FINAL REPORT

Gayoso Bayou Drainage Master Plan

City of Memphis





CITY OF MEMPHIS | September 2022

VOLUME II

CDM Smith

Section 1

Background and Data Collection

1.1 Introduction

This section contains the background information for the Gayoso Bayou watershed stormwater evaluations, including the purpose of the evaluations, the history and description of the Gayoso Bayou watershed study area and drainage system, previous studies performed, and a description of the model software used to complete the evaluations. Volume II collects and expands on the content from Volume I, with the intent of providing additional technical detail for those interested in the development of the model and alternatives.

1.1.1 Purpose

The City of Memphis was originally founded in 1819 on the Fourth Chickasaw Bluff along the Mississippi River. Since the earliest years, several drainage criteria have been used to develop or improve infrastructure. Although well-intended, the drainage criteria implemented throughout many areas of the city were inadequate to properly characterize and manage the storm water runoff and flooding potential in Memphis. The result is numerous areas of the city have repetitive flooding and erosion problems that affect roadways and structures, particularly in the older areas of the city.

A 2012 review of the storm water program identified seven major study districts, largely corresponding to City Council Districts, which have been subdivided into approximately 70 smaller study areas. The intent of the Division of Engineering is to complete one storm water master plan (SWMP) in each of the study districts each year, starting in fiscal year 2014. This document provides a SWMP for the South Cypress Creek watershed located in southern Memphis. The eventual goal is to study each drainage basin in the City over a ten year period and undertake projects in each basin to mitigate existing flooding and erosion problems and the impacts of future storm events on the public infrastructure and private property.

While water quality is also a focal point of the City's comprehensive storm water management program, the primary purpose of this study is to address flooding concerns. However, potential water quality improvement options should be considered during detailed design of the flood reduction projects included herein.

1.1.2 Memphis' Storm Water Drainage System History

The City of Memphis encompasses a total land area of approximately 325 square miles. Storm water drainage in the city is directed to the Mississippi River, either directly or via one of three major water bodies: the Nonconnah Creek, the Wolf River, or the Loosahatchie River. Because of urbanization and channelization of numerous water bodies over the years, stream flow in the city can have extreme fluctuation. The storm water drainage system in the urban area generally proceeds as follows: inlets along the streets collect runoff during storms and direct it into underground pipes, which connect with larger trunk lines. The trunk lines connect with primarily concrete-lined open channels (although some natural sections still exist), which follow the former route of natural streams before development. The open channels flow into one of the three large streams mentioned above or directly into the Mississippi River.

For years, Memphis has been addressing storm water quantity issues (drainage and flooding) through ordinances and internal policies, which are approved by the City Council. However, Memphis has experienced numerous flooding and stream bank erosion problems associated with rapid increases in urban development and rainfall runoff. In 1994, 2007, and 2013, Flood Insurance Rate Maps for Shelby County were updated. The 1994 updates revealed a 2-foot increase in the 100-year water surface elevations along some streams in the area. Residences and businesses which were not in the 100-year floodplain prior to 1994 are now in the floodplain. (City of Memphis / Shelby County, 2013)

In 1997, the U.S. Army Corps of Engineers (USACE), Memphis District, conducted a study (The Memphis Metro Study) to determine the need for flood control improvements in the Memphis metropolitan area, which cited the sources of area flooding as flash flooding from heavy rainfalls, backwater flooding from inadequate drainage channels or bridge/culvert constrictions, and backwater flooding from a combination of high water surface elevation on the Mississippi River and high water on the headwater tributary streams. In addition to significant flooding events in 1996, 1997, 1998, and 2001 that caused secondary road closures and localized urban flooding, a historic flood occurred in 2011 that further raised concerns about flooding in Memphis and the need to address the issue in a more comprehensive way.

1.1.3 Overview of Project Area

The Gayoso Bayou watershed is 2,100 acres (3.28 square miles) and is located completely within the limits of the City of Memphis. The basin historically drained to Wolf River Harbor, a direct tributary of the Mississippi River, but it is currently controlled by a berm that averages 12 feet in height above surrounding terrain. This berm was built in the early 20th century to protect the lowest areas of the watershed from high Mississippi River stages. At the original point of discharge, a gate was constructed to allow normal drainage when stages of the Mississippi are low enough to allow it. When the river gage reaches a height of 26 feet above the USGS gauge 07032000, which has a datum of 184’ NAVD, the gate is closed and flow must be pumped out of the area. The construction of Gayoso Bayou Pump Station was completed in 1915, concurrent with the construction of the berm and the channelization and enclosure of the lower portions of Gayoso Bayou. The pump station consists of three large pumps, each capable of roughly 133,000 GPM for a combined peak discharge of 400,000 GPM. Before drainage reaches the pump station, there are five rectangular pools that allow for excess flow to be collected. During moderately high stages of the Mississippi River water from Wolf River Harbor can back up through the open gate of the drainage system and flood the open pools in the downstream portion of the watershed.

See ***Figure 1-1*** for the location of the Gayoso Bayou watershed within the City of Memphis.

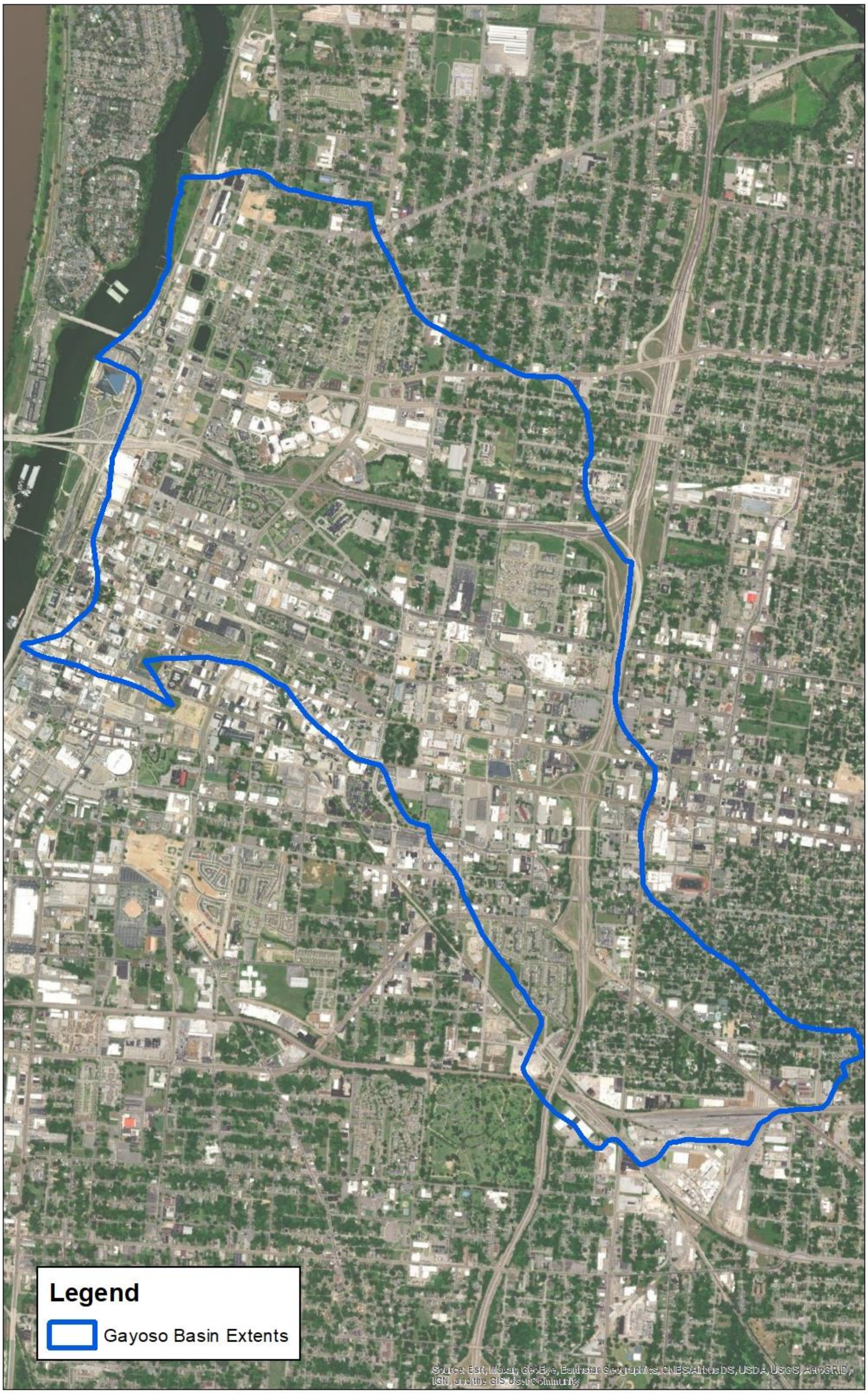

Figure 1-1
Gayoso Bayou Watershed Location

1.1.4 Model Software Description

The City of Memphis chose InfoSWMM as the required modeling platform for all its drainage basin study efforts. InfoSWMM is a dynamic hydrologic and hydraulic model capable of performing continuous or event simulations of surface runoff and groundwater base flow, and subsequent hydraulic conveyance in open channel and pipe systems. CDM Smith chose to use a similar product, PC-SWMM, to develop the baseline models. The two platforms utilize the same hydraulic engines and hydrologic equations to perform simulations.

The hydrologic system operates by applying precipitation across hydrologic units (HUs), and then through overland flow and infiltration, conveying surface runoff to loading points on the user-defined primary storm water management system (PSMS). Runoff hydrographs for these loading points provide input for hydraulic routing in the downstream system.

The hydraulic flow routing routine of PC-SWMM uses a link-node representation of the PSMS to dynamically route flows by continuously solving the complete one-dimensional Saint-Venant flow equations. The dynamic flow routing allows for representation of channel storage, branched or looped networks, backwater effects, free surface flow, pressure flow, entrance and exit losses, weirs, orifices, pumping facilities, rating curves, and other special structures or links.

1.2 Previous Studies

The Gayoso Bayou drainage basin was chosen for the third round of City master plans due to the existing of known flooding/drainage issues. To support the development of this plan, CDM Smith began the process by collecting and reviewing available information and data about the watershed, including existing FEMA mapping, flooding complaints, and work orders performed by the City of Memphis Drain Maintenance staff. The following subsections summarize the information learned from this exercise.

1.2.1 Heat Map Report

In 2012, CDM Smith performed the "Storm Water Program Review and Needs Assessment" report for the City. The report represented a collaborative effort between CDM Smith and the City to document the major accomplishments of the Storm Water Program since the inception of the storm water utility funding program in 2006, to evaluate the services provided by the City to its customers, and to identify future program needs. As a part of the Storm Water Program Review and Needs Assessment study, CDM Smith performed a review of customer complaints and work orders processed by the City's Drain Maintenance Division to gain an understanding of the type, quantity, and location of storm water-related issues city-wide.

For this report, City staff provided updated work order records from 2005 through 2011, which represented nearly 42,500 customer calls and responses by City crews. CDM Smith created a "heat map" of these work orders to identify areas that received frequent customer complaints and/or required routine maintenance to preserve the function of the storm water drainage system. The heat map for the Gayoso Bayou watershed is included in ***Figure 1-2***.

Due to the interference of the COVID-19 pandemic, public meetings were not held for this watershed. A website was created with a form for input from stakeholders, which was then compiled and added to the recorded flooding areas in the basin.

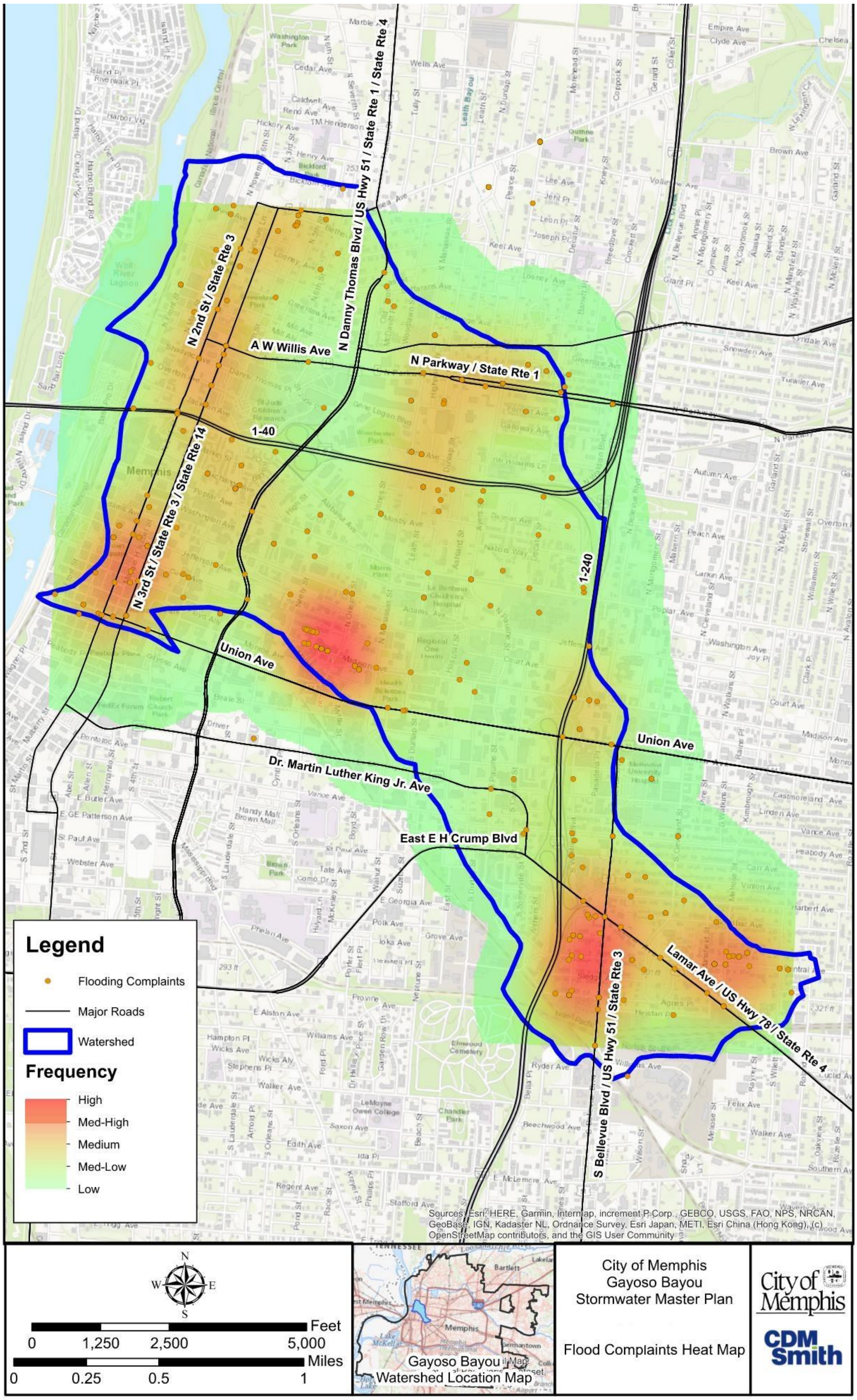

Figure 1-2
Flood Complaints Heat Map

As shown, the highest intensity of complaints/work orders is near the intersection of N Orleans Street and Madison Avenue. Additional areas of intensity include the intersection of S Bellevue Boulevard and Central Avenue and the intersection of central avenue and Melrose Street in the southeastern portion of the watershed. Work orders themselves are not always indicative of every location that floods in a watershed, and similarly, areas with high amounts of work orders may not experience the most significant flooding. Model verification clarifies the breadth of flooding issues.

In addition to the heat map data, CDM Smith also received updated flood complaint information from City staff for the 2019 calendar year as well as documented complaints from the public meetings performed for this project. All work orders and complaint data were inspected and given a relevance score that weighted orders with descriptions of chronic or serious flooding more highly than those with maintenance issues or nondescript issues. CDM Smith noted all of these areas of concern during the model-build and provided additional detail in relevant areas of the model in order to evaluate potential issues/improvements for these areas.

1.2.2 FEMA FIS

Gayoso Bayou is located within the Lower Mississippi-Memphis Hydrologic Unit Code (HUC) 8 basin (HUC8 code: 08010210), although it does not discharge directly into the Mississippi River.

CDM Smith acquired the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Gayoso Bayou to identify areas previously designated at risk for flooding. Only Zone X Areas with reduced risk due to levee are present from flooding sources within Gayoso Bayou. No discharges or water surface elevations for the Zone X flood zones were available for comparison with model results. Wolf River Lagoon is located along the northwest extent of Gayoso Bayou and is backwater of the Mississippi River. Although Wolf River Lagoon is designated a Zone AE flood zone with Base Flood Elevations (BFEs), it is not a flooding source within Gayoso Bayou and, thus, is not included in this study. The FEMA flood zones are shown in ***Figure 1-3***.

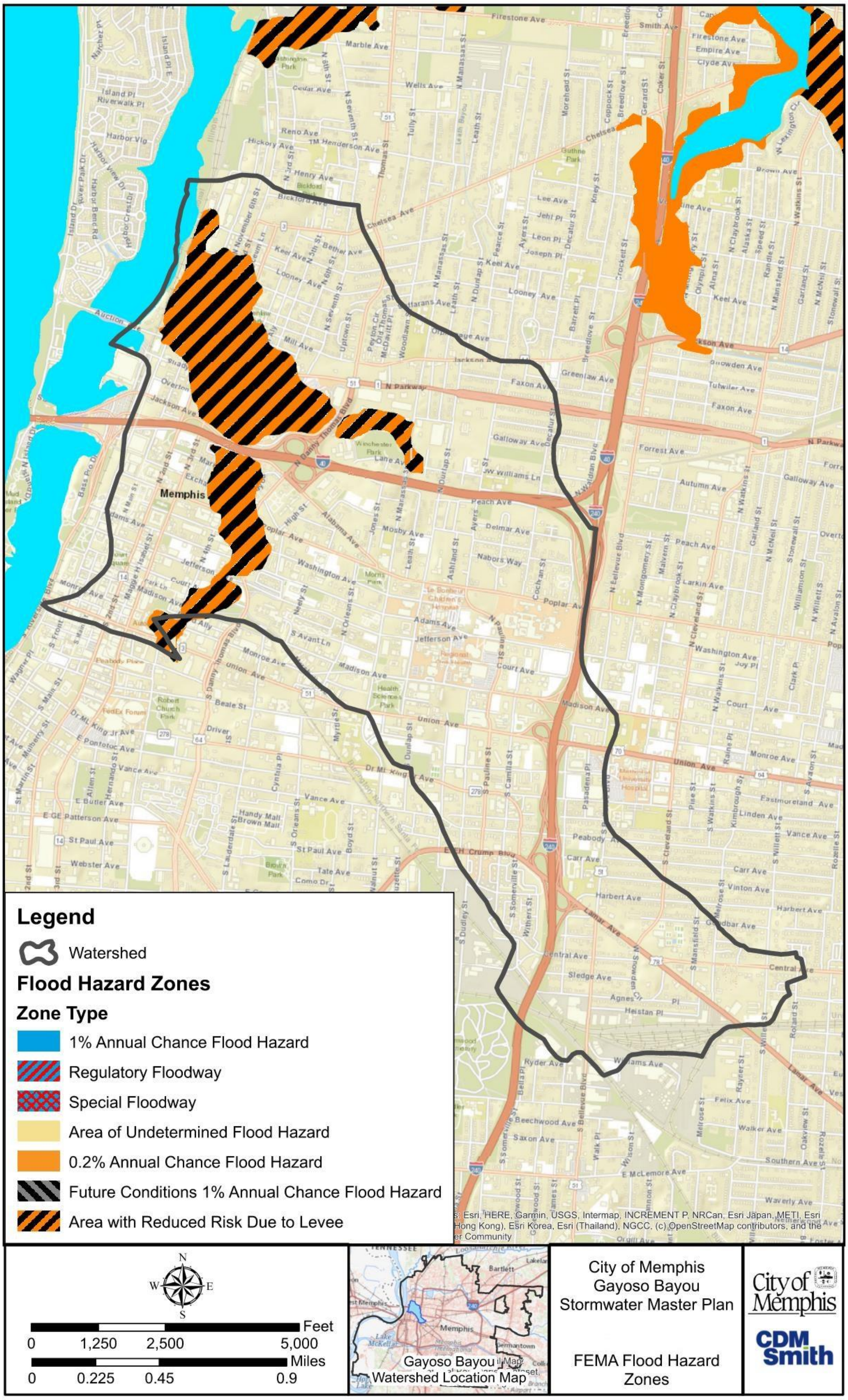

Figure 1-3
FEMA Flood Hazard Zones

Table 1-1 summarizes the peak discharges and stages for the Mississippi River near the study basin.

Table 1-1. Summary of FEMA FIS Discharge and Stage for the Mississippi River at Memphis Southern Corporate Limits (FEMA, 2007)

	10% Annual-Chance	2% Annual-Chance	1% Annual-Chance
Peak Discharge (cfs)	**1,435,000**	**1,810,000**	**1,960,000**
Stage (ft NAVD88)	**225.3**	**231.8**	**234.3**

1.3 Study Area Characteristics

In general, the data collected is either temporal (such as rainfall) and distributed evenly throughout the model, or spatial, and is first added to a GIS dataset as a layer. If multiple gages are available, rainfall may be both temporal and spatial. Spatial data includes point layers such as survey and high water mark locations, linear layers such as the pipe network, polygon layers such as soils and land use, and raster surface layers such as topography.

1.3.1 Topography

Topographic data are used to define hydrologic boundaries, overland flow paths and slopes, out-of-bank channel cross-sections, critical flood elevations, and stage-area-storage relationships.

The City of Memphis (City) provided a LAS dataset of Light Detection and Ranging (LiDAR) point cloud data. The geodetic reference system used was Tennessee State Plane (NAD 1983, State Plane, Tennessee) and the vertical datum was in North American Vertical Datum (NAVD88) of 1988. The topography of the city of Memphis ranges from an approximate high of 380 feet NAVD in the southeast portion of the city to a low of approximately 190 feet NAVD88 along the Mississippi River. The Gayoso Bayou watershed is located in the central part of the City of Memphis near the Mississippi River with elevations ranging from 344 feet NAVD88 to 123 feet NAVD88.

Using the LAS dataset provided, a Digital Elevation Model (DEM) was created of the watershed area. A DEM is a two-dimensional surface with elevation values at discrete points on the surface. These discrete points are tiles each having a specific elevation value. The DEM was created at a resolution of ten feet in length and width. This DEM was utilized in order to determine slope, overland flow paths, stage-area-storage relationships, and Hydrologic Unit (HU) boundaries.

Average slopes across the watershed range from flat to 3:1 with the steeper slopes in the downstream portions of the watershed near main stem reaches. Steep slopes were also observed for overland flow to the open channel reaches in the downstream portion of the watershed. ***Figure 1-4*** shows the DEM and 5-foot contours for the study area.

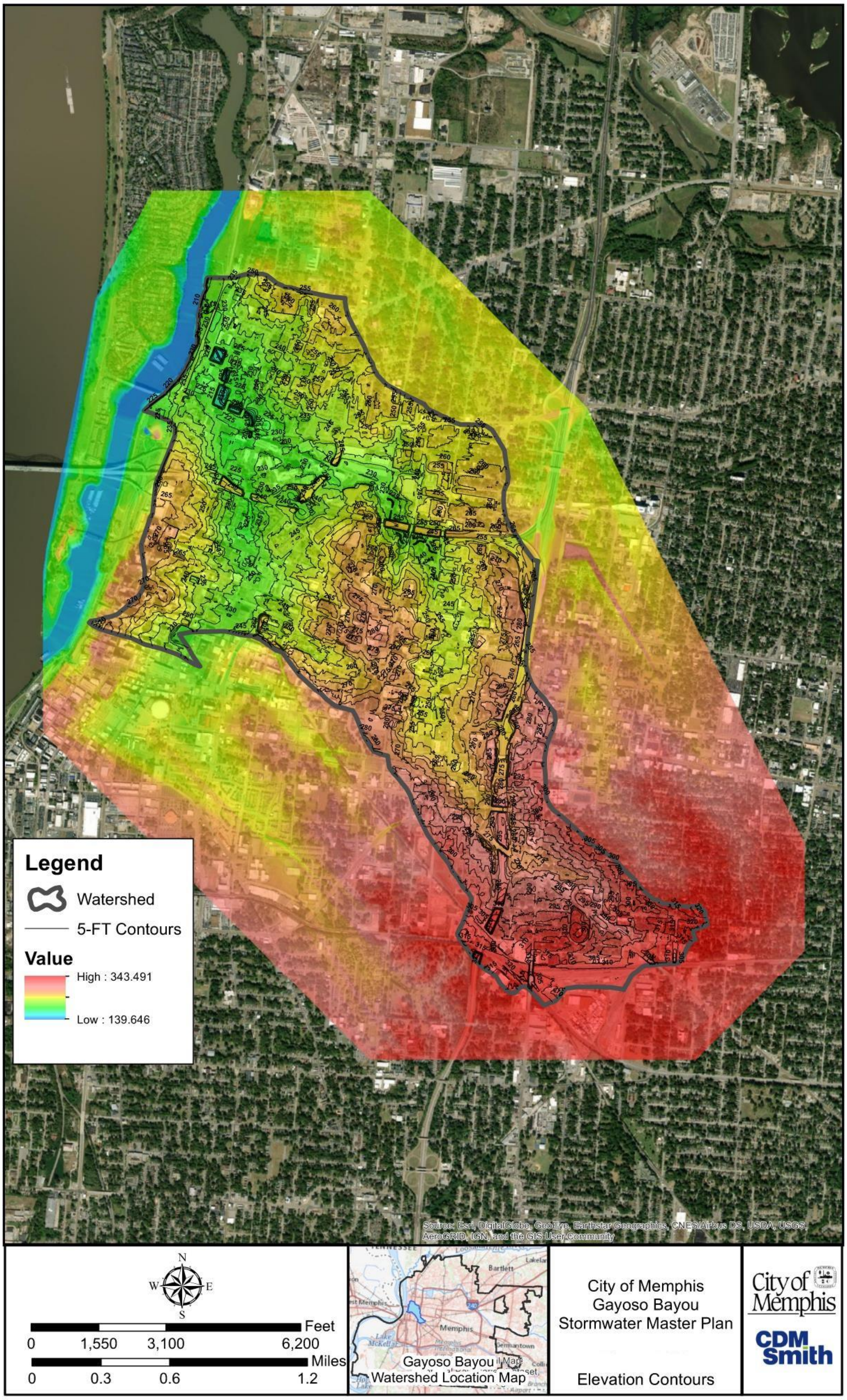

Figure 1-4
Elevation Contours and DEM

Datum

The elevation data used in PC-SWMM and provided in this report are referenced to the North American Vertical Datum (NAVD 1988).

1.3.2 Land Cover

Percent Impervious

The model was built using the impervious geospatial data provided by Shelby County. This high-resolution dataset provides a detailed spatial representation of roadways, sidewalks, buildings, and driveways. No permanently inundated waterbodies or wetlands are present in the study area due to its highly urbanized nature, so consideration of the impact of waterbody and wetland imperviousness on the overall imperviousness of the study area was not necessary for calibration. For the Design Storm and Alternatives Analysis models, conditions are more conservatively applied, and the downstream ponds are considered full of water and are thus treated as open water. These spatial extents were intersected with the catchment boundary polygons to find the average imperviousness over each catchment.

The impervious percentage represents both the impervious surfaces with a direct hydraulic connection to the storm water system (such as paved roads or parking lots that drain to storm water inlets) and the non-directly connected impervious areas (NDCIA, such as rooftops, patios, driveways or parking lots that shed water onto pervious areas where infiltration may occur prior to intercepting the storm water system).

Land Use

Land use data are used to estimate surface friction factors, initial abstractions, and percent directly connected impervious areas (DCIA) and NDCIA for each hydrologic unit. Based on parcel data provided by the City, CDM Smith developed a land use shapefile. The Gayoso Bayou watershed was classified into eight land use categories of relatively homogeneous geophysical parameters as shown in ***Table 1-2***. The majority of land use in the watershed is Commercial (26 percent). Institutional (School, Hospital), Residential – Medium Density, and Parking Lots and Highways account for another 52 percent of the watershed. A map of land use distributions is provided in ***Figure 1-5.***

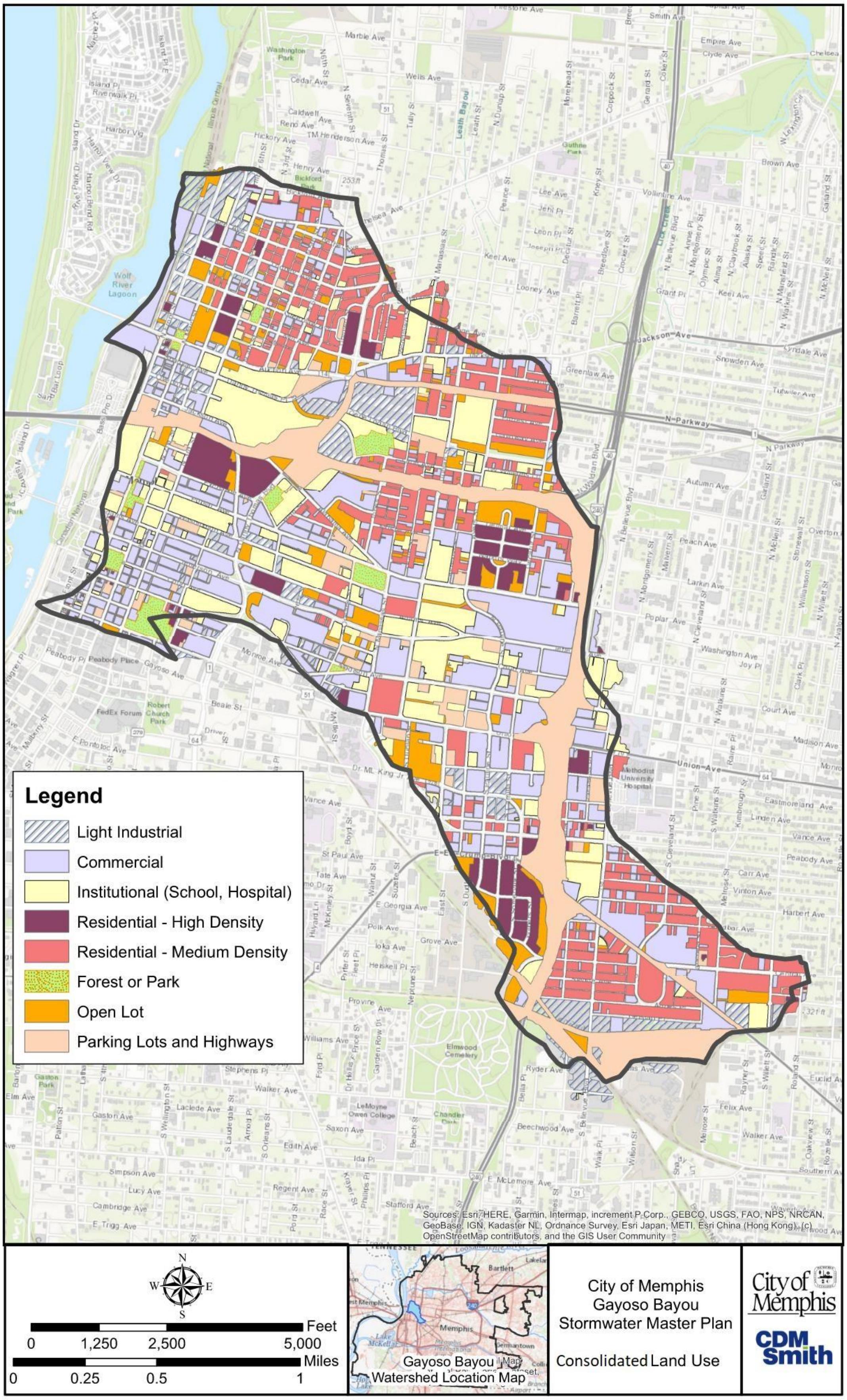

Figure 1-5
Consolidated Land Use

Table 1-2 Gayoso Bayou Land Use

Land Use Type	% of Watershed
Forest or Park	2%
Institutional (School, Hospital)	16%
Open Lot	7%
Residential - Medium Density	19%
Residential - High Density	6%
Light Industrial	7%
Commercial	26%
Parking Lots and Highways	17%
Total	100%

Manning n roughness factors (n) and initial abstraction (Ia) values for overland flows were set to values typically used for respective land use, based on technical literature and previous experience. Manning n roughness values are scaling factors applied to flow equations in order to represent the friction and retardances of overland flow through vegetative and land features. Ia is a factor that accounts for the fractions of precipitation quantities that do not eventually result in runoff. Ia includes water intercepted by vegetation and water retained in depressions. Both Manning n roughness and Ia are calculated for pervious and impervious areas separately.

PC-SWMM includes various options to route runoff between pervious and impervious areas. The option selected routes runoff from impervious areas to pervious areas based on the percent NDCIA estimated from land-use and based on literature and past experience. Routing flow back to pervious areas provides the opportunity for additional infiltration and slows the flow down compared to flow along a path of DCIA.

The global values for roughness and percent routed to pervious were adjusted during calibration. The final values used are shown in ***Table 1-3.*** Wetlands and waterbodies have a value of 0% because waterbodies in PC-SWMM are considered impervious as there is no direct connection with the soil to allow for infiltration.

Table 1-3: Gayoso Bayou Land Use Global Parameters

Land Use Type	% Impervious Flow Routed to Pervious	Impervious n	Pervious n	Impervious Ia (in)	Pervious Ia (in)
Forest or Park	80%	0.015	0.30	0.1	0.25
Institutional (School, Hospital)	4.7%	0.015	0.25	0.1	0.25
Open Lot	80%	0.015	0.40	0.1	0.25
Residential - Medium Density	34.3%	0.015	0.25	0.1	0.25
Residential - High Density	21.2%	0.015	0.25	0.1	0.25
Light Industrial and Commercial	4.7%	0.015	0.25	0.1	0.25
Parking Lots and Highways	10%	0.015	0.25	0.1	0.25
Wetlands, Watercourses and Waterbodies	0%	0.015	N/A	0.1	N/A

Area-weighted hydrologic model parameters were determined for each HU by creating weighted averages of the global parameter values by percentage of land use category using GIS and spreadsheets.

1.3.3 Soils

The most detailed standardized national soils mapping completed by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) was used to create the Soil Survey Geographic (SSURGO) database. SSURGO soil maps are compiled at scales from 1:12,000 to 1:63,360. Digital versions of SSURGO are available from the NRCS Soil Data Mart (SoilDataMart.nrcs.usda.gov). SSURGO data include soil polygons and extensive attribute data that define soil characteristics, properties, and potential uses. The three most common soil types in the project area are Memphis silt loam, filled silt, and Graded land, silty materials.

Memphis Silt Loam

Memphis silt loam (MeB) is a deep, well-drained, silty soil on the uplands. Runoff is the main management problem. The soil is silty and erodes easily when cultivated. Erosion is often the cause for the removal of the original surface layer of soil in the area of steeper slopes. This soil has a range of slopes under which different levels of erosion occur. The soil can forms gullies in the steeper areas which expand to form deep, narrow, meandering, V-shaped valleys on hillsides as they slope from the narrow, winding ridgetops. Grass should be established in the natural watercourses. The available water capacity is high.

Graded Land, Silty Materials

Graded land, silty materials (Gr) consists of areas that have been graded in preparation for residential or site development. The depth to which these areas have been graded varies from a few inches to five or more feet and is most commonly about three feet. The slope, after grading, is generally between one and five percent. Grenada, Loring, and Memphis soils were predominant in these areas before grading. The areas of this land range in size from a few acres to about 400 acres. They are on the outer edges of the city of Memphis.

Filled Silt

Filled land, silty (Fs) consists of soil material that has been moved for the purpose of leveling and building up sites for development. The areas are five to 40 acres in size. Most are near the outer edges of Memphis and include some gravel pits that have been filled. A few areas have been filled with trash, tree trunks and roots, overlapping slabs of concrete, and other types of filling material that could cause settling of built structures and cause difficulty in sinking pilings. Areas that are adjacent to Graded land, silty materials, generally consist of clean silty fill.

Figure 1-6 displays the USDA soil classification of the soils in the Gayoso watershed. 88% of the soils are classified B soils and 12% were considered D, with the largest cluster of the hydraulically poor soils located in the downstream portions of the original channel of the bayou.

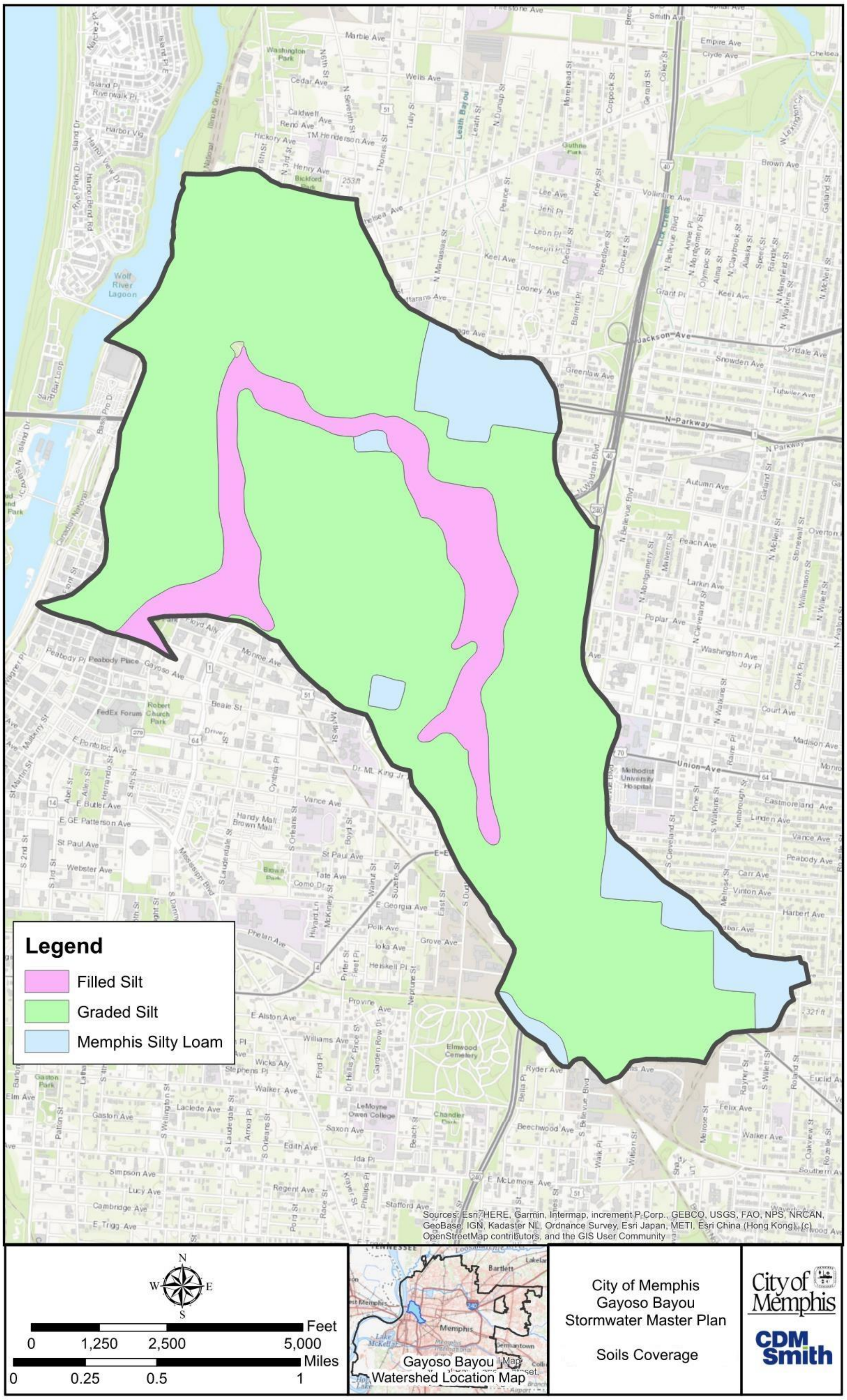

Figure 1-6
Soils Coverage

The soil layer was intersected with the HU boundaries to get the percentages of each soil type within each HU. Green-Ampt soils parameters including saturated hydraulic conductivity, initial moisture content, and capillary suction are assigned to each soil type (see ***Table 1-4*** below), and area weighted aggregates were determined using the assigned percentages.

Table 1-4. Soil Parameters

Soil Class	Suction Head (in)	Hydraulic Conductivity (in/hr)	Initial Deficit (in)
Silt	6.6	0.63	0.32
Silt Loam	6.6	0.60	0.32
Silty Clay	11.5	0.04	0.21

1.3.4 Precipitation

The climate of the Memphis area is characterized by relatively mild winters, hot summers, and abundant rainfall. The average annual rainfall is approximately 52 inches and the average annual snowfall is approximately 3 inches. In general, winter rains are of several days duration with a large coverage, but rarely is the intensity severe. Summer rains are usually categorized as thunderstorms with high intensities over small areas. Monthly averages differ depending on the source, as shown in ***Table 1-5.***

Table 1-5 Monthly Precipitation Average Total

Month	Average Total Precipitation (Inches) (1961-2010) NOAA
January	4.3
February	4.4
March	5.3
April	5.5
May	5.0
June	3.5
July	4.1
August	3.3
September	3.2
October	3.3
November	4.5
December	5.2
Year	51.6

[1] Source: https://w2.weather.gov/climate/xmacis.php?wfo=meg

Precipitation is heaviest during winter and early spring when low-pressure systems cause widespread rains. A second period of heavy precipitation occurs late in spring and early in summer, when local showers and thunderstorms are most common. Precipitation is generally lightest in summer and early in fall. (US Dept. of Agriculture Soil Conservation Service, 1989)

Heavy local rainstorms frequently drop more than four inches of precipitation. Maximum amounts of precipitation in a 24-hour period at nearby locations have been more than 5 inches. The highest total monthly precipitation recorded at Memphis during the period 1872 through 2015 is 18.16 inches for June 1877. The most recent wettest month on record is 16.20 inches for March 2016. Within the past fifteen years Memphis has experienced two of its top ten driest years (2007 with 34.8 inches and 2012 with 36.9 inches) and one of its top ten wettest years (2019 with 73.65 inches). (National Oceanic and Atmospheric Administration, 2020)

Storm depths for recurrence intervals relevant to this study are discussed in **Section 2**.

Section 2

Model Development

2.1 Approach

This section focuses on data collection/evaluation and the methodology used for the Gayoso Bayou watershed storm water evaluations, including model set-up and refinement, calibration, validation, and design storm modeling. As part of this Storm Water Master Plan (SWMP), surface water hydrologic and hydraulic (H&H) modeling was performed using PC-SWMM. As discussed in Section 1, PC-SWMM is built upon USEPA SWMM and was used to simulate existing conditions, estimate and evaluate flooding levels of service (LOS), and to simulate alternative solutions that would meet specific LOS.

Volume II, Section 3 presents alternative conditions and evaluations based on the modeled results presented in this section.

2.2 Model Elements

2.2.1 Hydrology

Hydrologic Units

The project watershed was sub-divided into 173 hydrologically distinct catchments defined as hydrologic units or HUs. The divisions were based on a combination of topographic information, city storm water pipes and catchments, and aerial photographs. The hydrologic parameters assigned to each HU include area, width, slope, directly connected impervious area (DCIA), surface roughness, initial abstraction, and infiltration parameters.

Rainfall

SCS Type-II curves were utilized for design rainfall distributions in the area. Depths were referenced from the City of Memphis' drainage design manual. Three rainfall monitors were located at Memphis Fire Department #2 (474 S Main St), Bruce Elementary (581 S Bellevue Blvd), and Robert Church Park. Rainfall increments were 5-minute.

Area

The tributary areas for each HU were determined directly from Geographic Information System (GIS) mapping. For the 173 HUs, the catchment areas ranged from a low of 1.4 acres to a high of 110.2 acres, with an average size of 12.1 acres.

Imperviousness

The percent impervious was developed from GIS data provided by Shelby County. The impervious area shapefile included delineations of impervious surfaces such as roads, building footprints, or driveways. Flow originating from a portion of this area was then routed to the pervious layer based on the weighted land use of the HU as described in more detail later in this section. The average imperviousness across the Gayoso Bayou area is 57%. Soil parameters were also developed using only the inverse of the impervious layer, or the implied pervious surface, as infiltration was assumed to only meaningfully occur within pervious surfaces.

Width

The SWMM hydrologic layer routes runoff in wide shallow overland flow channels to the collection system for loading into the hydraulic layer. The width of each HU was computed by measuring multiple flow path lengths per HU and dividing the area by the average length to get width. Width is then checked for reasonability. Depending on the HU shape, some flow paths may be weighted higher than others. Given the uncertainty in HU width, this parameter is often changed from the measured value during calibration. For this watershed, widths were increased (flow path lengths were decreased) as needed to match depth gage timing.

Slope

The average slope of each HU was determined using GIS. HU slopes, like flow paths, were weighted depending on HU geometry and were also adjusted during calibration. Slopes were increased as needed, again to match gage timing.

Evaporation

Evapotranspiration levels vary through the year with the low in January of 0.3 inches per month and a high in July at 6.8 inches per month. (US Dept. of Agriculture Soil Conservation Service, 1989) No evaporation was included in the model due to the limited duration of the calibration and design storm event model runs. Evaporation becomes important for long term continuous simulation of months and years.

Overland Roughness and Depression Storage

The overland Manning n roughness values were set to 0.015 for impervious areas and ranged from 0.20 to 0.40 for pervious areas depending on the land use. The pervious area roughness values are higher than those used for a channel bottom because the depth of flow is much shallower compared to the roughness features for surface runoff. The global land use roughness values were adjusted during calibration. Values for directly connected impervious area (DCIA) and % routed to pervious were also assigned by land use type. **Table 2-1** presents Gayoso Bayou's Land Use Global Parameters.

Depression storage, also known as initial abstraction, represents the volume of water that does not flow off the surface into the PSMS due to ponding. The values are set to 0.1 inches over impervious areas and 0.25 inches over pervious areas. The model is generally not sensitive to changes in these values, within ranges that are physically reasonable.

Table 2-1 Gayoso Bayou Land Use Area Distribution and Model Parameters

Land Use Type	Pervious Roughness	DCIA %	% Routed to Pervious	Area (Acres)	Percent of Total
Forest or Park	0.40	1	80	29.6	2.0%
Institutional (School, Hospital)	0.25	81	5	275.4	16.7%
Open Lot	0.30	1	80	117.1	7.2%
Residential - Medium Density	0.25	23	34	312.1	18.9%
Residential - High Density	0.25	65	21	99.7	6.3%
Light Industrial	0.25	81	5	103.4	6.4%
Commercial	0.25	81	5	429.7	26.0%
Parking Lots and Highways	0.25	90	10	288.8	17.5%
Totals				**1,655.8**	**100.0%**

Infiltration

The SWMM infiltration function uses soil characteristics to define infiltration parameters. Based on discussions at the City's facilitated meeting of the consultant teams for this project, the modified Green-Ampt soil infiltration method was selected for use on all models.

A single set of infiltration characteristics were assigned to each HU based on the average area-weighted parameters of soil types in the catchment. The soil information was collected from the SSURGO dataset as described in the **Volume II, Section 1**. The composite soil make-up was then used to determine weighted Green-Ampt soil characteristics including initial moisture deficit of the soil, the soil's hydraulic conductivity and the suction head at the wetting front. **Table 2-2** displays the soil parameters used in the model. Graded and filled soils were given a soil group of D due to their compacted and altered states.

Table 2-2 Gayoso Bayou Soils Distribution (US Dept. of Agriculture Soil Conservation Service, 1989)

Soil Type	Hydrologic Soil Group	Initial Moisture Deficit	Saturated Hydraulic Conductivity (in/hr)	Suction Head (inches)	Area (Acres)	Percent of Total
Graded land, silty materials	D	0.092	0.04	11.5	1,666	79.6%
Filled Silt	D	0.092	0.04	11.5	244	11.7%
Memphis silt loam	B	0.171	0.27	6.6	183	8.8%
Totals					**2,094**	**100.0%**

* The discrepancy in total acreage between soils and land use is due to surface streets and railways not being considered a unique land use by Shelby County, but as an inherent part/boundary of all land uses.

2.2.2 Hydraulics

The SWMM hydrologic/hydraulic model uses a node/link (junction/conduit) representation of the PSMS. For this model, the PSMS links are a mix of open channels (both natural and concrete lined) as well as closed conduits such as circular pipes and rectangular box culverts. Nodes are located at:

- Transitions between open channels and closed conduits;
- Locations where the stormwater pipes change diameter;
- Locations where channels or stormwater infrastructure converges;
- Locations where the open channel or flood plain area significantly changes shape;
- Locations where additional storage is not captured in the floodplain of the channel and a storage node is required.

The Gayoso Bayou model contains 499 nodes, 175 of which are storage nodes, and 658 links, 156 of which are overland flow paths, as shown in **Figure 2-1**. **Tables A-1** and **A-2** of **Appendix A** provide the hydraulic model data by node and by link.

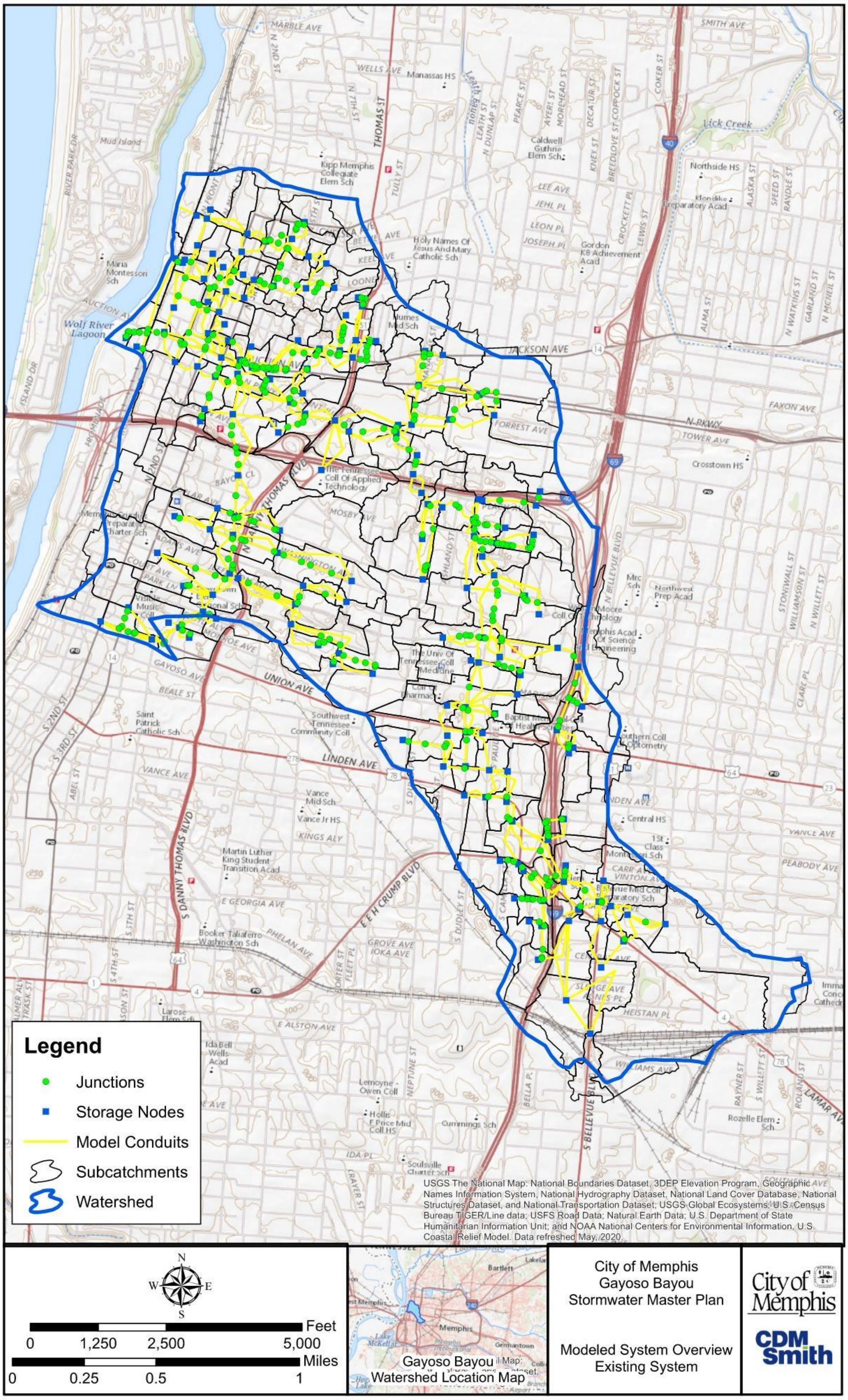

Figure 2-1
Model Links and Nodes

Model Resolution

In many areas within the Gayoso Bayou Watershed, there are numerous inlets and smaller pipes leading to a main PSMS trunk. It is the objective of this study to determine whether the trunk on the PSMS is sized properly to meet desired level of service (LOS) goals. The inlets and smaller connecting pipes (smaller than 24-inches) are considered secondary systems and are not always explicitly modeled. The local surface runoff is directed to the upstream end of the PSMS.

Model Nodes

Model nodes may be in the form of connection junctions, storage units, or outfalls. Storage units are used to define a stage-area–storage relationship above the top of an inlet. These units help determine depths of flooding. An example stage-area-storage relationship is shown in **Figure 2-2**. Due to the highly urbanized nature of the study area, stage-area-storage relations are used to represent the model basins at their particular load points, and may include small swales, detention areas, and floodplains not uniformly defined in stream channel cross-sections. Areas of the DEM that had significant storage, such as large best management practices (BMPs) included in the model and underground parking garages, were manually removed to ensure that they were not inappropriately utilized. The furthest upstream node on each tributary is modeled as a storage junction, to account for the smaller tributaries/secondary systems not modeled. Outfalls are placed at the boundaries of the model where flow is out of the model space. For Gayoso Bayou, these were all the Mississippi River. Outfalls will be discussed in detail in the following section.

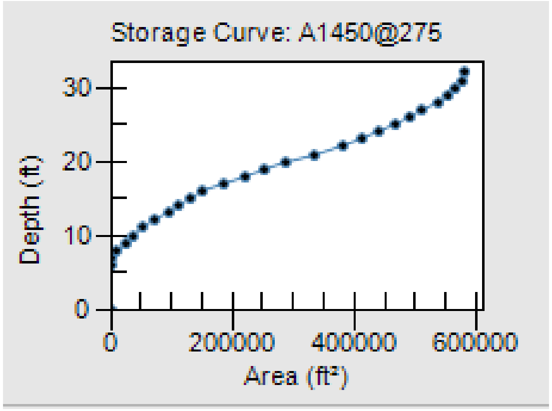

Figure 2-2
Typical Stage-Storage Curve

The loading from the hydrologic layer may be input to any node in the PSMS; however, all junctions representing the upstream end of a pipe system should have hydrologic loading in order that "dry" pipes not be created. Dry pipes are those pipes that have no flow from an upstream element (either link or loading) and therefore are not useful in the system analysis. Dry pipes may also cause numerical instabilities. Model node inverts were set to the lowest pipe invert intersecting the given node or where inverts were explicitly called out in survey.

Model Links

Model links may be conduits (pipes, culverts, and bridges), natural or manmade channels and road overflows, pumps, orifices, weirs, gates, valves or outfalls. A conduit may be an irregular channel, a trapezoid, a circular pipe, a box culvert, or of a special shape.

Pipe size and length were determined based upon the GIS information supplied by the City and size was verified with survey data. Pipe inlet and outlet inverts were determined by using the survey data or drawings/GIS provided by the City. If the element invert was not supplied with survey or available on drawings, the invert was interpolated or extrapolated from neighboring survey information and from the land surface contours.

Channel cross sections from the survey were combined with transects taken from the DEM described in **Volume II Section 1** to form the cross-section of each open channel. Upstream and downstream channel inverts were set using survey data at the link ends, where available. At times, inverts were offset to allow the floodplain at either the upstream or downstream end to better match the topography. In general, flood depths are better defined by the elevation of the floodplain than the elevation of the center channel. **Figure 2-3** displays a typical cross section from the hydraulic model.

Within the cross-section, the left bank, right bank, and main channel were defined and given distinct Manning n values based on the channel type and aerial photos of the overbank areas. These values were then adjusted during calibration. Concrete lined channels were given a default Manning n value of 0.015 while natural channels range from 0.02-0.04. Overbank areas range from well-maintained grass at 0.03 to shrubs and bushes at 0.1.

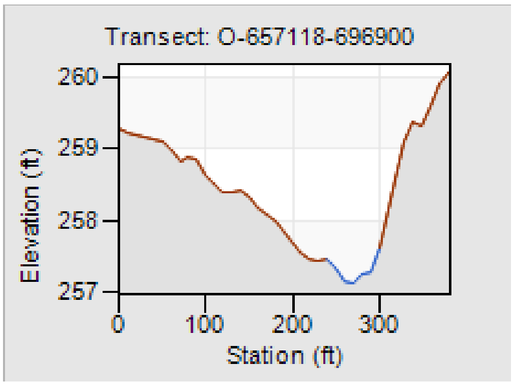

Figure 2-3
Typical Overland Flowpath Cross Section

Pipe roughness (Manning n) was uniformly set at 0.015 which corresponds to concrete and is indicative of unfinished or loosely maintained pipes. Due to the various conditions of management observed in survey photologs, this conservative Manning's n was chosen to be verified in calibration stages. Potential sediment and debris blockages are only included in the model if they were photo-verified from survey or other report materials. Therefore, a routine maintenance program will be required to meet the estimated LOS that the model predicts. Without maintenance, the likelihood of flooding cannot be predicted as any culvert, pipe or inlet in the system may act as a constraint.

Local entrance and exit losses account for head losses at inlets, pipe diameter changes, intersections, and outfalls. Losses were set utilizing PC-SWMM's form loss tool which utilizes bend angle at transitions to assign loss values (generally vary from 0.3 to 0.7), although the model is not very sensitive to these losses for intense storms where flooding is prevalent. Pipes with outfalls to bodies of water or large basins were assigned values of up to 1.

2.2.3 Outfalls with Pump Station and Gate Operations

Like most drainage basins in Memphis, Gayoso Bayou outfalls to the Mississippi River. As such, Gayoso Bayou's drainage capabilities are heavily influenced by fluctuations in Mississippi river stage. Along the northwest boundary of the basin is a levee built in the early 20th century to control routine flooding that inundated the lowest reaches of the basin. This levee is generally ten to twelve feet above upstream levels, or 235-237 feet NAVD. While this levee successfully prevents flooding caused by inflows from the river, it can sequester outflows when the river stages are high and gates that would allow normal drainage are closed. The gates are closed when the river is 210 feet above sea level, or 26 feet above the nearest USGS gage (07032000). The Gayoso Bayou Pump Station was constructed in 1915 and provides flood relief when river stages are high. The pump station is operated when levels in the upstream pond system are generally near 30 feet above gage datum, though the pump operation is manual and not controlled by precise indicators such as SCADA. The pumps also require up to 30 minutes to reach full operating flow rates. St. Jude maintains an action level of 30.6 ft above gage datum, at which point the hospital contacts operations and requests pump starts.

The Mississippi River had a wide range of stages during the calibration period, from a minimum of 194.3 feet NAVD88 in October to a maximum of 221.2 ft NAVD88 in early April. **Figure 2-4** shows the Mississippi River stages leading up to and during the study period.

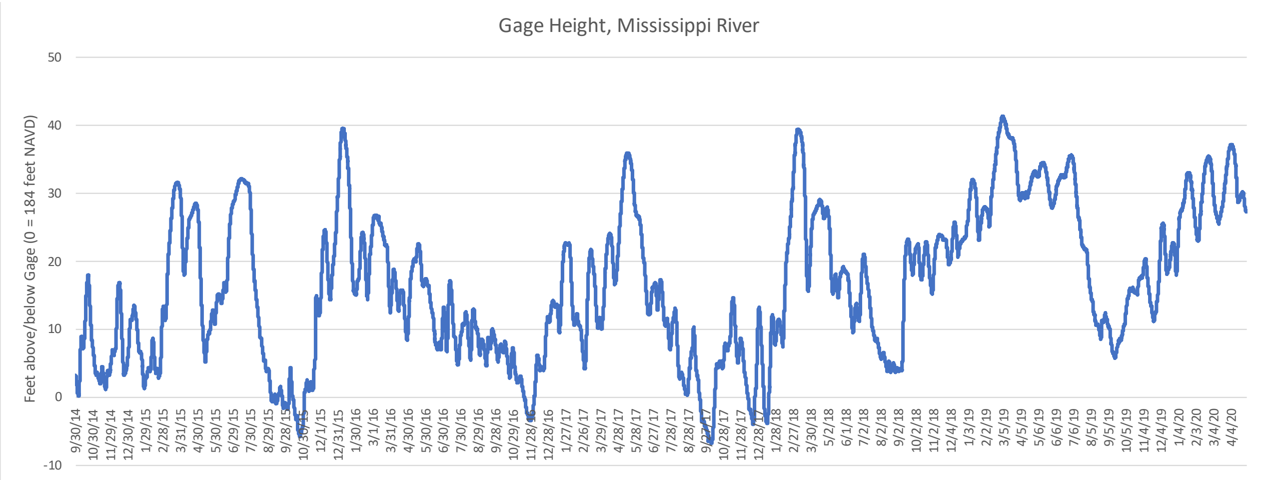

Figure 2-4
Mississippi River Stage, 2014-2020

In the hydraulic model, the pump station is modeled as a combination of three pumps with increasing capacity based on the stages of the ponds adjacent to the pump station. These pumps are powerful, with capacities nearing 575 MGD when fully utilized. When these pumps are utilized in small storms or dry weather, the entire bayou's levels can be lowered by several feet in less than an hour. During high volume storm events, all three pumps are utilized and stages in the ponds can reach bank. Pumps turn on as stages in the ponds rise, with the first starting at 30.6 ft above gage datum, and the additional two pumps turning on with each additional 1 foot of rise.

Three other non-pump station-oriented outfalls are included in the model, though they only receive local drainage considerations and do not relieve the PSMS.

2.3 Calibration to Monitoring Data

After being constructed from existing data sources, the hydraulic model was run for the period October 20, 2019 through April 13, 2020. The modeled data was compared to observed flow and level data to assess possible model adjustments that could be required to better reflect the system. This process is called Calibration and is defined by Rykiel (1996) as "*the estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set.*"

The two points of comparison are the monitors in box culverts at (1) Exchange Avenue and N Lauderdale Street and (2) just upstream of St. Jude Hospital near Winchester Park. The Exchange Avenue culvert is a 10x10-foot box culvert while the St. Jude monitor is comprised of two separate monitors on both conduits of a twin 9.5x10.5-foot culvert. The two St. Jude monitors are combined to create a single flow entity. Observed levels in both monitors were virtually indistinguishable during the observed period, suggesting that the system is often equilibrated throughout its lower reaches. **Figures 2-5 and 2-6** present the calibrated and observed time series at both locations for a rainfall event on November 26, 2019.

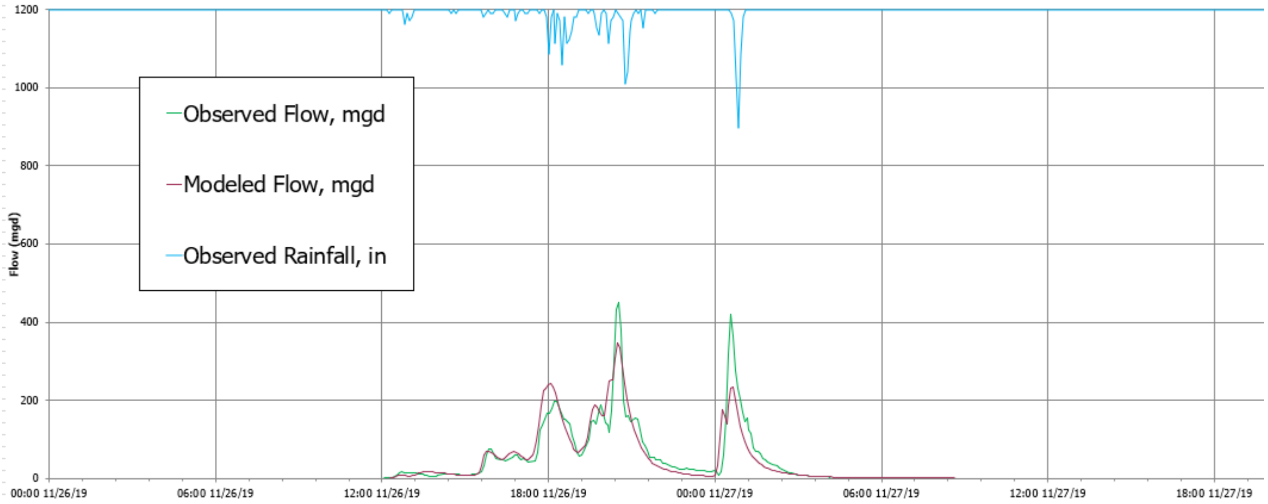

Figure 2-5
Flow at St. Jude monitor

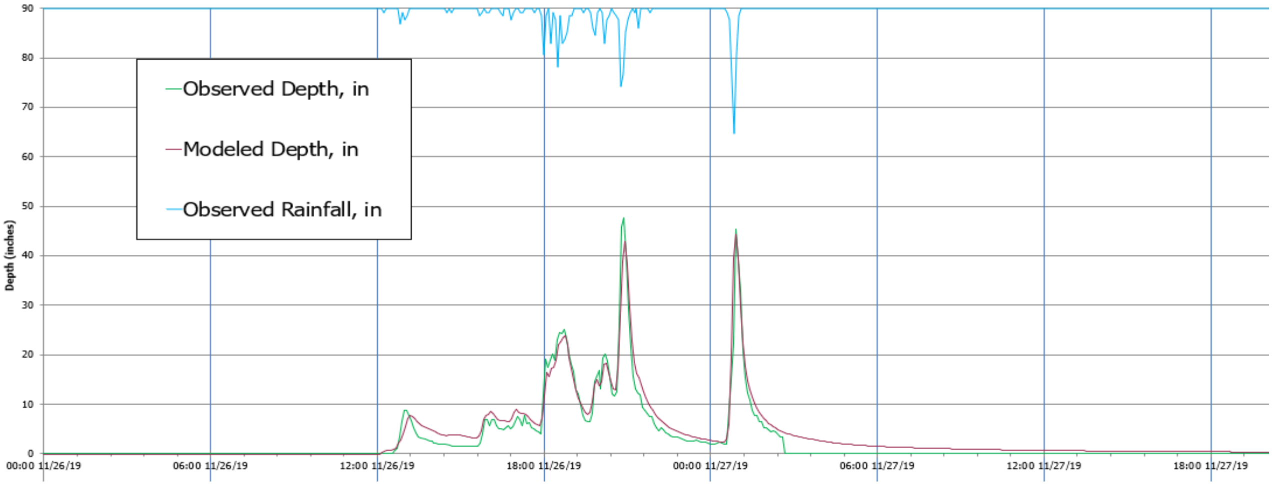

Figure 2-6
Depth at Exchange Avenue Monitor

Three rainfall recording devices were deployed at (1) Memphis Fire Station #1, (2) Robert Church Park, and (3) Bruce Elementary School. The rain gage at Robert Church park is missing several days of data in February due to vandalism of the gage, though observations at other gages confirmed that this period did not experience precipitation. Rainfall was also logged at the flow monitoring stations, but the hourly period of recording was not sufficiently detailed for use in calibration. The long-term rain gage at the Memphis International Airport was also used to verify the severity of the calibration storms and general rainfall volume over the calibration period.

Prior to January 3, 2020, the gate to the Mississippi River was open and flow was free to outfall. During these conditions, storms exhibit the peaks and decays typical of storm-related flow. Storms on November 26th and January 10th provided opportunities for comparing monitor to model data. The November 26th event where 2 to 2.1 inches of rainfall fell during 12 hours. A secondary event on January 10th was also utilized, and this event had the added benefit of occurring during a period in which the flood gate was closed. During this event 2.1 inches of rain fell in 6 hours. No event during the monitoring period was more intense than a mean annual storm, though the entire monitoring period was unusually wet, seeing a total of 45-46 inches of rain in 6 months. For context, Memphis generally receives 53 inches of rain per year.

In December, a five-day period of backflow from the river was observed. River stages were high enough to inundate the system but did not meet the criteria for gate closure. Depths were closely matched at both monitoring locations.

After the gates were closed on January 3, 2020, the model utilizes the Pump Station to drain the system when levels rise. These operations occur infrequently and are not always driven by rainfall. Model performance in this area performs well on a drainage outflow basis, but the manual nature of the pump operation makes drawdown difficult to precisely match. Based on the slow rise of levels in the absence of precipitation, it is likely that there is a small baseflow component of 2-3 cfs that ordinarily trickles out of the system but is detained in the closed system. The addition of this baseflow component enhances model agreement with day to day observed conditions but would be negligible during a design storm event when the system experiences flows nearly three orders of magnitude greater. **Figure 2-7** shows the backflow scenario and the cycling of the pump station in observed data.

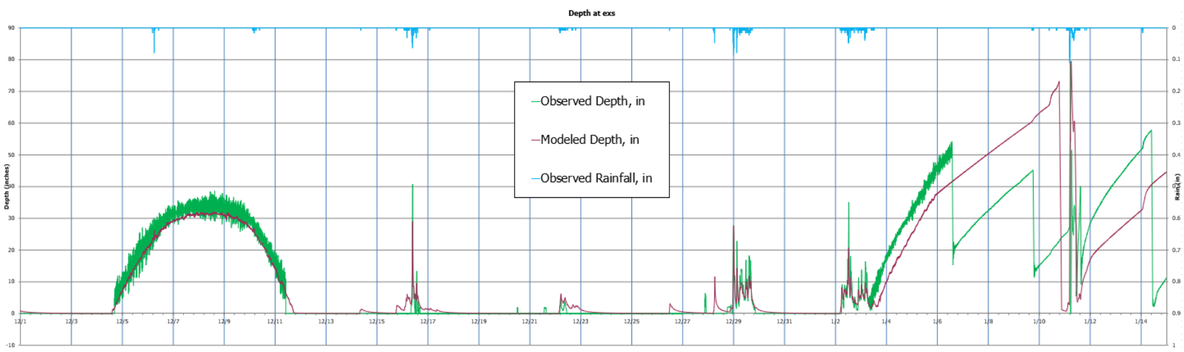

Figure 2-7
Depth at Exchange Street, December 2019 to January 2020

The calibration included testing many hydrologic features including the percentage of impervious flows routed to pervious areas (i.e. non-directly connected impervious area), slope, overland roughness, soil parameters, etc. The parameters were adjusted until the peak stage for the model and approximate curve shape provided a best match with the two depth gages.

2.4 Validation of Monitoring Data

In addition to calibrating the data to observed conditions, the hydraulic model was validated. According to Rykiel (1996), validation is "*a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model.*"

Validation of the model was performed using observed rainfall data at the three rain gages noted above. Aside from the calibration, depths during this rainfall period were compared to flooding complaints, observed conditions, and high-water marks. Pump and gate operations were also compared to model depths for these periods.

24-hour design storms were developed for the 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr recurrence intervals using an SCS Type II distribution. Depths for these storm events from NOAA's Atlas 14 (taken from the Memphis WB City station) are given in **Table 2-3.** These storms were applied to the validated model with a preceding dry day and five dry post-storm days to observe the system's long-term drainage capabilities. **Figure 2-7** displays a typical SCS Type II distribution used to determine flood inundation in the model for design storms.

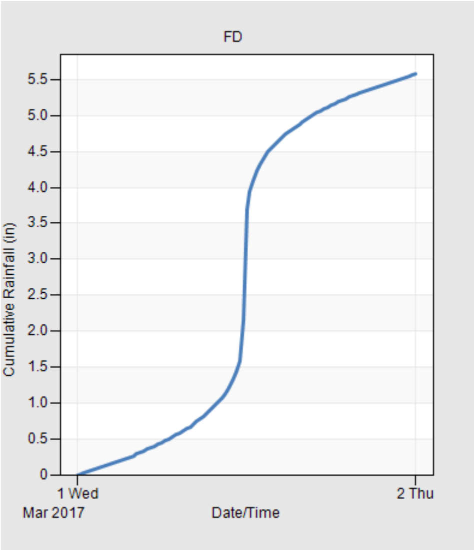

Figure 2-8
SCS Type II Curve for the 10-yr storm event

Recurrence Interval	Storm Depth (inches)
2-year, 24-hour	3.94
5-year, 24-hour	4.85
10-year, 24-hour	5.58
25-year, 24-hour	6.59
50-year, 24-hour	7.41
100-year, 24-hour	8.27

Table 2-3
Storm depths for selected recurrence intervals

Predicted flooding locations for the 10-yr storm with gate open were mapped and compared to flood locations identified in the City's maintenance database. A discussion of how the Heat Map was developed can be found in **Volume I, Section 2**. **Figure 2-8** shows the predicted flooding locations for the 10-yr storm event. The indicated flood locations largely echoed the frequency of tickets from the City's maintenance database, particularly in four main areas:

- The Bellevue/Lamar area east of I-240
- The Dunlap and Pauline street corridor in the mid-basin area
- Areas just east of downtown
- Areas northeast of the Pinch District.

Details of the roadways and structures affected by these flood extents are outlined in **Volume I, Section 3**. These locations were used as the basis for alternatives development that will be discussed in **Volume II, Section 3**.

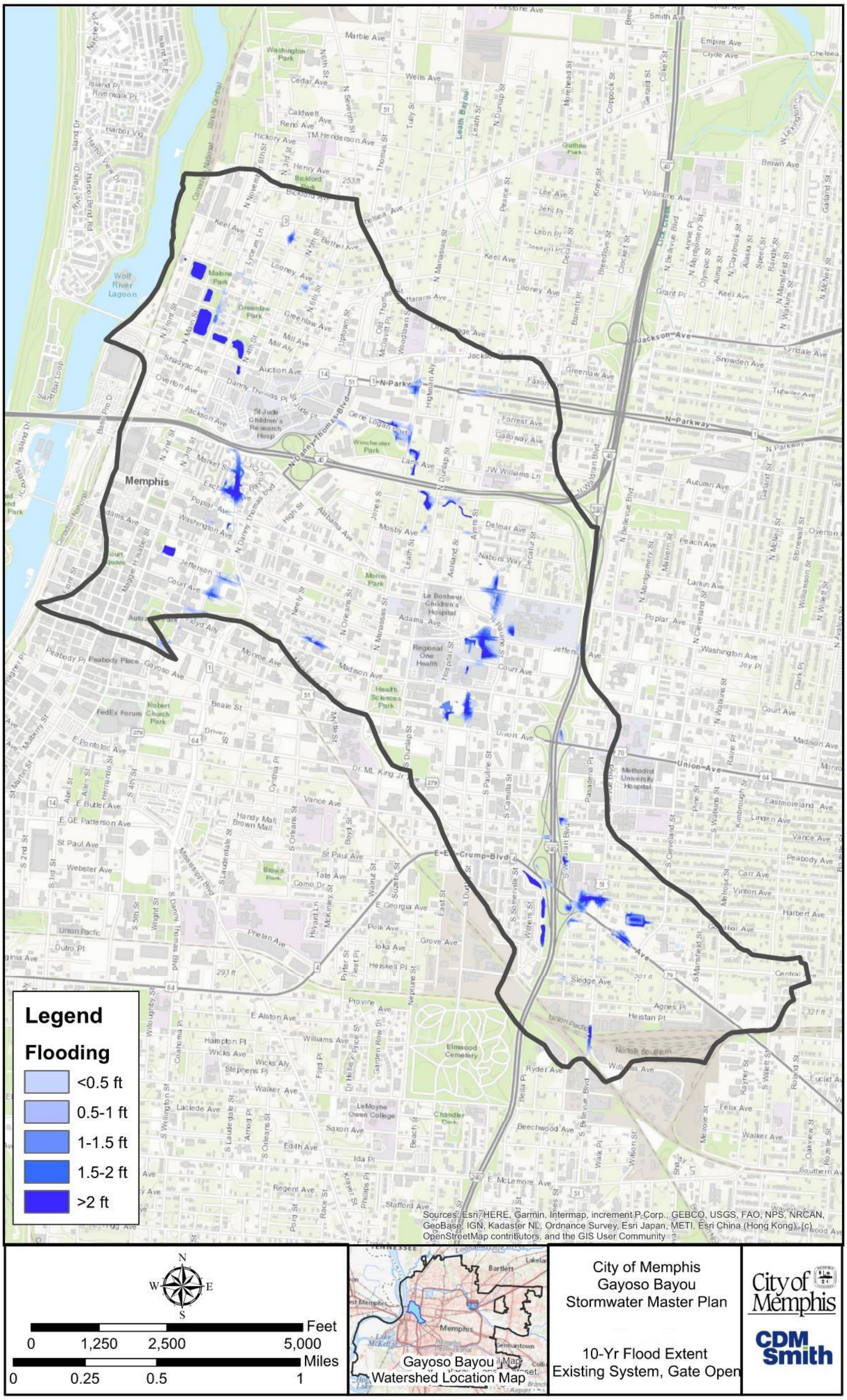

Figure 2-9
Inundation Extents for Existing Conditions, 10-yr storm

Section 3
Proposed Scenarios

Based on the modeling analyses described in **Volume II, Section 2**, fifteen alternatives are proposed to improve storm water flooding in the Gayoso Bayou watershed. These projects are organized by area but were developed to function both individually and together upon full implementation. The scenarios are described in detail in **Sections 3.2** through **Section 3.8**. They include an overview of benefits and an Engineer's estimate of conceptual construction costs. All alternatives were assessed using the 10-yr 24-hr SCS Type-II storm event. Scenarios are generally listed upstream to downstream, then by suggested implementation significance within each area. It should be noted that some project 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 alternative measures such as home buyouts, flood proofing or encouragement of property owners to purchase flood insurance. A total of 160 Finished Floor Elevations were collected for this study, though there are thousands more structures throughout the basin that were deemed unlikely to be in immediate threat of flooding. These areas were prioritized by assessing the Existing Conditions results overlain with topography and aerials.

Due to the urban nature of the basin, roads and road crossings make up hundreds of individual locations. Traditional basin studies may treat road crossings as culverts with roads atop them, of which Gayoso Bayou has very few. When discussing the improvement of "major" and "minor" road crossing depths, care was taken to assess the importance of each road within the improvement areas. Roads were considered major if they were a state route or an evacuation route, but interstates were not included as they are subject to their own drainage programs outside of the scope of this report. Minor roads were considered surface streets that would restrict access to neighborhoods or services. In a storm event as intense as the 10-yr, it is not unusual for localized ponding in gutters and curbs as the primary system accepts flow. The secondary system that serves as the interface between sheet flow and the primary system was not modeled. Thus, flood depths were assessed from the best available crown of the roadway such that vehicle passage could continue. Survey data collected during this study may also provide clues to locations where the secondary system requires maintenance and notes were provided to the City along with photographs taken by survey crews.

Four priority areas for the implementation of Green Stormwater Infrastructure (GSI) are included, though individual designs for each area were not prescribed. The intent of these GSI priority areas is to identify locations with local or infrequent drainage issues that could be served by the co-benefits of the implementation of GSI alongside the large-scale improvements recommended in this report. The GSI areas were modeled with the expectation that the first half-inch of runoff be captured and abstracted by the model. Though the first inch of capture is a commonly used value with respect to water quality permitting, from a modeling and planning standpoint, not every part of the basin can be captured and directed to GSI and retrofits throughout the extents of the basin may be unrealistic. Thus, a more conservative half-inch value was used. More discussion of potential GSI applications is included at the conclusion of this section.

Planned and known alterations to basin topography and network were added at the request of the City. Specifically, two developments around St. Jude Hospital were placed in the model to reflect future conditions.

- At the corner of N 3rd Street and Danny Thomas Place, the parcel on the southwest corner of the street is being developed and will require infill to reach a finished floor of at least 234 ft NAVD. The resulting loss of stage-storage was removed from the model at model node 688322.
- The location of the most upstream pond, bounded by A. W. Willis, N 3rd, and N 4th Streets, is planned to be enclosed into a large box culvert with a structure developed on the footprint. Preliminary plans were examined, and the resulting removal of stage-storage provided by the pond was applied to node A0106-1. The box culvert itself is a twin barrel 16.5x18.15-foot rectangular channel with two major turns. Exit losses of 0.7 were applied to account for these features.

Other model features were not modified unless they were part of the proposed improvements.

When estimating construction costs in the following sections, engineering, surveying, and permitting (E, S and P) would include civil and H&H design support, geotechnical, and other necessary engineering (e.g., structural, mechanical, electrical, et al). Surveying would include field topo and spot elevations survey (e.g., inverts, buildings, connections, conflicts, et al.) and identification of underground utilities. Projects sometimes must be re-designed for unidentified utility conflicts. Finding these during construction is generally the biggest impact to schedule and cost. A value of 15% for E, S, and P, is used, even with the City's ordinance that utility relocations in the City's right-of-way be performed at the owner's expense.

3.1 Proposed Scenario Summary

A summary of the proposed scenarios is itemized below. **Figure 3-1**, located at the end of this section, includes an overview map. Conveyance alternatives were prioritized to take place within City right-of-way to make use of an ordinance that requires utilities to pay for relocation themselves.

3.1.1 Scenario 1 – Pinch District Alternatives

Scenario 1 includes known issues of the central Gayoso Bayou watershed. This includes the critical Gayoso Bayou Pump Station and flood gate and its associated pond system.

3.1.1.1 Scenario 1A - Gate Operations and Pump Station Alternatives

Scenario 1A includes:

1. Implementation of concrete operational guidance for anticipated large storm events when the river is above action stage;

2. Additional study for feasibility, permitting, and costing of an 1,800 cfs pump station near the existing pump station.

3.1.1.2 Scenario 1B - Pinch District Conveyance Improvements

Scenario 1B includes:

1. 750 linear feet (LF) of replacement 60" pipe/culvert on 3rd Street between Overton and Shadyac;
2. 400 LF of replacement 48" pipe on 2nd Street south of Saffarans, 250 LF of 54" pipe along Greenlaw to the Gayoso Bayou ponds;
3. 200 LF of replacement 30" pipe on 4th Street north of Keel, 750 LF of 30" pipe on Keel Ave between 6th and 4th Street, 600 LFof 36" pipe on 4th Street between Keel and Saffarans.

3.1.1.3 Scenario 1C - Pinch District Storage Alternatives

Scenario 1C includes:

1. A detention basin near 4th Street and Saffarans Ave totaling 3.3 ac-ft, Potential Sites A-E.

3.1.1.4 Scenario 1C - Pinch District Green Infrastructure Alternatives

Scenario 1D includes:

1. Proposed green infrastructure implementation in the polygon generally east of N Main St, south of Keel Ave, west of 6th St, and north of Greenlaw Ave.

3.1.2 Scenario 2 – Lamar and Bellevue Area Alternatives

Scenario 2 is in the southeastern part of the Gayoso Bayou watershed. The scenario includes pipes/culverts along Bellevue Blvd, Agnes Place, Waldran Blvd, and Lamar Avenue. Two storage units are proposed, with one located at Waldran Rd and Minna Place and the other located at or near Lamar and Central Blvd for a total of 13.75 ac-ft. A priority overlay for the implementation of Green Stormwater Infrastructure (GSI) is also included.

3.1.2.1 Scenario 2A - Lamar and Bellevue Conveyance Alternatives

Scenario 2A includes:

1. 2,800 LF of 48" pipe along S Bellevue Blvd, Agnes Place, and Waldran Blvd to replace existing lines;
2. 850 LF of new 36" pipe along S Bellevue Blvd;
3. 1,100 LF of new 24" pipe along Lamar Ave;
4. 800 LF of relief 5x7' box culvert along Bellevue Blvd and Harbert Ave.

3.1.2.2 Scenario 2B - Lamar and Bellevue Storage Alternatives

Scenario 2B includes:

1. A detention basin at Waldran Blvd and Minna Place totaling 6.25 ac-ft, Potential Sites A-G;
2. A detention basin near Central Ave and Lamar Ave totaling 9 ac-ft, Potential Sites H-J.

3.1.2.3 Scenario 2C - Lamar and Bellevue Green Infrastructure Alternatives

Scenario 2C includes:

1. Proposed green infrastructure implementation in the polygon generally east of Waldran Blvd, south of Central Ave, west of Willett St, and north of Agnes Place.

3.1.3 Scenario 3 – Dunlap Street Corridor Alternatives

Scenario 3 is in the east-central part of the Gayoso Bayou watershed and is bisected by I-40. The scenario includes pipes and culverts in several locations. Three storage units are recommended for a total storage volume of 26.5 acre-feet.

3.1.3.1 Scenario 3A - Dunlap Street Corridor Conveyance Alternatives

Scenario 3A includes:

1. 950 LF of new 30” pipe along Ayers St from Poplar to Mosby;
2. 1,150 LF of relief 7x8’ box culvert following the existing Pauline St culvert between Poplar and Mosby;
3. 1,150 LF of new and relief 4x5’ box culvert between N Parkway and Gene Logan Blvd;
4. 700 LF of replacement 6x10’ box culvert between Adams and Pauline St.

3.1.3.2 Scenario 3B - Dunlap Street Corridor Storage Alternatives

Scenario 3B includes:

1. A detention basin near Dunlap St and N Parkway totaling 1 ac-ft, Potential Sites F-AO;
2. A detention basin at Mosby Ave and Ashland St totaling 8.5 ac-ft, Potential Sites AP, AO;
3. A detention basin near Poplar and Pauline St totaling 8.5 ac-ft, Potential Sites AR-AS;
4. A detention basin south of Dunlap St and I-40 totaling 8.5 ac-ft, site not proposed.

3.1.3.3 Scenario 3C - Dunlap Street Corridor Green Infrastructure Alternatives

Scenario 3C includes:

1. Proposed green infrastructure implementation in the polygon generally east of Manassas St, south of N Parkway, west of Decatur St, and north of Poplar Ave.

3.1.4 Scenario 4 – Tanyard Bayou / Medical District Alternatives

Scenario 4 is in the west-central part of the Gayoso Bayou watershed. The scenario includes pipe improvements along Avant Lane near the Edison Apartments and along Jefferson Ave between B.B. King and Danny Thomas. Storage totaling 3 acre-feet is included near Orleans St and Madison Ave.

3.1.4.1 Scenario 4A - Tanyard Bayou / Medical District Alternatives

Scenario 4A includes:

1. 300 LF of replacement 42” pipe and 400 LF of 60” pipe through the Edison Apartments;

3.1.4.2 Scenario 4B - Tanyard Bayou / Medical District Alternatives

Scenario 4B includes:

1. A detention basin near Orleans St and Madison Ave totaling 3 ac-ft, Potential Sites A-F.

3.1.4.3 Scenario 4C - Tanyard Bayou / Medical District Infrastructure Alternatives

Scenario 4C includes:

1. Proposed green infrastructure implementation within the polygon generally east of Neely St, north of Marshall Ave, west of Dunlap St, and south of Adams Ave.

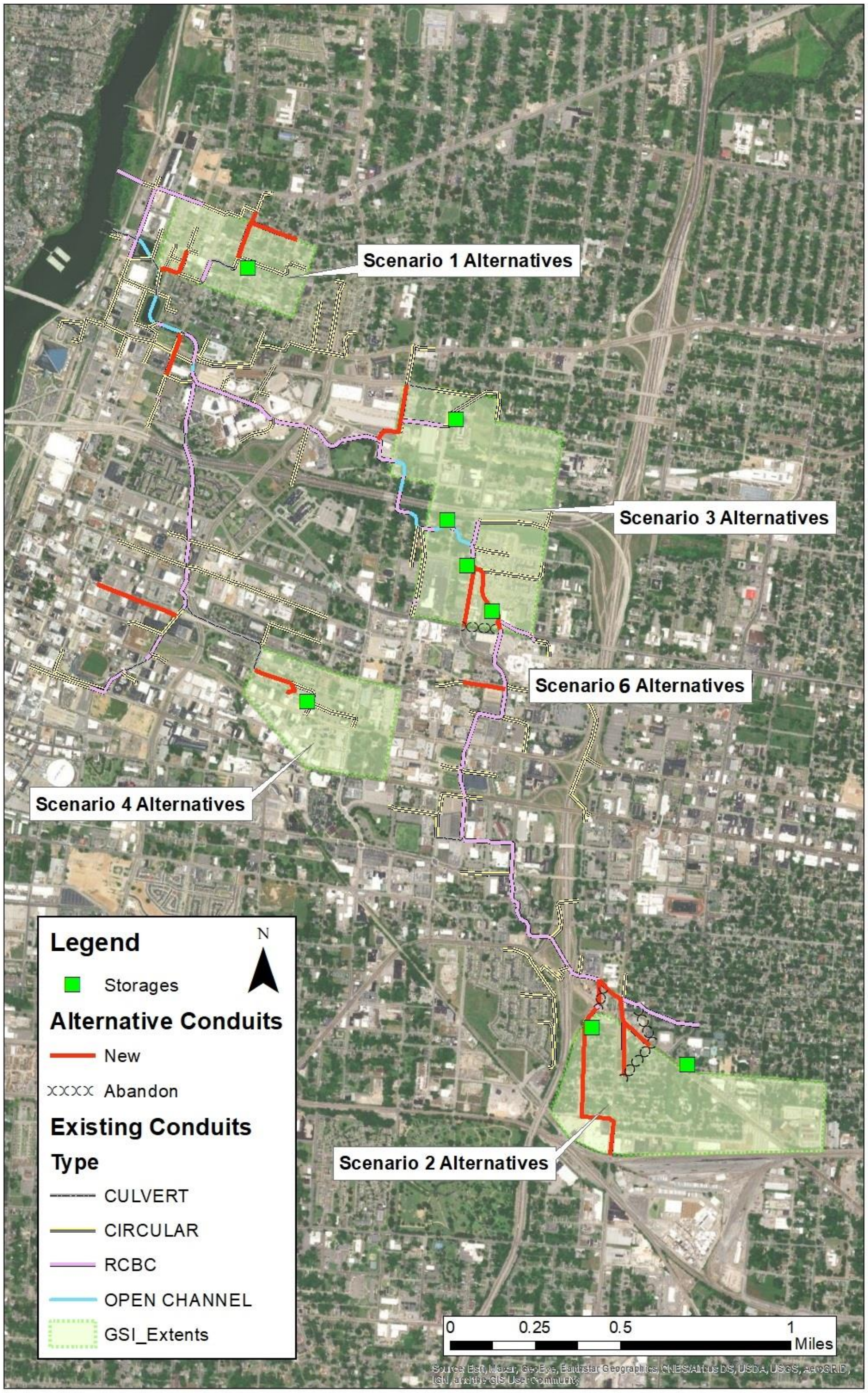

Figure 3-1
Alternatives Overview

3.2 Scenario 1 – Pinch District Alternatives

This scenario takes place in and around the most downstream extents of Gayoso Bayou, generally referred to as the Pinch District. **Figure 3-2** provides an overview of the alternatives proposed in this area.

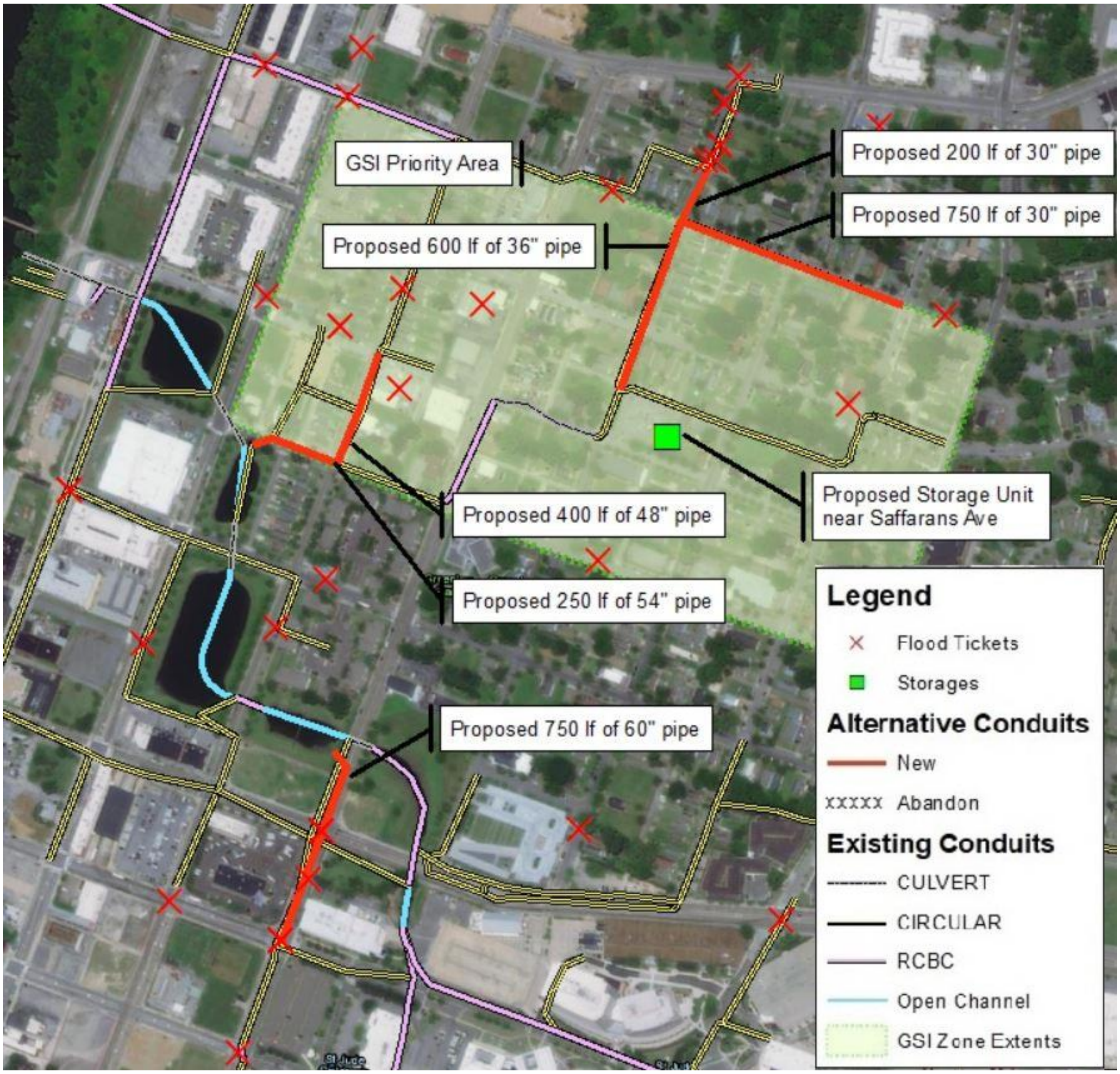

Figure 3-2
Scenario 1 – Pinch District Alternatives Overview

3.2.1 Scenario 1A – Gate Operations and Pump Station Alternatives

3.2.1.1 Description

Flood depths in the lower extents of Gayoso Bayou are heavily dependent on the operations of the Pump Station and Flood gate west of Front Street. When the river is above 26 feet, or 210 feet

NAVD, the flood gate closes to prevent backflow from the Mississippi River. This hinders drainage from within the basin and the adjacent pump station must be engaged to direct storm flow over the levee and out of the basin. The pump station's current capacity is roughly 900 cfs when all pumps are operating. The 10-yr SCS Type II storm's peak flow into the inlet of the pump station is 3,070 cfs, far above station capacity. Any alternatives developed with a closed-gate condition would first need to address the gap between the station's capacity and the peak flow. A pump station providing an additional 2,000 cfs would likely require extensive permitting, design, and construction costs, and is not recommended due to the reduced likelihood that a storm would occur with a closed gate condition.

Modeling was performed on a draft basis to assess at what point gate operations could be amended to remain open prior to a wet weather event. Tests with river levels up to 215 ft NAVD showed no significant increases in the model with alternatives applied, but with tailwater above that point, alternatives in the Pinch District would not be as effective and backflow from the river would threaten Finished Floor Elevations in the area. Further study with the alternatives model and tailwater conditions is recommended to understand the potential for optimization of gate operations.

3.2.1.2 Engineer's Estimate of Conceptual Construction Costs

An Engineer's estimate of conceptual construction costs was not developed for this alternative. Additional studies and collaboration with stakeholders should occur to ensure that the frequency of risk is established and feasibility is assessed.

3.2.2 Scenario 1B – Pinch District Conveyance Alternatives

3.2.2.1 Description

The first proposed improvement is the replacement of the abandoned 54" pipe with a new 60" interceptor beginning at the intersection of Shadyac and 3rd. Based on survey reports from the area, inlets will need replacement and new tie-ins placed to the newly constructed interceptor. 750 LF of 60" pipe should be laid at or near 0.2% slope north to the 4th pond in the system, which will be the final pond in the system after the planned construction of a parking garage and box culvert at the site of the 5th pond. A mitered end section and baffles should be placed at the terminus of the line to deliver 10-yr design storm flow without scouring.

The second proposed improvement is the replacement of 400 LF (linear feet) of 36"and 250 LF of 48" pipes 42" and 54" pipes, respectively. The improvement begins at Saffarans Avenue and Lyceum Lane, continuing south to Greenlaw Avenue, taking a western turn along Greenlaw before emptying into the second pond of the Gayoso system. Existing slopes should be maintained. A mitered end section and baffles should be placed at the terminus of the line to deliver 10-yr design storm flow without scouring.

The third proposed improvement consists of 200 LF of new 30" pipe on N 4th Street to connect the northern 24" to the newly upsized pipe to the south. The invert of this pipe should be high enough to accept wet weather flow, but the primary drainage source for this location should remain the 24" to the west. The new pipe will tie into 600 LF of 36" pipe that will replace the existing 18” and 24”. Additionally, 950 LF of 18” pipe to the east along Keel Street should be replaced with 30” RCP.

3.2.2.2 Engineer’s Estimate of Conceptual Construction Costs

The Engineer’s estimate of total conceptual construction costs is **$2,250,000**. Proposed segment costs are itemized in **Table 3-1**.

Table 3-1 Scenario 1B Engineer's Estimate of Conceptual Construction Costs

Segment	Cost
3rd and Shadyac – 750 LF of 60” RCP,	$460,000
2nd and Greenlaw – 400 LF of 48” RCP, 250lf of 54” RCP	$425,000
4th and Keel – 950lf of 30” RCP, 600lf of 36” RCP	$550,000
Scenario Subtotal	$1,435,000
Subtotal with Contingency (30%)	$1,865,000
with Contractor Overhead & Profit (12%)	$2,040,000
Engineering, Survey, & Permitting (15%)	$2,250,000
TOTAL COST	**$2,250,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes stormwater infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.2.3 Scenario 1C – Pinch District Storage Alternatives

3.2.3.1 Description

Storage volume was added to the model near 4th and Saffarans, with approximately 3.33 ac-ft added at a minimum elevation of 225 ft NAVD. Parcels in this area that are advantageous for potential storage are called out in red in **Figure 3-3**.

Storage at this location could be either an open-air detention/retention pond or subterranean storage depending on parcel selection and stakeholder input. Subterranean storage has been provided as a separate construction cost in addition to the cut and fill required for surface storage.

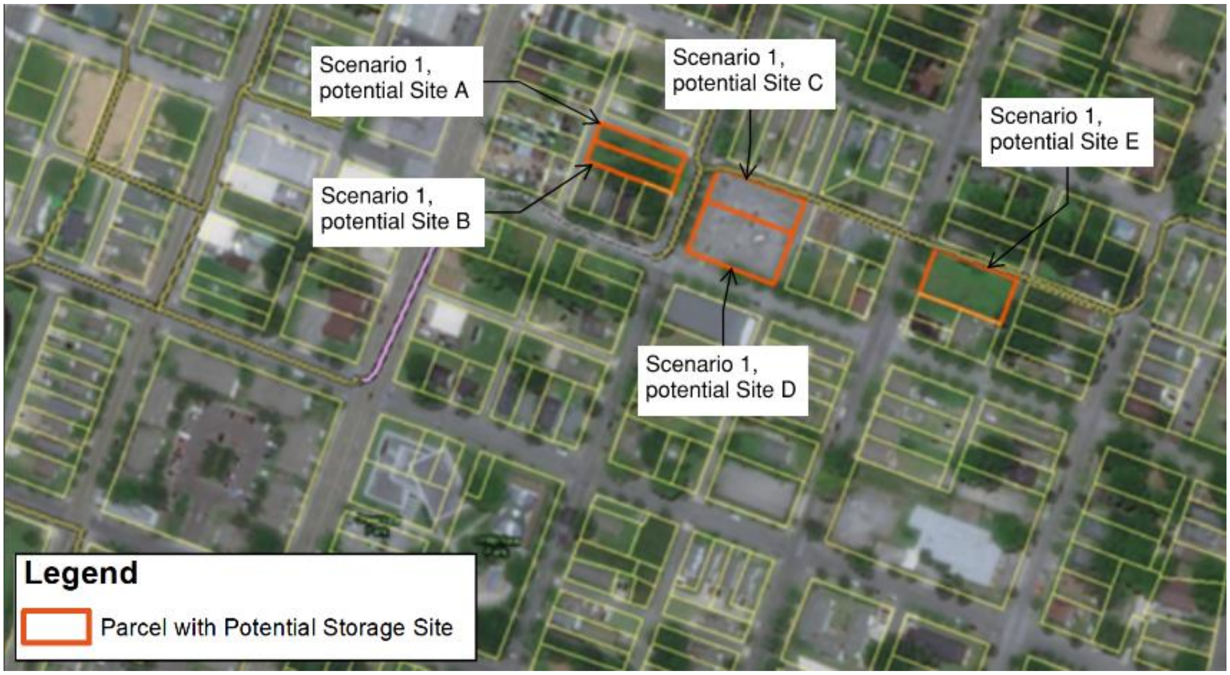

Figure 3-3
Scenario 1 – Pinch District Parcel Suggestions

3.2.3.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$2,195,000**. Proposed segment costs are itemized in **Table 3-2**. As with all storage alternatives included in this study, several assumptions are noted, but most notably the cost of property is not included. Values are per unit for the mobilization, subterranean structure, earthwork, and disposal of cut material only. Construction outside of City ROW may also incur utility relocation costs.

Table 3-2 Scenario 1C Engineer's Estimate of Probable Construction Costs

Segment	Cost
Saffarans – 5,400 cubic yards of cut and haul @ $46 per cy	$248,000
Cast-in-place Subterranean Concrete Structure with backfill	$1,150,000
Scenario Subtotal	$1,398,000
Subtotal with Contingency (30%)	$1,818,000
with Contractor Overhead & Profit (12%)	$1,985,000
Engineering, Survey, & Permitting (15%)	$2,195,000
TOTAL COST	**$2,195,000**

Assumptions:
1. Costs in 2021 dollars.
2. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.2.4 Scenario 1 – Pinch District Alternatives Benefits

Under existing conditions, one major road and three minor roadways are predicted to flood as shown in **Table 3-3**. However, with the proposed improvements, flooding is predicted to be eliminated at all major road crossings and to be improved at two minor road crossings for the 10-year gate-open design storm event. Based on collected finished floor elevations in the area, three structures are predicted to be protected from inundation within the improvement area, while another 65 structures are predicted to have their flood peak HGLs reduced in the vicinity of the improvements. The following is a summary of these benefits:

1. Major road protected from inundation: 1,250 LF
2. Minor road protected from inundation: 800 LF
3. Structures protected in improvement area: 3
4. Structures seeing improvements in other areas: 0

Table 3-3 Scenario 1 Existing and Proposed Maximum HGLs

Node ID	Existing Max HGL (ft)	Critical Address	Critical Elevation1 (ft)	Proposed		
				Max HGL (ft)	**Change (ft)**	**Below Critical Elevation (ft)**
837109	226.87	210 N 4th St	226.22	225.49	-1.38	-0.73
645698[2]	223.29	534 N 2nd St	223.34	218.71	-4.58	-4.63

1. For Structures, from FFE Survey; for major roads, estimated from DEM.
2. Location within one inch of flooding, thus was included to demonstrate benefits.

There are no increases in Max HGL elevation and all proposed HGL elevations are below critical FFEs. A peak flood stage map of the 10-year open-gate design storm for Proposed Scenario 1 is included in **Figure 3-4** at the end of this section. **Table 3-4** displays the improvements between pre- and post-alternative flows and levels at two critical points in the system along Greenlaw Avenue.

Table 3-4 Pre- and Post-Alternatives Flows and Levels Downstream of Improvements

Location	Max Level (feet)		Max Flow (cfs)	
	Existing	**Proposed**	**Existing**	**Proposed**
Greenlaw and 3rd	10.31	9.44	93.9	72.2
Greenlaw and 2nd*	9.18	3.11	69.8	185.4

*An increase in flow at this point is intentional, as it discharges to the outfall ponds and reduces flood levels.

3.2.5 Scenario 1 – Pinch District Alternatives Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$4,450,000**. Proposed segment costs are itemized in **Table 3-5**.

Table 3-5 Scenario 1 Engineer's Estimate of Conceptual Construction Costs

Segment	Cost
3rd and Shadyac – 750 LF of 60" RCP	$460,000
2nd and Greenlaw – 400 LF of 48"RCP , 250 LF of 54" RCP	$425,000
4th and Keel – 950 LF of 30" RCP, 600 LF of 36" RCP	$550,000
Saffarans – 5,400 cubic yards of cut and haul @ $46 per cy	$248,000
Cast-in-place Subterranean Concrete Structure with backfill	$1,150,000
Scenario Subtotal	$2,833,000
Subtotal with Contingency (30%)	$3,683,000
with Contractor Overhead & Profit (12%)	$4,023,000
Engineering, Survey, & Permitting (15%)	$4,450,000
TOTAL COST	**$4,450,000**

Assumptions:

1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

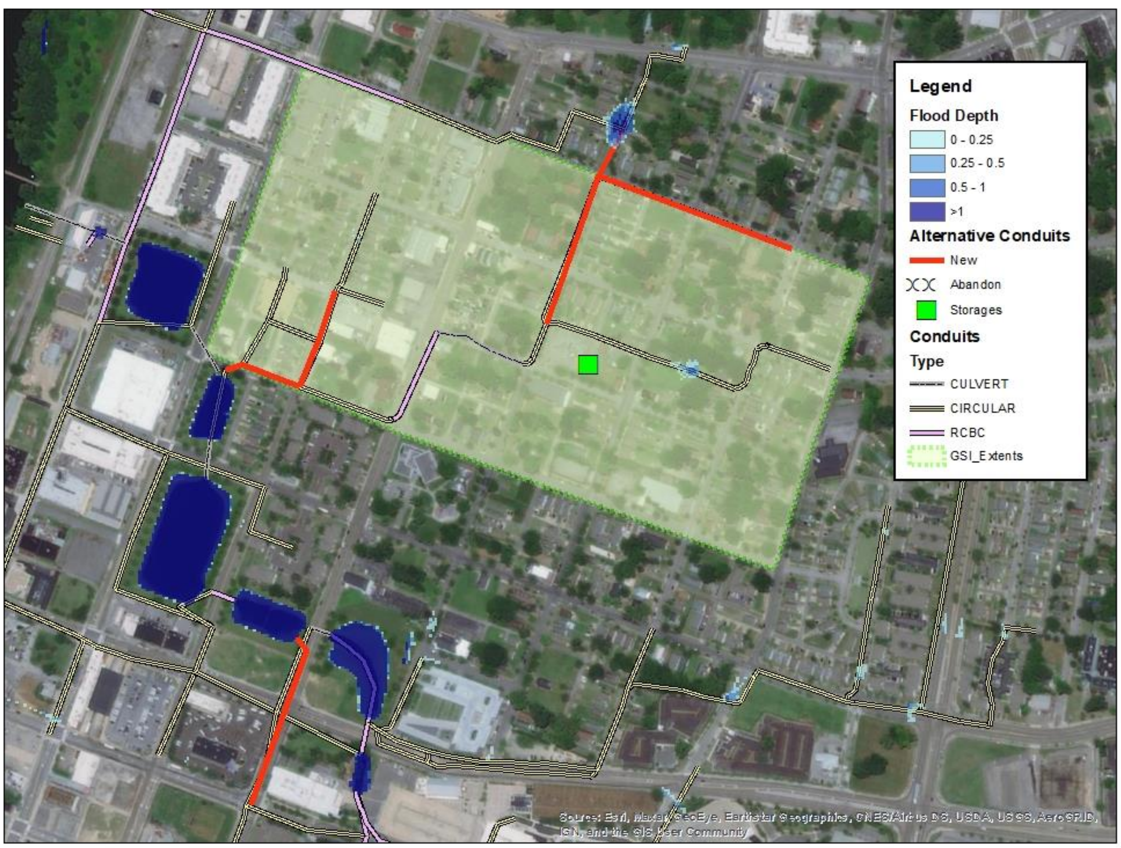

Figure 3-4
Flood Depths in Pinch District with Alternatives Applied

CDM Smith

3.3 Scenario 2 – Lamar and Bellevue Area Alternatives

Scenario 2 is in the southeast, and most upstream part of the watershed. Like other areas, the combination of conveyance improvements and detention ponds produces HGL reductions downstream and reduces flooding in roadways and neighborhoods. The scenario begins at the at the underpass of the Norfolk Southern railroad and S Bellevue Blvd. This scenario includes conveyance improvements, additional storage, and green infrastructure improvements that provide the best benefits when applied together. An overview of all the improvements under this alternative can be viewed in **Figure 3-6**.

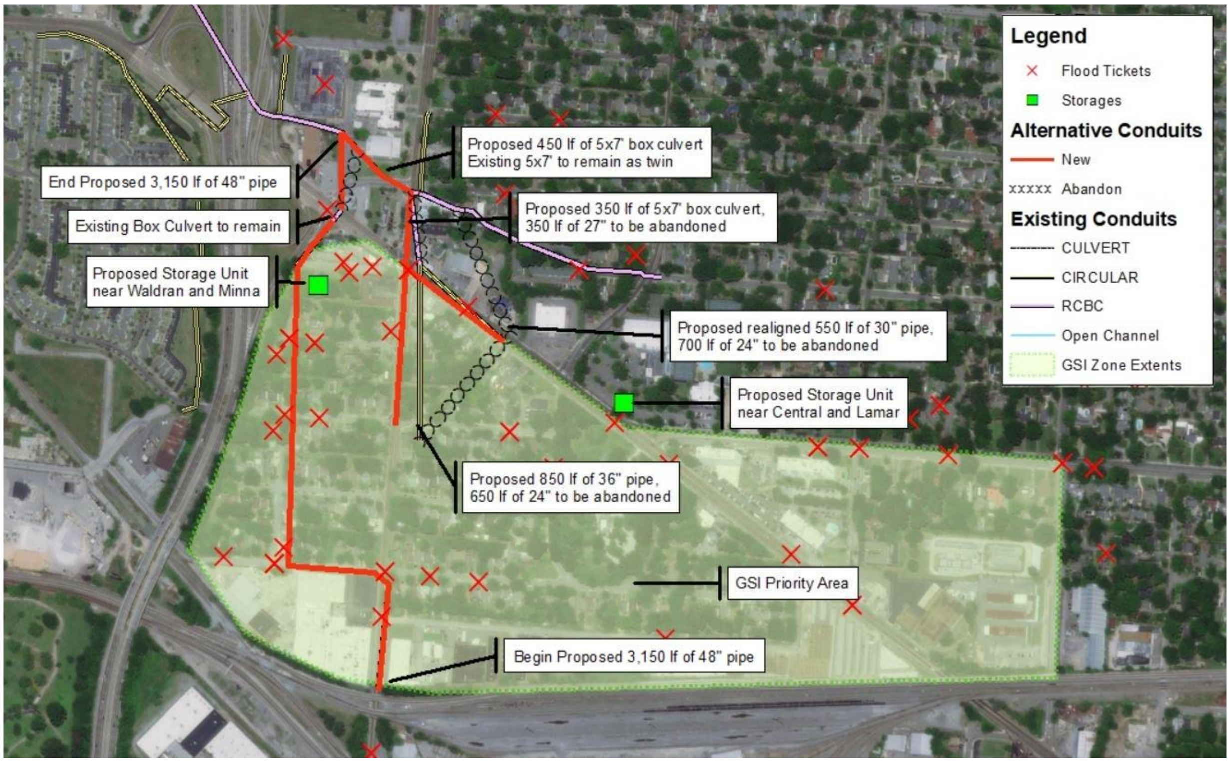

Figure 3-5
Scenario 2 – Lamar and Bellevue Area Alternatives Overview

3.3.1 Scenario 2A – Lamar and Bellevue Conveyance Alternatives

3.3.1.1 Description

The first proposed conveyance improvement begins on Bellevue Blvd at the railroad underpass to the south. The existing 2,800 LF of 24" pipe should be replaced with 48" RCP. This improvement includes pipes on Agnes Place and Waldran Blvd. At the intersection of Waldran and Lamar Avenue, the existing box culvert under the road should remain intact, and the new 48" pipe should connect the existing box culvert with the primary 5x7' box culvert near Bellevue Junior High School.

The second proposed conveyance improvement recommends abandoning the existing 24" pipe between Central Avenue and Lamar. The existing inlets upstream of this pipe should be the beginning for 850 LF of a new 36" pipe that will proceed north along Bellevue where, when it encounters the existing 27", replaces that pipe and ties into the existing 5x7' RCBC. At that point, a second, new 5x7’ RCBC parallel to the existing pipe should be placed for 800 LF until the tie in with the first proposed interceptor.

3.3.1.2 Engineer’s Estimate of Conceptual Construction Costs

The Engineer’s estimate of conceptual construction costs is **$4,780,000**. Proposed segment costs are itemized in **Table 3-6**. Abandonment costs were not estimated, as the City may prefer methods of varying complexity to abandon the existing pipes, or to leave them in operation.

Table 3-6 Scenario 2A Engineer's Estimate of Probable Construction Costs

Segment	Cost
Waldran – 3,150 LF of 48” RCP	$1,370,000
Lamar – 550 LF of 30” RCP	$240,000
Central and Lamar – 850lf of 36” RCP, 450lf of 5x7’ RCBC	$1,440,000
Scenario Subtotal	$3,050,000
Subtotal with Contingency (30%)	$3,965,000
with Contractor Overhead & Profit (12%)	$4,330,000
Engineering, Survey, & Permitting (15%)	$4,780,000
TOTAL COST	**$4,780,000**

Assumptions:

1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.3.2 Scenario 2B – Lamar and Bellevue Storage Alternatives

3.3.2.1 Description

Additional storage volume was added to the model with approximately 6.25 ac-ft added between elevations along Waldran Ave with a minimum elevation of 274’ NAVD. There are vacant parcels in the area that could be used as potential storage, as shown in **Table 3-6**.

Storage volume was also added to the model near Bellevue and Central, with approximately 9 ac-ft added. Parcels in this area available for potential storage are scarcer, however, though select locations are called out in red in **Figure 3-6**.

The storage volume along Waldran Ave would likely be an open-air retention/detention pond, while the Central location may require subterranean chambers as those produced by Stormtech and/or distribution of volume across multiple sites.

Figure 3-6
Scenario 2 – Bellevue and Lamar Parcel Suggestions

3.3.2.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$5,100,000**. Proposed segment costs are itemized in **Table 3-7**.

Table 3-7 Scenario 2B Engineer's Estimate of Probable Construction Costs

Segment	Cost
14,500 cubic yards of cut and haul @ $46 per cy	$667,000
10,000 cubic yards of cut and haul @ $46 per cy	$460,000
Cast-in-place Subterranean Concrete Structure with backfill	$2,120,000
Scenario Subtotal	$3,247,000
Subtotal with Contingency (30%)	$4,220,000
with Contractor Overhead & Profit (12%)	$4,610,000
Engineering, Survey, & Permitting (15%)	$5,100,000
TOTAL COST	**$5,100,000**

Assumptions:

1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.3.3 Scenario 2 – Lamar and Bellevue Area Alternatives Benefits

The improvement area for Scenario 2 contains drainage crossings of three major roads and three minor roads. Under existing conditions these crossings are predicted to flood. However, with the proposed improvements, flooding is predicted to be eliminated at one major and three minor road crossings, and to be improved at two major road crossings for the 10-year design storm event. Utilizing surveyed finished floor elevations of structures, 4 structures are predicted to be protected from inundation within the improvement areas, as shown in **Table 3-8**.

1. Major road protected from inundation: 2,450 LF
2. Minor road protected from inundation: 850 LF
3. Structures protected in improvement area: 4
4. Structures seeing improvements in other areas: 0

Table 3-8 Scenario 2 Existing and Proposed Maximum HGLs

Node ID	Existing Max HGL (ft)	Critical Address	Critical Elevation1 (ft)	Proposed		
				Max HGL (ft)	**Change (ft)**	**Below Critical Elevation(ft)**
857109	276.0	620 S Bellevue	274.35	273.59	-2.51	-0.76
664884	278.72	1301 Goodbar	277.49	274.82	-3.93	-2.67
664884	278.72	1300 Goodbar	277.57	274.82	-3.9	-2.75
665791	276.0	1192 Lamar	275.29	274.26	-1.74	-1.03

1. For Structures, from FFE Survey; for major roads, estimated from DEM.

There are no increases in Max HGL elevation and all proposed HGL elevations are below critical FFEs. A peak flood stage map of the 10-year design storm for Proposed Scenario 2 is included in **Figure 3-7** at the end of this section. **Table 3-9** displays the improvements between pre- and post-alternative flows and levels at one critical points in the system where the primary box culvert that drains the area passes under I-240.

Table 3-9 Pre- and Post-Alternatives Flows and Levels Downstream of Improvements

Location	Max Level (feet)		Max Flow (cfs)	
	Existing	**Proposed**	**Existing**	**Proposed**
I-240 and Lamar	11.36	11.32	466.8	461.7

3.3.4 Scenario 2 – Lamar and Bellevue Area Alternatives Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$9,890,000**. Proposed segment costs are itemized in **Table 3-10**.

Table 3-10 Scenario 2 Engineer's Estimate of Probable Construction Costs

Segment	Cost
Waldran – 3,150 LF of 48” RCP	$1,370,000
Lamar – 550 LF of 30” RCP	$240,000
Central and Lamar – 850 LF of 36” RCP, 450 LF of 5x7’ RCBC	$1,440,000
14,500 cubic yards of cut and haul @ $46 per cy	$667,000
10,000 cubic yards of cut and haul @ $46 per cy	$460,000
Cast-in-place Subterranean Concrete Structure with backfill	$2,120,000
Scenario Subtotal	$6,297,000
Subtotal with Contingency (30%)	$8,186,000
with Contractor Overhead & Profit (12%)	$8,940,000
Engineering, Survey, & Permitting (15%)	$9,890,000
TOTAL COST	**$9,890,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

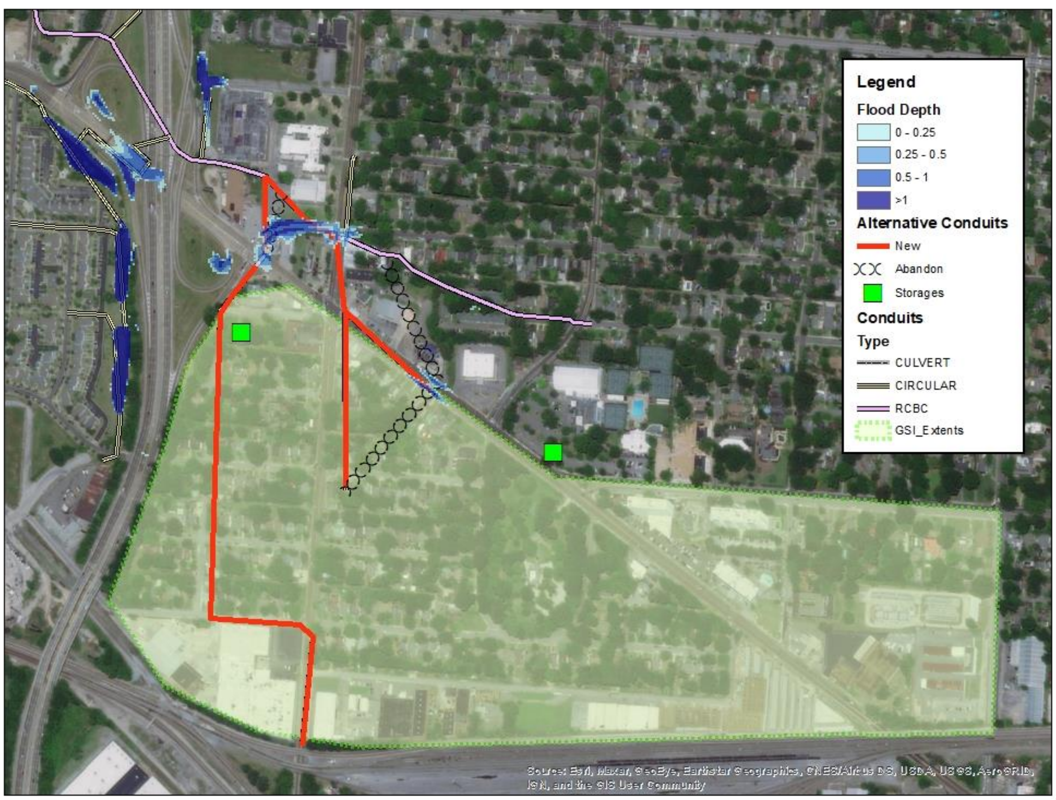

Figure 3-7
Flood Depths in Bellevue Area with Alternatives Applied

3.4 Scenario 3 – Dunlap Street Corridor Alternatives

Scenario 3 is in the eastern center of the watershed and covers a relatively large extent of the eastern interceptor from Poplar Street through Winchester Park. This scenario includes conveyance improvements, additional storage, and a recommended green infrastructure priority area. An overview of all the improvements under this alternative can be viewed in **Figure 3-8**.

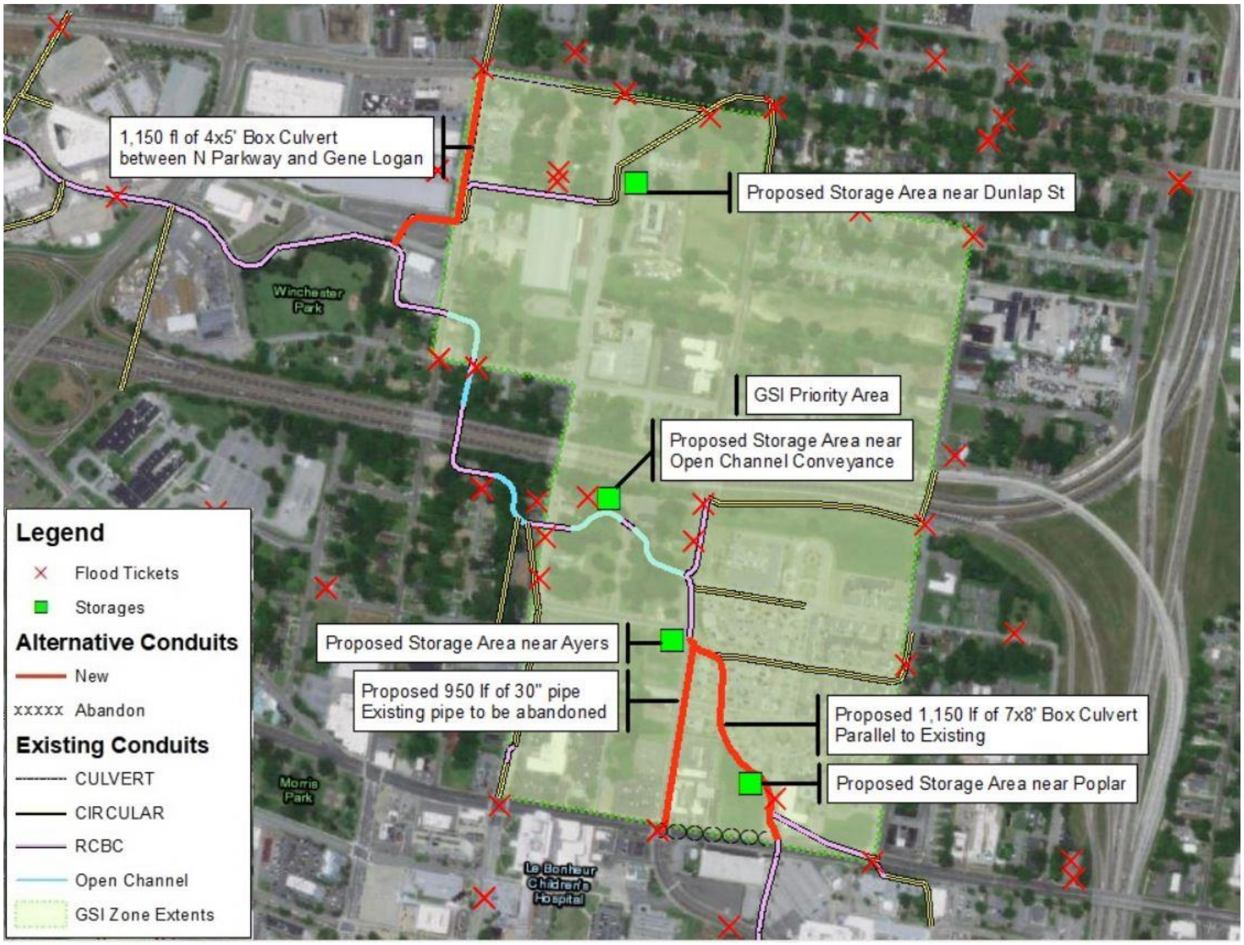

Figure 3-8
Scenario 3 – Dunlap Street Corridor Alternatives Overview

3.4.1 Scenario 3A – Dunlap Street Corridor Conveyance Alternatives

3.4.1.1 Description

The first proposed conveyance alternative begins at the intersection of N Manassas Street and North Parkway. The existing 3x5' box culvert should be replaced with 750 LF of a 4x5' box culvert. At the point where the box culvert meets the existing 5x5' box culvert, a new 4x5' should be constructed in parallel for 400 LF until the interceptor ties in with the primary box culvert. Existing slopes should be maintained.

The second proposed conveyance alternative begins at the intersection of Poplar Avenue and N Pauline Street. A new relief 7x8' box culvert should be constructed parallel to the existing pipe for 1,150 LF, using as near the original slope as possible.

The third proposed conveyance alternative begins at the intersection of Poplar and Ayers Street. The current 24" pipe that is oriented East-West should be abandoned and a new 950 LF of 30" RCP should be laid north along Ayers Street and tied into the existing interceptor at the corner of Pauline Street, the same location of a proposed storage area.

3.4.1.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$5,060,000**. Proposed segment costs are itemized in **Table 3-11**.

Table 3-11 Scenario 3A Engineer's Estimate of Probable Construction Costs

Segment	Cost
Manassas – 1,150 LF of 4x5' RCBC	$1,200,000
Pauline – 1,150 LF of 7x8' RCBC	$1,700,000
Ayers – 950 LF of 30" RCP	$320,000
Scenario Subtotal	$3,220,000
Subtotal with Contingency (30%)	$4,190,000
with Contractor Overhead & Profit (12%)	$4,580,000
Engineering, Survey, & Permitting (15%)	$5,060,000
TOTAL COST	**$5,060,000**

Assumptions:

1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.4.2 Scenario 3B – Dunlap Street Corridor Storage Alternatives

3.4.2.1 Description

Three storage alternatives are proposed in this scenario.

The first storage volume was added to the model near N Dunlap St and North Parkway. Approximately 1 ac-ft was added with a minimum elevation of 225 ft NAVD (sites A-F).

The second storage volume was added to the model south of I-40 between Dunlap Street and Ayers Street. Approximately 8.5 ac-ft was added with a minimum elevation of 225 ft NAVD (site AP).

The third storage volume was added to the model near Mosby Avenue and Ayers Street. Approximately 8.5 ac-ft was added with a minimum elevation of 227 ft NAVD (sites AQ-AS).

The final storage volume was added to the model near Poplar and Pauline Street. Approximately 8.5 ac-ft was added, with a minimum elevation of 230 ft NAVD (sites AQ-AS).

All the above storage units are anticipated to be open air detention/retention ponds. For each of these storage alternatives, there are advantageous parcels available nearby. They are highlighted in red as shown in **Figure 3-9**.

Figure 3-9
Scenario 3 – Dunlap Street Corridor Parcel Suggestions

3.4.2.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$3,080,000**. Proposed segment costs are itemized in **Table 3-12**.

Table 3-12 Scenario 3B Engineer's Estimate of Probable Construction Costs

Segment	Cost
Dunlap St. North – 1,600 cubic yards of cut and haul @ $46 per cy	$74,000
Dunlap St. South – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Ayers St. – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Poplar Ave – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Scenario Subtotal	$1,964,000
Subtotal with Contingency (30%)	$2,553,000
with Contractor Overhead & Profit (12%)	$2,789,000
Engineering, Survey, & Permitting (15%)	$3,080,000
TOTAL COST	**$3,080,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes stormwater infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.4.3 Scenario 3 – Dunlap Street Corridor Alternatives Benefits

The improvement area for Scenario 3 contains drainage crossings of two major roads and five minor roads. Under existing conditions these crossings are predicted to flood. However, with the proposed improvements, flooding is predicted to be eliminated at one major road crossing and five minor road crossings, and to be improved at one other major road crossing for the 10-year design storm event. Utilizing surveyed finished floor elevations of structures, 4 structures are predicted to be protected from inundation within the improvement areas as shown in **Table 3-13**.

1. Major road protected from inundation: 1,300 LF
2. Minor road protected from inundation: 4,150 LF
3. Structures protected in improvement area: 4
4. Structures seeing improvements in other areas: 0

Table 3-13 Scenario 2 Existing and Proposed Maximum HGLs

Node ID	Existing Max HGL (ft)	Critical Address	Critical Elevation1 (ft)	Proposed		
				Max HGL (ft)	**Change (ft)**	**Below Critical Elevation (ft)**
884232	232.22	435 N Manassas	231.34	230.67	-1.55	-0.67
844609	235.61	319 Dunlap	235.25	234.09	-1.52	-1.16
844609	235.61	331 Dunlap	235.42	234.09	-1.52	-1.33
844609	235.61	315 Dunlap	235.44	234.09	-1.52	-1.35

1. For Structures, from FFE Survey; for major roads, estimated from DEM.

A peak flood stage map of the 10-year design storm for Proposed Scenario 3 is included in **Figure 3-10** at the end of this section. **Table 3-14** displays the improvements between pre- and post-alternative flows and levels at one critical points in the system where the primary box culvert that drains the area passes under Dunlap Street just south of I-40.

Table 3-14 Pre- and Post-Alternatives Flows and Levels Downstream of Improvements

Location	Max Level (feet)		Max Flow (cfs)	
	Existing	Proposed	Existing	Proposed
I-240 and Lamar	11.36	11.32	466.8	461.7

3.4.4 Scenario 3 – Dunlap Street Corridor Alternatives Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$8,140,000**. Proposed segment costs are itemized in **Figure 3-15**.

Table 3-15 Scenario 3 Engineer's Estimate of Probable Construction Costs

Segment	Cost
Manassas – 1150 LF of 4x5' RCBC	$1,200,000
Pauline – 1,150 LF of 7x8' RCBC	$1,700,000
Ayers – 950 LF of 30" RCP	$320,000
Dunlap St. North – 1,600 cubic yards of cut and haul @ $46 per cy	$74,000
Dunlap St. South – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Ayers St. – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Poplar Ave – 13,700 cubic yards of cut and haul @ $46 per cy	$630,000
Scenario Subtotal	$5,184,000
Subtotal with Contingency (30%)	$6,740,000
with Contractor Overhead & Profit (12%)	$7,360,000
Engineering, Survey, & Permitting (15%)	$8,140,000
TOTAL COST	**$8,140,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

Figure 3-10
Flood Depths in Dunlap Area with Alternatives Applied

3.5 Scenario 4 – Tanyard Bayou / Medical District Alternatives

Scenario 4 is in the southern central portion of the basin, between Health Sciences Park and the Gayoso Bayou box culvert under Jefferson St and Danny Thomas. This scenario includes conveyance improvements, additional storage, and a green infrastructure priority area. An overview of all the improvements under this alternative is shown in **Figure 3-11**.

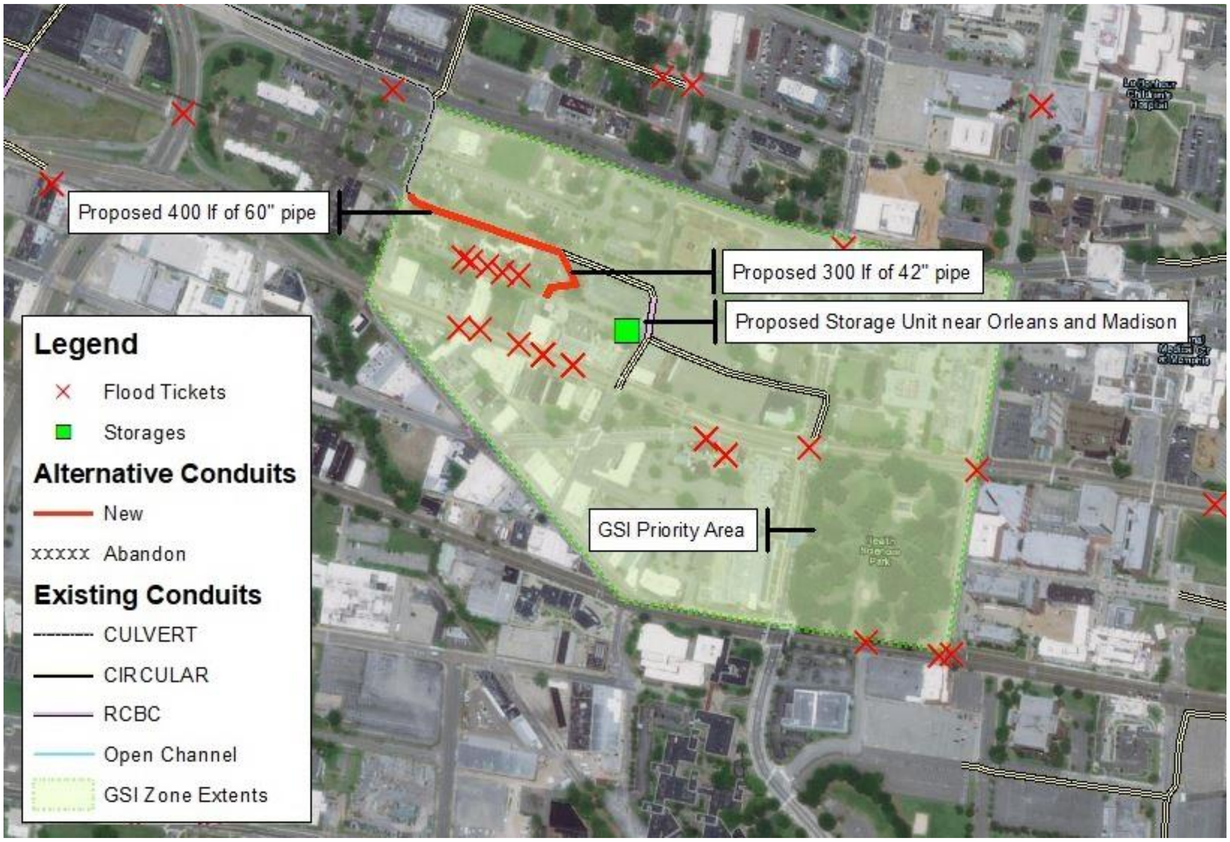

Figure 3-11
Scenario 4 – Tanyard Bayou / Medical District Alternatives Overview

3.5.1 Scenario 4A – Tanyard Bayou / Medical District Conveyance Alternatives

3.5.1.1 Description

There is one conveyance improvement recommended in this scenario. It begins in the courtyard of the Edison apartments between Avant Lane and Jefferson Avenue. The existing 18" pipe should be replaced with 300 LF of 42" RCP. Where this replacement interceptor meets the 3.1x5' elliptical pipe, a replacement 400 LF of 60" RCP should be installed at the same slope.

3.5.1.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$597,000**. Proposed segment costs are itemized in **Figure 3-16**.

Table 3-16 Scenario 4A Engineer's Estimate of Probable Construction Costs

Segment	Cost
Avant Lane – 300 LF of 42" RCP, 400 LF of 60" RCP	$380,000
Scenario Subtotal	$380,000
Subtotal with Contingency (30%)	$494,000
with Contractor Overhead & Profit (12%)	$540,000
Engineering, Survey, & Permitting (15%)	$597,000
TOTAL COST	**$597,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.5.2 Scenario 4B – Tanyard Bayou / Medical District Storage Alternatives

3.5.2.1 Description

Additional storage volume was added in the model near the corner of Orleans and Madison with approximately 3 ac-ft with a minimum elevation of 236' NAVD. There are several adjacent parcels to locate potential storage, as shown in red highlights in **Figure 3-12***.*

Storage at this location could be either an open-air detention/retention pond or subterranean storage depending on parcel selection and stakeholder input.

3.5.2.2 Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$1,985,000**. Proposed segment costs are itemized in **Table 3-17**.

Table 3-17 Scenario 4B Engineer's Estimate of Probable Construction Costs

Segment	Cost
Orleans – 4,900 cubic yards of cut and haul @ $46 per cy	$225,000
Cast-in-place Subterranean Concrete Structure with backfill	$1,040,000
Scenario Subtotal	$1,265,000
Subtotal with Contingency (30%)	$1,645,000
with Contractor Overhead & Profit (12%)	$1,800,000
Engineering, Survey, & Permitting (15%)	$1,985,000
TOTAL COST	**$1,985,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

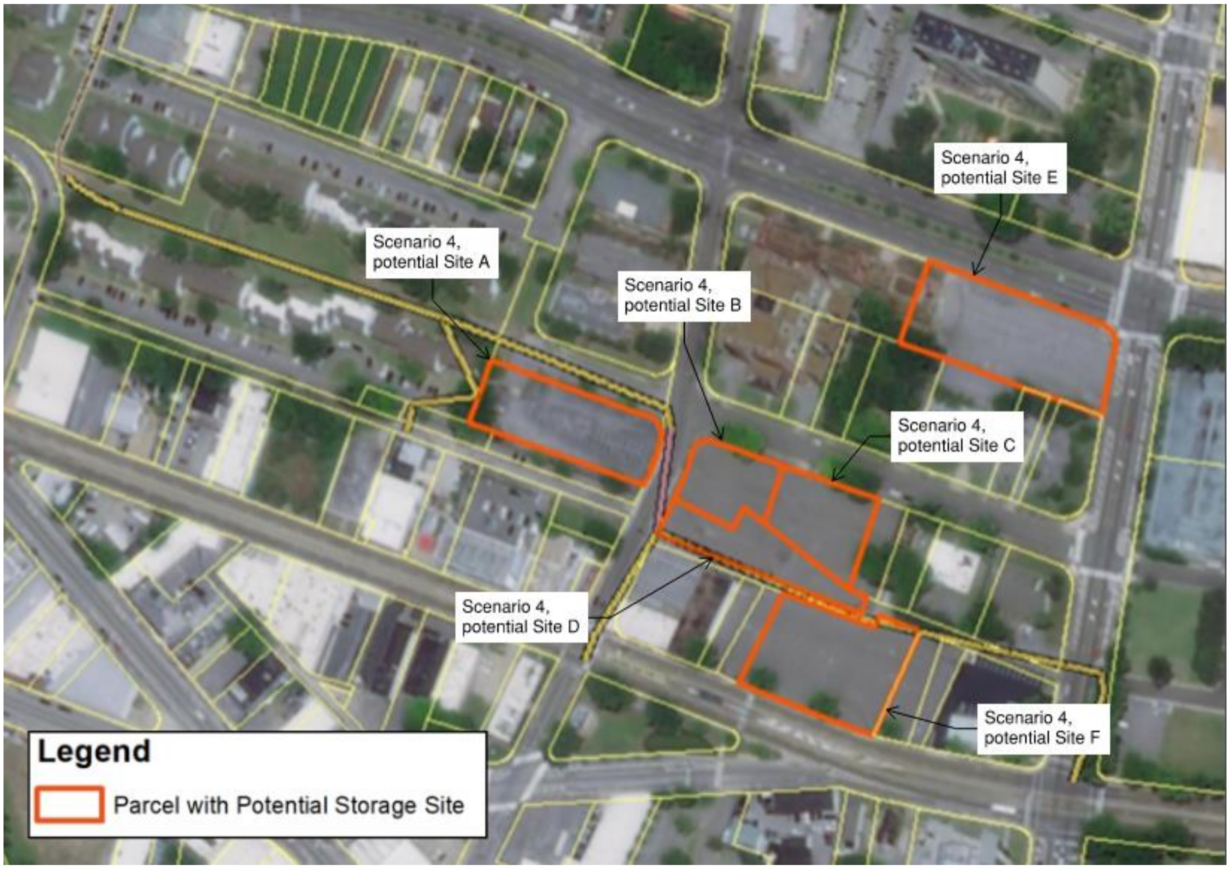

Figure 3-12
Tanyard Bayou / Medical District Parcel Suggestions

3.5.3 Scenario 4 – Tanyard Bayou / Medical District Alternatives Benefits

The improvement area for Scenario 4 contains drainage crossings of one major road and one minor road. Under existing conditions these crossings are predicted to flood, as are three downstream structures as shown in **Table 3-18**. However, with the proposed improvements, flooding is predicted to be eliminated at both major and minor road crossings for the 10-year design storm event. Utilizing surveyed finished floor elevations of structures, no structures are predicted to be protected from inundation within the improvement areas, while another 3 structures are predicted to be protected in other areas of the watershed. Highly concentrated flood tickets from this area suggest major repetitive flooding events, and though Finished Floor Elevations are above modeled peaks, conditions in the secondary system and locally deteriorated drainage features may exacerbate conditions.

1. Major road protected from inundation: 300 LF
2. Minor road protected from inundation: 500 LF
3. Structures protected in improvement area: 0
4. Structures seeing improvements in other areas: 3

Table 3-18 Scenario 4 Existing and Proposed Maximum HGLs

Node ID	Existing Max HGL (ft)	Critical Address	Critical Elevation1 (ft)	Proposed		
				Max HGL (ft)	Change (ft)	Below Critical Elevation (ft)
837109	226.87	211 Lauderdale	225.59	225.49	-1.38	-0.1
837109	226.87	252 Lauderdale	225.64	225.49	-1.38	-0.15
837109	226.87	252 Lauderdale	226.69	225.49	-1.38	-1.2

2. For Structures, from FFE Survey; for major roads, estimated from DEM.

A peak flood stage map of the 10-year design storm for Proposed Scenario 4 is included in **Figure 3-13** at the end of this section. **Table 3-19** displays the improvements between pre- and post-alternative flows and levels at one critical point in the system at the intersection of Jefferson Avenue and Neely Street.

Table 3-19 Pre- and Post-Alternatives Flows and Levels Downstream of Improvements

Location	Max Level (feet)		Max Flow (cfs)	
	Existing	**Proposed**	**Existing**	**Proposed**
Jefferson and Neely	21.33	20.01	174.4	159.3

3.5.4 Scenario 4 – Tanyard Bayou / Medical District Alternatives Engineer's Estimate of Conceptual Construction Costs

The Engineer's estimate of conceptual construction costs is **$2,580,000**. Proposed segment costs are itemized in **Table 3-20**.

Table 3-20 Scenario 4 Engineer's Estimate of Probable Construction Costs

Segment	Cost
Avant Lane – 300 LF of 42" RCP, 400 LF of 60" RCP	$380,000
Orleans – 4,800 cubic yards of cut and haul @ $46 per cy	$225,000
Cast-in-place Subterranean Concrete Structure with backfill	$1,040,000
Scenario Subtotal	$1,645,000
Subtotal with Contingency (30%)	$2,140,000
with Contractor Overhead & Profit (12%)	$2,335,000
Engineering, Survey, & Permitting (10%)	$2,580,000
TOTAL COST	**$2,580,000**

Assumptions:

1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

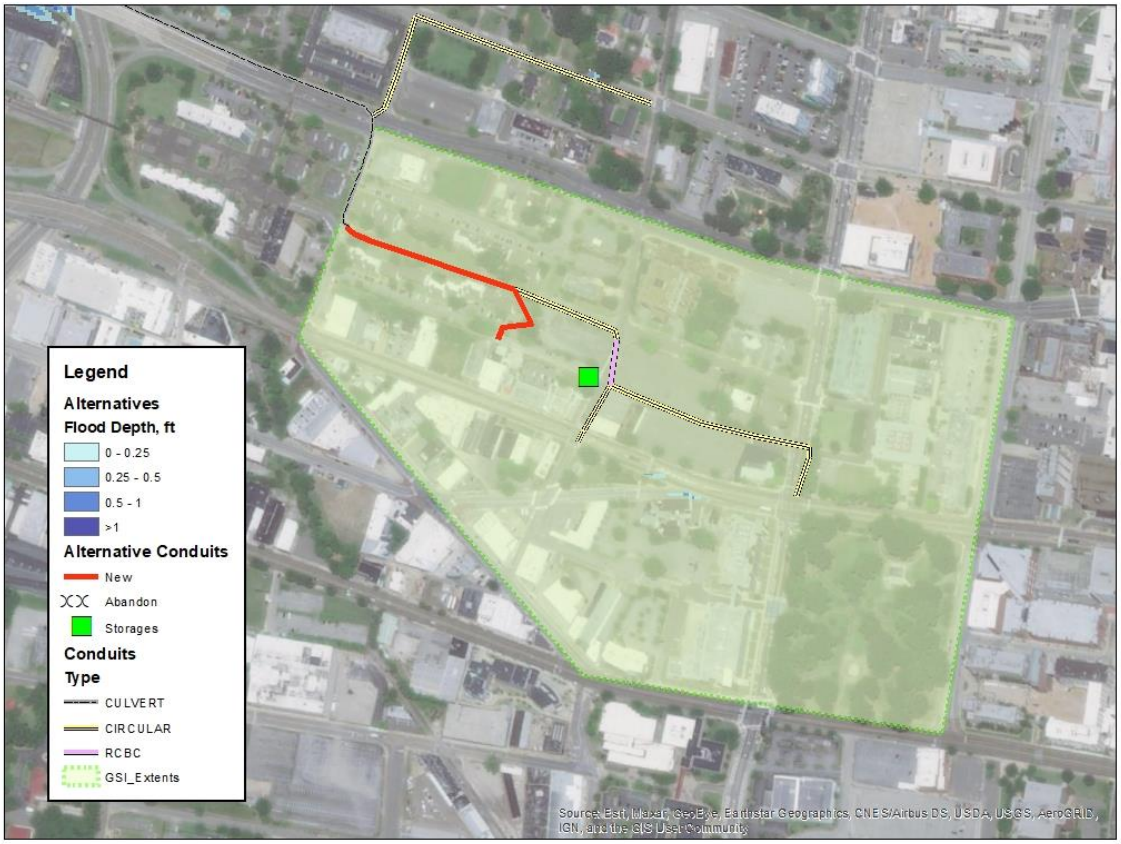

Figure 3-13
Flood Depths in Tanyard / Medical Area with Alternatives Applied

3.6 Scenario 5 – Home Buyouts and Green Stormwater Infrastructure

This scenario highlights infrastructure still at risk for inundation even with all the recommended improvements implemented. While the scenarios previously described cover areas deemed of highest concern, there remain locations where flooding is predicted but no projects have been investigated, particularly in storms with a greater intensity than the 10-yr event. In other situations, even with improvements to an area, some structures remain at risk and may be a better target for buy-out, flood proofing of the individual property, or protection via flood insurance.

3.6.1 Buyouts

Based on the predicted flood extent following implementation of all four previous scenarios, two structures remain at risk for inundation with over a foot of flooding predicted (**Table 3-21)**. The best option for these businesses will likely be buy-out, flood proofing, and/or purchase of flood insurance.

Table 3-21 Scenario 4 Existing and Proposed Maximum HGLs

Node ID	Existing Max HGL (ft)	Critical Address	Critical Elevation1 (ft)	Proposed		
				Max HGL (ft)	**Change (ft)**	**Below Critical Elevation (ft)**
837109	226.87	279 Exchange	223.38	225.49	-1.38	**+2.11**
837109	226.87	218 Lauderdale	224.48	225.49	-1.38	**+1.01**

Another 6 potentially inundated structures are in areas where no improvements have been investigated. These are often areas with less dense development or areas with very isolated predicted flooding. Modeling indicated that these structures were not at risk of flooding in the 10-yr event, but are at risk in higher return period events. Follow up study may show that the structures can be further protected with physical improvements or other options can be considered.

3.6.2 Green Stormwater Infrastructure

One of the drawbacks of only modeling the primary system is the chance that very local repetitive flooding issues may not rise to the surface. Hydraulic modeling naturally assumes that all flows enter the system and are handled by the PSMS. In practice, inlets, swales, and other secondary features may not function as intended. Flood tickets provided by the City show these issues throughout the watershed. To address these issues, green infrastructure priority areas were stated for areas surrounding current alternatives. An added benefit to utilizing green infrastructure in these areas is that the prescribed storage areas would have a higher likelihood of having available capacity to handle storm flow when storm events occur.

Possible green infrastructure implementations could take the form of rain gardens, rain barrels, cisterns, collared inlets in parks, pervious pavement, or bioretention areas. Individual methods should be tailored to the footprint and physical parameters of the location.

3.7 Scenario 6 – Areas with Potentially Surcharged Pipes

As this study progressed, isolated areas of the closed conduit drainage system were identified with the potential for severely surcharged pipes. Pipes in this condition run the risk of blowing out their manholes and creating hazards, particularly when they are in a roadway or sidewalk. Many of these areas were ameliorated by the improvements listed in previous sections, but two lengths of pipe remained with potential surcharge issues. **Figure 3-14** shows these two locations.

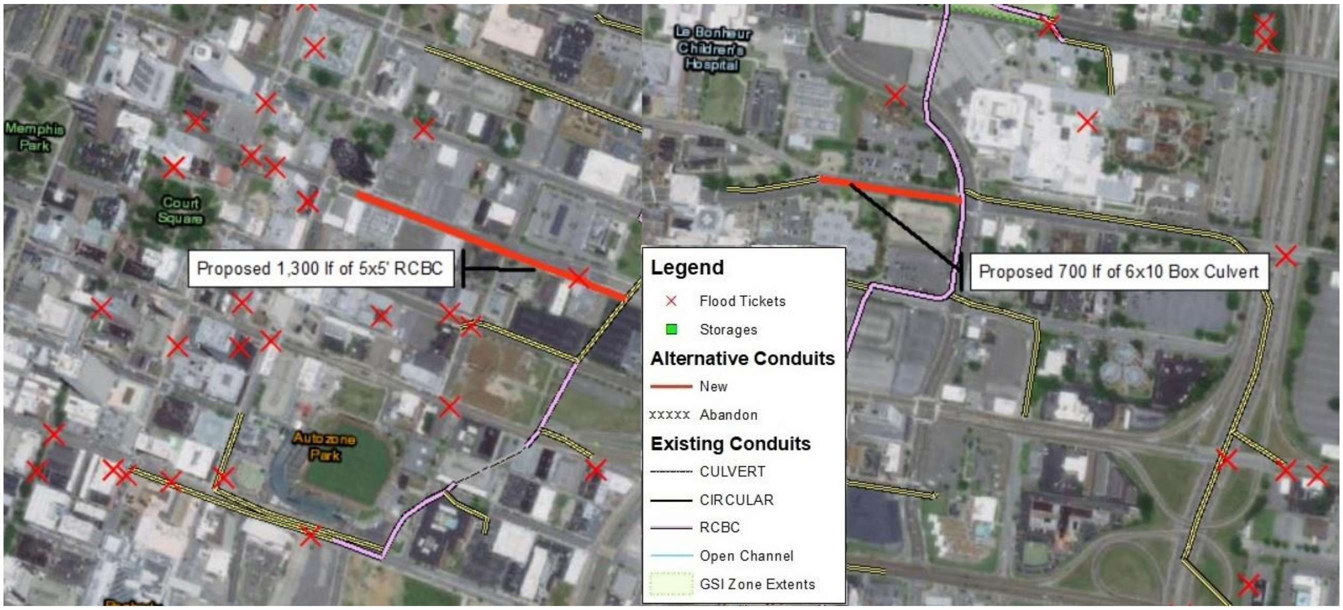

Figure 3-14
Scenario 6 – Areas with Potentially Surcharged Pipes (Left, W Jefferson Ave; Right, E Jefferson Ave)

Location one is Jefferson Avenue just east of downtown. The current 24" pipe is recommended to be replaced by 5x5' RCBC. This will not only provide improved conveyance, but its large size will provide 0.75 acre-feet of in-system storage in an area with limited real estate for storage volume.

Location two is also on Jefferson Avenue from where it converges with Adams Street through Pauline Street. The current 36" pipe is recommended to be replaced by a 6x10' RCBC. This will eliminate surcharging issues and provide nearly 1 acre-feet of in-system storage adjacent to the primary box culvert that serves the eastern portions of the basin.

The Engineer's estimate of conceptual construction costs is **$4,000,000**. Proposed segment costs are itemized in **Table 3-22**.

Table 3-22 Scenario 6 – Engineer's Estimate of Probable Construction Costs

Segment	Cost
Jefferson Street West – 1,300 LF of 5x5 RCBC	$1,450,000
Jefferson Street East – 700 LF of 6x10 RCBC	$1,100,000
Scenario Subtotal	$2,550,000
Subtotal with Contingency (30%)	$3,315,000
with Contractor Overhead & Profit (12%)	$3,620,000
Engineering, Survey, & Permitting (15%)	$4,000,000
TOTAL COST	**$4,000,000**

Assumptions:
1. Costs in 2021 dollars.
2. Includes storm water infrastructure only. Does not include potential utility replacement or upgrades.
3. Does not include potential hazardous material remediation.
4. Does not include potential wetland mitigation unless noted.
5. Does not include property costs.

3.8 Recommendations and Conclusions

3.8.1 Recommendations

The segment costs listed are only valid if completed within the whole scenario. If completed singularly, costs may increase and the estimated reduction in stage may not be achieved. Generally, the most advantageous phasing of drainage alternatives consists of implementing storage upstream to downstream, then constructing conveyance downstream back upstream, in order to prevent the potential increase in stages that comes with opening up flow restrictions upstream. Some storage features may require conveyance improvements to fulfill their intended functions, however.

Based on a basic analysis of number of houses or businesses protected versus cost, and with considerations given to the importance of major and minor road crossings kept passable, the following is the recommended sequence of scenario improvements:

1. Scenario 2B: Storage in the Lamar and Bellevue area

Scenario 2B consists of 9 ac-ft of storage in the vicinity of Lamar and Central Avenue and 6.25 ac-ft of storage near Minna Drive. This Scenario benefits large areas of the Gayoso basin as it is the most upstream storage location and would thus reduce flows throughout the eastern system.

- Engineer's Estimate of Conceptual Construction Costs: $ 5,100,000
- Total benefits acquired by Scenario 2B: 4 structures, 2,000 LF of major road

2. Scenario 1B: Pinch District conveyance improvements

Scenario 1B is in the Pinch District. The area directly west of St. Jude along 3rd Street is relieved by the installation of a 60" pipe. This area's criticality to St. Jude Hospital and lack of downstream flooding concerns rank it highly among the alternatives. The additional conveyance improvements to northeast also protect an additional 2 structures and improve road passability throughout the neighborhood.

- Engineer's Estimate of Conceptual Construction Costs: $ 2,325,000
- Total benefits acquired by Scenario 1B: 2 structures, 1,250 LF of major road, 500 LF of minor road

3. Scenario 3B: Storage in the Dunlap Street corridor

Scenario 3B consists of four storage locations in the central basin. The first is 1 ac-ft near N Dunlap St and North Parkway. The second is 8.5 ac-ft and is located south of I-40 between Dunlap Street and Ayers Street. The third is 8.5 ac-ft and is located near Mosby Avenue and Ayers Street. The fourth is 8.5 ac-ft and is located near Poplar and Pauline Street.

- Engineer's Estimate of Conceptual Construction Costs: $ 3,080,000
- Total benefits acquired by Scenario 3B: 4 structures

4. Scenario 3A: Dunlap Street Corridor Conveyance Improvements

Scenario 3A is in the central region of the Gayoso Bayou watershed. It includes three distinct conveyance improvements that will add significant drainage capacity in the area and improve the functionality of the recommended storage units. The first is located on N Manassas Street between North Parkway and Gene Logan. The next is a relief box culvert parallel to the existing box culvert near Poplar Avenue and N Pauline Street. Finally, the third conveyance improvement is a 30" pipe to redirect drainage north along Ayers Street.

- Engineer's Estimate of Conceptual Construction Costs: $ 5,060,000
- Total benefits acquired by Scenario 3A: 400 LF of major road, 700 LF of minor road

5. Scenario 4B: Storage in Tanyard Bayou

Scenario 4B consists of 3 ac-ft of storage in the vicinity of Orleans and Madison Avenue. This Scenario benefits most of the western portions of Gayoso basin as it is the most upstream storage location.

- Engineer's Estimate of Conceptual Construction Costs: $1,985,000
- Total benefits acquired by Scenario 4B: 3 structures

6. Scenario 1C: Storage in the Pinch District

Scenario 1C consists of 3.33 ac-ft of storage in the vicinity of 4th and Saffarans. This Scenario is most effective when employed along with the Pinch District conveyance improvements.

- Engineer's Estimate of Conceptual Construction Costs: $2,195,000
- Total benefits acquired by Scenario 4B: 300 LF of minor road

7. Scenario 2A: Waldran Road Conveyance Improvements

Scenario 2A is in the south region of the Gayoso Bayou watershed. The scenario begins at the railroad underpass and Bellevue Blvd and continues north along Agnes Place and Waldran Road until it meets the Gayoso Bayou interceptor. Additionally, new local pipes in the neighborhood which drain to a relief box culvert along Bellevue Boulevard will add significant drainage capacity in the area and improve the functionality of the recommended storage units.

- Engineer's Estimate of Conceptual Construction Costs: $ 4,780,000
- Total benefits acquired by Scenario 2A: 450 LF of major road, 850 LF of minor road

8. Scenario 4A: Tanyard Bayou Conveyance Improvements

Scenario 4A consists of a stretch of improved pipe beginning in the courtyard of the Edison apartments between Avant Lane and Jefferson Avenue and extending west along Jefferson.

- Engineer's Estimate of Conceptual Construction Costs: $ 597,000
- Total benefits acquired by Scenario 4A: 170 LF of major road, 350 LF of minor road

9. Scenario 6: Conveyance in areas with surcharged pipe

Scenario 6 consists of two lengths of pipe on separate stretches of Jefferson Avenue. This scenario adds further capacity to the PSMS and prevents local surcharging on major roads.

- Engineer's Estimate of Conceptual Construction Costs: $ 4,000,000
- Total benefits acquired by Scenario 6: Abatement of surcharge along 2,000 LF of pipe

Taken in total, 13 structures, 5,300 linear feet of major roads, and 6,300 linear feet of minor roads will be relieved of flooding concerns by the projects listed above. **Figures 3-15 to 3-18** focus on the locations of benefits by each scenario's focus area.

3.8.2 Conclusions

Level of Service

While multiple level of service criteria were discussed in **Volume II Section 2**, the driver for all of the projects identified in this section was the location of structures at risk of flooding in the 10-year storm event in existing conditions. Therefore, the proposed improvement projects were designed to address structural flooding while also improving nearby roadway flooding. The proposed improvements meet the level of service for the 10-year design storm event with an open gate and a 75th percentile high water level in the Mississippi River as a boundary.

As noted previously, the estimated construction cost of some of the scenarios was well as potential challenges with the permitting process may require an evaluation of alternative flood protection measures, such as property buyouts, flood proofing and/or flood insurance for homes that are not able to be removed from the floodplain in a cost-effective manner.

Water Quality

The proposed National Pollutant Discharge Elimination System (NPDES) renewal permit for the City of Memphis states that any time a flood control project is constructed that water quality improvements are evaluated. The proposed projects in this study do not specifically identify or address water quality concerns. Although some suggested improvements, such as detention ponds, have a water quality improvement benefit, these projects were developed to address flooding concerns alone. It is suggested that potential water quality improvements be evaluated in subsequent phases of these projects.

Figure 3-15
Scenario 1 – Areas Improved by Alternatives

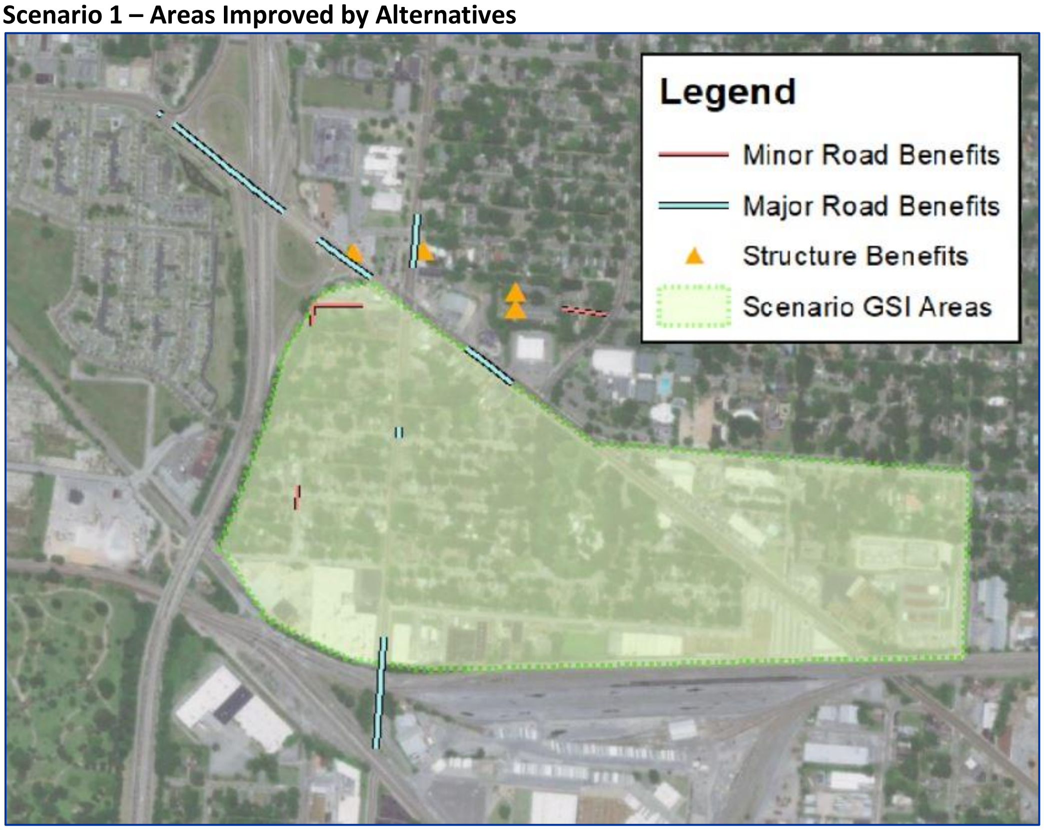

Figure 3-16
Scenario 2 – Areas Improved by Alternatives

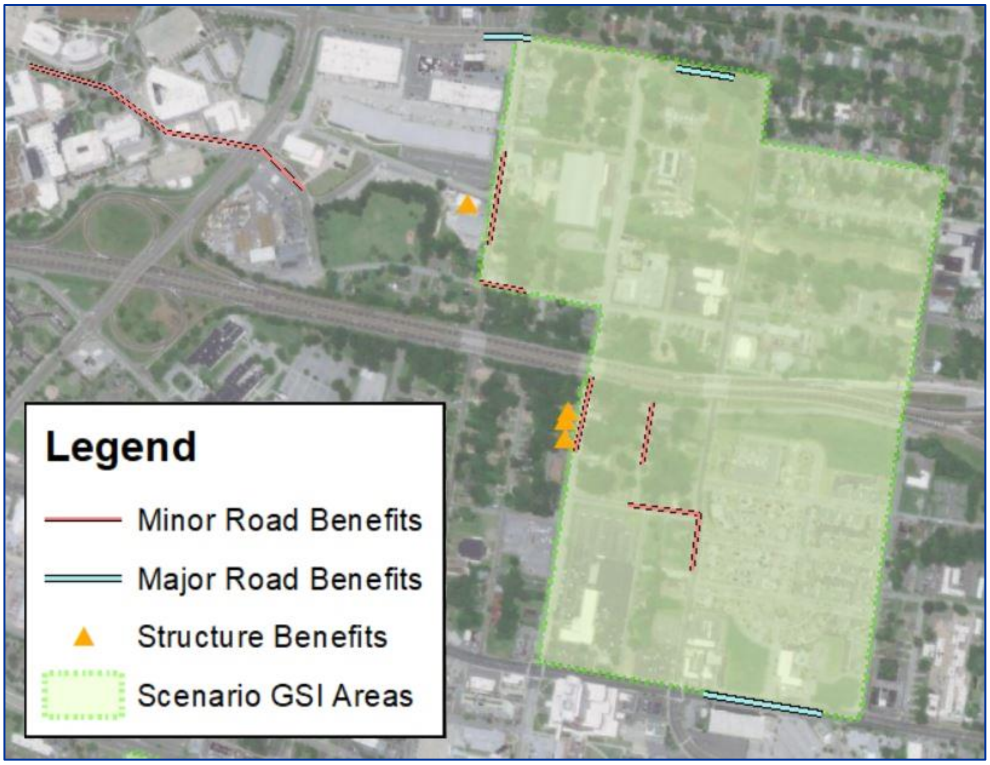

Figure 3-17
Scenario 3 – Areas Improved by Alternatives

Figure 3-18
Scenario 4 – Areas Improved by Alternatives






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