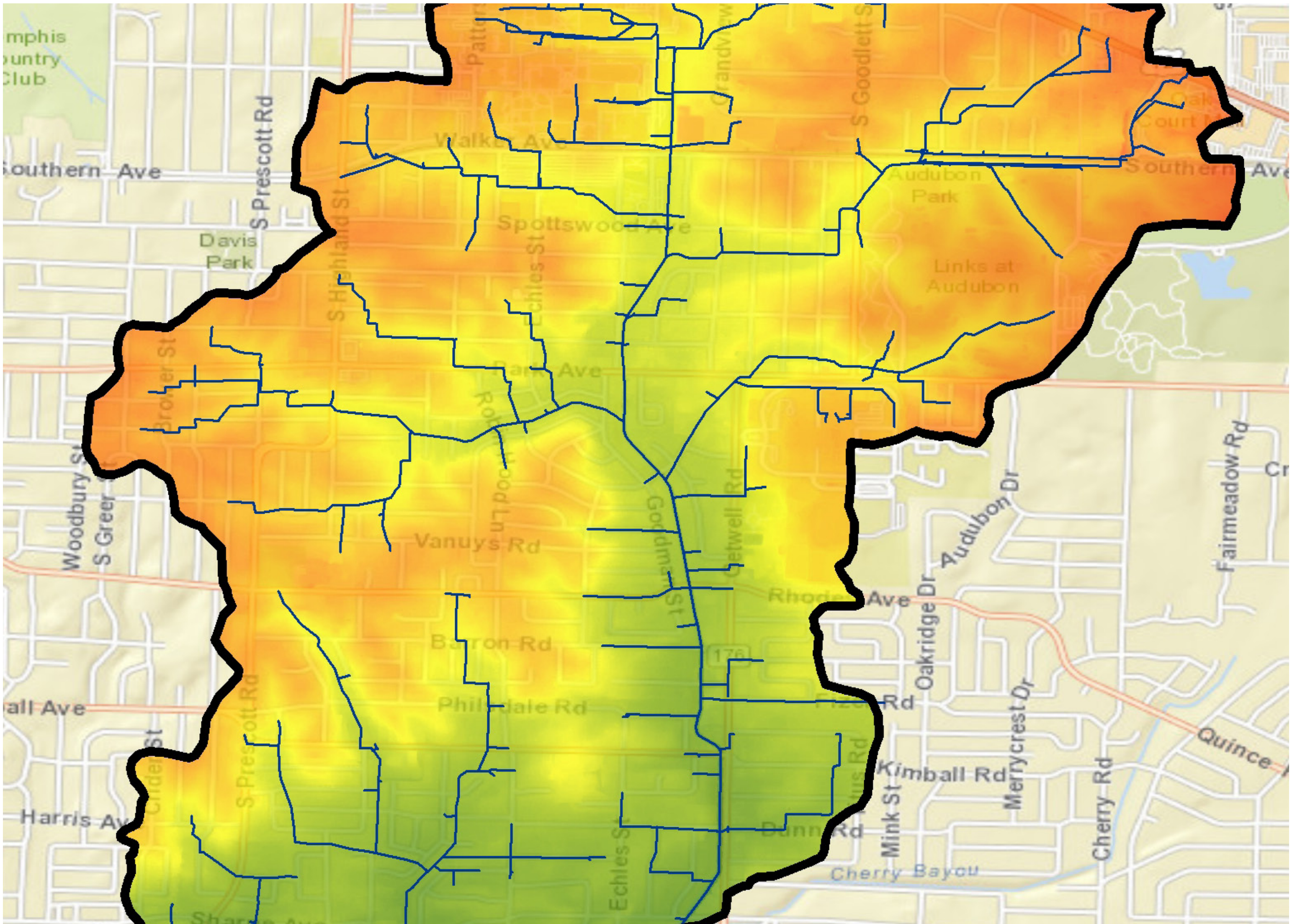


Comprehensive Drainage Report

BLACK BAYOU DRAINAGE BASIN STORMWATER MASTER PLAN

VOLUME TWO

City of Memphis, Tennessee

APRIL 2020

BARGE DESIGN SOLUTIONS

20180172

BLACK BAYOU DRAINAGE BASIN
STORM WATER MASTER PLAN

VOLUME II

CITY OF MEMPHIS, TENNESSEE

March 2020

Table of Contents

FIGURES

TABLES

1 DATA COLLECTION

In order to develop a model which would accurately depict the response of the Black Bayou Drainage Basin to the occurrence of a given theoretical or historical storm, a significant amount of data had to be collected and assimilated. The data consisted of a combination of the City's stormwater infrastructure Geographic Information System (GIS) database, digital LiDAR-derived topographic terrain models, and field-collected survey data. Precipitation and flow depth gage data collected by others under direct contract with the City were utilized to calibrate the model once it was developed. Below is a summary of the data collected for this study.

1.1 Field Survey

Field survey was completed by THY Inc., and Barge Design Solutions, Inc. Global Positioning System (GPS) was used to set control points throughout the basin. Traditional field survey with total stations was performed to survey the horizontal position and vertical elevation of the stormwater infrastructure elements within the basin, including open channels, culverts, bridges, storm drain pipes, and other structures. Data referenced to Tennessee State Plane (feet) and North American Vertical Datum of 1988 (NAVD 88). The survey data was collected beginning the fall of 2015 through the summer of 2016. After the completion of the field survey there were numerous developments built within the basin that potentially altered the stormwater infrastructure. These developments, specifically near the University of Memphis, are not included in this study.

1.1.1 Open Channel Cross-Sections and Road Crossings

Most of the open channel cross-sections surveyed were vertical wall concrete channels. These sections typically consisted of a five-point section with measurements taken at left top of wall, left bottom of wall, invert, right bottom of wall and right top of wall. Where needed for clarity or additional information, additional measurements were taken in one or both of the overbank areas. Road crossing surveys consisted of bridge or culvert opening sections at the upstream and downstream sides of the road as well as a centerline profile of the road in the vicinity of the bridge. Channel section locations were selected to provide the most information on channel alignment, size and other pertinent factors and were spaced at an average interval of approximately 230 feet. During the course of the field data collection for this project approximately 100 stream channel cross-sections and 35 road crossings in the Black Bayou basin were field-surveyed.

1.1.2 Storm Water Structures

The field-survey effort was also intended to verify and augment the information on existing drainage structures contained in the City's existing GIS database. Therefore, all existing pipes 24-inches in diameter or greater, were surveyed. Approximately 600 stormwater structures were surveyed in the basin.

1.1.3 Finished Floor Elevations

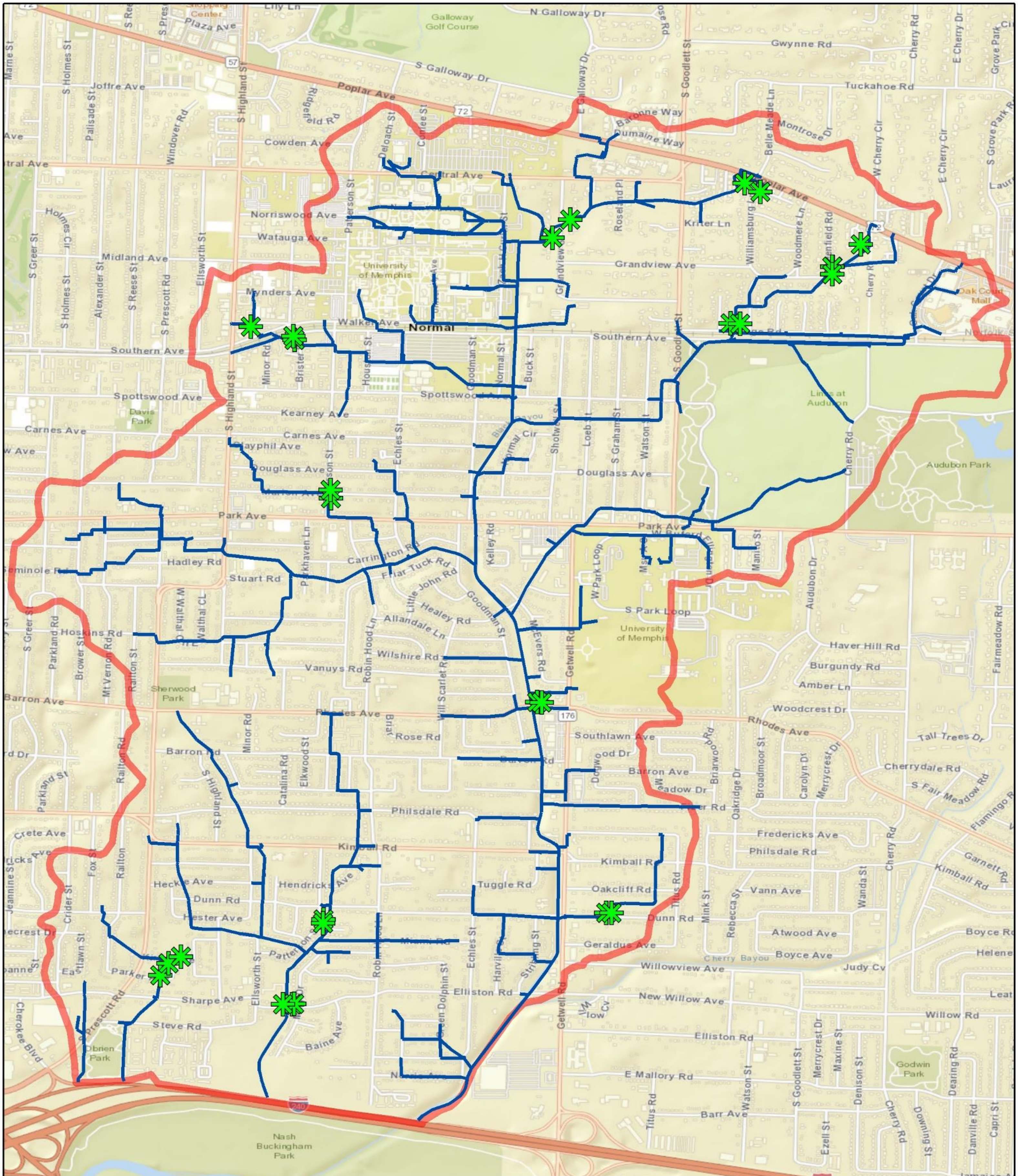
In evaluating the modeling results, inundation was indicated in some locations where it was not readily apparent if the inundation would cause actual flooding of homes or other habitable structures, or if it would just represent short-term nuisance flooding of the yard. In order to clarify the extent of the problem, finished floor elevations of the structures in question were collected by field-survey and compared to predicted water surface elevations. Approximately 25 finished floor elevations were collected for 23 buildings as shown in Figure 1-1.

1.2 GIS Inventory Update

The existing City of Memphis stormwater inventory geodatabase was used as the starting point to establish general system connectivity and served as the location guide used by survey crews for stormwater infrastructure. This base GIS stormwater inventory was appended when new stormwater infrastructure was identified in the field or record drawings provided updates to system information, such as underground detention to support the modeling effort.

The location, size, elevation, and geometry of stormwater infrastructure collected during the field survey effort produced a standard format of point files as the final deliverable that consisted of the x, y, z data of each point as well as a descriptive code that followed the City protocol defined in “Attachment A: Standard Survey Codes in the FY 2014 & FY 2015 Stormwater Modeling, Mapping & Analysis RFSOQ.” This survey geodatabase is included with the project deliverables as Attachment A.

The survey data were the primary source for updates to the location, size, and type of structure within the inventory. Additionally, connectivity between structures and stormwater conveyance routes were examined as part of the inventory update. The Black Bayou system analysis depends on runoff from specific drainage areas reaching the correct receiving storage, inlet, and conveyance structures. Size, terrain, road configurations, and parcel data were considered while making connectivity updates to the original inventory. The end result was a stormwater system that connected drainage from the upstream, outer portions of the Black Bayou Drainage Basin to the downstream Nonconnah Creek floodplain with the location, size and structure types updated from field survey. This updated inventory geodatabase is included with the project deliverables as Attachment A.



2,000

Feet

1 inch = 2,000 feet
Tennessee State Plane (feet) 4100fips
North American Datum 1983

N

BARGE DESIGN SOLUTIONS

Figure 1-1
Finished Floor Elevations Surveyed

Memphis, Tennessee

No. of Subbasins = 144
Average Subbasin Size = 20.6 Acres

Finished Floor Survey Locations

Conduits

1.3 Precipitation

As shown in Table 1-1, annual rainfall in Memphis is about 48 inches and is generally highest in late fall and early spring. December sees the most rainfall, on average 5.13 inches, and September sees the least rainfall, on average 2.20 inches. Memphis receives an average of about 2.5 inches of snowfall annually between the months of December and March. Average precipitation amounts are shown in Table 1-1. Point precipitation frequency estimates data for the watershed was retrieved from Atlas 14 and is shown in Figure 1-2. The point frequency estimates for over a 24-hour period for each storm is shown in Figure 1-3.

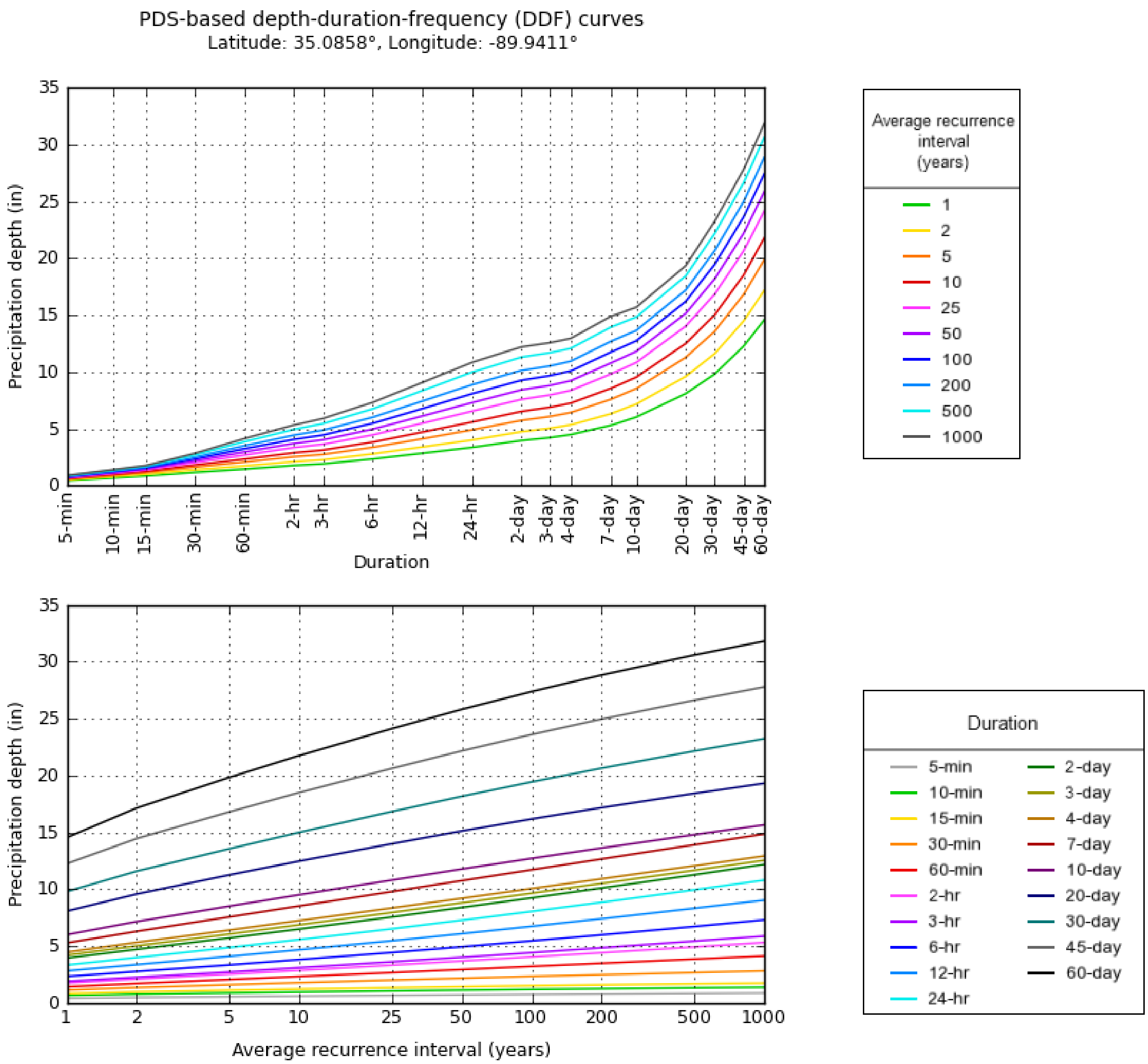


Figure 1-2 Durational Precipitation Frequency of Black Bayou Drainage Basin

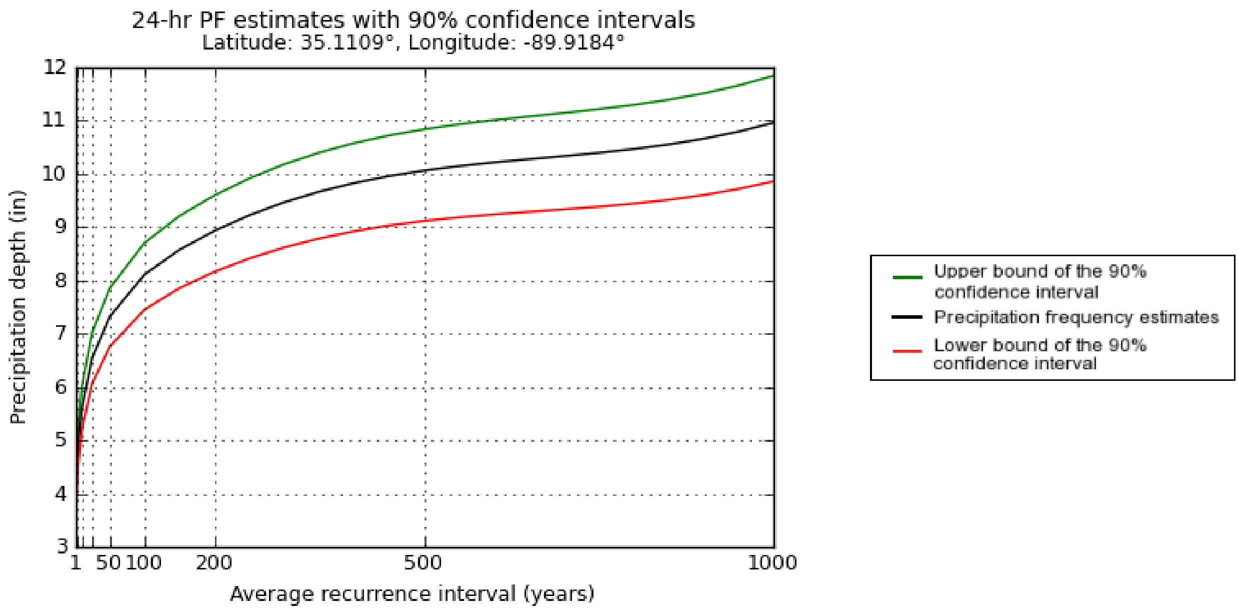


Figure 1-3 24-Hour Precipitation Frequency of Black Bayou Drainage Basin

Table 1-1 Average Precipitation Amounts in Black Bayou Drainage Basin

Month	Avg. Precipitation (in.) 1981-2010
January	3.90
February	4.09
March	4.34
April	4.89
May	4.81
June	3.55
July	4.26
August	2.75
September	2.20
October	3.73
November	4.71
December	5.13
Annual	48.36

1.4 Topography

As shown in Figure 1-4 the elevation in the Black Bayou Drainage Basin ranges from a high elevation of about 325 feet to a low elevation of about 230 feet. Elevation data referenced to North American Vertical Datum of 1988 (NAVD 88). The highest elevations in the basin area occur along the northern, eastern, and western basin boundary. Flow generally travels south through the hydrologic feature called Black Bayou (not to be confused with the name of the project area) to Nonconnah Creek, the lowest elevation in the basin. Slopes in the basin range from the steepest of 3% to the flattest of 1%.

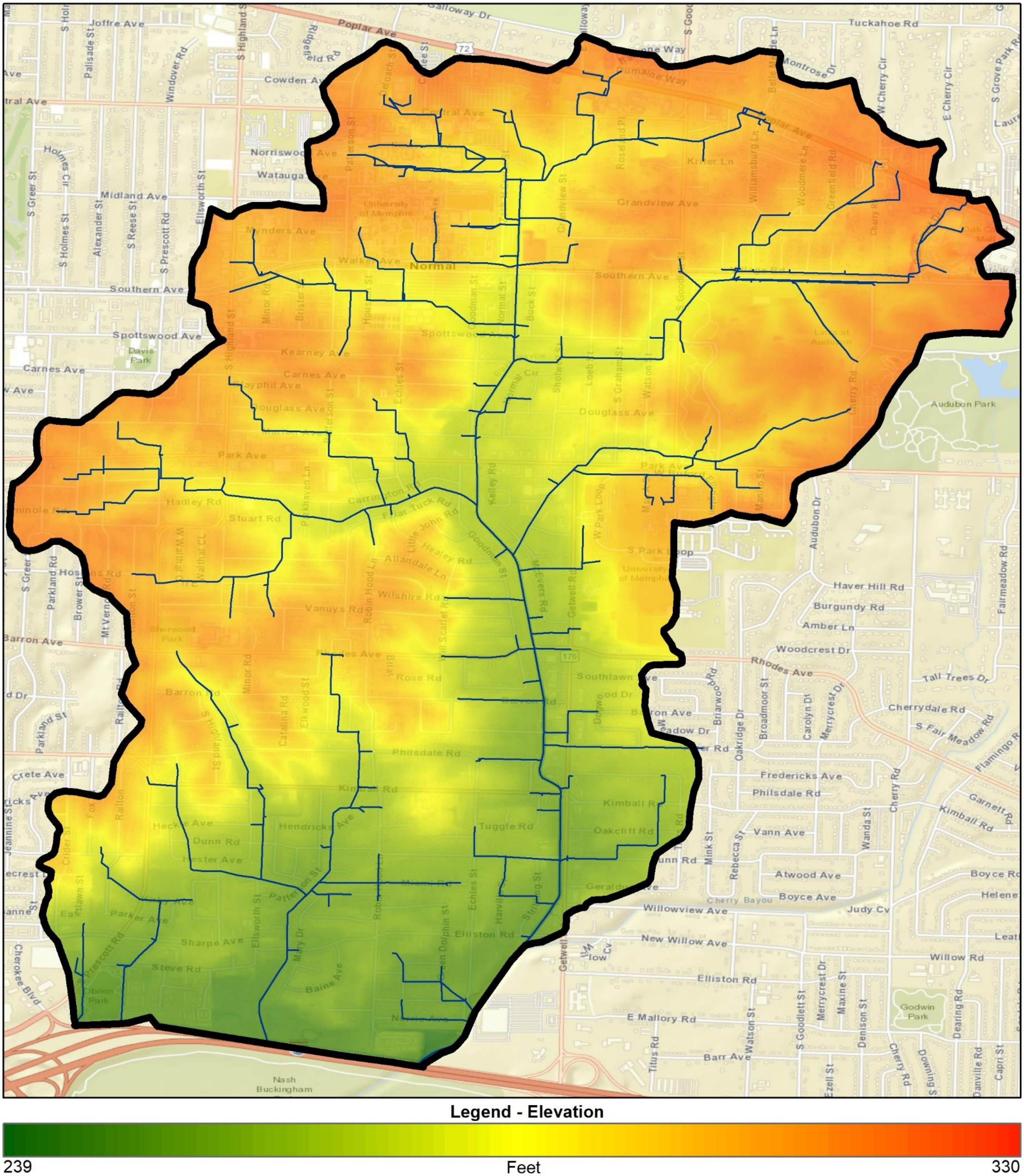


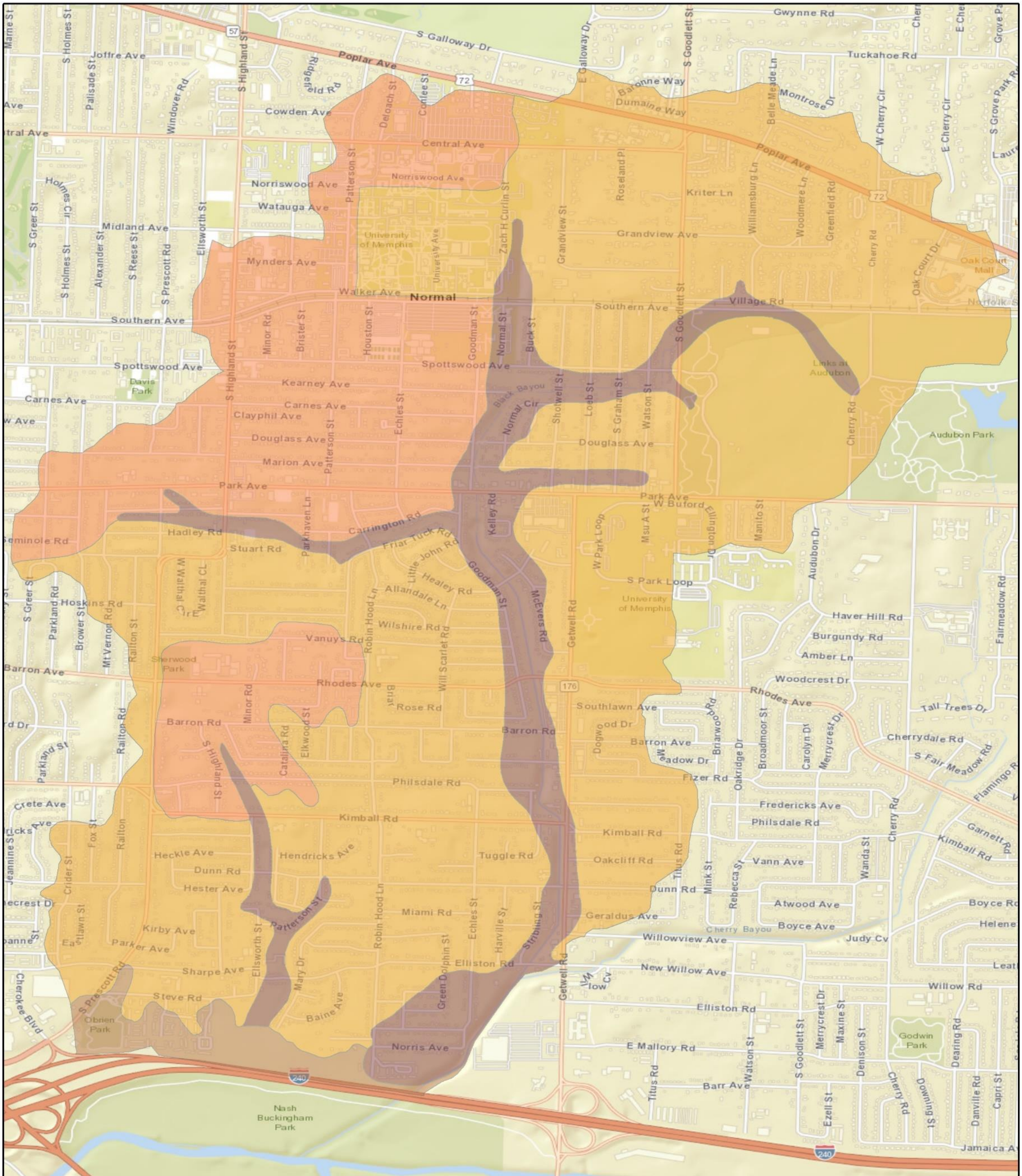
Figure 1-4
Topography of Black Bayou Drainage Basin
Memphis, Tennessee

1.5 Soils

Soil classification data for the project area was retrieved from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey. This survey shows that about 75% of the soil in the Black Bayou Drainage Basin is udorthent land, implying that this soil has been backfilled after the removal of the native surface. The remaining area is composed of various types of silt loam with moderate infiltration rates when thoroughly wet. Figure 1-5 shows the map result of the soil survey. Table 1-2 gives a summary of the soil classifications from the survey. Note that the udorthent land was not given a soil rating by the NRCS.

Table 1-2 Soil Classification in Black Bayou Drainage Basin

Map Unit symbol	Map Unit Name	Rating	Acres in AOI	Percent of AOI
Fm	Falaya silt loam	B/D	66.3	2.2%
Fs	Filled land, silty (udorthent, silty)	-	330.8	11.2%
Gr	Graded land, silty materials (udorthent, silty)	-	1,900.3	64.2%
MeB	Memphis silt loam, 2 to 5 percent slopes	B	663.7	22.4%
Totals for Area of Interest			**2,961.1**	**100.0%**



2,000

Feet

1 inch = 2,000 feet
Tennessee State Plane (feet) 4100fips
North American Datum 1983

N

BARGE
DESIGN SOLUTIONS

Figure 1-5
Soils Classification in Black Bayou Drainage Basin
Memphis, Tennessee

USGS Soil Classifications
- Falaya Silt Loam
- Filled Land, silty (udorthent, silty)
- Graded land, silty materials (udorthent, silty)
- Memphis Silt Loam, 2 to 5 percent slopes

1.6 Land Use

The land usage data for the project area were retrieved from the National Land Cover Database (NLCD) 2011 by the Multi-Resolution Land Characteristics Consortium. These data show that most of the land in the Black Bayou Drainage Basin is classified as “Developed Low Intensity” or “Developed Open Space”. These classifications are explained by the presence of many residential parcels. The next largest classifications of land usage are “Developed High Density” and “Developed Medium Density”. These classifications occur near intersections of larger roads where there are retail businesses, Oak Court Mall, Memphis Botanic Garden, several apartment complexes, and two public schools, and also the area around the two University of Memphis campuses that are within the drainage basin boundaries. These four land classifications account for 97% of the land usage in the project area. The remaining land classifications are forests, pastures, and wetlands. Figure 1-6 shows the map result of the land use. Table 1-3 shows a breakdown of the land use classification.

Table 1-3 Land Use in Black Bayou Drainage Basin

Land Use Classification	Area (acre)	% of Total Area
Developed Open Space	1410.9	47.65%
Developed Low Intensity	919.0	31.04%
Developed Medium Intensity	398.9	13.47%
Developed High Intensity	138.9	4.69%
Deciduous Forest	54.3	1.83%
Pasture	18.3	0.62%
Woody Wetlands	14.8	0.50%
Mixed Forest	5.7	0.19%
Evergreen Forest	0.2	<0.01%
Cultivated Crops	0.2	<0.01%
Total	**2961.1**	**100.00%**

1.7 Percent Impervious

The percent impervious data for the project area were retrieved from the NLCD 2011 by the Multi-Resolution Land Characteristics Consortium (MRLC). These data show that the sub-basins within the Black Bayou watershed ranged from approximately 2% to 81% impervious with the majority of impervious surfaces surrounding highly trafficked roadways, commercial centers and the University of Memphis. Figure 1-7 shows the percent of impervious surfaces assigned by NLCD to each grid point spaced at 30-meter intervals across the project area.

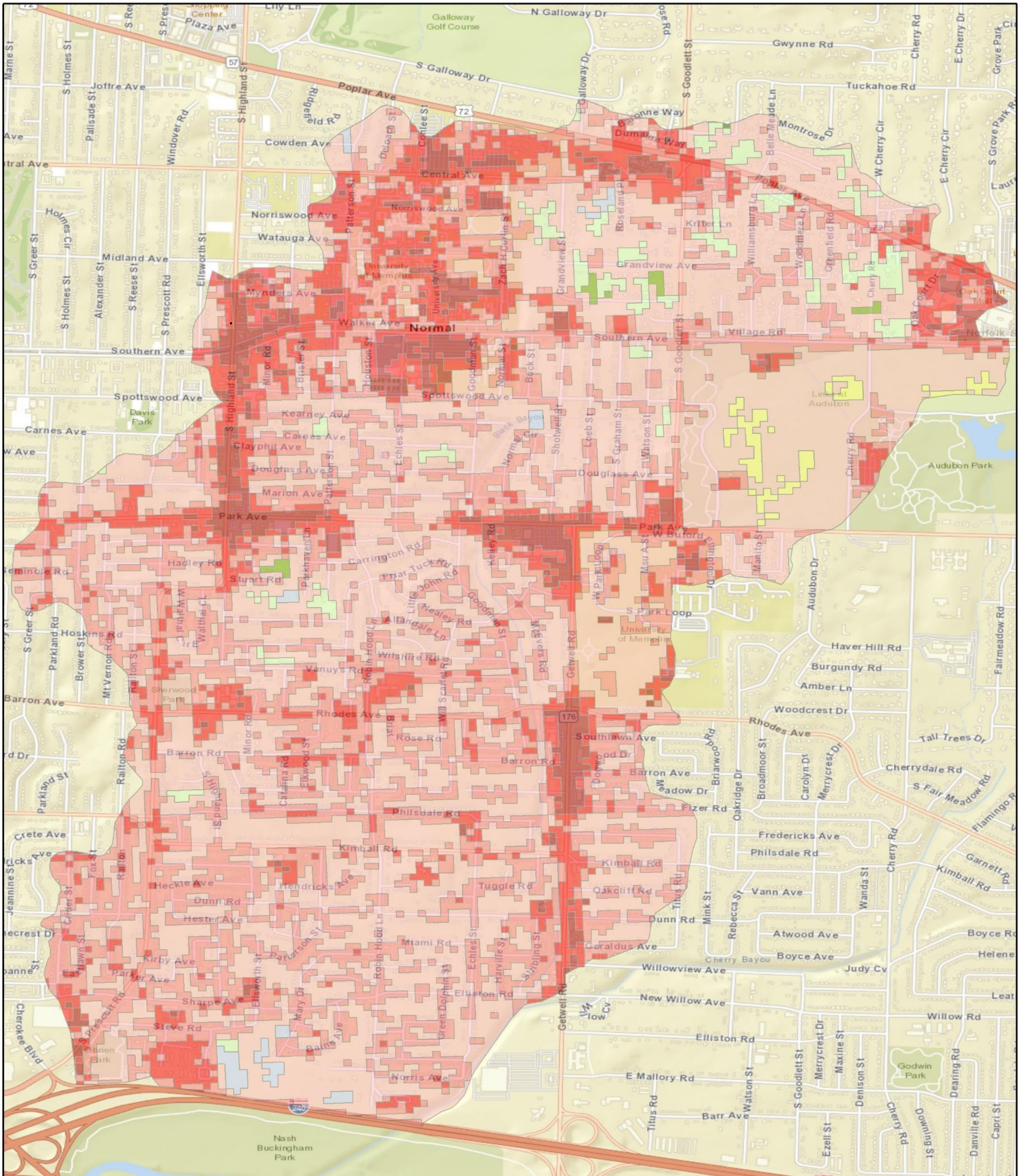
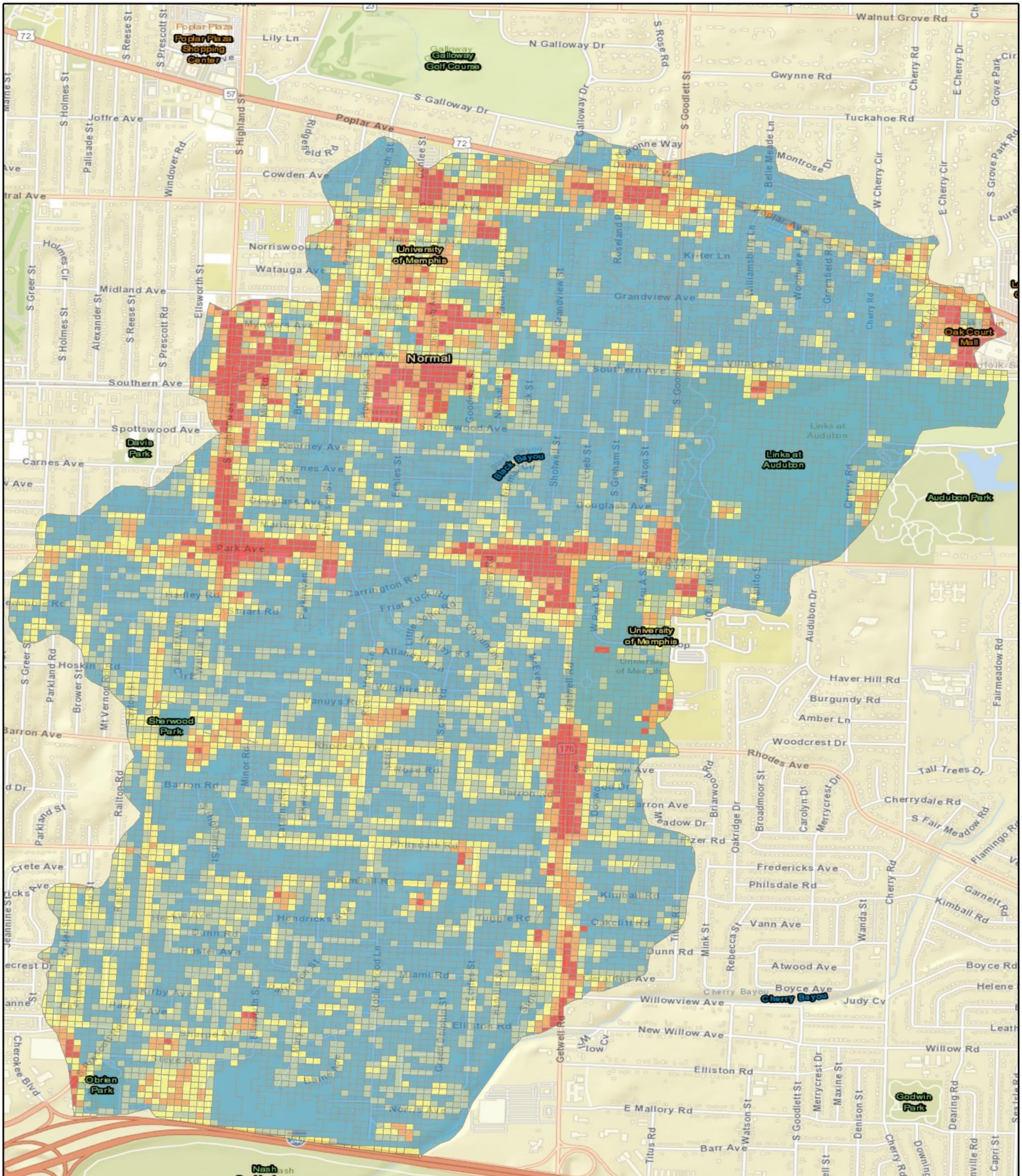


Figure 1-6
Land Use in Black Bayou Drainage Basin
Memphis, Tennessee

National Land Cover Database (NLCD 2011)

GRIDCODE
- Developed Open Space
- Developed Low Intensity
- Developed Medium Intensity
- Developed High Intensity
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Pasture
- Cultivated Crops
- Woody Wetlands



2,000 Feet
1 inch = 2,000 feet
Tennessee State Plane (feet) 4100fips
North American Datum 1983

BARGE DESIGN SOLUTIONS

Figure 1-7
Percent Impervious of the Black Bayou Basin
Memphis, Tennessee

National Land Cover Database (NLCD 2011)

- <=20% Impervious
- 20.01% - 40% Impervious
- 40.01% - 60% Impervious
- 60.01% - 80% Impervious
- >80% Impervious

2 MODEL DEVELOPMENT

This section describes the model development for the Black Bayou Drainage Basin stormwater evaluations including model set-up and refinement, calibration, validation and design storm modeling. To comprehensively model the Black Bayou Drainage Basin, Innovyze's InfoSWMM (Version 14.0, Service Pack 1, Update #3) simulation software was used. This software is integrated into the geographic information system (GIS) software ArcGIS and allows users to model the entire hydrologic cycle with a variety of land use and soil specific stormwater runoff equations.

Section 3 presents the results of the existing conditions model simulation and level of service analysis and Section 4 presents proposed improvements and evaluations.

2.1 Hydrology

The hydrology calculations for estimating the runoff characteristics of the modeled sub-basins were performed using Environmental Protection Agency (EPA) Stormwater Management Model (SWMM)'s Non-linear reservoir equations within the InfoSWMM modeling software. Infiltration is the primary loss from rainfall becoming runoff and is estimated within the model using the Green-Ampt equations. The method and parameters were consistent with the standards outlined in the draft *Memphis Drainage Mapping and Modeling Analysis Standards Manual (06-24-2015)*.

2.1.1 Precipitation

Total rainfall depths for the 2-, 5-, 10-, 25-, and 100-year, 24-hour storm events were taken from Figure 2-2 of the Memphis Drainage Manual. The intensity-duration-frequency (IDF) and depth-duration-frequency (DDF) curves and associated tabular data in the Memphis Drainage Manual were originally provided by NOAA Atlas 14 gathered at the Memphis NOAA observation station (NOAA station: Memphis WSCMO AP, Tennessee [40-5954] 35.0564 N 89.9864 W 249 feet). The rainfall depth was temporally distributed according to an NRCS Type II distribution for each return interval as provided in Table 2-2 of the Memphis Drainage Manual. The NOAA Atlas 14 data is discussed in Section 1.3.

2.1.2 Sub-basin Runoff

Initial values were assigned to each sub-basin's runoff and infiltration variables based on background data so an initial model estimate could be compared to gauge data for calibration. Table 2-1 summarizes the methodology and data sources used for assigning the initial sub-basin attributes required for the runoff characteristics.

Table 2-1: Sub-basin Runoff Variable Overview

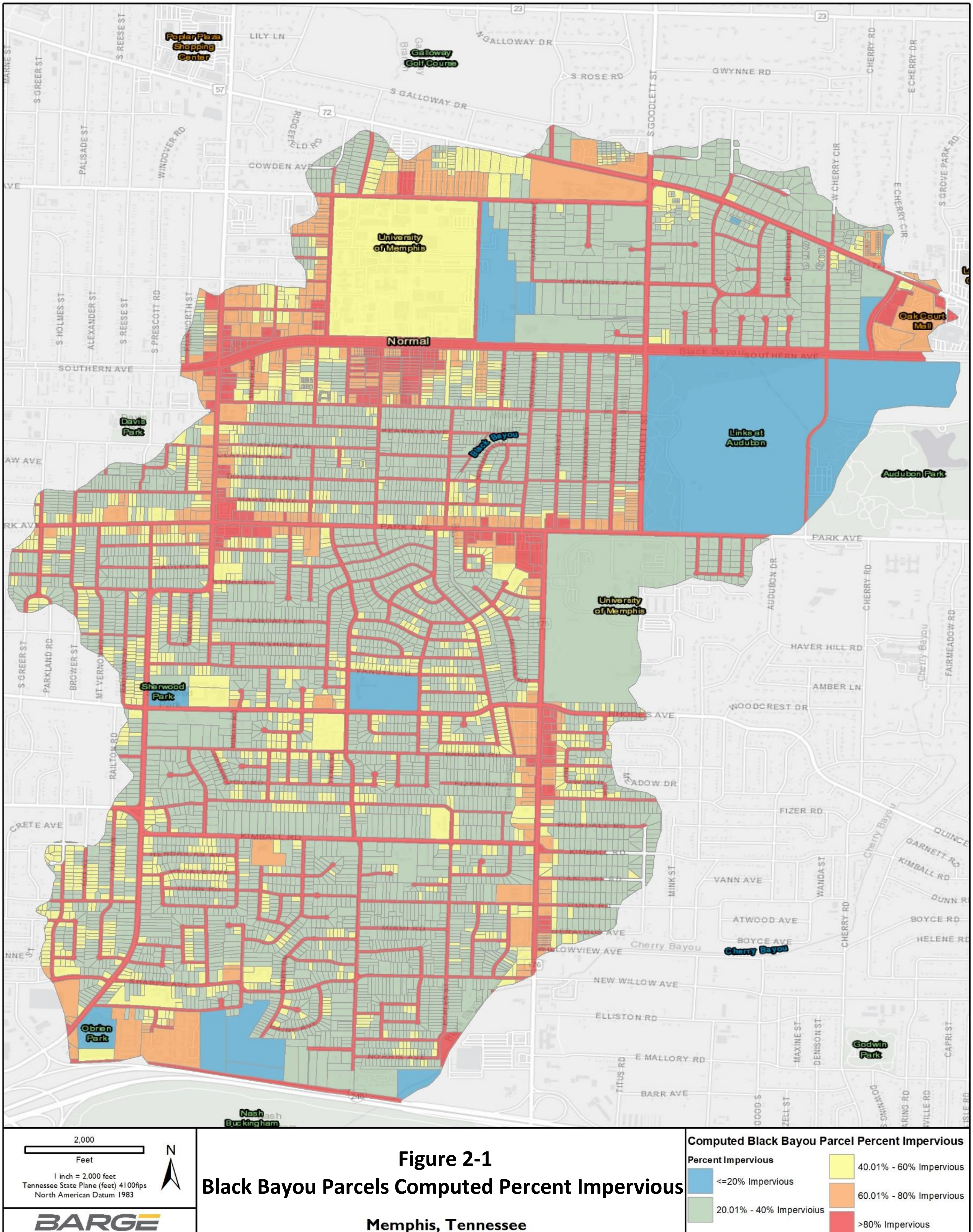
Sub-basin Runoff Variable	Data Sources (in descending priority)	Methodology
Area	LiDAR Survey City of Memphis GIS Flooding (Public) Database	The Black Bayou drainage basin was delineated into 122 sub-basins according to the primary conveyance routes and ridge boundaries as indicated by the LIDAR and the stormwater network (survey & City's GIS). Some areas were further subdivided resulting in a total of 144 sub-

Sub-basin Runoff Variable	Data Sources (in descending priority)	Methodology
	Black Bayou public meeting	basins to capture detail necessary to represent identified flooding issues.
Impervious Percentage	National Land Cover Data (NLCD) City Parcel Data	Summary section below
Width	LiDAR Survey City's GIS	Summary section below
Slope	LiDAR	Slope was calculated as the average subcatchment slope statistics based on LiDAR terrain data
Manning's N for Impervious/Pervious Portions	Aerial Photos NLCD City Parcel Data	• If the total percentage of Deciduous, Evergreen and Mixed Forest within a parcel was greater than 25% then a Pervious Manning's N Value of 0.24 was assigned • If the total percentage of Woody or Emergent Herbaceous Wetlands was greater than 25% then a Pervious Manning's N Value of 0.05 was assigned • If the total percentage of Shrub/Scrub, Grassland/Herbaceous, Pasture or Cultivated Crops was greater than 50% then a Pervious Manning's N value of 0.15 was assigned • If the total percentage of Developed (Open through High Intensity) was greater than 50% then a Pervious Manning's N value of 0.24 was assigned • Impervious Manning's N values were assigned at a value 0.012 assuming the impervious surface was going to be concrete/asphalt within an urban area such as the Black Bayou Basin.
Depression Storage for Impervious/Pervious Portions	NLCD	A majority of the Black Bayou drainage basin consists of residential, commercial, and institutional parcels. Depression storage of 0.05 inches for impervious areas and 0.10 inches for pervious areas were assigned.
Soil Infiltration	NRCS Web Soil Survey	The soils were assigned corresponding Green-Ampt infiltration variables according to soil texture class and the draft Memphis modeling manual. Additional detail is provided in a summary section below.

2.1.2.1 Impervious Percentage Estimation

To estimate the impervious percentage of each sub-basin the average of three methods was determined according to the following steps:

1. The percentage of each land use within a given parcel was computed.
2. Percent imperviousness was computed based on percentages of land uses within each parcel.
   - Table 1 - NLCD Land Cover Class Descriptions from "Development of a 2001 National Land-Cover Database for the United States" by Homer et.al provides typical percent imperviousness for the "Developed, Open Space", "Developed, Low Intensity", "Developed, Medium Intensity", and "Developed, High Intensity" categories.
   - The average of the range presented for the noted categories was utilized to determine a percent imperviousness of each parcel.
   - The remaining categories of land cover including Deciduous, Mixed Forest, Pasture/Crops, Wetlands, Grassland/Shrub and Evergreen forest were assigned an average percent imperviousness of 10 percent to be applied in the computation of percent imperviousness for each parcel.
3. Percent imperviousness was computed based on zoning provided in parcel data utilizing Table 2-4 from the Memphis and Shelby County Storm Water Management Manual. Some outdated zone designations were equated to the current designations by use of the Memphis/Shelby County Unified Development Code document.
4. Percent imperviousness was calculated for each parcel as based on the 2011 NLCD percent impervious data set representing urban impervious surfaces as a percentage of developed surface over every 30-meter pixel across the Black Bayou study area.
5. An average of the three percent impervious values was carried forward as the final percent impervious for each parcel. Figure 2-1 graphically displays the computed percent impervious for each parcel/roadway within the Black Bayou study area.
6. For areas greater than 3 acres a manual check and adjustment was performed to ensure appropriate impervious percentages. The average percent impervious for each sub-basin within the hydrologic and hydraulic model as determined from the parcel data is shown below in Figure 2-2.



1 inch = 2,000 feet
Tennessee State Plane (feet) 4100fips
North American Datum 1983

BARGE DESIGN SOLUTIONS

Figure 2-1
Black Bayou Parcels Computed Percent Impervious

Memphis, Tennessee

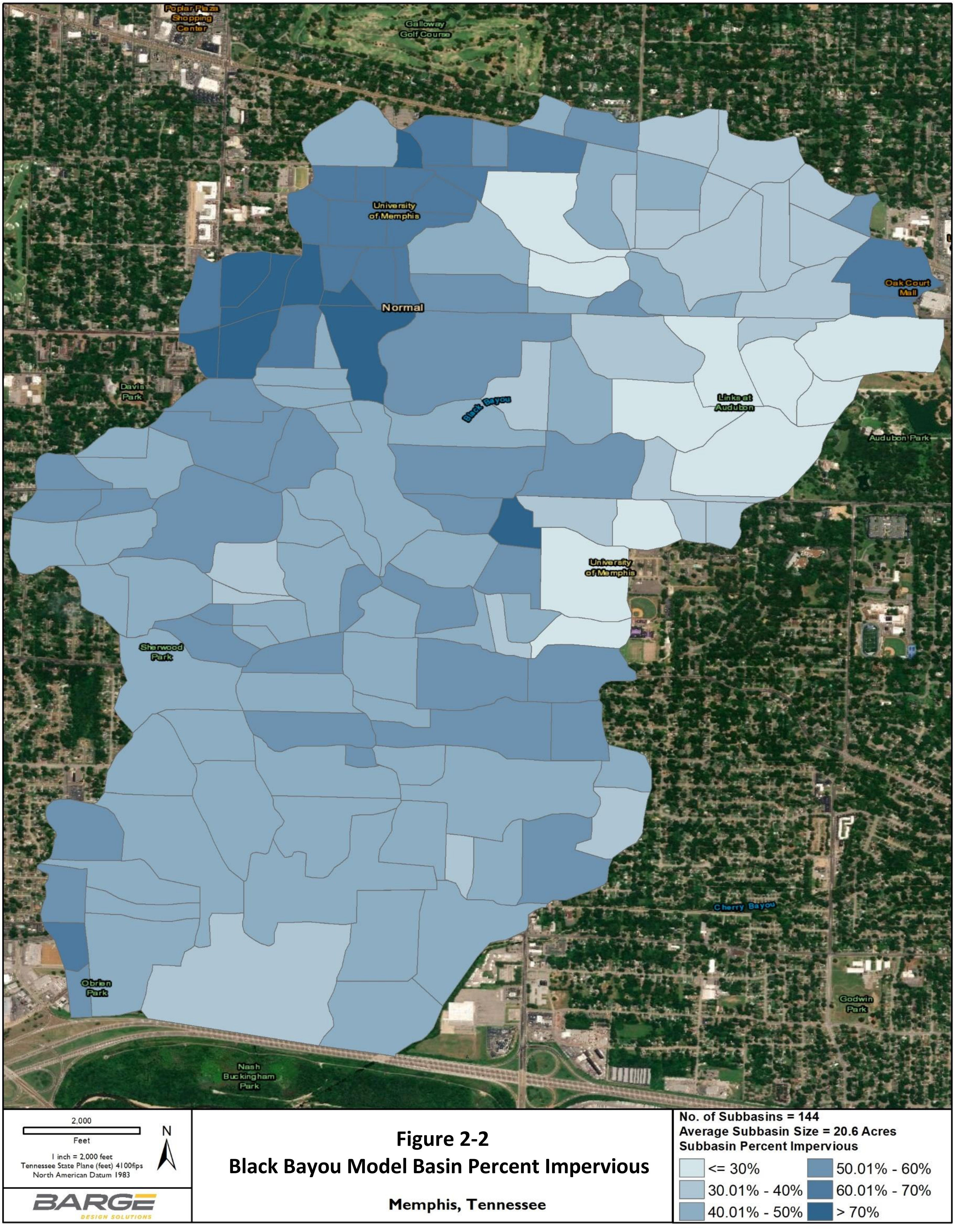


Figure 2-2
Black Bayou Model Basin Percent Impervious

Memphis, Tennessee

2.1.2.2 Sub-basin Width Estimation

The area and infiltration characteristics of a sub-basin dictate the volume of runoff resulting from rainfall events. However, the width is a critical SWMM variable in estimating a sub-basin's runoff hydrograph and peak flow when using the non-linear reservoir flow routing method. For the scale of sub-basin sizes used in the Memphis basin studies, the width is not simply the average width of the overall sub-basin, which could be estimated by dividing the area by the longest flow path, but rather the average width of the sub-basin's overland flow.

To estimate the average overland (non-channelized) flow width for each of the Black Bayou sub-basins, the average flow length for each watershed was first estimated. Commonly, the overland flow length in developed drainage areas is limited to under a few hundred feet, which shortens as more urbanization occurs. From inspection of Black Bayou sub-basins with differing amounts of impervious coverage, a range of 25 to 300 ft in potential overland flow was estimated for the sub-basins. The range of overland flow lengths was estimated by tracing the longest available flow paths from sub-basins until it reached either a road, channel, or pipe as represented by the City of Memphis GIS database.

After the range of potential overland flow lengths was established, a method was developed for estimating the relative overland flow lengths between Black Bayou sub-basins. It was assumed that a sub-basin with more gutter length (as estimated by the GIS roads data) and stormwater infrastructure (as estimated by City stormwater geodatabase) would have a shorter relative overland flow length because there is more opportunity for runoff to become channelized flow. The total potential channel length, represented by the road length plus the stormwater infrastructure (pipe and channel) length, was normalized by the sub-basin area to create a relative channel factor for each sub-basin. The range of channel factors was then used to apply a related overland flow length to each sub-basin between 25 and 300 ft.

Finally, an initial value for each sub-basin's overland width was estimated by dividing the area by the estimated overland flow length. This width value is an initial estimate for the SWMM non-linear reservoir variable that represents the relative difference in one Black Bayou sub-basin versus another, scaled by the opportunity for runoff to become channelized within that sub-basin. Because this is a relative width estimate between Black Bayou sub-basins, it lends itself to system-wide multipliers for calibration to improve the correlation between model results and stream gauge data.

2.1.2.3 Soil Infiltration Characteristics

According to the NRCS web soil survey data for the Black Bayou drainage basin presented in Section 1.5, there are four different soils within the area as summarized in Table 2-2.

Table 2-2: Soil Summary

Soil Symbol	Description	Texture Class
Fm	Falaya Silt Loam	Silt Loam
Fs	Filled land, silty	Silt Loam
Gr	Graded land, silty	Silt Loam
MeB	Memphis Silt Loam	Silt Loam

There is a variety of types of soil within the drainage basin, but the texture class of Silt Loam is consistent among the types of soil. Concerning the Green-Ampt infiltration variables, the texture class is indicative of the specific values to use. The variables applied to the soil infiltration parameters within the model are from the draft *Memphis Drainage Mapping and Modeling Analysis Standards Manual (06-24-2015)*, and these variables for a silt loam are summarized as:

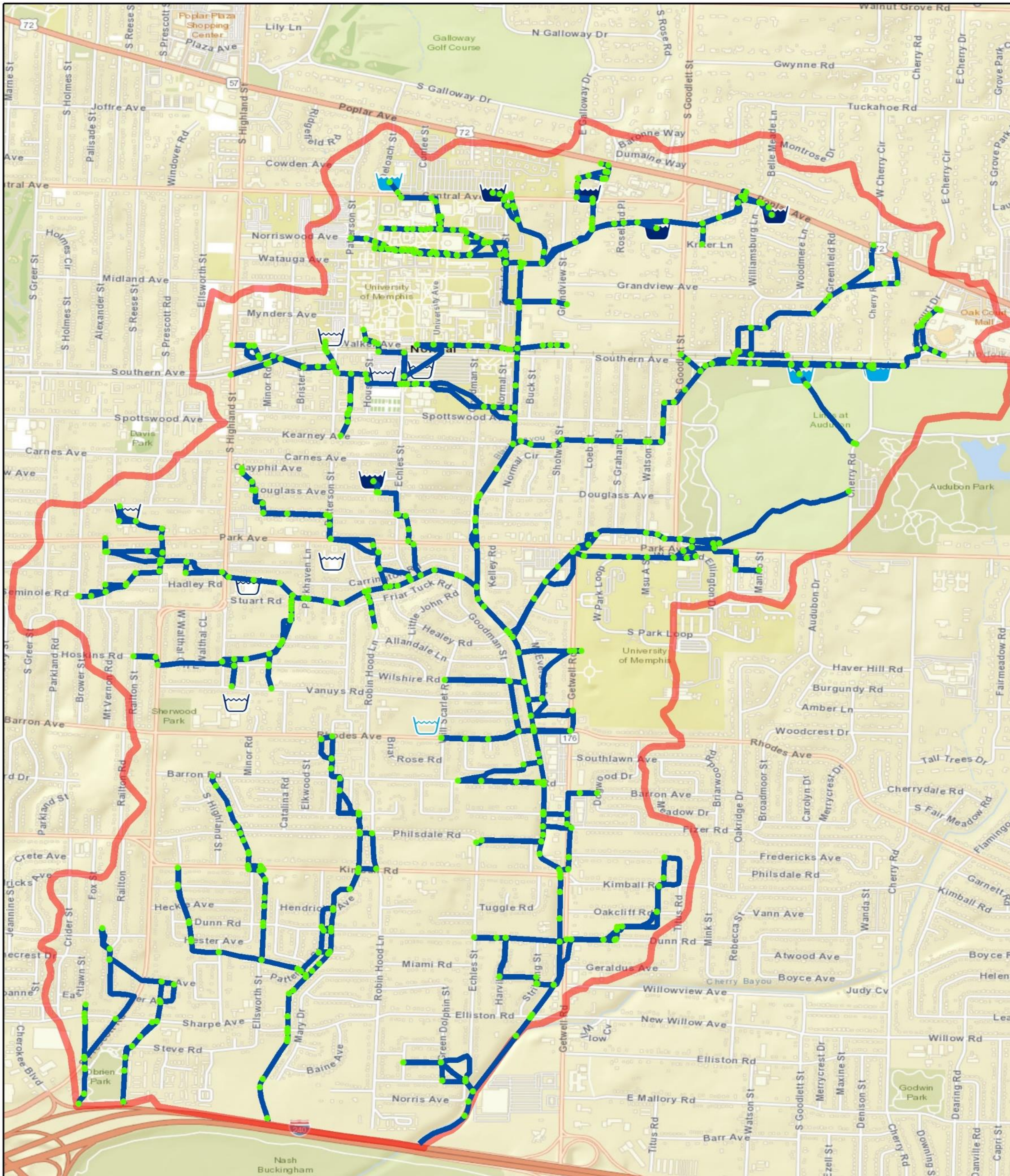
- Hydraulic Conductivity, K (in/hr) - 0.26
- Suction Head, ψ (in) - 6.69
- Initial Moisture Deficit - 0.217

2.2 Hydraulics

The hydraulic portion of the model analyzed the performance of the conveyance and drainage network. The model incorporated storm sewer, concrete channel connectivity and capacity attributes. Capacity attributes included material, slope, and geometry of the pipe, concrete, channel, or stream cross-section. The few known storage facilities within the Black Bayou Drainage Basin that detain stormwater were input from record drawings or previous studies. The model extent is from Prescott and Highland Streets to Getwell Road and Audubon Park and from Poplar Avenue to where is empties into Nonconnah Creek. The hydraulic modeling extents in the Black Bayou Drainage Basin are shown in Figure 2-3.

InfoSWMM utilizes the runoff hydrographs, computed as described in Section 2.1 and applies them to loading points to provide input for hydraulic routing. The Black Bayou Drainage Basin model contains more than 1000 links which represent open channels (mostly concrete) and closed conduits such as box culverts or circular pipes representing more than 40 miles of conveyance. Pipe sizes and lengths as well as channel data including cross-sections were collected as described in Section 1.

Surveyed conveyances included all pipes 24 inches in diameter or larger. Analyses extended upstream to model inflow locations but excluded any additional upstream stormwater infrastructure. The exclusion of conveyances upstream of model inflow locations prevented unintentional attenuation and/or storage of runoff within the model; consequently, of the approximately 850 drainage structures associated with conveyances of 24 inches in diameter or larger approximately 610 are included within the system analysis. The 610 drainage structures included within the analysis also comprised 7 nodes which are denoted as storage areas for the existing conditions analysis. Storage nodes could be overflow areas or storage areas such as detention ponds. Data for storage nodes were also collected as described in Section 1. Nodes and links on the most upstream reaches and above the most upstream inflow loading points were set to inactive if they were not receiving inflow. However, some side branches within the system remained set as active to allow for backwater to enter they system and to evaluate flooding as a result of the backwater from the main conveyance. As a result of ponding and flooding of areas during some of the storm return intervals analyzed more than 300 additional overland flow conveyances were included within the model. The overland flow conveyances allowed locations with inadequate stormwater conveyance to pond and move downstream along the ground or roadway surfaces to the next surface inflow location.



2,000 Feet 1 inch = 2,000 feet Tennessee State Plane (feet) 4100fips North American Datum 1983 N	**Figure 2-3** **Model Overview of** **Black Bayou Drainage Basin**

BARGE DESIGN SOLUTIONS

No. of Subbasins = 144
Average Subbasin Size = 20.6 Acres

- Junctions
- Conduits
- Underground
- Surface_Pond
- Prop. Underground
- Prop. Surface Pond

2.3 Model Calibration

The Center for Applied Earth Science and Engineering Research with the University of Memphis installed, maintained, and collected data from two stream gauge locations and two rain gauge locations within the Black Bayou Drainage Basin for the months of June through December 2015. A pressure transducer measuring depth and a crest-stage gauge measuring peak channel depth achieved between visits were installed at each gauge location. The stream gauge locations were within the primary concrete conveyance channel of the Basin with the northern, more upstream site near Marion Avenue and the southern, more downstream site near Elliston Road. The specific locations and surveyed elevations of each gauge component are summarized in Table 2-3 with data referenced to Tennessee State Plane (feet) and North American Vertical Datum of 1988 (NAVD 88).

Table 2.3 Stream and Rain Gauge Summary

LOCATION	NORTHING	EASTING	ELEVATION (ft)	DESCRIPTION
Marion Avenue (northern, upstream)	305939.958	791795.610	266.02	Pressure Transducer
	305940.750	791796.739	265.56	Flow Centerline
	305939.151	791813.991	267.84	Crest-Stage
Elliston Road (southern, downstream)	298178.364	792403.086	243.36	Pressure Transducer
	298179.007	792401.558	242.87	Flow Centerline
	298169.881	792427.049	246.41	Crest-Stage
Leftwich Tennis Center (4145 Southern Avenue)	307986.707	796083.378	N/A	Rain Gauge
O'Brian Park (Prescott and Steve Road)	296807.993	786274.814	N/A	Rain Gauge

The concrete lined channels, where the stream gauges were installed, were uniform triangular bottom and rectangular upper sections with the following geometry:

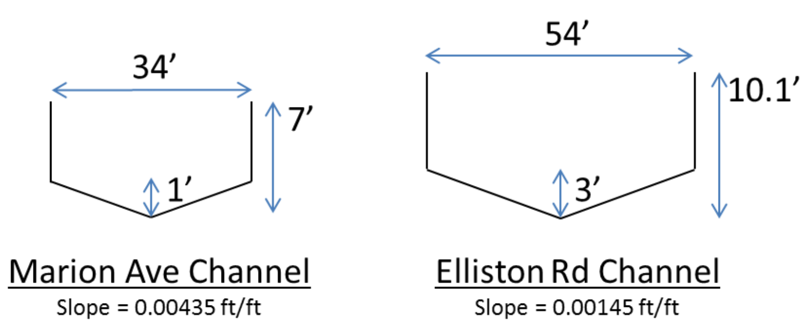


Figure 2-4 Stream Gauge Channel Dimensions (NTS)

Surveyed channel cross-sections upstream and downstream of the gauge locations were used to establish the dimensions and the average slope of the channel as illustrated in Figure 2-4. The channel attributes could then be paired with the measured channel depths during rainfall events to estimate flow within the channel using the Manning's Equation and Continuity Equation:

$$V = \frac{k}{n}\left(\frac{A}{P}\right)^{\frac{2}{3}} S^{\frac{1}{2}}$$

Manning's Equation

$$Q = VA$$

Continuity Equation

V = Velocity (ft/s)
k = Unit conversion factor, 1.49 English units
n = Manning's roughness factor
A = Flow area (ft^2)
P = Wetted perimeter (ft)
S = Slope (ft/ft)
Q = Flow rate (ft^3/s)

The pressure transducer provided 5-minute readings of channel depth, allowing for a flow hydrograph to be estimated for the rise and fall of flow within the channel. Additionally, the crest-stage gauge allowed for the peak depth to be captured for specific events, where students reset the gauge before the rainfall and manually recorded the measurement afterwards. Rainfall was also captured in 5-minute increments at the two Black Bayou rain gauge locations. The channel flow and rainfall data measured during a June 2015 storm event is illustrated in Figure 2-5.

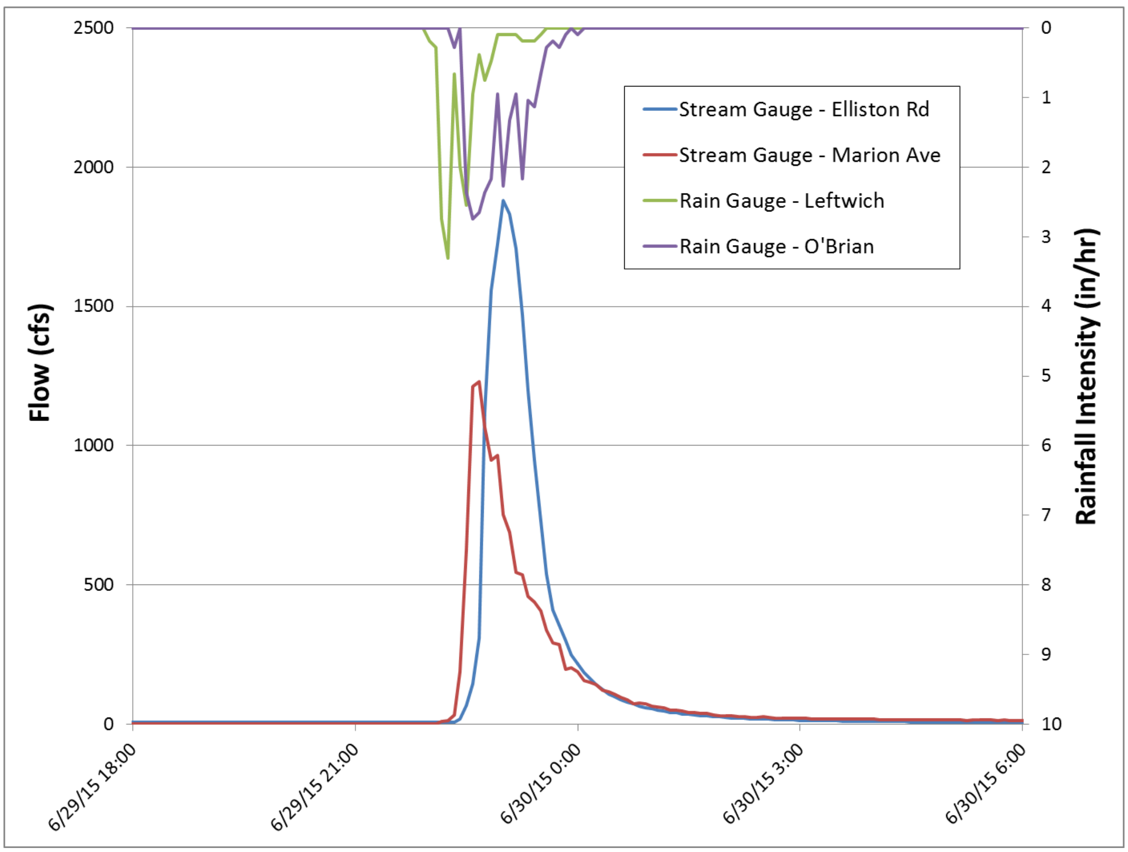


Figure 2-5 Black Bayou Stream and Rain Gauge Data

The June 29 – June 30, 2015 event was selected for calibration. Calibration tests several hydrologic and hydraulic parameters. Hydrologic and hydraulic model parameters including basin widths, pervious Manning's roughness and impervious Manning's roughness values were adjusted until a good match was achieved at the two depth gages. Sub-basin widths were uniformly increased across the Black Bayou watershed by 30% with pervious Manning's roughness values uniformly decreased by 25% across the watershed. Impervious Manning's roughness values were uniformly adjusted downwards to the minimum value of 0.011 within the Memphis Drainage Manual (Table 2-10). Following the uniform basin-wide adjustments to the three parameters noted above good agreement between the model and the two stream gauges was achieved as seen in Figures 2-6 and 2-7. A second storm event occurring on July 3, 2015 was selected as a validation event to confirm and/or adjust model calibration. Similar agreement between model results and observed storm flows is shown in Figure 2-8 thereby confirming model calibration with no further adjustments to hydrologic or hydraulic properties required.

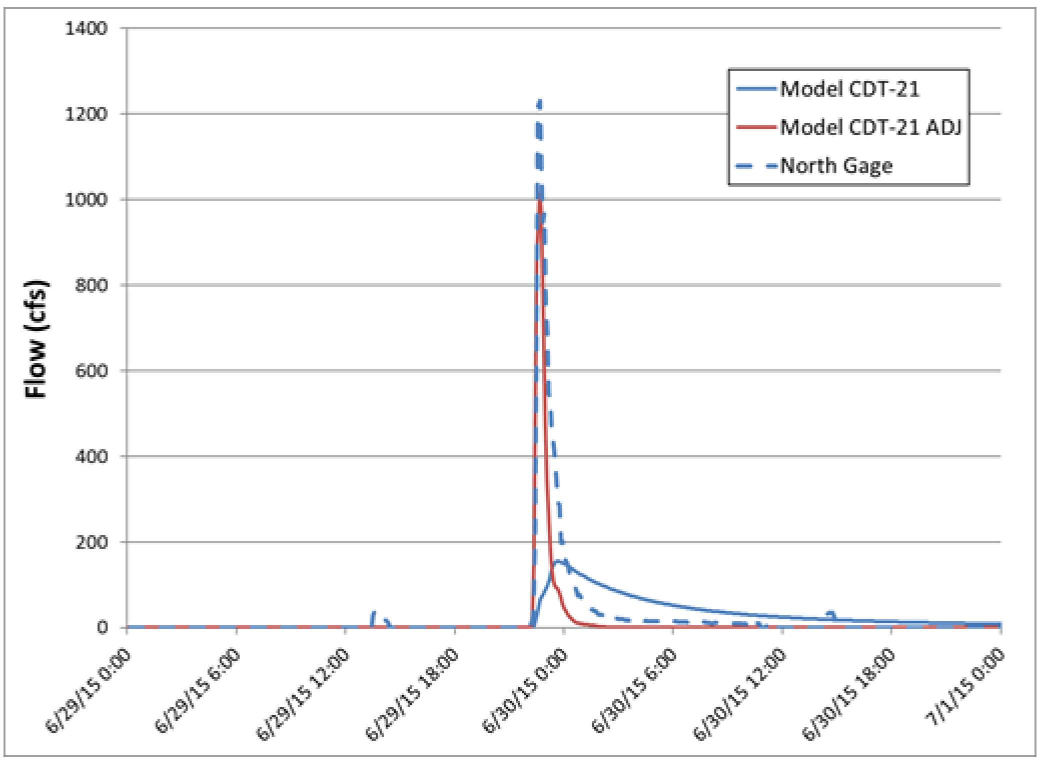


Figure 2-6. Black Bayou Model Calibration at the North Gauge

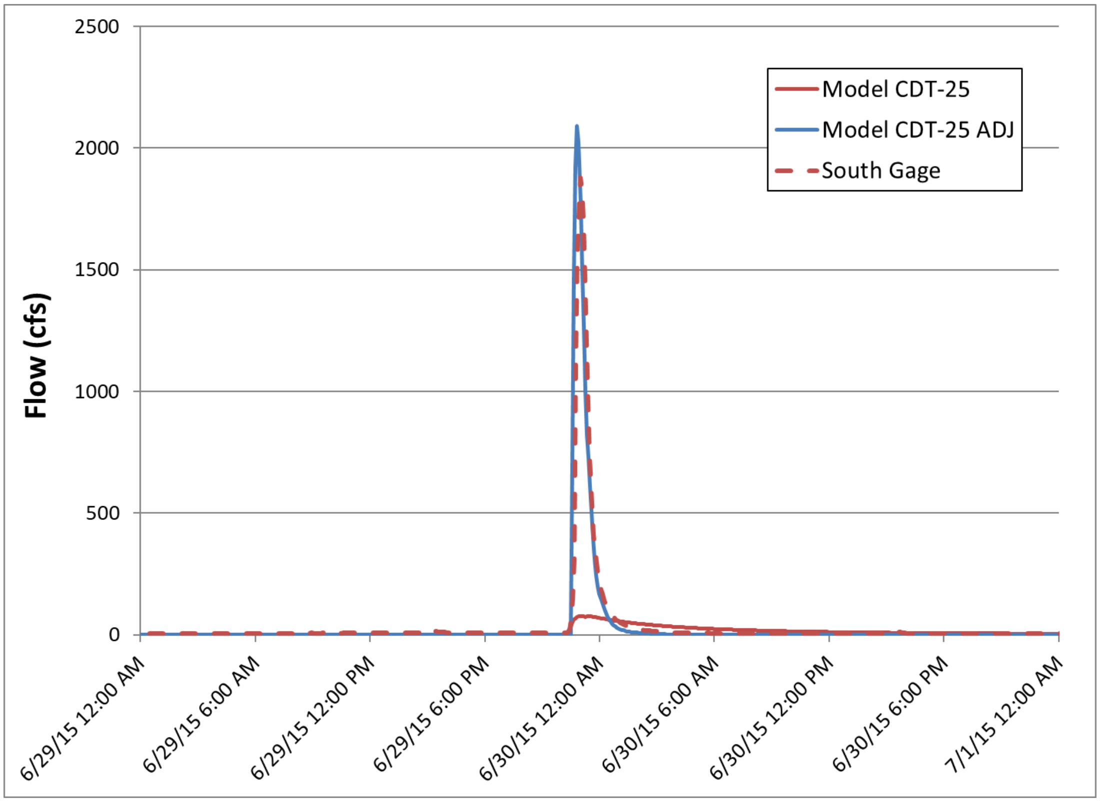


Figure 2-7. Black Bayou Model Calibration at the South Gauge

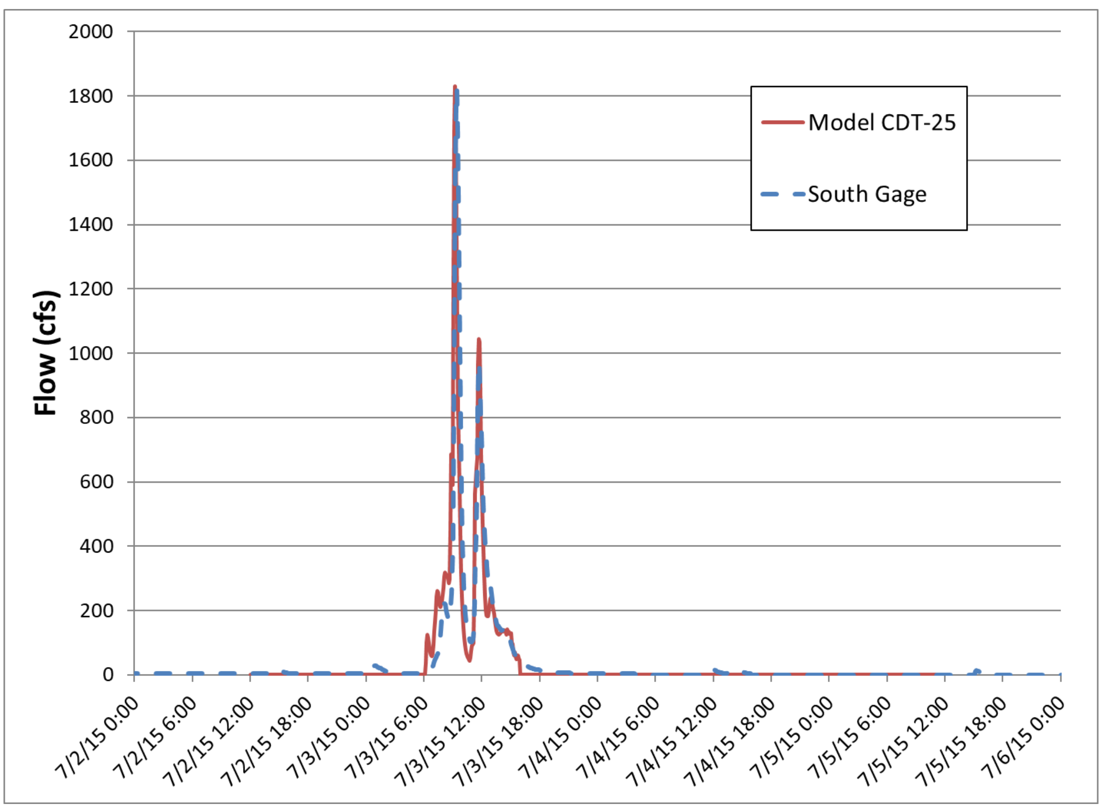


Figure 2-8. Black Bayou Model Validation at the South Gauge

3 EXISTING CONDITIONS RESULTS

3.1 Level of Service (LOS) Evaluation

The City of Memphis specifies that storm sewers shall be designed based on the 10-year 24-hour design storm. Within the Black Bayou Basin under existing conditions, the model showed that more than 300 stormwater structures were undersized. Additionally, the 10-year 24 hour design storm model produced flooding at more than 100 locations along roadways.

On June 7, 2016 a meeting was held with the City of Memphis to discuss preliminary modeling results. At the time, nineteen problem areas had been identified through the preliminary modeling. The meeting concluded that finished floor elevations were required to determine whether inundation would cause actual flooding of homes or other habitable structures, or if it would just represent short-term nuisance flooding of the yard.

As described in Section 1, finished floor elevations were surveyed for 23 buildings. After evaluating the finished floor elevation surveys, five locations were identified where flooding could cause damage to homes or other property. These areas are shown in Figure 3-1 and were selected for proposed improvements as described in Section 4.

3.2 Flood Extent/Inundation Mapping

To evaluate the flood extent both the area of inundation and the depth of flooding were considered. The InfoSWMM software includes a Risk Assessment Manager tool that generates inundation using the computed maximum hydraulic grade line (HGL) at each modeled node. The inundation produced by this tool was based on a simplistic approach of interpolating elevations between model nodes using a single line. A more detailed approach to generating inundation along the model segments was performed by creating cross-sections at model nodes. The cross-sections were assigned the computed maximum HGL. A water elevation surface was generated using the cross-sections. The computed water elevation surface was compared to the LiDAR derived ground surface data to determine a depth of inundation. Figures presented in Attachment B illustrate the flood inundation for each of the theoretical return frequencies evaluated during existing conditions. Attachment E presents the flood inundation extents for each of the theoretical return frequencies with the proposed alternatives included within the model configuration.

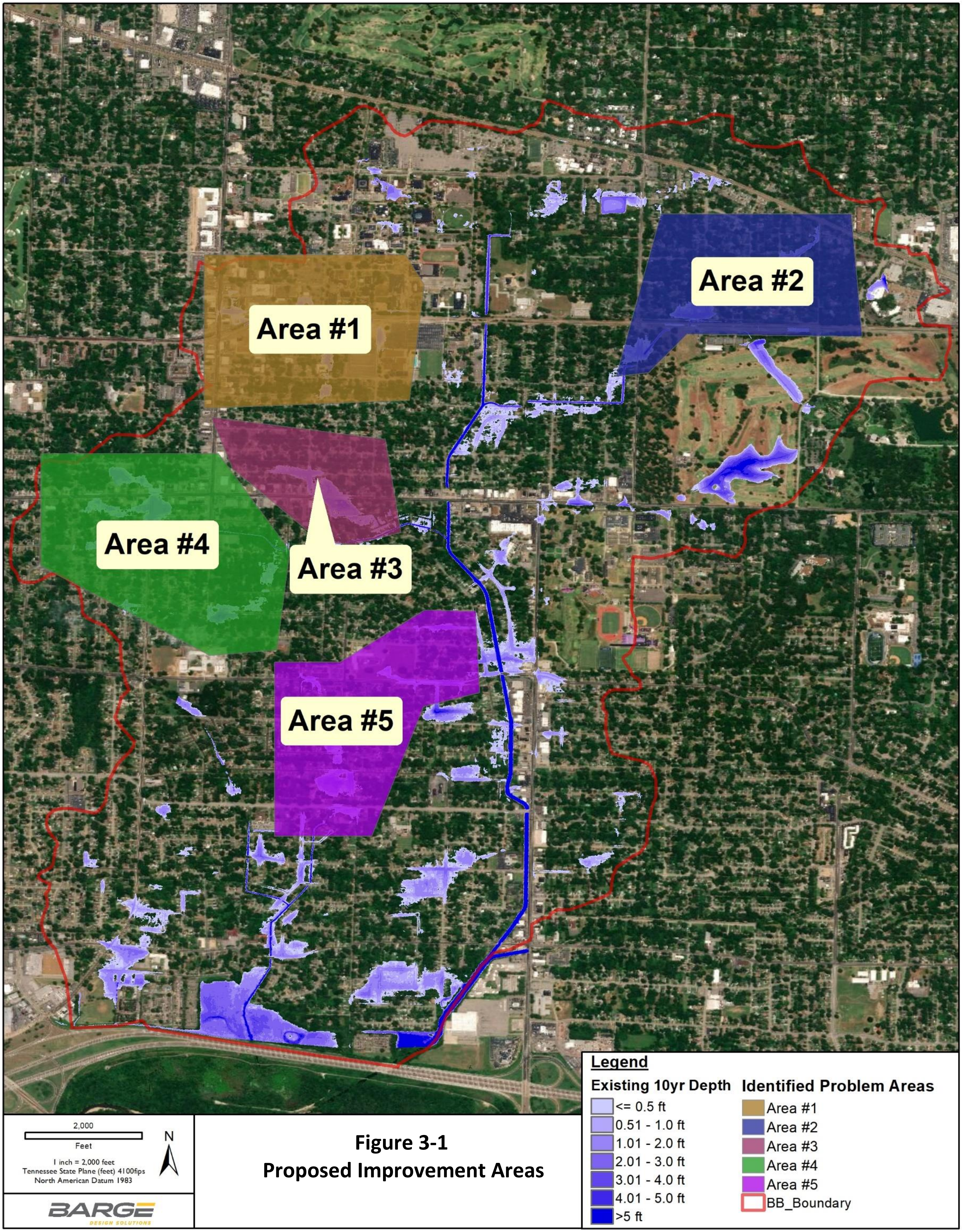


Figure 3-1
Proposed Improvement Areas

4 PROPOSED SCENARIOS

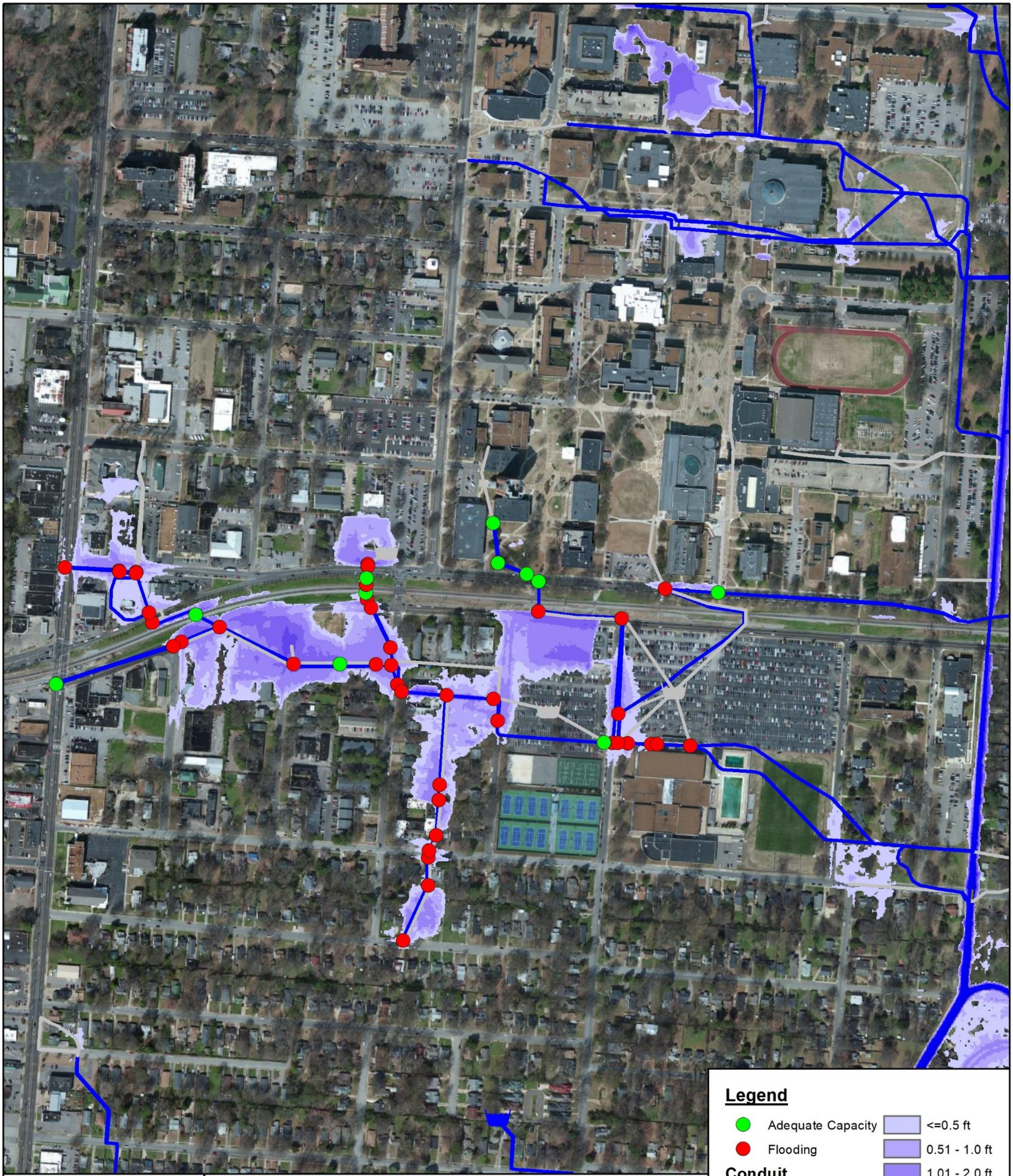
Based on the scope of work for this project, five separate improvement alternatives analyses were to be performed based on the identified flooding areas. The predicted flooding impacts and the elements of each proposed improvement are described in Sections 4.1 through 4.5. These sections also include an overview of benefits, a planning-level cost and benefit-cost analysis. It should be noted that some proposed scenario costs may exceed the cost of the structures and/or roadways that the projects are intended to protect. In those cases, the City may wish to consider a more detailed benefit-cost analysis such as the FEMA BCA toolkit to determine whether a proposed improvement is feasible.

4.1 Area 1 - Southern Avenue at University of Memphis

4.1.1 Description

Area 1 is located along Southern Avenue near the University of Memphis main campus. The area begins at the intersection of Southern Avenue and Highland Street and continues east to the Student Recreation Center. The area is located on the upper reaches of the Black Bayou watershed, but receives the drainage from the highly impervious University of Memphis main campus. Survey data were collected beginning the fall of 2015 through the summer of 2016. After the completion of the field survey there were numerous developments within the basin that potentially altered the stormwater infrastructure. These developments, specifically near the University of Memphis, are not included in this study. The existing conditions analysis indicated flooding of 41 of the 52 stormwater structures within this location during the 10-year event due to being undersized as shown in Figure 4-1. Additionally, 27 buildings would be inundated.

The proposed improvement includes increasing the size of approximately 2,000 linear feet of drainage conduit and installation of approximately 500 linear feet of additional drainage conduits acting as parallel conveyance to adequately convey the stormwater and prevent flooding during the 10-year event within Area 1. Three underground detention facilities including more than 1000 feet of conduit are also proposed in Area 1 to mitigate downstream flooding caused by the increase in conveyance of the improved stormwater structures. Tables 1a through 1f in the Microsoft Excel tab “Issue #1” within Attachment C detail the specific proposed improvements.



500
Feet
N
1 inch = 500 feet
Tennessee State Plane (feet) 4100fips
North American Datum 1983

BARGE
DESIGN SOLUTIONS

Figure 4-1
Area 1 Existing 10-Year Inundation

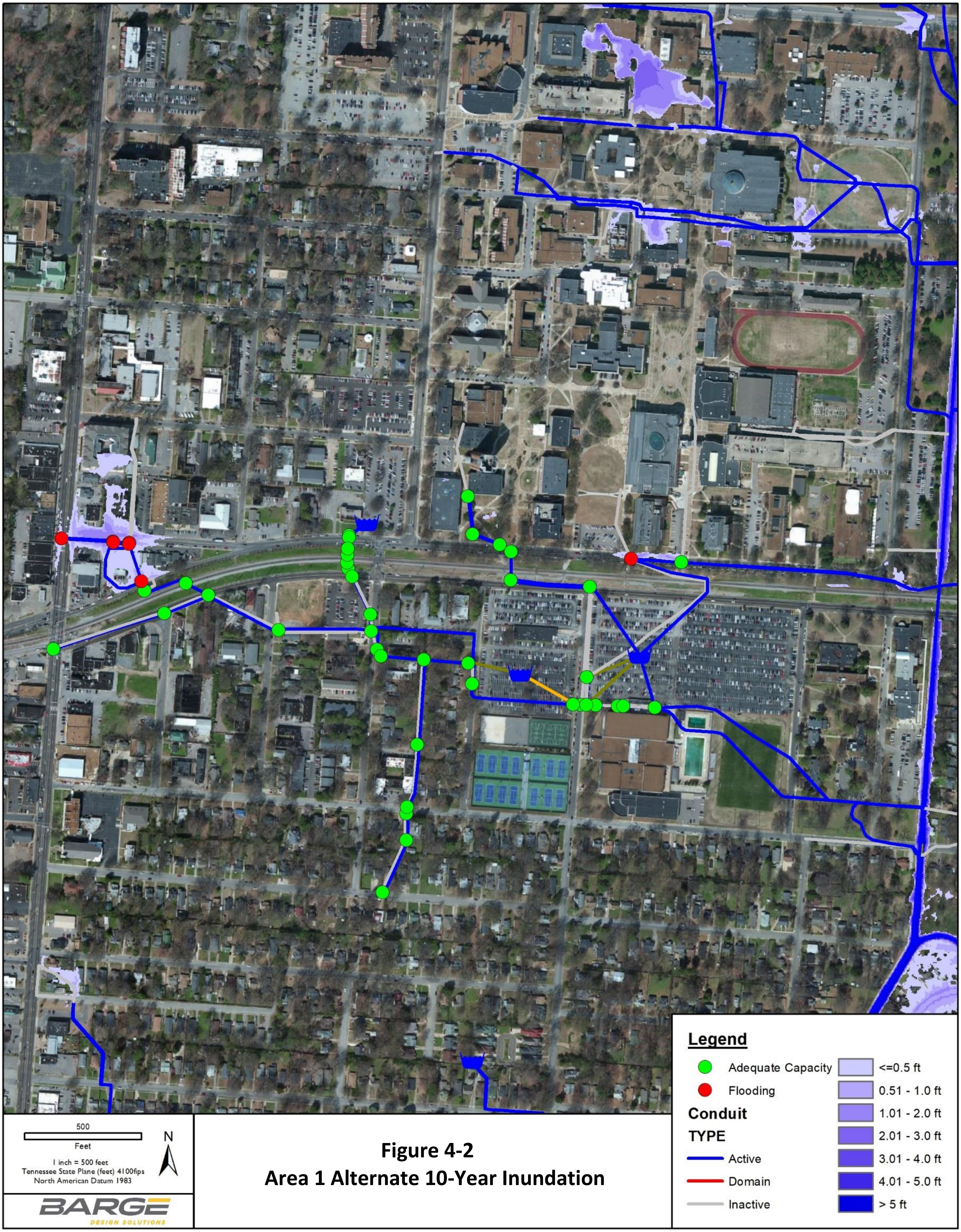


Figure 4-2
Area 1 Alternate 10-Year Inundation

4.1.2 Benefits

The additional stormwater pipes and larger stormwater pipes in combination with the detention facilities will alleviate flooding in Area 1, and attenuate the peak flows downstream. Figure 4-2 shows the improved flooding conditions after implementation of this improvement. Of the 27 buildings flooded under existing conditions, 24 would no longer experience flooding. Attachment D provides details of the property damage costs occurring as a result of flooding during the 10-year storm event before and after the proposed alternative. Additionally, flooding on Echles Street as well as other side streets would be alleviated.

4.1.3 Planning-Level Cost

The estimated cost for improvements in Area 1 is $13,820,000. A benefit-cost analysis was performed for Area 1 considering the reduction in loss of service of roads, reduction in amount of property damage and reduction in rental costs for displaced families. The benefit-cost ratio for Area 1 is 0.35. Attachment C provides details of the cost estimate and benefit-cost analysis.

4.2 Area 2 – Cherry Road between Poplar Ave and Southern Ave

4.2.1 Description

Area 2 is located in the upper reaches of the Black Bayou watershed near the Audubon park and golf course. It receives drainage from the Oak Court Mall area as well as the residential area between S. Goodlett Street and the mall. The existing conditions analysis indicated flooding of 29 of the 63 stormwater structures within this location during the 10-year event due to being undersized as well as flooding over Goodlett Street and Village Road near the intersection with Williamsburg Lane and over the railroad tracks that run between Southern Ave and Village Road as shown in Figure 4-3. Additionally, 15 buildings would be inundated.

The proposed improvement includes increasing the storage capacity of an above ground storage area along the park and golf course to detain some of the flooding. It then includes rerouting approximately 500 linear feet of drainage conduit, adding approximately 1,500 linear feet of new conduit to divert drainage from upstream of the railroad tracks directly to the storage area, and adding 275 linear feet of new conduit near Audubon Park. Tables 2a and 2b in the Microsoft Excel tab “Issue #2” within Attachment C detail the specific proposed improvements.

4.2.2 Benefits

The increased storage capacity in combination with the stormwater diversions will alleviate flooding in Area 2 and attenuate the peak flows downstream. Figure 4-4 shows the improved flooding conditions after implementation of this improvement. Of the 15 buildings flooded under existing conditions, 11 would no longer experience flooding. Attachment D provides details of the property damage costs occurring as a result of flooding during the 10-year storm event before and after the proposed alternative. Additionally, flooding on Goodlett Street, a relatively high traffic street, would be alleviated.

4.2.3 Planning-Level Cost

The estimated cost for improvements in Area 2 is $2,047,000. A benefit-cost analysis was performed for Area 2 considering the reduction in loss of service of roads, reduction in amount of property damage and reduction in rental costs for displaced families. The benefit-cost ratio for Area 2 is 8.35. Attachment C provides details of the cost estimate and benefit-cost analysis.

Figure 4-3
Area 2 Existing 10-Year Inundation

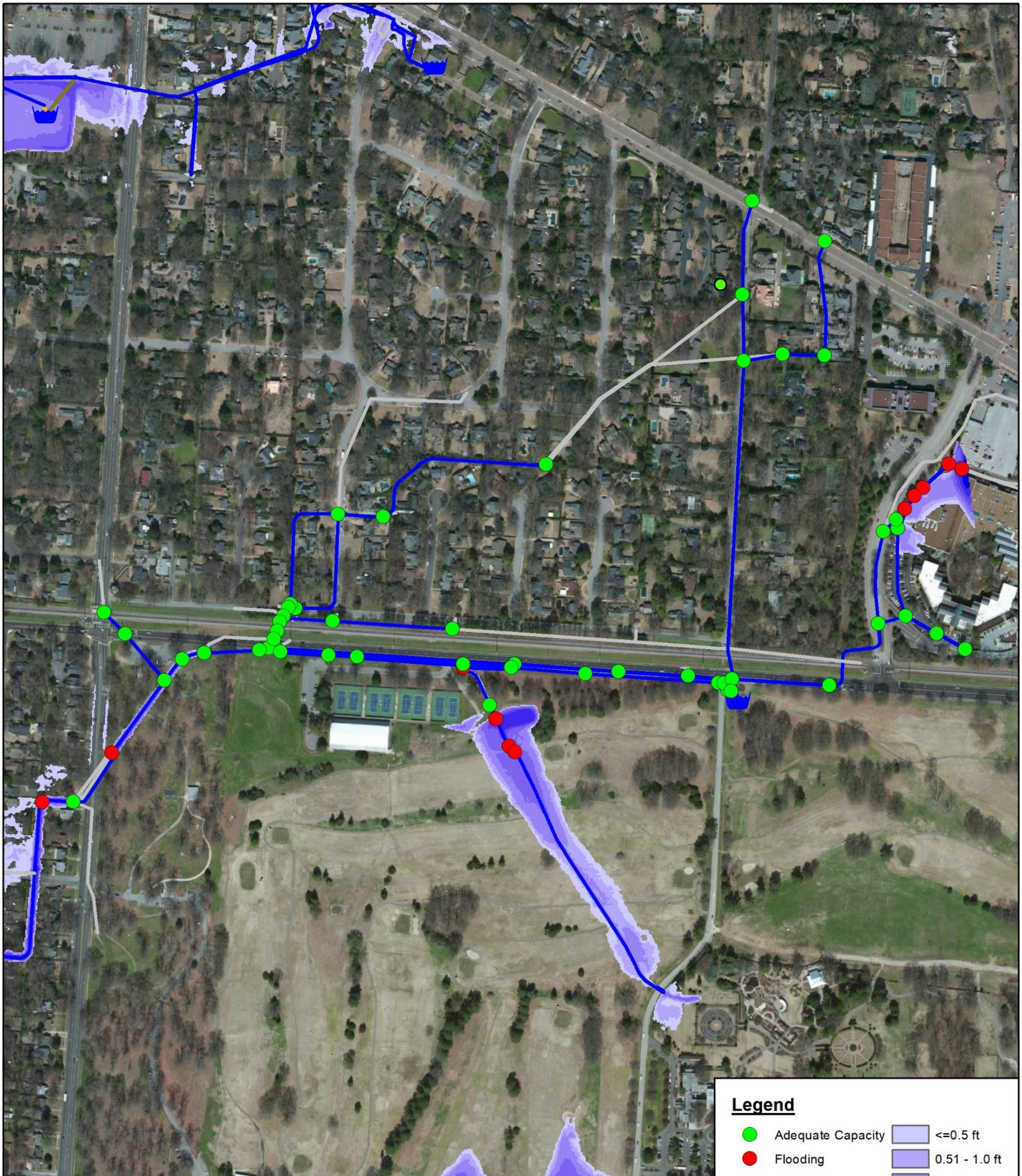


Figure 4-4
Area 2 Alternate 10-Year Inundation

4.3 Area 3 – Robin Hood Lane

4.3.1 Description

Area 3 is located from the intersection of Marion Avenue and Patterson Street South to the main Black Bayou canal at Robin Hood Lane. The drainage area is mostly residential with some retail areas and churches. The existing conditions analysis indicated flooding of 25 of the 45 stormwater structures within this location during the 10-year event due to being undersized as shown in Figure 4-5. Additionally, 35 buildings would be inundated.

The proposed improvement includes increasing the size of approximately 400 linear feet of conduit and adding approximately 670 linear feet of conduit down Robin Hood Lane. Additionally, a new underground detention facility is proposed. Table 3a in the Microsoft Excel tab "Issue #3" within Attachment C details the specific proposed improvements.

4.3.2 Benefits

The increased capacity and underground storage will alleviate flooding in Area 3 and attenuate the peak flows downstream. Figure 4-6 shows the improved flooding conditions after implementation of this improvement. Of the 35 buildings flooded under existing conditions, 32 would no longer experience flooding. Attachment D provides details of the property damage costs occurring as a result of flooding during the 10-year storm event before and after the proposed alternative. Additionally, flooding on Park Avenue and Robin Hood Lane would be alleviated.

4.3.3 Planning-Level Cost

The estimated cost for improvements in Area 3 is $3,634,000. A benefit-cost analysis was performed for Area 3 considering the reduction in loss of service of roads, reduction in amount of property damage and reduction in rental costs for displaced families. The benefit-cost ratio for Area 3 is 4.7. Attachment C provides details of the cost estimate and benefit-cost analysis.

4.4 Area 4 – Park Ave

4.4.1 Description

Area 4 is located from Brower Street at Park Avenue East to South Highland Street. The drainage area is mostly residential with some retail areas. The existing conditions analysis indicated flooding of 43 of the 56 stormwater structures within this location during the 10-year event due to being undersized as well as some flooding at the intersection of Carrington Road and South Prescott Road as shown in Figure 4-5. Additionally, 47 buildings would be inundated.

The proposed improvement includes increasing the size of approximately 1,800 linear feet of conduit and adding approximately 2,600 linear feet of conduit as well as three new underground storage areas. Tables 4a through 4e in the Microsoft Excel tab "Issue #4" within Attachment C detail the specific proposed improvements.

4.4.2 Benefits

The increased storage capacity will alleviate flooding in Area 4 and attenuate the peak flows downstream. Figure 4-6 shows the improved flooding conditions after implementation of this improvement. Of the 47 buildings flooded under existing conditions, 35 would no longer experience flooding. Attachment D provides details of the property damage costs occurring as a result of flooding during the 10-year storm event before and after the proposed alternative. Additionally, flooding on Park Avenue would be alleviated.

4.4.3 Planning-Level Cost

The estimated cost for improvements in Area 4 is $9,263,000. A benefit-cost analysis was performed for Area 4 considering the reduction in loss of service of roads, reduction in amount of property damage and reduction in rental costs for displaced families. The benefit-cost ratio for Area 4 is 1.40. Attachment C provides details of the cost estimate and benefit-cost analysis.

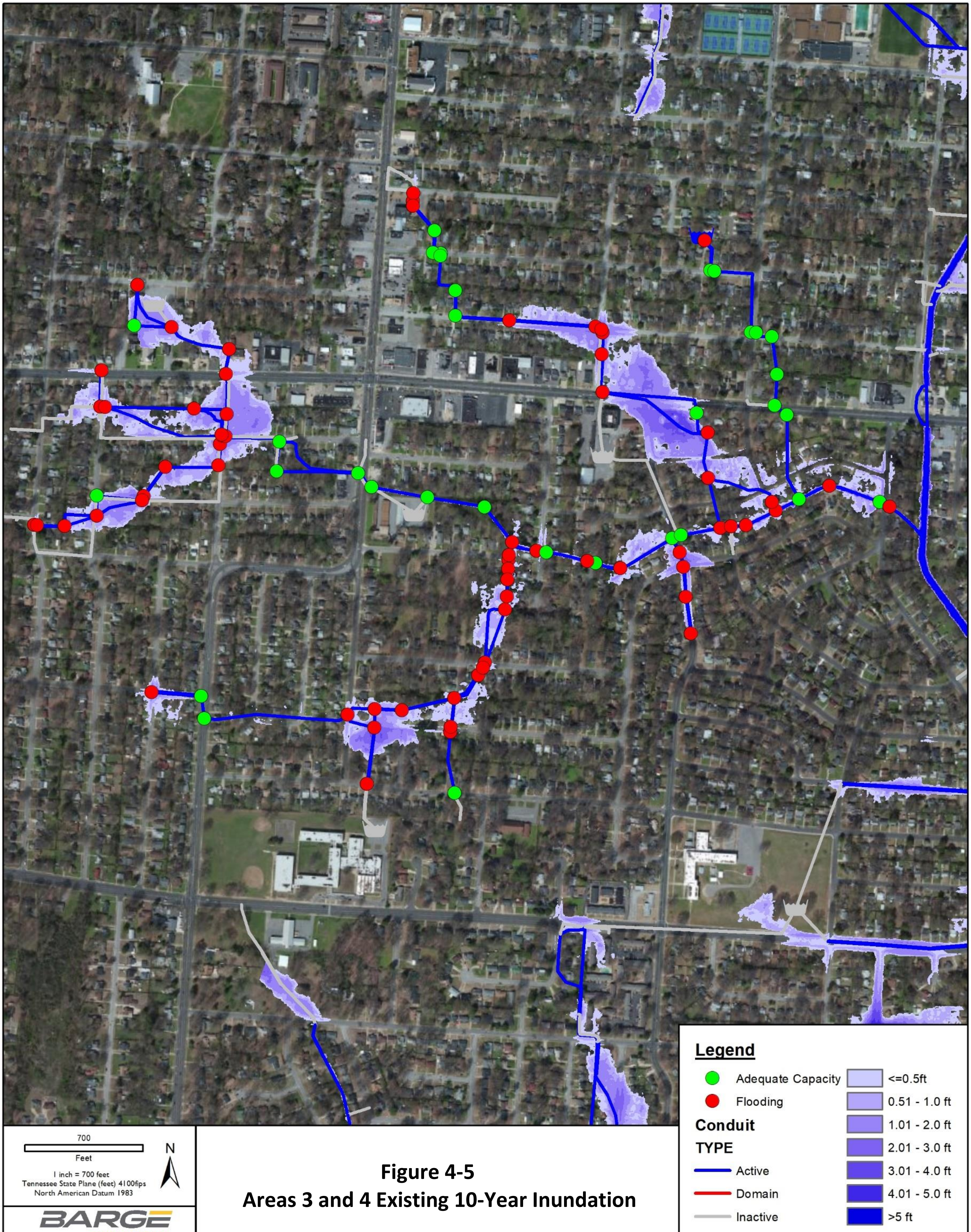


Figure 4-5
Areas 3 and 4 Existing 10-Year Inundation

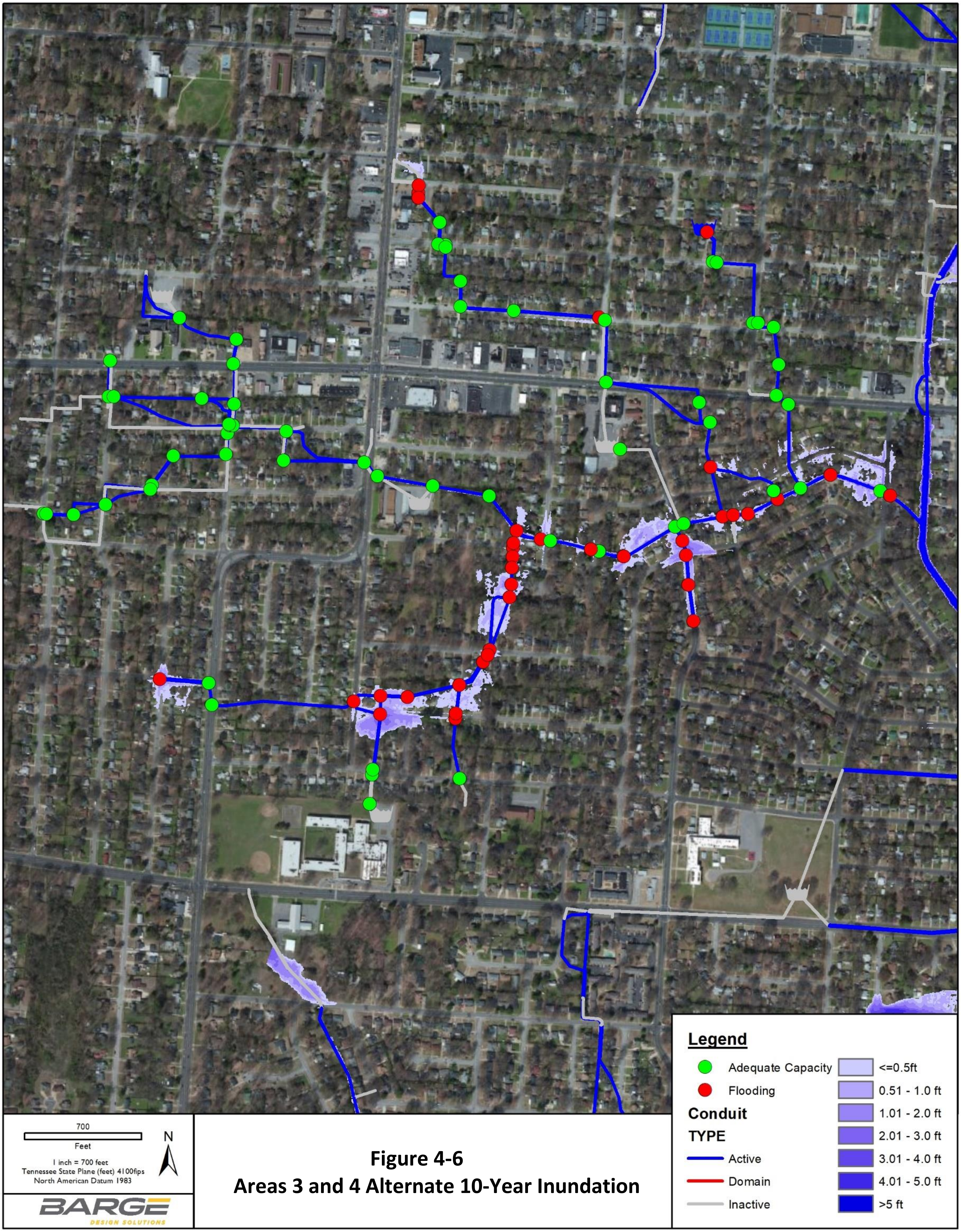


Figure 4-6
Areas 3 and 4 Alternate 10-Year Inundation

4.5 Area 5 – Rhodes Ave

4.5.1 Description

Area 5 is located from just north and east of Rhodes Avenue and Will Scarlet Road to just south of Kimball Road and Robin Hood Lane. The drainage area is mostly residential with one school. The existing conditions analysis indicated flooding of 31 of the 37 stormwater structures within this location during the 10-year event due to being undersized drainage as well as some flooding over Robin Hood Land near Philsdale Road and over Tyne Street near Deerwood Avenue as shown in Figure 4-7. Additionally, 26 buildings would be inundated.

The proposed improvement includes increasing the size of approximately 400 linear feet of conduit and adding approximately 3,500 linear feet of conduit including a new route down Robin Hood Lane. A new underground detention area would also be included to divert and store backwater from the canal. Table 5a in the Microsoft Excel tab "Issue #5" within Attachment C details the specific proposed improvements.

4.5.2 Benefits

The increased storage capacity will alleviate flooding in Area 5 and attenuate the peak flows downstream. Figure 4-8 shows the improved flooding conditions after implementation of this improvement. Of the 26 buildings flooded under existing conditions, 24 would no longer experience flooding. Attachment D provides details of the property damage costs occurring as a result of flooding during the 10-year storm event before and after the proposed alternative. Additionally, flooding on Rhodes Avenue and Robin Hood Lane would be alleviated.

4.5.3 Planning-Level Cost

The estimated cost for improvements in Area 5 is $1,346,000. A benefit-cost analysis was performed for Area 5 considering the reduction in loss of service of roads, reduction in amount of property damage and reduction in rental costs for displaced families. The benefit-cost ratio for Area 5 is 12.36. Attachment C provides details of the cost estimate and benefit-cost analysis.

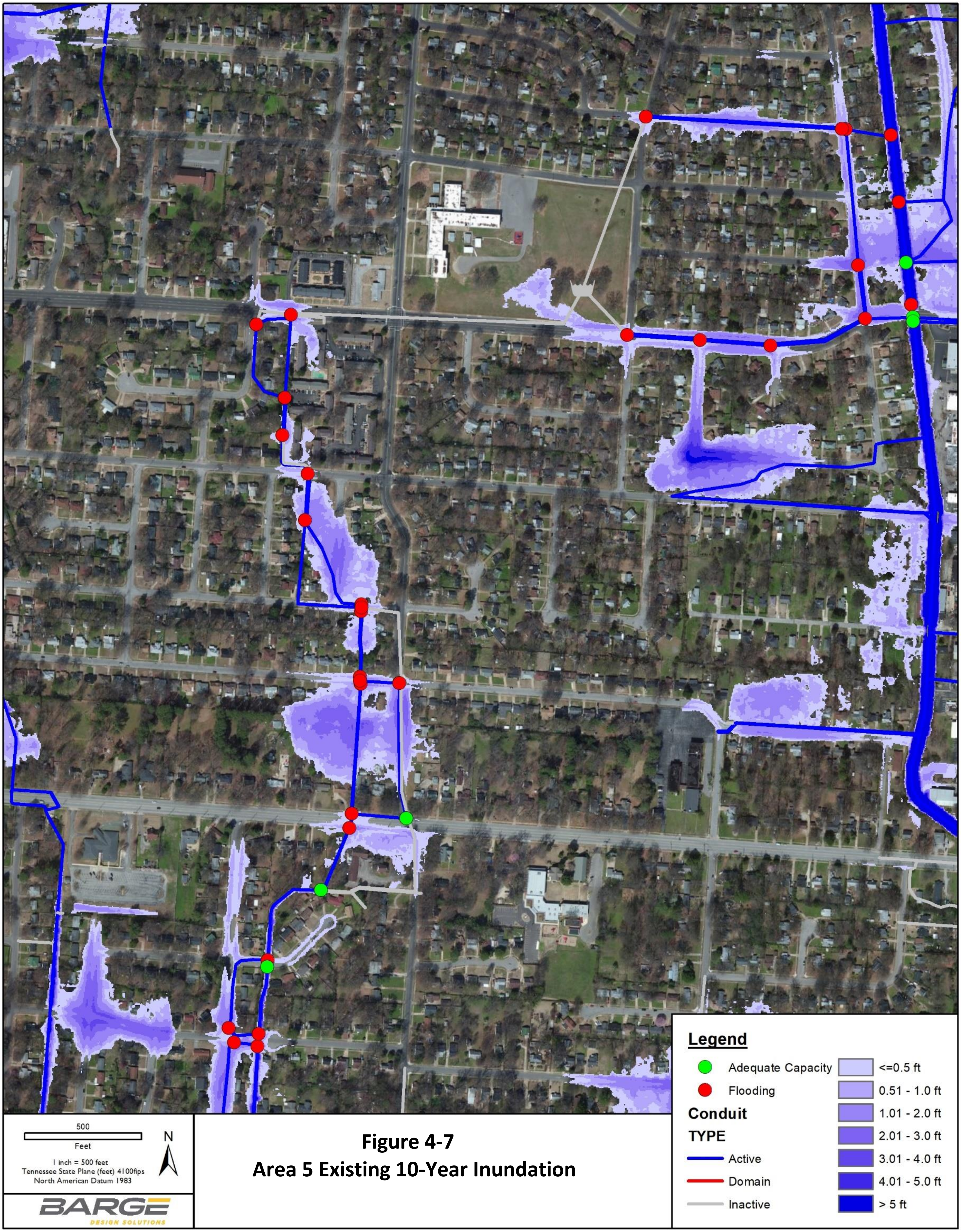


Figure 4-7
Area 5 Existing 10-Year Inundation

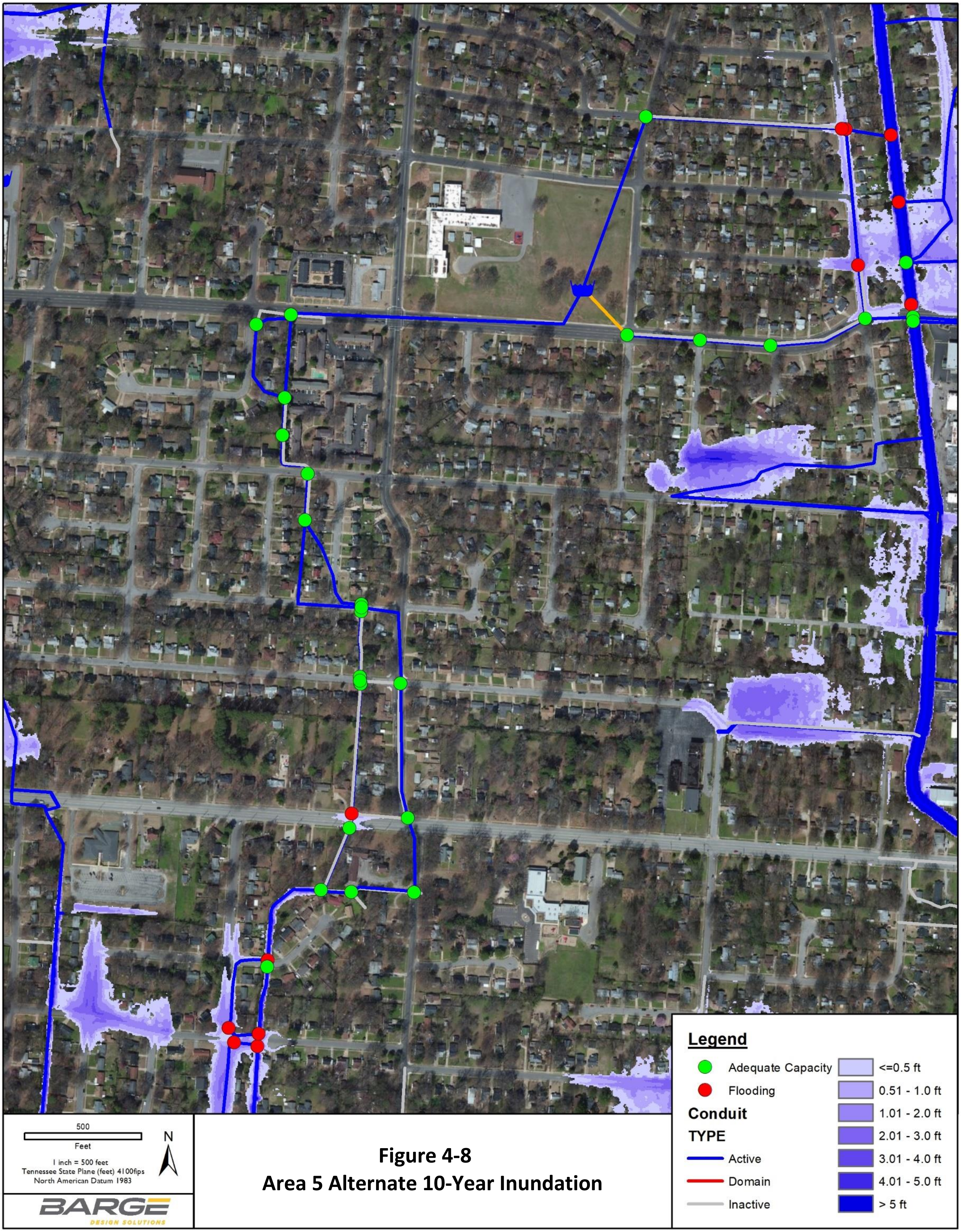


Figure 4-8
Area 5 Alternate 10-Year Inundation

5 RECOMMENDATIONS AND CONCLUSIONS

A comprehensive data collection and modeling effort in the Black Bayou Drainage Basin was completed. Flooding under existing conditions was evaluated for the 2-year, 5-year, 10-year, 25-year, 50-year and 100- year storms. Based on results of the 10-year design storm analysis, five areas were identified for further study of stormwater improvements. Specific improvements were evaluated and recommended for each area that would alleviate flooding. Planning-level costs were estimated for each of the improvements. A cost-benefit analysis was performed to determine the effectiveness and efficiency of the proposed improvements. Construction and implementation of all five improvements would cost an estimated $30,109,000 and result in a combined benefit-cost ratio of 2.28 for the five areas. Individual benefit-cost ratios for the five areas ranged from 0.35 to 12.36.