STAUNTON FLOOD STUDY REPORT

WILEY|WILSON COMMISSION NO. 220184.00

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1.0 INTRODUCTION

In the August 2020, two greater than 500-year storms hit the City of Staunton and surrounding area causing massive flooding and millions of dollars of damage to downtown businesses. Recognizing the deficiency of the existing stormwater infrastructure, the City commissioned Wiley|Wilson to conduct a hydrologic and hydraulic analysis of the watershed terminating at the Wharf. The goals of the study are to better understand and model the existing tunnel, define the magnitude of the flooding risk, and provide constructable projects that could reduce flooding risk. The project scope is limited to studying the tunnel portion of Peyton Creek from the Howard Johnson Hotel on Central Ave to the confluence with Lewis Creek at the Wharf parking lot, and the tunnel portion of Lewis Creek from Landes Park to South Augusta Street. See SK-12 in Appendix A for a map of project area.

Figure 1: Limits of Tunnel Evaluation

2.0 HYDROLOGY

Hydrology is the determination of rainfall hitting drainage areas and the runoff that flows off them. This project features three main drainage areas: DA-1 which outfalls at the mouth of the Peyton Creek tunnel; DA-2, which outfalls at the mouth of the Lewis Creek tunnel; and the total drainage, which outfalls at the confluence of Peyton and Lewis Creeks. The total drainage area combines DA-1, DA-2, and the downtown drainage area (DA-3). The downtown area is mostly comprised of impervious surfaces like parking lots, roads, sidewalks, and buildings. These surfaces prevent the natural infiltration of rainfall and create more rainwater runoff. This surface runoff, often described as “Flashy”, collects very quickly in the tunnel, long before stormwater from DA-1 or 2 reaches the system. Since DA-3 produces runoff that moves so quickly through the system and is also only two percent of the total drainage, it was not modeled for this analysis except as part of the peak flow from the total drainage area. DA-1 was divided into three subcatchments (DA-1A, DA-1B, DA-1C) to test the effectiveness of possible stormwater detention ponds in Gypsy Hill Park. See Table 1 for a breakdown of the drainage areas and Appendix A for the DA map.

Table 1: Drainage Area Summary

	Area (ac)	Area (sq mi)	Pct Urban	CN	TC
DA-1	2272	3.55	86.8	79	55.4
DA-1A	653	1.02	N/A	80	36.0
DA-1B	881	1.38	N/A	77	37.2
DA-1C	736	1.15	N/A	80	30.0
DA-2	5171	8.08	25.6	69	95.8
DA-3	109	0.17	N/A	92	N/A
DA Total	7552	11.80	45.0	72	95.8

Curve number (CN), which helps estimate runoff quantity in the TR-55 method, and time of concentration (TC), which is the amount of time it takes for runoff to travel from the most hydrologically distant point of a catchment to the outfall, were calculated for each catchment and subcatchment. To calculate CN, one needs to know the landcover and the hydrologic soil group (HSG). Each unique combination of landcover and HSG results in a curve number. Over complex catchments with many combinations of landcover and HSG, a composite curve number needs to be calculated. The landcover information comes from the 2016 Multi-Resolution Land Characteristics consortium National Land Cover Dataset (NLCD). The HSG layer was created in GIS from soils data downloaded from the USDA Web Soil Survey. The datasets were spatially related in GIS, then Table 2 was used to assign curve numbers to each discrete area. The composite CNs were calculated from a weighted average over all the CNs for the catchment. Times of concentration were calculated using the Kirpich method. The Kirpich method relates the flow path length to the slope along the flow path (see Appendix A).

After delineating the drainage areas and determining basic properties, several methods were evaluated to determine peaks flows. Figure 6-1 in VDOT's Drainage Manual (see Appendix B) recommends using SCS method for catchments between 200 and 2,000 acres. For catchments greater than 2,000 acres, VDOT recommends the use of the regression equations. The regression equations come from a USGS report titled "Methods and Equations for Estimating Peak Streamflow Per Square Mile in Virginia's Urban Basins" (relevant excerptions in Appendix B). The Percent Urban quantity comes from StreamStats, which uses regression equations for its peak flow estimates. Below is a comparison of the 10- and 500-year peak flows using the SCS method and regression equations.

Table 2: Peak Flow Method Comparison					
Drainage Area	Size (Acres)	10-Year		500-Year	
		SCS	**Regression**	*SCS*	**Regression**
DA-1	2272	*550*	**1,700**	*1,670*	**7,910**
DA-2	5168	*810*	**1,230**	*2,860*	**5,540**
DA Total	7552	*1,400*	**1,990**	*4,630*	**9,520**

To determine the appropriate method to use, the 10-year and 500-year storm peak flows calculated with the regression and SCS methods were run through the existing hydraulic model of the tunnel. More detail on the existing hydraulic model can be found in Section 3. Based on institutional knowledge, the City Staff believed the 10-year storm event remained within the Peyton Creek tunnel. WW also spoke with several residents with firsthand observations of the flooding extent during the August events. Based on this information, the SCS method should be used for DA-1 and its subcatchments. Peak flows determined by the regression formula should be used for DA-2 and DA Total. Table 3 summarizes the peak runoff flows for each drainage area by year of storm and peak flow method.

Table 3: Peak Flows (cfs) by Drainage Area						
Storm	Regression		SCS			
	DA-2	DA Total	DA-1	DA-1A	DA-1B	DA-1C
10-year	1229	1991	554	168	191	183
25-year	1857	2941	746	223	273	251
50-year	2441	3775	929	268	343	309
100-year	3012	4749	1133	318	422	374
500-year	5539	9523	1672	N/A	N/A	N/A

The Explicit (SWMM) solver in SewerGEMS was used to calculate the discharge from the DA-1 and DA-1A, 1B, and 1C. In addition to the CN and TC for each drainage area, the SewerGEMS solver requires a storm distribution and cumulative precipitations, both of which are provided by NOAA Atlas 14 (Appendix B). This modeling uses the 10, 25, 50, 100, and 500-year, 24-hour storms. The selected storm distribution was the 50%, 1st quartile storm distribution since that balanced the severity of the storm systems that produced the extreme flooding in August 2020 with the moderate storms that usually strike Staunton. According to NOAA Atlas 14 Volume 2, 1st quartile storms are the most common in this region (Ohio River basin and surrounding states) while the 50th percentile represents the median storm. First quartile storms are characterized by dropping the greatest percentage of their precipitation in the first quarter of the storm duration. To produce the rainfall amounts falling at a given time for a given level of storm, the cumulative precipitation value for that storm is applied over the dimensionless rainfall curve that represents the distribution (Table 4). The runoff hydrograph produced for each DA from a given level of storm is determined from the CN (higher CN equals more runoff) and the TC (lower TC equals shorter time to peak and a higher peak flow). For this steady-state analysis, only the peak flow from the catchment runoff hydrograph was input into the tunnel model. The runoff hydrographs for DA-1 and DA-1A, 1B, and 1C are found in Appendix B.

Table 4: Dimensionless Rainfall Curve

	Synthetic Time	Depth (%)
1	0.000	0.0
2	0.083	21.8
3	0.167	43.5
4	0.250	60.9
5	0.333	72.0
6	0.417	79.1
7	0.500	84.7
8	0.583	89.7
9	0.667	93.9
10	0.750	96.9
11	0.833	98.9
12	0.917	99.8
13	1.000	100.0

3.0 HYDRAULIC MODEL

Hydraulics is the conveyance of water through the tunnels and overland. The first challenge in creating the existing model was determining the size, slope, and material of the tunnels. The City of Staunton provided Wiley|Wilson with the 1938 plans of the Sanitary Sewerage system, the 1955 plans to pave over Lewis and Peyton Creeks in the Wharf parking lot, and the 2013 plans resulting from Draper Aden's inspection of the sanitary sewers that run inside the tunnels (Appendix C). They also provided Wiley|Wilson with photos and videos from a prior inspection of the tunnels and GIS information. Wiley|Wilson made three site visits (11-13-2020, 11-24-2020, and 02-09-2021) to walk the site, take pictures, collect testimony from affected property owners, and conduct topographic survey of the open channel sections at the Howard Johnson, behind Sunspots, at City Hall, and at Byers Street. On one of its site visits, W|W opened three manholes (one on Peyton and two on Lewis) and used a pole camera to inspect the tunnel. The topographic survey also recorded dimensions for the tunnel openings. Table 5 summarizes the data sources used to develop the tunnel model. Because the data from different sources often conflicted, the "quality" column ranks the sources from most trusted to least trusted. Although recent, the Draper Aden Study focused on assessing the sanitary sewer lines and not on accurately representing the storm sewer tunnels.

Table 5: Tunnel Geometry Sources				
Name	Date	Horizontal	Elevation	Quality
Topographic Survey 11-24	2020	Y	Y	1
WW Site Visit 2-9	2021	Y	Y	2
Inspection Pictures (from City)	unknown	Y	N	3
Old Sewer Lines Plan & Profile	1938	Y	Y	4
Johnson St Parking Lot	1955	Y	N	5
Draper Aden Inspection	2013	Y	N	6
Staunton GIS	varies	Y	N	7

The existing model was created in SewerGEMS as a system of conduits. SewerGEMS requires a new conduit section whenever the pipe changes slope, material, or dimension. Even though the tunnel is continuous and lacks structures, the SewerGEMS model divides it into discrete conduit sections joined by manholes or transition nodes. SK-13 and the tunnel geometry table following it in Appendix D summarize the spatial layout of the model and its basic geometry.

The tunnels feature four types of cross-section: Arch, Box, Arch with Shoulder, and Box with Shoulder (Figures 2 and 3 below). The Arch cross-section is only found at Conduit 3003 in the Existing Conditions model and uses SewerGEMS's built-in Arch type. The Box cross-section is defined only by the rise (or height) and span (or width). The Arch with Shoulder and Box with Shoulders are both user-defined types that add a two-foot wide, variable height cutout to both bottom corners of the normal cross-section to represent the parallel sanitary sewer lines running concurrent with the tunnel.

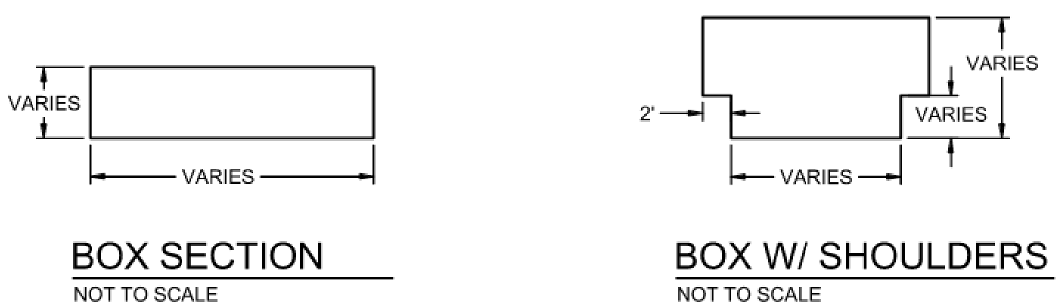


Figure 2: Box Cross Sections

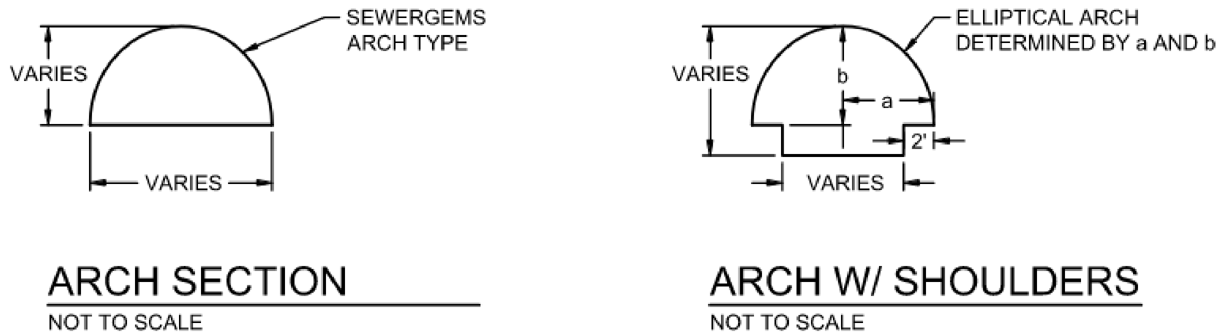


Figure 3: Arch Cross Sections

The model also includes overflow channels that approximate the area that would be flooded by any large storm. A low Manning's roughness coefficient was used because the majority of each overflow channel is street with little vegetation. An iterative process was used to determine the HGL in the tunnel by sending flow into the overflow section until the HGLs in the overflow section were within a foot of the tunnel segment.

Peak runoff discharges (as discussed in the Hydrology section) are input at three nodes in the system: MH-6 (Lewis Creek – DA-2), MH-9 (Peyton Creek – DA-1), and MH-48 (DA Total). These manholes do not exist in real life but are required to build the model and supply flow to the conduit network.

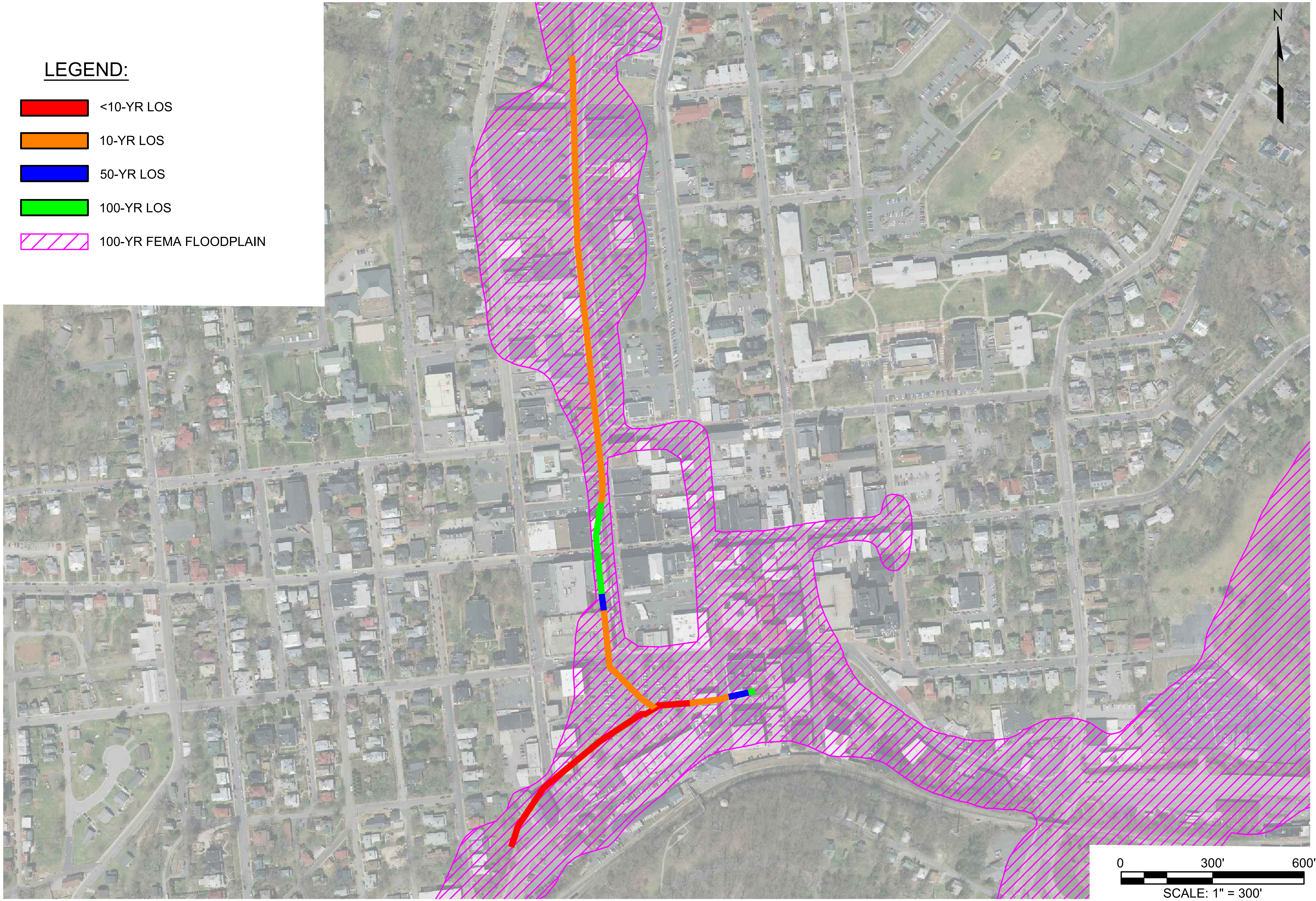
The model is a steady-state model. It uses the GVF-Convex solver to route flow through the pipe network. The degree of flooding is approximated by the hydraulic grade line (HGL) in the pipe and at each node. Because this is a peak flow, steady-state model, all drainage areas peak at the same which is more conservative than the reality. Realistically, DA-2 peaks later than DA-1. The lower two sections (4020 and 4031) of Peyton Creek are dependent on the tailwater of Lewis Creek. Therefore, the conduits representing the Peyton Creek tunnel terminate at an intermediate outfall node that sets the HGL at that structure to the HGL at MH-48 (where Peyton Creek joins to Lewis Creek).

The model was calibrated to the 10- and 500-year storms by adjusting conduit attributes such as slope and roughness coefficients to fit the model HGLs to the observed floodwater depth. The tunnel geometry was modified as needed with dimensions from the lower quality sources to fit the HGL to the expected flooding. The August 2020 were estimated as a 500-year plus storms. The August 8 storm produced flooding of 5-7 feet at the Wharf parking lot and 1-3 feet down Central Avenue.

After the model was satisfactorily correlated to the 10- and 500-year storms, the model was run with the 25-, 50-, and 100-year storms to establish existing conditions. The design storms for the potential solution modeling are the 10- through 100-year storms. As with the 10- and 500-year storms, the HGL in the tunnel was balanced to match that of the overflow channel. During the existing condition modeling, the section of Peyton Creek from segment 4000 to segment CH-CITYHALL was found to be independent of the tailwater condition at the wharf due to the large (~30 foot) drop in invert between Frederick Street and Johnson Street. This discontinuity means that improvements to Lewis Creek flooding will not affect flooding along Central Avenue. However, improvements to Peyton Creek could still increase or decrease flooding along Lewis Creek depending on whether flow is hurried downstream or diverted entirely.

The existing conditions models establish the Level of Service (LOS) of the current tunnels. The LOS is the largest storm that can be passed through a given tunnel segment without flooding. The figure on the next page shows the existing LOS for the system.

Although both creeks eventually flood, they flood differently because of different limiting factors or choke points. For Lewis Creek, the back wall of 120 S Augusta Street and the arch tunnel under S Augusta Street are choke points. Low slope throughout the Lewis Creek tunnel is a limiting factor. The Wharf parking lot acts like a small pond with the tunnel as its only outfall. Eventually, stormwater can overflow at the intersection of S Augusta Street and Johnson Street, but that causes over eight feet of flooding in the Wharf. Peyton Creek is limited by the tunnel entrance at the Howard Johnson Hotel. Excessive flow will jump the bank and flood down Central Avenue. Flooding on Central Avenue also occurred as basement drains backed up indicating that the tunnel was also at full capacity. Floodwater on Central Avenue is primarily coming from the tunnel entrance and propagating downstream.



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PROJECT
STAUNTON FLOOD STUDY

TITLE
EXISTING TUNNEL LEVEL OF SERVICE (LOS)

COMM. NO.	
220184	
DRAWN	CHECKED
SKETCH NO.	
SK-11	
DWG. REFERENCE NO.	
DATE:	REV.

4.0 PROJECTS

Wiley|Wilson developed twelve potential projects, illustrated in Exhibits 1 and 2 on the following pages, to reduce flooding risks along Central Avenue and at the Wharf. The model was set up to allow for different scenarios that include projects implemented alone or with other projects. A list of the scenarios and flooding reductions can be found in Appendix F. Detailed sketches of the Peyton and Lewis Creek scenarios are in Appendices G and H, respectively. Cost estimates were developed for each individual project. Scenario cost is the sum of all the costs of each of the projects involved. Appendix F also contains the tabulations of HGL differences between design scenarios and the existing conditions that were used to define LOS and 100-year flood reduction. Those tables draw data from the SewerGEMS profiles for Peyton and Lewis Creeks located in Appendices I and J, respectively. The profiles include the discharge and capacity of the tunnels by segment. Velocity and discharge for the tunnels is recorded in Appendix K.

The projects shown have been developed to a conceptual level to determine constructability and estimated construction cost. Additional engineering studies will be required. Part of that analysis will be to ensure that flooding is not eliminated in one area only to produce worse flooding downstream.

Project 3A - **Replace first 600' of Tunnel along Central Ave - $4,429,000**

- Open cut construction
- Remove existing 7'x10' Arch Tunnel
- Construct approximately 600', 8.5'x12' Box Tunnel
- Replace sidewalk and roadway

Project 3B - **Replace first 1,450' of Tunnel along Central Ave - $11,561,000**

- Open cut construction, remove first 600' of existing 7'x10' Arch Tunnel
- Open cut construction, remove 850' of existing 8.5'x12' Arch Tunnel
- Construct approximately 1,450', 8.5'x12' Box Tunnel
- Relocate utility crossings
- Replace sidewalk and roadway

Project 4A - **Flood Control Pond at Gypsy Hill Park - $13,396,000**

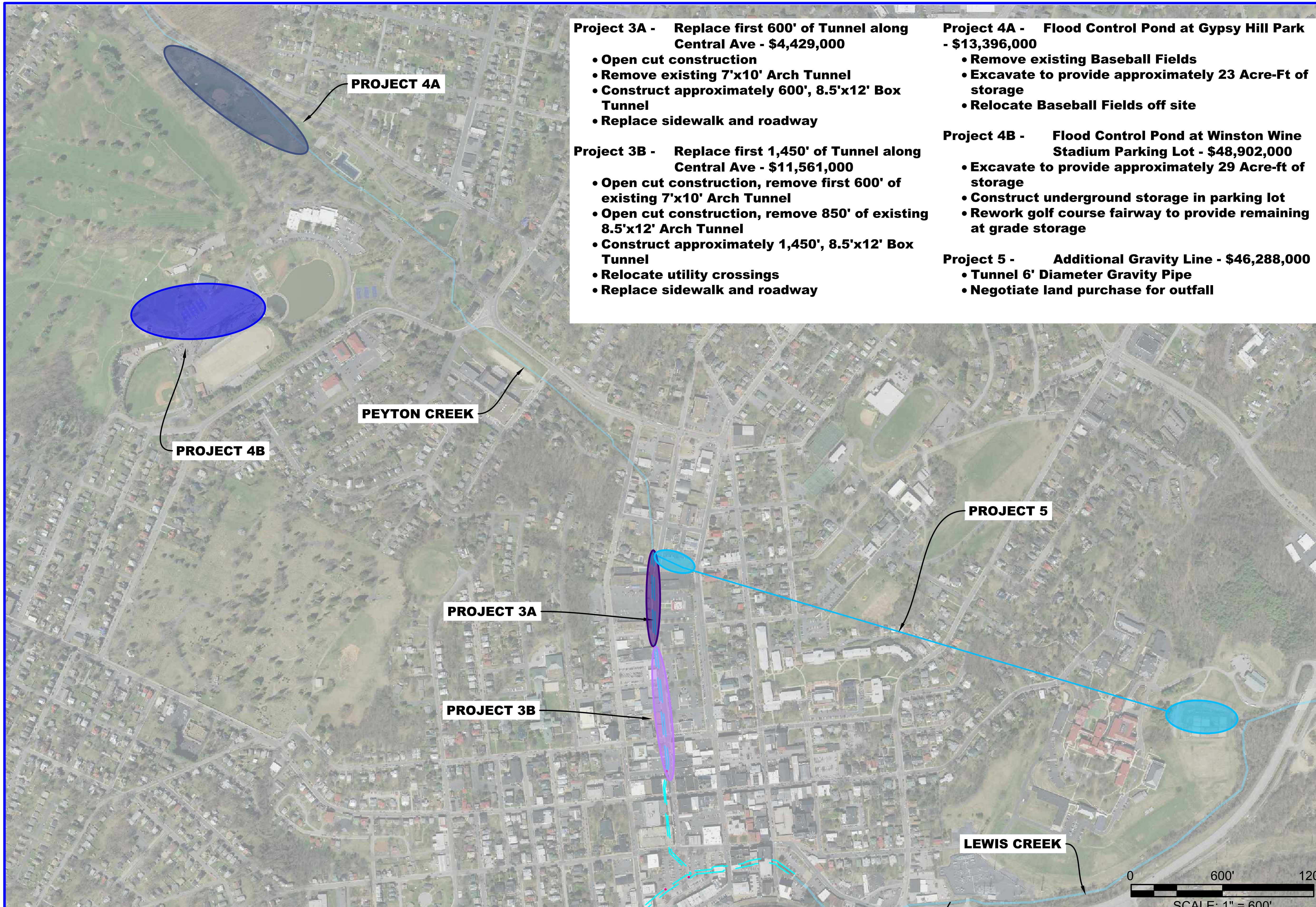
- Remove existing Baseball Fields
- Excavate to provide approximately 23 Acre-Ft of storage
- Relocate Baseball Fields off site

Project 4B - **Flood Control Pond at Winston Wine Stadium Parking Lot - $48,902,000**

- Excavate to provide approximately 29 Acre-ft of storage
- Construct underground storage in parking lot
- Rework golf course fairway to provide remaining at grade storage

Project 5 - **Additional Gravity Line - $46,288,000**

- Tunnel 6' Diameter Gravity Pipe
- Negotiate land purchase for outfall



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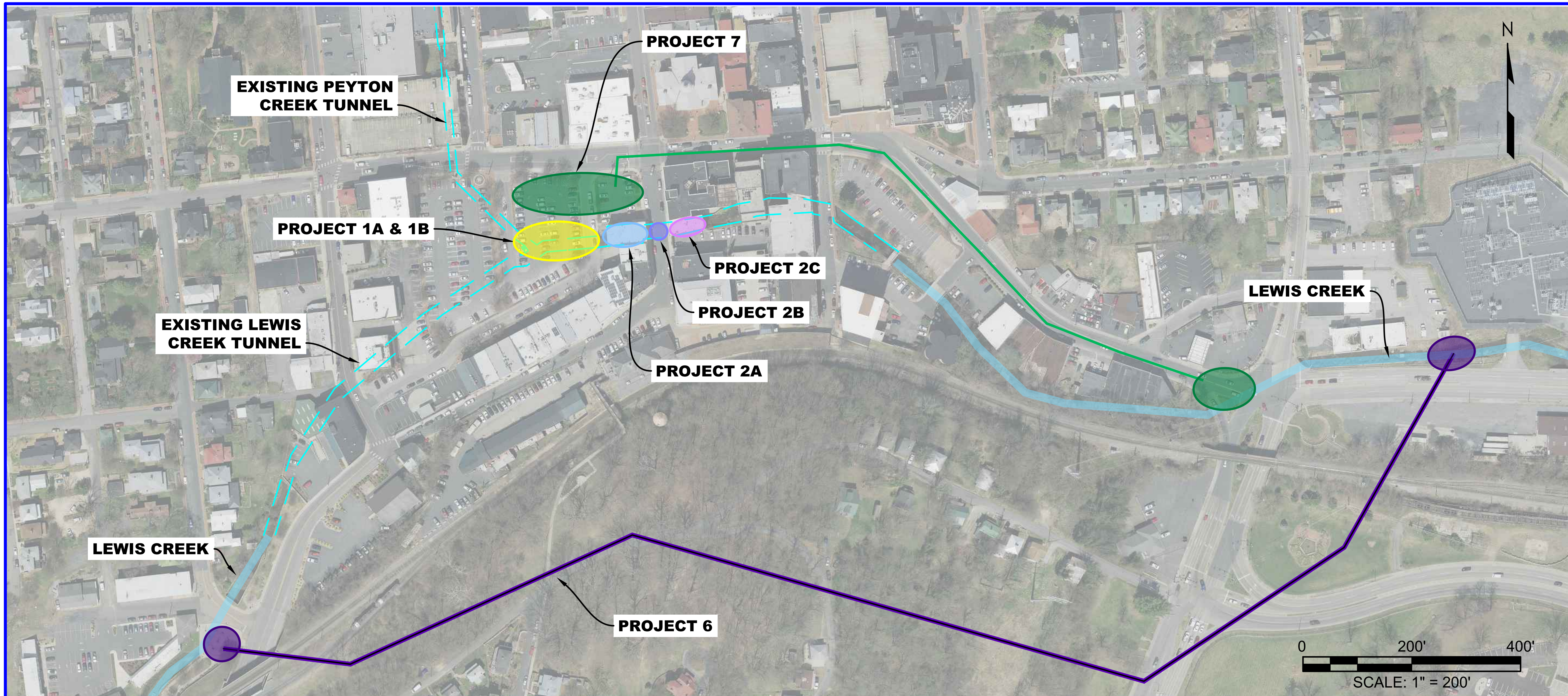
PROJECT: STAUNTON FLOOD STUDY

TITLE: PEYTON CREEK PROJECTS

COMM. NO. 220184	
DRAWN	CHECKED
SKETCH NO. EXHIBIT-1	
DWG. REFERENCE NO.	
DATE:	REV.



Project 1A - **Replace Tunnel, confluence of Lewis & Peyton Creeks to Byer Street, Box Tunnel - $2,796,000**
- Open cut construction
- Remove existing 7'x23' Box Tunnel
- Construct approximately 150', 7'x40' Box Tunnel
- Replace asphalt surface parking

Project 1B - **Remove Tunnel, confluence of Lewis & Peyton Creeks to Byer Street, Construct Open Channel - $3,605,000**
- Open cut construction
- Remove existing 7'x23' tunnel
- Permanently remove approximately 30 parking spaces
- Construct approximately 150', 10'x40' Open Channel

Project 2A - **Demolish 120 S Augusta St Building, Construct Open Channel - $2,197,000**
- Demolish 120 S Augusta St building
- Remove existing 16'x26' Box Tunnel
- Construct approximately 100', 16'x40' Open Channel

Project 2B - **Replace Tunnel, S Augusta Street, Box Tunnel**
- Open cut construction - $1,168,000
- Remove existing 16'x18' Arch Tunnel
- Construct approximately 50', 17'x19' Box Tunnel

Project 2C - **Demolish 113 S Augusta, Construct Open Channel - $2,319,000**
- Demolish 113 S August St building
- Remove existing 12'x19' Box Tunnel
- Construct approximately 60', 17'x19' Open Channel

Project 6 - **Additional Gravity Line - $46,288,000**
- Tunnel 8' Diameter Gravity Pipe
- Outfall near Commerce Drive

Project 7 - **Stormwater Pump Station - $49,140,000**
- Construct 30'x40' Pump Station
- Construct 50'x50' Inflow Well
- Permanently remove approximately 25 parking spaces
- Construct 1,200', Dual 4' Diameter Force Mains
- Construct 25'x25' Outflow Structure near Coalter St and Greenville Ave intersection

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PROJECT: STAUNTON FLOOD STUDY

TITLE: LEWIS CREEK PROJECTS

COMM. NO. 220184

DRAWN

CHECKED

SKETCH NO.

EXHIBIT-2

DWG. REFERENCE NO.

DATE:

REV.

5.0 CONCLUSION

The magnitude of flooding along Central Ave and the Wharf is great and will require significant infrastructure projects to produce meaningful reductions during large storm events. The projects listed above will positively affect flooding, but more study is needed to develop plans, enhance constructability, and project precise costs.

There are several initiatives the City can perform immediately. The first would be to perform a full tunnel evaluation with the following goals:

- Evaluate the structural soundness of the tunnel
- Identifies existing utility crossing and their ability to be relocated
- Identify debris needs to be removed
- Plan for future access points to be added for better evaluation and debris removal
- Plan for existing debris removal

A second initiative is to develop a maintenance plan to remove debris from the creek banks upstream of the tunnels. Regular bank cleaning may reduce the chances of large items creating obstructions in the tunnel in inconvenient to access spaces.