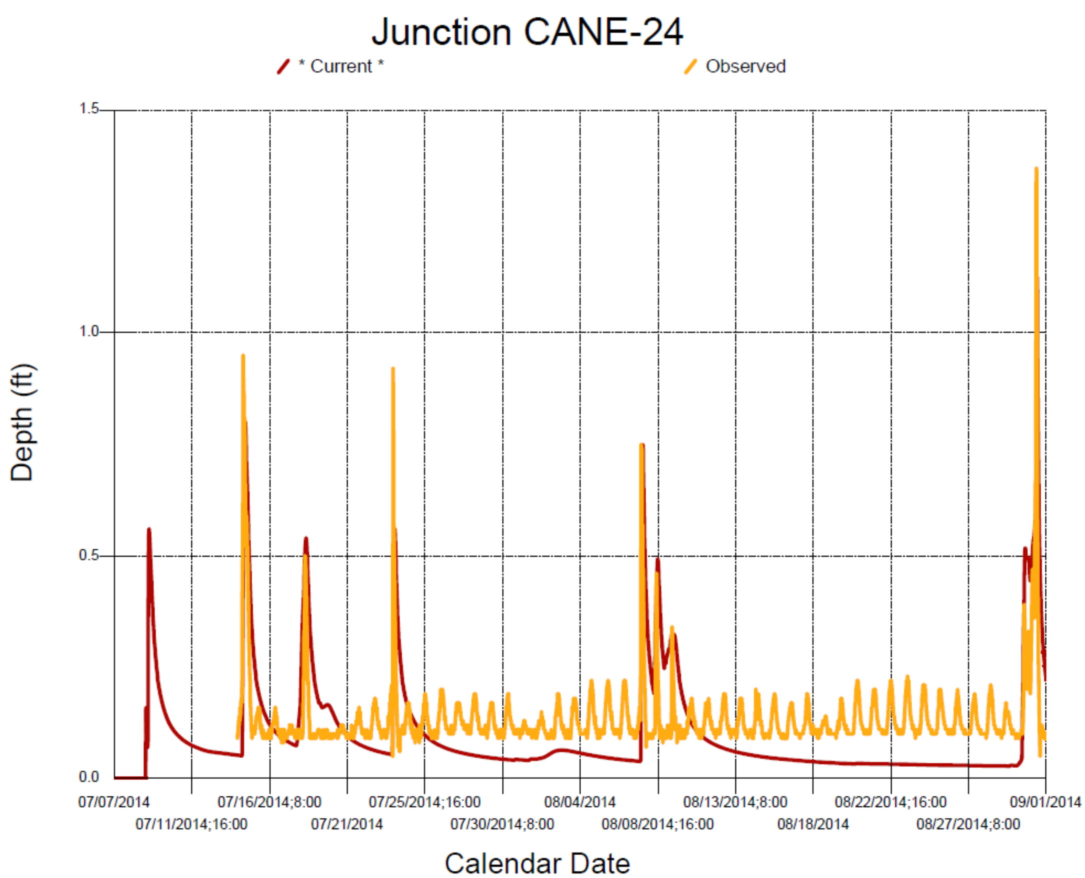


Figure 5b-Comparison of Malory Gage (*Current*/Model Value) v/s Observed/Field Measurement Depth at Model Junction CANE-24

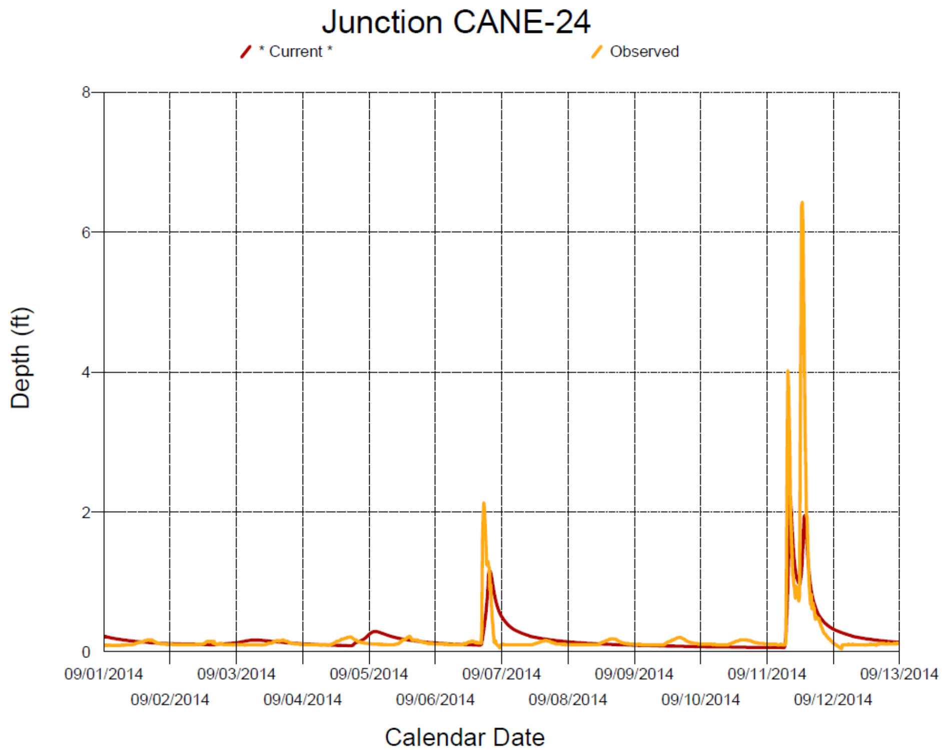


Figure 5c-Comparison of Malory Gage (*Current*/Model Value) v/s Observed/Field Measurement Depth at Model Junction CANE-24

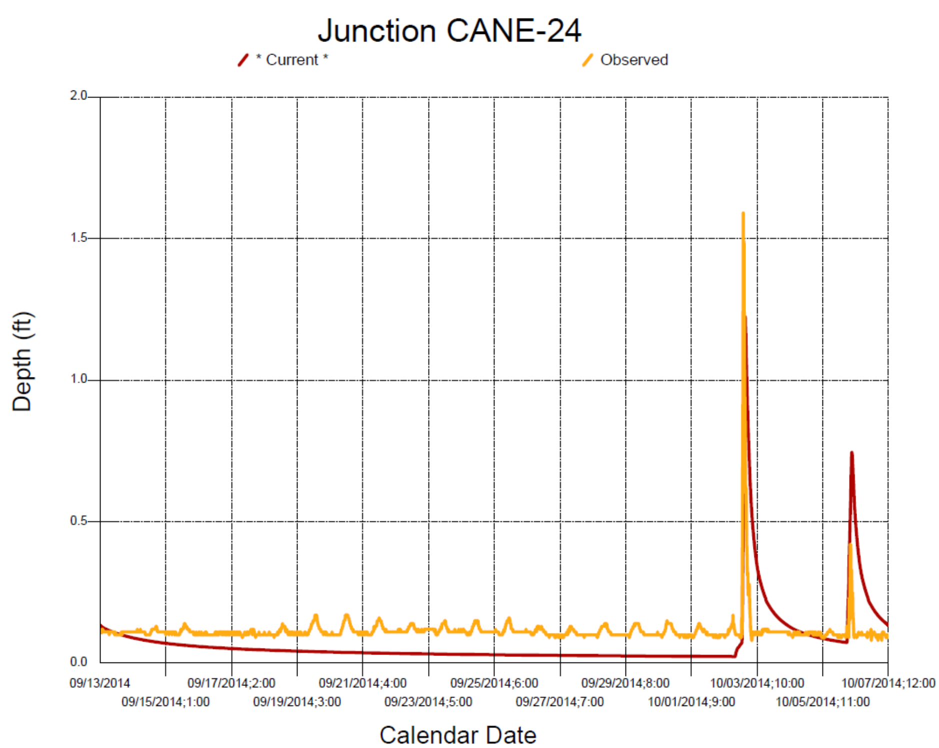
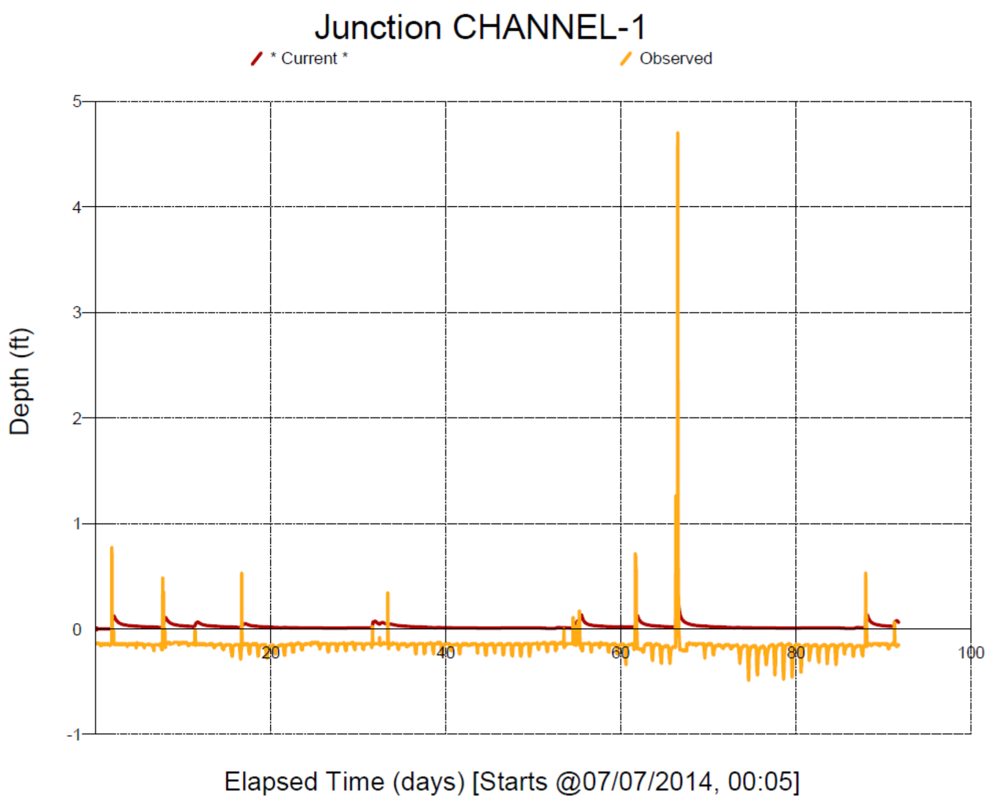


Figure 5d-Comparison of Wabash Gage (*Current*/Model Value) v/s Observed/Field Measurement Depth at Model Junction Channel-1



Using the rainfall gage data, the general response of the model follows the observed response pattern, but the timing of the peaks does not match well, as many of the peak water surface elevations from the model are substantially different from the observed peaks.

The second validation step was to use a radar-based rainfall estimate to see if the variability of actual rainfall, as compared to the uniform rainfall estimates based on the gage data, might better explain the differences between the modeled and observed water depths/elevations. Radar reflectivity data for the September 11, 2014 rainfall event was downloaded from the National Weather Service, and converted into a rainfall estimate with no ground-truth bias adjustment. The radar rainfall methodology creates one “rain gage” for each subcatchment, and creates a separate time series for each, with 5 minute time steps. A comparison of the radar rainfall total storm depth near the Glenview Park rain gage (the only gage available within the watershed during that event) showed a fairly close match, at 4.10 inches for radar and 4.07 inches for the gage. Figure 6 shows a comparison of the rainfall rates for the gage and radar, aggregated to 15 minute intervals. Aside from some relatively minor differences in timing that are because the radar is sampling a 2-acre area, while the gage is sampling point rainfall, the radar-gage comparison indicates that the unmodified radar is a reasonable estimate of rainfall values.

Figure 7 provides the radar rainfall total precipitation estimates for the September 11, 2014 rainfall event over the entire study area.

Figure 6: Radar vs Gage Rainfall near Glenview Park – September 11, 2014. (Radar Rainfall Aggregated to 15- Minute Increments.)

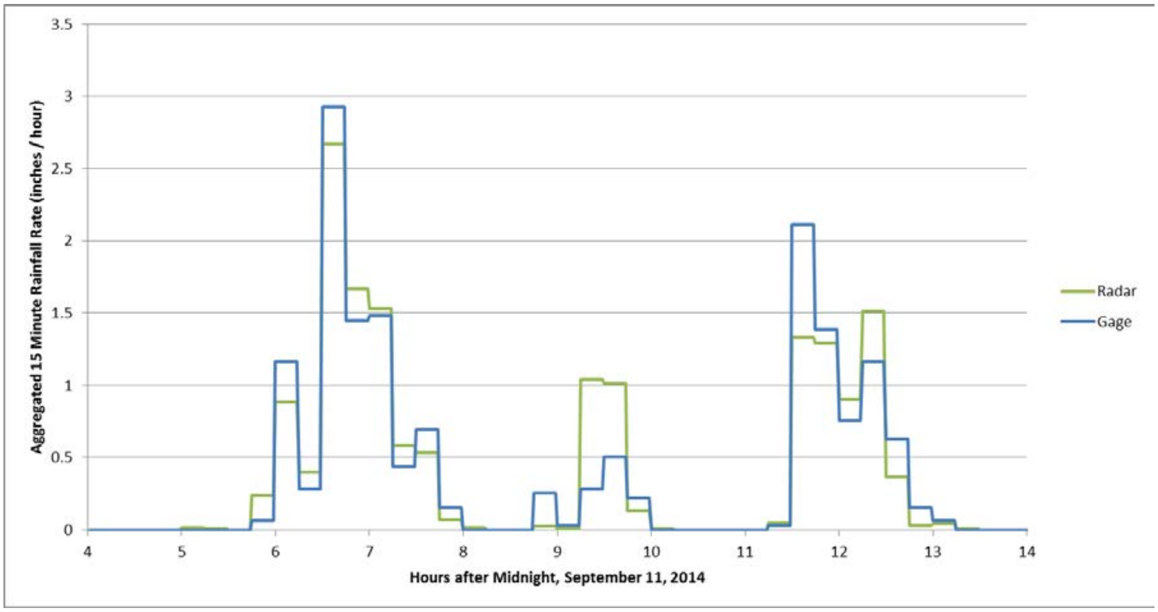
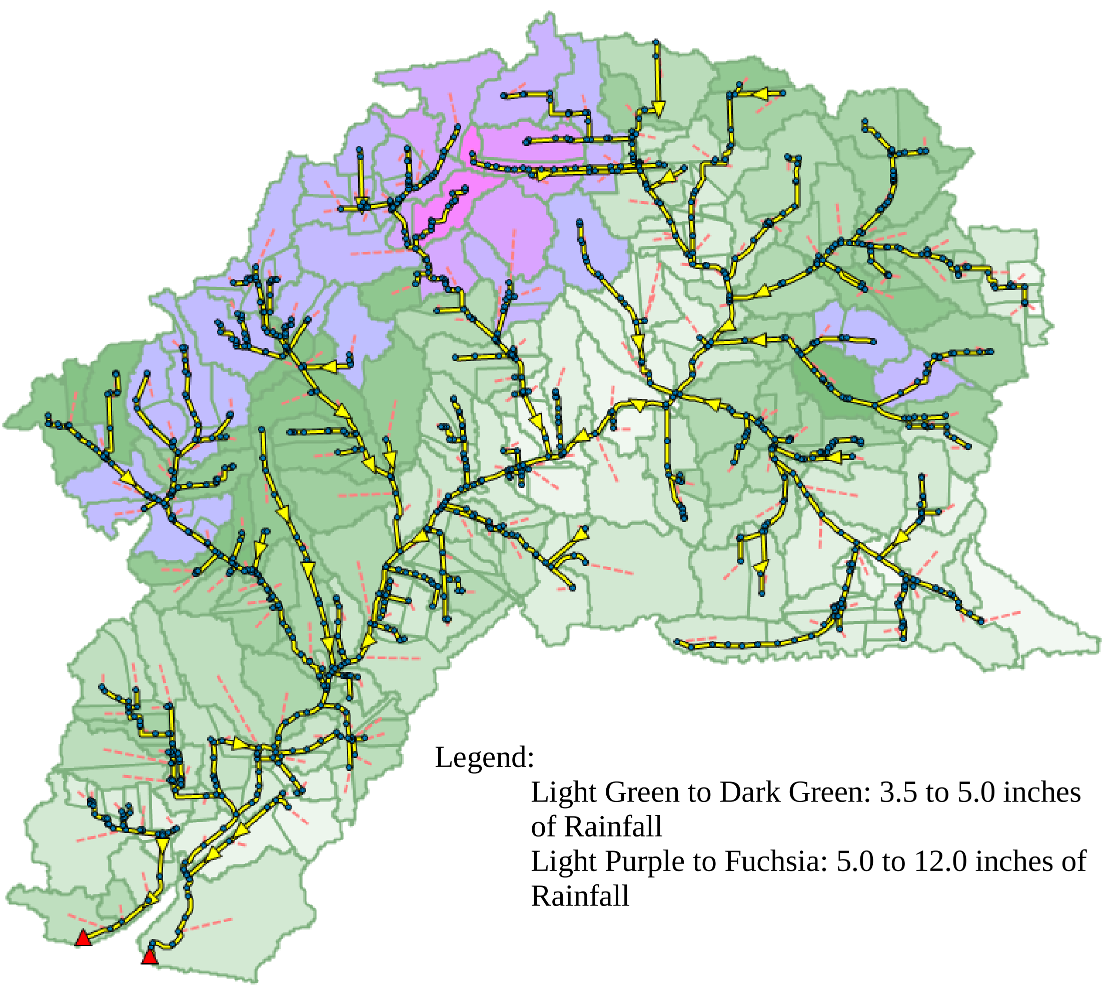


Figure 7: Radar Rainfall Total Precipitation Estimates – September 11, 2014



Legend:

Light Green to Dark Green: 3.5 to 5.0 inches of Rainfall

Light Purple to Fuchsia: 5.0 to 12.0 inches of Rainfall

Using the radar-based rainfall estimates, the model was run for the September 11, 2014 storm only. The results of that model at the two stream gage locations are shown in Figures 8 and 9 (shown as *Current*/Model Value). These model results were compared with the gage readings, noted as Observed/Field Measurement. These figures demonstrate that the additional spatial distribution information provided by the radar improves the timing and elevation fit between the observed and modeled rainfall at each of the two gage locations.

As a result of the validation analysis, it is clear that the physically based parameters used to develop the model do not provide an exact match to the observed values. To the extent that model validation is possible with the limited data available for comparison, the model appears to reasonably represent the overall hydrologic and hydraulic conditions within the Cane Creek Watershed.

Figure 8-Comparison of Radar Data (*Current*/Model Value) v/s Malory Gage (Observed/Field Measurement) at Model Junction CANE-24

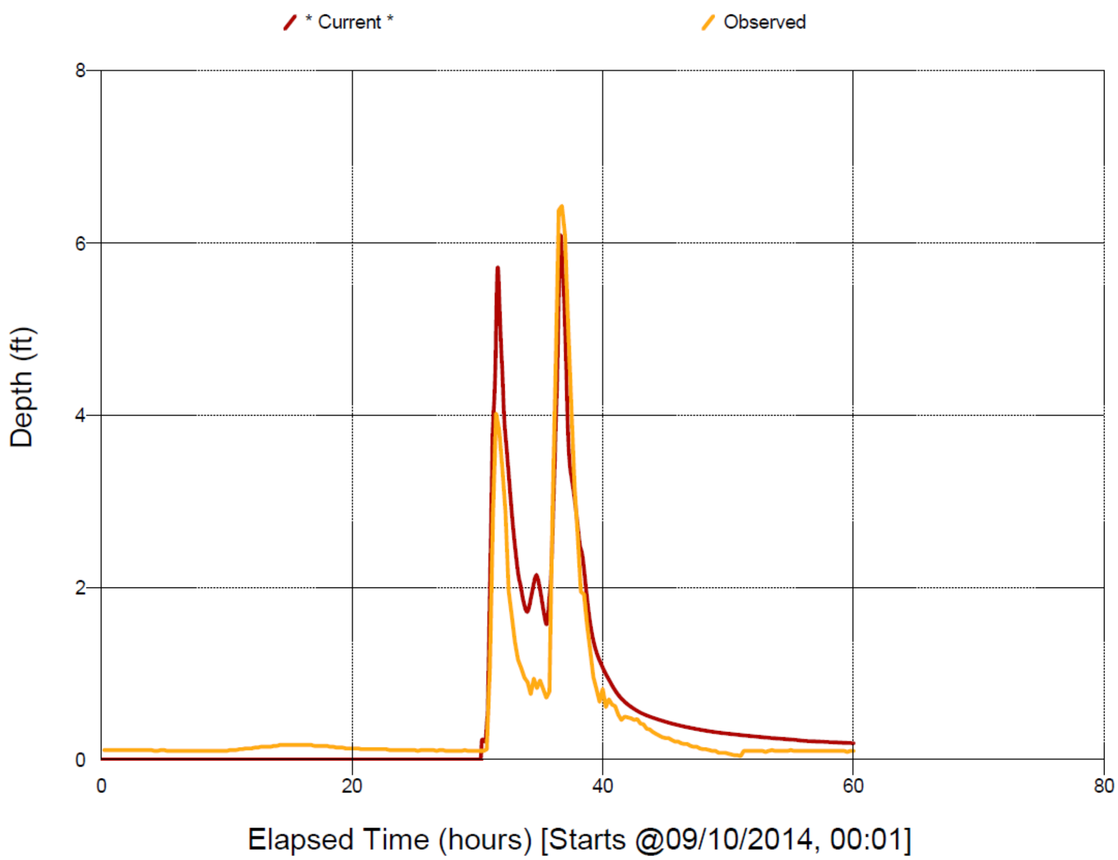
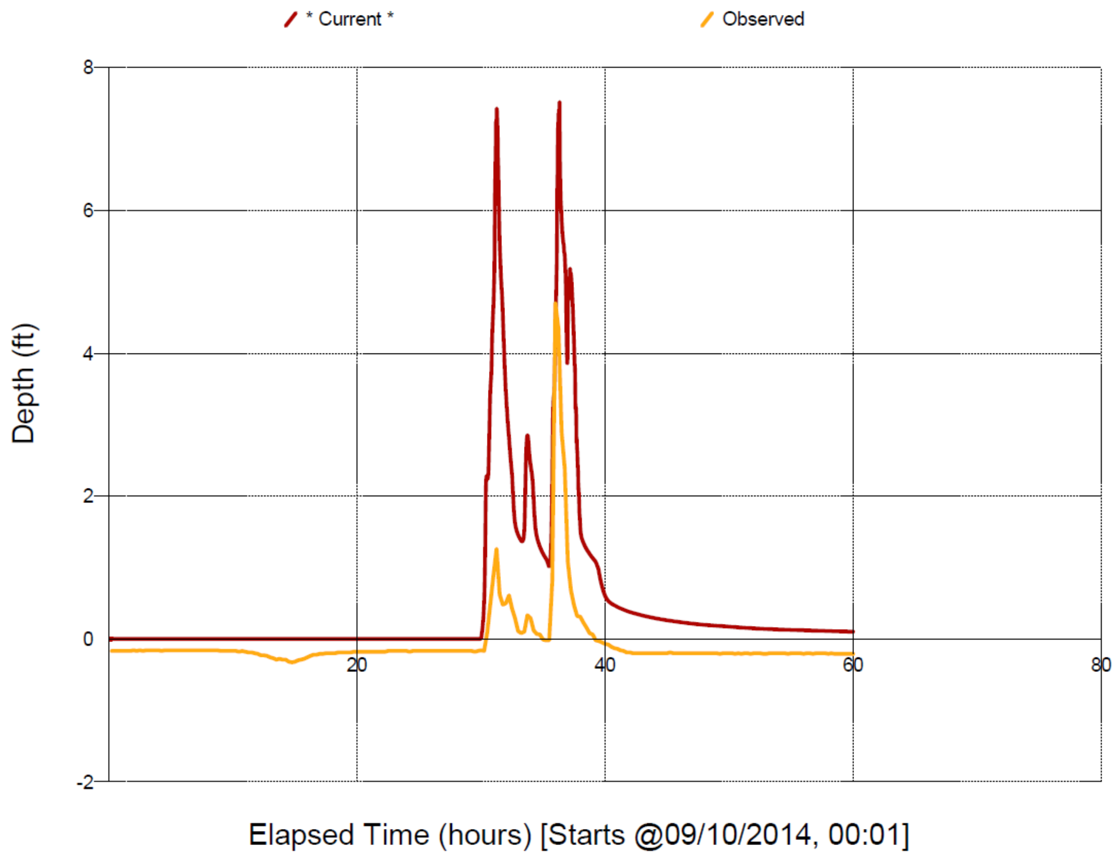


Figure 9-Comparison of Radar Data (*Current*/Model Value) v/s Wabash Gage (Observed/Field Measurement) at Model Junction CHANNEL-1



b. Existing Conditions Analysis and Review

The Cane Creek Watershed conveyance system was simplified for modeling purposes. Hydraulic modeling was limited to pipes that are, in general, 24-inch in diameter and greater and to those that provide for the primary drainage for each basin. Impervious area and drainage basin geometry are all approximations that simulate the Cane Creek Watershed system, but may not be an exact depiction of the existing system. The modeled system is meant to provide insight into the overall conditions and adequate function of the Cane Creek Watershed system under varying intensities of storms. When analyzing the model results, this degree of accuracy was considered in order to better interpret model output.

In looking for existing and future flooding areas, results were reviewed for the 10-year, and100-year storm events. These results were reviewed, and then used to predict areas of potential future flooding for identification and development of projects for the City's Capital Improvement Program (CIP). The InfoSWMM model indicates flooding by identifying nodes, or points in the model connecting two different conduits, with a water surface elevation calculated above the rim elevation of that particular node. The volume of water above the rim elevation and the duration in which the water surface elevation is above the rim elevation is also provided. By identifying nodes that experience flooding, the conduits that are potential candidates for CIP projects are also identified.

The model revealed approximately 12 areas where flooding may occur in the Cane Creek Watershed during a 10-year rainfall event. It is estimated that the floodplain boundary for this event could affect over 140 homes and businesses. Model results indicate that the impact of a 100-year rainfall event would be more extensive with over 200 homes and businesses potentially affected.

During existing and proposed conditions, there are several conduits that the model predicts to be undersized but do not result in the flooding of adjacent nodes. In other words, the pipes experience brief surcharge, but not sufficient enough to cause flooding in the upstream or downstream node. Given the model's degree of accuracy, these conduits were not considered a problem since no flooding was expected. In addition, some of the as-built information did not match the GIS topographic mapping that was used to supplement the model, indicating that rim elevations may not be accurate in some areas. Therefore, minor flooding predicted by the model was not considered a flooding problem, and no CIP projects were generated for these locations.

After assessing the potential severity of flooding predicted by the model, the six general areas that are predicted to experience the most significant flooding during the 10-year storm event are described below:

- Kellogg Avenue and Castalia Street – This is an industrial area in the eastern portion of the Cane Creek Watershed. Approximately 5 to 10 homes and businesses near this intersection are potentially impacted by the 10-year event. The stormwater conveyance system in this area is comprised of culverts and open channels, which the model predicted to overtop and create overbank flooding. (For area of impact see Exhibits 4a and 4b, Sheet 26 of 35 and Sheet 21 of 35)

- Wabash Avenue east of Castalia Street – Approximate 20 homes and small businesses are susceptible to flooding in this area which is northwest of the Kellogg / Castalia area described above. The stormwater conveyance system in this area is comprised of culverts and open channels which are projected to overtop and surcharge during the 10-year rainfall event. (For area of impact see Exhibits 4a and 4b, Sheet 21 of 35 and Sheet 15 of 35)

- Ragan Street north of Cane Creek / south of Ethlyn Avenue – The 10-year rainfall event will potentially impact 5 homes and businesses in this area. Flooding nodes were identified along Ragan Street north of the Cane Creek channel. The stormwater system along this section of Ragan Street is a pipe network with insufficient capacity to convey flow from high-frequency events. (For area of impact see Exhibits 4a and 4b, Sheet 14 of 35 and Sheet 20 of 35)

- Southeast of Glenview Park between Netherwood Avenue and Kendale Avenue – Glenview Park is in the north central portion of the watershed surrounded predominantly by residential properties. The stormwater conveyance system in this area is comprised of culverts and open channels, which were predicted to overtop and cause flooding downstream and southeast of the park potentially impacting 7 to 10 homes. (For area of impact see Exhibits 4a and 4b, Sheet 4 of 35, Sheet 8 of 35 and Sheet 9 of 35)

- Wilson Street north and south of East McLemore Avenue – This is a light industrial area with surrounding residential properties in the northwest portion of the watershed. Stormwater conveyance capacity in this area is insufficient for the 10-year event along Wilson Street and in the residential neighborhoods downstream to the south of this area. Approximately 5 homes and businesses could be impacted by the 10-year storm event. (For area of impact see Exhibits 4a and 4b, Sheet 3 of 35, Sheet 7 of 35, Sheet 13 of 35 and Sheet 19 of 35)

- Residential area east of Jesse Turner Park and Hamilton Elementary/Middle School campus – The model indicates that surcharging of conduits and overtopping of nodes along portions of Wilson Street, Trigg Avenue, Gleason Avenue, South Parkways East, and Richmond Avenue are likely during the 10-year storm event and could affect approximately 40 homes. (For area of impact see Exhibits 4a and 4b, Sheet 3 of 35, Sheet 7 of 35, Sheet 13 of 35 and Sheet 19 of 35)

Elevations at each node for 2-year, 5-year, 10-year, 25-year, 50-year and 100-year storm events under existing conditions are listed in Appendix C. Water surface elevations shown in red indicate the node locations where the hydraulic profile determined by the model exceeds the ground surface elevation.

All areas predicted by the model to experience flooding during existing conditions for 10-year and 100-year storm events are shown on Exhibit 4a and 4b respectively.

c. Development and Modeling of Potential Solutions

With the exception of isolated problem areas, the Cane Creek Watershed model indicates no serious flooding problems for existing land uses. Results and analysis of the InfoSWMM model indicate there are several locations under existing conditions that could experience routine flooding during the 10-year rainfall event. As described above, six of these areas were selected for further analysis and consideration of potential CIP projects for flood mitigation. Other areas where the model indicates flooding may occur were not evaluated in detail due to the limited depth and duration of flooding predicted by the model.

The modeling of potential flood mitigation alternatives was limited to increasing existing conduit sizes and the installation of stormwater detention basins.

<u>Increasing Existing Conduit Sizes</u> – For all six of the areas described above, a proposed conditions model was developed to analyze the feasibility of increasing conduit sizes to mitigate flooding. Various scenarios were considered including larger pipe diameters, re-constructed culverts with increased cross sections, or a combination thereof. It was determined that increasing the model conduit sizes did not provide enough flood mitigation benefit or that sizes became unreasonably large and impractical.

<u>Stormwater Detention Basins</u> – It was determined based on model analysis that the installation of stormwater detention basins in strategic areas could provide significant flood mitigation benefits. Upstream of each flood prone area described previously, aerial

photography was used to identify open areas suitable for detention. The Cane Creek Watershed is highly developed, however six locations were identified along or adjacent to the existing drainage system network for the installation of detention basins with sufficient storage capacity to yield meaningful benefits. These basins are described below.

The following Table 5 lists the proposed dimensions of each detention pond along with inlet and outlet pipe dimensions at each pond. The location of these basins are noted on Exhibit 4a and 4b respectively on the sheets referenced below. The rating curve information for each proposed pond is provided in Table 6.

TABLE 5 – PROPOSED DETENTION POND DIMENSIONS

Kellogg Avenue detention pond – (St 43.5; Sheet 26 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
5	15,000	72 / 263.50	30	100	100

Wabash Avenue detention pond – (STO-CHANNEL2-9; Sheet 21 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
5	8000	60 / 258.00	30	20	20

Ragan Street detention pond – (Storage-393; Sheet 14 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
5	12,000	36 / 248.00	24	50	50

Glenview Park detention pond – (St-611.1; Sheet 4 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
4	8000	48 / 268.50	18	50	50

Wilson Street (Lehman-Roberts area) detention pond – (Storage-512.6; Sheet 3 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
5	8000	30 / 293.00	24	50	50

Residential area detention pond (St-535.6; Sheet 3 of 35)

Depth(ft)	Area(ft^2)	Inlet Pipe(in) / Invert El (ft)	Outlet Pipe(in)	Inlet Pipe Length(ft)	Outlet Pipe Length(ft)
5	8000	48 / 275.00	12	50	50

TABLE 6 – PROPOSED DETENTION POND RATING CURVE DATA

Storage	ST-43.5	
Elevation	Depth	Area (sf)
264.5	1	500
265.5	2	3000
267.5	4	7000
268	4.5	12000
268.5	5	15000

STO-CHANNEL2-9		
Elevation	Depth	Area (sf)
259	1	500
260	2	3000
262	4	5000
262.5	4.5	6000
263	5	8000

STORAGE393		
Elevation	Depth	Area (sf)
249	1	1500
250	2	3000
251	3	6000
251.5	3.5	9000
253	5	12000

STORAGE-512.6		
Elevation	Depth	Area (sf)
294	1	500
295	2	1000
297	4	5000
297.5	4.5	7000
298	5	8000

STORAGE-535.6		
Elevation	Depth	Area (sf)
276	1	500
277	2	1000
279	4	5000
279.5	4.5	7000
280	5	8000

STORAGE-611.1		
Elevation	Depth	Area (sf)
269.5	1	500
270.5	2	2000
271	2.5	4000
271.5	3	6000
272.5	4	8000

With addition of these detention ponds, elevations at flooded nodes for the 2-year, 5-year, 10-year, 25-year, 50-year and 100-year storm event were lowered. All proposed condition node elevations are listed in Appendix D. Water surface elevations shown in red indicate the node locations where the hydraulic profile determined by the model exceeds the ground surface elevation. A comparison of elevation data for existing and proposed conditions at each node for 10-year and 100-year storm events is provided in Appendix E.

Hydraulic profiles for improved conditions based on implementation of these proposed detention ponds are provided in Appendix F for both the 10-year and 100-year storm events.

The proposed condition floodplain for the 10-year and 100-year storm events are shown in Exhibit 4a and 4b respectively.

Larger maps for the Cane Creek Watershed with infrastructure node identifications, proposed detention pond locations, and flood boundaries for existing and proposed conditions are provided in Appendix G and Appendix H for the 10-year and 100-year storm events, respectively.

d. Cost Estimates

A preliminary opinion of probable construction cost for each recommended detention pond is provided in Table 7 below.

TABLE 7 – PRELIMINARY OPINION OF PROBABLE CONSTRUCTION COST FOR PROPOSED DETENTION PONDS

Kellogg Avenue detention pond- (St 43.5)

ST-43.5				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	847.93	cy	$ 12.00	$ 10,175.11
Sod	15000	sf	$ 1.38	$ 20,625.00
72" Inlet Pipe	100	ft	$ 330.00	$ 33,000.00
30" Outlet Pipe	100	ft	$ 60.00	$ 6,000.00
Roadwork	1	LS	$ 20,000.00	$ 20,000.00
			Subtotal	$ 89,800.11
			20% Contingency	$ 17,960.02
			Total	$ 107,760.13

Wabash Avenue detention pond-(STO-CHANNEL2-9)

STO-CHANNEL 2-9				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	588.56	cy	$ 12.00	$ 7,062.67
Sod	8000	sf	$ 1.38	$ 11,000.00
60" Inlet Pipe	20	ft	$ 250.00	$ 5,000.00
30" Outlet Pipe	20	ft	$ 60.00	$ 1,200.00
			Subtotal	$ 24,262.67
			20% Contingency	$ 4,852.53
			Total	$ 29,115.20

Ragan St Detention pond – (Storage-393)

Storage 393				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	983.04	cy	$ 12.00	$ 11,796.44
Sod	12000	sf	$ 1.38	$ 16,500.00
36" Inlet Pipe	50	ft	$ 85.00	$ 4,250.00
24" Outlet Pipe	50	ft	$ 42.00	$ 2,100.00
Roadwork	1	LS	$ 20,000.00	$ 20,000.00
		Subtotal		$ 54,646.44
		20% Contingency		$ 10,929.29
		Total		$ 65,575.73

Glenview Park detention pond – (St-611.1)

ST-611.1				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	558.30	cy	$ 12.00	$ 6,699.56
Sod	8000	sf	$ 1.38	$ 11,000.00
48" Inlet Pipe	50	ft	$ 145.00	$ 7,250.00
18" Outlet Pipe	50	ft	$ 28.00	$ 1,400.00
Trail Repair	1	LS	$ 5,000.00	$ 5,000.00
		Subtotal		$ 31,349.56
		20% Contingency		$ 6,269.91
		Total		$ 37,619.47

Lehman-Roberts Company-detention pond (Storage-512.6)

Storage 512.6				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	486.15	cy	$ 12.00	$ 5,833.78
Sod	8000	sf	$ 1.38	$ 11,000.00
30" Inlet Pipe	50	ft	$ 60.00	$ 3,000.00
24" Outlet Pipe	50	ft	$ 42.00	$ 2,100.00
		Subtotal		$ 21,933.78
		20% Contingency		$ 4,386.76
		Total		$ 26,320.53

Residential area detention pond (St-535.6)

ST-535.6				
Description	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Earthwork	486.15	cy	$ 12.00	$ 5,833.78
Sod	8000	sf	$ 1.38	$ 11,000.00
40" Inlet Pipe	50	ft	$ 115.00	$ 5,750.00
12" Outlet Pipe	50	ft	$ 20.00	$ 1,000.00
			Subtotal	$ 23,583.78
			20% Contingency	$ 4,716.76
			Total	$ 28,300.53

4. Final Recommendations

The recommended CIP projects to alleviate flooding in the six target areas are described below:

- Kellogg Avenue and Castalia Street (Pond ST 43.5) – A proposed stormwater detention basin located along the south side of Frisco Avenue south of the Kellogg manufacturing facility will mitigate flooding potential for 5 to 10 homes and businesses in this area.

- Wabash Avenue east of Castalia Street (Pond STO-CHANNEL 2-9) – A detention pond adjacent to the open channel in this area is proposed along the south side of Wabash Avenue east of Castalia Street to mitigate flooding of approximately 20 homes and small businesses.

- Ragan Street north of Cane Creek / south of Ethlyn Avenue (Pond ST 393) – A detention facility is recommended near the southeast corner of Ragan Street and Gold Avenue to reduce or remove flooding threat to 5 homes and businesses.

- Southeast of Glenview Park between Netherwood Avenue and Kendale Avenue (Pond ST 611.1) – A detention basin is proposed in Glenview Park to mitigate flooding potential to approximately 7 to 10 homes in this area.

- Wilson Street north and south of East McLemore Avenue (Pond ST 512.6) – Two storm water storage facilities are proposed in this area, one located east of the Lehman-Roberts facility on Wilson Street and the other located along the south side of East McLemore Avenue west of Wilson Street. These basins will reduce flooding potential for 5 homes and businesses in this area and more than 40 homes in the area described below.

- Residential area east of Jesse Turner Park and Hamilton Elementary/Middle School campus (Pond ST 535.6) – The two stormwater detention facilities identified above will help to eliminate or reduce flooding potential for over 40 homes in this area during the 10-year storm event.

5. **Benefit-Cost Analysis**

To evaluate proposed hazard mitigation projects prior to funding, FEMA requires a Benefit-Cost Analysis (BCA) to validate cost effectiveness. The FEMA BCA is a tool for organizing data to allow comparing the relative value of alternative public investments. If the value of significant benefits and costs can be expressed in monetary terms, the net value (i.e. benefits minus costs) of the alternatives under consideration can be computed and used to compare which alternative yields the greatest relative advantage. A fair comparison is possible only if it a dollar value can be assigned to all relevant costs and benefits and they are on a common time basis.

The process of conducting a Benefit-Cost Analysis involves weighing the total expected costs against the total expected benefits of one or more actions in order to choose the best or most profitable option/alternative.

For this project, FEMA BCA version 5.1.0 was used to performed benefit cost analysis for all proposed detention ponds in Cane Creek Watershed.

Parameters:

The following values in Table 8 from the FEMA BCA software were used for calculations:

TABLE 8 – FEMA BCA COST VALUES

Demolition Threshold	50%
Displacement Costs/day	$155
Current federal meals per diem	$46*
Current federal lodging per diem	$77*
Treatment Costs per person	$2,443
Productivity Loss per person	$8,736

*Data in FEMA BCA software does not match current Federal per diem rates for Memphis, TN (2016 rates: Meals - $59; Lodging - $106)

Assumptions:

BCA calculation requires the following data for each affected structure:

- First floor elevation.
- Foundation type (slab, pier, pile)
- Building type (One Story, two or more stories, split level, mobile home etc)
- Total size of the building (Sq Feet)
- Building replacement value (BRV- $/Sq Feet)

In the absence of above mentioned data for each affected structure, first floor elevation was taken from the DEM data, foundation type was assumed to be all slab, all building types were assumed to be one story, and approximate building size was measured from aerials. The BCA done for this project is for analysis purpose only. Hence it could not be used as an official submittal to FEMA as a part of the grant application process without further refinement and more detailed input data.

The following Table 9 lists all the properties which are benefited by each proposed detention pond:

TABLE 9 – PROPERTIES BENEFITED BY PROPOSED DETENTION PONDS

Detention Basin 43.5		
Address	**City**	**State**
2000 Boyle Ave	Memphis	TN
2007 E Person Ave	Memphis	TN
2008 Boyle Ave	Memphis	TN
2014 Boyle Ave	Memphis	TN
2021 Boyle Ave	Memphis	TN
2022 Boyle Ave	Memphis	TN
2024 Boyle Ave	Memphis	TN
Apartment building	Memphis	TN
C&J Barbeque	Memphis	TN
J&C Community Super Store	Memphis	TN
Kellogg Industry	Memphis	TN
House next to 2022 Boyle Ave	Memphis	TN

Detention Pond-STO-CHANNEL2-9		
Address	City	State
1561 W Dianne Cir	Memphis	TN
1565 W Dianne Cir	Memphis	TN
1571 W Dianne Cir	Memphis	TN
1577 W Dianne Cir	Memphis	TN
1581 W Dianne Cir	Memphis	TN
1585 W Dianne Cir	Memphis	TN
1589 W Dianne Cir	Memphis	TN
1987 S Dianne Cir	Memphis	TN
1991 S Dianne Cir	Memphis	TN
1995 Dianne Cir	Memphis	TN
1999 S Dianne Cir	Memphis	TN

Detention Pond-STO-CHANNEL2-9		
2001 S Dianne Cir	Memphis	TN
1590 E Dianne Cir	Memphis	TN
1568 W Dianne Cir	Memphis	TN
1574 W Dianne Cir	Memphis	TN
1578 W Dianne Cir	Memphis	TN
1990 S Dianne Cir	Memphis	TN
1994 S Dianne Cir	Memphis	TN
1575 E Dianne Cir	Memphis	TN

Storage 535.6		
Address	**City**	**State**
1205 Wilson St	Memphis	TN
1209 Wilson St	Memphis	TN
1215 Wilson St	Memphis	TN
1221 Wilson St	Memphis	TN
1223 Wilson St	Memphis	TN
1229 Wilson St	Memphis	TN
1233 Wilson St	Memphis	TN
1239 Wilson St	Memphis	TN
1243 Wilson St	Memphis	TN
1245 Wilson St	Memphis	TN
1220 Wilson St	Memphis	TN
1224 Wilson St	Memphis	TN
1234 Wilson St	Memphis	TN
1254 Wilson St	Memphis	TN
1349 Orgill Ave	Memphis	TN
1377 Trigg Ave	Memphis	TN
1378 Gleason Ave	Memphis	TN
1336 Gleason Ave	Memphis	TN
1408 South Parkway E	Memphis	TN
1410 South Parkway E	Memphis	TN
1393 South Parkway E	Memphis	TN
1388 South Parkway E	Memphis	TN
1392 Richmond Ave	Memphis	TN
1386 Richmond Ave	Memphis	TN

Storage 512.6		
Address	**City**	**State**
1293 Edith Ave	Memphis	TN
1362 E McLemore Ave	Memphis	TN

Storage-396		
Address	**City**	**State**
Storage 393	Memphis	TN
1551 Ragan St	Memphis	TN
1545 Ragan St	Memphis	TN
1609 Ragan St	Memphis	TN
1615 Ragan St	Memphis	TN
1619 Ragan St	Memphis	TN
1623 Ragan St	Memphis	TN
1633 Ragan St	Memphis	TN
1639 Ragan St	Memphis	TN
1643 Ragan St	Memphis	TN
1588 Ragan St	Memphis	TN

Detention Pond ST-611.1		
Address	**City**	**State**
1850 Foster Ave	Memphis	TN
1856 Foster Ave	Memphis	TN
1862 Foster Ave	Memphis	TN
1872 Foster Ave	Memphis	TN
1841 Netherwood Ave	Memphis	TN
1833 Netherwood Ave	Memphis	TN
1889 Foster Ave	Memphis	TN
1883 Foster Ave	Memphis	TN
1873 Foster Ave	Memphis	TN
1867 Foster Ave	Memphis	TN
1863 Foster Ave	Memphis	TN
1857 Foster Ave	Memphis	TN
1853 Foster Ave	Memphis	TN
1847 Foster Ave	Memphis	TN
1247 C Barksdale St	Memphis	TN
1253 S Barksdale St	Memphis	TN
1259 S Barksdale St	Memphis	TN
1878 Kendale Ave	Memphis	TN

1872 Kendale Ave	Memphis	TN
1866 Kendale Ave	Memphis	TN
1862 Kendale Ave	Memphis	TN
1856 Kendale Ave	Memphis	TN
1887 Kendale Ave	Memphis	TN
1877 Kendale Ave	Memphis	TN
1873 Kendale Ave	Memphis	TN
1867 Kendale Ave	Memphis	TN
1279 S Barksdale St	Memphis	TN
1283 S Barksdale St	Memphis	TN
1287 S Barksdale St	Memphis	TN
1907 Kendale Ave	Memphis	TN
1919 Kendale Ave	Memphis	TN
1286 S Barksdale St	Memphis	TN
1288 s Barksdale St	Memphis	TN
1298 S Barksdale St	Memphis	TN
1287 Lapaloma St	Memphis	TN
1293 Lapaloma Cir	Memphis	TN

BCA Results:

The end result is a benefit-cost ratio (BCR) model, which is derived from a project's total net benefits divided by its total project cost. The BCR is a numerical expression of the cost effectiveness of a project. A project is considered to be cost effective when the BCR is 1.0 or greater, indicating the benefits of a prospective hazard mitigation project are sufficient to justify the costs. As seen from the BCA output Table 10, the BCR number for all prospective hazard mitigation projects is greater than 1.0, hence the cost of constructing all recommended detention ponds is justified.

TABLE 10 – FEMA BCA OUTPUT

Project Name	BCR	Costs	Benefits
Detention Basin-43.5	24.12	$107,681	$2,597,139
STO-CHANNEL2-9	7.37	$29,133	$214,754
Storage 535.6	19.16	$28,323	$542,662
Storage 512.6	3.59	$26,322	$94,546
Storage-396	4.27	$65,584	$279,864
Detention Pond ST-611.1	14.57	$37,662	$548,633

Detailed output for the BCA analysis for each proposed detention pond is attached in Appendix I.