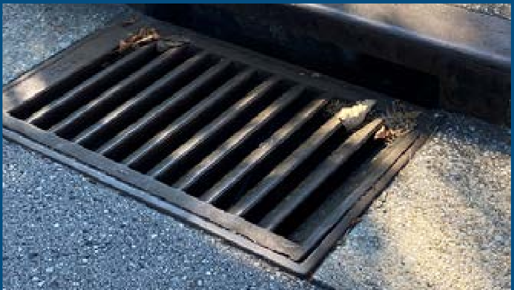
COMBINED SEWER SYSTEM FLOODING MASTER PLAN

Clean Water Nashville

FINAL REPORT | JANUARY 2024



cleanwater NASHVILLE OVERFLOW ABATEMENT PROGRAM

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1.0 Introduction

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In much of the core urban area of Nashville, sanitary sewage and stormwater runoff are collected in a single network of pipes, known as a combined sewer system (CSS). To prepare for growth and address flooding within the combined sewer system, Metro Water Services (Metro or MWS), through its Clean Water Nashville Program, has prepared this CSS Flooding Master Plan (Master Plan).

This report addresses growth and flooding in the CSS. The Central Pump Station, which is located at the Central Water Reclamation Facility and pumps flow into the treatment facility, serves the majority of the CSS. This report does not address growth or flooding within the municipal separate storm sewer system (MS4) nor does it address flooding caused by high Cumberland River levels.

1.1 Background

Combined sewer systems, like those found in Nashville, were often constructed in cities that developed in the 19th century to address public health issues caused by lack of proper sanitation. Since there were no facilities for treating wastewater in that era, it was common practice that sewage and stormwater were both discharged directly to the rivers and streams.

The treatment of wastewater began in the 20th century when pipelines were constructed to intercept sanitary sewage along with stormwater and redirect flows to treatment plants to improve water quality. Wastewater treatment plants, however, have limitations to the volume of flow that can be effectively treated during rainfall events. Intense rainfall often leads to flows of stormwater in the CSS that exceed treatment plant capacity. These high flows of primarily stormwater are discharged without treatment and referred to as combined sewer overflows or CSOs. The U.S. Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC) regulate CSOs under the terms of a permit issued under the Clean Water Act. CSOs are actively monitored at each discharge location.

In 2011, Metro finalized a study evaluating the impacts of their CSOs on water quality in the Cumberland River and identifying potential projects to further improve water quality. Through the *Long Term Control Plan for Combined Sewer Overflows* (LTCP) and subsequent addenda, Metro committed to completing several projects to further reduce CSO discharges.

The LTCP, however, primarily focuses on CSO discharges to the Cumberland River, and it does not address capacity limitations within the CSS itself. Those capacity limitations, such as a lack of pipe or inlet capacity, may result in surface flooding, causing impacts such as life and safety issues, property damage, or nuisance flooding.

This Master Plan summarizes the study to evaluate known flooding issues within the combined sewer system and identify solutions to remedy those issues. It also assesses the impact of growth on the performance of the CSS. This study was led by CDM Smith through Metro's Clean Water Nashville Program.

1.2 Project Approach

As part of the LTCP development, AECOM developed the MWS CSS hydraulic and hydrologic model from 2008 to 2011. It has been updated and recalibrated several times through the Clean Water Nashville Program. The model was developed primarily to assess system performance as it relates to CSOs and to evaluate CSO improvement alternatives as described in the LTCP. At the time of the LTCP development, the number and location of calibration points in upstream portions of the CSS were limited. Subsequent model updates added calibration points, improving the level of confidence in the model, particularly in the Benedict & Crutcher, Boscobel, Kerrigan, and Schrader basins. Model updates based on recently collected data in the Washington basin were completed in early 2023. **Section 2** includes additional descriptions of the existing CSS.

To facilitate use of the model for master planning and flooding assessment within the CSS, MWS elected to further refine the model for this project. The model was updated to include additional infrastructure in areas subject to frequent flooding, as well as areas anticipated to undergo substantial redevelopment. The model was also updated to facilitate support for assessment of low-impact development (LID) practices and flood reduction strategies by reducing average sub-catchment size, providing refined surface parameters, and standardizing development of existing parameters. The updated model was compared against the existing model and calibration data to ensure its validity and consistency with previous results.

The updated model was used to assess flood-prone locations, evaluate improvement alternatives to remedy flooding and address projected growth, and understand potential impacts on CSOs. This Master Plan summarizes that evaluation and provides a project list to address flooding and support growth.

This work consisted of the following major tasks:

- Identification and review of flood-prone areas relative to existing model results
- Review of planning-level growth projections and their impact on the CSS
- Refinement of model hydrology and model infrastructure expansion
- Validation and assessment of modeled flooding and capacity constraints
- Evaluation of improvement alternatives
- Development of proposed projects
- Assessment of costs
- MWS stakeholder meetings
- Report preparation

1.3 Report Organization

This Master Plan is organized into seven sections. **Sections 1** and **2** provide background, document known flooding issues, and describe the future scenario considered. **Section 3** documents the hydraulic and hydrologic model update. **Section 4** presents the approach for analyzing the CSS, including design storms, Cumberland River assumptions, and level of service. **Section 5** summarizes model results under dry-weather and wet-weather conditions and presents observations from the model applicable to the entire CSS. **Section 6** describes the projects identified to address flooding and provides performance expectations if all projects are constructed. **Section 7** provides a summary of the system improvements and study limitations.

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- Section 2 – Existing System and Anticipated Growth
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- Section 6 – Alternatives to Address Flooding
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2.0 Existing System and Anticipated Growth

2.0 Existing System and Anticipated Growth

This section describes the existing CSS, summarizes known flood-prone locations, and describes the development of future (2045) conditions.

2.1 Description of the Combined Sewer System

The CSS generally serves Nashville's core urban area while a separate sanitary sewer and stormwater conveyance systems serve the surrounding area. The CSS covers approximately 12.6 square miles of drainage area, which constitutes 2 percent of Davidson County's land area.

Nashville currently has six CSO locations, as shown on **Figure 2-1**. Each CSO location consists of a regulator that channels dry-weather flow through the CSS until capacity is exhausted, at which time the CSO is "activated" and flow is diverted to a waterway. All CSO locations discharge to the Cumberland River (part of the Cheatham Reservoir). Starting with the most upstream location, the CSOs are described as follows:

- **Boscobel:** The Boscobel CSO is on the east bank of the Cumberland River, upstream of downtown. The Boscobel CSS basin consists predominantly of fairly dense residential housing, primarily single-family structures, with pockets of light commercial areas. The existing Boscobel CSS basin represents the upper portion of a larger basin that was once served entirely by combined sewers. The former Boscobel CSO regulator was moved upstream to its present location at Boscobel Street between 14th and 15th Streets when sewers in the lower half of the basin were separated in the 1960s.
- **Driftwood:** The Driftwood CSO is on the west bank of the Cumberland River, also upstream of downtown. A storage facility is located before the CSO discharge location to temporarily store combined sewer flow during rainfall events.

A 2013 facility reconfiguration increased the storage volume from 3.2 million gallons to 7.9 million gallons by using inline system storage. The Lewis Street Tunnel, completed in 1998, provided an interceptor sewer to consolidate three smaller CSS basins into the Driftwood CSS basin, eliminating three CSOs to Browns Creek. The Driftwood basin consists of residential, commercial, and industrial developments.

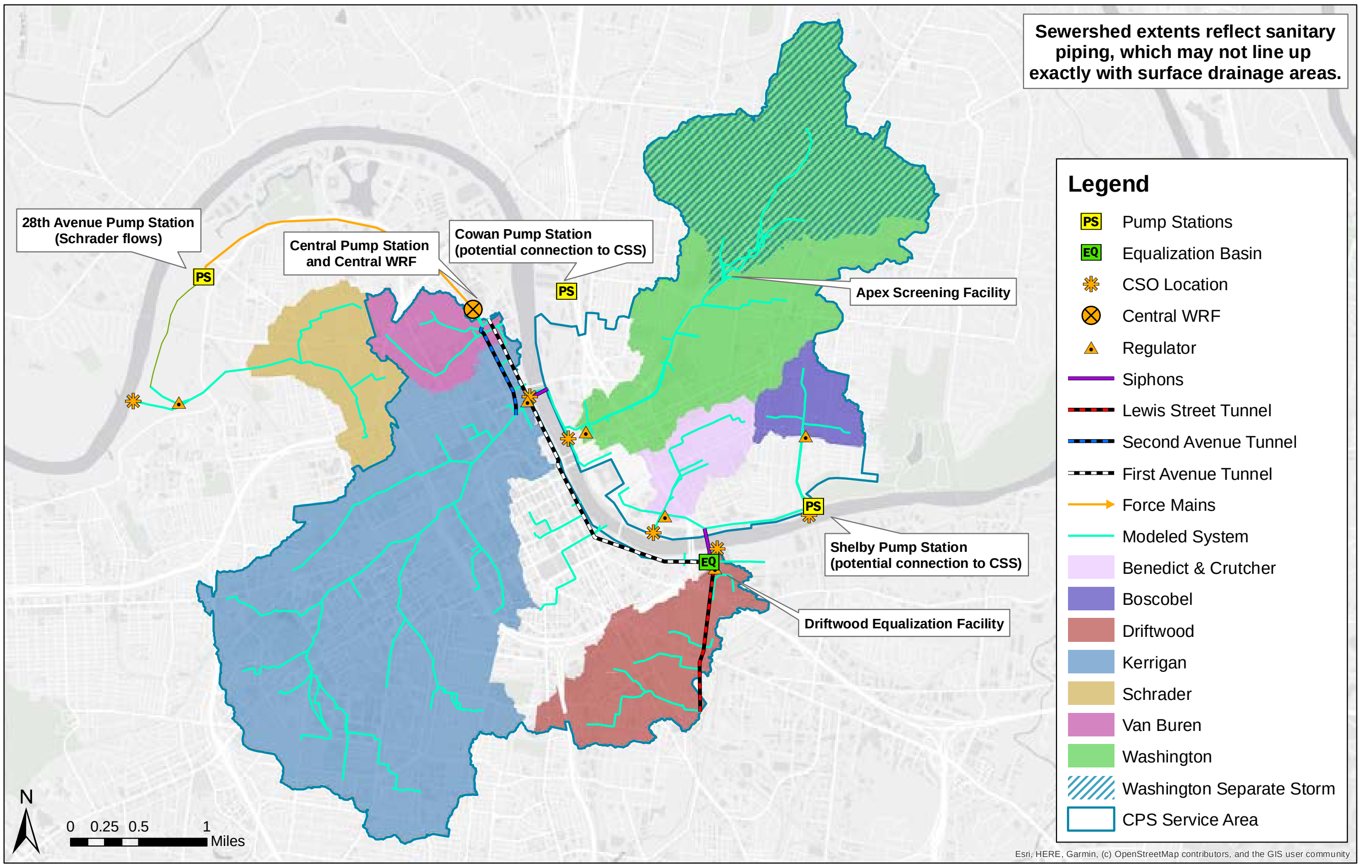
- **Benedict & Crutcher:** The Benedict & Crutcher CSO is on the east bank of the Cumberland River, also upstream of downtown. High-density residential housing, single family homes, and some commercial properties characterize the upper section of the Benedict & Crutcher CSS basin; the lower portion currently contains industrial areas. Significant redevelopment is underway or planned for portions of this basin, including the Metropolitan Development and Housing Agency's Envision Cayce redevelopment (currently underway) and potential redevelopment for areas west of the interstate as part of the Metro's Imagine East Bank Vision Plan.
- **Washington:** The Washington CSO is on the east bank, just north of James Robertson Parkway. The Washington CSS basin is the second largest within the MWS system, accounting for almost one-third of the CSS. The upper part of the basin contains separate sanitary sewer and stormwater (predominately open channel) systems. Stormwater from this area is routed to the Apex Street Stormwater Screening Facility, located just south of Granada Avenue at Apex Street. This facility removes large debris before routing the stormwater runoff to an interceptor sewer where the screened stormwater is combined with the sanitary flows from the area. Combined sewers generally serve the remainder of the Washington CSS basin. In 2012, MWS completed the construction of a new screening, flow control, and outfall structure for the Washington CSO, which provides additional screening and inline storage, reducing the frequency of CSOs at this site in accordance with EPA's Nine Minimum Controls policy.
- **Kerrigan:** The Kerrigan CSO is just south of Jefferson Street on the west bank of the Cumberland River. The Kerrigan CSS basin is the largest MWS CSS basin, accounting for more than 40 percent of Nashville's CSS. The lower third of the Kerrigan CSS basin is highly urban and contains the Gulch, parts of the central business district, and southern Germantown. The upper two-thirds of the basin includes Vanderbilt University, several hospitals and medical facilities, and residential and light commercial areas near Centennial Park.
- **Schrader:** The Schrader CSO is on the west bank of the Cumberland River, near Tennessee State University's agricultural campus. The Schrader CSS basin consists predominantly of residential, light commercial, and institutional developments. The existing Schrader CSS basin represents the upper portion of a larger basin that was once served entirely by combined sewers before sewer separation activities, which were completed in the 1960s. Unlike the other CSS basins, Schrader is not tributary to the Central Pump Station. Under dry-weather and other low-flow conditions, flow from the Schrader CSS basin is routed through a trunk sewer that also receives flow from nearby sanitary sewer systems. The 28th Avenue Pump Station transmits these sanitary and combined flows to the Central Water Reclamation Facility (CWRF) for treatment.

All CSS areas drain to the Central WRF located north of downtown Nashville. Except for the Schrader basin, all CSS flows are routed through the Central Pump Station (CPS) located at the Central WRF. CPS receives flow via the First and Second Avenue Tunnels, known as FAT and SAT, respectively. **Figure 2-1** shows the general connectivity of the system.

CSO activations, a term used for an event in which a CSO occurs, at each active CSO location for the last four years are given in **Table 2-1**.

Table 2-1. Combined Sewer Overflow Activations, 2019 to 2022

Year	Benedict & Crutcher	Boscobel	Driftwood	Kerrigan	Schrader	Washington
2019	46	38	0	39	38	19
2020	40	43	0	35	36	21
2021	33	40	0	35	36	15
2022	38	34	0	30	39	16
Average	39	39	0	35	37	18



Sewershed extents reflect sanitary piping, which may not line up exactly with surface drainage areas.

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Figure 2-1. Combined Sewer System Schematic

FAT extends from the Driftwood CSO storage facility to CPS, generally following the Cumberland River and First Avenue. Flows from the Boscobel CSS basin, the Benedict & Crutcher CSS basin, and separate sanitary areas south of Boscobel and along Davidson Street are delivered to FAT via an inverted siphon river crossing located east of the Silliman Evans Bridge (Interstate 24). As FAT continues northward, sanitary sewer flows are collected, including the Demonbreun area, which underwent a series of projects in the 1990s to separate the combined sewers in this area and eliminate eight CSOs. At Broadway, FAT also receives flow from the Broadway CSS basin. The Broadway CSO was eliminated in 2011 through modifications to the regulator structure, and all flows from this combined sewer area are captured and sent to FAT.

Flows from the Washington CSS basin are also routed to FAT via a multi-barrel, inverted siphon that crosses the Cumberland River just south of the Jefferson Street bridge. As FAT continues north down First Avenue toward Central WRF, high flows from the Van Buren CSS basin are also diverted to FAT. Like the Broadway CSS basin, the Van Buren CSO was eliminated in 2011 through modifications to the regulator structure, and all flows from this combined sewer area are captured and treated.

Part of the wet-weather flow from the Kerrigan CSS basin is also conveyed to the Central WRF via FAT, though the primary path from the Kerrigan CSS basin to the Central WRF is via SAT. SAT receives flow from the Kerrigan trunk just north of Stockyard Street and generally runs down Second Avenue to CPS. SAT also conveys some flows from the Van Buren CSS basin. However, the Van Buren flows are small compared to Kerrigan; therefore, the SAT is considered primarily a Kerrigan conveyance conduit.

One CSS basin, Schrader, is not tributary to CPS. Under dry-weather and other low-flow conditions, flow from the Schrader CSS basin is routed through a trunk sewer that also receives flow from nearby sanitary sewer systems. The 28th Avenue Pump Station transmits these flows to the Central WRF for treatment.

Within the CSS, isolated stretches of separate storm sewer pipes are common. In most cases, they are combined with the CSS at a convenient downstream location. Often this occurs at the extents of a development or at a location where surface flows enter a closed conduit system. The largest example of surface flows entering the CSS is within the Washington basin, upstream of the Apex Street Stormwater Screening Facility. This area is the largest single separate area in the CSS model at 1,280 acres.

2.2 Identification of Flood-Prone Areas

The identification of flood-prone areas is a key part of this Master Plan. MWS provided a heat map showing locations of open stormwater services requests to initiate research into flood-prone locations. The heat map, news reports of flooding, and anecdotal flooding locations were compiled and presented to MWS staff. Additional feedback from MWS staff was incorporated to establish known flooding locations throughout the CSS. Twenty-eight specific locations were originally identified, though two locations were found to be outside of the CSS and one was associated with Interstate 40, which was outside the scope of this study. **Figure 2-2** and **Table 2-2** provide the 25 identified locations. **Section 5.3** provides further description of the comparison of model-predicted flooding locations to these areas.

Table 2-2. Identified Flood-Prone Areas

# on Map	Location Descriptor	Basin	Model-Predicted
1	Rosa Parks Boulevard between 10th Circle North and Jefferson Street (Farmers Market)	Kerrigan	Yes
2	12th and 14th Avenues North near Herman Street	Kerrigan	Yes
3	Jo Johnston Avenue and 10th Circle North, Capitol View	Kerrigan	Yes
4	Nelson Merry and 10th Avenue	Kerrigan	Yes
5	Charlotte Avenue Between I-24 and 17th Avenue	Kerrigan	Yes
6	323 21st Avenue North	Kerrigan	No
7	Murphy Street from 23rd to 22nd Avenue North	Kerrigan	No
8	25th Avenue North and Brandau Place	Kerrigan	Yes

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# on Map	Location Descriptor	Basin	Model-Predicted
9	West End and Natchez Trace	Kerrigan	Yes
10	31st Avenue North and Long Boulevard	Kerrigan	Yes
11	Jess Neely at McGugin – Vanderbilt Sports	Kerrigan	Yes
12	Ellington Parkway, including Cleveland Street and West Eastland Street	Washington	Yes
13	Apex Street at Granada	Washington	Yes
14	Boscobel Street between 14th and 15th Streets	Boscobel	Yes
15	14th Street between Fatherland Street and Forrest Avenue	Boscobel	Yes
16	Lillian Street and 15th Street	Boscobel	No
17	25th Avenue North and Osage Street	Schrader	Yes
18	Hermitage Avenue and Driftwood Street	Driftwood	Yes
19	Rosa L Parks Boulevard near Jefferson Street	Kerrigan	Yes
20	Herman Street and 10th Avenue North	Kerrigan	Yes
21	2700 West End Avenue	Kerrigan	Yes
22	Houston Street between Martin Street and 4th Avenue	Driftwood	Yes
23	5th Street and Sylvan Street	Benedict & Crutcher	Yes
24	21st Avenue South and Wedgewood Avenue	Kerrigan	Yes
25	25th and 24th Avenues South of Highland (Veterans Affairs [VA] Hospital Parking Garage)	Kerrigan	Yes

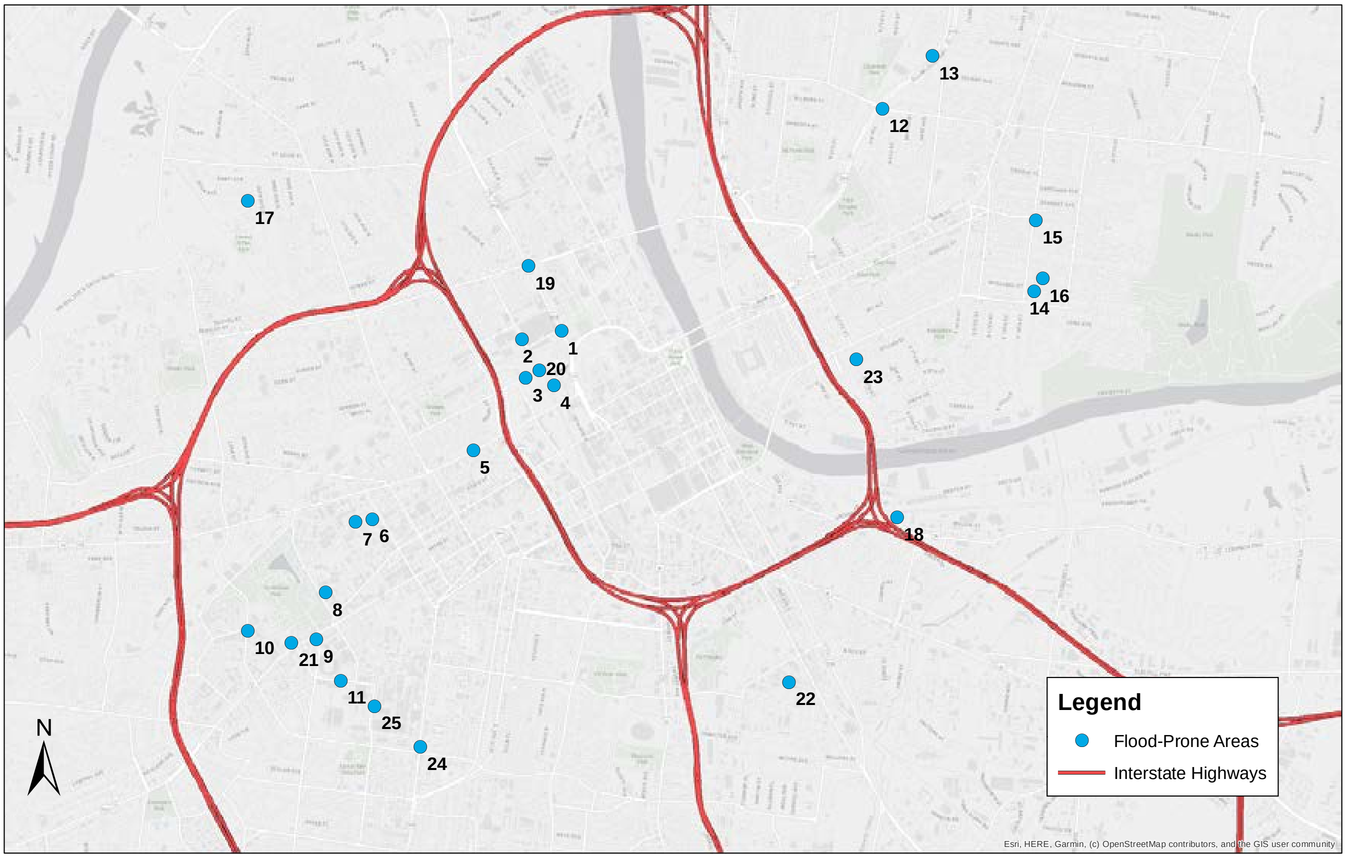

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Figure 2-2. Identified Problem Areas

2.3 Future Flow Development

New sanitary flows and runoff conditions must be forecast to adequately reflect future conditions. Through discussions with MWS, a planning horizon of 2045 was selected. This time frame corresponds to the most recent population and employee projections provided by the Greater Nashville Regional Council.

2.3.1 Future Dry-Weather Flows

Dry-weather flow comprises base wastewater flow from residential, commercial, institutional, and industrial sources, along with groundwater infiltration. Increases in dry-weather flow because of projected residential population and employee growth were accounted for in the modeled analyses representing future (2045) conditions.

Residential population and employee growth projections use census-block-level data provided by MWS and developed by the Greater Nashville Regional Council. These projections were derived using 2017 as a basis, and review of the projections relative to current conditions suggests that the future projections may be understated in many areas. Since the projections were developed, numerous high-density developments have been constructed or approved for construction in Nashville, particularly in the CSS. The projections to 2045 may not reflect the impact of these high-density developments, and future modeled scenarios should be revisited when updated projections are available.

Using a geographical information system (GIS), each census block was allocated to an appropriate sewershed area in the model (i.e., model load point). The projected changes from 2017 to 2045 for residential population and employees for each census block then were correlated to changes in flows.

The 2045 future dry-weather flows for each load area include the following items:

- Dry-weather flow (base wastewater flow + groundwater infiltration) representing the existing system
- Residential growth times 70 gallons per capita per day (flow factor)
- Employee growth times 35 gallons per capita per day (flow factor)

Future flows assigned to each sewershed were equally distributed among available model nodes falling within the sewershed. This distribution intends to account for developments that may use various unforeseen tie-in points throughout the individual sewersheds. For example, in Kerrigan sub-catchment KE-08-040, 0.12 million gallons per day (MGD) of increased sanitary flow is anticipated (presently 0.337 MGD). Instead of loading that to the single load point, the increase was evenly allocated among the six modeled manholes that fell within the sewershed's extents. Loading the model in this manner accomplishes three goals:

- Eliminates the process for selection of a single new load point for a sewershed where one may not exist
- Eliminates "dry pipes," which are modeled conduits that did not have upstream loadings
- Distributes the capacity impacts of future loadings

If future flow in a sewershed resulted in distributed loadings of less than 0.001 MGD per manhole, a single load point was assigned, with preference given to existing sanitary or sub-catchment loadings.

Unlike MWS's sanitary sewer model where observed flows from the long-term flow monitors are reviewed and compared to the model results annually, updates to the model have been limited to periodic temporary flow monitoring studies and recalibration efforts. This may result in underestimation of dry-weather flow in portions of the model that have experienced significant growth since the last flow monitoring period. The most recent monitoring and calibration for key areas of the system occurred in 2017 for Schrader, in 2019 for Benedict & Crutcher, Boscobel, and near the Driftwood storage facility, in 2020 for Kerrigan, and in 2022 for Washington.

To be conservative and account for the age of the most recent flow monitoring data, residential and employee growth between the 2017 estimates (also provided by Greater Nashville Regional Council) and 2045 projected values was used for the CSS. **Table 2-3** provides the existing and projected dry-weather flows for the area tributary to CPS and the Schrader CSS basin. As shown, growth in the CSS is projected to increase dry-weather flows by approximately 9 percent. These flows are added directly to the existing model flows.

Table 2-3. Existing and 2045 Projected Dry-Weather Flows

Area	Residential Population		Employee Population		Dry-weather Flow		Flow Increase
	2017	2045	2017	2045	Existing	Projected	
Schrader and Areas Tributary to CPS	54,510	71,400	228,525	292,655	38.3 MGD	41.7 MGD	8.9%

2.3.2 Future Impacts on Runoff

Because the CSS is fully sewered and the modeled sub-catchments account for all areas, no additional future area is projected for the CSS. From a runoff perspective, existing conditions in the combined area are highly developed; thus, a significant increase in imperviousness is not expected. Imperviousness averages 68 percent with many areas as high as 90 percent. (Impervious areas were derived from the National Land Cover Database [NLCD]. **Section 3.2.2** provides additional information).

While areas with high imperviousness values may not change significantly during redevelopment, areas with low imperviousness may increase because of density changes such as construction of outbuildings or buildings with larger impervious footprints than those currently present. Although MWS has regulations requiring appropriate stormwater management for large developments, smaller residential infill often has little to no capture of its increased stormwater runoff relative to the size of the 100-year design storm.

Areas within the CSS that have already experienced significant infill (such as Van Buren) were manually sampled to establish possible future impervious area extents. This process yielded a 55 percent average imperviousness, which was agreed upon in workshops with MWS as a sufficiently conservative value to assign to areas in the CSS where redevelopment is anticipated. Thus, in the 2045 scenarios, a minimum imperviousness of 55 percent is applied to all sub-catchments to represent future conditions.

Figure 2-3 shows sub-catchment areas with imperviousness less than 55 percent. As shown in the figure, the application of a minimum percent impervious primarily affects the upper Washington basin, as well as the Benedict & Crutcher, Boscobel, and Schrader basins. Areas such as Centennial Park and the City Cemetary were excluded from the minimum percent impervious assumption.

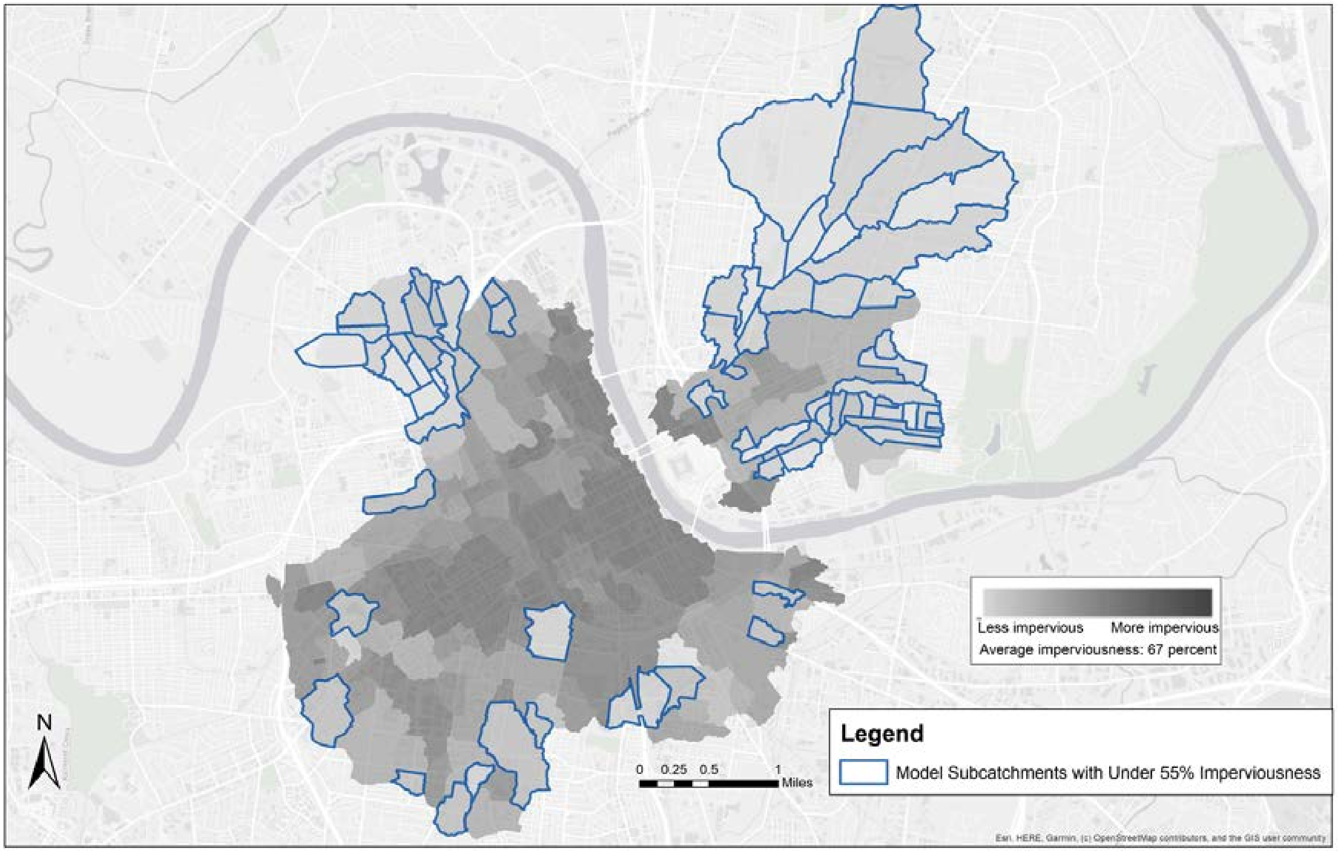

Figure 2-3. Areas with Increased Imperviousness Assumed

3.0 Hydraulic and Hydrologic Model Update

3.0 Hydraulic and Hydrologic Model Update

The hydraulic and hydrologic model used in developing the Master Plan is a crucial planning tool with a long history. AECOM originally created the model to support development of the LTCP. The model since has undergone several studies to review and improve its representation of existing conditions. However, the initial model development and updates prior to this Master Plan primarily focused on understanding CSO discharges to the Cumberland River. Updates to the model were necessary to better represent conditions within the CSS, including instances of surface flooding. This section describes the updated model's development, characteristics, and limitations.

3.1 Long-Term Control Plan Modeling

As part of the development of the LTCP, a hydraulic and hydrologic model of the CSS was developed to assess system performance as it relates to CSOs and to evaluate CSO improvement alternatives as described in the LTCP. The model primarily contained only large-diameter portions of the CSS and representations of major facilities such as CPS and the Driftwood CSO storage facility.

Because the model primarily focused on CSO discharges, the number and location of calibration points in upstream parts of the CSS were limited at that time. Subsequent model updates added calibration points, improving the level of confidence in the model in upstream areas. AECOM performed CSS model calibration exercises using flow monitoring data collected in 2017 (Schrader), 2019 (Benedict & Crutcher, Boscobel, and near the Driftwood facility), 2020 (Kerrigan), and 2022 (Washington).

The CSS model was developed in EPA's Stormwater Management Model (SWMM) and currently uses SWMM version 5.1.013. PCSWMM, a commercial software package that uses EPA's SWMM computational engine, may be used to update and run the models because of its suite of utilities and analysis tools. ArcGIS was used to assess model validity and view the system alongside other infrastructure and surface features.

The LTCP and technical memoranda issued through Clean Water Nashville describes the initial model development and subsequent model updates.

3.2 Model Updates

To facilitate use of the model for master planning and flooding assessment within the CSS, MWS elected to further refine the model for this project. The model was updated to include additional infrastructure in areas subject to frequent flooding, as well as areas anticipated to undergo substantial redevelopment. The model also was updated to standardize sub-catchment parameters and better define surface layers used to model overland flow. These model updates increase the detail and applicability of the model for surface-related systems.

It was not necessary to alter all portions of the model to expand the LTCP model's capabilities. The sewer network assets, dry-weather flows and diurnal patterns, pump curves, and control rules were left as-is with few exceptions. Modifications included minor expansions or adjustments of the modeled infrastructure but primarily focused on sub-catchments, soils/runoff parameters, and overland flow paths.

3.2.1 Expansion of Modeled Infrastructure

To ensure a proper level of detail, the modeled system extents have been aligned with the model's purpose to assess growth and flood-prone areas. Generally, the extents of the updated model match those of the original model developed as part of the LTCP. Interceptors, trunk sewers, and smaller tributary lines considered necessary for connectivity and precision of load allocation are included in the model, while collector sewers, individual inlets, and private service lines are omitted.

Figure 3-1 depicts linear infrastructure added to the model through this update. Where the model was expanded, pipes and manhole data were derived from MWS record or design drawings. The hydraulic performance of pipes is calibrated in the model space by the application of Manning's roughness values and entrance/exit losses.

Following are the significant updates to the physical infrastructure network of the model:

- Areas upstream of the Apex facility were added.
- Areas upstream of Centennial Park near Long Boulevard were added.
- FAT's slope was updated at one location.
- Schrader CSO outfall structure was updated.
- Shelby Park Pump Station and associated piping was added. Although this is not part of the CSS, the connection between the CSS and the Shelby Park sanitary sewer system may be activated when the system experiences high levels of surcharging.

Following the expansion of the modeled infrastructure through this update, the existing conditions model consists of 232 sub-catchments, 1,047 nodes, and 1,228 conduits, 187 of which are overland (surface) flows.

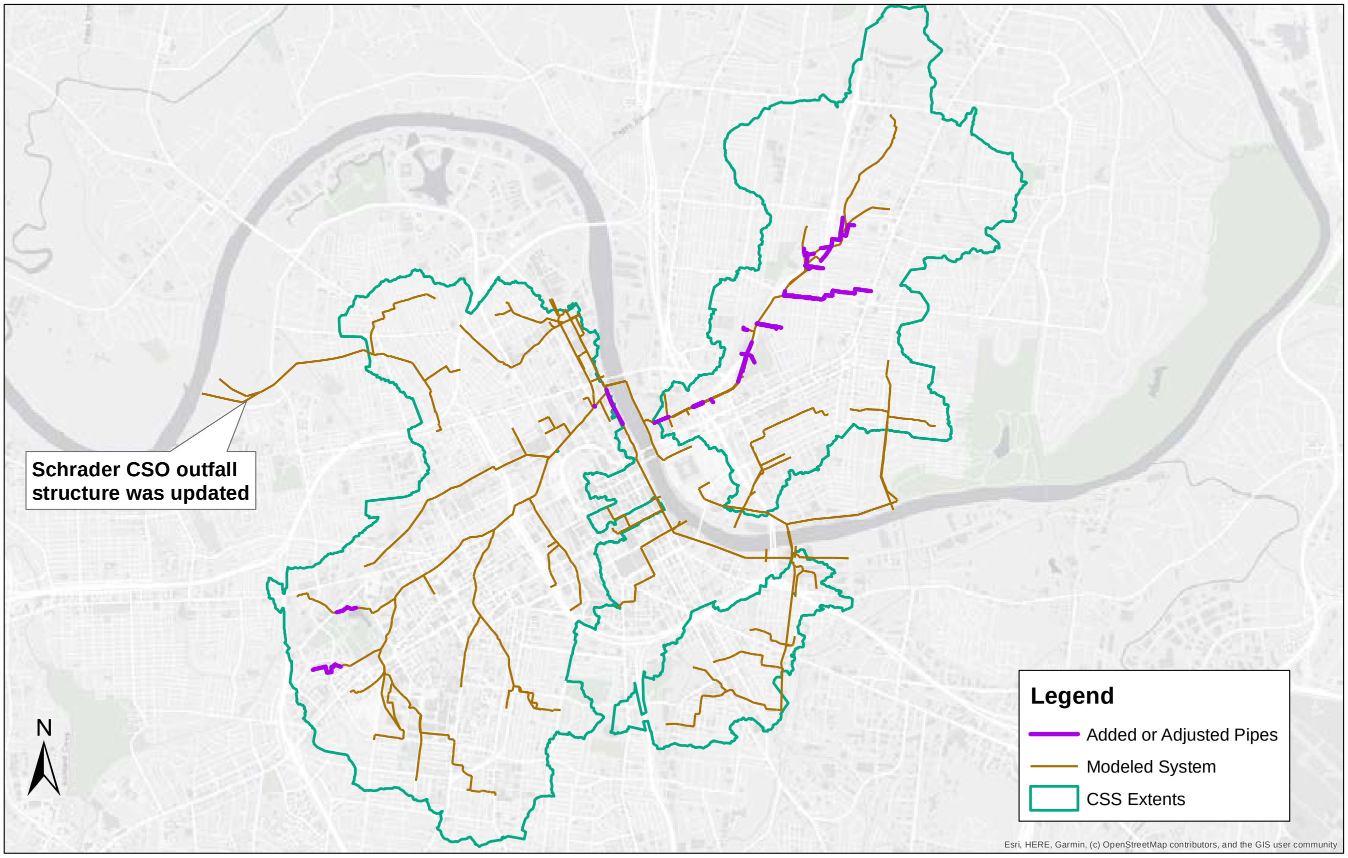

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Figure 3-1. Added or Adjusted Infrastructure

3.2.2 Revisions to Modeled Sub-Catchments

The most significant model updates were made to the model's sub-catchments. Sub-catchments represent land areas containing a mix of pervious and impervious surfaces that generate runoff when a rainfall time series is applied. These time series may be observed rainfall or synthetic storms, depending on the model's intended use. In the CSS model, runoff is generated using the Modified Green-Ampt schema.

Sub-catchments have many parameters that influence the volume and flow rate entering the system. Some parameters, such as initial abstraction and surface roughness, are applied as global factors, while others may be specific to the individual sub-catchment.

Sub-catchment parameters that were adjusted as part of the model update are described in the following subsections. The relevant sub-catchment parameters for adjusting runoff generation during model updates and calibration are soil parameters, directly or non-directly connected impervious area (DCIA and nDCIA), and flow width.

3.2.2.1 Soil Parameters

Green-Ampt soil parameters were estimated based on publicly available U.S. Department of Agriculture (USDA) soil coverages and estimates derived from Rawls (1983). Sub-catchments were intersected with USDA coverages, and an area-weighted average of soil type was applied. Soil parameters were developed in a batch process, updated in the model for all sub-catchments, and were not modified after their initial derivation.

3.2.2.2 Imperviousness

The model update included revisions to modeled imperviousness derived from the 2019 NLCD. The NLCD approximates impervious area based on land use type. Manual sampling of sub-catchments in GIS was also performed to assess the validity of these values, as was MWS's stormwater billing coverage. Manual sampling consisted of digitally rendering visible extents of impervious area from an aerial image. NLCD was generally consistent with values found in sampled areas and was commensurate in detail with those derived from land use or other rough-scale estimates. MWS's stormwater utility fee billing coverage was found to slightly underestimate imperviousness because of the lack of some driveway and outbuilding areas. **Table 3-1** displays average imperviousness by basin.

Imperviousness is a key parameter in runoff estimation and has a large bearing on both the intensity and volume of storm runoff. Imperviousness can vary on a block-by-block basis; therefore, each sub-catchment within a basin has a unique imperviousness value.

Table 3-1. Imperviousness by Combined Sewer System Basin

Basin	Imperviousness %
Benedict & Crutcher	56.3
Boscobel	47.9
Driftwood	64.4
Kerrigan	75.1
Schrader	45.4
Van Buren	60.8
Washington	55.6
All Basins	67.6

Imperviousness is characterized further into DCIA and nDCIA. DCIA refers to impervious area that is routed directly to the collection system, whereas nDCIA may be routed to pervious surfaces before encountering the collection system. These values were derived from land. **Table 3-2** lists the default model values for percent routed.

Table 3-2. Default Model Parameter Sets

Land Use	Open Land	Pasture/ Golf Course	Medium-Density Residential	High-Density Residential	Commercial/ Light Industrial	Heavy Industrial
DCIA	1	1	23	65	81	81
Pervious Manning's n	0.4	0.3	0.25	0.25	0.25	0.25
% Routed to Pervious	100	80	34	21	10	10

3.2.2.3 Slope and Width

CDM Smith also reviewed and standardized sub-catchment slopes and widths as part of CDM Smith's updates to sub-catchments. Sub-catchment slopes influence the time of concentration of a basin and the intensity of peak runoff. A digital elevation model (DEM) was used to estimate a representative longest flow path from high to low areas of each sub-catchment, like the length that would be used to calculate time of concentration. Representative flow paths were derived in GIS and verified for each sub-catchment. The rise over run of these paths provides the sub-catchment's slope. Slopes vary in Nashville's topographically diverse neighborhoods. The mean slope among all modeled sub-catchments is 4.1 percent, with the maximum modeled slope of 12.8 percent found in a small sub-catchment in Boscobel.

Sub-catchment width also affects the shape of the runoff hydrograph. It can be estimated as the sub-catchment area divided by the length of the longest flow path; this calculation is performed automatically by PCSWMM. Ideally, sub-catchment length-to-width ratios are less than 10:1.

3.2.2.4 Initial Abstraction

Initial abstraction or depression storage is a measure of the influence of small depressions and surfaces on runoff generated by the model. Surfaces include features such as tree leaves and buildings that capture and store rainfall. Like imperviousness, initial abstraction can be determined from land use. Standard values of 0.1 inch for impervious areas and 0.25 inches for pervious areas were used in the updated model. While high concentrations of factors such as low impact development (LID), forest cover, or urban development can influence these values, these parameters were fixed in the updated model in conformance with common engineering practice.

3.2.2.5 Surface Roughness (Manning's n for Sub-Catchments)

Manning's n value for sub-catchments measures the roughness of the overland surface that generates runoff. Surface roughness controls the shape of the hydrograph (along with sub-catchment slope and width) and affects the peak flow entering the CSS. A standard value is assumed for the entirety of each sub-catchment. These values are derived by land use and separate values are used for pervious and impervious surfaces. Through the model update, impervious surfaces were given the universal value of 0.02. **Table 3-2** provide pervious n values used in the model and the values vary by land use. These values are derived from the South Florida Water Management District's 2004 guidance for overland flow and are in general agreement with EPA's *Storm Water Management Model User's Manual Version 5.1* and other sources. Pervious n values may be higher than standard roughness values used for channelized flow. During model validation, which is discussed further in **Section 3.3**, the fitness provided by these values was satisfactory for the observed peak flows in the system.

3.2.2.6 Subarea Routing

Subarea routing in sub-catchments is set to PERVIOUS, which allows a portion of runoff from impervious areas to be applied first to pervious surfaces before being applied to the model network. This represents a scenario such as a roof that is routed to a lawn or grass strip. This percent-routed value is derived from area-weighted land use and varies in the LTCP model from 15 to 66 percent. **Table 3-2** shows the percent-routed assumptions based on land use.

3.2.3 Surface Features and Overland Flows

The model update also incorporated surface features that allowed the assessment of flooding depths and the depiction of overland flows. These features allow the model to better simulate the system's response to large rainfall events when the capacity of the CSS may be exceeded.

Stage–storage relationships are created from the topography of each sub-catchment's surface area and are represented in the model as curves. They were developed and applied at sub-catchment load points. These storage nodes allow water levels to rise at a rate commensurate with the volume of available surface ponding in the local area. This allows the models to use a "quasi-2D" representation of surface flow. The depths at these locations then are used to render flood extents to evaluate model-predicted flooding and to determine the efficacy of alternatives defined by the Master Plan.

Overland flows are open-channel conveyances that use transects derived from a DEM. They represent pathways that runoff takes when the collection system's capacity is exhausted. In urban environments, these are often roadways, though they include roadside swales, open land, and other routes that connect flooding locations. Overland flows connect stage–storage load points and allow water to equalize and travel among sub-catchments. They are given a short length to balance real-world travel time and the potentially unnecessary application of extra volume to the modeled system. Without these overland connections, stages may be rendered artificially high as they depend exclusively on the sewer network to convey flow. **Figure 3-2** shows a typical overland flow cross section from the model. The blue area represents flow depth during the modeled storm event.

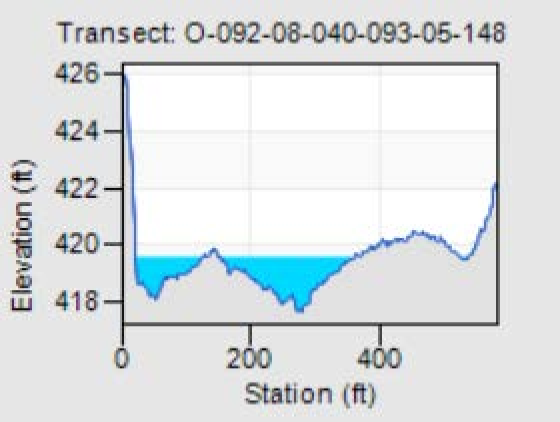


Figure 3-2.Typical Modeled Cross Section for Overland Flow

Each roadway within the combined area is not modeled; 187 overland flow paths exist within the model space. These locations were chosen based on perceived surcharging in the pipe system and previously identified flooding locations. If an area of the system is not experiencing capacity issues in the model, overland flows were not deemed necessary and were not developed.

3.2.4 Other Key Model Features

Although the following model features were not significantly changed during the model update, they are described below due to their potential impacts on model results.

3.2.4.1 Dry-Weather Flows

Modeled dry-weather flow represents sanitary wastewater flow from residential, commercial, institutional, and industrial sources as well as ambient dry-weather groundwater infiltration.

Dry-weather flow is loaded at junctions or storage nodes. Each load has unique diurnal and seasonal patterns that influence the temporal variation of these flows. Patterns and volumes are typically developed from observed flow data and may be revised as new data become available. No changes to existing dry-weather flows or their allocation were made as part of the model updates. **Section 2.3.1** describes the development of future dry-weather flows.

3.2.4.2 Groundwater

Although no significant alternations to groundwater elements were incorporated as part of the model update, groundwater and aquifers are included in the model to simulate groundwater infiltration and long-period wet-weather flow response. Not all sub-catchments have a groundwater component in the model. These components were added at AECOM's discretion to fit the long-term runoff responses observed in monitor data. The A1 and B1 parameters in SWMM are the controlling parameters for groundwater flow generation. These values determine the length and magnitude of responses like those in unit hydrographs. Aquifers are the practical "holding place" for groundwater flow in the model. They are subject to evaporation and infiltration to deeper subsurface layers, which determines depth to water table and, thus, the amount of groundwater discharged to the system. Evaporation varies by month, while infiltration rates are SWMM defaults.

Sub-catchments that feature groundwater application may see that component as a significant percentage of total pipe network flow. Groundwater flow is generally more significant in inter-storm event periods during extended simulations rather than in a short, high-intensity event. This is because of the slower rate of groundwater discharge compared to runoff. For example, in a 10-year, 24-hour storm event, an average of 2 percent of total flow from sub-catchments is derived from groundwater contributions, whereas a typical year run averages 31 percent of its total flow from sub-catchments as groundwater. (**Section 4** provides descriptions of design storms and the typical year.)

3.2.4.3 Rainfall-Derived Infiltration and Inflow

Rainfall-derived infiltration and inflow (RDII) represents the fraction of rainfall that enters a sanitary sewer system through system defects. It is applied only in areas that have separate sanitary sewer systems (as opposed to combined sewer systems), such as the Demonbreun area that underwent sewer separation in the 1990s. The sewershed size is the most significant parameter in RDII hydrograph generation, followed by the local area's unit hydrograph. Existing hydrographs were not adjusted, and no new hydrographs were derived for the CSS model update.

3.3 Model Validation

The updated model was compared against the original model and calibration data to ensure its validity. The updated model was run for calibration periods in 2017, 2019, and 2020 to assess the fitness of parameters across multiple basins. Collaboration between CDM Smith and AECOM, the original developers of the CSS model for the LTCP, was necessary to ensure that the key components of runoff and peak flows were being captured and that model elements that did not need modification were kept intact. Part of AECOM's chosen criteria for calibration is that peak flows fall within -15 to +25 percent of observed values, and that volumes fall within -10 to +20 percent of observed values.

These criteria also were used as a gauge for the impact of model updates by comparing peak flows and volumes between the original model and the updated model.

In the Schrader basin (2017), adjustments to the model yielded peak flow values within -15 to +25 percent of the original model in wet-weather calibration events at six of seven monitors during the March 14, March 23, and April 6 rainfall events. Runoff volumes were generally higher than the original model, though well-matched with the observed data. Volumes fell within -10 to +20 percent of the original LTCP model at six of seven monitors.

In Benedict & Crutcher and Boscobel basins (2019), adjustments to the model yielded peak flow values within -15 to +25 percent of the original model in wet-weather calibration events at 13 of the 17 monitors during the February 6, 10, and 21, and March 28 events. Volumes fell within -10 to +20 percent of the original model at 14 of the 17 monitors. Like Schrader, runoff volumes were generally higher than the previous model, though the fit to observed data was not greatly impacted.

In the Kerrigan basin (2020), adjustments to the model yielded peak flow values within -15 to +25 percent of the original LTCP model in wet-weather calibration events at 25 of the 32 monitors during the February 4, 10, and 24, and March 2 events. Volumes fell within -10 to +20 percent of the original LTCP model at 23 of the 32 monitors. Trends in volume were mixed in Kerrigan. Many monitors exhibit high fluctuations in flow behavior, particularly near the siphons that connect to the FAT.

From a model performance standpoint, continuity error improved by approximately 0.5 percent, and model "flooding," which is a metric for flow that leaves the simulated system during a storm event and does not return, was eliminated. The latter was expected because of the incorporation of surface features and overland flow as described in **Section 3.2.3.**

The final step in the model validation process was to compare model-predicted CSO statistics under the typical year to confirm the updated model remained consistent with LTCP modeling efforts. (**Section 4.2** provides a description and more information on the typical year.)

Table 3-3 displays the pre- and post-update values for activations and volumes at each CSO. Except for Schrader, activations were maintained or decreased, while volume was increased at all locations except Benedict & Crutcher. This increase in CSO volume was reviewed and was determined to be reasonable based on the following factors:

- Observed flow data were better matched, particularly in the post-event decay performance of the hydrographs.
- Addition of overland flows prevented more intense storm flows from exiting the system via SWMM's flooding mechanism.

Table 3-3. Pre- and Post-Update Combined Sewer Overflow Statistics

CSO Location	Benedict & Crutcher	Boscobel	Kerrigan	Schrader	Washington
Pre-Update Activations	22	17	30	22	17
Post-Update Activations	22	16	25	25	18
Pre-Update Volume (MG)	33	9	668	24	133
Post-Update Volume (MG)	32	13	892	43	224

Driftwood does not have activations in the typical year in the previous or updated models.

In addition to the points described above, Schrader's increase in activations and volume may be linked to an update of infrastructure at the regulator based on a review of record drawings conducted during the Master Plan's development.

Following the calibration of the Washington basin in 2023, Washington exhibited 18 CSO activations and 224 MG of CSO volume for the typical year. Because of the additional updates within the basin, this change was found to be reasonable, and a memo detailing the calibration of Washington was prepared by AECOM in the summer of 2023.

After a review of the model results by the CDM Smith and AECOM modeling teams, the models' discrepancy in volume and activations were considered reasonable, and the model updates were applied to all models used in the Master Plan.

3.4 Model Limitations

When modeling a complex system, many assumptions must be made to create a model that is useful, concise, and representative. The following assumptions and limitations are noted:

- Model reporting time steps are in 15-minute increments. This is consistent with the granularity of the rainfall time series' data, which only varies its intensity every 15 minutes during calibration exercises and design storms.
- The condition of pipes and manholes is assumed to be generally commensurate with the age of the system unless field observations or survey have provided additional detail. This affects the roughness and losses used in the model. Pipes are assumed to be free of sediment unless calibration exercises have indicated its presence.
- The minor system (stormwater inlets, smaller-diameter pipes, and laterals) is not modeled and thus its capacity is not evaluated.
- Some portions of the model have not had a detailed calibration performed in many years, including upstream parts of Driftwood and Van Buren.
- During model calibrations, the observed amount of runoff entering the system is considered a reflection of inlet performance. Inlets in non-calibrated areas, which includes improvements, are assumed to be working properly; that is, any flow generated from runoff could enter the system at its local load point and is not inlet-limited.
- Pumps and other operations data are logic-controlled and do not reflect situations introduced by operational decisions.
- LiDAR data from 2016 were used to generate stage–storage curves, overland transects, and flood depths from model results. In areas with recent development, the land surface may vary from these values.

4.0 Approach to System Analyses

4.0 Approach to System Analyses

Following its update and validation, CSS model was used to simulate the system's performance under a variety of design conditions. A description of the storms analyzed, potential impacts caused by Cumberland River levels, and Metro's stormwater levels of service (LOS) are described below. This section also presents the development of the baseline model, as well as key criteria for evaluating system performance.

4.1 Design Storms

A range of design storms was used to evaluate capacity limitations within the CSS and assess flooding. These include the 2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour design storms. Design storms with a 2-year recurrence interval have a 50 percent chance of being exceeded in any given year; a 100-year recurrence interval represents a 1 percent chance.

The 24-hour depths obtained from Chapter 2 of Metro's *Stormwater Management Manual, Volume 2* were compared to National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation frequency estimates for the Nashville International Airport. Note that the estimated values from Atlas 14 vary across Davidson County, with the 100-year, 24-hour storm increasing by approximately 0.5 inches in the southwest part of the county. As shown in **Table 4-1**, except for the 2-year estimate, the 24-hour storm depths from the *Stormwater Management Manual* are outside (higher) than the 90 percent confidence interval presented by NOAA. This suggests that the design storms volumes from Volume 2 are conservative when considering the 24-hour duration.

Table 4-1. Twenty-Four–Hour Design Storm Depths

Average Recurrence Interval (years)	24-hour Depth from Metro's Manual (inches)[1]	Atlas 14 24-hour Depth at the Nashville Airport (inches)[2]	Range of 24-hour Depth from Atlas 14 (inches)[3]
2	3.39	3.37	3.19–3.59
5	4.50	4.11	3.88–4.36
10	5.23	4.70	4.44–4.99
25	6.16	5.53	5.21–5.87
50	6.85	6.20	5.82–6.57
100	7.53	6.89	6.44–7.30

[1] 24-hour depth from Metro's *Stormwater Management Manual, Volume 2*.
[2] 24-hour depth used for this study. Atlas 14 values vary noticeably across the MWS service area.
[3] Range represents the upper and lower bounds of the 90 percent confidence interval established by NOAA Atlas 14 for the Nashville International Airport.

With a range of 24-hour design-storm depths estimated, a time variable distribution (hyetograph) is also required for use in the analysis. Metro's *Stormwater Management Manual* includes dimensionless graphical and tabular hyetographs that are based on a balanced storm approach. This approach assumes the peak intensity occurs at the midpoint of the storm event, or at hour 12 for a 24-hour event.

Because of the small sub-catchments and short times of concentration of urban applications, a hyetograph in 15-minute increments (as opposed to hourly) was necessary. The peak 15-minute intensity from Metro's tabular hyetograph was compared to the NOAA Atlas 14 precipitation frequency estimates for 15-minute durations at each recurrence interval, as shown in **Table 4-2**. For all recurrence intervals, the value provided from Metro's tabular hyetograph is significantly lower than the lower bound of the 90 percent confidence interval provided in NOAA Atlas 14. The graphical dimensionless hyetograph presented in the *Stormwater Management Manual*, however, includes a significantly higher peak 15-minute intensity than represented in the tabular data, though they match closely when considering a peak 1-hour intensity.

Table 4-2 also provides the peak 15-minute intensity at each recurrence interval from NOAA Atlas 14. The rainfall frequency estimates from Atlas 14 were chosen for use in this study because they are based on long-term observed data and are sufficiently conservative.

Table 4-2. Peak 15-Minute Design-Storm Depths

Average Recurrence Interval (years)	Peak 15-minute Rainfall from Metro's Manual (inches)1	Peak 15-minute Rainfall from Atlas 14 at the Nashville Airport (inches)[2]	Range of Peak 15-minute Rainfall from Atlas 14 (inches)[3]
2	0.43	0.90	0.835–0.978
5	0.50	1.04	0.965–1.13
10	0.58	1.15	1.06–1.25
25	0.68	1.29	1.18–1.40
50	0.75	1.39	1.27–1.50
100	0.83	1.48	1.34–1.61

[1] Peak 15-minute depth from Table 2-2 of Metro's *Stormwater Management Manual, Volume 2*.
[2] Peak 15-minute depth used for this study.
[3] Range represents the upper and lower bounds of the 90 percent confidence interval established by NOAA Atlas 14.

A Soil Conservation Service (SCS) Type II distribution was evaluated for use in this study, though its peak 15-minute value of 2.09 inches in the 100-year event was considered too conservative and well outside the range of NOAA's confidence intervals. Instead, the study uses a balanced hyteograph that was developed from the NOAA Atlas 14 data. This approach provides a hyteograph that embeds rainfall estimates for the same recurrence interval for each time increment of the storm. In other words, for the 24-hour storm, it assumes the peak 15-minute rainfall occurs at the midpoint of the storm, i.e., at noon, but also includes the rainfall estimates for durations of 30 minutes, 1 hour, etc., to 24 hours.

An areal reduction factor for rainfall was evaluated but not used in this analysis. For an area the size of the CSS, 12.6 square miles, the areal reduction factor for rainfall is approximately 7% when considering a 1-hour storm depth. While this reduction factor may be appropriate for a system this large, the individual drainage basins are often much smaller (less than 1 square mile), and an estimated areal reduction factor would be minimal in those scenarios.

Storm events with shorter total durations (less than 24 hours) were examined for their potential impacts in determining the size of alternatives, though it was decided not to pursue their use in this study. Shorter storms are more sensitive to the influence of dry soils and initial abstraction, which are exhausted early in a 24-hour event.

4.2 Typical Year Rainfall

The CSO level of control analyzed in the LTCP is based on the establishment of a typical year. Similar to an individual design storm, the typical year is simulated in the model to understand the system's performance under existing conditions and analyze the effectiveness of potential improvements. Unlike individual design storms, the typical year contains storms of various depths, durations, intensities, and groundwater conditions. When modeled, it can be used to understand the frequency, volume, and duration of CSO events throughout the simulation period.

During the development of the LTCP, 54 years of rainfall records for the Nashville International Airport were examined to select a period representing average annual rainfall conditions. The year 1995 was selected as the representative year, and its observed hourly rainfall time series serves as the basis for modeling associated with the LTCP.

Because the typical year represents average rainfall conditions, it does not contain storm events with high recurrence periods, which are less likely to occur during any given year. Those larger storms, as described in **Section 4.1**, serve as the basis of the Master Plan. However, as alternatives were evaluated to address flooding within the CSS, it was important to also understand potential impacts to CSOs. Those analyses used the typical year to compare results with and without a given improvement.

4.3 Rainfall Intensity Uncertainty

Although conservative in practice, the selection of a 100-year, 24-hour event as the LOS accepts that there is a small but non-zero chance that conditions could exhaust the capacity of any improvements. Rainfall intensities far greater than a 100-year, 24-hour event have been observed in Middle Tennessee in recent years. Three particular events are demonstrative of these rare intensities and their impact: the May 2010 floods in Davidson County, in which more than 13 inches of rain fell in two days, resulting in the deaths of 10 people; flooding in Humphries County in August of 2021, totaling more than 17 inches of rain in a 24-hour period, which resulted in the deaths of 20 people; and flash floods in southern Davidson County in March of 2021, totaling 7 inches in 6 hours, which resulted in the deaths of seven people. Although intensities of this magnitude were not explicitly assessed, improvements considered in this report are likely to improve drainage capabilities in these rare storm events.

Although not investigated as part of this Master Plan, the impact of climate change on rainfall intensity may result in the modification of design-storm standards in the future. These modifications, likely by way of NOAA Atlas 15, which is scheduled for publication in 2025–2026, may give higher rainfall volumes and intensities than current values. These modifications may not render alternatives obsolete, but they may reduce the LOS of constructed features. It will be imperative that design standards continue to evolve as rainfall trends become clearer.

4.4 Cumberland River Impacts

The Cumberland River is the eventual outfall for all of Metro Nashville's stormwater conveyances and CSO discharge points. Its flows and levels are controlled by the operation of dams both upstream and downstream of Nashville. Old Hickory Dam and J. Percy Priest Dam, both upstream, are the primary drivers for levels in the portions of the Cumberland River in the Nashville area. The Cheatham Dam in Ashland City, downstream of Metro Nashville, also influences the stage of the Cumberland in the CSS area. The Cheatham Dam is critical in maintaining a minimum level, known as navigable pool. The target navigable pool in downtown Nashville is 385 feet North American Vertical Datum of 1988 (NAVD88). During dry periods, the river is often maintained at 385 feet for long periods of time. The Cumberland also experiences significant seasonal fluctuation that can elevate river levels for many months out of the year. According to the National Weather Service's Public Information Statement on the flood of May 2010, river levels at downtown Nashville peaked at 419.31 feet, the highest level on record since the river came under the influence of the dam system in the 1930s. The National Weather Service defines action stage at 398.1, flood stage at 408.1, moderate flood stage at 410.1, and major flood stage at 413.1.

Table 4-3 summarizes the results of an analysis of river levels at Demonbreun Street from 2012 to 2021. Hourly river levels for this period were compiled and their percentiles determined to assist in understanding how often river levels are *at or above* that stage. River levels, their percentile, and their frequency are given in average days per year.

Table 4-3. Cumberland River Stages

River Stage (feet NAVD88)	Percentile	Number of Days per Calendar Year at or above Stage
385	20th	300+
386	48th	190
389	68th	117
392	83rd	62
395	93rd	26
398	97th	12
401	99th	4

River levels are used in the modeling analysis to assess the river's influence on the CSS or stormwater system's ability to discharge to the river. The values are applied at the model's outfalls as a fixed boundary condition in design storms and as a time series representing observed stages during calibration simulations. Higher river levels may significantly submerge outfall locations, reducing the rate of discharge. In the typical year analysis used for CSO modeling, the river is kept at 385 feet NAVD88; this minimizes the river's influence. For the modeling of potential improvements, the river level has been set at levels ranging from 385 to 408 feet NAVD88 to determine whether the river may impede the improvements' drainage capabilities and, if so, beginning at what level.

4.5 Stormwater Design Criteria

When assessing the drainage capabilities of a stormwater system, an appropriate baseline for its expected performance must be established. This also applies to the CSS since it serves as the stormwater network.

Metro has established guidelines, criteria, and procedures for stormwater management activities, as described in the *Stormwater Management Manual*. That information is focused primarily on stormwater management practices associated with development, though key elements from that program are applicable to this study.

The *Stormwater Management Manual, Volume 1* defines minor and major systems of a stormwater management network. Minor systems include appurtenances such as inlets, manholes, roadside ditches, and small channels or pipes. Major systems may consist of natural waterways, large storm sewers, and major culverts. Major systems receive flow from minor systems but also account for overland flow paths when minor systems are exhausted. The CSS model and the extents of this study are limited to the major system.

Based on review of Metro Nashville's *Stormwater Management Manual Volume 1*, Chapter 6, Metro Nashville has established the following LOS for new stormwater infrastructure in major systems:

- Closed systems should be capable of containing the 100-year design flow within the system (ground surface elevation). Designs for closed systems that cannot contain the 100-year flow should coordinate with MWS during the preliminary design phase to determine a method of overland relief to safely convey storm flows.
- The major system should provide relief such that no building will be flooded with a 100-year design flow even if the minor system capacity is exceeded.
- Culverts are to be designed with upstream and downstream headwalls. The design flow for culverts must be based on the following return frequencies: 1) 100-year for residential collector and commercial road crossings and 2) 10-year for residential roads and crossings. In addition, building elevations must be checked for flooding caused by the 100-year, 24-hour storm.

These criteria are intended as guidance for new systems. The goal of this Master Plan is to provide the expected LOS for the areas directly served by the listed improvements while acknowledging that portions of the existing system may not meet that LOS. Because the CSS is highly urbanized, few culverts and open-channel conveyances are present in the physical system.

LOS criteria for the minor system require the following:

- The minor system must be based on a storm frequency of 10 years. However, if the 10-year design flow for an open-channel system is greater than 100 cubic feet per second, then the open or closed system must be capable of passing the 100-year design flow within the drainage easement.
- Inlets must be designed to convey the 10-year frequency and time of concentration storm event.
- Closed conduits must be designed for the total flow intercepted by the inlets during the design-storm event. The minimum diameter for all storm drains must be 15 inches.

The parts of the CSS modeled as part of this plan are considered to be the major system; the minor system was not analyzed. The amount of model development and the resulting analysis required to represent the minor system was not considered necessary to identify significant flooding issues and the resulting improvements required to address them. The LOS criteria for major systems were used in this plan.

A notable limitation of the modeled system is the assumption that unmodeled inlets and minor systems can convey all flow routed to them and deliver all flow to the major system. The hydraulics of the greater system typically constrain the intake of flow into the model, rather than issues with operation and maintenance of collectors. The hydraulic model also includes roadway links that simulate flow along roadways throughout the system when the minor system is exhausted. **Section 3** presents a more extensive discussion of these links.

Metro specifies that major system storm sewers must be designed for total intercepted flow based on a 100-year design storm with the duration of the event established considering the time of concentration. Using the guidance provided in the *Stormwater Management Manual* and additional discussions with Metro, conveyance alternatives consider sizing based on both the 10-year and 100-year design storms. Improvements fully convey the 10-year design storm without surcharging. For the 100-year design storm, system surcharging is acceptable and limited surface flow in aboveground elements is permissible if that flow does not impact homes, roadways, or other structures.

4.6 Baseline Model Development

As discussed in previous sections, several projects identified in the LTCP and its addenda are currently under construction, in design, or planned. These projects, which are described in the following subsections, include:

- Sewer separation to eliminate Benedict & Crutcher, Boscobel, and Schrader CSOs
- Pumping improvements at CPS to 240 MGD
- A dynamic weir at the SAT regulator (Kerrigan)
- Continued maintenance of FAT/SAT to ensure full capacity for conveyance

These projects form a baseline condition for the assessment of additional alternatives. All proposed results consider these projects to be complete and operating as intended.

4.6.1 Sewer Separation in Benedict & Crutcher, Boscobel, and Schrader

As part of the LTCP's second addendum, separation was prescribed for three CSS basins: Benedict & Crutcher, Boscobel, and Schrader. This will fully eliminate the three CSO points and collectively will separate almost 1,000 acres.

The baseline conditions model includes dry-weather flow from these basins, though stormwater runoff was routed to a new stormwater network that discharges to the Cumberland River. To be conservative, a unit hydrograph to represent RDII was modeled. In historically separate areas, these unit hydrographs are derived from flow monitoring data and vary from sub-catchment to sub-catchment. For the baseline conditions model, a future R-value of 4 percent RDII is assumed. This conservative assumption allows evaluation of downstream impacts if all properties cannot be fully separated or the system deteriorates over time following construction.

The sizing and placement of separate sanitary and storm systems will be evaluated further through the design of those projects. It is assumed that the separation activities and their resulting stormwater infrastructure would be sized such that predicted flooding in these basins is mitigated. These include the following flood-prone areas identified through discussions with MWS, which were generally confirmed through modeling of the existing system (as opposed to the baseline conditions model):

- 5th Street South and Sylvan Street, Benedict & Crutcher
- Boscobel Street between 14th and 15th Streets, Boscobel
- Lillian and 15th Streets, Boscobel
- 25th Avenue and Osage Street, Schrader

This Master Plan does not evaluate or address these flooding problem areas.

The 25th Avenue and Osage Street area, though technically outside of the CSS, is adjacent to the Schrader basin. Additional review indicated that flooding was likely caused by restrictions in the open-channel flow adjacent to and downstream of the CSS. The railroad tracks approximately 500 feet west of 25th Avenue North and Osage Street appear to form a significant bottleneck for surface flow, which may be worsened by heavy brush, further restricting flow. Because the Schrader CSO outfall pipe runs through this corridor, it is recommended that this the Schrader separation project include an analysis of the hydraulics of this bottleneck and its impact of delivering higher flows to this area via a separate stormwater system.

4.6.2 Central Pumping Station

As part of the Central Wastewater Treatment Plant (CWWTP) Capacity Improvements and CSO Reduction project, CPS is being upgraded to convey up to 240 MGD into the plant for treatment. Peak plant capacity is currently 330 MGD, and the improvements project will provide more than 400 MGD of capacity when it is completed. The CPS improvements are included in the baseline conditions model in the form of an additional force main to the headworks and updated head curves in the modeled pumps. This change is one of the primary drivers for the reduction in CSO discharges at Kerrigan between the existing system CSS model and the baseline conditions model.

4.6.3 Kerrigan Dynamic Weir

At the location where the Kerrigan trunk sewer intersects SAT, a diversion weir exists that sends dry-weather flow into SAT. Currently, this weir is set at an elevation of approximately 5 feet above the invert in the 16-foot combined sewer. If stages rise beyond this point, flow moves across the weir and continues northeast to another regulator structure at FAT. The proposed modification to the weir presented in the LTCP would raise the weir to a height of 14.2 feet (388 feet NAVD88) under dry-weather and low-flow conditions. However, it will allow the weir to be lowered during larger events when surcharging caused by the higher weir may negatively impact the upstream system.

Since storms included in the typical year are generally smaller, less-intense events, the higher weir elevation provided the Kerrigan Dynamic Weir benefits performance of the Kerrigan CSO. However, because this Master Plan focuses on larger storm events, a design-storm analysis was performed with the weir both up and down to determine the threshold at which operating the weir in an up position could introduce flooding in Kerrigan.

It was determined that the 10-year storm event was the inflection point beyond which CSO reduction was diminished, and the resulting grade line in the Kerrigan brick sewer was high enough to increase upstream surface flooding. If the dynamic weir can be operated in such a way that it can be lowered when a storm intensity greater than a 10-year storm event is anticipated, the weir would be a valuable addition for CSO reduction.

During the weir investigation, the most significant factor for weir performance was the level of the Cumberland River. Beginning at a river level of 389 feet NAVD88, which is approximately the 70th percentile, the influence of the river's level controls the weir's performance. For nearly four months of the year, the river level may limit the efficacy of the weir's intended operation.

Based on this information, and the guidance that larger design storms would see negative impacts from its operation, the Kerrigan Dynamic Weir is assumed to be *down* for all design-storm results presented in the following sections and *up* for the typical year analyses. The diligent operation of the Kerrigan Weir will be an important factor in gaining the desired benefits from alternatives.

4.6.4 First and Second Avenue Tunnels

FAT and SAT are critical conveyance paths to deliver flows from the CSS to CPS. Initial model calibrations performed by AECOM to support the LTCP development included significant sediment accumulation along both FAT and SAT. FAT was estimated to be 20 percent full of sediment along its 14,000-foot length, and SAT was estimated to be 50 percent full of sediment for a 180-foot section near CPS. The presence and proliferation of sediment was not confirmed because of the deep and difficult-to-access nature of the tunnels, though the presence of sediment and large debris was considered likely.

Following the May 2010 flood, FAT was cleaned from the Driftwood facility to the junction with Kerrigan, which removed significant quantities of debris, including some boulder-sized rocks. That confirmed the initial modeling assumptions in that area, but the condition of SAT and the part of FAT between Kerrigan and CPS remains unknown.

As part of the baseline model, these sediment blockages were assumed to be removed. This results in the unrestricted performance of FAT and SAT. Ongoing maintenance of the tunnels will increase the likelihood of success for the improvements provided by this plan.

4.7 Flooding Evaluation Criteria

With establishment of design storms, Cumberland River levels, and the baseline model, conditions causing flooding and potential improvements to remedy those conditions can be evaluated further. Defining an improvement's effectiveness requires additional parameters to quantify the benefits of the reduction in flooding. Common flood mitigation goals include maintaining passable roads for emergency vehicles and controlling flood stages below roads, homes, and other buildings. This distinction is important because flooding that may occur in open areas such as parks and roadway medians may be frequent and visible but not critical to mitigate.

MWS evaluates flooding issues and generally prioritizes the implementation of potential solutions based on the following, in order of importance:

1. **Life and Safety:** Protecting human life and safety is of utmost importance in flood mitigation.
2. **Property Damage:** Evaluating the potential damage to properties caused by flooding is another crucial aspect.
3. **Nuisance Flooding:** Addressing nuisance flooding, which does not threaten life or safety and does not cause property damage, is also important, though to a lesser extent.

For purposes of this study, those general priorities were translated into metrics that can be more clearly used to evaluate how potential projects may reduce flooding. In addition to visually reviewing the extent and depth of flooding predicted through inundation maps, building and roads impacted were also tracked to understand the benefits and limitations of potential projects.

Buildings are considered impacted if the model-predicted flooding intersects with the building footprint provided in Metro's GIS. The evaluation of finished floor elevations relative to predicted flooding is outside the scope of this work; however, even if finished floor elevations are higher than the predicted flooding, these properties are still considered exposed to risk.

Roadways are considered impacted if they are inundated with 6 inches or more of water at their crown; however, tracking of road impacts is limited to critical roadways. These include interstates, freeways, major roads, and minor roads as defined in Metro's GIS. These represent corridors with high traffic volumes and are critical to the passage of emergency vehicles. Impacts to local roads and alleys were generally not tracked separately unless identified as significant through discussions with MWS.

In addition to flood reduction, this study also must consider the impact of alternatives on CSOs. How MWS addresses flooding issues within the CSS has the potential to significantly impact CSO discharges. If flooding is addressed by directing additional flow to the CSS, CSO discharges may increase. Conversely, if flooding is addressed by removing stormwater from the CSS and routing it through new stormwater infrastructure, CSO performance may improve. Therefore, the alternatives analysis includes a summary of any changes in the frequency and volume of CSO activations during the typical year.

Lastly, the analysis considers the potential benefits of partnerships for near-future development projects. Infrastructure improvements in areas of rapid redevelopment can be coordinated with private development projects for mutual cost savings or allow for the development to progress in a different form or function.

5.0 Model Results and Approach to Alternatives

5.0 Model Results and Approach to Alternatives

The updated CSS model was used to simulate existing and future conditions to understand the impacts of growth and evaluate the extent of flooding predicted. Model-predicted flooding locations were compared to flood-prone areas identified through discussions with MWS, allowing an assessment of the storm conditions that cause flooding. This section includes a discussion of the methodology for alternatives evaluation.

5.1 Existing and Future Dry-Weather Flow Conditions

The total CSS area currently has an average dry-weather flow of roughly 38.3 MGD. This value varies throughout the year because of seasonal groundwater infiltration, which is highest in the winter and spring. This is accounted for in the model by an application of a monthly factor that increases flow by 15 percent from January through May, resulting in dry-weather flows of roughly 44 MGD during those months.

As detailed in **Section 2.3**, an additional 3.4 MGD of flow is anticipated by the year 2045, resulting in a dry-weather flow of 41.7 MGD in the summer and fall months and roughly 48 MGD in the winter and spring. This flow is applied throughout the model at locations nearest the census block where the individual flow values were derived. Increases in dry-weather flow have an impact on CSO activations and volume but are considered negligible in high-intensity storm events where peak flows are orders of magnitude higher.

An assessment was made comparing the existing system's dry-weather capacity to the system with 2045 dry-weather flow. In existing conditions, approximately 19 percent of the CSS is flowing 25 percent full or higher during periods of high seasonal groundwater infiltration. With 2045 flow projections, this number grows to 25 percent of the system. This increase represents an additional 15,000 linear feet of CSS flowing at or above 25 percent full.

As discussed in **Section 2.3**, the 2045 flow projections, which use 2017 as the base, are generally thought to be understated in high-growth areas.

5.2 Model-Predicted Capacity Limitations

The updated CSS model representing existing conditions, i.e., not future/2045 or baseline conditions, was used to evaluate the capacity of modeled CSS network under the 10-year storm. This is assessed by locating pipes that are full or surcharged during the peak of the storm. The "d/D" value is the ratio of flow depth–to–pipe diameter. If d/D is 1, the pipe is full. This may not correspond directly with an individual pipe's direct capacity to convey flow, because the pipe may be full as a result of downstream conditions. **Figure 5-1** shows the modeled combined sewers that are full or surcharged during the 10-year, 24-hour design storm. **Table 5-1** summarizes the sewers by pipe diameter. More than 173,000 feet (32.8 miles) of combined sewer is shown as surcharging under the 10-year, 24-hour storm. This represents 69 percent of the closed conduits in the modeled system. This does not include local service lines and smaller-diameter conveyances that the LTCP model does not include. It also does not include open-channel conveyances.

As shown in the figure, full or surcharged pipes are predicted for nearly the entire length of each major conveyance in the CSS model, including the Kerrigan trunk, the Washington trunk, FAT, SAT, and the Lewis Street Tunnel.

Table 5-1. Surcharged Sewers During the Existing System 10-Year Design Storm

Conduit Type	Diameter/Size (inches)	Length Surcharged (feet)	Percent of Total Length
Circular	<36	39,741	73
	36	13,707	54
	42	16,400	66
	48	19,214	71
	54	5,402	67
	60	5,219	54
	66	6,582	62
	72	18,296	84
	84	9,184	71
	96	4,523	36
	>96	33,641	84
Box Culvert	Any	1,260	54
Total		173,169	69

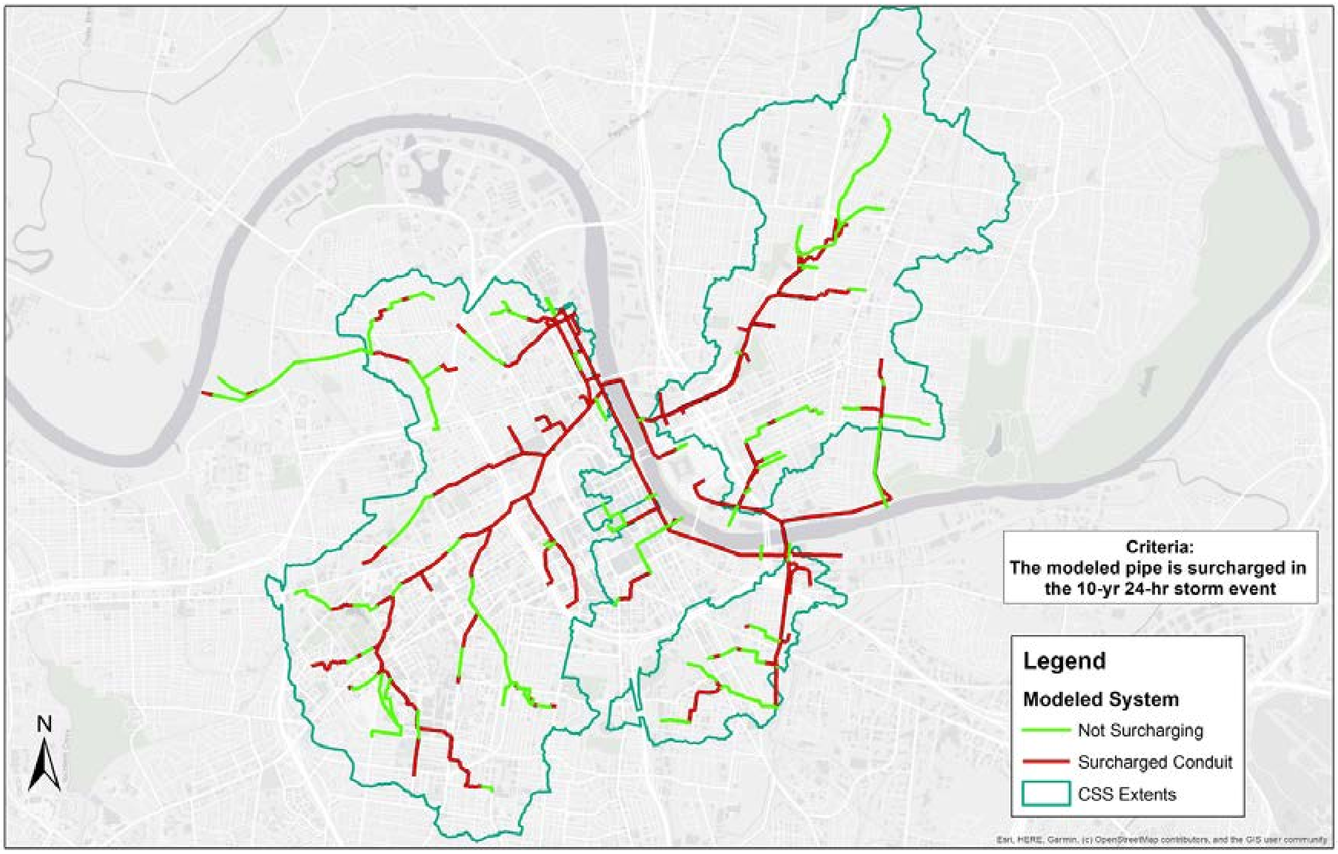


Figure 5-1. Surcharge Evaluation for a 10-Year, 24-Hour Event

5.3 Model-Predicted Flooding

The updated CSS model representing existing conditions also was used to assess model-predicted flooding relative to observed flood-prone areas. Design storms with recurrence intervals ranging from 2 years to 100 years were simulated for this comparison. **Section 2.2** shows flood-prone areas identified through research and discussions with MWS.

In some cases, the model did not predict flooding at a location that was identified as a flooding issue. This could be because of two primary factors:

- Flooding was related to maintenance or a malfunction of the local system.
- Flooding was in an isolated area of the minor system not captured by the scope of the CSS model.

Two occasions of the model not simulating a listed flooding problem area were observed. These locations are near one another in Midtown, 323 21st Avenue North and 23rd Avenue North near Tristar Hospital. These locations did not exhibit modeled flooding in the 100-year, 24-hour storm.

Likewise, simulated flooding occurred at some locations where flooding had not been reported in the system. There are four occurrences of this, three of which were added to the list of problem areas to be assessed:

- 5th Street South and Sylvan Street in Benedict & Crutcher
- Houston Street between Martin Street and 4th Avenue in Driftwood
- 2nd Avenue North and Madison Street in Kerrigan

MWS did not identify these locations initially in the flood location analysis, but they were included based on their relatively high model-predicted frequency of occurrence. Another model-predicted location at Hermitage Avenue and Driftwood did not present an issue with roadways or potential property damage and was not considered for improvement alternatives.

After a review of the updated model, the model-predicted flooding areas were consolidated to 18 locations based on their proximity to one another and nature of their flooding issues. The consolidation also considered the ability of the model to portray distinct flooding extents. For instance, though flooding may occur on Bicentennial Mall and Rosa Parks Boulevard, these locations were functionally identical in their hydraulic condition despite being several hundred yards apart. The locations given in this analysis may refer to multiple blocks and encompass several properties. In these cases, a shorthand name is given to them to promote ease of discussion, such as Farmers Market for the aforementioned example.

Table 5-2 and **Figure 5-2** present the consolidated locations. **Table 5-2** identifies the storm event with the lowest intensity in which model-predicted flooding intersects a structure or is 6 inches above roadway crown on a major or minor road.

Table 5-2. Consolidated Flooding Problem Areas

Location	Basin	Smallest Design Storm with Observed Flooding (years)
5th Street North and Sylvan Street	Benedict & Crutcher	5
14th Street between Fatherland Street and Forrest Avenue	Boscobel	2
Boscobel Street between 14th and 15th Streets	Boscobel	2
Houston Street between Martin Street and 4th Avenue	Driftwood	5
Jo Johnston Avenue and 10th Circle North through Capitol View	Kerrigan	2
Rosa Parks Boulevard between 10th Circle North and Jefferson Street (Farmers Market)	Kerrigan	2
25th and 24th Avenues South of Highland (VA Hospital Parking Garage)	Kerrigan	5
Herman Street and 10th Avenue North	Kerrigan	5
25th Avenue North and Brandau Place	Kerrigan	5
12th and 14th Avenues North near Herman Street	Kerrigan	10
Charlotte Avenue Between I-24 and 17th Avenue	Kerrigan	10
31st Avenue North and Long Boulevard	Kerrigan	10
2nd Avenue North and Madison Street	Kerrigan	25
21st Avenue South and Wedgewood Avenue	Kerrigan	25
West End and Natchez Trace	Kerrigan	100
25th Avenue North and Osage Street	Schrader	10
Ellington Parkway, including Cleveland and West Eastland Streets	Washington	2
Upstream of Apex, including Sharpe Avenue	Washington	25

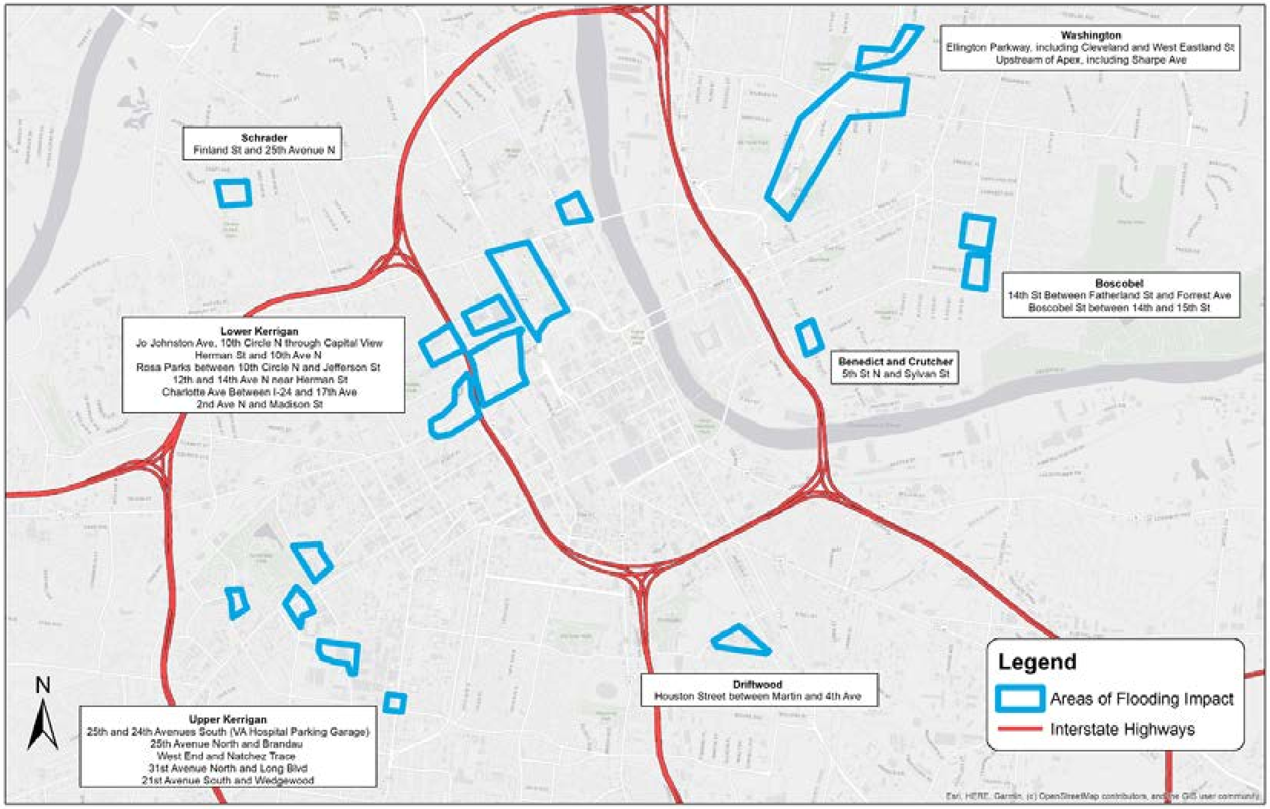


Figure 5-2. Consolidated Problem Areas

Figure 5-3 through **Figure 5-8** map simulated flood extents for each design storm. **Section 6** presents detailed views of these flood extents. These flood extents were created with GIS using a DEM and relevant SWMM output. This process uses the maximum hydraulic grade line of each load point in the model along with approximate ground surface elevation to produce a map of predicted flood depths and extents. The State of Tennessee LiDAR Program produced the DEM used in this study in 2016. It has a 1-meter by 1-meter resolution. Land surface elevations change over time as areas are developed or improved. Locations in which unusually low areas exist, such as parking garages or large excavations associated with construction projects, were removed on a discretionary basis. Smaller BMPs and stormwater ponds were not removed, because they are intended to hold stormwater.

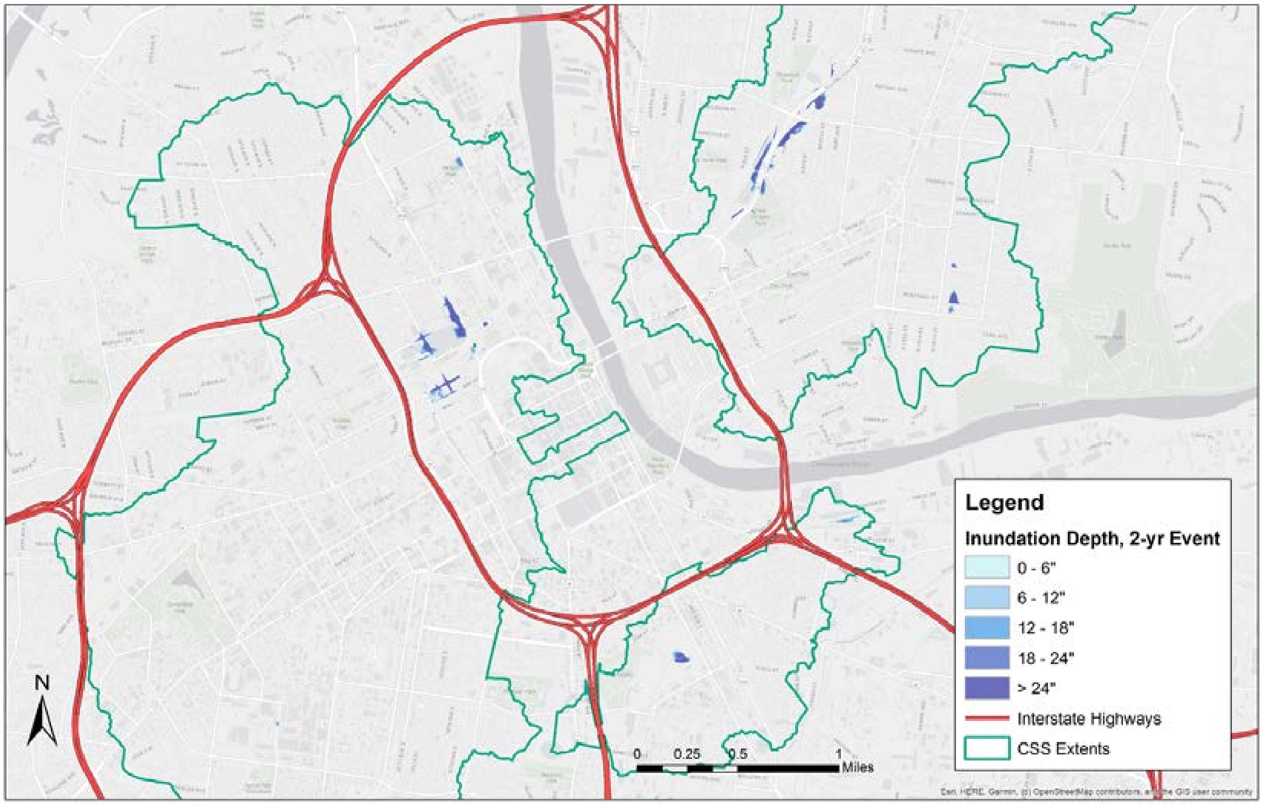


Figure 5-3. Two-Year, 24-Hour Storm Event, Existing Conditions

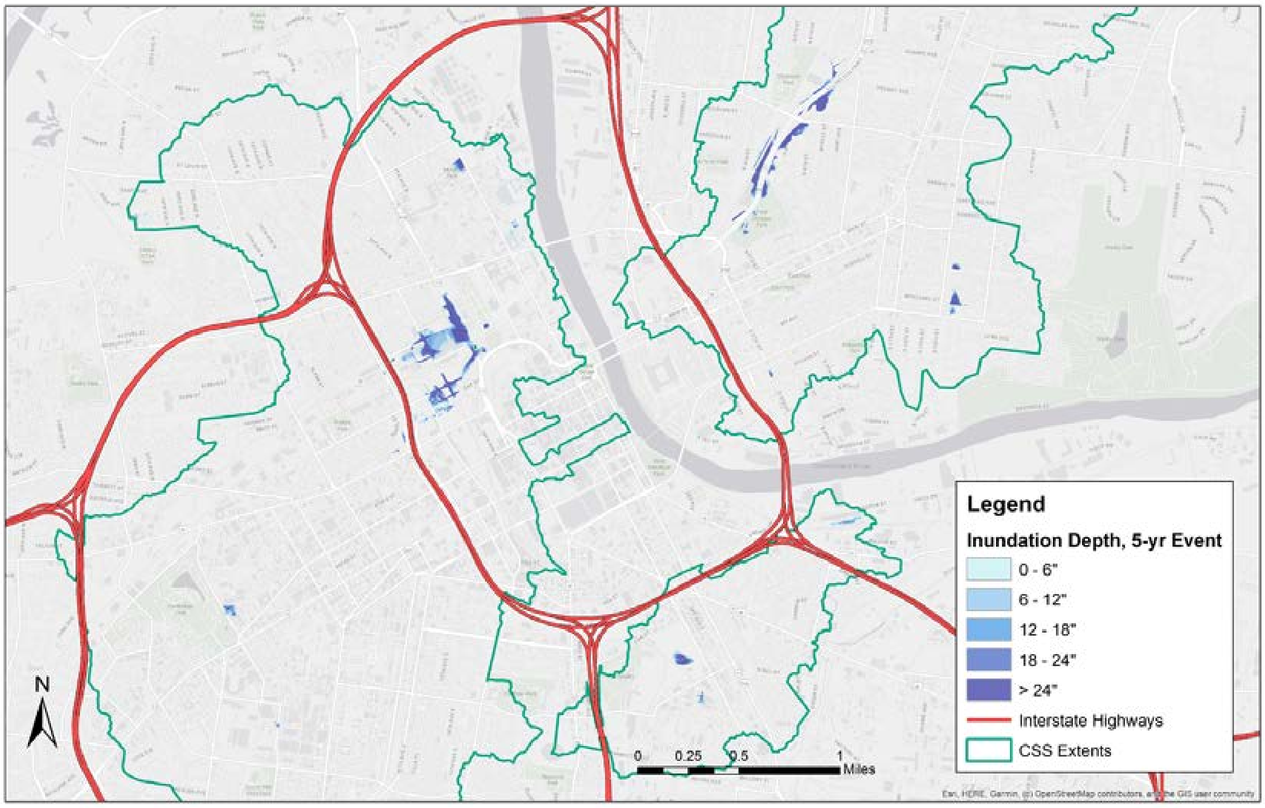


Figure 5-4. Five-Year, 24-Hour Storm Event, Existing Conditions

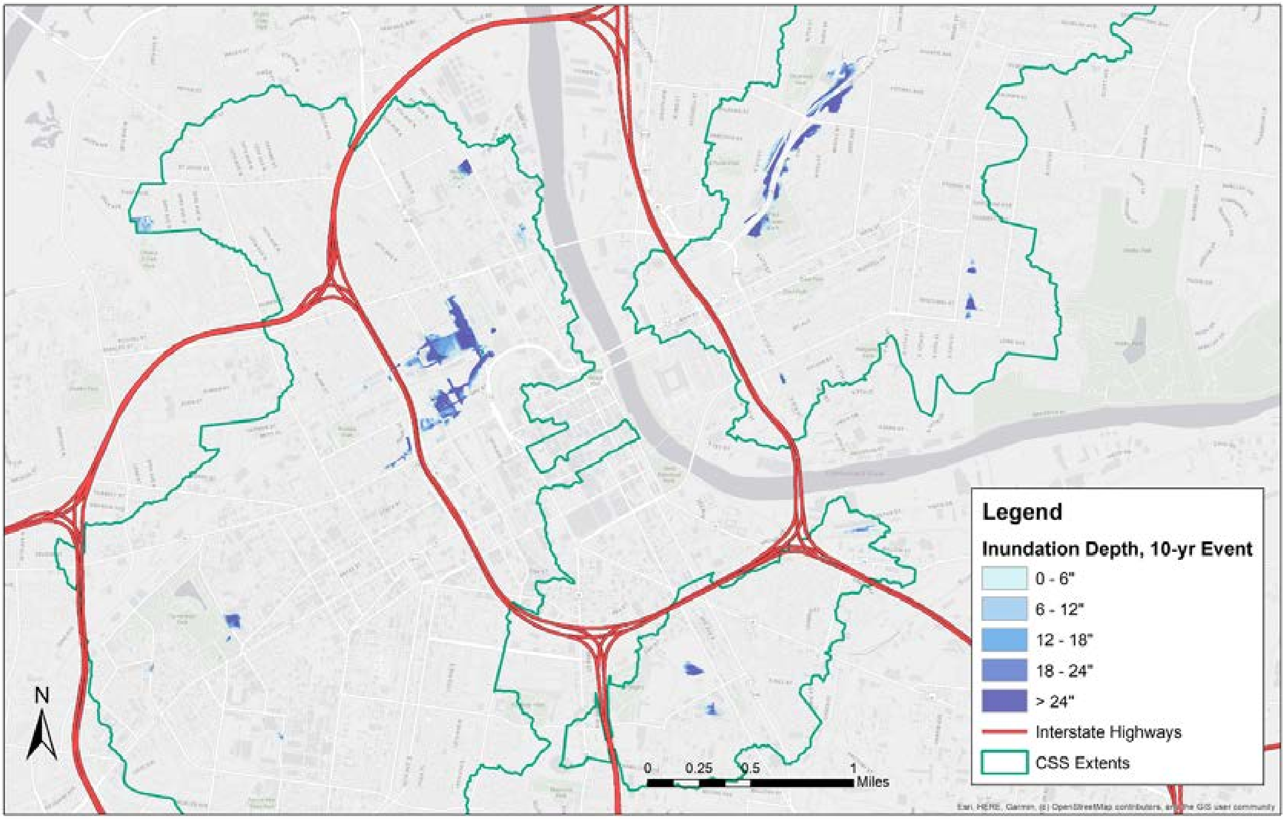


Figure 5-5. Ten-Year, 24-Hour Storm Event, Existing Conditions

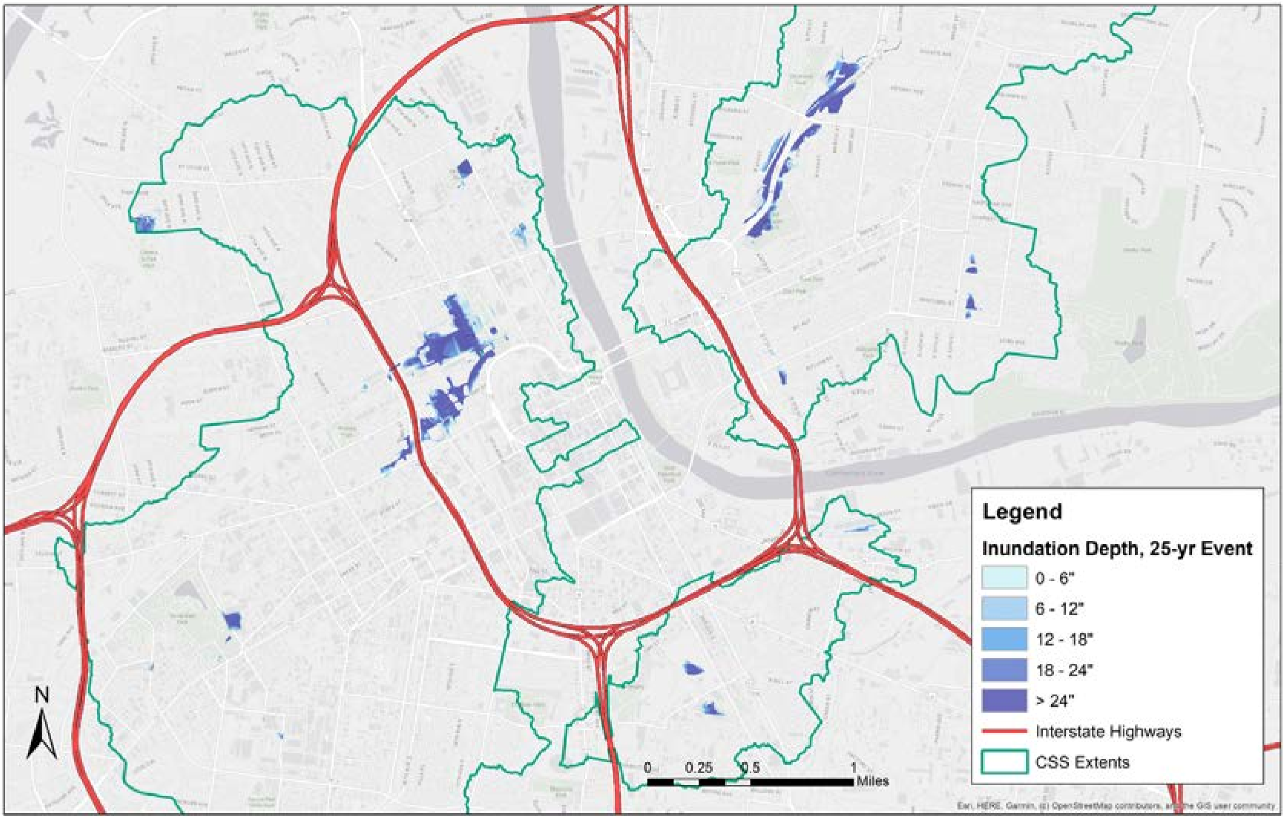


Figure 5-6. Twenty-five–Year, 24-Hour Storm Event, Existing Conditions

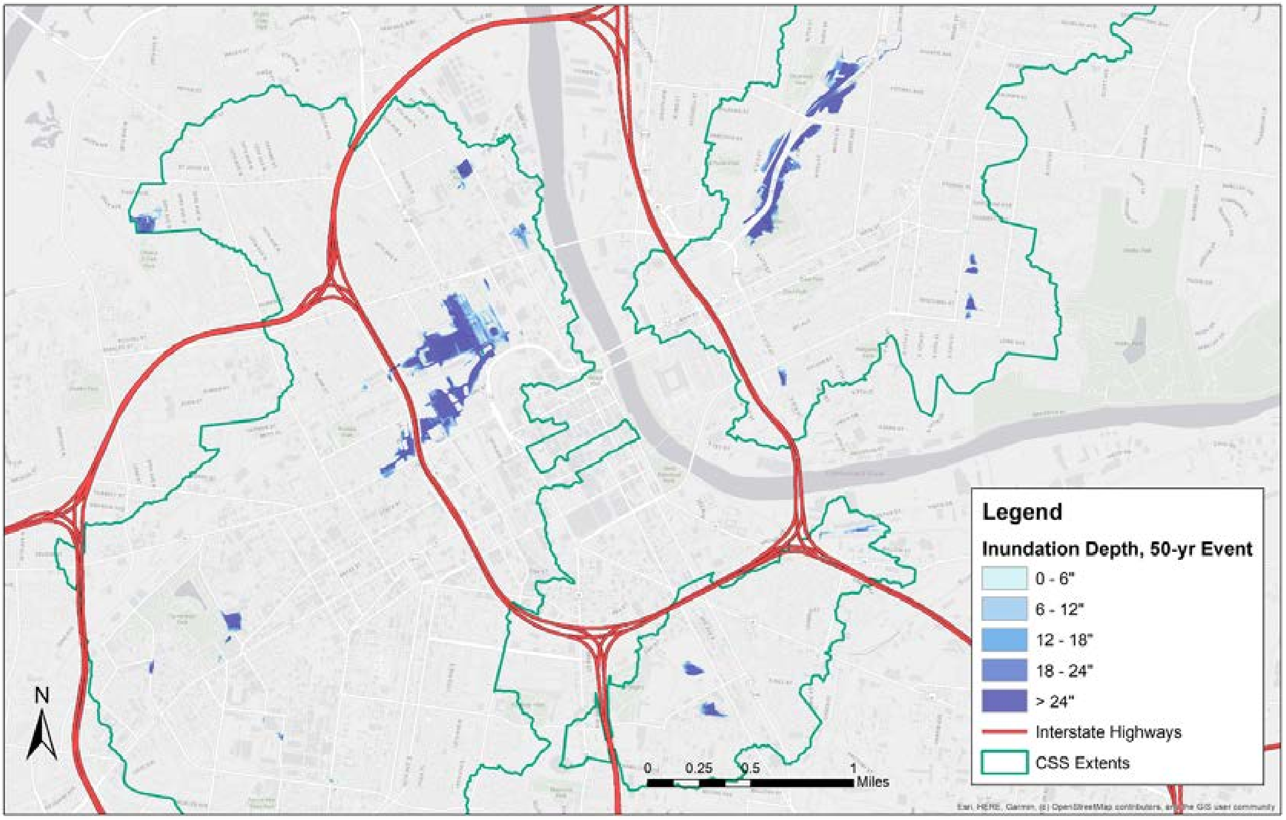


Figure 5-7. Fifty-Year, 24-Hour Storm Event, Existing Conditions

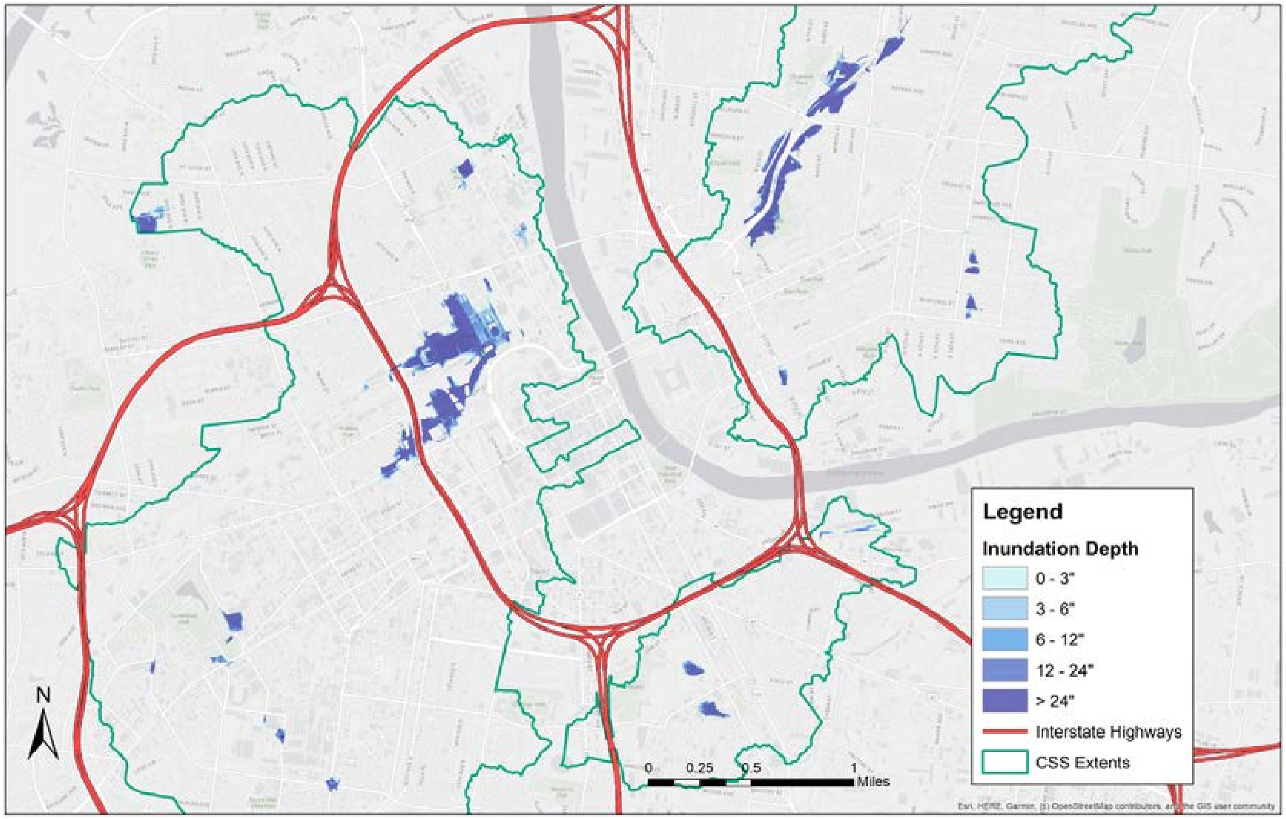


Figure 5-8. One-Hundred–Year, 24-Hour Storm Event, Existing Conditions

5.4 Baseline Model Combined Sewer Overflow Predictions

As discussed in **Section 4.6**, the baseline model incorporates projects that are currently under construction, in design, or planned. These baseline conditions can be simulated in the model to assess the number and volume of CSOs in the typical year. That data will be used as a comparison of the efficacy of proposed alternatives on CSO activations.

Table 5-3 presents the number and volume of CSOs predicted for the baseline model under the typical year. These values represent dry-weather flows at the time of the most recent model calibration for a given area. As shown in the table, the projects included in the baseline model significantly reduce CSOs at Kerrigan and eliminate CSOs at Benedict & Crutcher, Boscobel, and Schrader.

Table 5-3. Model-Predicted Combined Sewer Overflows in the Typical Year, Baseline Model with Existing Flows

CSO	Number of Activations in Typical Year	Volume of Discharge in Typical Year
Benedict & Crutcher	0	0
Boscobel	0	0
Driftwood	0	0
Kerrigan	15	490
Schrader	0	0
Washington	17	229

When the projected 2045 sanitary flows and increased imperviousness are modeled, CSO activations and volume at Kerrigan and Washington increase relative to the existing system flows (**Table 5-4**).

Table 5-4. Model-Predicted Combined Sewer Overflows in the Typical Year, Baseline Model with Future Flows

CSO	Number of Activations in Typical Year	Volume of Discharge in Typical Year
Benedict & Crutcher	0	0
Boscobel	0	0
Driftwood	0	0
Kerrigan	15	519
Schrader	0	0
Washington	19	297

5.5 Approach to Alternatives

The baseline model with 2045 sanitary flows and increased imperviousness serves as the basis for evaluating potential improvements to address flooding within the CSS. The following subsections provide descriptions for the general categories of improvements and their effectiveness at addressing flooding within Nashville's CSS.

5.5.1 Separation and Conveyance

Most of the projects included by the Master Plan rely on the development of separate stormwater networks to be effective. Combined sewers cannot be routed directly to surface water and the detention of combined flow presents operations and maintenance challenges that stormwater detention does not. Sewer separation produces new stormwater and/or sanitary infrastructure as needed to convey separate flows, but it can be costly and disruptive.

Stormwater networks established through separation projects may require conveyance beyond the extents of the separated area to reach a suitable stormwater outfall point. These large-diameter lines may require long distances to reach the Cumberland River or Browns Creek, the two waterways considered as outfalls in this report. Conveyance projects feature prominently in the strategy of this Master Plan.

For CSS areas assumed to be separated as part of this study, a certain amount of RDII is anticipated to be present in the system. This RDII is quantified as an R-value, which is the percentage of rainfall that falls on a catchment and enters the sanitary sewer system. In sanitary areas that are considered for separation, an R-value of 4 percent is assumed. This conservative assumption allows evaluation of downstream impacts if not all properties cannot be fully separated or the system deteriorates over time following construction.

5.5.2 Green Infrastructure / Low Impact Development

Green infrastructure and LID were considered during the early stages of alternative development. Practices such as permeable pavement and rain gardens are effective strategies for introducing distributed storage and water quality benefits. In terms of flooding reduction, LID typically may contribute up to an inch of runoff reduction in a basin. The implementation of LID may be effective for reducing frequent CSOs, but the reduction of an inch of rainfall was found to yield negligible benefits in the high-intensity design-storm events evaluated in this study. For those storms, the first inch of rain falls well before the high-intensity peak of the storms, which drives runoff and causes flooding.

5.5.3 Storage / Distributed Detention

Storage in the form of detention or retention is another common tactic for flood control. In addition to peak flow mitigation, storage also may produce water quality benefits for the system. Storage may take the form of either dry or wet open ponds or it may consist of underground vaults that infiltrate flow and/or discharge it slowly back into the system. For this study, storage in the combined system is anticipated as stormwater-only; thus, a dedicated stormwater inflow is required. Combined flow also may be stored, but the form of that storage would require the ability to drain captured flows back into the CSS for treatment or provide on-site treatment prior to discharge to a receiving stream.

Storage is contingent upon the availability of medium- to large-sized footprints to be effective. In urban environments such as the CSS, the areas available to detain flow may be limited and the property values of potential storage sites may be costly. Storage opportunities are evaluated as part of the Master Plan, though the volumes are purposefully modest considering the reality of siting and maintaining these features in an urban environment.

5.5.4 Pumping

Pumping floodwaters to a waterway is sometimes used to draw down rapidly flooding areas. Modern stormwater pumping systems such as those found in New Orleans or Memphis can provide close to a billion gallons a day of peak pumping. These stations, however, must be sized to handle a wide range of flows, especially if capturing infrequent storms, such as a 100-year design storm, is required.

Although siting such large pump stations is a challenge in densely developed areas, force mains (as opposed to gravity conveyance) offer greater routing flexibility and generally allow for smaller-diameter pipes. For pumped systems, the location receiving pumped stormwater flow would need to have adequate capacity to receive the flows. Although the Cumberland River could be assumed to have capacity, smaller streams and existing stormwater infrastructure likely lack capacity. Future energy costs and operations and maintenance of pump stations also could be prohibitive.

6.0 Alternatives to Address Flooding

6.0 Alternatives to Address Flooding

Development of the Master Plan is a result of detailed review of the model-predicted flooding locations, evaluation of potential improvements to address those locations, and numerous discussions with MWS staff. Although various options were considered, the most effective alternatives to reduce flooding risks in the CSS generally rely on separating stormwater from the CSS, providing stormwater-only conveyance to the Cumberland River or Browns Creek, and, in limited cases, providing stormwater-only detention to better manage peak runoff.

Each of the suggested alternatives included in this section must undergo design-level analysis to assess the specifics of their implementation, including but not limited to routing evaluation, geotechnical survey, materials selection, utilities conflicts, and potential land acquisition needs. The projects presented are conceptual, planning-level alternatives to reduce, but not eliminate, flooding risks in the CSS.

6.1 Proposed Alternatives Summary

Sections 6.3 through **6.6** summarize the project concepts to reduce flooding in the CSS. The sections provide more detailed descriptions of the projects, their impacts on flooding, major constructability issues, and their costs. **Figure 6-1** displays all projects proposed in this Master Plan.

Washington

- A 13-foot-diameter conveyance tunnel routing storm flow from the Apex screening facility southwest, generally following Ellington Parkway and the railroad right-of-way, collecting additional runoff from Cleveland Street, and terminating at the Cumberland River adjacent to the existing Washington Facility.
- A 54-inch pipe collecting excess runoff from the Cleveland Street corridor and delivering it to the 13-foot-diameter tunnel.

Houston Street/Driftwood

- Separation and conveyance of stormwater flows along Houston Street, continuing east under 4th Avenue South to Browns Creek.
- A 2.25-acre-foot (730,000-gallon) stormwater storage unit/facility near Dudley Park.

Van Buren

- Separation and conveyance of stormwater flows along Van Buren Street beginning at 6th Avenue North and terminating at the existing 72-inch outfall east of Adams Street / 1st Avenue North.

Lower Kerrigan

- Separation and conveyance of stormwater flows to the Cumberland River from the area generally between 1st Avenue North, Harrison Street, 4th Avenue North, and Jefferson Street.

Capitol/Farmers Market

- Separation and conveyance of stormwater flows from the Capitol View area and the north side of the Capitol, with the conveyance terminating at the Cumberland River near Gay Street and 1st Avenue North.
- A 7.75-acre-foot (2.5-million-gallon) stormwater storage unit/facility in the Herman Street corridor.

West End/Vanderbilt

- A 16-foot-diameter conveyance tunnel originating at West End and 25th Avenue North, routed under West End and Broadway, collecting flow at intermediate points near the Gulch, and terminating at the Cumberland River.
- Separation and conveyance of stormwater flows upstream of the Vanderbilt campus and designated areas along the 16-foot-diameter tunnel corridor, as well as an 8-foot-diameter tunnel along 21st Avenue North to capture separated stormwater from upstream of Vanderbilt's campus.
- *Alternative Routing* – All of the above except routing the proposed tunnel along Elliston Place / Church Street and terminating at the Cumberland River near Church Street and 1st Avenue North.

Long Boulevard

- Separation and conveyance of stormwater flow in the Long Boulevard and 31st Avenue North area, which is routed east near Centennial Park, eventually terminating at the proposed 16-foot-diameter stormwater tunnel on West End (West End/Vanderbilt project).
- *Alternative* – All of the above except a 5-acre-foot (1.6-million-gallon) stormwater storage unit/facility near Centennial Park to detain flows from the Long Boulevard project area in lieu of a connection to the West End/Vanderbilt project.

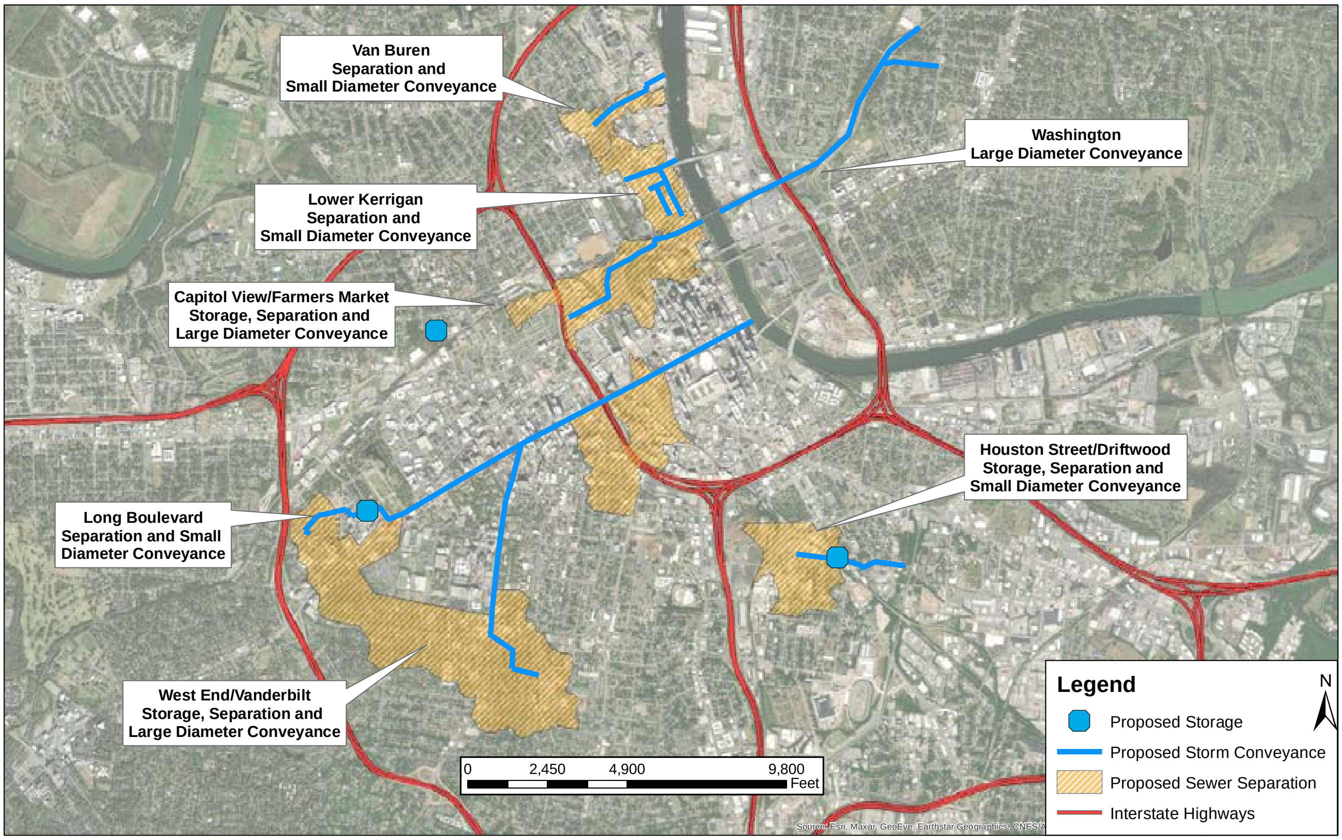


Figure 6-1. All Proposed Alternatives

6.2 Alternatives Selection and Cost Development

As noted in **Section 4**, potential projects were assessed based on their effectiveness in reducing observed and predicted flooding in the CSS, with a focus on flooding that impacts buildings and significant roadways. This is consistent with MWS's desire to prioritize flood mitigation projects focusing first on life and safety, then property damage, and finally nuisance flooding. Several additional considerations were made to determine the practicality and ease of implementation of the potential alternatives, including:

- Availability of properties and easements for routing/siting
- Profile and depth of conveyance improvements
- Susceptibility to the influence of levels in the Cumberland River or Browns Creek
- Major utility conflicts
- Existing infrastructure for tie-ins
- Potential stakeholder partnerships
- Costs

Alternatives in the following sections present an assessment of these considerations as appropriate. Alternatives that considered various routings for conveyance are noted in the respective sections.

Cost Development

Planning-level project development and construction costs were generated for each of the projects identified in the following sections. These costs can be used to generate a capital program associated with flood mitigation in the CSS. Project costs were subdivided into three main areas: 1) construction cost of major conveyance and storage improvements, 2) construction cost of sewer separation, and 3) project development costs (i.e., planning, design, and construction administration). All costs presented are in 2023 dollars. Because of the ongoing volatility of costs and the unknown time frame of implementation, future costs were not evaluated.

Due to the anticipated long duration for program implementation, significant escalation of costs is expected, and costs should be further reviewed as anticipated construction timeframes for individual projects are determined.

Construction Cost of Major Conveyance and Storage Improvements

Construction cost for major conveyance and storage improvements considers installation of the large, separate trunk storm sewer pipes/boxes and/or tunneling projects identified in each project description. Costs also include excavation and installation of storage improvements when identified. Following are several key assumptions required to develop these costs:

Assumptions for Open Cut Installation:

- Open cut installation method is assumed for pipes with a diameter of 72 inches or smaller and/or depths less than 15 feet.
- Junction boxes and manholes are included for bends and line breaks.
- Open cut installation values are derived from TDOT bid tabs and RS Means.
- Excavation trenches are assumed to consist of 75 percent rock content.
- Inlets/manholes are assumed to be required every 500 feet along the installation.
- Other costs include excavation, surface restoration, and mobilization expenses.

Assumptions for Tunneling Applications:

- Tunnels are assumed for pipes with a diameter of 72 inches or larger.
- The majority of tunneling is expected to encounter rock.
- Larger drop shafts at strategic locations are accounted for in the cost estimation.
- Segmental lining is used for tunnels larger than 10 feet in diameter, while jacked pipe method is used for smaller-diameter tunnels.
- Other costs taken into consideration include mobilization expenses, hauling costs, coffer dams at outfalls, and surface restoration.
- Tunneling costs were derived primarily from recent bid tabs within CDM Smith's portfolio of tunneling projects throughout the country.

Assumptions for Storage Applications:

- Storage was assumed to be applied in the form of underground vaults.
- Site purchase and/or easement acquisition is not included.

The major conveyance and storage construction costs include consideration of both raw construction costs as well as associated project delivery costs. These project delivery costs include 10 percent for contractor general conditions, 3.5 percent for permits and bonds, 10 percent for overhead and profit, and 30 percent for contingencies.

Construction Cost of Sewer Separation

Many of the highlighted projects, which are described in detail in the following sections will require separation of currently combined storm and sewer systems throughout local areas. At the planning level, it is difficult to assess the extent of separation required throughout each area because many new developments and infill developments may have been required to install separate storm systems for future connection. To be conservative, all areas where separation is identified include a construction cost of $200,000 per acre. This cost is consistent with other planning-level estimates within the Clean Water Nashville Program and includes separation of all local pipes within the areas shown on the associated project figures. Cost per acre could vary based on the amount of existing storm network, density of developments, local conflicts, etc. As noted, major conveyance trunk lines are not included within this cost.

Project Development Costs

The total cost to MWS for delivering projects includes certain costs that are not accounted for in the construction costs. These costs, referred to as project development costs, are added to the estimated construction costs to determine the total project cost. The project development costs are assumed to be 35 percent of the estimated construction cost and include planning, design, construction inspection services, management, and miscellaneous additional costs. They do not include costs associated with land or easement acquisition.

The sections that follow provide detailed descriptions of each project, the project elements included in the cost breakdowns, and the identified benefits that may be realized through installation of each project.

6.3 Washington

Washington is a large and rapidly developing basin on the east bank of the Cumberland River. Historically, Washington has been primarily residential and industrial in nature, but in recent decades it has become a highly desirable location for both residential infill and commercial development. Part of Washington's northern drainage area—1,280 acres of it—contains separate storm conveyances and sanitary sewer infrastructure. These flows combine at the Apex screening structure. From there, flow continues southwest toward the Cumberland River picking up additional combined sewer flow along the route. **Figure 6-2** shows the location of Washington basin's key features.

Flooding has been noted throughout the central portions of the basin, including Sharpe Avenue, West Eastland Street, and Ellington Parkway. **Figures 6-3** and **6-4** show the model-predicted flood extents for this area in the 2045 system. Recall that much of the Washington basin, especially the northern part, is projected to have increased imperviousness in the 2045 scenario.

Based on modeling results for 2045 conditions, following are the major roadways and properties impacted by flooding in the Washington basin for the 100-year, 24-hour storm:

- 1,100 feet of Ellington Parkway
- 28 structures, 24 of which are residences

Inundation also exists in Frederick Douglass Park and in low-lying areas near Ellington Parkway, though no properties or roadways are significantly impacted.

Barge Cauthen performed a previous stormwater study in the area of West Eastland Street that included various small-footprint alternatives distributed throughout the basin. Based on discussions with MWS, the recommended projects provided by that study are not planned as of the time of this writing.

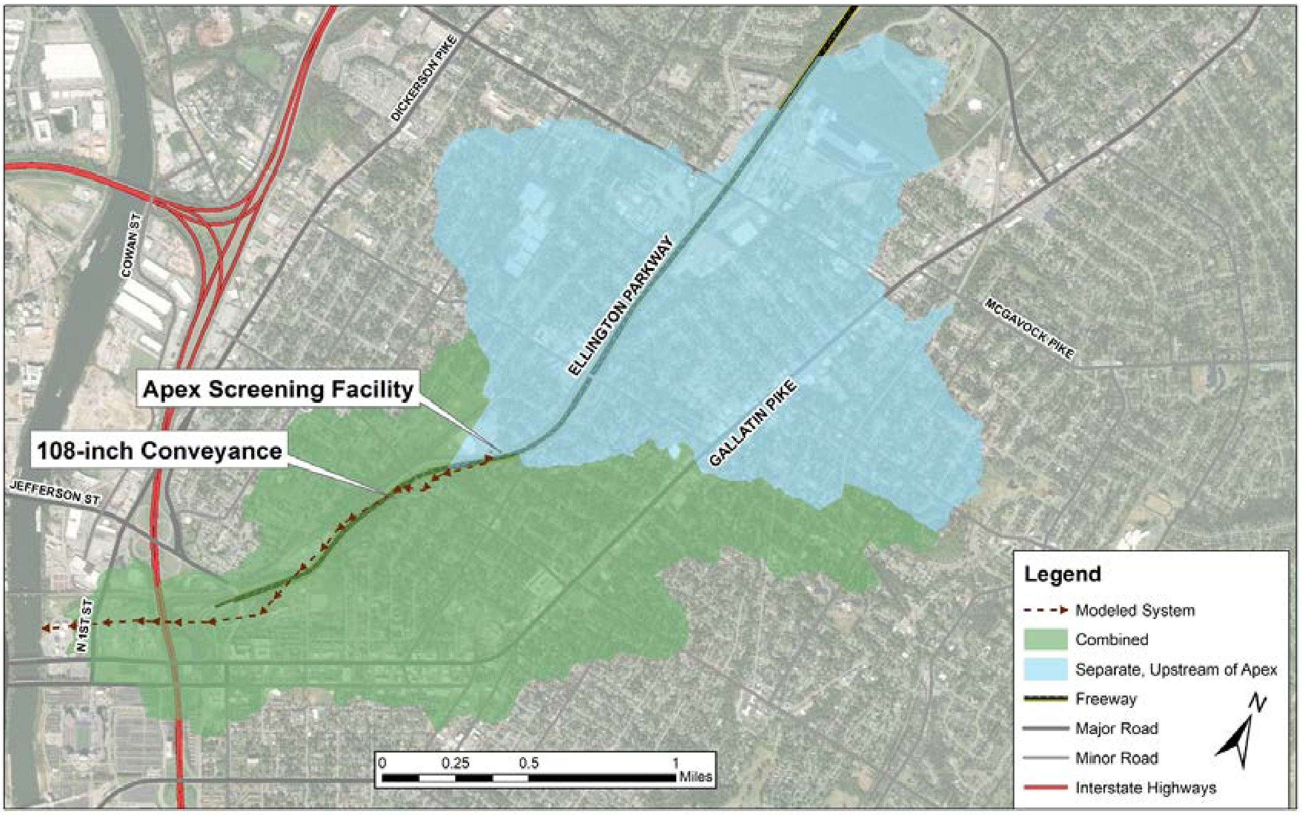


Figure 6-2. Schematic of Washington's Primary Drainage Areas

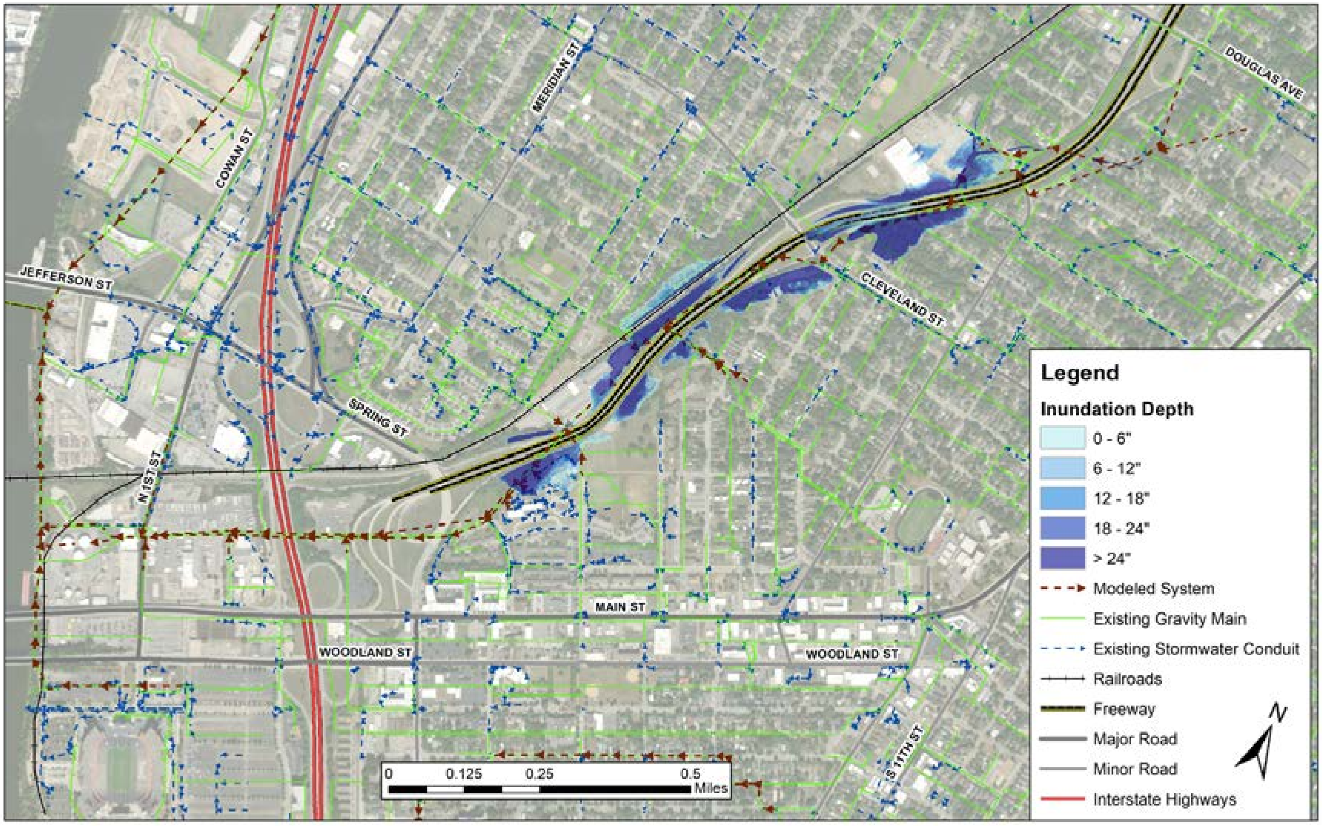


Figure 6-3. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

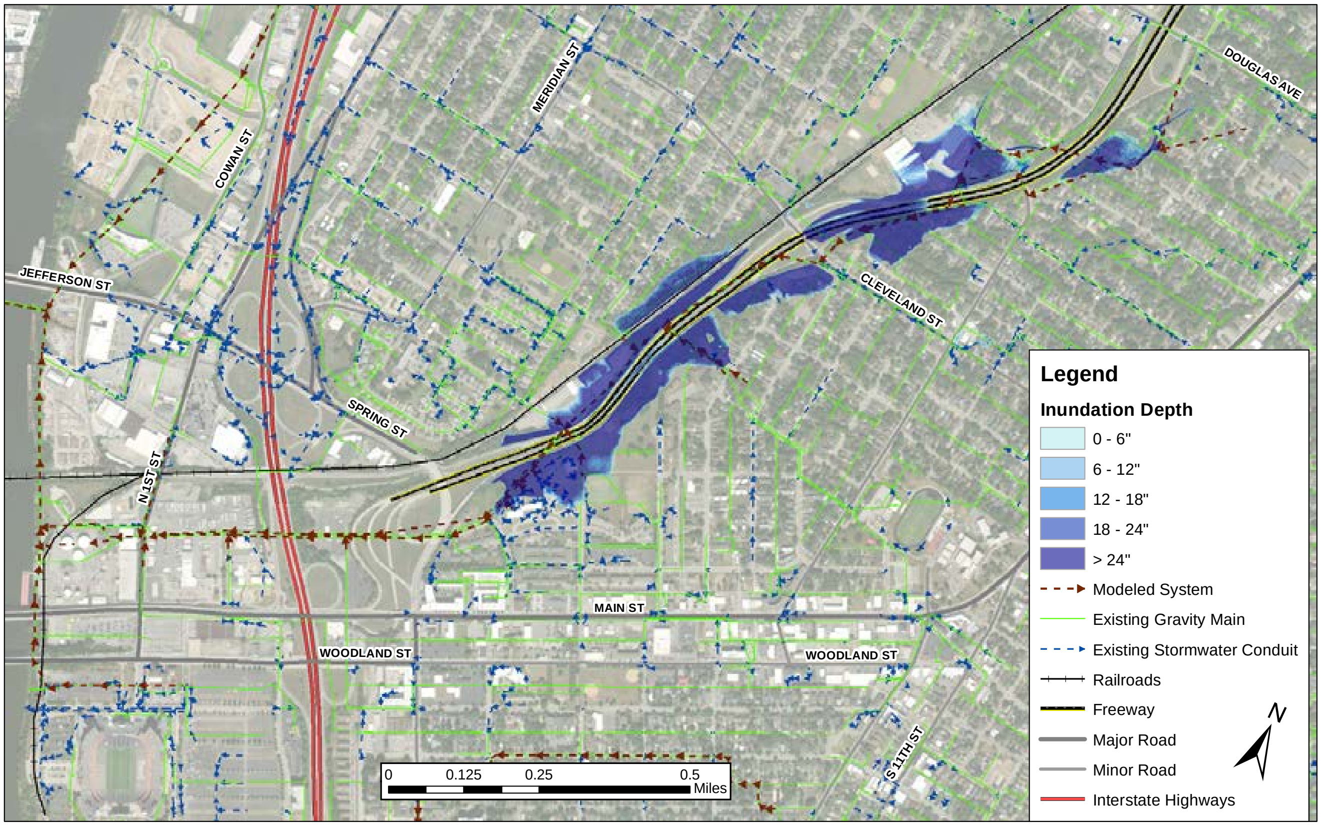


Figure 6-4. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

Proposed Alternative

Washington's unique layout of separate stormwater and sanitary flows that are combined at a single point makes it a strong candidate for direct conveyance to the Cumberland River. As shown in **Figure 6-5**, the proposed alternative for Washington is:

- 8,800 linear feet of a 13-foot-diameter conveyance will route storm flow from the Apex facility southwest along the route of Ellington Parkway, then will parallel the CSX right-of-way before terminating at the Cumberland River near the existing Washington CSO.
- Approximately 1,500 linear feet of 54-inch-diameter stormwater conveyance will collect excess street flow in the McFerrin-Eastland area and route the flow directly to the 13-foot-diameter conveyance.

In 1995, CT&A recommended this primary conveyance configuration, reaching similar conclusions about routing and conduit size in a study of the area.

Because of the size of the conveyance, this alternative would require tunneling and an energy dissipation structure at the discharge point. Shafts for access and future drainage connections (if stormwater from adjacent areas along the route are separated) also would be required. Sufficient cover exists for most of the route, though the approach to the Cumberland River may present challenges with depth of cover.

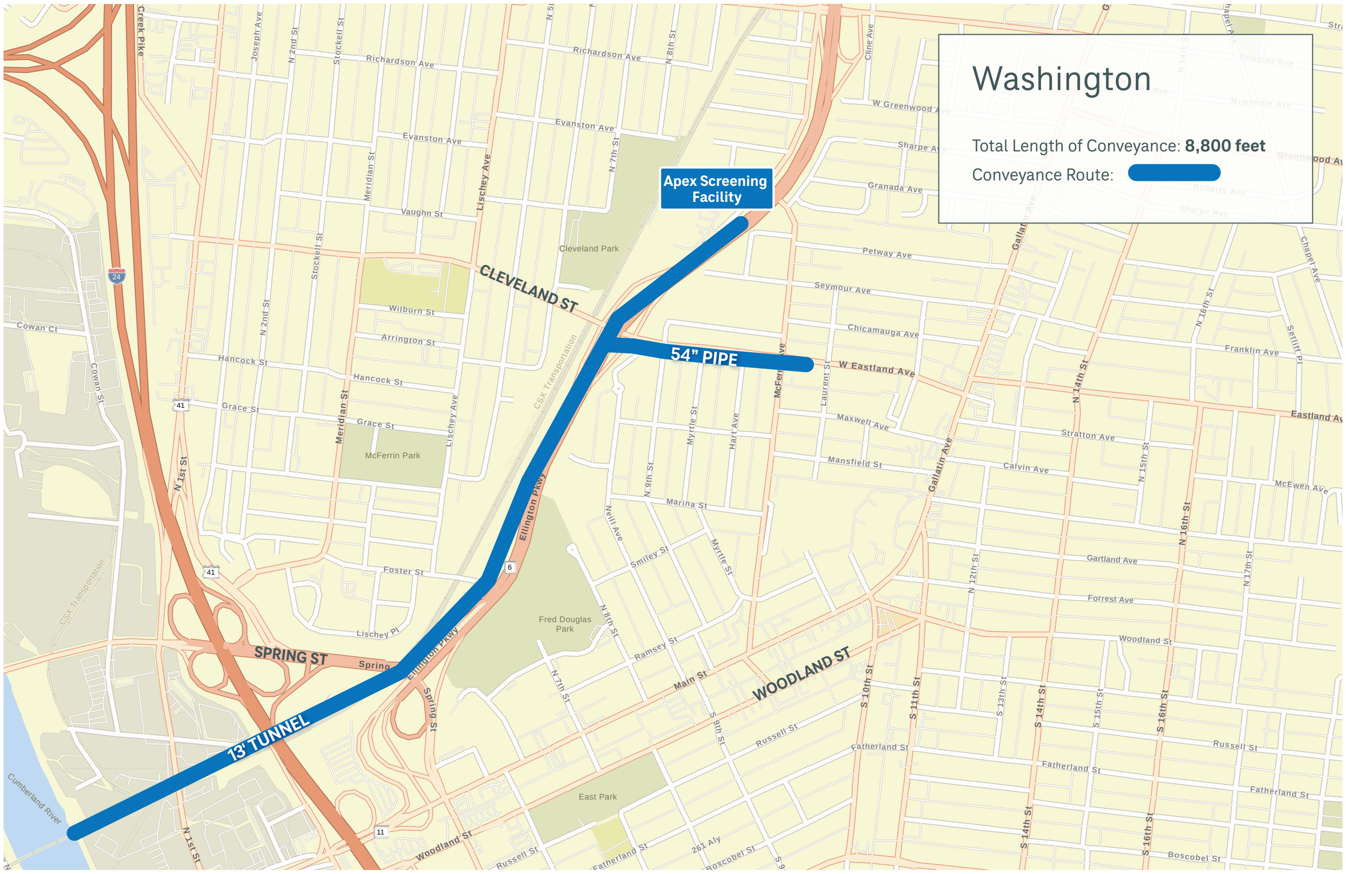


Figure 6-5. Proposed Washington Alternative

Routing of Conveyance Alternatives

Four distinct routes were considered in the initial stages of alternatives development. Each had a similar length but varied in the route as it approaches the Cumberland River. All routes are within close proximity to CSX railroad tracks.

The most direct route to the river was preferred following discussions with MWS. This option features the same number of conflicts yet introduces fewer bends, giving the most advantageous hydraulic profile. This route also may avoid potential conflicts with new development further north on the East Bank. Routes that were evaluated yet not selected include Oldham Street, Spring Street, and Berry Street. **Figure 6-6** shows these routes, along with potential connection points for local infrastructure.

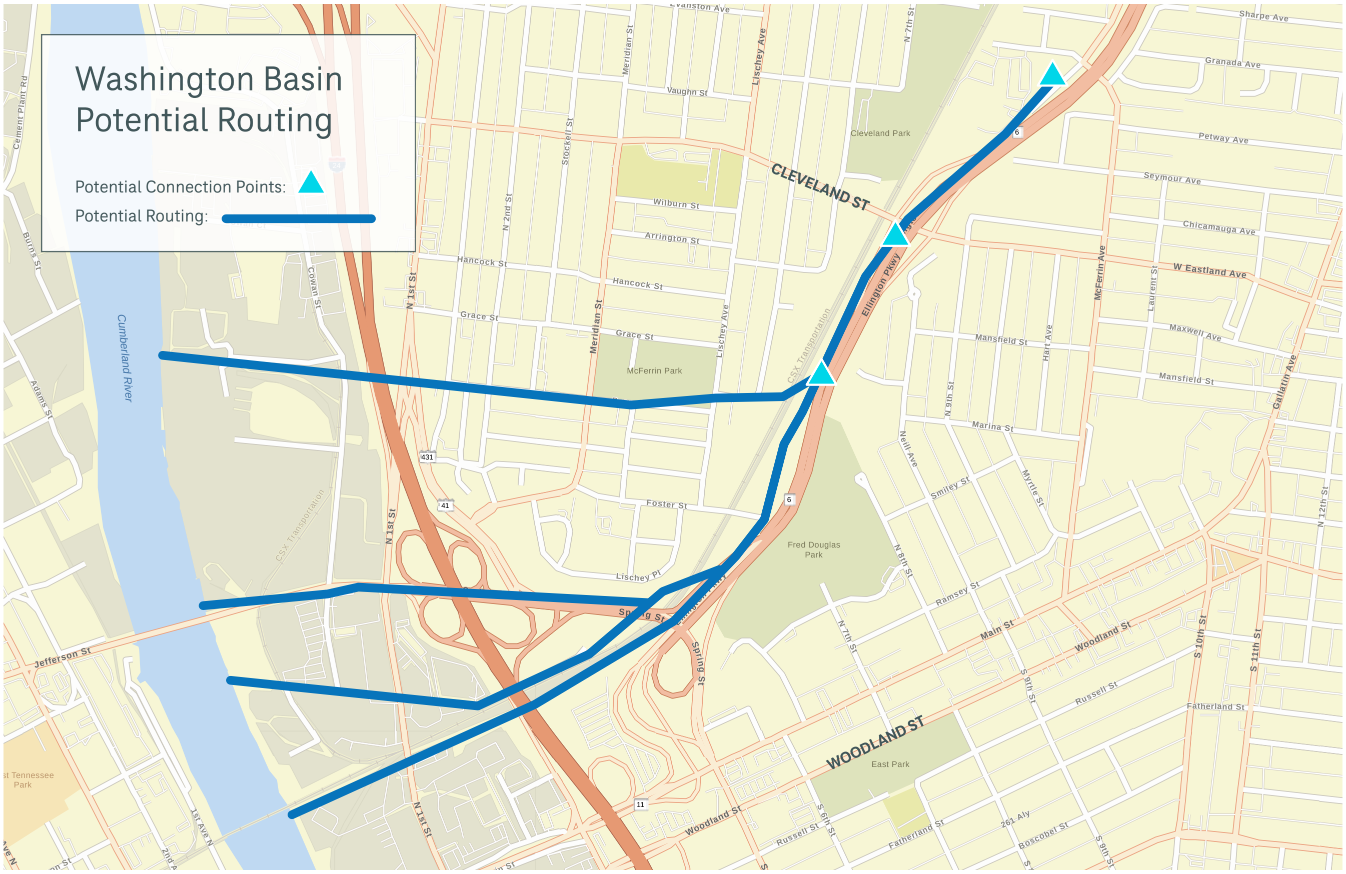


Figure 6-6. Routes Evaluated for Washington Conveyance

Conflicts

Design of the Washington stormwater tunnel would need to account for key infrastructure, especially in the region near the Cumberland River. The conflicts are listed from downstream to upstream, and elevations are based on record drawings.

1. The 36-inch sanitary sewer line that exits the Washington regulator and conveys flow to the siphon under the Cumberland River. This sanitary line is generally sited near 385 feet NAVD88 and is located near the banks of the Cumberland River.

2. CSX railroad spurs between First Street and the Washington regulator.
3. The 60-inch Browns Creek force main along First Street has inverts between 401 and 402 feet NAVD88 in this area.
4. The Colonial petroleum pipeline along First Street is near the 60-inch force main. This pipeline is an important conveyance for fuel to the region.
5. The 66-inch Browns Creek force main runs along Second Street and has inverts near 402 feet NAVD88.

Design of this alternative may require an adjustment to the geometry of its cross-sectional flow area to reduce the profile between these conflicts (e.g., a manifold into three 96-inch conduits to fit between conflicting utilities). It is assumed that in the future all listed conflicts will continue to exist in their present form.

Inlets and smaller storm connections to the 54-inch pipe along Cleveland Street were not included in the cost. It was assumed that surface flow in large storm events would route to the 54-inch pipe, along with existing small-diameter storm conveyances that currently deliver flow to the 108-inch combined pipe.

The effect of the Cumberland River's stage was evaluated for this alternative. Peak flows begin to be impacted at 398 feet NAVD88. At flood stage, 408.1, the ability of the tunnel to convey flow is limited, and stages at Apex remain elevated. **Table 6-1** shows a summary of the modeled peak flows for select river stages.

Table 6-1. Modeled Washington Tunnel Flows at Select Cumberland River Stages

River Stage (feet NAVD88)	100-year, 24-hour Storm Peak Flow (MGD)
385 (Navigable Pool)	1,246
396 (95th Percentile High)	1,246
398 (Pipe Outlet Submerged)	1,232
408.1 (Flood Stage)	1,049

Results

Flooding in the Washington basin is mitigated by several feet in many areas. **Figures 6-7** and **6-8** show the inundation extents for the 10-year, 24-hour storm and 100-year, 24-hour storms, respectively, with the alternative applied.

Eighteen of 28 structures were removed from inundation. All previously inundated portions of Ellington Parkway are passable up to and including the 100-year, 24-hour storm. Three apartment buildings on Neill Avenue and seven residences on Sharpe Avenue remain exposed to risk for inundation in the 100-year, 24-hour storm. Assessing the finished floor elevations of these properties will aid in understanding the likelihood of property damage. MWS has used property buyouts for three parcels upstream of the Apex facility, and further buyouts may be a viable strategy for interim flood protection near these sensitive properties. As previously mentioned, this flooding analysis uses 2045 conditions as its baseline. The upper portion of Washington is one of the areas most impacted by the projected increase in imperviousness in the 2045 scenario. The flooding anticipated at Sharpe Avenue is largely a product of these changes to the basin. Though it is beyond the scope of this Master Plan, stormwater management upstream in the basin may aid in mitigating the impact of this increased runoff.

The CSO reductions provided by the Washington alternative are substantial. Activations at Washington are reduced from 19 to 12 in the typical year, and the total volume of CSOs is reduced from 297 to 98 MG, a reduction of 68 percent. The Kerrigan CSO sees a negligible decrease in CSO volume under this alternative.

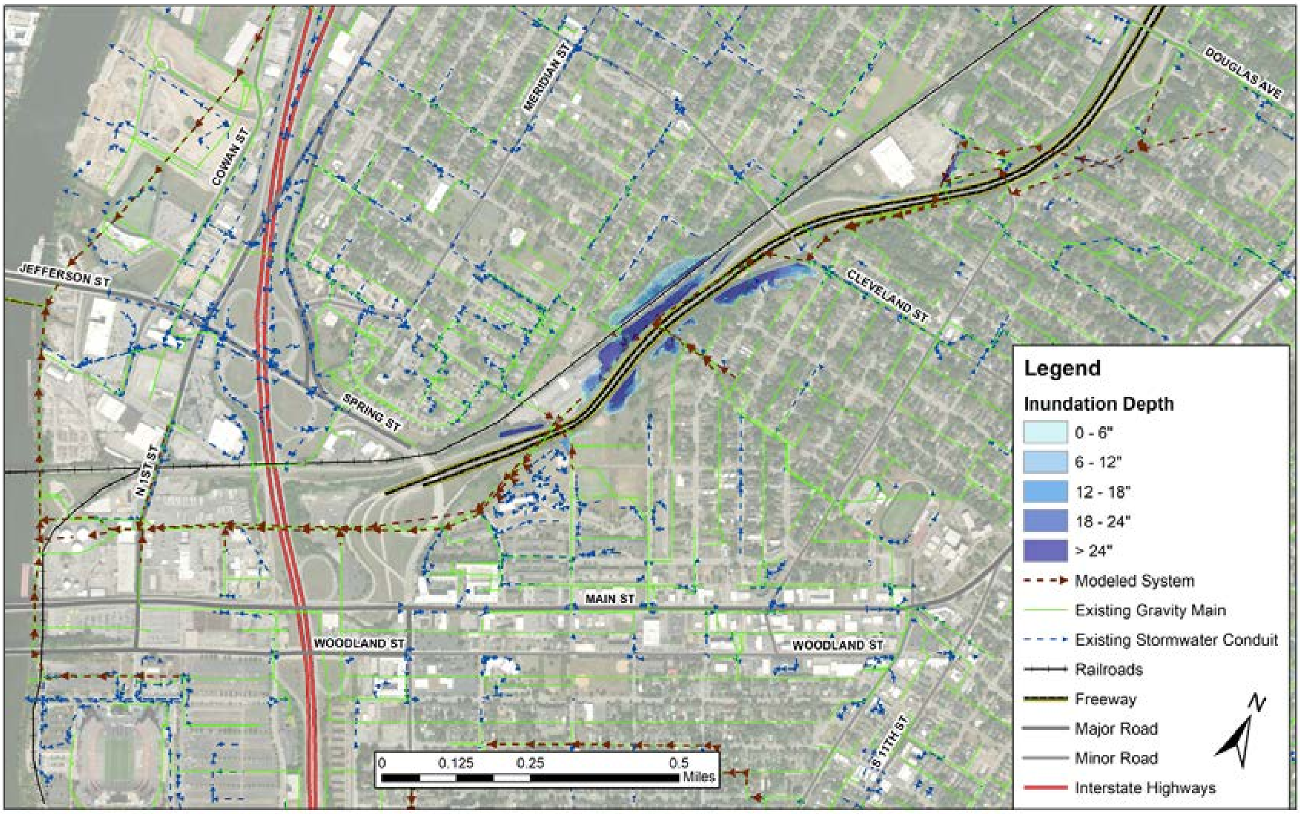


Figure 6-7. Flooding Extents in the 10-Year, 24-Hour Storm with Washington Alternative

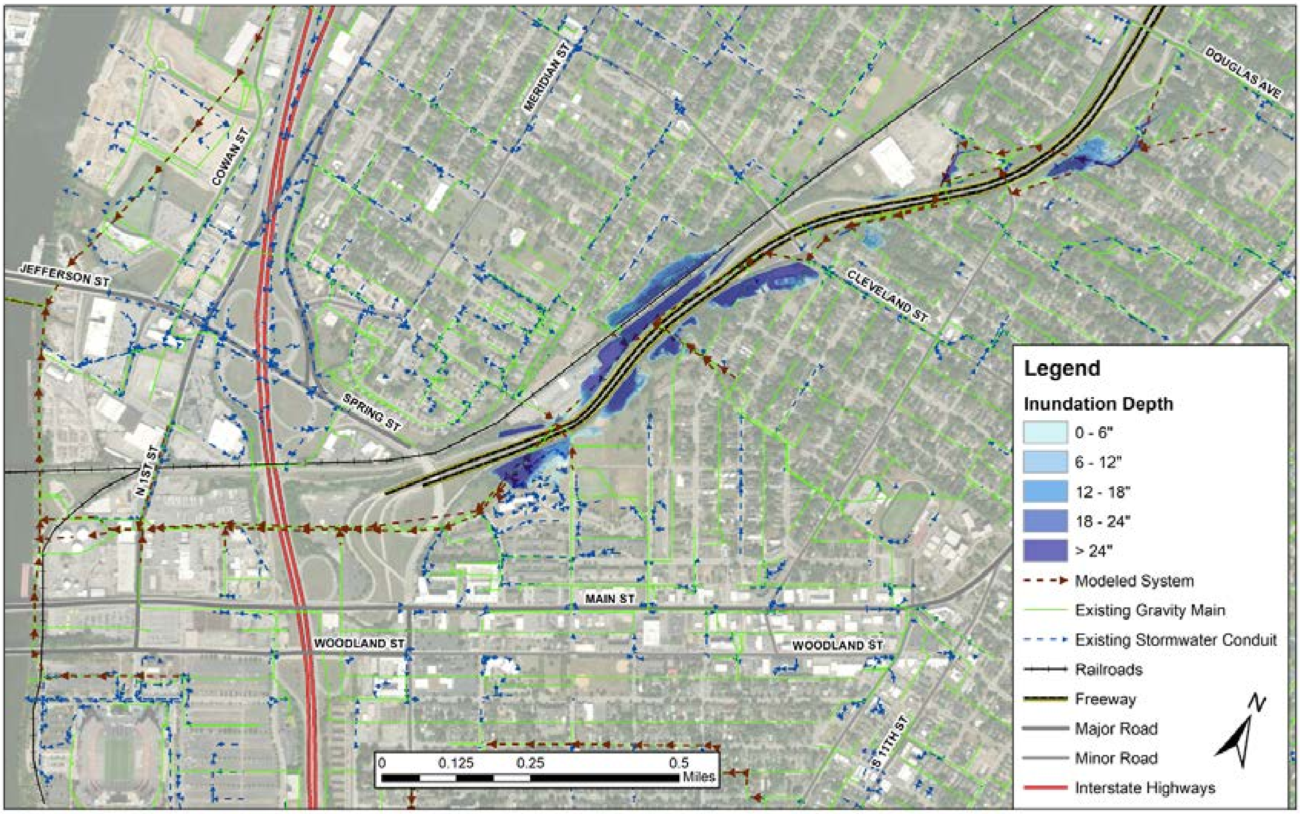


Figure 6-8. Flooding Extents in the 100-Year, 24-Hour Storm with Washington Alternative

Other Alternatives Evaluated

Pumping was also considered for Washington. Peak flows to Apex are within the operable range of modern stormwater pumping systems such as those found in New Orleans or Memphis. A force main would offer a much greater routing flexibility. However, three issues with pumping were found to be too limiting to make pumping a viable flood control option:

- If flow is pumped, no matter the routing, no additional future stormwater flows could be added to the system downstream of the station without an additional pump station and manifolded force main system.
- No locations other than the Cumberland River have the required capacity to receive the flows.
- Future costs of energy and operation and maintenance could be prohibitive.

Storage was also considered for areas near the Apex facility, although attenuating all peak stormwater flows would require an impractically large facility. With the introduction of the large-diameter conveyance, peak flow attenuation was not found to be necessary. As the project is designed, it is possible that a small amount of storage in the area may be beneficial to ensure that flow can enter the new conveyance and prevent flooding near the screening facility. During workshop phases of this Master Plan, it was noted that a small amount of storage at Apex also may assist in settling/screening large debris before it enters the new conveyance.

Estimated Costs

The total cost for the Washington alternative is $144,000,000. **Table 6-2** provides a breakdown of the cost components. No system separation costs are anticipated with this alternative.

Table 6-2. Washington Alternative Costs

Component	Cost (2023 dollars)
Conveyance Construction Cost	$115,000,000
Project Development Cost	$29,000,000
Total Project Cost	$144,000,000

6.4 Houston/Driftwood

The Houston Street corridor is a quickly redeveloping part of Nashville. The neighborhood is collectively known as Wedgewood-Houston and has historically been home to industrial facilities, a minor league baseball stadium, and warehouses. These facilities have been revitalized into a variety of commercial establishments that have increased the sanitary flows and further reduced the amount of pervious area in the basin. Many large developments have installed or plan to install separate stormwater and sanitary systems that currently tie into the CSS. Development pressure in the area provides the opportunity to collaborate with development on stormwater systems that could route flows to a new interceptor that would flow east to Browns Creek. **Figures 6-9** and **6-10** show the model-predicted flood extents for this area in the 2045 system. The Houston Street area is within the Driftwood CSS basin.

Based on modeling results for the 100-year storm, five commercial buildings along Houston Street are impacted.

No major or minor roads are impacted by flooding in this area. Although significant flooding impacts Houston Street and Brown Street, they are considered local roads. Flooding exists in City Cemetery; however, no structures or roadways are impacted by this inundation.

Proposed Alternative

Houston Street's proximity to Browns Creek makes it unique among the study areas. Direct conveyance to Browns Creek is the historical drainage pattern for this area. The proposed alternative to alleviate flooding is:

- 1,950 linear feet of 72-inch and 1,500 linear feet of 84-inch conveyances to route separate storm flow to Browns Creek
- Storage of up to 2.25 acre-feet in Dudley Park
- Separation of approximately 140 acres of area within the basin

Separation extents depend on the amount of existing combined infrastructure and potential future areas to be served. A large part of the proposed area identified for separation encompasses the hillside of Fort Negley and likely would not require separation activities, though it was included in the alternative to confirm that all runoff for the area is considered. **Figure 6-11** shows the proposed alternative.

Routing of Conveyance Alternatives

The conveyance of the Houston/Driftwood alternative is routed along Houston Street, passes under the railroad tracks near 4th Avenue South, and continues along Hart Street to an outfall at Browns Creek. The path east down Hart Street is the most direct route, though it may require multiple directional changes to use existing right-of-way. Future local stormwater connections in the area near Chestnut Hill are possible, though separation in those areas was not prescribed as part of this alternative.

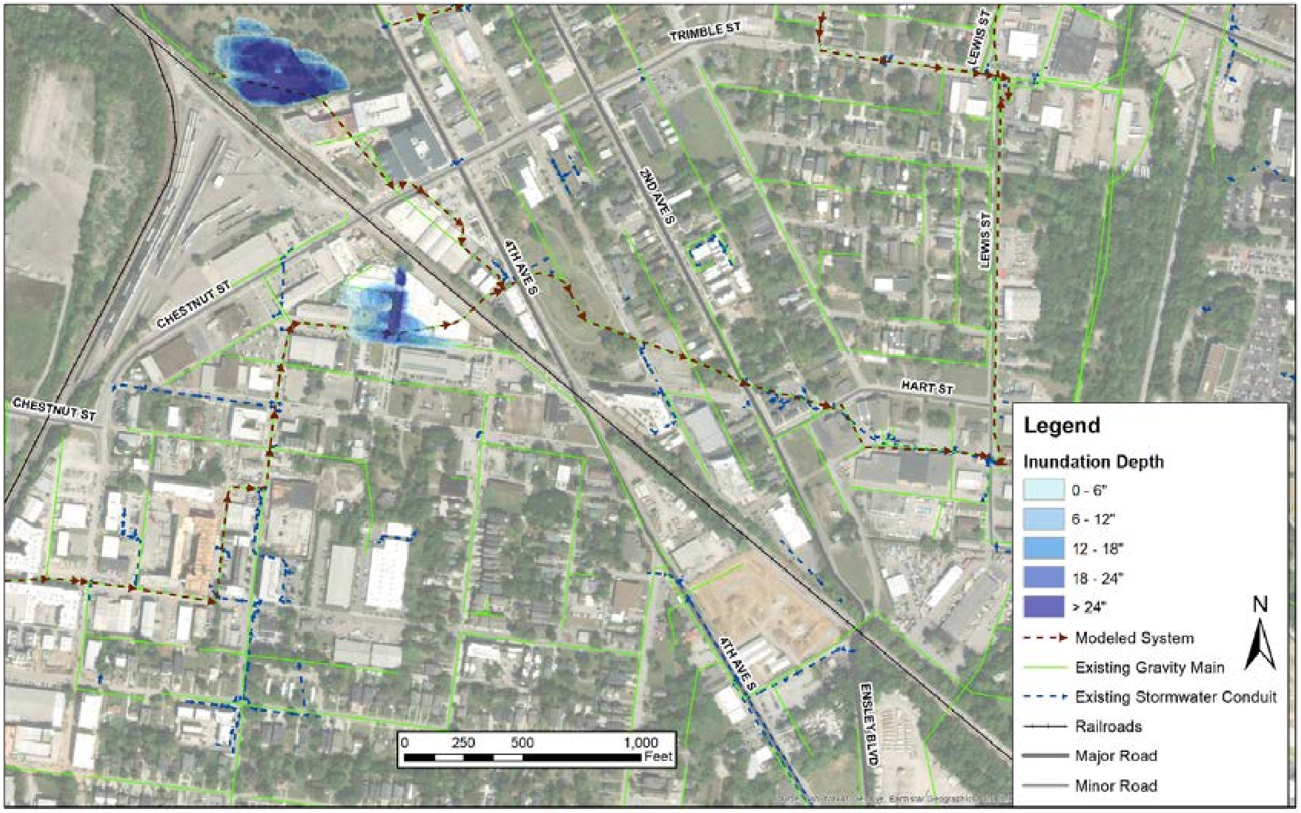


Figure 6-9. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

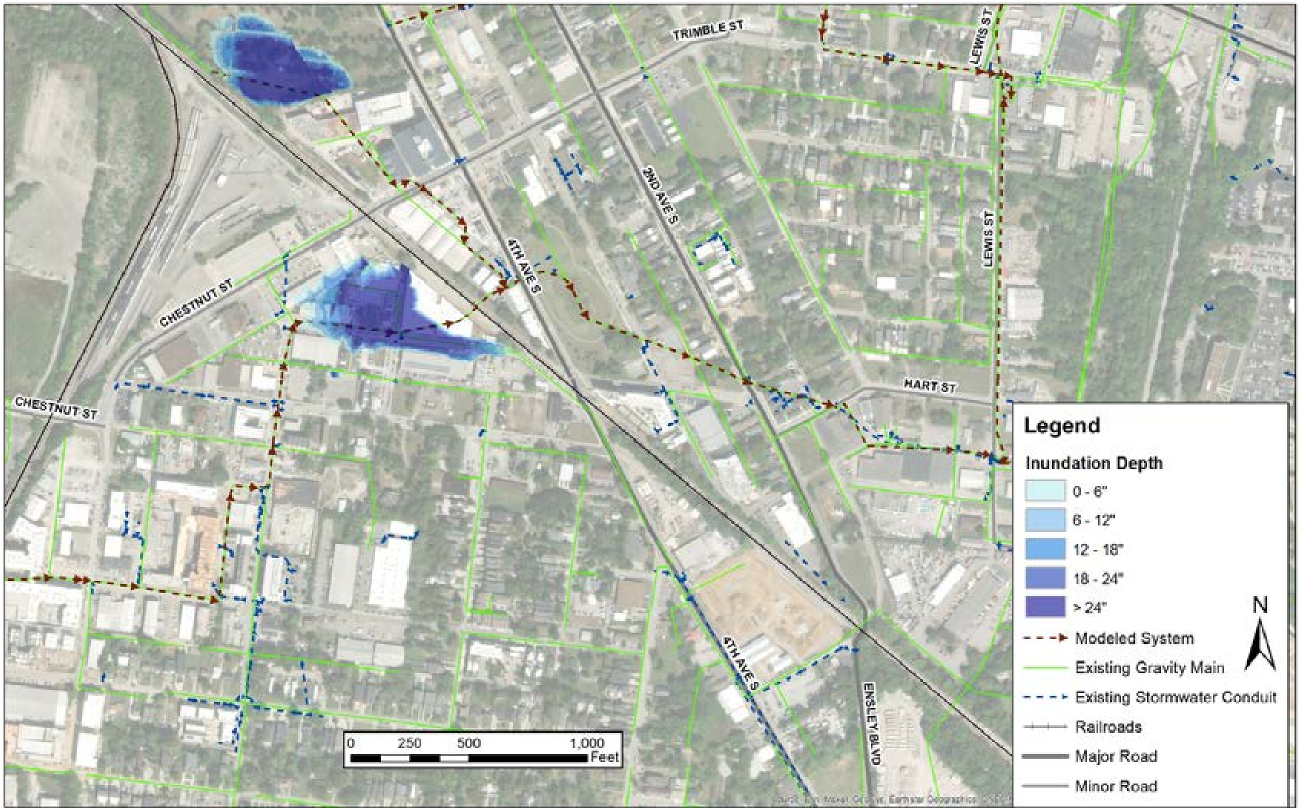


Figure 6-10. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

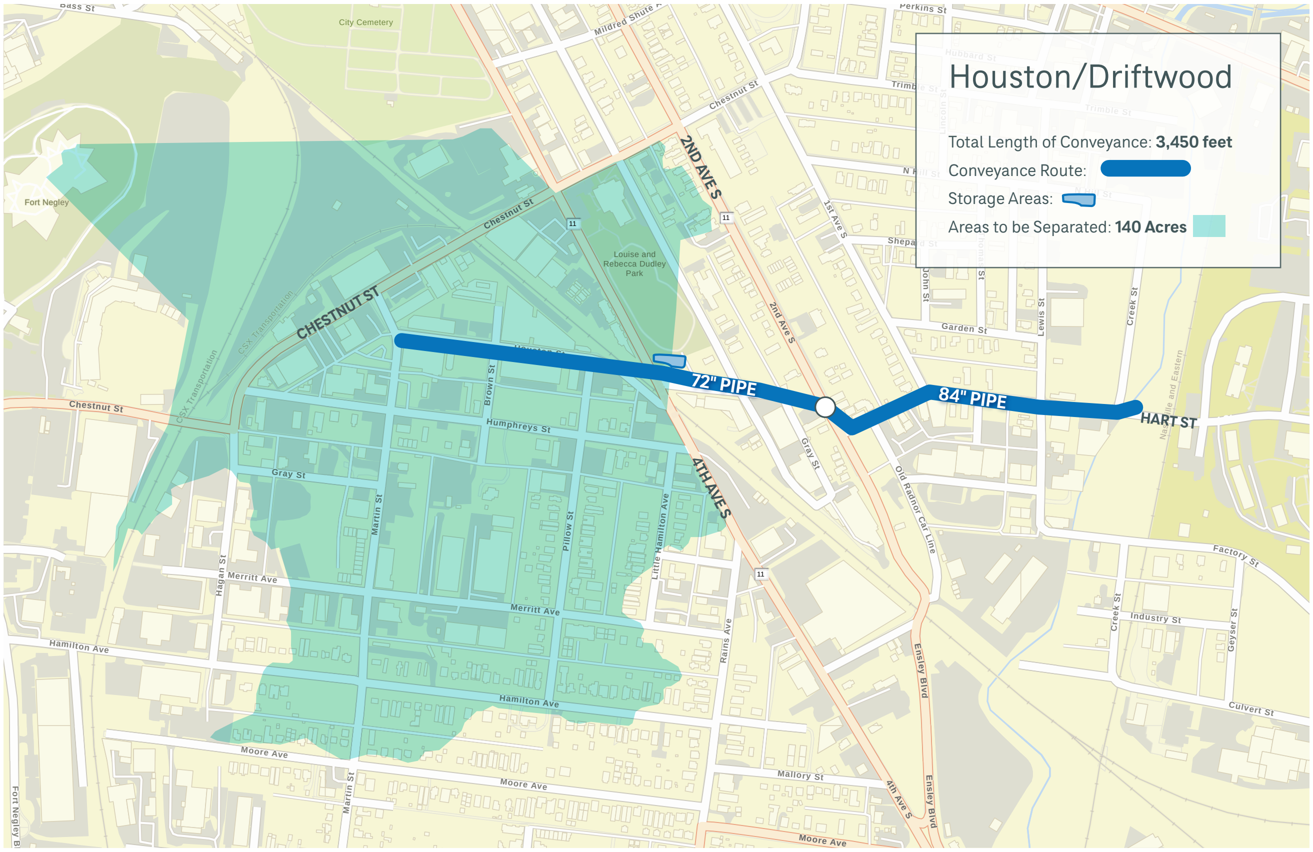


Figure 6-11. Proposed Houston/Driftwood Improvements

Browns Creek differs from the Cumberland River as an outfall condition. Because its drainage area is 13.2 square miles, it experiences a higher fluctuation in level during storm events. Dams or other structures do not actively control Browns Creek. It has a mapped floodway and floodplain that provides specific elevations for flood events along its reaches. At the proposed outfall location, the 100-year flood elevation is approximately 432 feet NAVD88. This is taken from Map Panel 47037C0244H, effective April 5, 2017, a selection of which is shown in **Figure 6-12**. At 432 feet NAVD88, much of the downstream neighborhood would be inundated.

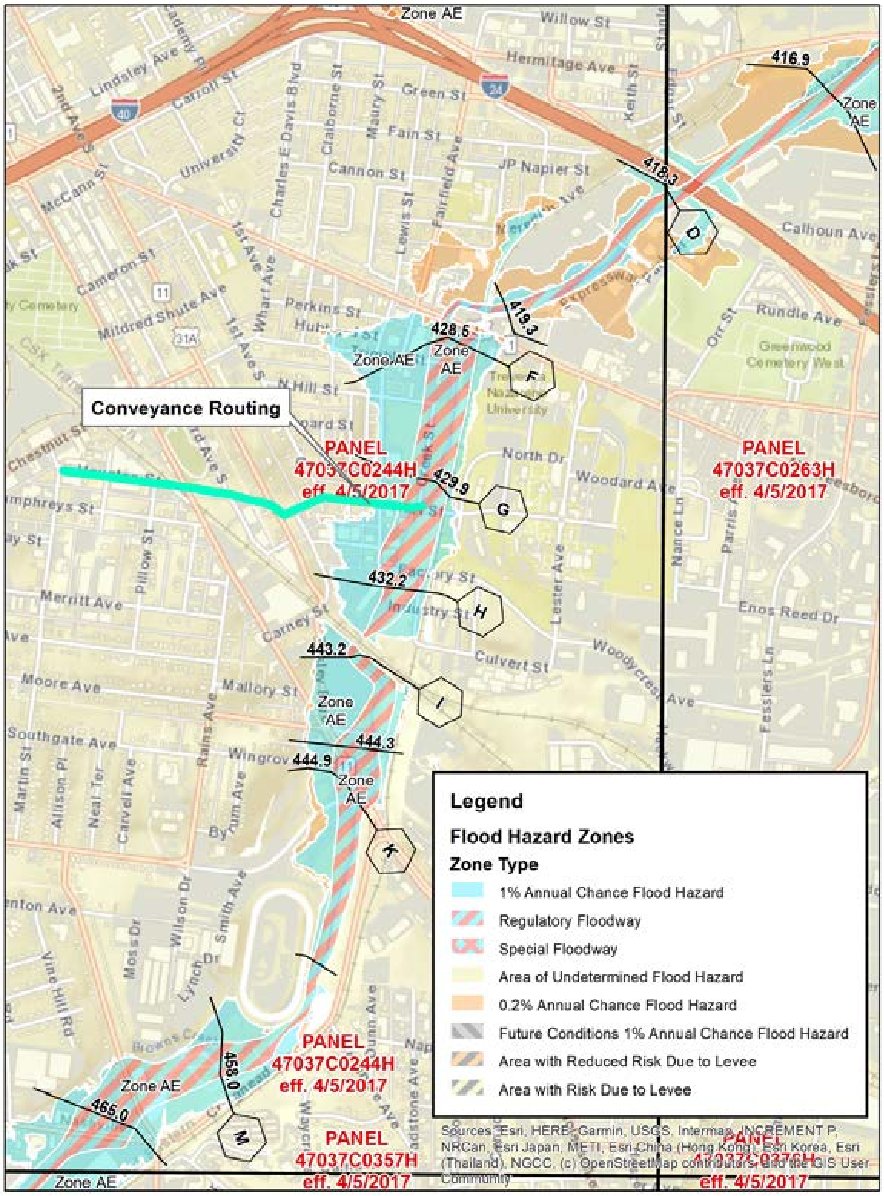


Figure 6-12. Floodplain Information for Browns Creek

The final 400 feet of the proposed conveyance is within the mapped floodplain for Browns Creek. Boundary conditions of differing stages were tested to determine the sensitivity of the alternative to elevated levels at the outfall. Despite the area being submerged in a 100-year flood, stormwater flow is modestly impacted because of sufficient driving head from upstream in the basin. **Table 6-3** provides a summary of the modeled peak flows for select river stages.

Table 6-3. Modeled Houston/Driftwood Flows at Select Browns Creek Stages

River Stage (NAVD88)	100-year, 24-hour Storm Peak Flow (MGD)
418 (Low Flow)	314
426 (Pipe Outlet Submerged)	314
432 (100-Year Flood Stage)	293

According to the U.S. Geologic Survey's StreamStats program, the 1 percent discharge value at the gauge at Factory Street is approximately 4,400 MGD. The peak flow from the Houston/Driftwood improvement could add approximately 7 percent to the total flow in the basin for a 100-year storm. A more detailed study of Browns Creek is advised as this improvement design proceeds.

Results

The proposed alternative relieves all inundation in the Houston Street corridor. Five commercial buildings are no longer exposed to risk of inundation and Houston Street is not inundated. **Figure 6-13** shows the inundation extents with alternatives applied for the 100-year design storm.

The separation of these flows from the CSS also provides the benefit of reducing potential flows to the Driftwood Equalization Facility. Since the Driftwood facility is already sized to mitigate CSO discharges in the typical year, with the alternative in place, it likely would have capacity to store excess flow in higher-intensity storm events. The level of service provided by the facility improved from slightly better than a 2-year, 24-hour storm to a 5-year, 24-hour storm with the proposed alternative in place.

Typical year CSO reductions provided by the Houston/Driftwood alternative are minimal. Activations at Kerrigan are not impacted, and the total volume of CSOs is reduced by less than one percent. Washington also sees no change in activations and no reduction in CSO volume under this alternative.

No other alternatives were considered for the Houston Street area.

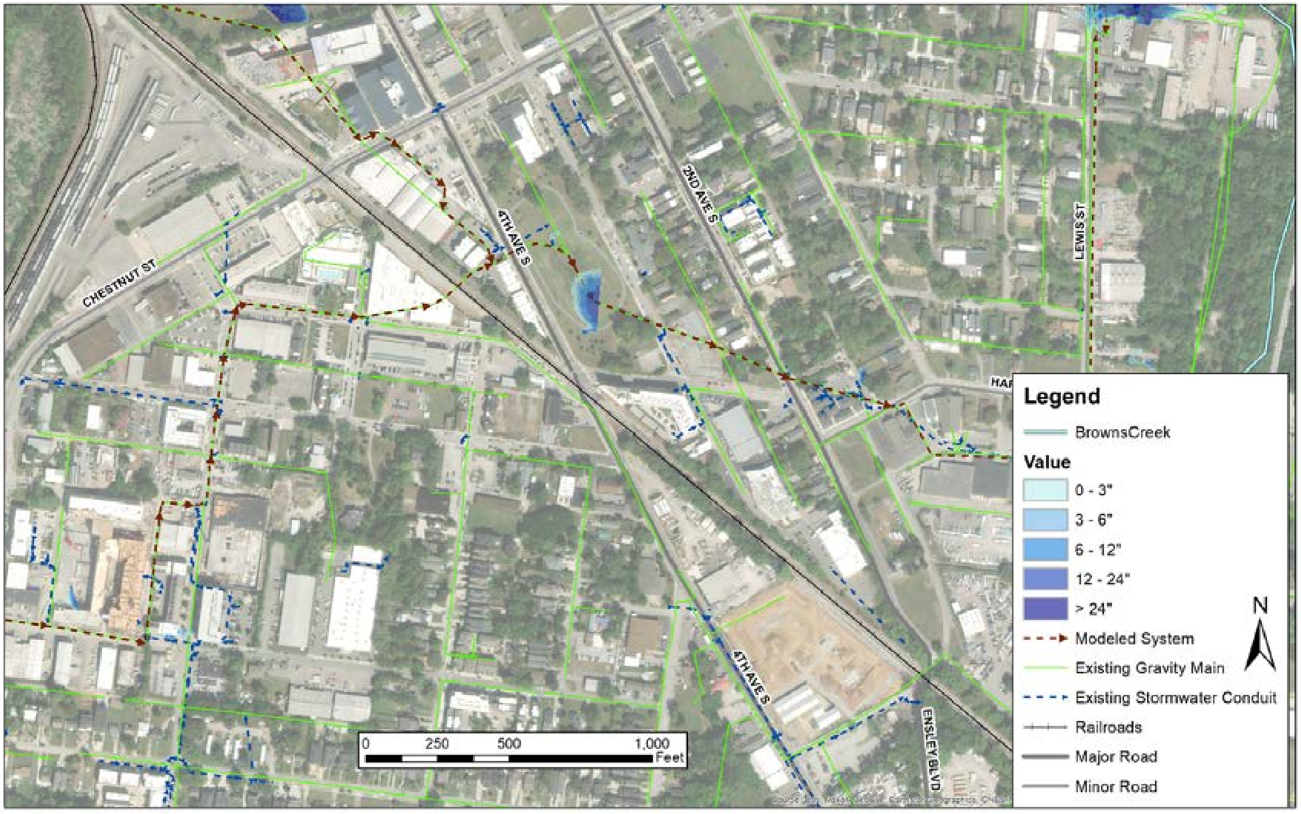


Figure 6-13. Flooding Extents in the 100-Year, 24-Hour Storm with Houston/Driftwood Alternative

Estimated Costs

The total cost for the Houston/Driftwood alternative is $89,000,000. **Table 6-4** provides a breakdown of the cost components.

Table 6-4. Houston/Driftwood Alternative Costs

Component	Cost (2023 dollars)
Conveyance and Storage Construction Cost	$43,000,000
Sewer Separation Cost	$28,000,000
Project Development Cost	$18,000,000
Total Project Cost	$89,000,000

6.5 Van Buren

The Van Buren Street corridor is in northern Germantown, just to the south and west of the Central WRF. This area is currently undergoing significant redevelopment with many large-scale, mixed-use developments recently completed, under construction, or planned. Nuisance flooding has been noted in the area, though significant property damage has not been noted. Morgan Park, just to the north of Van Buren Street, functions as a wet-weather detention area in large storm events. **Figures 6-14** and **6-15** show the 10-year, 24-hour and the 100-year, 24-hour inundation extents, respectively.

The Van Buren CSO was eliminated in 2011; however, combined sewers still exist throughout the Van Buren basin. Because it is near the Central WRF, this area is thought to contribute rapid runoff surges, which may impact CPS in high-intensity events.

Through model simulations of the 100-year storm, three structures were considered exposed to risk for inundation in this area, all of which are on 4th Avenue North. Surface streets saw a maximum of 12 inches inundation in the 100-year, 24-hour storm at the intersections of 4th Avenue North and Van Buren and 4th Avenue North and Hume Street.

Morgan Park currently acts as a holding area for excess stormwater in high-intensity events, as the following inundation figures show. It was assumed that Morgan Park would retain its current role as surface storage for the foreseeable future.

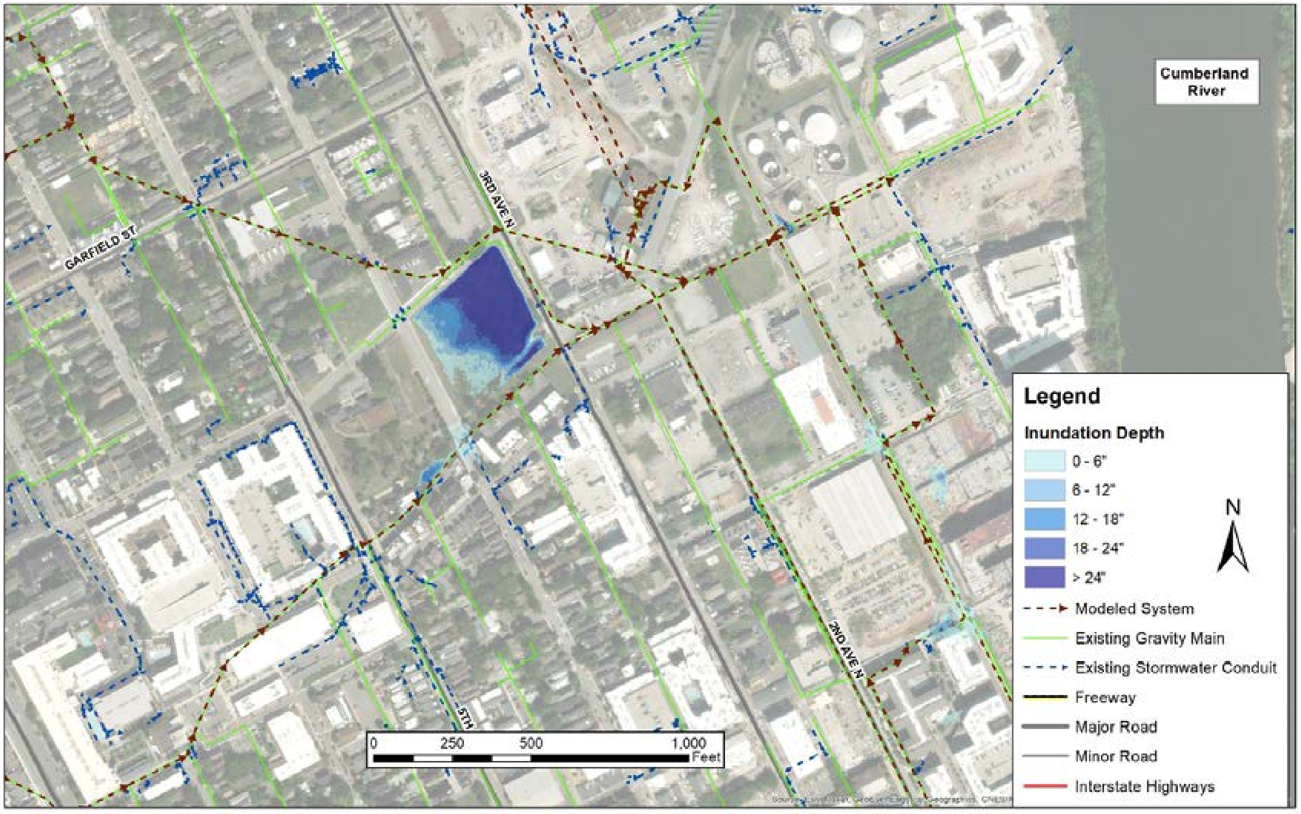


Figure 6-14. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

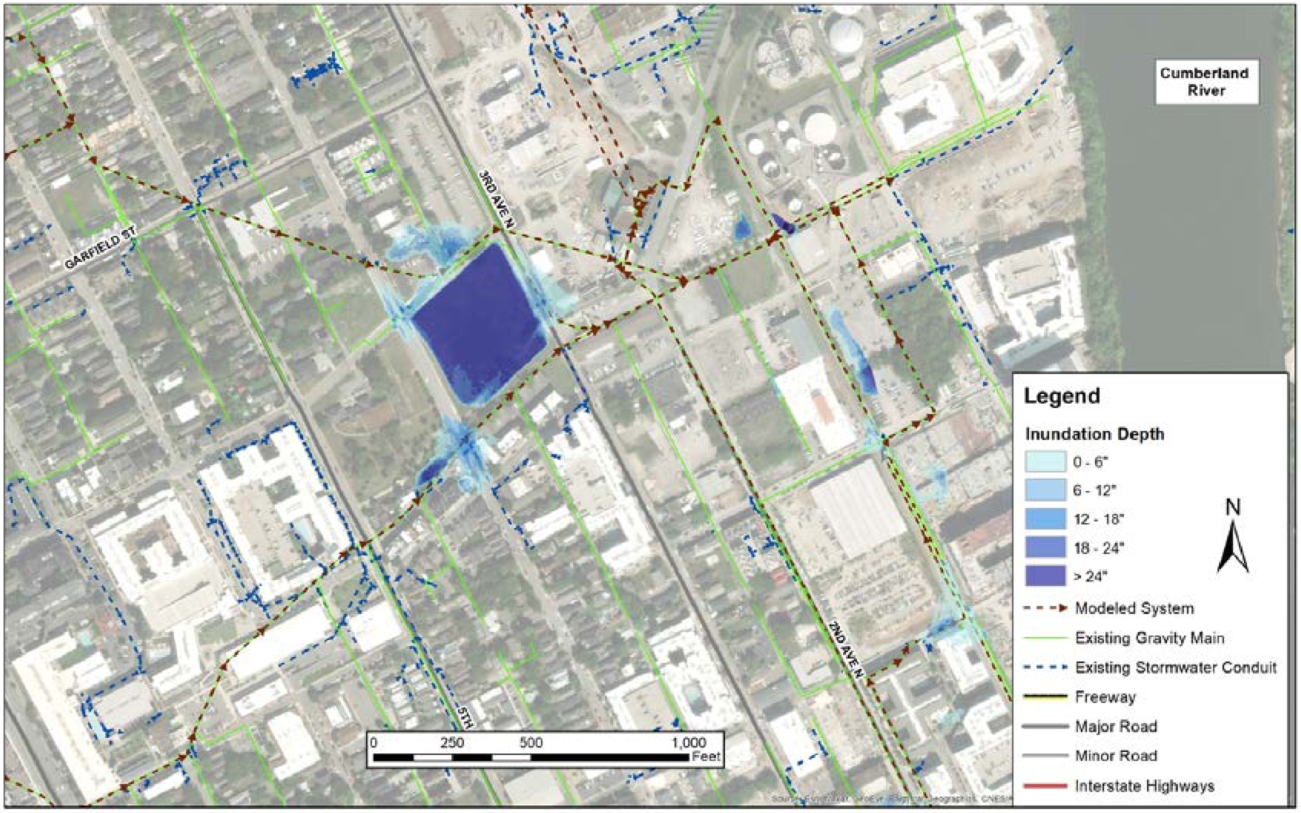


Figure 6-15. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

Proposed Alternatives

Because of the lack of available land for storage, separation and conveyance are the preferred improvements for this basin. The Van Buren conveyance alternative intends to make use of the existing, recently rehabilitated 72-inch storm outfall on the eastern terminus of Van Buren Street. The potential drainage area to the 72-inch storm sewer was evaluated to assess which areas reasonably could be separated and routed to the storm sewer to maximize its use during wet-weather events up to and including the 100-year design storm. Approximately 60 acres of moderate- to high-density commercial and residential area, portions of which already have separate stormwater networks installed by developers, could be routed without exhausting the capacity of the 72-inch outfall. In intense events, sheet flow from First Avenue south of Taylor may contribute to this drainage area.

Figure 6-16 shows the extents of proposed separation and conveyance improvements in this area. The size of the conveyance increases as it collects flow. The summary of lengths and proposed diameters are as follows:

- 460 linear feet of 48-inch pipe
- 420 linear feet of 54-inch pipe
- 810 linear feet of 60-inch pipe
- 620 linear feet of 72-inch pipe (not including the existing outfall pipe)

Sewer separation of approximately 60 acres within the basin is also included as part of the Van Buren project.

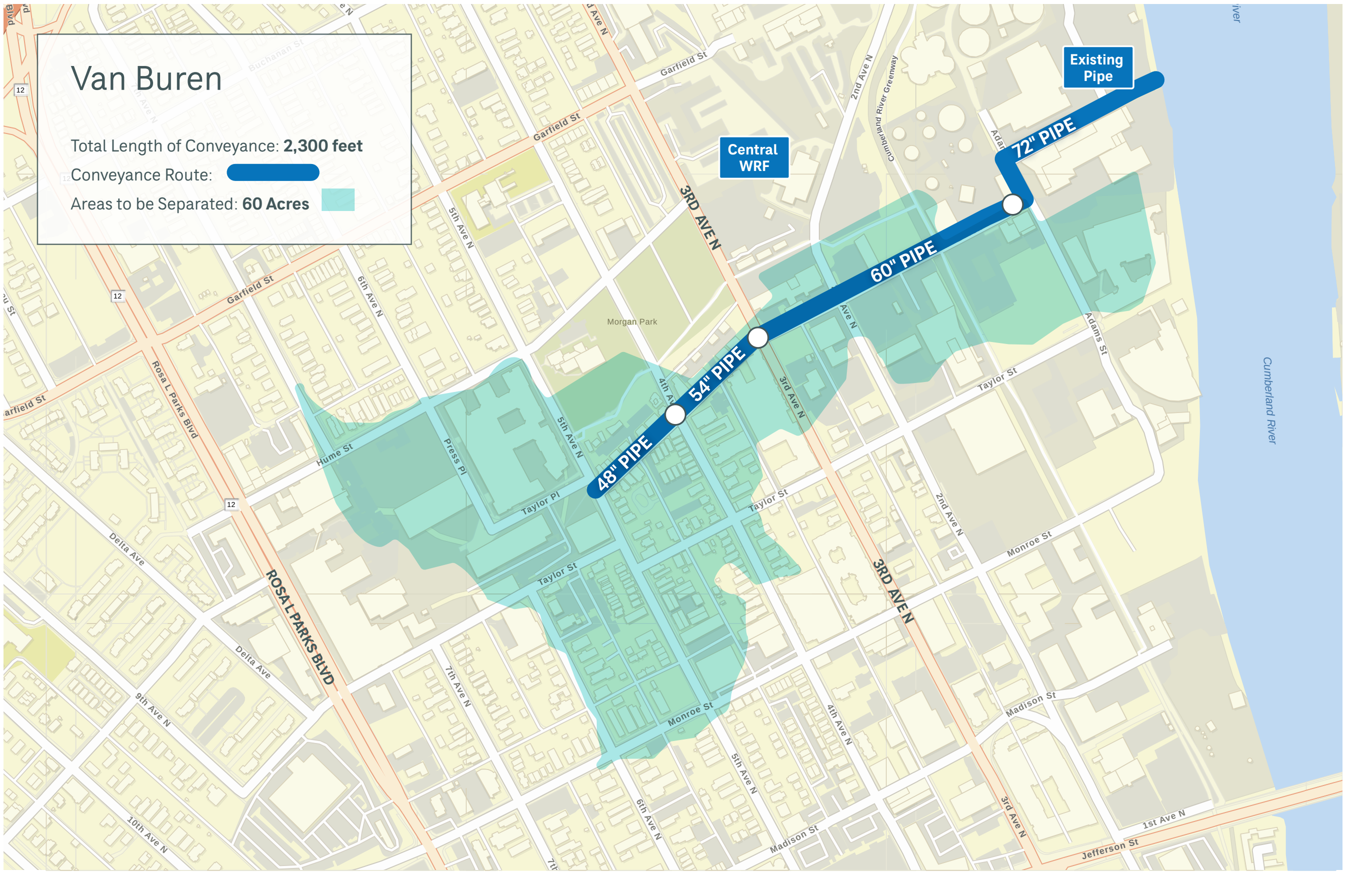


Figure 6-16. Proposed Van Buren Conveyance and Separation Extents

Routing of Conveyance Alternatives

The routing of the Van Buren conveyance is dictated by existing development tie-in locations and the existing outfall location. The conveyance must follow the Van Buren Street right-of-way and make use of the existing 72-inch pipe on Van Buren Street.

Because the entire Van Buren CSS basin is not proposed to be separated, areas upstream of the proposed separate storm drainage will remain routed to the existing combined pipe. No flooding issues have been identified in that area. This includes the 54-inch pipe to the northwest that currently serves Salemtown.

Conflicts

There are four known conflicts in the proposed conveyance route. From downstream to upstream, these conflicts are as follows:

1. FAT and SAT, though they are much deeper than the conveyance would require.
2. A 48-inch combined line that serves the First Avenue corridor.
3. CSX railroad between First and Second Avenue.
4. The 60-inch Browns Creek force main along Second Avenue.

Based on initial analyses, either the 48-inch combined sewer or the Browns Creek force main may need to be rerouted to accommodate the stormwater conveyance.

The effect of the Cumberland River's stage was evaluated for this alternative. Peak flows begin to reduce at 396 feet NAVD88; at flood stage, 408.1, the ability of the system to convey stormwater is limited. Because of surcharging in the pipe at flood stage, storm flow cannot enter the system and ponding may occur near Adams Street. At or near flood stage, many low-lying areas in Van Buren also may be exposed to the risk of river flooding unrelated to storm events. **Table 6-5** provides a summary of the modeled peak flows for select river stages.

Table 6-5. Modeled Van Buren Flows at Selected Cumberland River Stages

River Stage (NAVD88)	100-year, 24-hour Storm Peak Flow (MGD)
385 (Navigable Pool)	287
390 (Approximate Pipe Out Invert)	287
396 (95th Percentile High, Pipe Outlet Submerged)	250
408.1 (Flood Stage)	240

Results

These improvements resolved all three structures and all surface street flooding. **Figure 6-17** shows the extents of inundation in the 100-year, 24-hour storm. Morgan Park no longer appears inundated because the combined pipe provides drainage capacity in this area, although the park may still capture local stormwater runoff.

Typical year CSO reductions provided by the Van Buren alternative are minimal. Activations at Kerrigan remain at 13, and the total volume of CSOs is reduced by 1 percent. Washington sees no change in activations and no reduction in CSO volume under this alternative. This project is beneficial in its ability to use an existing outfall and convey existing separate stormwater to the Cumberland River as opposed to the Central WRF.

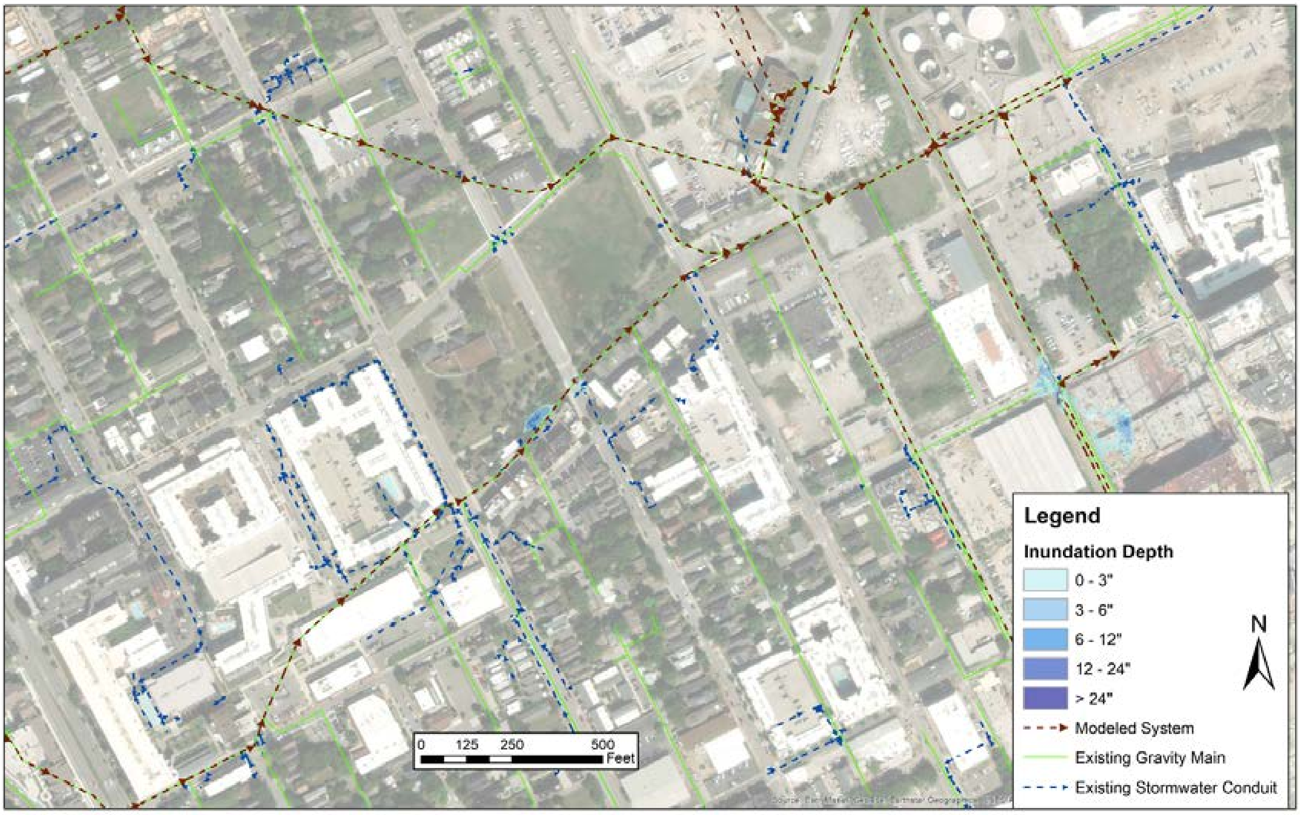


Figure 6-17. Flooding Extents in the 100-Year, 24-Hour Storm with Van Buren Alternative

Estimated Costs

The total cost for the Van Buren alternative is $40,000,000. **Table 6-6** provides a breakdown of the cost components.

Table 6-6. Van Buren Alternative Costs

Component	Cost (2023 dollars)
Conveyance Construction Cost	$20,000,000
Sewer Separation Cost	$12,000,000
Project Development Cost	$8,000,000
Total Project Cost	$40,000,000

6.6 Kerrigan

Kerrigan is the largest and most heavily developed drainage basin within the CSS. It is home to landmarks and institutions key to Nashville's culture and history, such as the State Capitol, Vanderbilt University, and Centennial Park. Its primary drainage corridor is the Kerrigan trunk conveyance that runs generally northeast from Centennial Park to the Cumberland River near the south side of the Jefferson Street bridge. At its largest, the Kerrigan trunk is a 16-foot-diameter sewer.

Urbanization and infill within the Kerrigan basin have increased both the storm and sanitary flow over the course of the 20th and 21st century. **Figures 6-17** and **6-18** show the 10-year and 100-year, 24-hour design storm inundation extents in the lower extents of Kerrigan, respectively. **Figures 6-19** through **6-22** show the 10-year, 24-hour and the 100-year, 24-hour inundation extents for the upper extents of Kerrigan near Centennial Park, Vanderbilt, and Hillsboro Village. Flooding locations in Kerrigan include:

- Rosa Parks Boulevard between 10th Circle North and Jefferson Street, which is the area surrounding the Farmers Market, sees flooding begin in a 2-year, 24-hour storm (**Figures 6-18, 6-19**).
- Jo Johnston Avenue, 10th Circle North through Capitol View, sees flooding begin in a 2-year, 24-hour storm (**Figures 6-18, 6-19**).
- Herman Street and 10th Avenue North sees flooding begin in a 5-year, 24-hour storm (**Figures 6-18, 6-19**).
- 12th and 14th Avenues North near Herman Street sees flooding begin in a 10-year, 24-hour storm (**Figures 6-18, 6-19**).
- Charlotte Avenue between I-24 and 17th Avenue sees flooding begin in a 10-year, 24-hour storm (**Figures 6-18, 6-19**).
- 25th and 24th Avenues South of Highland, or the area surrounding the VA Hospital, sees flooding begin in a 5-year, 24-hour storm. This area has been documented as inundated in recent, high-intensity storm events (**Figures 6-20, 6-21**).
- 21st Avenue South and Wedgewood, near Hillsboro Village, sees flooding begin in a 25-year, 24-hour storm (**Figures 6-20, 6-21**).
- 25th Avenue North and Brandau Place, near the Centennial SportsPlex, sees flooding begin in a 5-year, 24-hour storm. Flooding has been observed in this location, and in response, an apartment complex in the area has flood-proofed its first floor (**Figures 6-22, 6-23**).
- 31st Avenue North and Long Boulevard sees flooding begin in a 10-year, 24-hour storm intensity (**Figures 6-22, 6-23**).
- West End and Natchez Trace, the entrance to Centennial Park, sees flooding begin in a 100-year, 24-hour storm. Anecdotally, this area may flood more frequently than the modeling suggests (**Figures 6-22, 6-23**).

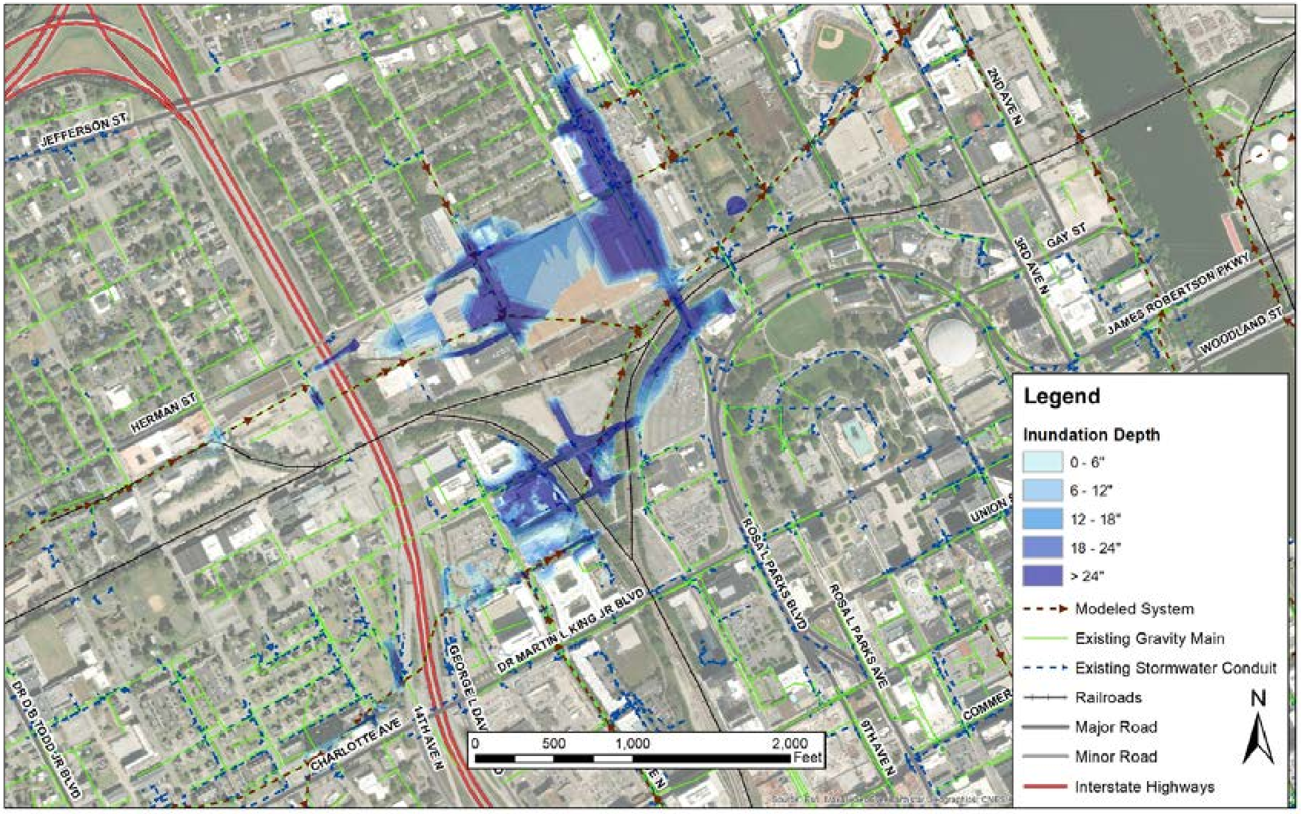


Figure 6-18. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

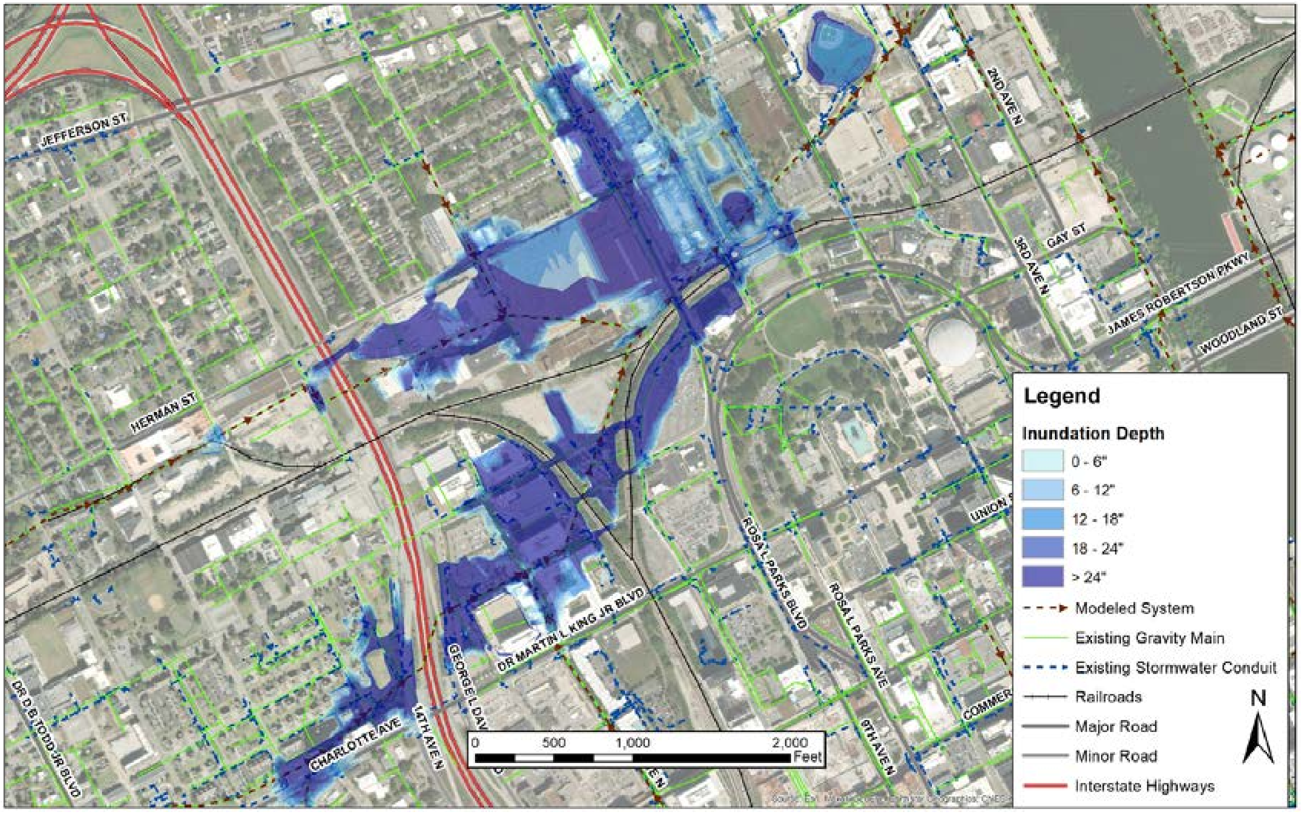


Figure 6-19. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

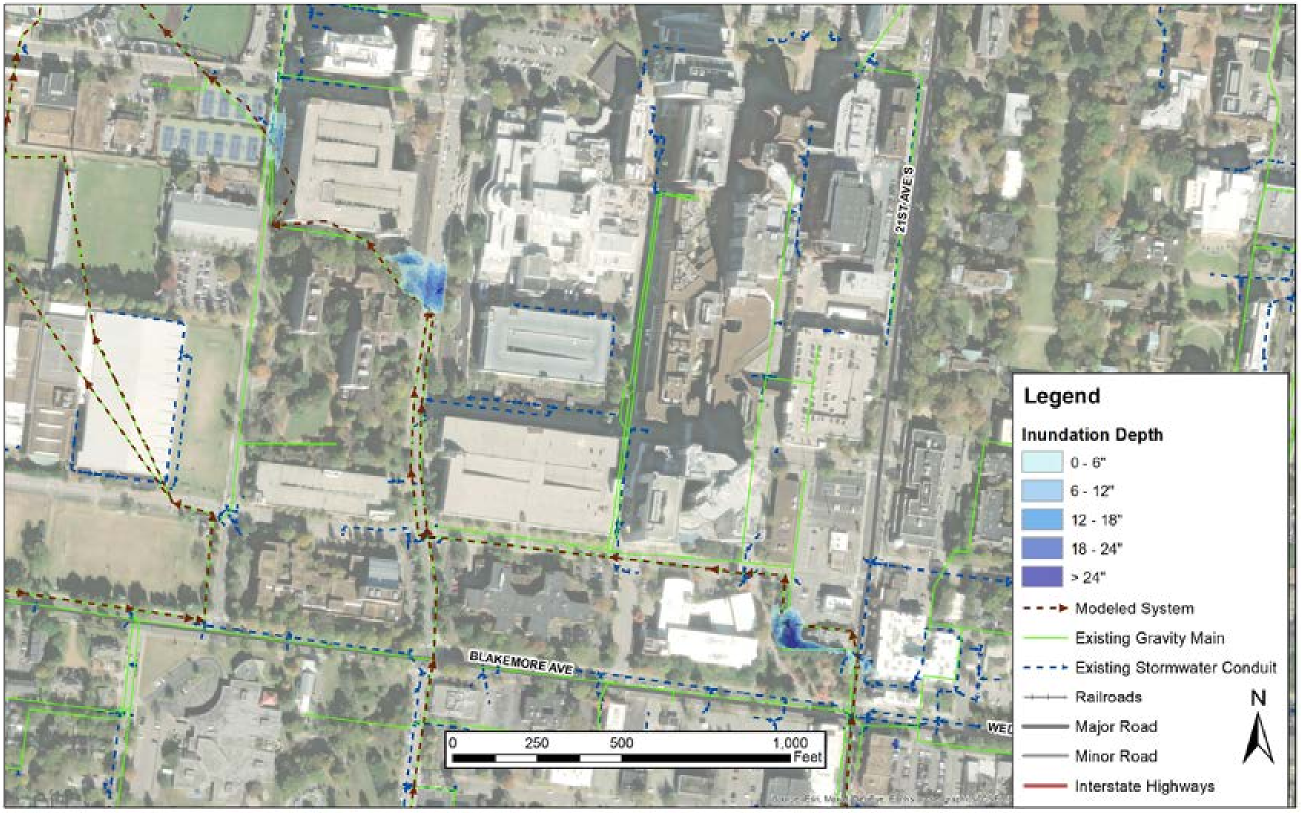


Figure 6-20. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

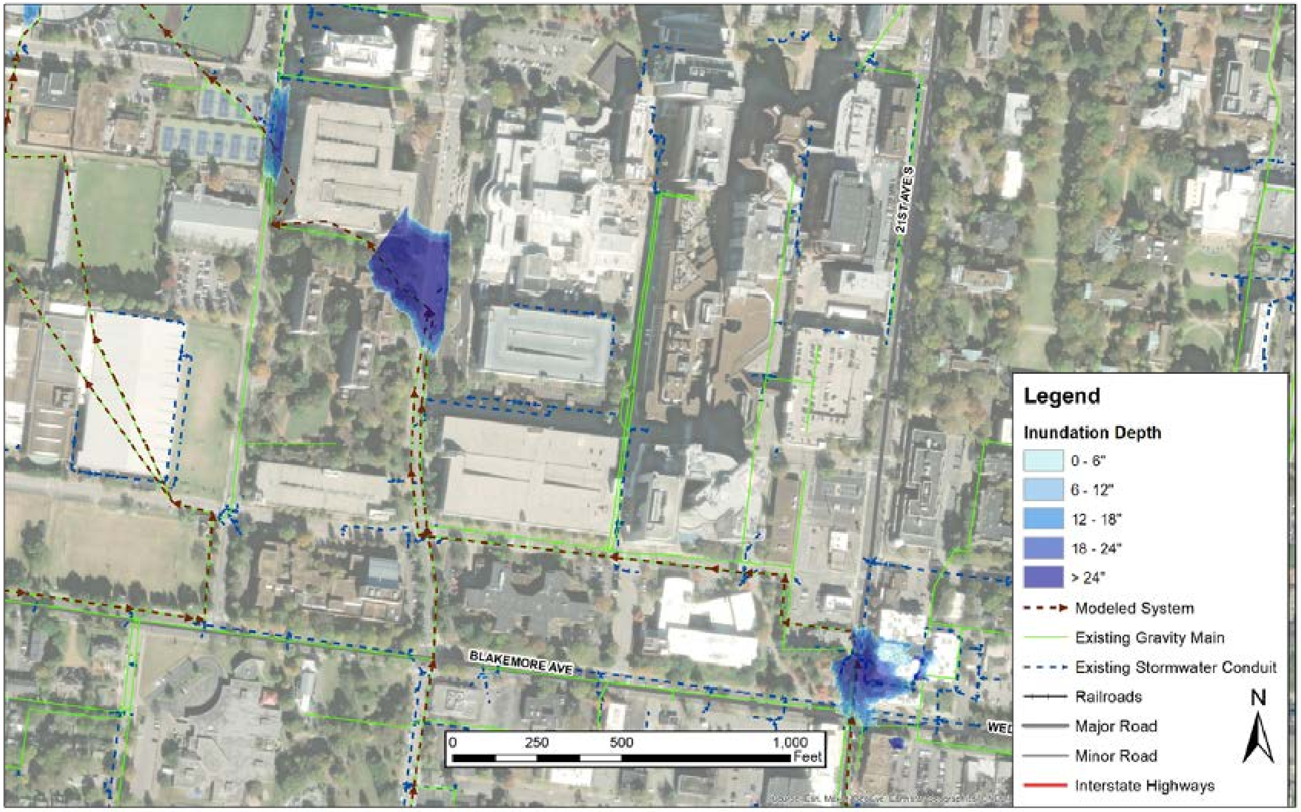


Figure 6-21. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

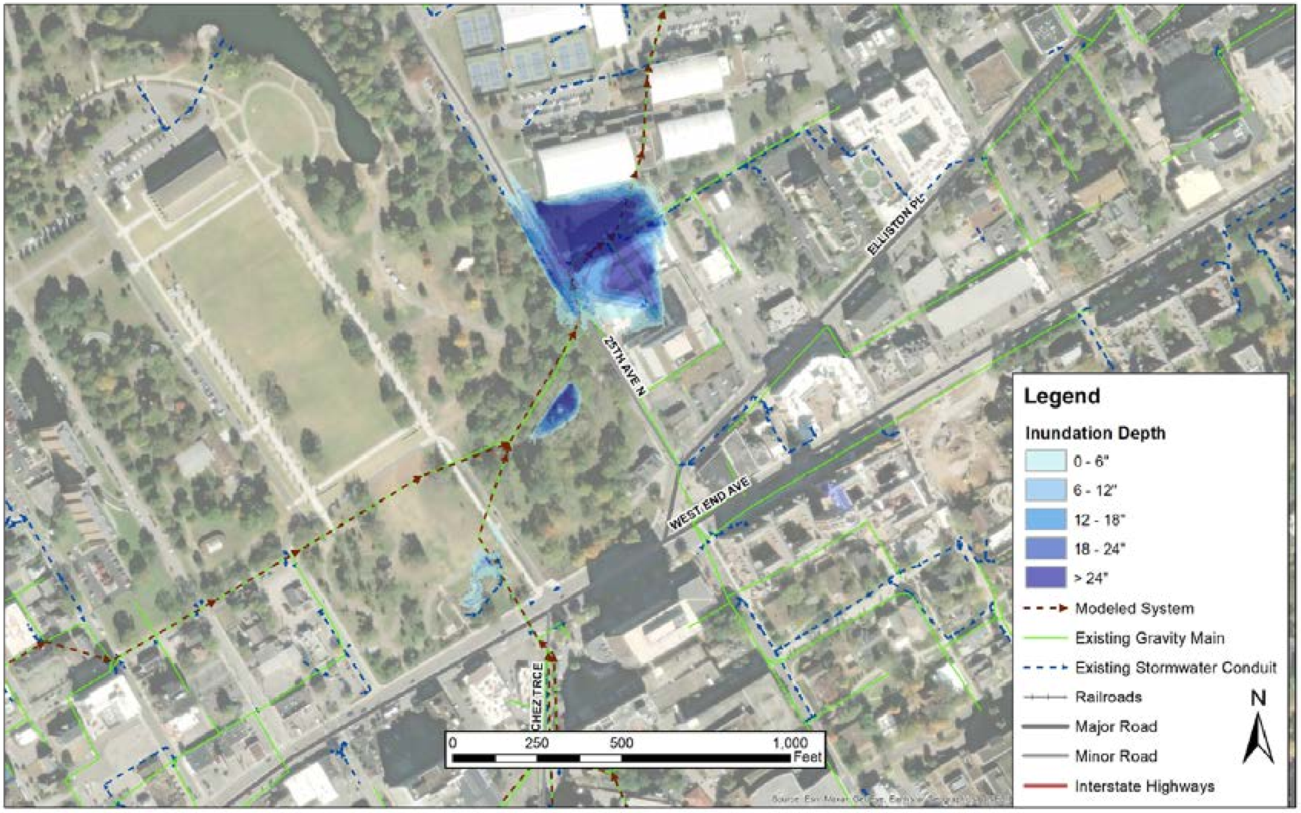


Figure 6-22. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

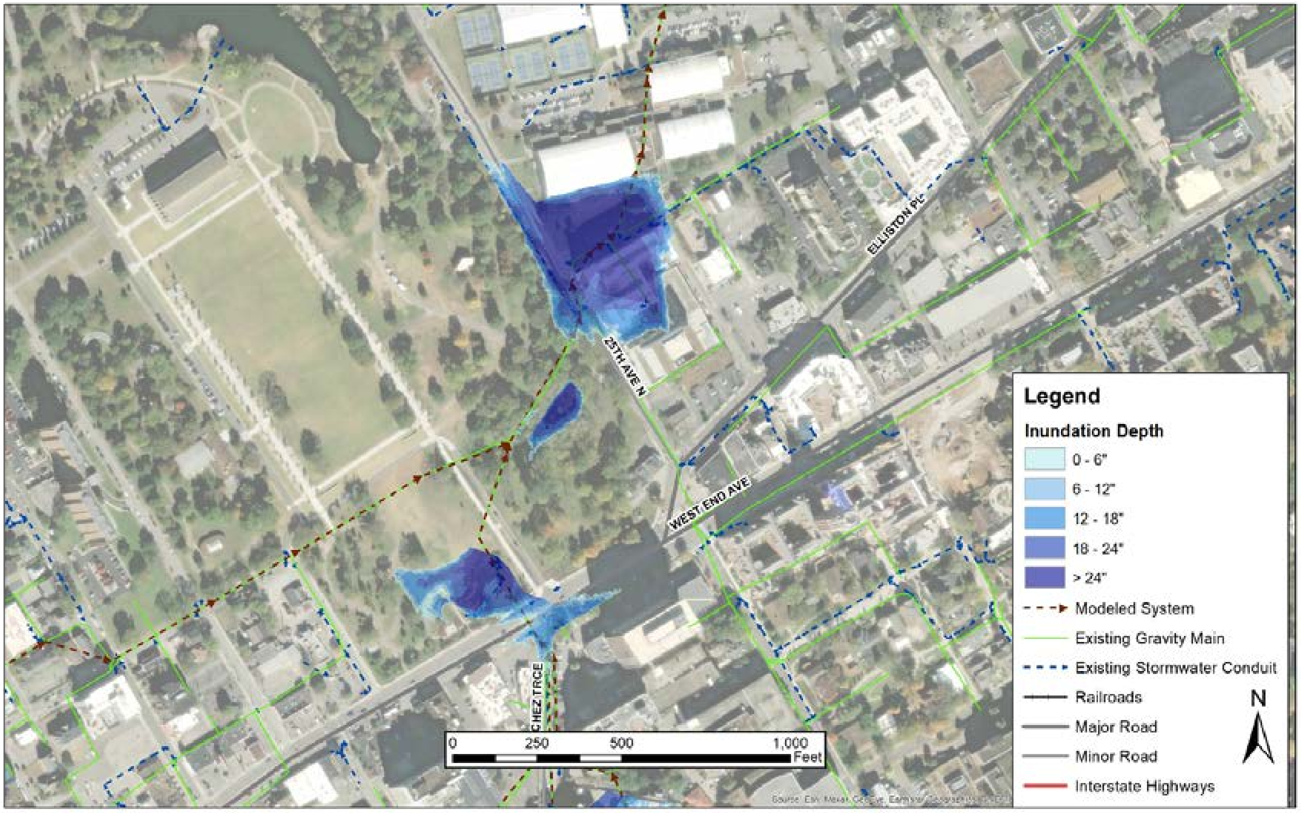


Figure 6-23. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

Because the Kerrigan CSS basin is large and encompasses numerous flooding locations, review of alternatives was divided into four main areas:

- Lower Kerrigan, which represents the area near Jefferson Street from 4th Street North to the Cumberland River
- Capitol/Farmers Market, which includes the Capitol View development and the Nashville Farmers Market
- Long Boulevard, which encompasses reporting flooding near Long Boulevard and 31st Avenue North
- West End/Vanderbilt, which extends from Wedgewood through Vanderbilt to the Centennial Park area

The following subsections provide discussion about projects associated with each of these general areas.

6.6.1 Lower Kerrigan

An area of approximately 43 acres north of Jefferson Street is currently separated and served by a 60-inch separate storm sewer outfall. The 60-inch pipe is not sufficiently sized to accept drainage from additional separated areas. Localized separate storm sewer networks exist beyond this area but are not currently connected such that the storm sewers can discharge through the existing outfall. This Lower Kerrigan project alternative, which was developed and proposed before the completion of the Master Plan, will connect these areas with a network of new storm conduits in the areas between 1st and 4th Avenues. Inundation for the 100-year, 24-hour storm is shown in **Figure 6-24**. Inundation is negligible in the 10-year, 24-hour event.

For the 100-year storm simulation, flooding is noted north of Jefferson Street along 2nd Avenue North with two structures exposed to risk of inundation. In a 100-year, 24-hour storm, 2nd Avenue North also sees greater than 6 inches of water.

Proposed Alternatives

For this analysis, the area north of Jefferson Street is considered tributary to this separate storm outfall included in this alternative. Plans exist in various stages of completion for pipes/inlets related to developments within the rest of the Lower Kerrigan area, though these were under development at the time of review and are not summarized. **Figure 6-25** shows the proposed stormwater conveyance in Lower Kerrigan.

The separation of up to 85 acres in the Lower Kerrigan area is included. Conveyance throughout Lower Kerrigan would route this separate stormwater flow directly through the Cumberland River via a new, larger 96-inch outfall. The following is a list of conveyance sizes and quantities:

- 850 linear feet of 24-inch pipe
- 330 linear feet of 30-inch pipe
- 190 linear feet of 36-inch pipe
- 1,150 linear feet of 42-inch pipe
- 320 linear feet of 48-inch pipe
- 700 linear feet of 54-inch pipe
- 350 linear feet of 60-inch pipe
- 450 linear feet of 72-inch pipe
- 500 linear feet of 96-inch pipe

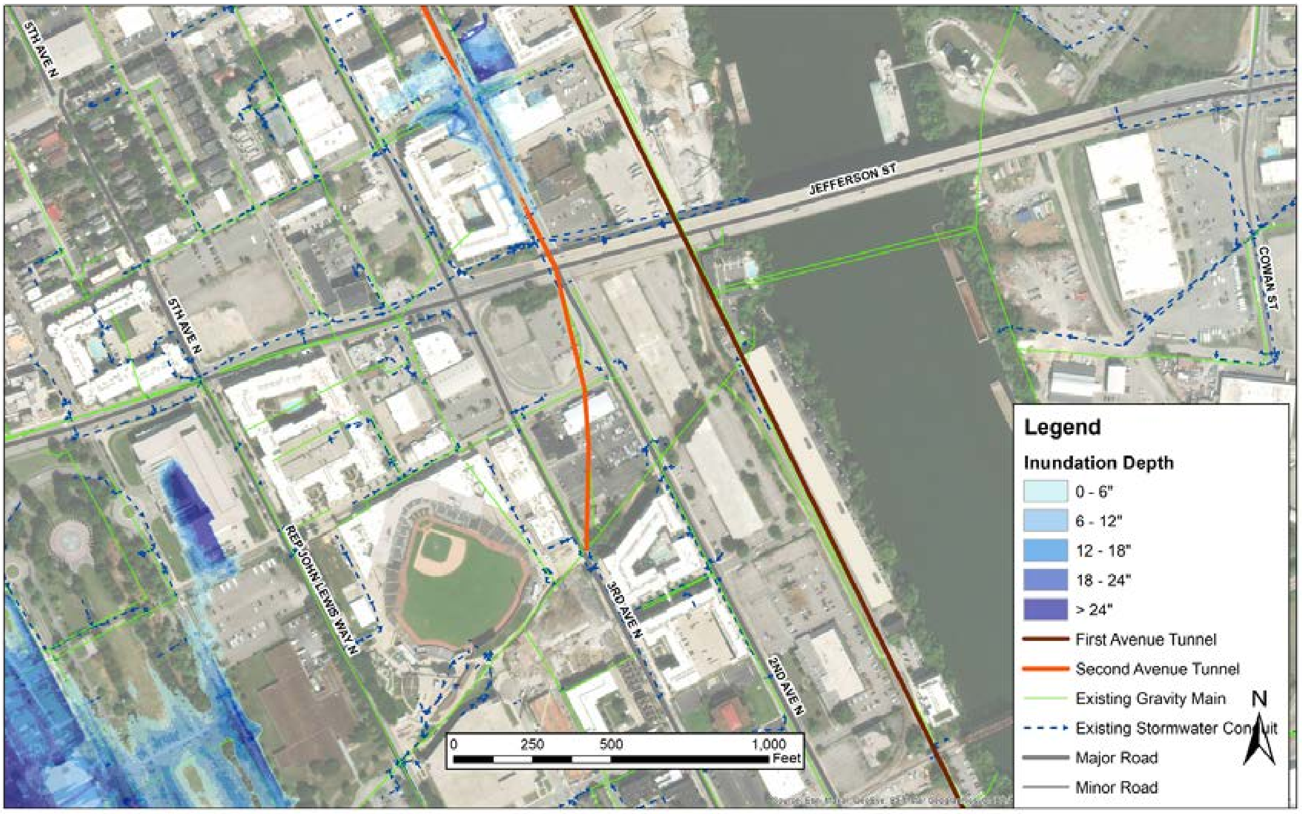


Figure 6-24. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

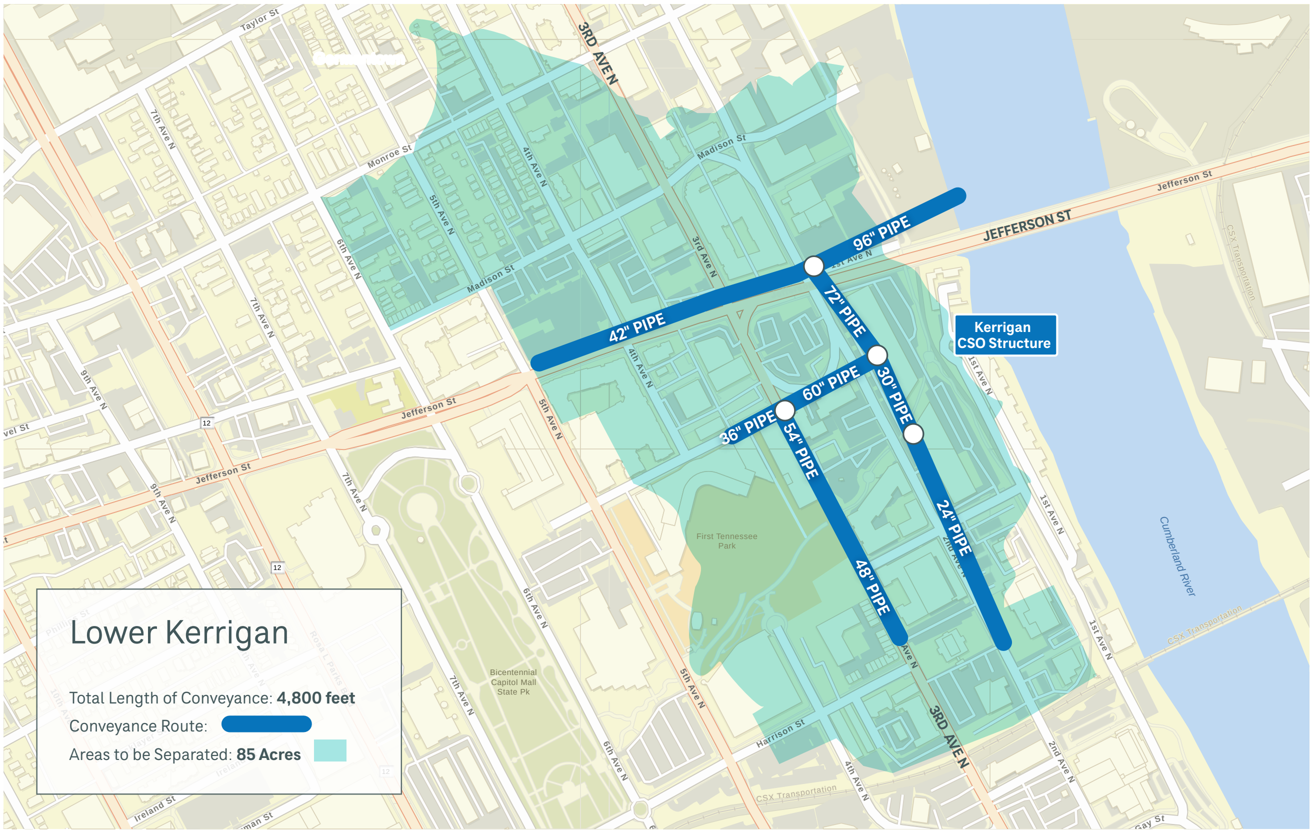


Figure 6-25. Lower Kerrigan Alternative

Results

All inundation in the Lower Kerrigan area is mitigated in this alternative, removing two structures from inundation exposure and removing flooding from 2nd Avenue North. **Figure 6-26** displays the flooding extents in Lower Kerrigan with the alternative applied.

The CSO reductions provided by the Lower Kerrigan alternative are moderate. Activations at Kerrigan remain at 13, and the total volume of CSOs is reduced by 6 percent. Washington sees a negligible impact on CSO volume under this alternative.

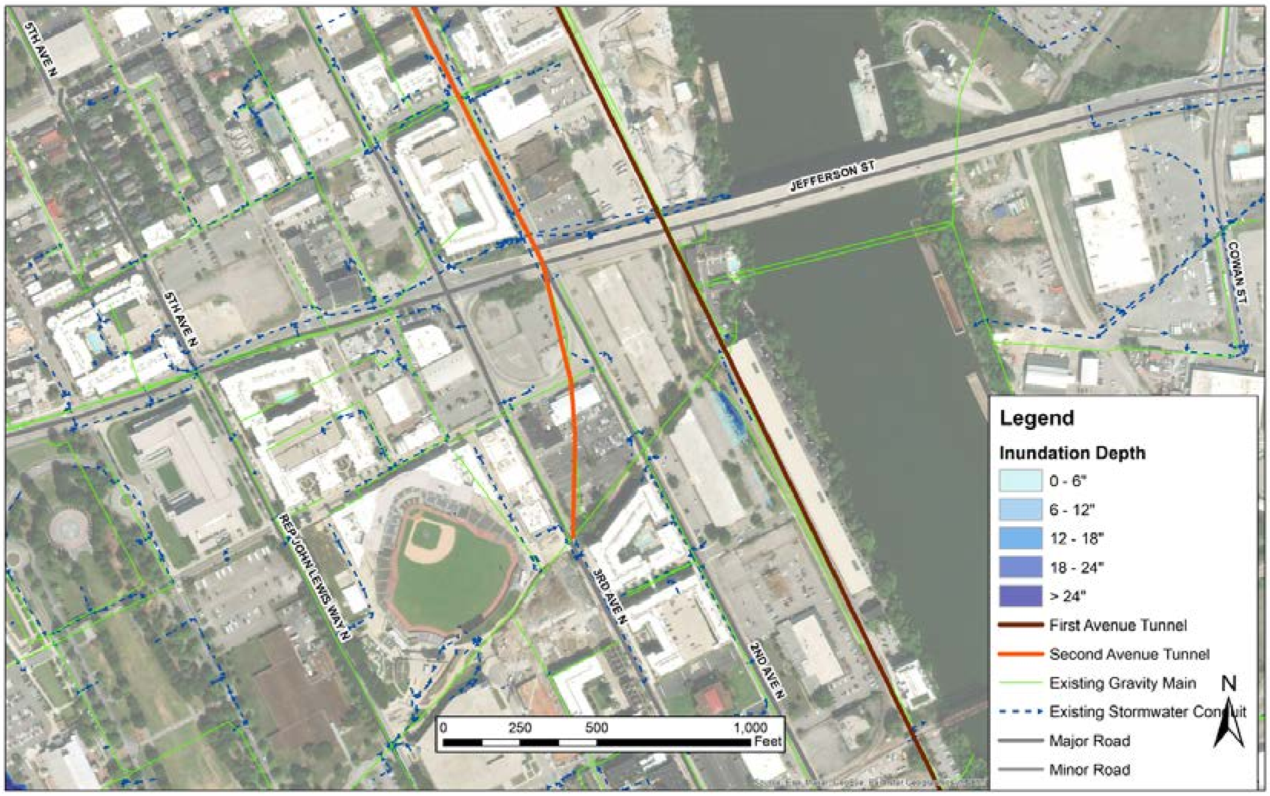


Figure 6-26. Flooding Extents in the 100-Year, 24-Hour Storm with Lower Kerrigan Alternative

Estimated Costs

The total cost for the Lower Kerrigan alternatives is $66,000,000. **Table 6-7** provides a breakdown of the cost components. If portions of this work have been or are being constructed in conjunction with developments, the estimated cost may go down.

Table 6-7. Lower Kerrigan Alternative Costs

Component	Cost (2023 dollars)
Conveyance Construction Cost	$36,000,000
Sewer Separation Cost	$17,000,000
Project Development Cost	$13,000,000
Total Project Cost	$66,000,000

6.6.2 Capitol/Farmers Market

Significant improvements in the Capitol/Farmers Market corridor are needed to mitigate the observed flooding in the areas north of Capitol Hill between 7th and 17th Avenues. Overall, 48 structures are exposed to risk of inundation as well as several main roads, including Rosa Parks Boulevard, 11th and 10th Avenues, Charlotte Avenue, and 14th Avenue North, which is an exit lane for I-40 East.

Proposed Alternatives

Conveyance sized at 72 to 96 inches is proposed to collect and convey stormwater out of the Capitol View area and to the Cumberland River. **Figure 6-27** shows the proposed routing. Up to 200 acres of separation is required to route separate storm flow to the proposed conveyance. Much of this area has been redeveloped recently as part of the Capitol View development. Conveyance quantities include:

- 2,100 linear feet of 72-inch pipe
- 3,500 linear feet of 96-inch pipe

Storage in the Heiman Street corridor is also part of this flood mitigation approach. Although not specifically sited, the storage was considered viable; currently there are open or available properties that may provide the opportunity for aboveground or subterranean detention sites. It was estimated that in a 100-year storm, 20 acre-feet would be required to maintain LOS in local pipes and effectively reduce flooding near Harrison Street when combined with the conveyance improvements. Twenty acre-feet is difficult to achieve within the available footprints of parcels in the area. The volume required to mitigate a 10-year, 24-hour storm was found to be roughly 7.75 acre-feet, which is a more manageable volume that still provides peak flow mitigation in larger events.

Sewer separation of approximately 200 acres within the basin is also included as part of the Capitol/Farmers Market project.

Routing of Alternatives

The routing of the Capitol/Farmers Market alternative uses the Gay Street corridor to pass under CSX railroad tracks before collecting flow in the area near Rosa Parks Boulevard and James Robertson Parkway. Route flexibility in this area is limited by existing easements and the footprints of several state administration buildings. The route then follows the James Robertson Parkway and Gay Street corridors before discharging to the Cumberland. Other routings were not considered because of the constraints of the CSX rail lines and Capitol Hill, although the routings may be evaluated further as the project is designed.

Conflicts

The Capitol/Farmers Market conveyance must pass over FAT. Although, FAT is likely sufficiently deep to not conflict with the routing of this alternative. The most significant conflict for this alternative is the passage under the elevated railroad tracks that form an arc around the Capitol area. The routing is proposed such that the conveyance would only have to pass under the railroad tracks once.

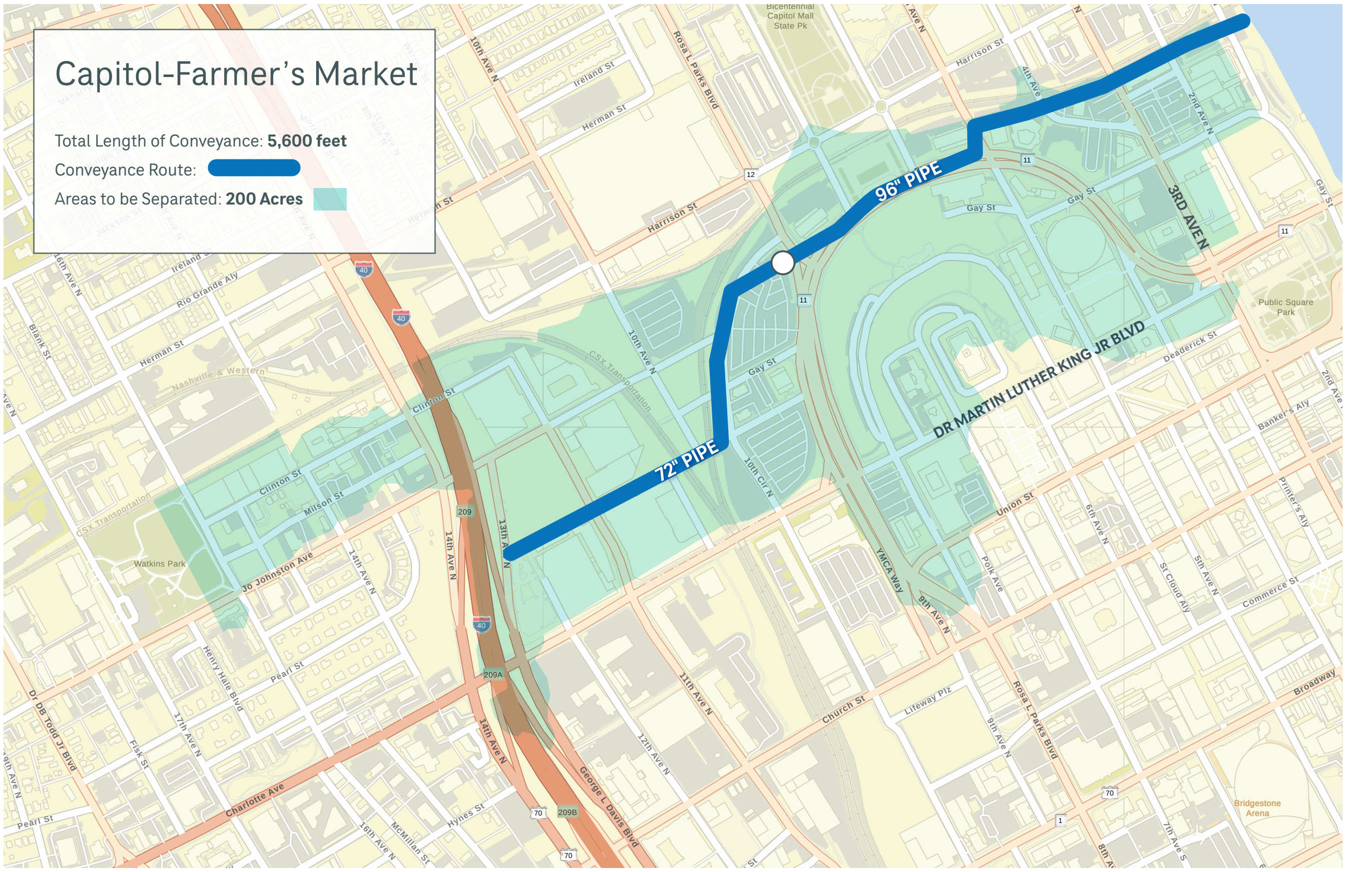


Figure 6-27. Proposed Alternatives for the Farmers Market

The proposed Cumberland River outlet location for this alternative is in an area where a discharge elevation higher than 385 feet NAVD88 could likely be achieved. The alternative was modeled with its outlet discharge at 390 feet NAVD88. Impacts of high river levels begin at or near 400 feet NAVD88. The impact of river levels on the area's drainage is most pronounced near the intersection of James Robertson Parkway and Rosa Parks Boulevard. Land surfaces in this area are as low as 413 feet NAVD88. **Table 6-8** presents a summary of the modeled peak flows for select river stages.

Sizing of the storage in the Heiman Street corridor also may prove challenging to site, as discussed.

Table 6-8. Modeled Capitol/Farmers Market Flows at Selected Cumberland River Stages

River Stage (NAVD88)	100-year, 24-hour Storm Peak Flow (MGD)
385 (Navigable Pool)	442
396 (95th Percentile High)	442
398 (Pipe Outlet Submerged)	442
401 (99th Percentile High)	416
408.1 (Flood Stage)	357

Results

With the Capitol/Farmers Market separation, conveyance, and storage, significant reductions in flooding are predicted; however, all model-predicted flooding is not remedied, especially beyond a 10-year, 24-hour storm event.

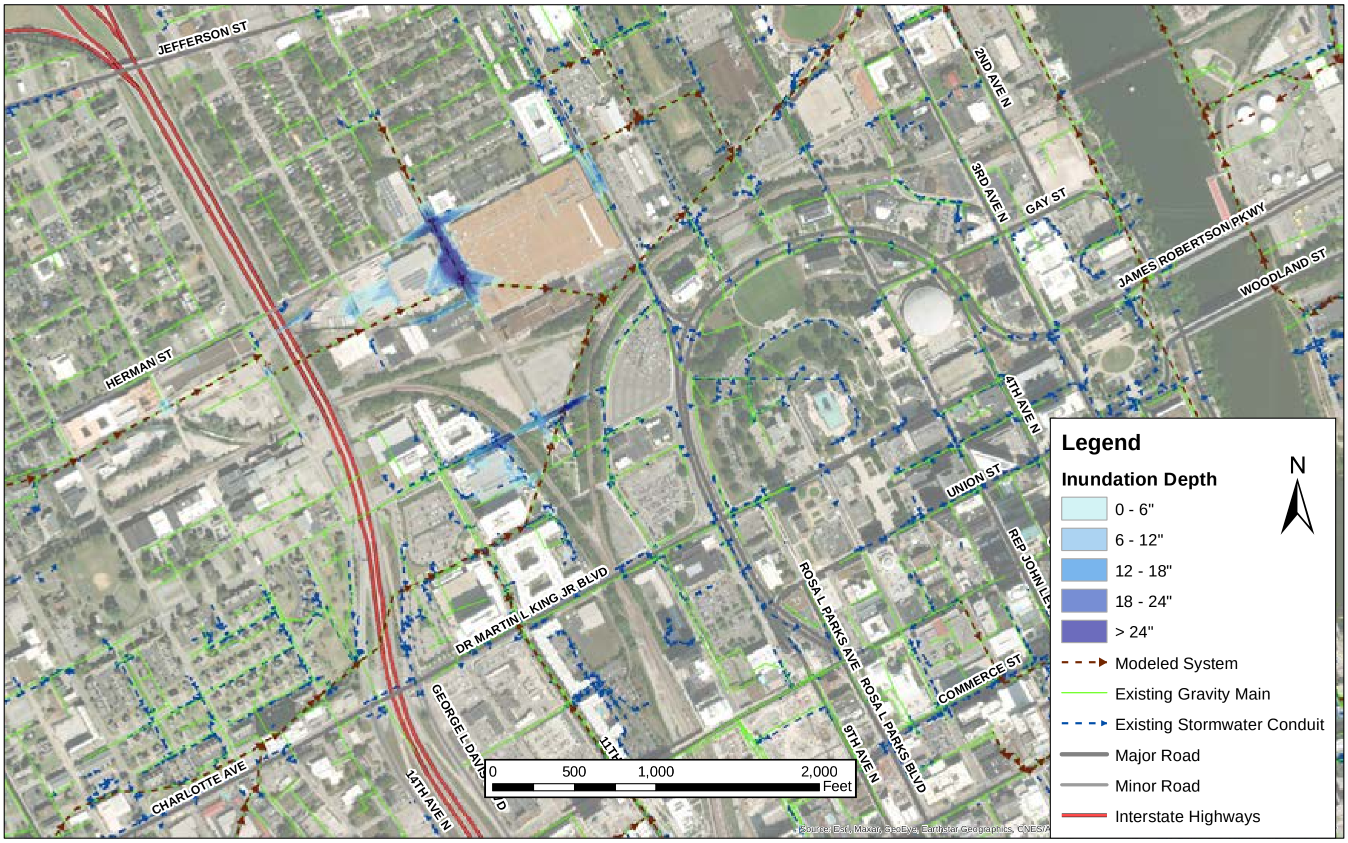
Figures 6-28 and **6-29** show the 10-year and 100-year inundation with only the Capitol/Farmers Market alternative active. As shown, significant flooding remains for the area of 10th Street between Herman Street and Jo Johnston

Avenue for the 10-year storm, and additional minor flooding remains along Rosa Park Boulevard. For the 100-year storm, predicted flooding with the improvements in place remains widespread, though to lesser extents and lower depths than the baseline model results. Storage volumes of up to 20 acre-feet were tested in the Herman Street corridor. A volume of 20 acre-feet resulted in an additional 0.3 feet of flood reduction at 10th and Herman Streets in the 100-year storm. This illustrates that additional storage throughout Kerrigan would mitigate flooding at the Farmers Market, though its impacts may be limited.

Flood depths predicted in this area likely would continue to threaten life and safety even with the Capitol/Farmers Market project implemented. Signage, barricades, and other strategies for reducing exposure to flooding risks to motorists or pedestrians are encouraged. Additional projects, such as the West End/Vanderbilt and Lower Kerrigan improvements, would be required to further remove stormwater flow from the CSS and allow lower hydraulic grade lines within the CSS trunk system during large storm events. **Section 6.7** describes the remaining inundation in this area with additional alternatives active.

CSO reductions provided by the Capitol/Farmers Market alternative are moderate. Activations at Kerrigan remain at 13, and the total volume of CSOs is reduced by 15 percent. Washington sees a decrease of almost one percent reduction in CSO volume under this alternative.

It was noted in meetings with MWS that Fisk University is embarking on a new campus plan that may provide a beneficial partnership for storing and conveying flow from that part of the basin. Further investigation of this potential partnership for storage and/or peak flow mitigation is recommended.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/A

Figure 6-28. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System with Capitol/Farmers Market Alternative

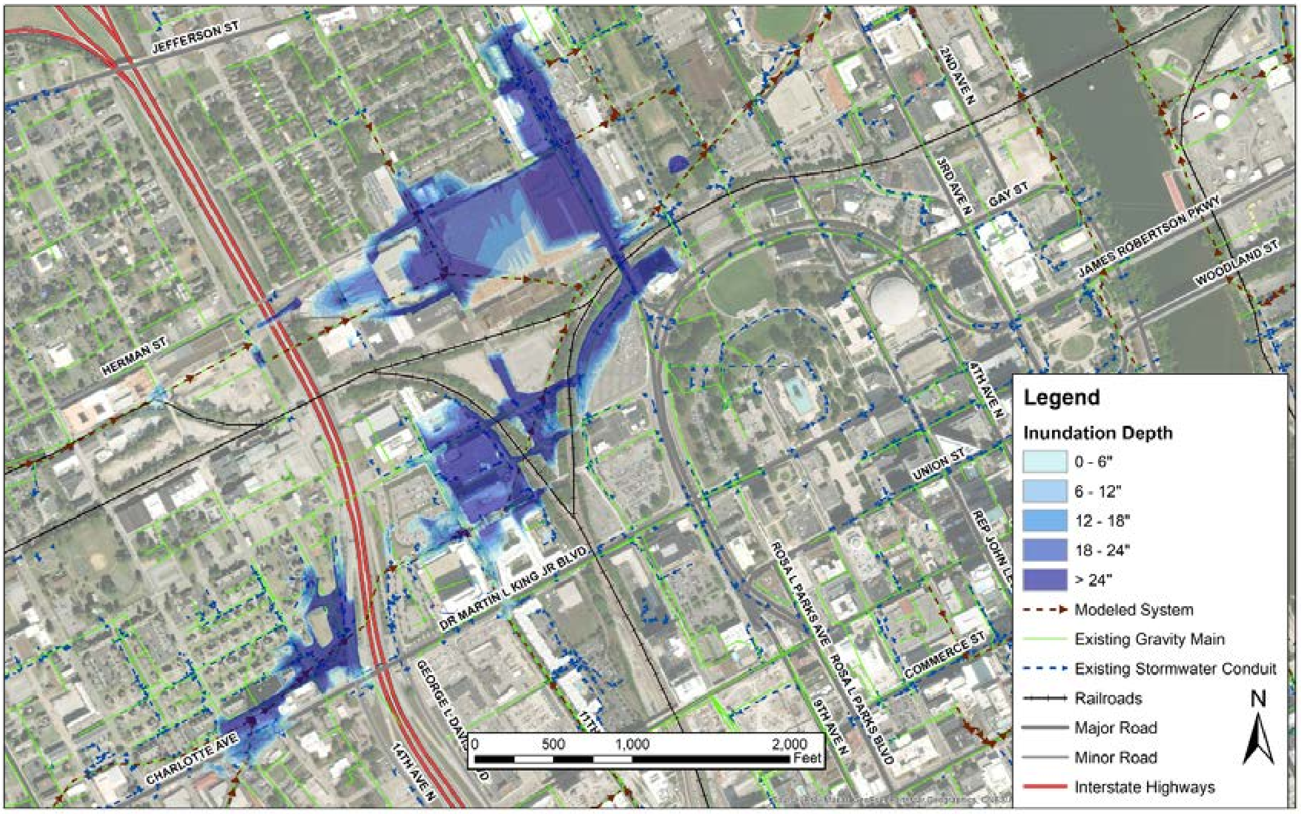


Figure 6-29. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System with Capitol/Farmers Market Alternative

Estimated Costs

The total cost for the Capitol/Farmers Market alternative is $138,000,000. **Table 6-9** provides a breakdown of the cost components. This includes construction of a detention basin with a capacity of 7.75 acre-feet, which is the estimated storage volume to mitigate the 10-year storm; 20 acre-feet would be required to mitigate the 100-year storm.

Table 6-9. Capitol/Farmers Market Alternative Costs

Component	Cost (2023 dollars)
Conveyance and Storage Construction Cost	$70,000,000
Sewer Separation Cost	$40,000,000
Project Development Cost	$28,000,000
Total Project Cost	$138,000,000

6.6.3 Long Boulevard

Flooding near 31st Avenue North and Long Boulevard prompted a close examination of the drainage and combined sewer system in that area. In the baseline conditions model, two structures were exposed to risk of inundation, and 31st Avenue North may be impassable in events of 10-year, 24-hour intensity and higher. **Figures 6-30** and **6-31** show flooding extents in the 10-year, 24-hour and 100-year, 24-hour storm events.

Proposed Alternatives

The Long Boulevard project consists of a new interceptor along Long Boulevard that would collect separate storm flow and eventually deliver it to a new West End/Vanderbilt stormwater conveyance tunnel. A total of 70 acres upstream of Long Boulevard would require separation. An additional 35 acres near West End and 27th Avenue North could also be routed to the new conveyance. Separation and capture of this additional 35 acres are not included in the estimated cost. The proposed conveyance for Long Boulevard includes:

- 4,650 linear feet of 48-inch pipe
- 150 linear feet of 36-inch pipe

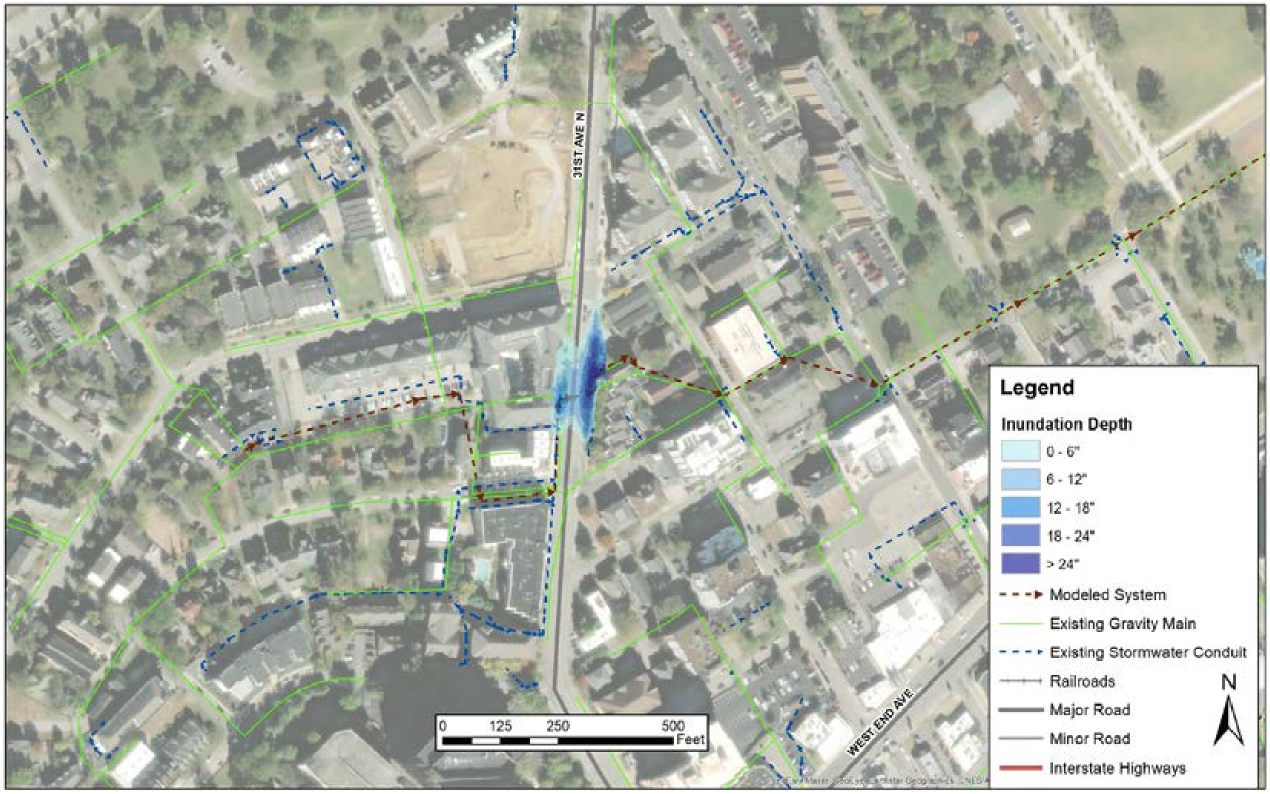


Figure 6-30. Flooding Extents in the 10-Year, 24-Hour Storm, 2045 System

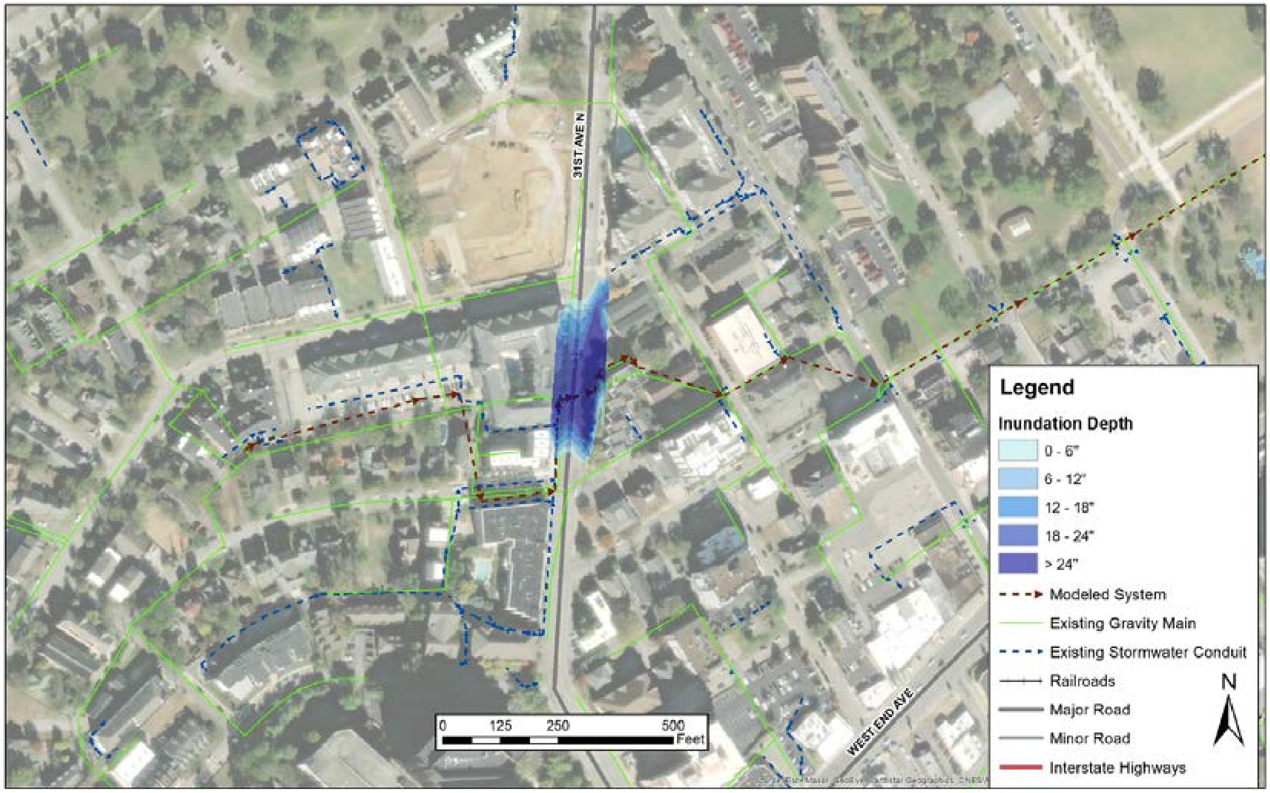


Figure 6-31. Flooding Extents in the 100-Year, 24-Hour Storm, 2045 System

A smaller area of storage near the Metropolitan Development and Housing Agency's property west of Centennial Park was evaluated as an interim solution if the Long Boulevard interceptor is built before construction of the West End/Vanderbilt stormwater conveyance. Recombination would be necessary near this location, with storage as an option to provide peak flow mitigation at the point of recombination. A volume of 5.5 acre-feet was found to be required to store excess 100-year, 24-hour storm flow before it can reenter the existing system downstream of the Long Boulevard improvements. This storage is costed as a subterranean storage vault with connections to the existing and future systems. **Figure 6-32** shows the total alternatives for this area.

An interim project to reduce the frequency of overflows was completed in the Long Boulevard area in March of 2023. The local 8-inch collector line south of Long Boulevard was replaced by an 18-inch pipe and a 12-inch crossover was installed to utilize an existing nearby 36-inch connection during high flow conditions. Data from 2023 suggests that the frequency of overflow incidents in this area have greatly diminished with the expanded drainage capacity.

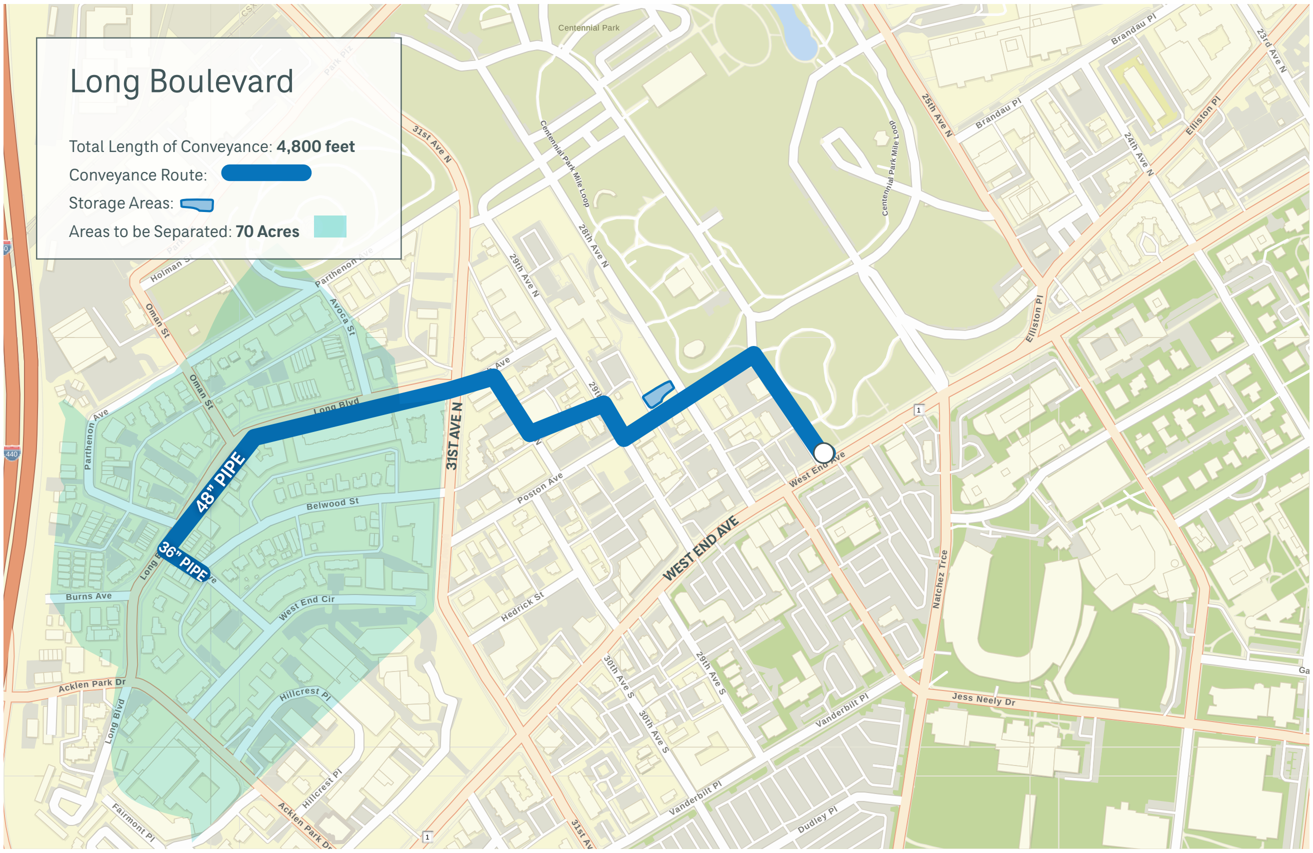


Figure 6-32. Long Boulevard Alternatives

Conflicts

No major conflicts were identified for the Long Boulevard corridor, although routing the conveyance existing right-of-way may pose challenging. Additionally, if storage is selected as an interim solution, siting the facility may be difficult.

Results

With the proposed alternatives in place, the flooding in the 31st Avenue North corridor no longer occurs in any modeled storm event. Two structures near the intersection of Long Boulevard and 31st Avenue North are no longer exposed to the risk of inundation.

Estimated Costs

The total cost for the Long Boulevard alternatives, including storage as an interim solution, is $55,000,000. Costs without the storage area are approximately $43,000,000. **Table 6-10** provides a breakdown of the cost components.

Table 6-10. Long Boulevard Alternative Costs

Component	Cost (2023 dollars)
Conveyance Construction Cost	$20,000,000
Sewer Separation Cost	$14,000,000
Project Development Cost	$9,000,000
Total Project Cost	$43,000,000*

* Interim storage area adds $12 million to total project cost.

6.6.4 West End/Vanderbilt

Due to the frequency of flooding in the areas near Centennial Park, Vanderbilt University, and Hillsboro Village, large-scale improvements are necessary. Nine structures are potentially inundated, and significant roadways, such as West End Boulevard, 21st Avenue South, 25th Avenue North, and 25th Avenue South, are susceptible to flooding.

Proposed Alternatives

A large-diameter stormwater conveyance is proposed from the corner of Natchez Trace and West End to the Cumberland River, using the West End/Broadway corridor as its route. This conveyance would allow stormwater to be diverted away from the Kerrigan CSS and would alleviate flooding; however, significant sewer separation would also be required.

Approximately 475 acres of combined sewer system will require separation prior to being routed to the stormwater tunnel. **Figure 6-33** shows the extents of these areas, which include much of Hillsboro Village and Love Circle. This area consists of medium-density residential and light commercial neighborhoods. Vanderbilt has stated its intention to fully separate the approximately 400 acres of its campus in the future. Additionally, the Long Boulevard project and adjacent areas that could be separated would be tributary to the West End conveyance.

MWS has expressed interest in this routing because it uses existing right-of-way and consists of little to no bends that would introduce losses and possibly raise costs. To maximize the use of this large conveyance, it is anticipated that stormwater from additional areas between the origin of the tunnel and the Cumberland River could be separated and routed into the tunnel through drop shafts along its route. Areas of Midtown and the Gulch may be good candidates for use of the tunnel's drainage, because a high amount of development is occurring and will continue to occur in these areas. This area is highly impervious, roughly 75 percent, and presents high peak flows that significantly affect performance of the existing system. The possibility for development partnerships for local separation and conveyance are high. An estimate of 210 additional acres of separate area in the Broadway corridor was assumed to determine the size of the tunnel and the location of its drop shafts, one of which is located near 11th Avenue and Broadway.

Given assumed separation areas, the tunnel was sized at 16 feet in diameter. The entire diameter is this size, because the methods required to construct the tunnel do not easily support changes in diameter. The total length of a route from the corner of Natchez Trace and West End to the Cumberland at the end of Broadway is approximately 12,000 feet.

When separation of the assumed area is complete, the 16-foot conveyance would be flowing full in its downstream extents, though no aboveground flow is noted. This meets the given LOS criteria. As with all alternatives, management of velocity in the conveyance must be taken into consideration during design to prevent damage to the pipe and its outfall.

To deliver separate flows to the proposed West End conveyance, a second 96-inch-diameter conveyance is proposed using 21st Avenue as its corridor. Micro-tunneling is suggested for this conveyance, because of its size and the depths of cover, which may be prohibitively high for open cut installation.

The 96-inch conveyance along 21st Avenue allows for separate flow from upstream areas to be diverted away from Vanderbilt's campus. This would allow existing combined pipes/boxes on Vanderbilt's campus to be used for stormwater in post-separation conditions, reducing new infrastructure costs and disruptions. The alternatives were modeled such that only new sanitary lines would be required for separation in those areas.

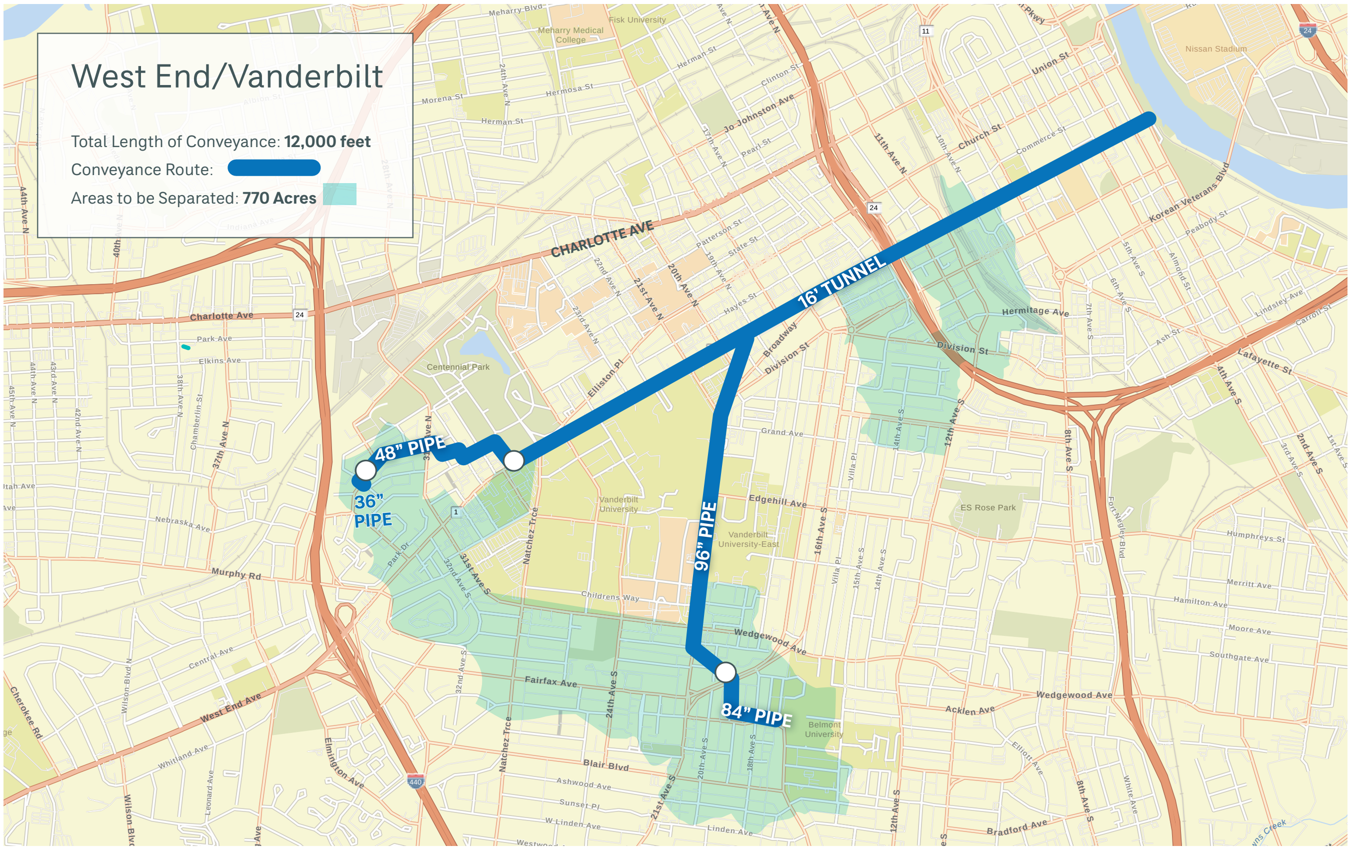


Figure 6-33. West End Conveyance and Proposed Separation Areas

Routing of Conveyance Alternatives

Routing of the proposed tunnel is constrained by three parameters:

- Utility conflicts
- Capability of the tunnel boring machine (TBM) to change direction
- Suitability of the outlet location

Conflicts for the tunnel may include fewer of the typical utility intersection issues that are common with shallower conveyances, but its routing through downtown may introduce conflicts with underground parking garages and building footings. Although the proposed routing uses Broadway's large right-of-way, geotechnical investigations must be made to ensure that construction activities do not disturb these peripheral conflicts.

TBMs generally have a long and limited arc in which they can turn. The alignment for this and all other tunnels follow the straightest feasible routes to account for the lack of TBM maneuverability.

The outlet location for the tunnel is not only an engineering and logistic challenge, but it is also a highly visible and critical location in Nashville. The plaza at the end of Broadway is often used for special events and is an important loading zone for traffic in the area. Construction processes likely would render this area inaccessible for more than 16 months. Additionally, restoration at this location may require a higher level of design and construction than in other less-visible areas. This could be seen as an opportunity for the City to reimagine the function of the location, though any structures or configurations beyond site restoration and tunnel outfall are outside the scope of this document and not costed.

Conflicts

Because of its depth, the West End/Vanderbilt conveyance tunnel is not likely to encounter ordinary utility conflicts along its route, although these will be encountered at drop structures and with the sewer separation work. Three major considerations for the tunnel include:

- Depth must be managed to provide adequate cover as it passes under I-40.
- Tunnel must pass over FAT.
- Excavations for parking garages and building footprints on either side of Broadway must be managed.

Tunneling activities may present geotechnical difficulties including natural gas pockets, differences in rock types, and inflow from groundwater. Additionally, construction will significantly impact high-profile locations downtown and/or near Centennial Park.

Fluctuations in the Cumberland River will influence the effectiveness of this alternative, though the large diameter and slope allows hydraulic performance to continue as designed until the river stage reaches 401 feet NAVD88, or the 99th percentile high stage. Above this point, the pipe discharge is completely submerged, assuming that its invert is 385 feet NAVD88. Although flows through the outlet are largely maintained, hydraulic grade lines may be higher under Broadway because of the surcharged state of the lower system. **Table 6-11** presents a summary of the modeled peak flows for select river stages.

Table 6-11. Modeled Broadway Tunnel Flows at Selected Cumberland River Stages

River Stage (NAVD88)	100-year, 24-hour Storm Peak Flow (MGD)
385 (Navigable Pool)	2,520
396 (95th Percentile High)	2,520
401 (Pipe Outlet Submerged)	2,459
408.1 (Flood Stage)	2,444

Results

All significant flooding locations in the West End/Vanderbilt area are mitigated with this alternative, including:

- 25th and 24th Avenues South, or the area surrounding the VA Hospital
- 25th Avenue North and Brandau Place, near the Centennial SportsPlex
- Natchez Trace and West End, the entrance to Centennial Park
- 21st and Wedgewood, or Hillsboro Village

This improves flooding at nine potentially inundated structures across the four areas. Major roads impacted by the inundation reduction include West End Boulevard, 25th Avenue North, 25th Avenue South, and 21st Avenue South at Wedgewood. **Figure 6-34** displays the inundation extents in the Midtown area with the West End/Vanderbilt alternative in place.

Although the West End conveyance is effective in mitigating flooding throughout Upper Kerrigan, it does not fully mitigate flooding near the Farmers Market. Stages are reduced, but many properties are still exposed to the risk of inundation in the Capitol View and Herman Street area. The design and construction of the proposed Farmers Market conveyance and storage would be required to further mitigate flooding in this area. The end of this section provides a discussion of the combined flood reduction of all alternatives.

CSO reductions provided by the West End/Vanderbilt alternative are substantial. Activations at Kerrigan are reduced from 15 to 8 per year, and the total volume of CSOs is 226 MG per year, a reduction of 56 percent. Washington also sees a 1 percent reduction in CSO volume under this alternative.

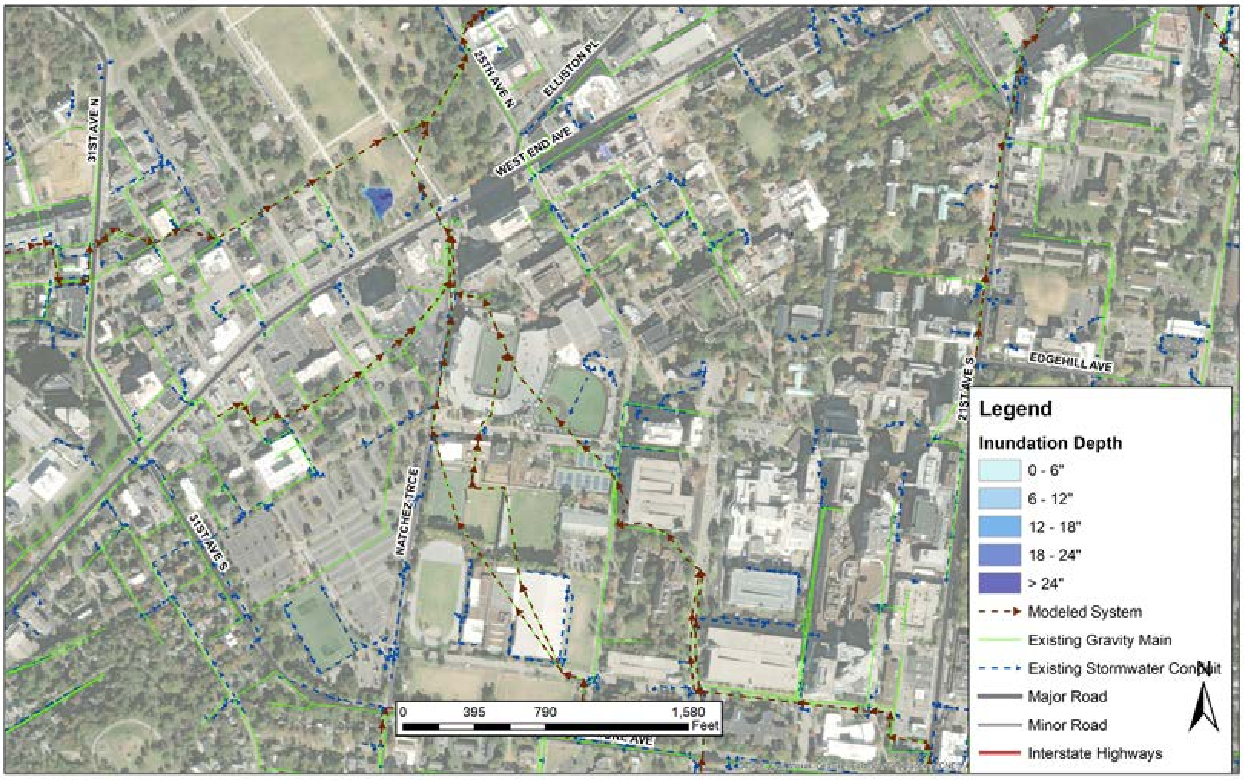


Figure 6-34. Flooding Extents in the 100-Year, 24-Hour Event for the Midtown Area with West End/Vanderbilt Alternative

Other Alternatives Evaluated

Other tunnel routings were considered but not chosen. A route following Elliston Place and Church Street to the River was considered, but the right-of-way was not as wide and the potential interference of building footings and parking garages in the downtown area were more considerable. Also, this route would require at least one relatively large turn near Ascension St. Thomas Hospital Midtown, whereas the Broadway route is straight and would require minimal route adjustments. This alignment was estimated to be $26,000,000 more expensive than the route down West End and Broadway.

A large amount of storage was initially considered in upstream areas of the basin near Centennial Park. The volume required to attenuate peak flows in this area was found to be prohibitively large, even for subterranean or distributed storage options. It was estimated that 18.3 acre-feet of storage would be required to mitigate the 10-year, 24-hour event. For context, this is a volume that would encompass the great lawn near the Parthenon to more than 3 feet in depth. A smaller storage option near Centennial Park was proposed and is described in the Long Boulevard section.

Stormwater pumping was also considered for this area but was determined to be impractical as discussed for the Washington area in **Section 6.3**.

Estimated Costs

The total cost for the West End/Vanderbilt alternative is $451,000,000. **Table 6-12** provides a breakdown of the cost components. The cost of the 16-foot-diameter tunnel and the 96-inch conveyance on 21st Avenue is included. Separation on Vanderbilt's campus is not included, nor are alternatives in the Long Boulevard area. An alternative route for the tunnel along Elliston Place and Church Street was estimated to add $29,000,000 to the project cost.

Table 6-12. West End Alternative Costs

Component	Cost (2023 dollars)
Conveyance Construction Cost	$224,000,000
Sewer Separation Cost	$137,000,000
Project Development Cost	$90,000,000
Total Project Cost	$451,000,000

6.7 Combined Impacts of All Projects

Along with the separation projects proposed as part of the LTCP, the projects listed in the previous sections meet the desired LOS in all modeled storm events for 14 of the 18 identified problem areas. Those areas include:

- 5th Street North and Sylvan Street
- 14th Street Between Fatherland Street and Forrest Avenue
- Boscobel Street between 14th and 15th Streets
- Houston Street between Martin Street and 4th Avenue
- 25th and 24th Avenues South of Highland (VA Hospital Parking Garage)
- 25th Avenue North and Brandau Place
- 12th and 14th Avenues North near Herman Street
- Charlotte Avenue Between I-24 and 17th Avenue
- 2nd Avenue North and Madison Street
- 21st Avenue South and Wedgewood Avenue
- West End and Natchez Trace
- 31st Avenue North and Long Boulevard
- Finland Street and 25th Avenue North
- Ellington Parkway, including Cleveland and West Eastland Streets

With the implementation of all projects, areas near the Farmers Market continue to exhibit limited flooding in the 10-year, 24-hour event and more significant flooding in the 100-year, 24-hour storm. This area of the system currently experiences extended flooding because of its large drainage area, the reliance on the Kerrigan regulator, and available capacity in the SAT and FAT.

Figures 6-35 and **6-36** show the 10-year, 24-hour and 100-year, 24-hour storms in the Farmers Market area with all alternatives applied, respectively. Significant additional reductions in flooding are achieved when all projects are included.

In the 100-year, 24-hour event, Sharpe Avenue in Washington has properties that remain exposed to the risk of inundation after the improvements at Washington. This is driven by projected increases in the imperviousness in the Washington basin and the limited capacity of the box culvert that passes under Ellington Parkway. Despite improvements to conveyance downstream at Apex, flood mitigation near Sharpe Avenue is limited by the capacity of this culvert, which was not assumed to be upgraded through this Master Plan.

When all projects are considered together, considerable reductions in CSO activations and volume are predicted for the typical year. As shown in **Table 6-13**, typical year activations at Kerrigan are reduced from 15 to 8, and CSO volume is reduced by 74 percent. Activations at Washington are reduced from 19 to 12, and the CSO volume is reduced by 69 percent.

Table 6-13. Typical Year Combined Sewer Overflow Reduction by Project

Modeled Scenario (Typical Year, 2045)		Kerrigan CSO		Washington CSO	
		Number of Activations	Volume (MG)	Number of Activations	Volume (MG)
Baseline Conditions		15	519	19	297
Individual Projects	Washington	15	517	12	98
	Houston/Driftwood	15	519	19	297
	Van Buren	15	515	19	297
	Lower Kerrigan	15	488	19	297
	Capitol/Farmers Market	15	442	19	297
	West End/Vanderbilt	8	226	19	293
All Projects		**8**	**134**	**12**	**93**

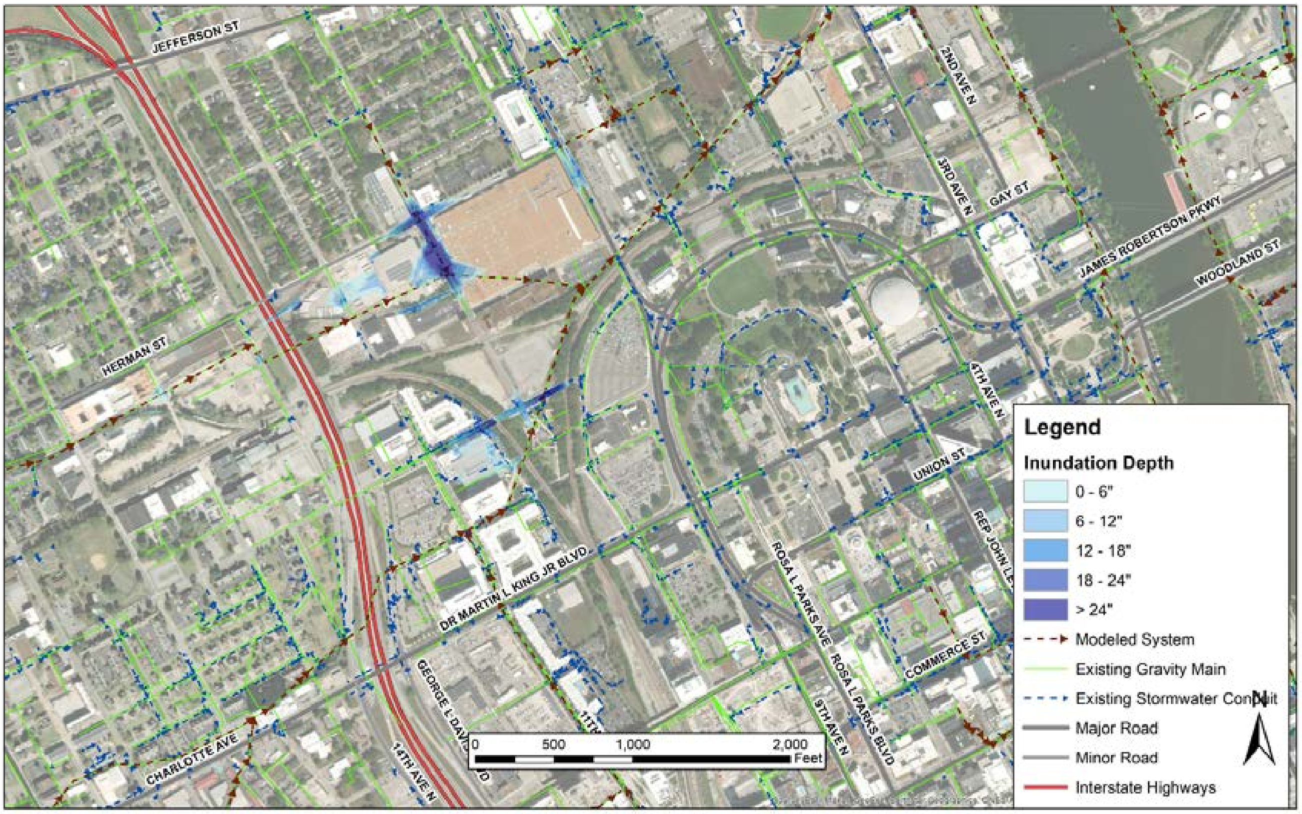


Figure 6-35. Flooding Extents in the 10-Year, 24-Hour Storm with All Alternatives Applied

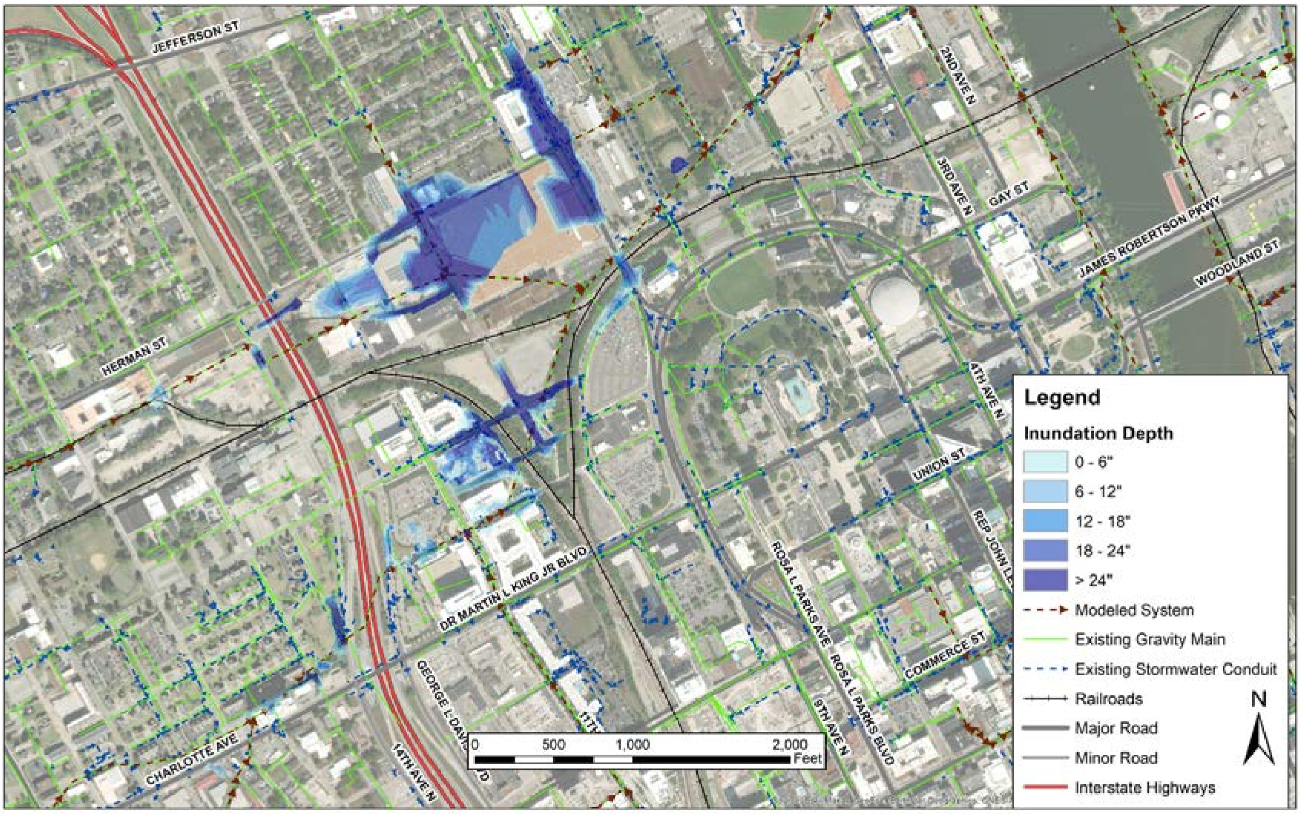


Figure 6-36. Flooding Extents in the 100-Year, 24-Hour Storm with All Alternatives Applied

7.0 Summary

7.0 Summary

The portfolio of projects in this Master Plan, summarized in **Table 7-1**, is large in scope and represents a new phase of investment in Nashville's infrastructure. While previous infrastructure investments within the CSS have focused primarily on water quality–related impacts under Metro's Consent Decree, these projects are intended to address persistent flooding issues that threaten life, safety, and property damage and/or may reduce the risk of future issues related to development.

Project costs are in 2023 dollars and reflect conceptual-level planning efforts. Funding projects of this magnitude will require long-term planning and coordination. Due to the anticipated long duration for program implementation, significant escalation of costs is expected, and costs should be further reviewed as anticipated construction timeframes for individual projects are determined. MWS intends to strategically proceed with individual projects considering their ability to lower flooding risks, further reduce water quality impacts from CSOs, and accommodate system changes due to development. A detailed benefit-cost analysis for the projects in this plan was not performed.

Table 7-1. Summary of Flood Improvement Project Costs

Project	**Project Construction Cost** (2023 dollars)		**Project Development Cost** (2023 dollars)	**Total Project Cost** (2023 dollars)
	Major Conveyance and Storage	**Separation**		
Washington	$115,000,000	n/a	$29,000,000	$144,000,000
Houston/Driftwood	$43,000,000	$28,000,000	$18,000,000	$89,000,000
Van Buren	$20,000,000	$12,000,000	$8,000,000	$40,000,000
Lower Kerrigan	$36,000,000	$17,000,000	$13,000,000	$66,000,000
Capitol/Farmers Market	$70,000,000	$40,000,000	$28,000,000	$138,000,000
West End/Vanderbilt	$224,000,000	$137,000,000	$90,000,000	$451,000,000
West End/Vanderbilt (alternate route)[1]	*$247,000,000*	*$137,000,000*	*$96,000,000*	*$480,000,000*
Long Boulevard	$20,000,000	$14,000,000	$9,000,000	$43,000,000
Long Boulevard (storage alternative)[1]	*$30,000,000*	*$14,000,000*	*$11,000,000*	*$55,000,000*
Totals	$528,000,000	$248,000,000	$195,000,000	$971,000,000

[1] Alternatives for West End/Vanderbilt and Long Boulevard are excluded from the total costs presented. These options, if selected, would replace the base project shown.

If the full list of improvements outlined in this report are constructed, areas remain with model-predicted flooding. These areas fall into two categories:

- Remaining flooding that was either considered nuisance flooding or is no longer impacting life and safety, such as the flooding in City Cemetery
- Remaining flooding that may still impact life and safety but has been mitigated to a point in which it may be too costly or disruptive to further improve inundation

There are two primary areas that fall under the second category of remaining flooding: the corridor along Ellington Parkway that includes homes on Sharpe Avenue and an apartment complex on Neill Avenue, and the area of North Rosa Parks Boulevard and Harrison Street, extending west to 10th Avenue. Additional study is warranted in these areas, such as obtaining finished floor elevations for impacted buildings, to further evaluate risks as projects proceed. Further separation and conveyance of stormwater in the Kerrigan and

Washington basins would continue to mitigate observed flooding, though the cost of mitigating less frequent flooding may outweigh the benefit.

Approaches that are "non-engineered" exist and may supplement the alternatives provided in this report, particularly in areas that still see flooding in high-intensity rain events despite the proposed improvements. These solutions also may be implemented as near-term improvements to better mitigate flood risks before construction of the long-term improvements. Examples include home and business buyouts, early warning systems, and signage in flood-prone locations. Non-engineered solutions such as buyouts and early warning systems already have been implemented with some success in Nashville. For example, a property near the Boscobel regulator that experienced repetitive flooding was purchased by MWS. NERVE, the Nashville Emergency Response Viewing Engine, provides information about road closures, evacuation routes, and other critical information related to a flooding emergency. These programs are effective in limiting human contact with flooding danger, but they do not mitigate the flooding itself.

As the projects presented continued to be prioritized and refined, the following considerations for ongoing tasks to support the implementation of the proposed alternatives and continued flood risk reduction in the CSS are recommended:

- Capacity limitations in the minor system (inlets and small conveyance) also may contribute to localized flooding. Areas identified for future sewer separation will benefit from the upgrade of the minor system, but flooding locations in the minor system warrant additional review.
- Continued diligence in applying stormwater management as outlined in Metro's *Stormwater Management Manual* will be an important practice for managing future runoff.
- Unless noted, modeled infrastructure was assumed to be in good condition and free of blockages. Ongoing system maintenance is recommended to ensure that the full capacity of the system remains available.
- The collection and consolidation of finished floor elevation data will greatly improve the understanding of flood risk.
- As projects proceed to design, care should be taken to understand the impacts of high river levels and manage velocities in the final design of the proposed conveyances.
- Continued updates to the CSS model will assist future design efforts for the projects recommended in this report. Additional flow monitoring and calibration of the model will refine the development of both storm and sanitary flows. Future versions of SWMM software may provide additional tools for flood assessment.
- Although the 2045 population and sanitary flow projections do not trigger improvements, redevelopment in the CSS should continue to be monitored for potential capacity impacts to the system.
- Updated LiDAR may improve the specificity of flood extents. New LiDAR data, which became available for Davidson County in late 2022, should be compared to peak hydraulic grade lines in identified flooding areas to assess changes to predicted inundation.
- Development of NOAA's Atlas 15 is underway with updated values likely to be released in 2025–2026. Updated design intensities may yield a further reduction in the existing system's LOS. Updated storm projections should be reviewed and incorporated as these projects are designed.

8.0 References

8.0 References

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