ARLINGTON
VIRGINIA

# FLOOD RISK ASSESSMENT AND MANAGEMENT PLAN

## VOLUME 3 - APPENDICES

March 2024

Jacobs

Jacobs Engineering Group Inc.
1100 N Glebe Road, Suite 500
Arlington, VA 22201

## Flood Risk Assessment and Management Plan (RAMP) – Final Report

| | | | |
|---|---|---|---|
| **Client name:** | Arlington County, Virginia | | |
| **Project Directors** | Demetra J McBride and Rich Dooley. | | |
| **Project name:** | Flood Risk Assessment and Management Plan (RAMP) | | |
| **Client reference:** | County of Arlington, Virginia | **Project no:** | E5X69605 |
| **Document no:** | 231003101158_a766d200 | **Project managers:** | Laurens van der Tak and Tara Ajello |
| **Version:** | Final | **Prepared by:** | Jacobs |
| **Date:** | March 29, 2024 | | |


# Acknowledgements

Thank you to the many people who contributed to the development of the Flood Risk Assessment Management Plan (RAMP), in particular the leadership and staff of the Arlington County Environmental Services Office of Sustainability and Environmental Management, as well as the County agencies and external stakeholders listed below, and the Jacobs consulting team. The RAMP—and its future development and implementation—represents a collaborative effort, built upon the work and dedication of many.

### County Agencies

- County Manager's Office (CMO)
- County Attorney (CAO)
- Arlington Economic Development (AED)
- Community Planning, Housing & Development (CPHD)
- Environmental Services (DES)
- Human Resources (HRD)
- Human Services (DHS)
- Management & Finance (DMF)
- Parks & Recreation (DPR)
- Public Safety Communications and Emergency Management (PSCEM)
- Technology Services (DTS)

### External Stakeholders

- Arlington Public Schools
- Cherrydale Health and Rehabilitation Center
- Virginia Hospital Center

# Table of Contents


## Volume 1 – Executive Summary (Bound Separately)

## Volume 2 – Summary Report (Bound Separately)

## Volume 3 – Appendices

A Climate Projections and Scenarios Technical Memorandum
B Arlington Interior and Riverine Flooding Technical Memorandum
C Coastal Surge Modeling Technical Memorandum
D Arlington Flood Vulnerability Assessment Technical Memorandum
E Arlington Flood Risk Assessment Technical Memorandum
F Arlington Flood Mitigation and Adaptation Strategy Technical Memorandum
G Programmatic Strategies for Flood Management Technical Memorandum
H Market Analysis on Climate Risk Technical Memorandum

# Appendix A
# Climate Projections and Scenarios Technical Memorandum

ARLINGTON
VIRGINIA

Jacobs

# Memorandum

2551 Dulles View Drive
7th Floor
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

| | |
|---|---|
| **Subject** | **Climate Projections and Scenarios** |
| **Project Name** | Flood Risk Assessment and Management Plan (RAMP) |
| **Attention** | Arlington County |
| **From** | Tyler Jantzen<br>Emma Rakestraw |
| **Original date** | July 24, 2020 |
| **Final date** | October 6, 2023 |
| **Copies to** | Laurens van der Tak, Emmanuel Brainoo, Tara Ajello, Elise Ibendahl, Jackeline Luque, Cheri Salas |

Arlington County, Virginia has initiated a study to support the Flood Risk Assessment and Management Plan (RAMP). Task 3.1 involves development of climate change projections and definition of climate change scenarios based on the latest data and climate science. The scenarios defined here are used as input for rainfall-driven flood modeling (interior and riverine) in Task 3.3.

The purpose of this technical memorandum is to present rainfall analysis, future climate precipitation projections, tide, and sea level rise (SLR) projections relevant to Arlington County (County). Results from this analysis will be used as input boundary conditions for two-dimensional rainfall-driven surface flood modeling, as well as coastal storm surge and sea level rise modeling, which are described in separate Technical Memoranda. In addition to being used as input to surface flood modeling, the precipitation, tide, and SLR values developed here can be used for wastewater collection system performance analysis, as well as other analyses requiring these data as input such as analysis of stormwater, road drainage design, and flood mitigation.

The following analyses are described:

**Precipitation**

- **Updated Baseline IDF Curves**: update of precipitation intensity-duration-frequency (IDF[1]) curves to reflect recent observed storm events in Section 2.1
- **Projected Future Climate IDF Curves**: projection of the Updated Baseline IDF curves to future climate conditions using the latest climate projection science in Section 2.2
- **Historical Events Rainfall Analysis**: analysis of two historical rainfall events in Section 2.3, based on Updated Baseline IDF curves.

[1] Although the term IDF is typically used, the values calculated in this analysis are depths (not intensity), however *IDF* is used instead of *DDF* (depth, duration, and frequency). Intensity and depth are used synonymously and are converted from one to the other based on duration: Intensity (inch/hour) = Depth (inch) / Duration (hours).

**Extreme Water Levels and Sea Level Rise**

- **Baseline Tide and Extreme Water Level**: historical tide and extreme water level (also known as storm surge) in Section 3.1
- **Sea Level Rise Projections**: projection of sea levels using the latest climate projection science in Section 3.2
- **Historical Events Tide Analysis**: analysis of tide during two historical events in Section 3.3.

Combined precipitation and water level scenarios are described in Section 4. Results are summarized in the Executive Summary, with full results and a detailed description of methodology in the following sections.

# 1. Executive Summary

Prior precipitation statistics (IDF curves) for Arlington County were developed by NOAA using observed precipitation records through 2000. Jacobs developed updated baseline IDF curves for the Vienna station with precipitation records through 2019, using methods similar to those used by NOAA. Statistics at the Vienna station were improved by using a regional approach which utilized data from four other nearby precipitation stations. These updated IDF values were then projected to future conditions in 2040 and 2070 using the latest climate change model science. Because future climate conditions are uncertain, a range of future IDF values were developed using two different greenhouse gas emissions scenarios (known as Representative Concentration Pathways [RCPs]) – RCP 6.0 and 8.5, and represent the median (50%) and high (90%) values for the range of climate model results.

Updated and future values for 100-year and 500-year return period events are shown in Table ES-1, Figure ES-1, and Figure ES-2. Additional details on updated baseline and future precipitation statistics can be found in Section 2.

In addition to precipitation statistics, baseline and projected future sea level data were obtained for the Washington DC tide station at Hains Point, near the confluence of the Potomac and Anacostia Rivers, about 2 miles north of Four Mile Run in Arlington County. Historical records show baseline value of 1.77 feet (NAVD88) for mean higher high water[2],10.5 feet (NAVD88) for the 100-year return period event, and 15.4 feet (NAVD88) for the 500-year return period event. Future projections of sea level rise are summarized in Table ES-2. These are added to baseline tide and extreme water level values. Additional details on baseline and future water levels can be found in Section 3.

Ten combinations of future precipitation and water level are presented in Table ES-3 to serve as inputs for interior and riverine flood modeling (Task 3.3).

[2] Mean Higher High Water is a term that is defined and regularly used by NOAA to describe tidal high water elevations. Two high tides occur each day; the higher of the two is referred to as *higher high tide*. Mean Higher High Tide refers to the average daily measurement of this value. See: https://tidesandcurrents.noaa.gov/datum_options.html.

**Table ES-1. Baseline and Projected Future 24-hour Precipitation Depths (inches) for Arlington County**

| Return Period | Planning Horizon | Baseline | RCP 6.0 | | RCP 8.5 | |
|---|---|---|---|---|---|---|
| | | | 50% | 90% | 50% | 90% |
| 100-year | Historical (NOAA Atlas 14) | 8.41 | | | | |
| | Updated Baseline | 8.48 | | | | |
| | 2040 | | 8.88 | 9.18 | 9.04 | 9.46 |
| | 2070 | | 9.14 | 9.64 | 9.57 | 10.40 |
| 500-year | Historical (NOAA Atlas 14) | 12.00 | | | | |
| | Updated Baseline | 11.47 | | | | |
| | 2040 | | 12.00 | 12.57 | 12.21 | 13.00 |
| | 2070 | | 12.35 | 13.29 | 12.94 | 14.48 |

Baseline and future projected precipitation depths developed using data from the Vienna station because that station was determined to most representative of the County as a whole. See Section 2.1.6 for additional discussion of station selection and spatial variability.

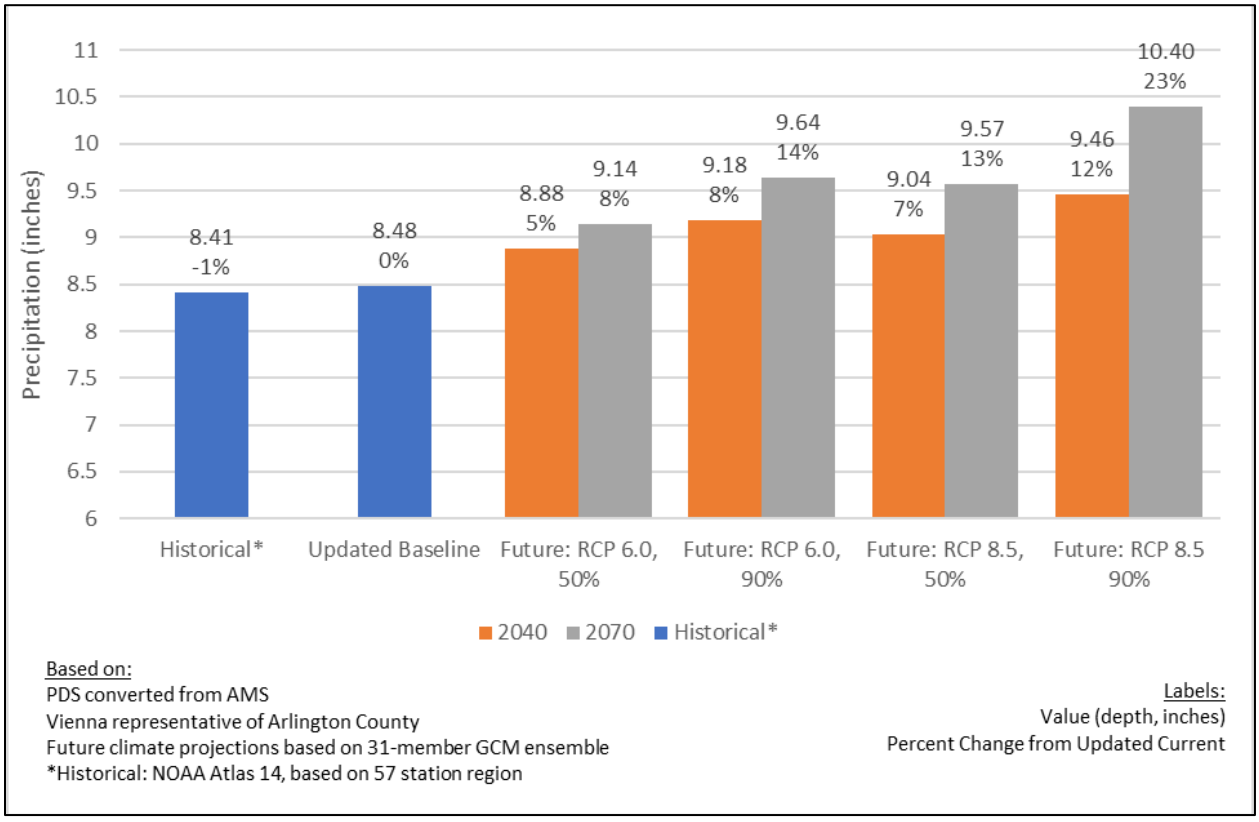



**Figure ES-1. Baseline and Future 100-year 24-Hour Precipitation Depths for Arlington County**

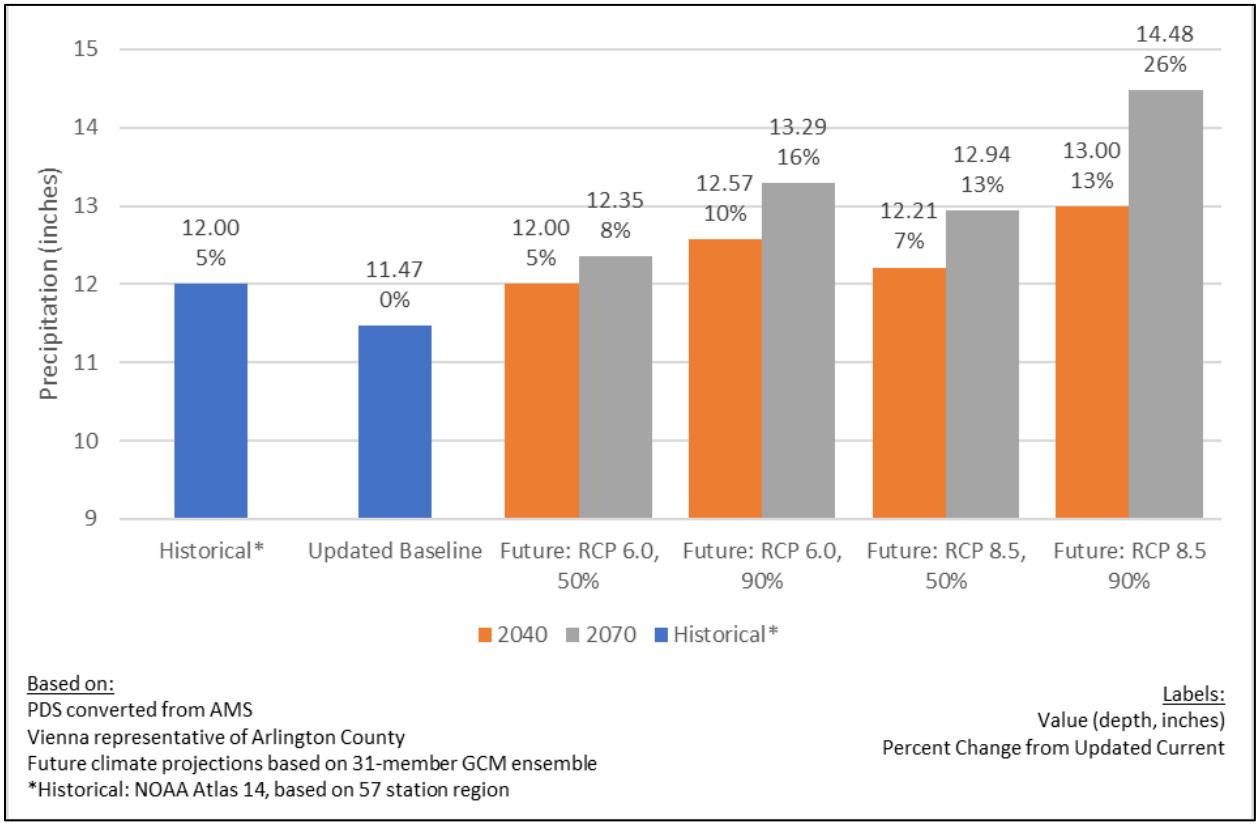



**Figure ES-2. Baseline and Future 500-year 24-Hour Precipitation Depths for Arlington County**

**Table ES-2. Sea Level Rise Projections for Washington DC (feet)**

| Year | Low | Int-Low | Intermediate | Int-High | High | Extreme |
|---|---|---|---|---|---|---|
| 2040 | 0.91 | 1.07 | 1.46 | 1.86 | 2.32 | 2.55 |
| 2070 | 1.43 | 1.69 | 2.78 | 3.86 | 5.14 | 6.12 |

All sea level rise projection values in feet relative to year 2000

To obtain absolute water elevation, add sea level rise to Mean Higher High Water (1.77 feet, NAVD88) or 100-year return period water level (12.40 feet, NAVD88)

**Table ES-3. Recommended Scenarios for Interior and Riverine Flood Modeling (Task 3.3)**

| Scenario | Planning Horizon | Precipitation Scenarioa | 24-hr Precipitation Amount (inches) | Extreme Water Level (feet, NAVD88) | SLR (feet) | Extreme Water Level + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Observed Event: July 8, 2019 | Current Conditions | AG4JW Arlington Station | 3.32 (in 2.5 hours) | Observed | None | 1.96 |
| 2. Baseline: 10-year | Current Conditions | Updated Baseline IDF | 5.16 | 10-year 5.8 | None | 5.8 |

**Table ES-3. Recommended Scenarios for Interior and Riverine Flood Modeling (Task 3.3)**

| Scenario | Planning Horizon | Precipitation Scenarioa | 24-hr Precipitation Amount (inches) | Extreme Water Level (feet, NAVD88) | SLR (feet) | Extreme Water Level + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 3. Baseline: 100-year | Current Conditions | Updated Baseline IDF | 8.48 | 100-year 10.5 | None | 10.5 |
| 4. Baseline: 500-year | Current Conditions | Updated Baseline IDF | 11.47 | 500-year 15.4 | None | 15.4 |
| 5 | 2040 | RCP 8.5, 50%, 10-year | 5.49 | 10-year 5.8 | Int-High 1.86 | 7.66 |
| 6 | 2040 | RCP 8.5, 50%, 100-year | 9.04 | 100-year 10.5 | Int-High 1.86 | 12.36 |
| 7 | 2040 | RCP 8.5, 50%, 500-year | 12.21 | 500-year 15.4 | Int-High 1.86 | 17.26 |
| 8 | 2070 | RCP 8.5, 50%, 10-year | 5.81 | 10-year 5.8 | Int-High 3.86 | 9.66 |
| 9 | 2070 | RCP 8.5, 50%, 100-year | 9.57 | 100-year 10.5 | Int-High 3.86 | 14.36 |
| 10 | 2070 | RCP 8.5, 50%, 500-year | 12.94 | 500-year 15.4 | Int-High 3.86 | 19.26 |

[a] All storms are based on the 24-hour SCS Type II distribution except for the observed events.

**Table ES-4. Recommended Scenarios for Coastal Flood Modeling (Task 3.4)**

| Scenario | Tide Scenario | Tide Value (feet, NAVD88) | Planning Horizon | SLR Scenario | SLR Value (feet) | Tide + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Baseline: 100-year | 100-year | 10.5 | Current Conditions | None | 0 | 10.5 |
| 2. Baseline: 500-year | 500-year | 15.4 | Current Conditions | None | 0 | 15.4 |
| 3 | 100-year | 10.5 | 2040 | Int-High | 1.86 | 12.36 |
| 4 | 500-year | 15.4 | 2040 | Int-High | 1.86 | 17.26 |
| 5 | 100-year | 10.5 | 2070 | Int-High | 3.86 | 14.36 |
| 6 | 500-year | 15.4 | 2070 | Int-High | 3.86 | 19.26 |

# 2. Precipitation

## 2.1 Updated Baseline IDF Curves based on Historical Data

This section describes the methodology used to develop updated IDF Curves, based on recent historical data in the project area.

Updated IDF curves were created using NOAA Atlas 14 annual maxima (Bonnin, et al. 2006), appended with recent precipitation data through 2019. The L-moments statistical package (Hosking, 1996) was used to develop updated 24-hour annual maxima series (AMS) precipitation depth statistics at seven stations, with a focus on data from the Vienna Station. As explained in Section 2.1.6, the Vienna station was selected instead of the station at Washington Reagan Airport (DCA) which is closer to the County because comparisons to other long-term gages in Virginia and Maryland show DCA is consistently lower than all surrounding stations. These 24-hour depth statistics were expanded to additional durations and converted from AMS to partial duration series (PDS) using Atlas 14 ratios. Precipitation statistics based on PDS are typically used for planning and engineering because they are more conservative and appropriate for flood related work. See Appendix C for additional discussion of AMS and PDS IDF curves.

### 2.1.1 Climate Station Selection

Seventeen climate stations near the County were considered for updated IDF curve analysis. Of those, seven stations were selected for IDF analysis. Selection criteria included:

- proximity to the County service area
- precipitation record length
- availability of recent data
- overall data completeness
- use in Atlas 14 analysis
- precipitation variability

A map of evaluated and selected stations is presented in Figure 1. Information about the selected stations is presented in Table 1. Note that the Atlas 14 analysis was based on precipitation records through 2000, which have been extended through 2019 for this analysis. Atlas 14 values are available at all seven stations selected for analysis.

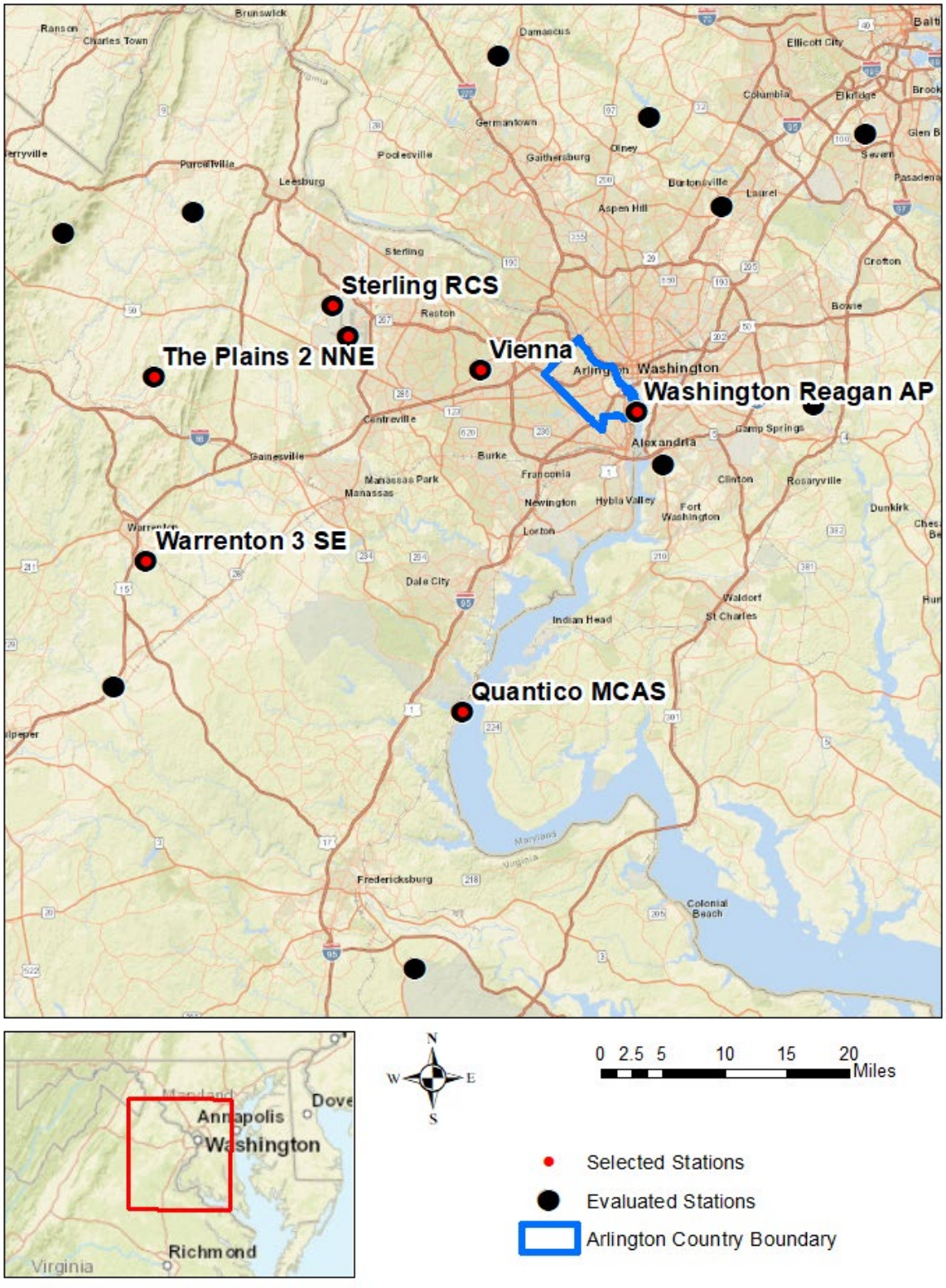



**Figure 1. Evaluated and Recommended Stations**

**Table 1. Selected Stations for IDF Analysis**

| GHCN* Station Name | Latitude | Longitude | GHCN Station ID | Atlas 14 Station Name | Atlas 14 Volume 2 Region Number | Atlas 14 Period of Record | Atlas 14 Years of Data*** | Period of Record | Years of Data** |
|---|---|---|---|---|---|---|---|---|---|
| Vienna | 38.9 | -77.2664 | USC00448737 | Vienna Tysons Center | 8 | 1942-2000 | 59 | 1925-2019 | 78 |
| Quantico MCAS | 38.5 | -77.3 | USW00013773 | Quantico 1 S | 1 | 1905-1975 | 66 | 1945-2019 | 103 |
| Sterling RCS | 38.9764 | -77.4869 | USC00448084 | N/A | N/A | N/A | N/A | 1977-2019 | 43 |
| The Plains 2 NNE | 38.8947 | -77.7547 | USC00448396 | The Plains 2 NNE | 8 | 1954-2000 | 47 | 1954-2009 | 56 |
| Warrenton 3 SE | 38.6811 | -77.7678 | USC00448888 | Warrenton 3 SE | 8 | 1951-2000 | 50 | 1987-2016 | 65 |
| Washington DC Dulles AP | 38.9408 | -77.4636 | USW00093738 | Washington WB Chantilly | 8 | 1954-2000 | 44 | 1960-2019 | 63 |
| Washington Reagan AP | 38.8483 | -77.0342 | USW00013743 | Washington Reagan AP | 8 | 1945-2000 | 56 | 1945-2019 | 75 |

* Global Historical Climate Network (GHCN)

** Number of years with sufficient data for IDF analysis. Years with more than 20% missing values and/or other data issues are excluded.

### 2.1.2 Data Sources

The following data were obtained from NOAA Atlas 14 Volume 2 (Bonnin, et al. 2006), via the NOAA Precipitation Frequency Data Server (https://hdsc.nws.noaa.gov/hdsc/pfds/):

- Station-based IDF curve values for five selected stations, using both AMS and PDS methodology.
- GIS Grids: IDF patterns for the 100-year 24-hour and 500-year 24-hour depths, as PDS. These are interpolated grid of IDF values for all locations not represented by a specific station.
- Annual maxima time series for all stations used to develop Atlas 14 Volume 2

Daily historical precipitation time series, updated through 2019, were obtained for the seven selected stations from the Global Historical Climate Network (GHCN)), using NOAA National Centers for Environmental Information Climate Data Online (https://gis.ncdc.noaa.gov/maps/ncei/cdo/daily).

### 2.1.3 Updated Annual Maxima Series

Updated 24-hour IDF curves were developed for the seven selected stations using the period of record in Table 1. Updated annual maxima for daily precipitation were compared to annual maxima used to develop Atlas 14 Volume 2, as shown in Figure 2 for the Vienna station. The annual maxima for the period where Atlas 14 Volume 2 and the GHCN record overlap, 1942 to 2000, were identical. Updated IDF curves were created with annual maxima through 2019, using the original Atlas 14 Volume 2 maxima through the year 2000 appended with more recent annual maxima from GHCN.

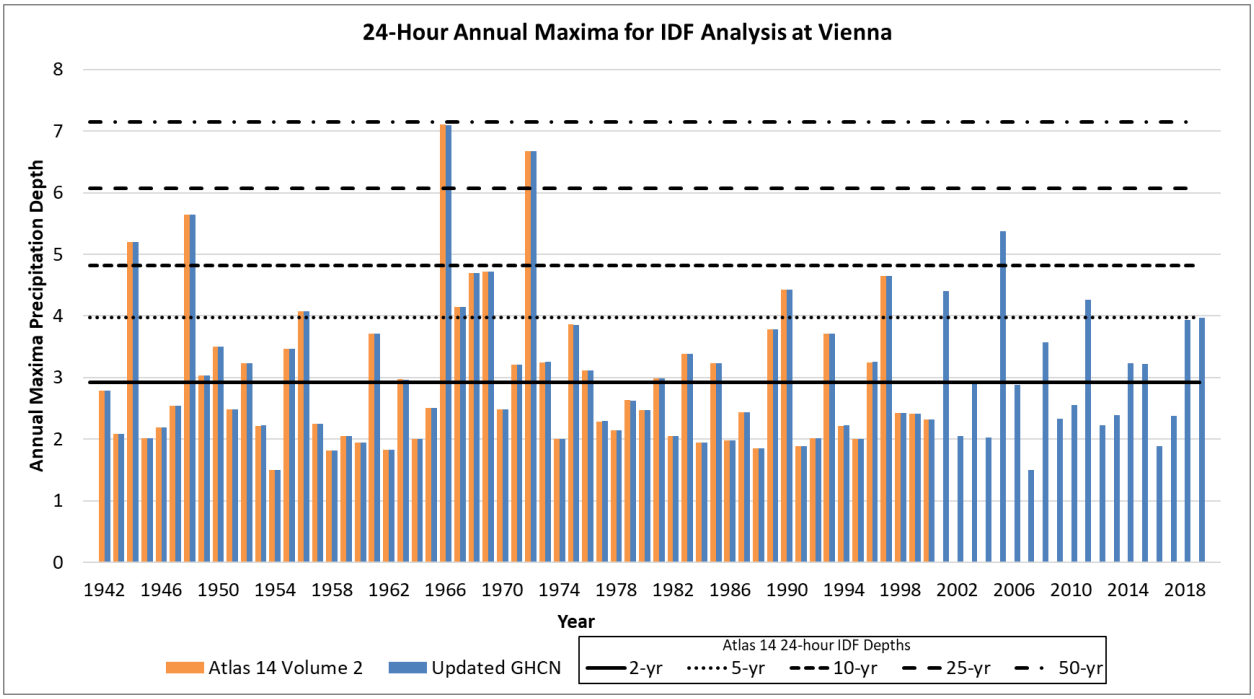



**Figure 2. 24-Hour Annual Maxima at Vienna (inches)**

### 2.1.4 L-Moments

Updated IDF curves were developed using the L-moments method. Hosking and Wallis (1997) developed L-moments that are linear combinations of order statistics. NOAA applies the L-moments method to develop estimates of rainfall frequency in Atlas 14 (Bonnin, et al. 2006). The methods are described in Appendix A.

The primary advantage of L-moments statistical analysis over conventional moments is that they suffer less from the effects of sampling variability. They also are more robust to outliers and virtually unbiased for small samples. The L-moments software developed by Hosking provides parameter estimates for seven distributions, provides station discordancy tests, network homogeneity tests, and confidence intervals.

Daily precipitation data were analyzed to obtain annual daily maximum values. The daily data used in this project came from stations from which observations were taken once every day at a fixed time (constrained observations). Due to the fixed beginning and ending of observation times (e.g., 7 am) at daily stations, it is likely that the constrained daily amounts are lower than the unconstrained 24-hour amounts that actually contribute to runoff. To account for the likely failure of capturing the true-interval maxima, a correction factor of 1.13, consistent with the approach taken in NOAA Atlas 14, was applied to the annual daily maximum precipitation used in this project.

Regional frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional frequency analysis involves: 1) data screening, 2) partitioning of data into homogeneous sub-regions, and 3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The L-moments software package (Hosking, 1996) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-moment method.

### 2.1.5 Updated IDF Curves

Updated IDF curves were developed using the L-moments method and updated annual maxima series from a region of the seven selected stations (Figure 1 and Table 1). These stations passed homogeneity tests described in Appendix B. Homogeneity tests ensure that an individual station's data are unbiased when compared to other stations in the region of study. The Generalized Extreme Value (GEV) distribution was selected as a suitable distribution, based on its use in Atlas 14 for the stations in Volume 2 Region 8. Region 8 comprises 57 stations across eastern Maryland, southeastern Pennsylvania, and northeastern Virginia. Five of the six Atlas 14 stations used in this analysis are in Atlas 14 Volume 2 Region 8 – all except Quantico, which is part of Region 1, which also used the GEV distribution in Atlas 14.

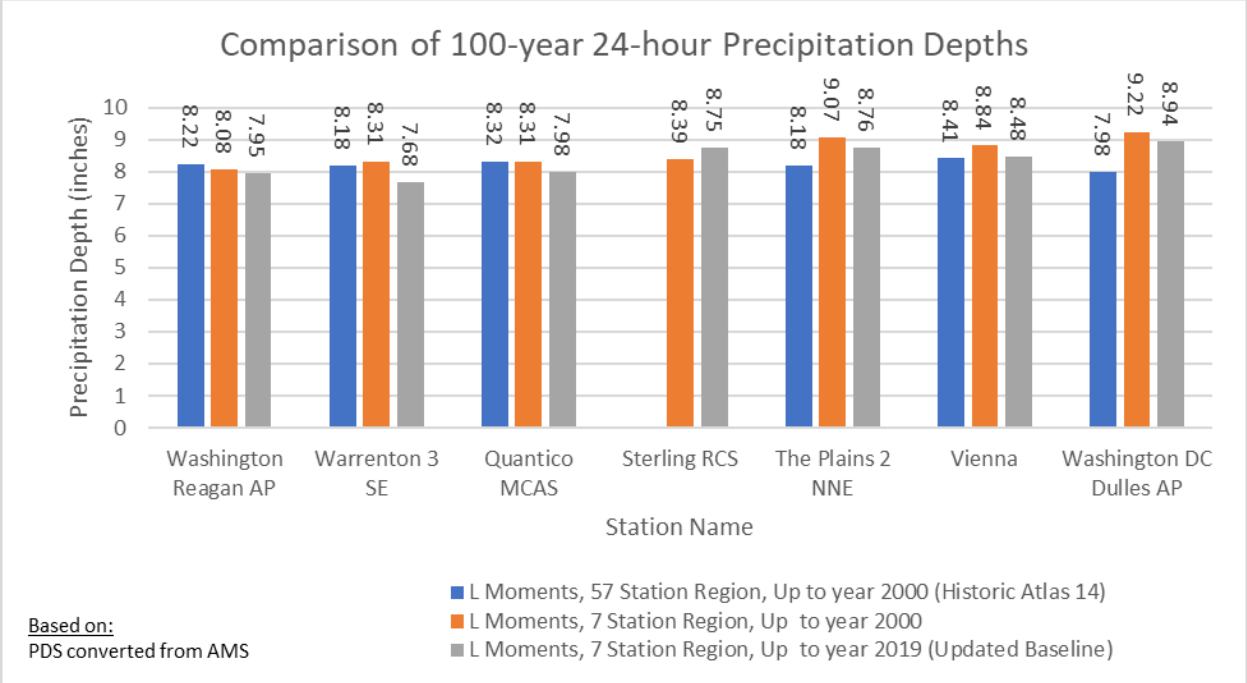
Updated 24-hour depths were compared to Atlas 14 values for the 100-year and 500-year 24-hour storms (Table 2 and Figure 3). Part of the difference between the updated IDF values and Atlas 14 values is caused by the difference in region size (number of stations) and thus different regional growth factors: this updated IDF curve analysis uses a 7-station region for L-moments analysis, and Atlas 14 uses a much larger 57-station region (Region 8, which includes Vienna). To isolate the impact of region size from increased record length, 24-hour depths were developed using L-moments for the 7-station region and the Atlas 14 annual maxima record through year 2000 (Table 2 and Figure 3). At the Vienna station, the change from Atlas 14 to 7-station region year 2000 accounts for a 5% increase in the 100-year 24-hour depth, while the increased record length through 2019 accounts for a 4% decrease, for a net increase of 1%. For the 500-year 24-hour depth, the change from Atlas 14 to 7-station region year 2000 accounts for a 3% increase, while the increased record length through 2019 accounts for an 8% decrease, for a net decrease of 5%.

**Table 2. Comparison of 24-hour Precipitation Depths (inches)**

| Station Name | 100-Year | | | 500-Year | | |
|---|---|---|---|---|---|---|
| | NOAA Atlas 14[1] | L-Moments up to Year 2000[2] | L-Moments up to Year 2019[2] (Updated) | NOAA Atlas 14[1] | L-Moments up to Year 2000[2] | L-Moments up to Year 2019[2] (Updated) |
| Vienna | 8.41 | 8.84 | 8.48 | 12.00 | 12.41 | 11.47 |
| Quantico MCAS | 8.32 | 8.31 | 7.98 | 11.80 | 11.66 | 10.78 |
| Sterling RCS | N/A | 8.39 | 8.75 | N/A | 11.76 | 11.83 |
| The Plains 2 NNE | 8.18 | 9.07 | 8.76 | 11.50 | 12.75 | 11.84 |
| Warrenton 3 SE | 8.18 | 8.31 | 7.68 | 11.60 | 11.68 | 10.39 |
| Washington DC Dulles AP | 7.98 | 9.22 | 8.94 | 11.30 | 12.84 | 12.00 |
| Washington Reagan AP | 8.22 | 8.08 | 7.95 | 11.70 | 11.35 | 10.74 |
| Median | 8.20 | 8.39 | 8.48 | 11.65 | 11.76 | 11.47 |

[1] Based on a 57-station region
[2] Based on a 7-station region

Values shown here converted to PDS using methods in Appendix C



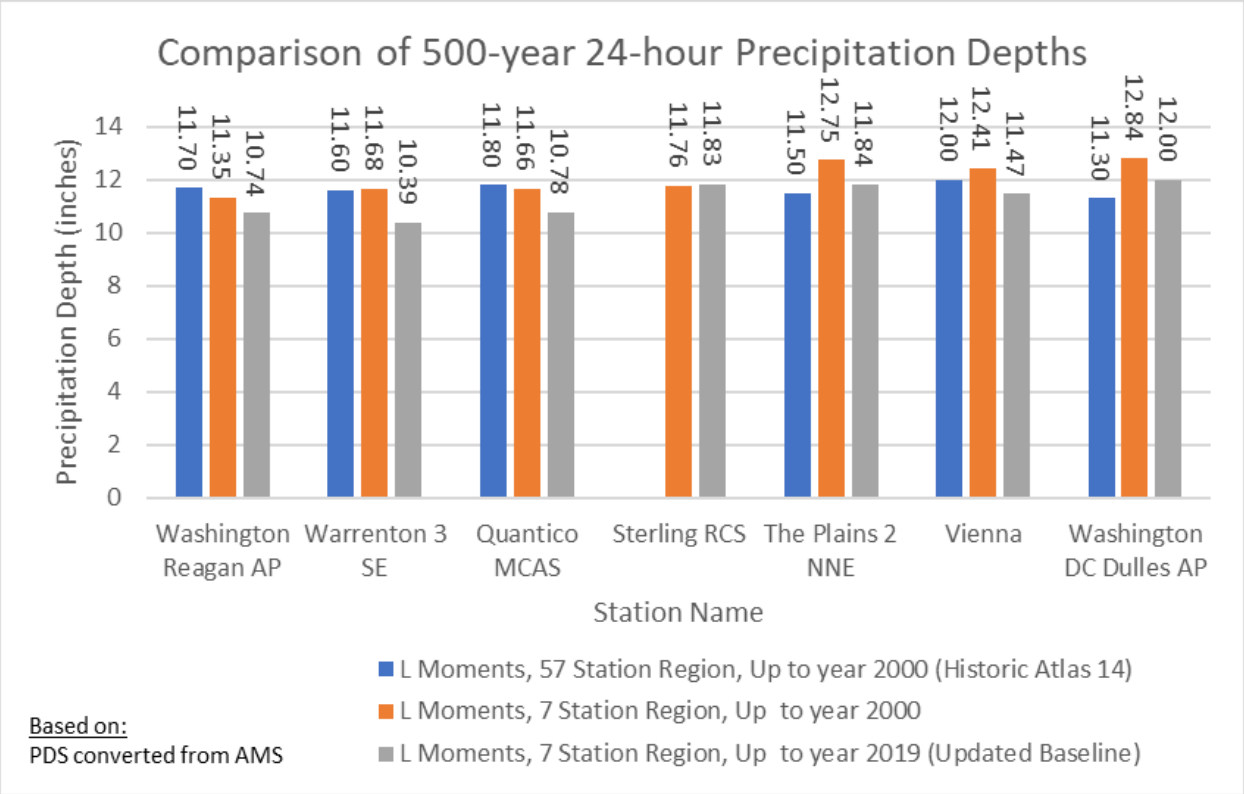



**Figure 3. Comparison of 100-Year and 500-Year 24-Hour Precipitation Depths**

### 2.1.6 Representative Station Selection

Precipitation statistics from the Vienna station were selected as representative of the County based on the proximity of the station to County limits and variability in spatially interpolated gridded IDF values from Atlas 14 as shown in Figure 4. The Washington Reagan Airport is the only station within the County limits, however the station tends to have lower IDF values that are less representative of the County as a whole. Although it is outside the County limits, IDF values from the Vienna station were selected as more conservative and more representative of County precipitation. Over the County limits, the Atlas 14 100-year 24-hour value ranges from 8.5 inches in the north-west of the County to 8.2 inches in the south-east of the County. The 500-year 24-hour value ranges from 12.0 inches in the north-west of the County and 11.7 inches to the south-east of the County.

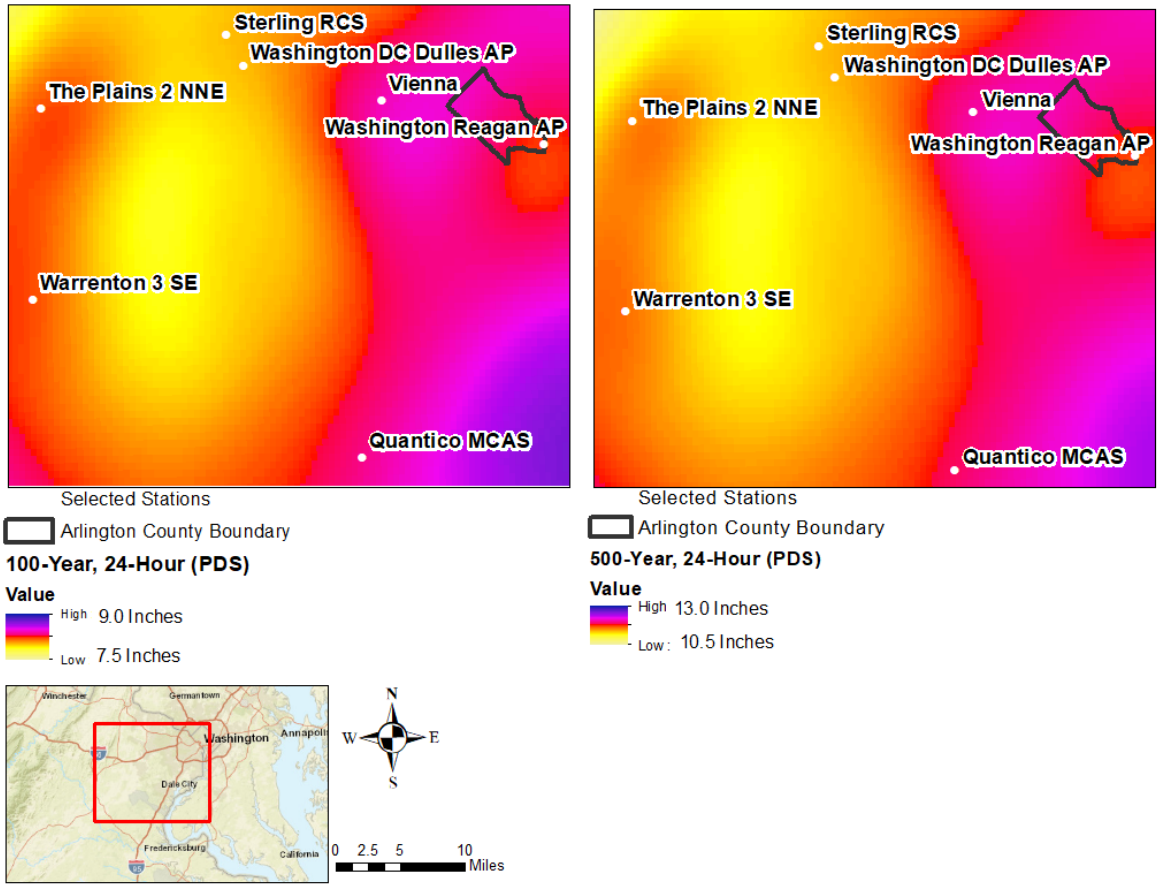



**Figure 4. Precipitation Variabilty over the County from Atlas 14**

### 2.1.7 Depths for durations other than 24-hour

Only the 24-hour duration depth-frequency statistics were updated using the L-moments method and annual maxima data through 2019. Additional durations were scaled from the 24-hour values using factors from Atlas 14. Ratios of multiple durations to 24-hour for the Vienna station are shown in Table 3.

**Table 3. Vienna Depth Ratios to 24 Hour Duration (unitless)**

| Duration | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year |
|---|---|---|---|---|---|---|---|
| 5 Minute | 0.13 | 0.12 | 0.12 | 0.11 | 0.10 | 0.09 | 0.07 |
| 10 Minute | 0.21 | 0.20 | 0.19 | 0.17 | 0.15 | 0.14 | 0.12 |
| 15 Minute | 0.27 | 0.25 | 0.23 | 0.21 | 0.20 | 0.18 | 0.15 |
| 30 Minute | 0.37 | 0.36 | 0.34 | 0.32 | 0.30 | 0.28 | 0.23 |
| 60 Minute | 0.47 | 0.46 | 0.44 | 0.42 | 0.40 | 0.38 | 0.33 |
| 2 Hour | 0.55 | 0.54 | 0.53 | 0.51 | 0.49 | 0.47 | 0.43 |
| 3 Hour | 0.58 | 0.58 | 0.56 | 0.55 | 0.53 | 0.51 | 0.47 |
| 6 Hour | 0.72 | 0.71 | 0.69 | 0.67 | 0.65 | 0.64 | 0.60 |

**Table 3. Vienna Depth Ratios to 24 Hour Duration (unitless)**

| Duration | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year |
|---|---|---|---|---|---|---|---|
| 12 Hour | 0.87 | 0.86 | 0.85 | 0.83 | 0.82 | 0.81 | 0.79 |
| 24 Hour | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 Day | 1.16 | 1.15 | 1.15 | 1.14 | 1.13 | 1.12 | 1.08 |
| 3 Day | 1.22 | 1.22 | 1.21 | 1.20 | 1.19 | 1.17 | 1.14 |
| 4 Day | 1.29 | 1.29 | 1.27 | 1.26 | 1.25 | 1.24 | 1.20 |
| 7 Day | 1.49 | 1.47 | 1.45 | 1.42 | 1.39 | 1.37 | 1.32 |

Based on Atlas 14 Partial Duration Series

### 2.1.8 Updated Baseline IDF Curves

Updated baseline IDF curves are presented both as a table with discrete values (Table 4) and a graph showing the relative difference between depths at varying durations (Figure 5). Frequency and duration combinations used for rainfall-driven surface flood modeling include the 100-year 24-hour and 500-year 24-hour.

**Table 4. Updated IDF Curves for Arlington County (inches)**

| Duration | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year |
|---|---|---|---|---|---|---|---|
| 5 Minute | 0.44 | 0.54 | 0.60 | 0.67 | 0.72 | 0.76 | 0.84 |
| 10 Minute | 0.71 | 0.86 | 0.96 | 1.07 | 1.14 | 1.21 | 1.33 |
| 15 Minute | 0.89 | 1.08 | 1.21 | 1.36 | 1.45 | 1.53 | 1.67 |
| 30 Minute | 1.23 | 1.55 | 1.76 | 2.01 | 2.18 | 2.34 | 2.67 |
| 60 Minute | 1.54 | 1.99 | 2.29 | 2.67 | 2.95 | 3.23 | 3.82 |
| 2 Hour | 1.81 | 2.34 | 2.71 | 3.22 | 3.60 | 3.98 | 4.87 |
| 3 Hour | 1.93 | 2.50 | 2.92 | 3.47 | 3.90 | 4.33 | 5.36 |
| 6 Hour | 2.36 | 3.05 | 3.56 | 4.26 | 4.83 | 5.41 | 6.86 |
| 12 Hour | 2.86 | 3.71 | 4.37 | 5.31 | 6.09 | 6.91 | 9.07 |
| 24 Hour | 3.30 | 4.33 | 5.16 | 6.36 | 7.38 | 8.48 | 11.47 |
| 2 Day | 3.82 | 5.00 | 5.93 | 7.24 | 8.32 | 9.47 | 12.42 |
| 3 Day | 4.04 | 5.28 | 6.25 | 7.62 | 8.76 | 9.96 | 13.09 |
| 4 Day | 4.26 | 5.56 | 6.57 | 8.01 | 9.20 | 10.49 | 13.76 |
| 7 Day | 4.92 | 6.35 | 7.46 | 9.02 | 10.28 | 11.60 | 15.10 |

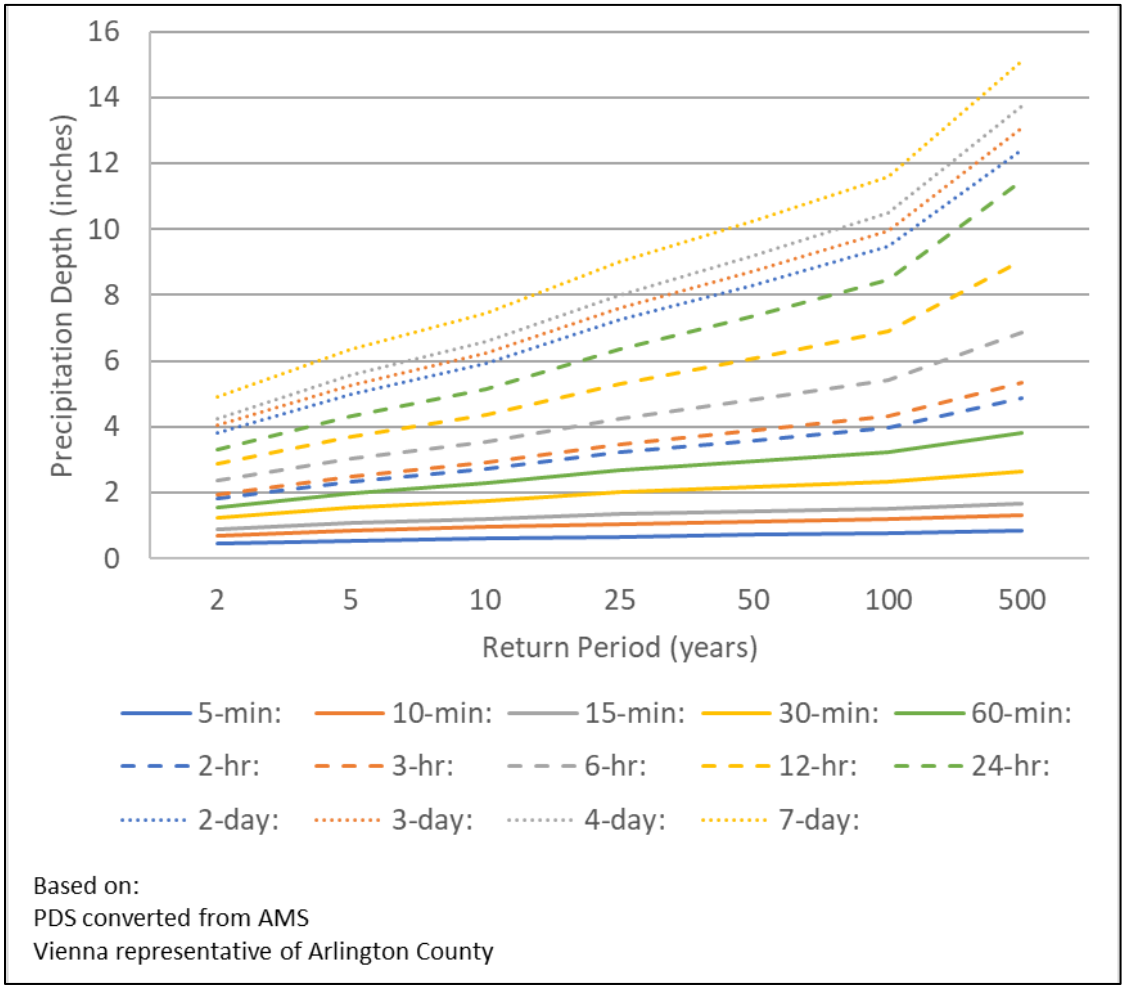



**Figure 5. Updated IDF Curves for Arlington County**

## 2.2 Projected Future Climate IDF Curves

The years 2040 and 2070 were selected as the planning horizons for which the future conditions were developed. A range of climate conditions could occur in the future corresponding to these planning horizons. Using the best available climate science, several climate scenarios have been defined to represent this range of potential future conditions based on projected future greenhouse gas concentrations and global climate models (GCMs). For this project, a total of four scenarios were selected for each planning horizon for use in developing the climate adjusted IDF curves, as summarized below.

### 2.2.1 Greenhouse Gas Concentration Scenario Selection

GCM results are influenced by the projected change in global greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) published GHG emissions scenarios known as Representative Concentration Pathways, or RCPs (Meinshausen et al., 2011). These RCPs were used as input for the current suite of models referenced in the IPCC Assessment Report 5 (AR5) (2013).

The available RCP GHG scenarios used by the GCMs are shown in Table 5 and Figure 6. The RCPs represent a cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter by year 2100. The RCPs were chosen to represent a broad range of climate outcomes, based on a literature review, and are neither forecasts nor policy recommendations.

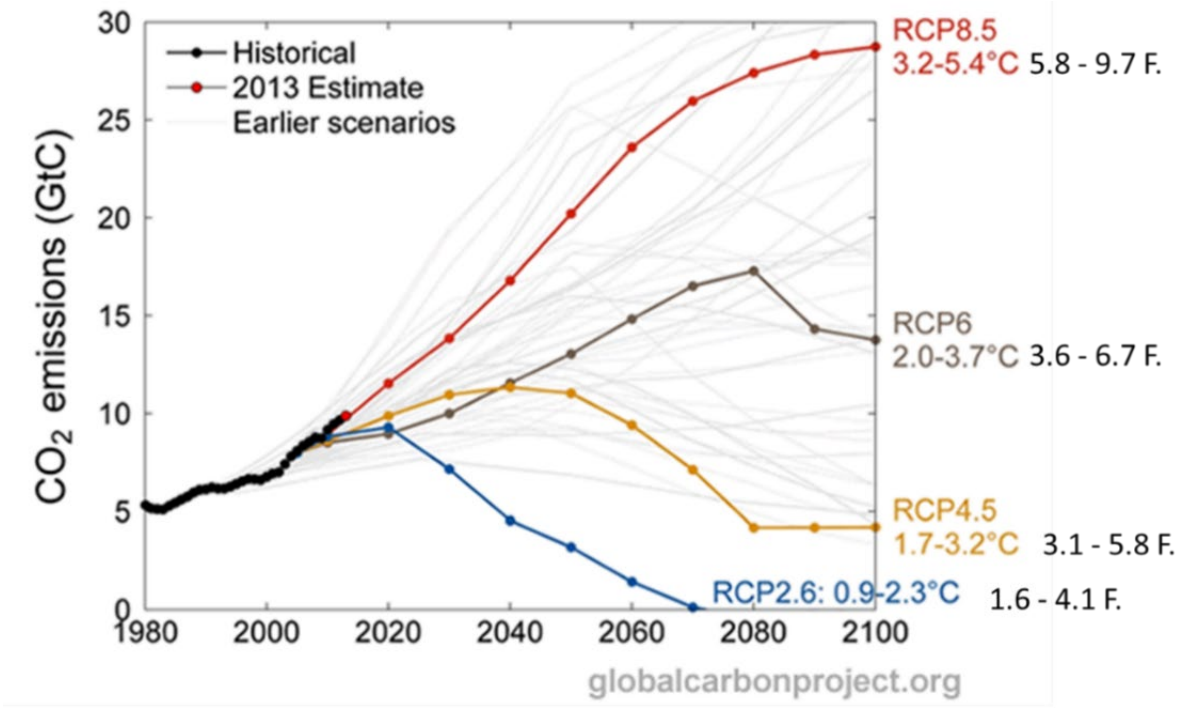
Each RCP could result from different combinations of economic, technological, demographic, policy, and institutional futures. For example, the second-to-lowest RCP (RCP4.5) could be considered a moderate mitigation scenario. However, it also is consistent with a baseline scenario that assumes a global development that focuses on technological improvements and a shift to service industries, but does not aim to reduce GHGs as a goal in itself. It should be noted that since many of the major GHG emissions do remain in the atmosphere from tens to hundreds of years after being released, their warming effects on the climate persist over a long time and can therefore affect both present and future generations.

The RCP 6.0 and RCP 8.5 scenarios were selected for this analysis as reasonable (medium) and slightly conservative (high) projections for future IDF curves. The RCP 6.0 GHG emissions peak in 2080 and the RCP 8.5 GHG emissions level off by 2100.

**Table 5. Overview of representative concentration pathways**

| | Description | $CO_2$ Equivalent | Publication |
|---|---|---|---|
| RCP8.5 | Rising radiative forcing pathway leading to 8.5 W/m2 in 2100. | 1,370 | Raiahi *et al.* 2007 |
| RCP6.0 | Stabilization without overshoot pathway to 6 W/m2 at 2100 | 850 | Fujino *et al.*; Hijioka *et al.* 2008 |
| RCP4.5 | Stabilization without overshoot pathway to 4.5 W/m2 2100 | 650 | Clark *et al.* 2006; Smith and Wigley 2006; Wise *et al.* 2009 |
| RCP2.6 | Peak in radiative forcing at approximately 3 W/m2 before 2100 and decline | 490 | van Vuuren *et al.*, 2007; van Vuuren *et al.* 2006 |

Source: van Vuuren et al., 2011; Moss et al., 2010; Rojeli et al. 2012




Source Globalcarbonproject.org

**Figure 6. Representative concentration pathways used as input for AR5 GCMs**

### 2.2.2 Daily General Circulation Model Selection

The SimCLIM tool (version 4.11.7109.0, CLIMsystems, 2018 using updated Generalized Extreme Value precipitation patterns from 6/16/2020) was used to develop projected future precipitation IDF estimates at the representative station for the County, for the selected time horizons and GHG scenarios. IDF precipitation projections for the years 2040 and 2070 were created for both the RCP 6.0 and RCP 8.5 scenarios at the Vienna station using an ensemble of 31 daily GCMs in SimCLIM as described in Appendix E. The 50 percent (i.e., the median), and 90 percent non-exceedance values of all 31 GCMs were both obtained for each RCP scenario.

SimCLIM uses GCM results from the CMIP5 (Coupled Model Intercomparison Project Phase 5) database located at the following web address http://cmip-pcmdi.llnl.gov/cmip5/%20guide_to_cmip5.html. Thirty-one daily GCMs provide results that SimCLIM can use to estimate changes in precipitation IDF. Appendix D lists the thirty-one daily GCMs that were used as an ensemble in the IDF analysis.

GCM results are produced at a coarse resolution (200 kilometers) and must be downscaled to capture the effects of local climate characteristics. Statistical downscaling is a two-step process basically consisting of development of statistical relationships between local climate variables (for example, surface air temperature and precipitation) and large-scale predictors, and application of such relationships to the output of GCM to simulate local climate characteristics. The SimCLIM application uses a statistical pattern scaling method developed by Santer et al. (1990) to create downscaled precipitation patterns at a resolution of approximately 1-kilometer.

### 2.2.3 Projected Climate IDF Scaling Factors

The SimCLIM Extreme Value module was used to develop 24-hour depths at multiple return periods, using the GEV distribution, for both baseline and future climate. The SimCLIM baseline and future IDF values were used to create future IDF percent change factors that were applied to the updated IDF curves developed using L-moments.

The SimCLIM baseline IDF uses the same annual maxima used in the updated IDF curves based on Lmoments (Section 2.1.5). The SimCLIM baseline 24-hour depths differ from updated (L-moments) values because the SimCLIM module is based on a single station, while L-moments uses a 7-station regional approach (Section 2.1.4 and Appendix A). Table 6 and Figure 7 compare the Atlas 14 24-hour values to the updated (L-moments) and the SimCLIM baseline values at the Vienna station. The updated values show an increase over the Atlas 14 values, with a higher increase at the higher return periods. The SimCLIM baseline values vary between approximately equal to 9% lower than the updated (L-moments) values, due to the single station versus regional approach.

**Table 6. 24-Hour Depths at the Vienna Station (inches)**

| Return Period | NOAA Atlas 14 | Updated (L-moments) | SimCLIM Baseline |
|---|---|---|---|
| 2 | 3.17 | 3.30 | 3.31 |
| 5 | 4.07 | 4.33 | 4.20 |
| 10 | 4.87 | 5.16 | 4.97 |
| 25 | 6.09 | 6.36 | 5.80 |
| 50 | 7.18 | 7.38 | 7.08 |

**Table 6. 24-Hour Depths at the Vienna Station (inches)**

| Return Period | NOAA Atlas 14 | Updated (L-moments) | SimCLIM Baseline |
|---|---|---|---|
| 100 | 8.41 | 8.48 | 8.15 |
| 500 | 12.00 | 11.47 | 11.17 |

Based on PDS converted from AMS

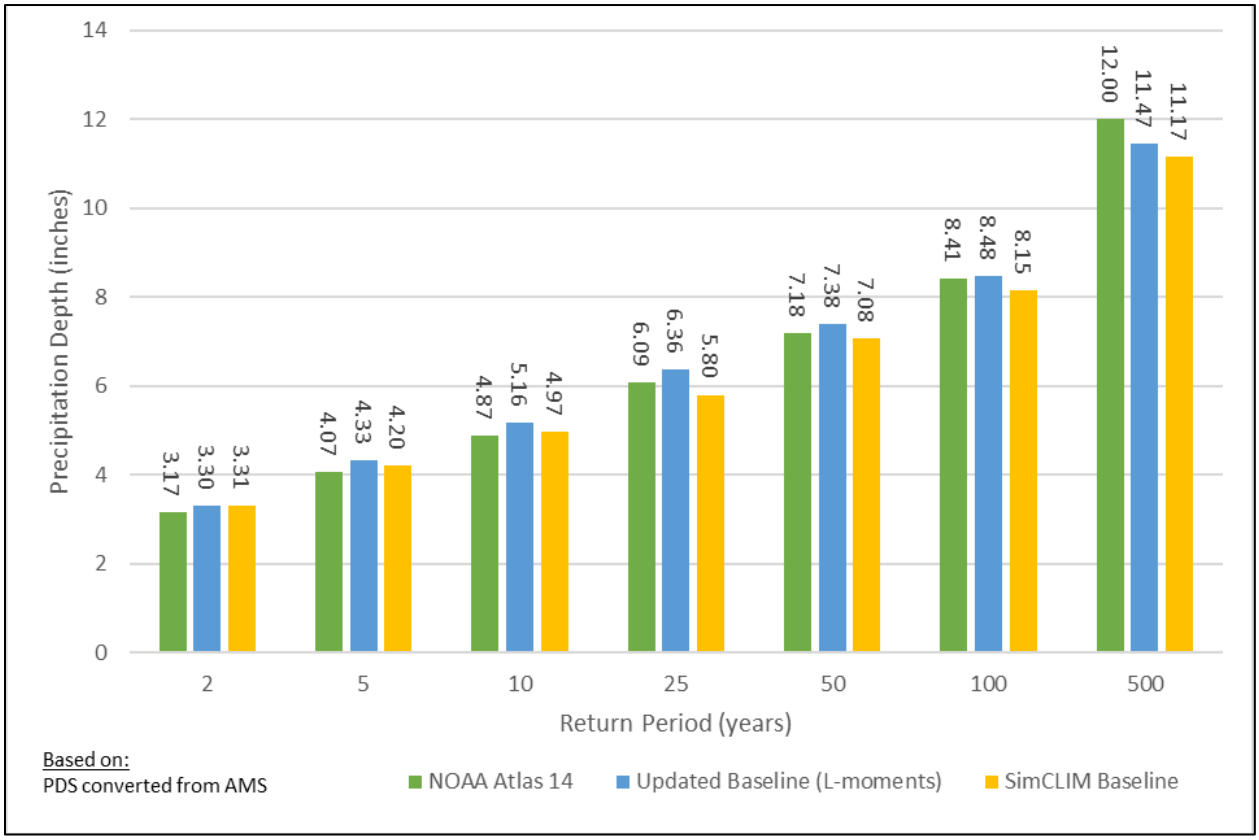



**Figure 7. 24-hour Depths at Vienna Station**

The Updated Baseline IDF curves were used as the starting point for projected future IDF curves. SimCLIM baseline and projected future 24-hour precipitation amounts for the Vienna station were converted to a percentage change and applied to the Updated Baseline 24-hour precipitation depth (Section 2.1.5) for the representative station (Vienna) for 2040 and 2070 for four future climate scenarios.

The percentage increase from the baseline 24-hour precipitation depth for the 2-, 5-, 10-, 25-, 50-, 100-, and 500- year return periods are shown in Figure 8 for the median (50% non-exceedance), which is the central tendency from the ensemble of climate models. To communicate the range in future climate projections and as a measure of climate model uncertainty, a conservative high percent increase (90% non-exceedance), is shown in Figure 9.

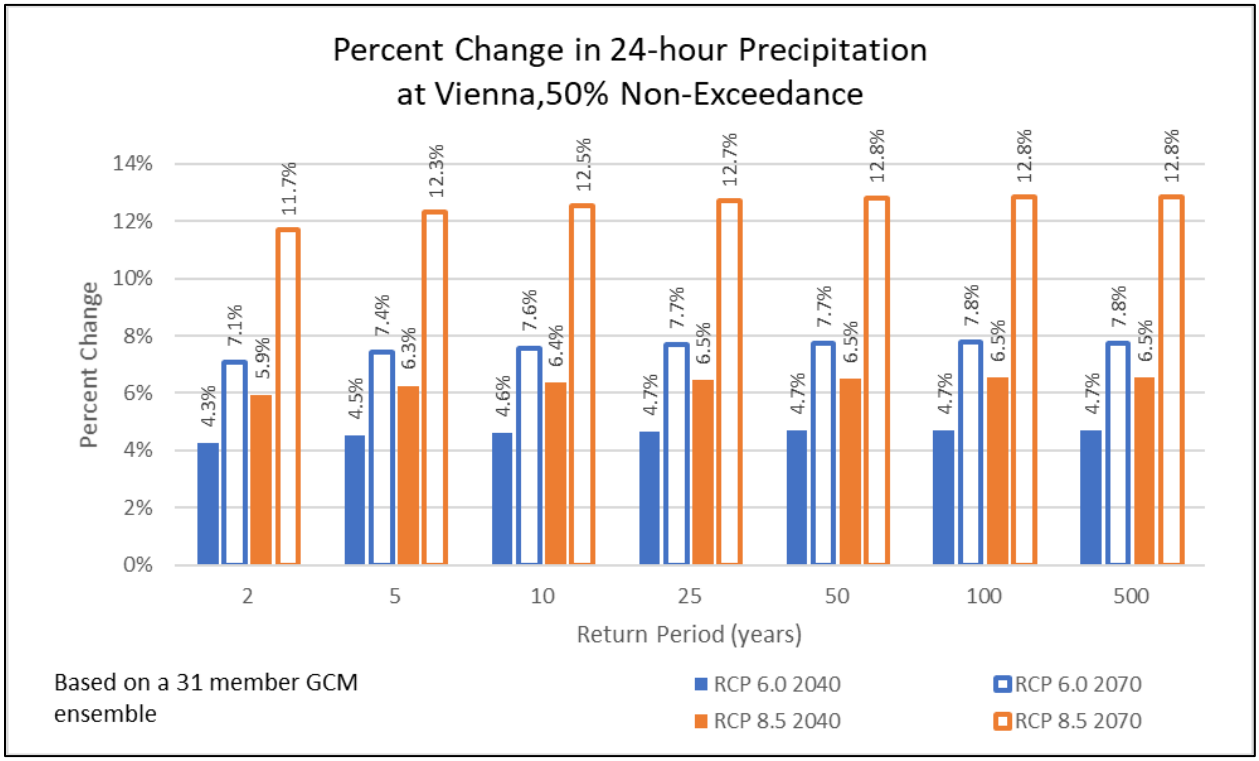



**Figure 8. Percent Change in 24-hour Precipitation at Vienna, Median (50% Non-Exceedance)**

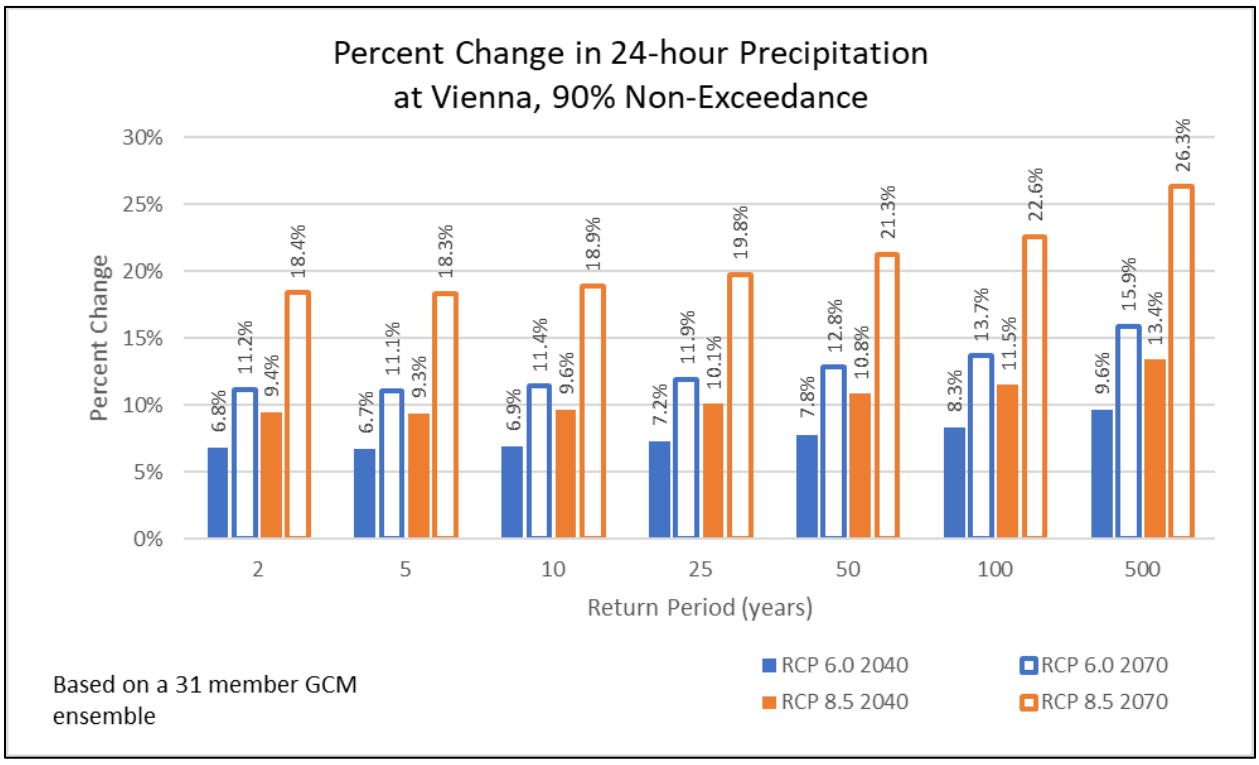



**Figure 9. Percent Change in 24-hour Precipitation at Vienna, High (90% Non-Exceedance)**

### 2.2.4 Resulting Projected Future IDF Curves

Resulting projected future 24-hour precipitation depths are presented for four future climate scenarios and two future planning horizons in Table 7, Figure 10, and Figure 11. To obtain projected future precipitation depths for durations other than 24-hour, the ratios in Table 3 should be applied to future precipitation 24-hour depths.

**Table 7. Projected Future 24-hour Precipitation Depths for Arlington County (inches)**

| Planning Horizon | Scenario | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year |
|---|---|---|---|---|---|---|---|---|
| Baseline | Historical – NOAA Atlas 14 | 3.17 | 4.07 | 4.87 | 6.09 | 7.18 | 8.41 | 12 |
| | Updated | 3.30 | 4.33 | 5.16 | 6.36 | 7.38 | 8.48 | 11.47 |
| 2040 | RCP 6.0 50% | 3.44 | 4.52 | 5.40 | 6.66 | 7.73 | 8.88 | 12.00 |
| | RCP 6.0 90% | 3.52 | 4.62 | 5.52 | 6.82 | 7.96 | 9.18 | 12.57 |
| | RCP 8.5 50% | 3.50 | 4.60 | 5.49 | 6.77 | 7.86 | 9.04 | 12.21 |
| | RCP 8.5 90% | 3.61 | 4.73 | 5.66 | 7.00 | 8.18 | 9.46 | 13.00 |
| 2070 | RCP 6.0 50% | 3.53 | 4.65 | 5.55 | 6.85 | 7.95 | 9.14 | 12.35 |
| | RCP 6.0 90% | 3.67 | 4.81 | 5.75 | 7.12 | 8.33 | 9.64 | 13.29 |
| | RCP 8.5 50% | 3.69 | 4.86 | 5.81 | 7.17 | 8.33 | 9.57 | 12.94 |
| | RCP 8.5 90% | 3.91 | 5.12 | 6.14 | 7.62 | 8.95 | 10.40 | 14.48 |

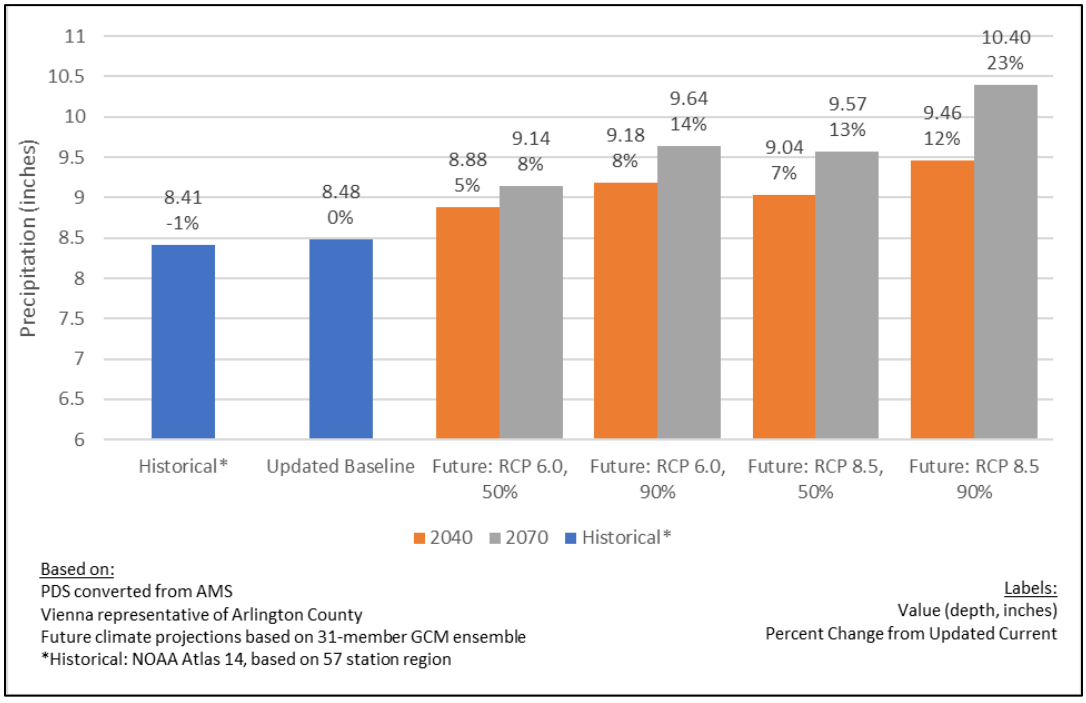



**Figure 10. Baseline and Future 100-year 24-Hour Precipitation Depths for Vienna**

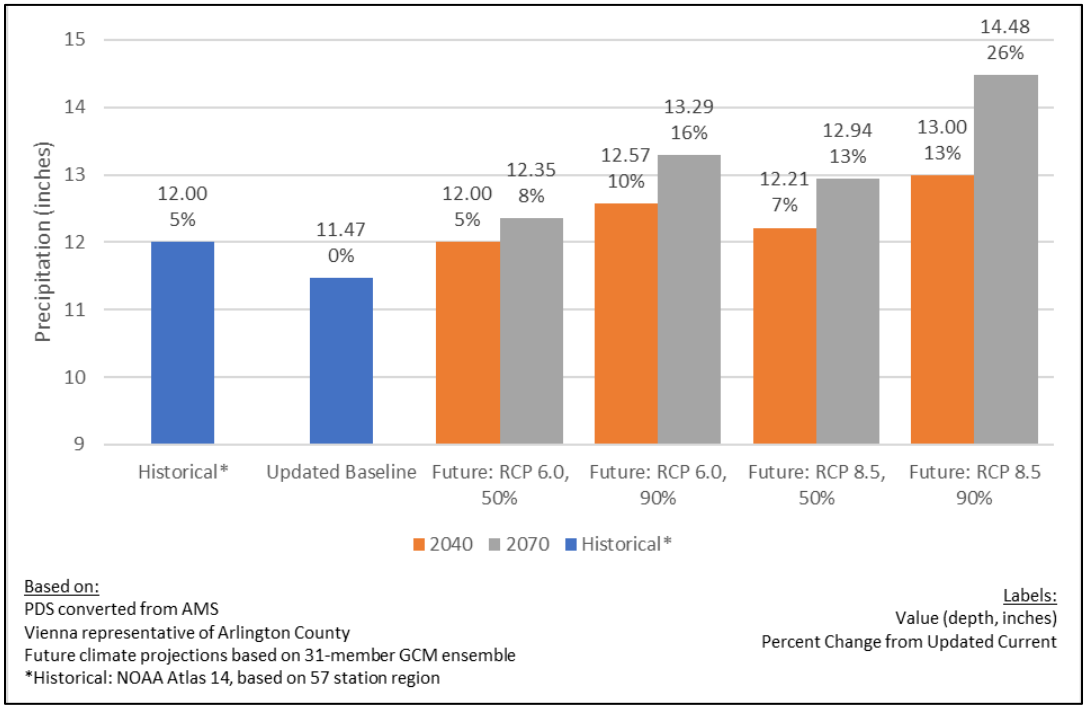



**Figure 11. Baseline and Future 500-year 24-Hour Precipitation Depths for Vienna**

## 2.3 Historic Events Rainfall Analysis

The following two flood events were evaluated for use in two-dimensional rainfall-driven surface flood modeling:

- 6/25/2006-6/27/2006
- 7/8/2019

Quality control was performed on data from stations in and around Arlington County. Incomplete or unreliable data was not used in the analysis. Stations that passed quality control checks are shown in Figure 12 and in tabular form in Table 8. Cumulative precipitation is plotted for the June 2006 and July 2019 events in Figure 13 and Figure 14.

For the 2006 event, 5-minute precipitation data was provided by the County for Donaldson Run lift station. Two other stations, Washington Reagan Airport and Washington DC Dulles Airport were available from the GHCN hourly network. For the 2019 event, 5 stations were available from MesoWest in either 5-minute, 10-minute, or 15-minute increments. Depths of interest for each station were then compared to the updated IDF curve (Table 4 and Figure 5) to determine the event. This data is summarized in tabular form in Table 9 and Table 10.

**Table 8. Historic Event Stations**

| Station | Data Interval | Event | Source |
|---|---|---|---|
| FW1583 Falls Church | 5 min | July 2019 | MesoWest |
| AG4JW Arlington | 10 min | July 2019 | MesoWest |
| CW8838 Douglas Park | 5 min | July 2019 | MesoWest |

**Table 8. Historic Event Stations**

| Station | Data Interval | Event | Source |
|---|---|---|---|
| Washington/Reagan National Airport | 60 min<br>5 min | June 2006<br>July 2019 | GHCN<br>MesoWest |
| EW3336 Arlington | 15 min | July 2019 | MesoWest |
| Donaldson Run Lift Station | 5 min | June 2006 | Provided by County |
| Washington DC Dulles Airport | 60 min | June 2006 | GHCN |

MesoWest from University of Utah (2020)

Global Historical Climate Network (GHCN) from NCEI (2020)

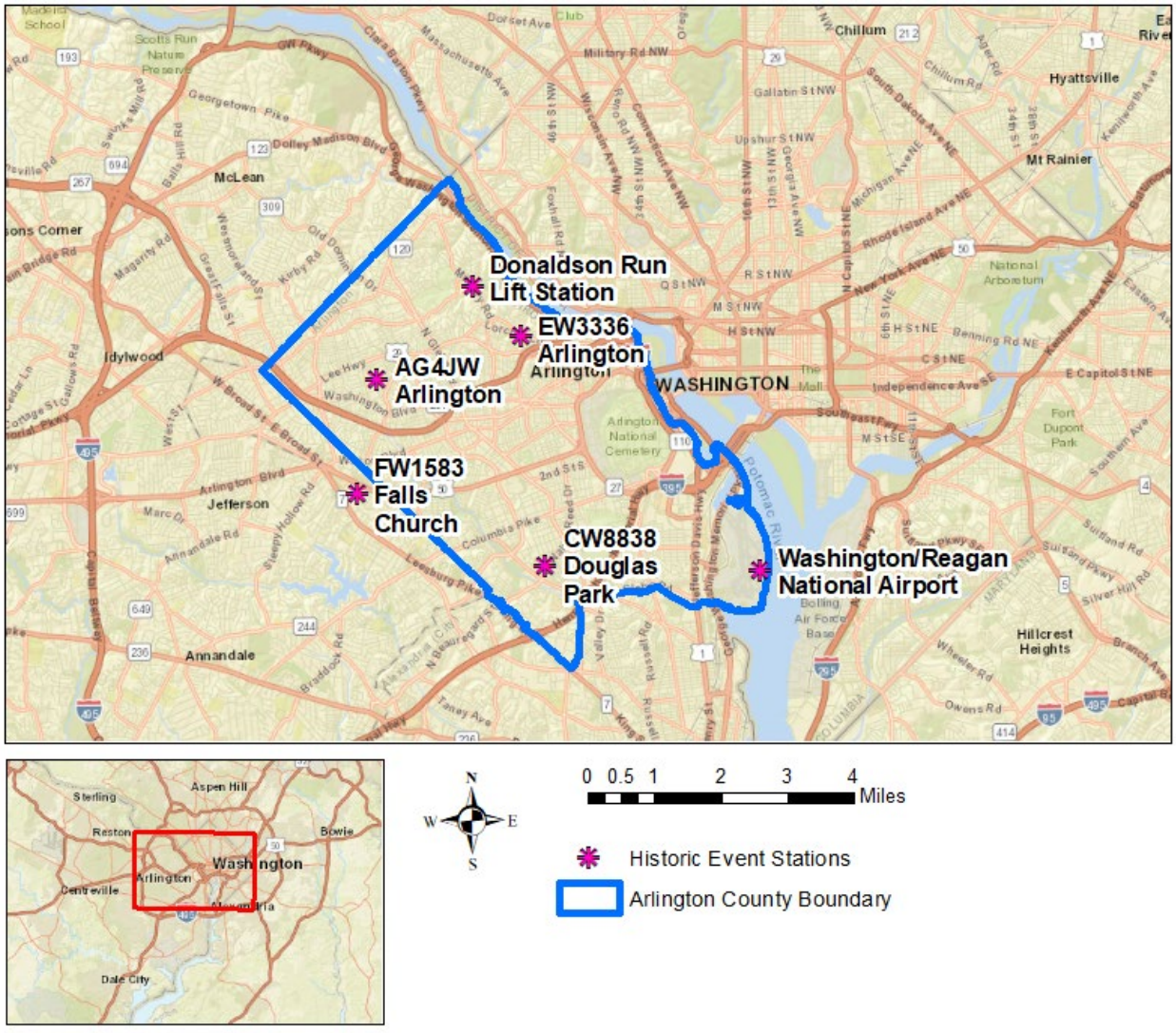



**Figure 12. Historic Event Stations**

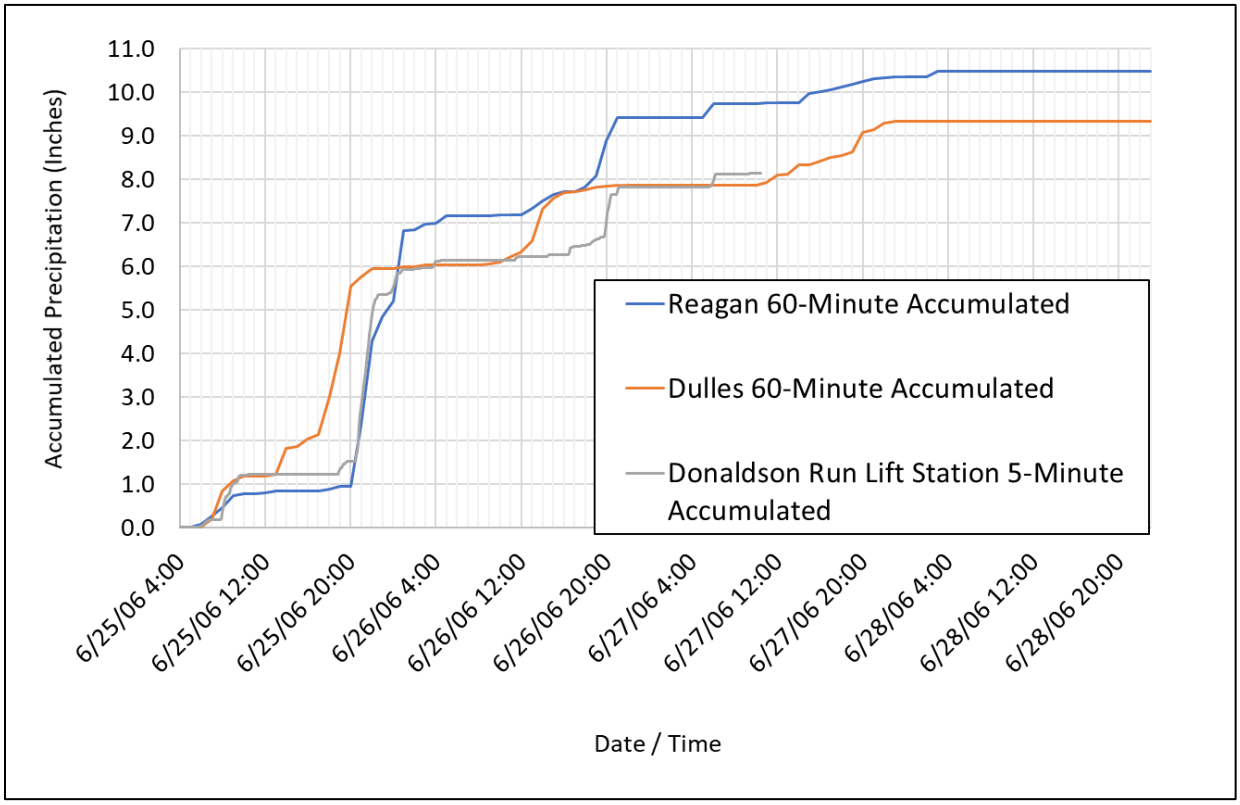



**Figure 13. Cumulative Event Depth During a June 2006 Event**

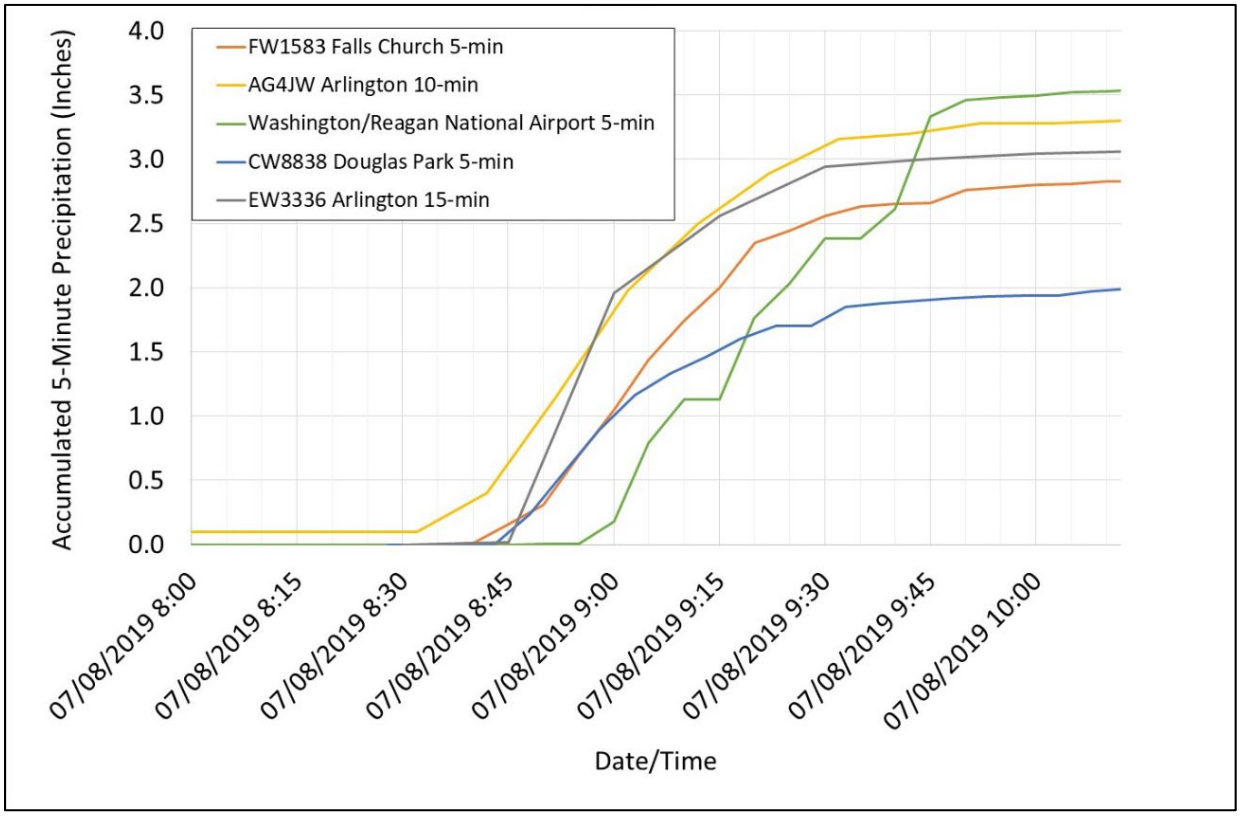



**Figure 14. Cumulative Event Depth During a July 2019 Event**

**Table 9. Total Event Depths and Return Periods for a June 2006 Event**

| Duration | Donaldson Run Lift Station | Washington DC Dulles Airport | Washington Reagan Airport |
|---|---|---|---|
| ***Maximum Depths at Multiple Durations of Interest (inches)*** | | | |
| 5 min | 0.40 | — | — |
| 15 min | 0.86 | — | — |
| 30 min | 1.34 | — | — |
| 60-minute | 2.44 | 1.55 | 1.93 |
| 2-hour | 3.74 | 2.54 | 3.34 |
| 3-hr | 3.84 | 3.42 | 3.90 |
| 6-hr | 4.69 | 3.90 | 4.32 |
| 12-hr | 4.91 | 4.77 | 4.40 |
| 24-hr | 6.12 | 5.94 | 5.19 |
| 48-hr | 8.06 | 7.86 | 9.56 |
| 72-hr | — | 9.33 | 10.48 |
| ***Return Periods at Multiple Durations of Interest* (years)*** | | | |
| 5 min | <2 | — | — |
| 15 min | <2 | — | — |
| 30 min | 2 | — | — |
| 60-minute | 10 | 2 | 2 |
| 2-hour | 50 | 5 | 25 |
| 3-hr | 25 | 10 | 50 |
| 6-hr | 25 | 10 | 25 |
| 12-hr | 10 | 10 | 10 |
| 24-hr | 10 | 10 | 10 |
| 48-hr | 25 | 25 | 100 |
| 72-hr | — | 50 | 100 |

*Return periods and are rounded down

**Table 10. Total Event Depths and Return Periods for a July 2019 Event**

| Duration | FW1583 Falls Church | AG4JW Arlington | CW8838 Douglas Park | Washington/ Reagan National Airport | EW3336 Arlington |
|---|---|---|---|---|---|
| ***Maximum Depths at Multiple Durations of Interest (inches)*** | | | | | |
| 5 min | 0.39 | — | 0.34 | 0.72 | — |
| 10 min | 0.75 | 0.81 | 0.66 | 0.95 | — |
| 15 min | 1.13 | — | 0.93 | 1.25 | 1.94 |
| 30 min | 2.04 | 2.10 | 1.46 | 2.20 | 2.54 |
| 60-minute | 2.64 | 3.06 | 1.90 | 3.48 | 2.98 |
| 2-hour | — | 3.21 | 2.01 | 3.60 | 3.07 |
| Maximum Event Depth | 2.84 | 3.32 | 2.01 | 3.60 | 3.07 |
| ***Return Periods at Multiple Durations of Interest* (years)*** | | | | | |
| 5 min | <2 | — | <2 | 50 | — |
| 10 min | 2 | 2 | <2 | 5 | — |
| 15 min | 5 | — | 2 | 10 | >1000 |
| 30 min | 25 | 25 | 2 | 50 | 100 |
| 60-minute | 10 | 50 | 2 | 100 | 50 |
| 2-hour | — | 10 | 2 | 50 | 10 |
| Maximum as 24 Hr | <2 | 2 | <2 | 2 | <2 |

*Return periods are rounded down

# 3. Extreme Water Levels and Sea Level Rise

## 3.1 Baseline Tide and Extreme Water Levels

Tide and extreme water levels are used as part of the downstream boundary condition for flood modeling. They represent the water elevation to which local stormwater and riverine flow drains, as well as a boundary condition for coastal storm surge modeling. Baseline tide and extreme water level information was obtained for the Washington DC station, shown in Table 11 and Figure 15. This station was selected based on proximity to the County and availability of Sea Level Rise projection values for the same location.

Baseline extreme water level values are presented in Table 12. Extreme water level values were obtained from FEMA (2010) for the 10-year and 100-year return periods[3], and with extreme value analysis conducted herein for the 2-year and 500-year return periods.

Extreme value analysis was conducted using the Generalized Pareto distribution and Maximum Likelihood estimator and the Peaks-Over-Threshold (POT) method as calculated by MIKE EVA software (MIKE by DHI, 2020), 95.5 years (1925 to 2020 monthly maxima, with some months of missing data) of extreme monthly water levels, and a threshold value of 3 feet (NAVD88), resulting in 290 data points. The Generalized Pareto distribution/Maximum Likelihood estimator was selected because it resulted in better goodness of fit and narrower 90% confidence bands than other distribution/estimator combinations.

The 500-year Generalized Pareto result was used because it is more conservative (higher) than the corresponding FEMA (2010) value, as well as more robust than the FEMA (2010) value as it is based on 290 data points instead of 71 based on the annual maxima. In addition, the added conservatism is consistent with the larger uncertainty associated with larger returns periods.

For extreme value analysis, the length of the time series data should be sufficiently long in order to be able to determine the marginal extremes with sufficient accuracy. A common guideline is that the data should be one third as long as the return period of interest. For example, Hogg and Swail (2007) in a study on the Atlantic coast of Canada obtained up to 25% variation in the estimated 100-year offshore wave height using 10-year datasets instead of the entire 41-year data set available for their study, which is not in accordance with the recommended factor of 3. By extension, the recommended length of data used to estimate a 500-year extreme value is 500/3 = 168 years. Because this period of record is typically not available, added conservatism is typically recommended.

The 2-year Generalized Pareto results was used because FEMA (2010) does not provide a 2-year extreme water level.

**Table 11. Tide and Extreme Water Level Station**

| Location | NOAA Station ID | PSMSL Station ID | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Washington DC* | 8594900 | 360 | 38.873333 | −77.021667 | Extreme Water Levels and Sea Level Rise available |

*Depending on the source, this location is variously referred to as “Haines Point” or “Hains Point” tide station.

**Table 12. Baseline Extreme Water Levels**

| Description/Return Period | Water Elevation (ft, NAVD88) | Source |
|---|---|---|
| Mean Higher High Water | 1.77 | NOAA (2020) |
| 2-year | 4.1 | Generalized Pareto distribution, Maximum Likelihood estimator |
| 10-year | 5.8 | From FEMA (2010), Table 6 |

[3] Extreme water level values developed directly by NOAA (2020) were considered, but ultimately discarded because the NOAA 100-year value of 12.4 feet (NAVD88) is nearly two feet higher than values for the same return period developed by multiple other publications (FEMA, 2010; USACE, 2014) and independent Jacobs extreme value analysis using a full 95.5-year record of NOAA tide data. The highest recorded level at this station is +9.65 ft NAVD. Based on the definition of return period we could expect that the 100-year extreme water level about the same as the largest event in 95.5 years, i.e., io the order of +10 ft NAVD.

**Table 12. Baseline Extreme Water Levels**

| Description/Return Period | Water Elevation (ft, NAVD88) | Source |
|---|---|---|
| 100-year | 10.5 | From FEMA (2010), Table 6 |
| 500-year | 15.4 | Generalized Pareto distribution, Maximum Likelihood estimator |

All values at Washington DC tide station

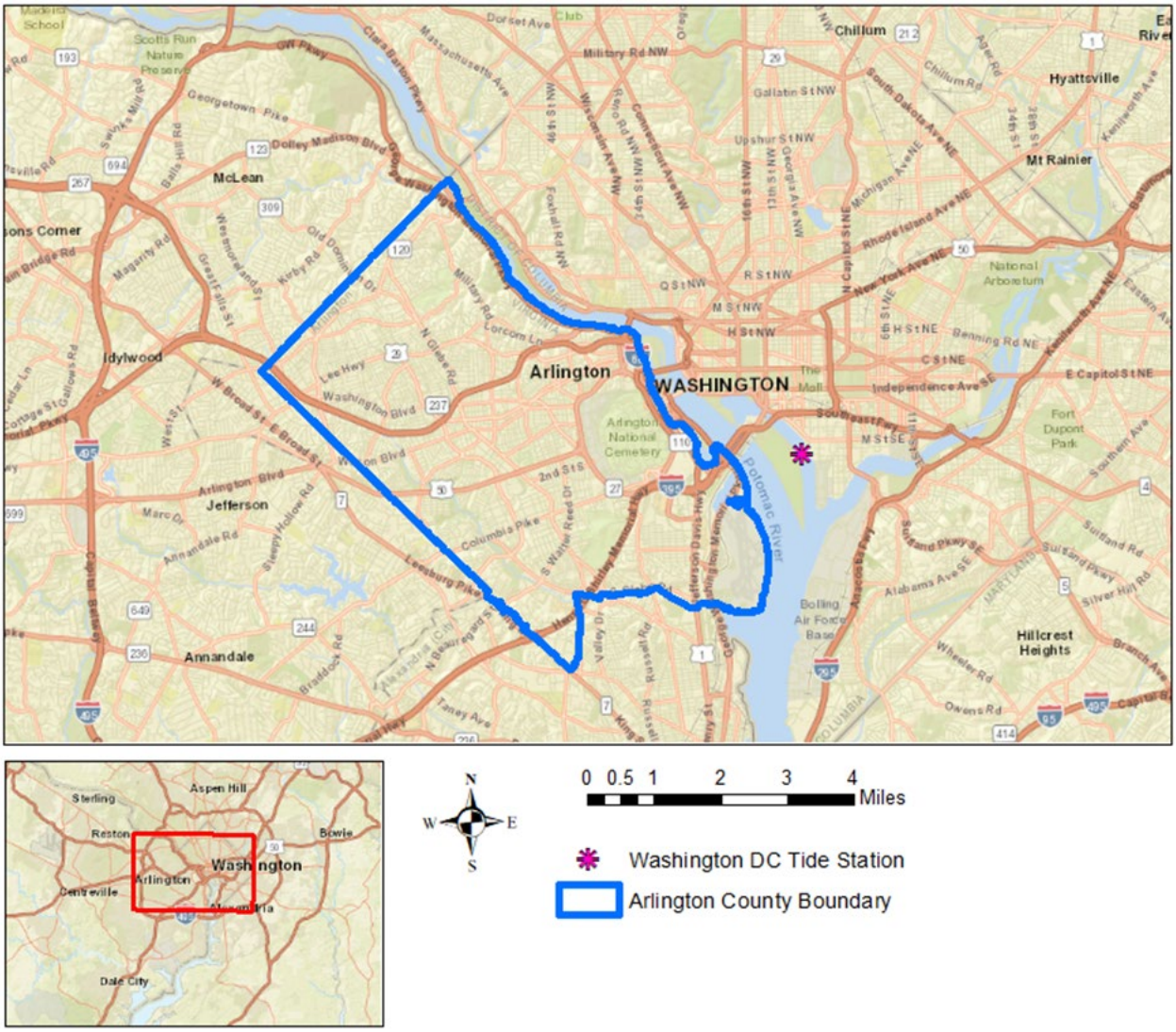



**Figure 15. Tide Stations Near Arlington County**

## 3.2 Sea Level Rise Projections

Sea level rise projections were obtained from the US Army Corps of Engineers Sea-Level Change Curve Calculator (USACE, 2019), using the option for results from NOAA et al. (2017). Net SLR projection, inclusive of an estimate for vertical land movement, was obtained for the same tide station described in Table 4. The USACE (2019) tool provides six SLR curves, from *Low* to *Extreme*. The range of curves represents a range of potential future scenarios based on the same climate modeling described for precipitation in Section 2, with additional inclusions for glacial ice-sheet melt. Although there is a conceptual similarity to the precipitation scenarios, there is not a one-to-one relationship between the scenarios used for precipitation and those used for SLR.

SLR results are provided by USACE (2019) as change each decade starting in 2000, up through 2100. While it is possible to use these values to calculate change since 2020, the year 2000 was used as the baseline period for SLR projections in this study because it more closely approximates the Mean Higher High Water epoch (Section 3.1), which is the baseline datum over which SLR is added.

Sea level rise projections for the six scenarios at the Washington DC station are shown in Figure 16 and Table 13.

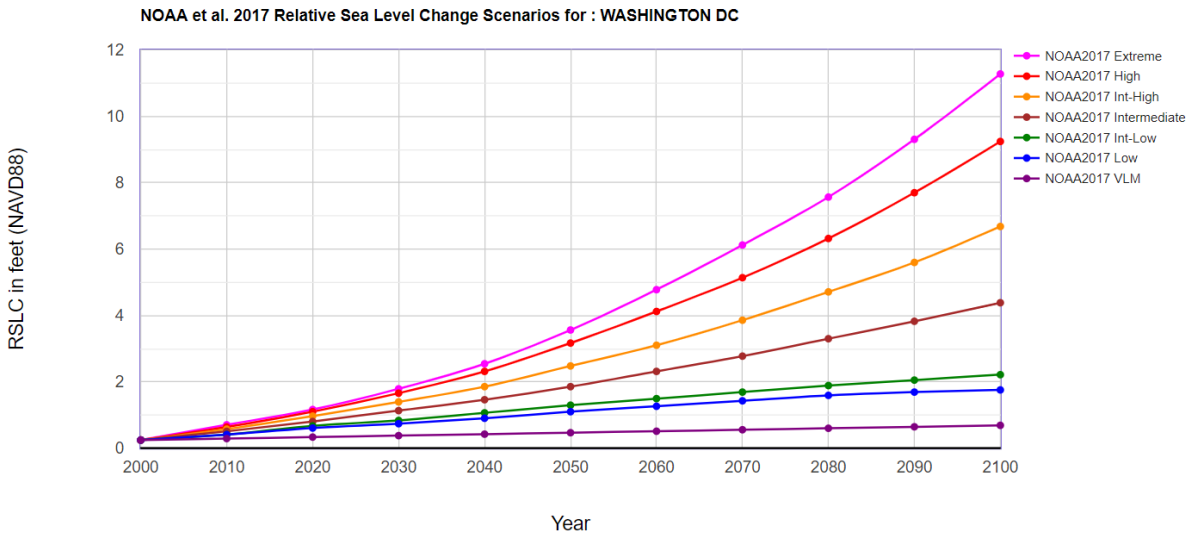



**Figure 16. Sea Level Rise Projections for Washington DC**

**Table 13. Sea Level Rise Projections for Washington DC (feet)**

| Year | Low | Int-Low | Intermediate | Int-High | High | Extreme |
|---|---|---|---|---|---|---|
| 2040 | 0.91 | 1.07 | 1.46 | 1.86 | 2.32 | 2.55 |
| 2070 | 1.43 | 1.69 | 2.78 | 3.86 | 5.14 | 6.12 |

All sea level rise projection values in feet relative to year 2000

## 3.3 Historic Events Tide Analysis

Tidal conditions for the two events described in Section 2.3 were obtained at Washington DC tide station (Section 3.1) from NOAA (2020). The peak water level from each event can be used as the downstream boundary condition for flood modeling. Water level values and corresponding return period are shown in Table 14.

**Table 14. Historic Event High Water Level**

| Event | Extreme High Water Level (feet, NAVD88) | Corresponding Return Period (years) |
|---|---|---|
| June 25-27, 2006 | 3.43 | <2 |
| July 8, 2019 | 1.96 | <2 |

All values at Washington DC tide station

# 4. Scenarios for Flood Modeling

Rainfall-driven flood modeling (interior and riverine) performed in Task 3.3 requires precipitation depth and, depending on the watershed, downstream (coastal) water elevation (tide and extreme water level combined). Coastal flood modeling performed in Task 3.4 requires tide and extreme water level. There are numerous combinations of precipitation and high water level scenarios for the baseline condition, and the number of potential scenarios greatly expands when a range of potential future climate conditions is considered.

Ten combinations of precipitation and water level are presented in Table 14 to serve as inputs for interior and riverine flood modeling (Task 3.3). Scenario 1, the observed event from July 8, 2019 was selected because it is a recent short duration flood event for which model results can readily be compared to observed flooding. Also, for the initial volume-based screening level modeling using Flood Modeller FAST, the June 2006 event is quite similar to the 100-year event volume, and thus duplicative of Scenario 3. Scenarios 3 and 4 were selected with high return periods (100-year and 500-year, respectively) for both the precipitation and extreme water level. While it is unlikely for both the 100-year precipitation and 100-year extreme water level to occur concurrently, this combination is recommended as a conservative representation of flood conditions.

Six future water level scenarios are presented in Table 15 to serve as inputs for coastal flood modeling (Task 3.4).

**Table 15. Recommended Scenarios for Interior and Riverine Flood Modeling (Task 3.3)**

| Scenario | Planning Horizon | Precipitation Scenario [a] | 24-hr Precipitation Amount (inches) | Extreme Water Level (feet, NAVD88) | SLR (feet) | Extreme Water Level + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Observed Event: July 8, 2019 | Current Conditions | AG4JW Arlington Station | 3.32 (in 2.5 hours) | Observed | None | 1.96 |
| 2. Baseline: 10-year | Current Conditions | Updated Baseline IDF | 5.16 | 10-year 5.8 | None | 5.8 |
| 3. Baseline: 100-year | Current Conditions | Updated Baseline IDF | 8.48 | 100-year 10.5 | None | 10.5 |

**Table 15. Recommended Scenarios for Interior and Riverine Flood Modeling (Task 3.3)**

| Scenario | Planning Horizon | Precipitation Scenario [a] | 24-hr Precipitation Amount (inches) | Extreme Water Level (feet, NAVD88) | SLR (feet) | Extreme Water Level + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 4. Baseline: 500-year | Current Conditions | Updated Baseline IDF | 11.47 | 500-year 15.4 | None | 15.4 |
| 5 | 2040 | RCP 8.5, 50%, 10-year | 5.49 | 10-year 5.8 | Int-High 1.86 | 7.66 |
| 6 | 2040 | RCP 8.5, 50%, 100-year | 9.04 | 100-year 10.5 | Int-High 1.86 | 12.36 |
| 7 | 2040 | RCP 8.5, 50%, 500-year | 12.21 | 500-year 15.4 | Int-High 1.86 | 17.26 |
| 8 | 2070 | RCP 8.5, 50%, 10-year | 5.81 | 10-year 5.8 | Int-High 3.86 | 9.66 |
| 9 | 2070 | RCP 8.5, 50%, 100-year | 9.57 | 100-year 10.5 | Int-High 3.86 | 14.36 |
| 10 | 2070 | RCP 8.5, 50%, 500-year | 12.94 | 500-year 15.4 | Int-High 3.86 | 19.26 |

[a] All storms are based on the 24-hour SCS Type II distribution except for the observed events.

**Table 16. Recommended Scenarios for Coastal Flood Modeling (Task 3.4)**

| Scenario | Tide Scenario | Extreme Water Level (feet, NAVD88) | Planning Horizon | SLR Scenario | SLR Value (feet) | Extreme Water Level + SLR (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Baseline: 100-year | 100-year | 10.5 | Current Conditions | None | 0 | 10.5 |
| 2. Baseline: 500-year | 500-year | 15.4 | Current Conditions | None | 0 | 15.4 |
| 3 | 100-year | 10.5 | 2040 | Int-High | 1.86 | 12.36 |
| 4 | 500-year | 15.4 | 2040 | Int-High | 1.86 | 17.26 |
| 5 | 100-year | 10.5 | 2070 | Int-High | 3.86 | 14.36 |
| 6 | 500-year | 15.4 | 2070 | Int-High | 3.86 | 19.26 |

# 5. References

Bonnin, G. M., D. Martin, B. Lin, T. Parzybok, M. Yekta, D. Riley. 2006. NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 2 Version 3.0: Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia. https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas2_Volume2.pdf

CLIMsystems. 2018. *SimCLIM 4.0 Data Manual*. April 13. http://documents.climsystems.com/SimCLIM%204.0/SimCLIM%204.0%20for%20Desktop%20Data%20Manual.pdf

Federal Emergency Management Agency (FEMA). 2010. Flood Insurance Study for the District of Columbia, Washington D.C. Revised September 27.

Hogg, W.D. & V.R. Swail. 2007: Effects of distributions and fitting techniques on extreme value analysis of modelled wave heights. (Downloaded from Google Scholar, March 2007).

Hosking, J.R.M. 1996. "Fortran Routines for Use with the Method of L-Moments," Research Report, IBM Research Division, Yorktown Heights, NY.

Hosking, J.R.M., and J. R. Wallis. 1997. *Regional Frequency Analysis an Approach Based on L-Moments*. Cambridge University Press, Cambridge, U.K. 20

International Panel on Climate Change (IPCC). 2013. Summary for Policymakers. In Climate Change 2013 The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (editors, Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Meinshausen, M., *et al.* (November 2011), "The RCP greenhouse gas concentrations and their extensions from 1765 to 2300 (open access)", *Climatic Change* 109 (1-2) 213–241, doi10.1007/s10584-011-0156-z.

MIKE by DHI. (2020). MIKE Extreme Value Analysis (EVA) module, user manual.

National Centers for Environmental Information (NCEI). 2020. Global Historical Climate Network – Daily. Accessed for 5 stations on June 17, 2020. https://www.ncdc.noaa.gov/ghcn-daily-description.

National Oceanic and Atmospheric Administration (NOAA). 2017. Global and Regional Seal Level Rise Scenarios for the United States. Technical Report NOS CO-OPS 083. January. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

National Oceanic and Atmospheric Administration (NOAA). 2020. Tide station data for Washington DC tide station. https://tidesandcurrents.noaa.gov/map/index.html. Accessed July 16, 2020.

Perica, S., D. Martin, S. Pavlovic, I. Roy, M. St. Laurent, C. Trypaluk, D. Unruh, M. Yekta, G. Bonnin. 2013. NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. Volume 9 Version 2.0: Southeastern States (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi) https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume9.pdf.

Santer, B.D., T.M.L. Wigley, M.E. Schlesinger, and J.F.B. Mitchell. 1990. Developing Climate Scenarios from Equilibrium GCM results. Report No. 47, Max-Planck-Institut-für-Meteorologie, Hamburg, 29 pp.

University of Utah. 2020. MesoWest Climatologial Data. https://mesowest.utah.edu/. Accessed July 7, 2020.

US Army Corps of Engineers (USACE). 2014. North Atlantic Coast Comprehensive Study Phase I: Statistical Analysis of Historical Extreme Water Levels with Sea Level Change. September.

US Army Corps of Engineers (USACE). 2019. Sea-Level Change Curve Calculator (Version 2019.21). http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html. Accessed July 16, 2020.

# Appendix A
# L-Moment Regional Method

# Appendix A. L-Moment Regional Method

Regional flood frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional flood frequency analysis involves (1) screening of data, (2) partitioning of data into homogeneous sub-regions, and (3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The L-moments package (Hosking, 1996; Hosking and Wallis, 1997) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-moment method. L-moments have been shown in various Monte Carlo studies (e.g., Delicado and Goria, 2008) to outperform other estimation methods, such as the method of moments and method of maximum likelihood, in terms of bias and robustness. The L-moments package (Hosking, 1996) was used to perform the frequency analysis of the precipitation data in this study.

The annual maximum precipitation data for various durations were fitted to selected frequency distributions, using L-moments to estimate the distribution parameters. In the L-moment method, a regional frequency curve is obtained by averaging the slopes of the station frequency curves in a given homogeneous region. L-moments are analogous to ordinary moments in that the purpose is to summarize theoretical probability distributions and observed samples. Because L-moments are computed as linear combinations of the ranked observations (instead of squaring and cubing the observations), they are subject to less variability in small samples than ordinary moments (Hosking, 1990).

The sample L-moments or sample L-moment ratios needed to describe the frequency distributions and apply various statistical tests incudes

$l_1$ = first L-moment, measure of location (mean)

$l_2$ = second L-moment, measure of scale (dispersion)

$l_2/l_1$ = L coefficient of variation (L-CV)

$l_3$ = third L-moment

$l_4$ = fourth L-moment

$l_3/l_2$ = measure of skewness (L skewness)

$l_4/l_2$ = measure of kurtosis (L kurtosis)

Regionalization involves forming clusters of subregions from the entire data set based on site characteristics. The primary goal is to choose site characteristics that best capture the relevant indicators upon which climatological homogeneity can be predicated.

After the initial formation of subregions, the next goal is to ascertain that the sites within the tentative sub-regions can reasonably be assumed to be homogeneous. The L-moments package incorporates three tests for homogeneity

- H1 – the weighted standard deviation of the sample L-CVs
- H2 – the average distance from the site to the regional average on a graph of L-CV vs. L skewness
- H3 – the average distance from the site to the regional average on a graph of L skewness vs. L kurtosis

These compare the between-site variations in sample L-moments for sites in a subregion. The use of only one of the three options is often adequate. A subregion is acceptably homogeneous if $H < 1$, likely heterogeneous if $H > 1$, and most likely heterogeneous if $H > 2$. These thresholds are based on expert judgment but are not definitive. Several adjustments are required when a given subregion is not homogenous. The options include moving sites between subregions, deleting sites from the data set, subdividing subregions and merging sub-regions. The three tests noted above were used in defining homogeneous regions for this analysis.

## Fitting Frequency Distributions

Given homogeneous regions, the objective is to find the regional frequency distributions that, on average, describe the observations at each site. The L-moments package fits sample data to the following three-parameter (location, scale, and skewness) frequency distributions

- Generalized Logistic
- Generalized Extreme Value
- Generalized Normal
- Pearson Type III
- Generalized Pareto

The goodness-of-fit is quantified using test statistics internal to the L-moments package at a 90-percent confidence level (implying only a 10-percent chance of choosing an erroneous distribution). More details on the goodness-of-fit test are provided by Hosking (1990), Hosking (1996), and Hosking and Wallis (1997).

# Appendix B
# Results of XTEST Station Discordancy and Heterogeneity Test

# Appendix B. Results of XTEST Station Discordancy and Heterogeneity Test

## Discordancy Results

Discordancy is used to assist in identifying those sites whose L-moment ratios (variability, skewness, and kurtosis) are markedly different relative to L-moment ratios for the stations used in the analysis. The discordancy value is a measure of data quality and homogeneity that can be used to identify stations containing questionable data.

The following results were generated by the L-moments XTEST software. They show the results of the station discordancy test for each of the six stations used for the IDF analysis. Hosking and Wallis suggest the formula $D(I) \leq (N-1)/3$ provides the threshold for a discordancy based on the number of stations used for the analysis (N).

Solving the equation for the seven stations used in this project yields a threshold value of 2.0, which is higher than the discordancy station values shown in the XTEST analysis, meaning that all stations passed.

```
SITE N NAME L-CV L-SKEW L-KURT D(I)

1 65 Warrenton US 0.2059 0.3386 0.2974 1.72

2 43 Sterling USC 0.2125 0.2619 0.1557 0.89

3 56 Plains USC00 0.2369 0.2824 0.2184 1.10

4 78 Vienna USC00 0.2148 0.2337 0.1709 0.09

5 75 Reagan USW00 0.2169 0.1935 0.1034 0.81

6 103 Quantico USW 0.2128 0.1685 0.1577 1.36

7 63 Washington D 0.2344 0.3510 0.2470 1.04

WEIGHTED MEANS 0.2184 0.2511 0.1887

PARAMETERS OF REGIONAL KAPPA DISTRIBUTION 0.8046 0.2751 -0.1263 -0.0177
```

## Heterogeneity Results

A subregion is acceptably homogeneous if values of H are less than 1. Each of the H values are less than one, so the subregion selected for this analysis is homogeneous.

```
***** HETEROGENEITY MEASURES *****
(NUMBER OF SIMULATIONS = 1000)

OBSERVED S.D. OF GROUP L-CV = 0.0103
SIM. MEAN OF S.D. OF GROUP L-CV = 0.0198
SIM. S.D. OF S.D. OF GROUP L-CV = 0.0060
STANDARDIZED TEST VALUE H(1) = -1.58

OBSERVED AVE. OF L-CV / L-SKEW DISTANCE = 0.0599
SIM. MEAN OF AVE. L-CV / L-SKEW DISTANCE = 0.0554
SIM. S.D. OF AVE. L-CV / L-SKEW DISTANCE = 0.0154
STANDARDIZED TEST VALUE H(2) = 0.29
```

```
OBSERVED AVE. OF L-SKEW/L-KURT DISTANCE = 0.0808
SIM. MEAN OF AVE. L-SKEW/L-KURT DISTANCE = 0.0710
SIM. S.D. OF AVE. L-SKEW/L-KURT DISTANCE = 0.0181
STANDARDIZED TEST VALUE H(3) = 0.54


***** GOODNESS-OF-FIT MEASURES *****
(NUMBER OF SIMULATIONS = 1000)

GEN. LOGISTIC L-KURTOSIS= 0.219 Z VALUE= 1.17 *
GEN. EXTREME VALUE L-KURTOSIS= 0.187 Z VALUE= -0.27 *
GEN. NORMAL L-KURTOSIS= 0.172 Z VALUE= -0.94 *
PEARSON TYPE III L-KURTOSIS= 0.145 Z VALUE= -2.16
GEN. PARETO L-KURTOSIS= 0.108 Z VALUE= -3.82


PARAMETER ESTIMATES FOR DISTRIBUTIONS ACCEPTED AT THE 90% LEVEL

GEN. LOGISTIC 0.913 0.196 -0.251
GEN. EXTREME VALUE 0.802 0.278 -0.123
GEN. NORMAL 0.903 0.346 -0.522
WAKEBY 0.420 1.457 6.262 0.363 0.045

QUANTILE ESTIMATES
0.010 0.020 0.050 0.100 0.200 0.500 0.900 0.950 0.990 0.999
GEN. LOGISTIC 0.377 0.425 0.504 0.581 0.683 0.913 1.489 1.769 2.611 4.563
GEN. EXRME VAL 0.415 0.453 0.517 0.582 0.673 0.906 1.521 1.796 2.517 3.818
GEN. NORMAL 0.438 0.468 0.522 0.581 0.668 0.903 1.534 1.803 2.471 3.562
WAKEBY 0.438 0.455 0.502 0.570 0.676 0.905 1.532 1.815 2.507 3.588


ALL DATA PROCESSED
```

# Appendix C
# Annual Maxima Series and Partial Duration Series

# Appendix C. Annual Maxima Series and Partial Duration Series

NOAA developed Atlas 14 IDF curves separately for Annual Maxima Series (AMS) and Partial Duration Series (Bonnin, et al. 2006). AMS and PDS precipitation depths are generally similar for low frequency events (>10-year return period); for more frequent events (< 10-year return period) PDS precipitation depths are higher than AMS. Analysis that uses more frequent events should use PDS values as a more realistic representation of these types of events. Final results for the analysis in this memorandum are presented as PDS depths. However, because direct comparison between updated IDF curves and NOAA Atlas 14 is best conducted using AMS, and in order to maintain consistency with future IDF curves developed using SimCLIM and AMS methods, all updated and future IDF curve analysis was conducted as AMS, and then converted to PDS. Conversion of AMS IDF curves to PDS IDF curves (as opposed to direct calculation of PDS curves) was performed in later volumes of NOAA Atlas 14; for instance, Volume 9 converts AMS to PDS using the Langbein formula (Perica et al., 2013).

For this analysis, AMS statistics were converted to PDS statistics using ratios of PDS to AMS from Atlas 14 Volume 2, specific to individual durations, and frequency, as shown for 24-hour durations in the table below. PDS to AMS ratios are generally similar for all stations, and for all durations (the 2-year 5-minute PDS to AMS ratio is similar to the 2-year 7-day ratio).

**PDS to AMS Rations – 24 Hour**

| Station Name | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year |
|---|---|---|---|---|---|---|---|
| Vienna | 1.09 | 1.02 | 1.01 | 1.00 | 1.00 | 1.00 | 1.01 |

# Appendix D
# SimCLIM Daily General Circulation Models

# Appendix D. SimCLIM Daily General Circulation Models

Thirty-One SimCLIM daily GCMs were used for precipitation IDF estimates (CLIMsystems, 2018).

**SimCLIM daily general circulation models used for precipitation intensity, duration, and frequency estimates.**

| No | Name | Country |
|---|---|---|
| **1*** | ACCESS1.0 | Australia |
| **2** | ACCESS1-3 | Australia |
| **3*** | bcc-csm1-1 | China |
| **4*** | BNU-ESM | China |
| **5** | CanESM2 | Canada |
| **6** | CCSM4 | United States |
| **7** | CESM1-BGC | United States |
| **8** | CMCC-CM | Italy |
| **9** | CMCC-CMS | Italy |
| **10** | CNRM-CM5 | France |
| **11** | CSIRO-Mk-3-6 | Australia |
| **12*** | GDFL-CM3 | United States |
| **13** | GFDL-ESM2G | United States |
| **14** | GFDL-ESM2M | United States |
| **15*** | GISS-E2-H | United States |
| **16*** | GISS-E2-R | United States |
| **17*** | HADGEM2-AO | United Kingdom |
| **18*** | HADGEM2-CC | United Kingdom |
| **19** | HADGEM2-ES | United Kingdom |
| **20** | INMCM4 | Russia |
| **21** | IPSL-CM5A-LR | France |
| **22** | IPSL-CM5A-MR | France |
| **23** | IPSL-CM5B-LR | France |
| **24** | MIROC5 | Japan |
| **25** | MIROC-ESM | Japan |
| **26** | MIROC-ESM-CHEM | Japan |
| **27** | MPI-ESM-LR | Germany |
| **28** | MPI-ESM-MR | Germany |

| No | Name | Country |
|---|---|---|
| **29** | MRI-CGCM3 | Japan |
| **30** | NorESM1-M | Norway |
| **31** | EC-EARTH | European Community |

*Added in SimCLIM Version 4

# Appendix E
# Daily GCM Extreme Value Analysis Methodology

# Appendix E. Daily GCM Extreme Value Analysis Methodology

## General Circulation Models Pattern Preparation

The following method is used to analyze climate change impact on extreme precipitation events, using daily GCM outputs at their original spatial resolution (i.e., not downscaled). The steps of such a method are listed below

1) Build a GEV distribution for one GCM baseline period (1981 to 2000 or 1980 to 1999) daily data and calculate its extreme precipitation intensity values for seven selected return periods (2, 5, 10, 25, 50, 100, and 500-year).
2) Build GEV distribution for the above GCM based on its future daily data (2050 and 2070). Select two emissions scenarios (RCPs) RCP 6.0 and RCP 8.5 available from IPCC AR5 data archive. Calculate its extreme precipitation intensity values for the selected return periods as baseline period.
3) Calculate the difference in percentage of the extreme precipitation intensity values of between baseline and each future period.
4) Calculate the annual global average mean temperature change between the future periods and its baseline for the above GCM.
5) Normalize the extreme precipitation changes by using linear least square regression method using following equation

$$\Delta V'_{ij} = \frac{\sum_{y=1}^{m} \Delta T_y \cdot \Delta V_{yij}}{\sum_{y=1}^{m} (\Delta T_y)^2}$$

$\Delta V'_{ij}$ the normalized change value a grid cell (*i*) and return period (*j*); $\Delta V_{yij}$ is the change percentage for $\Delta T_y$ for global mean temperature change for future period *y*; *m* is the number of future sample periods used.

A bi-linear interpolation method is used to obtain a finer scale extreme precipitation change pattern at the required spatial resolution. By applying the change pattern generated from daily GCM data for extreme precipitation event analysis for the study region

1) Build GEV distribution from data of the study region and calculate the extreme precipitation values for selected return periods.
2) Extract the change pattern values from global change patterns generated in step 6.
3) Obtain the global average mean temperature change for the selected study time slices (2050, 2070) and GHG emission scenarios (RCP 6.0, RCP 8.5) in mid climate sensitivity from SimCLIM.
4) Calculate the extreme precipitation values by calculating the change patterns with global mean temperature using following equation

$$P_1 = P_o \cdot (1 + \Delta P/100 \times \Delta GMT_1)$$

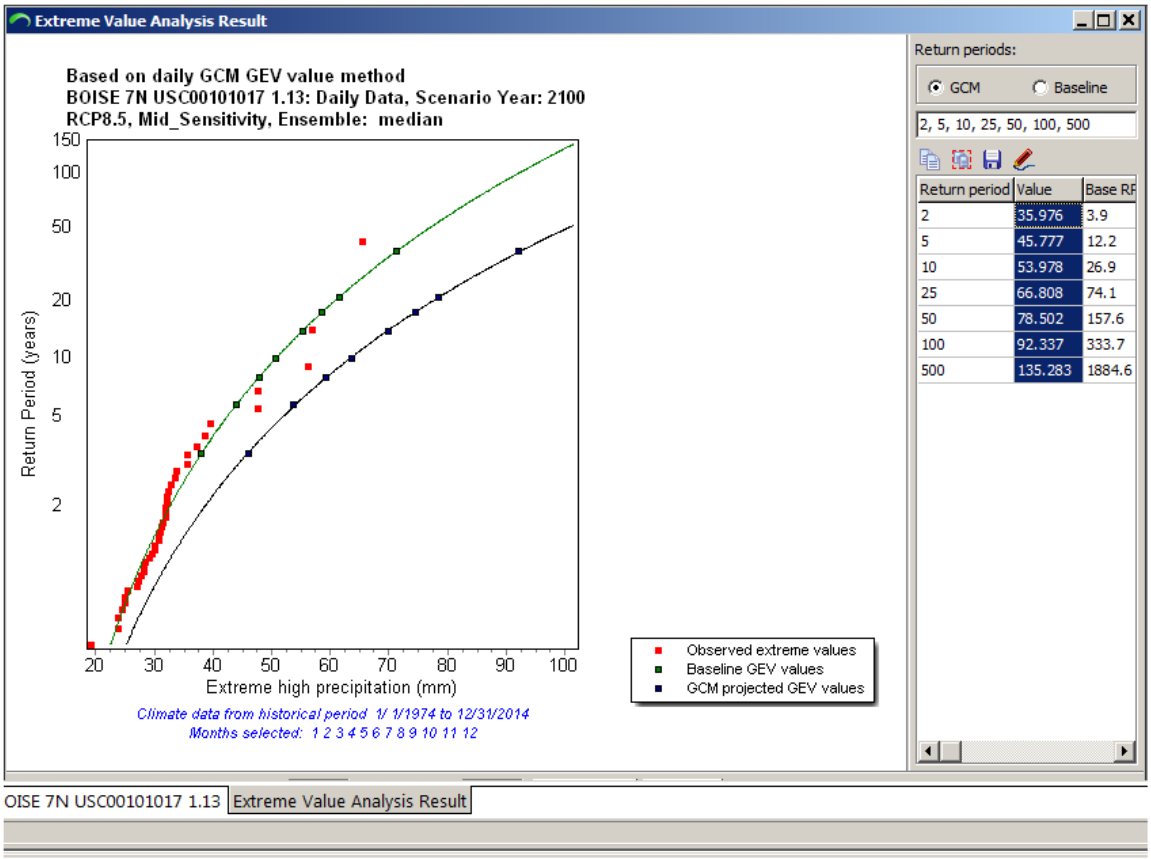
$P_1$ and $P_0$ represent the future and baseline extreme precipitation; $\Delta P$ is the change percentage generated from GCM data; *ΔGMT*, the scalar, is the change of global mean temperature increase in a future time slice.

## Generalized Extreme Value Process

The following steps assume that the local to global relationships outlined above have been performed.

1) From the observed time-series, extract the yearly maxima.
2) Fit a GEV curve.
3) The curve gives the extreme values for defined return periods (5, 10, 15, 20, 30, 40, 50, 100, 150, 200 and 300).
4) From the GCMs that produce daily projections, global patterns were extracted that contain the normalized (percent change per degree of global warming) change in the extreme event for these 11 return periods.
5) The model (or ensemble) change (from the normalized value, times the global mean temperature increase from the combination of RCP, climate sensitivity and year) is applied to the extreme values of the fitted curve (from step 2).
6) A new curve is fitted to these (climate changed) extremes.

An example of the GEV process is shown below with the following description. The red dots (in both graphs) are the observations (the highest value from each year). The green line is the GEV curve fitted through these observations (thus corresponding to the baseline – no climate change). The green dots correspond to the extreme values from the curve for the 11 specific return-periods. The blue dots correspond to the climate changed extremes for these return periods (constructed from the normalized patterns for the 30 models) (the blue dots are the climate changed green dots). The blue line corresponds to the GEV-curve fitted through these blue dots.



# Appendix B
# Arlington Interior and Riverine Flooding Technical Memorandum

ARLINGTON
VIRGINIA

Jacobs

# Flood Risk Assessment and Management Plan (RAMP)

## Arlington Interior and Riverine Flooding Report (Task 3.3)

Final

July 2021

Arlington County, Virginia

# Flood Risk Assessment and Management Plan (RAMP)

| | |
|---|---|
| Project No: | E5X65609 |
| Document Title: | Arlington Interior and Riverine Flooding Report (Task 3.3) |
| Revision: | 0 |
| Date: | July 2, 2021 |
| Client Name: | Arlington County, Virginia |
| Project Manager: | Laurens van der Tak |
| Authors: | Cheri Salas, Megan Dever, Elise Ibendahl, Megan Daubenmier, and Sayedul Choudhury (STI) |
| File Name: | RAMP_ModelingReport_REV3 |

Jacobs Engineering Group Inc.

2551 Dulles View Drive
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

# Executive Summary

## Purpose

Arlington County, Virginia (the County) initiated a study to support the Flood Risk Assessment and Management Plan (RAMP) in May 2020. This report documents the development of 13 interior and riverine flooding models to accurately represent flooding under existing conditions and projected future conditions in priority watersheds in Arlington County. Models developed in this task were used to project Arlington County flooding under Years 2040 and 2070 climate conditions. The flood modeling results will be used in subsequent tasks to support vulnerability assessments, flood risk, and alternatives analysis.

### Methods

Modeling was conducted in three steps, with an increasing level of detail for selected watersheds. In a first step, Flood Modeller FAST was developed and applied with two storm scenarios, the observed rainfall from the July 8, 2019 storm and a synthetic 100-year, 24-hour rainfall event. The 2D FAST solver is a "reduced physics" simplified model of 2D overland flooding but does not include storm drainage pipe network below ground. The FAST model was applied initially to all 36 county watersheds. This step was used to prioritize watersheds for detailed 1D/2D modeling of belowground pipe network and surface drainage channels, with surface overland flow modeling. Eight watersheds were prioritized for detailed 1D/2D modeling using Personal Computer Stormwater Management Model (PCSWMM), while five watersheds were identified for additional FAST modeling. Figure ES-2 identifies the eight watersheds with detailed modeling and five with refined FAST modeling.

Detailed models included pipes up to 30 inches or larger in Four Mile Run sheds and 36 inches or larger in other modeled sheds. Models were updated as appropriate and where possible based on available as-built drawings and updated geographic information system (GIS) data from the County, as documented in this report. Model results were validated by comparison of model extents to reported flood calls.

Ten modeling scenarios were analyzed with the models, as listed in Table ES-1. Boundary conditions were established at the downstream end of each model based on either coastal model results from the Four Mile Run Northern Virginia Regional Commission models or the separate coastal modeling task results (Jacobs 2020b).

**Table ES-1. Modeled Scenarios for Interior and Riverine Flood Modeling**

| Scenario | 24-hour Precipitation Amount (inches) | Sea Level Rise (feet) |
|---|---|---|
| 1. Observed Event: July 8, 2019 | 3.32 (in 2.5 hours) | None |
| 2. Baseline: 10-year | 5.16 | None |
| 3. Baseline: 100-year | 8.48 | None |
| 4. Baseline: 500-year | 11.47 | None |
| 5. 2040: 10-year | 5.49 | Int-High 1.86 |
| 6. 2040: 100-year | 9.04 | Int-High 1.86 |
| 7. 2040: 500-year | 12.21 | Int-High 1.86 |
| 8. 2070: 10-year | 5.81 | Int-High 3.86 |
| 9. 2070: 100-year | 9.57 | Int-High 3.86 |
| 10. 2070: 500-year | 12.94 | Int-High 3.86 |

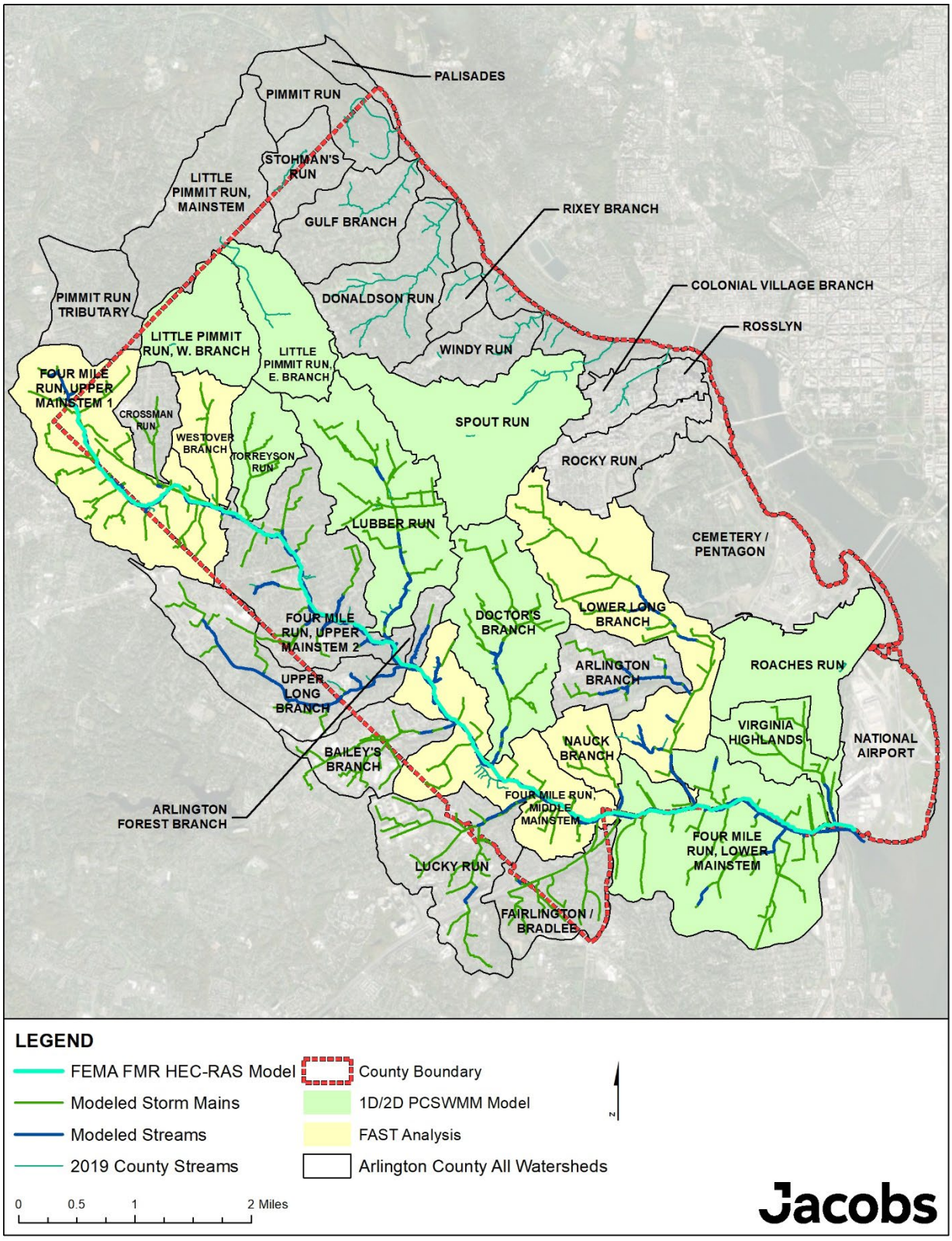



**Figure ES-1. Arlington County Watershed Modeling Overview**

**Results**

Flood mapping results were provided to the County in two separate formats, a GIS geodatabase, as well as eight layered PDF files, one for each of the watersheds with detailed PCSWMM modeling. The GIS data include both the PCSWMM and FAST modeling results.

A preliminary GIS analysis was conducted of the flood modeling results to quantify the extent of flooded area for each watershed, for the three different return frequency storms under current and future conditions. Figure ES-2 and Figure ES-3 provide graphic summaries of the percent of each watershed area that is flooded and the total area flooded for the 100-year storm. Similar figures are included in this report for all three return frequency storms.

Other than Lower Four Mile Run, no single watershed stands out as the most or least problematic across all storm events. General observations are as follows:

- Based on total flooded area and percent flooded area, the Lower Four Mile Run watershed has by far the largest flood extent for any storm recurrence interval or planning scenario, with 114 acres (25 percent) flooded for the 100-year event.
- On the basis of percentage area flooded, Lower Four Mile Run stands out for all scenarios, with as much as 7 percent flooded for the July 2019 event and 9.7 percent flooded for the 10-year, 24-hour events, increasing to as much as 32 percent flooded for the extreme scenario (500-year storm in 2070).
- On a percentage basis Virginia Highlands is second highest, ranging from 9.2 percent for the 100-year storm in 2020 to 20.5 percent for the extreme scenario.
- For the 100-year event, six of the eight watersheds are about 5 percent impacted, except for Virginia Highlands and Lower Four Mile Run, which are two to nearly four times higher.
- After Lower Four Mile Run, which is high, Lubber Run and Spout Run flood the most by area for the 500-year and 100-year events. Lubber Run is not as impacted as others by the 10-year event.
- Spout Run and Little Pimmit Run have the highest acres flooded for smaller storm events (10-year) and the July 2019 event (except Lower Four Mile Run, which is high).
- Virginia Highlands and Torreyson Run flood the most by percentage for 10-year event (except Lower Four Mile Run, which is high), but Torreyson Run is the least by acres because it is smaller.
- Roaches Run and Doctor's Branch flood the least by percentage for the 10-year and July 2019 events and has the least area of the larger three watersheds for these events. Relative to others, the impact increase by acre in Doctor's Branch increases for larger storm events.
- Little Pimmit Run floods the least by percentage for the 100-year and 500-year events and is the least in acres aside from Torreyson Run, which is small.

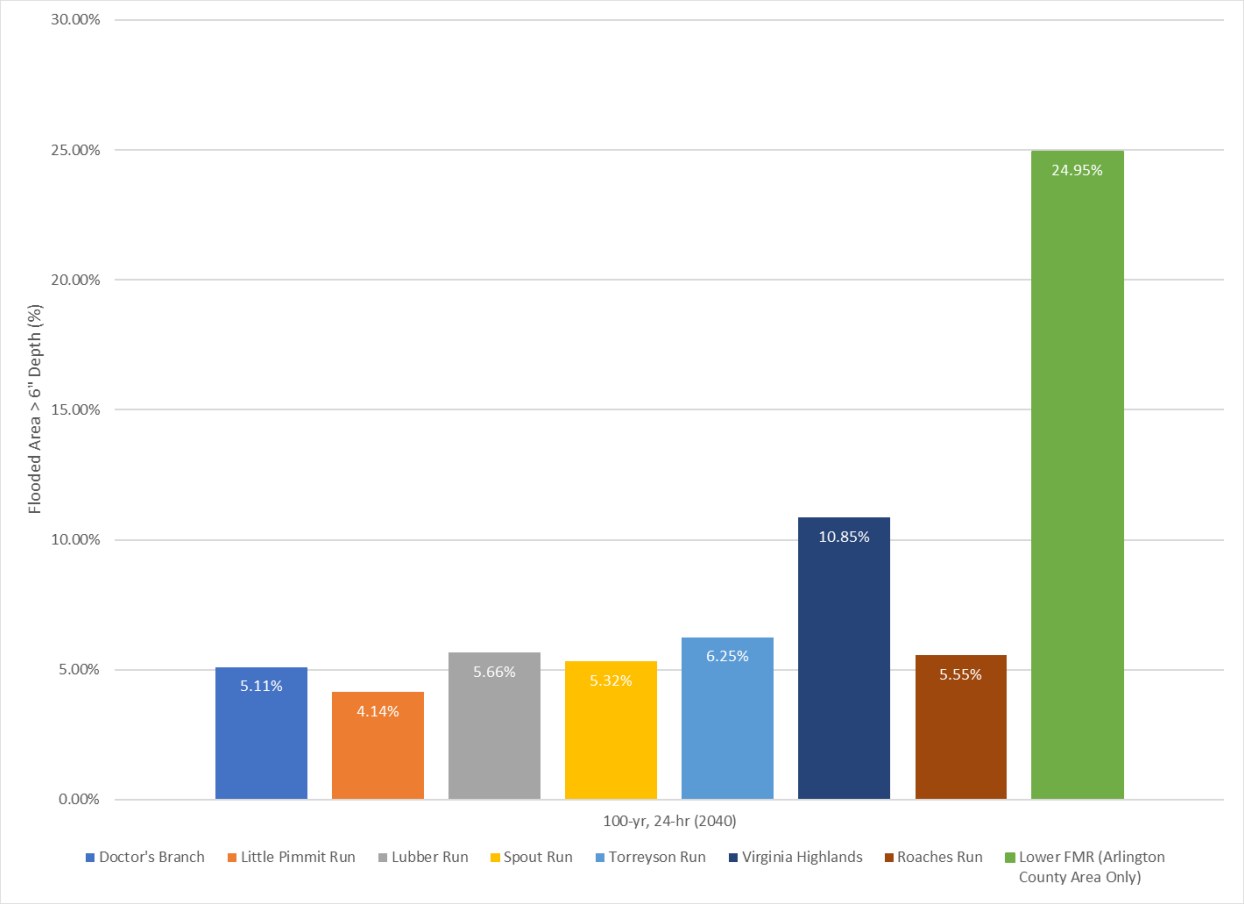



**Figure ES-2. Percent Flooded Values for 100-year, 24-hour (Year 2040) Storm Event**

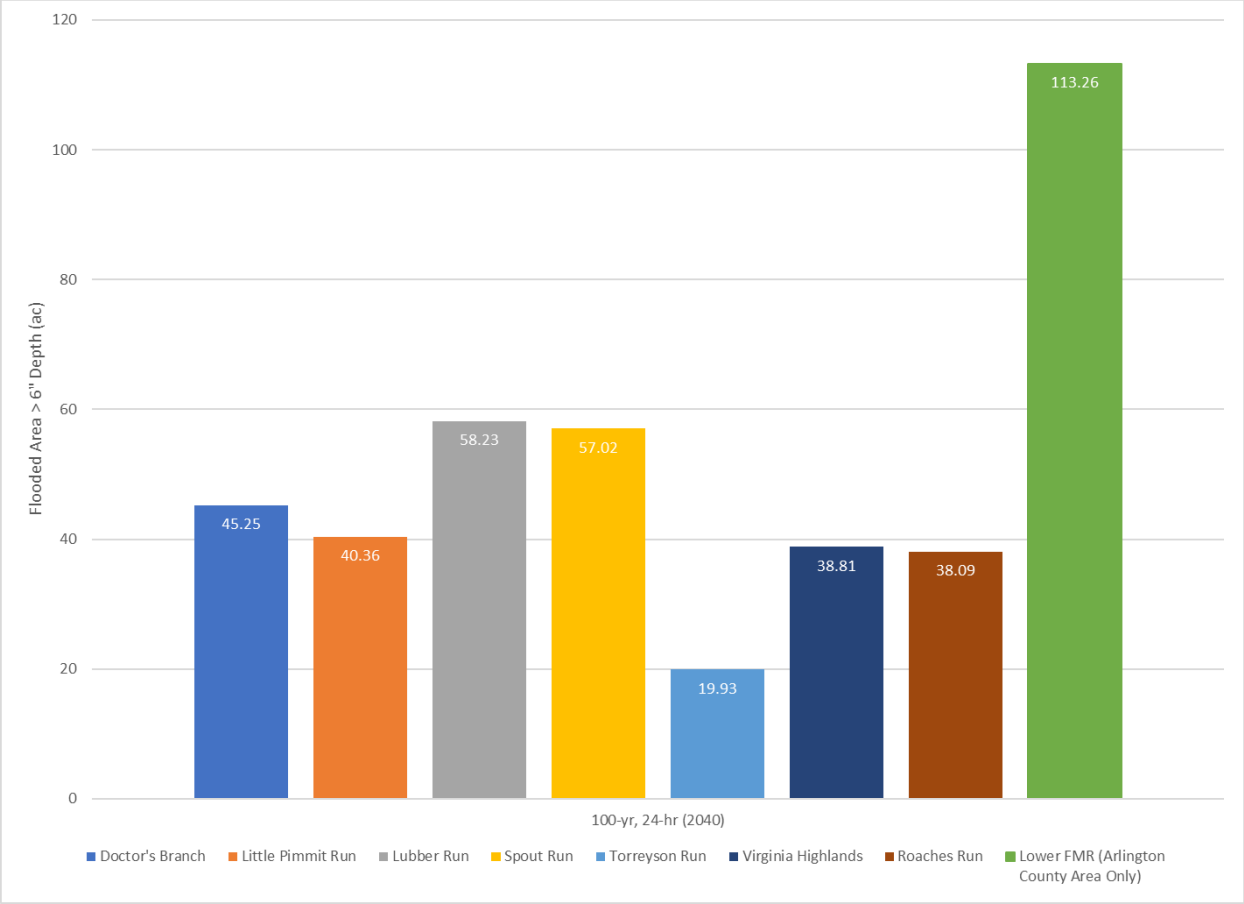



**Figure ES-3. Area Flooded Values for 100-year, 24-hour (Year 2040) Storm Event**

# Contents

**Executive Summary** ..... **ES-1**

**Acronyms and Abbreviations** ..... **iii**

**1. Introduction** ..... **1-1**
- 1.1 Project Purpose ..... 1-1
- 1.2 Background ..... 1-1
- 1.3 Scope of Modeling ..... 1-2

**2. Modeling Approach** ..... **2-1**
- 2.1 FAST Modeling ..... 2-1
  - 2.1.1 Screening Model ..... 2-2
  - 2.1.2 Refined Flood Modeller FAST Modeling ..... 2-2
- 2.2 PCSWMM Modeling ..... 2-2
  - 2.2.1 Approach ..... 2-2
  - 2.2.2 1D Model Elements ..... 2-4
  - 2.2.3 2D Model Surface Network ..... 2-5
  - 2.2.4 Model Comparison and Validation ..... 2-5
  - 2.2.5 Model Scenarios ..... 2-8

**3. Results and Conclusions** ..... **3-1**

**4. References** ..... **4-1**

**Appendices**

A Watershed Prioritization
B FAST Modeling
C Watershed Modeling Details
D Detailed Approach to 1D/2D PCSWMM Modeling
E Rainfall Distributions
F 1D/2D PCSWWM Modeling Downstream Boundary Conditions

**Tables**

ES-1 Modeled Scenarios for Interior and Riverine Flood Modeling ..... ES-1
1-1 Base Model Source ..... 1-1
2-1 Modeled Scenarios for Interior and Riverine Flood Modeling ..... 2-8
2-2 Downstream Boundary Condition Type & Location by Watershed ..... 2-9

**Figures**

ES-1 Arlington County Watershed Modeling Overview ..... ES-2
ES-2 Percent Flooded Values for 100-year, 24-hour (Year 2040) Storm Event ..... ES-4
ES-3 Area Flooded Values for 100-year, 24-hour (Year 2040) Storm Event ..... ES-5
1-1 Arlington County Watershed Modeling Overview ..... 1-3
2-1 FAST Modeling Surface Adjustments ..... 2-3
2-2 As-Built Model Update Locations ..... 2-6

2-3 Example 1D/2D PCSWMM July 2019 Event Validation Map ..... 2-7
2-4 Watershed Downstream Boundary Condition Summary ..... 2-10
3-1 Flooded Area Comparison (Percent) ..... 3-2
3-2 Flooded Area Comparison (Acres) ..... 3-3

# Acronyms and Abbreviations

| | |
|---|---|
| 1D | one-dimensional |
| 2D | two-dimensional |
| DEM | digital elevation model |
| FEMA | Federal Emergency Management Agency |
| ft | foot(feet) |
| GIS | geographic information system |
| HEC-RAS | Hydrologic Engineering Center – River Analysis System |
| NAVD88 | North American Vertical Datum of 1988 |
| NVRC | Northern Virginia Regional Commission |
| PCSWMM | Personal Computer Stormwater Management Model |
| RAMP | Risk Assessment Management Program |
| SLR | sea level rise |

# 1. Introduction

Arlington County, Virginia (the County) initiated a study to support the Stormwater Program Risk Assessment Management Plan (RAMP) in May 2020. Task 3.3 involved the development of 13 interior and riverine flooding models to accurately represent flooding under existing conditions and predict flooding under future condition scenarios in Arlington County. Modeling done for future conditions evaluation included performing model runs with the climate change-induced rainfall increase and sea level rise (SLR) scenarios developed in the Task 3.1 technical memorandum entitled *Climate Projections and Scenarios* (Jacobs 2020a). Models developed in this task were used to project Arlington County flooding under Years 2040 and 2070 climate conditions.

## 1.1 Project Purpose

The purpose of this task was to represent rainfall-driven flooding in Arlington County. This includes both flooding that occurs independent of an overflowing water body, such as overland relief of an existing storm sewer system when its capacity is exceeded, and flow in open channels from upstream hydrologic inputs that can overflow a river or stream bank.

Task 3.3 included the modeling of existing, 2040, and 2070 rainfall conditions for the 10-, 100-, and 500-year events along with the July 8, 2019 historical event. Specifically, this modeling was performed to determine which aboveground structures and facilities are at flooding risk for present and future climate conditions.

## 1.2 Background

Eight one-dimensional (1D)/two-dimensional (2D) Personal Computer Stormwater Management Models (PCSWMM; [CHI, n.d.]) were developed for this task, with 1D representing pipes and open channel flow linked to the 2D overland flow model. These models were based on previously developed storm drainage pipe models in these watersheds, as described in the following paragraphs.

A 10-year storm sewer capacity analysis was completed for several watersheds located in Arlington County in 2011-2012. The existing stormwater system at that time was modeled in PCSWMM and included closed conduits such as gravity storm drains 36 inches and greater in diameter, and drainage inlets and junctions such as roadside curb inlets, manholes, catch basins, and yard and grate inlets. These PCSWMM models were used as a basis for the 1D/2D PCSWMM interior and riverine models built for five of the watersheds studied in Task 3.3 and listed in Table 1-1.

1D PCSWMM models of Four Mile Run and its subwatersheds were developed for the Northern Virginia Regional Commission (NVRC), in coordination with Arlington County in 2018. These NVRC models were used as the base model for three of the 1D/2D PCSWMM interior and riverine models built in Task 3.3, as shown in Table 1-1. The NVRC models include storm sewers 30 inches and greater in diameter.

**Table 1-1. Base Model Source**

| Interior/Riverine Model | Base Model |
|---|---|
| Lubber Run | Arlington County Model |
| Spout Run | Arlington County Model |
| Little Pimmit Run | Arlington County Model |

**Table 1-1. Base Model Source**

| Interior/Riverine Model | Base Model |
|---|---|
| Torreyson Run | NVRC Model |
| Doctor's Branch | Arlington County Model |
| Four Mile Run, Lower Mainstem | NVRC Model and Preliminary FEMA HEC-RAS Model |
| Roaches Run | Arlington County Model |
| Virginia Highlands | NVRC Model |

FEMA = Federal Emergency Management Agency
HEC-RAS = Hydrologic Engineering Center – River Analysis System

FEMA developed a Hydrologic Engineering Center – River Analysis System (HEC-RAS) model for the Four Mile Run mainstem for FEMA's Preliminary Flood Study (September 2020). The preliminary FEMA HEC-RAS model for Four Mile Run, dated September 18, 2020, was used to determine downstream boundary conditions for those watersheds that outlet to Four Mile Run (Doctor's Branch, Lubber Run, and Torreyson Run). Cross sections from this model were also used to define the channel within the Four Mile Run, Lower Mainstem model. In addition to FEMA's internal quality control by its contractor, Arlington County and Streams Tech staff reviewed the FEMA HECRAS model, which had been shared by FEMA in early 2020. Any issues identified during the review were addressed by FEMA in their September 18, 2020 HEC-RAS model for Four Mile Run. Therefore, the model was adequately checked to ensure accurate flood predictions along the mainstem of Four Mile Run.

## 1.3 Scope of Modeling

Reduced physics modeling was performed using Flood Modeller with the 2D FAST engine to prioritize Arlington County's 36 watersheds for analysis (). Watersheds were prioritized for detailed modeling based on this FAST modeling and several other factors as noted in Section 2.1.1. Eight watersheds were selected for detailed 1D/2D modeling in the PCSWMM. Five additional watersheds were prioritized for further modeling using Flood Modeller's FAST analysis. The watershed prioritization is shown on Figure 1-1. Further details on watershed prioritization and selection are included in Section 2.1.1 and Appendix A.

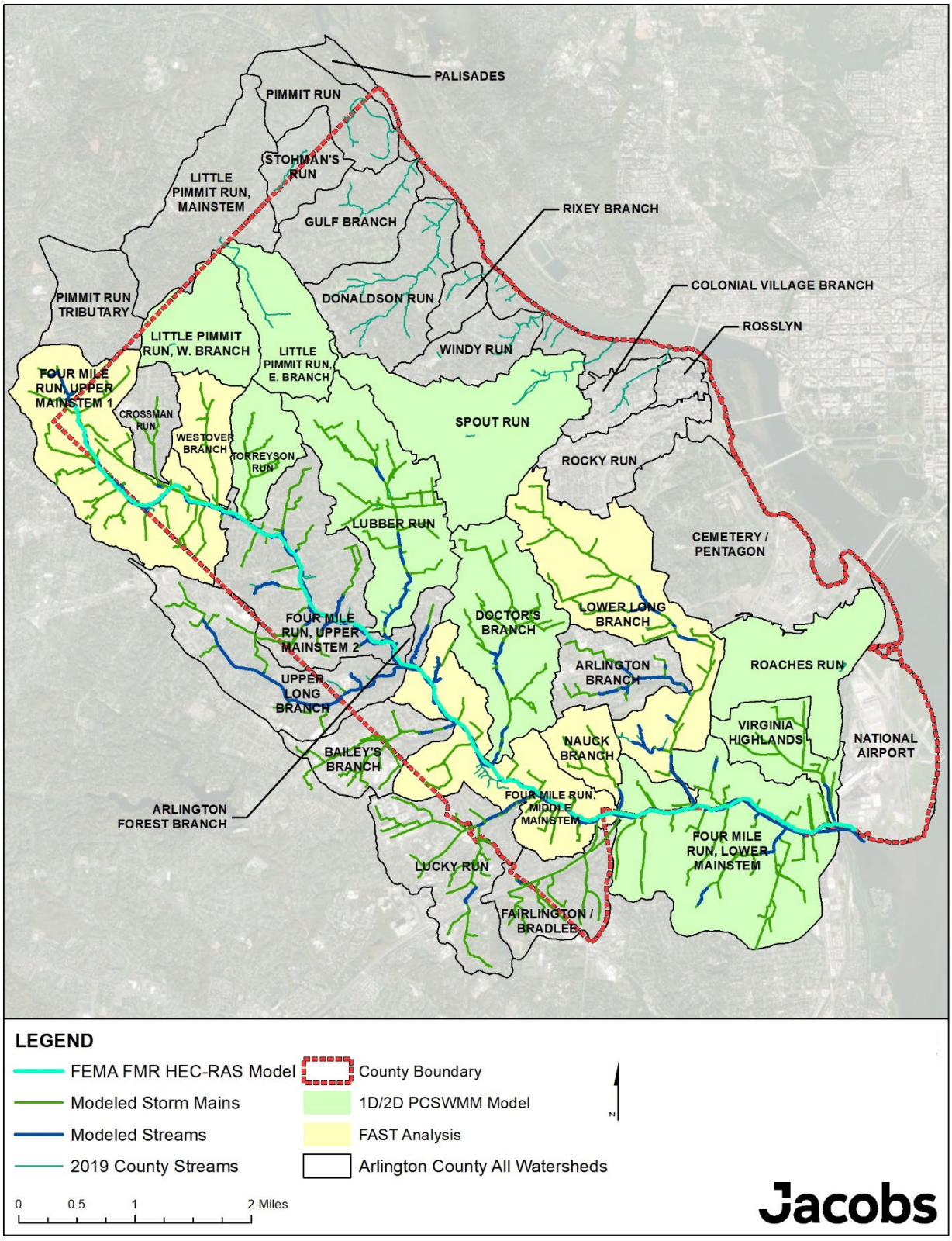



**Figure 1-1. Arlington County Watershed Modeling Overview**

# 2. Modeling Approach

Two different types of modeling were used: reduced physics modeling in Flood Modeller FAST and PCSWMM.

Flood Modeller FAST is a computational engine that routes water over the floodplain using a simple set of rules based on how water levels respond to the topography described in the digital elevation model (DEM). FAST works by preprocessing DEM data to identify depressional subcatchments in the ground surface. Applicable hydrological input data such as rainfall, inflow, and tidal/water level boundaries are then routed through the models to generate flood extent and depth results. This analysis does not provide a temporal resolution but rather an inundation extent based on the total volume of rainfall.

Flood Modeller's FAST analysis was used in two stages of the modeling approach. In the first stage of FAST modeling, the 100-year, 24-hour synthetic and the July 2019 historical rainfall events were run for all of Arlington County to prioritize which watersheds would be modeled in detail with PCSWMM, which would be modeled with additional climate scenarios using FAST analysis, and which would not undergo further scenario analysis. In Stage 2 of the FAST analysis, watersheds selected for continued modeling using FAST were further refined, although still using reduced physics analysis techniques and the FAST simulation engine.

For those watersheds selected for more detailed modeling in PCSWMM, the existing Arlington County and NVRC models were used as the backbone for the 1D/2D modeling effort, with some updates to reflect system modifications and newer information.

For the modeling of Four Mile Run, Lower Mainstem, the NVRC model containing all of Four Mile Run was truncated to just include the Lower Mainstem portion. Flow hydrographs from the upstream end of the Lower Mainstem and Lower Long Branch were taken from the NVRC 1D PCSWMM model and used as the upstream boundary conditions in the 1D/2D PCSWMM model for Four Mile Run, Lower Mainstem. Cross sections from the preliminary FEMA HEC-RAS model for Four Mile Run were used in the 1D/2D PCSWMM model developed for this RAMP project. The Roaches Run, Virginia Highlands, and Four Mile Run, Lower Mainstem 1D/2D PCSWMM models developed for this task were merged into one model for all modeled scenarios to properly model surface flooding as flood flows are exchanged across the watershed boundaries during some events. In addition to the flow exchange across watershed boundaries, the downstream boundary condition for Virginia Highlands is Four Mile Run, and the combined model assists in capturing this dynamic condition. The Roaches Run model can be run separately for smaller events when there is no flow exchange at the watershed boundaries. Model results suggest Roaches Run could be modeled separately for events smaller than a 10-year event.

Water surface elevations from the steady-state HEC-RAS model runs with NVRC 1D PCSWMM peak flows were used as boundary conditions for the Lubber Run, Doctor's Branch, and Torreyson Run 1D/2D PCSWMM models. The HEC-RAS model for the Four Mile Run mainstem was developed for FEMA's Preliminary Flood Study (September 2020).

## 2.1 FAST Modeling

FAST modeling provides an assessment of maximum flooding depths using simplified hydraulic principles to generate results up to 1,000 times more rapidly when compared to other tools and methods available for flood inundation simulations. The software works by first identifying depressions on the floodplain before routing water through these depressions. Water depths in the depressions are determined by volume of water flowing into that depression, level at which water can spill into neighboring depressions, and water level in neighboring depressions. FAST represents connectivity and volume filling effects on the floodplain without having to represent detailed hydraulics.

It must be noted that no subsurface pipe network is represented in the FAST model and therefore, it must be recognized this tool should not be considered a substitute for fully hydrodynamic models needed for high accuracy (or high risk) tasks such as required for detailed engineering design or mapping products. However, because of the rapid setup time and fast simulation speed, these tools can leverage available data to assist feasibility study work and planning of data collection process by identifying critical locations for assessment.

### 2.1.1 Screening Model

FAST modeling was performed for all 36 watersheds in Arlington County to support the selection of eight watersheds for detailed 1D/2D modeling in PCSWMM and five watersheds for further modeling with Flood Modeller's FAST process. Two rain events were modeled in this initial screening process: a 100-year, 24-hour synthetic rainfall event and the July 2019 historical event. A downstream boundary condition, representing the Potomac River, of 1.77 feet North American Vertical Datum of 1988 (NAVD88) (mean higher high water tidal level) and 1.96 feet NAVD88 were used for the synthetic and the historical event, respectively. Topographic data for the model were based on a DEM developed from the 2018 U.S. Geological Survey light detection and ranging dataset.

Once the screening model runs were complete, watersheds were prioritized based on the following criteria:

- Number of historical flood calls (2006, 2018, 2019)
- Observed high water marks (2019)
- Amount of FAST predicted flooding
- Extent of FEMA floodplain

The project team developed a final watershed prioritization after discussion with Arlington County staff as shown on Figure 1-1. More details on watershed prioritization are included in Appendix A.

### 2.1.2 Refined Flood Modeller FAST Modeling

For the detailed FAST modeling, surface adjustments were made to the topographic data within the five watersheds selected. These adjustments included editing at 16 culvert locations to represent existing conditions more accurately by adjusting the DEM ground surface to better represent channelized locations. The locations of these changes are shown on Figure 2-1.

Results from the refined FAST modeling are included in Appendix B.

## 2.2 PCSWMM Modeling

### 2.2.1 Approach

1D/2D PCSWMM models for Little Pimmit Run, Spout Run, Lubber Run, Doctors Branch, and Roaches Run were built on the foundation of existing Arlington County models for those watersheds. 1D/2D PCSWMM models for Torreyson Run, Virginia Highlands, and Four Mile Run, Lower Mainstem were built on existing 1D PCSWMM models originally developed for NVRC. General modeling assumptions and decisions for these eight watersheds are as follows:

- Closed conduit systems:
  - Conduits 30 inches in diameter and greater are included in Four Mile Run sheds.
  - Conduits 36 inches in diameter and greater are included in other modeled sheds.

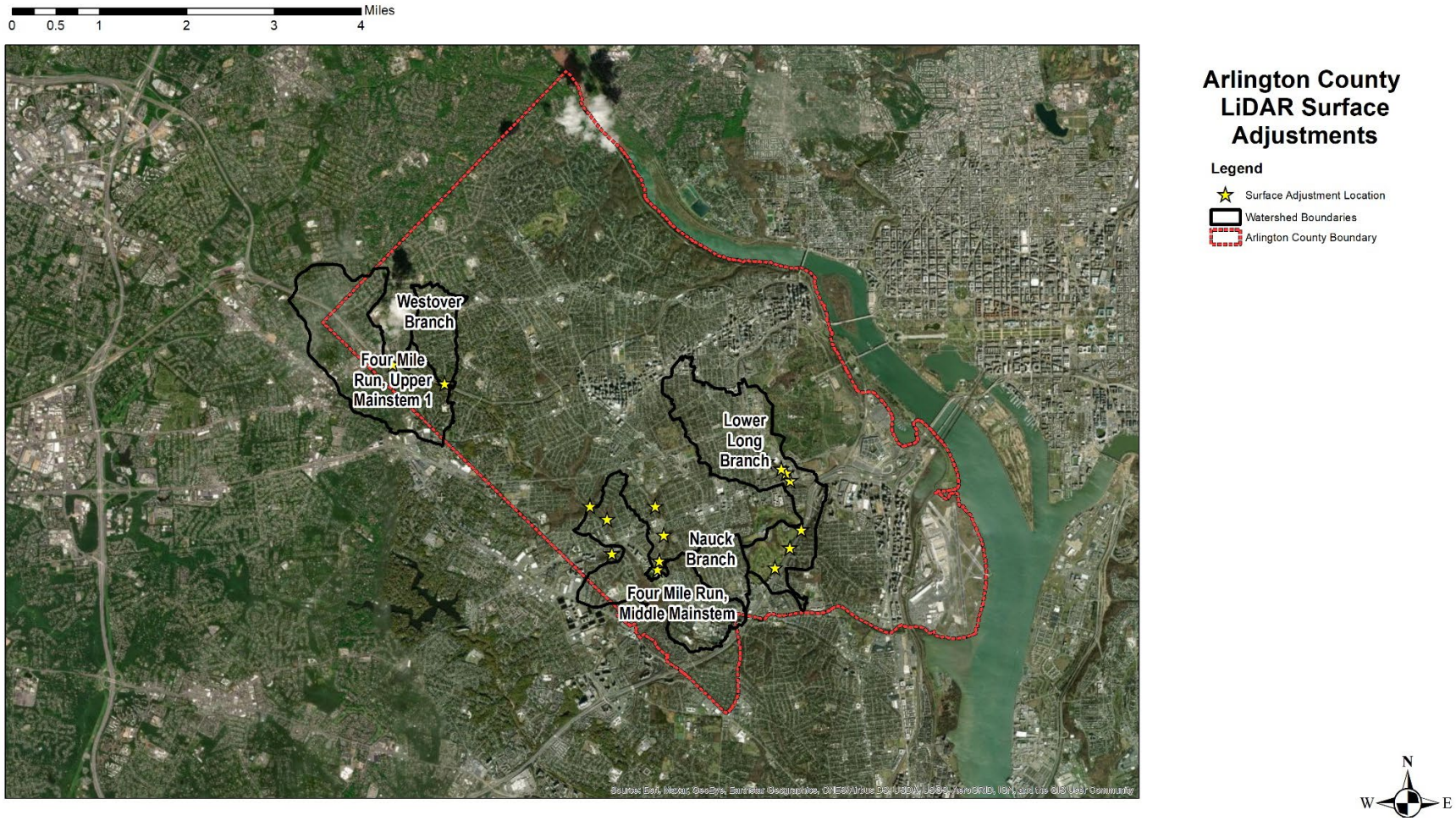



**Figure 2-1. FAST Modeling Surface Adjustments**

- Six project areas were updated in the models to account for changes (either constructed or planned) to collection system assets.
- One 1D/2D orifice connection was included for every four existing inlets.
- No other changes were made to hydrologic models or pipe networks relative to existing models with the exception of Virginia Highlands as follows:
  - A data comparison (1D PCSWMM model versus 2020 geographic information system [GIS] inventory provided by the County) was completed to validate the assumption that the existing 1D PCSWMM models sufficiently represent currently available data. A technical memorandum, entitled *Comparison of Data Sources from Existing Models to Current GIS Asset Data*, documents the comparison (Jacobs 2021). In consultation with the County, it was determined that the data changes in most sheds would not substantially change the results of the RAMP, and therefore the County preferred to move forward with the RAMP and address model updates at a later date as part of routine model maintenance. The one exception is Virginia Highlands. In this watershed there were large data gaps during initial model development, which had since been updated in GIS. The Virginia Highlands watershed model was updated to reflect the 2020 GIS data, and remaining data gaps and anomalies were coordinated with the County, as documented in Appendix C.
- Open channel systems:
  - Models include open channels downstream of modeled pipe networks to the shed outlet and in some cases interspersed between storm sewers in the modeled system.
  - Ponds were not added as part of this modeling effort, but the pond previously modeled in the Arlington County model for Lubber Run was included in the PCSWMM 1D/2D model.
- Best management practice were not included in previous models, with limited exceptions and the addition of any best management practices facilities to the models were excluded from this scope.
- No updates were made to the hydrologic modeling with the exception of incorporating new storm events and limited updates to accommodate extensions to pipe networks. The latter are noted for each watershed in Appendix C.

### 2.2.2 1D Model Elements

1D/2D modeling performed in this study was based on the previously developed Arlington County and NVRC models as described in Table 1-1.

As-builts were used to update the base models in six total locations, as shown on Figure 2-2. Technical memorandums detailing model updates for each watershed modeled in PCSWMM are included in Appendix C**.** As-builts incorporated into the models were as follows:

- West Little Pimmit Run – Phase I (Storm Drainage Improvements and Bioretentions) From North Nottingham Street To 34th Street North
- Virginia Hospital Center
- Skyview at Pentagon Centre Building C
- 23rd Street South Utility Relocation Plan Crystal City Block M
- American Legion 3445 Washington Blvd Proposed
- Washington Boulevard at Kirkwood Road Proposed

A GIS comparison was performed for the eight watersheds modeled in PCSWMM where the modeled conduits were compared against 2020 GIS data. There were some differences in the comparison for these eight watersheds, but the County elected to move forward without updating modeled conduits in most cases because the differences were determined to have minimal impact on results. The exception was the Virginia Highlands watershed, where updates were made to the 1D model elements based on 2020 GIS data provided by the County.

The base Arlington County models included storage nodes at the upstream ends of the subcatchments in each watershed model. These storage nodes represented storage in the subsurface system of unmodeled small-diameter pipes. These models were converted to junctions, and the storage area associated with them was removed to prevent any double-counting of storage once the 2D mesh was constructed.

### 2.2.3 2D Model Surface Network

A PCSWMM 2D network was built for each watershed using the available DEM for topographic data. The 2D networks for each watershed excluded existing buildings, except in rare cases as noted in each watershed's detailed modeling notes in Appendix C.

An iterative process was used to determine the mesh extents for each watershed that optimized the mesh extents to reduce runtime to the extent possible while accommodating the full flood extents for the largest event modeled (Year 2070 500-year, 24-hour synthetic event). The 2D mesh for each watershed was modified over open bodies of water such as streams and ponds to ensure that double-counting of storage volume did not occur. Details on these 2D mesh accommodations to facilitate open channel interactions may be found in Appendix D.

A curb and street inlet review was also conducted for each of the eight 1D/2D PCSWMM models developed for this task. Orifices were modeled to represent the street-facing width of four existing inlets. Google Earth imagery was spot-checked to develop the initial assumption, with additional targeted checks undertaken to confirm accurate representation of surface to subsurface flow interactions in areas of known flooding. Further details on the 2D model development can be found in Appendix D.

### 2.2.4 Model Comparison and Validation

Before the 2D model was completed, a 1D model run was performed to validate model surcharge locations against general known problem area locations for each watershed modeled in PCSWMM. In this run, the 500-year, 24-hour future conditions (Year 2070) synthetic rainfall event was modeled. The results from this event were compared against the locations of reported flooding and historical flood call data.

After this 1D model run, a 1D/2D model run of the 500-year, 24-hour future conditions synthetic rainfall event was completed as well as a simulation using the July 8, 2019 historical event rainfall. The flooded 2D cells from these model simulations were compared against the FAST result data and known flood call locations to validate model performance against known problem areas. Any calibration adjustments made as a result of these validation runs may be found in each watershed's model notes in Appendix C. An example of July 2019 2D model results validated against July 2019 historical flood call data is provided on Figure 2-3.

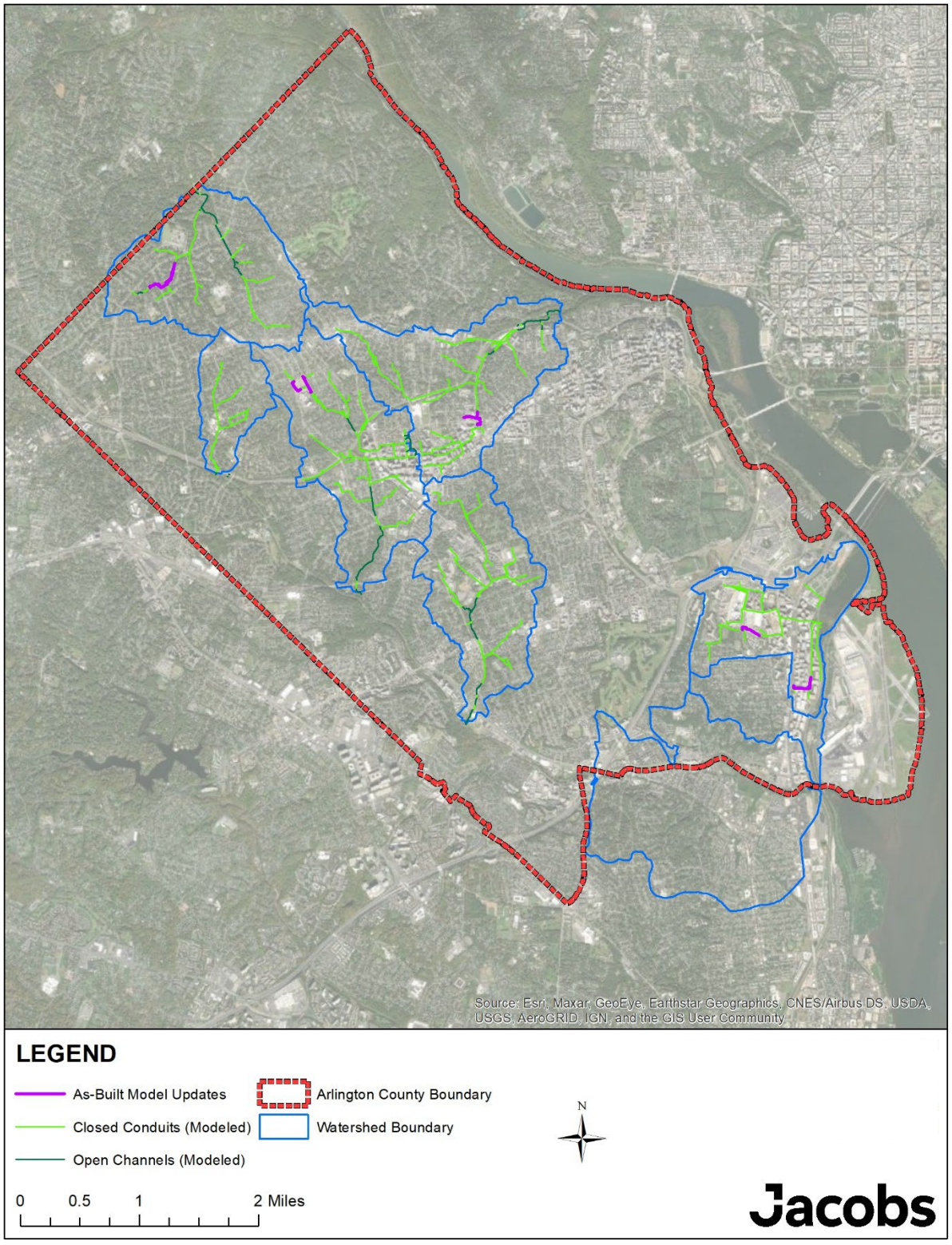



**Figure 2-2. As-Built Model Update Locations**

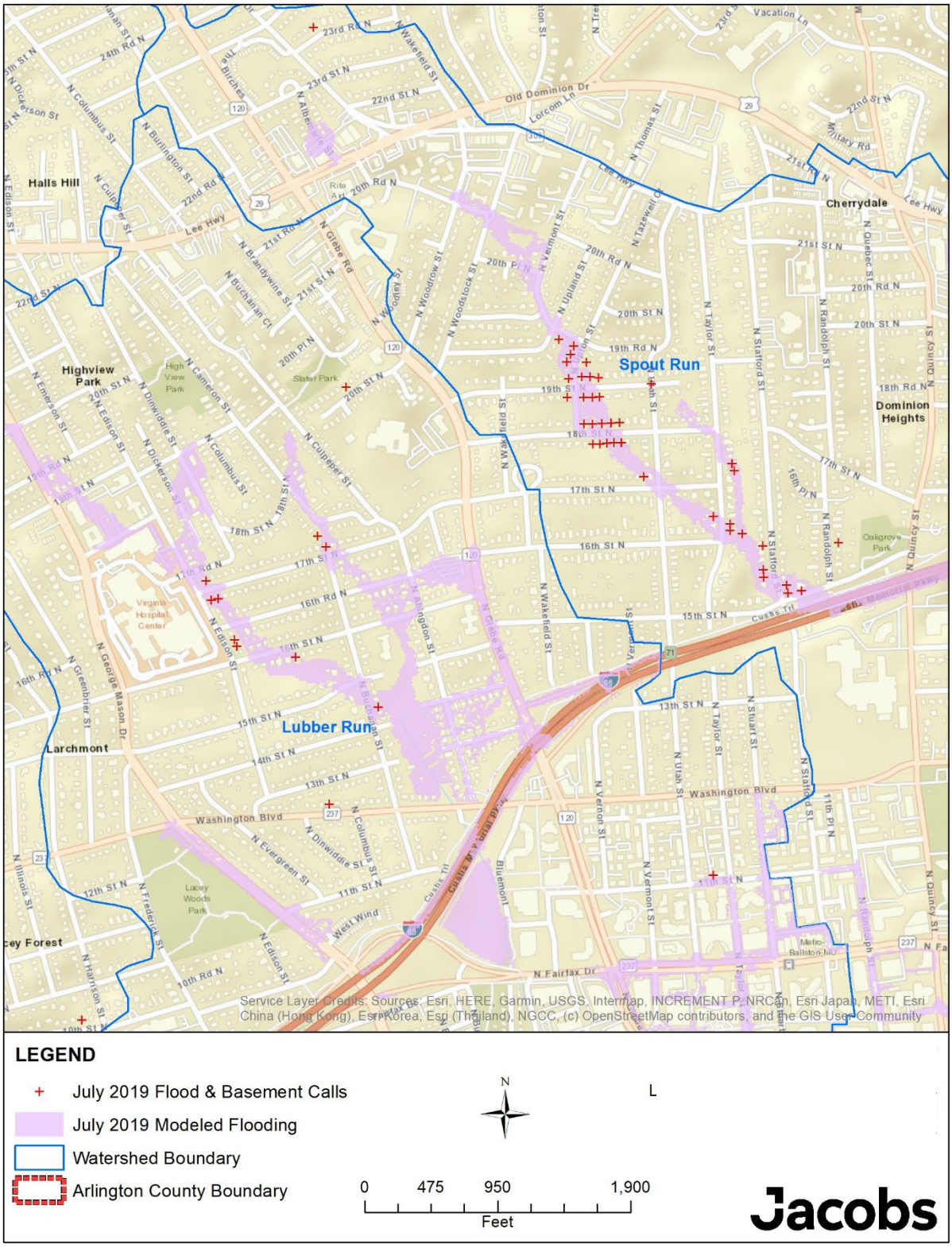



**Figure 2-3. Example 1D/2D PCSWMM July 2019 Event Validation Map**

### 2.2.5 Model Scenarios

Recommended model scenarios cover a range of current and future climate scenarios for multiple synthetic storm events as proposed in the technical memorandum for Task 3.1 (Jacobs 2020a). One historical storm event from July 8, 2019, was also simulated using local rain gauge data. The scenarios performed are listed in Table 2-1. After discussion with County staff, subcatchment percent impervious values were not adjusted to reflect future land use conditions because the evaluated watersheds are currently heavily developed.

**Table 2-1. Modeled Scenarios for Interior and Riverine Flood Modeling**

| Scenario | Planning Horizon | Precipitation Scenario[a] | 24-hr Precipitation Amount (in) | Extreme Water Level (ft, NAVD88) | SLR (ft) |
|---|---|---|---|---|---|
| 1. Observed Event: July 8, 2019 | Current Conditions | AG4JW Arlington Station | 3.32 (in 2.5 hours) | Observed | None |
| 2. Baseline: 10-year | Current Conditions | Updated Baseline IDF | 5.16 | 5.8 | None |
| 3. Baseline: 100-year | Current Conditions | Updated Baseline IDF | 8.48 | 10.5 | None |
| 4. Baseline: 500-year | Current Conditions | Updated Baseline IDF | 11.47 | 15.4 | None |
| 5. 2040: 10-year | 2040 | RCP 8.5, 50% | 5.49 | 5.8 | Int-High 1.86 |
| 6. 2040: 100-year | 2040 | RCP 8.5, 50% | 9.04 | 10.5 | Int-High 1.86 |
| 7. 2040: 500-year | 2040 | RCP 8.5, 50% | 12.21 | 15.4 | Int-High 1.86 |
| 8. 2070: 10-year | 2070 | RCP 8.5, 50% | 5.81 | 5.8 | Int-High 3.86 |
| 9. 2070: 100-year | 2070 | RCP 8.5, 50% | 9.57 | 10.5 | Int-High 3.86 |
| 10. 2070: 500-year | 2070 | RCP 8.5, 50% | 12.94 | 15.4 | Int-High 3.86 |

[a] All storms are based on the 24-hour SCS Type II distribution except for the observed events.

IDF = intensity-duration-frequency
RCP = representative concentration pathway

#### 2.2.5.1 Storm Events

Model runs were performed for each of the storm events listed in Table 2-1. Detailed tables of rainfall distributions for these events can be found in Appendix E.

#### 2.2.5.2 Downstream Boundary Conditions

The eight watersheds selected for detailed 1D/2D modeling in PCSWMM outfall to the following water bodies as shown in Table 2-2.

**Table 2-2. Downstream Boundary Condition Type & Location by Watershed**

| Watershed | Outfall Type | Location |
|---|---|---|
| Doctor's Branch | Fixed Stage | Four Mile Run |
| Four Mile Run, Lower Mainstem | Fixed Stage | Potomac River |
| Little Pimmit Run | Free Outfall | — |
| Lubber Run | Fixed Stage | Four Mile Run |
| Roaches Run | Fixed Stage | Potomac River |
| Spout Run | Free Outfall | — |
| Torreyson Run | Fixed Stage | Four Mile Run |
| Virginia Highlands | Combined with Four Mile Run Model | Four Mile Run |

Downstream boundary conditions used for each model run are summarized on Figure 2-4. Further details on boundary condition development is provided in Appendix F.

- **Watersheds with Four Mile Run as a Boundary Condition**
  - Includes Doctor's Branch, Lubber Run, and Torreyson Run
  - Used flows from the previously-developed Four Mile Run 1D PCSWMM model as inputs into the preliminary FEMA HECRAS steady-state model.
    - Confirmed historical conditions flows were comparable between the PCSWMM model and the Preliminary FEMA model
    - This allowed escalation of Climate Conditions for the boundary conditions
      - Able to run escalated rainfall in PCSWMM; this capability was not readily available with the FEMA dataset
    - Resulting HEC-RAS WSEs were used as downstream boundaries for these watersheds.
- **Coastal Model results were used as boundary conditions for Lower Four Mile Run (Lower Mainstem) and Roaches Run**
- **Combined Models to run for larger storm events**
  - Roaches Run, Virginia Highlands, and Four Mile Run (Lower Mainstem)
  - Allows overland flow to seamlessly cross from one shed to another
  - Allows cross-shed interactions for boundary conditions

**Figure 2-4. Watershed Downstream Boundary Condition Summary**

# 3. Results and Conclusions

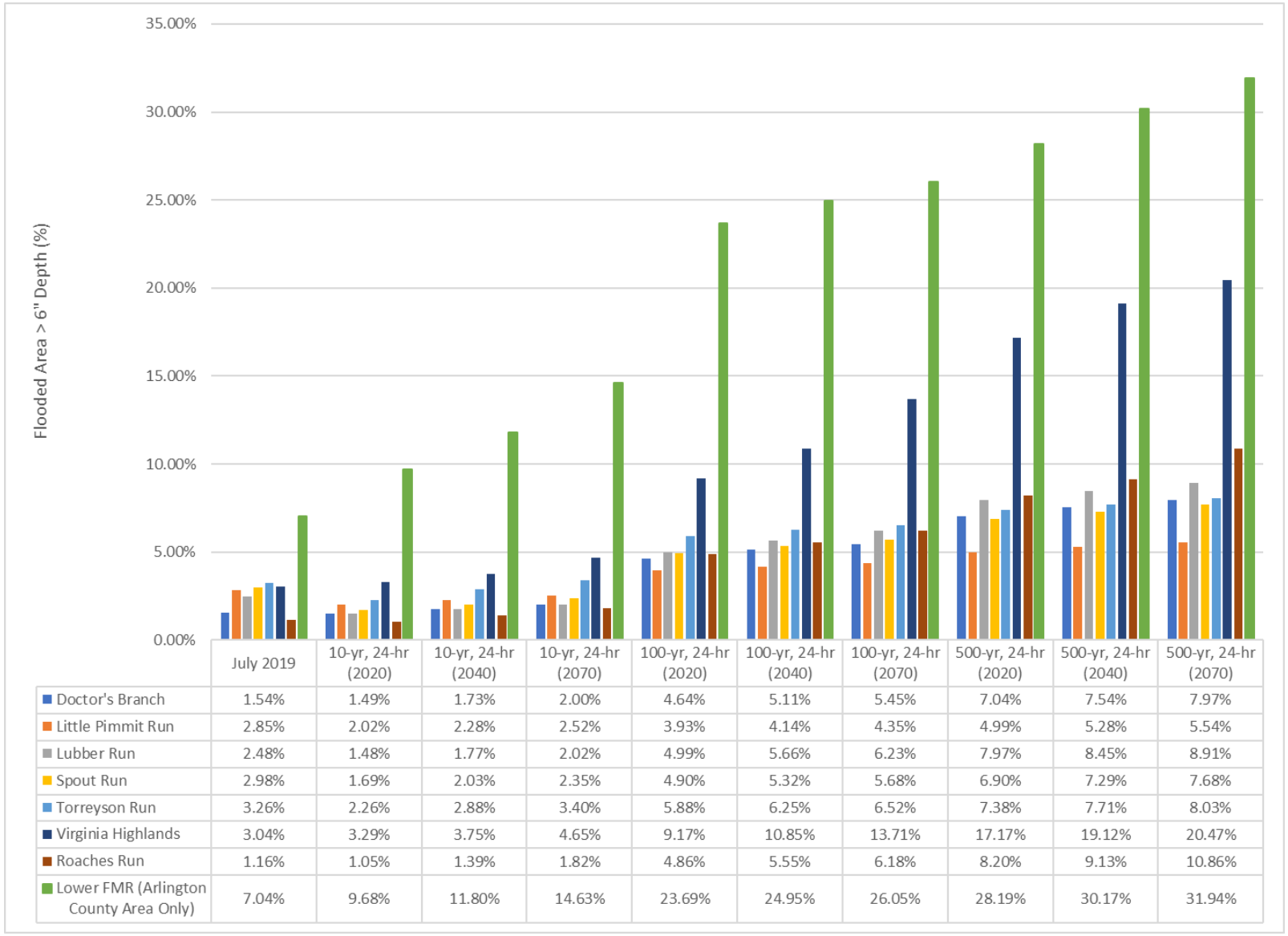
As described in previous sections and in Appendix C, models are well-validated and accurately replicate historical flood call locations.

Flood mapping results were provided to the County in two separate formats, a GIS geodatabase and eight layered PDF files that contain all 10 of the modeling scenarios for each of the eight watersheds with PCSWMM detailed modeling results. The GIS data include both the PCSWMM and FAST modeling results.

The flood modeling results will be used in subsequent tasks to support vulnerability assessments, flood risk, and alternatives analysis. A preliminary GIS analysis was conducted of the flood modeling results to quantify the extent of the flooded area for each watershed, for the three different return frequency storms under current and future conditions. Figure 3-1 and Figure 3-2 provide graphic summaries of the percent of each watershed area that is flooded and the total area flooded. Note that these summaries are only for areas with more than a 6-inch flood. Appendix C provides similar charts for each watershed, with further analysis of depth of flooding in the flood areas.

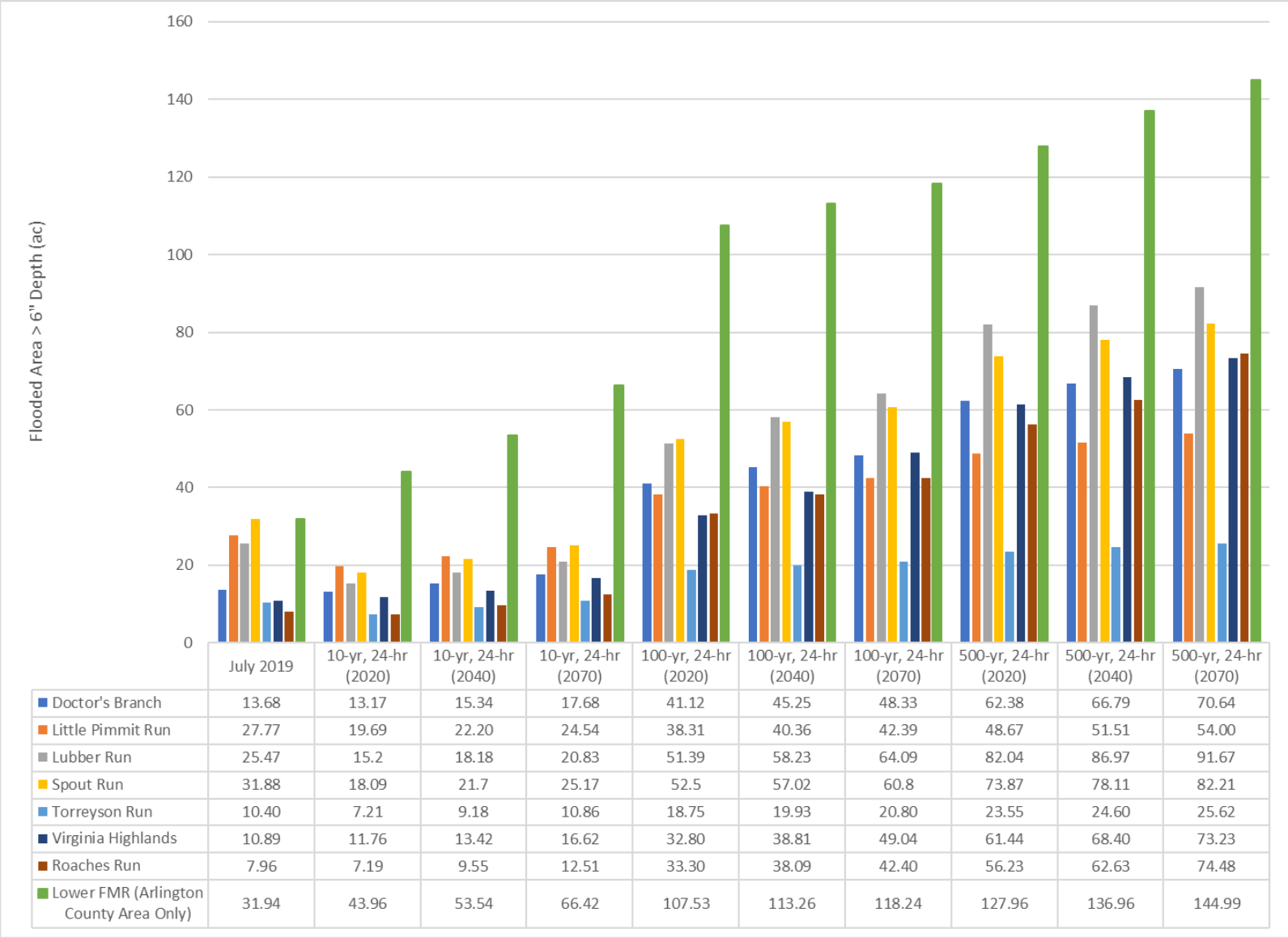
Other than Lower Four Mile Run, no single watershed stands out as the most or least problematic across all storm events. General observations are as follows:

- Based on total flooded area and percent flooded area, the Lower Four Mile Run watershed has by far the largest flood extent for any storm recurrence interval or planning scenario. The one exception is for the July 2019 historic storm. The model results showed that Spout Run had a similar flood extent (31.9 acres) as Lower Four Mile Run, followed closely by Little Pimmit Run (27.8 acres) and Lubber Run (25.5 acres).
- On the basis of percentage area flooded, Lower Four Mile Run stands out for all scenarios, with as much as 7 percent flooded for the July 2019 event and 9.7 percent flooded for the 10-year 24-hour events, increasing to as much as 32 percent flooded for the extreme scenario (500-year storm in 2070).
- On a percentage basis, Virginia Highlands is second highest, standing nearly twice as any other watershed other than Lower Four Mile Run, ranging from 9.2 percent for the 100-year storm in 2020 to 20.5 percent for the extreme scenario.
- For the 100-year event, six of the eight watersheds are about 5 percent impacted except for Virginia Highlands and Four Mile Run, Lower Mainstem, which are two to nearly four times higher.
- After Lower Four Mile Run, which is high, Lubber Run and Spout Run flood the most by area for the 500-year and 100-year events. Lubber Run is not as impacted as others by the 10-year event.
- Spout Run and Little Pimmit Run have the highest acres flooded for smaller storm events (10-year) and the July 2019 event (except Lower Four Mile Run, which is high).
- Virginia Highlands and Torreyson Run flood the most by percentage for 10-year event (excepting Lower Four Mile Run, which is high), but Torreyson Run is the least by acres because it is smaller.
- Roaches Run and Doctor's Branch flood the least by percentage for the 10-year and July 2019 events and has the least area of the larger three watersheds for these events. Relative to others, the impact increase by acre in Doctor's Branch increases for larger storm events.
- Little Pimmit Run floods the least by percentage for the 100-year and 500-year events and is the least in acres aside from Torreyson Run, which is small.




| | July 2019 | 10-yr, 24-hr (2020) | 10-yr, 24-hr (2040) | 10-yr, 24-hr (2070) | 100-yr, 24-hr (2020) | 100-yr, 24-hr (2040) | 100-yr, 24-hr (2070) | 500-yr, 24-hr (2020) | 500-yr, 24-hr (2040) | 500-yr, 24-hr (2070) |
|---|---|---|---|---|---|---|---|---|---|---|
| Doctor's Branch | 1.54% | 1.49% | 1.73% | 2.00% | 4.64% | 5.11% | 5.45% | 7.04% | 7.54% | 7.97% |
| Little Pimmit Run | 2.85% | 2.02% | 2.28% | 2.52% | 3.93% | 4.14% | 4.35% | 4.99% | 5.28% | 5.54% |
| Lubber Run | 2.48% | 1.48% | 1.77% | 2.02% | 4.99% | 5.66% | 6.23% | 7.97% | 8.45% | 8.91% |
| Spout Run | 2.98% | 1.69% | 2.03% | 2.35% | 4.90% | 5.32% | 5.68% | 6.90% | 7.29% | 7.68% |
| Torreyson Run | 3.26% | 2.26% | 2.88% | 3.40% | 5.88% | 6.25% | 6.52% | 7.38% | 7.71% | 8.03% |
| Virginia Highlands | 3.04% | 3.29% | 3.75% | 4.65% | 9.17% | 10.85% | 13.71% | 17.17% | 19.12% | 20.47% |
| Roaches Run | 1.16% | 1.05% | 1.39% | 1.82% | 4.86% | 5.55% | 6.18% | 8.20% | 9.13% | 10.86% |
| Lower FMR (Arlington County Area Only) | 7.04% | 9.68% | 11.80% | 14.63% | 23.69% | 24.95% | 26.05% | 28.19% | 30.17% | 31.94% |

**Figure 3-1. Flooded Area Comparison (Percent)**




| | July 2019 | 10-yr, 24-hr (2020) | 10-yr, 24-hr (2040) | 10-yr, 24-hr (2070) | 100-yr, 24-hr (2020) | 100-yr, 24-hr (2040) | 100-yr, 24-hr (2070) | 500-yr, 24-hr (2020) | 500-yr, 24-hr (2040) | 500-yr, 24-hr (2070) |
|---|---|---|---|---|---|---|---|---|---|---|
| Doctor's Branch | 13.68 | 13.17 | 15.34 | 17.68 | 41.12 | 45.25 | 48.33 | 62.38 | 66.79 | 70.64 |
| Little Pimmit Run | 27.77 | 19.69 | 22.20 | 24.54 | 38.31 | 40.36 | 42.39 | 48.67 | 51.51 | 54.00 |
| Lubber Run | 25.47 | 15.2 | 18.18 | 20.83 | 51.39 | 58.23 | 64.09 | 82.04 | 86.97 | 91.67 |
| Spout Run | 31.88 | 18.09 | 21.7 | 25.17 | 52.5 | 57.02 | 60.8 | 73.87 | 78.11 | 82.21 |
| Torreyson Run | 10.40 | 7.21 | 9.18 | 10.86 | 18.75 | 19.93 | 20.80 | 23.55 | 24.60 | 25.62 |
| Virginia Highlands | 10.89 | 11.76 | 13.42 | 16.62 | 32.80 | 38.81 | 49.04 | 61.44 | 68.40 | 73.23 |
| Roaches Run | 7.96 | 7.19 | 9.55 | 12.51 | 33.30 | 38.09 | 42.40 | 56.23 | 62.63 | 74.48 |
| Lower FMR (Arlington County Area Only) | 31.94 | 43.96 | 53.54 | 66.42 | 107.53 | 113.26 | 118.24 | 127.96 | 136.96 | 144.99 |

**Figure 3-2. Flooded Area Comparison (Acres)**

# 4. References

Computational Hydraulics International (CHI). n.d. "PCSWMM." https://www.pcswmm.com/.

Jacobs. n.d. "Flood Modeller by Jacobs." https://www.floodmodeller.com/.

Jacobs. 2020a. *Technical Memorandum: Climate Projections and Scenarios*. Prepared for Arlington County, VA. July 24.

Jacobs. 2020b. *Technical Memorandum: Coastal Surge Modeling*. Prepared for Arlington County, VA. October 5.

Jacobs. 2021. *Comparison of Data Sources from Existing Models to Current GIS Asset Data*. Technical Memorandum.

# Appendix A
# Watershed Prioritization

# Appendix A. Watershed Prioritization

FAST modeling was performed in Flood Modeller for all 36 watersheds in Arlington County to support the selection of 8 watersheds for detailed 1D/2D modeling in PCSWMM and 5 watersheds for further modeling with Flood Modeller's FAST process. Two rain events were modeled in this initial screening process: a 100-year, 24-hour synthetic rainfall event, and the July 2019 historical event. A downstream boundary condition, representing the Potomac River, of 1.77 feet NAVD88 (MHHW tidal level) and 1.96 feet NAVD88 were used for the synthetic and the historical event, respectively. Topographic data for the model was based on a digital elevation model (DEM) developed from the 2018 USGS LiDAR dataset.

Once the screening model runs were complete, watersheds were prioritized based on the following criteria:

- Number of Historical Flood Calls (2006, 2018, 2019)
- Observed High Water Marks (2019)
- Amount of FAST predicted flooding
- Extent of FEMA Floodplain

As shown in Table A-1. The project team developed an initial prioritization for the 36 watersheds based on FAST modeling and the number of flood calls by watershed for the historical June 2006 storm event.

**Table A-1. Recommended Prioritization Based on Initial FAST Screening**

| Watershed Name | Priority Tier | Watershed Area (Square Miles) | Percentage of Watershed with 100-yr FAST flooding | June 2006 Historical Flood Call Count |
|---|---|---|---|---|
| Lubber Run | 1 | 1.61 | 8.5% | 26 |
| Spout Run | 1 | 1.67 | 7.2% | 14 |
| Little Pimmit Run, East Branch | 1 | 0.76 | 4.3% | 14 |
| Little Pimmit Run, West Branch | 1 | 0.76 | 4.5% | 11 |
| Torreyson Run | 1 | 0.50 | 3.8% | 3 |
| Crossman Run | 1 | 0.36 | 5.0% | 2 |
| Four Mile Run, Lower Mainstem | 1 | 2.48 | 29.7% | 1 |
| Roaches Run | 1 | 1.07 | 29.2% | 0 |
| Virginia Highlands | 1 | 0.56 | 12.9% | 0 |
| Lower Long Branch | 2 | 1.89 | 7.8% | 7 |
| Four Mile Run, Middle Mainstem | 2 | 1.49 | 6.0% | 6 |
| Westover Branch | 2 | 0.46 | 3.9% | 3 |
| Four Mile Run, Upper Mainstem 1 | 2 | 1.89 | 7.6% | 1 |
| Doctor's Branch | 3 | 1.38 | 6.3% | 4 |
| Nauck Branch | 3 | 0.36 | 3.8% | 3 |
| Arlington Branch | 3 | 0.65 | 6.5% | 1 |

After discussion with Arlington County staff, watershed prioritization rankings were reprioritized as shown in Table A-2. Watersheds included in Priority Tier 1 in Table A-2 were modeled in PCSWMM. The east and west branches of Little Pimmit Run were combined into one PCSWMM model for the 1D/2D modeling. All watersheds in Priority Tier 2 were modeled using Flood Modeller's FAST analysis. Watersheds in Priority Tier 3 were not modeled. Watershed prioritization is depicted graphically in Figure A-1.

Key factors influencing the final prioritization tiering structure included the following:

- In the original recommendation Crossman Run was prioritized for PCSWMM modeling. However, it was determined through dialogue with Arlington County staff that Crossman Run's stormwater situation was similar to Torreyson Run's. Furthermore, the County felt that they had a good understanding of the situation in Crossman Run from previous modeling efforts. Therefore, the decision was made to do no further modeling on Crossman Run, and to prioritize Doctor's Branch for PCSWMM modeling instead.
- Arlington Branch was not prioritized for further modeling due to its small size and relatively small total number of historical flood calls.

Four Mile Run, Middle Mainstem has some areas of concern, but it was not prioritized for PCSWMM analysis because it is located in the FEMA floodplain, so the FEMA analysis could be used for the Vulnerability Assessment task. Four Mile Run, Middle Mainstem was further modeled using FAST analysis.

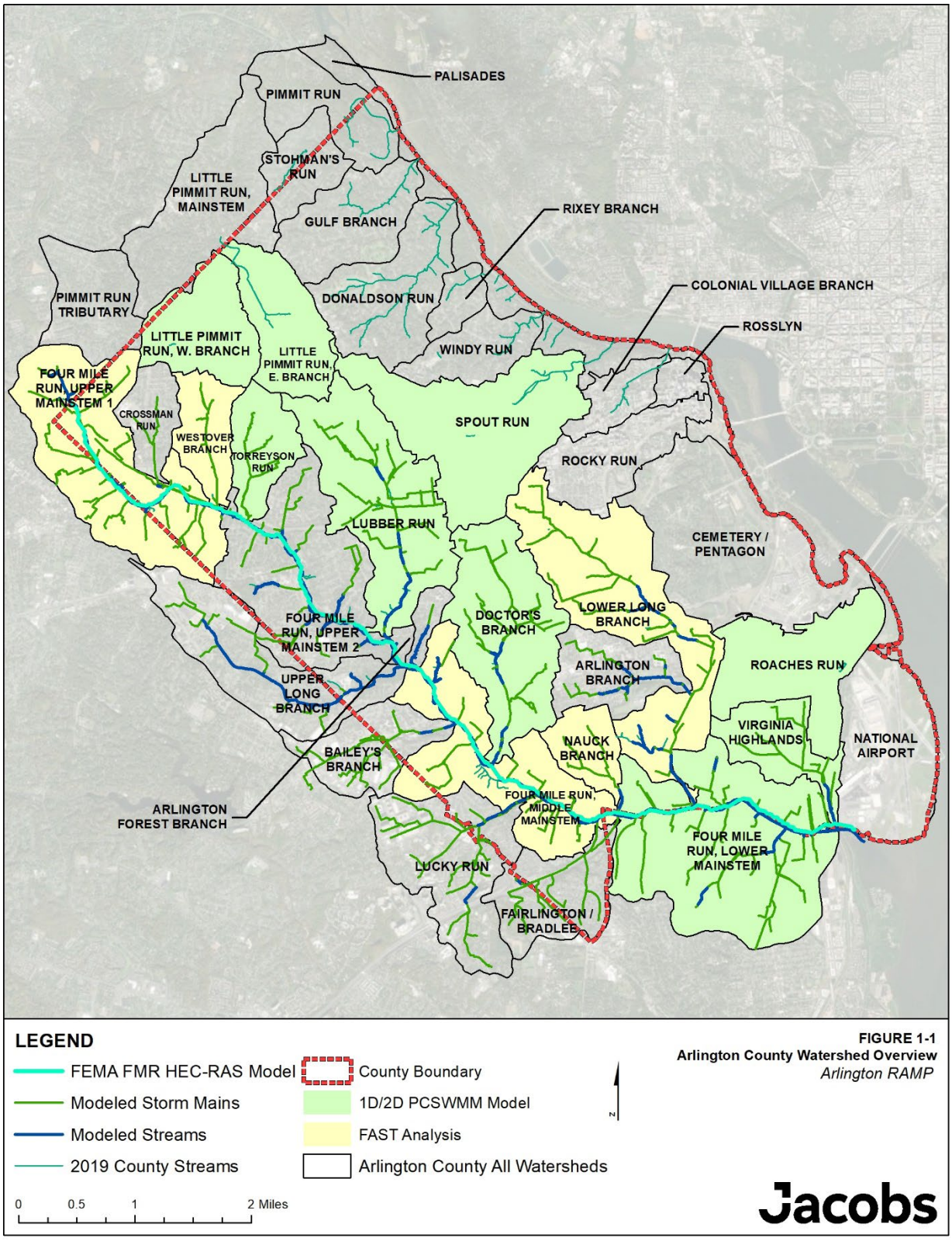



**Figure A-1. Arlington County Watershed Prioritization Overview**

**Table A-2. Final Prioritization Utilized in Study**

| Watershed Name | Priority Tier | Watershed Area ($mi^2$) | June 2006 Historical Flood Call Count | 5/22/2018 Historical Flood Call Count | 7/25/2018 Historical Flood Call Count | 7/8/2019 Historical Flood Call Count | 2019 Basement Historical Flood Call Count | Historical Flood Calls/ Sq Mi | % of Watershed with 100yr FAST flooding |
|---|---|---|---|---|---|---|---|---|---|
| Lubber Run | 1 | 1.61 | 26 | 5 | 0 | 12 | 3 | 28.6 | 8.5% |
| Spout Run | 1 | 1.67 | 14 | 9 | 15 | 37 | 13 | 52.6 | 7.2% |
| Little Pimmit Run, East Branch | 1 | 0.76 | 14 | 2 | 1 | 7 | 3 | 35.4 | 4.3% |
| Little Pimmit Run, West Branch | 1 | 0.76 | 11 | 6 | 0 | 11 | 10 | 50.1 | 4.5% |
| Torreyson Run | 1 | 0.50 | 3 | 5 | 0 | 18 | 13 | 78.0 | 3.8% |
| Doctor's Branch | 1 | 1.38 | 4 | 0 | 0 | 1 | 0 | 3.6 | 6.3% |
| Four Mile Run, Lower Mainstem | 1 | 2.48 | 1 | 1 | 0 | 2 | 0 | 1.6 | 29.7% |
| Roaches Run | 1 | 1.07 | 0 | 1 | 0 | 0 | 0 | 0.9 | 29.2% |
| Virginia Highlands | 1 | 0.56 | 0 | 0 | 0 | 0 | 0 | 0.0 | 12.9% |
| Lower Long Branch | 2 | 1.89 | 7 | 1 | 0 | 2 | 2 | 6.3 | 7.8% |
| Four Mile Run, Middle Mainstem | 2 | 1.49 | 6 | 2 | 0 | 3 | 1 | 8.1 | 6.0% |
| Westover Branch | 2 | 0.46 | 3 | 2 | 0 | 6 | 3 | 30.1 | 3.9% |
| Four Mile Run, Upper Mainstem 1 | 2 | 1.89 | 1 | 1 | 0 | 4 | 4 | 5.3 | 7.6% |
| Nauck Branch | 2 | 0.36 | 3 | 0 | 0 | 0 | 1 | 11.0 | 3.8% |
| Crossman Run | 3 | 0.36 | 2 | 3 | 0 | 4 | 2 | 30.5 | 5.0% |
| Arlington Branch | 3 | 0.65 | 1 | 0 | 0 | 2 | 0 | 4.6 | 6.5% |

# Appendix B
# FAST Modeling

# Appendix B. Rapid Flood Inundation Model Assessment

## B.1 Flood Modeller Pro FAST

This appendix provides an overview of how Flood Modeller Pro FAST (FAST) was applied to Arlington County. More details on the FAST software are available at https://www.floodmodeller.com/2dfastsolver. FAST is a computational engine which routes water over the floodplain using a simple set of rules based on how water levels respond to the topography described in the digital elevation map (DEM). FAST works by pre-processing DEM data to identify depressional sub-catchments in the ground surface. Hydrological input data, such as rainfall, inflows, tidal/water level boundaries are then routed through the models to generate flood extent and depth results.

FAST will provide a quick assessment of flooding using these simplified hydraulic principles to generate results up to 1,000 times more rapidly when compared to other tools and methods available for flood inundation simulations – i.e. delivering results in minutes as opposed to hours or days. As mentioned above, the software works by first identifying depressions on the floodplain before routing water through these depressions. Water depths in the depressions are determined by volume of water flowing into that depression; level at which water can spill into neighboring depressions; and water level in neighboring depressions. FAST represents connectivity and volume filling effects on the floodplain, without having to represent detailed hydraulics.

It must be noted that no subsurface connectivity is represented in the FAST model and therefore, it must be recognized this tool should not be considered a substitute for fully hydrodynamic models needed for high accuracy (or high risk) tasks such as required for detailed engineering design or mapping products. However, because of the rapid setup time and fast simulation speed, these tools can leverage available data to assist feasibility study work and planning of data collection process by identifying critical locations of assessment.

### B.1.1 Model Setup

The following inputs are required for the model:

- 1-meter by 1-meter LiDAR data (elevations in meter NAVD88) from USGS 3D Elevation Program (3DEP) – 2018 LiDAR Point Cloud (LPC) Product
- 24-hour precipitation data for the 100-year event and cumulative depth for the July 2019 rainfall event
- Mean Higher High Water and July 2019 event tidal values

Figure B-1 depicts the LiDAR data, Arlington County boundary, and extents of the modeled area that were used in the model setup. As shown, the modeled area extends beyond the County boundary to ensure drainage from upstream areas is included in the results.

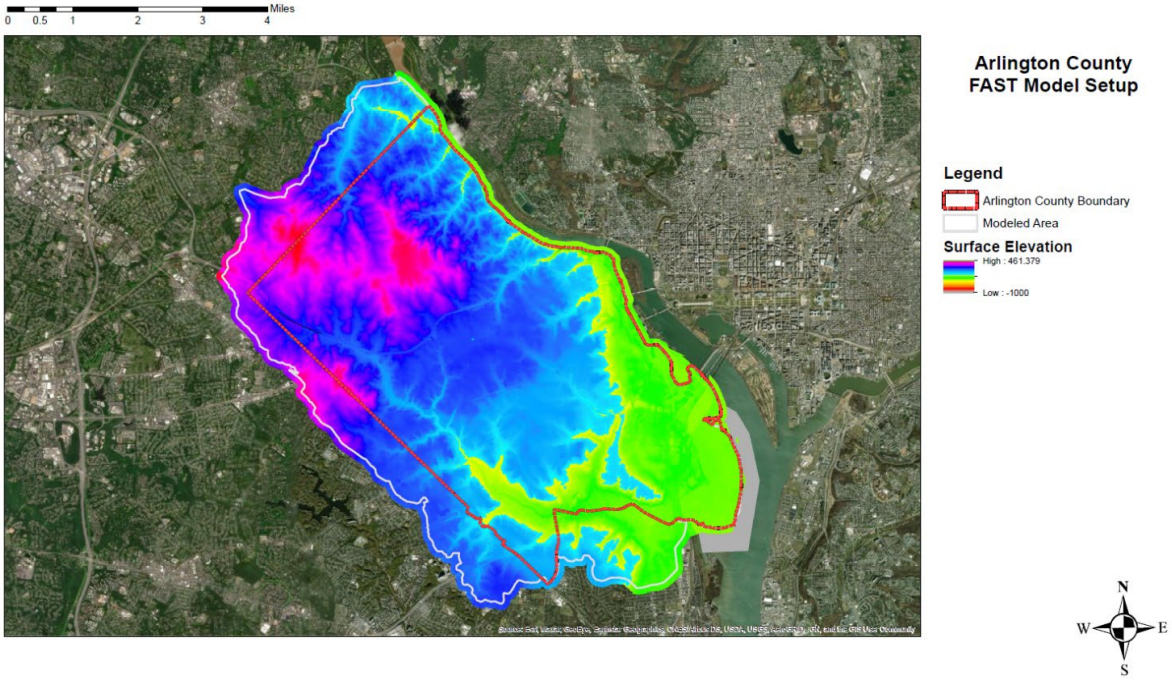



**Figure B-1. Model Boundaries**

### B.1.2 Modeled Scenarios

Two scenarios were modeled using Flood Modeller's FAST analysis. As a preliminary decision-making tool, the existing conditions 100-year event and the July 8, 2019 rainfall event were modeled for each of Arlington County's 36 watersheds utilizing the inputs described in Table B-1.

**Table B-1. Model Inputs**

| Scenario | Cumulative Precipitation (inches) | Tidal Values (feet, NAVD88)* |
|---|---|---|
| 100-yr Event | 8.48 | 1.77 |
| 7/8/2019 Event | 3.32 | 1.96 |

After prioritization of the watersheds, five watersheds, listed in Table B-2, were selected for additional FAST modeling. For these watersheds, the preliminary modeling results were analyzed to identify locations that the LiDAR could be refined to more accurately reflect real life conditions, such as locations of culverts.

**Table B-2. Watersheds of Interest for FAST Model**

| Watersheds Selected for Additional FAST Modeling |
|---|
| Lower Long Branch |
| Four Mile Run, Middle Mainstem |
| Westover Branch |
| Four Mile Run, Upper Mainstem 1 |
| Nauck Branch |

Locations that patches, or surface adjustments, were made to the LiDAR are depicted on Figure B-2. A total of 16 culvert locations were edited to more accurately model results.

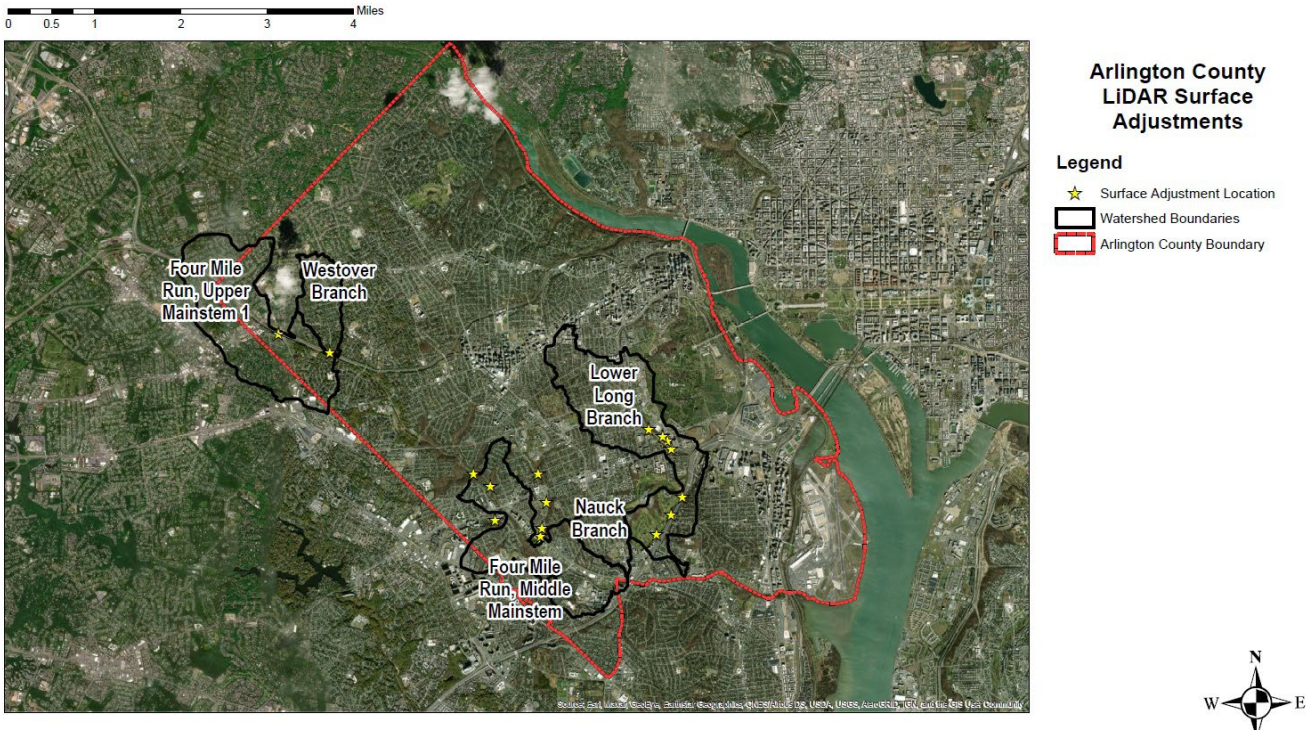



**Figure B-2. Locations of LiDAR Adjustments**

### B.1.3 Model Results

The primary results from the Flood Modeller FAST model runs are maximum flood inundation water depth and elevation grids. These results are used to develop flood extents and depth maps of the area. The following figures show overall results for the preliminary and adjusted model, as well watershed specific results for the identified watersheds of interest with the LiDAR refined model. Model results are depicted in the following figures.

## Initial FAST Model Prioritization Run Results

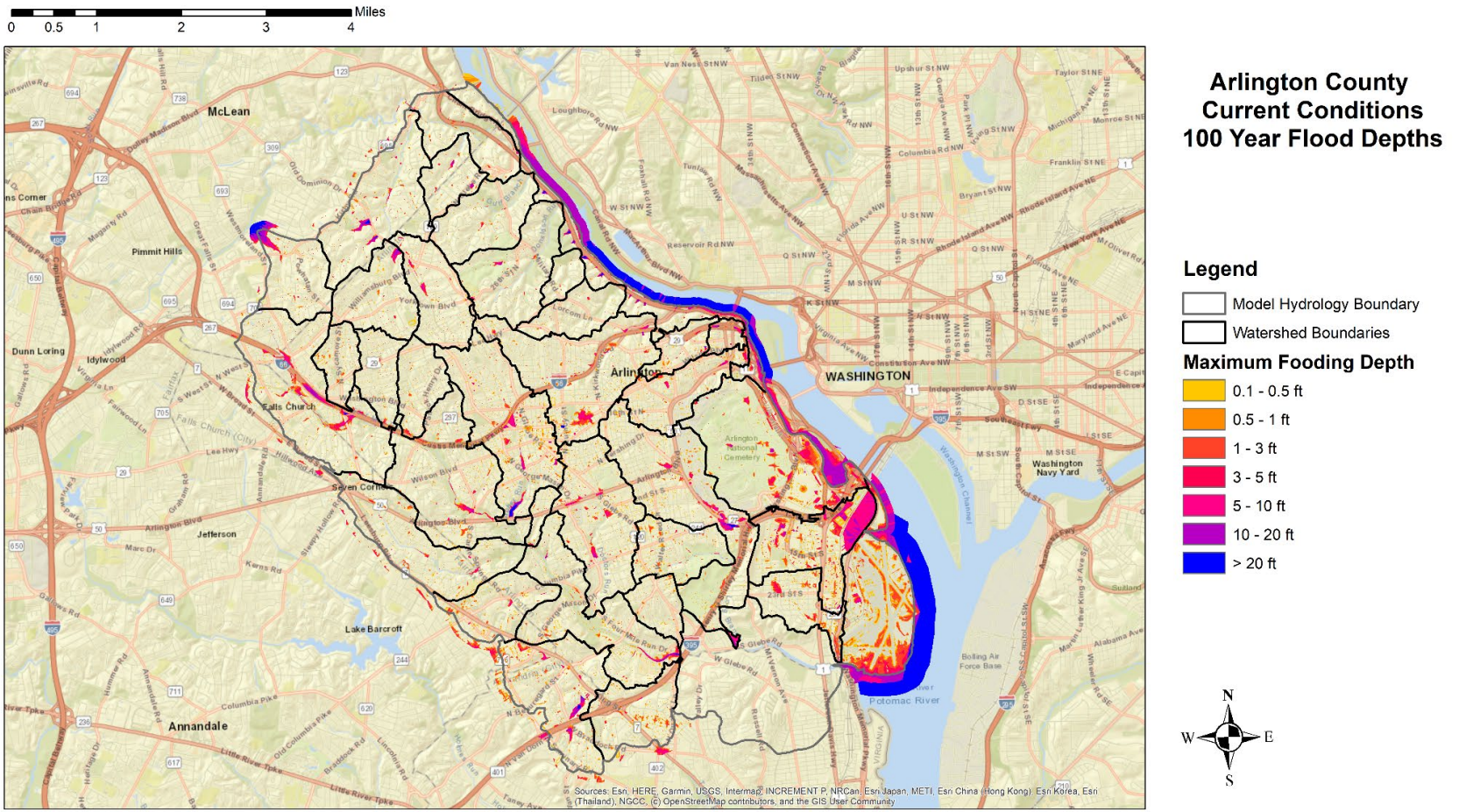



**Figure B-3. 100-year Prioritization Model Run Results**

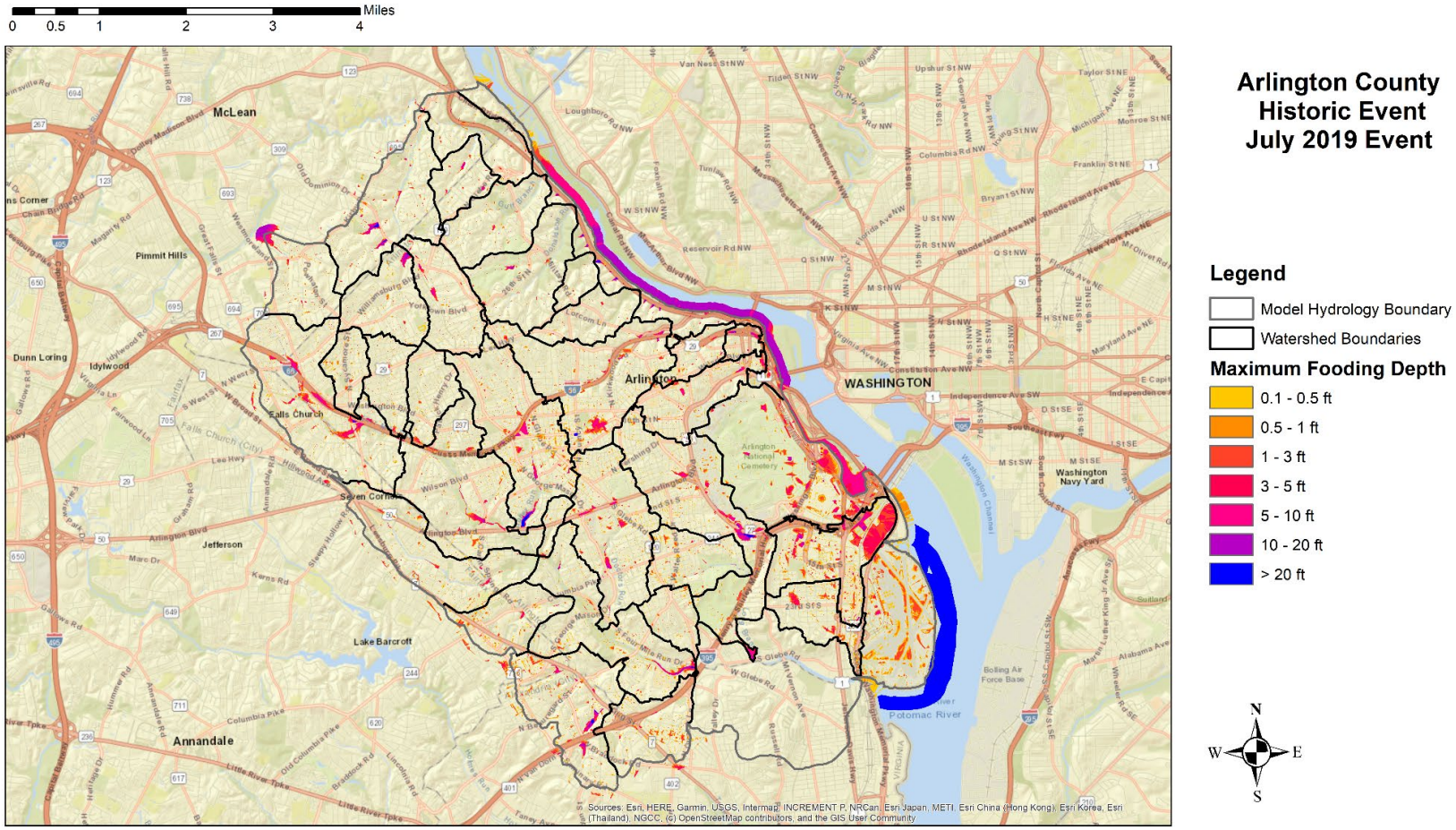



**Figure B-4. July 2019 Prioritization Model Run Results**

**100-year Refined Run Model Results**

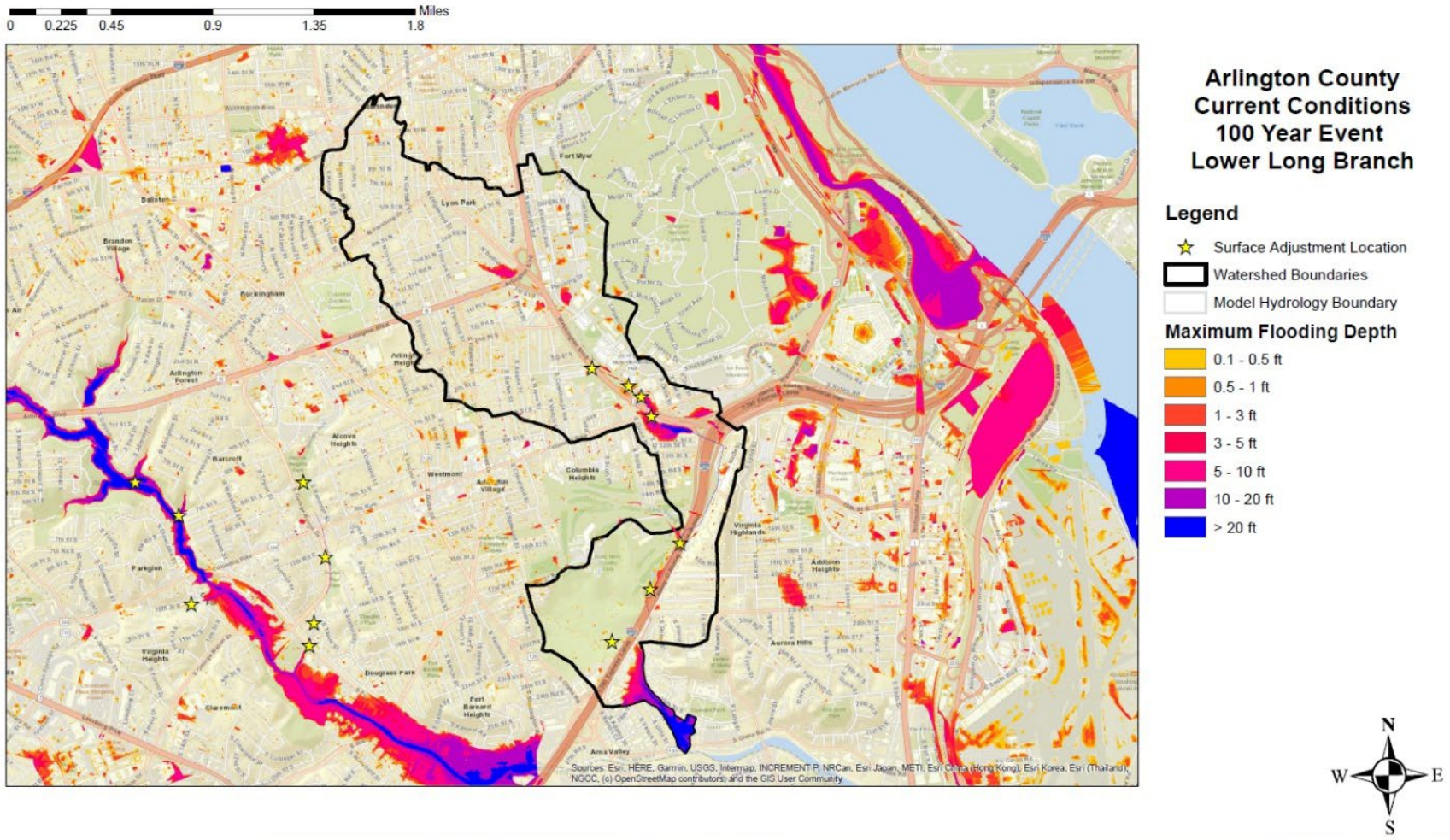



**Figure B-5. 100-year Model Results – Lower Long Branch Refined Run**

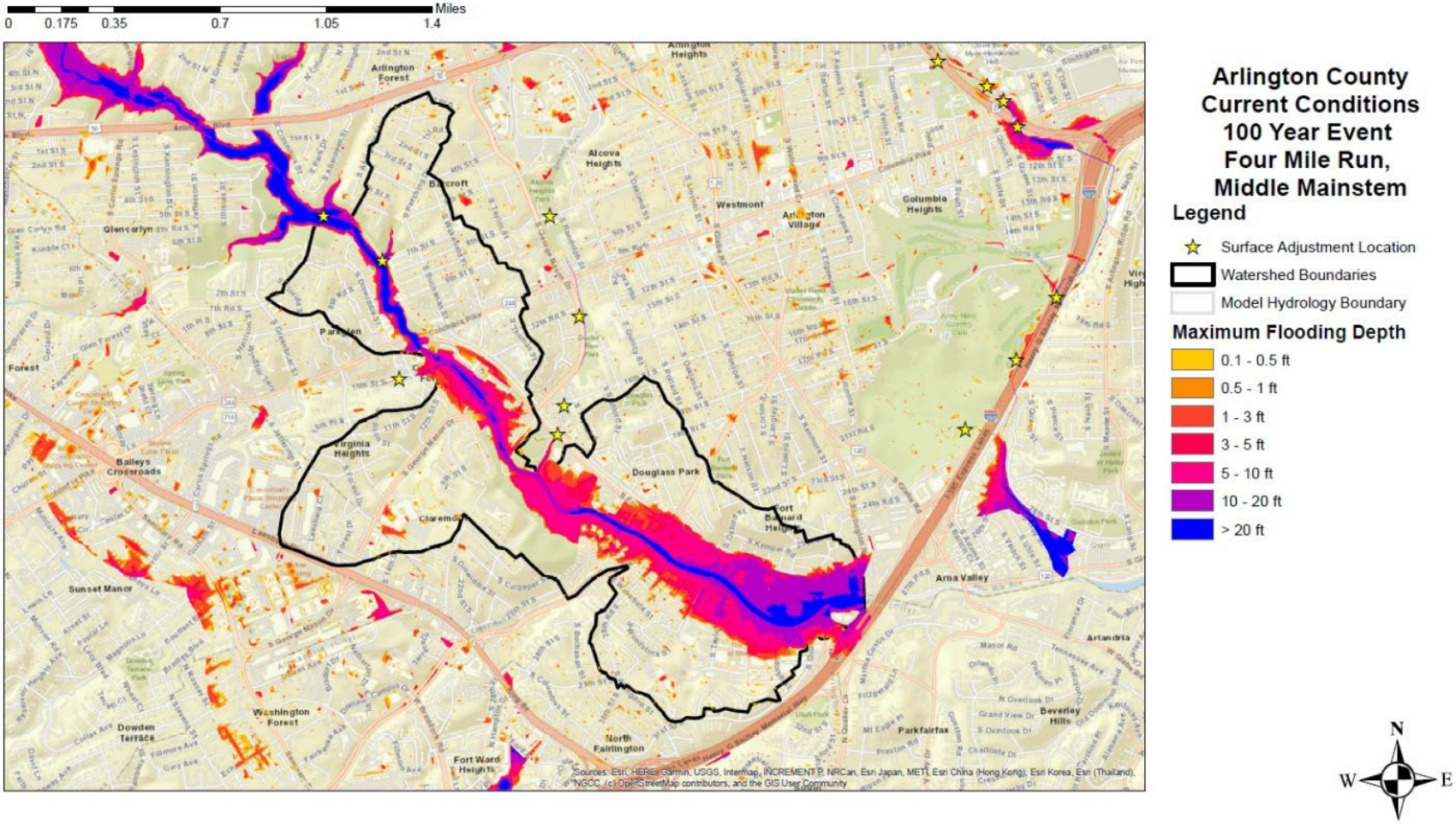



**Figure B-6. 100-year Model Results – Four Mile Run, Middle Mainstem Refined Run**

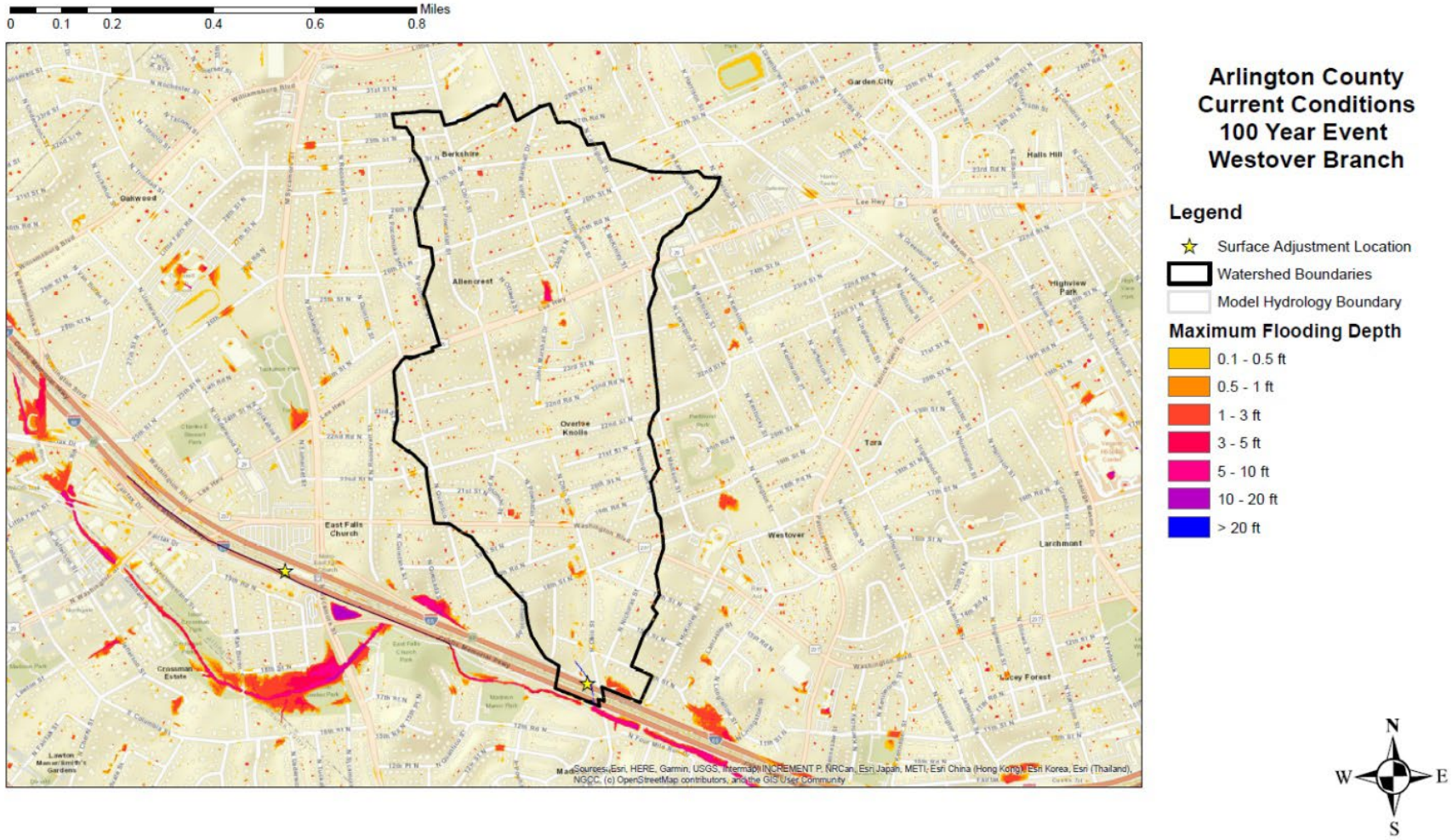



**Figure B-7. 100-year Model Results – Westover Branch Refined Run**

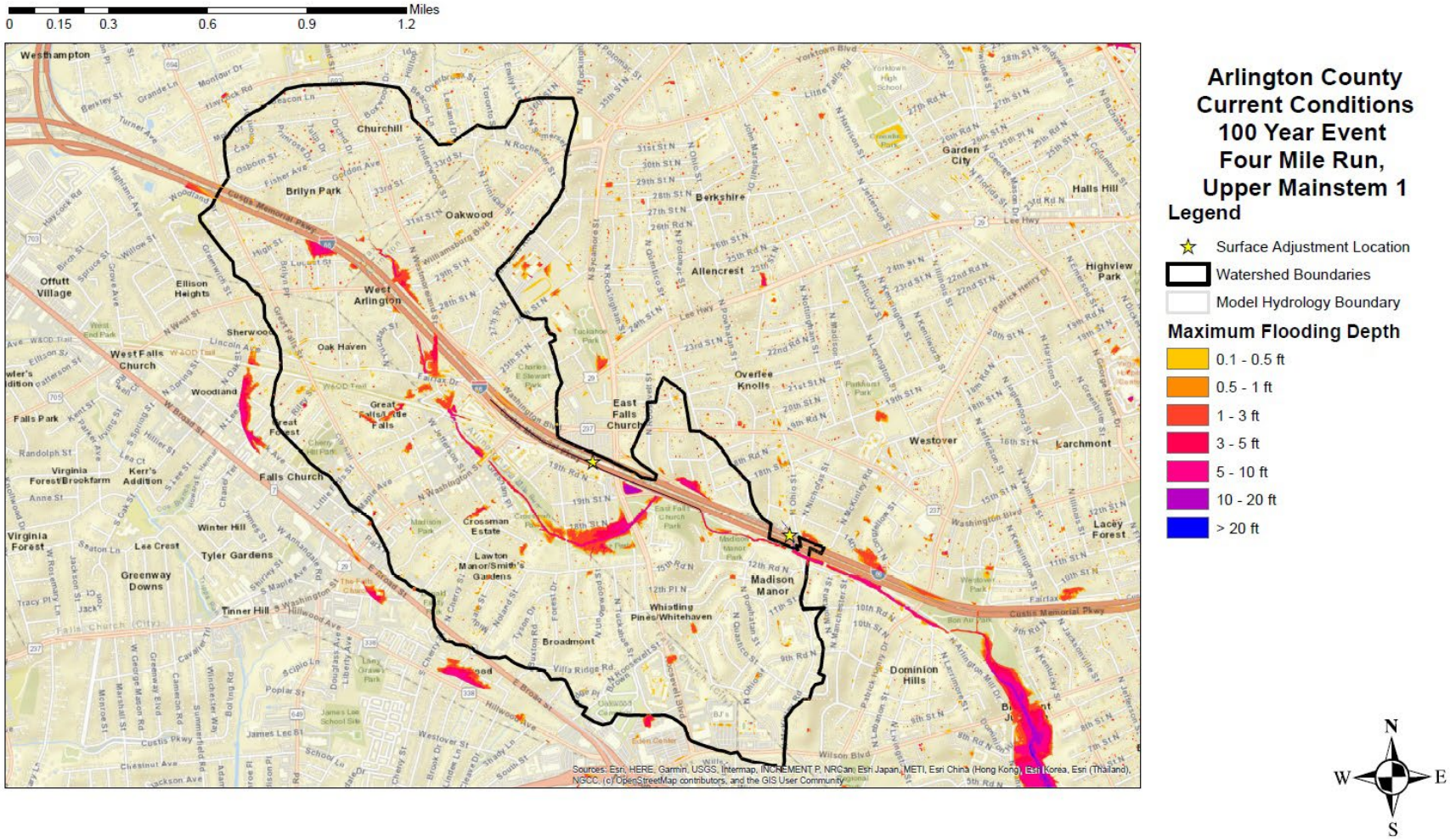



**Figure B-8. 100-year Model Results – Four Mile Run, Upper Mainstem 1 Refined Run**

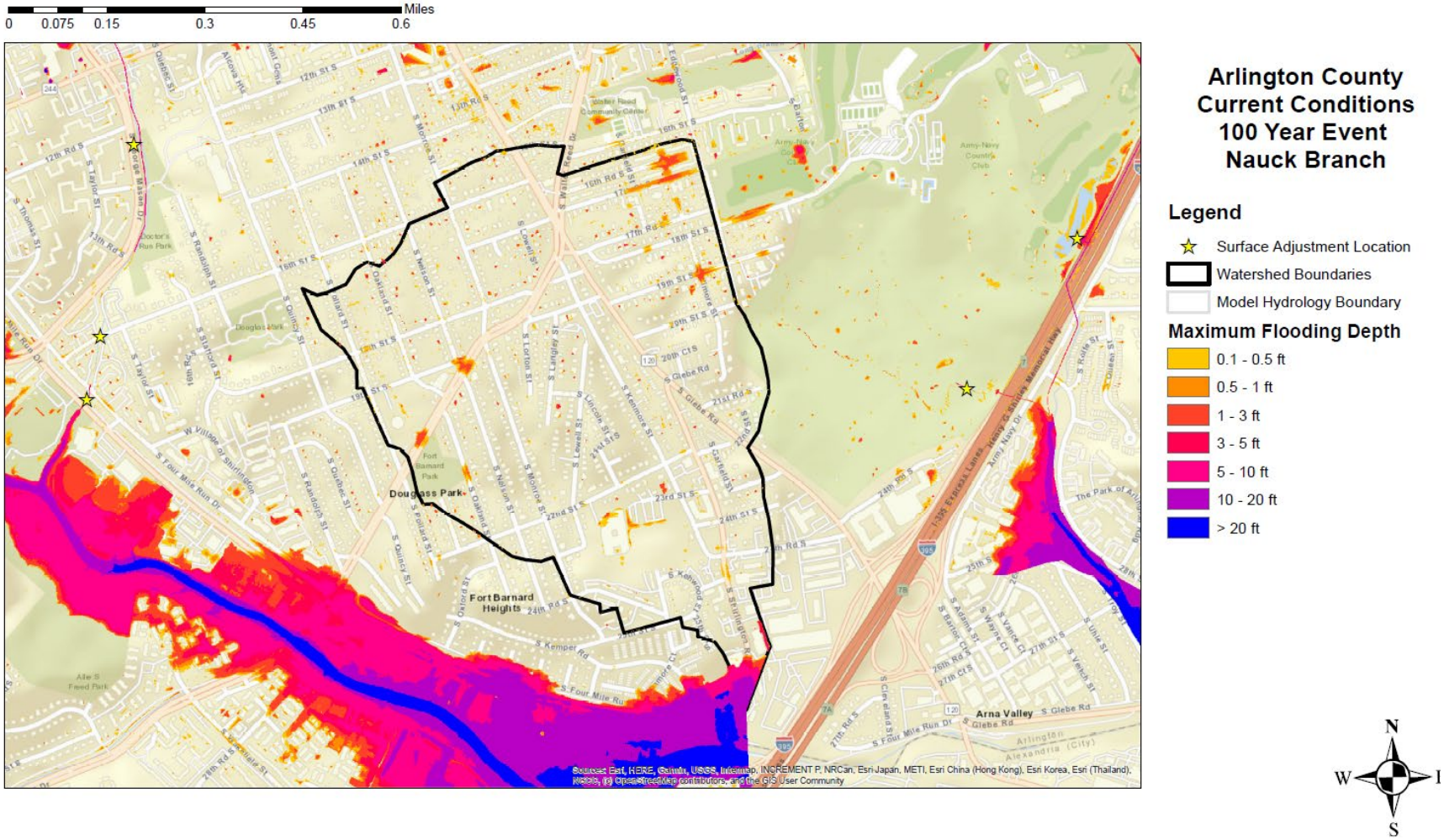



**Figure B-9. 100-year Model Results – Nauck Branch Refined Run**

**July 2019 Historical Event Refined Run Model Results**

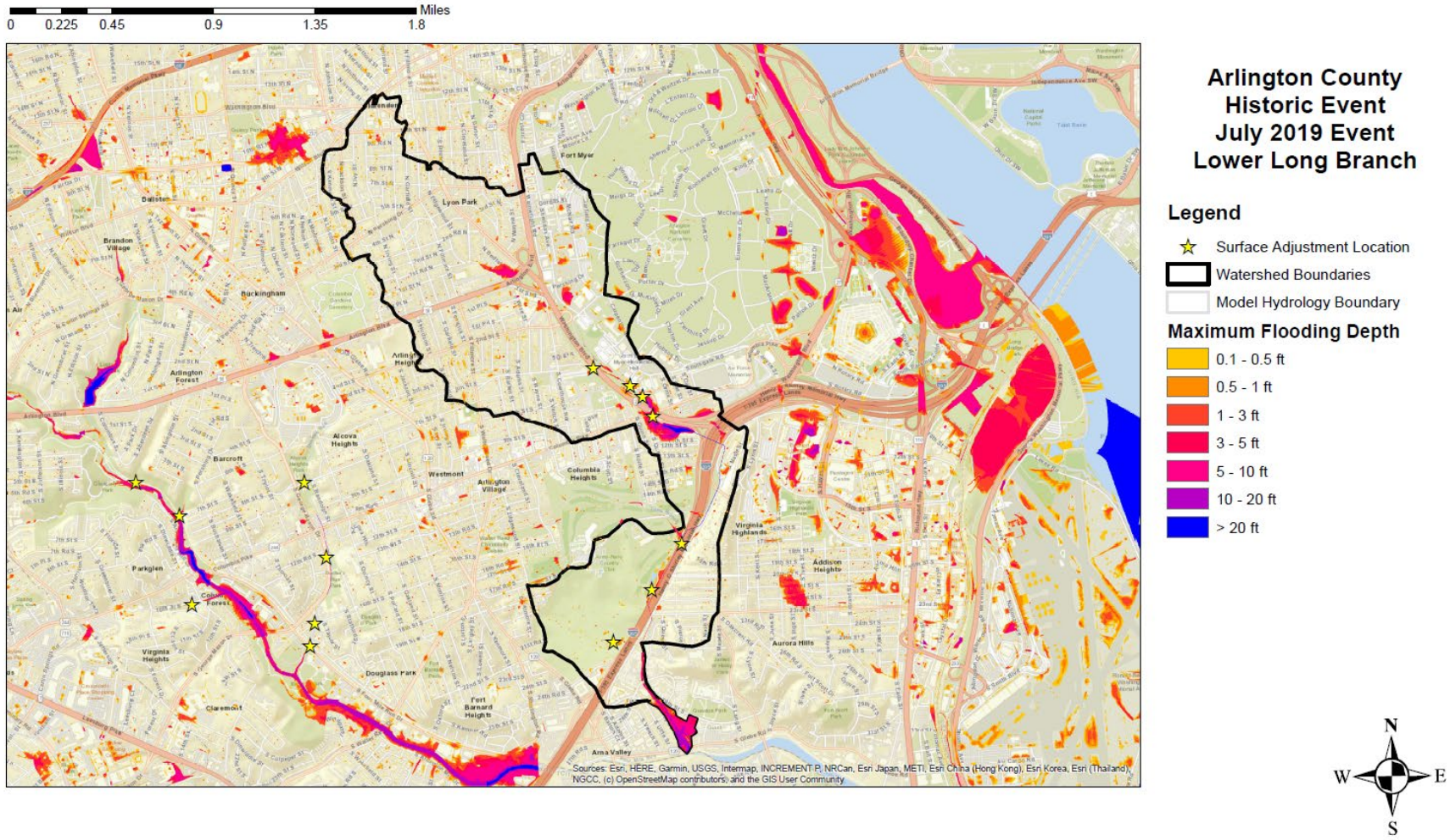



**Figure B-10. July 2019 Historical Event Model Results – Lower Long Branch Refined Run**

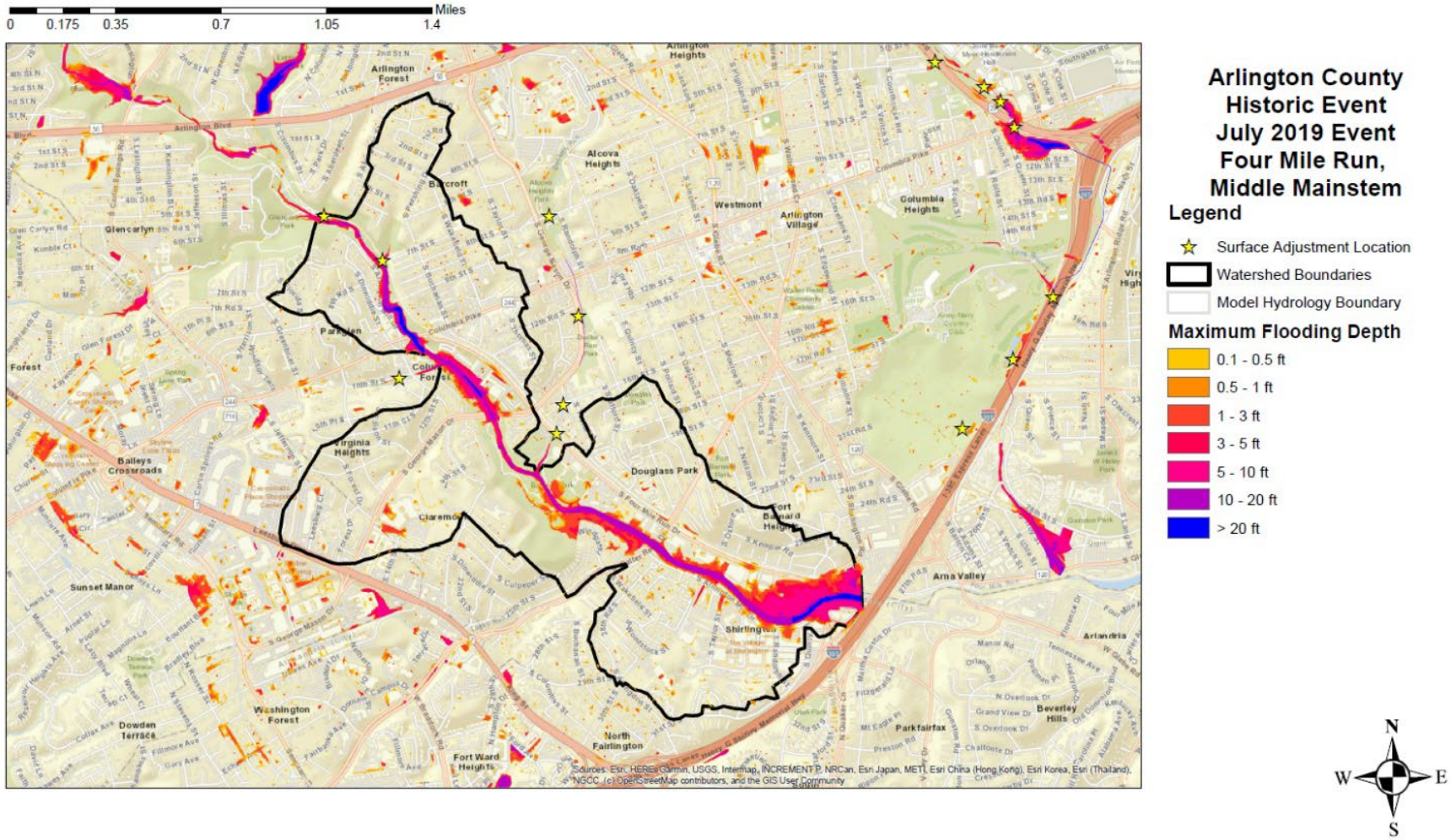



**Figure B-11. July 2019 Historical Event Model Results – Four Mile Run, Middle Mainstem Refined Run**

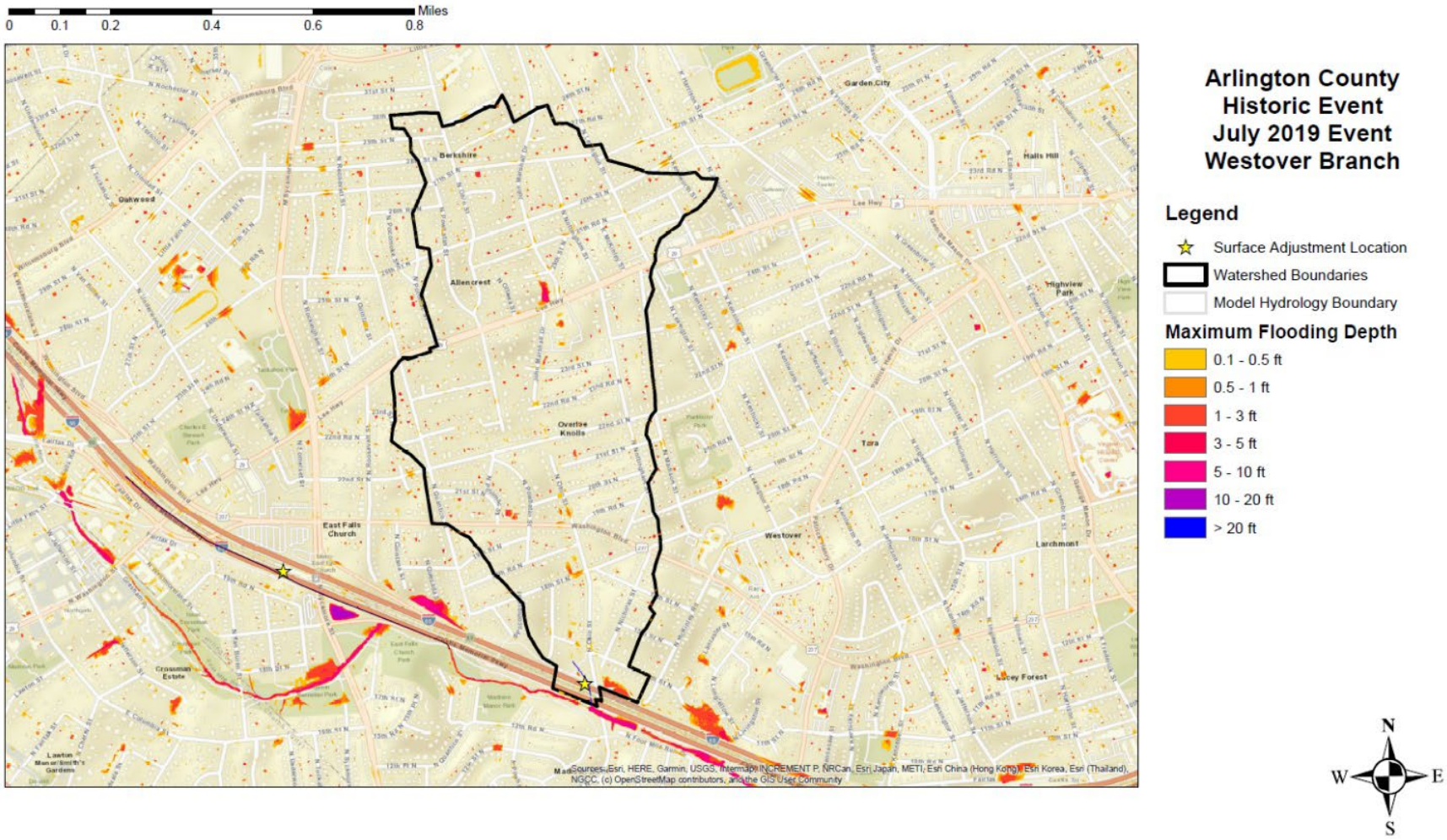



**Figure B-12. July 2019 Historical Event Model Results – Westover Branch Refined Run**

**Figure B-13. July 2019 Historical Event Model Results – Four Mile Run, Upper Mainstem 1 Refined Run**

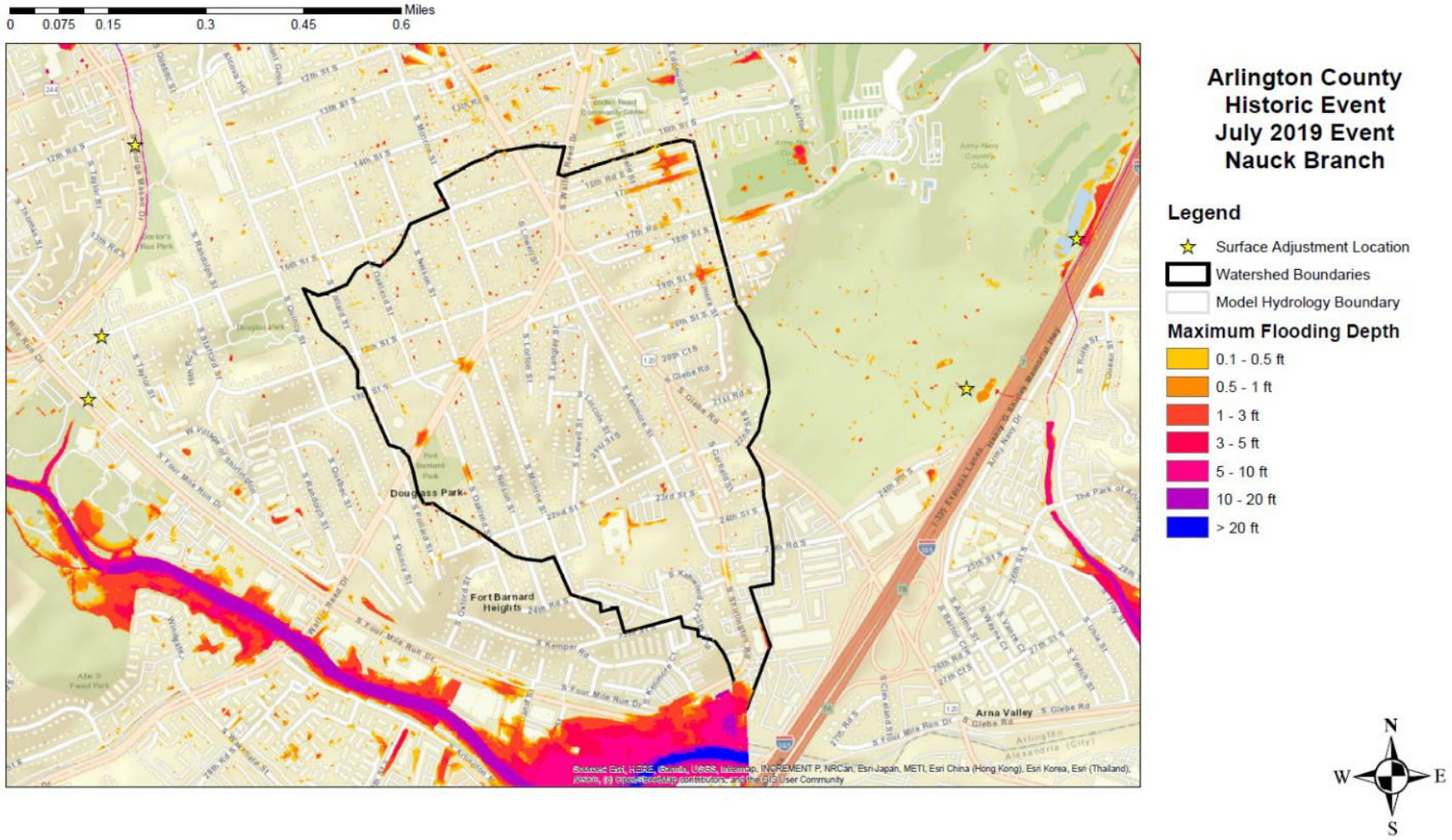



**Figure B-14. July 2019 Historical Event Model Results – Nauck Branch Refined Run**

# Appendix C
# Watershed Modeling Details

# Appendix C1. Four Mile Run (Lower Mainstem), Virginia Highlands, and Roaches Run Modeling Details

## C1.1 Watershed and Model Description

To allow overland flow to cross seamlessly from one watershed to another, the Four Mile Run (Lower Mainstem), Virginia Highlands and Roaches Run watersheds were combined into one 1D/2D PCSWMM model. The combined modeled area was approximately 2,624 acres. The drainage areas of Four Mile Run (Lower Mainstem), Virginia Highlands, and Roaches Run were 1,626, 381, and 617 acres, respectively. The combined area is located near the Potomac River at the southeast of Arlington County and drains into the Potomac River. Detailed 1D/2D modeling was performed for this combined watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2012 Arlington County model as a base for Roaches Run and the 1D Northern Virginia Regional Commission (NVRC) PCSWMM model as a base for the Virginia Highlands and Four Mile Run, Lower Mainstem watersheds. The locations of the three watersheds that make up the combined model are shown in Figure C1-1, Figure C1-2, and Figure C1-3.

## C1.2 Watershed-Specific Model Updates

### C1.2.1 1D Model Updates

#### C1.2.1.1 Four Mile Run, Lower Mainstem

1D model updates made to the Four Mile Run, Lower Mainstem watershed model were minor. No as-built updates were determined by Arlington County to be necessary for the Four Mile Run, Lower Mainstem watershed. The overland flow paths of the NVRC PCSWMM model were removed from the 1D model to avoid double-counting storage volume when the 2D mesh was built. Transects used to define the shape of the 1D open channel conduits were updated using the data from FEMA's preliminary HEC-RAS model dated 2020. These modifications are detailed in Appendix F.

#### C1.2.1.2 Roaches Run

1D model updates for the Roaches Run watershed were based on as-built plans entitled "Skyview at Pentagon Centre Building C" and "23rd Street South – Utility Relocation Plan Crystal City – Block M" and were determined by Arlington County to be necessary for the Roaches Run watershed. This as-built update consisted of updating 11 junctions and 14 conduits, and the addition of 7 junctions and 7 to the model. 2 junctions and 2 conduits were adjusted to merge the existing model with the as-built data in a hydraulically functional fashion. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built.

#### C1.2.1.3 Virginia Highlands

In the case of the Virginia Highlands watershed, 1D model updates involved major changes. The Virginia Highlands watershed boundary and network data were modified based on Arlington County's 2020 GIS dataset. Initial base layers consisting of geographic information system (GIS) shapefiles were obtained from Arlington County in 2020. Arlington County staff reviewed the record drawings available directly through the County and completed data updates in the County's GIS database. Arlington County GIS staff exported this information to an ArcGIS Geodatabase (GDB). The 1D updates to the Virginia Highlands model were based on this dataset.

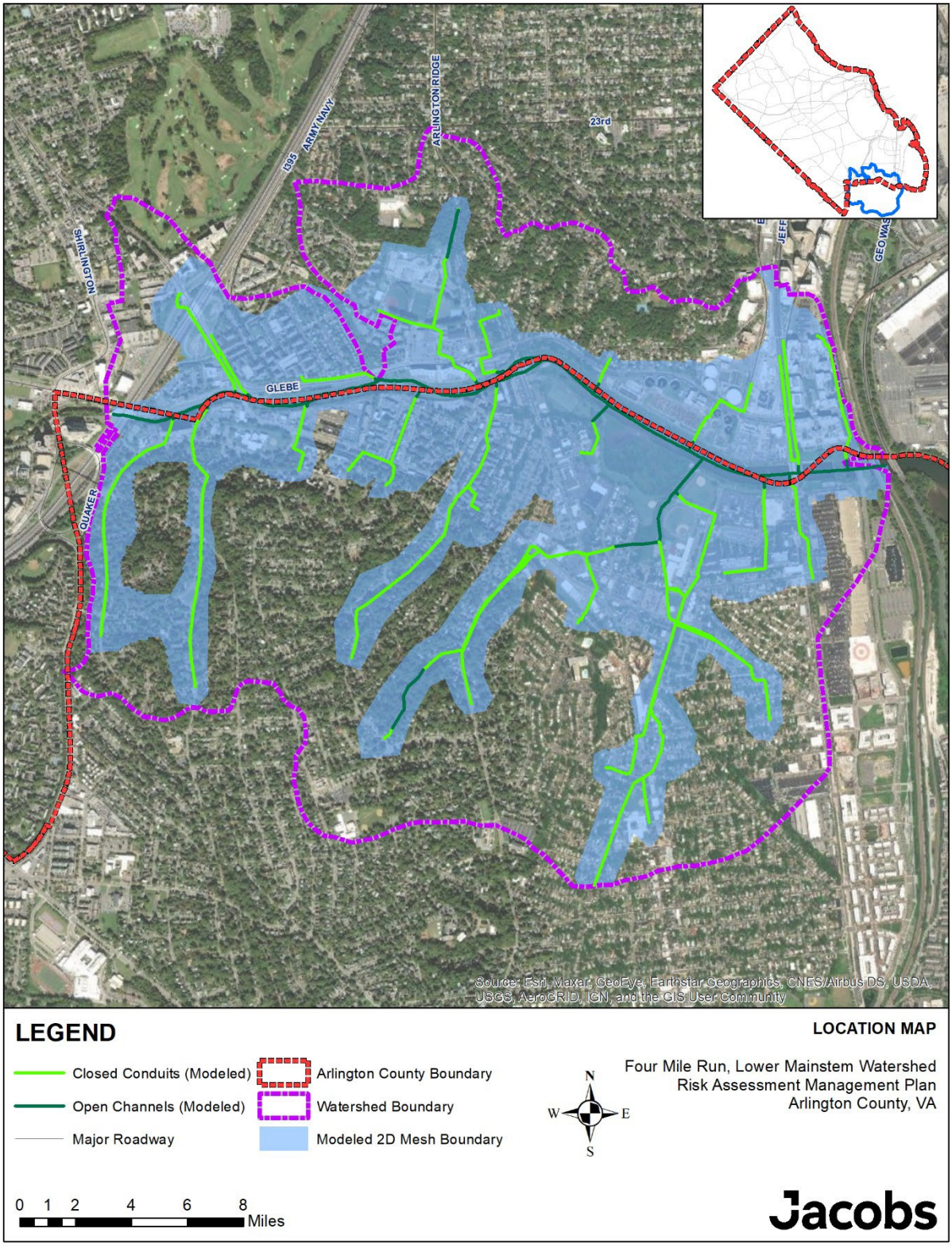



**Figure C1-1. Watershed Location Map – Four Mile Run, Lower Mainstem**

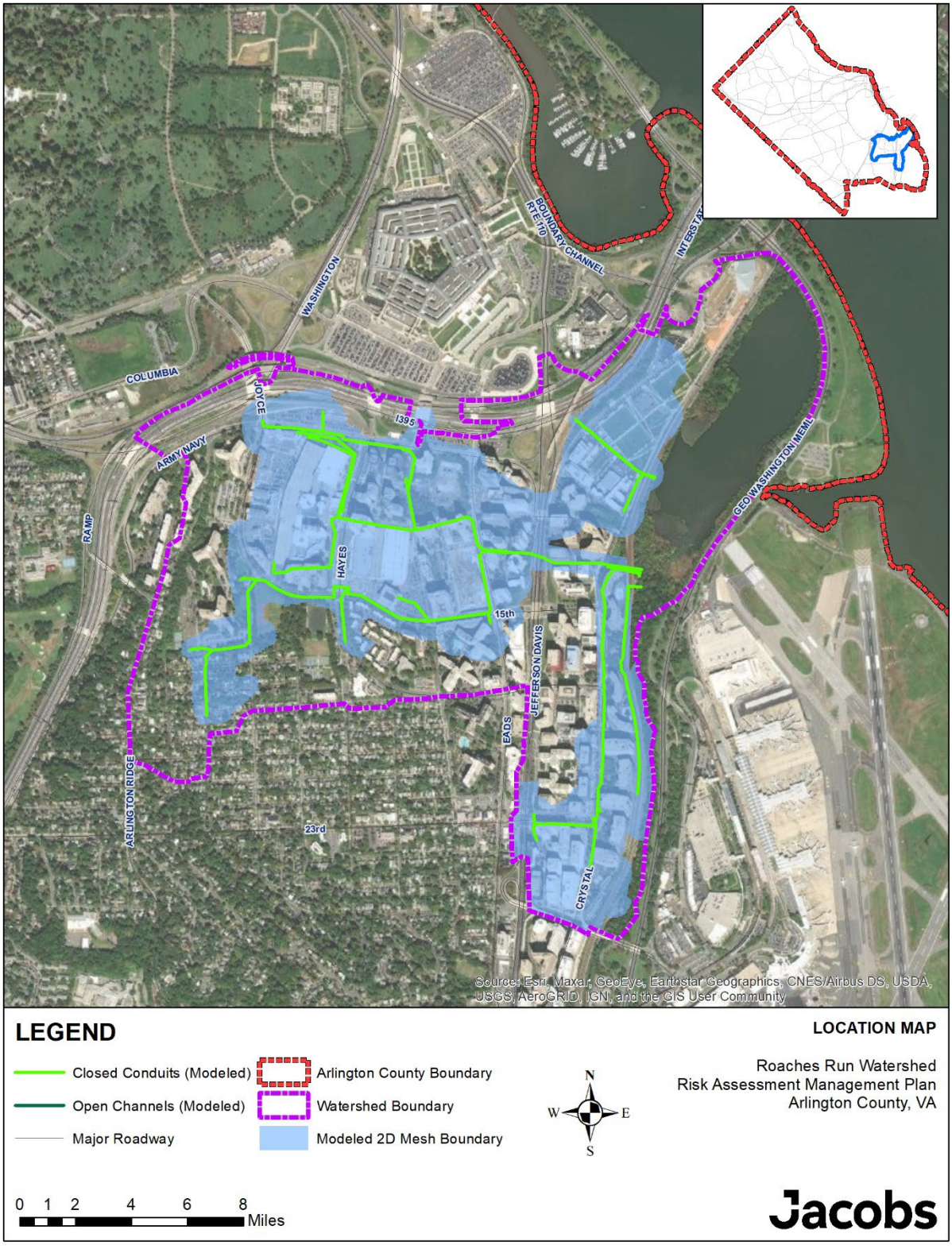



**Figure C1-2. Watershed Location Map – Roaches Run**

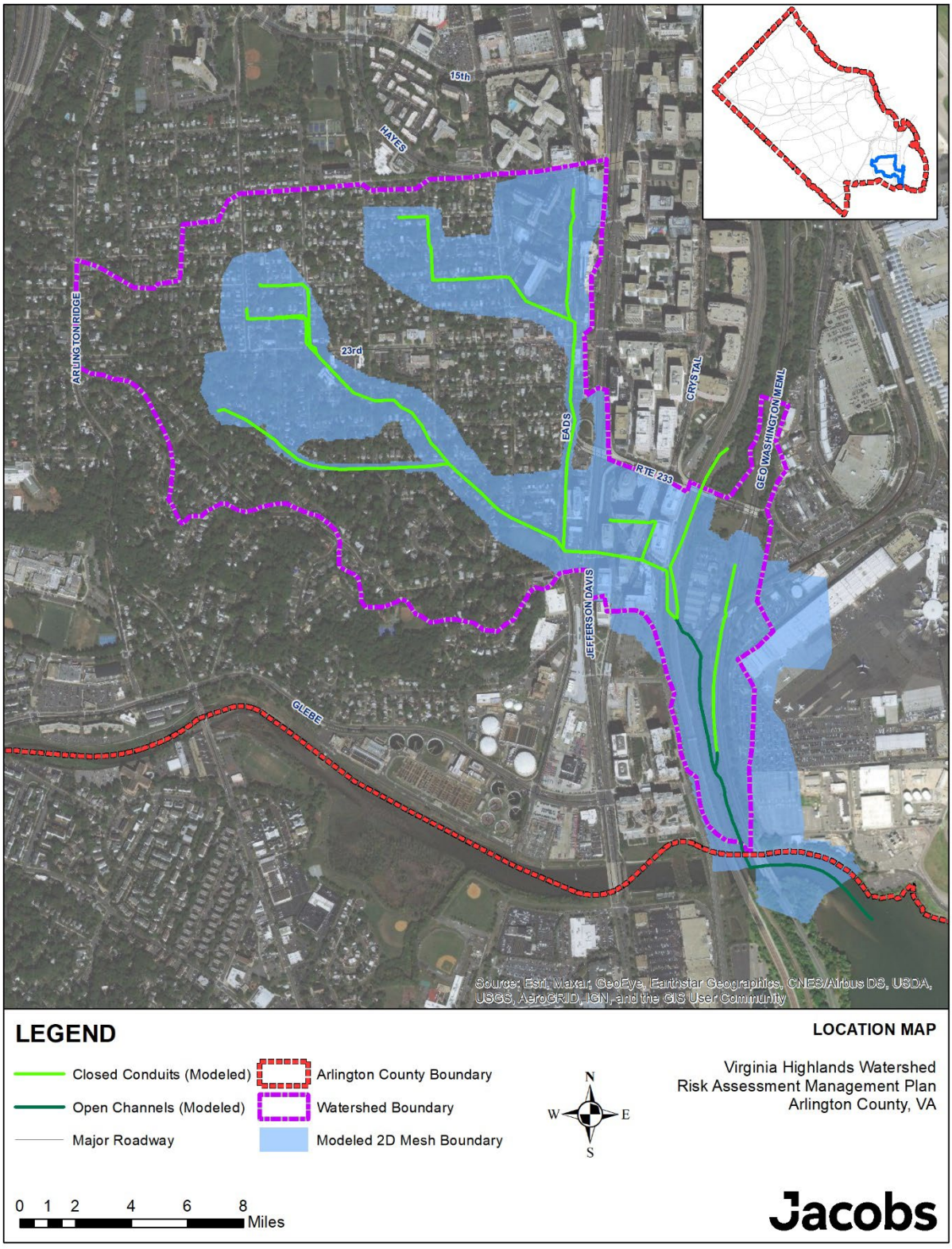



**Figure C1-3. Watershed Location Map – Virginia Highlands**

**Methodology**

The information provided by the County was used to find solutions to the data gaps and anomalies found in the ArcGIS GDB. The data gaps and anomalies were resolved by (in order of precedence):

1) Reviewing the information in the ArcGIS GDB
2) Interpolating across two or more links
3) Extrapolating from adjacent links

If a solution could not be found, the issue was discussed with the County and resolved. The model was then updated by incorporating the data with agreed upon resolutions.

#### C1.2.1.4 Updating Watershed Boundary

The watershed boundary of the Virginia Highlands of the NVRC PCSWMM model was originally developed using DEM data. According to the Arlington County 2020 GIS database, a number of links and nodes belonging to other watersheds were included in Virginia Highlands, and some links and nodes belonging to this watershed were excluded. The boundary was modified to ensure that all links and nodes only belonging to the Virginia Highlands watersheds are included. After updating the boundary of the Virginia Highlands watershed, all hydrological properties of the watershed were calculated and updated in the model.
All changes made to the watershed boundary are listed in Table C1-1 and illustrated on Figure C1-3.

**Table C1-1. Virginia Highlands Watershed Boundary Modification Details**

| Subwatershed Name | Outlet | Area (ac) | Width (ft) | Flow Length (ft) | Slope (%) | Imperv. (%) |
|---|---|---|---|---|---|---|
| VH_10019 | 18071 | 1.74 | 346.72 | 218.60 | 3.25 | 36.11 |
| VH_10014 | 27888 | 53.71 | 3729.75 | 627.28 | 5.09 | 49.51 |
| VH_10013 | 17194 | 17.10 | 2161.89 | 344.55 | 5.29 | 75.87 |
| VH_10021 | 18089 | 22.92 | 625.85 | 1595.26 | 11.39 | 37.59 |
| VH_10020 | 18079 | 2.03 | 694.87 | 127.26 | 4.92 | 48.20 |
| VH_10017 | 18104 | 4.39 | 461.64 | 414.24 | 4.33 | 41.85 |
| VH_10016 | 18608 | 51.33 | 2735.02 | 817.52 | 7.84 | 43.29 |
| VH_10022 | 18981 | 14.37 | 1851.31 | 338.12 | 14.09 | 39.99 |
| VH_10015 | 19119 | 36.16 | 2375.02 | 663.21 | 12.24 | 34.69 |
| VH_10012 | 18096 | 29.86 | 3096.44 | 420.06 | 4.95 | 60.17 |
| VH_10011 | 19637 | 23.78 | 1311.27 | 789.97 | 9.81 | 58.94 |
| VH_10010 | 19439 | 4.15 | 81.96 | 2205.64 | 3.68 | 85.69 |
| VH_10007 | 19729 | 11.31 | 1045.01 | 471.44 | 3.68 | 72.84 |
| VH_10006 | 29364 | 11.69 | 671.53 | 758.29 | 9.42 | 34.12 |
| VH_10004 | 20049 | 20.60 | 2203.51 | 407.23 | 11.00 | 28.60 |
| VH_10003 | 19762 | 12.05 | 1124.47 | 466.80 | 9.91 | 37.82 |
| VH_10002 | 20269 | 18.27 | 1475.32 | 539.44 | 5.67 | 63.66 |

**Table C1-1. Virginia Highlands Watershed Boundary Modification Details**

| Subwatershed Name | Outlet | Area (ac) | Width (ft) | Flow Length (ft) | Slope (%) | Imperv. (%) |
|---|---|---|---|---|---|---|
| VH_10001 | STIC0004 | 4.45 | 1527.82 | 126.88 | 19.17 | 7.59 |
| VH_10018 | 17824 | 20.54 | 1130.63 | 791.35 | 4.35 | 45.06 |
| VH_10023 | 18752 | 13.39 | 891.29 | 654.41 | 11.97 | 41.24 |
| VH_10009 | 19459 | 2.12 | 427.39 | 216.07 | 2.04 | 86.37 |
| VH_10008 | 25914 | 1.82 | 624.08 | 127.03 | 1.94 | 83.19 |
| VH_10005 | 25910 | 3.34 | 1777.73 | 81.84 | 4.61 | 37.52 |

**Resolving Link and Network Gaps and Anomalies**

Link gaps and anomalies occur when a link has incorrect size, type, material, or upstream/downstream node information. Link anomalies were resolved through discussions with the County.

Network anomalies included a number of segments where the pipe diameter was changed as illustrated on Figure C1-3. Through communication with the County, the pipe segments that had correct diameters were validated and those that required changes were updated with the data provided by the County. Additionally, a number of pipes that had not been included in the model previously were added to the model as illustrated in Figure C1-3.

**Resolving Invert and Rim Elevation Data Gaps and Anomalies**

Invert and rim elevation data gaps occur when a node is missing its invert/rim elevation or when a link is missing its upstream/downstream invert elevation. Rim elevation data gaps and anomalies were resolved by interpolating from the DEM data. Invert elevation data gaps and anomalies were resolved by using known invert elevations from connected links or interpolating between two or more links assuming a constant slope.

The following types of invert anomalies were identified:

- Invert of incoming link lower than node invert
- Invert of outgoing link lower than node invert
- Invert of outgoing link higher than node invert
- Invert of outgoing link higher than the invert of incoming link at a node
- Invert of incoming link more than 4 feet higher than the node invert (drop over 4 feet)
- Downstream invert is higher than upstream invert of a link (negative slope)

**Virginia Highlands 1D Model Update Summary**

In total, 15 links and 83 nodes were identified with data gaps and anomalies. These represent 10 percent of the links (148) and 57 percent of the nodes (148) utilized in the 1D model. All of these data gaps were resolved by interpolating values from known information and discussing with County staff. The updated node and link information was used to develop the Virginia Highlands 1D/2D PCSWMM model.

### C1.2.2 2D Model Updates

A hexagonal 2D mesh with a 20 feet resolution was constructed for the Four Mile Run, Lower Mainstem and Virginia Highland watersheds, and a mesh with 25 feet resolution was constructed for the Roaches Run watershed. The total number of cells in the combined watershed was 91,492. 932 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C1.2.2.1 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the combined watershed. Three types of orifice modifications were performed:

- In one case scenario, orifices were removed in locations where there were no existing street/curb or area inlets. Alternatively, in some cases orifice width was modified from 24′ to 10′ or 6′ instead of being removed where there was potential for water being lost from the system without an orifice but the density of existing inlets was low.
- In a second case scenario, extended orifices were added with a width of either 12′ or 24′ at locations where there was a high density of existing inlets, or where the model was inaccurately showing flooding in the areas of no known or suspected flooding.
- In a third case scenario, orifice width was increased for all orifices adjacent to the open channel to more accurately represent the flow from 1D open channel to 2D mesh.

#### C1.2.2.2 Open Channel Modeling

After the initial 2D mesh was built and the initial 1D/2D model was run for the 2070 500-year, 24-hour synthetic event, it was observed that refinements of the 1D open channel conduits in the Four Mile Run, Lower Mainstem and Virginia Highlands models were needed to more accurately reflect the overbank/ channel dynamics. The following paragraphs detail the adjustments made to the model in the vicinity of the open channels in order to more accurately represent channel flow during flood events.

Some open channel 1D conduits were split to allow for more detailed modeling of the open channels and overbank/channel interactions. In these cases, the transect that had been used in FEMA's HECRAS Model 2020 to represent a typical cross section for the entire reach was copied, and low bank elevations were modified to reflect the low bank elevation for the new, shorter reach. In the combined model a total of 103 transects were copied and the 1D open channel conduit was split accordingly. The invert elevations or overbank tops were adjusted, with the copied versions named with suffixes "_v2", "_v3", etc. (e.g. "21668_v2") in order to indicate the base transect.

Transect modifications were made in order to trim the transects copied from FEMA's preliminary HEC-RAS model dated 2020 so that there was no overlap between the volume accounted for in the open channel by the 1D conduit and the volume accounted for in the overbank by the 2D mesh. The transects were trimmed so that the 1D conduits represent water flowing within the channel and exclude water flowing in the overbank or over the low bank elevation during flood conditions. More information on this process is provided in Appendix D.

The 2D mesh node inverts over open channels were modified so that there was no overlap between the volume accounted for in the 1D open channel conduit and the volume accounted for in the 2D mesh. The invert elevations of all 2D mesh elements that fell within the transect width were adjusted to match the low bank elevation of the channel (the 2D mesh invert elevations had been automatically set to the channel invert during the 2D mesh build). More information on this process is provided in Appendix D.

Modifications were made to the inlet offset elevations of orifices adjacent to open channels to more accurately represent flow in channels. Specifically, there were many locations in FEMA's preliminary HECRAS model where the transects for the open channel conduits had bank elevations higher than the bank elevations indicated by the DEM. In these cases, the orifice inlet offset elevations, which were automatically assigned to its associated 1D node's rim elevation during the 2D mesh build, were modified to reflect the DEM elevation instead.

#### C1.2.2.3 Glass Wall at Downstream Boundary of Mesh

Particular attention was taken when modeling the 2D mesh to prevent the creation of a "glass wall", where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. The glass wall effect inconsistently represents flooding because water that would have naturally cross the 2D mesh extent boundary in the existing condition is limited to a certain area by the limit of the model extent. Care was taken to expand the mesh extents in areas where glass-walling occurred to cover the low spot. However, in some cases the creation of a glass wall was unavoidable (e.g. at downstream boundaries). This was the case in the combined watershed 1D/2D model. To account for the pooling at the watershed's outlet to Potomac River, wide conduits were used to connect the 2D mesh to an outfall to reduce the depth of water in the cells at the boundary of the mesh to accurate levels. Also, 5 outlets were added along the George Washington Memorial Parkway near Ronald Reagan Washington National Airport at the boundary cells of the mesh so that the model can accurately calculate the water level. More information on this process is provided in Appendix D.

## C1.3 Model Validation

The 1D/2D model was validated against several synthetic and historic rainfall events.

### C1.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C1.3.2 Historical Event Validation

Historical flood call data was reviewed for the June 2006, May 2018, July 2018, and July 2019 historic events. The Four Mile Run, Lower Mainstem watershed had 26 recorded flooding incidents from the June 2006 event, one recorded incident from the June 2018 event and 2 recorded incident from the July 2019 event, and the Virginia Highlands watershed had 8 recorded flooding incidents from the June 2006 event. The model was found to generally match incident data and available flood location observations for the historic events, and accurately represented chronic flood locations. The blanket orifice assumptions were customized where anecdotal flood information was available to more accurately represent documented flooding. Orifice modifications were made as specified in the three case scenarios presented in Section C1.2.2.

## C1.4 Model Results

Flood inundation areas greater than 6" in depth for each scenario and watershed are presented in Table C1-2.

**Table C1-2. Flood Inundation Areas for Four Mile Run, Lower Mainstem**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 132.24 ac | 8.13% |
| 10-yr, 24-hr (2020) | 180.56 ac | 11.11% |
| 10-yr, 24-hr, (2040) | 207.10 ac | 12.74% |
| 10-yr, 24-hr (2070) | 236.72 ac | 14.56% |
| 100-yr, 24-hr (2020) | 319.21 ac | 19.63% |
| 100-yr, 24-hr (2040) | 337.09 ac | 20.73% |
| 100-yr, 24-hr (2070) | 353.96 ac | 21.77% |
| 500-yr, 24-hr (2020) | 380.00 ac | 23.37% |
| 500-yr, 24-hr (2040) | 398.12 ac | 24.49% |
| 500-yr, 24-hr (2070) | 413.20 ac | 25.41% |

**Table C1-3. Flood Inundation Areas for Virginia Highlands**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 11.85 ac | 3.11% |
| 10-yr, 24-hr (2020) | 12.11 ac | 3.18% |
| 10-yr, 24-hr, (2040) | 13.91 ac | 3.65% |
| 10-yr, 24-hr (2070) | 16.52 ac | 4.33% |
| 100-yr, 24-hr (2020) | 30.84 ac | 8.09% |
| 100-yr, 24-hr (2040) | 34.34 ac | 9.01% |
| 100-yr, 24-hr (2070) | 39.57 ac | 10.38% |
| 500-yr, 24-hr (2020) | 51.01 ac | 13.38% |
| 500-yr, 24-hr (2040) | 58.19 ac | 15.27% |
| 500-yr, 24-hr (2070) | 63.31 ac | 16.61% |

**Table C1-4. Flood Inundation Areas for Roaches Run**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 7.97 ac | 1.29% |
| 10-yr, 24-hr (2020) | 7.19 ac | 1.16% |
| 10-yr, 24-hr, (2040) | 9.49 ac | 1.54% |
| 10-yr, 24-hr (2070) | 12.14 ac | 1.97% |
| 100-yr, 24-hr (2020) | 32.75 ac | 5.31% |

**Table C1-4. Flood Inundation Areas for Roaches Run**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| 100-yr, 24-hr (2040) | 37.44 ac | 6.06% |
| 100-yr, 24-hr (2070) | 41.61 ac | 6.74% |
| 500-yr, 24-hr (2020) | 55.16 ac | 8.94% |
| 500-yr, 24-hr (2040) | 61.32 ac | 9.93% |
| 500-yr, 24-hr (2070) | 72.29 ac | 11.71% |

# Appendix C2. Doctor's Branch Modeling Details

## C2.1 Watershed and Model Description

The Doctor's Branch watershed has a modeled tributary area of approximately 886 acres. It is located near the center of Arlington County and drains into Four Mile Run. Detailed 1D/2D modeling was performed for this watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2012 Arlington County model for Doctor's Branch as a base. The location of the Doctor's Branch watershed is shown on Figure C2-1.

## C2.2 Watershed-Specific Model Updates

### C2.2.1 1D Model Updates

1D model updates for this watershed were minor. No as-built updates were determined by Arlington County to be necessary for the Doctor's Branch watershed. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built. Additionally, some modifications were made to subcatchment routing to more accurately represent inflow into the system. These modifications are detailed in Table C2-1.

**Table C2-1. Subcatchment Routing Modification Documentation**

| 1D Junction Name | Orifice Modification |
|---|---|
| W14190 | Changed outlet from 1D junction 14320 to 1D junction 24756 |
| W14510 | Changed outlet from 1D junction 24888 to 1D junction 24887 |

### C2.2.2 2D Model Updates

A hexagonal 2D mesh with 47,195 cells and a resolution of 20 feet was constructed for the Doctor's Branch watershed. 292 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C2.2.2.1 Flood Modeller FAST Comparison

As described in Section 2.2.4 in the main body of the report, 2D results from the 500-year, 24-hour future conditions (Year 2070) storm event run in the PCSWMM 1D/2D model were compared against 2D FAST model results. There was one location where the FAST results exceeded the flooding in the PCSWMM model. However, it was determined that buildings had been constructed in that location in 2008-2009, after the topographic data used for the FAST runs were developed. The ground surface was modified in PCSWMM to accurately reflect the presence of these buildings and was determined to accurately represent surface flow dynamics based on the existing condition.

#### C2.2.2.2 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the Doctor's Branch watershed. Three types of orifice modifications were performed:

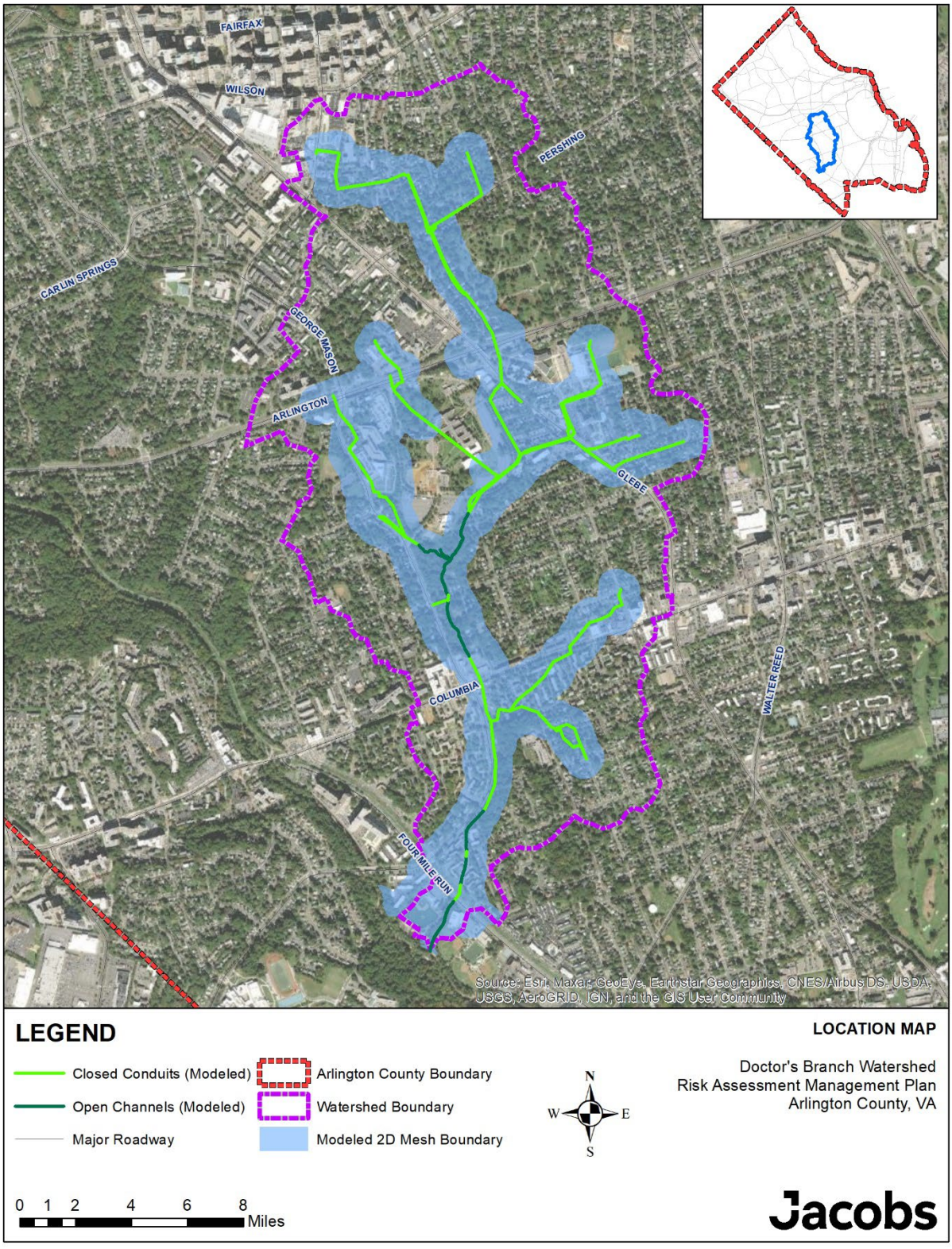



**Figure C2-1. Watershed Location Map**

- In one case, orifices were removed in locations where there were no existing street/curb or area inlets. Alternatively, in some cases orifice width was modified from 24' to 6' instead of being removed where there was potential for water being lost from the system without an orifice.
- In a second case, orifice width was reduced from 24' to 12' in locations where there were a low density of existing inlets.
- In a third case, extended orifices were added with a width of either 12' or 24' in locations where there was a high density of existing inlets, or where the model was inaccurately showing flooding where there is no known or suspected flooding.

#### C2.2.2.3 Open Channel Modeling

After the initial 2D mesh build and initial 1D/2D run of the 2070 500-year, 24-hour synthetic event, it was observed that refinement of the 1D open channel conduits in the Doctor's Branch model were needed to more accurately reflect the overbank/channel dynamics. The following paragraphs detail adjustments made to the model in the vicinity of the open channels in order to more accurately represent channel flow during flood events.

Some open channel 1D conduits were split to allow for more detailed modeling of the open channels and overbank/channel interaction. In these cases, the transect that had been used in the base model to represent a typical cross section for the entire reach was copied, and low bank elevations were modified to reflect the low bank elevation for the new, shorter reach. 1D open channel conduits corresponding to transects xsec1, xsec2, xsec5a, xsec5b, xsec6, and xsec7b were split for this reason. These transects were copied and invert elevations or overbank tops adjusted, with the copied versions named with suffixes "_v2", "_v3", etc. (eg. "xsec1_v2") in order to indicate the base transect.

Transect modifications were made in order to trim the transects in the Arlington County base model so that there was no overlap between the volume accounted for in the open channel by the 1D conduit and the volume accounted for in the overbank by the 2D mesh. The transects were trimmed so that the 1D conduits represent water flowing within the channel and exclude water flowing in the overbank or over the low bank elevation during flood conditions. More information on this process is provided in Appendix A. This trimming process was performed for transects xsec1 and xsec3.

The 2D mesh node inverts over open channels were modified so that there was no overlap between the volume accounted for in the 1D open channel conduit and the volume accounted for in the 2D mesh. The invert elevations of all 2D mesh elements that fell within the transect width were adjusted to match the low bank elevation of the channel (the 2D mesh invert elevations had been automatically set to the channel invert during the 2D mesh build). More information on this process is provided in Appendix D.

Modifications were made to the inlet offset elevations of orifices adjacent to open channels to more accurately represent flow in channels. Specifically, there were many locations in the Arlington County base model where the transects for the open channel conduits had bank elevations higher than the bank elevations indicated by the DEM. In these cases the orifice inlet offset elevations, which were automatically assigned to its associated 1D node's rim elevation during the 2D mesh build, where modified to reflect the DEM elevation instead.

#### C2.2.2.4 Glass Wall at Downstream Boundary of Mesh

Particular attention was taken when modeling the 2D mesh to prevent the creation of a "glass wall", where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. The glass wall effect inconsistently represents flooding because water that would have naturally cross the 2D mesh extent boundary in the existing condition is limited to a certain area by the limit of the model extent.

Care was taken to expand the mesh extents in areas where glasswalling occurred to cover the low spot. However, in some cases the creation of a glass wall was unavoidable (i.e. at downstream boundaries). This was the case in the Doctor's Branch 1D/2D model. To account for the pooling at the watershed's outlet to Four Mile Run, wide conduits were used to connect the 2D mesh to an outfall to reduce the depth of water in the cells at the boundary of the mesh to accurate levels. More information on this process is provided in Appendix D.

## C2.3 Model Validation

The 1D/2D model was validated against several synthetic and historical rainfall events.

### C2.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C2.3.2 Historic Event Validation

Reported flood incident data was reviewed for the June 2006, May 2018, July 2018, and July 2019 historical events. The Doctor's Branch watershed had 4 recorded flooding incidents from the June 2006 event and one recorded incident from the July 2019 event. The model was found to generally match incident data and available flood location observations for the historical events, and accurately represented chronic flood locations. The blanket orifice assumptions were customized where anecdotal flood information was available to more accurately represent documented flooding. Orifice modifications were made as specified in the three case scenarios presented in Section C2.2.2.

## C2.4 Model Results

Flood inundation area greater than 6" depth for each scenario is presented in Table C2-2.

**Table C2-2. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 13.68 ac | 1.54% |
| 10-yr, 24-hr (2020) | 13.17 ac | 1.49% |
| 10-yr, 24-hr, (2040) | 15.34 ac | 1.73% |
| 10-yr, 24-hr (2070) | 17.68 ac | 2.00% |
| 100-yr, 24-hr (2020) | 41.12 ac | 4.64% |
| 100-yr, 24-hr (2040) | 45.25 ac | 5.11% |
| 100-yr, 24-hr (2070) | 48.33 ac | 5.46% |
| 500-yr, 24-hr (2020) | 62.38 ac | 7.04% |
| 500-yr, 24-hr (2040) | 66.79 ac | 7.54% |
| 500-yr, 24-hr (2070) | 70.64 ac | 7.97% |

# Appendix C3. Little Pimmit Run Modeling Details

## C3.1 Watershed and Model Description

The Little Pimmit Run 1D/2D model includes the watersheds of Little Pimmit Run West Branch and Little Pimmit Run East Branch; the model does not include Little Pimmit Main Stem. The Little Pimmit Run model has a tributary area of approximately 975 acres. It is located in northwest Arlington County and drains into Little Pimmit Mainstem. Detailed 1D/2D modeling was performed for this watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2012 Arlington County model for Little Pimmit Run as a base. The location of the Little Pimmit Run watershed is shown on Figure C3-1.

## C3.2 Watershed-Specific Model Updates

### C3.2.1 1D Model Updates

1D model updates for this watershed were based on one as-built update titled "West Little Pimmit Run – Phase I (Storm Drainage Improvements & Bioretentions) From North Nottingham Street To 34th Street North" and was determined by Arlington County to be necessary for the Little Pimmit watershed. This as-built update consisted of updating 32 junctions and 31 conduits. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built.

### C3.2.2 2D Model Updates

A hexagonal 2D mesh with 39,251 cells and a resolution of 15 feet was constructed for the Little Pimmit Run watershed. 181 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C3.2.2.1 Flood Modeller FAST Comparison

As described in Section 2.2.4 in the main body of the report, 2D results from the 500-year, 24-hour future conditions (Year 2070) storm event run in the PCSWMM 1D/2D model were compared against 2D FAST model results. There was one location where the FAST results exceeded the flooding in the PCSWMM model. The area that shows the greatest difference is a triangular residential zone bounded by Old Dominion Drive, North Edison Street and 37 Street N. The PCSWMM model shows the inundation to be more channelized between the residential structures whereas the FAST results show a wider inundation around the residential homes' neighboring roadways. Reviewing problem data sets provides no evidence of residential structure flooding or roadway flooding. Based on this review, the PCSWMM flooding results provide a more accurate representation of flooding in the area.

#### C3.2.2.2 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the Little Pimmit Run watershed. Just one type of orifice modification was performed:

- Orifice width was reduced from 24' to 12' in locations where there was a low density of existing inlets.

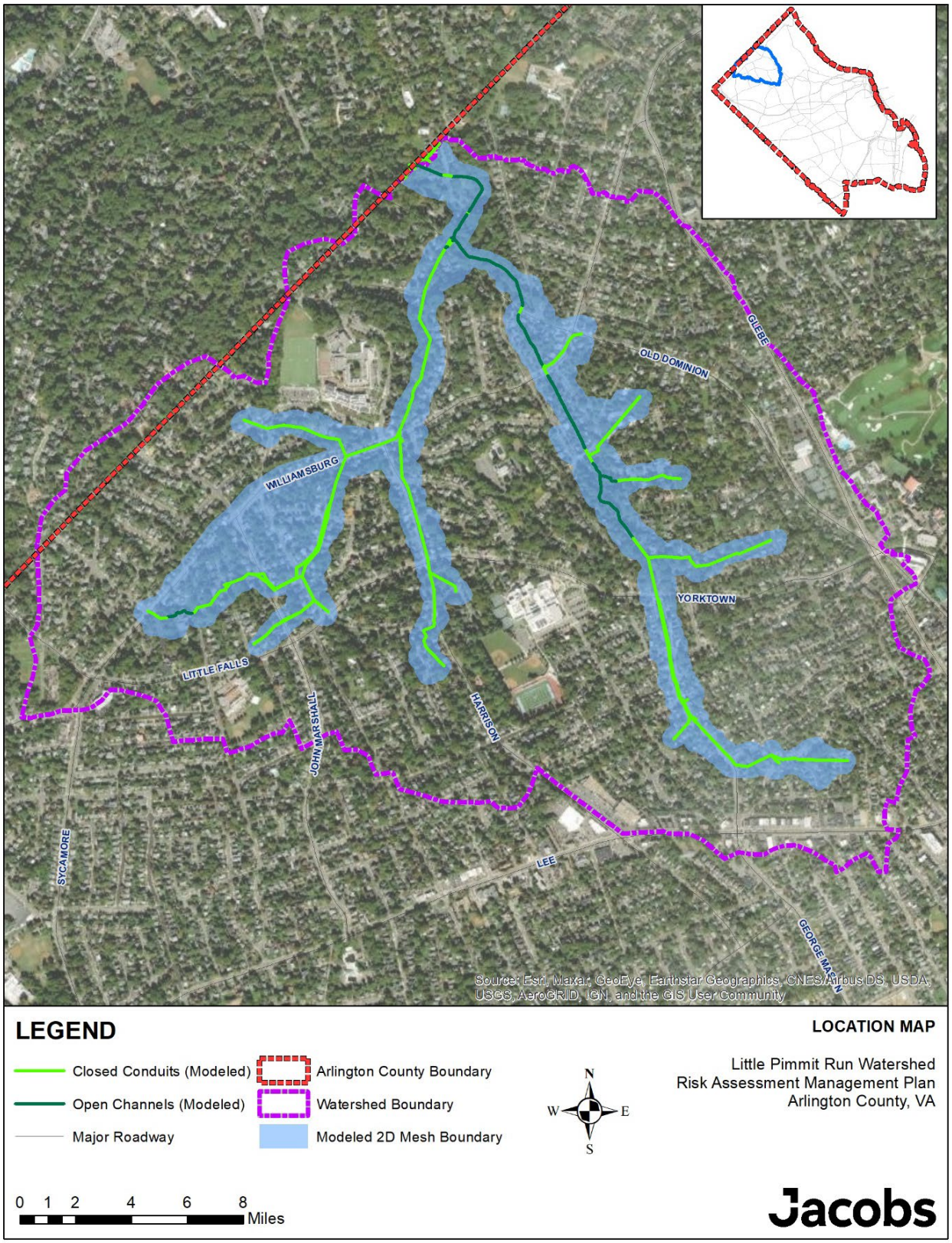



**Figure C3-1. Watershed Location Map**

#### C3.2.2.3 Open Channel Modeling

After the initial 2D mesh build and initial 1D/2D run of the 2070 500-year, 24-hour synthetic event, it was observed that refinement of the 1D open channel conduits in the Little Pimmit Run model was needed to more accurately reflect the overbank/channel dynamics. The following paragraphs detail adjustments made to the model in the vicinity of the open channels in order to more accurately represent channel flow during flood events.

Transect modifications were made in order to trim the transects in the Arlington County base model so that there was no overlap between the volume accounted for in the open channel by the 1D conduits and the volume accounted for in the overbanks by the 2D mesh. The transects were trimmed so that the 1D conduits represent water flowing within the channel and exclude water flowing in the overbank or over the low bank elevation during flood conditions. More information on this process is provided in Appendix D. This trimming process was performed for transects 20183, 20184, 20189, 20944, 22151, 22152, 22443, 22444, 4534, 6105, 6268, 6269, 6278, 6280, and 6287.

The 2D mesh node inverts over open channels were modified so that there was no overlap between the volume accounted for in the 1D open channel conduits and the volume accounted for in the 2D mesh. The invert elevations of all 2D mesh elements that fell within the transect width were adjusted to match the low bank elevation of the channel (the 2D mesh invert elevations had been automatically set to the channel invert during the 2D mesh build). More information on this process is provided in Appendix D.

#### C3.2.2.4 Glass Wall at Downstream Boundary of Mesh

Particular attention was taken when modeling the 2D mesh to prevent the creation of a "glass wall," where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. The glass wall effect inconsistently represents flooding because water that would have naturally cross the 2D mesh extent boundary in the existing condition is limited to a certain area by the limit of the model extent. Care was taken to expand the mesh extents in areas where glasswalling occurred to cover the low spot. However, in some cases the creation of a glass wall was unavoidable (i.e., at downstream boundaries). This was the case in Little Pimmit Run. To account for the pooling at the watershed's outlet to Little Pimmit Lower Mainstem, wide conduits were used to connect the 2D mesh to an outfall to reduce the depth of water in the cells at the boundary of the mesh to accurate levels. More information on this process is provided in Appendix D.

## C3.3 Model Validation

The 1D/2D model was validated against several synthetic and historical rainfall events.

### C3.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C3.3.2 Historical Event Validation

Historical flood call data was reviewed for the June 2006, May 2018, July 2018, and July 2019 historical events. The Little Pimmit Run watershed had 25 recorded flooding incidents from the June 2006 event, 8 incidents from the May 2018 event, 1 incident from the July 2018 event, and 18 recorded incidents from the July 2019 event. The model was found to generally match incident data and available flood location observations for the historical events, and accurately represented chronic flood locations. Some areas were not picked up by 2D flooding results for the 2070 500-year, 24-hour event. These areas were primarily found to be located on small collector sewers with nearby inlets. These small collectors were not included in the scope of this task, and therefore were not included in the model, resulting in the small inconsistencies between the incident data and the PCSWMM model results. The blanket orifice assumptions were customized where anecdotal flood information was available to more accurately represent documented flooding. Orifice modifications were made as specified in Section C3.2.2.

## C3.4 Model Results

Flood inundation area greater than 6" depth for each scenario is presented in Table C3-1.

**Table C3-1. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 27.77 ac | 2.85% |
| 10-yr, 24-hr (2020) | 19.69 ac | 2.02% |
| 10-yr, 24-hr, (2040) | 22.20 ac | 2.28% |
| 10-yr, 24-hr (2070) | 24.54 ac | 2.52% |
| 100-yr, 24-hr (2020) | 38.31 ac | 3.93% |
| 100-yr, 24-hr (2040) | 40.36 ac | 4.14% |
| 100-yr, 24-hr (2070) | 42.39 ac | 4.35% |
| 500-yr, 24-hr (2020) | 48.67 ac | 4.99% |
| 500-yr, 24-hr (2040) | 51.51 ac | 5.29% |
| 500-yr, 24-hr (2070) | 54.00 ac | 5.54% |

# Appendix C4. Lubber Run Modeling Details

## C4.1 Watershed and Model Description

The Lubber Run watershed has a modeled tributary area of approximately 1,029 acres. It is located near the center of Arlington County and drains into Four Mile Run. Detailed 1D/2D modeling was performed for this watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2012 Arlington County model for Lubber Run as a base. The location of the Lubber Run watershed is shown in Figure C4-1.

## C4.2 Watershed-Specific Model Updates

### C4.2.1 1D Model Updates

1D model updates for this watershed were based on as-built plans entitled "Virginia Hospital Center" and were determined by Arlington County to be necessary for the Lubber Run watershed. Through the course of modeling efforts, updates to the sheets originally provided by Arlington County were supplied by Arlington County as well as the design engineer. This as-built update consisted of updating 12 junctions and 11 conduits. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built. Additionally, a model extension was made from North Wakefield Street to North Tazewell Street. The model extension included the addition of 14 junctions and 14 conduits. The extension was connected to the original model at junction 11622. As a result of the extension, subcatchment W1840 was split into three subcatchments. The model extension contains small-diameter pipes and loading the original subcatchment caused unrealistic surface flooding-based pipe constriction due to pipe diameter. These loading modifications for the three subcatchments are detailed in Table C4-1.

**Table C4-1. Subcatchment Routing Modification Documentation**

| 1D Junction Name | Junction Modification |
|---|---|
| W1840_2 | Subcatchment outlet assigned to 1D junction 11404 |
| W1840_3 | Subcatchment outlet assigned to 1D junction 11229 |
| W1840_4 | Subcatchment outlet assigned to 1D junction 11072 |

### C4.2.2 2D Model Updates

A hexagonal 2D mesh with 55,474 cells and a resolution of 20 feet was constructed for the Lubber Run watershed. 347 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C4.2.2.1 Flood Modeller FAST Comparison

As described in Section 2.2.4 in the main body of the report, 2D results from the 500-year, 24-hour future conditions (Year 2070) storm event run in the PCSWMM 1D/2D model were compared against 2D FAST model results. In general, the FAST results showed similar flooding extents as the PCSWMM model. Open channel areas are more channelized in the PCSWMM model than in the FAST results. The PCSWMM model also shows more overland flow paths than the FAST Results.

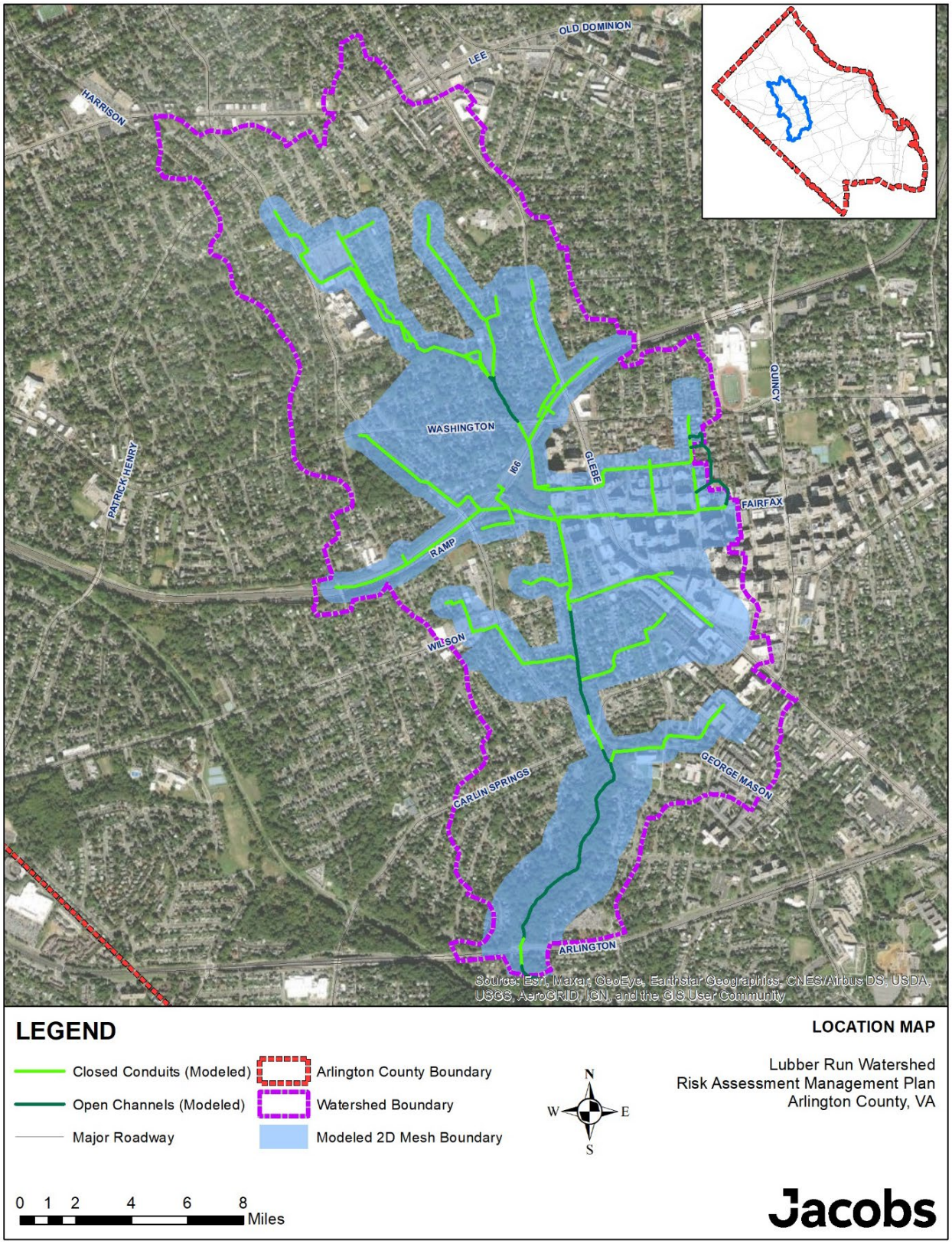



**Figure C4-1. Watershed Location Map**

#### C4.2.2.2 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the Lubber Run watershed. Three types of orifice modifications were performed:

- In some cases orifice width was reduced from 24' to 12' in locations where there were a low density of existing inlets.
- In a second case, orifice width was increased from 24' to 48' in locations where there were a high density of existing inlets or larger inlets than assumed.
- In a third case, extended orifices were added with a width of either 12' or 24' in locations where there was a high density of existing inlets, or where the model was inaccurately showing flooding where there is no known or suspected flooding.

#### C4.2.2.3 Open Channel Modeling

After the initial 2D mesh build and initial 1D/2D run of the 2070 500-year, 24-hour synthetic event, it was observed that refinement of the 1D open channel conduits in the Lubber Run model was needed to more accurately reflect the overbank/channel dynamics. The following paragraphs detail adjustments made to the model in the vicinity of the open channels in order to more accurately represent channel flow during flood events.

Transect modifications were made in order to trim the transects in the Arlington County base model so that there was no overlap between the volume accounted for in the open channel by the 1D conduit and the volume accounted for in the overbank by the 2D mesh. The transects were trimmed so that the 1D conduits represent water flowing within the channel and exclude water flowing in the overbank or over the low bank elevation during flood conditions. More information on this process is provided in Appendix D. This trimming process was performed for transects r1s1_E, r1s1_W, r1s2, r1s3, r1s4, r3s1, r3s2, r4s1, r4s2, r4s3, r4s4, r4s5, r4s6, and r4s6_1.

The 2D mesh node inverts over open channels were modified so that there was no overlap between the volume accounted for in the 1D open channel conduit and the volume accounted for in the 2D mesh. The invert elevations of all 2D mesh elements that fell within the transect width were adjusted to match the low bank elevation of the channel (the 2D mesh invert elevations had been automatically set to the channel invert during the 2D mesh build). More information on this process is provided in Appendix A.

Modifications were made to the inlet offset elevations of orifices adjacent to open channels to more accurately represent flow in channels. Specifically, there were many locations in the Arlington County base model where the transects for the open channel conduits had bank elevations higher than the bank elevations indicated by the DEM. In these cases the orifice inlet offset elevations, which were automatically assigned to its associated 1D node's rim elevation during the 2D mesh build, where modified to reflect the DEM elevation instead.

#### C4.2.2.4 Glass Wall at East Boundary of Mesh

Particular attention was taken when modeling the 2D mesh to prevent the creation of a "glass wall," where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. The glass wall effect inconsistently represents flooding because water that would have naturally cross the 2D mesh extent boundary in the existing condition is limited to a certain area by the limit of the model extent. Care was taken to expand the mesh extents in areas where glasswalling occurred to cover the low spot. However, in some cases the creation of a glass wall was unavoidable (i.e., at downstream boundaries).

This was the case in Lubber Run. To account for the pooling at the watershed's east boundary between Washington Boulevard and Fairfax Drive, overland flow paths were used to route water. These overland flow paths were originally modeled by STI for the NVRC modeling tasks. More information on this process is provided in Appendix D.

## C4.3 Model Validation

The 1D/2D model was validated against several synthetic and historical rainfall events.

### C4.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C4.3.2 Historical Event Validation

Historical flood call data were reviewed for the June 2006, May 2018, July 2018, and July 2019 historical events. The Lubber Run watershed had 26 recorded flooding incidents from the June 2006 event, 5 incidents from the May 2018 event, and 12 recorded incidents from the July 2019 event. The model was found to generally match incident data and available flood location observations for the historic events, and accurately represented chronic flood locations. The blanket orifice assumptions were customized where anecdotal flood information was available to more accurately represent documented flooding. Orifice modifications were made as specified in the three case scenarios presented in Section C4.2.2.

## C4.4 Model Results

Flood inundation area greater than 6" depth for each scenario is presented in Table C4-2.

**Table C4-2. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 25.47 ac | 2.47% |
| 10-yr, 24-hr (2020) | 15.20 ac | 1.48% |
| 10-yr, 24-hr, (2040) | 18.18 ac | 1.77% |
| 10-yr, 24-hr (2070) | 20.83 ac | 2.02% |
| 100-yr, 24-hr (2020) | 51.39 ac | 4.99% |
| 100-yr, 24-hr (2040) | 58.23 ac | 5.66% |
| 100-yr, 24-hr (2070) | 64.09 ac | 6.23% |
| 500-yr, 24-hr (2020) | 82.04 ac | 7.97% |
| 500-yr, 24-hr (2040) | 86.97 ac | 8.45% |
| 500-yr, 24-hr (2070) | 91.67 ac | 8.91% |

# Appendix C5. Spout Run Modeling Details

## C5.1 Watershed and Model Description

The Spout Run watershed has a modeled tributary area of approximately 1,071 acres. It is located near the center of Arlington County on the east county boundary along the Potomac River and drains into Potomac River. Detailed 1D/2D modeling was performed for this watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2012 Arlington County model for Spout Run as a base. The location of the Spout Run watershed is shown on Figure C5-1.

## C5.2 Watershed-Specific Model Updates

### C5.2.1 1D Model Updates

1D model updates for this watershed were based on two as-built plansets titled "American Legion 3445 Washington Blvd Proposed" and "Washington Boulevard at Kirkwood Road Proposed" and were determined by Arlington County to be necessary for the Spout Run watershed. This as-built update consisted of updating 10 junctions and 10 conduits. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built. Additionally, a model extension was made from I-66 towards the intersection of 20th Street North and 20th Road North. The model extension included the addition of 5 junctions and 5 conduits to the model and was connected to the original model at junction 5409. The above noted model changes and additions affected the outlet node for two subcatchments. These modifications are detailed in Table C5-1.

**Table C5-1. Subcatchment Routing Modification Documentation**

| 1D Junction Name | Junction Modification |
|---|---|
| W900 | Changed outlet from 1D junction 5409 to 1D junction 5230 |
| W1130 | Changed outlet from 1D junction 8132 to 1D junction AB-J-00001 |

### C5.2.2 2D Model Updates

A hexagonal 2D mesh with 64,725 cells and a resolution of 15 feet was constructed for the Spout Run watershed. 388 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C5.2.2.1 Flood Modeller FAST Comparison

As described in Section 2.2.4 in the main body of the report, 2D results from the 500-year, 24-hour future conditions (Year 2070) storm event run in the PCSWMM 1D/2D model were compared against 2D FAST model results. The FAST results showed similar flooding to the PCSWMM model. In general, the PCSWMM results show more overland flow paths. The areas shown in FAST and PCSWMM modeling show similar locations and widths of inundation. One parcel located at Fairfax Drive and North Quincy Street was being constructed at the time the DEM was flown. The DEM picked up the excavation of the foundation of the multi-floor mixed-use building, which created unrealistic water depths. The foundation excavation was not taken out of the FAST results but was updated in the PCSWMM model to more accurately show depths of inundation.

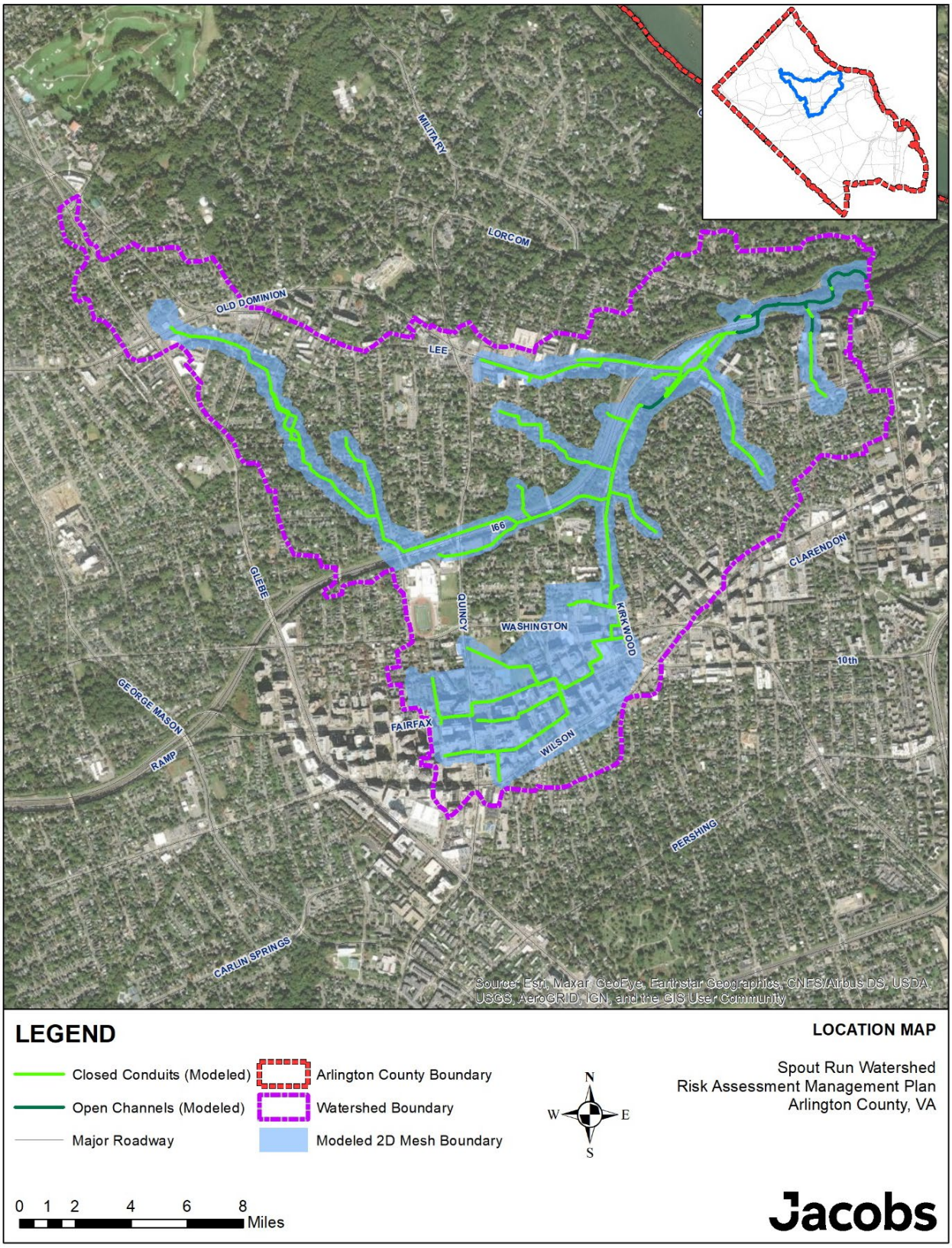



**Figure C5-1. Watershed Location Map**

#### C5.2.2.2 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the Spout Run watershed. Three types of orifice modifications were performed:

- In one case, orifice width was modified from 24' to 6' instead of being removed where there was potential for water being lost from the system without an orifice.
- In a second case, orifice width was reduced from 24' to 12' in locations where there were a low density of existing inlets.
- In a third case, extended orifices were added with a width of either 12' or 24' in locations where there was a high density of existing inlets, or where the model was inaccurately showing flooding where there is no known or suspected flooding.

#### C5.2.2.3 Open Channel Modeling

After the initial 2D mesh build and initial 1D/2D run of the 2070 500-year, 24-hour synthetic event, it was observed that refinement of the 1D open channel conduits in the Spout Run's model were needed to more accurately reflect the overbank/channel dynamics. The following paragraphs detail adjustments made to the model in the vicinity of the open channels in order to more accurately represent channel flow during flood events.

Transect modifications were made in order to trim the transects in the Arlington County base model so that there was no overlap between the volume accounted for in the open channel by the 1D conduit and the volume accounted for in the overbank by the 2D mesh. The transects were trimmed so that the 1D conduits represent water flowing within the channel and exclude water flowing in the overbank or over the low bank elevation during flood conditions. More information on this process is provided in Appendix D. This trimming process was performed for transects xsec8b, xsec7b, xsec6, xsec5, xsec4b, xsec1b, xsec18b, xsec18a, xsec12, xsec11, xsec10b, xsec10a, Standard1, and 6642.

The 2D mesh node inverts over open channels were modified so that there was no overlap between the volume accounted for in the 1D open channel conduit and the volume accounted for in the 2D mesh. The invert elevations of all 2D mesh elements that fell within the transect width were adjusted to match the low bank elevation of the channel (the 2D mesh invert elevations had been automatically set to the channel invert during the 2D mesh build). More information on this process is provided in Appendix D.

Modifications were made to the inlet offset elevations of orifices adjacent to open channels to more accurately represent flow in channels. Specifically, there were many locations in the Arlington County base model where the transects for the open channel conduits had bank elevations higher than the bank elevations indicated by the DEM. In these cases, the orifice inlet offset elevations, which were automatically assigned to its associated 1D node's rim elevation during the 2D mesh build, where modified to reflect the DEM elevation instead.

One building that was provided in the county GIS data was removed after a review of Google Earth. Building GIS_ID 37808 created a wall in the mesh which was not allowing flow to move upstream to downstream. The building is a parking lot over I-66 and is south of 15$^{th}$ Street North and bound by North Stafford Street and North Quincy Street. Removing this building from the mesh allowed flow east-northeast down I-66 in a more accurate manner. Flooding of I-66 has been documented in news outlets.

#### C5.2.2.4 Glass Wall at Downstream Boundary of Mesh

Particular attention was taken when modeling the 2D mesh to prevent the creation of a "glass wall" where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. The glass wall effect inconsistently represents flooding because water that would have naturally cross the 2D mesh extent boundary in the existing condition is limited to a certain area by the limit of the model extent. Care was taken to expand the mesh extents in areas where glasswalling occurred to cover the low spot. However, in some cases the creation of a glass wall was unavoidable (i.e. at downstream boundaries). This was the case in Spout Run. To account for the pooling at the downstream conduit wide conduits were connected from the mesh to an outfall to reduce the depth of water in the cells at the boundary of the mesh. More information on this process is provided in Appendix D.

## C5.3 Model Validation

The 1D/2D model was validated against several synthetic and historical rainfall events.

### C5.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C5.3.2 Historic Event Validation

Historical flood call data was reviewed for the June 2006, May 2018, July 2018, and July 2019 historic events. The Spout Run watershed had 14 recorded flooding incidents from the June 2006 event, 9 incidents from the May 2018 event, 15 events from the July 2018 event, and 37 recorded incidents from the July 2019 event. The model was found to generally match incident data and available flood location observations for the historic events, and accurately represented chronic flood locations. The blanket orifice assumptions were customized where anecdotal flood information was available to more accurately represent documented flooding. Orifice modifications were made as specified in the three case scenarios presented in Section C5.2.2.

## C5.4 Model Results

Flood inundation area greater than 6" depth for each scenario is presented in Table C5-2.

**Table C5-2. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 31.88 ac | 2.98% |
| 10-yr, 24-hr (2020) | 18.09 ac | 1.69% |
| 10-yr, 24-hr, (2040) | 21.70 ac | 2.03% |
| 10-yr, 24-hr (2070) | 25.17 ac | 2.35% |
| 100-yr, 24-hr (2020) | 52.50 ac | 4.90% |
| 100-yr, 24-hr (2040) | 57.02 ac | 5.32% |
| 100-yr, 24-hr (2070) | 60.80 ac | 5.68% |

**Table C5-2. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| 500-yr, 24-hr (2020) | 73.87 ac | 6.90% |
| 500-yr, 24-hr (2040) | 78.11 ac | 7.29% |
| 500-yr, 24-hr (2070) | 82.21 ac | 7.68% |

# Appendix C6. Torreyson Run Modeling Details

## C6.1 Watershed and Model Description

The Torreyson Run watershed has a modeled tributary area of approximately 320 acres. It is located near the center of Arlington County and drains into Four Mile Run. Detailed 1D/2D modeling was performed for this watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D/2D model used the 2014 Arlington County model for Torreyson Run as a base. The location of the Torreyson Run watershed is shown in Figure C6-1.

## C6.2 Watershed-Specific Model Updates

### C6.2.1 1D Model Updates

1D model updates for this watershed were minor. No as-built updates were determined by Arlington County to be necessary for the Torreyson Run watershed. Storage nodes at the upstream ends of the subcatchments in the base model were converted to junctions to avoid double-counting storage volume when the 2D mesh was built. Additionally, some modifications were made to open channel cross-sections to more accurately represent the conveyance system. These modifications are detailed in Table C6-1.

**Table C6-1. Open Channel Conduits Modification Documentation**

| 1D Conduit Name | Transect Modifications |
|---|---|
| 7646 | Cross-section was updated using DEM developed from 2-ft contour for Transect ID 7646 |
| 7647 | Cross-section was updated using DEM developed from 2-ft contour for Transect ID 7647 |
| 7658 | Cross-section was updated using DEM developed from 2-ft contour for Transect ID 7658 |

### C6.2.2 2D Model Updates

A hexagonal 2D mesh with 11,450 cells and a resolution of 20 feet was constructed for the Torreyson Run watershed. 125 bottom orifices were modeled to connect the 1D and 2D modeled systems.

#### C6.2.2.1 Inlet Review and Orifice Modifications

Several changes to the 1D/2D orifice connections were made to calibrate the model and more accurately represent surface flooding observational data during validation efforts for the Torreyson Run watershed. Two types of orifice modifications were performed:

- In one case scenario, orifice widths were modified from 24’ to 10’ to more accurately represent the density of existing inlets in a given area.
- In a second case scenario, extended orifices were added at the locations of existing street/curb inlets (along I-66) that were not considered in the base Torreyson Run model.

#### C6.2.2.2 Open Channel Modeling

After the initial 2D mesh build and initial 1D/2D run of the 2070 500-year, 24-hour synthetic event, it was observed that no further refinements of the 1D open channel conduits in the Torreyson Run model were needed to more accurately reflect the overbank/channel dynamics. The Torreyson Run model includes only one open channel segment near the watershed outlet connecting the upstream pipe network to Four Mile Run.

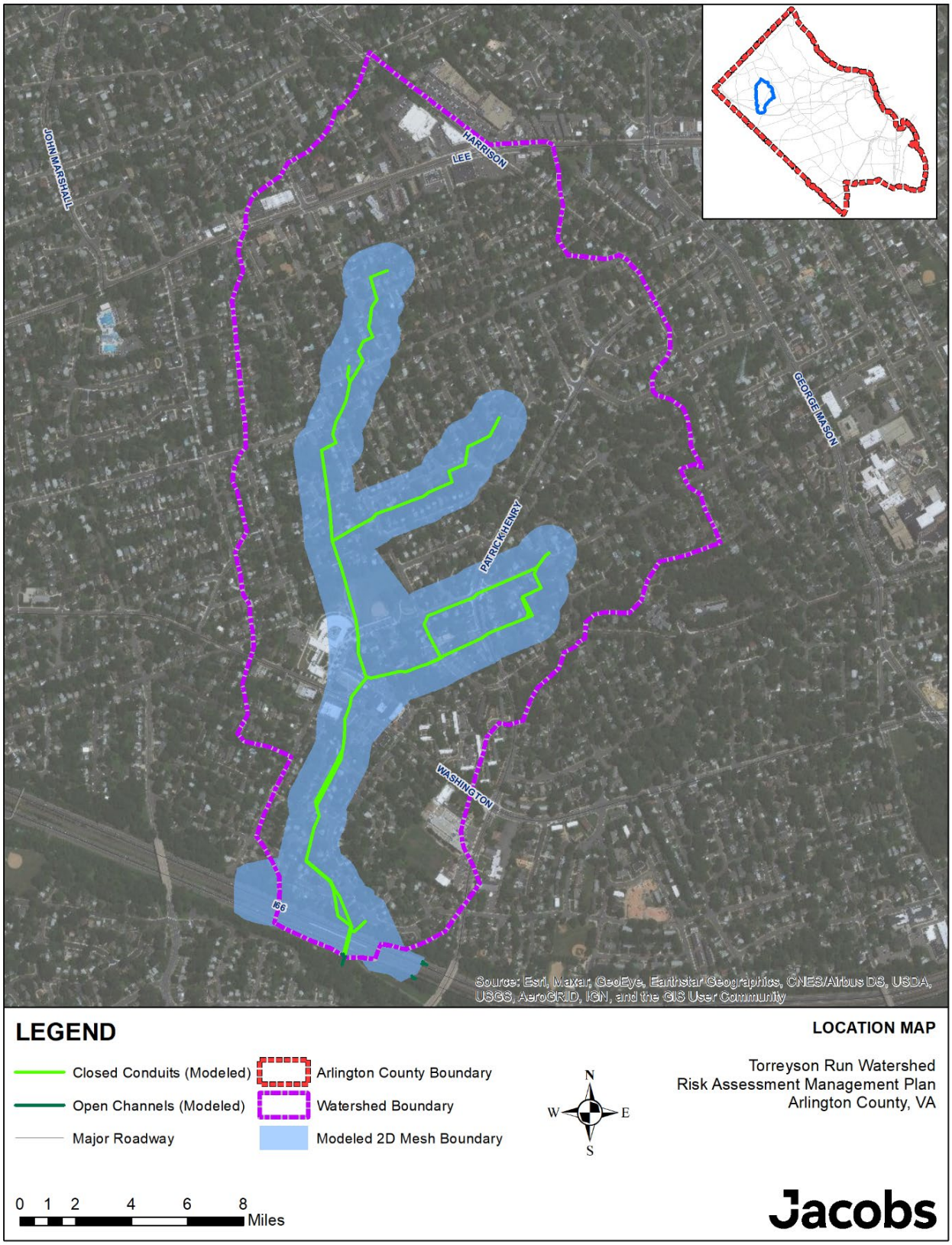



**Figure C6-1. Watershed Location Map**

#### C6.2.2.3 Glass Wall at Downstream Boundary of Mesh

The 2D mesh was carefully created to prevent the formation of a "glass wall" where inundation spreads to the edge of the 2D mesh extent and has nowhere to go in the model space. When "glass walling" occurs, flooding is inaccurately represented because the water that would have naturally crossed the 2D mesh extent boundary becomes constrained by the limit of the mesh extent. Special care was taken to generally expand the mesh extent to cover the low spots and prevent glass walling. However, glass walls could not be completely avoided at some locations (e.g. near the downstream boundary) in the Torreyson Run watershed. Significant pooling of water between I-66 crossing and the watershed's outlet was avoided by using wide conduits to connect the 2D mesh to the outfall and, thereby, allowing the model to accurately calculate the depth of water in the boundary cells. More information on this process is provided in Appendix D.

## C6.3 Model Validation

The 1D/2D model was validated against several synthetic and historic rainfall events.

### C6.3.1 Synthetic Event Validation

Known flooding areas were compared with model results for the 2070 500-year, 24-hour, 2020 100-year, 24-hour, and 2020 10-year, 24-hour synthetic events, checking that known flood areas had surface flood risk indicated where expected by the model. The modeled flooding for these events was determined to be appropriate once an inlet review and key intersection checks were performed.

### C6.3.2 Historical Event Validation

Historical flood call data was reviewed for the June 2006, May 2018, and July 2019 historical events. The Torreyson Run watershed had 5 recorded flooding incidents from the June 2006 event, 5 recorded flooding incidents from the May 2018 event and 31 recorded incidents from the July 2019 event. The model was found to generally match incident data and available flood location observations for the historical events, and accurately represented chronic flood locations.

## C6.4 Model Results

Flood inundation area greater than 6" depth for each scenario is presented in Table C6-2.

**Table C6-2. Flood Inundation Areas**

| Storm Event | Area Flooded (>6" Depth) | Percent Flooded (>6" Depth) |
|---|---|---|
| July 8, 2019 Historical | 10.40 ac | 3.25% |
| 10-yr, 24-hr (2020) | 7.21 ac | 2.26% |
| 10-yr, 24-hr, (2040) | 9.18 ac | 2.87% |
| 10-yr, 24-hr (2070) | 10.86 ac | 3.40% |
| 100-yr, 24-hr (2020) | 18.75 ac | 5.87% |
| 100-yr, 24-hr (2040) | 19.93 ac | 6.24% |
| 100-yr, 24-hr (2070) | 20.80 ac | 6.51% |
| 500-yr, 24-hr (2020) | 23.55 ac | 7.37% |
| 500-yr, 24-hr (2040) | 24.60 ac | 7.70% |
| 500-yr, 24-hr (2070) | 25.62 ac | 8.02% |

# Appendix D
# Detailed Approach to 1D/2D PCSWMM Modeling

# Appendix D. Detailed Approach to Modeling

## D.1 Modeling Approach Overview

The purpose of this document is to outline the steps and procedures performed to build 1D/2D PCSWMM models for Arlington County and to provide supplemental technical information for the overall modeling approach outlined in the main body of the report. For this modeling effort PCSWMM version 7.3 was utilized, paired with SWMM5 engine 5.1.015. 1D/2D PCSWWM models were built for eight Arlington County watersheds. These watersheds were prioritized for detailed modeling as described in Appendix E. These eight models used previously-developed 1D PCSWWM models as a base, as described in the main body of the report. Downstream boundary conditions for the eight watershed models were determined as described in Appendix F.

## D.2 Initial 1D 2070 500-year, 24-hour Model Run

Before the 2D mesh and runs were created, a 1D run of the 500-yr, 24-hour Year 2070 synthetic rainfall event was completed using the 1D PCSWMM models previously developed for Arlington County and NVRC. The existing models were used for this run after being reviewed by the project team to verify consistency with documentation from the previous modeling effort. A results comparison of the original 10-year model surcharge location results from the 2011-2012 project reports against the models was performed for the following watersheds to verify inundation extents in expected locations, to verify that the models ran appropriately in the updated SWMM engine, and to serve as a basis of flood problem areas against known flooding locations and FAST model results.

The projection used in this model build was NAD 1983 StatePlane Virginia North FIPS 4501 Feet.
In preparation for 2D modeling, all upstream storage nodes were converted to junctions. These upstream nodes had been used in previous models to represent storage in the upstream smaller-diameter (unmodeled) pipes. In some instances, an NVRC model with overland flow paths was used as a resource to inform 2D mesh locations. In these instances, the overland flow paths were removed from those models before 2D modeling efforts were undertaken.

For some watersheds, as-builts were incorporated into the 1D model to reflect updates to the storm sewer system since the original 1D models were completed. Note some of the sewer updates have been or will be completed on private sewers. Private sewers were not added to the updated 1D/2D models unless they are needed to convey flows downstream. Watersheds with newly developed areas incorporated into the models are pictured on Figure D-1 and are located in the following watersheds:

- Roaches Run
- Spout Run
- Lubber Run
- Four Mile Run, Upper Mainstem (Not modeled in 2D as part of this effort)
- Westover Branch (Not modeled as part of this effort)
- Crossman's Run (Not modeled as part of this effort)
- Little Pimmit West Branch

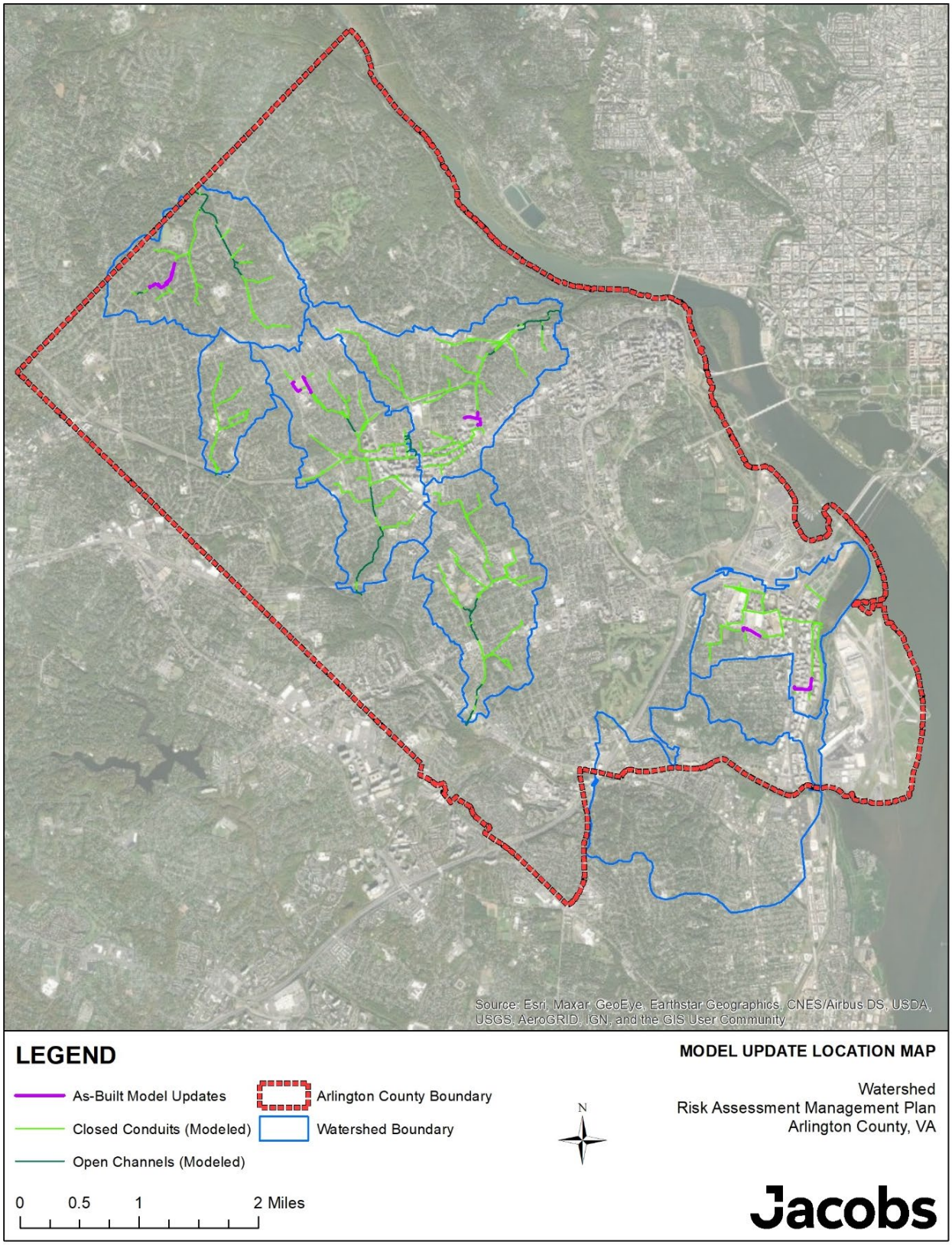



**Figure D-1. Arlington County Newly Developed Areas**

When updating the models with as-built information, entry and exit losses were added to newly modeled closed conduits consistent with previous Arlington County modeling protocols. In order to be consistent with original modeling of conduits, Table D-1 was used to assign a loss for each closed conduit in an as-built area based on pipe orientation in the manhole. Manning's n values were assigned consistent with previous modeling efforts, for example 0.014 was used for concrete pipes.

**Table D-1. Standard Head Loss Coefficients**

| Structure Configuration | Loss Coefficient |
|---|---|
| Inlet—straight run | 0.50 |
| Inlet—angled through | |
| 90° | 1.50 |
| 60° | 1.25 |
| 45° | 1.10 |
| 22.5° | 0.70 |
| Manhole—straight run | 0.15 |
| Manhole—angled through | |
| 90° | 1.00 |
| 60° | 0.85 |
| 45° | 0.75 |
| 22.5° | 0.45 |

Source: U.S. DOT, *Urban Drainage Design Manual,* 2nd ed., Hydraulic Engineering Circular No. 22, 2001.

Each junction, conduit, or other model element that is updated because of as-builts was tagged in the updated model, and a description entry was also included with the date the element was added, the initials of the modeler, and the modeler's company. Once the model updates were completed, the 1D model run was performed using the 500-year synthetic storm event rainfall time series, escalated to year 2070, to allow evaluation of the highest flows and HGLs for the project and aid in assessing the model's robustness. The following simulation options were set for this initial 1D run:

**Simulation Options:**

- Process model
  - Rainfall/Runoff
  - Flow routing
- Routing method
  - Dynamic Wave
- Infiltration model
  - Green-Ampt
- Miscellaneous
  - Allow ponding
  - Minimum conduit slope (%): 0
  - Flow units CFS

**Dates:**

- Start analysis on Date (M/D/Y) 01/01/2070 Time (H:M:S) 0:00:00
- Start reporting on Date (M/D/Y) 01/01/2070 Time (H:M:S) 0:00:00
- End analysis on Date (M/D/Y) 01/02/2070 Time (H:M:S) 0:00:00
- Start sweeping on 01/01
- End sweeping on 12/31

**Time Steps:**

- Reporting Days: 0 Time (H:M:S): 0:05:00
- Runoff dry weather: 0 Time (H:M:S): 0:05:00
- Runoff wet weather: 0 Time (H:M:S): 0:01:00
- Control rule 0:00:00
- Routing: 0.05 seconds

**Dynamic Wave:**

- Inertial term: Dampen
- Normal flow criterion: Slope & Froude
- Force main equation: Hazen-Williams
- Surcharge method: Extran
- Use variable time steps, adjusted by 75 %
- Minimum variable time step 0.001 seconds
- Time step for conduit lengthening 0 seconds
- Minimum nodal surface area 0 $ft^2$
- Maximum trials per time step 30
- Head convergence tolerance 0.005 ft
- **Number of Threads 7** (This assumes a computer is being used exclusively for a model run. This can be lowered if access is needed to more CPUs for other tasks)

**Climatology**

- Evaporation: Monthly averages were utilized (in/day), as shown in Table D-2:

**Table D-2. Monthly Evaporation Rate Averages (in/day)**

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 0.1 | 0.15 | 0.3 | 0.35 | 0.7 | 0.7 | 0.8 | 0.7 | 0.5 | 0.15 | 0.1 |

For this initial run, boundary conditions at the outfalls were set to FREE.

### D.2.1 2070 500-year, 24-hour Model Results: Determining Initial 2D Extents and Initial Review of Flooding Locations

Once the initial model run was completed, model results were compared against FAST results as an initial part of the validation process. For this comparison, the junctions were symbolized in ArcGIS based on flooded volumes and compared against a flooded extents raster from the FAST model runs for the 2070 500-year, 24-hour synthetic rainfall event. Problem report location data were also used for comparison as an indicator of where 1D surcharging would be expected. The team looked for any correlations between the flooding in the 1D model and the FAST inundation extents and problem report data in order to guide the definition of the 1D/2D mesh extents and to ensure there were no major inconsistencies between the FAST results, problem report data, and 1D model flooded nodes. Overland flow path data from the 1D NVRC models available for Lubber Run, Torreyson Run, and Doctor's Branch were also used to guide 2D mesh extents and correlate to overland flood flow paths. High water mark photos were also used for a visual comparison for the 2019 historical event where available. Additional information regarding validation data can be found in Section 5 for validation of the 2019 Event Storm against problem areas.

### D.2.2 Initial 1D/2D Modeled Mesh

For the initial mesh creation, a bounding layer was created with extents set back 1,000 feet on all sides from the watershed boundary. Efforts were made to modify the boundary layer extents and mesh resolution to ensure that the number of 2D nodes was less than 100,000. Building more than 100,000 nodes can excessively extend model run times, and PCSWMM recommends creating a mesh with less than 100,000 nodes. Final bounding layer extents were determined using the following considerations:

- Problem layers (calls, hot spots, and interview outcomes)
- Critical facilities
- FAST Results
- Max flooding volumes from the 1D 2070 24 hr 500 yr junctions

If applicable, the overland flow path flood network of the NVRC models. Table D-3 shows the attribute field values for the bounding layer.

**Table D-3. Bounding Layer Attribute Field Values**

| Full Field Name | Field Name | Description | Initial Inputs |
|---|---|---|---|
| Style | STYLE | Describes the style to be applied to the mesh. Options include Hexagonal, Rectangular, Directional and Adaptive. | HEXAGONAL |
| Angle (degrees) | ANGLE | Angle that the mesh used in generating points. Measured counter-clockwise from due East. | 0 |
| Resolution (feet) | RESOLUTION | Spatial resolution or distance between 2D nodes. This defines the resolution of the 2D mesh, and the size of the 2D cells. | 20 |
| Sampling Factor | SAMPLING | Density of elevation layer points, expressed as a multiple of the mesh resolution. | 0 |
| Distance Tolerance (feet) | DISTOL | The distance tolerance used for an adaptive style 2D mesh. Should normally be greater than the resolution. | 3 |
| Elevation Tolerance (feet) | ELEVTOL | The elevation tolerance used for an adaptive style 2D mesh. | 0 |
| Roughness | ROUGHNESS | Manning's roughness coefficient for generating the mesh within the bounding polygon. | 0.03 |

**Table D-3. Bounding Layer Attribute Field Values**

| Full Field Name | Field Name | Description | Initial Inputs |
|---|---|---|---|
| Seepage Rate (in/hr) | SEEPAGE | Seepage rate for generating the mesh within the bounding polygon. | 0 |
| Edge | EDGE | Determines if bounding polygon acts as an internal boundary for 2D cells. | No |

An obstructions layer was used in the creation of the 2D mesh to prevent construction of the 2D mesh over existing buildings. A buildings footprint layer provided by the Arlington county was utilized as the obstructions layer in the 2D mesh creation. The 2D mesh node inverts were pulled automatically by PCSWMM from the DEM. The 2D mesh was connected to the 1D modeled system by using PCSWMM's Connect 1D to 2D tool. All 1D junctions within the bounding layer extents were tagged "Connect2D" and connected to the nearest 2D surface node using a bottom orifice. The 1D to 2D connections were checked to ensure flows were routed accurately. All PCSWMM recommended simulation parameters for 2D models were utilized in the 2D model runs. The following simulation options were utilized for the 2D model runs:

**Simulation Options:**

- Process model
  - Rainfall/Runoff
  - Flow routing
- Routing method
  - Dynamic Wave
- Infiltration model
  - Green-Ampt
- Miscellaneous
  - Allow ponding
  - Minimum conduit slope (%): 0
  - Flow units CFS
- Dates: (this is for the initial run; this should be updated based on the year in which the storm event occurs for other storm runs)
  - INITIAL RUN ONLY: END ANALYSIS ON DATE (M/D/Y) 01/01/2070 TIME (H:M:S) 14:00:00
  - Start analysis on Date (M/D/Y) 01/01/2070 Time (H:M:S) 0:00:00
  - Start reporting on Date (M/D/Y) 01/01/2070 Time (H:M:S) 0:00:00
  - End analysis on Date (M/D/Y) 01/02/2070 Time (H:M:S) 0:00:00
  - Start sweeping on 01/01
  - End sweeping on 12/31
- Time Steps
  - Reporting Days: 0 Time (H:M:S): 0:05:00
  - Runoff dry weather: 0 Time (H:M:S): 0:05:00
  - Runoff wet weather: 0 Time (H:M:S): 0:01:00
  - Control rule 0:00:00
  - Routing: 0.5 seconds

- Dynamic Wave
  - Inertial term: Ignore
  - Normal flow criterion: Slope & Froude
  - Force main equation: Hazen-Williams
  - Surcharge method: Extran
  - Use variable time steps, adjusted by 75 %
  - Minimum variable time step 0.001 seconds
  - Time step for conduit lengthening 0 seconds
  - Minimum nodal surface area 1 $ft^2$
  - Maximum trials per time step 30
  - Head convergence tolerance 0.005 ft
  - **Number of Threads 7** (This assumes a computer is being used exclusively for a model run. This can be lowered if access is needed to more CPUs for other tasks)

For this initial run, the boundary condition for the outfall type was set to FREE.

After the initial 2D model was run for the 2070 500yr 24h, the 2D cells were exported from the PCSWMM model and brought into ArcGIS. The query "MAXDEPTH<>0" was applied to the 2D cells layer and reviewed against problem data for correlation. The model was then reviewed for any hydrological, hydraulic, or mesh extent refinements needed before moving on to the creation of the more defined mesh.

## D.3 Iterations of the 2D Model Following the Initial Run ("Mesh 2.0")

Once the model with the initial mesh was reviewed, a more defined mesh (Mesh 2.0) was created based on the initial mesh. Before the more defined mesh was created, any hydraulic or hydrologic updates were made to the model as necessary based on the review. The intent of the second version of the mesh was to create a smaller mesh based on the initial mesh 2D inundation while still including areas of interest and extending the mesh extent where any "glasswalling" may have occurred. Smaller meshes increase overall runtime but can allow for a higher resolution of 2D nodes. The goal of the "Mesh 2.0" refinement was to achieve a balance between mesh extent, resolution, and runtime.

### D.3.1 Refining Mesh Boundaries

Mesh 2.0 was created by merging the 2D cells showing inundation from the initial mesh run (2070 500 yr 24 hr storm event) together in ArcGIS and buffering those inundation extents by 100-200 feet. This approach ensured that the Mesh 2.0 encapsulated the expected inundation for the largest storm. If the initial 1D/2D run showed inundation pooling at the edge of the mesh ("glasswalling"), that area was reviewed in more detail and in some cases the Mesh 2.0 was extended beyond the extents of the original mesh to prevent glasswalling in those areas. If the Mesh 2.0 extents reached beyond the subcatchment boundaries once it was buffered, it was trimmed back down to the subcatchment extents, except in the cases of glasswalling as previously mentioned. There were some limited instances of flow leaving one watershed and entering another. These were carefully reviewed to understand the local system dynamics and resolved on a case-by-case basis as described in the individual Appendix B writeups for each watershed.

### D.3.2 Truncating Transects

In the Mesh 2.0 model and subsequent versions of the models the team modified the transects corresponding to the open channels to only represent the inundation within the banks of the open channel, not the water in the over bank areas or floodplain, which was represented separately by the 2D mesh. Modifying the transects in this way prevents double-counting of the channel volume where the transect and the 2D mesh overlap. To do this, modifications to the model transects were completed. First, all open channel segments were identified in each PCSWMM model. Each transect was reviewed separately to determine where best to truncate it for consistency with the mesh and DEM. The first step was to identify the lowest elevation for top of bank for the transect. After identifying the lowest elevation for top of bank to be used, the transect horizontal length from the furthest left/right station to that elevation on each side of the stream was recorded. Then the associated rows of the transects where elevations exceed the low bank elevation were deleted. For each transect the station length removed from the left and right banks was recorded. Figure D-2 shows an example of an original model transect and its corresponding truncated transect.

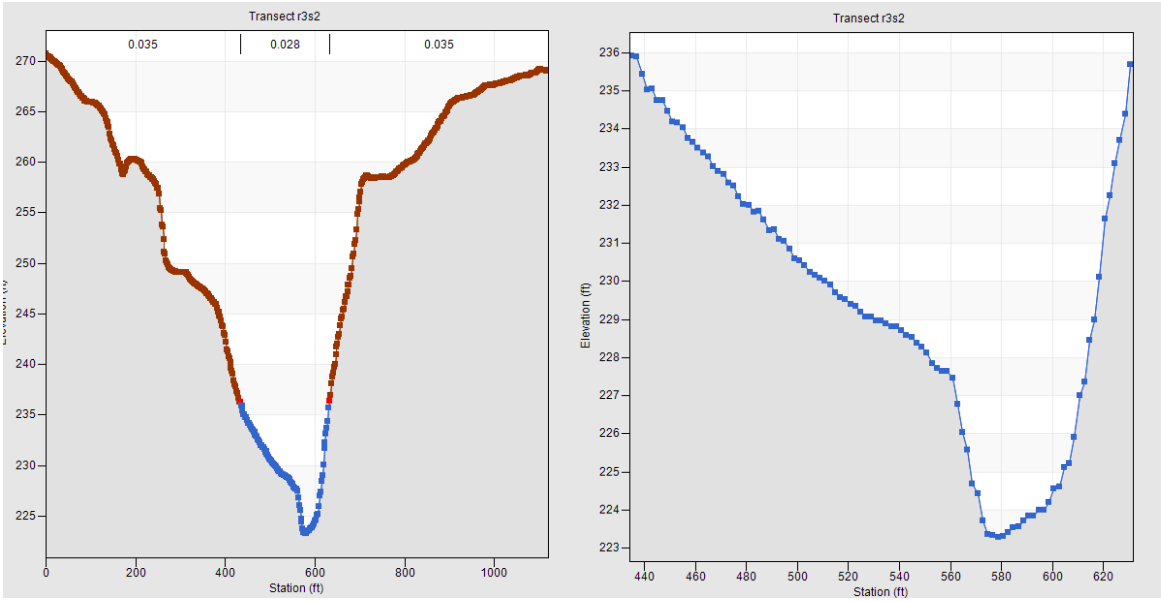



**Figure D-2. Model Transects: the left figure shows the original transect; the right figure shows the truncated transect.**

### D.3.3 Modification of 2D Mesh Over Open Channels

For the initial mesh build, PCSWMM assigned elevations to the mesh based on the DEM. In the Mesh 2.0 model and any subsequent versions of the model, efforts were made to ensure that the 2D mesh nodes and conduits over open channels did not use the channel invert elevations, but instead used the channel low bank station elevations specified in Section D.3.2. This precluded double-counting of storage that could occur if storage was counted both in the stream cross section as well as in the 2D mesh (where ground surface inverts are driven by LiDAR data). Methodologies undertaken to ensure that the 2D mesh elevations integrated accurately with the 1D channel geometries included:

- Removing 2D junctions in stream beds so that 2D mesh inverts only reflected bank station elevations
- Modifying 2D junction elevations in the stream bed; raising them to match bank station elevations
- Adding/modifying 1D/2D connection placement to ensure free flow between 2D mesh and channels in these locations

### D.3.4 Modification of Transects

The lines shown on Figure D-3 represent the plan view of transects that are present in the PCSWMM Model. The transect lengths were trimmed by removing the same length from the left and right bank that was removed in the PCSWMM model transects as specified in Section D.3.2. An additional polygon layer (named Node_Adjustment) was then created in ArcGIS to visually signify the area in the model represented by the truncated transects. Polygons were drawn in this layer from the upstream junction to the downstream junction of each open channel reach, covering the width of the revised transects between those two points. Figure D-3 shows the original modeled transects (hot pink), truncated transects (blue), and Node Adjustment Polygons (light pink).

**Figure D-3. Truncated Transects and Node Adjustment Polygons**

Next, the shapefile representing the PCSWMM junctions were brought into ArcGIS and queried to filter out any junctions not in the 2D mesh. The Node_Adjustment polygons were reviewed one by one. Using the select by location function, the 2D junctions located within a given polygon in the Node_Adjustment layer were selected, and their inverts were set to the low bank elevation for that polygon as previously determined in the steps outlined in Section D.3.2 using the Field Calculate function. Once the junction inverts were modified to the desired elevation, the Field Calculate function was used to set the junctions' rim elevations to an elevation 30 feet higher than the revised invert elevations. Next, the Field Calculate function was used to adjust the inverts of the corresponding 2D conduits to match the revised junction invert elevations. These steps were repeated for each polygon in the Node_Adjustment layer.

### D.3.5 Modification Over Ponds

To avoid double-counting of available volume, the mesh was adjusted over the modeled ponds as well. Lubber Run is the only watershed that contains a modeled pond.

Similar to the process used for mesh modification over the open channels, a polygon layer was created to represent the pond footprint. Using the contours generated from the DEM, the highest closed contour around the pond was identified. This contour was converted into a polygon using an ArcGIS tool, and its elevation was recorded. This polygon was added to the Node_Adjustment shapefile described in Section D.3.3. The inverts of the 2D model elements located within this polygon were adjusted to the contour's elevation using the same process performed for the other Node_Adjustment polygons as detailed in Section D.3.3.

Figure D-4 shows the selection of the contour representing the embankment elevation for the basin.

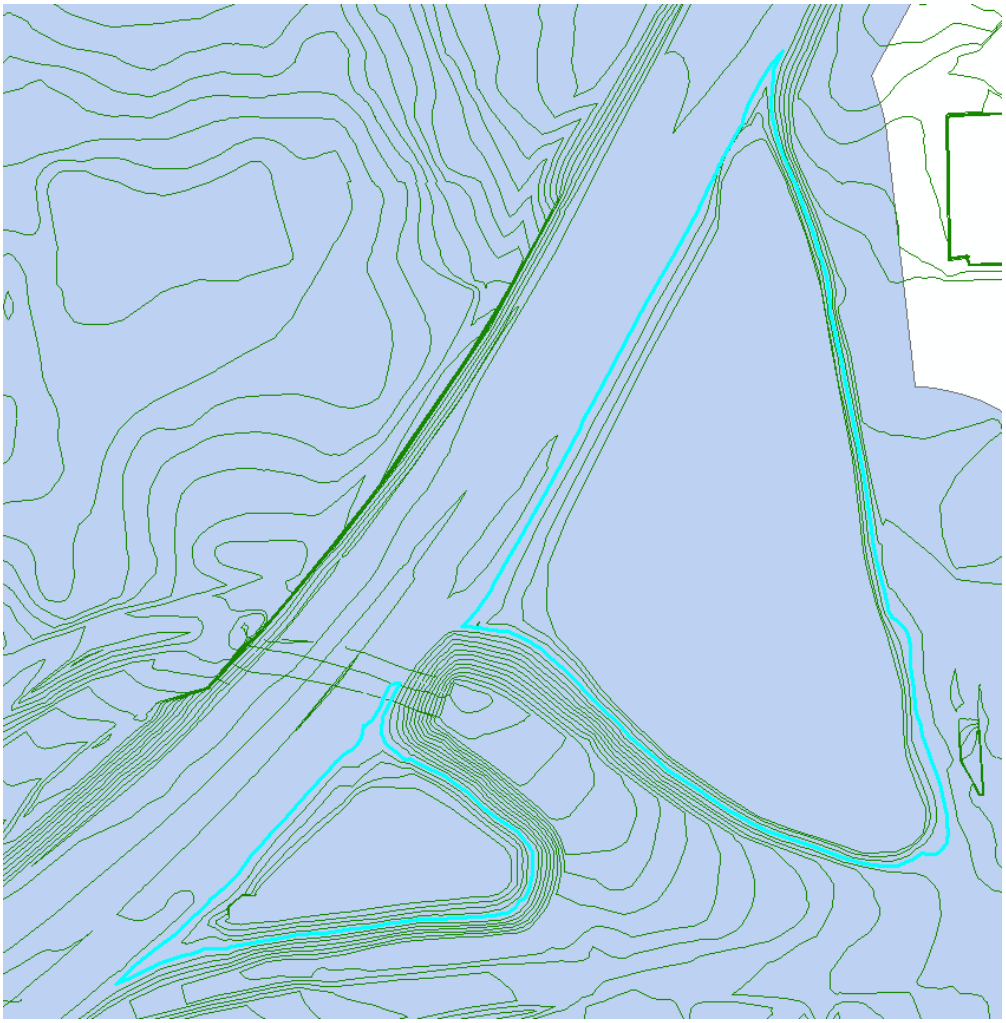


**Figure D-4. Selection of Embank Contour from the Dataset**

## D.4 Boundary Conditions

For models with Mesh 2.0 and beyond, boundary conditions were applied according to Table F-5 as provided in Appendix F.

## D.5 Additional Considerations

The 1D/2D connection orifices were modeled and dimensioned to represent a width of four six-foot catch basin inlets. This blanket assumption was based on a Google Earth review of the area looking at inlet formations at intersections. However, based on additional observations made from both Google Earth and the Arlington County geodatabase inventory of inlets, some major highways and boulevards were found to have a higher concentration of VDOT grate inlets. These roads were found to have larger and/or more grates than our assumption. After running the 2020 10 year 24-hour storm these major highways and boulevards were checked to ensure that flooding did not cover more than ½ of the roadway. For example, for a 12' roadway (typical) the team would ensure that there was not a flooding band across the road more than 6' perpendicular to the roadway. For any event, flooding across the entire roadway was seen as a red flag that warranted investigation. It is of note that in general, 4 in/hr is the design criteria for VDOT inlets. Where roadway flooding was observed for the 2020 10 year, 24 hour storm, an inlet review was conducted in the surrounding area, and the orifice width and number of orifices were adjusted as necessary to accurately represent the number and widths of existing inlets in the area of concern.

### D.5.1 Documentation

Each time a new version of the mesh was created, a new version of the model of the model was created as well. When a new version was created the following notes were provided in the model's Project Notes:

- Watershed Name
- Name of Modeler
- Date of Model
- Storm Event Run for Model
- List of Modifications from Previous Version (i.e., 2D layer added, As-builts)

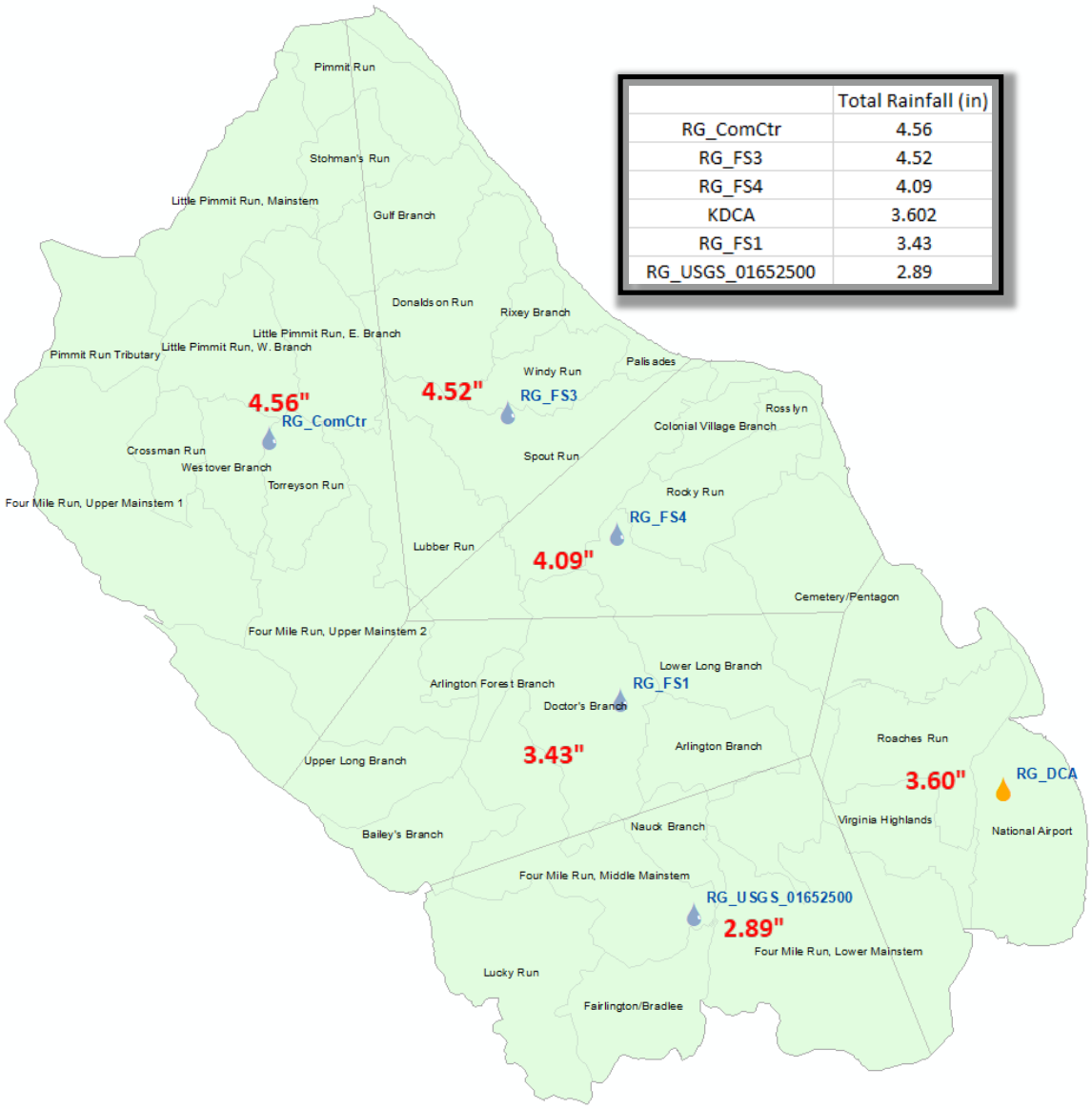
### D.5.2 QC

Once the 1D/2D model mesh was iterated and calibrated to the point that it accurately represented correlation between problem areas a detailed, standardized QC process was performed prior to model finalization.

### D.5.3 2019 Validation Process

The July 8$^{th}$, 2019 historical event was run in each watershed's model to validate modeled flooding against problem data. Problem data was compared against the 2D flood extents produced by each watershed's model. Each model was found to generally validate well within the 2D model extents.

Unique rain gauge(s) were associated to each watershed's subcatchments depending on their geospatial location. A weighted average was not performed for those polygons overlapping two gage areas. If a subcatchment fell within two Thiessen rain gauge polygons, the rain gauge where the majority of the subcatchment area is contained was used for that subcatchment. Figure D-5 shows the watersheds of Arlington County and the Thiessen rain gauge polygons.




| | Total Rainfall (in) |
|---|---|
| RG_ComCtr | 4.56 |
| RG_FS3 | 4.52 |
| RG_FS4 | 4.09 |
| KDCA | 3.602 |
| RG_FS1 | 3.43 |
| RG_USGS_01652500 | 2.89 |

**Figure D-5. Thiessen Polygons for July 8th, 2019 Event (rain gage totals in inches for the July 8th event are shown in red for each gage)**

The proper rain gauge was assigned to each subcatchment in each watershed according to the information shown on Figure D-5. Boundary conditions were applied for the July 8th, 2019 rainfall event as shown on documented in Appendix F.

# Appendix E
# Rainfall Distributions

# Appendix E. Rainfall Distributions

Table E-1 summarizes the distributions of incremental rainfall that were used for the nine modeling scenarios using synthetic 24-hour storms for the current, 2040 and 2070 planning horizons with the 10-year, 100-year, and 500-year storms. The background on climate projections and rainfall distributions were developed in RAMP Task 3.1 and documented in and documented a Draft Technical Memorandum: *Climate Projections and Scenarios* (Jacobs 2020a).

Table E-2 summarized the measured distribution of incremental rainfall for 6 rain gages used to drive models for the July 8, 2019 historical rainfall event. Analysis of the July 2019 storm was also documented in the Technical Memorandum on Climate Projections and Scenarios (Jacobs 2020a).

**Table E-1. Incremental Synthetic Rainfall Event Distributions**

| Date | Time | Year 2020: 10-yr (inches) | Year 2020: 100-yr (inches) | Year 2020: 500-yr (inches) | Year 2040: 10-yr RCP 8.5, 50% (inches) | Year 2040: 100-yr RCP 8.5, 50% (inches) | Year 2040: 500-yr RCP 8.5, 50% (inches) | Year 2070: 10-yr RCP 8.5, 50% (inches) | Year 2070: 100-yr RCP 8.5, 50% (inches) | Year 2070: 500-yr RCP 8.5, 50% (inches) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/1/2020 | 0:00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1/1/2020 | 0:15 | 0.01032 | 0.01696 | 0.02294 | 0.01098 | 0.01808 | 0.02442 | 0.01162 | 0.01914 | 0.02588 |
| 1/1/2020 | 0:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 0:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 1:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 1:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 1:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 1:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 2:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 2:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 2:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 2:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 3:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 3:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 3:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 3:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 4:00 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 4:15 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 4:30 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 4:45 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 5:00 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 5:15 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 5:30 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 5:45 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 6:00 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 6:15 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 6:30 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 6:45 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 7:00 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 7:15 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |

**Table E-1. Incremental Synthetic Rainfall Event Distributions**

| Date | Time | Year 2020: 10-yr (inches) | Year 2020: 100-yr (inches) | Year 2020: 500-yr (inches) | Year 2040: 10-yr RCP 8.5, 50% (inches) | Year 2040: 100-yr RCP 8.5, 50% (inches) | Year 2040: 500-yr RCP 8.5, 50% (inches) | Year 2070: 10-yr RCP 8.5, 50% (inches) | Year 2070: 100-yr RCP 8.5, 50% (inches) | Year 2070: 500-yr RCP 8.5, 50% (inches) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/1/2020 | 7:30 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 7:45 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 8:00 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 8:15 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |
| 1/1/2020 | 8:30 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 8:45 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 9:00 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 9:15 | 0.04128 | 0.06784 | 0.09176 | 0.04392 | 0.07232 | 0.09768 | 0.04648 | 0.07656 | 0.10352 |
| 1/1/2020 | 9:30 | 0.04128 | 0.06784 | 0.09176 | 0.04392 | 0.07232 | 0.09768 | 0.04648 | 0.07656 | 0.10352 |
| 1/1/2020 | 9:45 | 0.04644 | 0.07632 | 0.10323 | 0.04941 | 0.08136 | 0.10989 | 0.05229 | 0.08613 | 0.11646 |
| 1/1/2020 | 10:00 | 0.04644 | 0.07632 | 0.10323 | 0.04941 | 0.08136 | 0.10989 | 0.05229 | 0.08613 | 0.11646 |
| 1/1/2020 | 10:15 | 0.0516 | 0.0848 | 0.1147 | 0.0549 | 0.0904 | 0.1221 | 0.0581 | 0.0957 | 0.1294 |
| 1/1/2020 | 10:30 | 0.06192 | 0.10176 | 0.13764 | 0.06588 | 0.10848 | 0.14652 | 0.06972 | 0.11484 | 0.15528 |
| 1/1/2020 | 10:45 | 0.0774 | 0.1272 | 0.17205 | 0.08235 | 0.1356 | 0.18315 | 0.08715 | 0.14355 | 0.1941 |
| 1/1/2020 | 11:00 | 0.09288 | 0.15264 | 0.20646 | 0.09882 | 0.16272 | 0.21978 | 0.10458 | 0.17226 | 0.23292 |
| 1/1/2020 | 11:15 | 0.10836 | 0.17808 | 0.24087 | 0.11529 | 0.18984 | 0.25641 | 0.12201 | 0.20097 | 0.27174 |
| 1/1/2020 | 11:30 | 0.13416 | 0.22048 | 0.29822 | 0.14274 | 0.23504 | 0.31746 | 0.15106 | 0.24882 | 0.33644 |
| 1/1/2020 | 11:45 | 0.53664 | 0.88192 | 1.19288 | 0.57096 | 0.94016 | 1.26984 | 0.60424 | 0.99528 | 1.34576 |
| 1/1/2020 | 12:00 | 1.42416 | 2.34048 | 3.16572 | 1.51524 | 2.49504 | 3.36996 | 1.60356 | 2.64132 | 3.57144 |
| 1/1/2020 | 12:15 | 0.22704 | 0.37312 | 0.50468 | 0.24156 | 0.39776 | 0.53724 | 0.25564 | 0.42108 | 0.56936 |
| 1/1/2020 | 12:30 | 0.14448 | 0.23744 | 0.32116 | 0.15372 | 0.25312 | 0.34188 | 0.16268 | 0.26796 | 0.36232 |
| 1/1/2020 | 12:45 | 0.11868 | 0.19504 | 0.26381 | 0.12627 | 0.20792 | 0.28083 | 0.13363 | 0.22011 | 0.29762 |
| 1/1/2020 | 13:00 | 0.09288 | 0.15264 | 0.20646 | 0.09882 | 0.16272 | 0.21978 | 0.10458 | 0.17226 | 0.23292 |
| 1/1/2020 | 13:15 | 0.0774 | 0.1272 | 0.17205 | 0.08235 | 0.1356 | 0.18315 | 0.08715 | 0.14355 | 0.1941 |
| 1/1/2020 | 13:30 | 0.06708 | 0.11024 | 0.14911 | 0.07137 | 0.11752 | 0.15873 | 0.07553 | 0.12441 | 0.16822 |
| 1/1/2020 | 13:45 | 0.05676 | 0.09328 | 0.12617 | 0.06039 | 0.09944 | 0.13431 | 0.06391 | 0.10527 | 0.14234 |
| 1/1/2020 | 14:00 | 0.0516 | 0.0848 | 0.1147 | 0.0549 | 0.0904 | 0.1221 | 0.0581 | 0.0957 | 0.1294 |
| 1/1/2020 | 14:15 | 0.04644 | 0.07632 | 0.10323 | 0.04941 | 0.08136 | 0.10989 | 0.05229 | 0.08613 | 0.11646 |
| 1/1/2020 | 14:30 | 0.04128 | 0.06784 | 0.09176 | 0.04392 | 0.07232 | 0.09768 | 0.04648 | 0.07656 | 0.10352 |
| 1/1/2020 | 14:45 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 15:00 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 15:15 | 0.03612 | 0.05936 | 0.08029 | 0.03843 | 0.06328 | 0.08547 | 0.04067 | 0.06699 | 0.09058 |
| 1/1/2020 | 15:30 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |
| 1/1/2020 | 15:45 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |
| 1/1/2020 | 16:00 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |
| 1/1/2020 | 16:15 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |
| 1/1/2020 | 16:30 | 0.03096 | 0.05088 | 0.06882 | 0.03294 | 0.05424 | 0.07326 | 0.03486 | 0.05742 | 0.07764 |

**Table E-1. Incremental Synthetic Rainfall Event Distributions**

| Date | Time | Year 2020: 10-yr (inches) | Year 2020: 100-yr (inches) | Year 2020: 500-yr (inches) | Year 2040: 10-yr RCP 8.5, 50% (inches) | Year 2040: 100-yr RCP 8.5, 50% (inches) | Year 2040: 500-yr RCP 8.5, 50% (inches) | Year 2070: 10-yr RCP 8.5, 50% (inches) | Year 2070: 100-yr RCP 8.5, 50% (inches) | Year 2070: 500-yr RCP 8.5, 50% (inches) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/1/2020 | 16:45 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 17:00 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 17:15 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 17:30 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 17:45 | 0.0258 | 0.0424 | 0.05735 | 0.02745 | 0.0452 | 0.06105 | 0.02905 | 0.04785 | 0.0647 |
| 1/1/2020 | 18:00 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 18:15 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 18:30 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 18:45 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 19:00 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 19:15 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 19:30 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 19:45 | 0.02064 | 0.03392 | 0.04588 | 0.02196 | 0.03616 | 0.04884 | 0.02324 | 0.03828 | 0.05176 |
| 1/1/2020 | 20:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 20:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 20:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 20:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 21:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 21:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 21:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 21:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 22:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 22:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 22:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 22:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 23:00 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 23:15 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 23:30 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/1/2020 | 23:45 | 0.01548 | 0.02544 | 0.03441 | 0.01647 | 0.02712 | 0.03663 | 0.01743 | 0.02871 | 0.03882 |
| 1/2/2020 | 0:00 | 0.01032 | 0.01696 | 0.02294 | 0.01098 | 0.01808 | 0.02442 | 0.01162 | 0.01914 | 0.02588 |

**Table E-2. Incremental Rainfall Distribution by Rain Gage for July 2019 Historical Event**

| Date/Time | RG_ComCtr (inches) | RG_DCA (inches) | RG_FS1 (inches) | RG_FS3 (inches) | RG_FS4 (inches) | RG_USGS (inches) |
|---|---|---|---|---|---|---|
| 7/8/2019 4:25 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 4:30 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 4:35 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 4:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 4:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 4:50 | 0 | — | 0.01 | 0 | 0 | 0 |
| 7/8/2019 4:55 | 0 | — | 0.01 | 0 | 0 | 0 |
| 7/8/2019 5:00 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 5:05 | 0.03 | — | 0.01 | 0 | 0 | 0 |
| 7/8/2019 5:10 | 0.02 | — | 0.02 | 0.02 | 0.01 | 0 |
| 7/8/2019 5:15 | 0.03 | — | 0 | 0.03 | 0 | 0 |
| 7/8/2019 5:20 | 0.01 | — | 0 | 0.01 | 0.01 | 0 |
| 7/8/2019 5:25 | 0.01 | — | 0 | 0.01 | 0.01 | 0 |
| 7/8/2019 5:30 | 0.01 | — | 0 | 0 | 0.01 | 0 |
| 7/8/2019 5:35 | 0 | — | 0 | 0.01 | 0 | 0 |
| 7/8/2019 5:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 5:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 5:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 5:55 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:00 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:05 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:10 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:15 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:20 | 0.01 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:25 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:30 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:35 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 6:55 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:00 | 0 | — | 0 | 0 | 0 | 0 |

**Table E-2. Incremental Rainfall Distribution by Rain Gage for July 2019 Historical Event**

| Date/Time | RG_ComCtr (inches) | RG_DCA (inches) | RG_FS1 (inches) | RG_FS3 (inches) | RG_FS4 (inches) | RG_USGS (inches) |
|---|---|---|---|---|---|---|
| 7/8/2019 7:05 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:10 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:15 | 0.01 | — | 0 | 0.01 | 0 | 0 |
| 7/8/2019 7:20 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:25 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:30 | 0 | — | 0 | 0 | 0.01 | 0 |
| 7/8/2019 7:35 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 7:55 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:00 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:05 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:10 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:15 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:20 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:25 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:30 | 0.01 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 8:35 | 0.2 | 0.00 | 0 | 0.2 | 0 | 0 |
| 7/8/2019 8:40 | 0.43 | 0.00 | 0 | 0.58 | 0.2 | 0 |
| 7/8/2019 8:45 | 0.54 | 0.00 | 0 | 0.71 | 0.51 | 0 |
| 7/8/2019 8:50 | 0.64 | 0.00 | 0.21 | 0.6 | 0.58 | 0 |
| 7/8/2019 8:55 | 0.62 | 0.00 | 0.41 | 0.5 | 0.46 | 0.26 |
| 7/8/2019 9:00 | 0.44 | 0.18 | 0.38 | 0.43 | 0.42 | 0.33 |
| 7/8/2019 9:05 | 0.33 | 0.61 | 0.43 | 0.3 | 0.39 | 0.39 |
| 7/8/2019 9:10 | 0.26 | 0.34 | 0.44 | 0.22 | 0.29 | 0.42 |
| 7/8/2019 9:15 | 0.27 | 0.00 | 0.31 | 0.23 | 0.23 | 0.22 |
| 7/8/2019 9:20 | 0.19 | 0.63 | 0.23 | 0.15 | 0.25 | 0.24 |
| 7/8/2019 9:25 | 0.16 | 0.27 | 0.3 | 0.09 | 0.2 | 0.28 |
| 7/8/2019 9:30 | 0.08 | 0.35 | 0.24 | 0.08 | 0.09 | 0.23 |
| 7/8/2019 9:35 | 0.03 | 0.00 | 0.09 | 0.05 | 0.05 | 0.11 |
| 7/8/2019 9:40 | 0.04 | 0.23 | 0.09 | 0.02 | 0.03 | 0.1 |

**Table E-2. Incremental Rainfall Distribution by Rain Gage for July 2019 Historical Event**

| Date/Time | RG_ComCtr (inches) | RG_DCA (inches) | RG_FS1 (inches) | RG_FS3 (inches) | RG_FS4 (inches) | RG_USGS (inches) |
|---|---|---|---|---|---|---|
| 7/8/2019 9:45 | 0.04 | 0.72 | 0.04 | 0.05 | 0.02 | 0.05 |
| 7/8/2019 9:50 | 0.02 | 0.13 | 0.02 | 0.03 | 0.02 | 0.07 |
| 7/8/2019 9:55 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.03 |
| 7/8/2019 10:00 | 0 | 0.01 | 0.02 | 0.01 | 0.02 | 0 |
| 7/8/2019 10:05 | 0.02 | 0.03 | 0.02 | 0.01 | 0.01 | 0.02 |
| 7/8/2019 10:10 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| 7/8/2019 10:15 | 0 | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 |
| 7/8/2019 10:20 | 0 | 0.00 | 0.01 | 0.03 | 0.04 | 0.02 |
| 7/8/2019 10:25 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 |
| 7/8/2019 10:30 | 0 | 0.02 | 0.01 | 0 | 0.01 | 0 |
| 7/8/2019 10:35 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 10:40 | 0.01 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 10:45 | 0 | 0.00 | 0 | 0.01 | 0 | 0.01 |
| 7/8/2019 10:50 | 0 | 0.01 | 0.01 | 0 | 0 | 0 |
| 7/8/2019 10:55 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 11:00 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 11:05 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 11:10 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 11:15 | 0 | 0.00 | 0 | 0 | 0 | 0 |
| 7/8/2019 11:20 | 0 | 0.00 | 0 | 0.01 | 0.01 | 0 |
| 7/8/2019 11:25 | 0.01 | 0.00 | 0 | 0 | 0.06 | 0 |
| 7/8/2019 11:30 | 0 | 0.00 | 0 | 0 | 0.01 | 0 |
| 7/8/2019 11:35 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 11:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 11:45 | 0.01 | — | 0 | 0 | 0 | 0.01 |
| 7/8/2019 11:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 11:55 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:00 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:05 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:10 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:15 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:20 | 0 | — | 0 | 0 | 0 | 0 |

**Table E-2. Incremental Rainfall Distribution by Rain Gage for July 2019 Historical Event**

| Date/Time | RG_ComCtr (inches) | RG_DCA (inches) | RG_FS1 (inches) | RG_FS3 (inches) | RG_FS4 (inches) | RG_USGS (inches) |
|---|---|---|---|---|---|---|
| 7/8/2019 12:25 | 0.01 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:30 | 0 | — | 0 | 0.01 | 0.01 | 0 |
| 7/8/2019 12:35 | 0.01 | — | 0.01 | 0 | 0 | 0 |
| 7/8/2019 12:40 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 12:55 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:00 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:05 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:10 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:15 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:20 | 0 | — | 0 | 0.01 | 0.01 | 0.01 |
| 7/8/2019 13:25 | 0 | — | 0 | 0.01 | 0.01 | 0 |
| 7/8/2019 13:30 | 0.01 | — | 0.01 | 0 | 0.01 | 0.01 |
| 7/8/2019 13:35 | 0.01 | — | 0.01 | 0.01 | 0 | 0 |
| 7/8/2019 13:40 | 0 | — | 0.01 | 0 | 0.01 | 0.01 |
| 7/8/2019 13:45 | 0.01 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 13:50 | 0 | — | 0.01 | 0.01 | 0 | 0.01 |
| 7/8/2019 13:55 | 0 | — | 0 | 0 | 0.01 | 0 |
| 7/8/2019 14:00 | 0 | — | 0.02 | 0 | 0 | 0 |
| 7/8/2019 14:05 | 0 | — | 0 | 0 | 0 | 0.01 |
| 7/8/2019 14:10 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:15 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:20 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:25 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:30 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:35 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:40 | 0 | — | 0 | 0 | 0 | 0.01 |
| 7/8/2019 14:45 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:50 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 14:55 | 0 | — | 0 | 0 | 0 | 0 |
| 7/8/2019 15:00 | 0 | — | 0 | 0 | 0 | 0 |

# Appendix F
# 1D/2D PCSWWM Modeling Downstream Boundary Conditions

# Appendix F. 1D/2D PCSWMM Modeling Downstream Boundary Conditions

## F.1 Downstream Boundary Development

To ensure that flood modeling scenarios in each watershed account for the potential for backwater from high water levels at their downstream discharge point, backwater boundary conditions were established based on each watershed's unique outfall type based on slope and the downstream waterway. The eight watersheds selected for detailed 1D/2D modeling in PCSWMM outfall to the following water bodies as shown in Table F-1.

**Table F-1. Downstream Outfall Type and Location by Watershed**

| Watershed | Outfall Type | Location |
|---|---|---|
| Doctor's Branch | Fixed Stage | Four Mile Run |
| Four Mile Run, Lower Mainstem | Fixed Stage | Potomac River |
| Little Pimmit Run | Free Outfall | — |
| Lubber Run | Fixed Stage | Four Mile Run |
| Roaches Run | Fixed Stage | Potomac River |
| Spout Run | Free Outfall | — |
| Torreyson Run | Fixed Stage | Four Mile Run |
| Virginia Highlands | Combined with FMR Model | Four Mile Run |

## F.2 Potomac River Boundaries

Roaches Run and Four Mile Run, Lower Mainstem outlet into the Potomac River. To assess the extent of flooding in the Potomac due to the projected effects of climate change on the project area, Jacobs adapted the existing Potomac and Anacostia River models developed and applied previously for the Potomac using the MIKE 21 Flow Model FM (Flexible Mesh) module[1]. Further information on coastal modeling with MIKE 21 is provided in the Task 3.4 technical memorandum entitled *Coastal Surge Modeling* (Jacobs 2020b). The calibrated model was run for a total of 6 scenarios, two baseline scenarios for the 100-year and 500-year storm events, and 4 future scenarios with various SLR scenarios based on a combination of planning horizons, storm return periods and SLR projections as summarized in Table F-2.

[1] MIKE Powered by DHI. 2020. MIKE 21 Flow Model FM. https://www.mikepoweredbydhi.com/products/mike-21-3.

**Table F-2. Climate Scenarios for Coastal Flood Modeling**

| Scenario | Extreme Water Level Scenario | Extreme Water Level Value applied at Lewisetta[a] (feet, NAVD88) | Planning Horizon | SLR Scenario | SLR Value at Solomon Island[b] (feet, relative sea level change) | Extreme Water Level (Lewisetta[a]) + SLR (Solomon Island[b]) (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Baseline: 100-year | 100-year | 4.9 | Current Conditions | None | 0 | 4.9 |
| 2. Baseline: 500-year | 500-year | 5.7 | Current Conditions | None | 0 | 5.7 |
| 3. Year 2040: 100-year | 100-year | 4.9 | 2040 | Int-High | 1.7 | 6.6 |
| 4. Year 2040: 500-year | 500-year | 5.7 | 2040 | Int-High | 1.7 | 7.4 |
| 5. Year 2070: 100-year | 100-year | 4.9 | 2070 | Int-High | 3.7 | 8.6 |
| 6. Year 2070: 500-year | 500-year | 5.7 | 2070 | Int-High | 3.7 | 9.4 |

[a] Lewisetta is located at the downstream open boundary of the Potomac River Model
[b] SLR projections from Solomons Island station, using NOAA 2017 projections.

The baseline and projected flood elevations at the mouth of Four Mile Run and Roaches Run are tabulated in Table F-3. These values were used as boundary conditions for Four Mile Run, Lower Mainstem and Roaches Run.

**Table F-3. Summary of Modeled Maximum Flood Elevation Results for Two Baseline and Four Climate Scenarios at the Mouth of Four Mile Run and Roaches Run**

| Scenario | Extreme Water Level Scenario | Planning Horizon | SLR Scenario | SLR Value Applied at Open Boundary (ft) | Modeled Maximum Flood Elevation (ft, NAVD) | |
|---|---|---|---|---|---|---|
| | | | | | Four Mile Run Confluence | Roaches Run Confluence |
| 1. Baseline: 100-year | 100-year | Current Conditions | None | 0 | 10.5 | 11.0 |
| 2. Baseline: 500-year | 500-year | Current Conditions | None | 0 | 14.0 | 14.0 |
| 3. Year 2040: 100-year | 100-year | 2040 | Int-High | 1.7 | 11.5 | 11.8 |
| 4. Year 2040: 500-year | 500-year | 2040 | Int-High | 1.7 | 14.7 | 14.9 |
| 5. Year 2070: 100-year | 100-year | 2070 | Int-High | 3.73 | 12.7 | 13.0 |
| 6. Year 2070: 500-year | 500-year | 2070 | Int-High | 3.73 | 15.6 | 15.7 |

Further information on coastal modeling is provided in the Task 3.4 technical memorandum entitled *Coastal Surge Modeling* (Jacobs 2020b).

## F.3 Four Mile Run Boundaries

### F.3.1 Watershed and Model Description

The NVRC Four Mile Run watershed has a modeled tributary area of approximately 12,602 acres. The watershed is in southwest Arlington County and drains into the Potomac River. Detailed 1D modeling was performed for the whole Four Mile Run watershed in PCSWMM version 7.3.3095 using SWMM engine 5.1.015. The 1D PCSWMM model for Four Mile Run, which included overland flow paths previously developed by NVRC and Arlington County in 2018, was used as the base model. The location of the Four Mile Run watershed is shown on Figure F-1.

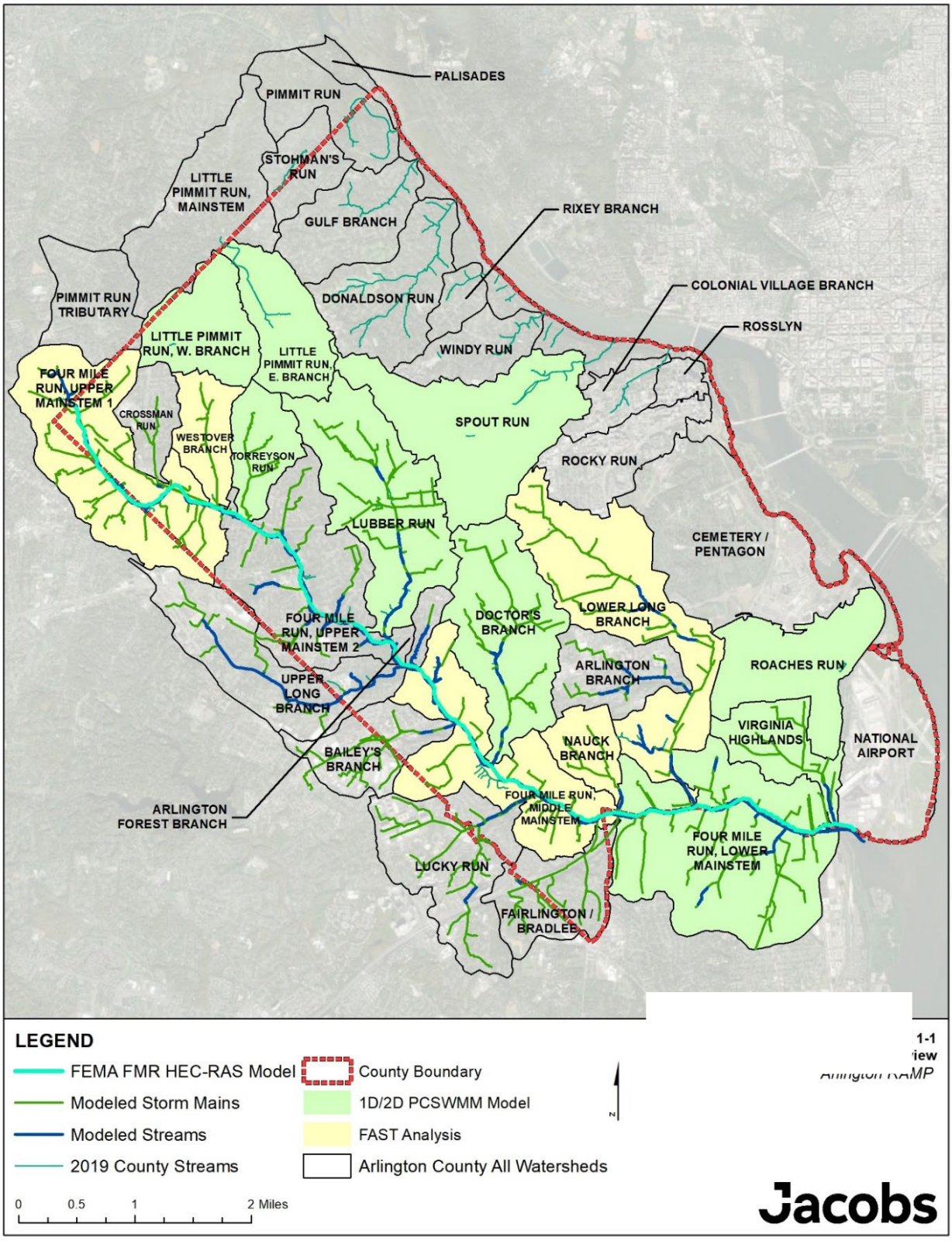



**Figure F-1. Arlington County Watershed Overview**

The Four Mile Run watersheds modeled under RAMP are individual subwatersheds in the Four Mile Run watershed. To model flooding in these watersheds the water level on the downstream end must be known and provided as an input to the watershed models. The NVRC Four Mile Run model and FEMA Preliminary Flood Study (September 18, 2020) HEC-RAS model for the mainstem of Four Mile Run were used together to generate the water level at the watershed outlets under various scenarios. This process is discussed in detail in the following sections.

### F.3.2 Inflows to Four Mile Run Model under Climate Change

The FEMA Preliminary Flood Study does not include a hydrology model that estimates flow rates along the Four Mile Run mainstem as a function of rainfall. Therefore, if the effects of climate change on rainfall are to be applied in establishing boundary conditions for each watershed the peak flow rates at each location needs to be established. The NVRC model was used for this purpose, as follows.

As a first step, the peak flow rates were compared between three models to determine which to use as a basis for developing riverine boundary condition runs for Lubber Run, Doctor's Branch, and Torreyson Run:

- The effective FEMA Flood Insurance Study report dated August 19, 2013
- The FEMA Preliminary Flood Study HEC-RAS model dated September 18, 2020
- The NVRC 1D PCSWMM model for Four Mile Run

A comparison of peak flow rates at key locations throughout Four Mile Run for these three models is shown in Table F-4.

Flows from the NVRC 1D PCSWMM model were determined to be comparable to the FEMA Preliminary Flood Study 2020 values. Due to the difficulty in extrapolating FEMA's statistically-derived flows to determine future condition flows impacted by climate change, the NVRC 1D PCSWMM model was run for all modeled scenarios, including for climate escalated rainfall, with additional updates as described below. The FEMA Preliminary Flood Study 2020 HEC-RAS model for the Four Mile Run mainstem was then updated using these 1D NVRC PCSWMM model flows (Table F-5) and simulated for the all 10 scenarios to estimate the boundary water surface elevation at the outfalls of Torreyson Run, Lubber Run and Doctor's Branch.

The Four Mile Run, Lower Mainstem has two inflow boundaries – one at the upstream boundary of the mainstem near Shirlington Road (Junction ID 20928) and another from the Lower Long Branch (Junction ID 20651) tributary. The 1D NVRC PCSWMM model also provided the flow timeseries at these locations for each of the 10 scenarios. These flow timeseries were used to define the upstream boundary conditions of the 1D and 2D Four Mile Run, Lower Mainstem and the combined Lower Four Mile Run, Virginia Highlands and Roaches Run models.

### F.3.3 NVRC Four Mile Run Model Updates

Minor updates were made to NVRC Four Mile Run model for the simulation of boundary conditions. In order to generate results consistent with FEMA Preliminary Flood Study 2020 HEC-RAS model for Four Mile Run, 141 nodes were created and the surveyed invert elevations were added to the 1D NVRC PCSWMM model at the HEC-RAS cross-section locations along the Four Mile Run mainstream. Additionally, 32 cross section transects in the 1D NVRC PCSWMM model were updated using the surveyed data obtained from the FEMA 2020 HEC-RAS model. These modifications are provided in detail in Table F-6 (included at the end of Appendix F).

## F.4 Finalized Downstream Boundaries

Downstream boundary conditions utilized for Task 3.3 are listed by watershed and storm event in Table F-7. These boundary conditions resulted from running the updated 1D NVRC PCSWMM model for 10 scenarios (3 current conditions, July 8, 2019 historical event, and 6 future climate scenarios) and the modeled peak flows were exported for input in HEC-RAS. The HEC-RAS model results are summarized in Table F-7.

**Table F-4. Four Mile Run Model Comparison: Effective FEMA HEC-RAS (2013), NVRC 1D PCSWMM, and FEMA Preliminary HEC-RAS Model (2020)**

| Location | Effective FEMA Flood Insurance Study Report (2013) | | Preliminary Flood Study (Sep 18, 2020) | | NVRC 1D PCSWMM Model (2018) | | FEMA Preliminary HEC-RAS Model (2020) |
|---|---|---|---|---|---|---|---|
| | Drainage Area ($mi^2$) | 100-yr Flow (cfs) | Drainage Area ($mi^2$) | 100-yr Flow (cfs) | NVRC's 100-yr 4-hr Flow (cfs) | SCS 100-yr 24-hr Flow (cfs) | 100yr, 4-hr Storm from SCS 24-hr (cfs) |
| Downstream of Lee Highway | 1 | 1,709 | 0.9 | 1,695 | 2,038 | 2,119 | 1,935 |
| Downstream of North Van Buren Street | 1.4 | 2,049 | 1.4 | 2,035 | 2,608 | 2,796 | 2,715 |
| Downstream of North Sycamore Street | 1.4 | 2,211 | 2.1 | 2,782 | 3,815 | 3,982 | 3,549 |
| Downstream of confluence of Left Bank Tributary | 3.3 | 2,800 | 2.7 | 3,257 | 5,019 | 5,430 | 4,852 |
| Downstream of confluence of Right Bank Tributary | 4.6 | 7,000 | 4.8 | 4,444 | 7,071 | 7,610 | 6,863 |
| Downstream of confluence of Lubber Run | 6.5 | 7,000 | 6.6 | 8,369 | 11,120 | 11,338 | 10,679 |
| Downstream of confluence of Upper Long Branch | 7.8 | 9,600 | 8.1 | 10,237 | 11,926 | 12,004 | 11,298 |
| Downstream of confluence of Right Bank Tributary | 8.9 | 12,100 | 8.8 | 11,209 | 13,475 | 13,230 | 12,763 |
| At Confluence with Doctors Run | —- | —- | 9.2 | 11,654 | 13,989 | 14,140 | 13,120 |
| Downstream of confluence of Doctors Branch | 10.8 | 14,900 | 10.8 | 13,735 | 15,668 | 15,608 | 14,930 |
| Downstream of confluence of Lucky Run | 12.3 | 22,100 | 12.5 | 15,875 | 18,714 | 18,696 | 17,590 |
| USGS 01652500 | —- | —- | 13.1 | 16,670 | 18,005 | 17,650 | 16,598 |
| Downstream of S Shirlington Rd | —- | —- | 13.2 | 16,813 | 20,058 | 18,400 | 18,220 |
| Downstream of W Glebe Rd | —- | —- | 14.2 | 17,985 | 19,287 | 18,745 | 18,126 |
| Downstream of Mount Vernon Ave | —- | —- | 16.3 | 20,635 | 20,472 | 20,552 | 19,063 |
| Downstream of confluence of Lower Long Branch | 17.3 | 26,000 | 17.3 | 21,964 | 18,831 | 19,482 | 18,066 |
| Downstream of George Washington Memorial Pkwy | —- | —- | 18.4 | 23,319 | 19,455 | 20,137 | 18,642 |

**Table F-5. Flow Results for Boundary Condition Simulations**

| HEC-RAS Model River Station | Flow (cfs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10-yr, 24-hr (2020) | 100-yr, 24-hr (2020) | 500-yr, 24-hr (2020) | 10-yr, 24-hr, (2040) | 100-yr, 24-hr (2040) | 500-yr, 24-hr (2040) | 10-yr, 24-hr (2070) | 100-yr, 24-hr (2070) | 500-yr, 24-hr (2070) | July 8, 2019 Historical |
| 50631 | 1153.32 | 2151.04 | 3730.58 | 1256.7 | 2382.16 | 4162.36 | 1389.69 | 2733.03 | 4740.56 | 1681.63 |
| 45599 | 1595.5 | 3151.02 | 4226.22 | 1793.14 | 3469.64 | 4480.55 | 1811.61 | 3915.36 | 4651.04 | 2424.41 |
| 41381 | 2254.67 | 3787.57 | 4904.92 | 2380.34 | 4005.41 | 5231.97 | 2556.46 | 4240.44 | 5563.41 | 3244.52 |
| 40556 | 2822.12 | 4535.64 | 5950.21 | 3199.04 | 4774.11 | 6178.38 | 3215.16 | 5009.53 | 6565.11 | 3871.79 |
| 38877 | 5694.92 | 8190.8 | 10679.88 | 5554.46 | 9293.3 | 11609.02 | 6537.45 | 9303.81 | 12229.19 | 7161.93 |
| 28597 | 6181.81 | 11559.29 | 12664.65 | 6708.37 | 12115.99 | 13523.63 | 8461.98 | 12807.03 | 14267.09 | 8511.64 |
| 26174 | 7611.38 | 11877.23 | 15707.19 | 8139.57 | 12494.79 | 16864.97 | 8671.83 | 13189.05 | 17986.37 | 10719.04 |
| 23035 | 8086.72 | 13483.67 | 17814.16 | 8393.19 | 14174.18 | 19221.59 | 8747.2 | 14982.22 | 20756.81 | 11878.15 |
| 20884 | 8327.34 | 13826.32 | 18561.13 | 8643.56 | 15046.61 | 20155.31 | 9183.22 | 16655.89 | 22070.94 | 12542.93 |
| 19961 | 9299.38 | 15532.41 | 20812.67 | 9995.31 | 16879.82 | 22266.26 | 10626.76 | 17664.31 | 23826.01 | 13460.26 |
| 17266 | 11110.05 | 19673.5 | 23437.55 | 11324.38 | 19749.73 | 23755.65 | 11649.15 | 19994.71 | 25100.75 | 15636.96 |
| 14051 | 11840.94 | 19387.85 | 23306.67 | 12154.77 | 19613.85 | 23891.24 | 12076.06 | 19936.85 | 26320.35 | 13896.23 |
| 12571 | 10947.13 | 18665.7 | 23346.23 | 11453.28 | 19739.04 | 25713.78 | 12477.28 | 20969.33 | 26920.3 | 15697.57 |
| 9919 | 11984.17 | 20870.79 | 29722.01 | 13430.19 | 20888.49 | 27953.79 | 14984.07 | 21651.26 | 30313.71 | 17832 |
| 5956 | 10813.67 | 17525.04 | 22469.87 | 10948.95 | 19908.56 | 24701.97 | 13110.08 | 20031.56 | 31752.48 | 14197.52 |

**Table F-7. Boundary Conditions by Storm Event and Watershed**

| Scenario | Observed Event: July 8, 2019 | Baseline: 10-year | Baseline: 100-year | Baseline: 500-year | Baseline: 10-year | Baseline: 100-year | Baseline: 500-year | Baseline: 10-year | Baseline: 100-year | Baseline: 500-year |
|---|---|---|---|---|---|---|---|---|---|---|
| Planning Horizon | Current Conditions | Current Conditions | Current Conditions | Current Conditions | 2040 | 2040 | 2040 | 2070 | 2070 | 2070 |
| Four Mile Run Downstream Boundary (feet,NAVD88) | 1.96 | 5.8 | 10.5 | 14.0 | 7.66 | 11.8 | 15.3 | 9.66 | 13.4 | 16.7 |
| Roaches Downstream Boundary (feet,NAVD88) | 1.96 | 5.8 | 11.0 | 14.0 | 7.66 | 12.2 | 15.2 | 9.66 | 13.6 | 16.5 |
| Spout Run Downstream Boundary (feet,NAVD88) | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall |
| Little Pimmit Run Downstream Boundary (feet,NAVD88) | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall | Free Outfall |
| Lubber Run Downstream Boundary (feet,NAVD88) | 165.3 | 162.7 | 170.51 | 170.86 | 162.97 | 170.68 | 171.13 | 165.18 | 170.81 | 171.36 |
| Doctors Branch Downstream Boundary (feet,NAVD88) | 81.01 | 79.94 | 82.1 | 81.9 | 80.18 | 82.55 | 82.18 | 80.44 | 81.15 | 82.6 |
| Torreyson Run Downstream Boundary (feet,NAVD88) | 242.91 | 241.6 | 243.84 | 245.82 | 241.4 | 244.74 | 246.63 | 242.34 | 244.75 | 247.08 |
| Virginia Highlands Downstream Boundary (feet,NAVD88) | 1.96 | 5.8 | 10.5 | 14.0 | 7.66 | 11.8 | 15.3 | 9.66 | 13.4 | 16.7 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 2317 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 2317 |
| 2626 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 2626 |
| 2849 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 2849 |
| 3149 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 3149 |
| 3248 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 3248 |
| 3481 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 3481 |
| 4023 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 4023 |
| 3773 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 3773 |
| 4409 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 4409 |
| 5956 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 5956 |
| 6980 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 6980 |
| 7777 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 7777 |
| 8077 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 8077 |
| 8278 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 8278 |
| 9023 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 9023 |
| 9919 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 9919 |
| 10245 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 10245 |
| 10506 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 10506 |
| 10835 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 10835 |
| 11268 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 11268 |
| 11546 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 11546 |
| 12226 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 12226 |
| 12571 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 12571 |
| 13219 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 13219 |
| 13662 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 13662 |
| 14051 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 14051 |
| 14440 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 14440 |
| 15085 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 15085 |
| 15632 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 15632 |
| 16077 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 16077 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 17982 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 17982 |
| 18620 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 18620 |
| 18900 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 18900 |
| 19281 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 19281 |
| 19451 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 19451 |
| 19775 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 19775 |
| 19961 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 19961 |
| 20150 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 20150 |
| 21785 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 21785 |
| 21962 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 21962 |
| 22214 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 22214 |
| 22522 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 22522 |
| 23035 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 23035 |
| 23592 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 23592 |
| 23833 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 23833 |
| 23962 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 23962 |
| 24067 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 24067 |
| 24267 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 24267 |
| 24548 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 24548 |
| 24834 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 24834 |
| 25109 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 25109 |
| 25833 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 25833 |
| 26174 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 26174 |
| 26626 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 26626 |
| 26943 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 26943 |
| 27237 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 27237 |
| 27309 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 27309 |
| 27576 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 27576 |
| 27755 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 27755 |
| 27929 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 27929 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 28032 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 28032 |
| 28402 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 28402 |
| 28597 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 28597 |
| 28845 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 28845 |
| 29074 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29074 |
| 29241 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29241 |
| 29462 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29462 |
| 29706 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29706 |
| 29827 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29827 |
| 29886 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 29886 |
| 30668 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 30668 |
| 30864 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 30864 |
| 31101 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 31101 |
| 31194 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 31194 |
| 31430 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 31430 |
| 31738 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 31738 |
| 31886 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 31886 |
| 32118 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 32118 |
| 32507 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 32507 |
| 32781 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 32781 |
| 33048 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 33048 |
| 33416 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 33416 |
| 33852 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 33852 |
| 33997 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 33997 |
| 34030 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 34030 |
| 34206 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 34206 |
| 34453 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 34453 |
| 34741 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 34741 |
| 35090 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 35090 |
| 35271 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 35271 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 35413 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 35413 |
| 35628 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 35628 |
| 35938 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 35938 |
| 36233 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 36233 |
| 36533 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 36533 |
| 36976 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 36976 |
| 37302 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 37302 |
| 37369 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 37369 |
| 37756 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 37756 |
| 37896 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 37896 |
| 38075 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 38075 |
| 38451 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 38451 |
| 38877 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 38877 |
| 39703 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 39703 |
| 39802 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 39802 |
| 39921 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 39921 |
| 40171 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 40171 |
| 40311 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 40311 |
| 40556 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 40556 |
| 41028 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 41028 |
| 41381 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 41381 |
| 41651 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 41651 |
| 42963 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 42963 |
| 43181 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 43181 |
| 43220 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 43220 |
| 43342 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 43342 |
| 43706 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 43706 |
| 43925 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 43925 |
| 44091 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44091 |
| 44142 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44142 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 44401 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44401 |
| 44613 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44613 |
| 44706 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44706 |
| 44848 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 44848 |
| 45599 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 45599 |
| 46063 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46063 |
| 46323 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46323 |
| 46435 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46435 |
| 46611 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46611 |
| 46735 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46735 |
| 46965 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 46965 |
| 47247 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 47247 |
| 47357 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 47357 |
| 47509 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 47509 |
| 48264 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 48264 |
| 48418 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 48418 |
| 48621 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 48621 |
| 14685 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 14685 |
| 16261 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 16261 |
| 16766 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 16766 |
| 30141 | Added a node in the NVRC SWMM Model at HEC-RAS river station ID 30141 |
| 2317 | Transect Cross-Section updated from HEC-RAS model river station ID 2317 |
| 2626 | Transect Cross-Section updated from HEC-RAS model river station ID 2626 |
| 2849 | Transect Cross-Section updated from HEC-RAS model river station ID 2849 |
| 3052 | Transect Cross-Section updated from HEC-RAS model river station ID 3052 |
| 3149 | Transect Cross-Section updated from HEC-RAS model river station ID 3149 |
| 3248 | Transect Cross-Section updated from HEC-RAS model river station ID 3248 |
| 3481 | Transect Cross-Section updated from HEC-RAS model river station ID 3481 |
| 3522 | Transect Cross-Section updated from HEC-RAS model river station ID 3522 |
| 3773 | Transect Cross-Section updated from HEC-RAS model river station ID 3773 |

**Table F-6. 1D NVRC PCSWMM Model Modification Documentation**

| Name/ID | Modification |
|---|---|
| 4023 | Transect Cross-Section updated from HEC-RAS model river station ID 4023 |
| 4409 | Transect Cross-Section updated from HEC-RAS model river station ID 4409 |
| 5956 | Transect Cross-Section updated from HEC-RAS model river station ID 5956 |
| 6980 | Transect Cross-Section updated from HEC-RAS model river station ID 6980 |
| 7777 | Transect Cross-Section updated from HEC-RAS model river station ID 7777 |
| 8077 | Transect Cross-Section updated from HEC-RAS model river station ID 8077 |
| 8278 | Transect Cross-Section updated from HEC-RAS model river station ID 8278 |
| 8566 | Transect Cross-Section updated from HEC-RAS model river station ID 8566 |
| 9023 | Transect Cross-Section updated from HEC-RAS model river station ID 9023 |
| 9489 | Transect Cross-Section updated from HEC-RAS model river station ID 9489 |
| 9919 | Transect Cross-Section updated from HEC-RAS model river station ID 9919 |
| 10245 | Transect Cross-Section updated from HEC-RAS model river station ID 10245 |
| 10506 | Transect Cross-Section updated from HEC-RAS model river station ID 10506 |
| 10835 | Transect Cross-Section updated from HEC-RAS model river station ID 10835 |
| 11268 | Transect Cross-Section updated from HEC-RAS model river station ID 11268 |
| 11546 | Transect Cross-Section updated from HEC-RAS model river station ID 11546 |
| 11767 | Transect Cross-Section updated from HEC-RAS model river station ID 11767 |
| 11953 | Transect Cross-Section updated from HEC-RAS model river station ID 11953 |
| 12226 | Transect Cross-Section updated from HEC-RAS model river station ID 12226 |
| 12571 | Transect Cross-Section updated from HEC-RAS model river station ID 12571 |
| 12781 | Transect Cross-Section updated from HEC-RAS model river station ID 12781 |
| 13219 | Transect Cross-Section updated from HEC-RAS model river station ID 13219 |
| 13662 | Transect Cross-Section updated from HEC-RAS model river station ID 13662 |

# Appendix C
# Coastal Surge Modeling Technical Memorandum

ARLINGTON
VIRGINIA

Jacobs

# Memorandum

2411 Dulles Corner Park, Suite 500
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

| | |
|---|---|
| **Subject** | **Coastal Surge Modeling** |
| **Project Name** | Flood Risk Assessment and Management Plan (RAMP) |
| **Attention** | Arlington County |
| **From** | Say Chong Lee |
| **Date** | October 13, 2020 |
| **Copies to** | Laurens van der Tak, Emmanuel Brainoo, Tara Ajello, Elise Ibendahl, Cheri Salas |

**Introduction**

Arlington County, Virginia has initiated a study to support the Flood Risk Assessment and Management Plan (RAMP). Task 3.4 involves the development of a coastal surge model followed by the conduct of coastal flood modeling to assess changes in flooding within the project area under future climate change conditions using the projections of climate change-induced sea level rise (SLR) scenarios developed under Task 3.1.

**Purpose**

The purpose of this technical memorandum (TM) is to document the development, calibration, and the subsequent simulation of coastal surge propagation under selected future sea level rise (SLR) scenarios using the previously developed Potomac River model (CH2M, 2019) with site-specific adaptations. The model adaptations entail updating the topographic/bathymetric data used in generating the model bathymetry and refining the mesh resolution in the project vicinity. In this regard, additional model calibration using site-specific flow data was conducted.

Results from this analysis will be used as input (downstream control) boundary conditions for the companion inland and riverine modeling that considers rainfall-driven events and described in a separate TM. The resulting coastal surge and SLR boundary conditions are expected to primarily have impacts for the Four Mile Run riverine and subwatershed models, but will be applied to all models that outfall directly to the Potomac. The coastal modeling analysis will also be used to conduct vulnerability and risk assessments in subsequent tasks.

## 1. Executive Summary

To assess the extent of flooding due to the projected effects of climate change of the project area, Jacobs adapted the existing Potomac River Basin Model by using the MIKE 21 Flow FM (Flexible Mesh) module (MIKE by DHI, 2020). The calibrated model was run for a total of 6 scenarios, two baseline scenarios for the 100-year and 500-year storm events, and 4 future scenarios with various SLR scenarios based on a combination of planning horizons, storm return periods and SLR projections as summarized in Table ES-1.

**Table ES-1. Adopted Scenarios for Coastal Flood Modeling**

| Scenario | Extreme Water Level Scenario | Extreme Water Level Value applied at Lewisetta* (feet, NAVD88) | Planning Horizon | SLR Scenario | SLR Value at Solomon Island** (feet, relative sea level change) | Extreme Water Level (Lewisetta*) + SLR (Solomon Island**) (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Baseline: 100-year | 100-year | 4.9 | Current Conditions | None | 0 | 4.9 |
| 2. Baseline: 500-year | 500-year | 5.7 | Current Conditions | None | 0 | 5.7 |
| 3 | 100-year | 4.9 | 2040 | Int-High | 1.7 | 6.6 |
| 4 | 500-year | 5.7 | 2040 | Int-High | 1.7 | 7.4 |
| 5 | 100-year | 4.9 | 2070 | Int-High | 3.7 | 8.6 |
| 6 | 500-year | 5.7 | 2070 | Int-High | 3.7 | 9.4 |

* Lewisetta is located at the downstream open boundary of the Potomac River Model
** SLR projections from Solomons Island station, using NOAA 2017 projections.

The baseline and projected flood elevations at the mouth of Four Mile Run and Roaches Run are tabulated in the results section along with maps of the projected flood extents, compared to current FEMA flood extents. The flood extent maps for Scenarios 5 and 6 are replicated in Figures ES-1 and ES-2.

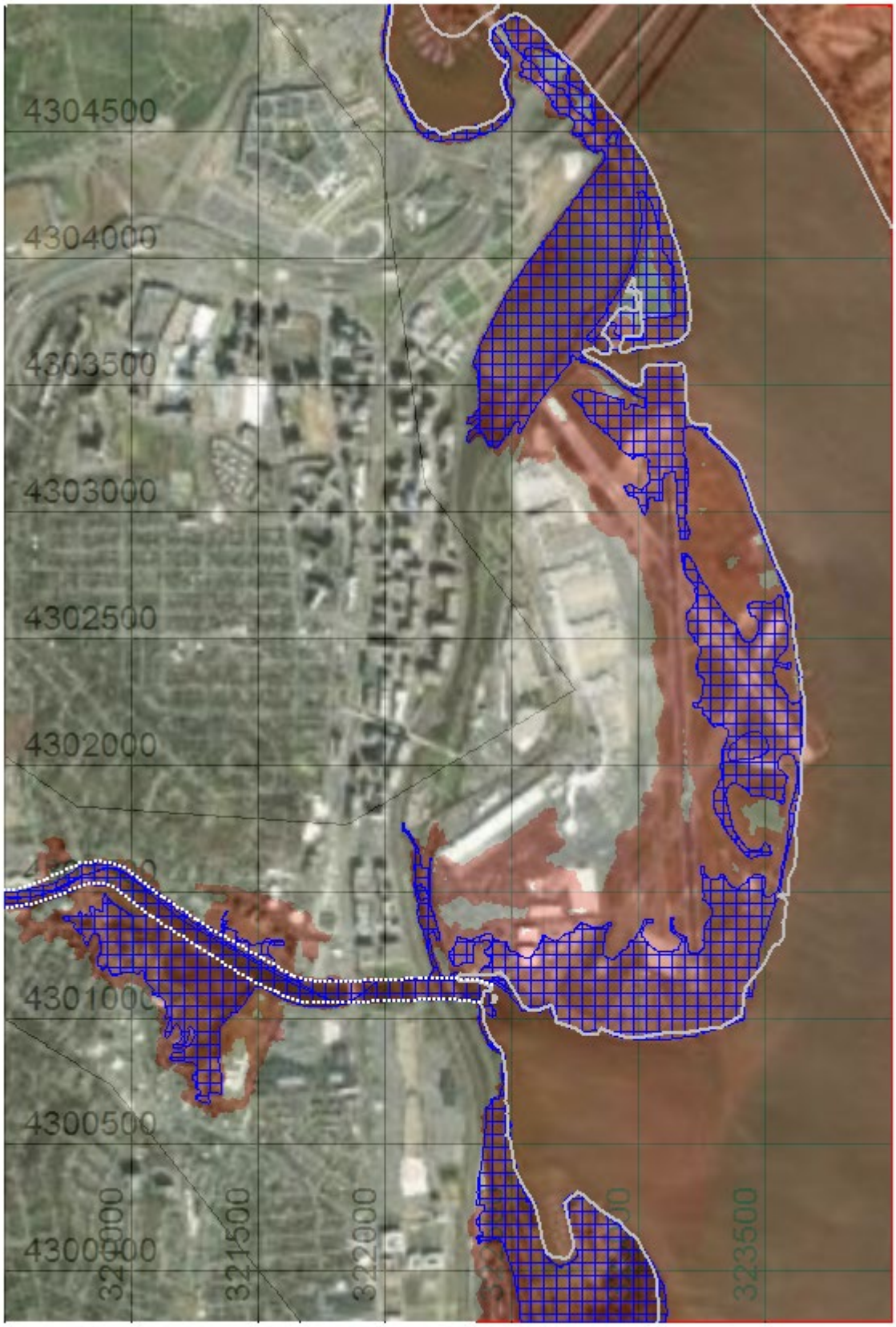



**Figure ES-1. Modeled flood extent (red), Scenario 5 (100-yr, with 2070 SLR of 3.7 ft)**

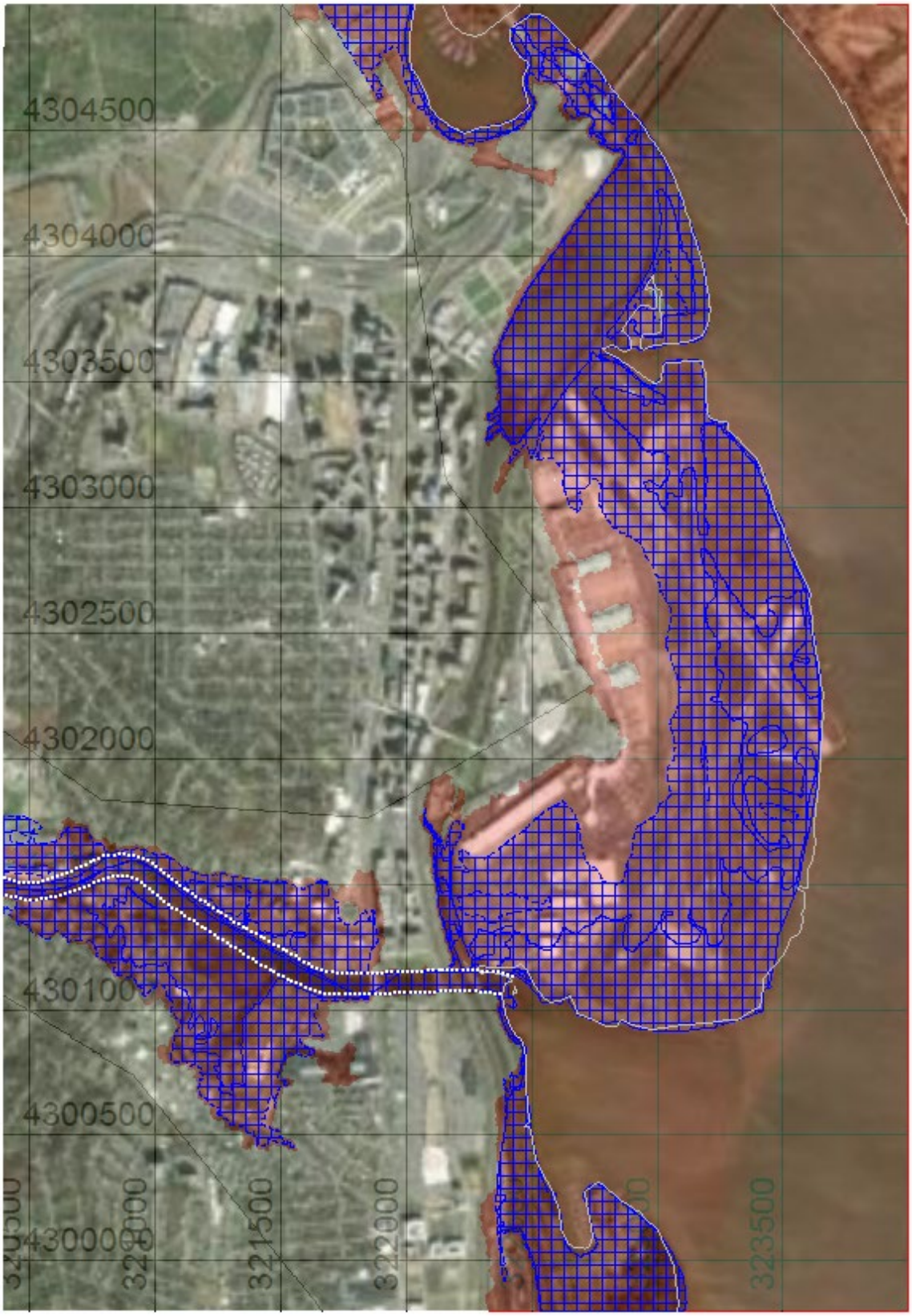



**Figure ES-2. Modeled flood extent (red), Scenario 6 (500-yr, with 2070 SLR of 3.7 ft)**

# 2. Background

## 2.1 Study Area

The study area occupies the Arlington County area of Virginia and is located on the west bank of the Potomac River north of Alexandria as shown in Figure 1. The Four Mile River Run flows along its south side in an approximately northwest to southeast alignment at its upstream stretch and approximately west-east alignment at its downstream stretch before joining the Potomac River. The north side of its downstream stretch (Lower Four Mile Run) is heavily built up featuring the Ronald Reagan Washington National Airport (Reagan National Airport) located next to the shoreline.

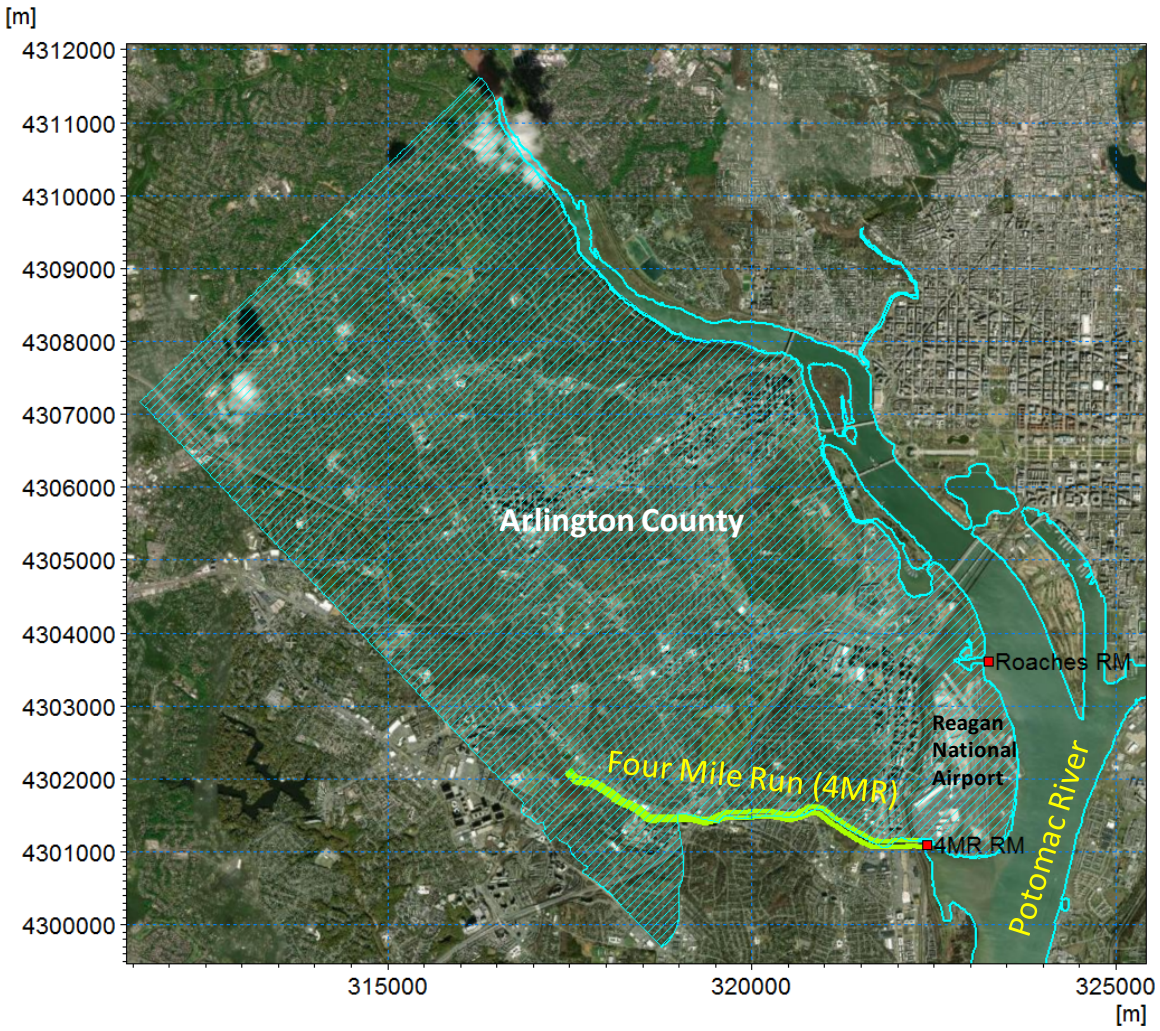



**Figure 1. Project site (Reagan National Airport denotes Ronald Reagan Washington National Airport; RM denotes River Mouth; the light blue hatched lines denote the Arlington County extent)**

## 2.2 Modeling Scope

The modeling scope includes the following tasks:

1) Source for and review additional Digital Elevation Domain (DEM) data specific to the project site to locally update the previously developed Potomac River Basin model mesh;
2) Re-calibrate the Potomac River Basin model by varying the bottom roughness map and the upstream discharge boundary conditions as appropriate to reproduce the published Federal Emergency Management Agency (FEMA) Stillwater Elevation (SWEs)[1] for the 100-yr and 500-yr events at the river mouth of Four Mile Run and Roaches Run, the latter located at the Reagan National Airport as shown in Figure 2;
3) Conduct surge and flood modeling for a suite of selected future SLR scenarios identified in Task 3.1; and
4) Extract the resulting peak flood elevation of (iii) at the two river mouths of (ii) for use as the respective downstream water level control in the riverine flood modeling.

The linkages among the tasks listed above are illustrated in the form of a flow chart shown in Figure 2.

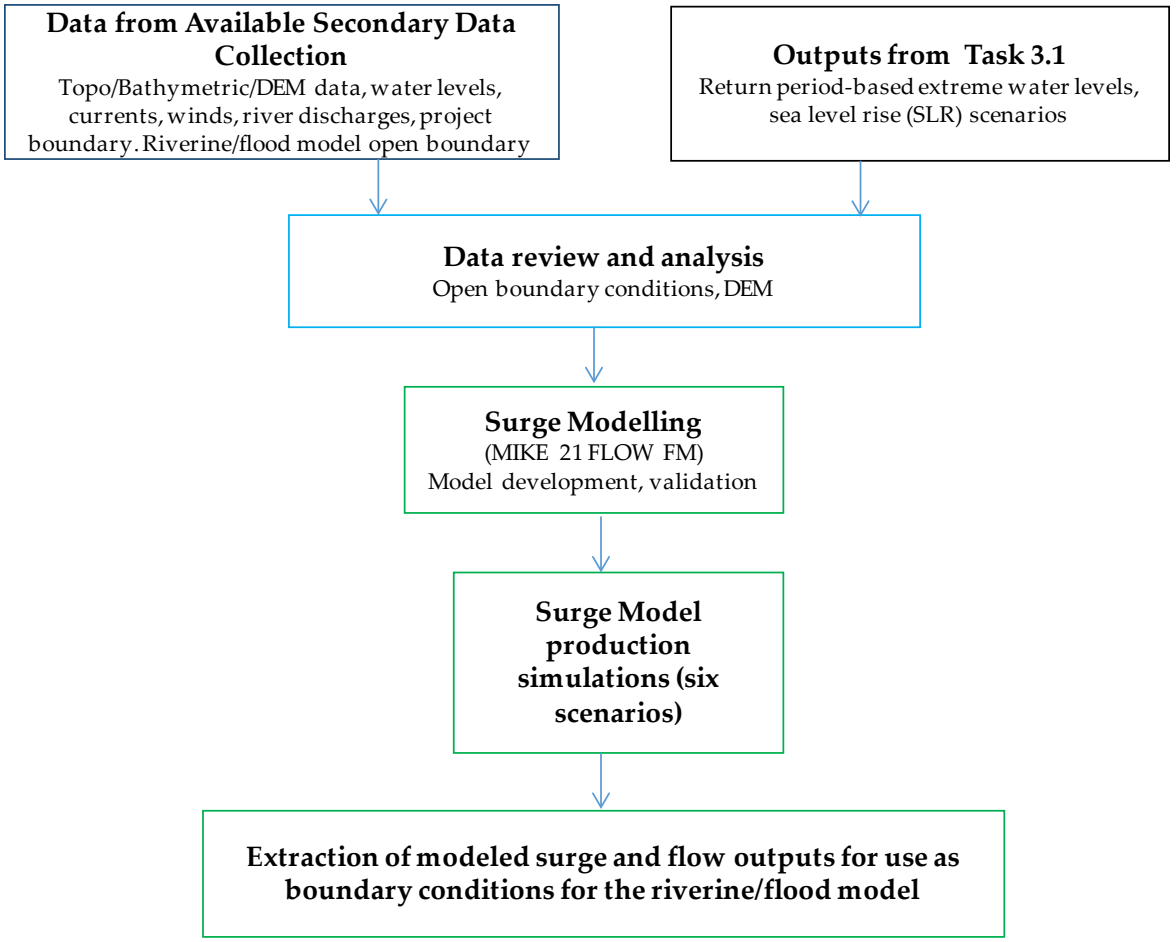



**Figure 2. Flow chart of coastal surge modeling tasks**
*(DEM = Digital Elevation Model; FM = Flexible Mesh)*

[1] The 100-yr or 500-yr Stillwater Elevations (SWE) are the FEMA published modeled flood elevation having a 1% or 0.2% chance of being equalled or exceeded in any given year, respectively, in the absence of waves resulting from wind or seismic effects.

# 3. Modeling Approach

To assess the extent of flooding due to the projected effects of climate change of the project area, Jacobs adapted the existing Potomac River Basin Model by using the MIKE 21 Flow FM (Flexible Mesh) module (MIKE by DHI, 2020). MIKE 21 Flow FM is a two-dimensional depth-averaged module developed by the Danish Hydraulic Institute (DHI). The present model domain incorporates riparian floodplain zones along tidal rivers adjacent to the project area, which previously included the Potomac River and Anacostia River but now expanded to include the Four Mile Run to accommodate the new project needs as shown in Figure 3.

The Potomac River Basin Model is a sub-domain of the Chesapeake Bay Model. The model extends from the mouth where an open boundary resides (Lewisetta shown in Figure 3). It then extends upstream to cover the main Potomac River and an upstream portion in the northwest direction, Anacostia River in the northeast direction, and the newly added Four Mile Run not far north of Alexandria. Contributions from catchment flow upstream of the model river boundaries are captured in the respective discharge boundary conditions except for the Four Mile Run as explained in a subsequent section.

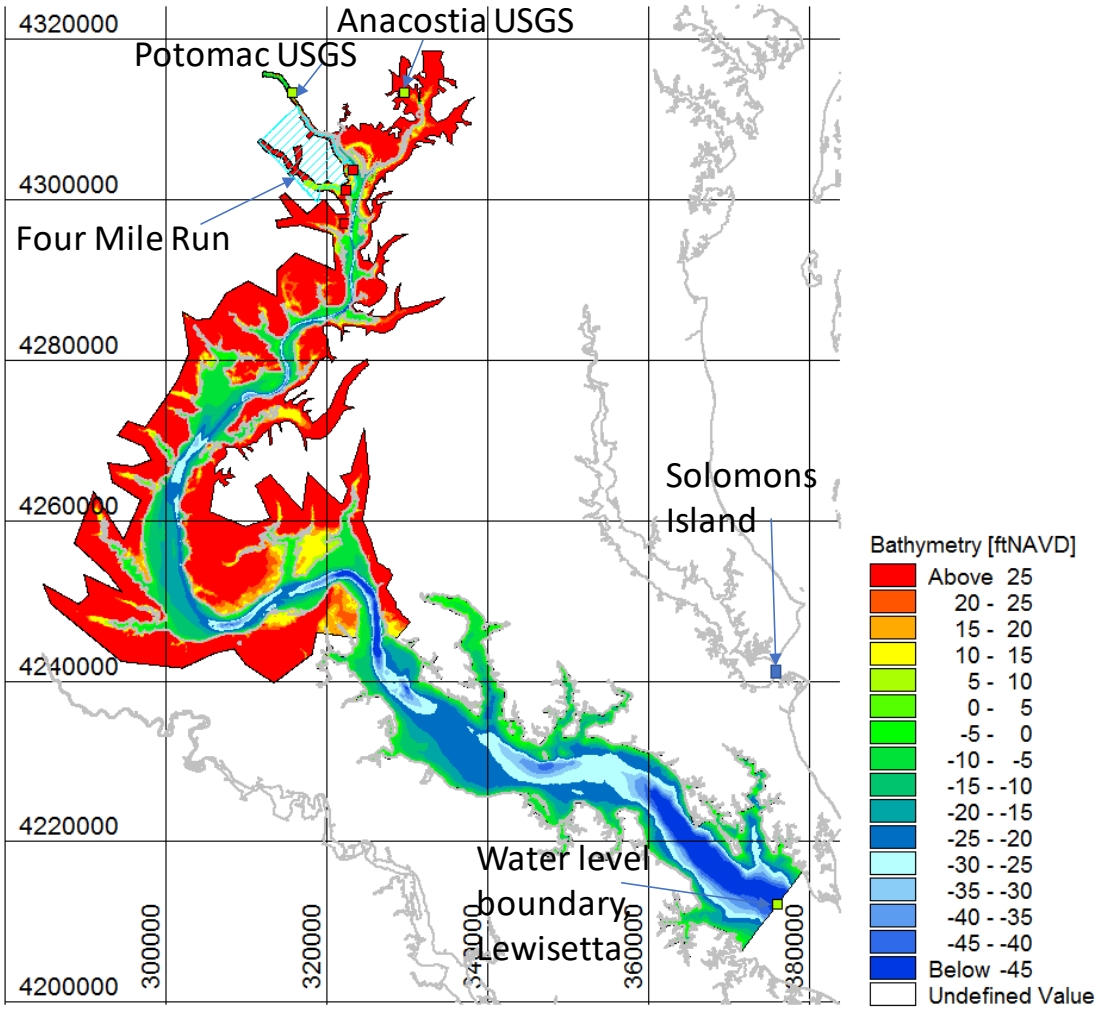



**Figure 3. Potomac River Basin Model (the red areas denote the riparian flood plain areas included in the model domain)**

The water-level boundary conditions for the model were driven by the highest storm surge profile recorded at the National Oceanic and Atmospheric Administration (NOAA) Tide Gage at Lewisetta (Station ID: 8635750). This station has continuous verified hourly height water level data since 1979 to the present. The peak-surge elevation was scaled to the published FEMA's stillwater elevations (SWEs) for the selected return period events to serve as the open boundary water level conditions. Similarly, the corresponding measured discharge profiles at the United States Geological Survey (USGS) discharge gage stations, which command the catchment flow contributions from the upper watersheds beyond the model boundary for the Potomac and Anacostia rivers, were scaled linearly using the ratio of the desired discharge peak and the measured discharge peak to provide the two discharge boundary conditions (see Figure 3 for locations). In this way, the scaling factors applied also serve as model calibration parameter in addition to bottom friction.

The respective SLR magnitude was then applied as a uniform uplift over the entire storm profile. Multiple scenarios of SLR coupled with storm surge were modeled.

The present study follows the same modeling approach in CH2M (2019) and only the salient features are presented below for brevity.

# 4. Modeling Scenarios

In addition to the two baseline runs for the present conditions needed for model calibration, 6 model production runs were conducted using the calibrated model for the various SLR scenarios based on a combination of planning horizons, storm return periods and SLR projections as adopted in Jacobs (2020) and summarized in Table 1. In Table 1, the tide values denote the peak water levels of the respective water level boundary conditions based on the NOAA Lewisetta water level data. For the SLR values, the latest NOAA Intermediate High projections (NOAA, 2017) were adopted. However, this latest SLR projections are not available for Lewisetta, the downstream model boundary at the Potomac River mouth. Therefore, the SLR values projected for the nearest NOAA tide station of Solomons Island were adopted, which is located at the river mouth of the Patuxent River approximately 24 miles further to the north along the Potomac River.

**Table 1. Adopted Scenarios for Coastal Flood Modeling**

| Scenario | Extreme Water Level Scenario | Extreme Water Level Value applied at Lewisetta* (feet, NAVD88) | Planning Horizon | SLR Scenario | SLR Value at Solomon Island** (feet, relative sea level change) | Extreme Water Level (Lewisetta*) + SLR (Solomons Island**) (feet, NAVD88) |
|---|---|---|---|---|---|---|
| 1. Baseline: 100-year | 100-year | 4.9 | Current Conditions | None | 0 | 4.9 |
| 2. Baseline: 500-year | 500-year | 5.7 | Current Conditions | None | 0 | 5.7 |
| 3 | 100-year | 4.9 | 2040 | Int-High | 1.7 | 6.6 |
| 4 | 500-year | 5.7 | 2040 | Int-High | 1.7 | 7.4 |
| 5 | 100-year | 4.9 | 2070 | Int-High | 3.7 | 8.6 |
| 6 | 500-year | 5.7 | 2070 | Int-High | 3.7 | 9.4 |

* Lewisetta is located at the downstream open boundary of the Potomac River Model

** SLR projections from Solomons Island station, using NOAA 2017 projections.

# 5. Methodology

## 5.1 Data Sources

### 5.1.1 Topography/Bathymetry

The modeling utilized topographic/bathymetric data from two sources listed below in decreasing priority of use:

- 2018 USGS Lidar Point Cloud VA (Virginia) Fairfax County 2018 (herein also referred to as the Digital Elevation Model, DEM), 3.28 ft point density/resolution, vertical datum = ftNAVD, but resampled to 16.4 ft point density for use (see Figure 4 for the data coverage); and
- Existing Potomac River Basin model topo-bathymetry from CH2M (2019).

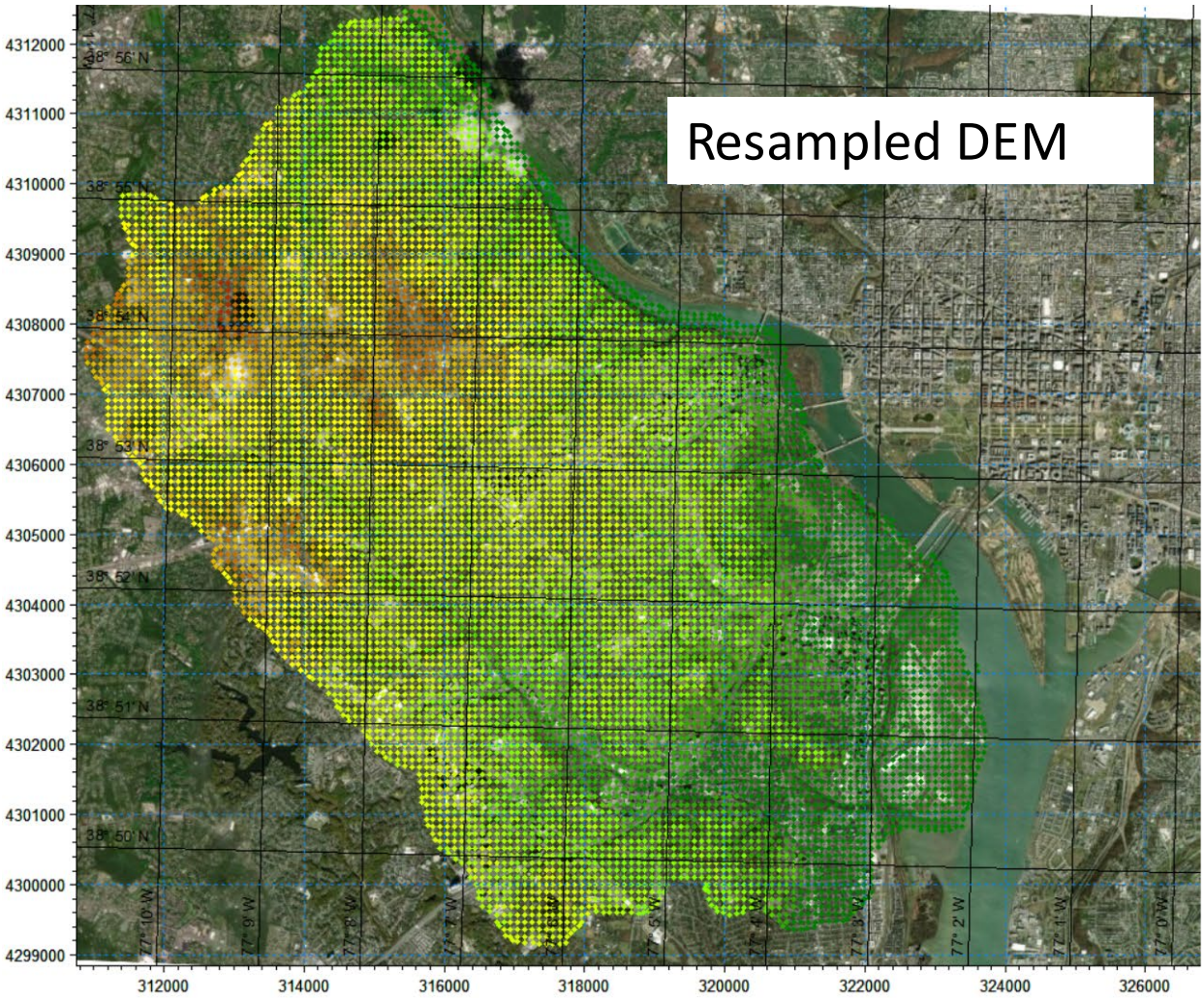



**Figure 4. Spatial extent (colored dots) of the USGS 2018 Lidar data**

### 5.1.2 Published FEMA SWEs

The most recent flood profile for the Potomac River abutting the project area was extracted from FEMA (2016), which provides the 100-yr and 500-yr SWEs at the confluences of Four Mile Run and Roaches Run with Potomac River as shown in Figure 5. While an updated Flood Insurance Study (FIS) report has been published subsequently (FEMA, 2020), it does not contain any transect information, but does include an updated set of preliminary Flood Insurance Rate Maps (FIRMs). The FIRMs contain the Base Flood Elevation (BFE) values, which include the maximum wave crest elevation (wave height effect) in addition to SWEs, in the vicinity of the two confluences as shown in Figure 6, which shows a BFE value of 10.5 ftNAVD (North American Vertical Datum) for the Four Mile Run confluence while that for the Roaches Run confluence remains the same as the SWE, i.e., 11.0 ftNAVD.

For clarity, the main difference between SWEs and BFEs is illustrated in Figure 7. In Figure 7, items 1 and 2 comprise the SWEs, which are the direct outputs from combined HD and wave modeling, i.e., wave setup is implicitly included in the modeled flood elevation.

For Flood Zone AE, which is designated for the shoreline area abutting the Four Mile Run confluence, the BFE value is considered similar to the corresponding SWE value because of limited wave effect by definition. Since the BFE value is more recent, its value was adopted for use as summarized in Table 2.

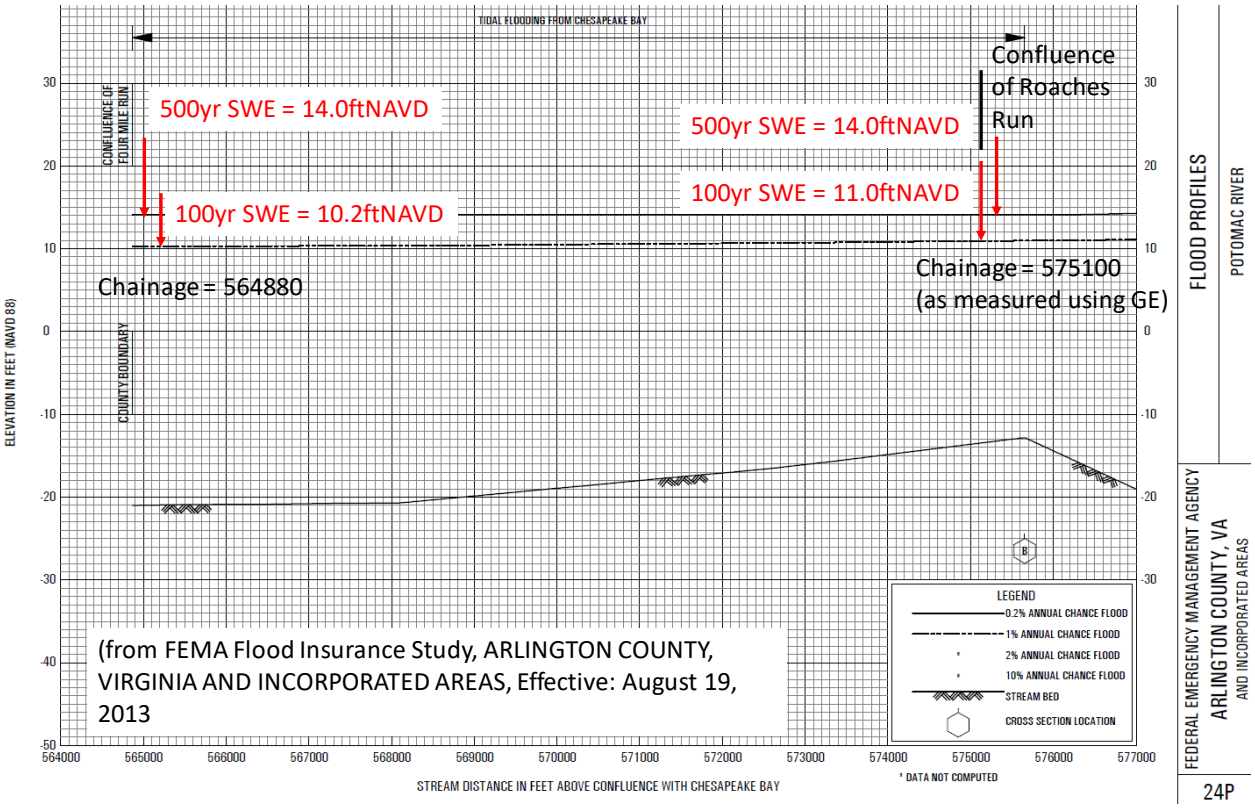



**Figure 5. The flood profile of Potomac River in the project vicinity (FEMA, 2016) (GE denotes Google Earth)**

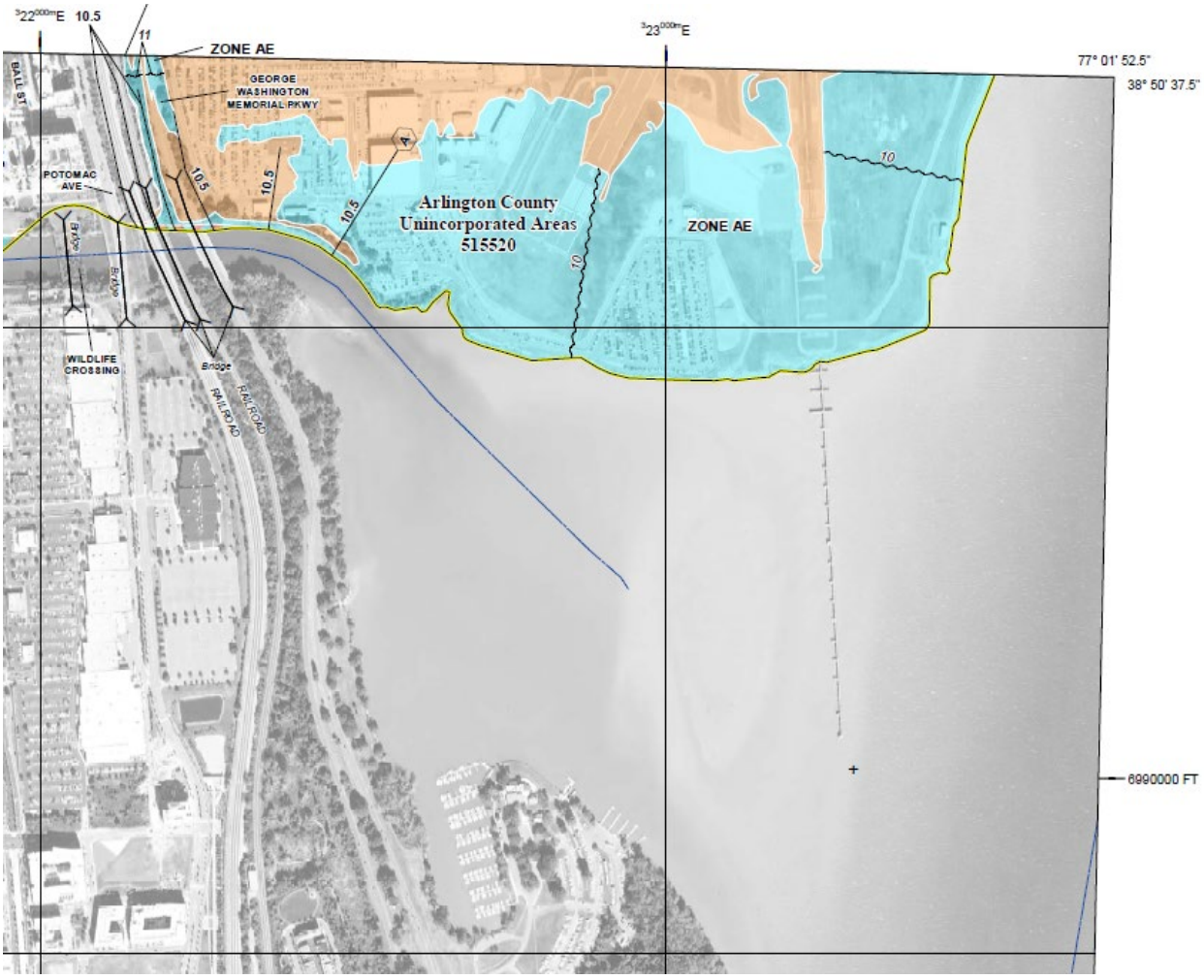
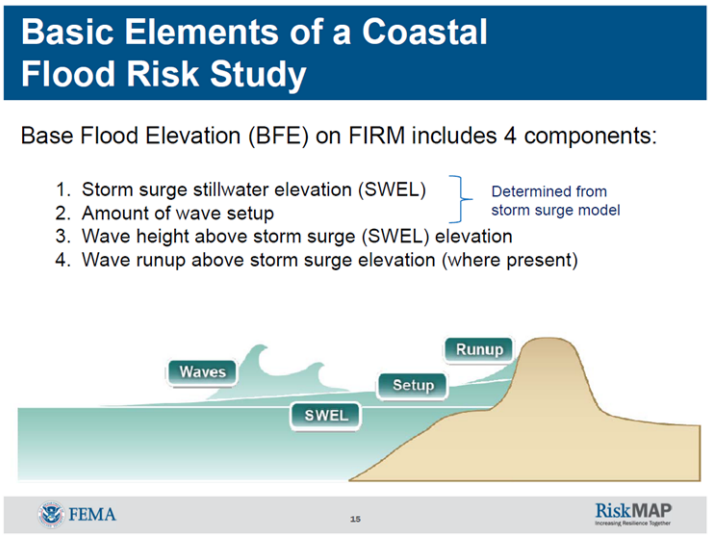



**Figure 6. Panel 51013C0083D displaying the BFE values in the vicinity of the Four Mile Run confluence, Preliminary FIRM (FEMA 2020)**

# Basic Definitions




Notes:

- Wave effects are less significant in riverine setting (i.e. BFE ~ SWE) than coastal
- BFEs are rounded to integer ft (e.g. 6 ft NAVD88, not 6.2 ft NAVD88)

**Figure 7. Graphical representation of the difference between SWEs and BFEs (Source: FEMA)**

**Table 2. Adopted SWEs for Model Calibration**

| Location | Adopted SWEs for Model Calibration (ftNAVD) by Return Period (yr) | |
|---|---|---|
| | 100 | 500 |
| Four Mile Run confluence | 10.5 | 14.0 |
| Roaches Run confluence | 11.0 | 14.0 |

## 5.2 Modeling Platform and Engine

Surge modeling was conducted using the MIKE 21 Flow Flexible Mesh (FM) module (MIKE by DHI, 2020) available in the MIKE 21 suite of hydraulic software. Jacobs has successfully applied this module on numerous storm surge projects along the Atlantic seaboard as well as internationally.

MIKE 21 Flow FM uses a flexible Mesh (FM) and solves the 2-dimensional, depth-integrated, shallow water equations of continuity and momentum. The equations are spatially discretized using a cell-centered finite volume approach with triangular and/or quadrilateral elements.

## 5.3 Modeling Assumptions

- The surge modeling was conducted using a scaled storm surge profile with its peaks pegged at published Stillwater elevations based on FEMA FIS reports. This scaled approach builds on the Monte Carlo-based storm surge study results embedded in the FIS reports of FEMA (2016 and 2020), which are considered a more efficient approach than repeating the Monte Carlo simulations of synthetic tropical storms herein.

- In addition, FEMA's Stillwater elevations include both meteorologically induced water-level changes (wind setup and inverse barometric effect) and wave-breaking-induced wave setup using coupled storm surge and wave modeling. While the storm surge model applied herein does not include wave setup, which is a wave transformation model output, the wave setup contribution has been considered at the open boundaries by using FEMA's Stillwater elevations where its effect is the largest. Wave setup is a function of the breaking wave height, which is considered small within the confined and meandering Potomac River. Thus, the omission of wave setup effect within the upper Potomac River where the project site is located is deemed within the range of model uncertainty.
- The scaled storm surge profile was developed using a representative surge profile from known historical storm surges that have impacted the region measured at NOAA's tide gages located at the open boundary, in this case Lewisetta, as first developed in CH2M (2016). An implicit assumption of adopting the scaled storm profile based on historical storms is that the lag relationship between the surge peak and river discharge peak inherent in historical storms is maintained. Since the largest storms have been considered and barring significant changes in the watershed regime, this assumption is considered reasonable.
- Since interior and riverine flooding is covered under a separate task, flow contribution from the watershed of Four Mile Run and its tributaries is not considered in surge modeling based on the understanding that river runoff and surge interaction is significant within the river channel only and not at the river mouths where downstream control conditions are sought to feed into the riverine model.
- The SLR projections at the open water-level boundary stations were incorporated as a uniform uplift representing the associated SLR component applied at the open boundary.
- The computed difference in the modeled maximum flood elevations between the base scenario and the corresponding SLR scenarios (i.e., same return period event) is added to the corresponding SWEs to obtain the maximum flood elevations for the respective SLR scenarios. This rationalization/ adjustment is deemed adequate to compensate for the difference in the modeled results for the base scenarios and the SWEs in model calibration, provided the percentage difference between the two falls within model uncertainty (estimated to be in the range 3%–5%).

## 5.4 Model Development

### 5.4.1 Model Mesh and Bathymetry

As indicated in Figure 3, the flood plain areas on both banks were included to provide flood passage at high stages exceeding the elevation of the banks. However, to keep the number of computational cells comprising triangular elements within manageable limits, the "on land" mesh resolution was set to 80 meters narrowing to 10 m within the DEM coverage area, while a mesh resolution of 180 m was applied to the river channel area narrowing to 30 m within the stretch abutting the project shoreline.

Further mesh refinements were made in the Four Mile Run channel where a quadrilateral mesh size of 10m x 3m was specified. The resulting model mesh comprises 721,478 elements and 375,945 nodes.

The bathymetric inputs into the model bathymetries are sourced from publicly-available bathymetric and DEM datasets as previously discussed under the sub-section on Topography/bathymetry.

### 5.4.2 Model Re-Calibration

The Potomac River Basin model was previously calibrated (CH2M, 2016) to measured peak surge elevation during the passage of Hurricane Sandy (2012) using the measured water level data at NOAA tide gage at Washington, DC (8594900). The primary calibration parameter was the bottom roughness represented by Manning M (having the unit $m^{1/3}/s$), which is the inverse of the conventional Manning's n in the metric unit.

Additional comparisons were made in CH2M (2019) using the results of the scaled storm profile runs driven by the FEMA 100-year and 500-year Stillwater elevations at Lewisetta (base cases, water level peaks of 4.9 ftNAVD and 5.7 ftNAVD, respectively) to reproduce the corresponding 100-year and 500-year Stillwater elevations at Washington DC. This latter approach is similar to the previous efforts documented in CH2M (2016) except for the following:

- The bottom roughness for the flood plain and channel was varied to be consistent with those used in CH2M (2019b) for the adjacent Patuxent River Basin model. While the channel roughness was kept the same as n = 0.03, that for the flood plain roughness was reduced slightly from 0.12 to 0.09.
- The two upstream discharge boundary conditions were varied within the limits of the return period-based discharge extremes taken from the FIS.

Peak flood levels were compared at the NOAA Washington DC tide gage between the modeled and published FEMA's SWEs for the two return period events (100-yr and 500-yr). The best agreement between the modeled maximum water surface elevations and the FEMA SWEs was achieved using the 10-yr peak discharge and the 35-yr peak discharge at the upstream discharge boundary conditions, respectively.

For the present study, additional model calibration was conducted, this time using the published SWEs at two transects along the project shoreline as summarized in Table 2. Since the bottom roughness has recently been updated in Jacobs (2019), only the two upstream discharge boundaries were varied herein, necessitating the application of a scale factor of 1.03 to the discharge boundary condition at Anacostia River only to achieve the best agreement with SWEs as summarized in Table 3.

Table 3 indicates that the percentage difference between the SWEs and modeled results varies from −8.6% (higher modeled results) to 1.9% (lower SWE). Generally, a percentage difference of 3–5% either way can be considered as within model uncertainty, which can arise from different sources ranging from measurement errors such as topography/bathymetric surveys, and inherent model uncertainty due to model assumptions and simplifications.

For the largest percentage difference seen at Roaches Run confluence for the 500-yr event of −8.6%, it is noted that the SWEs do not show a spatial gradient between the two locations as seen for the 100-yr event (increase of 0.5 ft). It is then reasonable to infer that the same spatial gradient potentially exists but is not reflected in the SWEs. A check of the flood profiles of the Potomac River upstream of Roaches Run confluence in FEMA (2016) indicates that the 500-yr SWE does increase upstream of the Roaches Run confluence, reaching a magnitude of 15 ftNAVD at some 3,000 ft further upstream. This trend tends to reduce the impact of the over-projection in the modeled results.

In addition, the use of the computed difference in the modeled maximum flood elevations as a rationalization/adjustment step as explained under Model Assumptions (last bullet) further mitigate its impact of over-estimation.

Overall, the results of the model calibration are considered adequate for the model to be used in the simulations of SLR scenarios, and the resulting computed maximum flood elevations at the two confluences for use as the downstream controls for the riverine model are deemed reasonable.

The resulting comparisons of the 100-yr and 500-yr flood maps between FEMA (2016) and modeled outputs are shown in Figures 7 and 8, respectively. For the 100-yr base scenario, they display similar spatial extent while the modeled spatial extent for the 500-yr base scenario is slightly larger at several places, which is expected based on the 8.9% point increase in the 500-yr flood peak comparison shown in Table 3.

**Table 3. Comparison of Published SWEs and Modeled Results**

| Location | Maximum Flood Elevation by return period (ftNAVD) | | | | | |
|---|---|---|---|---|---|---|
| | 100-yr | | | 500-yr | | |
| | SWE | Modeled, base scenario | Percentage Difference (%) | SWE | Modeled, base scenario | Percentage Difference (%) |
| Four Mile Run confluence | 10.5 | 10.3 | 1.9 | 14.0 | 14.4 | −2.9 |
| Roaches Run confluence | 11.0 | 11.2 | −1.8 | 14.0 | 15.2 | −8.6 |

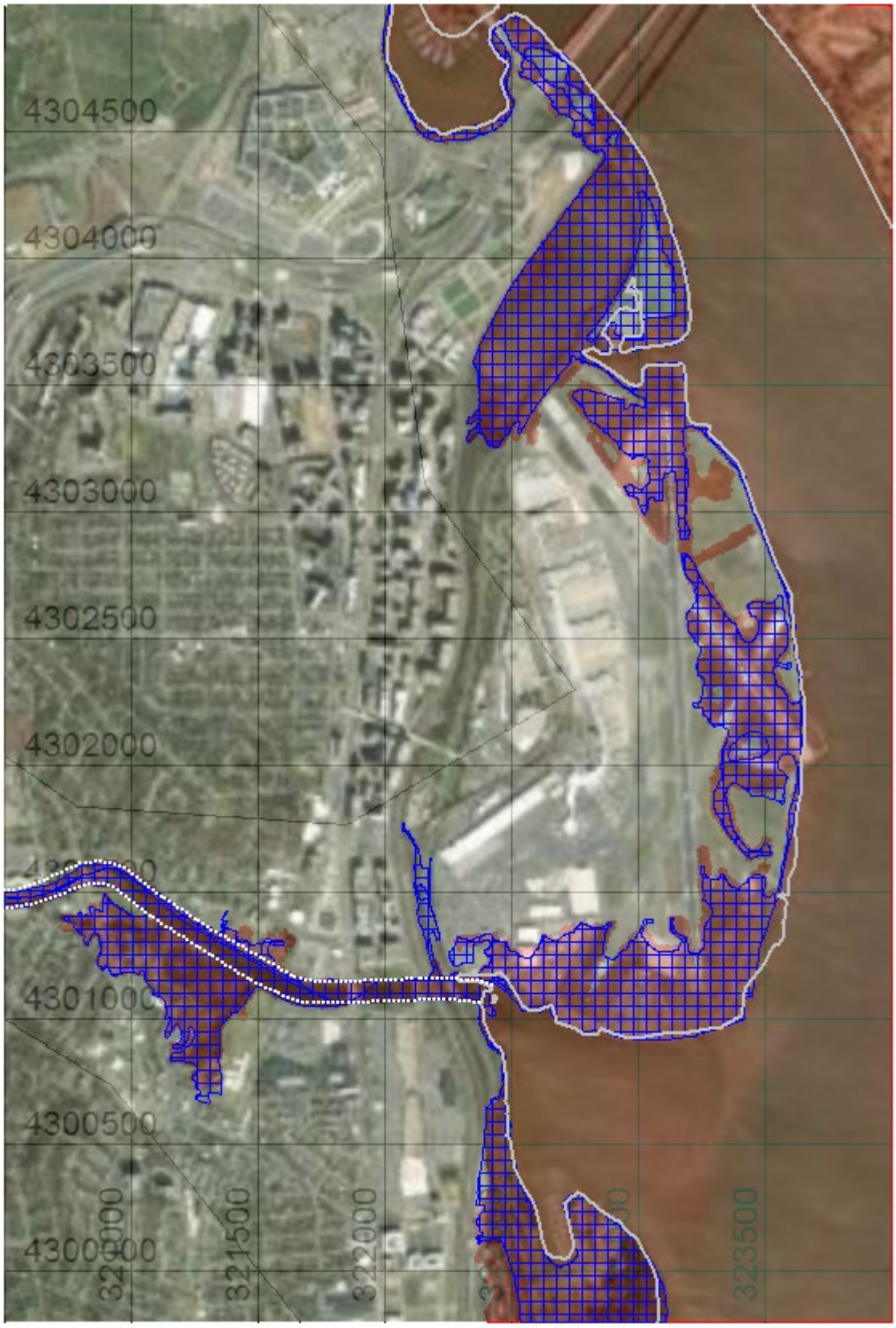



**Figure 7. Comparison of 100-yr flood maps: FEMA: blue hatched: modeled: red**

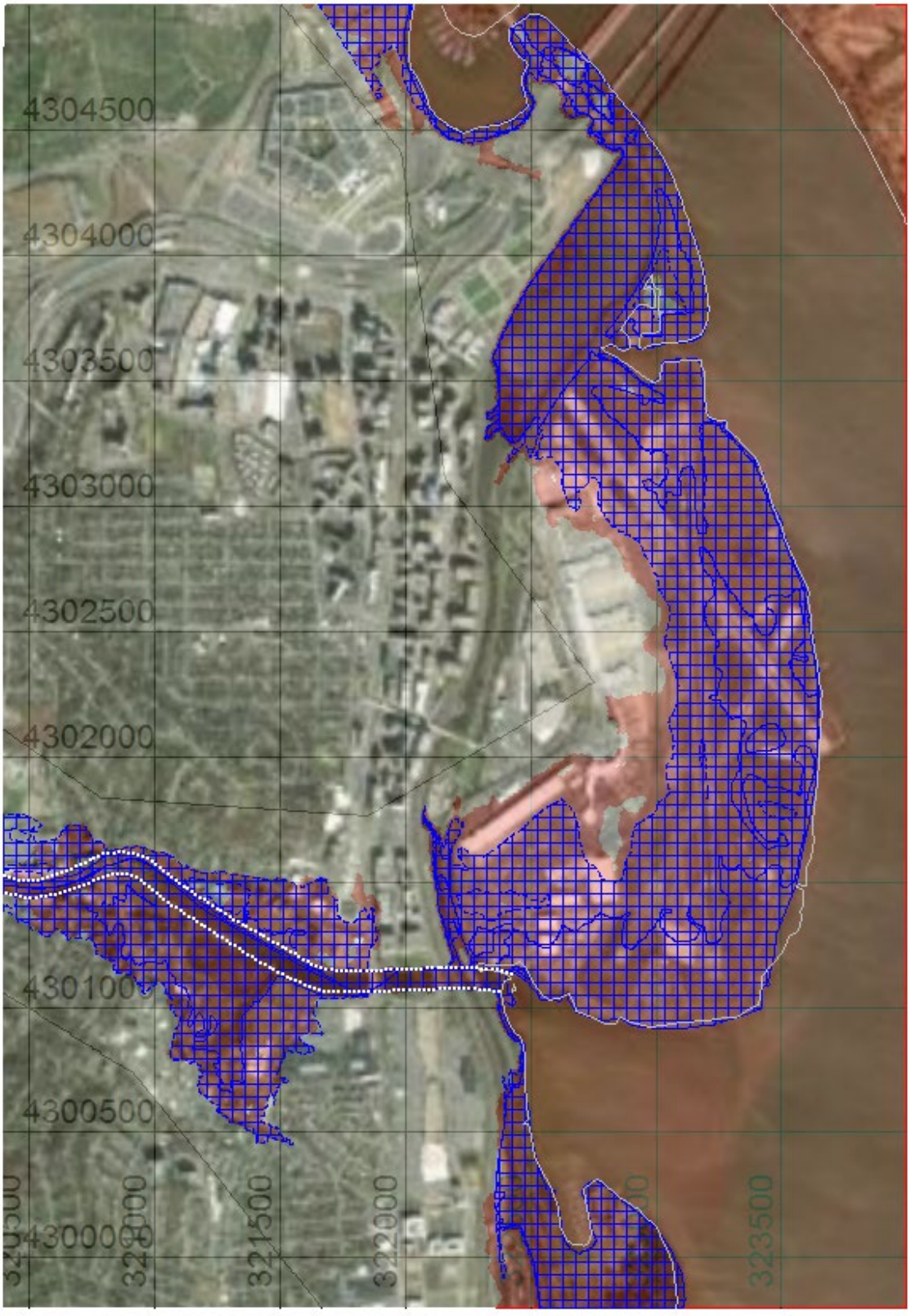



**Figure 8. Comparison of 500-yr flood maps: FEMA: blue hatched: modeled: red**

# 6. Model Results

The modeled results of the SLR scenarios are presented in the following formats.

- Maximum Flood Elevations at the two confluences as summarized in Table 4.

**Table 4. Summary of Modeled Maximum Flood Elevation Results for Two Baseline and Four Climate Scenarios at the Mouth of Four Mile Run and Roaches Run.**

| Scenario | Extreme Water Level Scenario | Planning Horizon | SLR Scenario | SLR Value applied at open boundary (ft) | Modeled Maximum Flood Elevation (ftNAVD) | |
|---|---|---|---|---|---|---|
| | | | | | Four Mile Run confluence | Roaches Run confluence |
| 1. Baseline: 100-year | 100-year | Current Conditions | None | 0 | 10.5 | 11.0 |
| 2. Baseline: 500-year | 500-year | Current Conditions | None | 0 | 14.0 | 14.0 |
| 3 | 100-year | 2040 | Int-High | 1.7 | 11.5 | 11.8 |
| 4 | 500-year | 2040 | Int-High | 1.7 | 14.7 | 14.9 |
| 5 | 100-year | 2070 | Int-High | 3.73 | 12.7 | 13.0 |
| 6 | 500-year | 2070 | Int-High | 3.73 | 15.6 | 15.7 |

The modeled maximum flood elevations for each scenario were provided to the riverine modeling team to serve as the downstream controls.

- Flood Maps shown in Figures 9 – 12 for each of the SLR scenarios.

The flood extent is seen to increase progressively with both increasing return period of storm event and the magnitude of SLR. It is also seen that expanded flooding is confined mainly to the 100-year event in 2040 and 2070 for the Lower Four Mile Run subwatershed and the landward flooded edge of Reagan National Airport (compare Scenarios 3 and 5 in Figures 9 and 11 to 100-yr baseline Scenario 1 in Figure 7). Little change is projected for the 500-year flood extents in the future compared to baseline (compare Scenarios 4 and 6 in Figures 10 and 12 to 500-yr baseline Scenario 2 in Figure 8).

These flood maps can be used to extract the maximum flood depths by points within the coastal flood zone by subtracting the point ground elevation from the corresponding maximum flood elevation for use in the subsequent task on Facility Vulnerability assessment. The ground elevation will be based on the raw DEM (3.28 ft resolution) to avoid interpolation error arising from the use of coarser model mesh sizes required for computational efficiency.

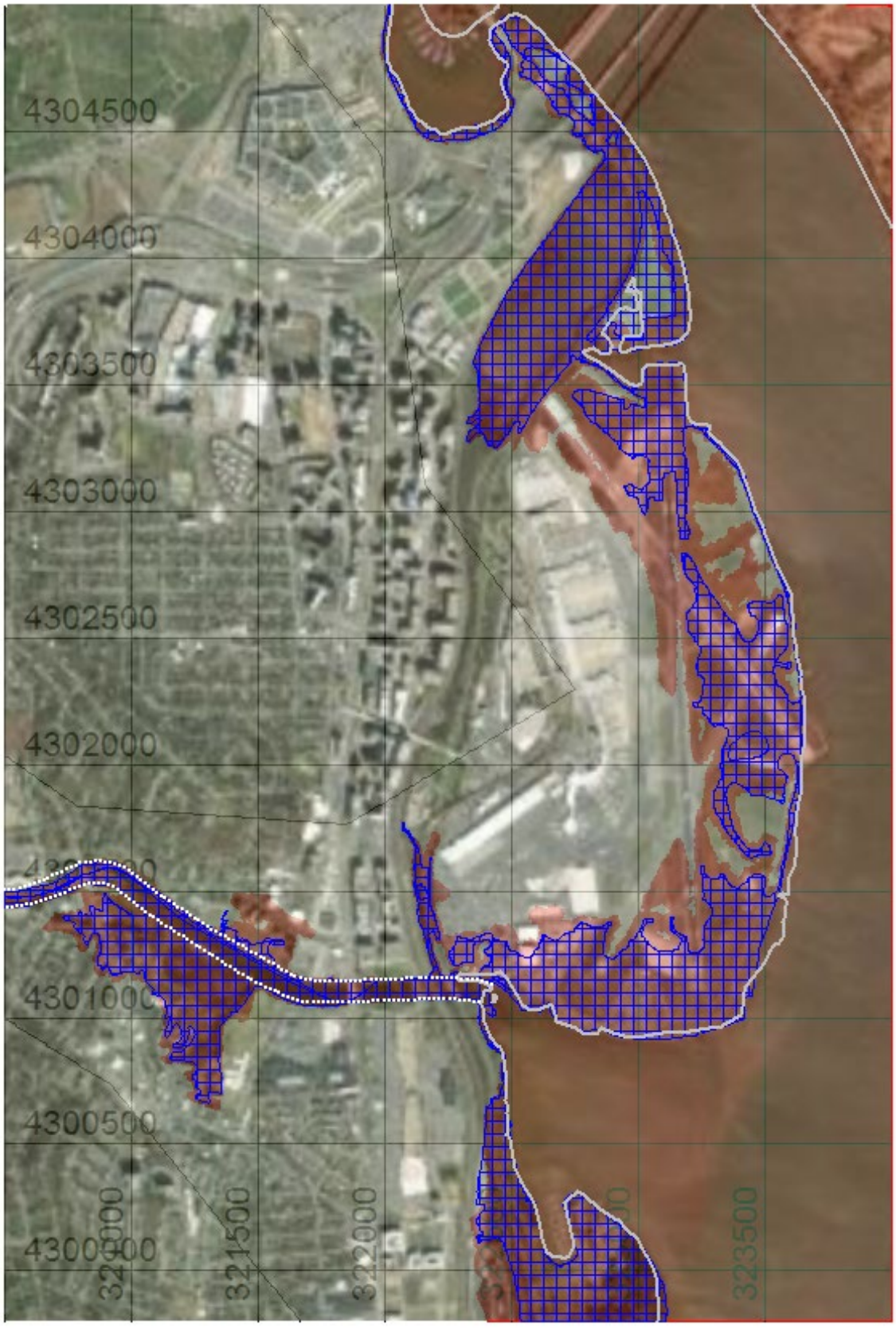



**Figure 9. Modeled flood extent (red), Scenario 3 (100-yr, with 2040 SLR of 1.7 ft)**

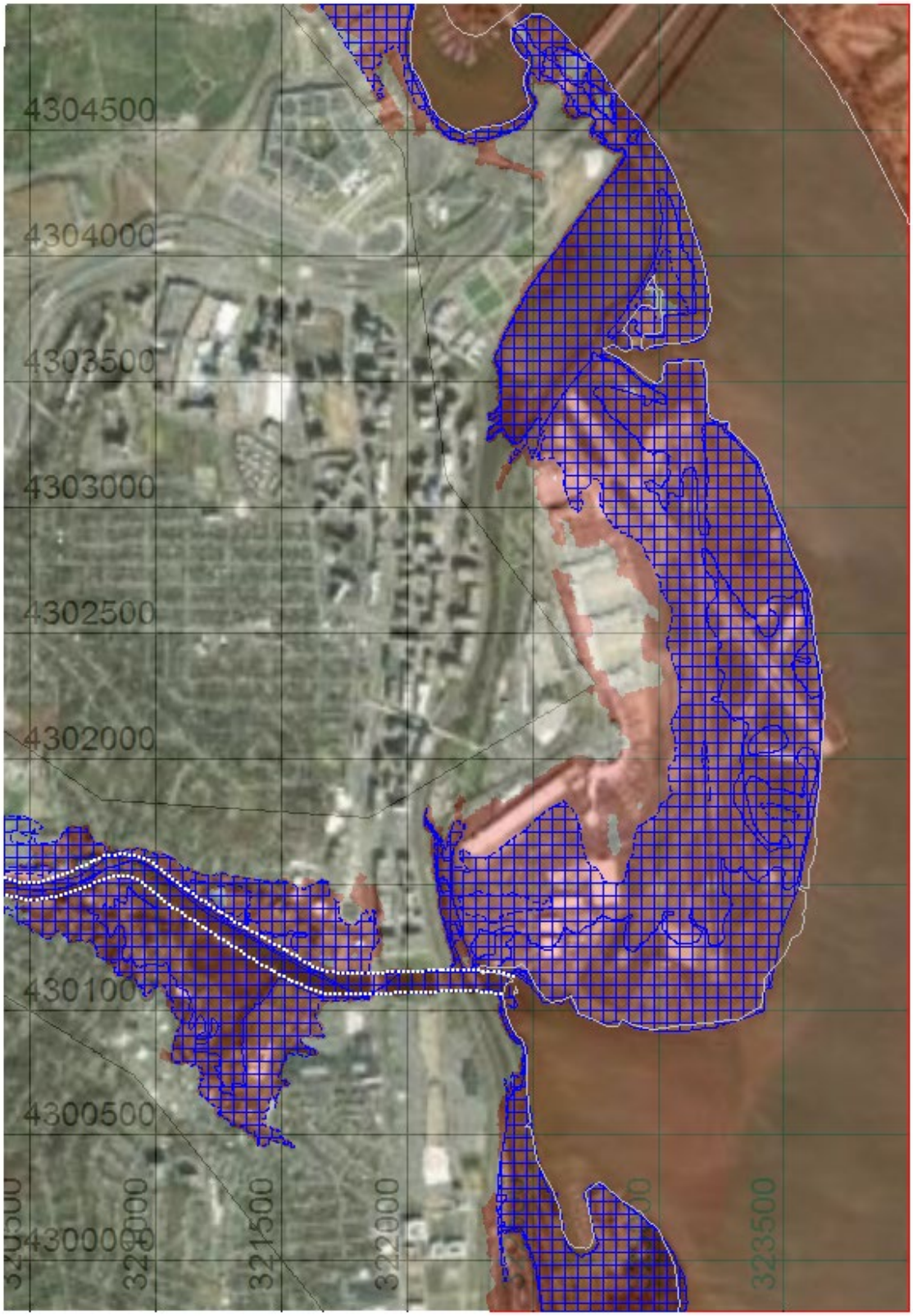



**Figure 10. Modeled flood extent (red), Scenario 4 (500-yr, with 2040 SLR of 1.7 ft)**

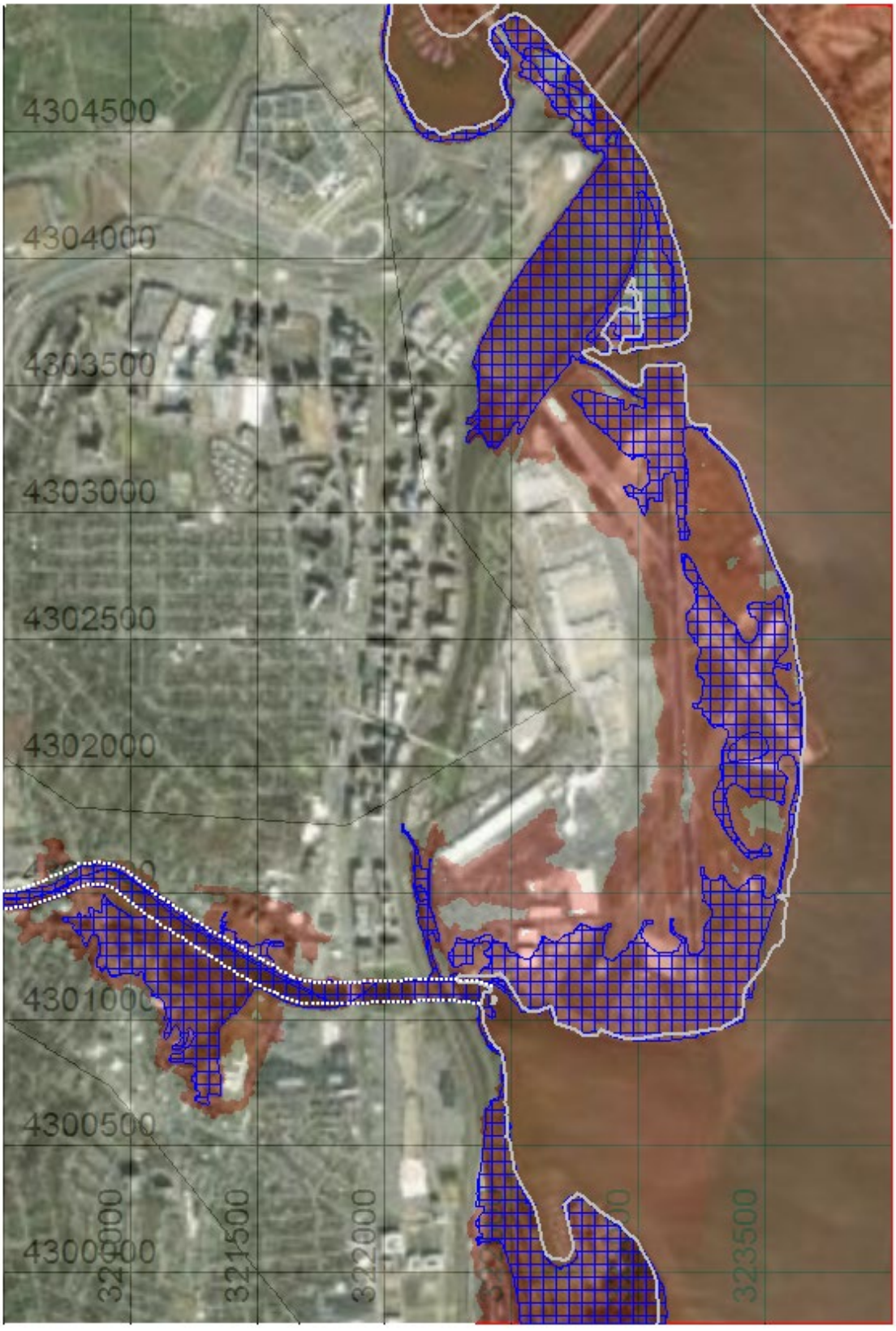



**Figure 11. Modeled flood extent (red), Scenario 5 (100-yr, with 2070 SLR of 3.7 ft)**

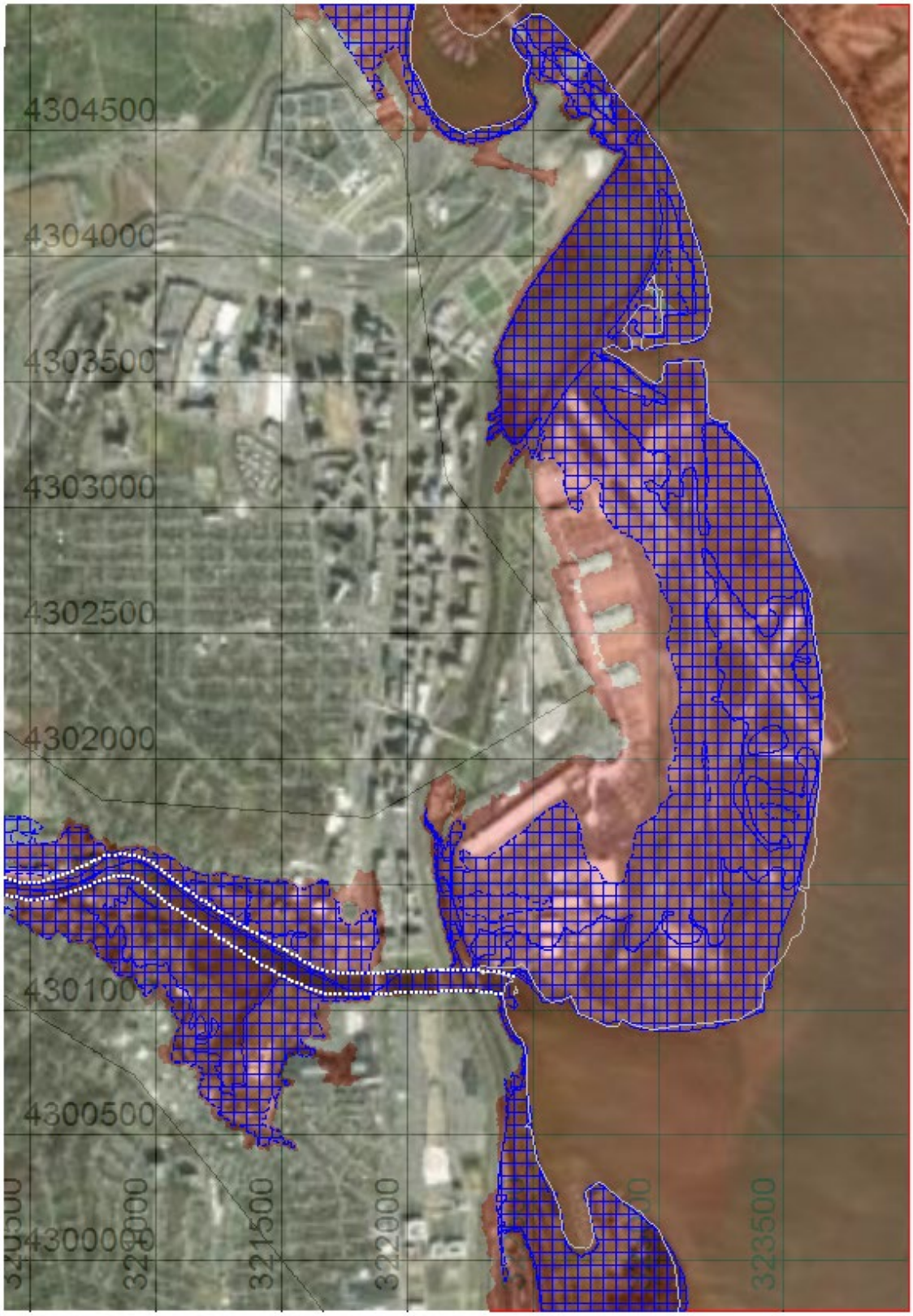



**Figure 12. Modeled flood extent (red), Scenario 6 (500-yr, with 2070 SLR of 3.7 ft)**

# 7. References

Federal Emergency Management Agency (FEMA). 2013. Flood Insurance Study for Arlington, Virginia and Incorporated Areas, Effective August 19, 2013, 63p.

Federal Emergency Management Agency (FEMA). 2016. Digital flood maps.

Federal Emergency Management Agency (FEMA). 2020. FIRM Panel 51013C0083D, Preliminary, Sep 18, 2020.

CH2M Hill (CH2M). 2016. Surge and Sea Level Rise Modeling Washington Suburban Sanitary Commission Climate Change Vulnerability Assessment, Adaptation and Mitigation Plan, 2016.

CH2M Hill (CH2M). (2019). Surge and Flood Modeling, Buzzard Point Floodplain Feasibility Study, Technical Memorandum prepared for DDOT.

CH2M Hill (CH2M). (2019b). Flood Risk Modeling Refinements Washington Suburban Sanitary Commission Climate Change Vulnerability Assessment, Adaptation and Mitigation Plan – Western Branch Modeling Update, May 13, 2019.

MIKE by DHI. (2020). MIKE 21 Flow Module FM, user manual.

National Oceanic and Atmospheric Administration (NOAA). 2017. Global and Regional Seal Level Rise Scenarios for the United States. Technical Report NOS CO-OPS 083. January. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

US Army Corps of Engineers (USACE). 2019. Sea-Level Change Curve Calculator (Version 2019.21). http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html. Accessed July 16, 2020.

# Appendix D
# Arlington Flood Vulnerability Assessment Technical Memorandum

ARLINGTON
VIRGINIA

# Flood Risk Assessment and Management Plan (RAMP)

## Arlington Flood Vulnerability Assessment (Task 4)

**Final**

**October 2023**

**Arlington County, Virginia**

# Flood Risk Assessment and Management Plan (RAMP)

| | |
|---|---|
| Project No: | E5X65609 |
| Document Title: | Arlington Flood Vulnerability Assessment (Task 4) |
| Revision: | 1 |
| Date: | October 2023 |
| Client Name: | Arlington County, Virginia |
| Project Manager: | Laurens van der Tak |
| Authors: | Cameron Lancaster, Enrique Lopezcalva |
| File Name: | Arlington_Stormwater_RAMP_TM_4 Final |

Jacobs Engineering Group Inc.

2551 Dulles View Drive
7th Floor
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

**Document History and Status**

| Revision | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| 0 | August 2021 | Draft | Jacobs Team | Enrique Lopezcalva | Enrique Lopezcalva | Laurens van der Tak |
| 1 | October 2023 | Final | Jacobs Team | Enrique Lopezcalva | Enrique Lopezcalva | Tara Ajello |

# Executive Summary

## Purpose

Arlington County, Virginia (the County), initiated a study to support the Flood Risk Assessment and Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for Arlington County Department of Environmental Services resulting in a comprehensive RAMP, which addresses the risk and uncertainty of flooding due to current and future climate. The RAMP will project and map risk and consequential impacts in support of a long-term resiliency strategy. Task 4 of the RAMP leverages the flood modeling conducted in Task 3 to assess vulnerability of watersheds in the project area and to prioritize watersheds for further risk analysis under future tasks. This technical memorandum (TM) documents Task 4.

### Methods

The RAMP follows a process of prioritization of watersheds to allow for progressively more detailed analysis of exposure, vulnerability and risk and to provide recommendations for adaptation and mitigation. Figure ES-1 presents the main steps of prioritization to arrive to Task 5, Risk Assessment, and shows that Task 4 conducted vulnerability analysis for nine watersheds resulting from Task 3. The watersheds shown as modeled by one-dimensional/two-dimensional Personal Computer Stormwater Management Model map in Figure ES-2 were the basis for Task 4. The interior and riverine flood modeling and coastal modeling conducted during Task 3 for those watersheds was the basis for the exposure information under Task 4.

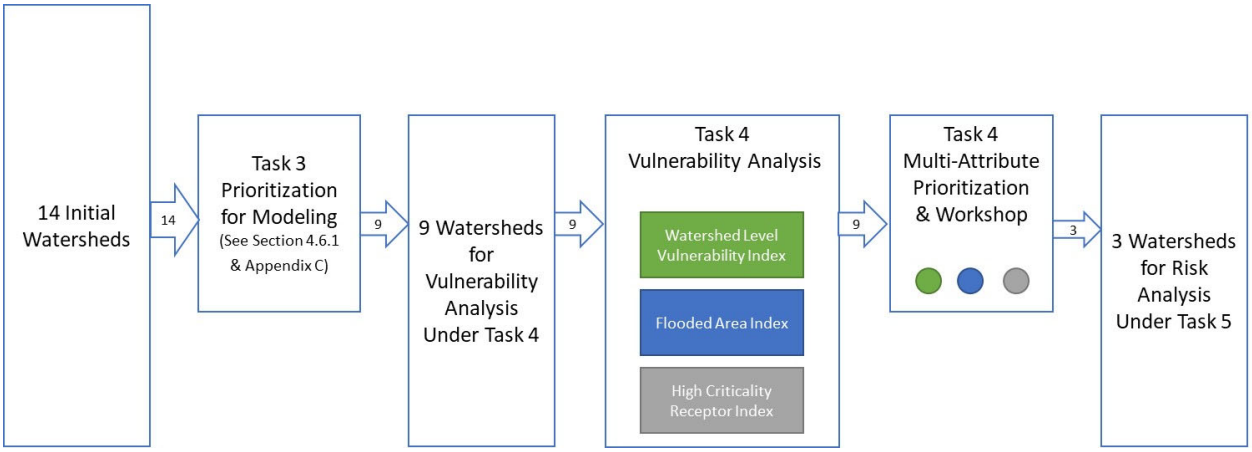



**Figure ES-1. Overall Process of Prioritization for Risk Analysis in the RAMP**

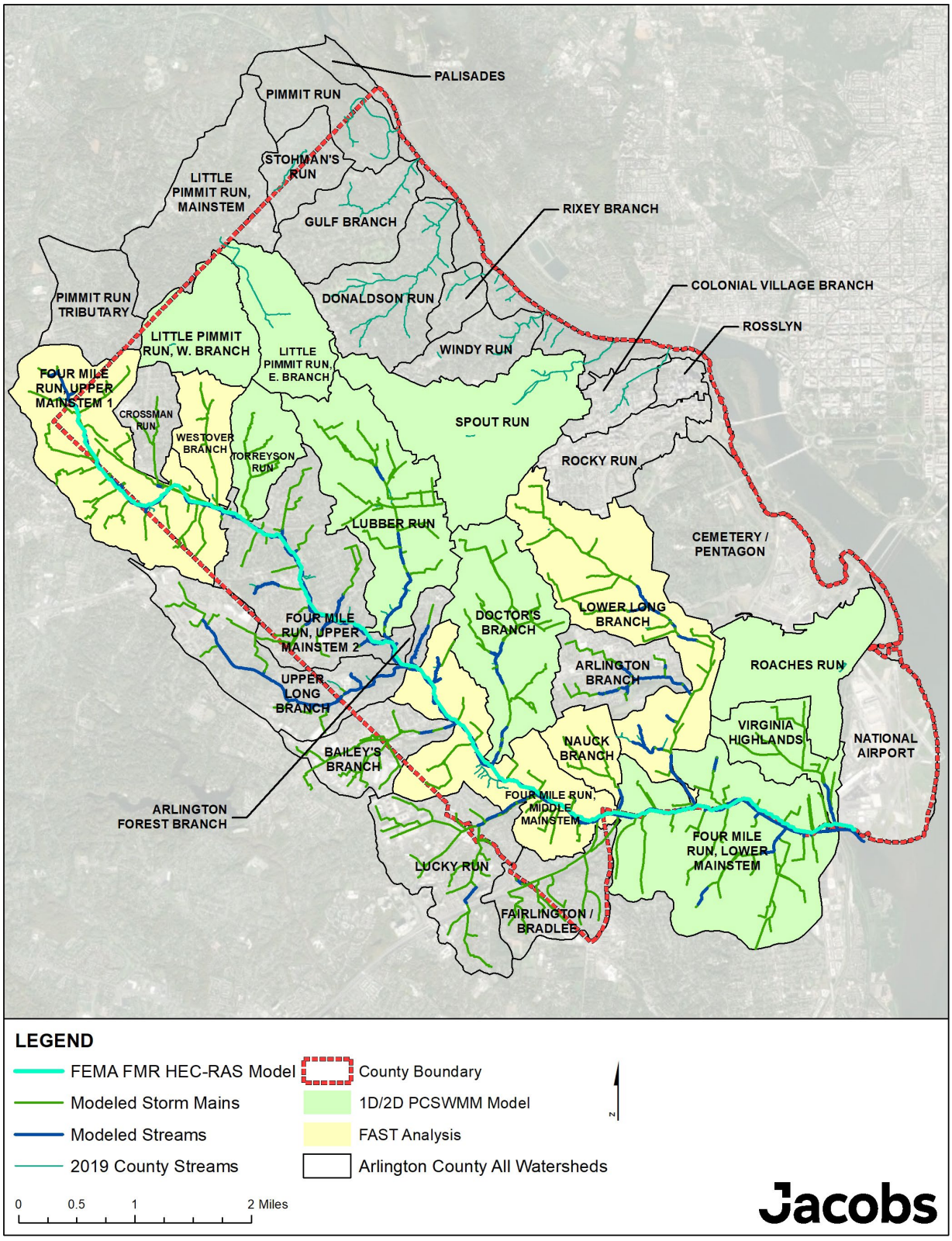



**Figure ES-2. Arlington County Watershed Modeling Overview**

A vulnerability analysis was conducted for each receptor in a watershed. Vulnerability values for each receptor were obtained by applying a vulnerability formula based on exposure, sensitivity and adaptive capacity (key outcome) as follows:

*Vulnerability per Receptor = (Exposure + Sensitivity) / (Adaptive Capacity)*

While the vulnerability by receptor is a key outcome of Task 4, it is insufficient for watershed prioritization. The watershed prioritization method is based on a multi-attribute rating technique (MART)[1] given that vulnerability values for receptors alone in each watershed do not reflect impacts on highly critical receptors, neighborhoods, businesses, socially vulnerable groups and environmental resources. For this RAMP's vulnerability assessment, the three attributes for prioritization, shown in Figure ES-1, are:

**Watershed-Level Vulnerability Index:** The Watershed-Level Vulnerability Index is an aggregate measure of the vulnerability of receptors in the watershed and it is computed as the average vulnerability of all receptors in a given watershed. The values computed with the vulnerability formula for each receptor are summed across the watershed and divided by the number of receptors in it.

**Flooded Area Index:** The Flooded Area Index is a measure of the geographic extent of flooding in the watershed, with specific measure of flooding in high social vulnerability areas and commercial areas. While Task 3 analyzed the total area flooded in each watershed under multiple scenarios, Task 4 adds the specificity to account for the relative importance of commercial districts and socially vulnerable areas. The Flooded Area Index accounts for the return period of the scenarios in which the different types of area are flooded by estimating a probability-weighted area. That probability-weighted area for flooded commercial districts, socially vulnerable areas and the remainder of the flooded area in a watershed is then aggregated into the index. Aggregation is performed by applying a weight factor to each type of area.

The weight factor for commercial areas, socially vulnerable areas and the rest of the area flooded is subjective and requires discussion and decision-making by County staff. These weight factors will be discussed during the Task 4 workshop.

**High Criticality Receptor Index:** The High Criticality Receptor Index is a measure of how many *highly critical* receptors flood in a watershed with considerations for the frequency with which they flood (based on the return period of the scenarios modeled). Given that the vulnerability formula applied to each receptor does not account for the degree of criticality of the receptor, this High Criticality Receptor Index specifically looks at highly critical receptors and whether or not they are exposed to flooding. The analysis includes weight factors to account for the fact that a 10-year return period is more frequent than a 100-year that this in turn is more frequent than a 500-year return period.

Applying the MART methodology results in a draft watershed prioritization that will be a key input to discussion and decision-making during the Task 4 workshop. Figure ES-3 shows key analyses and outcomes of Task 4 and the role of the Task 4 workshop in arriving to a final watershed prioritization.

[1] MART is sometimes also referred to as MODA (Multi-Objective Decision Analysis) and MCA (Multi-Criteria Analysis)

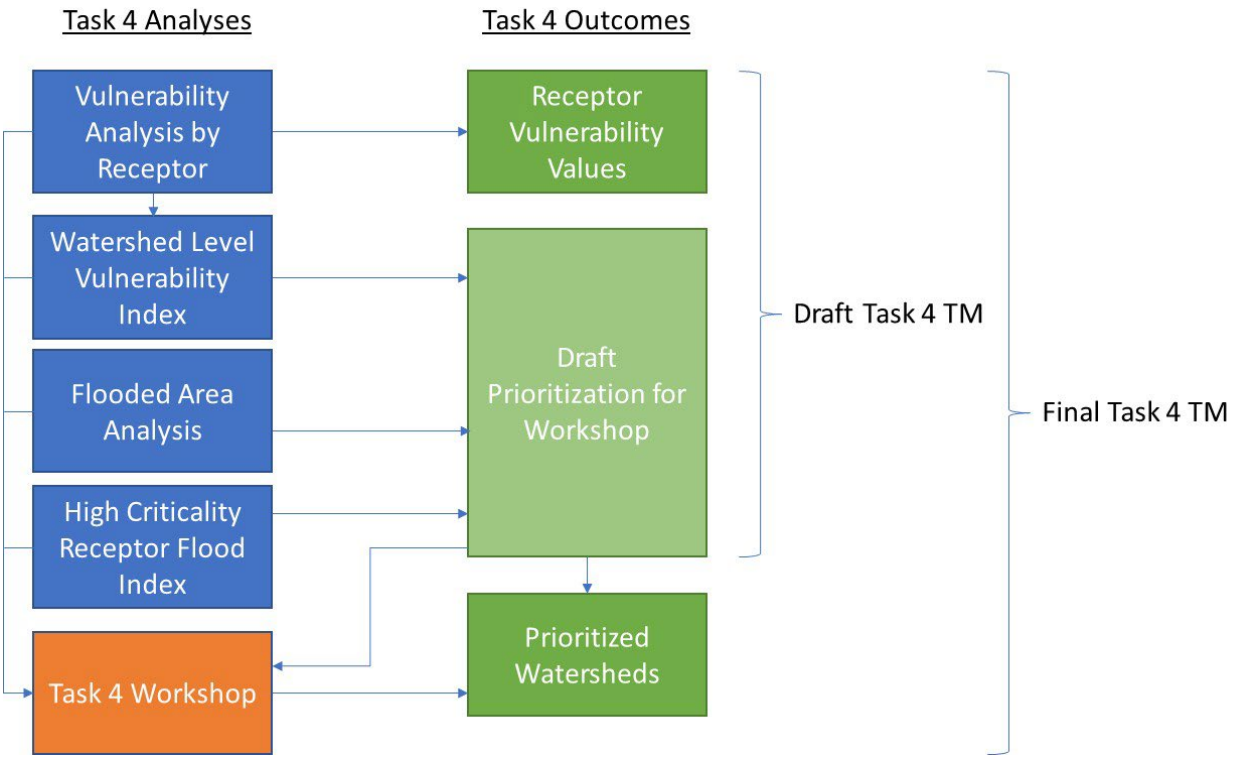



**Figure ES-3. Task 4 Analyses, Outcomes and Draft and Final Results**

Key information for Task 4 from earlier tasks included the exposure information (modeling results) from Task 3, the list and geodataset of receptors from Task 2, including the categorization of degree of criticality for each receptor. Modeling results are available for 13 total scenarios which generally include 9 riverine and interior flooding scenarios with 3 return periods (10-year, 100-year and 500-year) under 3 planning horizons (baseline, 2040 and 2070); as well as 4 coastal scenarios.

Information specifically collected for Task 4 includes commercial district areas; Social Vulnerability Index (SVI) information and geodatasets from the Centers for Disease Control and Prevention (CDC); information on the use of social vulnerability information on County programs and studies; environmental information from the County on Resource Protection Areas, supplemented by U.S. Fish and Wildlife's National Wetlands Inventory; and neighborhood geodatasets. The information and data collection included discussion and interaction with and feedback from County staff, especially in the definition of commercial and socially vulnerable areas. Additional interaction and feedback with County staff took place in the definition of the degree of criticality for all receptors identified during Task 2 for the analysis.

The information collected, which also included facilities information from Dominion Power and Washington Gas under confidentiality agreements, was used in multiple analyses for receptor-level vulnerability, Flooded Area Index and High Criticality Receptor Index.

## Results

The receptor-level analysis and application of the vulnerability formula resulted in a vulnerability value for each receptor in each watershed. Results in this TM include specific exposure scores (based on the number of scenarios under which each receptor floods) as well as scores for sensitivity, adaptive capacity and vulnerability. With the individual receptor scores for all receptors in a watershed, the Watershed-Level Vulnerability Index computed is presented in Figure ES-4.

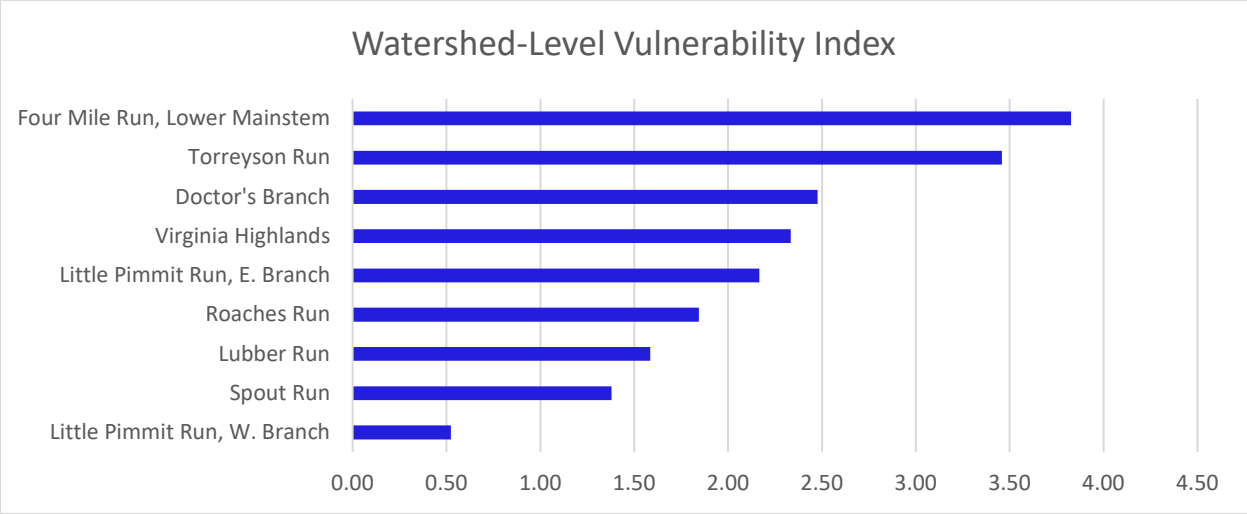



**Figure ES-4. Watershed-Level Vulnerability Index**

Four Mile Run Lower Mainstem and Torreyson Run are watersheds with the highest values with Little Pimmit Run West Branch ranking the lowest. Results can be a function of the extent of flooding (causing more exposure) as well as the vulnerability (resulting from sensitivity and adaptive capacity) of the receptors flooded.

For the area flooded analyses, commercial and socially vulnerable areas were used to compute the Flooded Area Index. The index is influenced by the extent of area that floods for each type of area. Figure ES-5 presents the commercial areas flooded by watershed for two scenarios (sample scenarios for illustration).

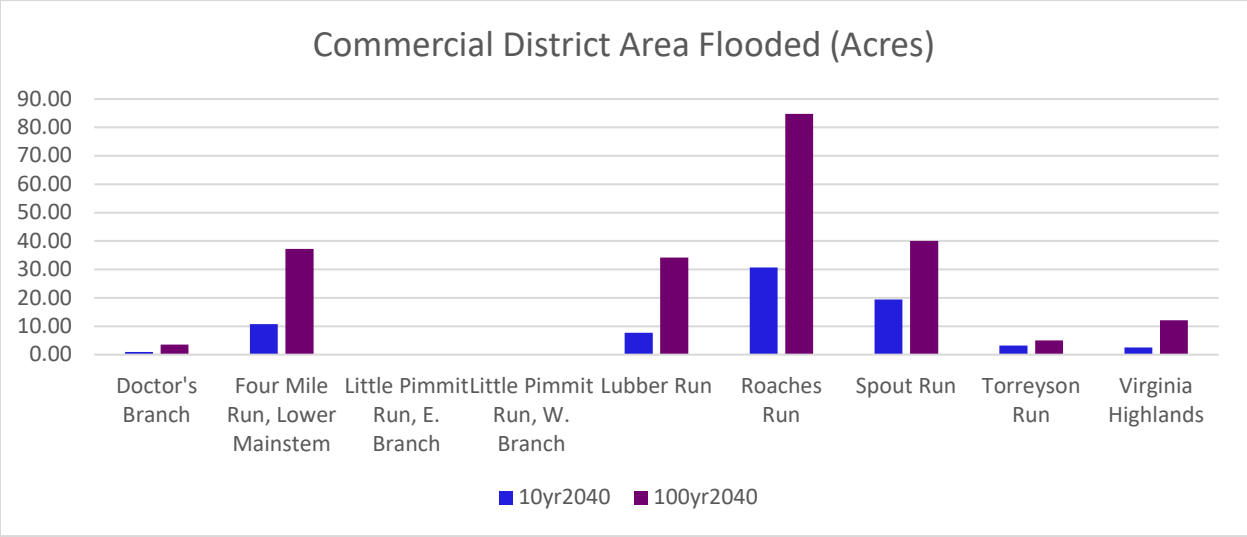



**Figure ES-5. Extent of Commercial District Areas Flooded Above 6 Inches for Two Sample Scenarios**

Figure ES-6 presents the same scenarios with extent of socially vulnerable areas flooded by watershed.

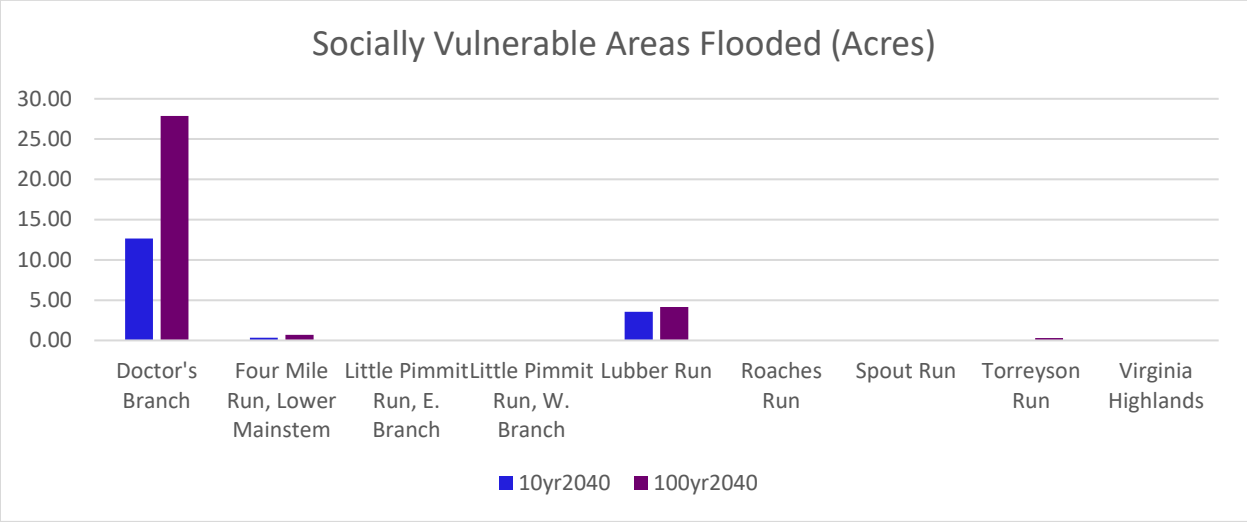



**Figure ES-6. Extent of Socially Vulnerable Areas Flooded Above 6 Inches for Two Sample Scenarios**

These areas flooded combined into the Flooded Area Index result in the ranking presented in Figure ES-7, when using the following weighting factors for aggregation:

Commercial District Area Weight = 0.3
Socially Vulnerable Area Weight = 0.55
Other Area (non-commercial and not socially vulnerable) Weight = 0.15

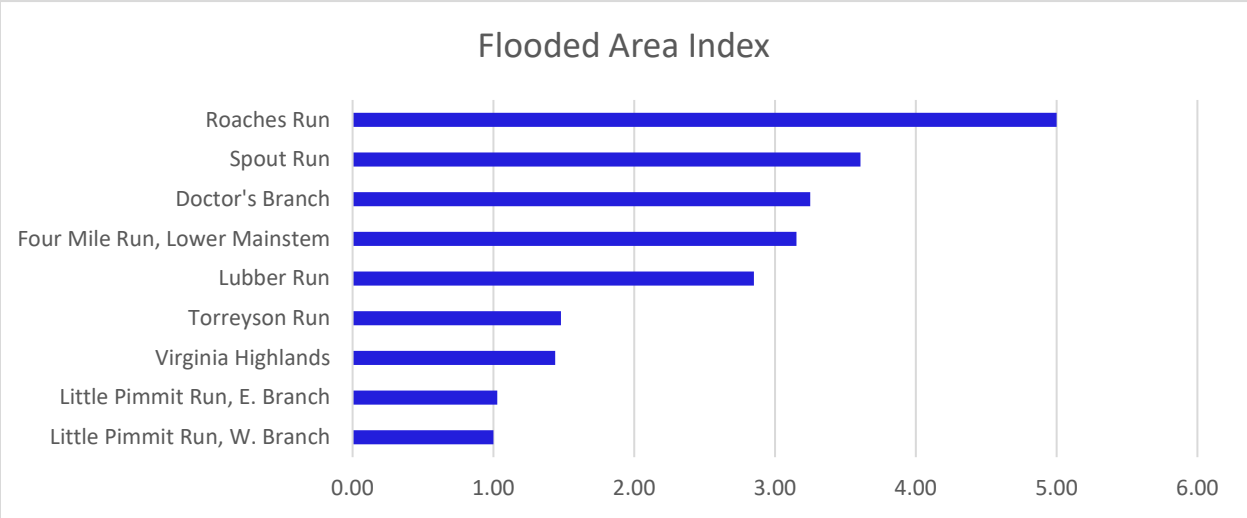



**Figure ES-7. Flooded Area Index Using the Factors Listed Above**

The weight factors will be a key discussion item during the Task 4 workshop.

When taking into account the criticality of the receptors flooded in each watershed, the High Criticality Receptor Index computed is presented in Figure ES-8.

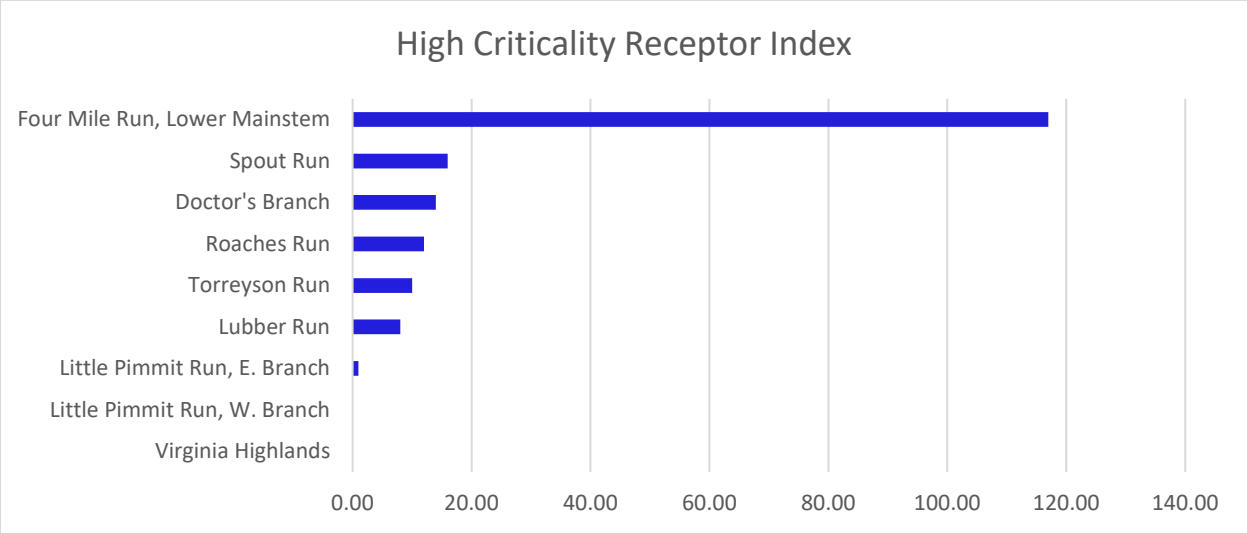



**Figure ES-8. High Criticality Receptor Index**

Applying the MART method with the three attributes in Task 4 (Watershed-Level Vulnerability Index, Flooded Area Index, and High Criticality Receptor Index), and assuming equal weights for them, the resulting draft watershed prioritization is presented in Figure ES-9. This draft prioritization will be a key input for decision-making during the Task 4 workshop. The draft ranking shows Four Mile Run Lower Mainstem as the top watershed to prioritize, we the Little Pimmit watersheds and Virginia Highlands as low priority watersheds. Doctor's Branch (second) to Lubber Run (sixth) are likely to change prioritization rank as weights/if weights for the MART and the Flooded Area Index are modified as part of the workshop.

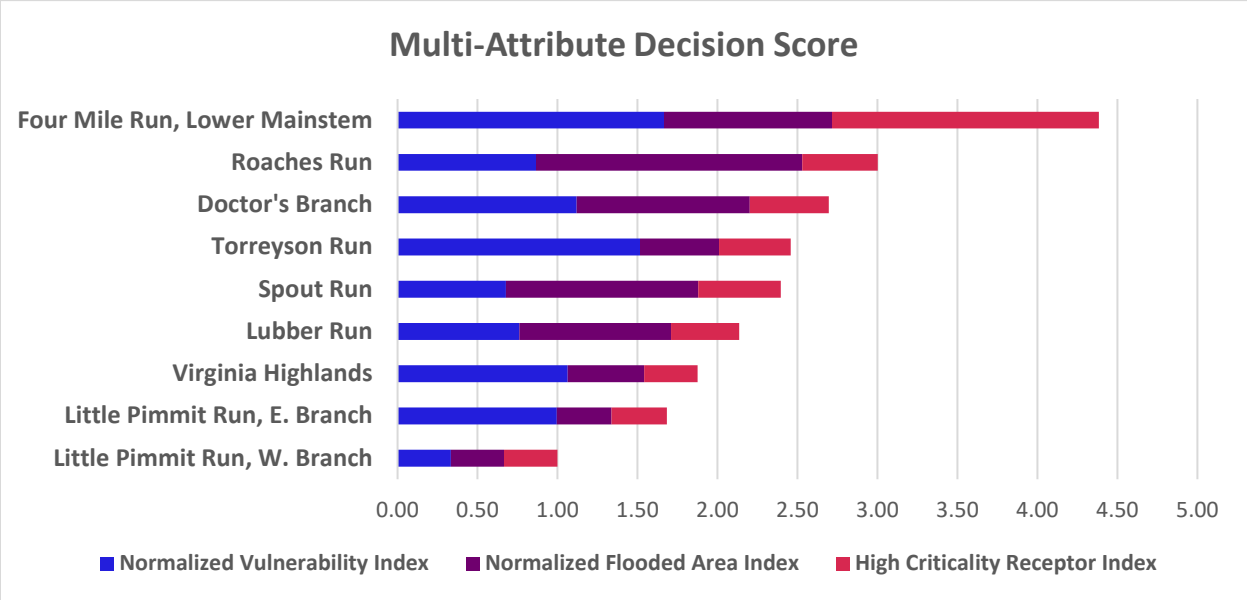



**Figure ES-9. Draft Watershed Prioritization**

# Contents

**Executive Summary** ..... **ES-1**

**Acronyms and Abbreviations** ..... **iv**

**1. Introduction** ..... **1-1**
- 1.1 Task Purpose ..... 1-1
- 1.2 Background ..... 1-1
- 1.3 Geographic Scope of Vulnerability Analysis ..... 1-2
- 1.4 Task Terminology ..... 1-3

**2. Overall Approach for the RAMP** ..... **2-1**
- 2.1 Task 4 Vulnerability Analysis Approach ..... 2-1
  - 2.1.1 Vulnerability Analysis by Receptor ..... 2-1
  - 2.1.2 Analyses for Watershed Prioritization ..... 2-2
  - 2.1.3 Process for Draft and Final Watershed Prioritization ..... 2-4

**3. Data and Information Sources** ..... **3-1**
- 3.1 Exposure ..... 3-1
- 3.2 Receptors ..... 3-3
- 3.3 Commercial Districts ..... 3-6
- 3.4 Environmental Receptors ..... 3-6
- 3.5 Social Vulnerability ..... 3-9
  - 3.5.1 Definition of High Social Vulnerability ..... 3-9

**4. Vulnerability Analysis Methodology** ..... **4-1**
- 4.1 Exposure ..... 4-1
- 4.2 Sensitivity and Adaptive Capacity ..... 4-1
- 4.3 Computing a Vulnerability Value from Exposure, Adaptive Capacity and Sensitivity ..... 4-4
  - 4.3.1 Watershed-Level Vulnerability Index ..... 4-5
- 4.4 Flooded Area Analysis and Flooded Area Index ..... 4-5
- 4.5 Criticality of Receptors and High Criticality Receptor Index ..... 4-8
- 4.6 Normalization of Scores for Watershed Prioritization Method ..... 4-9

**5. Vulnerability Analysis Results** ..... **5-1**
- 5.1 Watershed Results ..... 5-1
  - 5.1.1 Vulnerability by Receptor ..... 5-3
  - 5.1.2 High Criticality Receptors ..... 5-4
  - 5.1.3 Flooded Area Analysis ..... 5-5
- 5.2 Results Discussion ..... 5-9

**6. Watershed Prioritization** ..... **6-1**
- 6.1 Task 4 Workshop ..... 6-2

**7. References** ..... **7-1**

**Appendices**

A Flood Maps Used for the 2040 100-year 24-hour Exposure Analysis
B List of Critical Receptors
C Watershed Prioritization for Modeling
D Critical Receptors Exposure Results
E Vulnerability Analysis by Watershed
F Flooded Areas
G Social Vulnerability Index Background

**Tables**

3-1 Modeled Scenarios for Interior, Riverine and Coastal Flood Modeling Used in the Vulnerability Analysis ..... 3-1
4-1 Scores for Sensitivity and Adaptive Capacity for Types of Receptors ..... 4-2
4-2 Doctor's Branch Example of Flooded Areas by Type of Area and Return Period (Acres) ..... 4-6
5-1 Percent of Watershed Flooded Under All Scenarios (flood depth >6 inches) ..... 5-2
5-2 Sum of Vulnerability Values per Watershed (Sum of Vulnerability Values from All Receptors) ..... 5-3
5-3 Commercial District Area Flooded by Watershed for Each Scenario (Acres) ..... 5-6
5-4 Flooded Area with High Social Vulnerability (SVI 0.5 to 0.75 and greater than 0.75) by Watershed for Each Scenario (Acres) 1 ..... 5-6
6-1 Set of Weights Used for Computation of Normalized Flooded Area Index ..... 6-1
6-2 Set of Weights Used for Multi-Attribute Decision Score ..... 6-1

**Figures**

ES-1 Overall Process of Prioritization for Risk Analysis in the RAMP ..... ES-1
ES-2 Arlington County Watershed Modeling Overview ..... ES-2
ES-3 Task 4 Analyses, Outcomes and Draft and Final Results ..... ES-4
ES-4 Watershed-Level Vulnerability Index ..... ES-5
ES-5 Extent of Commercial District Areas Flooded Above 6 Inches for Two Sample Scenarios ..... ES-5
ES-6 Extent of Socially Vulnerable Areas Flooded Above 6 Inches for Two Sample Scenarios ..... ES-6
ES-7 Flooded Area Index Using the Factors Listed Above ..... ES-6
ES-8 High Criticality Receptor Index ..... ES-7
ES-9 Draft Watershed Prioritization ..... ES-7
1-1 Arlington County Interior and Riverine Watershed Modeling Overview ..... 1-4
2-1 Overall Approach for RAMP ..... 2-1
2-2 Elements of Vulnerability (Adapted from AWWA 2021) ..... 2-2
2-3 Prioritization from 14 to 3 Watersheds for Risk Analysis Under Task 5 ..... 2-3
2-4 Task 4 Analyses, Outcomes and Draft and Final Results ..... 2-4
3-1 Flood Map for 100-year 24-hr event in 2040 ..... 3-2
3-2 Receptors Assessed in the Vulnerability Analysis (from RAMP Task 2) ..... 3-4
3-3 Receptor Density by Watershed (Number of Receptors per Acre) ..... 3-5
3-4 Commercial Districts Assessed in the Vulnerability Analysis (from RAMP Task 2) ..... 3-7
3-5 RPA and NWI Wetlands Assessed in the Vulnerability Analysis ..... 3-8
3-6 CDC Social Vulnerability Index Values within Arlington County ..... 3-10
4-1 Normalization Scale used in Draft Prioritization ..... 4-9
5-1 Extent of Flooded Areas by Watershed Under Different Scenarios ..... 5-1
5-2 Average Vulnerability for Exposed Receptors in Each Watershed ..... 5-4

5-3. High Criticality Receptor Index for Each Watershed ..... 5-4
5-4 High Social Vulnerability Areas (Probability-Weighted) for Each Watershed ..... 5-7
5-5 Commercial District Areas (Probability-Weighted) for Each Watershed ..... 5-7
5-6 Commercial District Areas for Each Watershed Flooded Under Two Sample Scenarios ..... 5-8
5-7 Watersheds Ranked by Normalized Flooded Area Index ..... 5-9
6-1 Draft Prioritization (Using Equal Weights for All Three Attributes in Multi-Attribute Decision Score) ..... 6-2

# Acronyms and Abbreviations

| | |
|---|---|
| 1D | one-dimensional |
| 2D | two-dimensional |
| ATSDR | United States Agency for Toxic Substances and Disease Registry |
| CDC | Centers for Disease Control and Prevention |
| FEMA | Federal Emergency Management Agency |
| FM | Flexible Mesh |
| GIS | geographic information system |
| MART | multi-attribute rating technique |
| NAVD88 | North American Vertical Datum of 1988 |
| NWI | National Wetlands Inventory |
| PCSWMM | Personal Computer Stormwater Management Model |
| RAMP | Risk Assessment Management Program |
| RPA | Resource Protection Area |
| SLR | sea level rise |
| SVI | Social Vulnerability Index |
| TM | Technical Memorandum |

# 1. Introduction

Arlington County, Virginia (the County) initiated a study to support the Stormwater Program Risk Assessment Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for Arlington County Department of Environmental Services resulting in a comprehensive RAMP. The intent of the Arlington County RAMP is to address the risk and uncertainty of flooding due to current and future climate, and to project and map risk and consequential impacts in support of a long-term resiliency strategy. The RAMP will inform a prioritized capital improvement plan, with enhanced design standards and forward-looking asset management and adaptation strategies that will allow the County to maintain a responsive level of service and a pathway for long-term system resilience.

Task 4 of the RAMP conducted analyses to assess vulnerability of watersheds in the project area. This technical memorandum (TM) documents Task 4.

## 1.1 Task Purpose

The purpose of Task 4 was twofold:

- To assess flood vulnerability for public infrastructure each watershed based on flooded locations of special interest[2], commercial and residential areas, vulnerable groups and environmental resources within the watershed boundaries, and
- To identify three[3] watersheds for further risk analysis in Task 5 based upon their respective vulnerability scores and other metrics and considerations

Task 4 uses key inputs from Task 2, Data Collection, which included identification of facilities and other key information about elements that may be exposed and vulnerable to flooding and Task 3, Modeling, in which flood modeling was conducted for interior, riverine and coastal flooding under multiple storm recurrence intervals (probabilities) and future climate scenarios. Tasks 2 and 3 are thus key inputs to Task 4. Task 4, in turn, will provide key inputs to Task 5 where a full risk assessment will be developed for selected areas and facilities within prioritized watersheds while Task 6, Mitigation & Adaptation, will explore and recommend risk mitigation measures.

## 1.2 Background

Within Task 2, Data Collection, the Jacobs team acquired, formatted, and created geographic information system (GIS)–compatible facility and watershed data to support modeling efforts and meteorologic data and climate change projections to support the development of future climate scenarios as part of Task 3. A key outcome of Task 2 that informs the vulnerability assessment is the list of critical "facilities"[4]. The list was developed from data collected from public and utility data inventories, and was also the result of discussions with County staff.

Task 3 included the modeling of existing, 2040, and 2070 rainfall and sea level conditions for the 10-, 100-, and 500-year events. Inundation maps were developed for 13 watersheds within Arlington County. Model results were utilized as a basis upon which the vulnerability assessment was completed. Modeling results are documented in detail in the following 2 TMs:

- *Arlington Interior and Riverine Flooding Report (Task 3.3)* (Jacobs 2021)
- *Coastal Surge Modeling Technical Memorandum (Task 3.4)* (Jacobs 2020)

[2] The term "receptors" is used in this document to refer to these locations of special interest. See Section 1.4.

[3] The number of watersheds for risk assessment during subsequent tasks could increase, pending Arlington County decision.

[4] The term "facilities" was used during Task 2 and has been modified in this task and for subsequent tasks. See Section 1.4.

## 1.3 Geographic Scope of Vulnerability Analysis

An overview of Arlington County watersheds is presented in Figure 1-1. The figure includes the 14 watersheds modeled for interior or riverine flooding with Personal Computer Stormwater Management Model (PCSWMM) one-dimensional (1D)/two-dimensional (2D) and Flood Modeller FAST as part of Task 3. Flood Modeller FAST-modeled watersheds were modeled using reduced-physics methodology. While FAST simulations do not represent detailed hydraulic modeling results, the results can be considered an indicator of flood risk. FAST modeling efforts included simulations of the July 2019 storm event and the future projected 2020 100-year storm event. A full description of FAST modeling methodology can be found in the Task 3.3 Report (Jacobs 2021).

PCSWMM 1D/2D watersheds were simulated using linked 1- and 2- dimensional modeling techniques with the fully hydrodynamic EPA SWMM modeling engine. Model simulations were performed for 9 different historical and climate-escalated storm event scenarios in addition to the historical July 2019 event. A full description of PCSWMM 2D modeling methodologies can be found in the Task 3.3 Report (Jacobs 2021).

The relevance of the two methods and simulations for the watershed prioritization in Task 4 is explained as part of Section 4 of this TM. The vulnerability analysis conducted in Task 4 included the nine watersheds simulated with PCSWMM for multiple scenarios.

Coastal modeling was also conducted to evaluate the potential impacts of coastal surge propagation under selected future sea level rise (SLR) scenarios. To assess the extent of flooding due to the projected effects of climate change of the project area, Jacobs adapted the existing Potomac River Basin Model by using the MIKE 21 Flow FM (Flexible Mesh) module (MIKE by DHI 2020). MIKE 21 Flow FM is a two-dimensional depth-averaged module developed by the Danish Hydraulic Institute. The present model domain incorporates riparian floodplain zones along tidal rivers adjacent to the project area, which previously included the Potomac River and Anacostia River but was expanded to include Four Mile Run.

Results from the coastal analysis were used as input (downstream control) boundary conditions for the inland and riverine modeling that considers rainfall-driven events and described in the Task 3.3 Report. The resulting coastal surge and SLR boundary conditions primarily have impacts for the Four Mile Run riverine and subwatershed models but were also applied to all models that outfall directly to the Potomac. The coastal modeling analysis provided exposure information for the vulnerability assessment in Task 4 and will be considered where appropriate in subsequent risk assessment and alternatives analysis tasks.

During Task 3, decisions were made to determine which watersheds would be modeled with a reduced-physics model (Flood Modeller FAST application), and for which fewer scenarios would be analyzed. The process resulted in the selection of five watersheds for FAST analysis. Nine additional watersheds were selected for detailed fully hydrodynamic integrated 1D/2D PCSWMM modeling. Note that for Task 3 modeling purposes, the East Pimmit and West Pimmit watersheds were combined into a single PCSWMM model for a total of eight PCSWMM models representing nine watersheds.

The Task 3 process to prioritize these nine watersheds was described in the Task 3.3 Report (Jacobs 2021) and is included in Appendix C of this TM. The analysis described in this TM for Task 4 were applied to the following nine watersheds:

- Doctor's Branch
- Four Mile Run, Lower Mainstem
- Little Pimmit Run E. Branch
- Little Pimmit Run W. Branch
- Lubber Run

- Roaches Run
- Spout Run
- Torreyson Run
- Virginia Highlands

## 1.4 Task Terminology

The following are some key terms and definitions for this task and future RAMP tasks:

**Facility**: a place in a geographic parcel or contiguous parcels with equipment and processes to provide a specific public function—for example, wastewater treatment plant

**Asset**: Piece of equipment or equipment sets within a facility—for example, electrical panel within a wastewater treatment plant

**Receptor**: any entity of interest that can be exposed to flooding—examples include a facility, an asset, a public building providing critical services, a Resource Protection Area. Receptors used in the vulnerability analysis documented in this TM come primarily from the work in Task 2, Data Collection, which compiled a list of "critical facilities." The term receptor in this TM refers primarily to the elements in that list, with some additions such as environmentally relevant locations and private electric and gas utility facilities.

**Problem area**: geographic area containing many receptors that are at high risk (only applicable for Task 6, Adaptation and Mitigation, and beyond)

**Sensitivity**: a measure of the degree to which an asset/facility/receptor would be impaired by flood exposure. For example, roadways are generally not sensitive to temporary flooding because they are unlikely to be damaged. In contrast, a non-submersible pump station is considered highly sensitive to flood events if exposed to water, as it may be damaged beyond repair.

**Adaptive capacity**: represents the existing asset/facility/receptor's inherent ability to adjust to maintain its primary functions. Examples include the existence of back-up generators or the ability to raise a seawall protecting a receptor.

**Exposure** is "presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by natural hazards and climate change" (IPCC 2014, Annex II).

**Vulnerability** represents "The predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm or damage, and lack of capacity to cope and adapt (adaptive capacity)" (IPCC 2014, Annex II).

**Risk:** The term risk is the expectation of the magnitude of an undesirable consequence when a system, asset or facility fails. The "expectation" means that magnitude of a consequence accounts for the likelihood of the failure of the system, facility or asset that triggers the undesirable consequence (UNDRR 2019). Risk is generally estimated as the product of likelihood (probability of occurrence, such as 10 percent chance from a 10-year storm) times consequence (such as damages avoided).

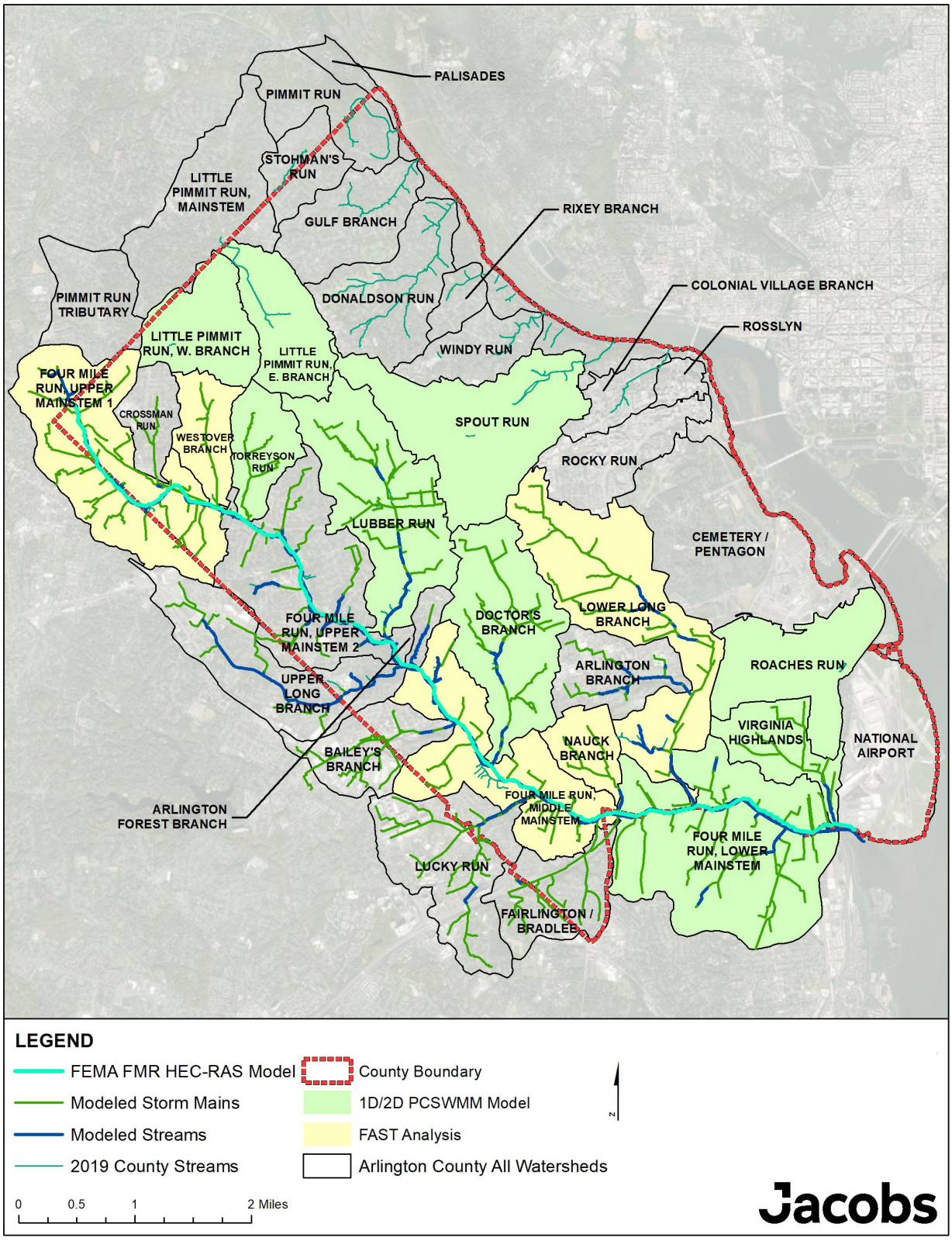



**Figure 1-1. Arlington County Interior and Riverine Watershed Modeling Overview**

# 2. Overall Approach for the RAMP

The approach followed for the vulnerability assessment is consistent with the overall approach for the RAMP. In a risk assessment study, vulnerability is a step in the process of analyzing full risk. The overall approach of the RAMP includes three critical steps: exposure, vulnerability, and risk, as shown in Figure 2-1. The vulnerability analysis approach is based on the required outcome from the analysis, which consists of a qualitative assessment of vulnerability for receptors within each watershed as well as the prioritization of watersheds for risk analysis under future tasks.

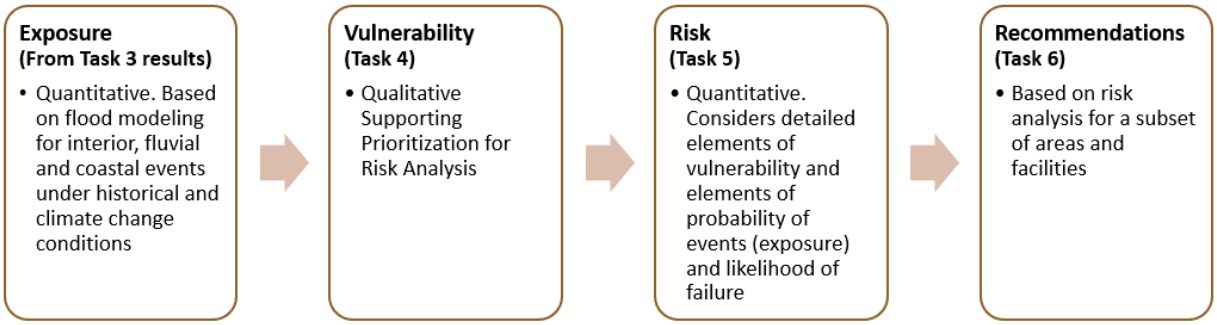



**Figure 2-1. Overall Approach for RAMP**

## 2.1 Task 4 Vulnerability Analysis Approach

Task 4 has two key objectives:

- Estimate vulnerability for each of the critical receptors in the study area
- Prioritize watersheds for further analysis (from 14 to 3[5])

To achieve these objectives Task 4 conducted analysis to obtain four main outcomes:

- Vulnerability analysis by receptor—Results in vulnerability values for each receptor by applying a vulnerability formula based on exposure, sensitivity and adaptive capacity (key outcome)
- Watershed-Level Vulnerability index—supports watershed prioritization
- Flooded area analysis and Flooded Area Index—supports watershed prioritization
- High Criticality Receptor Index—supports watershed prioritization

### 2.1.1 Vulnerability Analysis by Receptor

In the approach to define a qualitative vulnerability score vulnerability is defined by a receptor's exposure, adaptive capacity and sensitivity. As Figure 2-2 shows, vulnerability results from the combination of these three elements. Initially a receptor is not vulnerable if it is not exposed or projected to be exposed to the relevant hazards. When exposed, two inherent characteristics of the receptor will dictate its vulnerability: its sensitivity and its adaptive capacity. As the definitions for these terms in Section 1.4 indicate, sensitivity determines whether a receptor is likely to fail when exposed while adaptive capacity indicates the receptor's inherent degree to which the exposure can be mitigated to avoid failure. Detailed information regarding each component of vulnerability scoring can be reviewed in Section 4 of this TM.

[5] This may be increased from 3 watersheds to 4 or 5 watersheds for the final TM. Public infrastructure will also be prioritized for further analysis in Task 5.

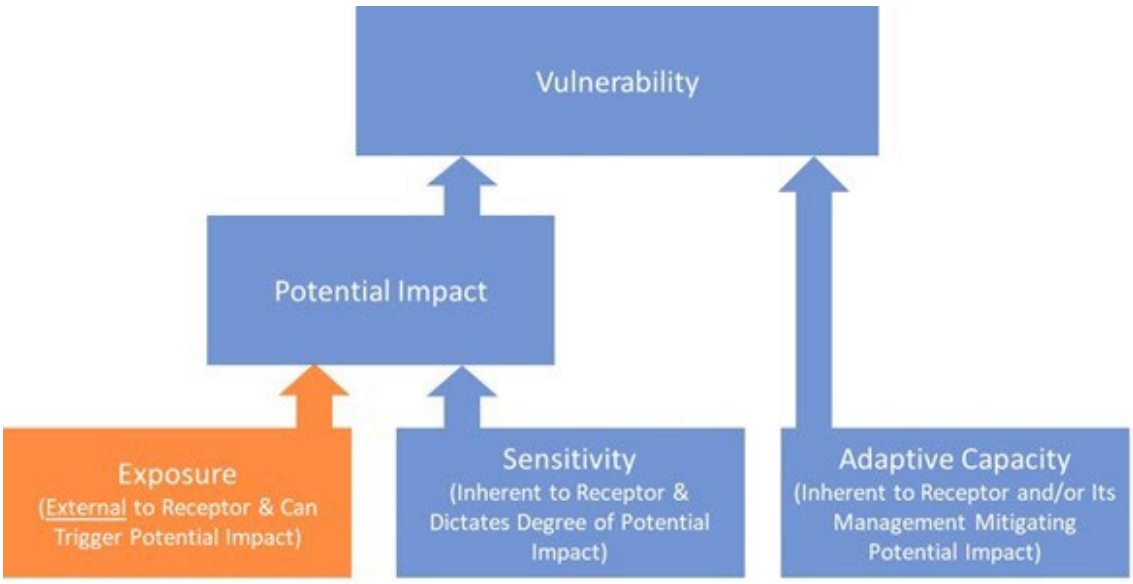



**Figure 2-2. Elements of Vulnerability (Adapted from AWWA 2021)**

For each watershed, the data collected and analyzed from Task 2 was pivotal in identifying the receptors to be included in the analysis. Discussion on how the list of receptors for this Task was formed can be reviewed in Section 3.2. Receptors included locations such as government facilities, community centers, schools, power facilities, and environmentally sensitive areas to name a few.

For each individual receptor, once scores are defined for sensitivity and adaptive capacity and the exposure is determined for each scenario, the receptor's vulnerability score is computed with the following formula:

*Vulnerability per Receptor = (Exposure + Sensitivity) / (Adaptive Capacity)*

where:

*Exposure*: is the sum of the exposure scores for all 13 scenarios (maximum possible value of 13 if receptor is exposed to flooding under each scenario) *Sensitivity*: score of 1, 2 or 3 based on sensitivity scale by receptor type *Adaptive Capacity*: score of 1, 2 or 3 based on adaptive capacity scale by receptor type

### 2.1.2 Analyses for Watershed Prioritization

The watershed prioritization method is based on a multi-attribute rating technique (MART)[6] given that vulnerability values for receptors alone in each watershed do not reflect impacts on highly critical receptors, neighborhoods, businesses, socially vulnerable groups and environmental resources. MART is a common prioritization method where criteria (attributes) are defined, weighted relative to each other, and applied for a total score based on the individual scores of each attribute. For this RAMP's vulnerability assessment, the three attributes for prioritization, as mentioned before, are:

- Watershed-Level Vulnerability Index
- Flooded Area Index
- High Criticality Receptor Index: measure of how many highly critical receptors flood in a watershed and the frequency with which they flood

[6] MART is sometimes also referred to as MODA (Multi-Objective Decision Analysis) and MCA (Multi-Criteria Analysis).

#### 2.1.2.1 Watershed-Level Vulnerability Index

The Watershed-Level Vulnerability Index is an aggregate measure of the vulnerability of receptors in the watershed and it is computed as the average vulnerability of all receptors in a given watershed. The values computed with the vulnerability formula for each receptor are summed across the watershed and divided by the number of receptors in it. Section 4.3 presents more detail and a specific example.

#### 2.1.2.2 Flooded Area Index

The Flooded Area Index is a measure of the geographic extent of flooding in the watershed, with specific measure of flooding in high social vulnerability areas and commercial areas. While Task 3 analyzed the total area flooded in each watershed under multiple scenarios, Task 4 adds the specificity to account for the relative importance of commercial districts and socially vulnerable areas. The Flooded Area Index accounts for the return period of the scenarios in which the different types of area are flooded by estimating a probability-weighted area. That probability-weighted area for flooded commercial districts, socially vulnerable areas and the remainder of the flooded area in a watershed is then aggregated into the index. Aggregation is performed by applying a weight factor to each type of area. Section 4.4 presents more detailed descriptions and a specific example for a watershed.

The weight factor for commercial areas, socially vulnerable areas and the rest of the area flooded is subjective and requires discussion and decision-making by County staff. These weight factors will be discussed during the Task 4 workshop.

#### 2.1.2.3 High Criticality Receptor Index

The High Criticality Receptor Index is a measure of how many *highly critical* receptors flood in a watershed with considerations for the frequency with which they flood (based on the return period of the scenarios modeled). Given that the vulnerability formula applied to each receptor does not account for the degree of criticality of the receptor, this High Criticality Receptor Index specifically looks at highly critical receptors and whether or not they are exposed to flooding. The analysis includes weight factors to account for the fact that a 10-year return period is more frequent than a 100-year that this in turn is more frequent than a 500-year return period. Section 4.5 presents more detail and a specific example.

Figure 2-3 presents the overall prioritization steps from 14 initial watersheds to 3 watersheds for risk analysis under Task 5.

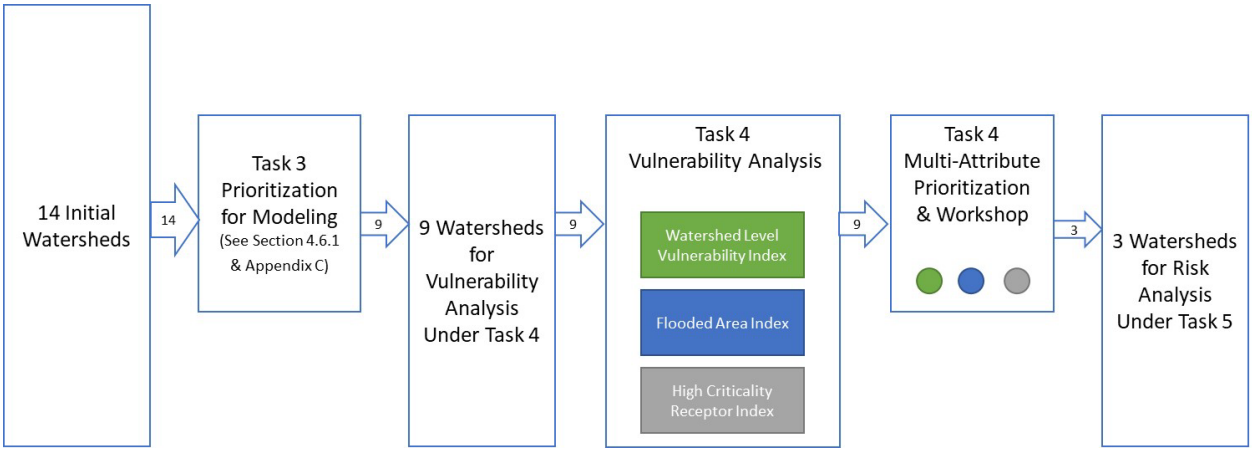



**Figure 2-3. Prioritization from 14 to 3 Watersheds for Risk Analysis Under Task 5**

### 2.1.3 Process for Draft and Final Watershed Prioritization

The draft watershed prioritization documented in this draft TM will be one of the main inputs for a Task 4 workshop with County staff. During the workshop, draft prioritization methodology and results will be discussed along with additional prioritization considerations. A key goal of the workshop is to define a final watershed prioritization. The draft prioritization presented in Section 6 of this TM represents the outcome of an analytical process with flood modeling and multiple analyses that are defensible, reproducible, and provide a sound basis for watershed planning efforts.

While the outcomes of this draft TM provide a critical input for decision-making, the series of analysis documented herein should not be seen as a final outcome in terms of prioritization. The technical analysis, while comprehensive, cannot capture all factors and considerations pertinent for prioritization and thus, the Task 4 workshop plays a key role in the process to define the short list of watersheds that will be analyzed under Task 5 and beyond in this RAMP. Section 6 therefore includes a section, to be completed after the workshop, which will memorialize the decision-making for prioritization, as well as the final watershed prioritization. Figure 2-4 presents the key analyses in Task 4 linked to the task's key outcomes.

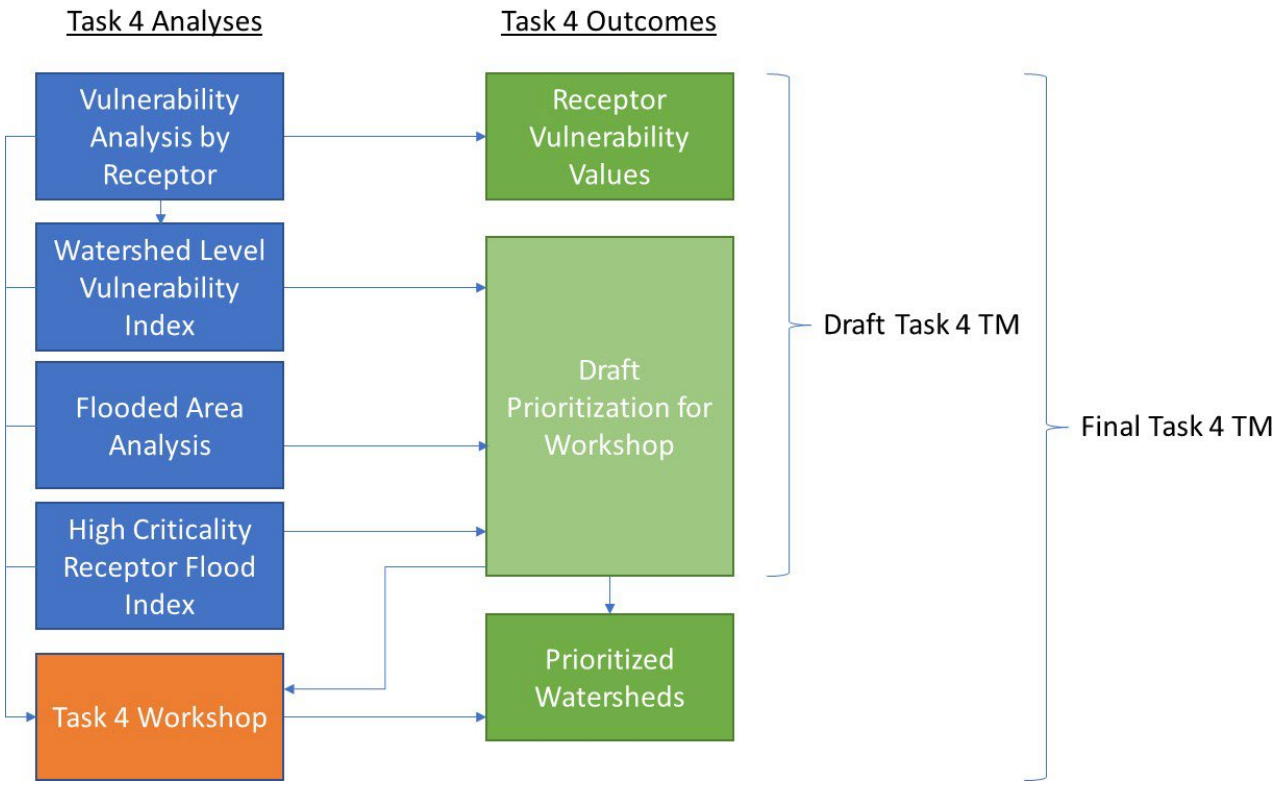



**Figure 2-4. Task 4 Analyses, Outcomes and Draft and Final Results**

# 3. Data and Information Sources

## 3.1 Exposure

The main input for exposure in the RAMP Vulnerability Assessment was the flood model inundation results for each modeled scenario from the previous task. Output from the flood models were used as the input to the exposure assessment. Flood inundation results were processed to define areas with projected flood depths greater than 6 inches for the baseline (current), 2040 and 2070 scenarios over the range of storm recurrence intervals. The 6-inch threshold was established to filter out minimal flood depths that do not cause disruption and to provide a realistic interpretation of flood inundation area extents that excludes nuisance flooding. The 6-inch threshold also excludes flood depths that do not exceed the typical street curb height. An example of a flood map for the 100-yr event in 2040 (including climate change impacts) is presented in Figure 3-1. Since the scale of Figure 3-1 does not allow to see detail in flood exposure, flood maps for the 2040 scenario for each watershed are presented in Appendix A. The RAMP includes a GIS data viewer where all scenarios can be visualized.

A total of 13 scenarios are used in the vulnerability analysis, which correspond to riverine, interior, and coastal flooding under baseline conditions and projected future conditions that account for climate change impacts with two planning horizons: year 2040 and year 2070. The full list of scenarios used for the analysis is presented in Table 3-1.

**Table 3-1. Modeled Scenarios for Interior, Riverine and Coastal Flood Modeling Used in the Vulnerability Analysis**

| Scenario | Interior/Riverine or Coastal Storm Surge | 24-hour Precipitation Amount (inches) | Sea Level Rise (feet, NAVD88) |
|---|---|---|---|
| Baseline: 10-year[1] | Interior/Riverine | 5.16 | None |
| Baseline: 100-year[1] | Interior/Riverine | 8.48 | None |
| Baseline: 500-year[1] | Interior/Riverine | 11.47 | None |
| 2040: 10-year[1] | Interior/Riverine | 5.49 | Int-High 1.86 |
| 2040: 100-year[1] | Interior/Riverine | 9.04 | Int-High 1.86 |
| 2040: 500-year[1] | Interior/Riverine | 12.21 | Int-High 1.86 |
| 2070: 10-year[1] | Interior/Riverine | 5.81 | Int-High 3.86 |
| 2070: 100-year[1] | Interior/Riverine | 9.57 | Int-High 3.86 |
| 2070: 500-year[1] | Interior/Riverine | 12.94 | Int-High 3.86 |
| 2040 100-year[2] | Coastal Storm Surge | NA | 6.6 [3] |
| 2040 500-year[2] | Coastal Storm Surge | NA | 7.4 [3] |
| 2070 100-year[2] | Coastal Storm Surge | NA | 8.6 [3] |
| 2070 500-year[2] | Coastal Storm Surge | NA | 9.4 [3] |

[1] Documented in Arlington Interior and Riverine Flooding Report (Task 3.3) (Jacobs 2021)

[2] Documented in Coastal Surge Modeling Technical Memorandum (Task 3.4) (Jacobs 2020)

[3] Storm Surge (Extreme Water Level analysis at Lewisetta) added to the National Oceanic and Atmospheric Administration's intermediate-high sea level rise at Solomon Island, at downstream boundary condition for coastal surge model for Potomac River

NAVD88 = North American Vertical Datum of 1988

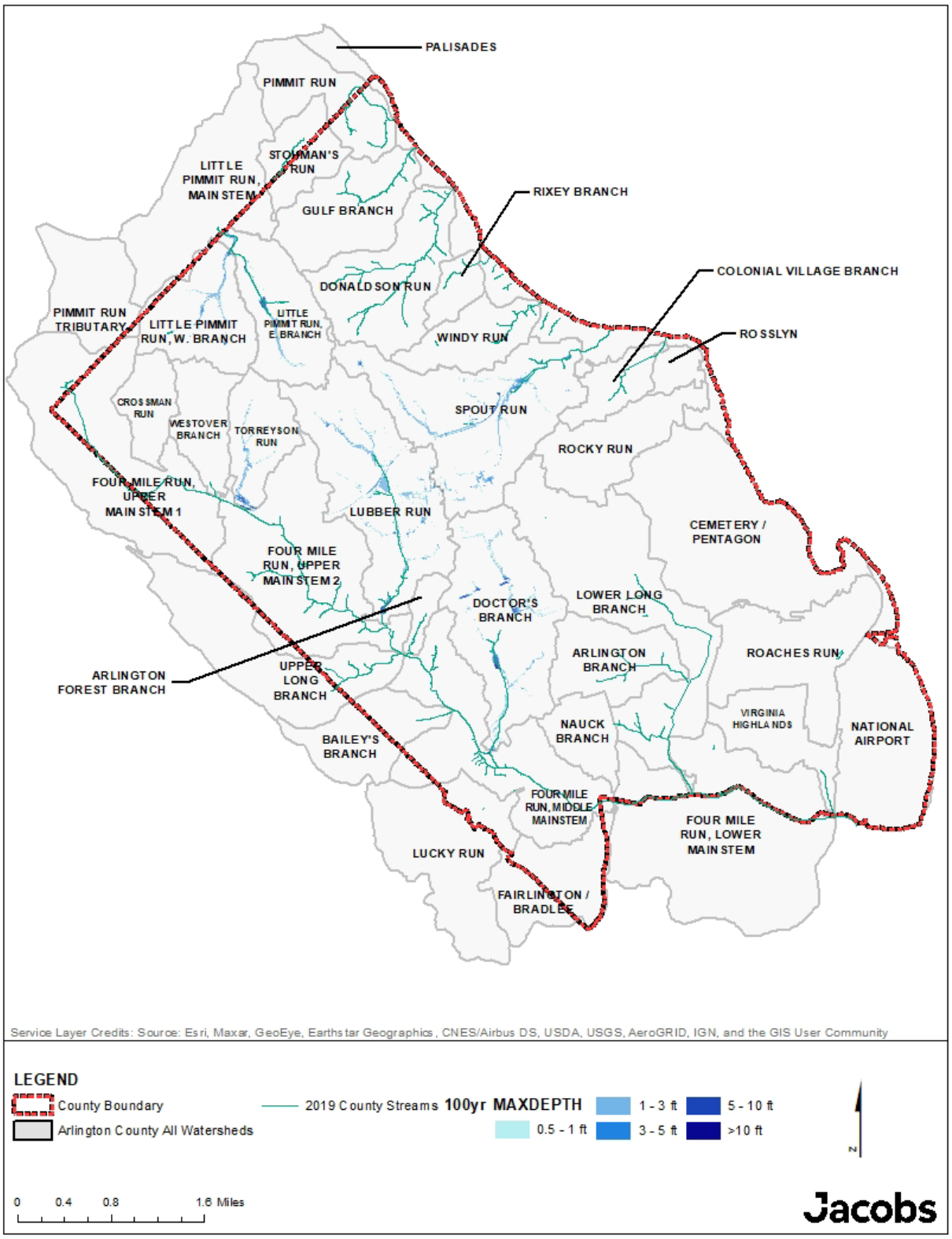



**Figure 3-1. Flood Map for 100-year 24-hr event in 2040**

## 3.2 Receptors

Working in conjunction with the County during Task 2 data collection activities, Jacobs assisted with identifying "critical facilities." Critical facilities were defined based on criteria that was discussed with County staff. Entities that were referred to as "critical facilities" in Task 2 are referred to as receptors for the Vulnerability Assessment. This provides clarity in the analysis given that some of the receptors are not facilities (see rationale for terminology in Section 4.1). Jacobs performed the following data gathering and analysis for identifying critical receptors:

- Performed interviews with County staff regarding the identification of critical County owned facilities such as utilities and transportation facilities.
- Reviewed historical flooding occurrences.

Continuous discussions with County staff ultimately concluded with Figure 3-2 below, a map of known receptors within Arlington County. Appendix B (List of Critical Receptors) lists the receptors used for the analysis, by facility type and watershed.

The receptors were categorized as having High, Medium or Low criticality. While all receptors identified are deemed critical, the degree of criticality is an important consideration in the prioritization of watersheds and areas for further analysis. The characterization of degree of criticality was qualitative and took into account elements of consequence of failure and elements of emergency response. Emergency response considerations included, qualitatively, redundancy, sustaining lifelines during emergencies, and the need for preparedness, response and recovery phases.

Consequence of failure considerations included qualitative discussions with County staff and information on:

- Interruption of service consequences such as population served, facilities served (hospitals, fire stations, and similar) and the function of the assets for overall the County operations.
- Social consequences were discussed such as impacts to public health and safety, general displacement, and social vulnerability
- Economic consequences: Workforce disruption, loss or damage to private and public infrastructure, impacts to businesses and economic activity
- Environmental consequences: Deterioration or loss of habitats or species and water quality impacts

The high, medium and low categorization of receptors is included in Appendix B (List of Critical Receptors).

The vulnerability analysis will be based on receptors exposed to flooding, which will be a function of both the density of critical receptors in each watershed and the degree to which the watersheds flood. Figure 3-3 presents the density of receptors per watershed. While a review of the receptor density is informative as background information, the density does is not directly used as a metric for vulnerability since it is independent of exposure.

Information collected for receptors also included facilities information from Dominion Power and Washington Gas under confidentiality agreements.

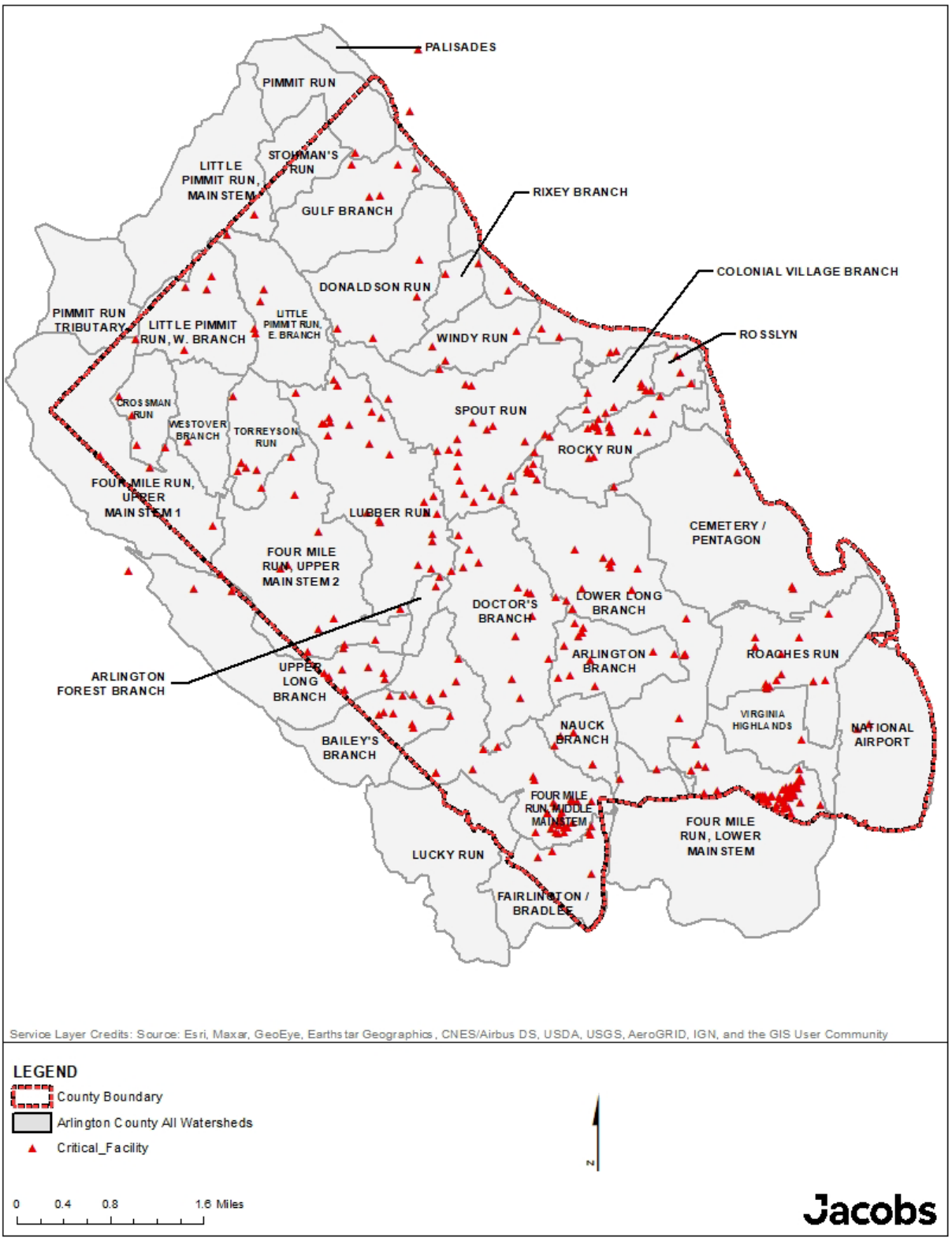



**Figure 3-2. Receptors Assessed in the Vulnerability Analysis (from RAMP Task 2)**

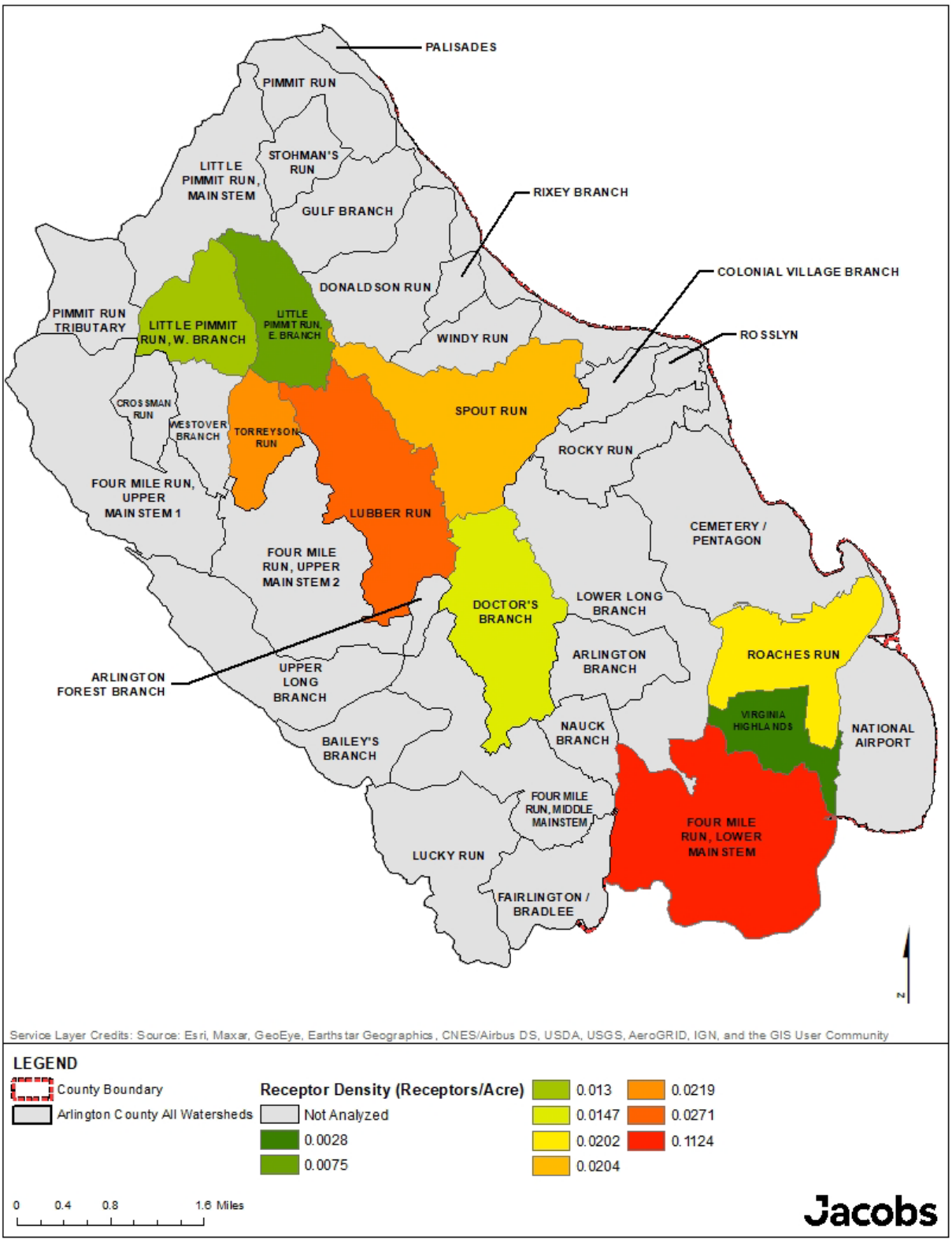



**Figure 3-3. Receptor Density by Watershed (Number of Receptors per Acre)**

## 3.3 Commercial Districts

Areas with significant commercial activity are termed "commercial districts" and were defined using land use and zoning information and discussions with County staff during Task 2. The County's current zoning map was the starting point for the definition of this area designation (Arlington County Zoning Division 2020). The zoning map includes approximately 40 unique zoning classifications. Additionally, The County's General Land Use Map (Arlington County Planning Commission 2020) uses designations for business and commercial activity to provide a higher level of aggregation than the zoning map for these two classifications. Working with County staff, the following land use classifications were selected by Jacobs for aggregation of zoning to ultimately define the "commercial districts" for the vulnerability assessment:

- Commercial & Industrial
- Office-Apartment-Hotel
- Mixed Use

The outcome of the work is a commercial districts layer as presented in Figure 3-4.

The commercial district areas were used in flooded area analysis for the watershed prioritization, as will be described in Section 4.6. These areas do not constitute as critical receptors and are not included in the specific scoring of vulnerability (see Section 4 for a detailed overview of vulnerability methodology).

## 3.4 Environmental Receptors

Areas of environmental value for the County were based on areas from established sources, including the National Wetlands Inventory (NWI) and the Chesapeake Bay Preservation Ordinance (the Ordinance) (Arlington County 2003). The Ordinance was adopted to protect streams and the Chesapeake Bay from pollution due to land use and development. All of Arlington County's water is tributary to the Potomac River and ultimately the Chesapeake Bay. In the Ordinance, sensitive areas along streams throughout Arlington have been designated as Resource Protection Areas (RPAs). The RPAs are natural buffers that help protect streams, rivers, and other water bodies. They include the environmentally sensitive lands within 100 feet of these water resources. These areas are known as stream or wetland buffers, and help protect water quality by:

- filtering out pollutants from stormwater runoff,
- reducing the volume of stormwater runoff,
- minimizing erosion, and
- providing wildlife habitat.

Additionally, a fully vegetated stream buffer can help protect private property by preventing erosion along a water body. Steep slopes (25 percent or greater) that are adjacent to buffers are also part of the RPA because of the potential for erosion in these areas, including during flooding events and high flow events. In RPAs, existing trees and other vegetation are protected and building projects are regulated.

The RPA information and its geodataset were supplemented with the NWI wetlands delineation. The Inventory is developed, updated and managed by U.S. Fish and Wildlife Service. The NWI is a publicly available resource (USFWS 2021) that provides detailed information on the abundance, characteristics, and distribution of U.S. wetlands. Wetlands were included in the vulnerability analysis in Task 4 given their potential vulnerability to certain natural hazards and the fact that they provide a multitude of ecological, economic and social benefits.

The areas included in the vulnerability analysis for environmental receptors are presented in Figure 3-5.

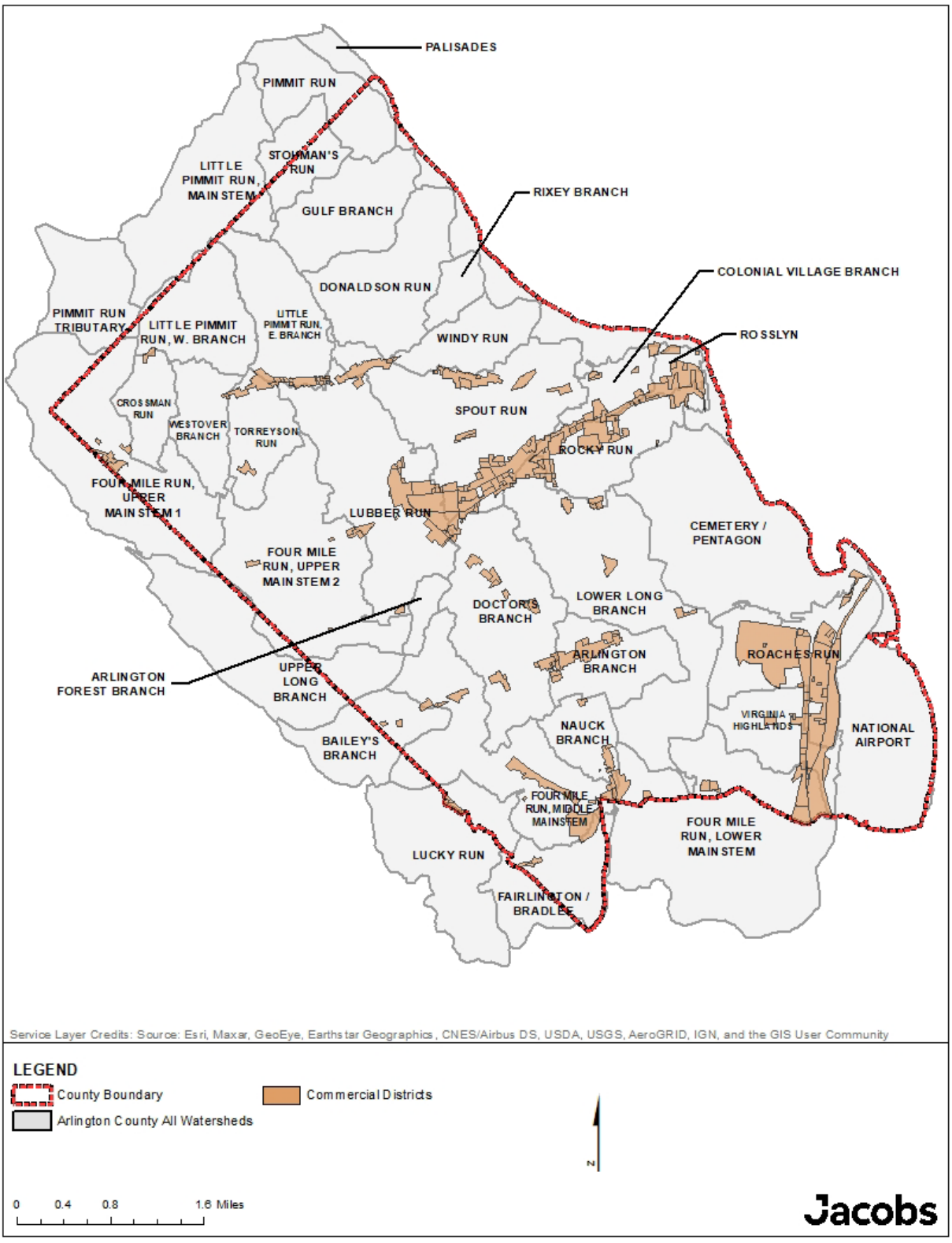



**Figure 3-4. Commercial Districts Assessed in the Vulnerability Analysis (from RAMP Task 2)**

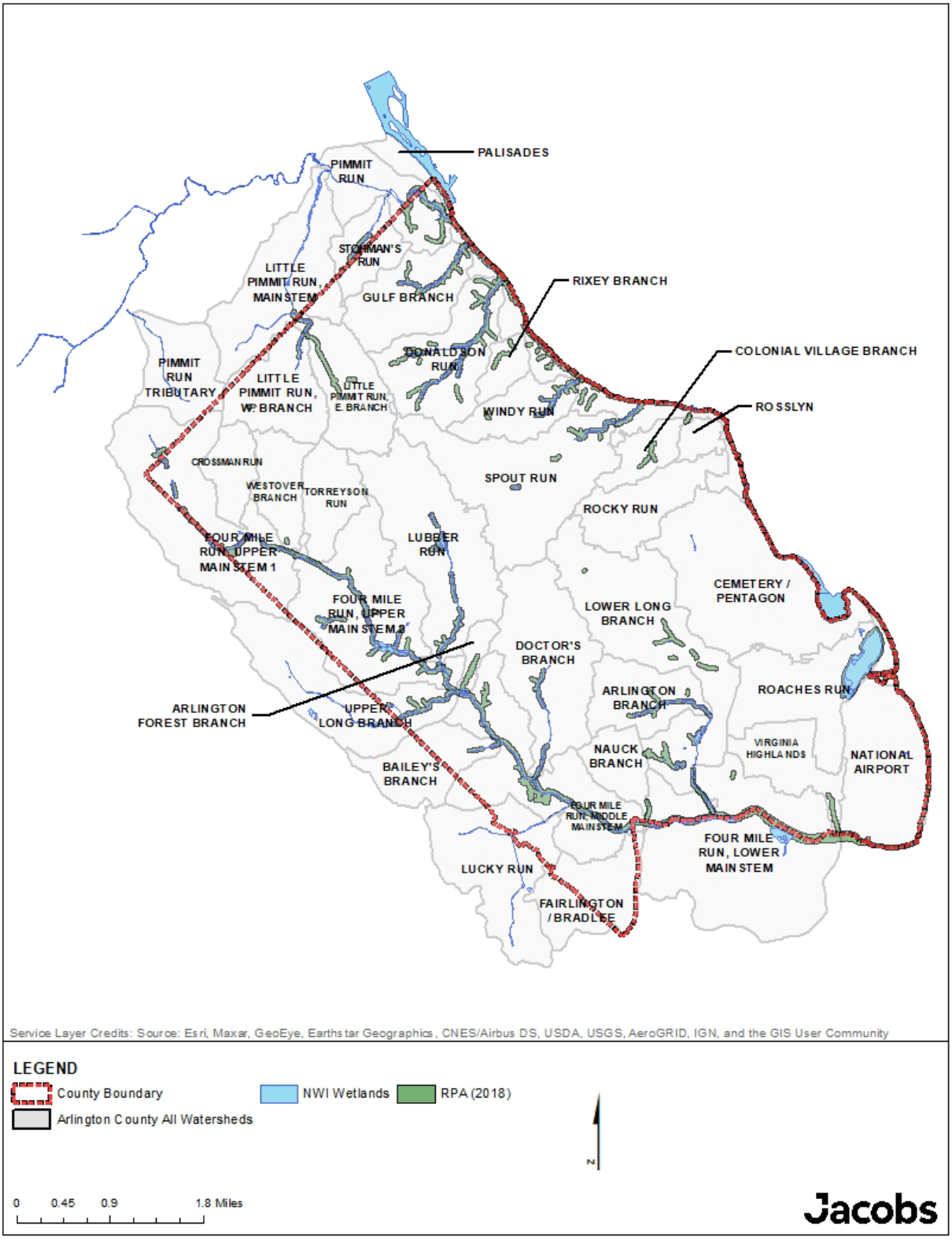



**Figure 3-5. RPA and NWI Wetlands Assessed in the Vulnerability Analysis**

## 3.5 Social Vulnerability

Social vulnerability is an important consideration in many of Arlington County's programs, policies, and services. The County's Department of Public Safety Communications & Emergency Management considers social vulnerability in the County's Emergency Operations Plan (Arlington County 2017a) and other programs and initiatives including programs related to health equity and the recent Covid19 Equitable Vaccine Access Strategy. Other County programs related to childcare and other services use social vulnerability to guide actions and outcomes. This RAMP considers social vulnerability, given that natural hazards and specifically flood can have adverse impacts that amplify for socially vulnerable populations.

According to the United States Agency for Toxic Substances and Disease Registry (ATSDR), which is part of the Centers for Disease Control and Prevention (CDC), "social vulnerability refers to the potential negative effects on communities caused by external stresses on human health" (ATSDR 2021). In the context of this task, the external stress is flooding. Social Vulnerability Index (SVI) values were developed by the CDC/ATSDR by Census Block and is based on data from the 2010 U.S. Census. The CDC/ASTDR SVI aggregates an index from a combination of 15 social factors such as poverty, lack of access to transportation, overcrowded housing, and lack of medical facilities. Further information on SVI can be reviewed in Appendix G.

As part of the RAMP, Jacobs reviewed different sources of information related to the County's use of social vulnerability and decided to use the CDCs SVI (SVI). The SVI is used by the County in recent initiatives including equitable vaccine distribution and childcare risk and reach (Arlington County 2017b) and it is consistent with the SocioNeeds Index also used by the County in other areas related to health indicators (Healthier Arlington 2021).

Figure 3-6 identifies the SVI values within Arlington County based on U.S. Census data.

The areas of high social vulnerability were used in flooded area analyses to support the watershed prioritization, as will be described in Section 4.6. While socially vulnerable areas do not constitute receptors, they are a critical component of the prioritization process (see Section 4 for detail vulnerability methodology).

### 3.5.1 Definition of High Social Vulnerability

The SVI was the basis for defining social vulnerability and from its values (from 0 to 1), which are available by census tract, two thresholds were derived for medium to high social vulnerability and high social vulnerability. The thresholds based on SVI values were 0.5 to 0.75 (for medium to high) and above 0.75 (for high). After an analysis that compared the SVI to the SocioNeeds Index specifically for the County, it was determined that these thresholds were consistent with the County's current use SocioNeeds Index and rank.

The basis for the recommendation of these two thresholds included the review of the Equitable Vaccine Access Strategy Report (no reference provided since it is a confidential report). This report uses SVI as one of the metrics to determine equitable distribution. The report background information uses four categories with thresholds of 0.25, 0.5, and 0.75. It assigns a category of vulnerability for specific sites using five categories. The top categories are "Moderate to High" (SVI from 0.5 to 0.75) and "High" (SVI above 0.75).

Additionally, the Childcare Reach and Risk Study uses SVI as one of the metrics of social vulnerability. It utilizes four bins linearly with the top two categories labeled as "Higher" and "Highest" and thresholds that are also 0.25, 0.5 and 0.75.

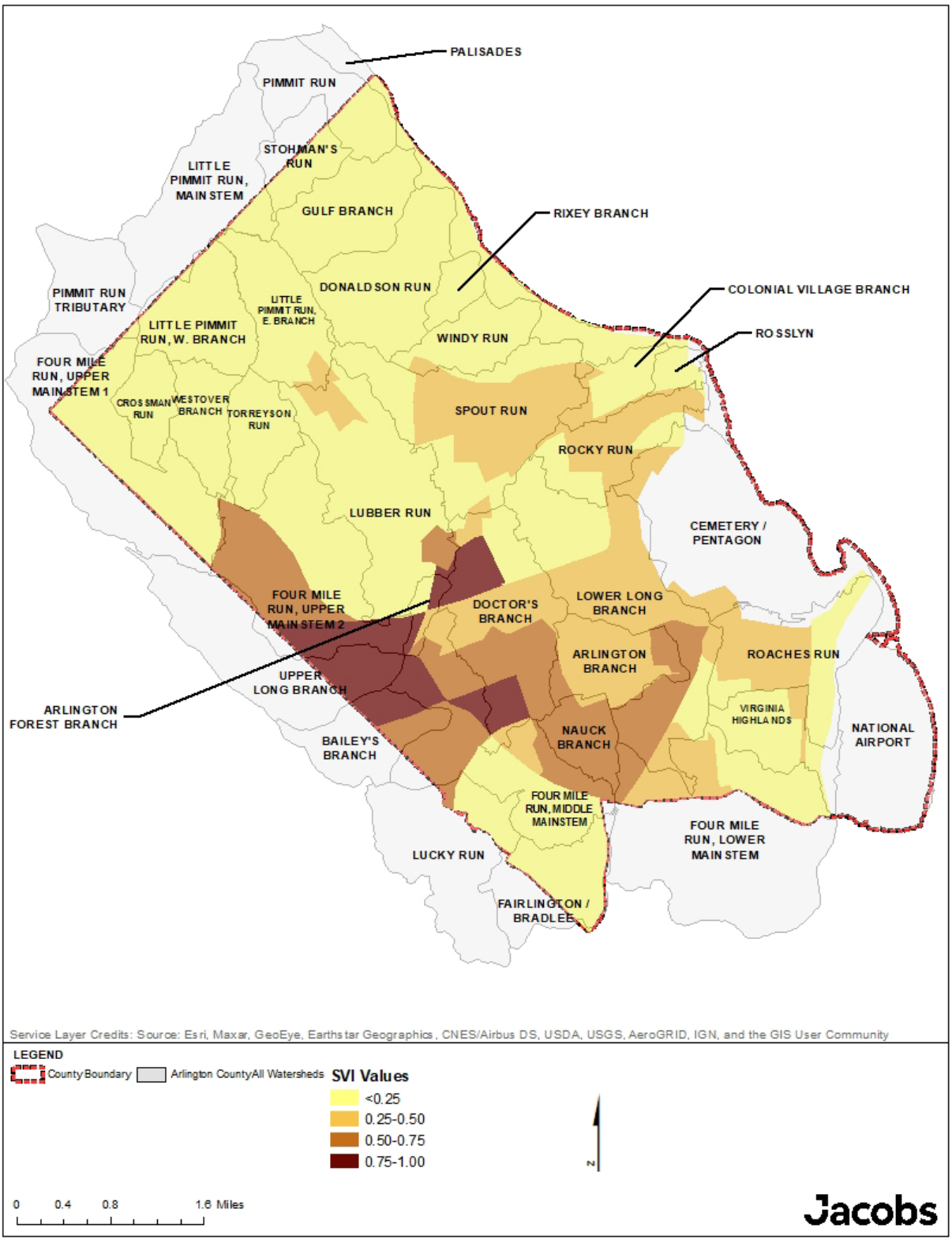



**Figure 3-6. CDC Social Vulnerability Index Values within Arlington County**

The recommended thresholds were presented to the County with using neighborhoods as a reference to visualize the resulting high social vulnerability definition.

For the rest of this TM, while the analysis specifically tracks areas between 0.5 and 0.75 and above 0.75, when we refer to areas of "high social vulnerability" we are referring to census tracts that have SVI values above 0.5.

The areas of high social vulnerability were used in flooded area analyses to support the watershed prioritization, as will be described in Section 4.6.

# 4. Vulnerability Analysis Methodology

As explained in Section 2.1, the approach for the RAMP vulnerability analysis is based on the individual components of exposure, sensitivity and adaptive capacity, which are assessed at the critical receptor level. The combination of these elements defines the degree of vulnerability for a specific critical receptor (Figure 2-1). The following sections explain the methods used to score critical receptors according to these three elements of vulnerability.

## 4.1 Exposure

The source of exposure information is the series of modeling scenarios and the resulting flood maps as described in Section 3.1. Critical receptors were geo-referenced and flood maps were overlaid with critical receptor locations, on a watershed-by-watershed basis and for each of the thirteen modeled scenarios. While detailed risk assessment requires consideration of the degree of flooding, this Task 4 qualitative vulnerability assessment looks only at the exposure to flood depths greater than 6 inches for each modeled scenario and assigns a binary score for each receptor:

- A value of 1 when exposed to flooding greater than 6 inches in depth (for each scenario)
- A value of 0 when no exposure or flooding less than 6 inches in depth (for each scenario)

The fact that exposure scores are assigned for each scenario modeled means that a given receptor subject to flooding under multiple events of varying magnitude, recurrence interval, and time horizons (scenarios) can have multiple values of 1. The total exposure score for a receptor is the sum of all scenarios and thus, the maximum possible exposure score for a given receptor is 13 (if it floods under all scenarios, as listed in Section 3.1).

For example, the Upper Pimmit Meter Station is in the flood area for the interior/riverine scenarios for 100-year baseline, 500-year baseline, and for the 100- and 500-year storms in 2040 and 2070 (6 of 13 scenarios listed in Table 3-1) and it is thus given an exposure score of 6 out of a maximum of 13 (see Appendix D for exposure scores for each receptor[7]).

## 4.2 Sensitivity and Adaptive Capacity

While exposure is an external factor (external to the receptor), sensitivity and adaptive capacity are characteristics of a specific receptor. As implied in the definitions presented in Section 1.4, sensitivity provides information on the degree to which a receptor would be impaired by flood exposure. For example, roadways are generally not sensitive to temporary flooding because they are unlikely to be damaged (unless floodwaters are fast flowing) and can therefore continue to be used once the waters recede. In contrast, a non-submersible pump station is considered highly sensitive to flood events if exposed to water, as it may be damaged beyond repair. In turn, adaptive capacity provides information on the existing receptor's inherent ability to adjust to maintain its primary functions. Examples include the existence of back-up generators or the ability to raise deployable barriers.

The qualitative vulnerability assessment applied scores for sensitivity based on the following 1 to 3 scale.

[7] Note that the last 4 columns in Appendix D do not correspond to exposure for the vulnerability formula. The last 4 columns correspond to exposure weighted by return period and are used for the High Criticality Receptor Index described in Section 4.5.

**Sensitivity Scale:**

1 = impact or function disruption with significant flood depth
2 = impact or function disruption with moderate flood depth
3 = impact or function disruption even with minimal flood depth

Based on this scale, a high score means the receptor has high sensitivity (which could result in higher vulnerability). The degree of flood depth is subjective, qualitative and will depend on the characteristics of the specific receptor relative to other receptors.

Similarly, the qualitative vulnerability assessment applied scores for **adaptive capacity** based on the following 1 to 3 scale.

Adaptive Capacity Scale:

1= no ability to mitigate impact to sustain operations/mission
2= some ability to mitigate impact to sustain operations/mission
3= significant ability to mitigate impact to sustain operations/mission

Based on this scale, a high score means the receptor has high adaptive capacity (which could result in lower vulnerability).

Task 2 resulted in a list of more than 300 critical receptors that are included in the RAMP analysis (with varying degrees of criticality). The large number of critical receptors limits the ability to characterize each critical receptor in terms of sensitivity and adaptive capacity. In risk assessment work, quantitative determinations about a specific facility or asset typically involve site visits and/or verification of site-specific information including as-built drawings, aerial images, interviews with operators, and other direct or indirect evidence. However, this study utilizes a qualitative vulnerability assessment with a lesser level of detail. The qualitative approach was based on the category and type of receptor, establishing generic sensitivity and adaptive capacity scores for each receptor type.

The categories and receptor types were used in Task 2 in collaboration with County staff as part of the definition of criticality. The same categories and types were used for the application of sensitivity and adaptive capacity scores in Task 4. The scores by receptor type are presented in Table 4-1.

**Table 4-1. Scores for Sensitivity and Adaptive Capacity for Types of Receptors**

| Category | Receptor Type | Sensitivity Score | Adaptive Capacity Score |
|---|---|---|---|
| Government Facilities | Administrative | 2 | 1 |
| Mass Care/Public Assistance Facility | Affordable Housing | 3 | 1 |
| Transportation System Facilities | Airport | 2 | 2 |
| Utilities Systems | Chemical Storage | 2 | 1 |
| Healthcare/Public Health Facility | Clinic | 2 | 1 |
| Healthcare/Public Health Facility | Clinic—Dialysis | 2 | 1 |
| Communications Sector | Communications Infrastructure | 2 | 2 |
| Community Centers | Community Center | 3 | 1 |

**Table 4-1. Scores for Sensitivity and Adaptive Capacity for Types of Receptors**

| Category | Receptor Type | Sensitivity Score | Adaptive Capacity Score |
|---|---|---|---|
| Utilities Systems | Critical Equipment Storage | 3 | 2 |
| Utilities Systems | Electrical Facility | 2 | 2 |
| Fire Stations/Facilities | Emergency Response—Fire/EMS | 1 | 3 |
| Government Facilities | Emergency Response—Police | 1 | 3 |
| Fire Stations/Emergency Operations Facilities | Emergency Communications & Operations | 1 | 3 |
| Defense/Industrial Base | Federal—Defense | 2 | 2 |
| Fire Stations/Facilities | Fire Logistics | 1 | 3 |
| Government Facilities | Government Training | 2 | 3 |
| Utilities Systems | Hazardous Substances Storage | 3 | 2 |
| Healthcare/Public Health Facility | Hospice | 3 | 1 |
| Healthcare/Public Health Facility | Hospital—ER | 2 | 3 |
| Libraries | Library | 2 | 1 |
| Government Facilities/Transportation/ Utilities | Maintenance Facility | 2 | 2 |
| Government Facilities | Parks & Rec | 1 | 3 |
| Government Facilities | Public Assistance Facility | 2 | 1 |
| Radio Sites | Radio Sites | 2 | 2 |
| Schools | School (Elementary/Middle) | 2 | 1 |
| Schools | School (High School) | 2 | 1 |
| Schools | School (Other) | 2 | 1 |
| Transportation System Facilities | Transportation Maintenance | 2 | 2 |
| Transportation System Facilities | Transportation Storage | 2 | 2 |
| Utilities Systems | Warehouse (non-critical Equipment) | 2 | 2 |
| Utilities Systems | Wastewater Pump Station | 2 | 2 |
| Utilities Systems | Wastewater System | 2 | 2 |
| Utilities Systems | Wastewater Treatment | 2 | 2 |
| Transportation System Facilities | WMATA Metro Station | 2 | 2 |
| Environmental | NWI Wetland | 3 | 2 |
| Environmental | Resource Protection Area | 3 | 2 |

**Table 4-1. Scores for Sensitivity and Adaptive Capacity for Types of Receptors**

| Category | Receptor Type | Sensitivity Score | Adaptive Capacity Score |
|---|---|---|---|
| Utilities Systems | Washington Gas (Confidential Facilities) | 2 | 2 |
| Utilities Systems | Dominion Power (Confidential Facilities) | 2 | 2 |
| Utilities Systems | Solid Waste | 2 | 2 |
| Government Facilities | Postal | 1 | 3 |

Notes:

EMS = emergency medical service
ER = emergency room
WMATA = Washington Metropolitan Area Transit Authority

The scores corresponding to each specific critical receptor, by watershed, are based on the scores presented in Table 4-1, and are presented in the vulnerability analysis results in Section 5 and Appendix E.

## 4.3 Computing a Vulnerability Value from Exposure, Adaptive Capacity and Sensitivity

For each individual receptor described in Section 3.2 (complete list in Appendix B), once scores are defined for sensitivity and adaptive capacity and the exposure is determined for each scenario, the receptor's vulnerability score is computed with the following formula:

*Vulnerability per Receptor = (Exposure + Sensitivity) / (Adaptive Capacity)*

where:

*Exposure*: is the sum of the exposure scores for all 13 scenarios (maximum possible value of 13 if receptor is exposed to flooding under each scenario)

*Sensitivity*: score of 1, 2 or 3 based on sensitivity scale by receptor type

*Adaptive Capacity*: score of 1, 2 or 3 based on adaptive capacity scale by receptor type

The vulnerability value for each receptor is a key outcome of Task 4. The list of receptors with the corresponding vulnerability value will be provided to the County with the final TM for Task 4.

In addition to the individual vulnerability value for receptors, metrics of vulnerability were computed for each watershed. These metrics included:

- Total vulnerability value (sum of vulnerability values of all receptors in each watershed)
- Average vulnerability value (sum of vulnerability values of all receptors in a given watershed divided by the number of receptors in the watershed)

Given that the vulnerability is based on qualitative sensitivity and adaptive capacity scores by receptor type (not on specific receptor's quantitative analysis), a sensitivity analysis was performed for the overall Vulnerability Index per watershed, varying the scores and comparing the vulnerability ranking of watersheds as a result. More detail is provided in Section 5.

### 4.3.1 Watershed-Level Vulnerability Index

From the individual receptor vulnerability values, the Watershed-Level Vulnerability Index is simply estimated as the average of all receptors in the watershed. For example, in the Virginia Highlands watershed, only two receptors exist with individual vulnerability values (from applying the vulnerability formula) of 0.00 (no exposure) and 4.67. The sum across all receptors is thus 4.67. The Watershed-Level Vulnerability Index is 2.335 (simple average).

## 4.4 Flooded Area Analysis and Flooded Area Index

"Area Metrics" refers to the physical land area inundated by more than 6 inches of water for a given scenario. The area flooded with over 6 inches of floodwater was computed for each of the 13 modeled scenarios as part of Task 3, to determine the increase in flooded area as the recurrence interval of events increased (from 10-year to 100-year and from that to 500-year events) and with climate-escalated rainfall or SLR (from baseline to 2040 to 2070). Task 3 also presented information about the percent of the watershed area that floods under the different modeled scenarios. Area metrics can inform decisions related to flood mitigation priorities based on impacted areas relative to other watersheds. Area metrics in Task 4, however, go beyond the total area flooded. To help prioritize watersheds, the type of areas flooded were considered. Tracked flooded area metrics included:

- High and medium to high SVI areas (per Section 3.5 definitions)
- Commercial district areas (per Section 3.3 definitions)
- Public and private non-commercial land use areas
- Areas defined as not socially vulnerable (per Section 3.5 definitions)

Given that we have 10-year, 100-year and 500-year return intervals and areas computed for each, all areas in the equation above are weighted by the annual probability of each return period. The following formula is used for the probability-weighted areas:

Area Flooded Weighted by Probability = Area flooded under 10-yr * 0.1 +
Area flooded under 100-yr * 0.01 +
Area flooded under 500-yr * 0.002

Using Doctor's Branch as an example, its exposure Table 4-2 presents the areas exposed to flooding for different return periods and for commercial district, socially vulnerable locations and the remainder of the flooded area in the watershed.

**Table 4-2. Doctor's Branch Example of Flooded Areas by Type of Area and Return Period (Acres)**

| Watershed | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
|---|---|---|---|---|---|---|---|---|---|
| Total Area Flooded | 18.24 | 56.48 | 81.89 | 20.87 | 61.20 | 86.81 | 27.24 | 65.38 | 90.83 |
| Commercial District Flooded Area | 0.88 | 3.12 | 4.87 | 0.97 | 3.56 | 5.22 | 1.04 | 3.99 | 5.37 |
| Socially Vulnerable Area Flooded Area | 11.37 | 26.17 | 35.55 | 12.66 | 27.89 | 37.88 | 12.79 | 29.60 | 39.62 |
| Additional Flooded Area | 5.99 | 27.20 | 41.47 | 7.24 | 29.75 | 43.71 | 13.41 | 31.79 | 45.85 |

Based on the values above, the probability-weighted area for commercial district area (as an example) is:

Commercial Area Flooded Weighted by Probability = (0.88+0.97+1.04)*0.1 +
(3.12+3.56+3.99)*0.01+
(4.87+5.22+5.37)*0.002 = 0.42

In risk analysis literature, this probability-weighted value could be called the "expected value" of commercial area flooded. Applying the same formula, the probability-weighted values for socially vulnerable area and the rest of the area flooded are:

Socially Vulnerable Area Flooded Weighted by Probability = 4.74

Other Area Flooded Weighted by Probability = 3.81

The units of these probability-weighted areas are "acres" with the understanding that these are not areas but "expected value" of areas.

One more step is required in the area analysis to be able to compare watersheds in terms of flooded areas and the type of land that is flooding. A Flooded Area Index was derived that aggregates the three types of areas for comparison by watersheds with the following equation:

Flooded Area Index = Commercial District Area Flooded * Weight of Commercial District +
Socially Vulnerable Area Flooded * Weight of Social Vulnerability +
Other Area Flooded * Weight of Other Areas

This equation combining commercial district and socially vulnerable areas (as well as the remainder of the area flooded above 6 inches in the watershed) requires assigning relative importance (a weight factor) to the three types of areas (that is, commercial, socially vulnerable, and remainder of the area flooded). If the weights are equal, that would be mathematically the same as not tracking the type of area that is flooding. There would be no need to track commercial district and socially vulnerable areas if the weights are not intended to change. Changing the weights is expected and desirable to reflect considerations of community values and goals. It does, however, require discussion and agreement. The weights of socially vulnerable areas and commercial district areas will be a topic of discussion and testing in the Task 4 workshop.

Using the Doctor's Branch example, and the following set of weights, the Flooded Area Index for it would be:

If:

Weight of Commercial District = 0.3
Weight of Social Vulnerability = 0.5
Weight of Other Areas = 0.2

Then:

Doctor's Branch Flooded Area Index = (0.42*0.3) + (4.74*0.5) + (3.81*0.2) = 3.26

The use of the Flooded Area Index in watershed prioritization is described in Section 4.6.

## 4.5 Criticality of Receptors and High Criticality Receptor Index

The information from receptors in terms of their level of criticality (high, medium and low scores developed during Task 2 and included in Appendix B) was used to develop a count of high criticality receptors flooded with over 6 inches of floodwater within each watershed. All critical receptors with a "High" criticality score were identified per watershed and the exposure to flooding under each scenario was determined. A score was then computed for high criticality receptor flooding as follows:

- Exposure under 10-year event = 1 multiplied by a factor of 4
- Exposure under 100-year event = 1 multiplied by a factor of 2
- Exposure under 500-year event = 1 multiplied by a factor of 1

The factors of 4, 2 and 1 are used to account for the lower likelihood of the 500-year and 100-year event respectively and with respect to the 10-year event.

This High Criticality Receptor Index is important given that vulnerability and criticality are not necessarily related. While vulnerability is accounted for in the Vulnerability Index, the criticality of the receptors flooding is not included in it. Some receptors may be highly vulnerable, but they may be of low criticality.

The High Criticality Receptor Index is computed with the following formula and steps:

- Step 1: verify if a receptor is of high criticality, and if so:
- Step 2: if the high criticality receptor has exposure under a 10-year scenario, assign a value of 4
- Step 3: if the high criticality receptor has exposure under a 100-year scenario, assign a value of 2
- Step 4: if the high criticality receptor has exposure under a 500-year scenario, assign a value of 1
- Step 5: Sum values in steps 2, 3, and 4 for the high criticality receptor
- Step 6: Compute the watershed-level High Criticality Receptor Index by adding the values of Step 5 across all high criticality receptors in the watershed

Using Walter Reed Elementary School in the Torreyson Run watershed as an example, the receptor was classified as high criticality and it floods under 100-year and 500-year scenarios (not under 10-year scenarios). Applying the steps:

- Step 1: verify if a receptor is of high criticality: Yes. Move to Step 2
- Step 2: if the high criticality receptor has exposure under a 10-year scenario: No. Value of 0.
- Step 3: if the high criticality receptor has exposure under a 100-year scenario: Yes. value of 2
- Step 4: if the high criticality receptor has exposure under a 500-year scenario: Yes. Value of 1
- Step 5: Sum values in steps 2, 3 and 4 for the high criticality receptor: 0+2+1 = 3
- Step 6: Compute the watershed-level High Criticality Receptor Index by adding the values of Step 5 across all high criticality receptors in the watershed: Torreyson Run watershed has one additional high criticality receptor with a Step 5 value of 7[8]. Therefore:

Torreyson Run Watershed High Criticality Receptor Index = 3 + 7 = 10

The use of this metric in watershed prioritization is described in Section 4.6.

[8] See Appendix D in the last 4 columns for exposure and Appendix E last two columns for High Criticality Receptor scores (Step 5) and High Criticality Receptor Index (Step 6 or sum across all receptors).

## 4.6 Normalization of Scores for Watershed Prioritization Method

A methodological characteristic of MART is that all scores for attributes are normalized to a common scale. For this vulnerability assessment the normalizing scale is a scale of 1 to 5 (unitless), established as shown in Figure 4-1.

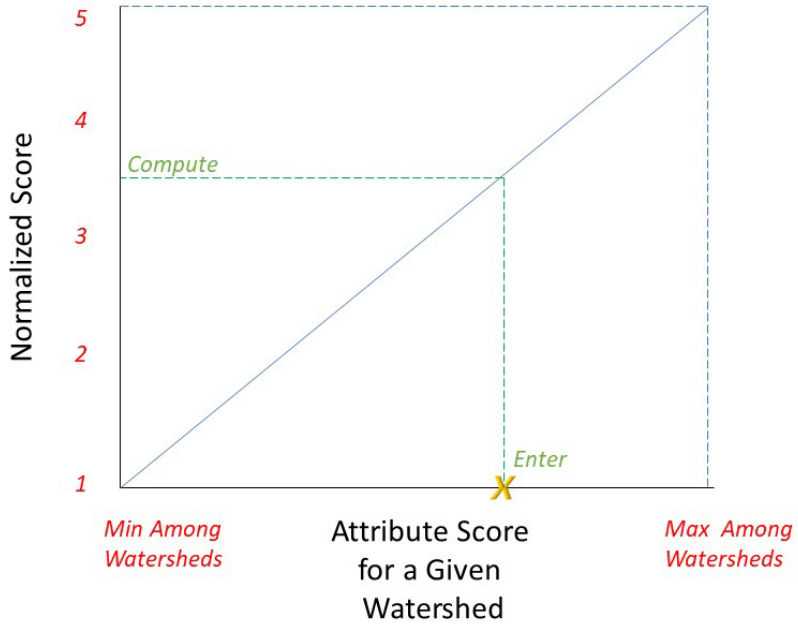



**Figure 4-1. Normalization Scale used in Draft Prioritization**

The draft prioritization presented in Section 6 currently assumes equal weights for these three attributes. During the Task 4 workshop, the relative weights of these three attributes can be explored with the resulting changes in prioritization, in real time. The prioritization score, for purposes of the draft prioritization, is thus based on the following formula:

Decision Score = (Normalized Vulnerability Index * 0.333) +
+ (Normalized High Criticality Receptor Index * 0.333)
+ (Normalized Flooded Area Index * 0.333) +

Weighting adjustments made during the Task 4 workshop will allow variance of the multipliers in the formula above while keeping the sum of the weighting factors at 1.0 to maintain normalization.

The following sections describe the results of the prioritization analysis and present the draft watershed prioritization results.

# 5. Vulnerability Analysis Results

This section presents the results of vulnerability, flooded area and high criticality receptor analyses as part of Task 4, summarizing values for all watersheds. Section 6 uses the results presented and discussed in Section 5 for the draft prioritization of the watersheds analyzed.

## 5.1 Watershed Results

The watershed analyses presented in this section correspond to the watersheds listed under Section 4.6 (those modeled with 1D/2D PCSWMM). The Little Pimmit Run watershed will be presented as Little Pimmit Run East Branch and Little Pimmit Run West Branch within the prioritization analysis discussion. The watersheds are thus (refer to Figure 1-1 for geographic location):

- Doctor's Branch
- Four Mile Run, Lower Mainstem
- Little Pimmit Run E. Branch
- Little Pimmit Run W. Branch
- Lubber Run
- Roaches Run
- Spout Run
- Torreyson Run
- Virginia Highlands

Figure 5-1 presents an overview of the flood extents (for inundation depths greater than 6 inches) for different scenarios (watersheds impacted by coastal flooding include the flooded area under coastal flood scenarios).

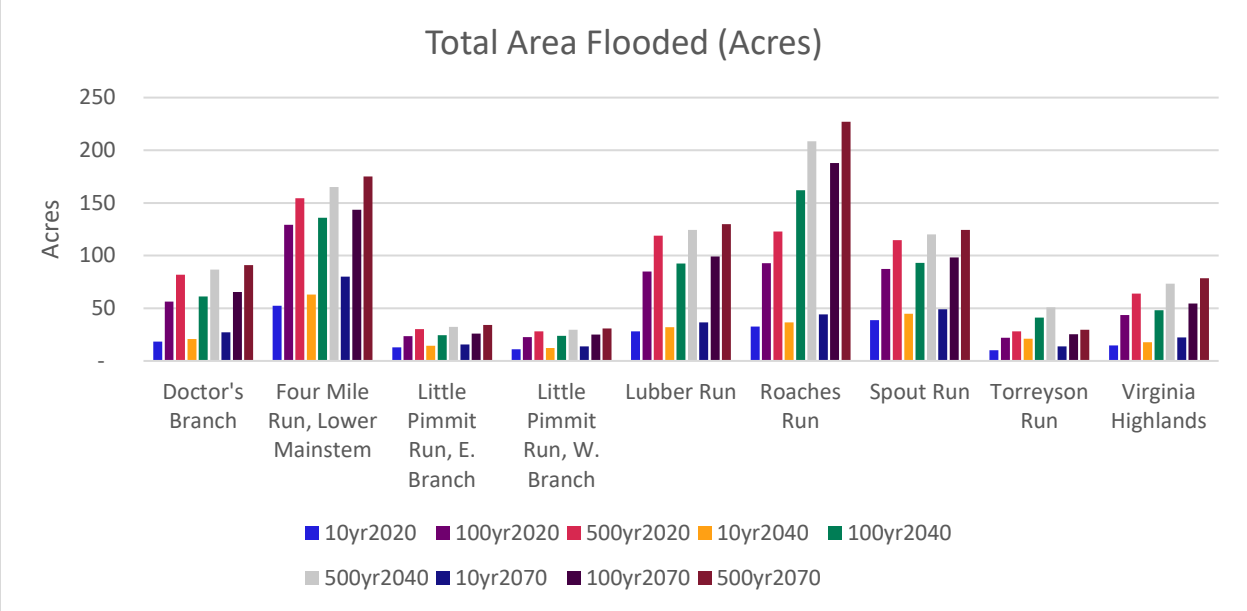



**Figure 5-1. Extent of Flooded Areas by Watershed Under Different Scenarios**

The extent of flooding with an inundation depth greater than 6 inches was analyzed in the context of the total area of each watershed. Table 5-1 includes the total watershed area for each watershed, and Table 5-2 presents the percent of each watershed that is flooded under multiple scenarios.

**Table 5-1. Percent of Watershed Flooded Under All Scenarios (flood depth >6 inches)**

| Watershed | Total Contributing Watershed Area (Acres) | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
|---|---|---|---|---|---|---|---|---|---|---|
| Doctor's Branch | 882 | 2 | 6 | 9 | 2 | 7 | 10 | 3 | 7 | 10 |
| Four Mile Run, Lower Mainstem | 454 | 12 | 29 | 34 | 14 | 30 | 36 | 18 | 32 | 39 |
| Little Pimmit Run, E. Branch | 530 | 2 | 4 | 6 | 3 | 5 | 6 | 3 | 5 | 6 |
| Little Pimmit Run, W. Branch | 462 | 2 | 5 | 6 | 3 | 5 | 6 | 3 | 5 | 7 |
| Lubber Run | 1033 | 3 | 8 | 12 | 3 | 9 | 12 | 4 | 10 | 13 |
| Roaches Run | 692 | 5 | 13 | 18 | 5 | 23 | 30 | 6 | 27 | 33 |
| Spout Run | 1125 | 3 | 8 | 10 | 4 | 8 | 11 | 4 | 9 | 11 |
| Torreyson Run | 319 | 3 | 7 | 9 | 7 | 13 | 16 | 4 | 8 | 9 |
| Virginia Highlands | | 4 | 12 | 18 | 5 | 13 | 21 | 6 | 15 | 22 |

It should be noted that Four Mile Run, Roaches Run and Virginia Highlands, which are the three watersheds with the highest percentage of flooding under any given scenario, are the three watersheds in the analysis that are also exposed to coastal flooding.

While the area information in Figure 5-1 and Table 5-2 is informative and can serve as a reference for the rest of this section, the key to Task 4 and its vulnerability analyses is not merely the area that floods but what is flooding when the events happen. Which receptors are flooding, how vulnerable they are, how critical they are, and what are the commercial or social vulnerability attributes of the flooded area are key factors for prioritization. The analysis of these key factors is presented in the sections below.

### 5.1.1 Vulnerability by Receptor

The vulnerability formula accounting for exposure, adaptive capacity and sensitivity is applied to each receptor in each individual watershed. The calculated vulnerability for each receptor is a key result of Task 4 because it provides a bottom-up picture of the vulnerability in a watershed, with geo-specificity. The vulnerability value computed for a given receptor starts with the exposure under each scenario. Appendix D presents the full list of receptors by watershed and the corresponding exposure results for each. Results of applying the vulnerability formula are presented in Appendix E (receptors in rows with their respective vulnerability value from the application of the vulnerability formula).

For a watershed analysis, the vulnerability by receptor can be aggregated by watershed as described in Section 4.3. Two aggregation metrics have been computed: the sum of vulnerability values (sum across receptors) and the average vulnerability value (sum divided by the number of receptors). The aggregated vulnerability results as a sum and as an average are presented in Table 5-2 and Figure 5-2, respectively.

While the sum is a valid aggregation metric, it can easily be biased by the size of the watershed. This is because all 14 studied watersheds are subject to some level of flood exposure and have relatively similar critical receptor densities (Figure 3-3). The sum is also a number difficult to interpret because there is no clear scale, bookends or references. It is a rather abstract number.

The average vulnerability in the watershed, in turn, is easy to interpret since it directly relates to the vulnerability formula and can be compared with any receptor vulnerability value. The average is normalized by the number of receptors (shown in Table 5-2). The average is thus higher for watersheds that have more highly vulnerable receptors.

**Table 5-2. Sum of Vulnerability Values per Watershed (Sum of Vulnerability Values from All Receptors)**

| | Doctor's Branch | Four Mile Run, Lower Mainstem | Little Pimmit Run, E. Branch | Little Pimmit Run, W. Branch | Lubber Run | Roaches Run | Spout Run | Torreyson Run | Virginia Highlands |
|---|---|---|---|---|---|---|---|---|---|
| Sum of Vulnerability Values | 34.67 | 224.00 | 15.17 | 3.67 | 54.67 | 35.67 | 48.67 | 27.67 | 4.67 |
| Number of Receptors in the Analysis | 55 | 6 | 7 | 14 | 29 | 16 | 25 | 8 | 2 |
| Average Vulnerability Values | 2.48 | 4.07 | 2.53 | 0.52 | 1.89 | 2.23 | 1.95 | 3.46 | 2.33 |

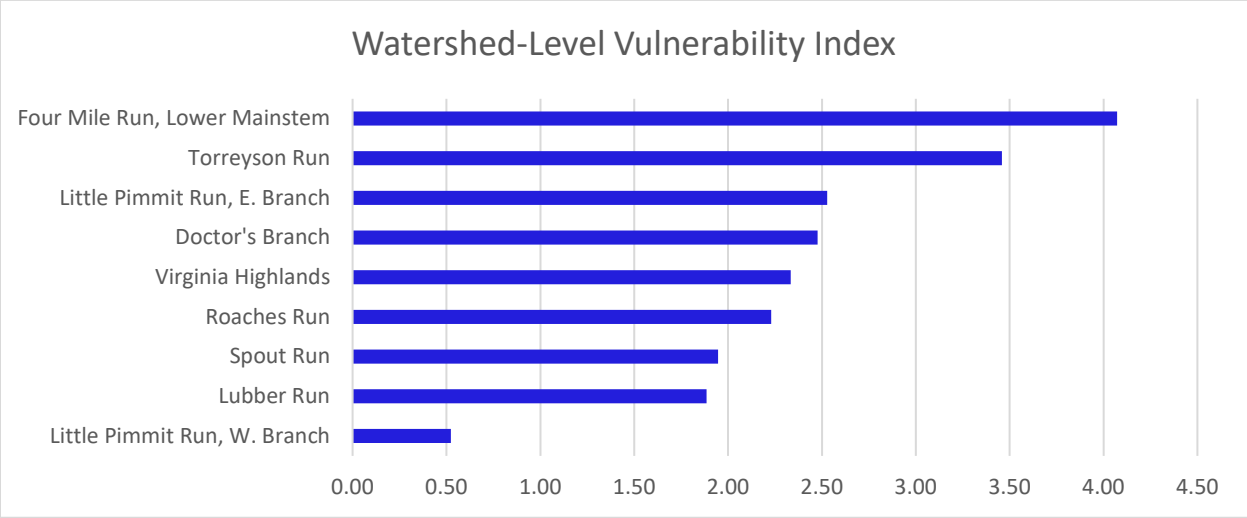



**Figure 5-2. Average Vulnerability for Exposed Receptors in Each Watershed**

Four Mile Run Lower Mainstem has vulnerability values that are clearly higher than any other watershed when both the sum and average are considered. Little Pimmit Run West Branch, on the other hand, presents relatively very low values of vulnerability (sum and average). Doctor's run and Roaches Run are two watersheds that present consistent middle values of vulnerability under sum and average metrics.

### 5.1.2 High Criticality Receptors

The second attribute for watershed prioritization is the impacted receptors that are consider highly critical. As explained in Section 4.5, an index was developed based on the highly critical receptors with exposure to flooding for varying return periods and climate escalation scenarios. The High Criticality Receptor Index is presented in Figure 5-3 for the nine analyzed watersheds.

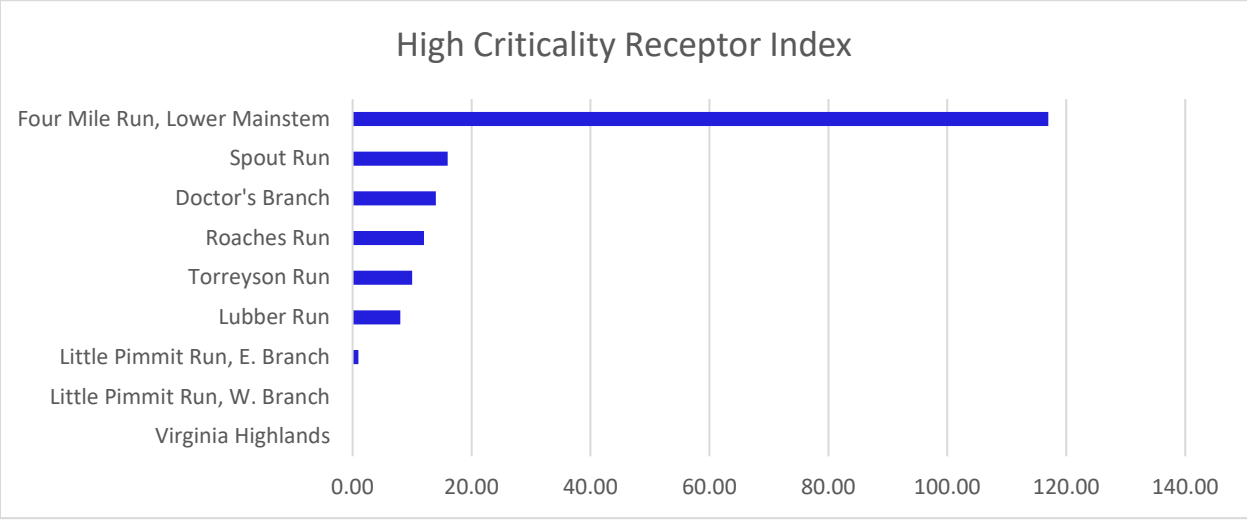



**Figure 5-3. High Criticality Receptor Index for Each Watershed**

As in the case of the vulnerability formula values discussed in Section 5.1.1, Four Mile Run Lower Mainstem presents a significantly higher index in high criticality facilities when compared to other watersheds. This is expected due to the high density of receptors (see Figure 3-3). Many of the Four Mile Run Lower Mainstem watershed receptors have high criticality which is coupled with the extensive areas of flooding for multiple scenarios. Doctor's run in this case ranks number 2 with scores driven by exposure of some critical receptors to 10-year floods (see Appendix D) which occur more frequently. In contrast, and also consistent with vulnerability formula values in Section 5.1.1, Little Pimmit Run West Branch ranks at the bottom and in this case with Little Pimmit Run East Branch as well.

### 5.1.3 Flooded Area Analysis

Section 4.4 described the approach to evaluate area flooded per watershed while Section 3.5 discussed the importance of assessing impacts to high social vulnerability areas. Flooded areas were computed for commercial district designation and for high social vulnerability (medium to high SVI and High SVI). Results are presented in Tables 5-3 and 5-4 respectively.

**Table 5-3. Commercial District Area Flooded by Watershed for Each Scenario (Acres)**

| Watershed | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
|---|---|---|---|---|---|---|---|---|---|
| Doctor's Branch | 0.88 | 3.12 | 4.87 | 0.97 | 3.56 | 5.22 | 1.04 | 3.99 | 5.37 |
| Four Mile Run, Lower Mainstem | 8.73 | 34.54 | 43.89 | 10.71 | 37.20 | 47.09 | 18.58 | 39.05 | 51.23 |
| Little Pimmit Run, E. Branch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Little Pimmit Run, W. Branch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lubber Run | 6.72 | 32.17 | 40.78 | 7.67 | 34.14 | 41.82 | 10.22 | 36.22 | 43.13 |
| Roaches Run | 27.68 | 75.62 | 100.69 | 30.67 | 84.78 | 112.20 | 36.69 | 90.12 | 122.59 |
| Spout Run | 16.31 | 38.11 | 48.71 | 19.44 | 39.99 | 50.45 | 21.48 | 42.28 | 51.55 |
| Torreyson Run | 2.12 | 3.22 | 3.49 | 3.25 | 4.96 | 5.40 | 2.48 | 3.33 | 3.53 |
| Virginia Highlands | 2.31 | 11.03 | 17.99 | 2.49 | 12.11 | 23.79 | 4.25 | 13.11 | 26.20 |

**Table 5-4. Flooded Area with High Social Vulnerability (SVI 0.5 to 0.75 and greater than 0.75) by Watershed for Each Scenario (Acres) 1**

| Watershed | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
|---|---|---|---|---|---|---|---|---|---|
| Doctor's Branch | 11.37 | 26.17 | 35.55 | 12.66 | 27.89 | 37.88 | 12.79 | 29.60 | 39.62 |
| Four Mile Run, Lower Mainstem | 0.30 | 0.63 | 0.94 | 0.33 | 0.70 | 1.34 | 0.37 | 0.74 | 1.44 |
| Little Pimmit Run, E. Branch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Little Pimmit Run, W. Branch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lubber Run | 3.47 | 4.07 | 4.70 | 3.56 | 4.15 | 4.81 | 3.62 | 4.16 | 4.88 |
| Roaches Run | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Spout Run | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Torreyson Run | 0.01 | 0.12 | 0.18 | 0.01 | 0.31 | 0.42 | 0.03 | 0.16 | 0.26 |
| Virginia Highlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] This table includes SVI census tracts with SVI > 0.5. The analysis keeps track of medium to high SVI (0.5 to 0.75) and High SVI (>0.75 SVI)

When using area metrics, it is important to consider the different probability (theoretical return period) of the different recurrence intervals and climate escalation simulated in the scenarios. Task 4 used a probability-weighted area computed with the product of area times the annual probability of the event flooding that area extent. After computing the probability-weighted area by watershed, results for socially vulnerable areas are consistent with results in Table 5-4 (areas not weighted by probability). Doctor's Branch is clearly at the top of areas with social vulnerability, followed (distantly) by Lubber Run and Four Mile Run Lower Mainstem.

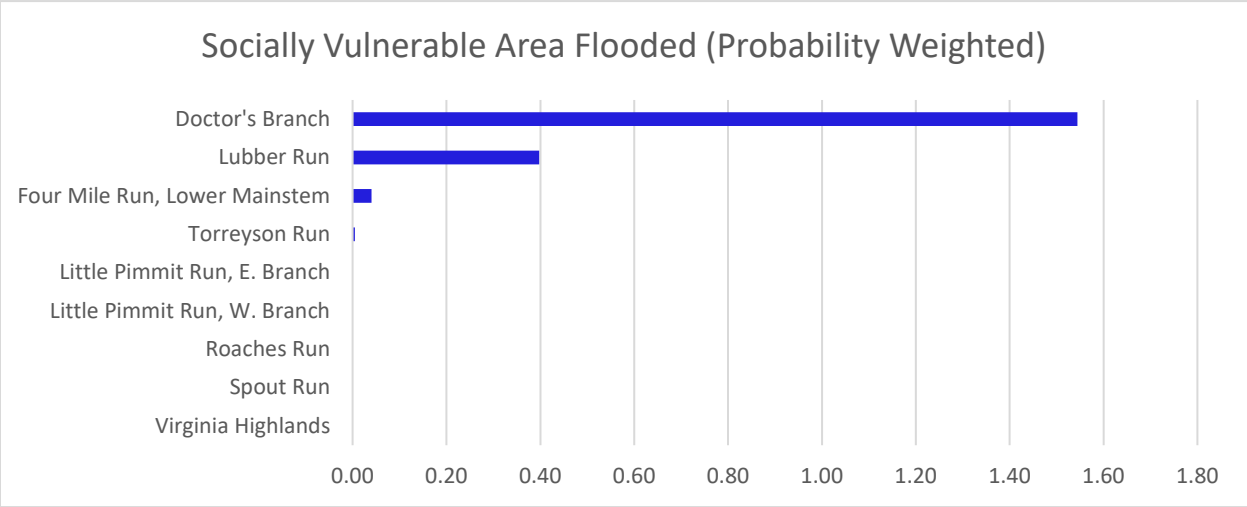



**Figure 5-4. High Social Vulnerability Areas (Probability-Weighted) for Each Watershed**

The relevance of tracking commercial district area and high social vulnerability areas is illustrated by Doctor's Branch ranking in these two metrics. For commercial district areas, the ranking of Doctor's Branch is opposite to its ranking based on high social vulnerability (Compare Figure 5-4 to Figure 5-5) given the watershed's small commercial district area. Commercial district area is presented in Figure 5-6 for reference with area flooded under two sample scenarios (10-year and 100-year in 2040 conditions). Appendix F presents areas flooded under all scenarios.

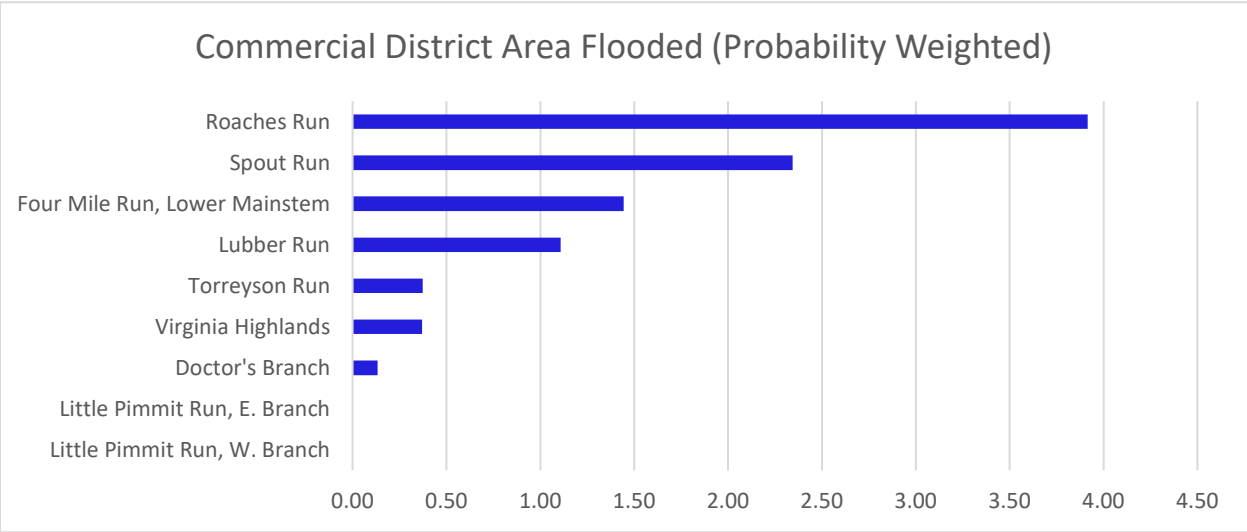



**Figure 5-5. Commercial District Areas (Probability-Weighted) for Each Watershed**

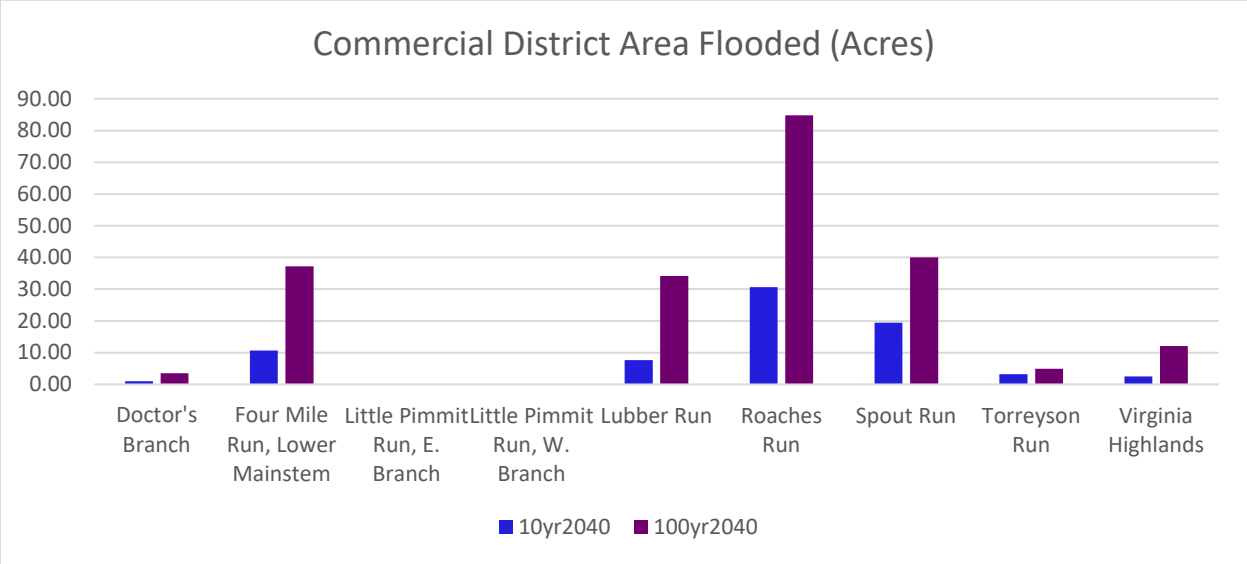



**Figure 5-6. Commercial District Areas for Each Watershed Flooded Under Two Sample Scenarios**

To use area metrics in watershed prioritization it is necessary to combine commercial district and socially vulnerable areas (as well as the remainder of the area flooded above 6 inches in the watershed). The aggregate can be performed by assigning the same relative importance to the three types of areas (that is, commercial, socially vulnerable, and remainder of the area flooded). Mathematically, assigning the same relative weight to all three is the same as not tracking the type of area that is flooding. There would be no need to track commercial district and socially vulnerable areas if the weights are not intended to change. Changing the weights is expected and desirable to reflect considerations of community values and goals. It does, however, require discussion and agreement. The weights of socially vulnerable areas and commercial district areas will be a topic of discussion and testing in the Task 4 workshop.

Prioritizing socially vulnerable areas for this RAMP would not be arbitrary or inconsistent with other County practices. On the contrary, the County has been using metrics of social vulnerability, including a county-specific SocioNeeds Index and the CDC's SVI (used in the RAMP), for other programs and initiatives, including the equitable vaccine distribution for Covid vaccination and a recent Reach and Risk study for childcare in Arlington. The Federal Emergency Management Agency (FEMA) has also invested significant resources in developing indices, metrics, methods, datasets and tools to account for social vulnerability in planning and implementation of resilience projects. FEMA is working to increase utilization of social vulnerability factors in its programs. For example, for FY2022 programs FEMA is encouraging a discussion of criteria related to benefits to socially vulnerable communities for narrative submissions under its grant programs for the 2022 rounds (Hazard Mitigation Assistance [HMA] and Building Resilient Infrastructure Communities [BRIC]).

The draft results presented below for the area-based index to be carried forward for prioritization is based on the following weights:

- Commercial District Flooded Area—30 percent weight
- Socially Vulnerable Areas (SVI > 0.5)—55 percent weight
- Other areas (remainder of area flooded above 6 inches) – 15 percent weight

Using these weights for the different areas measured, the resulting ranking is presented in Figure 5-7. Four Mile Run Lower Mainstem is, again, ranked at the top. This is because it includes both commercial and high socially vulnerability areas. For this specific set of weights, Doctor's Branch ranks number 4, even though its social vulnerability scores are much higher. Roaches Run and Spout Run outrank Doctor's Branch given their much more significant commercial area exposed compared to Doctor's Branch.

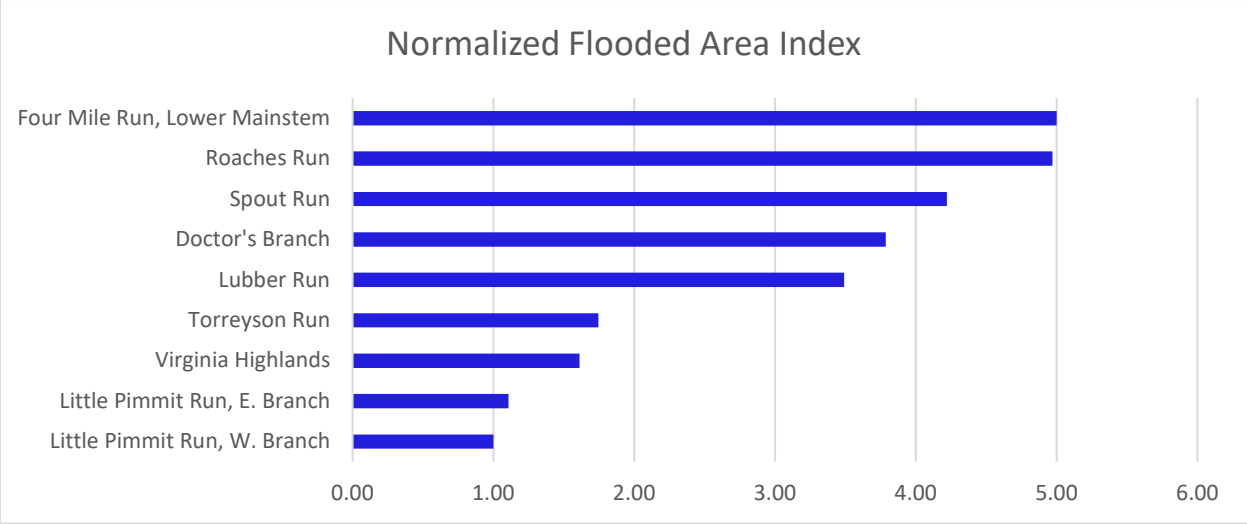



**Figure 5-7. Watersheds Ranked by Normalized Flooded Area Index**

## 5.2 Results Discussion

Results of the three main elements of prioritization (that is, vulnerability formula values, area-based metrics and high criticality index) indicate that the Four Mile Run Lower Mainstem is consistently prioritized over the rest of the watersheds. It is a function of:

- The scale (size) of the watershed
- The density of high criticality facilities in the watershed
- The extent of flooding with an inundation depth greater than 6 inches (coastal flooding adds significant area compared to watersheds that are exposed only to interior and fluvial)
- The presence of flood-impacted commercial district areas and high social vulnerability areas

In contrast, Little Pimmit Run (East and West) consistently rank lower than the rest of the watersheds with Virginia Highlands also ranking generally lower than the rest. Doctor's Branch, Lubber Run, Spout Run, Roaches Run and Torreyson Run are middle of the range watersheds. In the area-based analysis, Doctor's run is sensitive to the weight factor assigned to commercial district and socially vulnerable areas while Roaches Run and Spout Run are sensitive to the weight assigned to commercial district areas.

Section 6 presents the draft results of the vulnerability assessment ranking to be discussed in the Task 4 workshop for final decision-making.

# 6. Watershed Prioritization

The three attributes for prioritization include:

- Watershed-Level Vulnerability index
- Flooded area analysis and metrics
- High criticality receptor flood index

The final decision score is based on these three different attributes and the normalized scores resulting from the analysis and the results presented in Section 5.

Two key variables in the computation of decision scores, to be discussed as part of the Task 4 workshop, include:

- **Flooded Area Index Weights.** The weights assigned when computing the normalized Flooded Area Index (Table 6-1). The Flooded Area Index weights include commercial areas vs. high social vulnerability areas. The Flooded Area Index is computed with the following equation:
- Flooded Area Index = (Commercial District Area * Weight) +
  + (High Social Vulnerability Area * Weight) +
  + (Remainder of Area Flooded * Weight)
- **MART Weights.** The weights assigned to the three attributes in the MART (Table 6-2), which include watershed-level vulnerability, flooded areas, and High Criticality Receptor Index.

These two key values are important discussion points because the decision score for prioritization is computed with an assigned weight to each of the three attributes with the equation below:

Decision Score = (Normalized Vulnerability index * Weight) +
+ (Normalized Flooded Area Index * Weight) +
+ (Normalized High Criticality Receptor Index * Weight)

Draft prioritization results are computed with the following sets of weights in Table 6-1 and Table 6-2.

**Table 6-1. Set of Weights Used for Computation of Normalized Flooded Area Index**

| Time of Flooded Area | Weight for Index (Draft Analysis), percent |
|---|---|
| Commercial District Area | 30 |
| Socially Vulnerable Area | 55 |
| Other Area | 15 |

**Table 6-2. Set of Weights Used for Multi-Attribute Decision Score**

| Attribute | Weight for Decision Score (Draft Analysis), percent |
|---|---|
| Normalized Vulnerability index | 33.3 |
| Normalized Flooded Area Index | 33.3 |
| High Criticality Receptor Index | 33.3 |

Draft prioritization results are dictated by the multi-attribute decision score computed with the three indices in Table 6-2 (accounting for their respective weights). They will be used as they will be utilized as an input to the Task 4 workshop materials are presented below in Figure 6-1. These draft results with unadjusted weights show Four Mile Run Lower Mainstem as the top priority, Doctor's Branch as the second priority and Roaches Run as the third priority. Little Pimmit Run (East and West branches) and Virginia Highlands rank with the lowest priorities.

Figure 6-1 presents the relative contribution of each attribute to the multi-attribute decision score. Since the weights of each attribute equal and unadjusted, we can interpret the chart as each color in a bar directly representing the contribution of that attribute to the score. For example, we can observe that while Roaches Run has a greater Normalized Flood Area Index compared to Doctor's Branch, Doctor's Branch has both a higher Normalized Vulnerability Index and a higher High Criticality Receptor Index score. Little Pimmit East Branch for example has a higher Normalized Vulnerability Index than Doctor's Branch but ranks much lower overall given the considerably lower scores in the Normalized Flooded Area Index and the High Criticality Receptor Index.

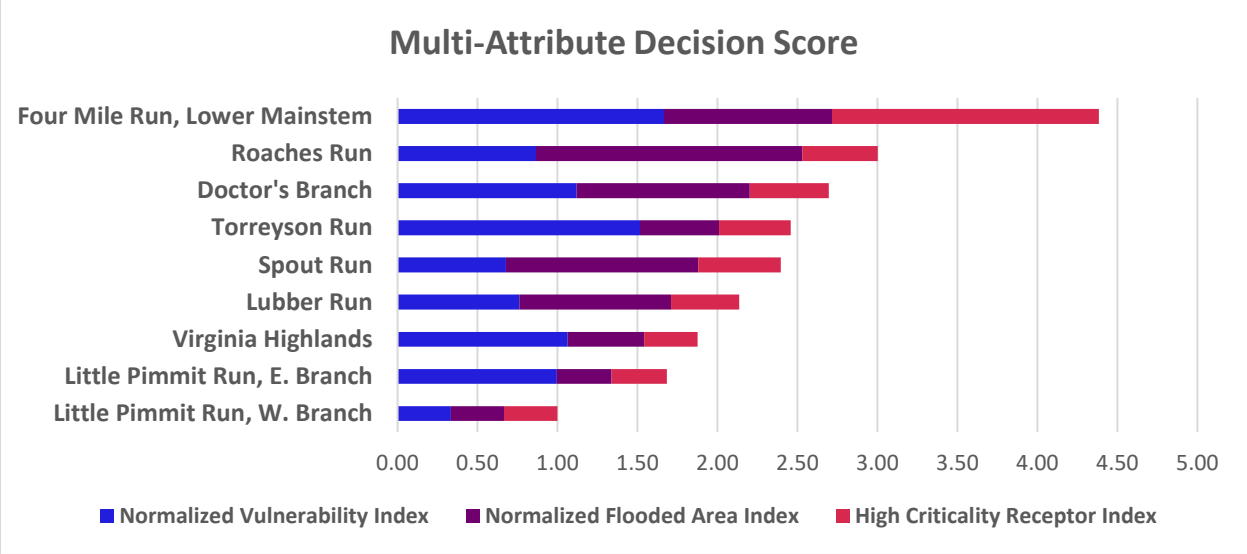



**Figure 6-1. Draft Prioritization (Using Equal Weights for All Three Attributes in Multi-Attribute Decision Score)**

The draft prioritization presented in Figure 6-1 is derived from the analytical process described in the TM and the modeling described in previous TMs under Task 3. While this draft prioritization represents a critical input for decision-making, it should not be seen as a final outcome in terms of prioritization. As mentioned in Section 4, the technical analysis cannot capture all considerations pertinent for prioritization and thus, the Task 4 workshop plays a key role in the process to define the short list of watersheds that will be analyzed under Task 5 and beyond in this RAMP.

## 6.1 Task 4 Workshop

The draft prioritization was presented and discussed at the September 17, 2021, workshop. The method uses multiple weighted criteria, and the weights of the criteria and the sensitivity of the results to those weights were discussed in the workshop. After presentation and general discussions about some specific questions regarding the meaning of the criteria and data used, the draft prioritization did not change during the workshop. A more focused meeting with the core RAMP team was scheduled for further discussions. As a result of that meeting, Bailey's Branch was included in the final prioritization because of known significant flood vulnerability and risk. In addition to Bailey's Branch, it was decided that the top six sheds in the prioritization list on Figure 6-1 would also be continued in the risk assessment work of Task 5.

# 7. References

Agency for Toxic Substances and Disease Registry (ATSDR). 2021. "CDC/ATSDR's Social Vulnerability Index (SVI)." Centers for Disease Control and Prevention. April 28. www.atsdr.cdc.gov/placeandhealth/svi/index.html.

American Water Works Association (AWWA). 2021. *Climate Action Plans—Adaptive Management for Water Utilities*. Manual of Water Supply Practices M71.

Arlington County. 2003. *Chesapeake Bay Preservation Ordinance, Chapter 61*. Arlington County Code. https://countyboard.arlingtonva.us/wp-content/uploads/sites/22/2016/04/Chapter-61-CHESAPEAKE-BAY-PRESERVATION-ORDINANCE.pdf.

Arlington County. 2017a. *Arlington County Emergency Operations Plan*. Final. March.

Arlington County. 2017b. *Child Care in Arlington: Risk and Reach Study*. Draft. December 1.

Arlington County Planning Commission. 2020. *2020 General Land Use Plan*. https://gis.arlingtonva.us/Maps/Standard_Maps/Planning_Maps/GLUP.pdf.

Arlington County Zoning Division. 2020. *Zoning Map*. https://gis.arlingtonva.us/Maps/Standard_Maps/Planning_Maps/Zoning_Map.pdf.

Healthier Arlington. 2021. "2021 SocioNeeds Index." http://www.healthierarlington.org/indicators/index/socioneeds.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team, R.K. Pachauri, and L.A. Meyer, eds. Geneva, Switzerland: IPCC.

Jacobs. 2020. *Coastal Surge Modeling Technical Memorandum (Task 3.4)*. October.

Jacobs. 2021. *Arlington Interior and Riverine Flooding Report (Task 3.3)*. July.

MIKE by the Danish Hydraulic Institute (DHI). 2020. *MIKE 21 Flow Module FM, User Guide*.

U.S. Fish and Wildlife Service (USFWS). 2021. National Wetlands Inventory. https://www.fws.gov/wetlands/.

United Nations Office for Disaster Risk Reduction (UNDRR). 2019. *Global Assessment Report (GAR) on Disaster Risk Reduction*. https://gar.unisdr.org/report-2019.

# Appendix A
# Flood Maps Used for the 2040 100-year 24-hour Exposure Analysis

# Figure A-1:
# Doctor's Branch
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary

# Figure A-2:
# Four Mile Run, Lower Mainstem
# 2040 100 year 24 hour
# and Coastal Flooding
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Coastal**

2040 100-year, Tide 10.5, SLR 1.86

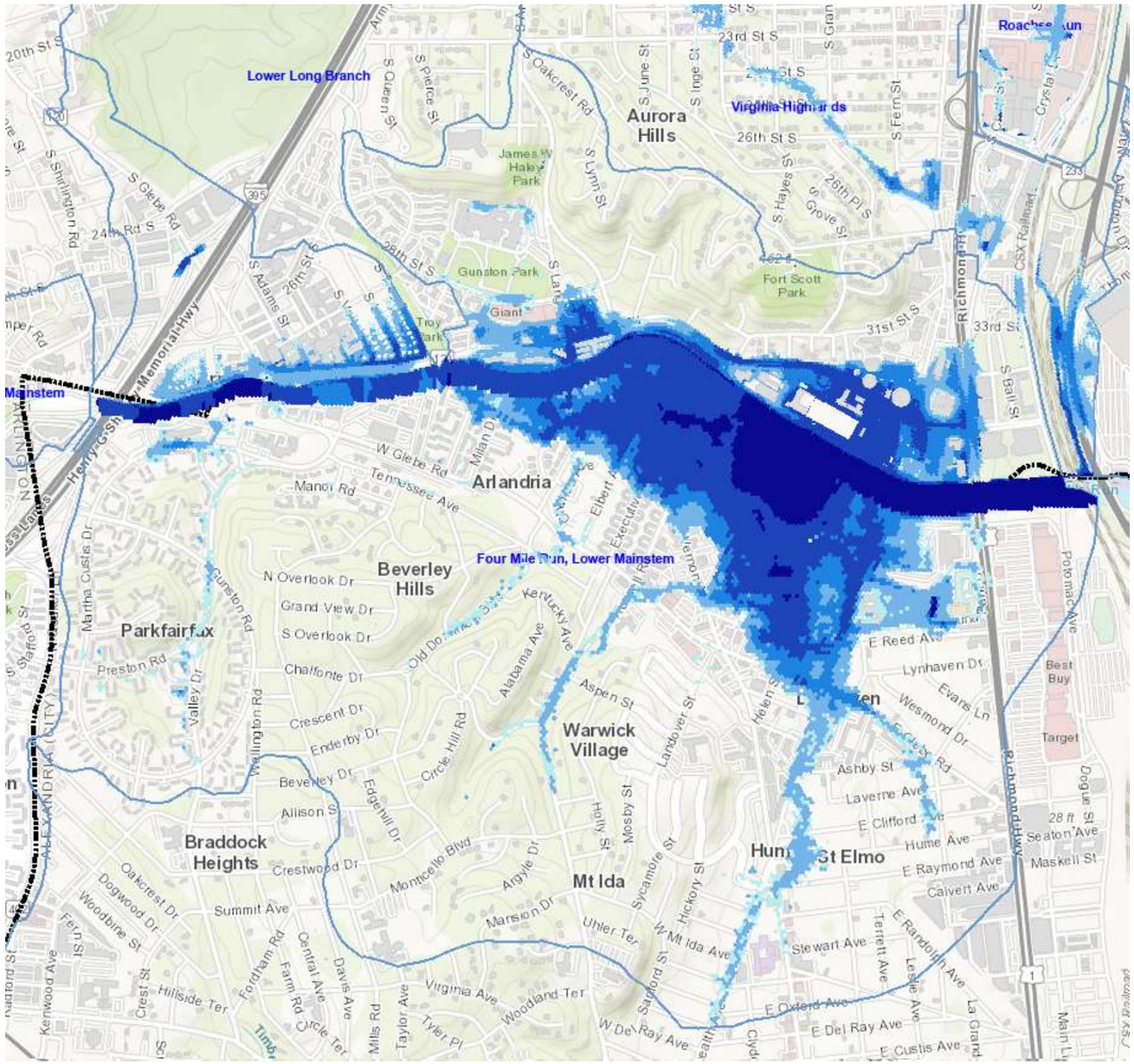
- .5-1 ft
- 1-3 ft
- 3-5 ft
- 5-10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Figure A-3:
# Little Pimmit Run, E. Branch
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

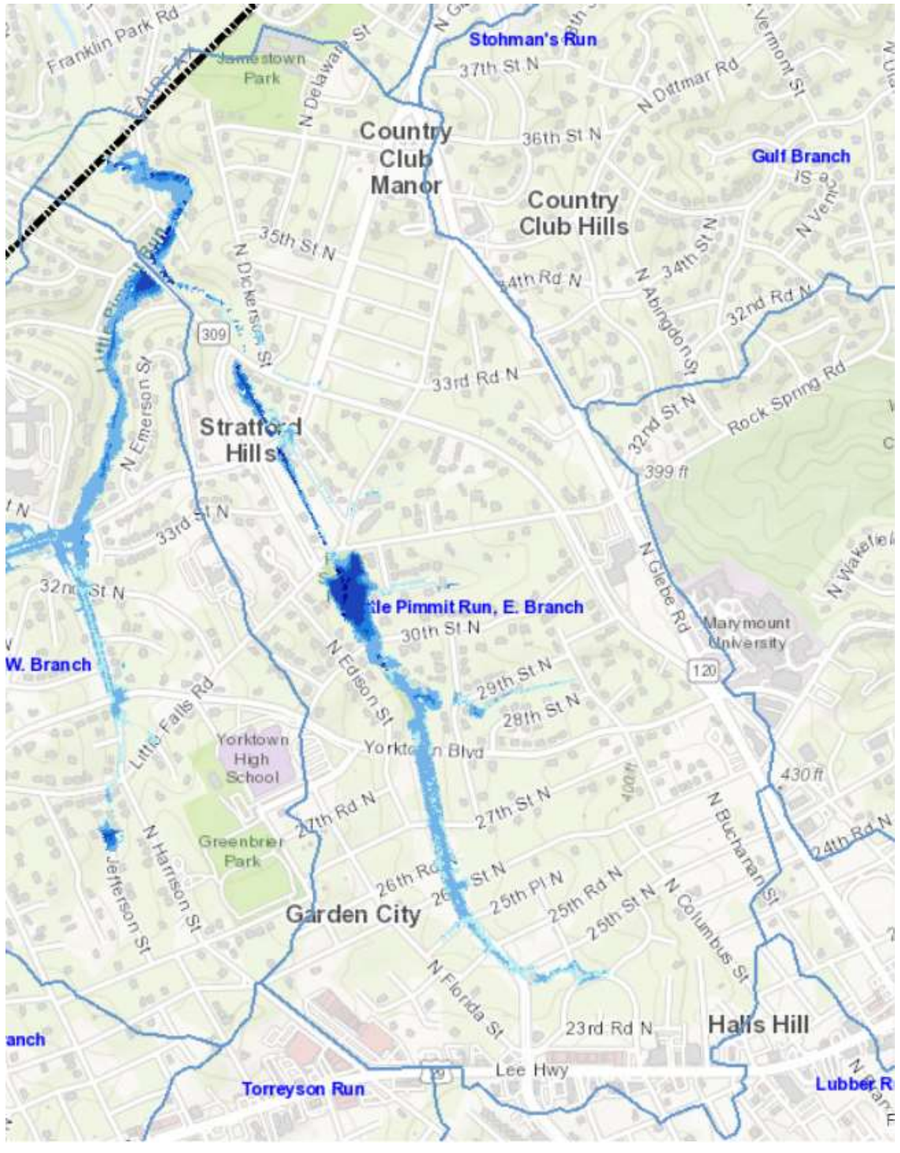
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Figure A-4:
# Little Pimmit Run, W. Branch
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary

# Figure A-5:
# Lubber Run
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

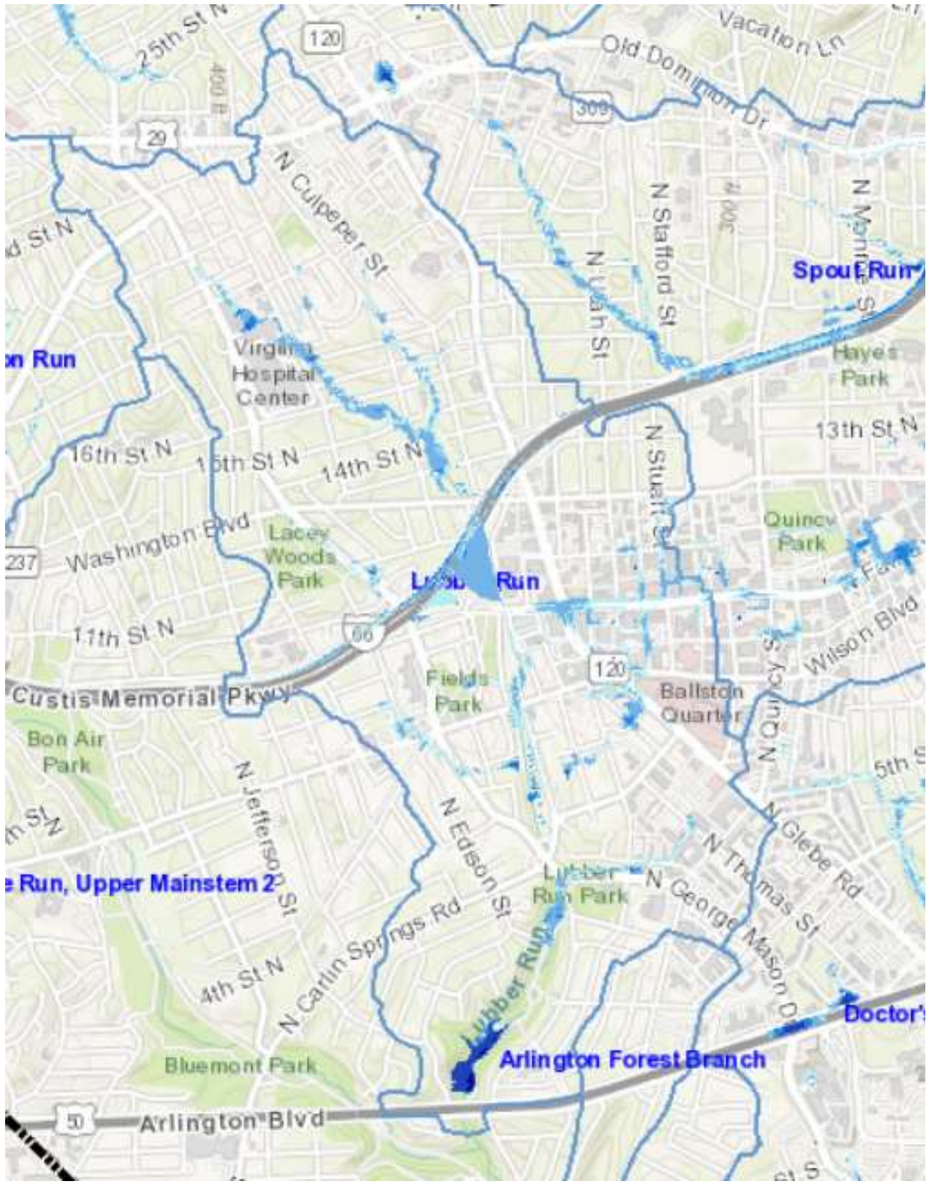
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Figure A-6:
# Roaches Run
# 2040 100 year 24 hour
# and Coastal Flooding
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Coastal**

2040 100-year, Tide 10.5, SLR 1.86

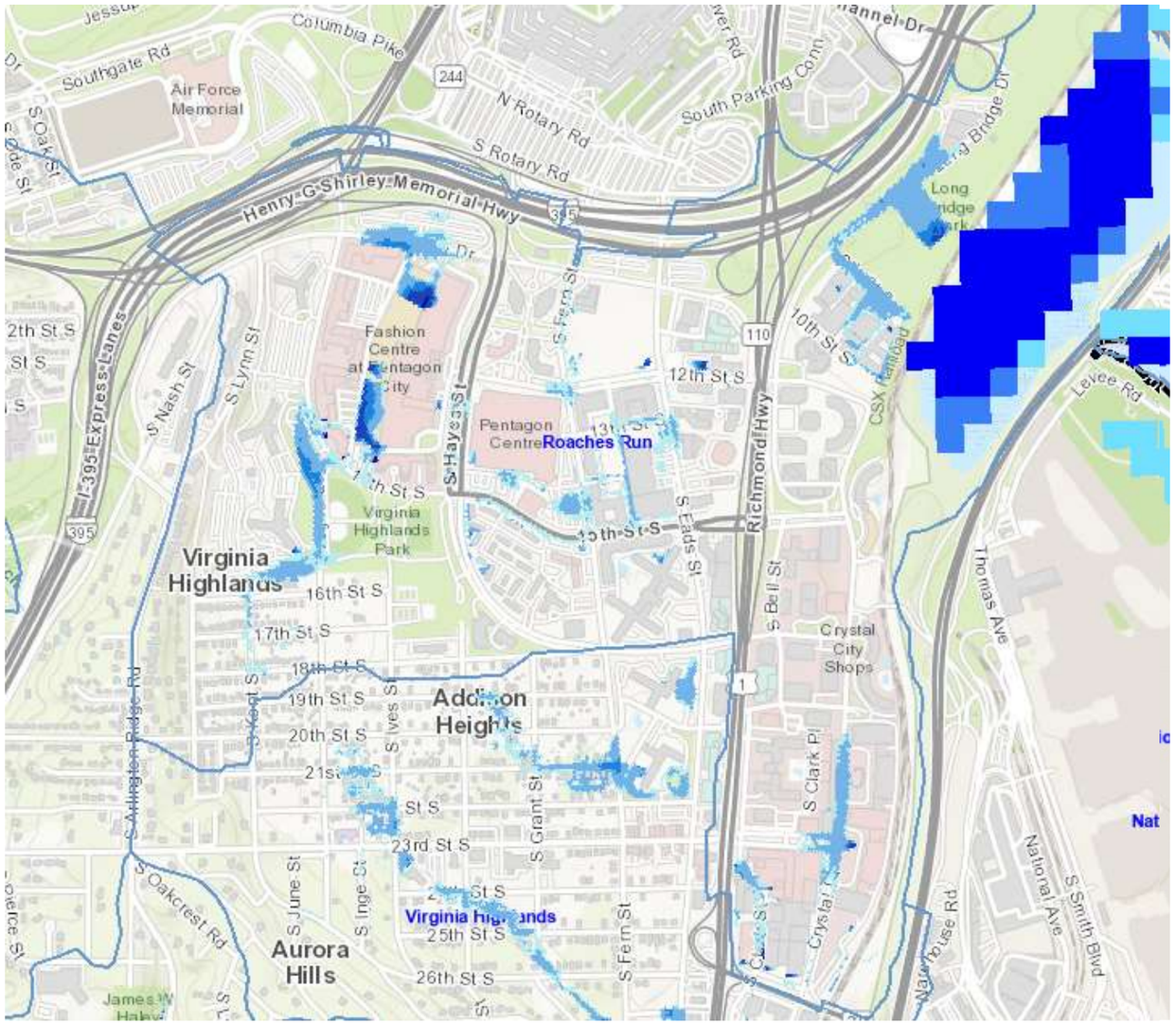
- .5-1 ft
- 1-3 ft
- 3-5 ft
- 5-10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Figure A-7:
# Spout Run
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

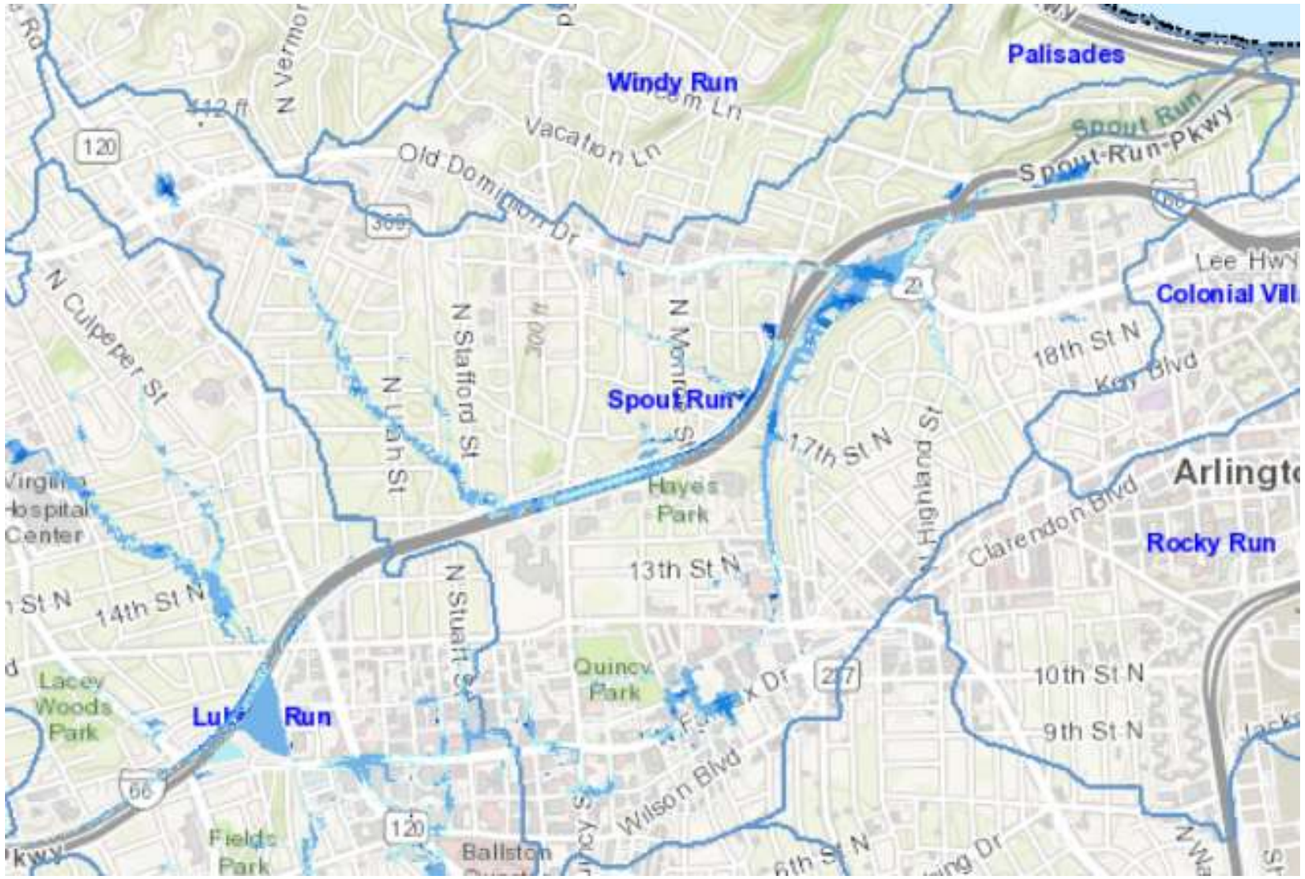
- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Figure A-8:
# Torreyson Run
# 2040 100 year 24 hour
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary

# Figure A-9:
# Virginia Highlands
# 2040 100 year 24 hour
# and Coastal Flooding
# Model Results

Legend

**2040**

2040 RCP 8.5, 50%, 100-year 24-hr storm (5.49 in)

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

**Coastal**

2040 100-year, Tide 10.5, SLR 1.86

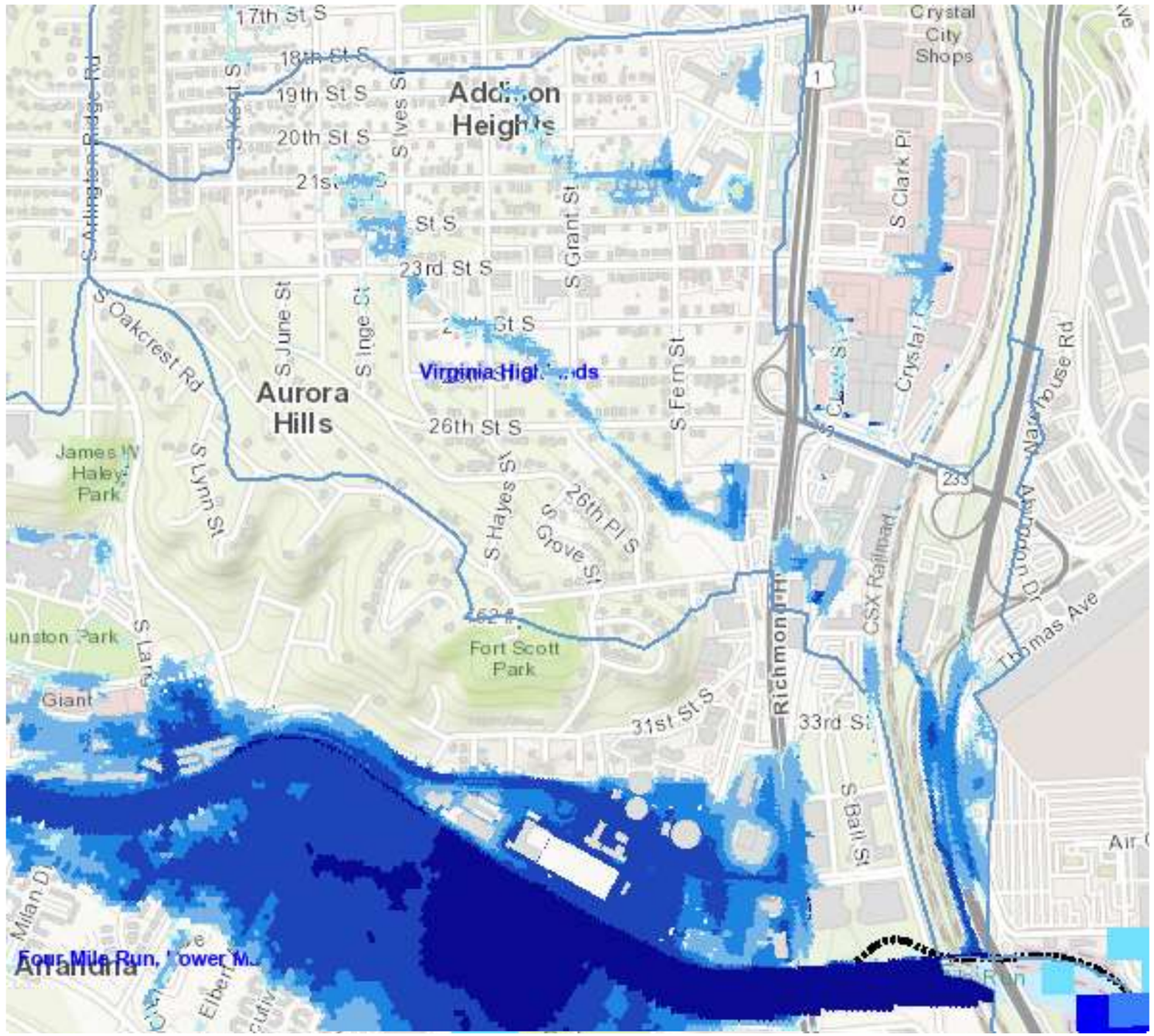
- .5-1 ft
- 1-3 ft
- 3-5 ft
- 5-10 ft
- >10 ft

**Watershed**

Watersheds

**County_Boundary**

County Boundary



# Appendix B
# List of Critical Receptors

| Category | Facility | Address | Watershed | Criticality Score | Type |
|---|---|---|---|---|---|
| Arlington Public Schools | Thomas Jefferson Middle School | 125 S OLD GLEBE RD | Doctor's Branch | H | Parks & Rec |
| Community Centers | Thomas Jefferson Community Center | 3501 2nd ST S | Doctor's Branch | H | Community Center |
| Fire Stations/Facilities | Station 1 – Glebe | 500 S GLEBE RD | Doctor's Branch | H | Wastewater System |
| Arlington Public Schools | Randolph Elementary School | 1306 S QUINCY ST | Doctor's Branch | H | School (Elementary/Middle) |
| Mass Care/Public Assistance Facility | Quebec Apartments | 4014 COLUMBIA PIKE | Doctor's Branch | M | Affordable Housing |
| Mass Care/Public Assistance Facility | Phoenix House | 521 N QUINCY ST | Doctor's Branch | H | Hospice |
| Mass Care Facility | Gates of Ballston | 4207 N PERSHING | Doctor's Branch | M | Affordable Housing |
| Mass Care/Public Assistance Facility | Doorways Family Home | 3127 7TH ST N | Doctor's Branch | H | Hospice |
| Mass Care/Public Assistance Facility | Clarendon Court Apartments | 3825 7TH ST | Doctor's Branch | M | Affordable Housing |
| Mass Care/Public Assistance Facility | Buckingham | 235 N GLEBE RD | Doctor's Branch | H | #N/A |
| Community Centers | Barcroft Sport & Fitness Center | 4200 S FOUR MILE RUN DR | Doctor's Branch | H | School (Highschool) |
| Mass Care Facility | Ballston Park at Historic Buckingham Village | 351 N GLEBE | Doctor's Branch | M | Parks & Rec |
| Arlington Public Schools | Alice West Fleet Elementary | 115 S OLD GLEBE RD | Doctor's Branch | H | School (Elementary/Middle) |
| SCADA - Lift Station | WPCB Plant Line (Main Site) | 3401 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Affordable Housing |
| Transportation System Facilities | WMATA - Four Mile Run Bus Maintenance | 3501 S GLEBE | Four Mile Run, Lower Mainstem | L | Transportation Maintenance |
| Utilities Systems | Wet Weather Filtration Facility | 3324 S GLEBE RDAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | West Secondary Pump Services Building - WSPSB | 3340 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| Utilities | West Mixed Liquor Flow Distribution Structures-WMLFDS | SOUTH GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Waste and Wastewater Systems | Water Pollution Control Plant | 3408 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Surface Waste Pump Station - SWPS | 3430 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| Utilities Systems | Standby Generator Facility | 3408 SOUTH GLEBE ROAD | Four Mile Run, Lower Mainstem | H | Critical Equipment Storage |
| Utilities Systems | South Ferric Facility (SFF) | 3448 S GLEBE ROAD | Four Mile Run, Lower Mainstem | H | Hazardous Substances Storage |
| Utilities Systems | Sludge Storage Tanks (SST1, SST2) | 3240 S EADS ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Secondary Clarifiers 1- to 6 | 3440 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Secondary Blower Building - SBB | 3404 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Secondary Aeration Tanks - SAT | 3330 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Satellite Warehouse (DWB area) | 3220 S EADS ST | Four Mile Run, Lower Mainstem | L | Warehouse (non-critical Equipment) |
| Utilities | Recycle Intercept Pump Station - RIPS Building #36 | S FERN ST | Four Mile Run, Lower Mainstem | M | Library |
| Utilities Systems | Primary Gravity Thickener Building and Tanks - PGTB | 3131 S FERN ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Primary Effluent Pumping Station - PEPS | 3248 S EADS ST | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| Utilities Systems | Primary Effluent Flume | NEAR 3248 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Primary Clarifiers - PCL | SOUTH EADS STREET | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Preliminary Treatment Building - PTB | 3139 S FERN ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Potomac Yards Pump Station | 3180 S EADS ST | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |

| Category | Facility | Address | Watershed | Criticality Score | Type |
|---|---|---|---|---|---|
| Utilities Systems | Post Aeration Facility (Chlorine Contact Tanks) | 3304 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Emergency Response - Fire/EMS |
| Arlington Public Schools | Oakridge Elementary School | 1414 24th ST S | Four Mile Run, Lower Mainstem | H | School (Elementary/Middle) |
| Utilities Systems | North Ferric Facility (NFF) | 3165 S FERN STREET | Four Mile Run, Lower Mainstem | H | Hazardous Substances Storage |
| Government Facilities | New Maintenance Building | 3111 S FERN ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Methanol Feed Facility | 3328 S GLEBE ROAD | Four Mile Run, Lower Mainstem | H | Hazardous Substances Storage |
| Low Level Pump Station | Low Level Pump Station | 3407 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| Facilities - Maint and Bldg | HEAD START | 2920 S GLEBE RD | Four Mile Run, Lower Mainstem | M | #N/A |
| Facilities - Maint and Bldg | Gunston Park | 1401 28 ST S | Four Mile Run, Lower Mainstem | M | #N/A |
| Arlington Public Schools | Gunston Middle School | 2700 S LANG ST | Four Mile Run, Lower Mainstem | L | Wastewater Treatment |
| Government Facilities | Gunston Bubble | 2700 S LANG ST | Four Mile Run, Lower Mainstem | L | Parks & Rec |
| Community Centers | Gunston Center | 2700 S LANG ST | Four Mile Run, Lower Mainstem | L | Parks & Rec |
| Utilities Systems | Four Mile Run Pumping Station - FMRL | 3115 S FERN ST | Four Mile Run, Lower Mainstem | M | Electrical Facility |
| Utilities Systems | Foam Collection Pumping Station Building - FCPS #33 | 3420 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| Utilities Systems | FMR meter vault | SOUTH GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Flow Equalization Tanks 1, 2, and 3 | 3145 S EADS ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Fire Stations/Facilities | Fire Logistics – Water Pollution Facility | 3402 S GLEBE RD | Four Mile Run, Lower Mainstem | H | Emergency Response & Operations |
| Facilities - Maint and Bldg | Fire Dept Butler Building/ Eads Warehouse | 3108 S EADS ST | Four Mile Run, Lower Mainstem | M | #N/A |
| Utilities Systems | Filtration and Disinfection Facility / Sodium Hypochlorite Facility | 3322 S GLEBE ROAD | Four Mile Run, Lower Mainstem | H | Wastewater Treatment |
| Utilities Systems | Electrical Distribution Center #1 (DC#1) | 544 31ST ST S | Four Mile Run, Lower Mainstem | H | Electrical Facility |
| Utilities Systems | East Tunnel Access Building - ETAB | 3244 S EADS ST | Four Mile Run, Lower Mainstem | M | Electrical Facility |
| Utilities Systems | Distribution Center No. 5 -DSB-5 | 3320 S GLEBE ROAD | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Dissolved Air Floatation Building - DAFT | 3135 S EADS ST | Four Mile Run, Lower Mainstem | M | Wastewater Treatment |
| Utilities Systems | Dewatering Building - DWB | 3208 S EADS ST | Four Mile Run, Lower Mainstem | M | Library |
| Utilities Systems | Biological Sludge Processing Building - BIO / Household Hazardous Waste Disposal Point - HHW | 537 31ST ST S | Four Mile Run, Lower Mainstem | H | Library |
| Transportation System Facilities | ART Transit Service District | 2900 SOUTH EADS STREET | Four Mile Run, Lower Mainstem | L | Transportation Maintenance |
| Transportation System Facilities | ART Light Maintenance Facility | 3201 S EADS ST | Four Mile Run, Lower Mainstem | L | Transportation Maintenance |
| Mass Care/Public Assistance Facility | Arna Valley View | 2300 25TH ST S | Four Mile Run, Lower Mainstem | M | Affordable Housing |
| Mass Care/Public Assistance Facility | Apex (the Berkeley) | 2900 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Affordable Housing |
| Utilities Systems | Advance Backwash Building - ABWB | 3326 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Electrical Facility |
| Utilities Systems | Activated Sludge Effluent Pump Station 1 - ASE1 | 3465 S GLEBE RD | Four Mile Run, Lower Mainstem | M | Wastewater Pump Station |
| SCADA-Flume Sites | Upper Pimmit Meter Station - UPMS | 3912 N DUMBARTON ST | Little Pimmit Run, E. Branch | M | Postal |
| Utilities Systems | Little Falls Booster Station | 5012 LITTLE FALLS RD | Little Pimmit Run, E. Branch | M | Wastewater Pump Station |
| SCADA-Pumping Stations | Little Falls | 4990 N LITTLE FALLS RD | Little Pimmit Run, E. Branch | M | #N/A |
| Arlington Public Schools | Jamestown Elementary School | 3700 N DELAWARE ST | Little Pimmit Run, E. Branch | H | Wastewater System |
| Arlington Public Schools | Yorktown High School Swimming Pool | 5201 N 28TH ST | Little Pimmit Run, W. Branch | L | #N/A |

| Category | Facility | Address | Watershed | Criticality Score | Type |
|---|---|---|---|---|---|
| Arlington Public Schools | Yorktown High School | 5200 YORKTOWN BL | Little Pimmit Run, W. Branch | M | School (Highschool) |
| Arlington Public Schools | Williamsburg Middle School | 3600 N HARRISON ST | Little Pimmit Run, W. Branch | H | School (Elementary/Middle) |
| Mass Care/Public Assistance Facility | Volunteers of America Group Home | 3607 N KENSINGTON ST | Little Pimmit Run, W. Branch | H | Hospice |
| Arlington Public Schools | Nottingham Elementary School | 5900 LITTLE FALLS RD | Little Pimmit Run, W. Branch | H | School (Elementary/Middle) |
| Arlington Public Schools | Discovery Elementary School | 5241 36th ST N | Little Pimmit Run, W. Branch | H | Wastewater System |
| Healthcare/Public Health Facility | Virginia Hospital Center | 1701 N GEORGE MASON DR | Lubber Run | H | Wastewater Pump Station |
| Mass Care/Public Assistance Facility | Vaughn Ball Group Home | 1710 N GLEBE RD | Lubber Run | H | Hospice |
| Healthcare/Public Health Facility | The Jefferson | 900 N TAYLOR ST | Lubber Run | M | Clinic |
| Mass Care Facility | The Carlin | 4300 N CARLIN SPRINGS RD | Lubber Run | H | Hospice |
| Healthcare/Public Health Facility | Sunrise Arlington | 2000 N GLEBE RD | Lubber Run | M | Clinic |
| Fire Stations/Facilities | Station 8 – Lee Hwy / Fueling Station Gas & Diesel | 4845 LEE HWY | Lubber Run | H | Hazardous Substances Storage |
| Fire Stations/Facilities | Station 2 – Ballston / Fueld hub | 4805 WILSON BL | Lubber Run | H | Hazardous Substances Storage |
| Mass Care/Public Assistance Facility | Oxford House Thomas Street | 525 N THOMAS STREET | Lubber Run | H | Hospice |
| Mass Care/Public Assistance Facility | Oxford House Arlington | 1305 N HERNDON STREET | Lubber Run | H | Maintenance Facility |
| Government Facilities | North Post Office | 2200 N GEORGE MASON DR | Lubber Run | M | Parks & Rec |
| Community Centers | Lubber Run Community Center | 300 N PARK DR | Lubber Run | H | Electrical Facility |
| Arlington Public Schools | Langston High School Continuation | 2121 N CULPEPER ST | Lubber Run | H | Community Center |
| Government Facilities | Human Services Facility | 1800 N EDISON ST | Lubber Run | M | Public Assistance Facility |
| Government Facilities | Human Services Facility | 1810 N EDISON ST | Lubber Run | M | Public Assistance Facility |
| Arlington Public Schools | Glebe Elementary School | 1770 N GLEBE RD | Lubber Run | H | School (Elementary/Middle) |
| Healthcare/Public Health Facility | George Mason Center | 1801 N GEORGE MASON DR | Lubber Run | H | Hospice |
| SCADA-Pumping Stations | Fire House 2 | 4805 WILSON BLVD | Lubber Run | H | #N/A |
| Healthcare/Public Health Facility | DaVita Dialysis Center (Rt 50) | 4805 1ST STREET N | Lubber Run | H | Wastewater Pump Station |
| Mass Care/Public Assistance Facility | Community Residences Group Home | 4933 N 18TH ST | Lubber Run | H | Hospice |
| Healthcare/Public Health Facility | Capital Hospice / Hospice of Northern Virginia | 4715 15TH ST N | Lubber Run | H | Hospice |
| Mass Care/Public Assistance Facility | Buckingham Village 3 | 315 N GEORGE MASON DR | Lubber Run | M | Affordable Housing |
| Arlington Public Schools | Barrett Elementary School | 4401 N Henderson Rd | Lubber Run | H | School (Elementary/Middle) |
| Transportation System Facilities | Ballston Metro Station | 4230 FAIRFAX DR | Lubber Run | M | Postal |
| Mass Care/Public Assistance Facility | Ballston Mall Parking Garage | 4328 WILSON BLVD | Lubber Run | M | Wastewater Pump Station |
| Mass Care Facility | Ballston Mall | 4238 WILSON BLVD | Lubber Run | M | Wastewater Pump Station |
| Arlington Public Schools | Arlington Traditional School | 855 N EDISON | Lubber Run | H | Maintenance Facility |

| Category | Facility | Address | Watershed | Criticality Score | Type |
|---|---|---|---|---|---|
| SCADA-Pumping Stations | Arlington Hospice | 1801 N GEORGE MASON DR | Lubber Run | H | #N/A |
| Community Centers | 1101 wilson blvd, arlington Virginia | 2121 N CULPEPER ST | Lubber Run | H | Community Center |
| Communications Sector | Verizon (Telecommunications Facility) | 400 11th ST S | Roaches Run | H | Postal |
| Fire Stations/Facilities | Station 5 – Aurora Highlands | 1750 S HAYES ST | Roaches Run | H | Emergency Response - Fire/EMS |
| Waste and Wastewater Systems | Roaches Run Pumping Station | 550 LONG BRIDGE DR | Roaches Run | M | Parks & Rec |
| Radio Sites | Ritz-Carlton | 1250 South Hayes St | Roaches Run | H | Radio Sites |
| Healthcare/Public Health Facility | Regency Care of Arlington & DaVita Dialysis Center (National Landing) | 1785 S HAYES ST | Roaches Run | M | Administrative |
| Mass Care Facility | Pentagon Mall | 1100 SOUTH HAYES ST | Roaches Run | M | Wastewater Pump Station |
| Transportation System Facilities | Pentagon City Metro Station | 1250 S HAYES ST | Roaches Run | M | WMATA Metro Station |
| Fire Stations/Facilities | Fire Logistics – Old Fire Station 5 | 1740 S HAYES ST | Roaches Run | H | Fire Logistics |
| SCADA-Pumping Stations | Fire House 5 | 735 S 18 ST | Roaches Run | H | Community Center |
| Sports Complex | Eads | 1301 S FERN ST | Roaches Run | M | #N/A |
| Transportation System Facilities | Crystal City Metro Station | 1750 S CLARK ST | Roaches Run | M | WMATA Metro Station |
| Mass Care/Public Assistance Facility | Crystal City | 1632 CRYSTAL SQUARE ARC | Roaches Run | H | Hospice |
| Mass Care Facility | Claridge House | 1500 S FERN ST | Roaches Run | H | Hospice |
| Library | Aurora Hills Library / Aurora Hills Community Center | 735 18TH ST S | Roaches Run | H | Community Center |
| Arlington Public Schools | Washington-Liberty High School Swimming Pool | 1300 N QUINCY ST | Spout Run | L | #N/A |
| Arlington Public Schools | Washington-Liberty High School | 1301 N STAFFORD ST | Spout Run | M | School (Highschool) |
| Transportation System Facilities | Virginia Square Metro Station | 3600 FAIRFAX DR | Spout Run | M | WMATA Metro Station |
| Fire Stations/Facilities | Station 3 – Cherrydale | 4100 OLD DOMINION DR | Spout Run | H | Emergency Response - Fire/EMS |
| Government Facilities | Recycling Center | 530 N QUINCY ST | Spout Run | M | #N/A |
| Fire Department | Quincy St Warehouse | 1425 N QUICY ST | Spout Run | L | Wastewater Pump Station |
| Mass Care/Public Assistance Facility | Oxford House Veitch | 1732 N VEITCH STREET | Spout Run | H | Hospice |
| Mass Care/Public Assistance Facility | Oxford House Arlington | 1305 N HERNDON STREET | Spout Run | H | Hospice |
| SCADA-Pressure Monitoring | Nelson Tunnel | NOR SIDE OF N NELSON ST AS IT DEAD-ES AT I-66 | Spout Run | M | Hospice |
| Waste and Wastewater Systems | Kirkwood Run Pumping Station | 1616 N Kirkwood Rd | Spout Run | M | Wastewater Pump Station |
| Mass Care Facility | Hunter's Park at Cherrydale | 2021 N NELSON ST | Spout Run | H | Hospice |
| Transportation System Facilities | Hess Gas Station | 3299 WILSON BLVD | Spout Run | M | WMATA Metro Station |
| Mass Care/Public Assistance Facility | Good Neighbor Homes Group Home | 4600 N 19TH RD | Spout Run | H | WMATA Metro Station |
| Healthcare/Public Health Facility | Fillmore St ALF | 1422 N FILLMORE ST | Spout Run | H | Hospice |
| Community Center | Dawson Terrace Community | 2133 N TAFT ST | Spout Run | H | #N/A |

| Category | Facility | Address | Watershed | Criticality Score | Type |
|---|---|---|---|---|---|
| Mass Care/Public Assistance Facility | Community Residences Group Home | 803 N LINCOLN ST | Spout Run | H | Library |
| Healthcare/Public Health Facility | Cherrydale Health and Rehab Center | 3710 LEE HWY | Spout Run | M | Clinic |
| Libraries | Central Library | 1015 N QUINCY ST | Spout Run | M | Library |
| Healthcare/Public Health Facility | Brookdale Arlington | 3821 WILSON BLVD | Spout Run | H | #N/A |
| Radio Sites | Ballston Place | 901 NORTH POLLARD STREET | Spout Run | H | Radio Sites |
| Arlington Public Schools | Arlington Science Focus Elementary | 1501 N LINCOLN ST | Spout Run | H | School (Elementary/Middle) |
| Community Centers | Arlington Art Center | 3550 WILSON BLVD | Spout Run | H | Hospice |
| Healthcare/Public Health Facility | 13th St ALF | 3824 13TH ST N | Spout Run | H | Hospice |
| Mass Care/Public Assistance Facility | Westover Apartments | 1649 N LONGFELLOW ST | Torreyson Run | M | Hospice |
| Libraries | Westover | 1644 N MCKINLEY RD | Torreyson Run | M | Community Center |
| Arlington Public Schools | Walter Reed Elementary School | 1644 MCKINLEY RD | Torreyson Run | H | #N/A |
| Arlington Public Schools | Swanson Middle School | 5800 WASHINGTON BL | Torreyson Run | H | #N/A |
| Mass Care/Public Assistance Facility | Preston King | 5877 WASHINGTON BL | Torreyson Run | H | #N/A |
| Community Centers | Lee Community Center | 5722 LEE HWY | Torreyson Run | H | Community Center |
| Healthcare/Public Health Facility | Community Residences ICF/ID | 1612 N MCKINLEY RD | Torreyson Run | H | Hospice |
| Government Facilities | National Center Station (NCES - Ejector Station) | 2525 S EADS ST | Virginia Highlands | M | Public Assistance Facility |

# Appendix C
# Watershed Prioritization for Modeling

# Appendix C. Watershed Prioritization for Modeling

FAST modeling was performed in Flood Modeller for all 36 watersheds in Arlington County to support the selection of nine watersheds[9] for detailed 1D/2D modeling in PCSWMM and 5 watersheds for further modeling with Flood Modeller's FAST process. Two rain events were modeled in this initial screening process: a 100-year, 24-hour synthetic rainfall event, and the July 2019 historical event. A downstream boundary condition, representing the Potomac River, of 1.77 feet NAVD88 (MHHW tidal level) and 1.96 feet NAVD88 were used for the synthetic and the historical event, respectively. Topographic data for the model was based on a digital elevation model developed from the 2018 U.S. Geological Survey lidar dataset.

Once the screening model runs were complete, watersheds were prioritized based on the following criteria:

- Number of Historical Flood Calls (2006, 2018, 2019)
- Observed High Water Marks (2019)
- Amount of FAST predicted flooding
- Extent of FEMA Floodplain

As shown in Table C-1, the project team developed an initial prioritization for the 36 watersheds based on FAST modeling and the number of flood calls by watershed for the historical June 2006 storm event.

**Table C-1. Recommended Prioritization Based on Initial FAST Screening**

| Watershed Name | Priority Tier | Watershed Area (Square Miles) | Percentage of Watershed with 100-yr FAST Flooding | June 2006 Historical Flood Call Count |
|---|---|---|---|---|
| Lubber Run | 1 | 1.61 | 8.5 | 26 |
| Spout Run | 1 | 1.67 | 7.2 | 14 |
| Little Pimmit Run, East Branch | 1 | 0.76 | 4.3 | 14 |
| Little Pimmit Run, West Branch | 1 | 0.76 | 4.5 | 11 |
| Torreyson Run | 1 | 0.50 | 3.8 | 3 |
| Crossman Run | 1 | 0.36 | 5.0 | 2 |
| Four Mile Run, Lower Mainstem | 1 | 2.48 | 29.7 | 1 |
| Roaches Run | 1 | 1.07 | 29.2 | 0 |
| Virginia Highlands | 1 | 0.56 | 12.9 | 0 |
| Lower Long Branch | 2 | 1.89 | 7.8 | 7 |
| Four Mile Run, Middle Mainstem | 2 | 1.49 | 6.0 | 6 |
| Westover Branch | 2 | 0.46 | 3.9 | 3 |
| Four Mile Run, Upper Mainstem 1 | 2 | 1.89 | 7.6 | 1 |
| Doctor's Branch | 3 | 1.38 | 6.3 | 4 |
| Nauck Branch | 3 | 0.36 | 3.8 | 3 |
| Arlington Branch | 3 | 0.65 | 6.5 | 1 |

[9] Little Pimmit Run East and West branches were combined for modeling for a total of eight models. Task 4 evaluates vulnerability for these two watersheds separately, for a total of nine watersheds.

After discussion with Arlington County staff, watershed prioritization rankings were reprioritized as shown in Table C-1. Watersheds included in Priority Tier 1 in Table C-1 were modeled in PCSWMM. The east and west branches of Little Pimmit Run were combined into one PCSWMM model for the 1D/2D modeling. All watersheds in Priority Tier 2 were modeled using Flood Modeller's FAST analysis. Watersheds in Priority Tier 3 were not modeled. Watershed prioritization is depicted graphically in Figure C-1.

Key factors influencing the final prioritization tiering structure included the following:

- In the original recommendation Crossman Run was prioritized for PCSWMM modeling. However, it was determined through dialogue with Arlington County staff that Crossman Run's stormwater situation was similar to Torreyson Run's. Furthermore, the County felt that they had a good understanding of the situation in Crossman Run from previous modeling efforts. Therefore, the decision was made to do no further modeling on Crossman Run, and to prioritize Doctor's Branch for PCSWMM modeling instead.
- Arlington Branch was not prioritized for further modeling due to its small size and relatively small total number of historical flood calls.

Four Mile Run, Middle Mainstem has some areas of concern, but it was not prioritized for PCSWMM analysis because it is located in the FEMA floodplain, so the FEMA analysis could be used for the Vulnerability Assessment task. Four Mile Run, Middle Mainstem was further modeled using FAST analysis.

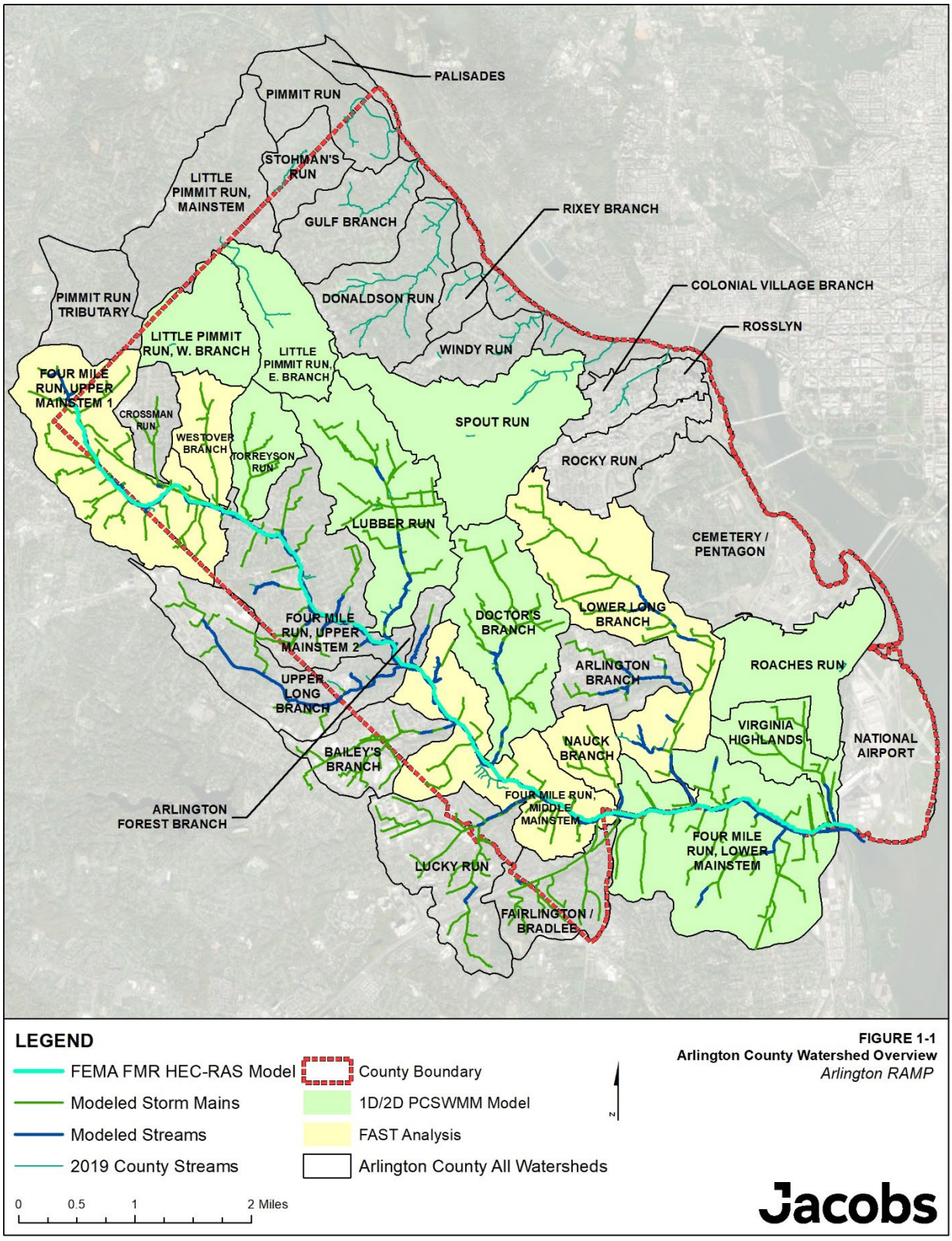

PALISADES
PIMMIT RUN
STOHMAN'S RUN
LITTLE PIMMIT RUN, MAINSTEM
GULF BRANCH
RIXEY BRANCH
COLONIAL VILLAGE BRANCH
ROSSLYN
PIMMIT RUN TRIBUTARY
DONALDSON RUN
LITTLE PIMMIT RUN, W. BRANCH
LITTLE PIMMIT RUN, E. BRANCH
WINDY RUN
FOUR MILE RUN, UPPER MAINSTEM 1
CROSSMAN RUN
WESTOVER BRANCH
TORREYSON RUN
SPOUT RUN
ROCKY RUN
LUBBER RUN
CEMETERY / PENTAGON
FOUR MILE RUN, UPPER MAINSTEM 2
DOCTOR'S BRANCH
LOWER LONG BRANCH
ARLINGTON BRANCH
ROACHES RUN
UPPER LONG BRANCH
VIRGINIA HIGHLANDS
NATIONAL AIRPORT
NAUCK BRANCH
BAILEY'S BRANCH
FOUR MILE RUN, MIDDLE MAINSTEM
ARLINGTON FOREST BRANCH
FOUR MILE RUN, LOWER MAINSTEM
LUCKY RUN
FAIRLINGTON / BRADLEE
LEGEND
FEMA FMR HEC-RAS Model
Modeled Storm Mains
Modeled Streams
2019 County Streams
County Boundary
1D/2D PCSWMM Model
FAST Analysis
Arlington County All Watersheds
0
0.5
1
2 Miles
N
FIGURE 1-1
Arlington County Watershed Overview
Arlington RAMP
Jacobs

**Table C-2. Final Prioritization Utilized in Study**

| Watershed Name | Priority Tier | Watershed Area ($mi^2$) | June 2006 Historical Flood Call Count | 5/22/2018 Historical Flood Call Count | 7/25/2018 Historical Flood Call Count | 7/8/2019 Historical Flood Call Count | 2019 Basement Historical Flood Call Count | Historical Flood Calls/ $mi^2$ | Percent of Watershed with 100yr FAST Flooding |
|---|---|---|---|---|---|---|---|---|---|
| Lubber Run | 1 | 1.61 | 26 | 5 | 0 | 12 | 3 | 28.6 | 8.5 |
| Spout Run | 1 | 1.67 | 14 | 9 | 15 | 37 | 13 | 52.6 | 7.2 |
| Little Pimmit Run, East Branch | 1 | 0.76 | 14 | 2 | 1 | 7 | 3 | 35.4 | 4.3 |
| Little Pimmit Run, West Branch | 1 | 0.76 | 11 | 6 | 0 | 11 | 10 | 50.1 | 4.5 |
| Torreyson Run | 1 | 0.50 | 3 | 5 | 0 | 18 | 13 | 78.0 | 3.8 |
| Doctor's Branch | 1 | 1.38 | 4 | 0 | 0 | 1 | 0 | 3.6 | 6.3 |
| Four Mile Run, Lower Mainstem | 1 | 2.48 | 1 | 1 | 0 | 2 | 0 | 1.6 | 29.7 |
| Roaches Run | 1 | 1.07 | 0 | 1 | 0 | 0 | 0 | 0.9 | 29.2 |
| Virginia Highlands | 1 | 0.56 | 0 | 0 | 0 | 0 | 0 | 0.0 | 12.9 |
| Lower Long Branch | 2 | 1.89 | 7 | 1 | 0 | 2 | 2 | 6.3 | 7.8 |
| Four Mile Run, Middle Mainstem | 2 | 1.49 | 6 | 2 | 0 | 3 | 1 | 8.1 | 6.0 |
| Westover Branch | 2 | 0.46 | 3 | 2 | 0 | 6 | 3 | 30.1 | 3.9 |
| Four Mile Run, Upper Mainstem 1 | 2 | 1.89 | 1 | 1 | 0 | 4 | 4 | 5.3 | 7.6 |
| Nauck Branch | 2 | 0.36 | 3 | 0 | 0 | 0 | 1 | 11.0 | 3.8 |
| Crossman Run | 3 | 0.36 | 2 | 3 | 0 | 4 | 2 | 30.5 | 5.0 |
| Arlington Branch | 3 | 0.65 | 1 | 0 | 0 | 2 | 0 | 4.6 | 6.5 |

$mi^2$ = square mile(s)

# Appendix D
# Critical Receptors Exposure Results

| Four Mile Run, Lower Mainstem | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | | Event Weights for Weighted Exposure | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 500 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure | 10 Yr Weight | 100 Yr Weight | 500 Yr Weight |
| WPCB Plant Line (Main Site) | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 11 | 1 | 1 | 1 | 1.00 | 0.571429 | 0.285714 | 0.142857 |
| WMATA - Four Mile Run Bus Maintenance | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Wet Weather Filtration Facility | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| West Secondary Pump Services Building - WSPSB | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 10 | 1 | 1 | 1 | 1.00 | | | |
| West Mixed Liquor Flow Distribution Structures-WMLFDS | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 10 | 1 | 1 | 1 | 1.00 | | | |
| Water Pollution Control Plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| Surface Waste Pump Station - SWPS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| Standby Generator Facility | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| South Ferric Facility (SFF) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| Sludge Storage Tanks (SST1, SST2) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Secondary Clarifiers 1- to 6 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Secondary Blower Building - SBB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| Secondary Aeration Tanks - SAT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 11 | 1 | 1 | 1 | 1.00 | | | |
| Satellite Warehouse (DWB area) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Recycle Intercept Pump Station - RIPS Building #36 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0.14 | | | |
| Primary Gravity Thickener Building and Tanks - PGTB | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0.14 | | | |
| Primary Effluent Pumping Station - PEPS | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Primary Effluent Flume | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 9 | 0 | 1 | 1 | 0.43 | | | |
| Primary Clarifiers - PCL | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 11 | 1 | 1 | 1 | 1.00 | | | |
| Preliminary Treatment Building - PTB | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Potomac Yards Pump Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Post Aeration Facility (Chlorine Contact Tanks) | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 7 | 1 | 1 | 1 | 1.00 | | | |
| Oakridge Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| North Ferric Facility (NFF) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| New Maintenance Building | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Methanol Feed Facility | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Low Level Pump Station | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| HEAD START | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Gunston Park | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Gunston Middle School | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Gunston Bubble | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Gunston Center | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Four Mile Run Pumping Station - FMRL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Foam Collection Pumping Station Building - FCPS #33 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| FMR meter vault | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Flow Equalization Tanks 1, 2, and 3 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Fire Logistics – Water Pollution Facility | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 | | | |
| Fire Dept Butler Building/ Eads Warehouse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Filtration and Disinfection Facility / Sodium Hypochlorite Facility | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 7 | 1 | 1 | 1 | 1.00 | | | |
| Electrical Distribution Center #1 (DC#1) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| East Tunnel Access Building - ETAB | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Distribution Center No. 5 -DSB-5 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Dissolved Air Floatation Building - DAFT | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0.14 | | | |
| Dewatering Building - DWB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Biological Sludge Processing Building - BIO / Household Hazardous Waste Disposal Point - HHW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| ART Transit Service District | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| ART Light Maintenance Facility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Arna Valley View | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Apex (the Berkeley) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| Advance Backwash Building - ABWB | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 | | | |
| Activated Sludge Effluent Pump Station 1 - ASE1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 | | | |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 | 1 | 1 | 1 | 1.00 | | | |
| Washington Gas Station B | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 9 | 0 | 1 | 1 | 0.43 | | | |
| Washington Gas Station C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | | | |
| Dominion P | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0.43 | | | |

| Little Pimmit Run, E. Branch | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Upper Pimmit Meter Station - UPMS | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| Little Falls Booster Station | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Little Falls | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Jamestown Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Dominion P | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.14 |

| Little Pimmit Run, W. Branch | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Yorktown High School Swimming Pool | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Yorktown High School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Williamsburg Middle School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Volunteers of America Group Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Nottingham Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Discovery Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |

| Doctor's Branch | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Thomas Jefferson Middle School | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 7 | 1 | 1 | 1 | 1.00 |
| Thomas Jefferson Community Center | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 7 | 1 | 1 | 1 | 1.00 |
| Station 1 – Glebe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Randolph Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Quebec Apartments | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Phoenix House | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Gates of Ballston | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Doorways Family Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Clarendon Court Apartments | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Buckingham | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Barcroft Sport & Fitness Center | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Ballston Park at Historic Buckingham Village | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Alice West Fleet Elementary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |

| Lubber Run | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Virginia Hospital Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Vaughn Ball Group Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| The Jefferson | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| The Carlin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Sunrise Arlington | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Station 8 – Lee Hwy / Fueling Station Gas & Diesel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Station 2 – Ballston / Fueld hub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Oxford House Thomas Street | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Oxford House Arlington | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| North Post Office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Lubber Run Community Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Langston High School Continuation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Human Services Facility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.14 |
| Human Services Facility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.14 |
| Glebe Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| George Mason Center | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Fire House 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| DaVita Dialysis Center (Rt 50) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Community Residences Group Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Capital Hospice / Hospice of Northern Virginia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Buckingham Village 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Barrett Elementary School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ballston Metro Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ballston Mall Parking Garage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Ballston Mall | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| Arlington Traditional School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Arlington Hospice | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0.14 |
| 1101 wilson blvd, arlington Virginia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |

| Roaches Run | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Verizon (Telecommunications Facility) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Station 5 – Aurora Highlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Roaches Run Pumping Station | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Ritz-Carlton | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Regency Care of Arlington & DaVita Dialysis Center (National Landing) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Pentagon Mall | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Pentagon City Metro Station | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| Fire Logistics – Old Fire Station 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Fire House 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Eads | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| Crystal City Metro Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Crystal City | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Claridge House | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Aurora Hills Library / Aurora Hills Community Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 5 | 0 | 1 | 1 | 0.43 |
| Dominion P | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0.29 |

| Spout Run | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Washington-Liberty High School Swimming Pool | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Washington-Liberty High School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Virginia Square Metro Station | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 0.43 |
| Station 3 – Cherrydale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Recycling Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Quincy St Warehouse | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Oxford House Veitch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Oxford House Arlington | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Nelson Tunnel | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 0.43 |
| Kirkwood Run Pumping Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Hunter's Park at Cherrydale | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 8 | 1 | 1 | 1 | 1.00 |
| Hess Gas Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Good Neighbor Homes Group Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Fillmore St ALF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Dawson Terrace Community | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Community Residences Group Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Cherrydale Health and Rehab Center | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Central Library | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 0.43 |
| Brookdale Arlington | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ballston Place | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0.14 |
| Arlington Science Focus Elementary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Arlington Art Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 13th St ALF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Dominion P | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0.14 |

| Torreyson Run | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Even | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| Westover Apartments | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Westover | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 0.43 |
| Walter Reed Elementary School | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 0.43 |
| Swanson Middle School | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Preston King | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |
| Lee Community Center | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Community Residences ICF/ID | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1.00 |

| Virginia Highlands | Exposure Values for Vulnerability Formula | | | | | | | | | | | | | | Weighted Exposure Used for High Criticality Receptor Index | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Receptors | 2020 10 YEAR 24 HR | 2020 100 YEAR 24 HR | 2020 500 YEAR 24 HR | 2040 10 YEAR 24 HR | 2040 100 YEAR 24 HR | 2040 500 YEAR 24 HR | 2070 10 YEAR 24 HR | 2070 100 YEAR 24 HR | 2070 500 YEAR 24 HR | Coastal 2070 100 YEAR 24HR | Coastal 2070 500 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Coastal 2040 100 YEAR 24HR | Total by Critical Receptor | 10 Yr Events Exposure | 100 Yr Events Exposure | 500 Yr Events Exposure | Weighted Exposure |
| National Center Station (NCES - Ejector Station) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| RPAs/NWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 12 | 1 | 1 | 1 | 1.00 |

# Appendix E
# Vulnerability Analysis by Watershed

**Vulnerability = (# of Exposure Scenarios + Sensitivity) / (Adaptive Capacity + Redundancy)**

## Four Mile Run, Lower Mainstem

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 224.00 | 4.07 |
| WPCB Plant Line (Main Site) | 11 | 2 | 2 | Not used | 6.50 | | |
| WMATA - Four Mile Run Bus Maintenance | 6 | 2 | 2 | Not used | 4.00 | | |
| Wet Weather Filtration Facility | 6 | 2 | 2 | Not used | 4.00 | | |
| West Secondary Pump Services Building - WSPSB | 10 | 2 | 2 | Not used | 6.00 | | |
| West Mixed Liquor Flow Distribution Structures- WMLF | 10 | 2 | 2 | Not used | 6.00 | | |
| Water Pollution Control Plant | 12 | 2 | 1 | Not used | 14.00 | | |
| Surface Waste Pump Station - SWPS | 12 | 2 | 2 | Not used | 7.00 | | |
| Standby Generator Facility | 12 | 3 | 2 | Not used | 7.50 | | |
| South Ferric Facility (SFF) | 12 | 3 | 2 | Not used | 7.50 | | |
| Sludge Storage Tanks (SST1, SST2) | 0 | 1 | 3 | Not used | 0.00 | | |
| Secondary Clarifiers 1- to 6 | 9 | 2 | 2 | Not used | 5.50 | | |
| Secondary Blower Building - SBB | 12 | 2 | 2 | Not used | 7.00 | | |
| Secondary Aeration Tanks - SAT | 11 | 2 | 2 | Not used | 6.50 | | |
| Satellite Warehouse (DWB area) | 0 | 2 | 2 | Not used | 0.00 | | |
| Recycle Intercept Pump Station - RIPS Building #36 | 2 | 2 | 2 | Not used | 2.00 | | |
| Primary Gravity Thickener Building and Tanks - PGTB | 3 | 2 | 2 | Not used | 2.50 | | |
| Primary Effluent Pumping Station - PEPS | 6 | 2 | 2 | Not used | 4.00 | | |
| Primary Effluent Flume | 9 | 2 | 2 | Not used | 5.50 | | |
| Primary Clarifiers - PCL | 11 | 2 | 2 | Not used | 6.50 | | |
| Preliminary Treatment Building - PTB | 6 | 2 | 2 | Not used | 4.00 | | |
| Potomac Yards Pump Station | 0 | 2 | 2 | Not used | 0.00 | | |
| Post Aeration Facility (Chlorine Contact Tanks) | 7 | 2 | 2 | Not used | 4.50 | | |
| Oakridge Elementary School | 0 | 2 | 2 | Not used | 0.00 | | |
| North Ferric Facility (NFF) | 12 | 3 | 2 | Not used | 7.50 | | |
| New Maintenance Building | 0 | 2 | 2 | Not used | 0.00 | | |
| Methanol Feed Facility | 6 | 3 | 2 | Not used | 4.50 | | |
| Low Level Pump Station | 12 | 2 | 2 | Not used | 7.00 | | |
| HEAD START | 9 | 2 | 2 | Not used | 5.50 | | |
| Gunston Park | 0 | 1 | 3 | Not used | 0.00 | | |
| Gunston Middle School | 9 | 2 | 2 | Not used | 5.50 | | |
| Gunston Bubble | 9 | 1 | 3 | Not used | 3.33 | | |
| Gunston Center | 9 | 1 | 3 | Not used | 3.33 | | |
| Four Mile Run Pumping Station - FMRL | 0 | 2 | 2 | Not used | 0.00 | | |
| Foam Collection Pumping Station Building - FCPS #33 | 12 | 2 | 2 | Not used | 7.00 | | |
| FMR meter vault | 0 | 2 | 2 | Not used | 0.00 | | |
| Flow Equalization Tanks 1, 2, and 3 | 6 | 2 | 2 | Not used | 4.00 | | |
| Fire Logistics – Water Pollution Facility | 12 | 1 | 3 | Not used | 4.33 | | |
| Fire Dept Butler Building/ Eads Warehouse | 0 | 2 | 2 | Not used | 0.00 | | |
| Filtration and Disinfection Facility / Sodium Hypochlorit | 7 | 3 | 2 | Not used | 5.00 | | |
| Electrical Distribution Center #1 (DC#1) | 0 | 1 | 3 | Not used | 0.00 | | |
| East Tunnel Access Building - ETAB | 6 | 2 | 2 | Not used | 4.00 | | |
| Distribution Center No. 5 -DSB-5 | 6 | 2 | 1 | Not used | 8.00 | | |
| Dissolved Air Floatation Building - DAFT | 3 | 2 | 2 | Not used | 2.50 | | |
| Dewatering Building - DWB | 0 | 2 | 2 | Not used | 0.00 | | |
| Biological Sludge Processing Building - BIO / Household | 0 | 3 | 2 | Not used | 0.00 | | |
| ART Transit Service District | 0 | 2 | 2 | Not used | 0.00 | | |
| ART Light Maintenance Facility | 0 | 2 | 2 | Not used | 0.00 | | |
| Arna Valley View | 0 | 3 | 1 | Not used | 0.00 | | |
| Apex (the Berkeley) | 9 | 3 | 1 | Not used | 12.00 | | |
| Advance Backwash Building - ABWB | 6 | 2 | 2 | Not used | 4.00 | | |
| Activated Sludge Effluent Pump Station 1 - ASE1 | 9 | 3 | 1 | Not used | 12.00 | | |
| RPAs | 13 | 2 | 3 | Not used | 5.00 | | |
| Washington Gas Facilities | 9 | 3 | 2 | Not used | 6.00 | | |
| Washington Gas Facilities | 0 | 3 | 2 | Not used | 0.00 | | |
| Dominion Power Facilities | 3 | 3 | 2 | Not used | 3.00 | | |

## Little Pimmit Run, E. Branch

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 15.17 | 2.53 |
| Upper Pimmit Meter Station - UPMS | 6 | 2 | 2 | Not used | 4.00 | | |
| Little Falls Booster Station | 9 | 2 | 2 | Not used | 5.50 | | |
| Little Falls | 0 | 2 | 2 | Not used | 0.00 | | |

| | | | | | |
|---|---|---|---|---|---|
| Jamestown Elementary School | 0 | 2 | 1 | Not used | 0.00 |
| RPAs | 9 | 2 | 3 | Not used | 3.67 |
| Dominion Power Facilities | 1 | 3 | 2 | Not used | 2.00 |

## Little Pimmit Run, W. Branch

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 3.67 | 0.52 |
| Yorktown High School Swimming Pool | 0 | 1 | 3 | Not used | 0.00 | | |
| Yorktown High School | 0 | 2 | 1 | Not used | 0.00 | | |
| Williamsburg Middle School | 0 | 2 | 1 | Not used | 0.00 | | |
| Volunteers of America Group Home | 0 | 3 | 1 | Not used | 0.00 | | |
| Nottingham Elementary School | 0 | 2 | 1 | Not used | 0.00 | | |
| Discovery Elementary School | 0 | 2 | 1 | Not used | 0.00 | | |
| RPAs | 9 | 2 | 3 | Not used | 3.67 | | |

## Doctor's Branch

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 34.67 | 2.48 |
| Thomas Jefferson Middle School | 7 | 2 | 1 | Not used | 9.00 | | |
| Thomas Jefferson Community Center | 7 | 3 | 1 | Not used | 10.00 | | |
| Station 1 – Glebe | 0 | 1 | 3 | Not used | 0.00 | | |
| Randolph Elementary School | 0 | 2 | 1 | Not used | 0.00 | | |
| Quebec Apartments | 0 | 3 | 1 | Not used | 0.00 | | |
| Phoenix House | 0 | 3 | 1 | Not used | 0.00 | | |
| Gates of Ballston | 0 | 3 | 1 | Not used | 0.00 | | |
| Doorways Family Home | 0 | 3 | 1 | Not used | 0.00 | | |
| Clarendon Court Apartments | 0 | 3 | 1 | Not used | 0.00 | | |
| Buckingham | 0 | 3 | 1 | Not used | 0.00 | | |
| Barcroft Sport & Fitness Center | 9 | 3 | 1 | Not used | 12.00 | | |
| Ballston Park at Historic Buckingham Village | 0 | 3 | 1 | Not used | 0.00 | | |
| Alice West Fleet Elementary | 0 | 2 | 2 | Not used | 0.00 | | |
| RPAs | 9 | 2 | 3 | Not used | 3.67 | | |

## Lubber Run

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 54.67 | 1.89 |
| Virginia Hospital Center | 0 | 2 | 3 | Not used | 0.00 | | |
| Vaughn Ball Group Home | 0 | 3 | 1 | Not used | 0.00 | | |
| The Jefferson | 6 | 2 | 1 | Not used | 8.00 | | |
| The Carlin | 0 | 3 | 1 | Not used | 0.00 | | |
| Sunrise Arlington | 0 | 2 | 1 | Not used | 0.00 | | |
| Station 8 – Lee Hwy / Fueling Station Gas & Diesel | 0 | 2 | 1 | Not used | 0.00 | | |
| Station 2 – Ballston / Fueld hub | 0 | 3 | 2 | Not used | 0.00 | | |
| Oxford House Thomas Street | 0 | 3 | 1 | Not used | 0.00 | | |
| Oxford House Arlington | 0 | 3 | 1 | Not used | 0.00 | | |
| North Post Office | 0 | 1 | 3 | Not used | 0.00 | | |
| Lubber Run Community Center | 0 | 3 | 1 | Not used | 0.00 | | |
| Langston High School Continuation | 0 | 3 | 1 | Not used | 0.00 | | |
| Human Services Facility | 1 | 2 | 1 | Not used | 3.00 | | |
| Human Services Facility | 1 | 2 | 1 | Not used | 3.00 | | |
| Glebe Elementary School | 0 | 2 | 1 | Not used | 0.00 | | |
| George Mason Center | 9 | 3 | 1 | Not used | 12.00 | | |
| Fire House 2 | 0 | 1 | 3 | Not used | 0.00 | | |
| DaVita Dialysis Center (Rt 50) | 0 | 2 | 1 | Not used | 0.00 | | |
| Community Residences Group Home | 0 | 3 | 1 | Not used | 0.00 | | |
| Capital Hospice / Hospice of Northern Virginia | 0 | 1 | 3 | Not used | 0.00 | | |
| Buckingham Village 3 | 0 | 3 | 1 | Not used | 0.00 | | |
| Barrett Elementary School | 0 | 2 | 1 | Not used | 0.00 | | |
| Ballston Metro Station | 0 | 2 | 2 | Not used | 0.00 | | |
| Ballston Mall Parking Garage | 9 | 2 | 1 | Not used | 11.00 | | |
| Ballston Mall | 6 | 2 | 1 | Not used | 8.00 | | |
| Arlington Traditional School | 0 | 3 | 1 | Not used | 0.00 | | |

| | | | | | |
|---|---|---|---|---|---|
| Arlington Hospice | 3 | 3 | 1 | Not used | 6.00 |
| 1101 wilson blvd, arlington Virginia | 0 | 3 | 1 | Not used | 0.00 |
| RPAs | 9 | 2 | 3 | Not used | 3.67 |

## Roaches Run

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 35.67 | 2.23 |
| Verizon (Telecommunications Facility) | 0 | 2 | 2 | Not used | 0.00 | | |
| Station 5 – Aurora Highlands | 0 | 1 | 3 | Not used | 0.00 | | |
| Roaches Run Pumping Station | 9 | 2 | 2 | Not used | 5.50 | | |
| Ritz-Carlton | 6 | 2 | 2 | Not used | 4.00 | | |
| Regency Care of Arlington & DaVita Dialysis Center (Nat | 0 | 2 | 1 | Not used | 0.00 | | |
| Pentagon Mall | 9 | 2 | 1 | Not used | 11.00 | | |
| Pentagon City Metro Station | 6 | 2 | 1 | Not used | 8.00 | | |
| Fire Logistics – Old Fire Station 5 | 0 | 1 | 3 | Not used | 0.00 | | |
| Fire House 5 | 0 | 1 | 3 | Not used | 0.00 | | |
| Eads | 6 | 1 | 3 | Not used | 2.33 | | |
| Crystal City Metro Station | 0 | 2 | 2 | Not used | 0.00 | | |
| Crystal City | 0 | 3 | 1 | Not used | 0.00 | | |
| Claridge House | 0 | 3 | 1 | Not used | 0.00 | | |
| Aurora Hills Library / Aurora Hills Community Center | 0 | 3 | 1 | Not used | 0.00 | | |
| RPAs | 5 | 2 | 3 | Not used | 2.33 | | |
| Dominion Power Facilities | 2 | 3 | 2 | Not used | 2.50 | | |

## Spout Run

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 48.67 | 1.95 |
| Washington-Liberty High School Swimming Pool | 0 | 1 | 3 | Not used | 0.00 | | |
| Washington-Liberty High School | 0 | 2 | 1 | Not used | 0.00 | | |
| Virginia Square Metro Station | 4 | 2 | 2 | Not used | 3.00 | | |
| Station 3 – Cherrydale | 0 | 1 | 3 | Not used | 0.00 | | |
| Recycling Center | 0 | 1 | 3 | Not used | 0.00 | | |
| Quincy St Warehouse | 0 | 2 | 2 | Not used | 0.00 | | |
| Oxford House Veitch | 0 | 3 | 1 | Not used | 0.00 | | |
| Oxford House Arlington | 0 | 3 | 1 | Not used | 0.00 | | |
| Nelson Tunnel | 4 | 2 | 2 | Not used | 3.00 | | |
| Kirkwood Run Pumping Station | 0 | 2 | 2 | Not used | 0.00 | | |
| Hunter's Park at Cherrydale | 8 | 3 | 1 | Not used | 11.00 | | |
| Hess Gas Station | 0 | 2 | 2 | Not used | 0.00 | | |
| Good Neighbor Homes Group Home | 0 | 3 | 1 | Not used | 0.00 | | |
| Fillmore St ALF | 0 | 3 | 1 | Not used | 0.00 | | |
| Dawson Terrace Community | 0 | 3 | 1 | Not used | 0.00 | | |
| Community Residences Group Home | 0 | 3 | 1 | Not used | 0.00 | | |
| Cherrydale Health and Rehab Center | 9 | 2 | 1 | Not used | 11.00 | | |
| Central Library | 6 | 2 | 1 | Not used | 8.00 | | |
| Brookdale Arlington | 0 | 3 | 1 | Not used | 0.00 | | |
| Ballston Place | 3 | 3 | 1 | Not used | 6.00 | | |
| Arlington Science Focus Elementary | 0 | 2 | 1 | Not used | 0.00 | | |
| Arlington Art Center | 0 | 3 | 1 | Not used | 0.00 | | |
| 13th St ALF | 0 | 3 | 1 | Not used | 0.00 | | |
| RPAs | 9 | 2 | 3 | Not used | 3.67 | | |
| Dominion Power Facilities | 3 | 3 | 2 | Not used | 3.00 | | |

## Torreyson Run

| Receptors | Exposure | Sensitivity | Adaptive Capacity | Redundancy | Vulnerablity (Formula) | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| | | | | | | 27.67 | 3.46 |
| Westover Apartments | 0 | 3 | 1 | Not used | 0.00 | | |
| Westover | 4 | 2 | 1 | Not used | 6.00 | | |
| Walter Reed Elementary School | 4 | 2 | 1 | Not used | 6.00 | | |
| Swanson Middle School | 0 | 2 | 1 | Not used | 0.00 | | |
| Preston King | 9 | 3 | 1 | Not used | 12.00 | | |
| Lee Community Center | 0 | 2 | 2 | Not used | 0.00 | | |

| | | | | | |
|---|---|---|---|---|---|
| Community Residences ICF/ID | 0 | 3 | 1 | Not used | 0.00 |
| RPAs | 9 | 2 | 3 | Not used | 3.67 |

| Virginia Highlands | | | | | | Vulnerability Sum | Average Vulnerability |
|---|---|---|---|---|---|---|---|
| **Receptors** | **Exposure** | **Sensitivity** | **Adaptive Capacity** | **Redundancy** | **Vulnerablity (Formula)** | **4.67** | **2.33** |
| National Center Station (NCES - Ejector Station) | 0 | 2 | 1 | Not used | 0.00 | | |
| RPAs | 12 | 2 | 3 | Not used | 4.67 | | |

# Appendix F
# Flooded Areas

# Table F-1: Commercial District Flooded Area per Watershed

| Watershed | Watershed Area (SqrFt) | Watershed Area Acres) | Business District Areas Flooded (Sqft) | | | | | | | | | Business District Areas Flooded (Acres) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
| Doctor's Branch | 38,412,989.98 | 881.84 | 38301.04 | 135750.48 | 212194.22 | 42167.85 | 155291.19 | 227320.50 | 45410.44 | 173678.74 | 233883.19 | 0.88 | 3.12 | 4.87 | 0.97 | 3.56 | 5.22 | 1.04 | 3.99 | 5.37 |
| Four Mile Run, Lower Mainstem | 19,773,036.41 | 453.93 | 380211.35 | 1504552.95 | 1911973.00 | 466620.53 | 1620632.39 | 2051374.51 | 809360.45 | 1701117.88 | 2231517.90 | 8.73 | 34.54 | 43.89 | 10.71 | 37.20 | 47.09 | 18.58 | 39.05 | 51.23 |
| Little Pimmit Run, E. Branch | 23,089,818.32 | 530.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | - | - | - | - | - | - | - | - | - |
| Little Pimmit Run, W. Branch | 20,134,549.96 | 462.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | - | - | - | - | - | - | - | - | - |
| Lubber Run | 44,997,296.51 | 1,033.00 | 292606.11 | 1401261.53 | 1776235.59 | 334134.96 | 1487054.94 | 1821746.04 | 445381.19 | 1577537.23 | 1878526.51 | 6.72 | 32.17 | 40.78 | 7.67 | 34.14 | 41.82 | 10.22 | 36.22 | 43.13 |
| Roaches Run | 30,157,584.96 | 692.32 | 1205957.91 | 3294183.82 | 4386102.25 | 1336049.34 | 3692988.66 | 4887581.29 | 1598189.10 | 3925773.77 | 5340159.05 | 27.68 | 75.62 | 100.69 | 30.67 | 84.78 | 112.20 | 36.69 | 90.12 | 122.59 |
| Spout Run | 48,995,866.68 | 1,124.79 | 710296.41 | 1659856.67 | 2121968.72 | 846680.95 | 1742040.31 | 2197736.10 | 935738.49 | 1841906.58 | 2245611.75 | 16.31 | 38.11 | 48.71 | 19.44 | 39.99 | 50.45 | 21.48 | 42.28 | 51.55 |
| Torreyson Run | 13,902,276.41 | 319.15 | 92247.80 | 140392.50 | 151929.08 | 141394.06 | 215849.22 | 235209.72 | 108217.66 | 145230.32 | 153941.88 | 2.12 | 3.22 | 3.49 | 3.25 | 4.96 | 5.40 | 2.48 | 3.33 | 3.53 |
| Virginia Highlands | 15,581,557.17 | 357.70 | 100613.73 | 480646.05 | 783587.08 | 108456.95 | 527708.00 | 1036259.96 | 184952.79 | 570889.07 | 1141091.89 | 2.31 | 11.03 | 17.99 | 2.49 | 12.11 | 23.79 | 4.25 | 13.11 | 26.20 |

**Note:**

Coastal flood included: 100yr2040, 100yr2070, 500yr2040, and 500yr2070

No Cloastal flood models for - 10yr2020,100yr2020,500yr2020,10yr2040, and 10yr2070

# Table F-2: Moderate to High SVI (0.50 to 0.75) Flooded Area per Watershed

| Watershed | Watershed Area (SqrFt) | Watershed Area Acres) | Moderate to High SVI Areas Flooded (Sqft) - SVI is between 0.5 and 0.75 | | | | | | | | | Moderate to High SVI Areas Flooded (Acres) - SVI is between 0.5 and 0.75 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
| Doctor's Branch | 38,412,990.0 | 881.84 | 264,899.76 | 502,555.87 | 686,134.03 | 296,435.93 | 539,011.48 | 728,817.76 | 326,537.48 | 563,946.52 | 755,917.22 | 6.08 | 11.54 | 15.75 | 6.81 | 12.37 | 16.73 | 7.50 | 12.95 | 17.35 |
| Four Mile Run, Lower Mainstem | 19,773,036.4 | 453.93 | 13,163.21 | 27,365.61 | 40,875.20 | 14,548.81 | 30,483.21 | 58,227.79 | 16,280.81 | 32,356.56 | 62,730.99 | 0.30 | 0.63 | 0.94 | 0.33 | 0.70 | 1.34 | 0.37 | 0.74 | 1.44 |
| Little Pimmit Run, E. Branch | 23,089,818.3 | 530.07 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Little Pimmit Run, W. Branch | 20,134,550.0 | 462.23 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Lubber Run | 44,997,296.5 | 1,033.00 | 151,097.49 | 177,462.62 | 204,879.32 | 155,141.58 | 180,571.46 | 209,327.11 | 157,621.61 | 181,392.31 | 212,716.68 | 3.47 | 4.07 | 4.70 | 3.56 | 4.15 | 4.81 | 3.62 | 4.16 | 4.88 |
| Roaches Run | 30,157,585.0 | 692.32 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Spout Run | 48,995,866.7 | 1,124.79 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Torreyson Run | 13,902,276.4 | 319.15 | 316.48 | 5,431.19 | 7,680.66 | 632.96 | 13,676.50 | 18,277.64 | 1,089.10 | 6,838.25 | 11,354.73 | 0.01 | 0.12 | 0.18 | 0.01 | 0.31 | 0.42 | 0.03 | 0.16 | 0.26 |
| Virginia Highlands | 15,581,557.2 | 357.70 | | | | | | | | | | - | - | - | - | - | - | - | - | - |

**Note:**

Coastal flood included: 100yr2040, 100yr2070, 500yr2040, and 500yr2070

No Cloastal flood models for - 10yr2020,100yr2020,500yr2020,10yr2040, and 10yr2070

# Table F-3: High SVI (0.50 to 0.75) Flooded Area per Watershed

| Watershed | Watershed Area (SqrFt) | Watershed Area Acres) | High SVI Areas Flooded (Sqft) SVI >=0.75 | | | | | | | | | High SVI Areas Flooded (Acres) SVI >=0.75 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 |
| Doctor's Branch | 38,412,990.0 | 881.84 | 230,427.2 | 637,192.5 | 862,503.8 | 254,841.5 | 675,673.9 | 921,188.9 | 230,427.2 | 725,529.9 | 969,777.9 | 5.29 | 14.63 | 19.80 | 5.85 | 15.51 | 21.15 | 5.29 | 16.66 | 22.26 |
| Four Mile Run, Lower Mainstem | 19,773,036.4 | 453.93 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Little Pimmit Run, E. Branch | 23,089,818.3 | 530.07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Little Pimmit Run, W. Branch | 20,134,550.0 | 462.23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Lubber Run | 44,997,296.5 | 1,033.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Roaches Run | 30,157,585.0 | 692.32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Spout Run | 48,995,866.7 | 1,124.79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Torreyson Run | 13,902,276.4 | 319.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |
| Virginia Highlands | 15,581,557.2 | 357.70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | - | - |

**Note:**

Coastal flood included: 100yr2040, 100yr2070, 500yr2040, and 500yr2070

No Cloastal flood models for - 10yr2020,100yr2020,500yr2020,10yr2040, and 10yr2070

# Table F-4: Overall Flooded Area per Watershed

| Watershed | Watershed Area (SqrFt) | Watershed Area Acres) | Flood Area (Sqft) | | | | | | | | | Flood Area (Acres) | | | | | | | | | Flood Area (Percent of Watershed) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | 10yr2020 | 100yr2020 | 500yr2020 | 10yr2040 | 100yr2040 | 500yr2040 | 10yr2070 | 100yr2070 | 500yr2070 | Min | Max |
| Doctor's Branch | 38,412,990.0 | 881.84 | 794,635.09 | 2,460,176.00 | 3,567,188.74 | 908,965.70 | 2,665,844.63 | 3,781,458.22 | 1,186,575.13 | 2,848,106.40 | 3,956,642.47 | 18.24 | 56.48 | 81.89 | 20.87 | 61.20 | 86.81 | 27.24 | 65.38 | 90.83 | 2% | 6% | 9% | 2% | 7% | 10% | 3% | 7% | 10% | **2%** | **10%** |
| Four Mile Run, Lower Mainstem | 19,773,036.4 | 453.93 | 2,283,478.62 | 5,635,850.89 | 6,723,152.07 | 2,742,113.11 | 5,924,381.87 | 7,192,475.71 | 3,483,690.06 | 6,255,138.05 | 7,630,898.58 | 52.42 | 129.38 | 154.34 | 62.95 | 136.01 | 165.12 | 79.97 | 143.60 | 175.18 | 12% | 29% | 34% | 14% | 30% | 36% | 18% | 32% | 39% | **12%** | **39%** |
| Little Pimmit Run, E. Branch | 23,089,818.3 | 530.07 | 559,268.88 | 1,018,299.91 | 1,317,345.56 | 621,365.70 | 1,065,033.17 | 1,411,330.68 | 683,249.68 | 1,124,785.06 | 1,487,774.19 | 12.84 | 23.38 | 30.24 | 14.26 | 24.45 | 32.40 | 15.69 | 25.82 | 34.15 | 2% | 4% | 6% | 3% | 5% | 6% | 3% | 5% | 6% | **2%** | **6%** |
| Little Pimmit Run, W. Branch | 20,134,550.0 | 462.23 | 477,811.33 | 983,136.09 | 1,222,286.60 | 534,283.00 | 1,043,243.49 | 1,290,590.01 | 607,460.05 | 1,092,672.32 | 1,336,717.81 | 10.97 | 22.57 | 28.06 | 12.27 | 23.95 | 29.63 | 13.95 | 25.08 | 30.69 | 2% | 5% | 6% | 3% | 5% | 6% | 3% | 5% | 7% | **2%** | **7%** |
| Lubber Run | 44,997,296.5 | 1,033.00 | 1,217,901.29 | 3,703,968.70 | 5,182,213.67 | 1,395,011.05 | 4,031,557.39 | 5,423,846.06 | 1,599,424.61 | 4,316,966.99 | 5,655,933.81 | 27.96 | 85.03 | 118.97 | 32.03 | 92.55 | 124.51 | 36.72 | 99.10 | 129.84 | 3% | 8% | 12% | 3% | 9% | 12% | 4% | 10% | 13% | **3%** | **13%** |
| Roaches Run | 30,157,585.0 | 692.32 | 1,416,026.67 | 4,038,893.34 | 5,350,384.11 | 1,590,747.68 | 7,058,068.88 | 9,082,911.46 | 1,921,222.68 | 8,187,940.90 | 9,885,367.54 | 32.51 | 92.72 | 122.83 | 36.52 | 162.03 | 208.51 | 44.11 | 187.97 | 226.94 | 5% | 13% | 18% | 5% | 23% | 30% | 6% | 27% | 33% | **5%** | **33%** |
| Spout Run | 48,995,866.7 | 1,124.79 | 1,685,313.62 | 3,803,935.21 | 4,988,578.60 | 1,952,087.26 | 4,061,252.98 | 5,226,582.50 | 2,137,455.19 | 4,276,826.42 | 5,421,532.06 | 38.69 | 87.33 | 114.52 | 44.81 | 93.23 | 119.99 | 49.07 | 98.18 | 124.46 | 3% | 8% | 10% | 4% | 8% | 11% | 4% | 9% | 11% | **3%** | **11%** |
| Torreyson Run | 13,902,276.4 | 319.15 | 445,976.96 | 962,712.01 | 1,218,925.37 | 919,621.72 | 1,797,367.98 | 2,221,706.97 | 604,273.41 | 1,098,820.41 | 1,292,778.76 | 10.24 | 22.10 | 27.98 | 21.11 | 41.26 | 51.00 | 13.87 | 25.23 | 29.68 | 3% | 7% | 9% | 7% | 13% | 16% | 4% | 8% | 9% | **3%** | **16%** |
| Virginia Highlands | 15,581,557.2 | 357.70 | 644,223.66 | 1,895,204.03 | 2,783,277.64 | 778,837.24 | 2,090,207.91 | 3,197,285.17 | 969,041.92 | 2,370,242.90 | 3,414,138.25 | 14.79 | 43.51 | 63.90 | 17.88 | 47.98 | 73.40 | 22.25 | 54.41 | 78.38 | 4% | 12% | 18% | 5% | 13% | 21% | 6% | 15% | 22% | **4%** | **22%** |
| | | | | | | | | | | | | | | | | | | | | | 2% | 4% | 6% | 2% | 5% | 6% | 3% | 5% | 6% | | |
| | | | | | | | | | | | | | | | | | | | | | 12% | 29% | 34% | 14% | 30% | 36% | 18% | 32% | 39% | | |

**Note:**

Coastal flood included: 100yr2040, 100yr2070, 500yr2040, and 500yr2070

No Cloastal flood models for - 10yr2020,100yr2020,500yr2020,10yr2040, and 10yr2070

# Appendix G
# Social Vulnerability Index Background

# CDC Social Vulnerability Index (CDC SVI)

A tool to identify socially vulnerable communities

## CDC Social Vulnerability Index

### What is social vulnerability?

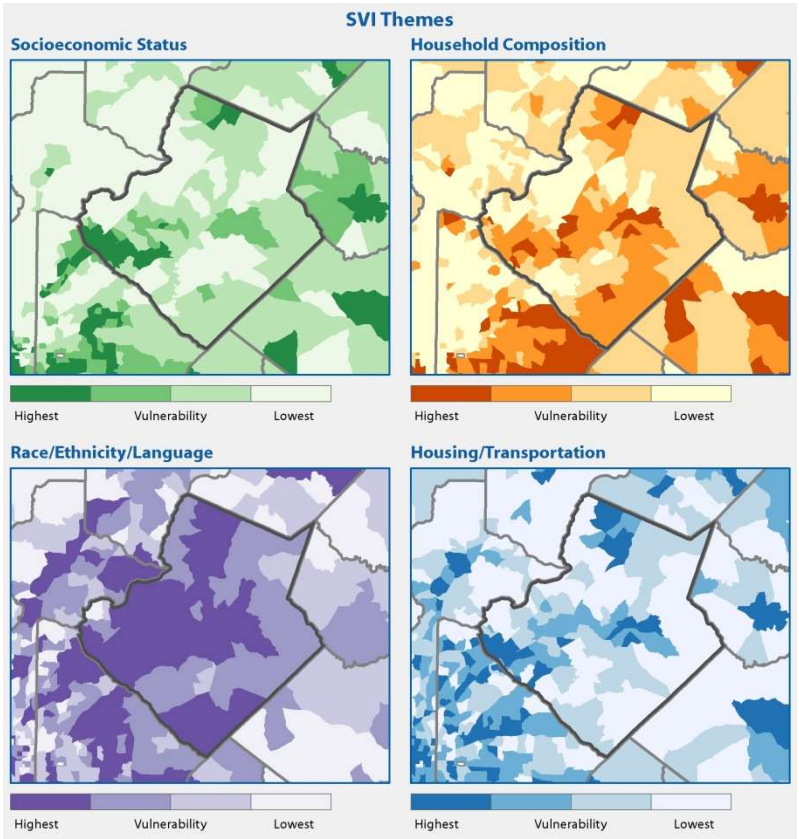
Every community must prepare for and respond to hazardous events, whether a natural disaster like a tornado or disease outbreak, or a human-made event such as a harmful chemical spill. A number of factors, including poverty, lack of access to transportation, and crowded housing may weaken a community's ability to prevent human suffering and financial loss in a disaster. These factors are known as **social vulnerability**.

### What is CDC Social Vulnerability Index?

ATSDR's Geospatial Research, Analysis & Services Program (GRASP) created databases to help emergency response planners and public health officials identify and map communities that will most likely need support before, during, and after a hazardous event.

Hurricane Sandy - Breezy Point, NY  Photographer – Pauline Tran

CDC SVI uses U.S. Census data to determine the social vulnerability of every census tract. Census tracts are subdivisions of counties for which the Census collects statistical data. CDC SVI ranks each tract on 15 social factors, including poverty, lack of vehicle access, and crowded housing, and groups them into four related themes. Maps of the four themes are shown in the figure below. Each tract receives a separate ranking for each of the four themes as well as an overall ranking.




Maps show the range of vulnerability in Gwinnett County, Georgia for the four themes.

### How can CDC SVI help communities be better prepared?

CDC SVI can help public health officials and local planners better prepare for and respond to emergency events like hurricanes, disease outbreaks, or exposure to dangerous chemicals.

CDC SVI databases and maps can be used to:

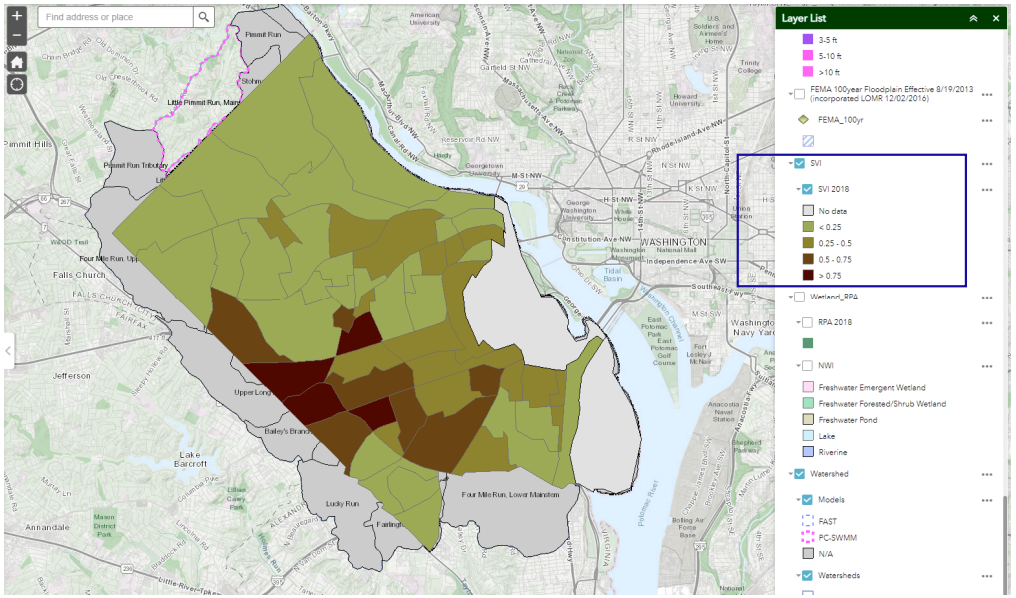
- Estimate the amount of needed supplies like food, water, medicine, and bedding.
- Help decide how many emergency personnel are required to assist people.
- Identify areas in need of emergency shelters.
- Plan the best way to evacuate people, accounting for those who have special needs, such as people without vehicles, the elderly, or people who do not understand English well.
- Identify communities that will need continued support to recover following an emergency or natural disaster.

For more information, please contact the CDC SVI Coordinator (svi_coordinator@cdc.gov).

Geospatial Research Analysis, and Services Program (GRASP)
Division of Toxicology and Human Health Sciences, ATSDR
Centers for Disease Control and Prevention
Agency for Toxic Substances and Disease Registry

# High SVI as Receptors for Vulnerability Analysis

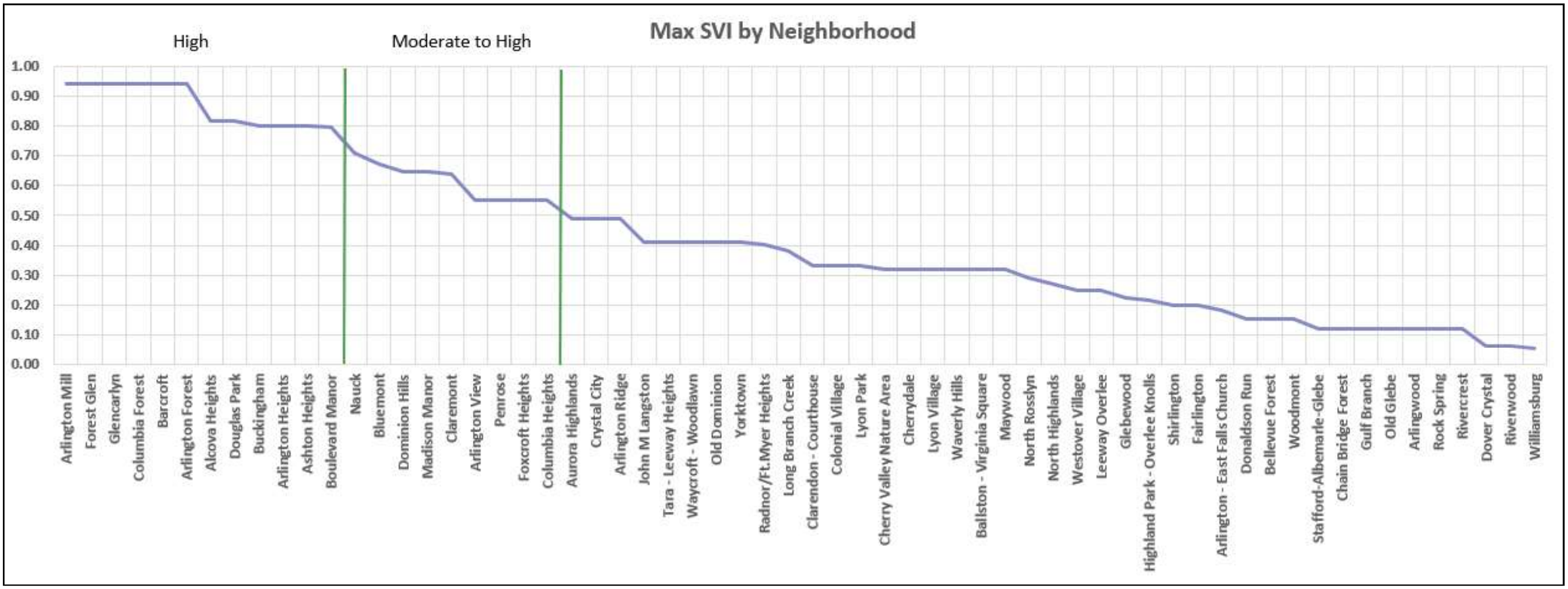
- A census tract with High SVI can be treated as a unit of analysis, the same way we treat facilities or business districts
- Sensitivity is, by definition, high
- Adaptive capacity is, by definition, low
- Exposure determined by flood analysis
- Decision: define the SVI threshold (which tracts are included/excluded as High SVI)






©Jacobs 2019

# Figure F-1: Maximum SVI Values per Neighborhood Area in Arlington County




Note:
This is done just as a reference since the analysis will not be conducted by neighborhood.
High SVI: 0.75 to 1.00
Moderate to High SVI: 0.50 to 0.75

# Appendix E
# Arlington Flood Risk Assessment Technical Memorandum

ARLINGTON
VIRGINIA

# Flood Risk Assessment and Management Plan (RAMP)

## Arlington Flood Risk Assessment (Task 5)

**Final**

**October 2023**

**Arlington County, Virginia**

# Flood Risk Assessment and Management Plan (RAMP)

| | |
|---|---|
| Project No: | E5X65609 |
| Document Title: | Arlington Flood Risk Assessment (Task 5) |
| Revision: | 1 |
| Date: | October 2023 |
| Client Name: | Arlington County, Virginia |
| Project Manager: | Laurens van der Tak |
| Authors: | Cameron Lancaster, Enrique Lopezcalva |
| File Name: | Arlington_Stormwater_RAMP_TM_5 Final |

Jacobs Engineering Group Inc.

2551 Dulles View Drive
7th Floor
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

**Document History and Status**

| Revision | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| 0 | September 2022 | Draft | Jacobs Team | Enrique Lopezcalva | Laurens van der Tak | Laurens van der Tak |
| 1 | October 2023 | Final | Jacobs Team | Enrique Lopezcalva | Laurens van der Tak | Tara Ajello |

# Executive Summary

Arlington County, Virginia (the County) initiated a study to support the Flood Risk Assessment and Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for the Arlington County Department of Environmental Services resulting in a comprehensive RAMP to address the risk of flooding due to current and future climate, and to project and map flood risk in support of a long-term resilience strategy and capital improvement plan.

## Purpose

The purpose of Task 5 was to quantify flood risk in some key areas and facilities through the following means:

- Using flood exposure in those key areas and facilities for different scenarios
- Accounting for the likelihood of those scenarios under which the areas and facilities of interest are exposed
- Accounting for the consequences of flood in the form of monetized impacts resulting from flood and extent of areas of social vulnerability and environmental value
- Computing monetized risk of flood
- Rank areas and facilities based on the risk analysis for definition of mitigation measures under future tasks

## Geographic Scope: Problem Areas and Public Facilities

The vulnerability assessment during Task 4 was conducted at a watershed scale to select watersheds with vulnerable Public Facilities and Problem Areas (PAs). For Task 5, the analysis is conducted at a sub-watershed scale, using 10 Public Facilities and 34 PAs as the receptors of interest. The watersheds are still relevant as a reference and will be mentioned in this TM as appropriate. The watersheds that contain Public Facilities and PAs in the analysis are listed below and depicted on Figure ES-1, including the abbreviation used in this TM for figures and tables:

- Bailey's Branch (BB)[1]
- Doctor's Branch (DB)
- Little Pimmit Run East Branch[2]
- Lubber Run (LR)
- Four Mile Run Lower Mainstem (FMRL)
- Four Mile Run Middle Mainstem (FMRM)[2]
- Roaches Run (RR)
- Spout Run (SP)
- Torreyson Run (TR)

[1] Bailey's Branch modeling included only a small segment of the watershed known to have flooding risk, and incudes a PA in the analysis.

[2] Little Pimmit Run and Four Mile Run Middle Mainstem model results were each used for the analysis of a Public Facility (Little Falls Booster Station and Trades Center – DPR Building/Network Operations Hub) but do not include any PA in it. No abbreviation is used (not included in PA analysis tables and figures).

With the information on exposure and considerations of criticality of the facilities, a short list of Public Facilities was prioritized during Task 4 for detailed analysis of risk under Task 5. These Public Facilities included:

- ART Operations & Maintenance Facility, located in Four Mile Run Lower Mainstem (with a part of it in Naucks Branch watershed)
- Cardinal Elementary School, located in Torreyson Run
- Cherrydale Health and Rehab Center, located in Spout Run
- Gunston Middle School and Community Center, located in Four Mile Run Lower Mainstem
- Little Falls Booster Station, located in Little Pimmit Run East Branch
- TJ Middle School and Community Center, located in Doctor's Branch
- Trades Center – DPR Building/Network Operations Hub, located in Four Mile Run Middle Mainstem
- Trades Center – Equipment Bureau, located in Four Mile Run Middle Mainstem
- VA Hospital Center, located in Lubber Run
- Water Pollution Control Plant (WPCP), located in Four Mile Run Lower Mainstem

In the context of this project, a "Problem Area" is defined as an area exposed to flooding within a county watershed, based on hydrologic/hydraulic modeling and flood complaint calls. The boundary of flooded area included in each PA was delineated approximately based on maximum contiguous extent of flood exposure and potential location of mitigation alternatives (conveyance or storage improvements) to hydraulic deficiencies for the flooded area. The PAs analyzed in Task 5 are presented on Figure ES-2.

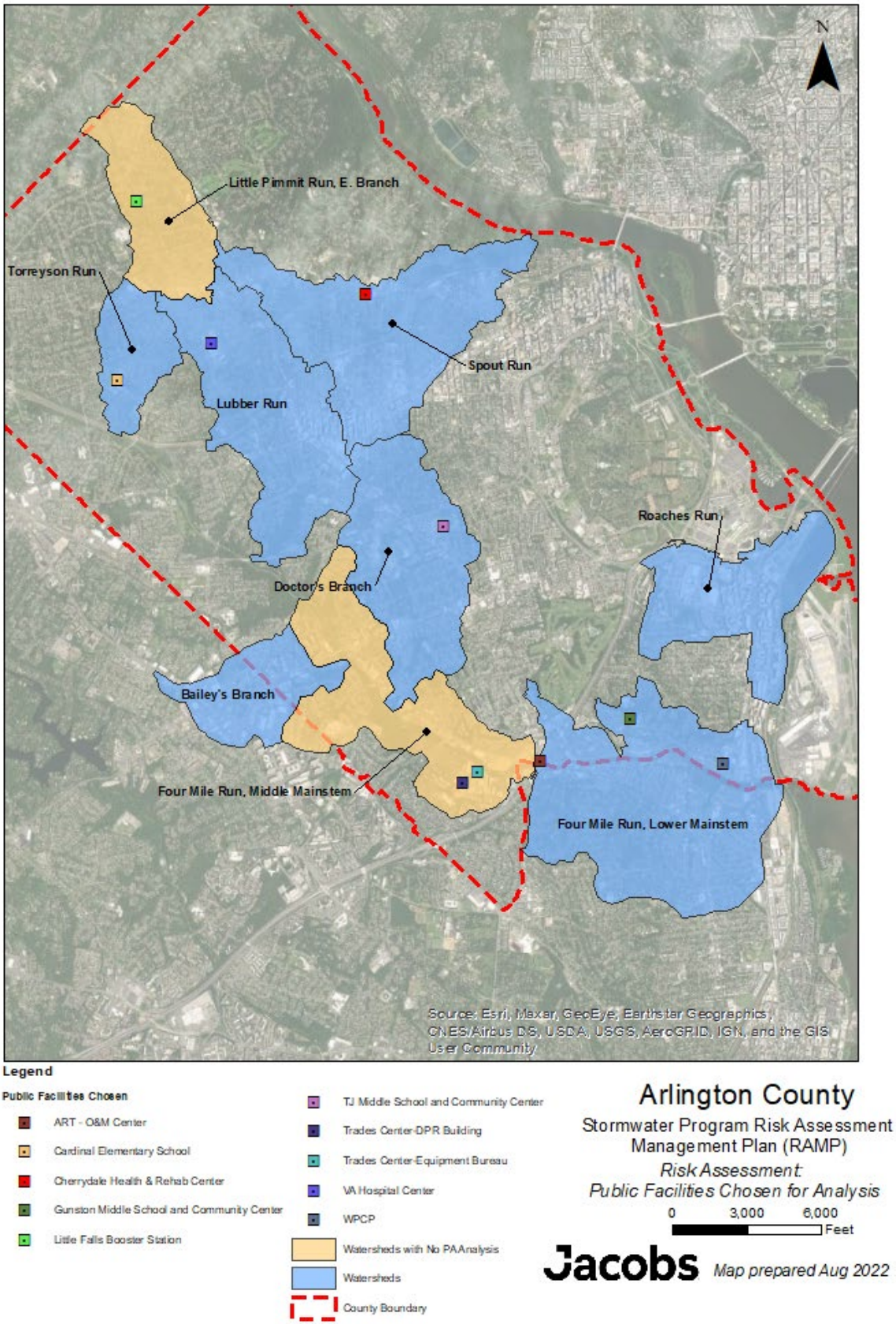



**Figure ES-1. Arlington County Public Facilities and Watersheds Selected for Risk Analysis**

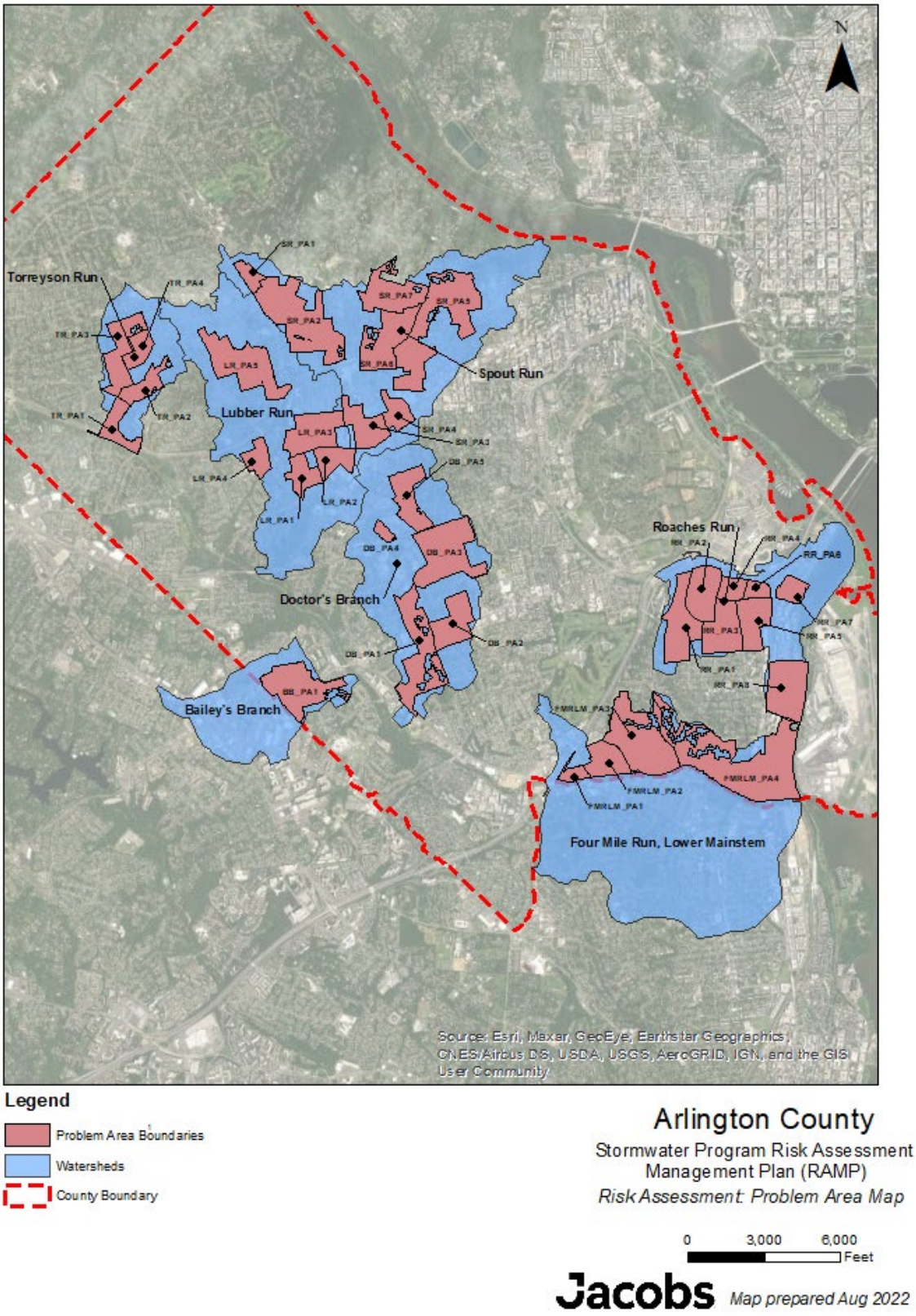



**Figure ES-2. Arlington County Problem Areas Selected for Risk Analysis**

## Methods

Risk Principles of probability of a flood event and resulting consequences of that event were used in the risk analysis for both PAs and Public Facilities. The PAs and Public Facilities, however, used different tools for the analysis, given the different nature (neighborhood scale vs parcel/property-scale).

### Problem Areas

To complete the overall problem area risk assessment site-specific flood inundation depth grids were developed for baseline 2020 and future 2070 design storm event scenarios as follows.

- Baseline 2020: 2-, 10-, 50-, 100- and 500-year storms
- Future 2070: 10-year and 100-year storms.

### Economic Risk Methodology

The hazard risk tool Hazus (developed by the Federal Emergency Management Administration, [FEMA]) was used for the Arlington RAMP, to estimate risk of losses due to potential flooding of flood PAs with the County. It was used to quantify and map potential economic risk of building and vehicle damage by floods. The Hazus flood model calculates physical damage and economic loss due to inundation from flood events.

The flood inundation depth grids were used in conjunction with damage and economic risk profiles included in Hazus database for Arlington County by census block (later aggregated at PA scale) to calculate annualized economic losses for buildings and vehicles.

### Social and Environmental Risk Methodology

Social and environmental and risk analysis is an area analysis using information on social vulnerability and environmentally relevant areas. The main outcome for Task 5 in social and environmental vulnerability includes:

- Social vulnerability in two categories, as follows:
  - Medium to High social vulnerability index (SVI) areas flooded for each PA
  - High SVI area flooded for each PA
- Resource Protection Areas (RPAs) area flooded for each PA (in some cases a PA does not have any RPA extent which means not flooded area)

The Centers for Disease Control SVI value range is 0.0 to 1.0 and Task 5 uses the same value thresholds for Medium to High (0.5 to 0.75) and High (larger than 0.75) definition used during Task 4.

RPAs are natural buffers that help protect streams, rivers, and other water bodies. They include the environmentally sensitive lands within 100 feet of most Arlington County water resources.

Given that we have 10-year, 100-year and 500-year return intervals and areas computed for each, areas estimated in Geographic Information System need to be adjusted (weighted) by the probability of the scenario (a key element of risk analysis is to account for the probability of each impact).

**Aggregation of Economic, Social, and Environmental Risk Methodology**

Since the PA risk analysis involves not only the economic impacts but also the socially vulnerable and environmental impact areas, aggregation of results is necessary. A simple multi-attribute rating technique (MART, also referred to Multi-Objective Decision Analysis or MODA), is used for the aggregation. An overall score for risk is computed by combining criteria and criteria weighting factors. For Task 5 we use the following simple formula:

Overall Risk Score = Economic Score * Economic Weight +
Environmental Score * Environmental Weight +
Social Score * Social Weight

A characteristic of MART is that all outputs for each criterion (economic, social and environmental) are normalized to a common scale. In the Task 5 PA analysis, the economic risk results are in dollars ($), while the social vulnerability areas and environmental areas are in square feet[3]. Normalization to a common scale adds the following benefits:

- Removes units for each variable and allows for a simple addition of a final score based on the three criteria
- A scale of 1 to 5 was used for this analysis (with 1 representing lowest impact and 5 representing highest impact). This allows for easier comparison of the relative ranking of PAs across different criteria.

**Public Facilities**

The main methodology steps in the Public Facilities analysis included the definition of flood elevations for multiple scenarios in specific locations in each facility and facility vicinity, and the overlay of that information with the asset inventory and elevations. The key to the analysis is the comparison of water surface elevations under multiple scenarios to the elevations of the assets (and the flow path to the assets). Nine flood scenarios were used to determine building and asset risk, representing 3 planning horizons:

- Baseline 2020: 10-yr, 100-yr and 500-yr
- 2040: 10-yr 100-yr and 500-yr
- 2070: 10-yr 100-yr and 500-yr

The two additional base scenarios (2020, 2-yr and 2020, 50-yr) were also included to create a best-fit curve of risk assessment based on water surface elevations (WSEs) in all scenarios. The curve allows for estimates of risk beyond the specific scenarios modeled.

Once the elevation threshold is reached for a given asset, the replacement cost of it is triggered in the analysis. Figure 4-2 illustrates the process. Figure 4-3 illustrates one sample facility and the flood elevation versus asset elevation comparison that the risk tool is performing.

[3] While outputs from the PA analysis, for each scenario are in dollars and square feet, the values of the risk analysis, which aggregates multiple scenarios with different probabilities, are "expected" dollars and "expected" square feet (since equations have been applied to account for probability).

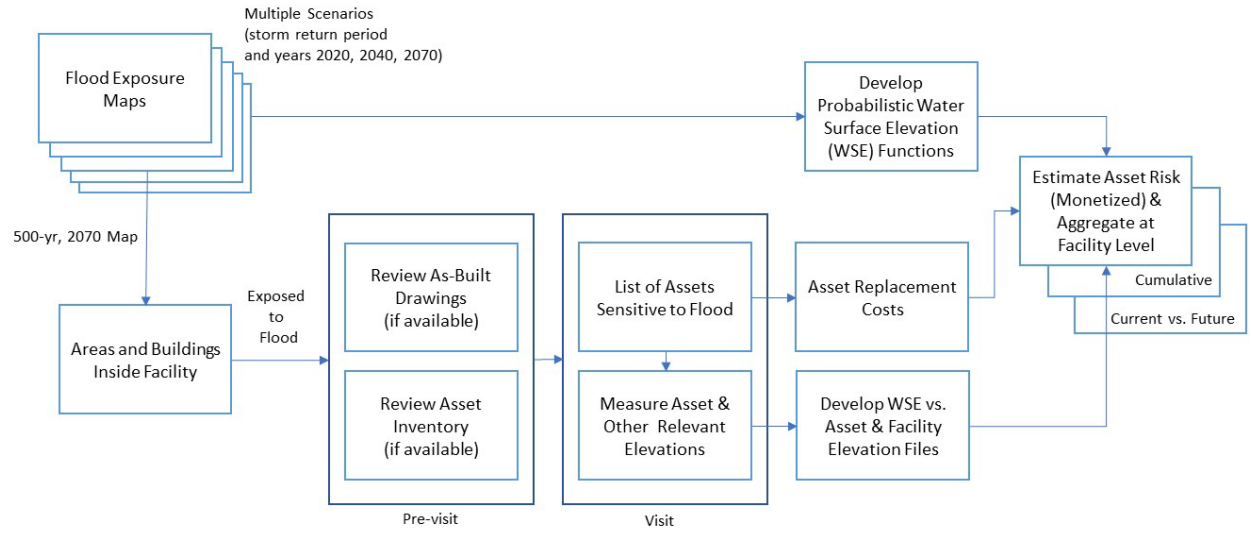



**Figure ES-3. Public Facilities Risk Analysis Overall Process**

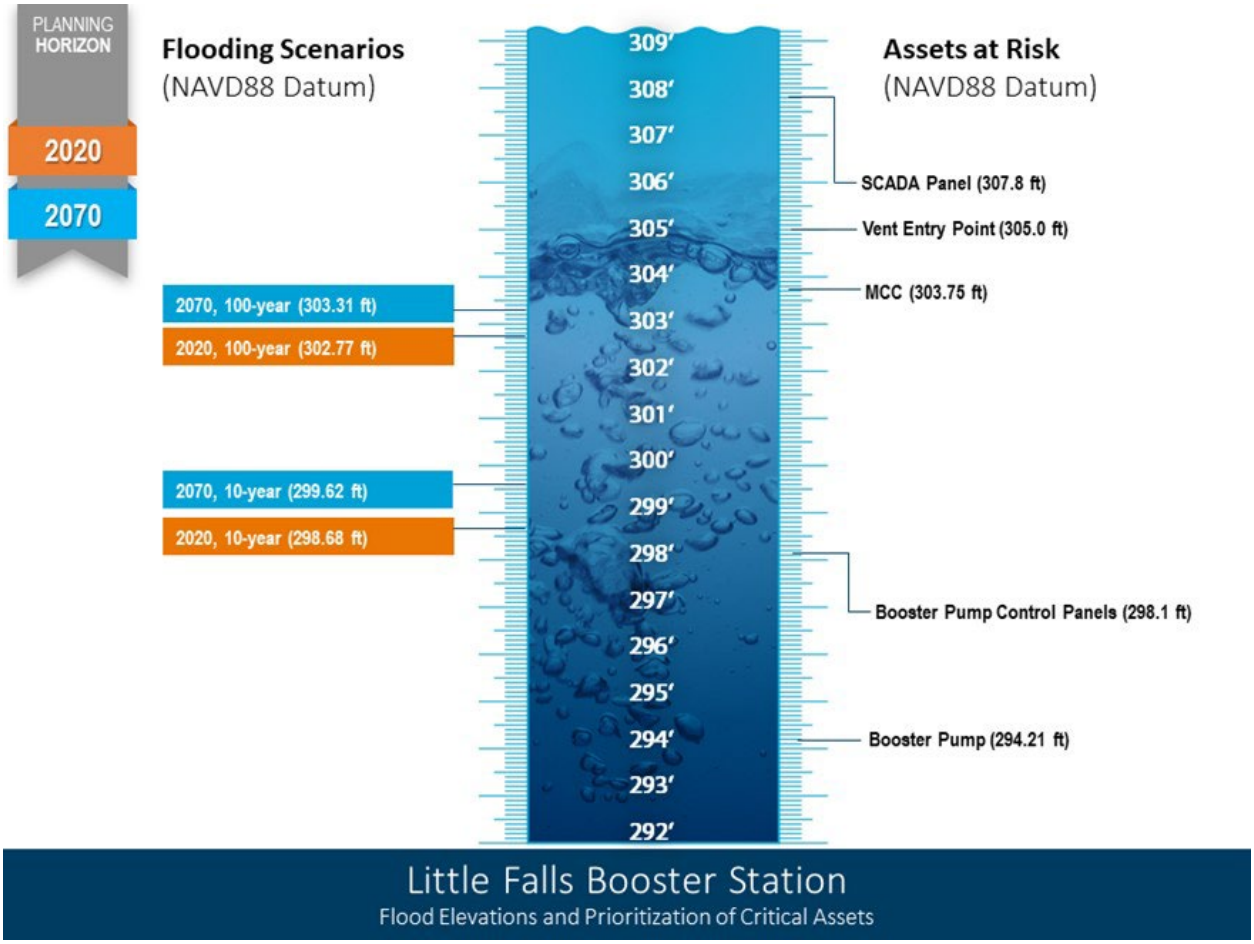



**Figure ES-4. Water Surface Elevation for Different Flood Scenarios Compared to Asset Elevations for a Sample Facility**

## Risk Results for Problem Areas

### Economic Risk

The economic risk analysis is the result of the Hazus analysis which uses an economic property valuation and economic losses database from 2018 (the Benefit-Cost Analysis in Task 6 will require escalation of losses to match costs estimates of mitigation solutions). Direct and indirect losses associated with building and vehicle stock are combined into an overall monetized risk value. Detailed results of economic losses for each PA are presented in Appendix E, in problem area fact sheets. Figure ES-5 presets the annualized risk result. The most significant economic risk as estimated by Hazus is observed in some PAs in Roaches Run, Lubber Run and Spot Run. Each of the PAs with significantly high economic risk coincide with areas that have commercial activity. These results illustrate the importance of considering criteria beyond economic impact in risk-based prioritization, related to social and environmental variables, which are included in this analysis and described in the following sections.

Although the watersheds are not the area of analysis for Task 5, the summary of economic risk by watershed illustrates that the most significant risk is generally associated to the areas with economic activity. Table ES-1 present the results by watershed.

**Table ES-1. Economic Risk by Watershed**

| Watershed | Annualized Risk of Total Losses (Thousands $)[1,2] | Potential losses for 100-yr Storm (Thousands $)[2] | |
|---|---|---|---|
| | | 100-yr storm in 2020: 8.5 inches in 24 hours | 100-yr storm in 2070: 9.6 inches in 24 hours |
| Roaches Run | 112,845 | 718,937 | 803,499 |
| Spout Run | 40,992 | 234,391 | 263,372 |
| Lubber Run | 32,422 | 297,178 | 344,221 |
| Four Mile Run Lower Mainstem | 14,690 | 109,245 | 136,793 |
| Doctor's Branch | 6,363 | 38,965 | 46,145 |
| Torreyson Run | 2,628 | 17,862 | 19,650 |
| Bailey's Branch | 1,028 | 7,507 | Not Available[3] |

Note:

[1] Hazus uses loss and economic property valuation data sets that were last updated in 2018

[2] Risk of losses accounts for the probability associated with different storm events generating losses

[3] This watershed was not modeled under 2070 conditions

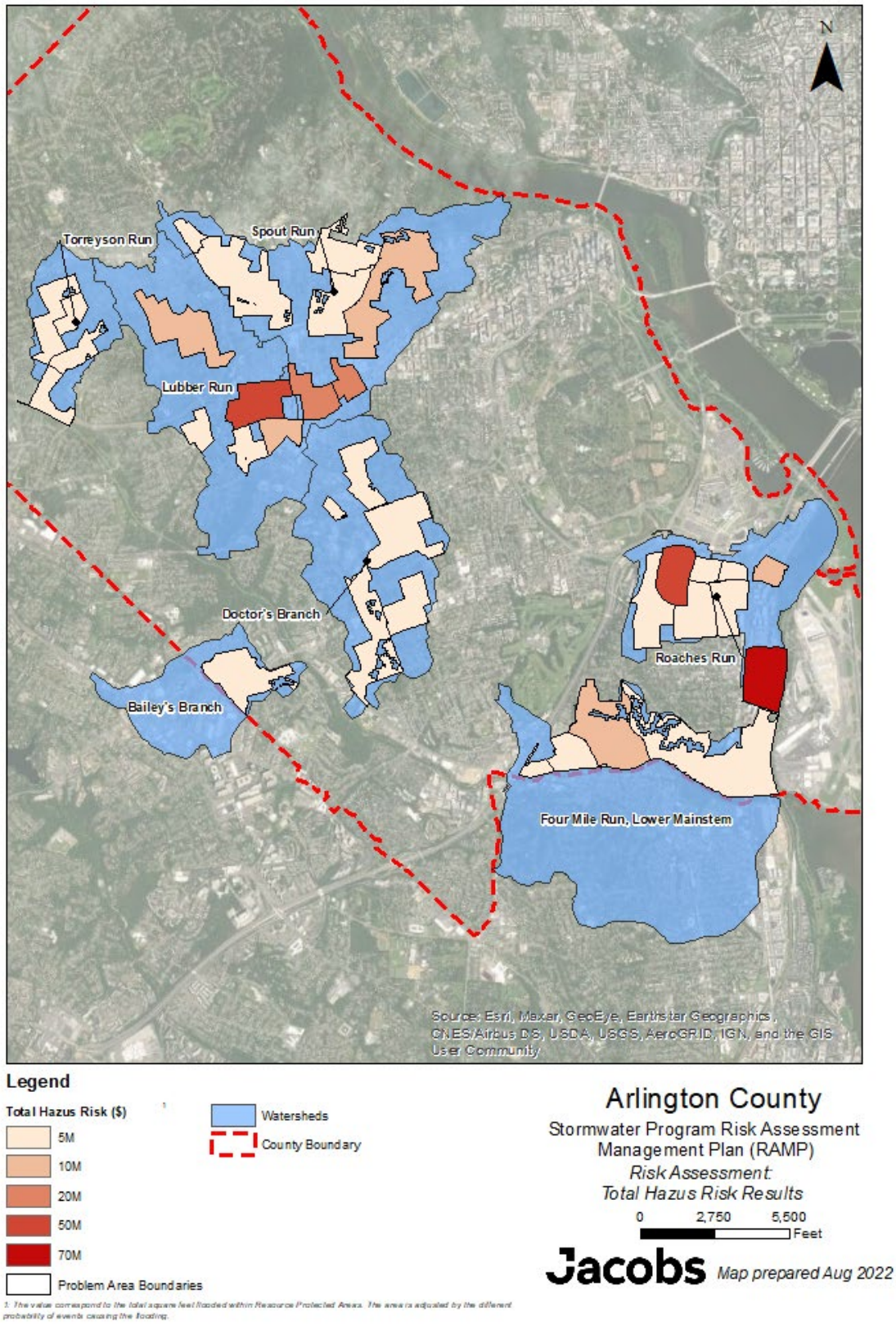



**Figure ES-5. Economic Risk for Problem Areas in the Analysis (Based on 2018 Loss and Economic Valuation)**

## Environmental and Social Risk

Results of amount RPA flooded in each PA per flood event scenario is presented in Appendix E, in the problem area fact sheets. Based on the results presented, PAs within Four Mile Run Lower Mainstem appear to show the most consistent flooding within their RPAs across all flood event scenarios. Four Mile Run Lower Mainstem watershed sits directly adjacent to the mouth of Four Mile Run as it exits into the Potomac River, as such the consistent flooding of its RPAs is understandable. In reviewing the RPA flooded area results it is important to point out that, while RPAs are areas of significant environmental value, a significant extent of the total RPA area in the county is in the floodplain for runs and creeks.

Results of flooded areas with high social vulnerability (SVI index values of 0.5 to 1.0) in each identified problem area are presented in Appendix E, in the problem area fact sheets. Doctor's Branch is clearly the watershed with the greatest flood risk to socially vulnerable communities. It is, in fact, a watershed that was prioritized during Task 4 for analysis in Task 5 due to the flood impacted areas with high SVI values (Jacobs 2021a).

Results of the social vulnerability flooded areas illustrates the importance of using more than economic parameters for risk prioritization. The Hazus results show Doctor's Branch ranked 5th out of 7 watersheds in economic risk.[4]

Figure 5-5 presents the map of PAs with total expected area flooded for high SVI areas (areas flooded for each scenario are normalized for probability of the scenario, for consistency with Hazus results).
Table ES-2 present the results of social vulnerability risk and environmental area risk by watershed.

**Table ES-2. Social and Environmentally Vulnerable Area Risk by Watershed**

| Watershed | RPA Expected[1] Flooded Area (square feet) | High SVI Expected[1] Flooded Area (square feet) |
|---|---|---|
| Bailey's Branch | 9,864 | 26,342 |
| Doctor's Branch | 352,243 | 511,763 |
| Four Mile Run Lower Mainstem | 860,826 | — |
| Lubber Run | 196,776 | — |
| Roaches Run | — | — |
| Spout Run | 107,988 | — |
| Torreyson Run | 2,172 | — |

[1] Areas estimated for each flood scenario and adjusted by probability, consistent with Hazus methodology for annualized economic risk.

[4] Bailey's Branch ranks 7th out of seven watersheds in terms of economic risk, but results for it can be misleading given that the flood analysis did not include the entire watershed.

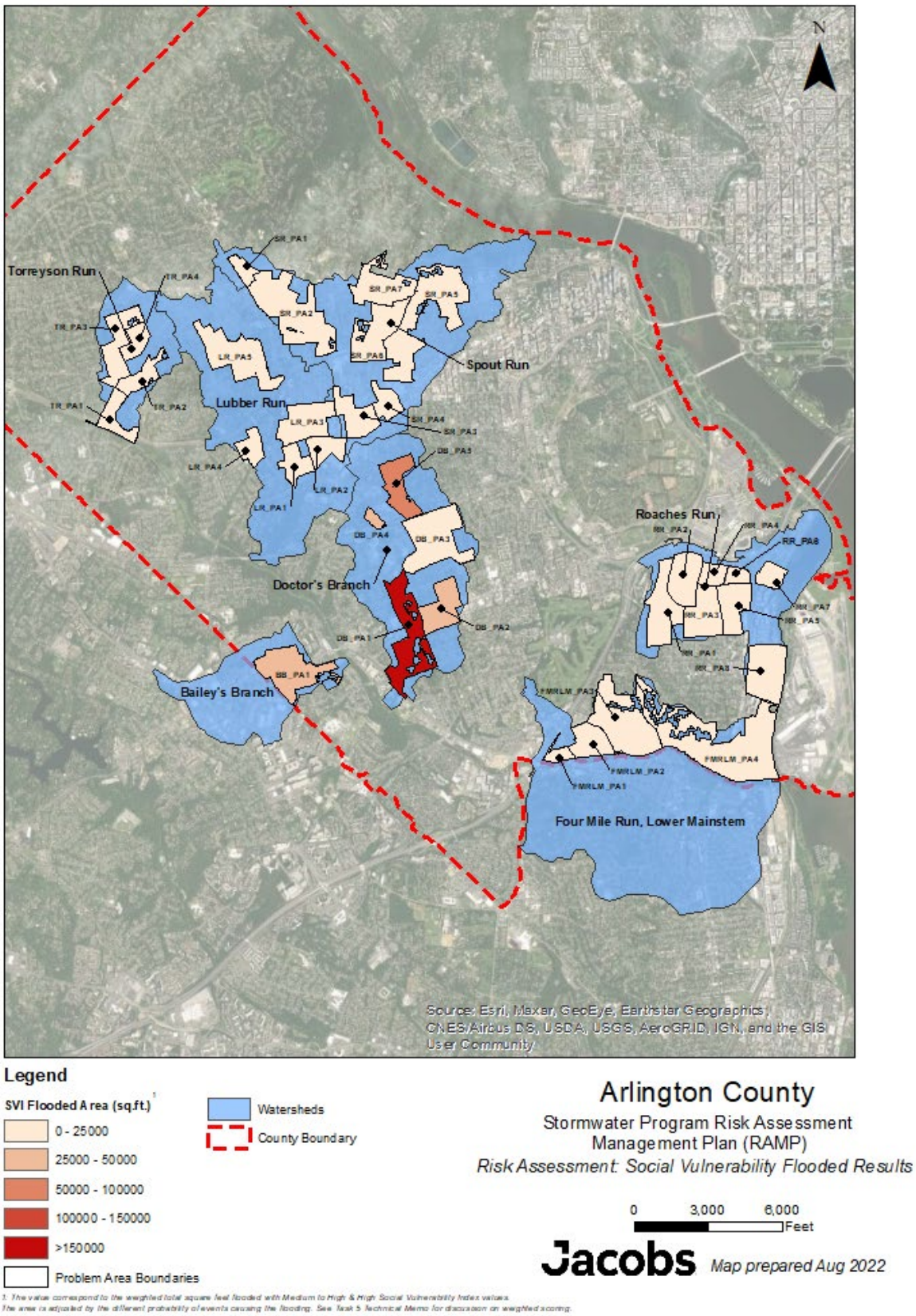



**Figure ES-6. Map of High Social Vulnerability Area Flooded, Accounting for Probability of Flood Scenarios**

## Summary of Risk for Problem Areas

The total risk score accounting for economic, social and environmental criteria scores is presented in Figure 5-8. The figure uses a stack bar that allows for a quick view of the contribution from each criterion to the final overall score. The sorting of PAs in Figure ES-7 assumes weights assigned to economic, social and environmental risk are 50%, 40%, and 10%, respectively.

Total Risk Score = (Economic Risk Normalized Score * 0.5) +
+ (Social Vulnerability Normalized Score * 0.4)
+ (Environmental Areas Normalized Score * 0.1)

The total risk score shows generally three tiers of PAs:

- A high tier with 4 PAs including RRA8, DBPA1, LRPA3 and EEPA2 (two PAs in Roaches Run, one in Lubber Run and one in Doctor's Branch)
- A middle tier from the 5th ranked PA (FMRLMPA4) to about the middle of the chart (17th PA)
- A low-ranking tier from about middle of the chart to the last PA in terms of total score

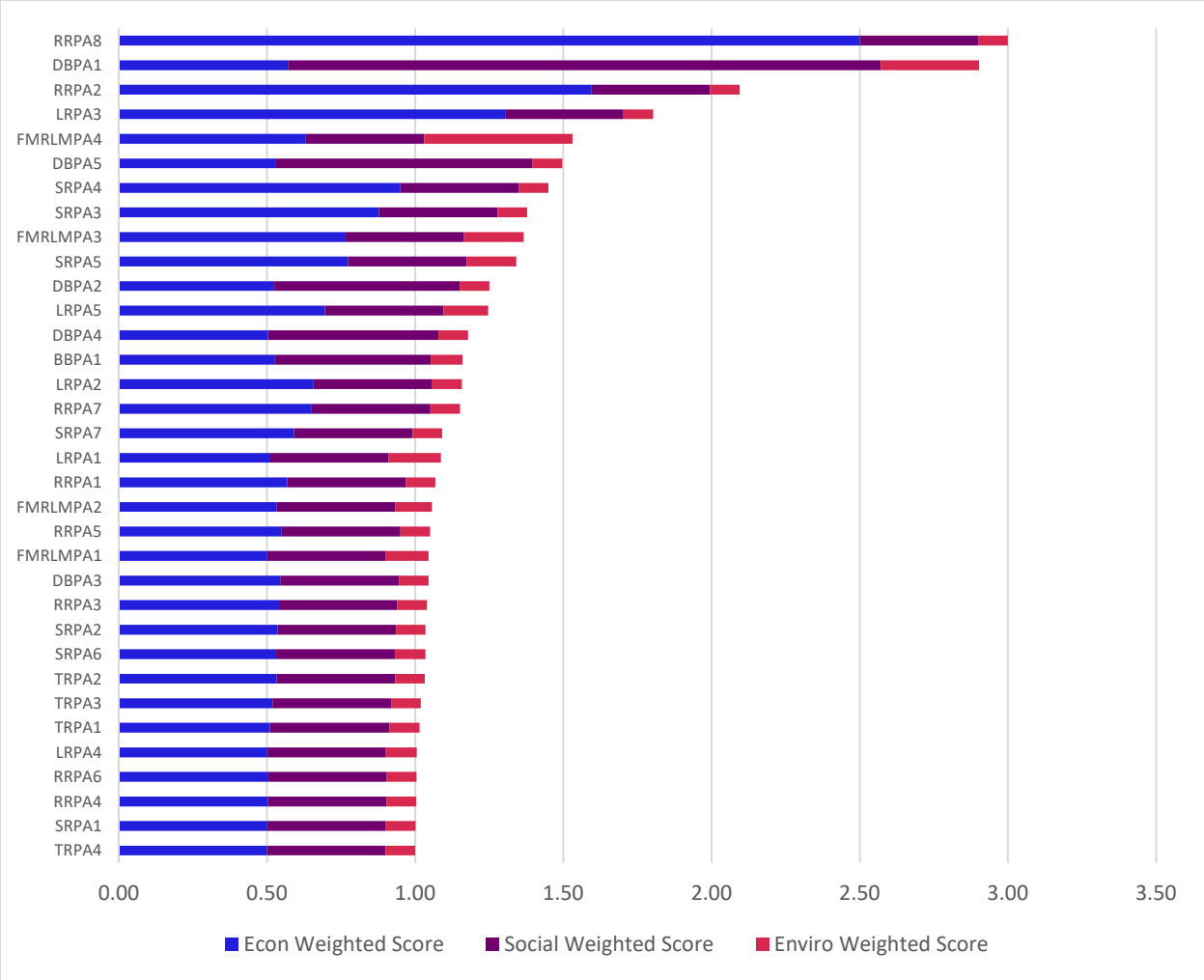



**Figure ES-7. Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria**

Analyzing the contribution of the individual criteria to the total score it is apparent that PA's can be high-ranking due to high economic risk, or high social risk. The environmental criterion is a significant contributor to FMRLPA4 and to DBPA1.

A sensitivity analysis of different weighted values for each of the economic, social and environmental criteria was tested and different ranking graphics in the sensitivity analysis are presented in **Appendix F**. The objective of the sensitivity analysis was to identify PAs that can move significantly higher or lower in the prioritization when the criteria weights change. The sensitivity analysis generally showed low sensitivity in the top-ranking PAs, with Roaches Run and Doctor's Branch PAs reaching the top spots as the economic criterion weight and social criterion weight increase, respectively.

## Risk Results for Public Facilities

Three main differences exist in the results of the Public Facilities risk analysis compared to the PAs analysis:

- The Public Facilities risk analysis includes only the economic criterion (no social or environmental criteria are needed)
- The estimates of losses are based on asset replacement values specifically for the assets identified in the field visit of each public facility. The cost estimates are in year 2022 dollars (compared to the 2018 loss and valuation datasets of Hazus used for PAs)
- Results of the Public Facilities account for cumulative risk over 20 years

The summary of risk by facility is presented in Table ES-3. The table also shows the number of assets that were identified as potentially vulnerable and the total replacement costs for those assets.

**Table ES-3. Summary of Economic Risk Cumulative Over a 20 Year Period for Public Facilities[1]**

| Public Facility | Number of Assets | Asset Replacement Cost (Thousands $)[2] | Total Cumulative Risk (Thousands $)[3] |
|---|---|---|---|
| WPCP South | 836 | 97,223 | 32,270 |
| WPCP North | 282 | 26,240 | 10,137 |
| VA Hospital | 68 | 19,882 | 5,659 |
| Thomas Jefferson Middle School | 92 | 8,724 | 1,798,042 |
| Little Falls Pump Station | 30 | 3,533 | 100 |
| Gunston School | 129 | 3,420 | 60 |
| Cherrydale Center | 68 | 3,343 | 1 |
| Cardinal Elementary School | 94 | 3,156 | <1[5] |
| ART O&M Center | 87 | 40,240 | <1[4] |

[1] The Trades Center NOCII & Equipment Bureau facilities are excluded from this table given that no asset damage was predicted. These facilities do observe flooding in access roads which could represent indirect losses that are not accounted for in our analysis, which is based on direct damages.

[2] In year 2022 basis. This represents the value of all assets in the facility that could be sensitive to flood and not only the assets that are predicted to be exposed.

[3] Over a 20-year period, using a discount rate of 4%

[4] Significant flooding can occur in the vicinity and parking lots

[5] Significant flooding observed in the vicinity and access roads

O&M = operations and maintenance

Results include a large range of cumulative risk, from minimal risk to the assets within the facilities, to tens of millions of dollars. It is important to mention that all facilities are in areas expected to flood based on historical information and model results. Some facilities, however, show limited monetary impact based on the approach used in this RAMP, which bases the monetization of flood impacts on "inside the fence".

The Trades Center NOCII, Trades Center Equipment Bureau, Cardinal Elementary School and ART O&M Center facilities do observe flood impacts in access roads under multiple scenarios. Flooding, in some cases significant, is projected by the models in the general vicinity of these facilities, which could impact access and exit from the site. The risk analysis in this task does not include monetary impacts to roads in the general perimeter of the facilities or to private vehicles in the area. These sites should not be considered flood risk free even though results in Task 5 show no risk associated with asset damage and potential replacement.

An additional consideration for the ART O&M Facility analysis is that the analysis used a projected asset inventory, location and elevations, based on 100% design drawings and assumptions (including assumptions about buses housed in the facility). The facility should not be considered risk free and a new analysis for it would be recommended after the new facility is completely constructed.

The Public Facilities analysis also shows that climate change exacerbation of the intensity of rainfall has an impact on risk, increasing risk over time for a given facility. Figure ES-8 shows the comparison of risk for three planning horizons (2020, 2040 and 2070) for one of the flood vulnerable locations visited at the WPCP (Activated Sludge Effluent Pump Station, used as example). The risk evolution shown in Figure ES-8 reflects the change in intensity of rainfall during the 10-yr, 100-yr and 500-yr storms, and the resulting flood exposure.

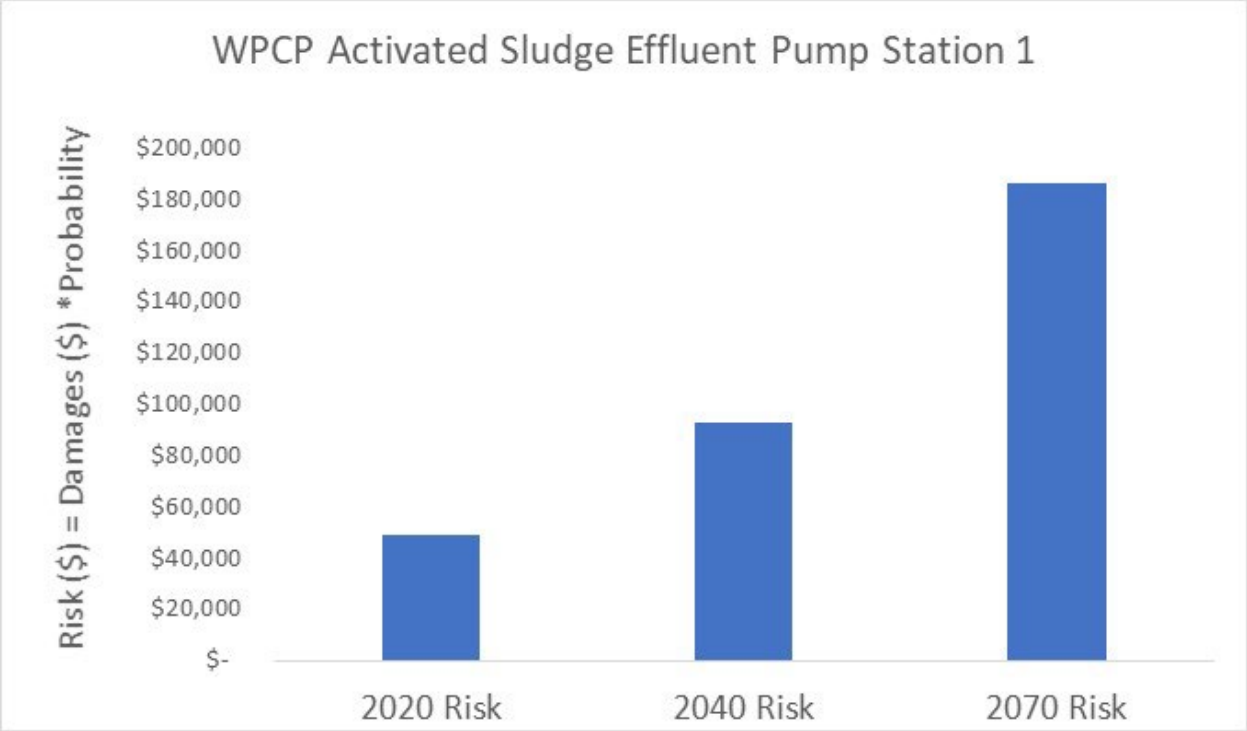



**Figure ES-8. Facility Flood Risk Increase Over Time as a Result of Climate Change**

## Next Steps

Task 5 analysis will be presented at a workshop setting to receive feedback and develop a final ranking of Public Facilities and PAs. Results from the workshop will be reflected in the RAMP final report and used during Task 6.

With conceptual risk and vulnerability profile developed for the PAs which include a variety of public and private assets within multiple facilities, conceptual flood mitigation strategies will be developed to address each problem area and site-specific mitigation strategies will be evaluated for up to 10 public facilities.

Strategies will be developed with attention to system design and operational practicability and cost effectiveness for each asset type. The list of strategies for the selected public facilities will be reviewed with the County staff and key stakeholders for refinement and buy in.

Planning level costs will be estimated for the selected strategies for current and future climate scenarios, and benefit-cost analysis will be performed to allow comparison of different return on investment for different levels of flood control (flood depths at different recurrence intervals). This will include the use of Hazus results and Public Facility risk results, which constitute a measure of benefit (avoided monetary risk of flood).

# Contents

**Executive Summary** ..... **i**

**Acronyms and Abbreviations** ..... **xix**

**1. Introduction** ..... **1**

1.1 Task Purpose ..... 1

1.2 Problem Areas and Public Facilities ..... 1

1.3 Geographic Scope of Risk Analysis ..... 2

1.3.1 Watersheds and Public Facilities ..... 2

1.3.2 Problem Areas ..... 5

1.4 Task Terminology ..... 7

**2. Risk Analysis Approach for the RAMP** ..... **7**

**3. Data and Information Sources** ..... **9**

3.1 Exposure and Scenarios ..... 9

3.2 Public Facilities Data ..... 9

3.2.1 Methodology for Public Facility Data Collection ..... 9

3.2.2 Outcome of Public Facility Visits and Data Collection Efforts ..... 10

3.3 Problem Areas Data ..... 10

3.3.1 Data Sources and Collection for Economic Analysis ..... 10

3.3.2 Data Sources and Collection for Environmental Analysis ..... 11

3.3.3 Data Sources and Collection for Social Vulnerability Analysis ..... 11

3.3.4 Data Sources for Roads Analysis ..... 11

**4. Risk Analysis Methodology** ..... **11**

4.1 Problem Areas ..... 12

4.1.1 Hazus – Economic Analysis ..... 12

4.1.2 Road Impacts ..... 13

4.1.3 Social and Environmental Impacts ..... 13

4.1.4 Aggregation of Economic, Social and Environmental ..... 14

4.2 Selected Public Facilities ..... 15

4.2.1 Flood Exposure of Sensitive Assets ..... 16

4.2.2 Monetized Impact ..... 17

**5. Risk Analysis Results** ..... **18**

5.1 Problem Areas ..... 18

5.1.1 Economic Risk Analysis ..... 20

5.1.2 Social and environmental Criteria ..... 24

5.1.3 Risk Evolution for Problem Areas Due to Climate Change ..... 29

5.1.4 Summary of Risk for Problem Areas ..... 29

5.2 Public Facilities ..... 32

5.3 Public Facilities and Problem Area Results Discussion ..... 35

**6. Next Steps** ..... **36**

**7. References** ..... **36**

**Appendices**


A Problem Area Definition
B Asset Replacement Cost Estimates
C Hazus Overview
D Social Vulnerability Index & Environmental Areas Background
E Problem Area Fact Sheets
F Criteria Weight Sensitivity for Problem Area Ranking
G Public Facilities Results


**Tables**


ES-1 Economic Risk by Watershed ..... viii
ES-2 Social and Environmentally Vulnerable Area Risk by Watershed ..... x
ES-3 Summary of Economic Risk Cumulative Over a 20 Year Period for Public Facilities[1] ..... xiii
5-1 Full List of All 34 Problem Areas in Risk Analysis ..... 19
5-2 Economic Risk by Watershed ..... 22
5-3 Top 10 PAs for Road Impacts by Flood ..... 23
5-4 Social and environmentally Vulnerable Area Risk by Watershed ..... 28
5-5 Summary of Economic Risk Cumulative Over a 20 Year Period for Public Facilities[1] ..... 33


**Figures**


ES-1 Arlington County Public Facilities and Watersheds Selected for Risk Analysis ..... iii
ES-2 Arlington County Problem Areas Selected for Risk Analysis ..... iv
ES-3 Public Facilities Risk Analysis Overall Process ..... vii
ES-4 Water Surface Elevation for Different Flood Scenarios Compared to Asset Elevations for a Sample Facility ..... vii
ES-5 Economic Risk for Problem Areas in the Analysis (Based on 2018 Loss and Economic Valuation) .. ix
ES-6 Map of High Social Vulnerability Area Flooded, Accounting for Probability of Flood Scenarios ..... xi
ES-7 Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria ..... xii
ES-8 Facility Flood Risk Increase Over Time as a Result of Climate Change ..... xv
1-1 Arlington County Public Facilities and Watersheds Selected for Risk Analysis ..... 4
1-2 Arlington County Problem Areas Selected for Risk Analysis ..... 6
2-1 Conceptual Representation of Risk at the intersection of Exposure, Vulnerability and Probability of Hazards ..... 8
4-1 Normalization Scale used in Draft Prioritization ..... 15
4-2 Public Facilities Risk Analysis Overall Process ..... 15
4-3 Water Surface Elevation for Different Flood Scenarios Compared to Asset Elevations for a Sample Facility ..... 17
4-4 Risk Over Time and Cumulative Risk Concept for Public Facilities ..... 18
5-1 Economic Risk in Problem Areas (Based on Year 2018 Loss and Economic Valuation) ..... 21
5-2 Annualized Economic Risk for All Problem Areas ..... 22
5-3 Map of RPA Area Flooded, Accounting for Probability of Flood Scenarios ..... 25
5-4 Environmental (RPA) Area Flooded (Square Feet) for PAs, Accounting for Probability of Flood Scenarios ..... 26
5-5 Map of High Social Vulnerability Area Flooded, Accounting for Probability of Flood Scenarios ..... 27
5-6 High Social Vulnerability Areas (Square Feet) for PAs, Accounting for Probability of Flood Scenarios ..... 28
5-7 Example of Risk Evolution in Problem Areas Due to Climate Change, for Two Representative Areas .. 29
5-8 Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria ..... 30

5-9 Map of Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria (Scale of 1 to 5) ..... 31
5-10 Cumulative Risk (20 Years) for Public Facilities (in $1,000s) ..... 34
5-11 Facility Flood Risk Increase Over Time as a Result of Climate Change ..... 35

# Acronyms and Abbreviations

| | |
|---|---|
| AACEI | Association for the Advancement of Cost Engineering International |
| ATSDR | United States Agency for Toxic Substances and Disease Registry |
| BCA | Benefit-Cost Analysis |
| CDC | Centers for Disease Control |
| County | Arlington County, Virginia |
| FEMA | Federal Emergency Management Agency |
| GIS | Geographic Information System |
| MART | multi-attribute rating technique |
| O&M | operations and maintenance |
| PA | Problem Area |
| RAMP | Risk Assessment Management Program |
| RPA | Resource Protection Area |
| SVI | Social Vulnerability Index |
| TM | technical memorandum |

# 1. Introduction

Arlington County, Virginia (the County) initiated a study to support the Stormwater Program Risk Assessment Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for Arlington County Department of Environmental Services resulting in a comprehensive RAMP. The intent of the Arlington County RAMP is to address the risk of flooding due to current and future climate, and to project and map risk and consequential impacts in support of a long-term resilience strategy. The RAMP will inform a prioritized capital improvement plan, with enhanced design standards and forward-looking asset management and adaptation strategies that will allow the County to maintain a responsive level of service and a pathway for long-term system resilience.

Task 5 of the RAMP conducted analyses to assess flood risk in specific problem areas (PAs) and selected public facilities in the project area. This technical memorandum (TM) documents Task 5.

## 1.1 Task Purpose

The purpose of Task 5 was to quantify flood risk in some key areas and facilities by:

- Using flood exposure in those key areas and facilities for different scenarios
- Accounting for the likelihood of those scenarios under which the areas and facilities of interest are exposed
- Accounting for the consequences of flood in the form of monetized impacts resulting from flood and extent of areas of social vulnerability and environmental value
- Computing monetized risk of flood
- Rank areas and facilities based on the risk analysis for definition of mitigation measures under future tasks

In the overall RAMP process, Task 5 is the risk quantification step after analysis of exposure and vulnerability at a watershed scale and precedes the definition of potential flood mitigation measures. Task 5 uses key inputs from Task 3 and 4 in the RAMP, corresponding to the flood modeling results and vulnerability assessment at a watershed level, respectively. Task 6, Mitigation & Adaptation, will explore and recommend risk mitigation measures and will use information from Task 5 in two ways:

- Risk ranking under Task 5 will inform a prioritization strategy
- Monetized flood impacts under Task 5 will be used for Benefit-Cost Analysis (BCA)

## 1.2 Problem Areas and Public Facilities

A key feature of Task 5 is the distinction between two types of receptors (areas or locations impacted by flood that are of special interest for the analysis): Public Facilities and Problem Areas. Task 5 includes risk analysis for:

- 10 Public Facilities (referred to in this TM as Public Facilities, capitalized): Identified as a result of Task 4, these public facilities were identified as potentially vulnerable to flood impacts and are critical for different public functions. The list, location and description of public facilities is included later in Section 1.3.1

- 34 Problem Areas (Referred to in this TM as Problem Areas and abbreviated as PA or PAs): These areas correspond to areas where flooding is anticipated based on flood modeling results in watersheds prioritized during Task 4 (Vulnerability Assessment) and can include any type of building with residential, commercial, governmental, educational and other uses, as well as emergency response or utility facilities. The PAs are described in Section 1.3.2.

While the framework of the risk analysis is the same for Public Facilities and PAs, the specific methodologies and results are different. In both cases, a key outcome is the monetized impact of flooding, processed with common risk analysis equations to provide annualized metrics of risk (in dollars). For PAs, the analysis also includes metrics related to social vulnerability and environmental areas impacted.

## 1.3 Geographic Scope of Risk Analysis

### 1.3.1 Watersheds and Public Facilities

The vulnerability assessment during Task 4 was conducted at a watershed scale. For Task 5, the analysis is conducted at a smaller scale, using the Public Facilities and PAs as the two receptors of interest. The watersheds are still relevant as a reference and will be mentioned in this TM as appropriate.

Watersheds were prioritized based on vulnerability metrics as part of Task 4 (Jacobs 2021a). Results of Task 4 analyses were presented and discussed in a workshop setting to develop a final list of priority watersheds. Those watersheds include all the receptors of interest for this Task 5 (each of the 10 Public Facilities and 34 PAs are included in these watersheds). The watersheds in the analysis are listed below, including the abbreviation used in this TM for figures and tables):

1) Bailey's Branch (BB)[5]
2) Doctor's Branch (DB)
3) Little Pimmit Run East Branch[6]
4) Lubber Run (LR)
5) Four Mile Run Lower Mainstem (FMRL)
6) Four Mile Run Middle Mainstem[2]
7) Roaches Run (RR)
8) Spout Run (SP)
9) Torreyson Run (TR)

As part of Task 4, a large set of county critical facilities was included in the analysis of exposure under multiple scenarios. With the information on exposure and considerations of criticality of the facilities, a short list of Public Facilities was prioritized for detailed analysis of risk under Task 5. These Public Facilities include:

- Little Falls Booster Station, located in Little Pimmit Run East Branch
- Cardinal Elementary School, located in Torreyson Run
- Water Pollution Control Plant (WPCP), located in Four Mile Run Lower Mainstem
- Trades Center – Equipment Bureau, located in Four Mile Run Middle Mainstem
- VA Hospital Center, located in Lubber Run

[5] Bailey's Branch modeling included only a small segment of the watershed known to have flooding risk, and incudes a PA in the analysis

[6] Little Pimmit Run model results were used for the analysis of a Public Facility (Little Falls Booster Station) but does not include any PA in it. Similarly, Four Mile Run Middle Mainstem model results were used for the analysis of Public Facilities (Trades Center) but no PAs are included in that watershed. No abbreviation used for Little Pimmit and Four Mile Run Middle watersheds (not included in PA analysis tables and figures)

- TJ Middle School and Community Center, located in Doctor's Branch
- Gunston Middle School and Community Center, located in Four Mile Run Lower Mainstem
- Cherrydale Health and Rehab Center, located in Spout Run
- ART Operations & Maintenance Facility, located in Four Mile Run Lower Mainstem (with a part of it in Nauck Branch watershed)
- Trades Center – DPR Building/Network Operations Hub, located in Four Mile Run Middle Mainstem

Figure 1-1 presents the watersheds and public facilities (Problem Area maps to be presented in the PAs section later as part of results).

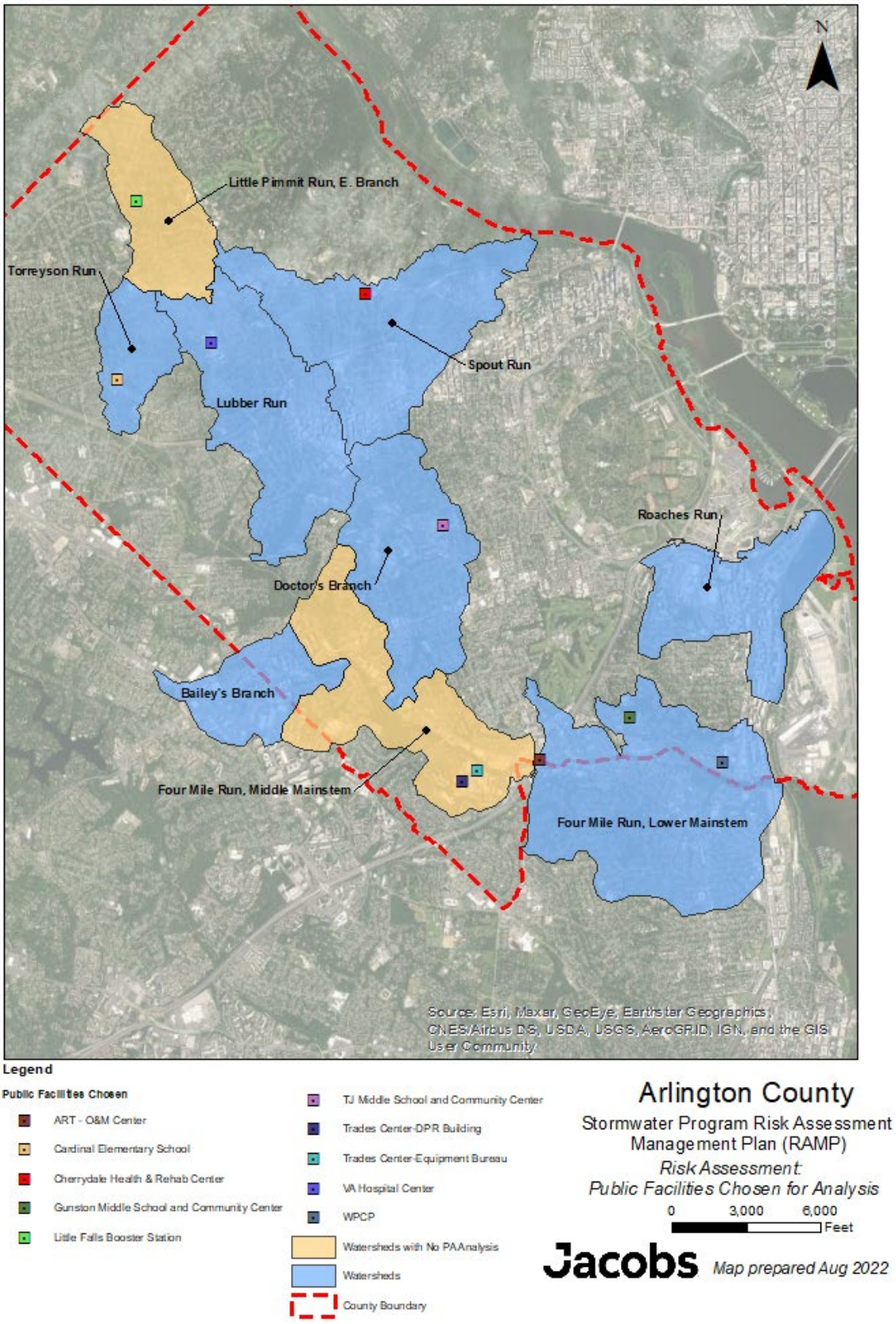



**Figure 1-1. Arlington County Public Facilities and Watersheds Selected for Risk Analysis**

### 1.3.2 Problem Areas

A total of 34 PAs were identified for the analysis in the priority watersheds. It should be noted that these areas do not comprise a full list of potential flooding PAs in the County, just those in the priority watersheds selected by the County based on the Vulnerability Assessment in Task 4. Figure 1-2 includes the PAs analyzed and their respective watersheds.

In the context of this project, a "Problem Area" is defined as an area exposed to flooding within a county watershed, based on hydrologic/hydraulic modeling and flood complaint calls. The boundary of flooded area included in each PA was delineated approximately based on maximum contiguous extent of flood exposure and potential location of mitigation alternatives (conveyance or storage improvements) to hydraulic deficiencies for the flooded area. This will allow benefits (flood damage reduction) to be associated with cost of specific mitigation alternatives to be developed in Task 6.

Flood exposure used for the identification of PAs is based on the 500-year event escalated by climate change impact in 2070. PA delineation considers event flood complaint calls and clusters of calls although many PAs do not have flood complaint calls associated with them. Flood complaint calls in areas of minimal to no inundation were not included since these areas may have been reported for reasons not covered under this scope, such as sanitary sewer backups.

The model drainage network in the Personal Computer Stormwater Management Model and model results analysis were utilized to delineate PAs based on direct underlying issues with the stormwater system. Appendix A documents the process used to define "draft" PAs.[7] These draft PAs were presented to the county and discussed for final PA definition.

[7] The document in Appendix A describes the use of the 2070 100-yr storm for PA identification and delineation and presents the PAs as simple circles and ovals encompassing flood problems. Further refinement of final PA boundaries included the use of streets and census blocks and the use of the 2070 500-yr storm.

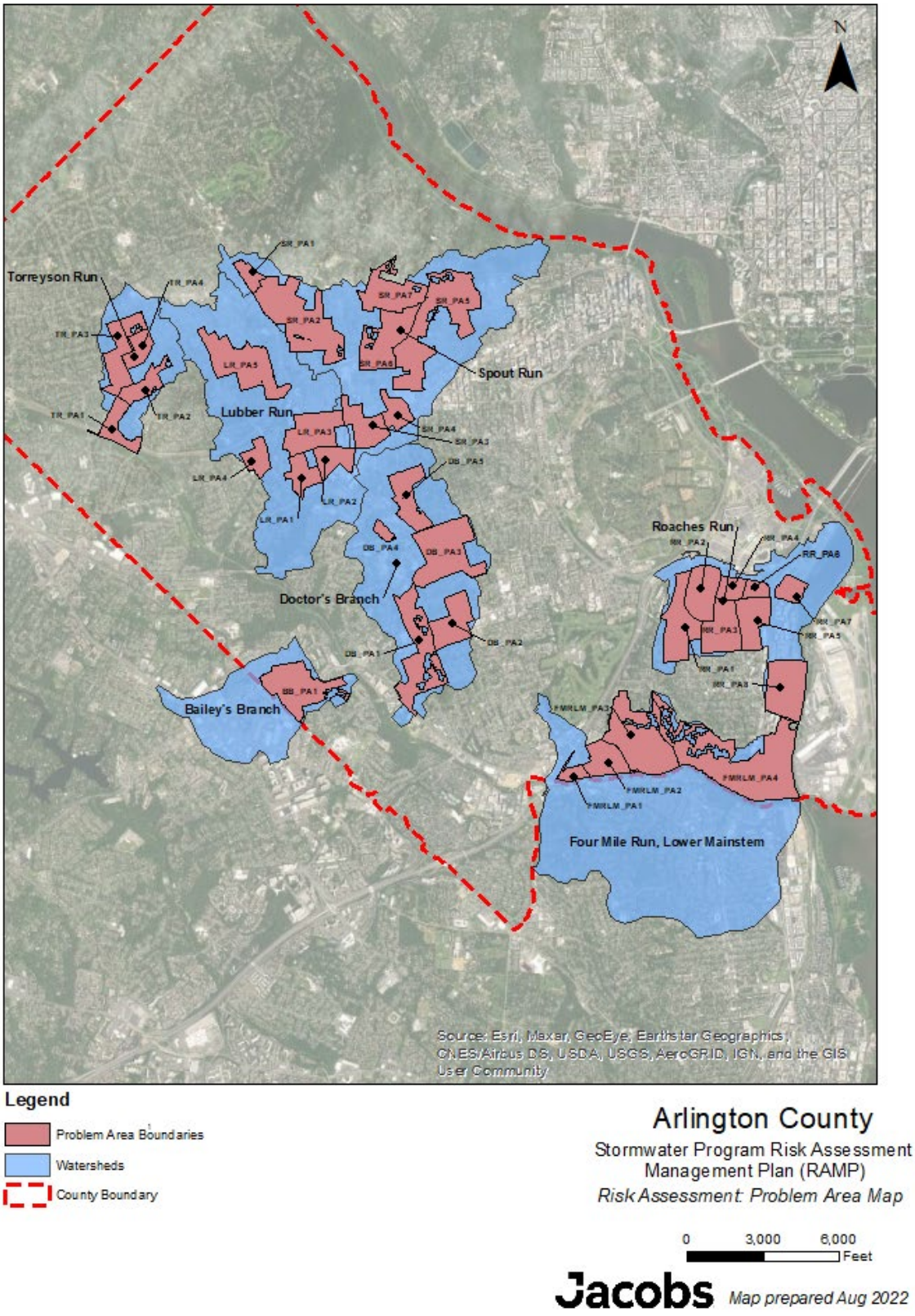



**Figure 1-2. Arlington County Problem Areas Selected for Risk Analysis**

## 1.4 Task Terminology

The following are some key terms and definitions for this task and future RAMP tasks:

**Adaptive capacity**: represents the existing asset/facility/receptor's inherent ability to adjust to maintain its primary functions. Examples include the existence of back-up generators or the ability to raise a seawall protecting a receptor.

**Asset**: Piece of equipment or equipment sets within a facility – example: electrical panel within a WWTP

**Exposure** is "presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by natural hazards and climate change" (IPCC 2014, Annex II).

**Facility**: a place in a geographic parcel or contiguous parcels with equipment and processes to provide a specific public function – example: wastewater treatment plant (WWTP).

**Problem area**: geographic area containing many receptors that are at high risk (abbreviated in this document as PA).

**Public Facility**: a specific facility selected for risk analysis under this Task 5.

**Receptor**: any entity of interest that can be exposed to flooding – examples include: a facility, an asset, a public building providing critical services, a resource protection area. Receptors used in the vulnerability analysis documented in this TM come primarily from the work in Task 2, Data Collection, which compiled a list of "critical facilities". The term receptor in this TM refers primarily to the elements in that list, with some additions such as environmentally relevant locations and private electric and gas utility facilities.

**Risk:** Risk is generally estimated as the product of likelihood (probability of occurrence, such as 10% annual chance from a 10-year storm) times consequence (such as physical damages). **Annualized Risk** is the monetary risk that accounts for the probability of events of different magnitudes occurring in a single year, and the consequences of those events.

**Sensitivity**: a measure of the degree to which an asset/facility/receptor would be impaired by flood exposure. For example, roadways are generally not sensitive to temporary flooding because they are unlikely to be damaged. In contrast, a non-submersible pump station is considered highly sensitive to flood events if exposed to water, as it may be damaged beyond repair.

**Vulnerability** represents "The predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm or damage, and lack of capacity to cope and adapt (adaptive capacity)" (IPCC 2014, Annex II).

# 2. Risk Analysis Approach for the RAMP

The risk analysis in the RAMP follows the same principles for PAs and Public Facilities where Risk results from the combination of receptors being exposed to flood, their proclivity to fail or be damaged when exposed to flood, and the likelihood of the event that causes the exposure (Figure 2-1). For the RAMP, the exposure characterization was completed under Task 3 with the modeling of different scenarios, which have different return periods (different probabilities). Task 3, thus, provided the characterization of the "Hazard Probability" and "Exposure" circles in **Figure 2-1**. While Task 4 in the RAMP was a vulnerability assessment, the purpose of that analysis was to select watersheds and facilities for the risk analysis in

Task 5 and did not include the level of spatial resolution and detail required to fully characterize risk. In Task 5, the "Vulnerability" circle in Figure 2-1 is completed by using information related to the vulnerability of the building stock, vehicle stock and roads within PAs, and the assets within the Public Facilities that are sensitive to flood.

The approach to quantify risk in the PAs and Public Facilities follows risk analysis principles but was not identical, mostly due to the different characteristics of the two receptors (with PAs being neighborhood scale areas where people live, work and recreate; while Public Facilities are parcel-scale with a specific function and assets that allow the facility to function).

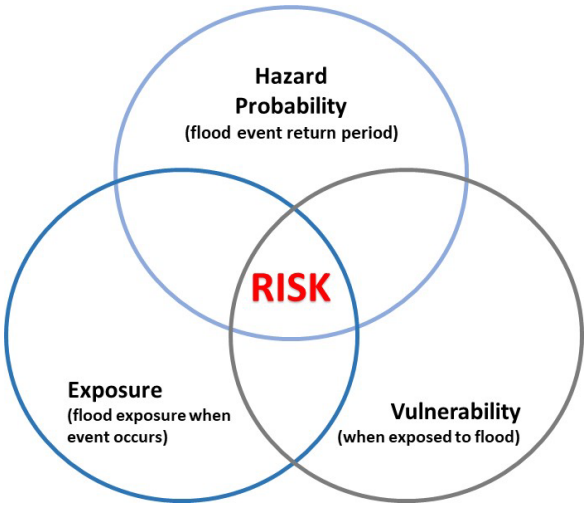



**Figure 2-1. Conceptual Representation of Risk at the intersection of Exposure, Vulnerability and Probability of Hazards**

The approach to quantify risk in the PAs was to use a tool developed and maintained by Federal Emergency Management Agency (FEMA) called Hazus (FEMA 2022). Hazus is a nationally standardized methodology for modeling risk associated with natural hazards. It is a free Geographic Information System (GIS)-based software managed by FEMA's Natural Hazards Risk Assessment Program and used to estimates physical, economic, and social impacts by its of earthquakes, hurricanes, floods, and tsunamis models (FEMA 2022). Hazus includes an inventory of receptors and their "failure functions" and allows for the use of flood modeling datasets. The failure functions establish the relationship between different depths of flooding and the losses that are generated by that flood depth, which has a specific probability of occurrence. Hazus provides results in the form of monetized risk. More details on the methodology for PAs are included in Section 4, which also describes the social vulnerability and environmental elements of the risk analysis.

For Public Facilities Hazus is not the appropriate tool given its larger spatial resolution. The approach for Public Facilities included visiting each facility to identify assets sensitive to flooding, such as electrical equipment, and measure specific ground, floor, flow paths and asset elevations. These elevations are then compared to water surface elevations (WSEs) under flood scenarios (accounting for the probability of those scenarios). Asset replacement costs are included in the analysis and are triggered when an asset is projected to be exposed to flood and a monetized risk value (similar to Hazus) is computed. More details on the methodology for PAs are included in Section 4.

The effects of climate change on the severity of the flood scenarios was assessed in Task 3 of this RAMP and is included in Task 5. The evolution of risk for both PAs and Public Facilities is characterized by using the exposure under year 2070 conditions of flood.

# 3. Data and Information Sources

Given that risk analysis is based on the overlay of the flood hazard and receptors of interest, the critical data relates to both the flood exposure and the inventory of assets included in the receptors of interest. For Task 5, the receptors are PAs and Public Facilities. Relevant assets for the analysis PAs are the building stock and the vehicle stock in each PA (which are sensitive to flood in different degrees). For Public Facilities, specific assets sensitive to flood were surveyed. Data sources and collection is described in the following sections.

In addition to monetary risk analysis, Task 5 included an analysis of risk of flood to high social vulnerability areas and areas with environmental value. Information for these parameters, which was obtained during Task 4, is described in this section.

The flood exposure information was obtained from Task 3 modeling efforts (Jacobs 2021b) supplemented as necessary with additional modeling in smaller areas.

## 3.1 Exposure and Scenarios

Analysis and the resulting data were based off selected storm events with varying return periods that were modeled in Task 3 (Jacobs 2021b): baseline (Current) scenarios for the 10-, 100-, and 500-year return periods as well as the future 2070 projected scenarios for the 10-, 100-, and 500-year return periods. Modeled results displayed varying locations of flood exposure. In addition to urban flood (interior flood) exposure from rainfall, results of exposure from the Four Mile Run riverine flood model in Task 3 were utilized.

## 3.2 Public Facilities Data

Data for the ten Public Facilities was collected by a means of county-provided as-builts, site visits, and survey results. In addition, one facility required additional collaboration with the County because of the proposed design and reconstruction of the ART Operations and Maintenance (ART O&M) facility. This section will describe the methodology and outcome of data collection for the public facilities.

### 3.2.1 Methodology for Public Facility Data Collection

The following list of steps describes the process of collecting the required facility information and the purpose for each data requirement.

- Connected with the appropriate point of contact to receive available facility as-builts and coordinate a site visit.
  - As-builts were used to prepare the field teams for locating the facility's critical assets and to determine the finished floor elevations, ground elevations, and vertical datum.
- Performed site visits.
  - The field teams were escorted by facility operations staff to access all critical assets. Only basements, first floors, and lower floors (e.g. boilers rooms, mechanical rooms) were visited for the facilities since any assets located higher than the first floor would not be impacted by flood levels.

  - The field teams took several photos and developed a list of critical assets sensitive to flood for each facility. Assets were determined as critical if failure or damage would cause disruption to the facility. Asset locations, quantities, capacities, failure heights, and flood paths were collected on site. The failure heights were determined by the point of entrance that would cause the asset to fail or be critically damaged. The teams also noted elements in which the assets were mounted or protected (i.e. steps into a building door providing extra elevation in the flood path).
- Connected with Arlington County to collaborate on developing a list of critical assets for the proposed design of the ART O&M facility.
  - The County's design team provided all the required information except asset failure heights since the equipment had yet to be selected. Asset failure heights were assumed based on average heights for similar assets found in the other public facilities.

### 3.2.2 Outcome of Public Facility Visits and Data Collection Efforts

The outcome of the data collection is a detailed list of assets sensitive to flood and the relevant elevations that will determine if an asset will be exposed under the modeled flood scenarios. Relevant elevations include finished floor elevations, asset failure elevations, and flood path elevations. Flood paths were established by the lowest point of flood entryway into a building. For assets located outside of buildings, such as emergency generators or transformer, flood path elevations were set at the ground elevations of the asset location given that flood can directly access the asset.

Asset replacement cost data is an additional key component of the inventory of assets for each facility. Sources for asset replacement cost data included:

- A comprehensive database of planning-level costs from Jacobs developed for other projects, with appropriate geo-adjustment and time escalation
- Asset-specific data obtained from Jacobs cost estimators and subject matter experts for assets not included in the main database
- Asset-specific estimates obtained from common industry costs tools such as RSMeans Cost Data Index

Appendix B presents additional information on asset replacement costs.

## 3.3 Problem Areas Data

### 3.3.1 Data Sources and Collection for Economic Analysis

Economic analysis of PAs was performed using Hazus. Flood inundation depth grids, database of building inventory, flood risk profiles by building category and economic data such as building replacement cost and income loss data etc. are needed to perform the basic level economic analysis on flood PAs in Hazus.

The data required for the Hazus analysis is included in the tool. Hazus uses baseline databases in the software for building area and value, population characteristics, costs of building repair, and certain basic economic data. Hazard data is uniformly applied or generated from minimal input data and applied to the baseline inventory data with little to no user modification. Direct economic and social losses associated with the general building stock and critical facilities are computed. Baseline data for transportation and utility systems are included in Hazus databases also. A disadvantage of Hazus is that data in its most recent datasets corresponds to 2010 Census and 2018 property valuations and loss unit costs. While this is not an issue for Task 5 and its comparative analysis of PAs and watersheds, the total losses will need to be escalated for Task 6 benefit costs analysis. Appendix C includes a description of Hazus.

### 3.3.2 Data Sources and Collection for Environmental Analysis

Areas of environmental value for the County were based on areas from established sources, including the National Wetlands Inventory and the Chesapeake Bay Preservation Ordinance (the Ordinance) (Arlington County 2003). The ordinance was adopted to protect streams and the Chesapeake Bay from pollution due to land use and development. In the Ordinance, sensitive areas along streams throughout Arlington have been designated as Resource Protection Areas (RPAs). The RPAs are natural buffers that help protect streams, rivers, and other water bodies. They include the environmentally sensitive lands within 100 feet of these water resources.

The RPA information and its geodataset were obtained during Task 4 (Jacobs 2021a). Appendix D further describes the data and information and the areas included in the risk analysis, which were overlayed with each of the PAs using GIS methods, are presented in Figure D-1.

### 3.3.3 Data Sources and Collection for Social Vulnerability Analysis

Social vulnerability is an important consideration in many of Arlington County's programs, policies, and services. The County's Department of Public Safety Communications & Emergency Management considers social vulnerability in the County's Emergency Operations Plan and other programs and initiatives including vaccine administration, childcare and other services use social vulnerability to guide actions and outcomes. This RAMP considers social vulnerability, given that natural hazards and specifically flood can have adverse impacts that amplify for socially vulnerable populations.

Data used for social vulnerability in this risk analysis was collected from the United States Agency for Toxic Substances and Disease Registry (ATSDR), which is part of the Centers for Disease Control (CDC), corresponding to the Social Vulnerability Index (SVI). Data was collected and used during Task 4 and is fully documented in the Task 4 Technical Memorandum (Jacobs 2021a). Appendix D includes further information on the SVI and Figure D-2 identifies the SVI values within Arlington County based on U.S. Census data. Task 5 included a GIS analysis to overlay the SVI areas used in Task 4 with the PAs delineated under Task 5.

### 3.3.4 Data Sources for Roads Analysis

Roadway risk of flooding used roadway centerline and roadway type information from the data collected in Task 2. Roadway typing is based off U.S. Census Data's MAF/TIGER Feature Class Code. Monetary impact from road flooding used a simple estimate of labor (assuming 80 people hours per mile) and a lump sum for mobilization, debris management and disposal and simple repairs of ($10,000 per mile).

# 4. Risk Analysis Methodology

This section describes the methods used for PAs and Public Facilities risk analysis based on the overall framework described in Section 2.

## 4.1 Problem Areas

### 4.1.1 Hazus – Economic Analysis

Hazus Flood Model was used for the Arlington RAMP, to estimate risk of losses due to potential flooding of flood PAs with the County. It was used to quantify and map potential economic risk of building and vehicle damage by floods. The Hazus flood model calculates physical damage and economic loss due to inundation from flood events. Losses are calculated using functions that relate the depth and type of flooding to the degree of damage for various categories of buildings and vehicles (Hazus 5.1, FEMA 2022). Basic ("Level 2", see Appendix C for a description of levels of analysis in Hazus) analysis was done based on the generalized national databases and best available information to estimate flood losses, combined with specific flood modeling results from the RAMP Task 3.

Site-specific flood inundation depth grids were developed for baseline 2020 and future 2070 design storm event scenarios as follows.

- Baseline 2020: 2-, 10-, 50-, 100- 500-year storms
- Future 2070: 10-year and 100-year storms.

The flood inundation depth grid was used in conjunction with damage and economic risk profiles included in Hazus database for Arlington County by census block to calculate annualized economic losses for buildings and vehicles. The economic losses due to risk to building and vehicle were calculated by the following categories (see Appendix C for a definition of losses items below):

- Economic losses for building stock
  - **Capital Stock Losses:** correspond to *direct* impacts from flood to buildings and their contents
    - **Building Loss**: resulting from direct damage to the actual building
    - **Contents Loss**: resulting from direct damage to contents in the building, excluding inventory for commercial and industrial buildings
    - **Inventory Loss**: resulting from direct damage to inventory for commercial and industrial buildings
  - **Income Losses:** *indirect* impacts of flood resulting from the temporary displacement of residents or disruption of economic activity
    - **Relocation Loss**: impacts associated with displacement of population
    - **Income Loss**: impacts associated with loss of economic activity, excluding wages, direct sales or output and rental income which are computed separately
    - **Rental income Loss**: impacts associated with loss of rental revenue due to damage of rental property
    - **Wage Losses**: impact to wage income for employees
    - **Direct Output Loss**: impact on sales and direct economic output from a building
- Direct Economic Losses for vehicles (computed for day and night since the stock in a given area has diurnal variability and the time of the flood event can thus have different consequences related to vehicle loss): includes direct impacts to cars, light trucks and heavy trucks.

Since Hazus spatial grid for analysis corresponds to census blocks, Task 5 required an additional step allocating the Hazus results to each PA, using the PA polygons and Hazus results in a GIS exercise. Losses from Hazus are then reported at a PA level.

### 4.1.2 Road Impacts

Roadway risk of flooding and potential monetary impacts were assessed first by obtaining roadway centerline and roadway type information from the data collected in Task 2. Roadway typing is based off U.S. Census Data's MAF/TIGER Feature Class Code, which was a field within the ArcGIS data that was analyzed. Types that were found within Arlington County included:

- Local neighborhood road, rural road, city street
- Vehicular trail
- Ramp
- Service drive
- Walkway/pedestrian trail, bike path, bridle path
- Stairways and alleys
- Private road for service vehicles
- Primary road
- Secondary road collector
- Parking lot road
- Interstate

Roadway centerlines were overlayed by individual PAs, as well as with flood inundation depth grids for the selected baseline 2020 and future 2070 storm events from Task 3. Within each Problem Area, varying roadway types exist, and the resulting overlay presented how many miles of each were flooded during each modelled storm event. Lastly, a calculation for the weighted annual average amount of flooding per problem area, per roadway type was completed for the analysis.

### 4.1.3 Social and Environmental Impacts

Social and environmental impact analysis is an area analysis using information on social vulnerability and environmentally relevant areas. The main outcome for Task 5 in social and environmental vulnerability includes:

- RPA area flooded for each PA (in some cases a PA does not have any RPA extent which means not flooded area)
- Medium to High SVI area flooded for each PA (in some cases a PA does not have any medium to high SVI extent which means not flooded area)
- High SVI area flooded for each PA (in some cases a PA does not have any medium to high SVI extent which means not flooded area)

RPAs are natural buffers that help protect streams, rivers, and other water bodies. They include the environmentally sensitive lands within 100 feet of most Arlington County water resources.

The CDC SVI value range is 0.0 to 1.0 and Task 5 uses the same value thresholds for Medium to High (0.5 to 0.75) and High (larger than 0.75) definition used during Task 4. The Task 4 TM (Jacobs 2021a) includes the description of the process to assign the thresholds to social vulnerability definitions, using actual neighborhoods as a reference.

The method to compute the areas is a simple GIS analysis, overlaying PA polygons with flooded area polygons for selected storm events, as well as the RPAs and SVI polygons.

Areas flooded vary with different scenarios. Given that we have 10-year, 100-year and 500-year return intervals and areas computed for each, areas estimated in GIS need to be adjusted (weighted) by the probability of the scenario (a key element of risk analysis is to account for the probability of each impact). The following formula is used for the probability-weighted areas:

Area Flooded Weighted by Probability = Area flooded under 10-yr * 0.1 +
Area flooded under 100-yr * 0.01 +
Area flooded under 500-yr * 0.002

#### 4.1.4 Aggregation of Economic, Social and Environmental

Since the PA risk analysis involves not only the economic impacts but also the socially vulnerable and environmental impact areas, aggregation of results is necessary. A simple multi-attribute rating technique (MART, also referred to Multi-Objective Decision Analysis or MODA), is used for the aggregation. An overall score for risk is computed by combining criteria and criteria weighting factors. For Task 5 we use the following simple formula:

Overall Risk Score = Economic Score * Economic Weight +
Environmental Score * Environmental Weight +
Social Score * Social Weight

While the weighting factors can be assigned an equal value, the methodology allows for changing the weight factors to give more importance to one criterion over another to reflect local policy choices.

A characteristic of MART is that all outputs for each criterion (economic, social and environmental) are normalized to a common scale. In the Task 5 PA analysis, the economic risk results are in dollars ($), while the social vulnerability areas and environmental areas are in square feet[8]. Normalization to a common scale adds the following benefits:

- Removes units for each variable and allows for a simple addition of a final score based on the three criteria
- It introduces an intuitive scale, common to all three criteria. This also allows for easier comparison of the relative ranking of PAs across different criteria

For the Task 5 risk analysis the normalizing scale is a scale of 1 to 5 (unitless), established with the minimum and maximum values measured for the entire collection of PAs for each criterion, as shown in Figure 4-1.

[8] While outputs from the PA analysis, for each scenario are in dollars and square feet, the values of the risk analysis, which aggregates multiple scenarios with different probabilities, are “expected” dollars and “expected” square feet (since equations have been applied to account for probability)

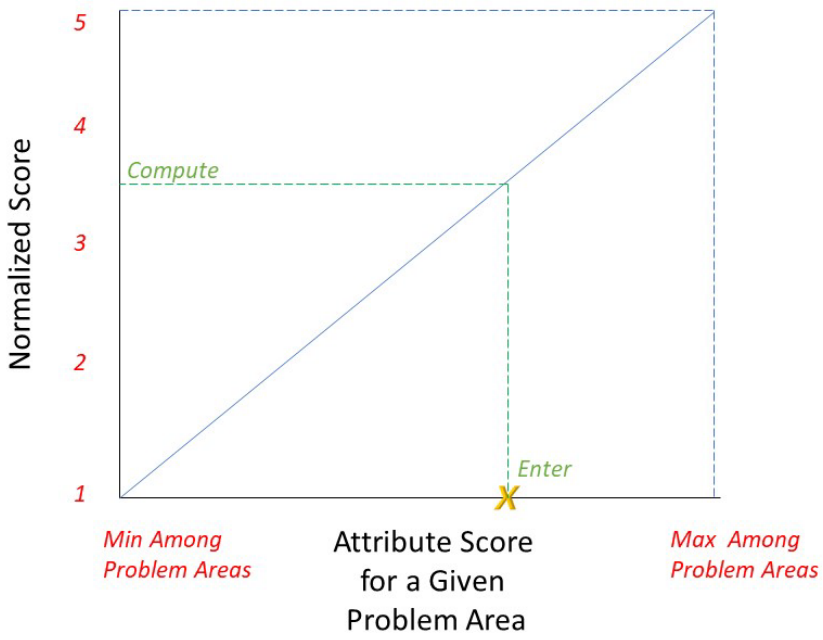



**Figure 4-1. Normalization Scale used in Draft Prioritization**

## 4.2 Selected Public Facilities

The main methodology steps in the Public Facilities analysis included the definition of flood elevations for multiple scenarios in specific locations in each facility and facility vicinity, and the overlay of that information with the asset inventory and elevations. The key to the analysis is the comparison of water surface elevations (WSEs) under multiple scenarios to the elevations of the assets (and the flow path to the assets). Once the elevation threshold is reached for a given asset, the replacement cost of it is triggered in the analysis. Figure 4-2 illustrates the process. Figure 4-3 illustrates one sample facility and the flood elevation versus asset elevation comparison that the risk tool is performing.

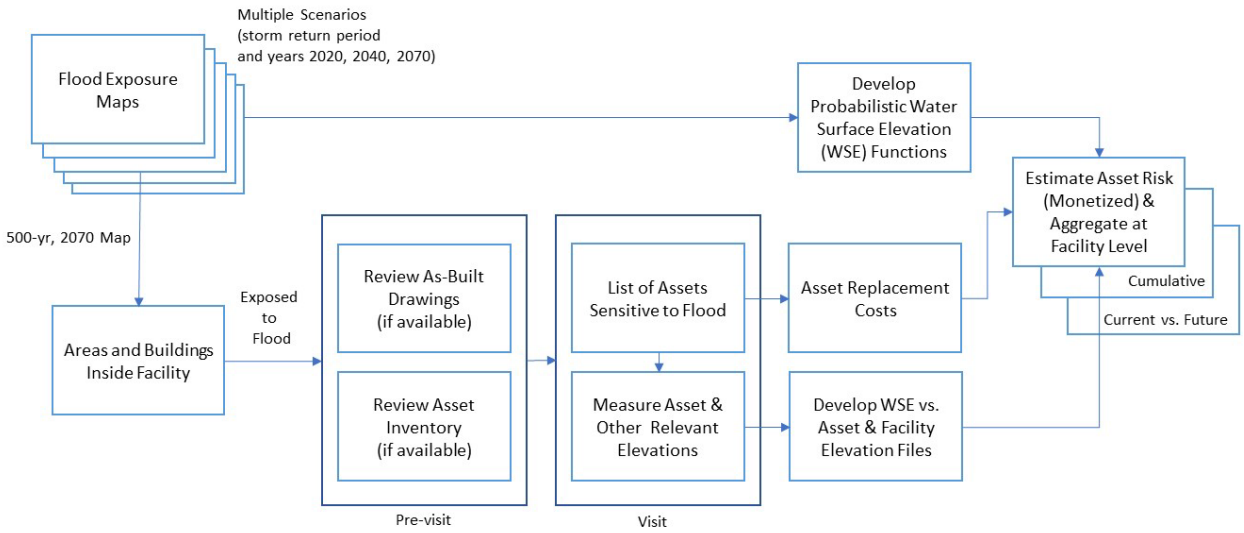



**Figure 4-2. Public Facilities Risk Analysis Overall Process**

### 4.2.1 Flood Exposure of Sensitive Assets

Nine flood scenarios were used to determine building and asset risk:

- Base 2020, 10-yr
- Base 2020, 100-yr
- Base 2020, 500-yr
- 2040, 10-yr
- 2040, 100-yr
- 2040, 500-yr
- 2070, 10-yr
- 2070, 100-yr
- 2070, 500-yr

The two additional base scenarios (2020, 2-yr and 2020, 50-yr) were also included to create a best-fit curve of risk assessment based on WSEs in those all scenarios. The curve allows for estimates of risk beyond the specific scenarios modeled.

To list the specific buildings to visit within a facility, buildings within the given facilities were identified as exposed if the 2070, 500-year flood scenario encroached on the building. For example, not all buildings within the Virginia Hospital Center and Arlington WPCP were projected to be impacted by the flood modelling. Only the buildings showing flood levels were chosen to inspect for critical assets.

WSEs from each scenario were sampled from model output to establish the flood levels at each facility (and buildings within the facility) for the comparison with elevations.

The WSEs for the FMR Middle Mainstem facilities (Trades Center Equipment Bureau and Network Operation Center II) were collected differently since the flood modelling was only available for the base scenarios. The WSEs for the future scenarios were provided by the county since they had modeling capabilities and results for the facility area. Model results were sampled based on the nearest flood levels for each scenario.

The WSEs for the ART Operations & Maintenance Facility were provided by the county for the original nine modeled scenarios since the facility is currently under plans of design and construction. Values for the additional base scenarios were interpolated.

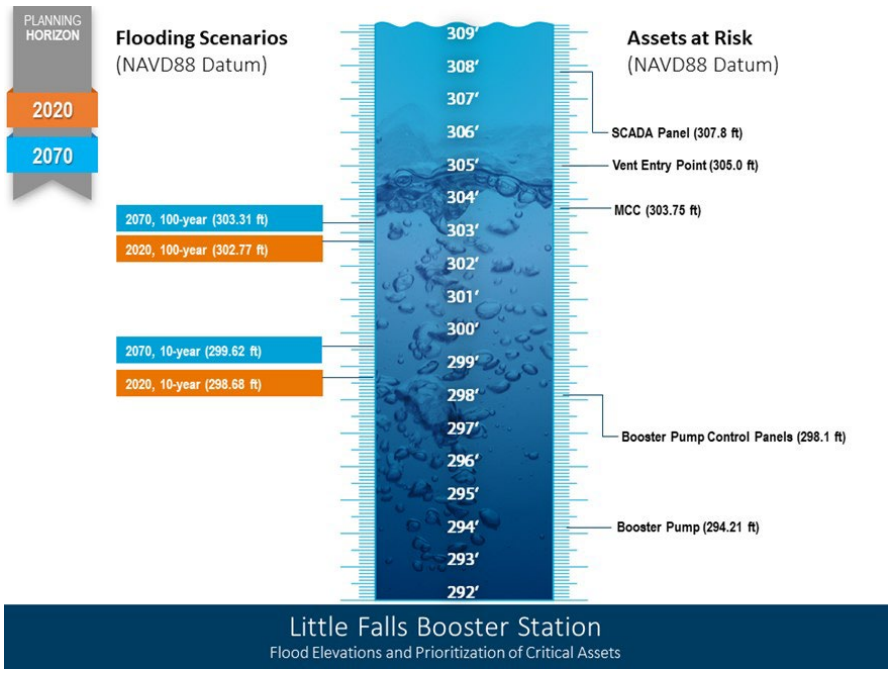



**Figure 4-3. Water Surface Elevation for Different Flood Scenarios Compared to Asset Elevations for a Sample Facility**

### 4.2.2 Monetized Impact

All critical assets were associated with an estimated cost of replacement which incorporated material and installation cost, with data sources for estimates described in Section 3. Appendix B provides information on the replacement costs for assets.

Three approaches were utilized to determine these costs:

- Used a similar project's values and applied adjusted inflation and location rates
- Used a cost estimation tool (RSMeans) for material costs and applied installation rates
- Used a cost estimation based on subject matter expertise and engineering judgment

The asset replacement costs are meant to be used only for relative risk comparisons based on the aggregate results for monetized risk, by facility. The asset replacement costs should not be used for budgeting purposes on any specific asset.

Some facilities visited contained old and outdated assets which would require modern asset replacements and associated lump sum costs. For example, the Cherrydale Health and Rehabilitation Center contains an outdated switchgear that if failure were to occur, an in-kind replacement would not be possible. A replacement Switchgear, Panelboard, and Arc Flash mitigation would be required.

An important element of the Public Facility risk analysis is that it accounts for increasing flood exposure projected to occur as the frequency and intensity of storms is exacerbated by climate change. The year 2040 and 2070 flood exposure data was used to estimate risk in those two planning years, and a risk was then interpolated to derive a cumulative risk over a 20-year period. Figure 4-4 illustrates the concept with the bars representing monetized risk for a single year, which increases over time due to expected increase in exposure for the same return period, due to climate change. Each of the bars in the Figure 4-4 chart do not represent a prediction, of course, but represent an expected value (i.e., the value that results from monetary consequence times the probability of those consequences to unfold).

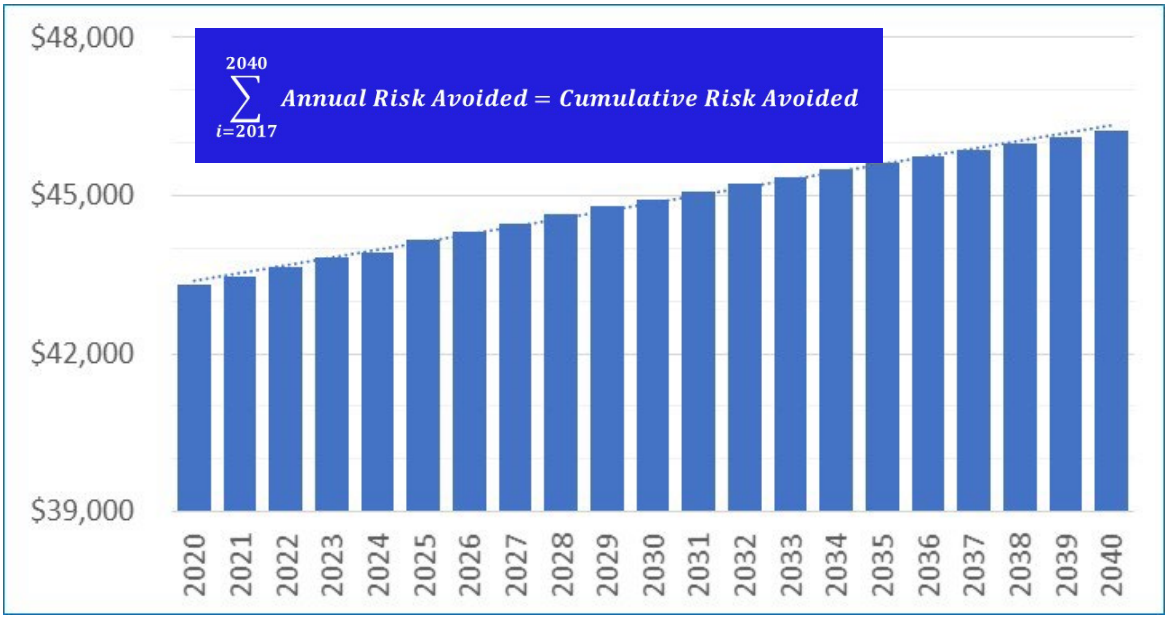



**Figure 4-4. Risk Over Time and Cumulative Risk Concept for Public Facilities**

# 5. Risk Analysis Results

The following sections describe results of the PAs and Public Facilities analysis.

## 5.1 Problem Areas

The PA results include multiple tables and graphics where abbreviations of the areas is used. Section 1.3.1 included the abbreviation used for the watersheds in which the PAs are located, as follows:

1) Bailey's Branch (BB)
2) Doctor's Branch (DB)
3) Lubber Run (LR)
4) Four Mile Run Lower Mainstem (FMRL)
5) Roaches Run (RR)
6) Spout Run (SP)
7) Torreyson Run (TR)

The result of applying the methodology for PA identification described in Section 4.1 and Appendix A, the following number of PAs have been identified in each of watersheds: Four Mile Run Lower Mainstem (4), Torreyson Run (4), Roaches Run (8), Sprout Run (7), Doctor's Branch (5), Lubber Run (5), Bailey's Branch (1). In Appendix A, figures illustrate the individual PAs. For a given problem area, the watershed abbreviation is followed by the PA designation sequentially as PA1, PA2, etc. For example, a PA in Doctor's Branch will have the name DBPA1 (or DB_PA_1) in the following figures and tables displaying the analysis results. All problem areas are mapped in the PA factsheets included in Appendix E. The full list of PAs is included in Table 5-1.

**Table 5-1. Full List of All 34 Problem Areas in Risk Analysis**

| Watershed | Abbreviation | Problem Areas (PAs) |
|---|---|---|
| Bailey's Branch | BB | BBPA1 |
| Doctor's Branch | DB | DBPA1<br>DBPA2<br>DBPA3<br>DBPA4<br>DBPA5 |
| Lubber Run | LB | LRPA1<br>LRPA2<br>LRPA3<br>LRPA4<br>LRPA5 |
| Four Mile Run Lower Mainstem | FMRLM | FMRLMPA1<br>FMRLMPA2<br>FMRLMPA3<br>FMRLMPA4 |
| Roaches Run | RR | RRPA1<br>RRPA2<br>RRPA3<br>RRPA4<br>RRPA5<br>RRPA6<br>RRPA7<br>RRPA8 |
| Spout Run | SR | SRPA1<br>SRPA2<br>SRPA3<br>SRPA4<br>SRPA5<br>SRPA6<br>SRPA7 |
| Torreyson Run | TR | TRPA1<br>TRPA2<br>TRPA3<br>TRPA4 |

Results of the economic, social and environmental analysis for each PA are compiled in PA fact sheets included in Appendix E. The fact sheet includes basic information on each PA and it lists the Hazus results break down by losses, the environmental, social and roads metrics, as well as a qualitative assessment of how the PA ranks, relative to other PAs for each criterion (High, Medium, or Low-ranking values are used). The fact sheets present a picture of risk for each individual PA.

The comparison of risk by PA, relative to the other PAs is better served with comparative figures, tables and maps in this section. Comparison of PAs can be made for economic risk, social and environmental areas, individually (sections 5.11, 5.1.2 and 5.1.3, respectively), and with the results of the overall risk for the PAs (Section 5.1.4).

### 5.1.1 Economic Risk Analysis

The economic risk analysis is the result of the Hazus analysis described in Section 4. Hazus uses an economic property valuation and economic losses database from 2018 (the BCA in Task 6 will require escalation of losses to match costs estimates of mitigation solutions). Direct and indirect losses associated with building and vehicle stock are combined into an overall monetized risk value. Hazus uses functions to derive the annualized monetary risk (accounting for the combined annual probability of multiple events). Appendix E presents detailed results for each PA in PA fact sheets. Figure 5-1 presets the annualized risk result, sorting the PAs from highest to lowest annualized risk. The most significant economic risk as estimated by Hazus is observed in some PAs in Roaches Run, Lubber Run and Spot Run. Figure 5-2 presents the map with all PAs and the estimated annualized risk. Each of the PAs with significantly high economic risk coincide with areas that have commercial activity (see Task 4 TM Figure 3-4. [Jacobs 2021a]). The fact sheets in Appendix E show the breakdown of losses in those PAs with significant losses related to economic activity. These results illustrate the importance of considering other criteria in risk-based prioritization, related to social and environmental variables, which are included in this analysis and described in the following sections.

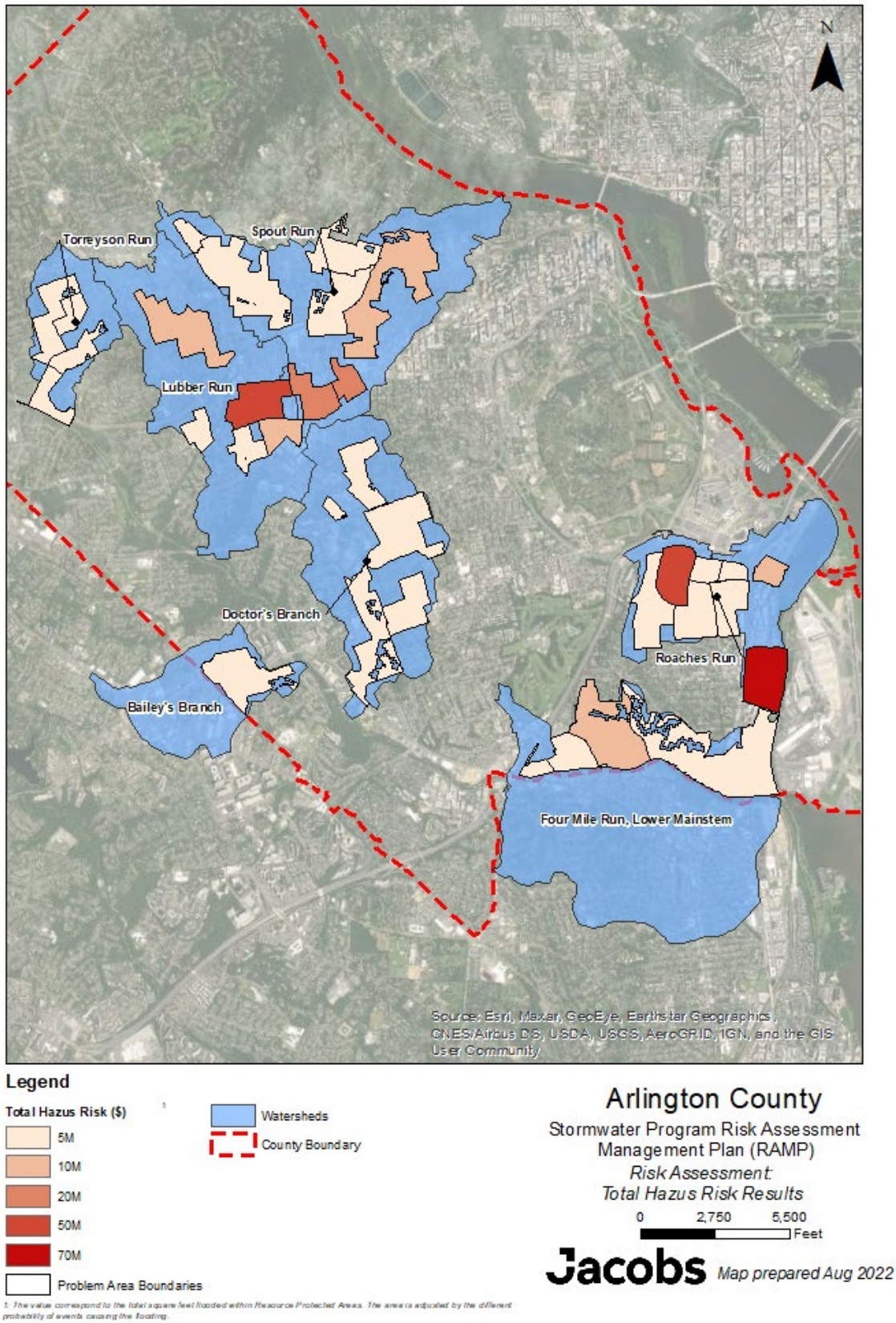



**Figure 5-1. Economic Risk in Problem Areas (Based on Year 2018 Loss and Economic Valuation)**

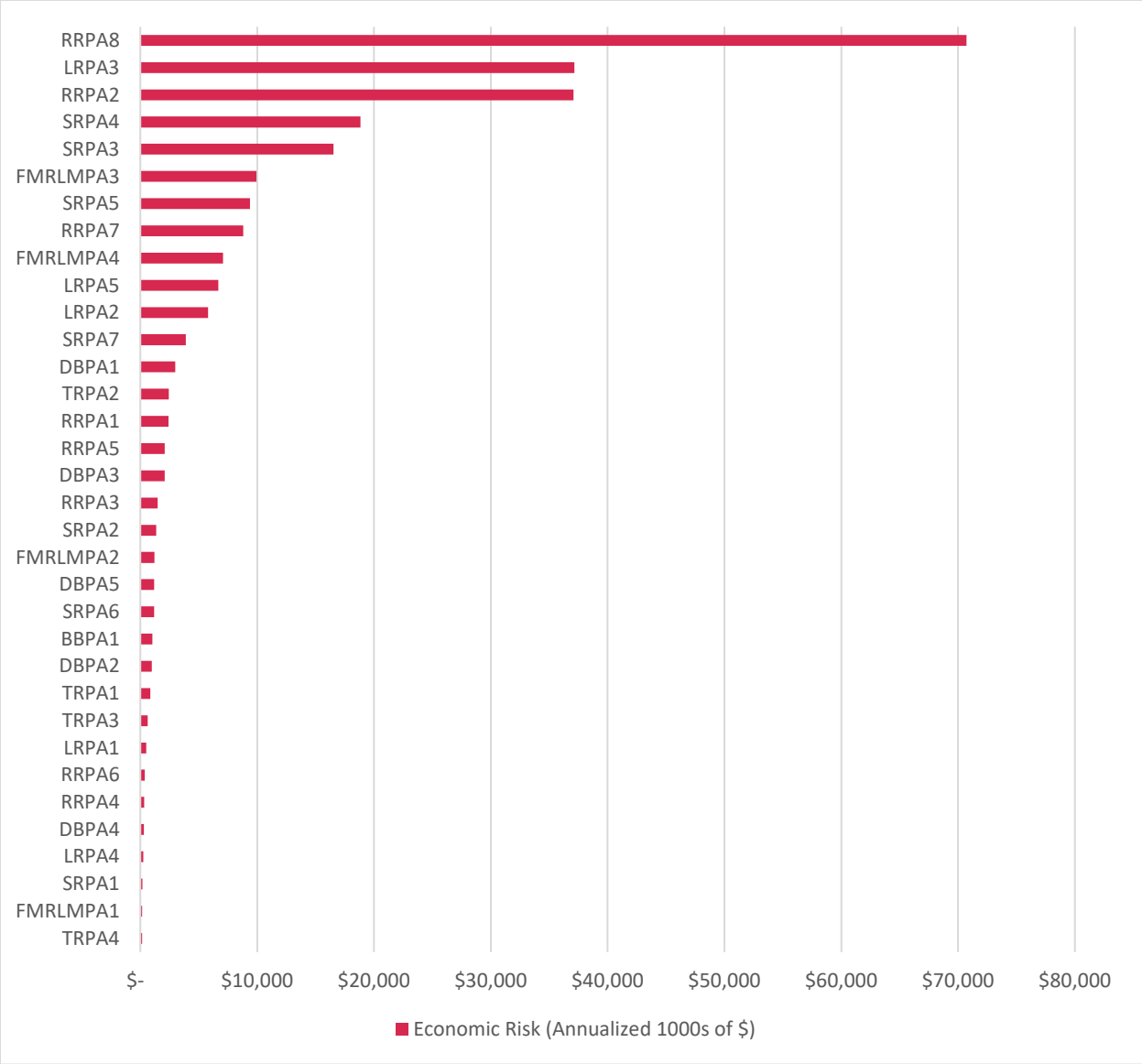



**Figure 5-2. Annualized Economic Risk for All Problem Areas**

Although the watersheds are not the area of analysis for Task 5, the summary of economic risk by watershed illustrates that the most significant risk is generally associated to the areas with economic activity. Table 5-2, presents the results by watershed.

**Table 5-2. Economic Risk by Watershed**

| Watershed | Annualized Risk of Total Losses (Thousands $)[1,2] | Potential losses for 100-yr Storm (Thousands $)[2] | |
|---|---|---|---|
| | | 100-yr storm in 2020: 8.5 inches in 24 hours | 100-yr storm in 2070: 9.6 inches in 24 hours |
| Roaches Run | 112,845 | 718,937 | 803,499 |
| Spout Run | 40,992 | 234,391 | 263,372 |
| Lubber Run | 32,422 | 297,178 | 344,221 |

**Table 5-2. Economic Risk by Watershed**

| Watershed | Annualized Risk of Total Losses (Thousands $)[1,2] | Potential losses for 100-yr Storm (Thousands $)[2] | |
|---|---|---|---|
| | | 100-yr storm in 2020: 8.5 inches in 24 hours | 100-yr storm in 2070: 9.6 inches in 24 hours |
| Four Mile Run Lower Mainstem | 14,690 | 109,245 | 136,793 |
| Doctor's Branch | 6,363 | 38,965 | 46,145 |
| Torreyson Run | 2,628 | 17,862 | 19,650 |
| Bailey's Branch | 1,028 | 7,507 | Not Available[3] |

Note:

[1] Hazus uses loss and economic property valuation data sets that were last updated in 2018
[2] Risk of losses accounts for the probability associated with different storm events generating losses
[3] This watershed was not modeled under 2070 conditions

#### 5.1.1.1 Roads

The roadway flooding per Problem Area calculated shows that flooding occurred commonly in residential and condensed commercial areas.

Based on the computed mileage flooded per Problem Area for each scenario, risk annualization formulas were applied to account for the annual probability of each scenario resulting on an expected mileage flooded. Table 5-3 presents the ten PAs with the highest annualized mileage flooded.

**Table 5-3. Top 10 PAs for Road Impacts by Flood**

| Problem Area ID | Expected Annualized Flooded Roadway (miles)[1] |
|---|---|
| SR_PA5 | 0.79 |
| FMRLM_PA4 | 0.56 |
| FMRLM_PA3 | 0.29 |
| SR_PA7 | 0.24 |
| SR_PA2 | 0.22 |
| LR_PA5 | 0.21 |
| SR_PA4 | 0.18 |
| LR_PA3 | 0.17 |
| RR_PA8 | 0.13 |
| RR_PA1 | 0.11 |

[1] Lengths estimated for each flood scenario and adjusted by probability, consistent with Hazus methodology for annualized risk.

Results show that Spout Run, and Four Mile Run Lower Mainstem are the watersheds with more road impacts, followed by Lubber Run and Roaches Run (refer to Table 5-3).

The resulting Expected Annualized Flooded Roadway lengths for each PA assessed can be used to estimate the cost of roadway flood recovery costs. Within the PA facts sheets presented in Appendix E, the following formula for the estimation for annualized cost per mile of road clean up and repair was utilized:

*Monetized Impact per Mile = $10,000/mile flooded + (80 labor hrs * $150/labor hr)*

### 5.1.2 Social and environmental Criteria

#### 5.1.2.1 Environmental Areas

Results of the modelling analysis regarding the amount RPA flooded in each identified problem area per flood event scenario is presented in Appendix E, in the problem area fact sheets. Based on the results presented, PAs within Four Mile Run Lower Mainstem appear to show the most consistent flooding within their RPAs across all flood event scenarios. Four Mile Run Lower Mainstem watershed sits directly adjacent to the mouth of Four Mile Run as it exits into the Potomac River, as such the consistent flooding of its RPAs is understandable.

In reviewing the RPA flooded area results it is important to point out that, while RPAs are areas of significant environmental value, a significant extent of the total RPA area in the county is in the floodplain for runs and creeks. Flood events can certainly cause damage to these RPAs depending on peak flows and peak velocities. The analysis in this task does not account for more detail than the total area flooded and it is thus recommended that the metric of RPA area flooded be given less weight than social and economic variables in the analysis (with sensitivity tested for different weights). Figure 5-3 presents the map of PAs with total expected area flooded for RPAs (areas flooded for each scenario are normalized for probability of the scenario, for consistency with Hazus results). Figure 5-4 presents the area flooded for all PAs with RPA area in them (i.e., PAs not shown in the figure are PAs that do not have RPA area in them and thus no risk).

#### 5.1.2.2 Socially Vulnerable Areas

Results of the modelling analysis regarding the flooded areas with high social vulnerability (SVI index values of 0.5 to 1.0) in each identified problem area are presented in Appendix E, in the problem area fact sheets. Doctor's Branch is clearly the watershed with the greatest flood risk to socially vulnerable communities. It is, in fact, a watershed that was prioritized during Task 4 for analysis in Task 5 due to the flood impacted areas with high SVI values (Jacobs 2021a).

A second watershed with flood risk in high social vulnerability areas is Bailey's Branch. Similarly to Doctor's Branch, this watershed was selected for Task 5 analysis due to the known flood risk to vulnerable communities in it. Bailey's Branch was, in fact, not analyzed during Task 4 but was included for risk analysis anticipating high risk results in high SVI areas.

Results of the social vulnerability flooded areas illustrates the importance of using more than economic parameters for risk prioritization. The Hazus results show Doctor's Branch ranked 5$^{th}$ out of 7 watersheds in economic risk.[9]

Figure 5-5 presents the map of PAs with total expected area flooded for high SVI areas (areas flooded for each scenario are normalized for probability of the scenario, for consistency with Hazus results). Figure 5-6 presents the area flooded for all PAs with high SVI areas in them (i.e., PAs not shown in the figure are PAs that do not have high SVI area in them and thus no risk).

[9] Bailey's Branch ranks 7$^{th}$ out of seven watersheds in terms of economic risk, but results for it can be misleading given that the flood analysis did not include the entire watershed.

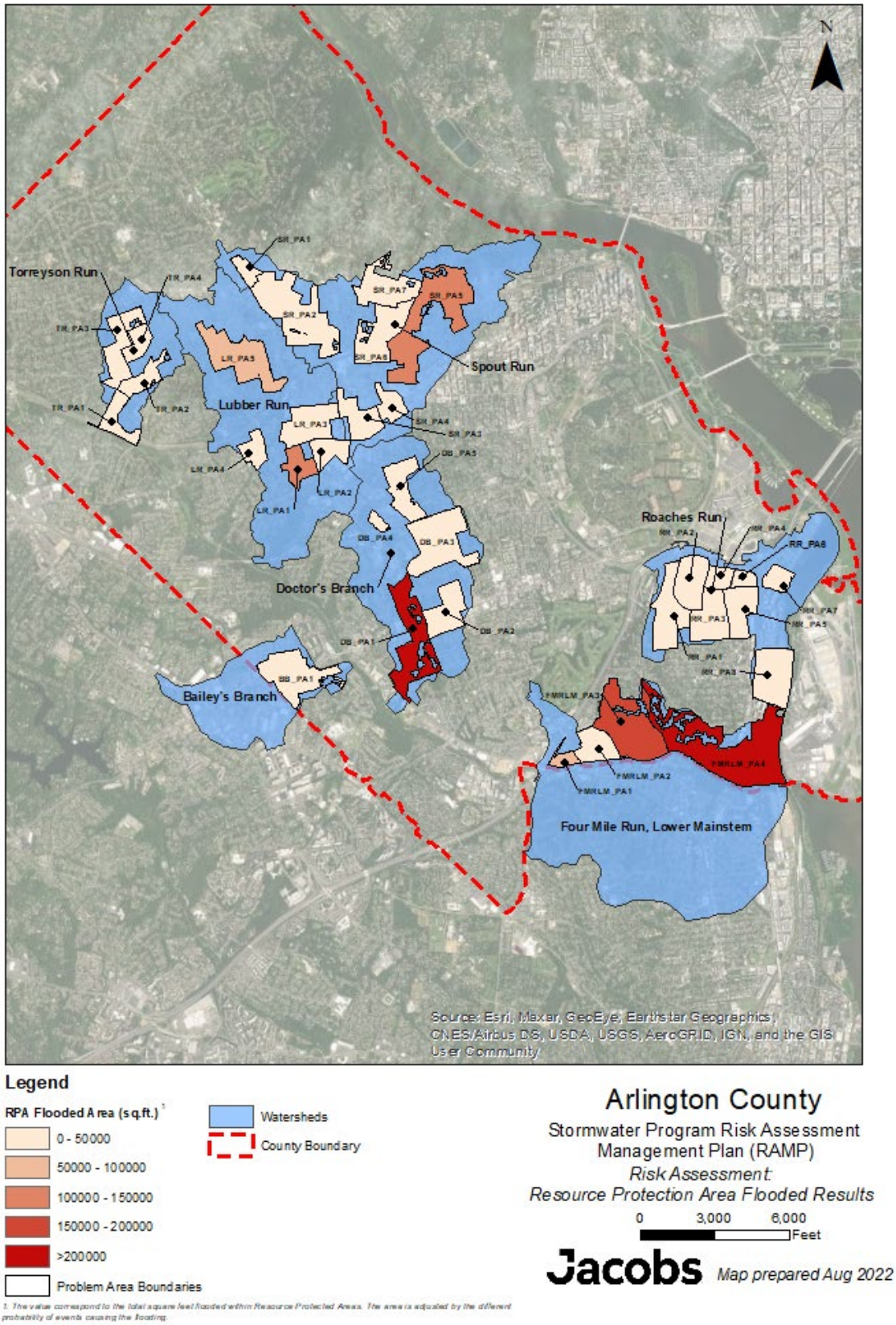



**Figure 5-3. Map of RPA Area Flooded, Accounting for Probability of Flood Scenarios**

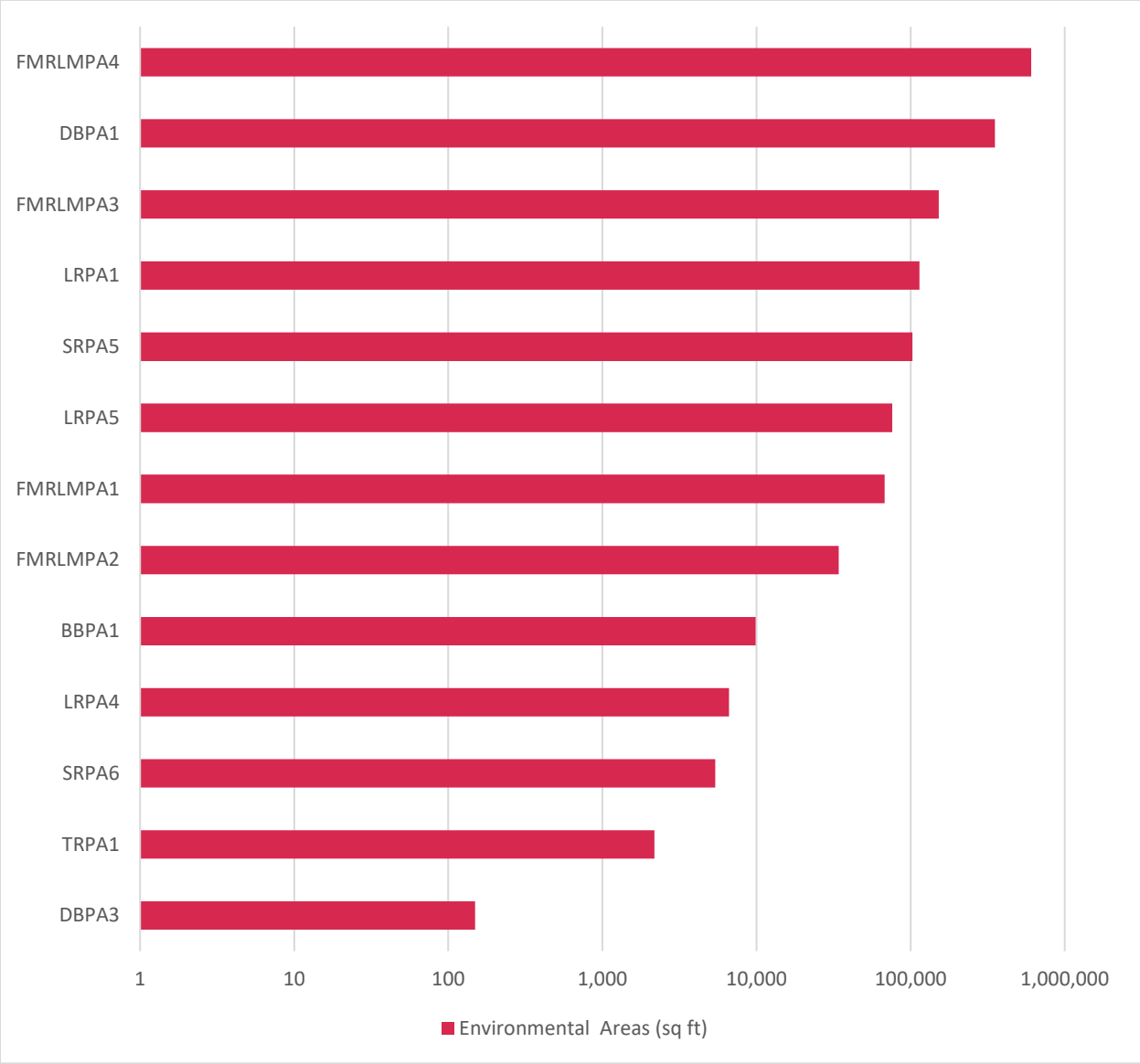



**Figure 5-4. Environmental (RPA) Area Flooded (Square Feet) for PAs, Accounting for Probability of Flood Scenarios**

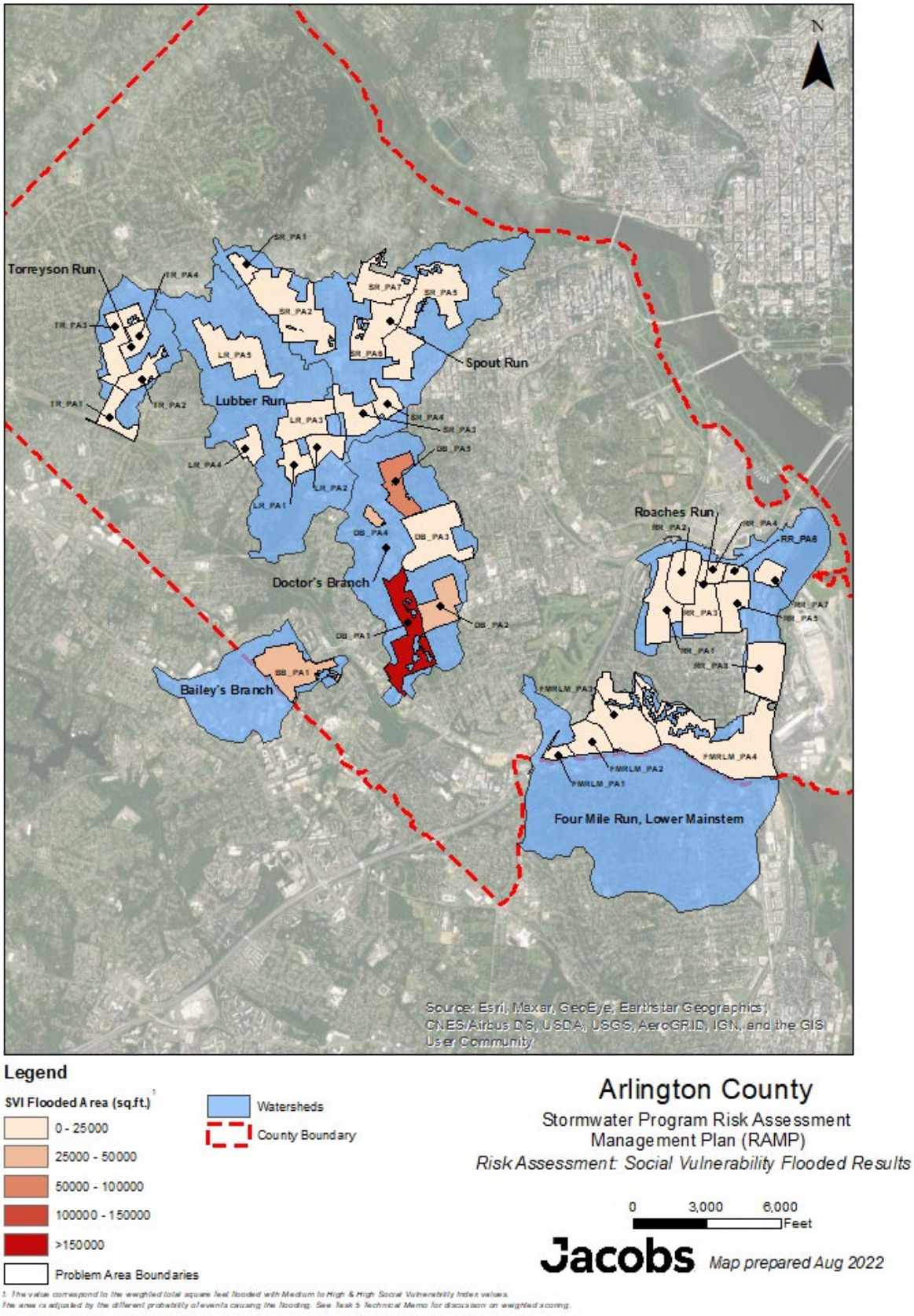



**Figure 5-5. Map of High Social Vulnerability Area Flooded, Accounting for Probability of Flood Scenarios**

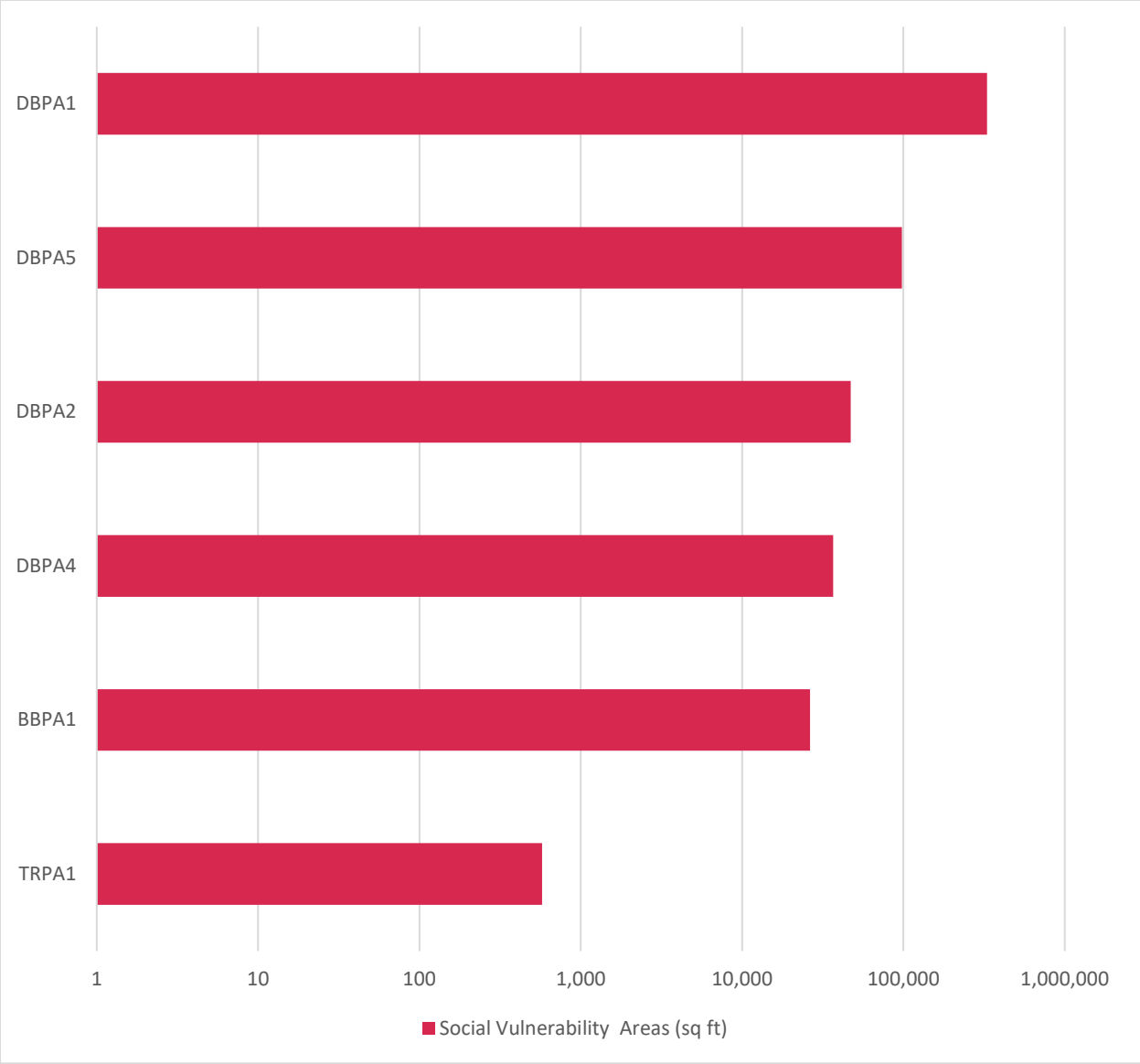



**Figure 5-6. High Social Vulnerability Areas (Square Feet) for PAs, Accounting for Probability of Flood Scenarios**

Although the watersheds are not the area of analysis for Task 5, the summary of environmental and socially vulnerable area risk by watershed illustrates that the most significant risk, expectedly, associated to the PAs with large RPAs and large areas of high SVI values. Table 5-4 present the results by watershed. Appendix D presents the SVI and RPA maps by watershed.

**Table 5-4. Social and environmentally Vulnerable Area Risk by Watershed**

| Watershed | RPA Expected[1] Flooded Area (square feet) | High SVI Expected[1] Flooded Area (square feet) |
|---|---|---|
| Bailey's Branch | 9,864 | 26,342 |
| Doctor's Branch | 352,243 | 511,763 |
| Four Mile Run Lower Mainstem | 860,826 | — |

**Table 5-4. Social and environmentally Vulnerable Area Risk by Watershed**

| Watershed | RPA Expected[1] Flooded Area (square feet) | High SVI Expected[1] Flooded Area (square feet) |
|---|---|---|
| Lubber Run | 196,776 | — |
| Roaches Run | — | — |
| Spout Run | 107,988 | — |
| Torreyson Run | 2,172 | — |

[1] Areas estimated for each flood scenario and adjusted by probability, consistent with Hazus methodology for annualized economic risk.

### 5.1.3 Risk Evolution for Problem Areas Due to Climate Change

The result of the assessment of future scenarios allows us to evaluate the impact that climate change will have in flood risk. Task 3 presented an extensive discussion on future magnitude of rainfall and flood exposure (Jacobs 2021b). With Task 5 results we are able to evaluate the consequences of those, more extreme, storms and flood areas, and obtain a picture of risk over time. Figure 5-7 shows how the economic risk increases for RRPA8 (a high-ranking PA in economic risk) from historical conditions (2020) to the year 2070. The figure also illustrates the social vulnerability area increase in risk (additional area) for DBPA1 (high-ranking PA in terms of social vulnerability risk). The figure shows that the impacts of a 100-yr storm under existing conditions will be similar to the impacts of a future (2070) 10-yr storm as climate change continues to unfold. For Doctor's Branch in DBPA1 (Figure b), the climate change impacts are in fact more significant in terms of total area flooded for high SVI areas, with the future 10-yr storm floods more area than the current 100-yr storm.

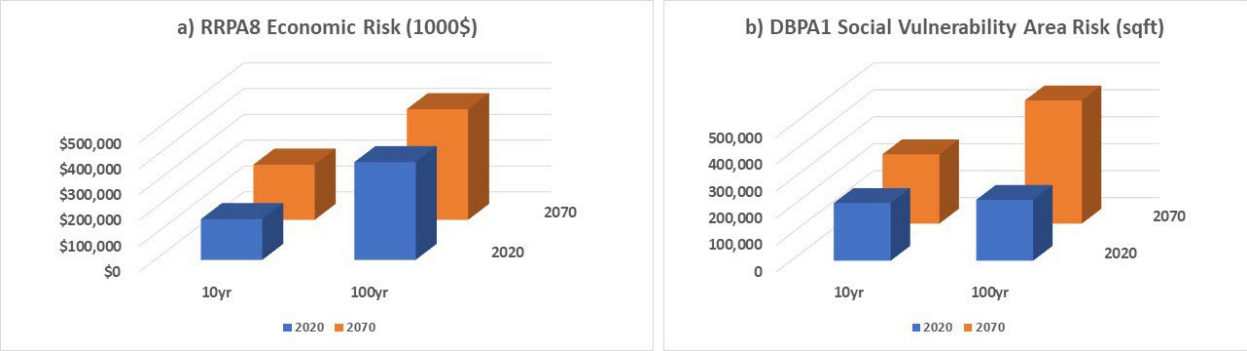



**Figure 5-7. Example of Risk Evolution in Problem Areas Due to Climate Change, for Two Representative Areas**

### 5.1.4 Summary of Risk for Problem Areas

While traditional risk assessment for flood, for many years, has focused on economic risk only, the Arlington County RAMP has included social and environmental criteria to provide a more comprehensive picture of the elements of risk. Section 4 described the method to combine the economic, social and environmental criteria using a MART approach. The MART approach allows for the computation of an aggregate score including all three criteria (normalized as explained in Section 4).

The total risk score accounting for economic, social and environmental criteria scores is presented in Figure 5-8. The figure uses a stack bar that allows for a quick view of the contribution from each criterion to the final overall score. Figure 5-8 assumes weights assigned to economic, social and environmental risk are 50, 40, and 10%, respectively.

The total risk score in Figure 5-8 shows generally three tiers of PAs:

- A high tier with 4 PAs including RRA8, DBPA1, LRPA3 and EEPA2 (two PAs in Roaches Run, one in Lubber Run and one in Doctor's Branch)
- A middle tier from the 5th ranked PA (FMRLMPA4) to about the middle of the chart (17th PA)
- A low-ranking tier from about middle of the chart to the last PA in terms of total score

Analyzing the contribution of the individual criteria to the total score it is apparent that PAs can be high-ranking due to high economic risk, or high social risk. The environmental criterion is a significant contributor to FMRLPA4 and to DBPA1.

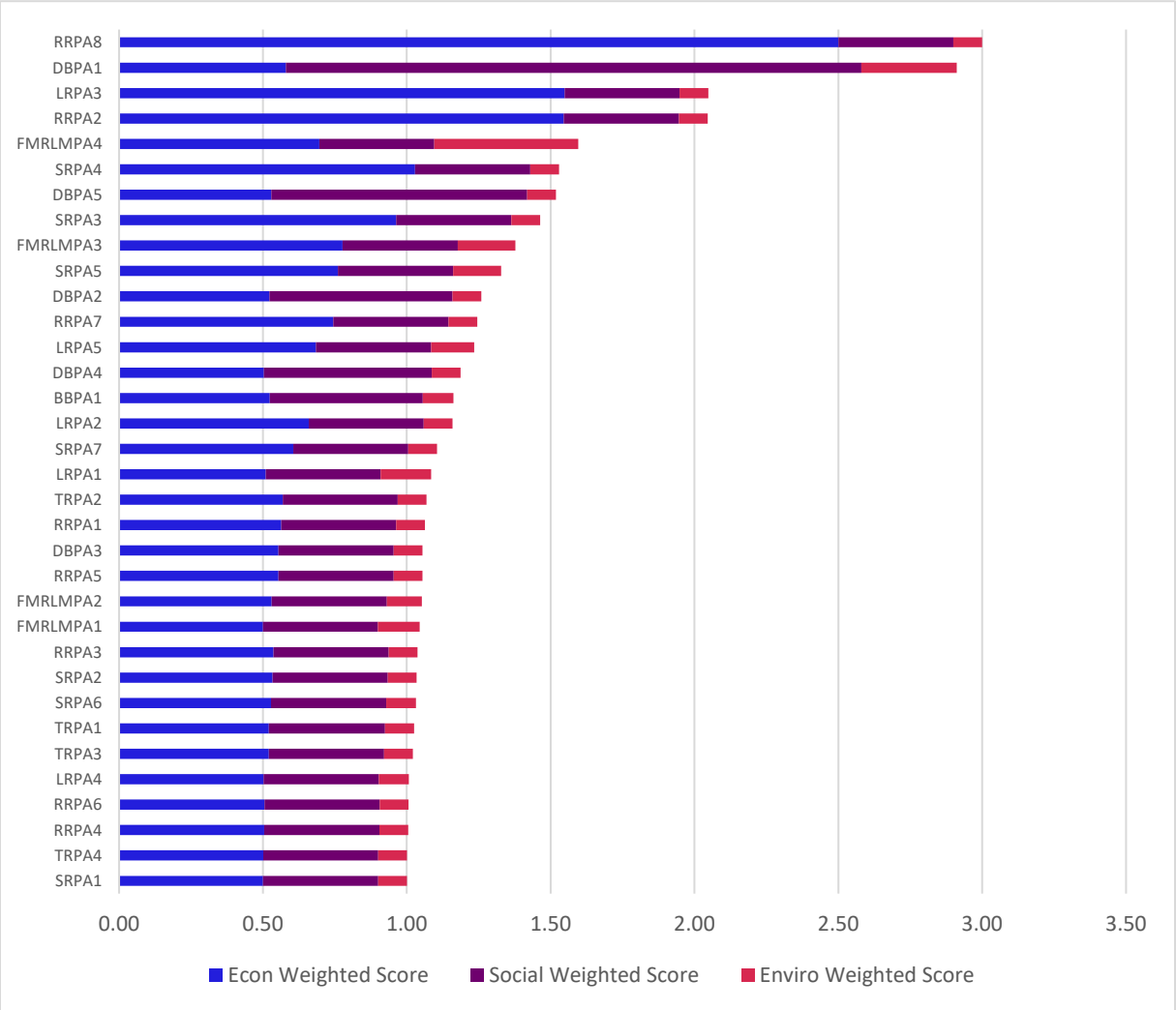



**Figure 5-8. Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria**

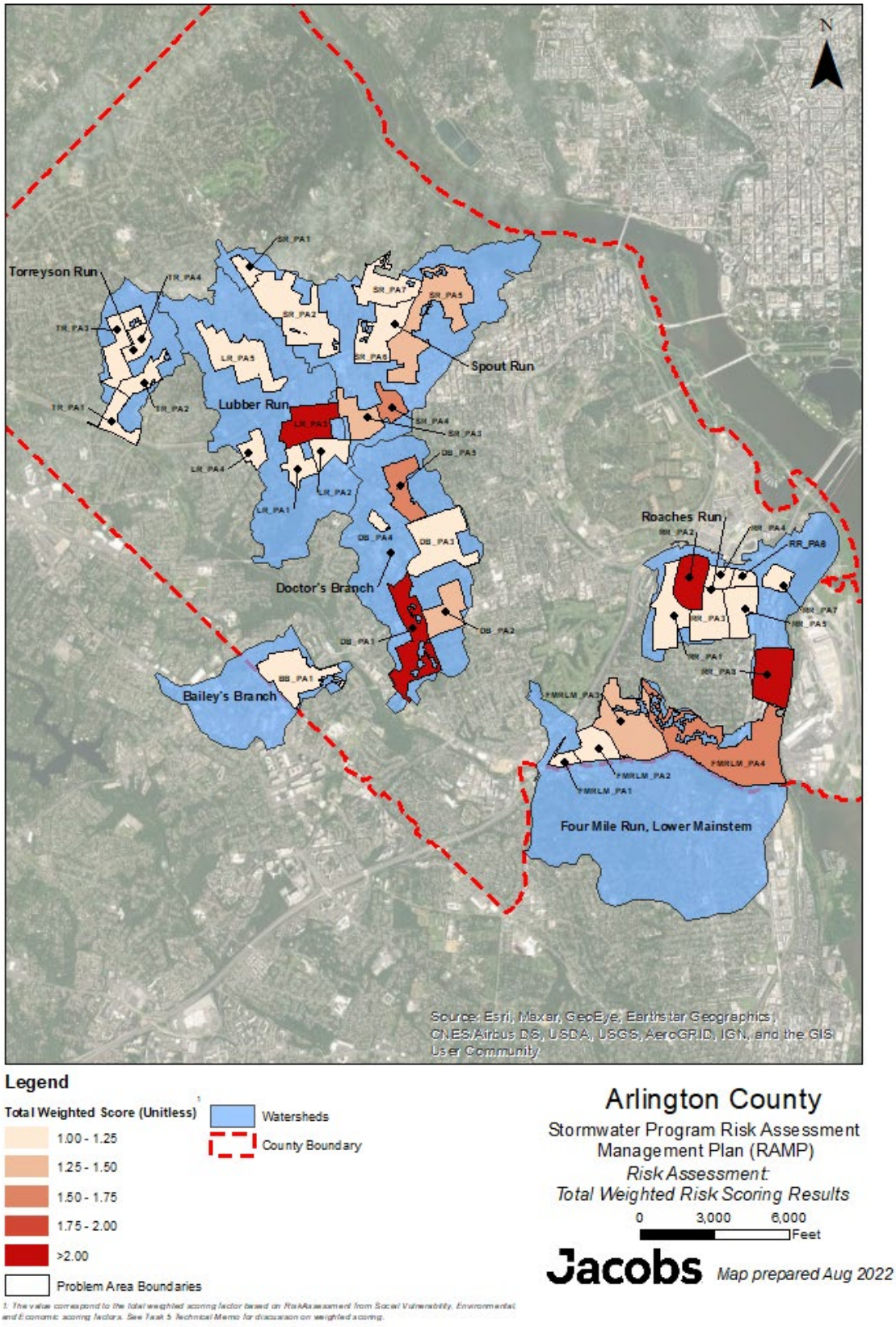



**Figure 5-9. Map of Problem Areas Aggregate Risk Score, Including Economic, Social and Environmental Criteria (Scale of 1 to 5)**

The draft ranking presented above in Figures 5-8 and 5-9 currently assume non-equal weights for social, environmental and economic criteria. During the Task 5 Workshop, the relative weights of these three attributes can be explored with the resulting changes in prioritization, in real time. The prioritization score, for purposes of the draft prioritization, is thus based on the following formula:

Total Risk Score = (Economic Risk Normalized Score * 0.5) +
+ (Social Vulnerability Normalized Score * 0.4)
+ (Environmental Areas Normalized Score * 0.1)

The sensitivity of different weighted values was tested and different ranking graphics in the sensitivity analysis are presented in **Appendix F**.

The sensitivity analysis generally shows low sensitivity in the top-ranking PAs, with Roaches Run and Doctor's Branch reaching the top spots as the economic criterion weight and social criterion weight increase, respectively.

The ranking of PAs is informative for implementation of actions to mitigate flooding. It is important to mention, however, that the definition of potential actions to mitigate flooding to be developed under Task 6, does not use this prioritization. Each of the PAs will be analyzed to provide up to two alternatives for flood mitigation.

## 5.2 Public Facilities

The key outcome of the Public Facilities analysis is the monetized risk of flooding. Section 4.2 described the details of combining flood elevations for scenarios with different probabilities, to the costs of replacement of assets that would be impacted in each of those scenarios. Three main differences exist in the results of the Public Facilities risk analysis compared to the PAs analysis:

- The Public Facilities risk analysis includes only the economic criterion (no social or environmental criteria are needed)
- The estimates of losses are based on asset replacement values specifically for the assets identified in the field visit of each public facility. The cost estimates are in year 2022 dollars (compared to the 2018 loss and valuation datasets of Hazus used for PAs)
- Results of the Public Facilities account for cumulative risk over 20 years, given that decisions at a facility scale will typically be embedded in capital improvement programs for projects for which 20 years is a common useful life

While all facilities analyzed are exposed to flood in different scenarios, the degree of exposure can vary significantly. For example, the WPCP faces significant exposure under multiple scenarios (storms with different return period and for historical or projected climate change intensities) while the Trades Center facilities or Gunston Middle School where exposure is significant in the vicinity and perimeter of the property with less impacts within the fence. The Task 4 technical memorandum (Jacobs 2021a) includes exposure scenario tables and the Arlington County Flood Risk Tool for flood exposure visualization[10] are sources of information for flood in the different Public Facilities.

The summary of risk by facility is presented in Table 5-5. The table also shows the number of assets that were identified as potentially vulnerable and the total replacement costs for those assets. Appendix B includes the information supporting the asset replacement costs estimates. The Asset Replacement Cost column in Table 5-5 and in Appendix F corresponds to the sum of costs for all assets sensitive to flood (e.g., electrical and mechanical equipment not water proof or designed to be submerged) in a given facility and not only the assets that are projected to be exposed to flooding.

[10] The visualization tool link can be provided upon request

**Table 5-5. Summary of Economic Risk Cumulative Over a 20 Year Period for Public Facilities[1]**

| Public Facility | Number of Assets | Asset Replacement Cost (Thousands $)[2] | Total Cumulative Risk (Thousands $)[3] |
|---|---|---|---|
| WPCP South | 836 | 97,223 | 32,270 |
| WPCP North | 282 | 26,240 | 10,137 |
| Virginia Hospital | 68 | 19,882 | 5,659 |
| Thomas Jefferson Middle School | 92 | 8,724 | 1,798 |
| Little Falls Pump Station | 30 | 3,533 | 100 |
| Gunston School | 129 | 3,420 | 60 |
| Cherrydale Center | 68 | 3,343 | 1 |
| Cardinal Elementary School | 94 | 3,156 | <1[5] |
| ART O&M Center | 87 | 40,240 | <1[4] |

[1] The Trades Center NOCII & Equipment Bureau facilities are excluded from this table given that no asset damage was predicted. These facilities do observe flooding in access roads which could represents expenses not accounted for in our analysis

[2] In year 2022 basis. This accounts for all assets in the facility that could be sensitive to flood and not only the assets that are predicted to be exposed to flood.

[3] Over a 20-year period, using a discount rate of 4%

[4] Significant flooding can occur in the vicinity and parking lots

[5] Significant flooding observed in the vicinity and access roads

Results include a large range of cumulative risk, from minimal risk to the assets withing the facilities, to tens of millions of dollars. It is important to mention that all facilities are in areas expected to flood based on historical information and model results. Some facilities, however, show limited monetary impact based on the approach used in this RAMP, which bases the monetization of flood impacts on "inside the fence".

The Trades Center NOCII and Trades Center Equipment Bureau facilities do observe flood impacts in access roads under multiple scenarios, including fluvial flood risk from Four Mile Run, impacting South Arlington Mill Drive. Flooding is also projected by the models in South Taylor Street and 29th Street South, which could impact access and exit from the site. The risk analysis in this task does not include monetary impacts to those roads and the site should thus not be considered flood risk free.

Cardinal Elementary School is in an area with past and projected flooding. Extensive flooding could occur in N McKinley Road (east access to the school) and in the north access road off of 19th Street North, which could impact access and exit from the site and damage private vehicles. The risk analysis in this task does not include monetary impacts to those roads (or private vehicles) and the site should thus not be considered flood risk free.

The ART O&M Center is another case of potential significant flooding in the general vicinity, access roads and in some of the parking lot expected to house dozens of buses. The risk analysis does account for potential damage to those buses since they are assets in that facility. The method applied used a failure curve used by FEMA in its Hazus tool, with progressively more monetary losses as flood depth increases where the vehicle is parked. Flood depths predicted by the modeling do not trigger significant losses due to transit bus damages.

An additional consideration for the ART O&M Facility analysis is that the analysis used a projected asset inventory, location and elevations, based on 100% design drawings and assumptions. The facility should not be considered risk free and a new analysis for it would be recommended after the new facility is completely constructed.

The total risk by facility, proportional to other facilities, is clearly higher for the WPCP than the rest of the facilities analyzed (Figure 5-10). Given the scale of the WPCP and the fact that the north side of the facility is generally higher than the south side, the WPCF was divided for analysis in North and South. Both, north and south sites, are high risk and observe the top monetary risk and the top 2 monetary risk for south and north, respectively. As part of Task 6, where flood mitigation options are explored and BCA is conducted, the north and south sites could be combined into one to the extent that some projects could protect both.

The Virginia Hospital Center shows significant risk and it is associated with generally fewer assets than many other facilities (assets have a larger cost replacement value). When the site was visited, construction was ongoing in some areas and some elevations related to flow path were assumed based on the best available information. Results for this site may be sensitive to assumptions about elevations given the high replacement value of some of the assets and the high probability of WSEs that would reach the assets. Appendix G presents risk for each facility broken down by building and location visited in each facility where it can be observed that the Foot & Ankle building in the Virginia Hospital Center accounts for more than 80% of the risk for it. That building and potential mitigation can be prioritized during Task 6.

Thomas Jefferson Middle School is the 4$^{th}$ highest risk facility by asset risk. This facility houses equipment in a room that could be potentially directly exposed to flooding for large events (model results show the 50-yr storm reaching the assets). A particular piece of equipment (a large modular switchboard with potential replacement value around $800,000) is inside this particular room (See Appendix G, Table G-2 and G-3, Asset ID 220). About 70% of the monetary risk is associated with that large asset. This finding will be used in Task 6 to look for potential mitigation solutions.

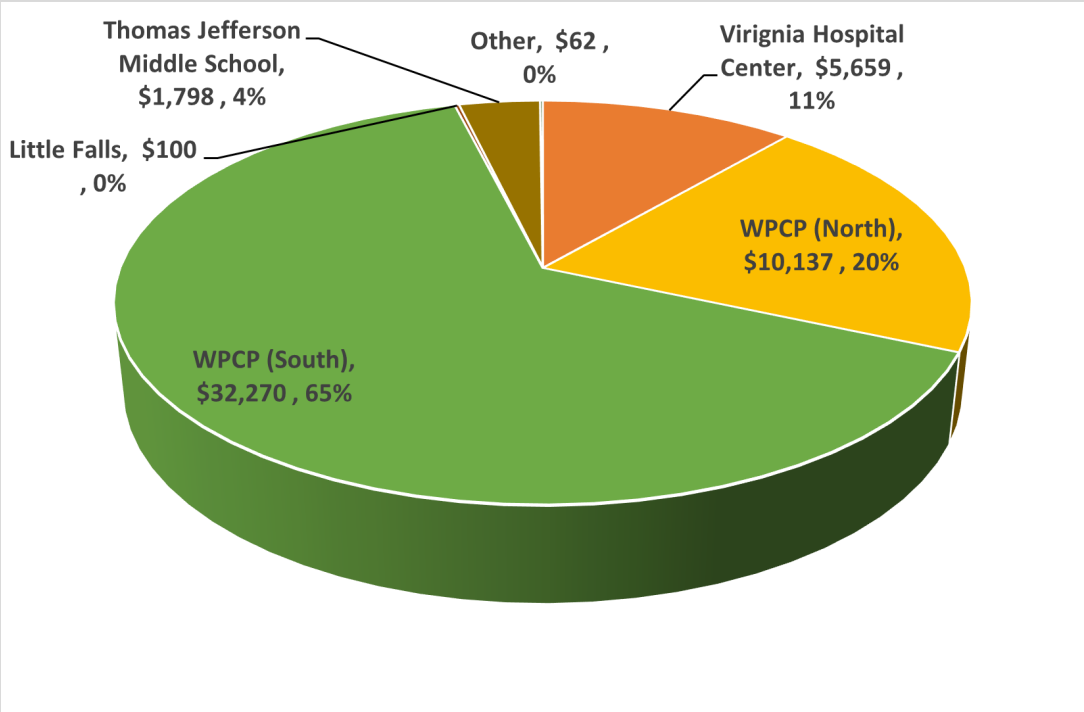



**Figure 5-10. Cumulative Risk (20 Years) for Public Facilities (in $1,000s)**

The Public Facilities analysis also shows that climate change exacerbation of the intensity of rainfall has an impact on risk, increasing risk over time for a given facility. This is the main reason for using cumulative risk over a period of time for this analysis. Figure 5-11 shows the comparison of risk for three planning horizons (2020, 2040 and 2070) for one of the flood vulnerable locations visited at the WPCP (Activated Sludge Effluent Pump Station, used as example). The risk evolution shown in Figure 5-11 accounts for the change in intensity of rainfall during the 10-yr, 100-yr and 500-yr storms, and the resulting flood exposure. This particular facility and location is significantly vulnerable to flood compare to other locations but the increase of risk over time is generally observed in all facilities.

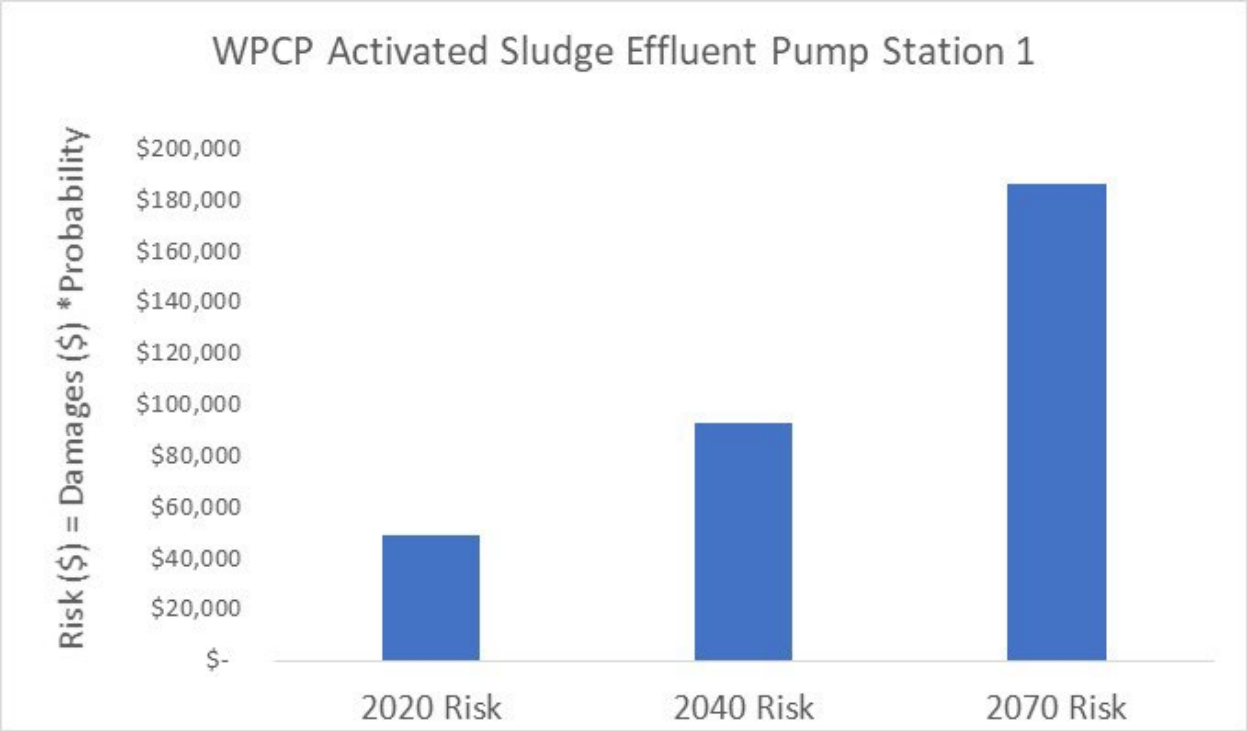



**Figure 5-11. Facility Flood Risk Increase Over Time as a Result of Climate Change**

## 5.3 Public Facilities and Problem Area Results Discussion

Risk results for PAs and Public Facilities have been presented separately in sections 5.1 and 5.2 above given that the methodology for risk is slightly different for them, driven by the different scales required for their analysis. For the overall risk picture of the county, however, the location of Public Facilities in relation to PAs is relevant. The most relevant co-located risk receptors in the watersheds analyzed are:

- In Four Mile Run Lower Mainstem, the FMRLMPA4 area is relatively high ranking (tier 2 and moves higher up in ranking as more weight is given to social and environmental criteria). At the same time, the WPCP is located in this PA, which is clearly the public facility with highest risk.
- In Lubber Run, the LRPA5 area is relatively high ranking (tier 2). At the same time, the Virginia Hospital Center, with significant risk estimated based on the Public Facilities analysis, is located within this PA.
- In Doctor's Branch, the Thomas Jefferson Middle School is located within the DBPA4 area. While DBPA4 does not rank as high as other PAs in this watershed, the middle school is estimated to have significant risk.

Some mitigation solutions could potentially benefit both, a PA and a Public Facility. Implementation of capital projects can also take into account the geographic location of projects for simultaneous mobilization and construction to limit impact to communities during construction. Specifically, for Four Mile Run in the WPCP and FMRLMPA4 area, large-scale projects currently being explored by the U.S. Army Corps of Engineers could potentially benefit both the area and the specific facility. These considerations will be explored in Task 6.

# 6. Next Steps

Task 5 analysis will be presented at a workshop setting to receive feedback and develop a final ranking of Public Facilities and PAs. Results from the workshop will be reflected in the RAMP final report and used during Task 6.

With conceptual risk and vulnerability profile developed for the PAs which include a variety of public and private assets within multiple facilities, conceptual flood mitigation strategies will be developed to address each problem area and site-specific mitigation strategies will be evaluated for up to 10 public facilities.

Strategies will be developed with attention to system design and operational practicability and cost effectiveness for each asset type. The list of strategies for the selected public facilities will be reviewed with the County staff and key stakeholders for refinement and buy in.

Planning level costs will be estimated for the selected strategies for current and future climate scenarios, and benefit-cost analysis will be performed to allow comparison of different return on investment for different levels of flood control (flood depths at different recurrence intervals). This will include the use of Hazus results and Public Facility risk results, which constitute a measure of benefit (avoided monetary risk of flood).

# 7. References

"CDC/ATSDR's Social Vulnerability INDEX (SVI)." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 28 Apr. 2021, www.atsdr.cdc.gov/placeandhealth/svi/index.html.
U.S. Fish and Wildlife Service. 2021. National Wetlands Inventory. https://www.fws.gov/wetlands/

Arlington County. 2003. Chesapeake Bay Preservation Ordinance https://building.arlingtonva.us/codes-ordinances/chesapeake-bay/

FEMA, 2022. Hazus Flood Model User Guidance, Hazus 5.1. April 2022.

IPCC. 2014. Climate change 2014: synthesis report. Core Writing Team, Pachauri R.K., Meyer L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland (2014). 151 pp

Jacobs 2021 a. Task 4 Technical Memorandum. Watershed Vulnerability Assessment (Task 4). August, 2021.

Jacobs 2021b. Task 3.3 Technical Memorandum. Arlington Interior and Riverine Flooding Report (Task 3.3). July, 2021.

UNDRR, 2019. Global Assessment Report (GAR) on Disaster Risk Reduction. UNDRR https://gar.unisdr.org/report-2019 (2019).

AWWA, 2021. Climate Action Plans: Adaptive Management for Water Utilities. M71Manual of Water Supply Practices. 163pp.

Arlington County Zoning Division, 2020. Zoning Map: https://gis.arlingtonva.us/Maps/Standard_Maps/Planning_Maps/Zoning_Map.pdfRlington County Planning Commission. 2020 General Land Use Plan. https://gis.arlingtonva.us/Maps/Standard_Maps/Planning_Maps/GLUP.pdf

Arlington County. Chesapeake Bay Preservation Ordinance Chapter 61. Arlington County Code. https://countyboard.arlingtonva.us/wp-content/uploads/sites/22/2016/04/Chapter-61-CHESAPEAKE-BAY-PRESERVATION-ORDINANCE.pdf.

GIS Resource Protection Area datasets available at: https://building.arlingtonva.us/codes-ordinances/chesapeake-bay/

# Appendix A
# Problem Area Definition

# Problem Area Definition for Risk Assessment (RAMP Task 5)

Contract number: 173482-Y2-02

The purpose of this document is to present recommended "Problem Areas" (PAs) selected for the risk assessment in HAZUS to be performed during Task 5 of the Risk Assessment Management Plan (RAMP). The scope of the RAMP includes the definition of 36 PAs[1] for risk assessment during Task 5 (using HAZUS and supplemented by social and environmental metrics), followed by the definition of concepts for flood mitigation and benefit-cost analysis during Task 6. This document does not represent a deliverable in the Scope of Work. It is prepared to document the definition of the problem areas to obtain feedback from the County.

The watersheds included in Tasks 5 and subsequent work in Task 6 include:

- Four Mile Run, Lower Mainstem
- Torreyson Run
- Roaches Run
- Doctor's Branch
- Spout Run
- Lubber Run
- Bailey's Branch & Four Mile Run, Middle Mainstem (Combined)

In the context of this project, a "Problem Area" is defined as an area in the County exposed to flooding, based on hydrologic/hydraulic modeling. The boundary of flooded area included in each PA is delineated approximately based on potential location of mitigation alternatives (conveyance or storage improvements) to hydraulic deficiencies for each flooded area. This allows benefits (flood damage reduction) to be associated with cost of specific mitigation alternatives to be developed in Task 6. Further criteria and information for the definition of the problem area includes:

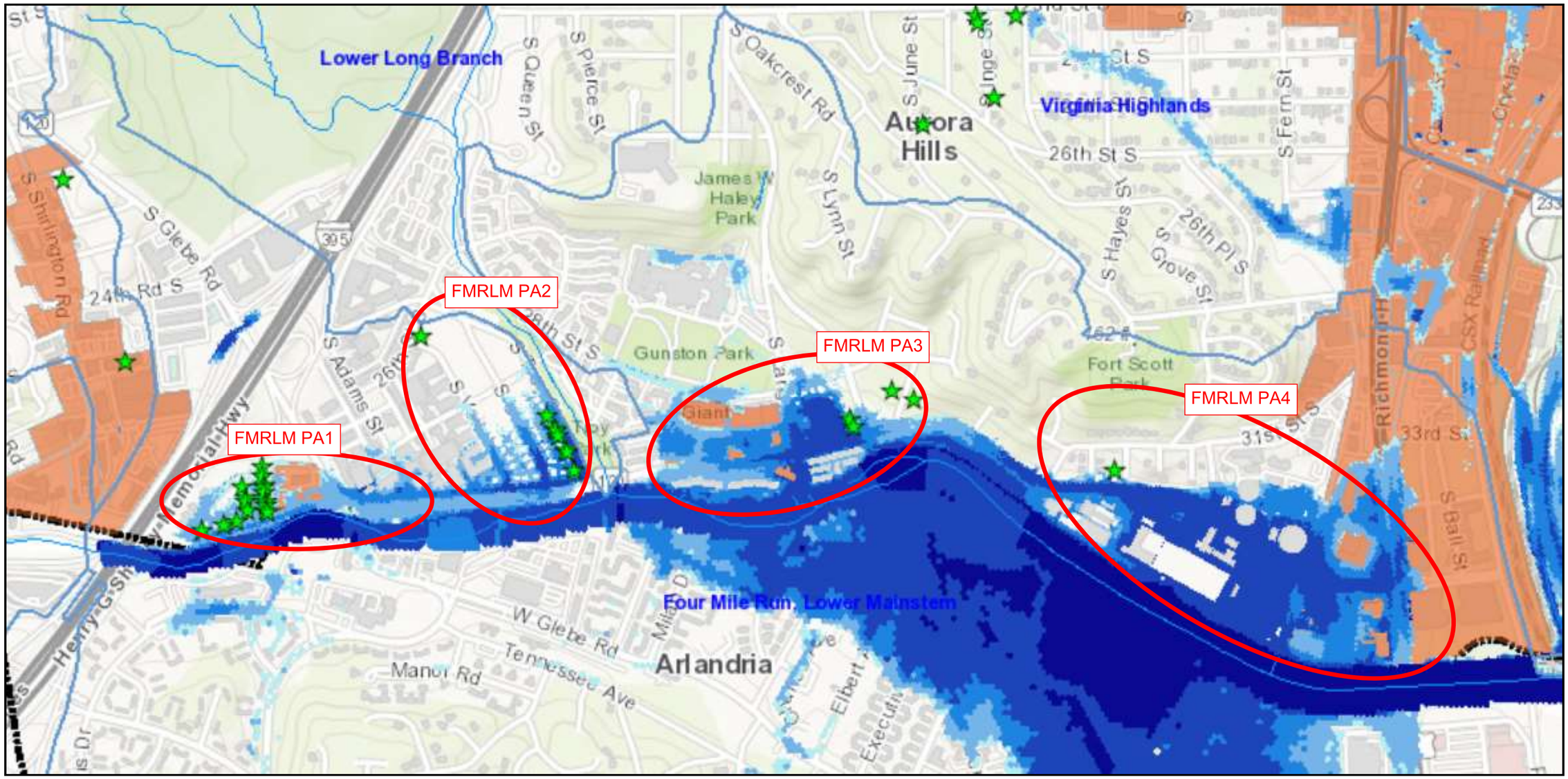
- Flood exposure used for the identification of problem areas is based on the 100-year event escalated by climate change impact in 2070. The 500-year in 2070 scenario was also used in "spot checking" additional extent and additional inundated areas to those areas affected by the 100-year storm scenario.[2] The problem area definition has low sensitivity to the 500-year event compared to the 100-year event (the definition of PAs would be very similar using either event)
- PA delineation considers event flood calls and clusters of calls although many PAs do not have flood calls associated with them. Flood calls in areas of minimal to no inundation were not included due to the fact that these areas may have had flood calls due to reasons not covered under this scope, such as sewer backups.

[1] The scope of work provides a number of problem areas by watershed. The number of problem areas by watershed in the scope was used only as a guideline to estimate a realistic total number of PAs for the project.

[2] The 500-year future event was not selected as the primary scenario for identification of PAs since it may include exposure that cannot be solved by the flood mitigation projects that will be explored during Task 6.

- The model drainage network in PCSWMM and model results analysis were utilized to delineate PAs based on direct underlying issues with the stormwater system.
- Several areas exposed to flooding are potential PAs but are located in green space and have not been included as PAs for assessment and flood mitigation. These flooded areas under green space have been flagged for flood inundation using a green circle in the following maps.
- Green space flooded areas (in green circles) can be included in the analysis, however, the total number of PAs for analysis cannot be more than 36.

Problem Area maps have been provided in the following pages of this document. Note that the brown polygons in the map correspond to commercial areas. The labels for PAs include a watershed identifier followed by a numeric ID. For example, a PA in Lubber Run will be labeled "LR PA-x" with LR corresponding to Lubber Run and "x" as the sequential number for the PA in that watershed. Currently, circles were used to identify each PA, however, these shapes will be refined further to fully encompass all vital areas of inundation based on feedback from the County team members. A total of 34 problem areas have been identified.




## FOUR MILE RUN, LOWER MAINSTEM

Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

Recommended PA

Flooded Area in Green Space not included as PA

Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number

Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

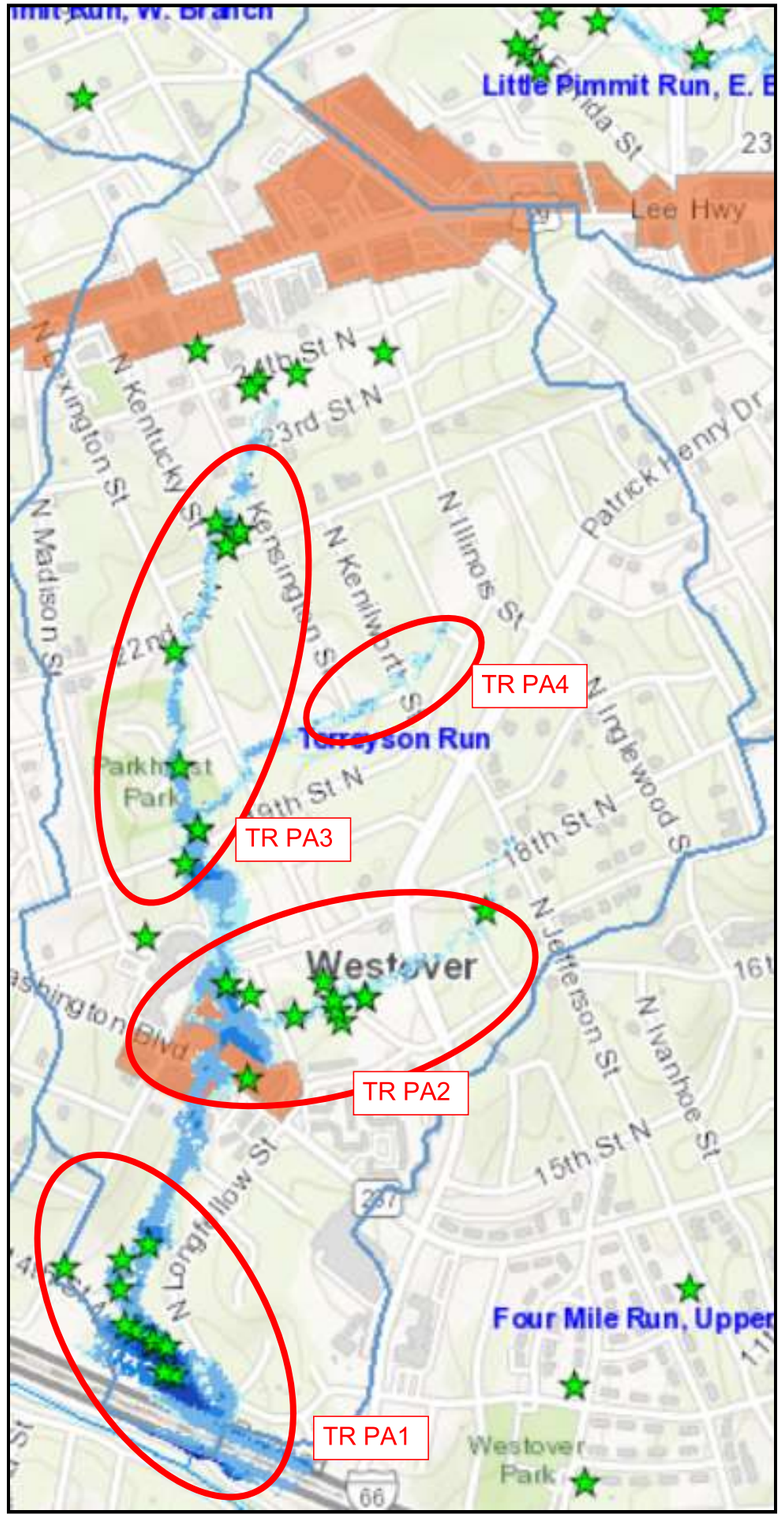
Recommended PA

Flooded Area in Green Space not included as PA

Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number




**TORREYSON RUN**

Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

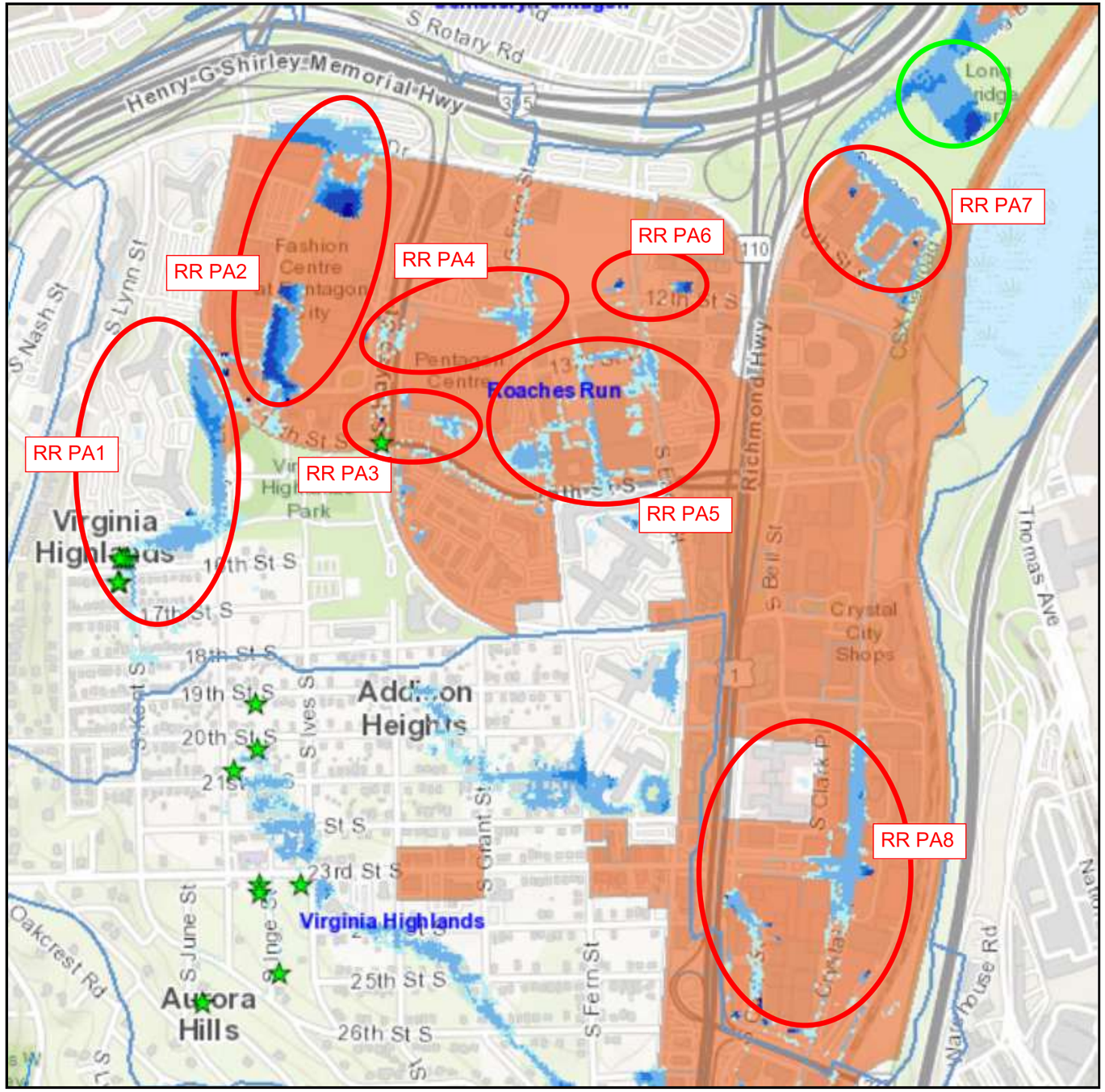
Recommended PA

Flooded Area in Green Space not included as PA

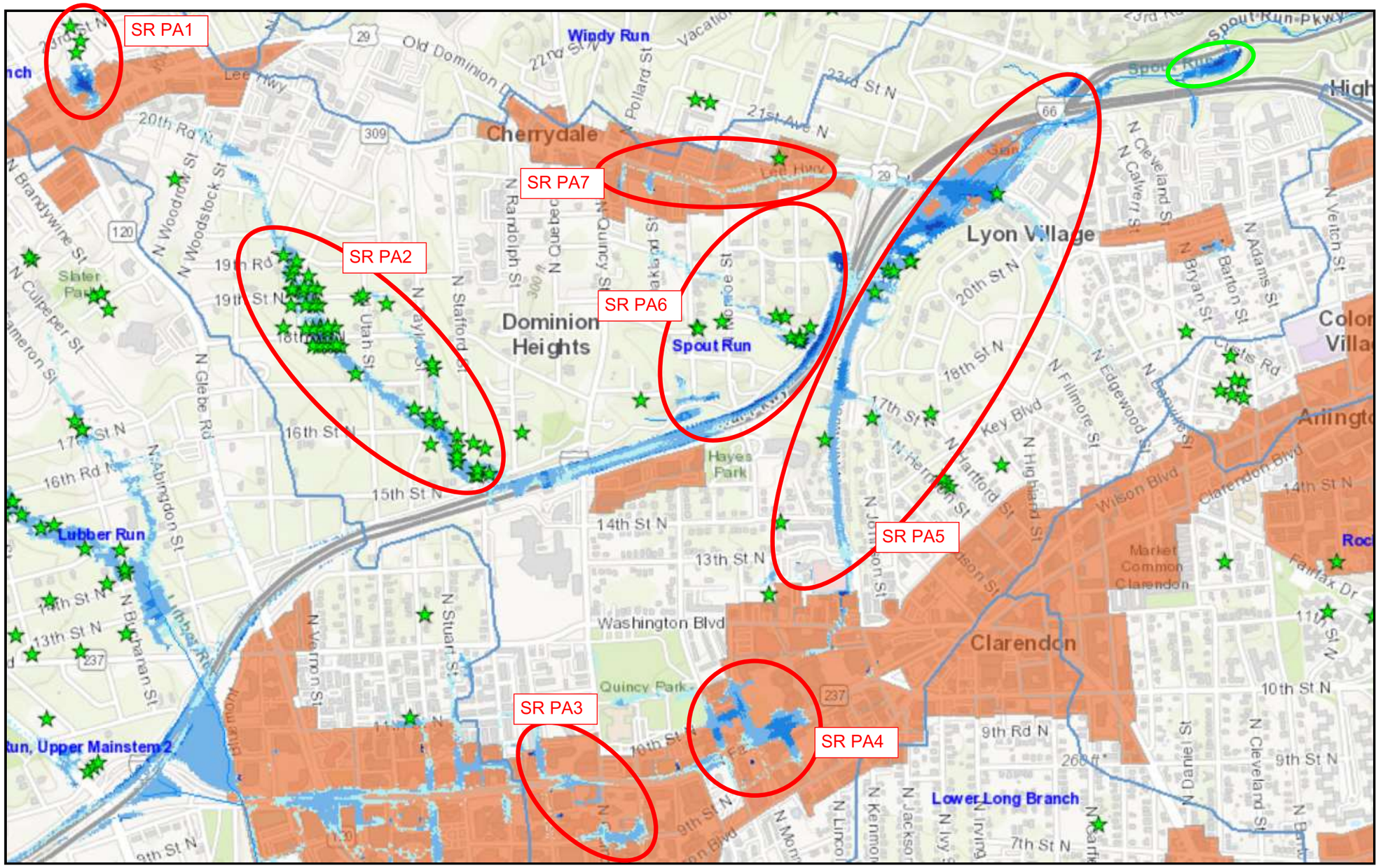
Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number




**ROACHES RUN**


SR PA1
SR PA2
SR PA3
SR PA4
SR PA5
SR PA6
SR PA7
Windy Run
Cherrydale
Dominion Heights
Spout Run
Lyon Village
Hayes Park
Washington Blvd
Clarendon
Quincy Park
Lower Long Branch
Lubber Run
Upper Mainstem 2
Old Dominion Dr
Lee Hwy
20th Rd N
19th Rd N
19th St N
18th St N
17th St N
16th St N
16th Rd N
15th St N
14th St N
13th St N
22nd St N
21st Ave N
20th St N
N Glebe Rd
N Stafford St
N Randolph St
N Quincy St
N Oakland St
N Monroe St
N Fillmore St
N Edgewood St
N Harrison St
N Hartford St
N Highland St
N Vermont St
N Stuart St
N Buchanan St
N Abingdon St
N Brandywine St
N Culpeper St
N Woodrow St
N Woodstock St
N Utah St
N Taylor St
N Cleveland St
N Calvert St
N Bryan St
N Adams St
N Veitch St
Barton St
Curtis Rd
Key Blvd
Wilson Blvd
Clarendon Blvd
14th St N
11th St N
10th St N
9th Rd N
9th St N
7th St N
N Daniel St
N Cleveland St
N Irving St
N Ivy St
N Kenmore St
N Lincoln St
Spout Run Pkwy
Fairfax Dr
Market Common Clarendon
Slater Park
Colonial Village
Arlington
Roc
120
309
29
66
237
50
Approximate Maximum Flood Depths for 2070 100-YR Scenario
0.5 - 1 ft
1 - 3 ft
3 - 5 ft
5 - 10 ft
>10 ft
Recommended PA
Flooded Area in Green Space not included as PA
Commercial/Economic Activity Area
Approximate Location of Flood Calls
SR PA4
Watershed Acronym plus Problem Area (PA) Number

**SPOUT RUN**

Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

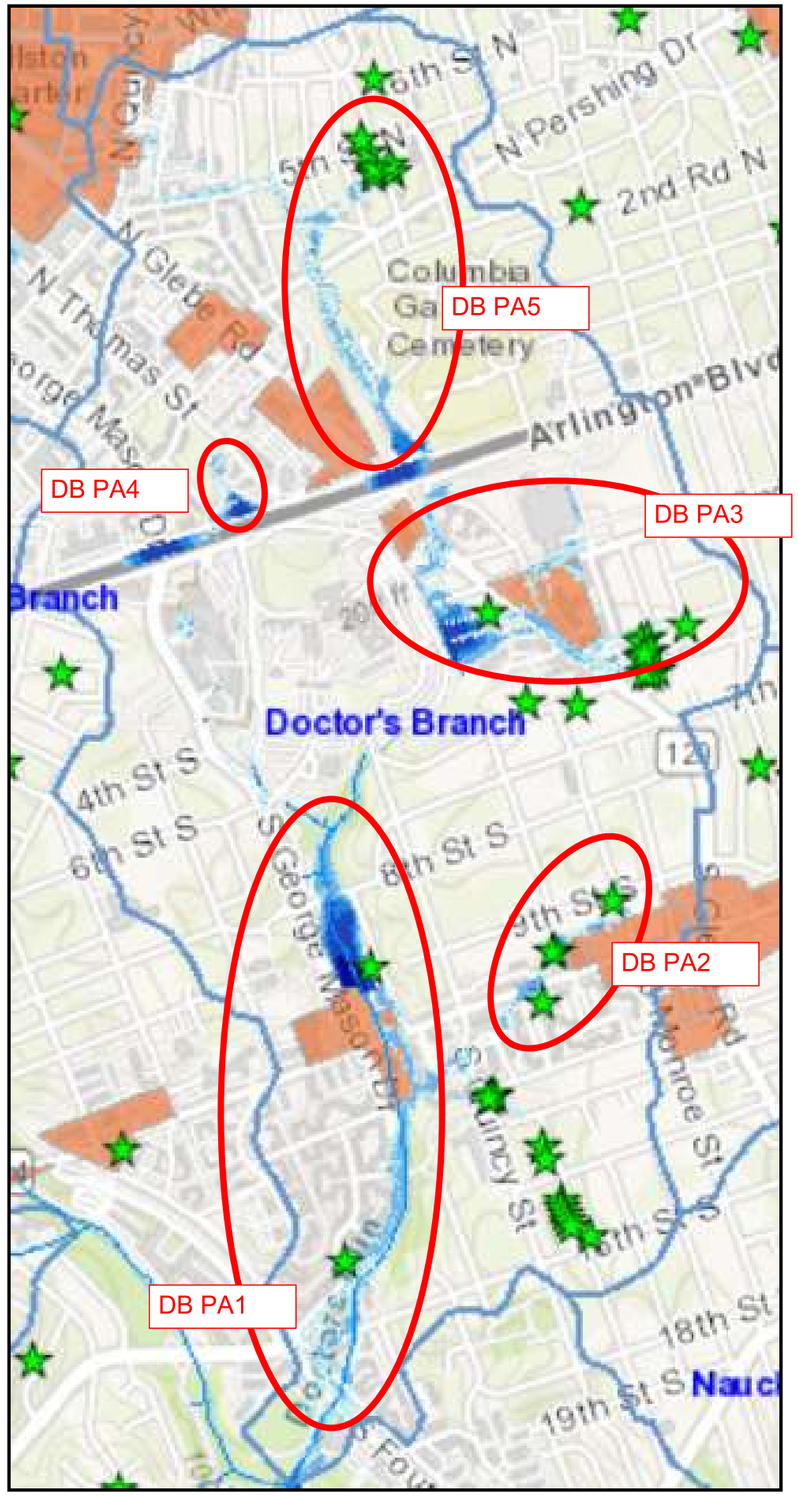
Recommended PA

Flooded Area in Green Space not included as PA

Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number




**DOCTOR'S BRANCH**

Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

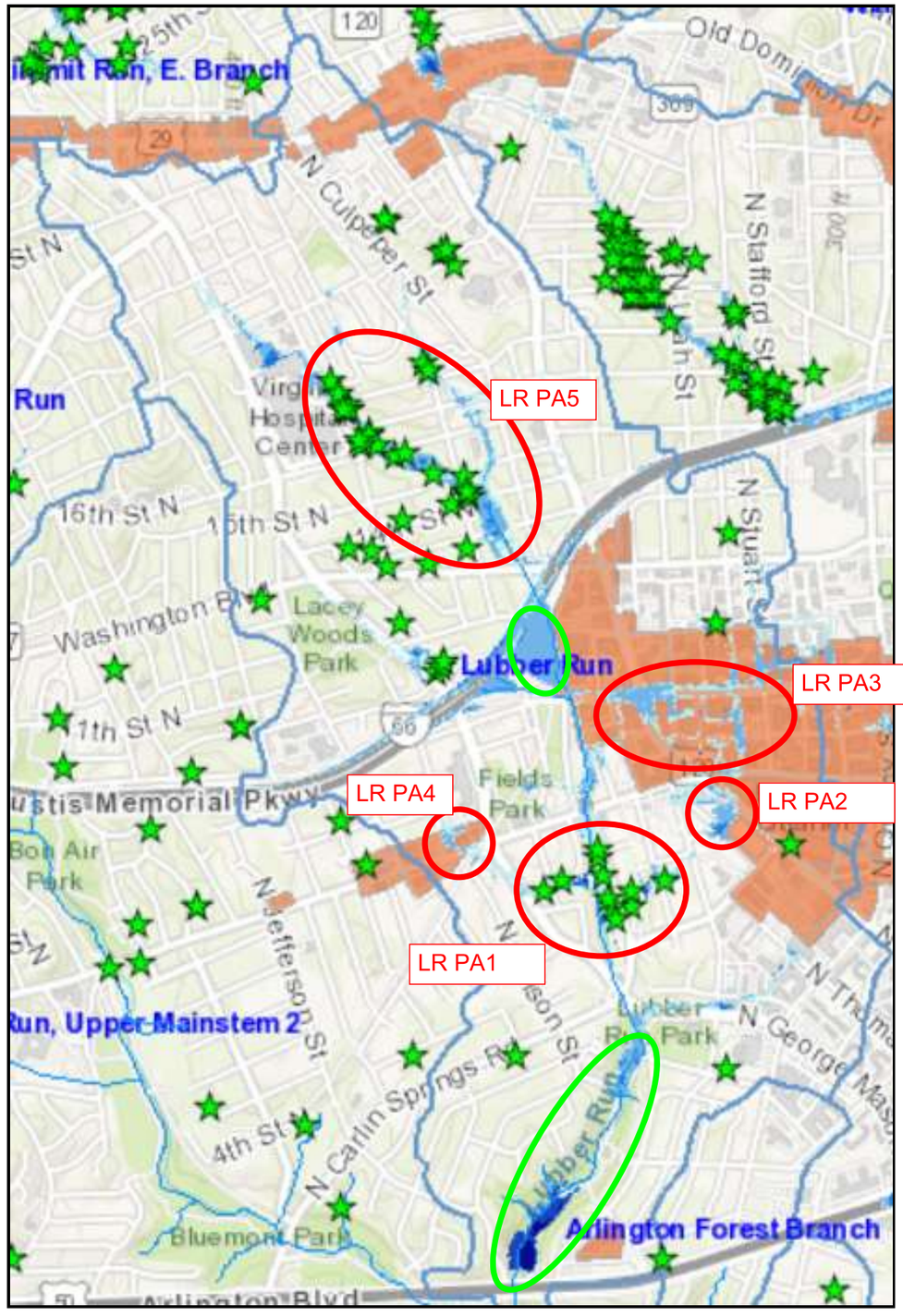
Recommended PA

Flooded Area in Green Space not included as PA

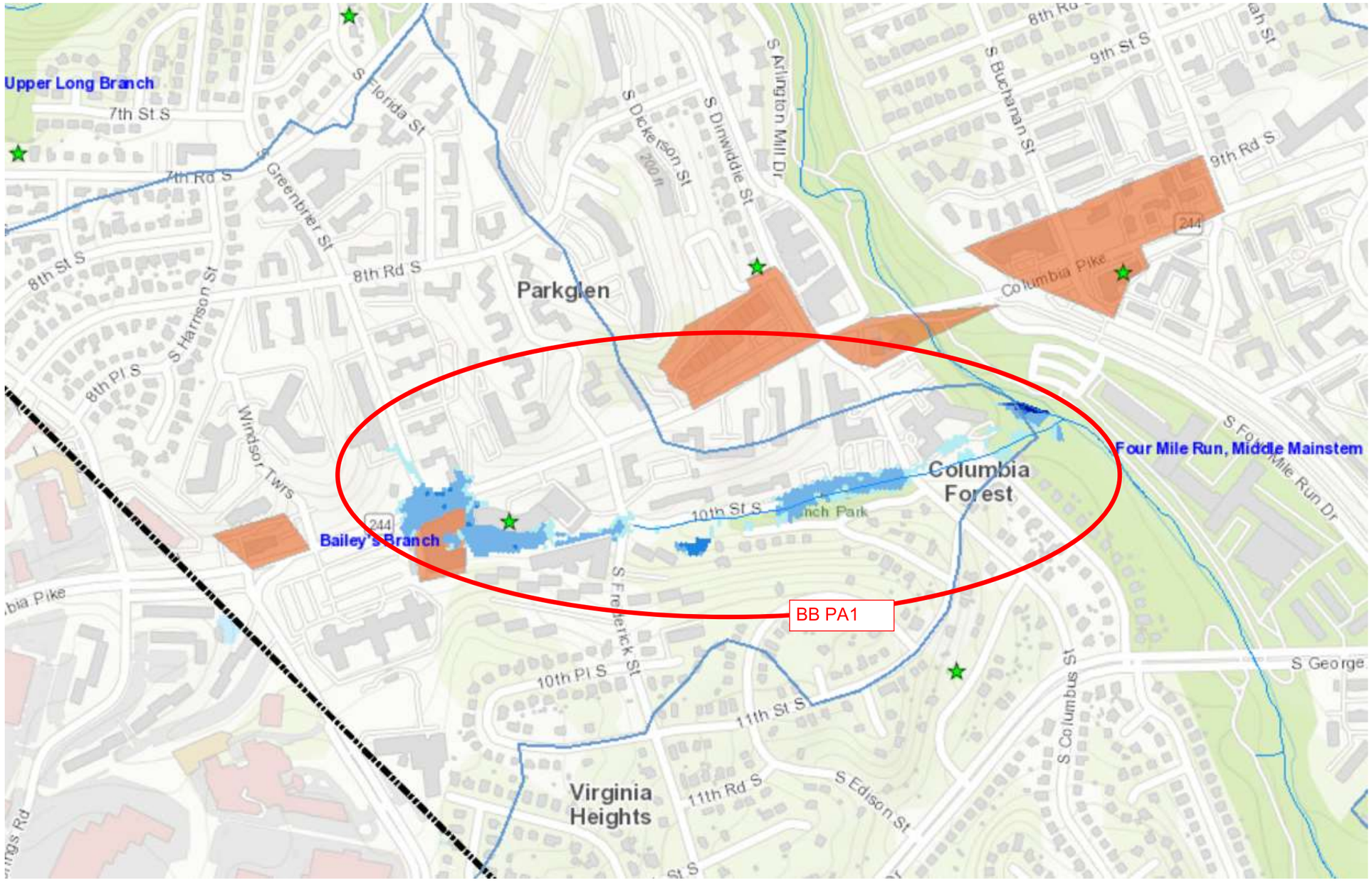
Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number




**LUBBER RUN**




Approximate Maximum Flood Depths for 2070 100-YR Scenario

- 0.5 - 1 ft
- 1 - 3 ft
- 3 - 5 ft
- 5 - 10 ft
- >10 ft

Recommended PA

Flooded Area in Green Space not included as PA

**BAILEY'S BRANCH**

Commercial/Economic Activity Area

Approximate Location of Flood Calls

SR PA4 — Watershed Acronym plus Problem Area (PA) Number

# Appendix B
# Asset Replacement Cost Estimates

The basis of the asset replacement costs for this study was a comprehensive databased developed for a similar study in 2019, with geographic adjustment and time escalation. A comprehensive flood vulnerability study completed in 2019 developed asset replacement costs for 230 asset categories using Jacobs' Timberline estimating tool and historical costs of actual replacement of assets from multiple projects to estimate material costs. The project cost estimates are based on 2019 dollars.

To develop equipment replacement costs including design and construction, the percentages included in Table B-1 were added to the material costs. Each percentage is applied to the subtotal of cost with previous percentage applied. For instance, if item installation cost is $100, then the 6% general conditions and 3% mobilization/demobilization are applied to $107 (the 7% material sales and use tax has been applied). The percentages in the table are listed in the order in which they were applied.

**Table B-1. Asset Replacement Costs Markup Percentages**

| Item | Percentage |
|---|---|
| Material Sales and Use Tax | 7% |
| General Conditions/Mobilization and Demobilization | 6%/3% |
| Overhead and Profit/Bonds and Insurance | 15%/2% |
| Contingency | 25% |
| Escalation | 5% |
| Engineering | 10% |

The estimates are Class 5 estimates in accordance with the Association for the Advancement of Cost Engineering International (AACEI) classification system. Based on AACEI guidelines, these estimates are considered to have a level of accuracy between -50 to +100 percent.

For the Arlington County Risk Assessment Management Program (RAMP), a critical step included the geographic adjustment to Arlington County (Northern Virginia, DC area) and escalation to 2022 indices. Exhibit B1 presents the escalation report for the RAMP.

Even with the comprehensive database, geographically adjusted and escalated, the RAMP required additional costs estimating for multiple assets that were not included in the 230 categories from previous projects. Three approaches were utilized to determine these costs:

- Used a similar project's values and applied adjusted inflation and location rates as well as markup rates
- Used a cost estimation tool (RSMeans) for asset and material costs and applied installation and markup rates
- Used a cost estimation based on subject matter expertise and engineering judgment

Specifically for buses that will be assets under potential exposure at the ART Operations and Maintenance Facility, a blend of diesel, CNG and battery electric buses were a assumed for a fleet of 59 buses expected to be housed at the facility. This assumes that the fleet will evolve over time from diesel (with a planning value estimate of approximately $400,000) to battery electric (with a planning value estimate of approximately $800,000).

The asset replacement costs are meant to be used only for relative risk comparisons based on the aggregate results for monetized risk, by facility. The asset replacement costs should not be used for budgeting purposes on any specific asset.

## Exhibit B1

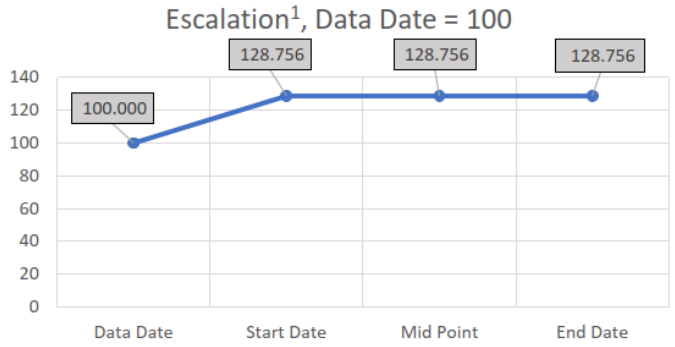
**Jacobs**

### Cost Estimating - Escalation Calculation Report

| | | | |
|---|---|---|---|
| Escalation report prepared: | 6/28/2022 | | |
| Escalation Model Used: | WWTP | - | *Wastewater Treatment Plant* |
| Project: | Arlington County Risk Assessment | | |

| Event | Date |
|---|---|
| Data Date | 7/1/2019 |
| Start Date | 6/28/2022 |
| Mid Point | 6/28/2022 |
| End Date | 6/28/2022 |

| Value | Calculation |
|---|---|
| Escalation[1] | 28.756% |
| Years[2] | 3.0 |
| Rate Per Annum[3] | 8.813% |
| Historical[4] | 3.4% |
| Volatility[5] | 4.7% |



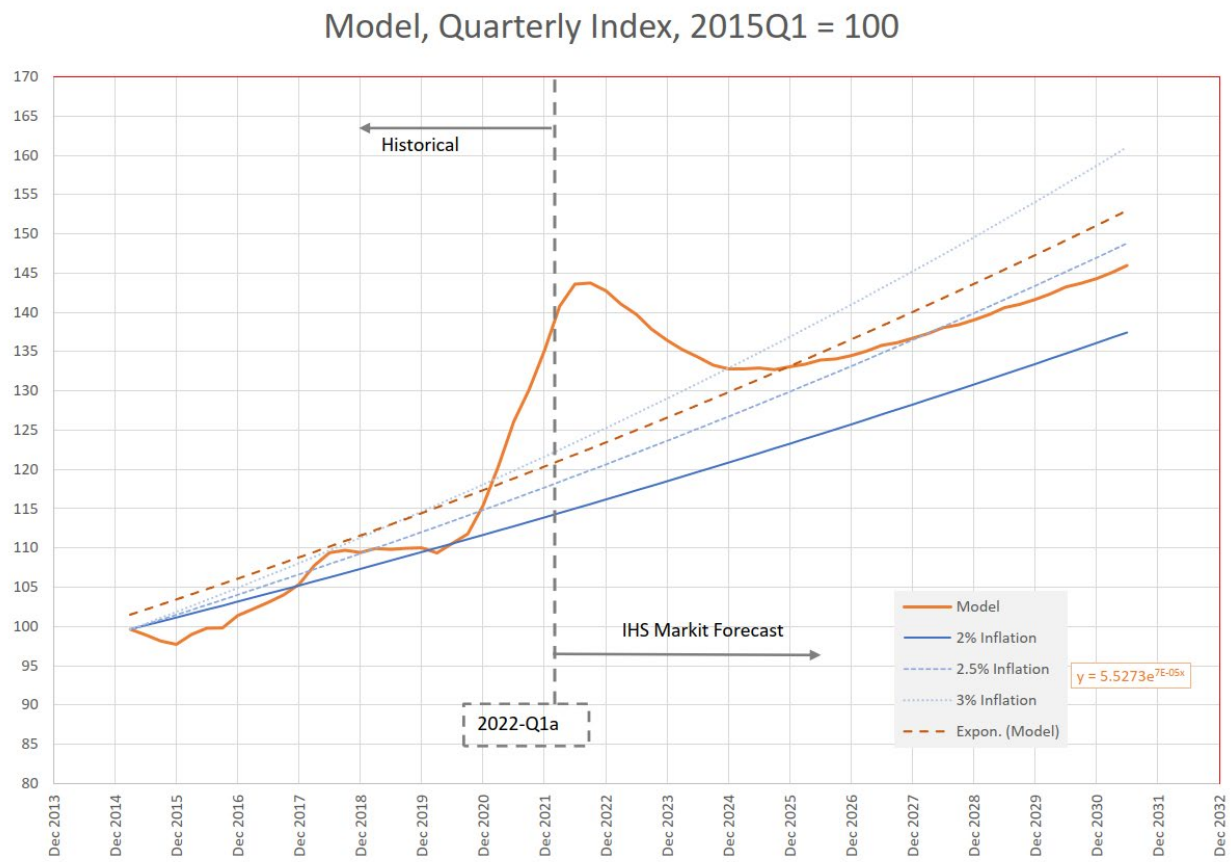

Notes:

1 - Escalation begins with the data date and assumes equal spending from project start to end dates
2 - Years is the duration from the Data (Estimate) date to the mid point of the project
3 - Rate Per Annum is the annual rate of escalation which when compounded over Years, equal Escalation
4 - Historical is the annual rate of escalation for the weighted model from 2015/Q1 to 2021/Q2
5 - Volatility is the std. deviation of the model's Historical annual rates of escalation, equivalent to a p=0.84 value

Forecasts are based on data provided by IHS Markit though 2022-Q1a with model weighting as given below:

1.3668% - PPI324110AY2.Q.FOS - USA, PPI, Diesel Fuel
0.4586% - WPIP1321.Q.FOS - USA, PPI, Sand Gravel and Crushed Stone
4.2616% - PPI327320P.Q.FOS - USA, PPI, Ready-Mix Concrete
2.5383% - PREBAR.Q.FOS - USA, Spot Price, Reinforcing Bar (Rebar) Steel
0.3281% - WPIP08.Q.FOS - USA, PPI, Lumber and Wood Products
0.3009% - WPIWP133.Q.FOS - USA, PPI, Concrete Products
0.4733% - PPI331318.Q.FOS - USA, PPI, Other Aluminum Rolling Drawing and Extruding
0.669% - PPI3311107.Q.FOS - USA, PPI, Hot Rolled Bars Plates and Structural Shapes
0.2604% - WPIP081.Q.FOS - USA, PPI, Lumber
0.3887% - PPI3241221.Q.FOS - USA, PPI, Roofing Asphalts, Pitches, Coatings, Cements
0.1766% - PPI332321.Q.FOS - USA, PPI, Metal Window and Door
0.3426% - PPI327420.Q.FOS - USA, PPI, Gypsum Wallboard
0.3426% - PPI325510.Q.FOS - USA, PPI, Paints and Coatings
0.1095% - WPIS30S.Q.FOS - USA, PPI, Finished Goods
20.5454% - WPIP11.Q.FOS - USA, PPI, Machinery and Equipment
0.4839% - PPI337214.Q.FOS - USA, PPI, Office Furniture
0.8041% - PPI334516.Q.FOS - USA, PPI, Laboratory Analytical Instruments
0.8041% - PPI3353141.Q.FOS - USA, PPI, Relay and Industrial Controls
0.556% - WPIP1144.Q.FOS - USA, PPI, Industrial Material Handling Equipment
1.5378% - PPI331511.Q.FOS - USA, PPI, Iron Foundries
0.8367% - WPIP0721.Q.FOS - USA, PPI, Plastic Construction Products (Primarily Pipe)
5.0255% - PPI332996.Q.FOS - USA, PPI, Fabricated Pipe and Fittings
2.5905% - PPI335929D.Q.FOS - USA, PPI, Building Wire and Cable
1.5543% - PPI335313.Q.FOS - USA, PPI, Switchgear and Switchboard Apparatus
5.8299% - PPI331210.Q.FOS - USA, PPI, Iron/Steel Pipe and Tube Mfg From Purch Steel
4.1091% - PPI3339121.Q.FOS - USA, PPI, Air and Gas Compressors
2.0545% - WPIP07.Q.FOS - USA, PPI, Rubber and Plastic Products
12.3272% - PPI333911.Q.FOS - USA, PPI, Pumps and Pumping Equipment
2.0545% - PSTAINSHEET304.Q.FOS - USA, Spot Price, Stainless Coil Steel, Grade 304
26.8695% - CEU2000000008.Q.FOS - USA, Average Hourly Earnings, Construction

## Exhibit B1


Model, Quarterly Index, 2015Q1 = 100
Historical
IHS Markit Forecast
2022-Q1a
Model
2% Inflation
2.5% Inflation
3% Inflation
Expon. (Model)
y = 5.5273e^7E-05x
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
Dec 2013
Dec 2014
Dec 2015
Dec 2016
Dec 2017
Dec 2018
Dec 2019
Dec 2020
Dec 2021
Dec 2022
Dec 2023
Dec 2024
Dec 2025
Dec 2026
Dec 2027
Dec 2028
Dec 2029
Dec 2030
Dec 2031
Dec 2032

# Appendix C
# Hazus Overview

# Hazus Software Background

This appendix presents some basic information about Hazus software, including excerpts from its technical user's manual which can be accessed in the following link: Hazus 5.1 Flood Model User Guidance (fema.gov).

The Hazus Flood Loss Estimation Methodology provides officials and analysist with a decision support software for estimating potential losses from flood events. This loss estimation capability enables users to anticipate the consequences of floods and develop plans and strategies for reducing risk. The Geographic Information System (GIS) based software can be applied to study geographic areas of varying scale with diverse population characteristics and can be implemented by users with a wide range of technical and subject matter expertise.

This Methodology has been developed, enhanced, and maintained by the Federal Emergency Management Agency (FEMA) to provide a tool for developing flood loss estimates. While the tool can be used in preparedness and recovery, Hazus has been used in this Arlington County Risk Assessment Management Program (RAMP) as a planning to quantify potential building and vehicle impacts and losses. Hazus can analyze flood hazards from a variety of inputs. For Task 5, the flood exposure information was generated by RAMP modeling as part of Task 3, under multiple scenarios with different probabilities.

Hazus flood methodology was developed by FEMA in the early 2000s and is updated with ongoing modifications based on newer methodology or software development. It is intended to help guide the allocation of federal resources to stimulate risk mitigation efforts and to plan for a flood-related disaster response at all levels of government.

The Hazus Flood Model Technical Manual (link provided above) documents the methods used in calculating losses. A companion document, the Hazus Inventory Technical Manual (Hazus 5.1 Flood Model User Guidance [fema.gov]), provides more detailed methodology and data descriptions for the inventory shared by each hazard model. The following pages are an excerpt of Section 2 of the Hazus 5.1 User Guidance.

# Excerpt from Hazus 5.1 User Guidance

(Hazus 5.1 Flood Model User Guidance [fema.gov])

Section 2. Overview of the Flood Model

This brief overview of the Flood Methodology is intended for SLTT officials contemplating a flood analysis. The Flood Model will generate an estimate of the consequences to a county or region of a scenario flood (i.e., a flood of a specified magnitude). The resulting "loss estimate" will generally describe the scale and extent of damage and disruption that may result from the modeled flood event. The following information can be obtained:

- Quantitative estimates of structural damage based on specific building and occupancy types that delineate how and to what extent a structure can be damaged by varying flood water depths.
- Quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings, direct costs associated with loss of function (e.g., loss of business revenue or relocation costs).
- Estimates of social and infrastructure impacts.

To generate this information, the Methodology includes:

- Classification systems used in assembling inventory and compiling information on the General Building Stock (GBS), demographic, and economic data.
- Standard calculations for estimating type and extent of damage, and for summarizing losses.
- National and regional databases containing information for use as baseline (built-in) data useable in the calculation of losses if there is an absence of user-supplied data.

These systems, methods, and data have been combined in a user-friendly GIS software for this loss estimation application. The Hazus software uses GIS technologies for performing analyses with inventory data and displaying losses and consequences on applicable tables and maps. The Methodology permits estimates to be made at several levels of complexity, based on the level of inventory data entered for the analysis (i.e., baseline data versus locally enhanced data). The more concise and complete the inventory information, the more accurate the results. The following figure provides a graphic representation of the modules that the Hazus Flood Model Methodology is comprised of, and their interrelation in deriving estimates.

While Figure C-1 shows the conceptual relationships, the steps used in the Hazus Flood Model are as follows:

- Select the area to be studied: The Hazus Study Region (the region of interest) is created based on Census block, tract, or county level aggregation of data. The area generally includes a city, county, or group of municipalities. It is generally desirable to select an area that is under the jurisdiction of an existing regional planning group.
- Specify the Flood hazard scenario: In developing the scenario, flood consideration should be given to the availability of data including depth grids or elevation models from Hydrologic Engineering Center – River Analysis System (HEC-RAS) or lidar-derived sources.
- Integrate local inventory data: Include user-defined facilities and updates to GBS characteristics.
- Use the formulas embedded in Hazus: Compute probability distributions for damage to different classes of buildings, facilities, and infrastructure system components.
- Compute estimates of direct economic loss, infrastructure, and social impacts using the damage and functionality information.

The user plays a major role in selecting the scope and nature of the output of a loss estimation analysis. A variety of maps can be generated for visualizing the extent of the losses. Generated reports provide numerical results that may be examined at the level of the Census block, tract, or aggregated by county or region.

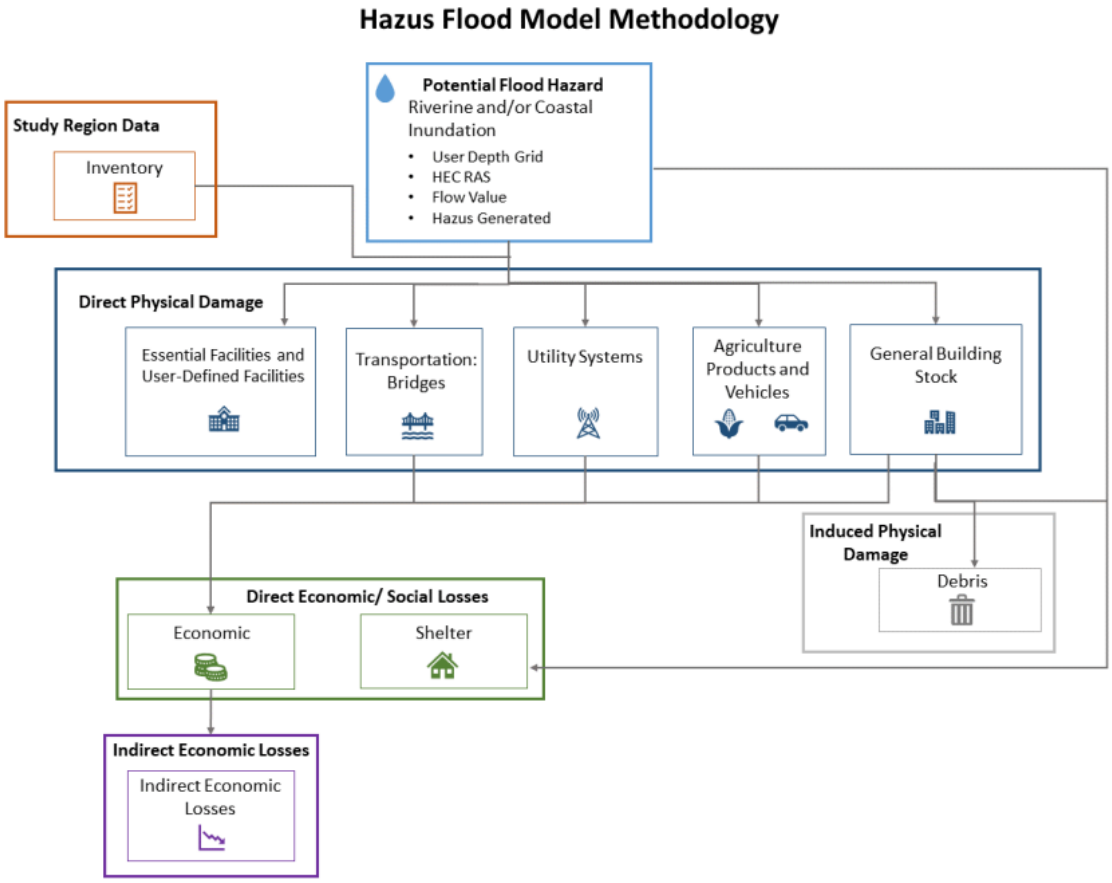



**Figure C-1. Hazus Flood Model Methodology Schematic**

## Definitions of Structures

There are differences between terminology used to designate distinctions between types or categories of structures. The term "structure" refers to all constructions, such as a building, bridge, water tank, shed, carport, or other man-made thing that is at least semi-permanent. A building is a structure with a roof and walls that is intended for use by people and/or inventory and contents, such as a house, school, office, or commercial storefront. A facility corresponds to a particular place, generally a building, with an intended purpose such as a school, hospital, electric power station, or water treatment facility. Some facilities are defined as 'essential facilities' meaning the facility is critical to maintaining services and functions vital to a community, especially during disaster events. The buildings, essential facilities, and transportation and utility systems considered by the Methodology are as follows:

- General Building Stock: The key GBS databases in Hazus include square footage by occupancy and building type, building count by occupancy, and building type, building and content valuation by occupancy and building type, and general occupancy mapping. The GBS commercial, industrial, and residential buildings in a region are not considered individually when calculating losses. These buildings within each Census block are aggregated and categorized. Building information derived from Census and employment data are used to form groups of 33 specific occupancy classes, seven foundation types, and five general building types (additional information on the Hazus baseline GBS inventory data is provided in the Hazus Inventory Technical Manual (FEMA 2021). Degree of damage is computed for each grouped combination of model building type and occupancy class.

- User-Defined Facilities (UDFs): A template database is available in Hazus to enter individual accurate results. structures to be analyzed, instead of or in addition to the aggregated GBS. Template databases are available in Hazus if the user is comfortable working with SQL Server. More information on how to set up a UDF database can be found in Section 9 of this document, the Hazus Inventory Technical Manual (FEMA 2021) or in the documentation and sample databases accompanying the Hazus FAST tool. Use of individual, site-specific data is highly encouraged for more.

## Levels of Analysis

Hazus is designed to support two general types of analysis (Basic and Advanced), split into three levels of data updates (Levels 1, 2, and 3). Figure C-2 provides a graphic representation of the various levels of analysis.

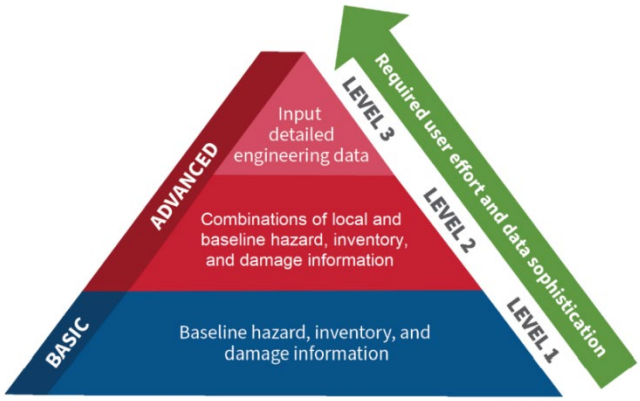



**Figure C-2. Level of Hazus Analysis**

### Analysis Based on Baseline Information

The basic level of analysis uses only the baseline databases built into the Hazus software and Methodology on building square footage and value, population characteristics, costs of building repair, and certain basic economic data. This level of analysis is commonly referred to as a Level 1 analysis. In a basic analysis (Level 1), the user must specify a drainage area for stream network delineation, and Hazus will use these inputs to estimate a depth grid for the study region. Direct economic and social losses associated with the GBS, and essential facilities are computed. Baseline data for transportation and utility systems are included; thus, these systems are considered in the basic level of analysis. However, there is a significant level of uncertainty pertaining to the estimates. Other than defining the Study Region, selecting the scenario flood(s), and making decisions concerning the extent and format of the output, an analysis based on baseline data requires minimal effort from the user. As indicated, the estimates involve large uncertainties when inventories are limited to the baseline data. This level of analysis is suitable primarily for preliminary evaluations and comparisons among different Study Regions. A basic Level 1 analysis could be used for comparisons and preliminary evaluations to assist in identifying potential mitigation actions within a community, which could be useful if evaluating funding priority for projects.

### Analysis with User Supplied Inventory [11]

Results from an analysis using only baseline inventory data can be improved greatly with at least a minimum amount of locally developed input. Improved results are highly dependent on the quality and quantity of improved inventory data. The significance of the improved results also relies on the user's analysis priorities. This level of advanced analysis is commonly referred to as a Level 2/Level 3 analysis. The following inventory improvements impact the accuracy of Level 2/Level 3 Advanced Analysis results:

- Use of locally available data or estimates of the square footage of buildings in different occupancy classes.
- Use of local expertise to modify the mapping scheme databases that determine the percentages of specific building types associated with different occupancy classes.

[11] The Arlington RAMP risk analysis using Hazus represents and advance Level 2, since it uses a combination of baseline inventory and damage information but also locally developed hazard (results from flood modeling developed specifically for Arlington County).

- Preparation of a detailed inventory of all essential facilities and infrastructure.
- Use of locally available data concerning construction costs or other economic parameters.
- Level 2 or 3 hazard data can also be incorporated in the form of independently generated depth grids. Sources for these grids may include local engineering offices, state water departments with access to lidar products, adapted DFIRMs from FEMA, or the HEC-RAS tool.

---

End of Excerpt from Hazus 5.1 User Guidance

## Definitions Used in the Arlington RAMP Task 5 Analysis

Losses computed by Hazus are divided in multiple categories that align with direct losses (direct damages to an asset from flooding) and indirect losses (consequences of the physical damage or activity disruption due to flood). The following categories are used in Task 5:

- Capital Stock Losses: Include losses related to physical damage to the building (structural and nonstructural) as well as the building contents and contents related to economic activity (inventory) for building categories that observe economic activity with inventory.

Under Capital Stock Losses, the following categories are relevant:

- Building Loss: building loss is the losses associated with direct damages to the building and are thus specific to building typology, accounted for in Hazus (multiple building types and materials are included in the database).
- Content Loss: Building contents are defined as furniture, equipment that is not integral with the structure, computers and other supplies. Contents do not include inventory or nonstructural components such as lighting, ceilings, mechanical and electrical equipment and other fixtures. Contents damage functions are applied in the same manner as building damage functions.
- Inventory Loss: Inventory losses in the flood module are determined in a manner consistent with the other building losses, as well as the methodology currently utilized in the Hazus earthquake module. For occupancies with inventory considerations (COM1, COM2, IND1 – IND6 and AGR1, as defined in the Hazus99 Earthquake Technical Manual), inventory losses are estimated using USACE-based depth-damage functions, in conjunction with Hazus default inventory values determined as a percentage of annual sales per square foot.

Income Losses: Income losses are related to the disrupted economic activity associated with the flood event. Their estimates require an estimation of building restoration time or outage time (they are time-dependent).

Under Income Losses, the following categories are relevant:

- Relocation Loss: losses incurred by occupants of a building after damages reach a certain threshold. Relocation expenses represent disruption costs to building owners for selected occupancies. Expenses include "… disruption costs that include the cost of shifting and transferring, and the rental of temporary space."
- Income Loss: Income losses account for temporary loss of income due to flooding and exclude wage loss (associated with employees) and sales output loss (for owners), which are accounted for separately.
- Wage Losses: includes the temporary loss of wages for employee occupants of a building after damages reach a certain threshold.

- Direct Output Loss: includes temporary loss of sales and other direct output loss for incurred by business owners after damages in a building reach a certain threshold.
- Rental Income Loss: includes the temporary loss of rental income associated with relocation triggered by the flood event.

The Hazus Technical Manual includes the specific methodologies, data, assumptions and equations to compute these losses.

# References

Hazus 5.1 User Guidance

# Appendix D
# Social Vulnerability Index & Environmental Areas Background

# Environmental Receptors

Areas of environmental value for Arlington County, Virginia (the County) were based on areas from established sources, including the National Wetlands Inventory (NWI) and the Chesapeake Bay Preservation Ordinance (the Ordinance) (Arlington County 2003). The ordinance was adopted to protect streams and the Chesapeake Bay from pollution due to land use and development. All of Arlington County's water is tributary to the Potomac River and ultimately the Chesapeake Bay. In the Ordinance, sensitive areas along streams throughout Arlington have been designated as Resource Protection Areas (RPAs). The RPAs are natural buffers that help protect streams, rivers, and other water bodies. They include the environmentally sensitive lands within 100 feet of these water resources. These areas are known as stream or wetland buffers, and help protect water quality by:

- filtering out pollutants from stormwater runoff,
- reducing the volume of stormwater runoff,
- minimizing erosion, and
- providing wildlife habitat.

Additionally, a fully vegetated stream buffer can help protect private property by preventing erosion along a water body. Steep slopes (25 percent or greater) that are adjacent to buffers are also part of the RPA because of the potential for erosion in these areas, including during flooding events and high flow events. In RPAs, existing trees and other vegetation are protected and building projects are regulated.

The RPA information and its geodataset were supplemented with the NWI wetlands delineation. The Inventory is developed, updated and managed by U.S. Fish and Wildlife Service. The NWI is a publicly available resource (USFWS 2021) that provides detailed information on the abundance, characteristics, and distribution of US wetlands. Wetlands were included in the vulnerability assessment in Task 4 given their potential vulnerability to certain natural hazards and the fact that they provide a multitude of ecological, economic and social benefits.

The areas included in the vulnerability analysis for environmental receptors are presented in Figure D-1.

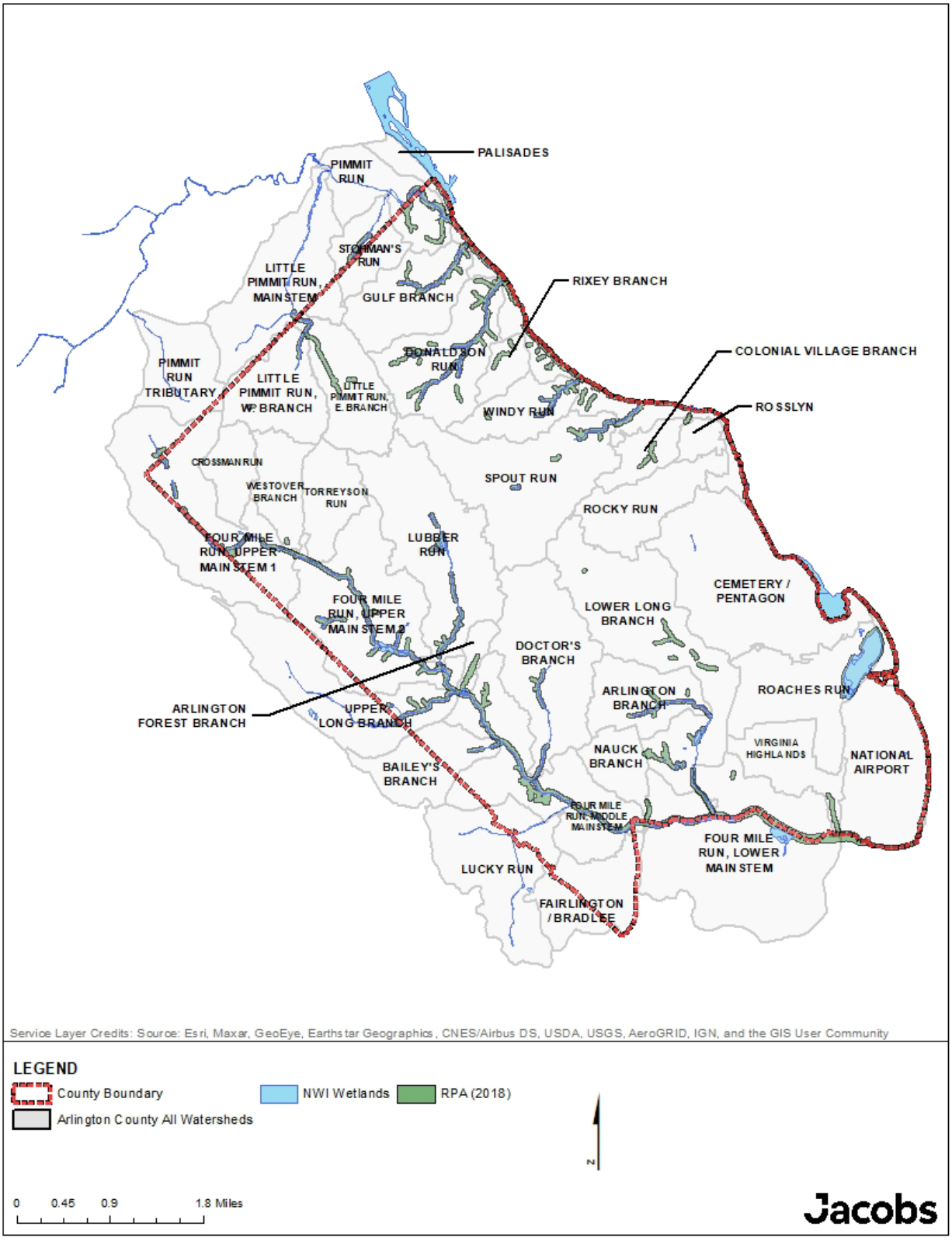



**Figure D-1. RPA AND NWI Wetlands Assessed in the Vulnerability Analysis**

# Social Vulnerability

Social vulnerability is an important consideration in many of the County's programs, policies, and services. The County's Department of Public Safety Communications & Emergency Management considers social vulnerability in the County's Emergency Operations Plan (Arlington County 2017) and other programs and initiatives including programs related to health equity and the recent Covid-19 Equitable Vaccine Access Strategy. Other County programs related to childcare and other services use social vulnerability to guide actions and outcomes. This RAMP considers social vulnerability, given that natural hazards and specifically flood can have adverse impacts that amplify for socially vulnerable populations.

According to the United States Agency for Toxic Substances and Disease Registry (ATSDR), which is part of the Centers for Disease Control (CDC), a Social Vulnerability Index (SVI) "refers to the potential negative effects on communities caused by external stresses on human health"[12]. In the context of this task, the external stress is flooding. SVI values were developed by the CDC/ATSDR by Census Block and is based on data from the 2010 U.S. Census. The CDC/ASTDR SVI aggregates an index from a combination of 15 social factors such as poverty, lack of access to transportation, overcrowded housing, and lack of medical facilities. Further information on SVI can be reviewed in Appendix F of TM4 (Jacobs 2021a).

As part of the RAMP, Jacobs reviewed different sources of information related to the County's use of social vulnerability and decided to use the CDCs SVI (SVI). The SVI is used by the County in recent initiatives including equitable vaccine distribution and childcare risk and reach (Arlington County 2017b) and it is consistent with the Socio-Needs Index also used by the County in other areas related to health indicators[13].

Figure D-2 below identifies the SVI values within Arlington County based on U.S. Census data.

The areas of high social vulnerability were used in flooded area analyses to support the watershed prioritization, as will be described in Section 4.6. While socially vulnerable areas do not constitute receptors they are a critical component of the prioritization process (see Section 4 for detail vulnerability methodology).

## Definition of High Social Vulnerability

The SVI was the basis for defining social vulnerability and from its values (from 0 to 1), which are available by census tract, two thresholds were derived for medium to high social vulnerability and high social vulnerability. The thresholds based on SVI values were 0.5 to 0.75 (for medium to high) and above 0.75 (for high). After an analysis that compared the SVI to the Socio-Needs Index specifically for the County, it was determined that these thresholds were consistent with the County's current use Socio Needs Index and rank.

The basis for the recommendation of these two thresholds included the review of the Equitable Vaccine Access Strategy Report (no reference provided since it is a confidential report). This report uses SVI as one of the metrics to determine equitable distribution. The report background information uses 4 categories with thresholds of 0.25, 0.5, and 0.75. It assigns a category of vulnerability for specific sites using 5 categories. The top categories are "Moderate to High" (SVI from 0.5 to 0.75) and "High" (SVI above 0.75).

[12] CDC/ATSDR's Social Vulnerability Index (SVI)

[13] http://www.healthierarlington.org/indicators/index/socioneeds

Additionally, the Childcare Reach and Risk Study uses SVI as one of the metrics of social vulnerability. It utilizes 4 bins linearly with the top 2 categories labeled as “Higher” and “Highest” and thresholds that are also 0.25, 0.5 and 0.75.

The recommended thresholds were presented to the county with using neighborhoods as a reference to visualize the resulting high social vulnerability definition.

For the rest of this TM, while the analysis specifically tracks areas between 0.5 and 0.75 and above 0.75, when we refer to areas of “high social vulnerability” we are referring to census tracts that have SVI values above 0.5.

The areas of high social vulnerability were used in flooded area analyses to support the watershed prioritization completed in Task 4.

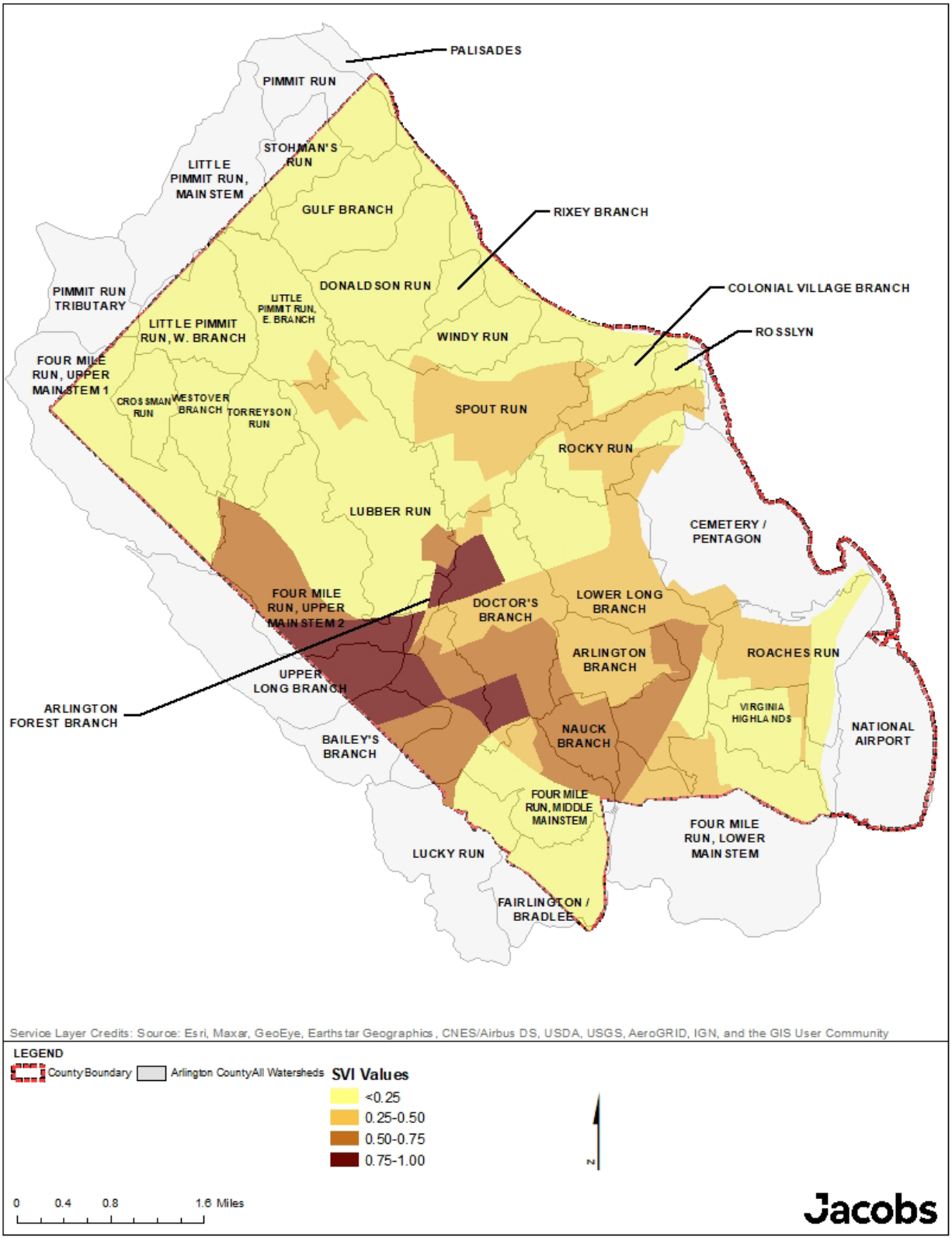



**Figure D-2. Centers for Disease Control Social Vulnerability Index (SVI) Values within Arlington County**

# Appendix E
# Problem Area Fact Sheets

# Bailey's Branch PA1 (BB_PA1)
# Fact Sheet

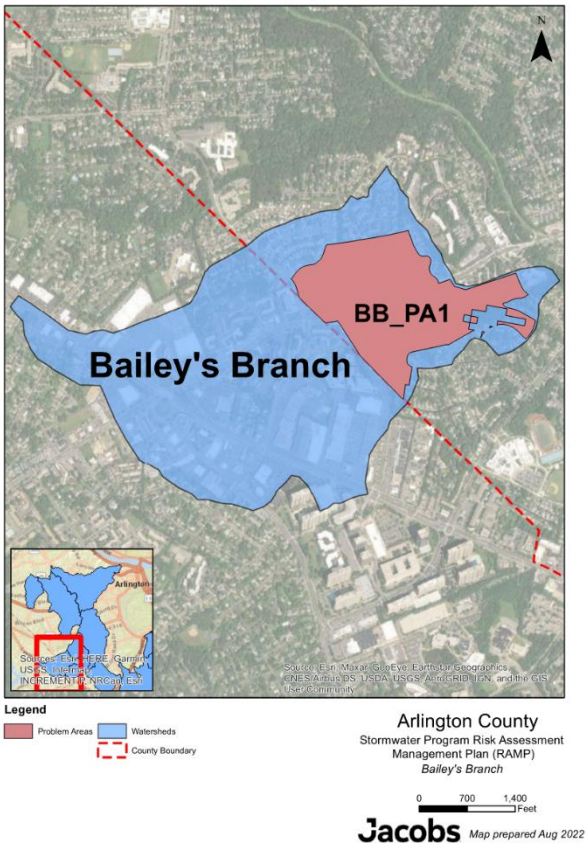
## Description

Area: 86 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 90,905 |
| 100yr Baseline | 225,718 |
| 500yr Baseline | 262,114 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 24,930 |
| 100yr Baseline | 34,195 |
| 500yr Baseline | 40,061 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 20,112 |
| 100yr Baseline | 0 |
| 500yr Baseline | 99,167 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.06

Monetary Impact: $ 12,640

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

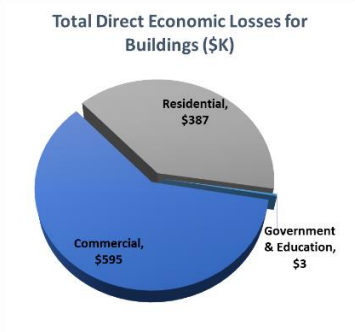
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| BB_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 12 | $ 33 | $ 0 | $ 42 | $ 179 | $ 24 | $ 305 | $ 698 | $ 595 |
| Education | $ - | $ 0 | $ - | $ - | $ 0 | $ - | $ 1 | $ 21 | $ 2 |
| Government | $ - | $ 0 | $ - | $ - | $ - | $ - | $ 2 | $ 0 | $ 2 |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 |
| Religious/Non-Profit | $ - | $ 0 | $ - | $ - | $ 1 | $ - | $ 2 | $ 15 | $ 3 |
| Residential | $ 128 | $ 70 | $ - | $ 101 | $ - | $ 88 | $ - | $ - | $ 387 |
| Scenario Total | $ 141 | $ 104 | $ 0 | $ 143 | $ 180 | $ 112 | $ 315 | $ 771 | $ 995 |

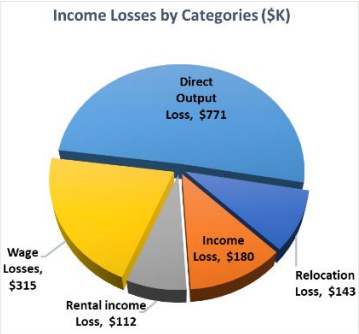
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

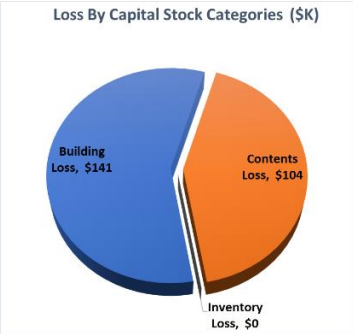
*All values are in thousand of dollars ($K)*

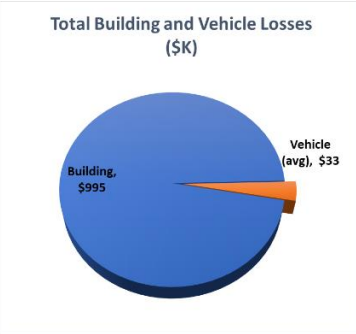
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 22 | $ 6 | $ 0 | $ 28 |
| Night Time | $ 29 | $ 8 | $ 0 | $ 38 |
| Scenario Total | $ 26 | $ 7 | $ 0 | $ 33 |

| | Total Loss ($K) |
|---|---|
| Building | $ 995 |
| Vehicle (avg) | $ 33 |
| Total | $ 1,028 |




# Ranking Summary

Relative to other Problem Areas, Bailey's Branch PA1 generally ranks as follows:

Social Vulnerability: Medium
Environmental: Medium
Economic Risk: Low

# Doctor's Branch PA1 (DB_PA1)
# Fact Sheet

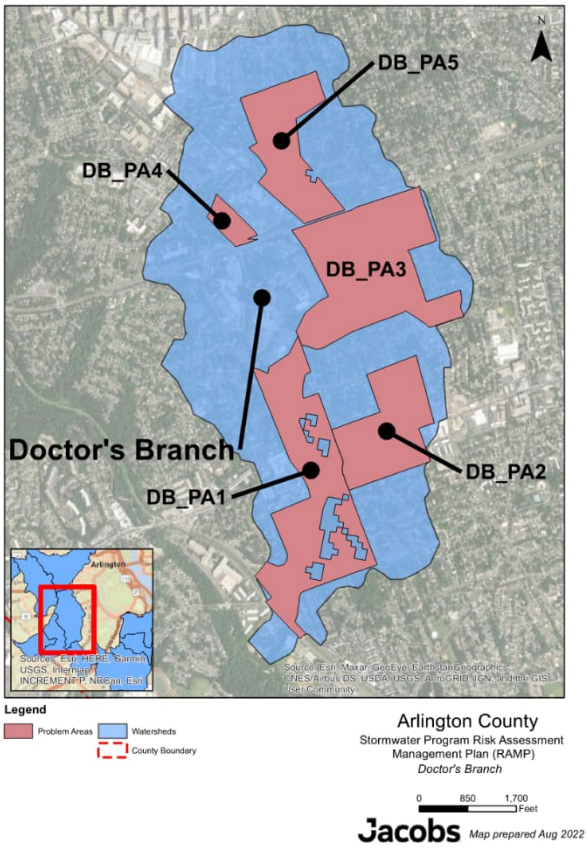
## Description

Area: 96 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 213,820 |
| 100yr Baseline | 435,134 |
| 500yr Baseline | 552,707 |
| 10yr 2070 | 256,981 |
| 100yr 2070 | 456,613 |
| 500yr 2070 | 583,312 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 328,124 |
| 100yr Baseline | 547,553 |
| 500yr Baseline | 665,372 |
| 10yr 2070 | 361,079 |
| 100yr 2070 | 592,377 |
| 500yr 2070 | 724,425 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 318,192 |
| 100yr Baseline | 463,796 |
| 500yr Baseline | 572,279 |
| 10yr 2070 | 351,887 |
| 100yr 2070 | 488,347 |
| 500yr 2070 | 597,578 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

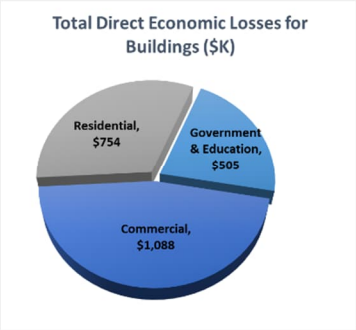
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DB_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 67 | $ 263 | $ 2 | $ 44 | $ 345 | $ 31 | $ 337 | $ 866 | $ 1,088 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 0 | $ 1 | $ - | $ 25 | $ 15 | $ 10 | $ 454 | $ 104 | $ 505 |
| Industrial | $ 4 | $ 8 | $ 0 | $ - | $ - | $ - | $ 0 | $ 1 | $ 11 |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 | $ - |
| Residential | $ 217 | $ 111 | $ - | $ 257 | $ - | $ 169 | $ - | $ - | $ 754 |
| Scenario Total | $ 291 | $ 392 | $ 2 | $ 351 | $ 376 | $ 219 | $ 1,244 | $ 1,077 | $ 2,876 |

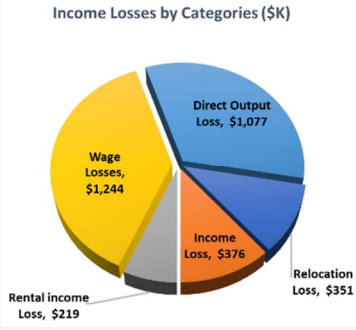
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

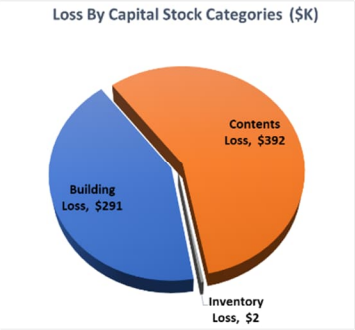
*All values are in thousand of dollars ($K)*

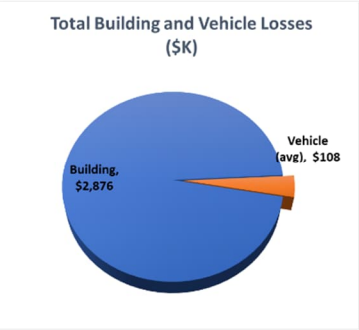
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 86 | $ 41 | $ 4 | $ 130 |
| Night Time | $ 60 | $ 22 | $ 4 | $ 85 |
| Scenario Total | $ 73 | $ 31 | $ 4 | $ 108 |

| | Total Loss ($K) |
|---|---|
| Building | $ 2,876 |
| Vehicle (avg) | $ 108 |
| Total | $ 2,984 |




# Ranking Summary

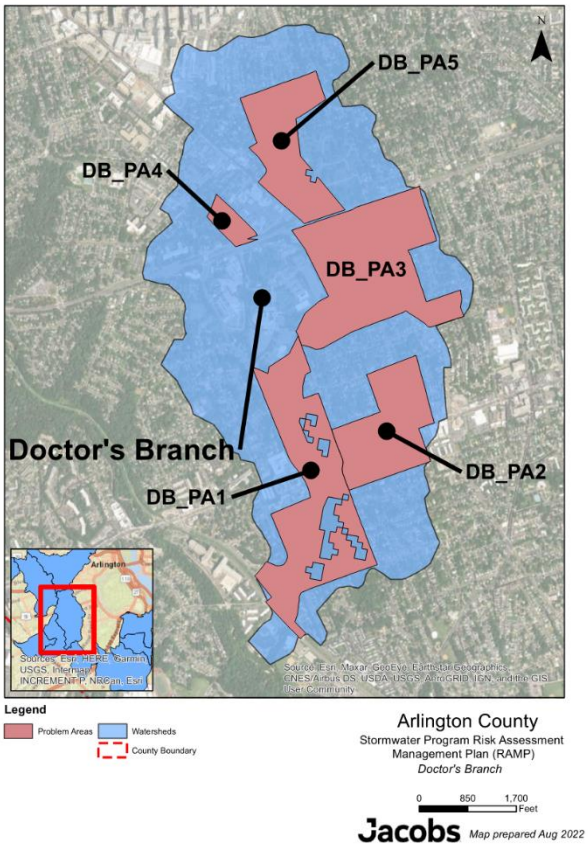
Relative to other Problem Areas, Doctor's Branch PA1 generally ranks as follows:

Social Vulnerability: High
Environmental: High
Economic Risk: Medium

# Doctor's Branch PA2 (DB_PA2)
# Fact Sheet

## Description

Area: 55 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 95,518 |
| 100yr Baseline | 234,944 |
| 500yr Baseline | 262,886 |
| 10yr 2070 | 142,202 |
| 100yr 2070 | 254,005 |
| 500yr 2070 | 271,466 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 3,209 |
| 100yr Baseline | 6,356 |
| 500yr Baseline | 6,570 |
| 10yr 2070 | 4,993 |
| 100yr 2070 | 6,356 |
| 500yr 2070 | 6,570 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

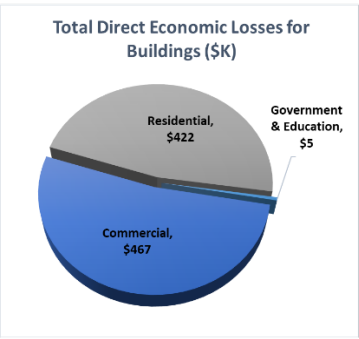
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| DB_PA2 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ 0 | $ 0 | $ - | $ - | $ 0 | $ - | $ 0 | $ 2 | $ 1 |
| Commercial | $ 21 | $ 63 | $ 0 | $ 33 | $ 186 | $ 25 | $ 138 | $ 332 | $ 467 |
| Education | $ - | $ 1 | $ - | $ - | $ 1 | $ - | $ 3 | $ 26 | $ 5 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 |
| Religious/Non-Profit | $ 0 | $ 3 | $ - | $ - | $ 4 | $ - | $ 10 | $ 60 | $ 18 |
| Residential | $ 163 | $ 87 | $ - | $ 120 | $ - | $ 51 | $ - | $ - | $ 422 |
| Scenario Total | $ 185 | $ 158 | $ 0 | $ 154 | $ 197 | $ 76 | $ 164 | $ 510 | $ 935 |

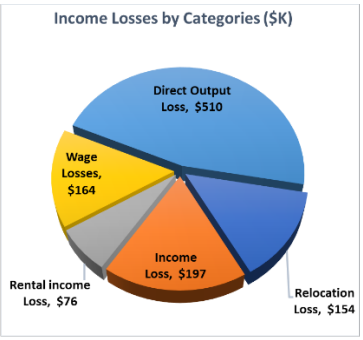
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

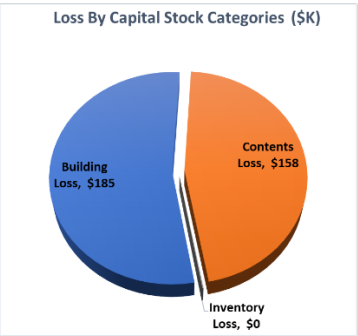
*All values are in thousand of dollars ($K)*

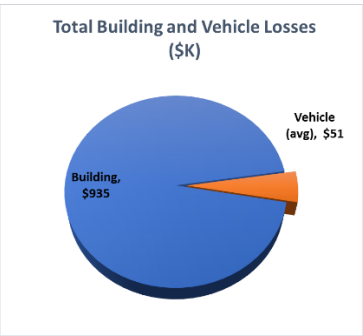
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 42 | $ 12 | $ 1 | $ 55 |
| Night Time | $ 36 | $ 10 | $ 1 | $ 47 |
| Scenario Total | $ 39 | $ 11 | $ 1 | $ 51 |

| | Total Loss ($K) |
|---|---|
| Building | $ 935 |
| Vehicle (avg) | $ 51 |
| Total | $ 986 |




# Ranking Summary

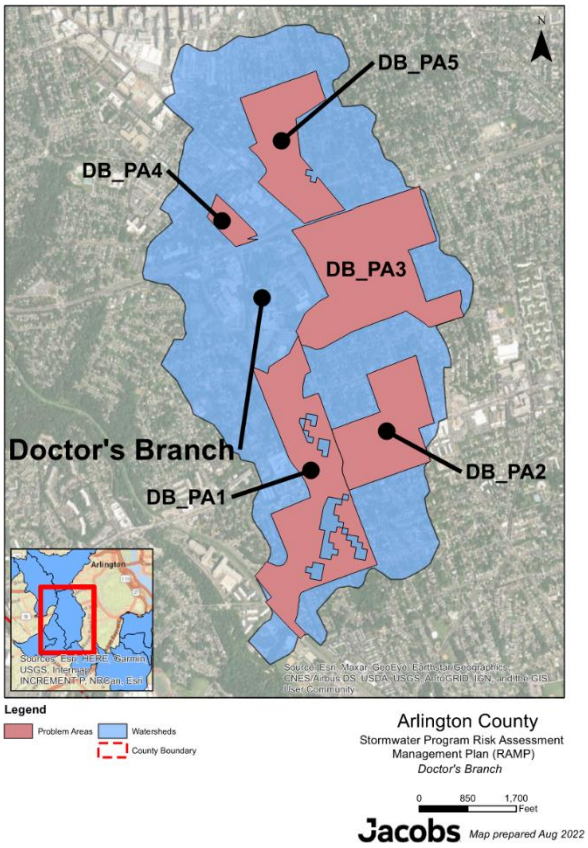
Relative to other Problem Areas, Doctor's Branch PA2 generally ranks as follows:

Social Vulnerability: High
Environmental: Low
Economic Risk: Low

# Doctor's Branch PA3 (DB_PA3)
# Fact Sheet

## Description

Area: 107 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 174 |
| 100yr Baseline | 434 |
| 500yr Baseline | 434 |
| 10yr 2070 | 174 |
| 100yr 2070 | 434 |
| 500yr 2070 | 838 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 5,582 |
| 10yr 2070 | 0 |
| 100yr 2070 | 1,041 |
| 500yr 2070 | 5,928 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

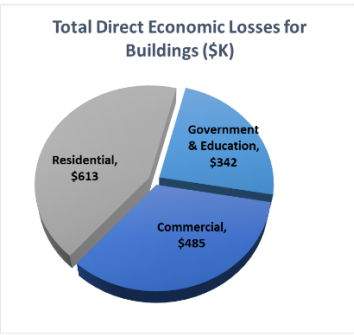
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| DB_PA3 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 7 | $ 25 | $ 0 | $ 44 | $ 176 | $ 31 | $ 201 | $ 470 | $ 485 |
| Education | $ 0 | $ 0 | $ - | $ - | $ 2 | $ - | $ 5 | $ 50 | $ 8 |
| Government | $ 1 | $ 7 | $ - | $ 15 | $ 10 | $ 6 | $ 295 | $ 68 | $ 334 |
| Industrial | $ 0 | $ 1 | $ 0 | $ - | $ 0 | $ - | $ 0 | $ 0 | $ 1 |
| Religious/Non-Profit | $ 2 | $ 18 | $ - | $ 11 | $ 27 | $ 1 | $ 65 | $ 366 | $ 124 |
| Residential | $ 199 | $ 110 | $ - | $ 182 | $ 6 | $ 100 | $ 16 | $ 36 | $ 613 |
| Scenario Total | $ 213 | $ 188 | $ 0 | $ 278 | $ 261 | $ 143 | $ 948 | $ 1,474 | $ 2,032 |

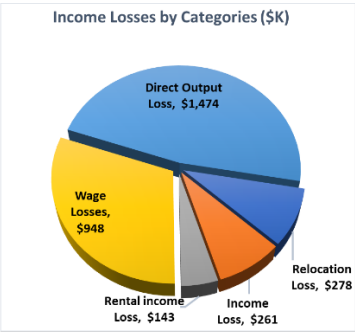
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

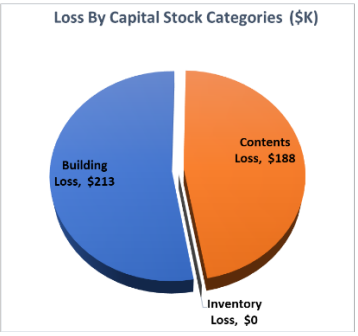
*All values are in thousand of dollars ($K)*

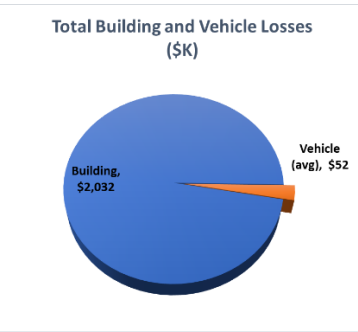
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 35 | $ 12 | $ 1 | $ 49 |
| Night Time | $ 40 | $ 14 | $ 1 | $ 56 |
| Scenario Total | $ 38 | $ 13 | $ 1 | $ 52 |

| | Total Loss ($K) |
|---|---|
| Building | $ 2,032 |
| Vehicle (avg) | $ 52 |
| Total | $ 2,084 |




# Ranking Summary

Relative to other Problem Areas, Doctor's Branch PA3 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Doctor's Branch PA4 (DB_PA4)
# Fact Sheet

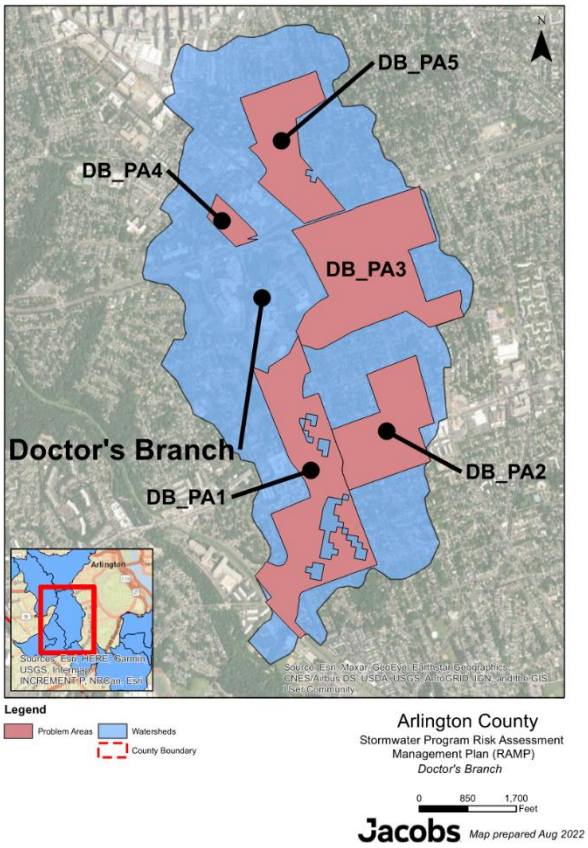
## Description

Area: 9 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 50,932 |
| 100yr Baseline | 71,369 |
| 500yr Baseline | 75,689 |
| 10yr 2070 | 54,613 |
| 100yr 2070 | 72,750 |
| 500yr 2070 | 78,460 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

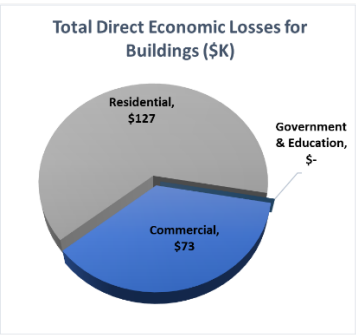
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DB_PA4 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 3 | $ 15 | $ - | $ 2 | $ 19 | $ 1 | $ 32 | $ 77 | $ 73 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 |
| Religious/Non-Profit | $ 1 | $ 13 | $ - | $ 1 | $ 7 | $ - | $ 18 | $ 104 | $ 40 |
| Residential | $ 59 | $ 34 | $ - | $ 15 | $ - | $ 18 | $ - | $ - | $ 127 |
| Scenario Total | $ 65 | $ 76 | $ - | $ 18 | $ 33 | $ 19 | $ 68 | $ 284 | $ 279 |

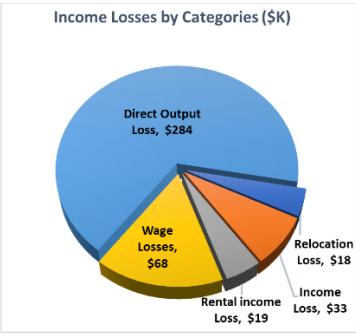
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

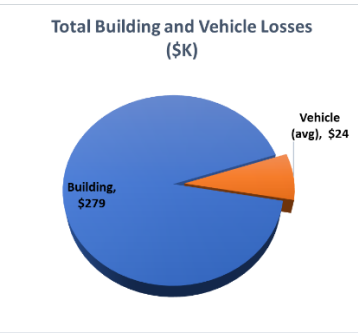
*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 14 | $ 5 | $ 0 | $ 20 |
| Night Time | $ 20 | $ 8 | $ 0 | $ 28 |
| Scenario Total | $ 17 | $ 7 | $ 0 | $ 24 |

| | Total Loss ($K) |
|---|---|
| Building | $ 279 |
| Vehicle (avg) | $ 24 |
| Total | $ 303 |






# Ranking Summary

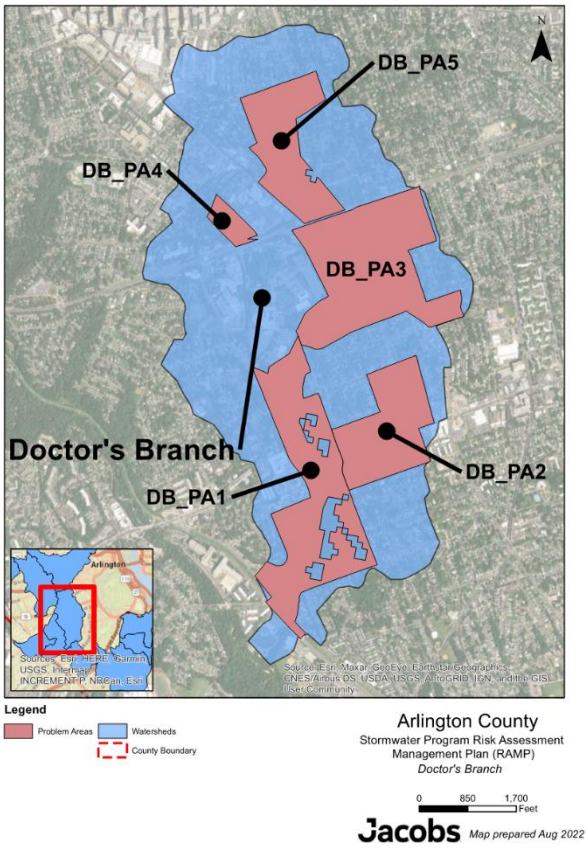
Relative to other Problem Areas, Doctor's Branch PA4 generally ranks as follows:

Social Vulnerability: Medium
Environmental: Low
Economic Risk: Low

# Doctor's Branch PA5 (DB_PA5)
# Fact Sheet

## Description

Area: 53 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 133,536 |
| 100yr Baseline | 185,964 |
| 500yr Baseline | 200,655 |
| 10yr 2070 | 149,448 |
| 100yr 2070 | 191,881 |
| 500yr 2070 | 206,155 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

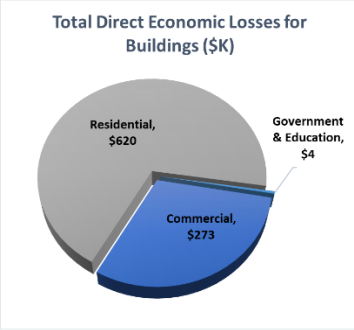
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DB_PA5 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ 0 | $ 0 | $ - | $ - | $ 0 | $ - | $ - | $ 1 | $ 0 |
| Commercial | $ 1 | $ 5 | $ 0 | $ 17 | $ 85 | $ 18 | $ 148 | $ 338 | $ 273 |
| Education | $ - | $ 0 | $ - | $ - | $ 1 | $ - | $ 2 | $ 26 | $ 4 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ 0 | $ 0 |
| Religious/Non-Profit | $ 0 | $ 7 | $ - | $ 16 | $ 32 | $ 1 | $ 76 | $ 428 | $ 132 |
| Residential | $ 171 | $ 92 | $ - | $ 171 | $ 26 | $ 98 | $ 61 | $ 138 | $ 620 |
| Scenario Total | $ 173 | $ 111 | $ 0 | $ 219 | $ 177 | $ 119 | $ 366 | $ 1,386 | $ 1,166 |

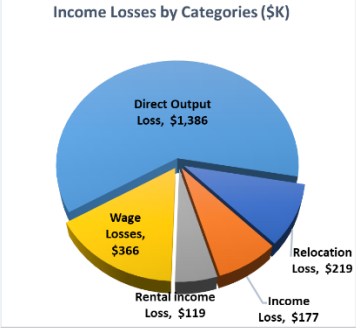
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

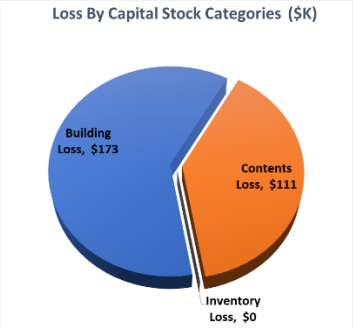
*All values are in thousand of dollars ($K)*

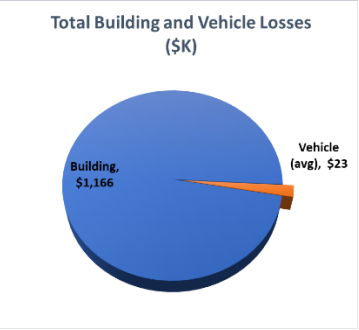
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 15 | $ 4 | $ 0 | $ 20 |
| Night Time | $ 20 | $ 6 | $ 0 | $ 26 |
| Scenario Total | $ 18 | $ 5 | $ 0 | $ 23 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,166 |
| Vehicle (avg) | $ 23 |
| Total | $ 1,189 |




# Ranking Summary

Relative to other Problem Areas, Doctor's Branch PA5 generally ranks as follows:

Social Vulnerability: High
Environmental: Low
Economic Risk: Low

# Four Mile Run Lower Mainstem PA1 (FMRLM_PA1)
# Fact Sheet

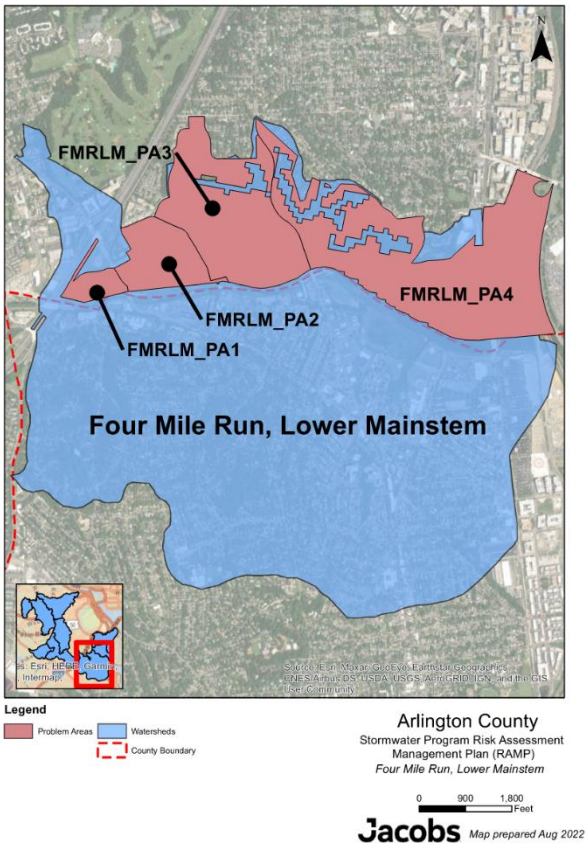
## Description

Area: 14 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 41,990 |
| 100yr Baseline | 132,294 |
| 500yr Baseline | 134,836 |
| 10yr 2070 | 78,049 |
| 100yr 2070 | 133,347 |
| 500yr 2070 | 136,482 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

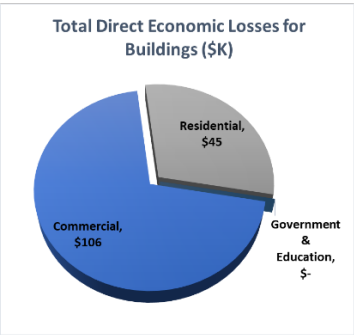
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| FMRLM_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ 0 | $ 2 | $ 0 | $ - | $ 0 | $ - | $ 0 | $ 2 | $ 3 |
| Commercial | $ 11 | $ 38 | $ 0 | $ 2 | $ 23 | $ 2 | $ 29 | $ 70 | $ 106 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 26 | $ 13 | $ - | $ 5 | $ - | $ 1 | $ - | $ - | $ 45 |
| Scenario Total | $ 38 | $ 56 | $ 1 | $ 7 | $ 23 | $ 3 | $ 29 | $ 75 | $ 157 |

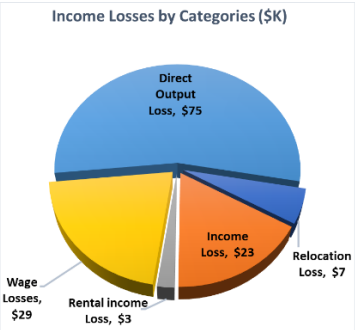
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

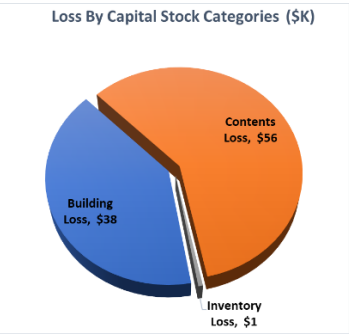
*All values are in thousand of dollars ($K)*

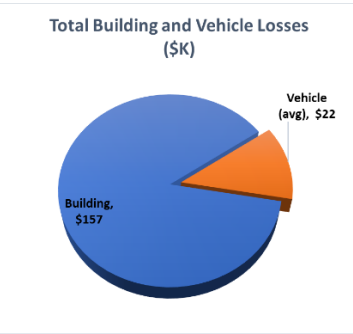
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 15 | $ 8 | $ 1 | $ 24 |
| Night Time | $ 12 | $ 6 | $ 2 | $ 21 |
| Scenario Total | $ 13 | $ 7 | $ 2 | $ 22 |

| | Total Loss ($K) |
|---|---|
| Building | $ 157 |
| Vehicle (avg) | $ 22 |
| Total | $ 180 |




# Ranking Summary

Relative to other Problem Areas, Four Mile Run Lower Mainstem PA1 generally ranks as follows:

Social Vulnerability: Low
Environmental: Medium
Economic Risk: Low

# Four Mile Run Lower Mainstem PA2 (FMRLM_PA2)
# Fact Sheet

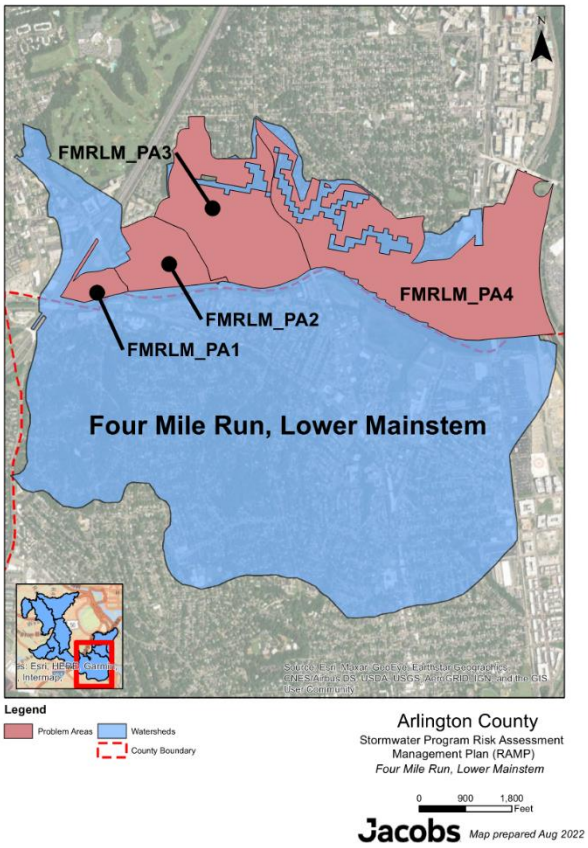
## Description

Area: 43 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 16,578 |
| 100yr Baseline | 79,407 |
| 500yr Baseline | 84,981 |
| 10yr 2070 | 40,110 |
| 100yr 2070 | 81,546 |
| 500yr 2070 | 94,941 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.04

Monetary Impact: $12,399

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

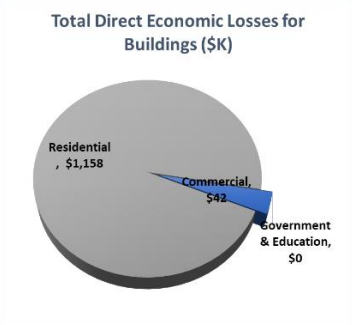
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| FMRLM_PA2 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 3 | $ 8 | $ - | $ 2 | $ 16 | $ 1 | $ 13 | $ 32 | $ 42 |
| Education | $ - | $ 0 | $ - | $ - | $ 0 | $ - | $ 0 | $ 1 | $ 0 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 542 | $ 315 | $ - | $ 166 | $ - | $ 134 | $ - | $ - | $ 1,158 |
| Scenario Total | $ 545 | $ 322 | $ - | $ 168 | $ 16 | $ 136 | $ 13 | $ 34 | $ 1,200 |

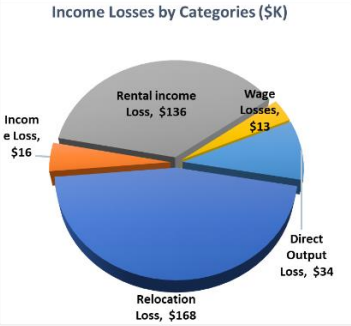
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

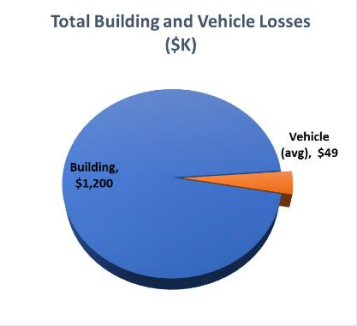
*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 23 | $ 9 | $ 1 | $ 32 |
| Night Time | $ 47 | $ 19 | $ 1 | $ 67 |
| Scenario Total | $ 35 | $ 14 | $ 1 | $ 49 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,200 |
| Vehicle (avg) | $ 49 |
| Total | $ 1,250 |






# Ranking Summary

Relative to other Problem Areas, Four Mile Run Lower Mainstem PA2 generally ranks as follows:

Social Vulnerability: Low
Environmental: Medium
Economic Risk: Medium

# Four Mile Run Lower Mainstem PA3 (FMRLM_PA3)
# Fact Sheet

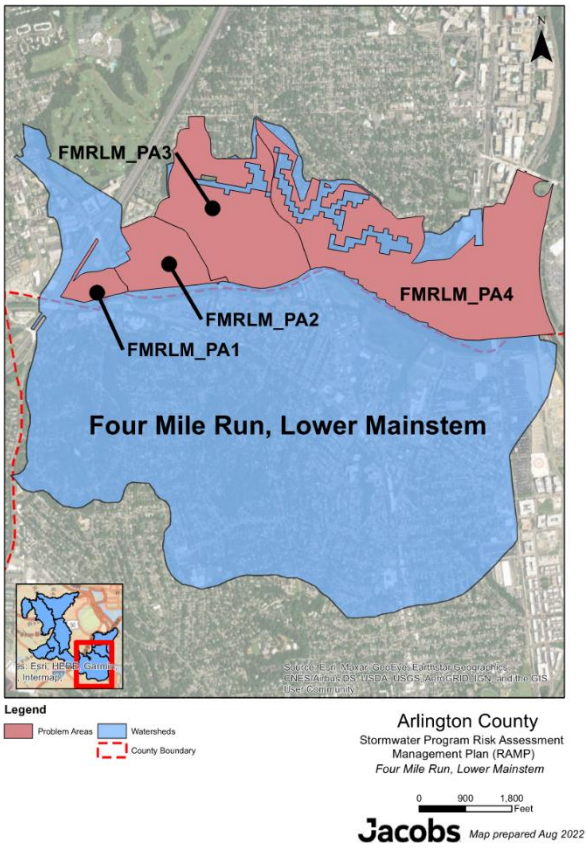
## Description

Area: 121 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 134,855 |
| 100yr Baseline | 190,934 |
| 500yr Baseline | 198,885 |
| 10yr 2070 | 158,825 |
| 100yr 2070 | 196,132 |
| 500yr 2070 | 210,754 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.29

Monetary Impact: $14,913

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

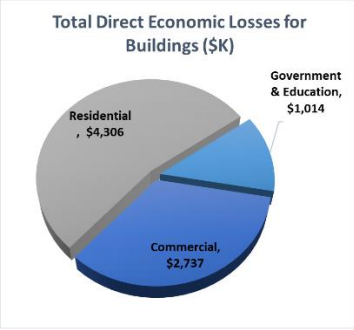
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| FMRLM_PA3 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ 1 | $ 5 | $ 0 | $ 1 | $ 3 | $ - | $ 1 | $ 13 | $ 13 |
| Commercial | $ 238 | $ 477 | $ 3 | $ 235 | $ 989 | $ 176 | $ 618 | $ 1,573 | $ 2,737 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 0 | $ 2 | $ - | $ 53 | $ 32 | $ 21 | $ 905 | $ 209 | $ 1,014 |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ 0 | $ 0 |
| Religious/Non-Profit | $ 2 | $ 18 | $ - | $ 7 | $ 16 | $ 0 | $ 40 | $ 228 | $ 83 |
| Residential | $ 1,933 | $ 1,122 | $ - | $ 688 | $ - | $ 563 | $ - | $ - | $ 4,306 |
| Scenario Total | $ 2,179 | $ 1,649 | $ 4 | $ 1,045 | $ 1,093 | $ 782 | $ 2,510 | $ 2,476 | $ 9,262 |

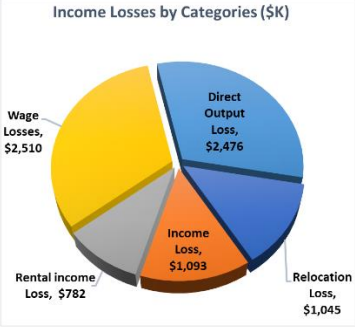
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

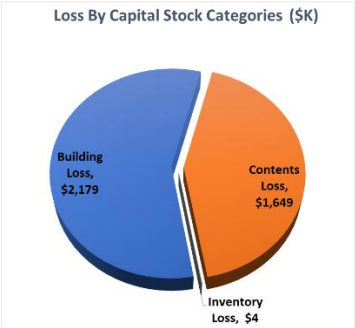
*All values are in thousand of dollars ($K)*

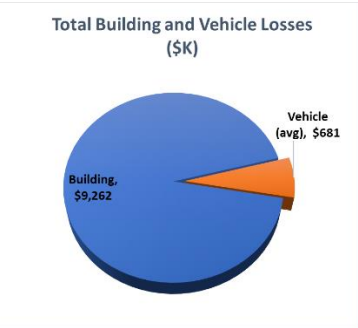
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 393 | $ 171 | $ 9 | $ 574 |
| Night Time | $ 538 | $ 241 | $ 9 | $ 788 |
| Scenario Total | $ 465 | $ 206 | $ 9 | $ 681 |

| | Total Loss ($K) |
|---|---|
| Building | $ 9,262 |
| Vehicle (avg) | $ 681 |
| Total | $ 9,943 |




# Ranking Summary

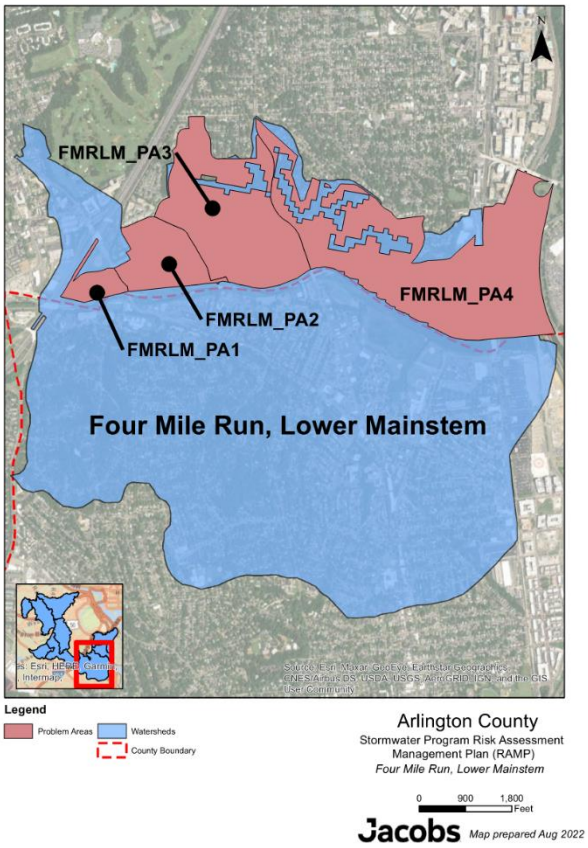
Relative to other Problem Areas, Four Mile Run Lower Mainstem PA3 generally ranks as follows:

Social Vulnerability: Low
Environmental: High
Economic Risk: High

# Four Mile Run Lower Mainstem PA4 (FMRLM_PA4)
# Fact Sheet

## Description

Area: 212 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 508,623 |
| 100yr Baseline | 773,004 |
| 500yr Baseline | 823,617 |
| 10yr 2070 | 658,745 |
| 100yr 2070 | 809,126 |
| 500yr 2070 | 860,336 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.56

Monetary Impact: $17,572

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

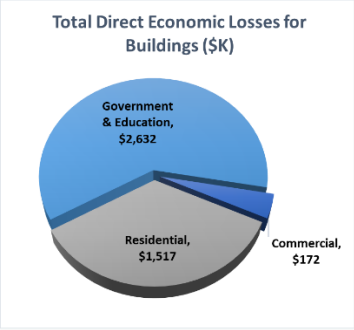
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| FMRLM_PA4 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 13 | $ 33 | $ 1 | $ 19 | $ 42 | $ 14 | $ 49 | $ 114 | $ 172 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 33 | $ 200 | $ - | $ 126 | $ 78 | $ 51 | $ 2,144 | $ 498 | $ 2,632 |
| Industrial | $ 7 | $ 8 | $ 1 | $ 1 | $ 1 | $ - | $ 2 | $ 7 | $ 19 |
| Religious/Non-Profit | $ - | $ 0 | $ - | $ - | $ 0 | $ - | $ 0 | $ 1 | $ 0 |
| Residential | $ 706 | $ 430 | $ - | $ 147 | $ 12 | $ 195 | $ 28 | $ 62 | $ 1,517 |
| Scenario Total | $ 799 | $ 879 | $ 3 | $ 421 | $ 210 | $ 311 | $ 4,368 | $ 1,187 | $ 6,992 |

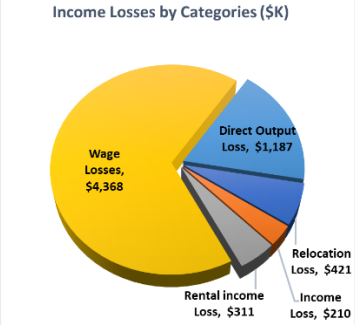
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

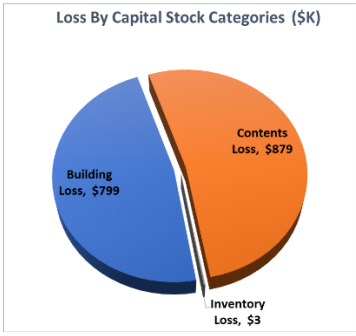
*All values are in thousand of dollars ($K)*

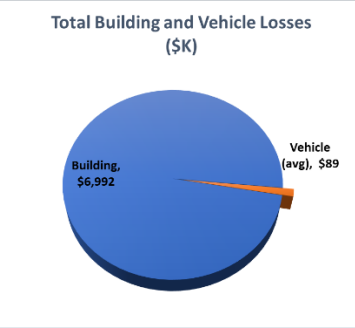
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 91 | $ 45 | $ 2 | $ 137 |
| Night Time | $ 27 | $ 12 | $ 2 | $ 41 |
| Scenario Total | $ 59 | $ 28 | $ 2 | $ 89 |

| | Total Loss ($K) |
|---|---|
| Building | $ 6,992 |
| Vehicle (avg) | $ 89 |
| Total | $ 7,081 |




# Ranking Summary

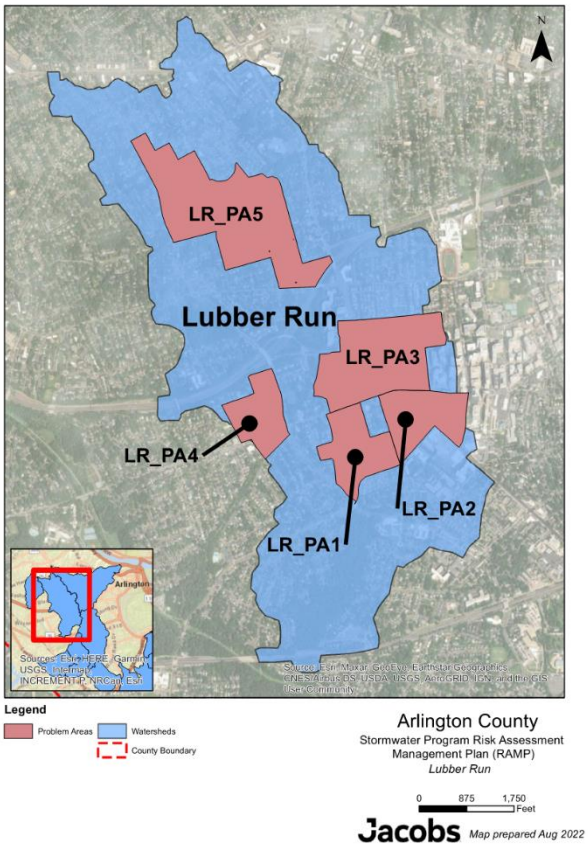
Relative to other Problem Areas, Four Mile Run Lower Mainstem PA4 generally ranks as follows:

Social Vulnerability: Low
Environmental: High
Economic Risk: High

# Lubber Run PA1 (LR_PA1)
# Fact Sheet

## Description

Area: 32 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 100,224 |
| 100yr Baseline | 142,514 |
| 500yr Baseline | 233,513 |
| 10yr 2070 | 112,990 |
| 100yr 2070 | 183,964 |
| 500yr 2070 | 256,531 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.05

Monetary Impact: $12,549

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

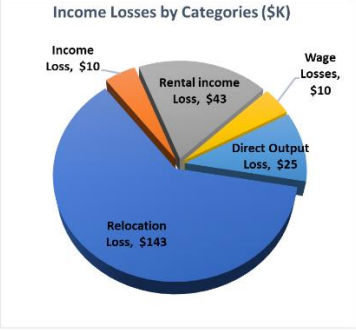
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| LR_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 0 | $ 1 | $ - | $ 0 | $ 10 | $ 0 | $ 10 | $ 25 | $ 22 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 184 | $ 99 | $ - | $ 143 | $ - | $ 43 | $ - | $ - | $ 469 |
| Scenario Total | $ 185 | $ 100 | $ - | $ 143 | $ 10 | $ 43 | $ 10 | $ 25 | $ 491 |

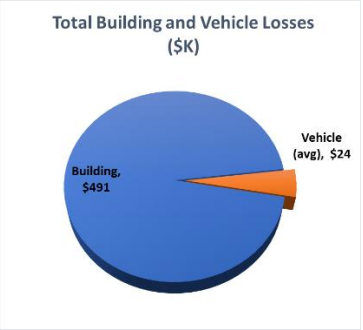
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 11 | $ 4 | $ 0 | $ 16 |
| Night Time | $ 24 | $ 8 | $ 0 | $ 33 |
| Scenario Total | $ 18 | $ 6 | $ 0 | $ 24 |

| | Total Loss ($K) |
|---|---|
| Building | $ 491 |
| Vehicle (avg) | $ 24 |
| Total | $ 516 |






# Ranking Summary

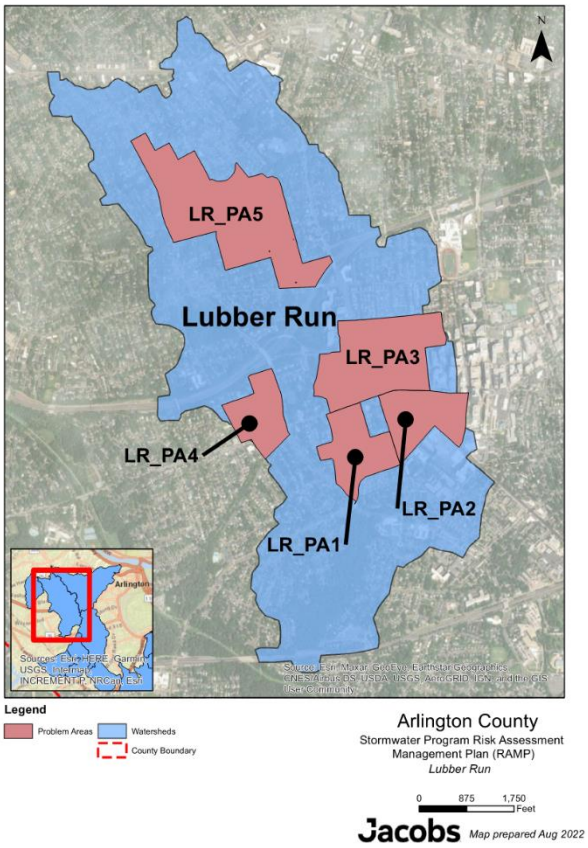
Relative to other Problem Areas, Lubber Run PA1 generally ranks as follows:

Social Vulnerability: Low
Environmental: High
Economic Risk: Low

# Lubber Run PA2 (LR_PA2)
# Fact Sheet

## Description

Area: 32 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 152 |
| 500yr Baseline | 827 |
| 10yr 2070 | 0 |
| 100yr 2070 | 152 |
| 500yr 2070 | 827 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.09

Monetary Impact: $12,865

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

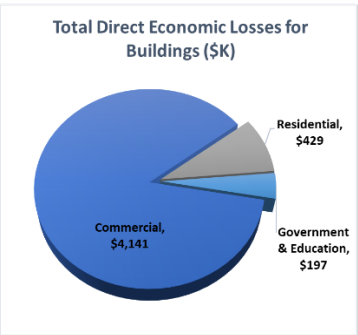
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LR_PA2 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 145 | $ 434 | $ 20 | $ 519 | $ 1,329 | $ 393 | $ 1,301 | $ 3,053 | $ 4,141 |
| Education | $ 0 | $ 0 | $ - | $ 1 | $ 2 | $ - | $ 5 | $ 47 | $ 8 |
| Government | $ 0 | $ 2 | $ - | $ 9 | $ 6 | $ 4 | $ 168 | $ 39 | $ 189 |
| Industrial | $ 7 | $ 29 | $ 3 | $ 8 | $ 13 | $ 5 | $ 22 | $ 94 | $ 87 |
| Religious/Non-Profit | $ 2 | $ 25 | $ - | $ 23 | $ 45 | $ 2 | $ 105 | $ 590 | $ 201 |
| Residential | $ 129 | $ 69 | $ - | $ 90 | $ 23 | $ 64 | $ 54 | $ 121 | $ 429 |
| Scenario Total | $ 293 | $ 614 | $ 25 | $ 691 | $ 1,485 | $ 477 | $ 1,956 | $ 4,711 | $ 5,541 |

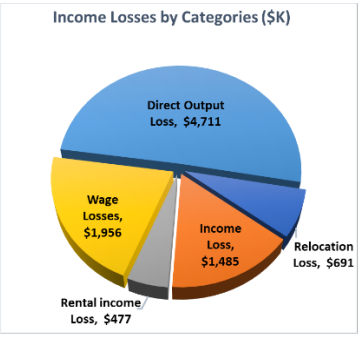
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

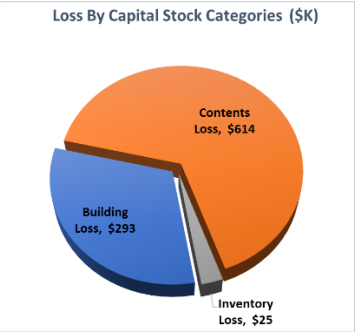
*All values are in thousand of dollars ($K)*

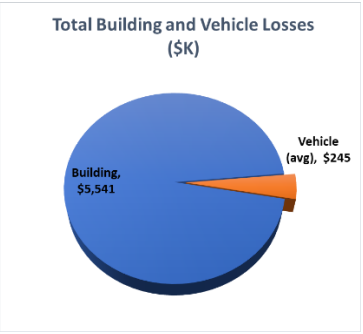
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 258 | $ 69 | $ 17 | $ 343 |
| Night Time | $ 102 | $ 27 | $ 19 | $ 147 |
| Scenario Total | $ 180 | $ 48 | $ 18 | $ 245 |

| | Total Loss ($K) |
|---|---|
| Building | $ 5,541 |
| Vehicle (avg) | $ 245 |
| Total | $ 5,786 |




# Ranking Summary

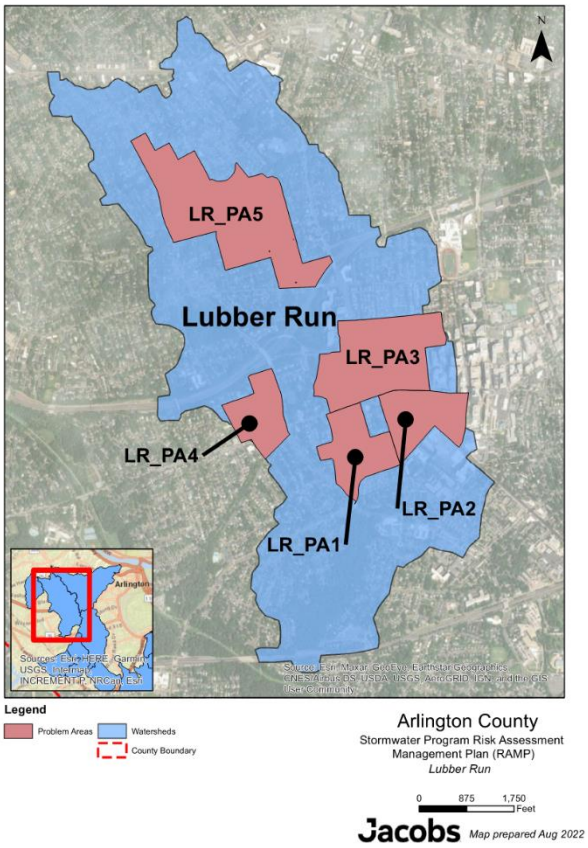
Relative to other Problem Areas, Lubber Run PA2 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Lubber Run PA3 (LR_PA3)
# Fact Sheet

## Description

Area: 68 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 89 |
| 100yr Baseline | 89 |
| 500yr Baseline | 89 |
| 10yr 2070 | 89 |
| 100yr 2070 | 89 |
| 500yr 2070 | 89 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.17

Monetary Impact: $13,671

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

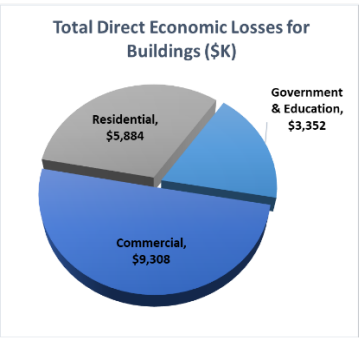
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| LR_PA3 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ 0 | $ 1 | $ 0 | $ 0 | $ 1 | $ - | $ 0 | $ 3 | $ 2 |
| Commercial | $ 246 | $ 455 | $ 1 | $ 1,100 | $ 4,190 | $ 815 | $ 2,500 | $ 6,266 | $ 9,308 |
| Education | $ 1 | $ 5 | $ - | $ 37 | $ 77 | $ 1 | $ 184 | $ 1,595 | $ 306 |
| Government | $ 4 | $ 22 | $ - | $ 161 | $ 97 | $ 65 | $ 2,698 | $ 626 | $ 3,046 |
| Industrial | $ 9 | $ 13 | $ 2 | $ 1 | $ 1 | $ - | $ 2 | $ 8 | $ 27 |
| Religious/Non-Profit | $ 69 | $ 786 | $ - | $ 962 | $ 1,627 | $ 100 | $ 3,815 | $ 21,276 | $ 7,359 |
| Residential | $ 1,874 | $ 1,038 | $ - | $ 1,218 | $ 133 | $ 1,310 | $ 312 | $ 699 | $ 5,884 |
| Scenario Total | $ 2,288 | $ 3,145 | $ 4 | $ 4,641 | $ 7,927 | $ 2,457 | $ 16,211 | $ 53,979 | $ 36,672 |

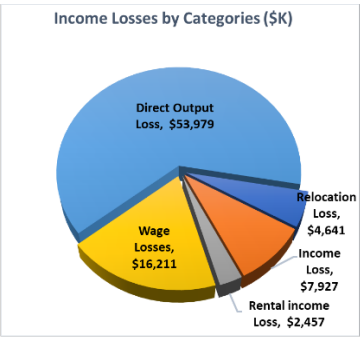
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

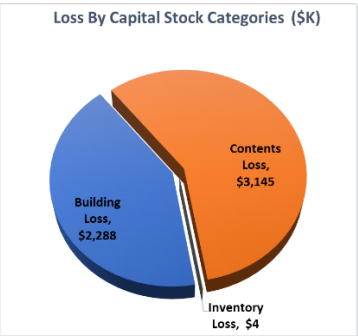
*All values are in thousand of dollars ($K)*

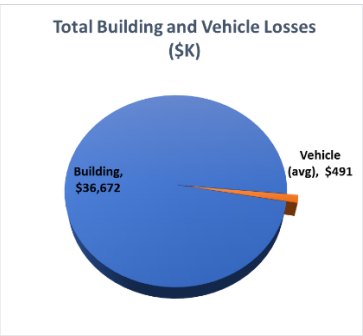
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 398 | $ 137 | $ 13 | $ 548 |
| Night Time | $ 316 | $ 106 | $ 13 | $ 435 |
| Scenario Total | $ 357 | $ 122 | $ 13 | $ 491 |

| | Total Loss ($K) |
|---|---|
| Building | $ 36,672 |
| Vehicle (avg) | $ 491 |
| Total | $ 37,163 |




# Ranking Summary

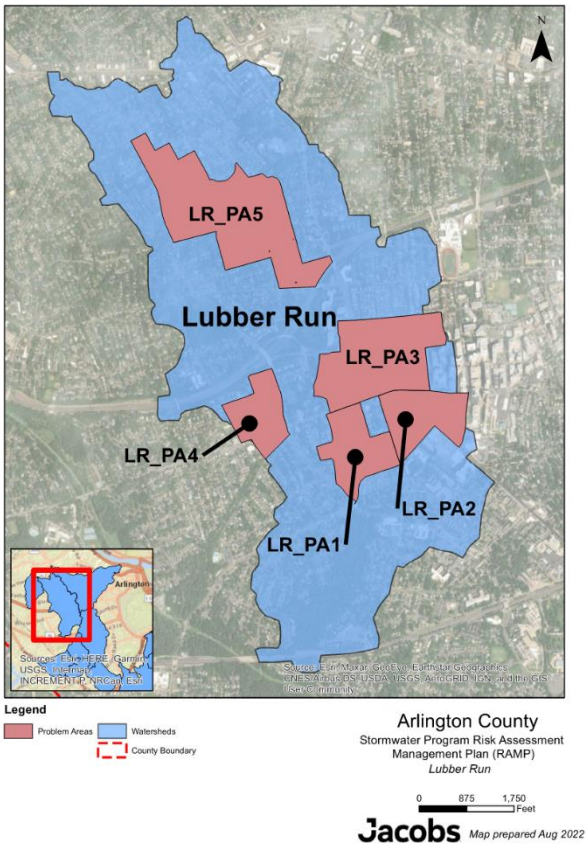
Relative to other Problem Areas, Lubber Run PA3 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Lubber Run PA4 (LR_PA4)
# Fact Sheet

## Description

Area: 26 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 148587 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.03

Monetary Impact: $12,330

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

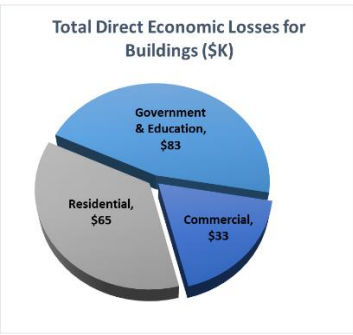
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LR_PA4 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 0 | $ 1 | $ - | $ 1 | $ 15 | $ 1 | $ 15 | $ 36 | $ 33 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 0 | $ 0 | $ - | $ 4 | $ 3 | $ 2 | $ 74 | $ 17 | $ 83 |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 15 | $ 8 | $ - | $ 21 | $ 3 | $ 11 | $ 7 | $ 16 | $ 65 |
| Scenario Total | $ 15 | $ 9 | $ - | $ 31 | $ 23 | $ 15 | $ 170 | $ 86 | $ 263 |

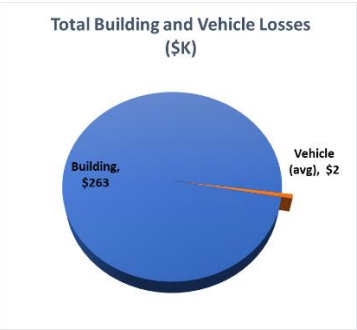
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 2 | $ 0 | $ 0 | $ 2 |
| Night Time | $ 1 | $ 0 | $ 0 | $ 2 |
| Scenario Total | $ 1 | $ 0 | $ 0 | $ 2 |

| | Total Loss ($K) |
|---|---|
| Building | $ 263 |
| Vehicle (avg) | $ 2 |
| Total | $ 265 |






# Ranking Summary

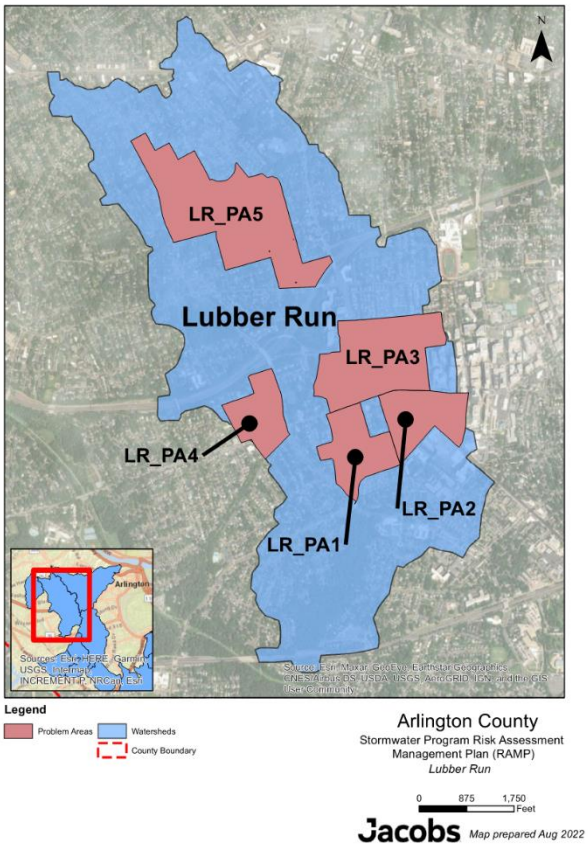
Relative to other Problem Areas, Lubber Run PA4 generally ranks as follows:

Social Vulnerability: Low
Environmental: Medium
Economic Risk: Low

# Lubber Run PA5 (LR_PA5)
# Fact Sheet

## Description

Area: 100 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 63,534 |
| 100yr Baseline | 87,331 |
| 500yr Baseline | 173,311 |
| 10yr 2070 | 74,541 |
| 100yr 2070 | 162,875 |
| 500yr 2070 | 174,736 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.21

Monetary Impact: $14,114

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

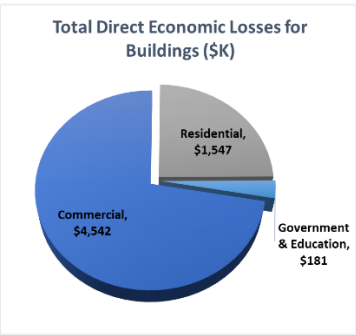
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| LR_PA5 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 130 | $ 490 | $ 0 | $ 419 | $ 1,062 | $ 110 | $ 2,330 | $ 5,204 | $ 4,542 |
| Education | $ 0 | $ 0 | $ - | $ - | $ 3 | $ - | $ 7 | $ 65 | $ 11 |
| Government | $ 2 | $ 11 | $ - | $ 7 | $ 5 | $ 3 | $ 143 | $ 33 | $ 170 |
| Industrial | $ 14 | $ 50 | $ 9 | $ 4 | $ 3 | $ 1 | $ 5 | $ 23 | $ 86 |
| Religious/Non-Profit | $ 1 | $ 9 | $ - | $ 3 | $ 11 | $ - | $ 27 | $ 151 | $ 50 |
| Residential | $ 392 | $ 228 | $ - | $ 399 | $ 109 | $ 161 | $ 258 | $ 573 | $ 1,547 |
| Scenario Total | $ 555 | $ 858 | $ 19 | $ 846 | $ 1,215 | $ 278 | $ 2,951 | $ 6,321 | $ 6,721 |

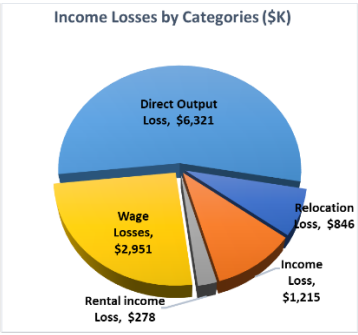
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

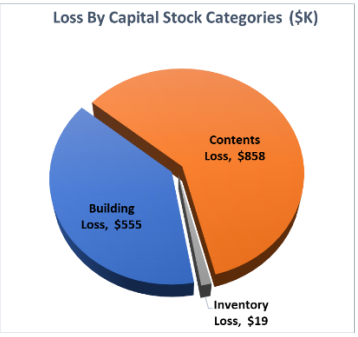
*All values are in thousand of dollars ($K)*

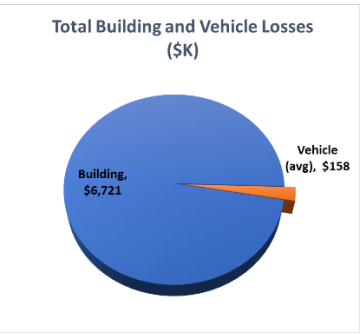
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 177 | $ 54 | $ 3 | $ 233 |
| Night Time | $ 63 | $ 18 | $ 3 | $ 83 |
| Scenario Total | $ 120 | $ 36 | $ 3 | $ 158 |

| | Total Loss ($K) |
|---|---|
| Building | $ 6,721 |
| Vehicle (avg) | $ 158 |
| Total | $ 6,880 |




# Ranking Summary

Relative to other Problem Areas, Lubber Run PA5 generally ranks as follows:

Social Vulnerability: Low
Environmental: Medium
Economic Risk: High

# Roaches Run PA1 (RR_PA1)
# Fact Sheet

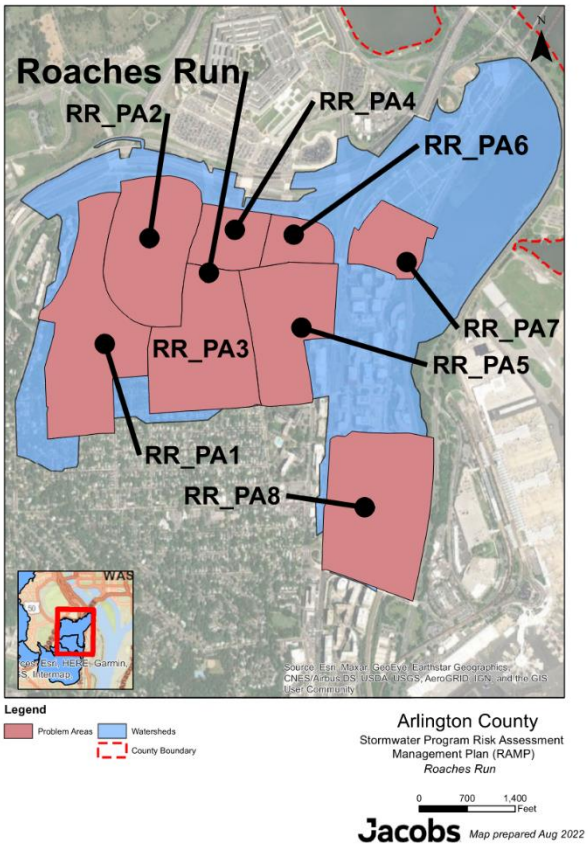
## Description

Area: 73 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.11

Monetary Impact: $13,140

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

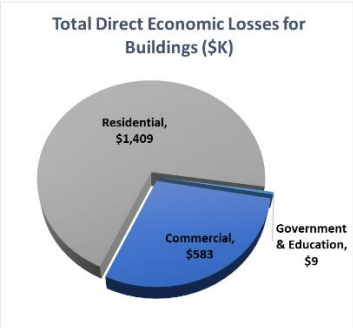
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 38 | $ 97 | $ 0 | $ 39 | $ 206 | $ 29 | $ 173 | $ 414 | $ 583 |
| Education | $ - | $ 0 | $ - | $ - | $ 2 | $ - | $ 4 | $ 40 | $ 6 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ 3 | $ 0 | $ 3 |
| Industrial | $ 3 | $ 7 | $ 0 | $ - | $ 0 | $ - | $ 0 | $ 4 | $ 10 |
| Religious/Non-Profit | $ - | $ 0 | $ - | $ 0 | $ 2 | $ - | $ 5 | $ 28 | $ 7 |
| Residential | $ 619 | $ 363 | $ - | $ 193 | $ - | $ 234 | $ - | $ - | $ 1,409 |
| Scenario Total | $ 663 | $ 474 | $ 1 | $ 232 | $ 214 | $ 263 | $ 197 | $ 557 | $ 2,044 |

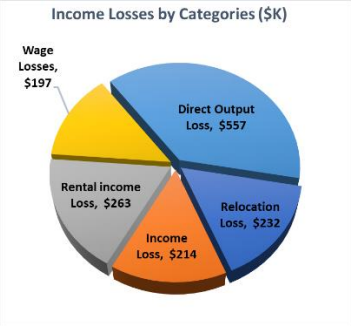
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

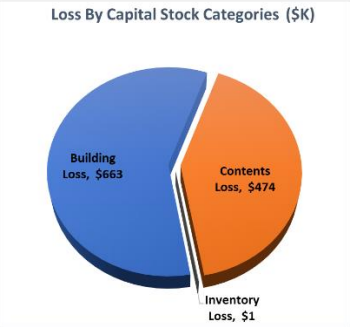
*All values are in thousand of dollars ($K)*

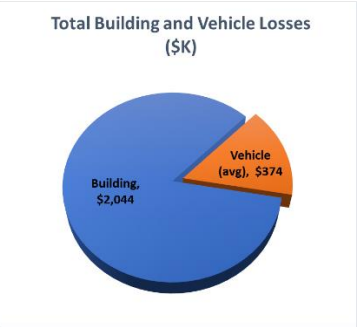
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 173 | $ 82 | $ 5 | $ 261 |
| Night Time | $ 328 | $ 155 | $ 5 | $ 488 |
| Scenario Total | $ 251 | $ 119 | $ 5 | $ 374 |

| | Total Loss ($K) |
|---|---|
| Building | $ 2,044 |
| Vehicle (avg) | $ 374 |
| Total | $ 2,418 |




# Ranking Summary

Relative to other Problem Areas, Roaches Run PA1 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Roaches Run PA2 (RR_PA2)
# Fact Sheet

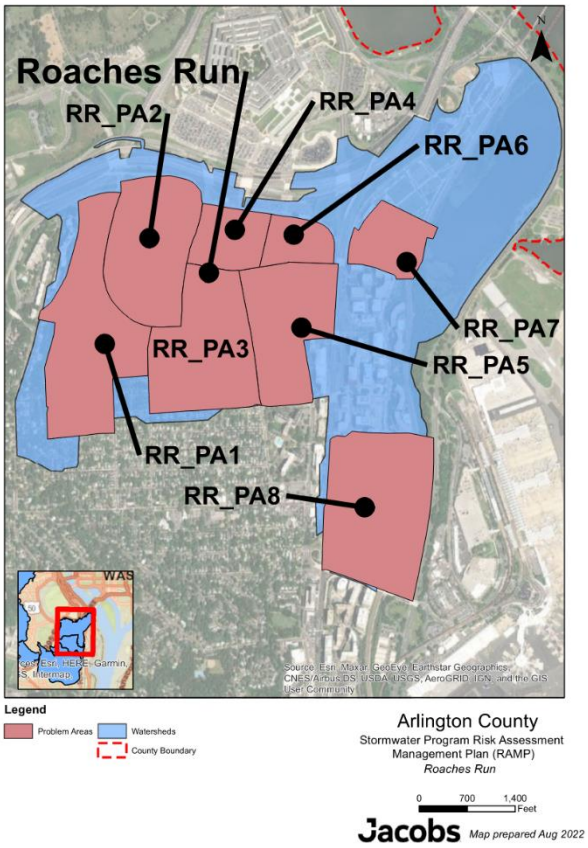
## Description

Area: 56 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.08

Monetary Impact: $12,807

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

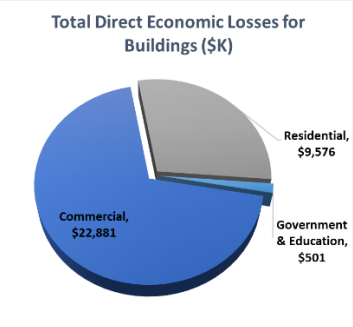
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA2 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ 5 | $ 15 | $ 2 | $ 2 | $ 5 | $ - | $ 2 | $ 20 | $ 32 |
| Commercial | $ 1,973 | $ 5,816 | $ 258 | $ 2,377 | $ 5,045 | $ 1,595 | $ 5,817 | $ 13,140 | $ 22,881 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 8 | $ 50 | $ - | $ 22 | $ 14 | $ 9 | $ 397 | $ 92 | $ 501 |
| Industrial | $ 138 | $ 245 | $ 31 | $ 13 | $ 8 | $ 2 | $ 15 | $ 64 | $ 453 |
| Religious/Non-Profit | $ 6 | $ 39 | $ - | $ 10 | $ 18 | $ 1 | $ 44 | $ 246 | $ 118 |
| Residential | $ 3,918 | $ 2,509 | $ - | $ 1,133 | $ 109 | $ 1,652 | $ 256 | $ 571 | $ 9,576 |
| Scenario Total | $ 6,207 | $ 9,024 | $ 324 | $ 3,603 | $ 5,246 | $ 3,271 | $ 6,988 | $ 14,555 | $ 34,663 |

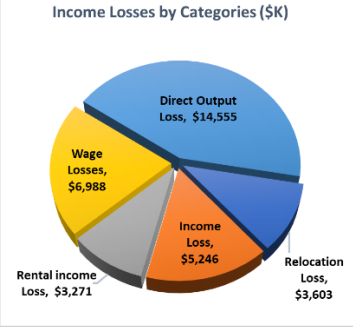
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

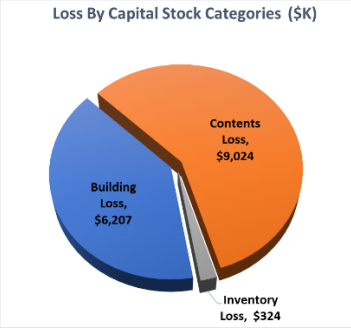
*All values are in thousand of dollars ($K)*

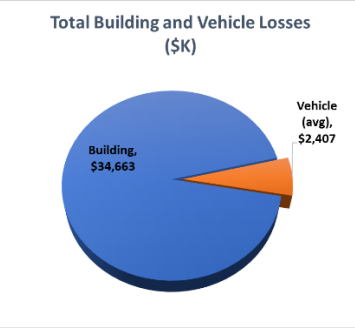
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 2,242 | $ 733 | $ 210 | $ 3,185 |
| Night Time | $ 1,061 | $ 346 | $ 221 | $ 1,628 |
| Scenario Total | $ 1,652 | $ 540 | $ 215 | $ 2,407 |

| | Total Loss ($K) |
|---|---|
| Building | $ 34,663 |
| Vehicle (avg) | $ 2,407 |
| Total | $ 37,070 |




# Ranking Summary

Relative to other Problem Areas, Roaches Run PA2 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Roaches Run PA3 (RR_PA3)
# Fact Sheet

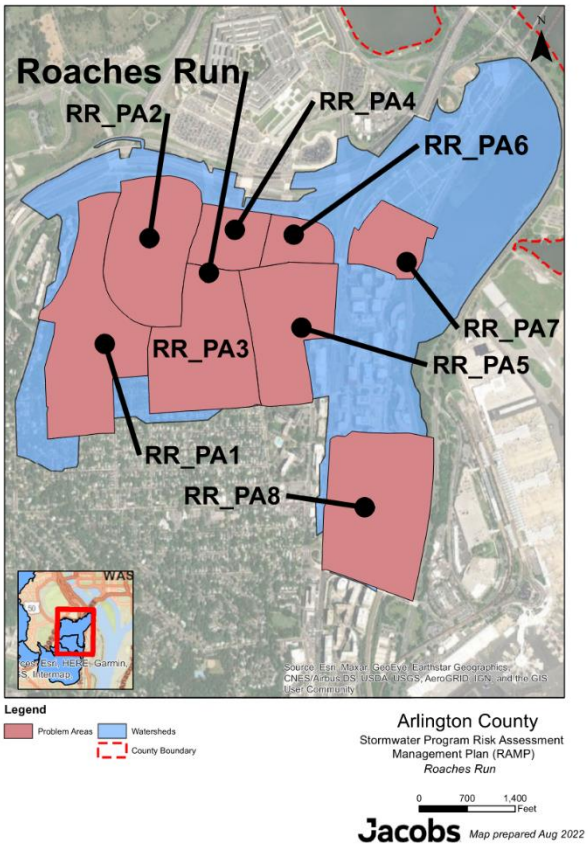
## Description

Area: 61 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.05

Monetary Impact: $12,496

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

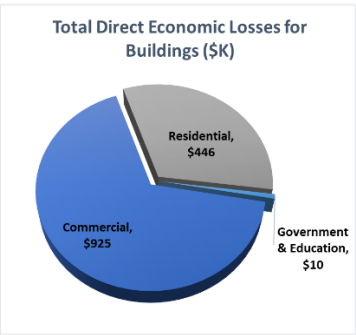
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA3 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 50 | $ 157 | $ 9 | $ 141 | $ 192 | $ 106 | $ 270 | $ 599 | $ 925 |
| Education | $ - | $ 0 | $ - | $ - | $ 2 | $ - | $ 6 | $ 51 | $ 8 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ 3 | $ 0 | $ 3 |
| Industrial | $ 1 | $ 2 | $ 0 | $ 0 | $ 0 | $ - | $ 0 | $ 1 | $ 4 |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 131 | $ 90 | $ - | $ 113 | $ - | $ 112 | $ - | $ - | $ 446 |
| Scenario Total | $ 183 | $ 250 | $ 10 | $ 254 | $ 196 | $ 218 | $ 287 | $ 705 | $ 1,398 |

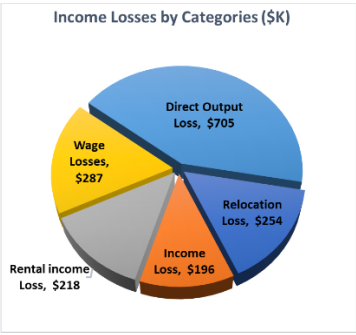
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

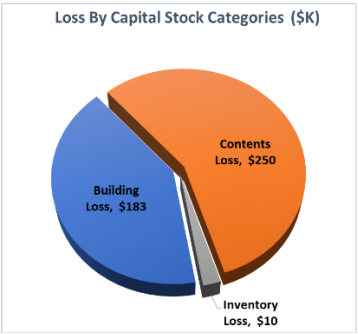
*All values are in thousand of dollars ($K)*

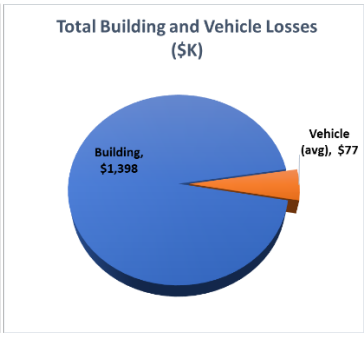
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 69 | $ 19 | $ 6 | $ 93 |
| Night Time | $ 44 | $ 12 | $ 6 | $ 62 |
| Scenario Total | $ 56 | $ 15 | $ 6 | $ 77 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,398 |
| Vehicle (avg) | $ 77 |
| Total | $ 1,476 |




# Ranking Summary

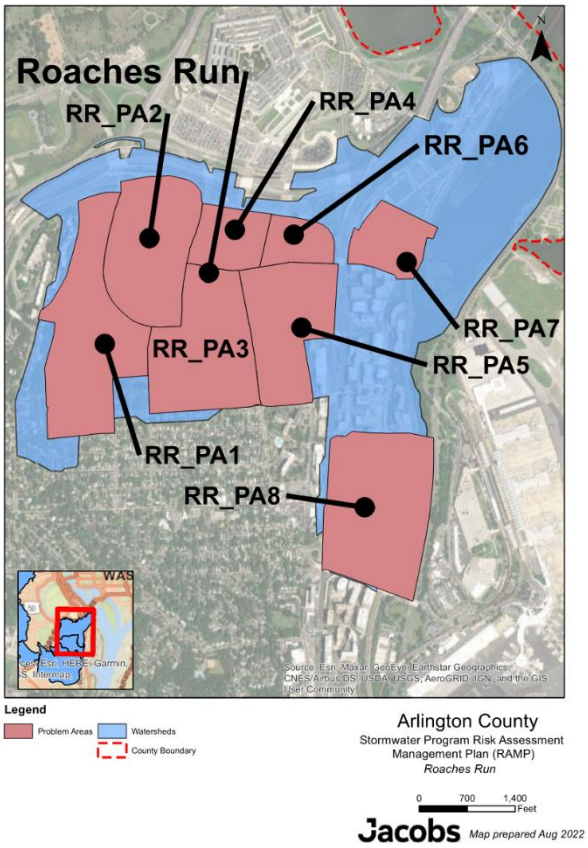
Relative to other Problem Areas, Roaches Run PA3 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Roaches Run PA4 (RR_PA4)
# Fact Sheet

## Description

Area: 21 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

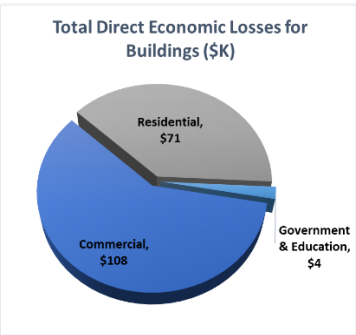
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA4 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 5 | $ 16 | $ 1 | $ 13 | $ 22 | $ 6 | $ 45 | $ 101 | $ 108 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 0 | $ 0 | $ - | $ 0 | $ 0 | $ 0 | $ 3 | $ 1 | $ 4 |
| Industrial | $ 11 | $ 18 | $ 1 | $ 3 | $ 1 | $ 0 | $ 2 | $ 9 | $ 36 |
| Religious/Non-Profit | $ 1 | $ 9 | $ - | $ 3 | $ 6 | $ 0 | $ 15 | $ 83 | $ 36 |
| Residential | $ 27 | $ 17 | $ - | $ 11 | $ - | $ 15 | $ - | $ - | $ 71 |
| Scenario Total | $ 56 | $ 88 | $ 4 | $ 37 | $ 37 | $ 23 | $ 85 | $ 287 | $ 329 |

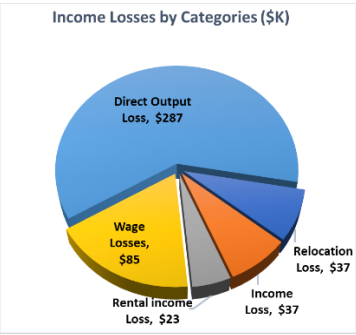
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

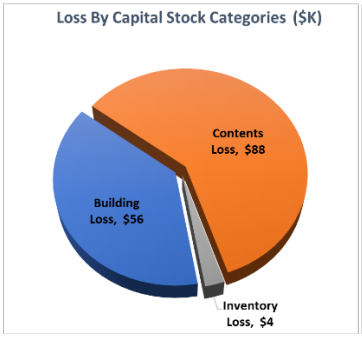
*All values are in thousand of dollars ($K)*

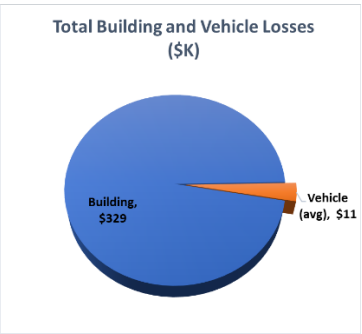
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 7 | $ 2 | $ 0 | $ 9 |
| Night Time | $ 10 | $ 2 | $ 1 | $ 12 |
| Scenario Total | $ 8 | $ 2 | $ 1 | $ 11 |

| | Total Loss ($K) |
|---|---|
| Building | $ 329 |
| Vehicle (avg) | $ 11 |
| Total | $ 340 |




# Ranking Summary

Relative to other Problem Areas, Roaches Run PA4 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Low

# Roaches Run PA5 (RR_PA5)
# Fact Sheet

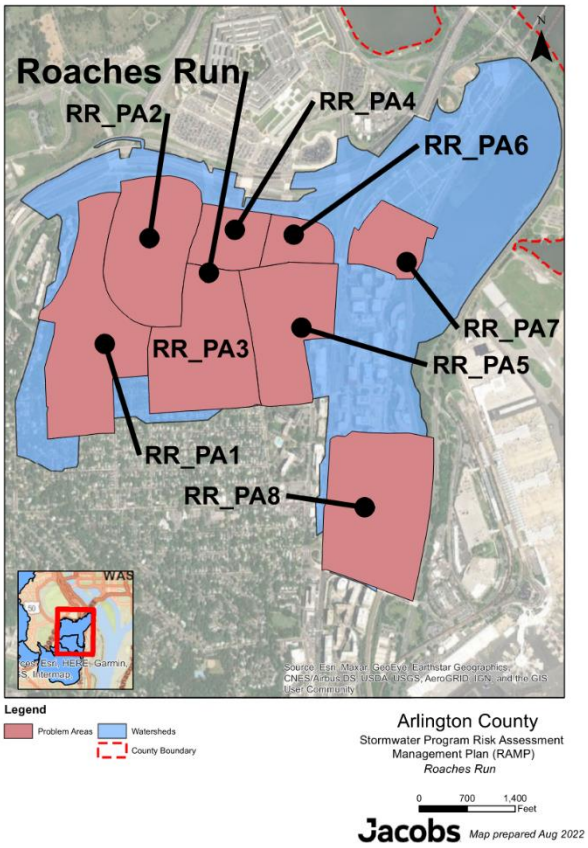
## Description

Area: 50 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.04

Monetary Impact: $12,398

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

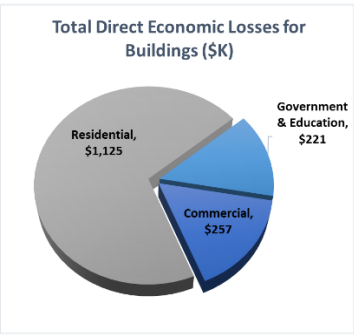
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA5 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 9 | $ 25 | $ 1 | $ 31 | $ 87 | $ 19 | $ 86 | $ 206 | $ 257 |
| Education | $ 1 | $ 3 | $ - | $ 5 | $ 10 | $ 0 | $ 24 | $ 209 | $ 44 |
| Government | $ 1 | $ 6 | $ - | $ 9 | $ 5 | $ 4 | $ 152 | $ 35 | $ 178 |
| Industrial | $ 11 | $ 19 | $ 2 | $ 4 | $ 1 | $ 1 | $ 2 | $ 11 | $ 40 |
| Religious/Non-Profit | $ 2 | $ 11 | $ - | $ 5 | $ 9 | $ 0 | $ 21 | $ 118 | $ 47 |
| Residential | $ 419 | $ 228 | $ - | $ 199 | $ 2 | $ 273 | $ 4 | $ 9 | $ 1,125 |
| Scenario Total | $ 457 | $ 331 | $ 4 | $ 275 | $ 141 | $ 302 | $ 489 | $ 963 | $ 1,998 |

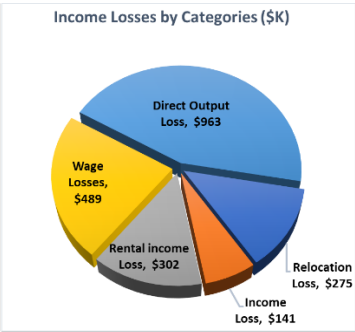
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

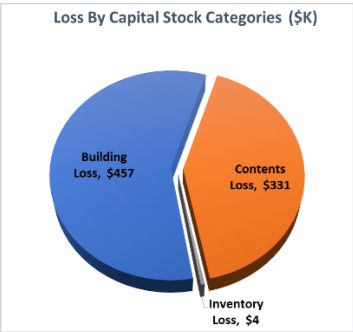
*All values are in thousand of dollars ($K)*

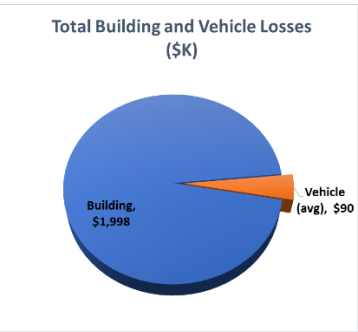
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 51 | $ 16 | $ 2 | $ 69 |
| Night Time | $ 84 | $ 27 | $ 2 | $ 112 |
| Scenario Total | $ 67 | $ 22 | $ 2 | $ 90 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,998 |
| Vehicle (avg) | $ 90 |
| Total | $ 2,089 |




# Ranking Summary

Relative to other Problem Areas, Roaches Run PA5 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Roaches Run PA6 (RR_PA6)
# Fact Sheet

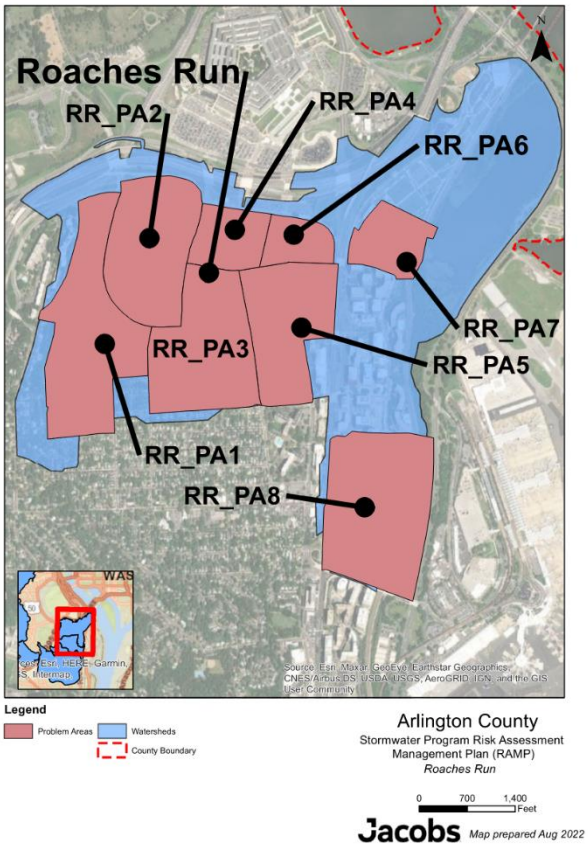
## Description

Area: 15 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.00

Monetary Impact: $0.00

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

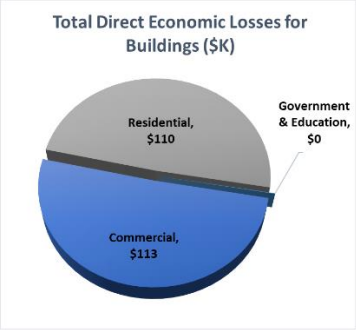
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA6 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 6 | $ 18 | $ 1 | $ 13 | $ 23 | $ 7 | $ 46 | $ 103 | $ 113 |
| Education | $ - | $ 0 | $ - | $ - | $ 0 | $ - | $ 0 | $ 1 | $ 0 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 11 | $ 18 | $ 1 | $ 3 | $ 1 | $ 0 | $ 2 | $ 9 | $ 36 |
| Religious/Non-Profit | $ 1 | $ 9 | $ - | $ 3 | $ 6 | $ 0 | $ 15 | $ 83 | $ 36 |
| Residential | $ 47 | $ 29 | $ - | $ 14 | $ - | $ 19 | $ - | $ - | $ 110 |
| Scenario Total | $ 77 | $ 101 | $ 4 | $ 40 | $ 38 | $ 27 | $ 80 | $ 289 | $ 367 |

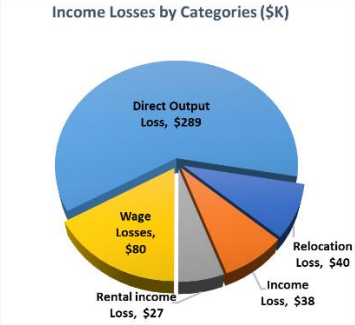
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

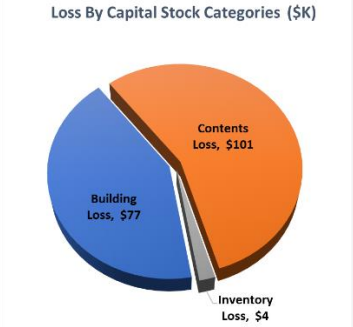
*All values are in thousand of dollars ($K)*

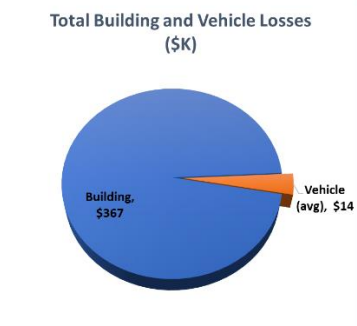
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 7 | $ 3 | $ 0 | $ 10 |
| Night Time | $ 11 | $ 5 | $ 0 | $ 17 |
| Scenario Total | $ 9 | $ 4 | $ 0 | $ 14 |

| | Total Loss ($K) |
|---|---|
| Building | $ 367 |
| Vehicle (avg) | $ 14 |
| Total | $ 380 |




# Ranking Summary

Relative to other Problem Areas, Roaches Run PA6 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Low

# Roaches Run PA7 (RR_PA7)
# Fact Sheet

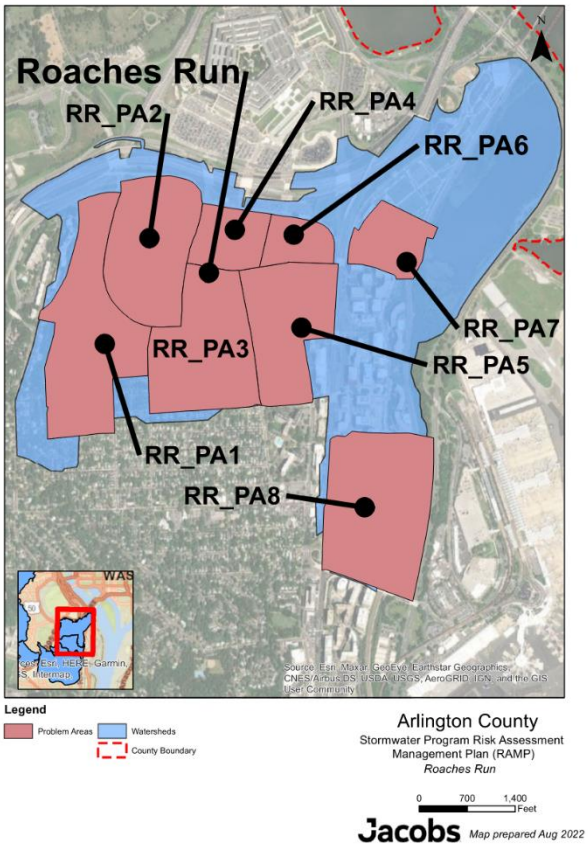
## Description

Area: 22 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 260 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.04

Monetary Impact: $12,420

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

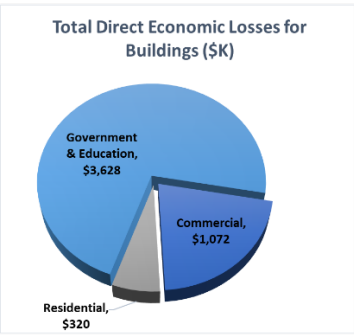
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA7 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ 0 | $ 0 | $ - | $ - | $ 0 | $ - | $ - | $ 1 | $ 0 |
| Commercial | $ 46 | $ 74 | $ 0 | $ 136 | $ 502 | $ 103 | $ 210 | $ 558 | $ 1,072 |
| Education | $ 0 | $ 0 | $ - | $ 0 | $ 3 | $ - | $ 9 | $ 62 | $ 13 |
| Government | $ 4 | $ 16 | $ - | $ 32 | $ 0 | $ 1 | $ 3,562 | $ 625 | $ 3,616 |
| Industrial | $ 2 | $ 5 | $ 1 | $ 0 | $ 0 | $ 0 | $ 0 | $ 3 | $ 8 |
| Religious/Non-Profit | $ 1 | $ 11 | $ - | $ 6 | $ 14 | $ 0 | $ 33 | $ 190 | $ 64 |
| Residential | $ 111 | $ 63 | $ - | $ 53 | $ 4 | $ 81 | $ 8 | $ 19 | $ 320 |
| Scenario Total | $ 171 | $ 200 | $ 2 | $ 266 | $ 541 | $ 187 | $ 7,427 | $ 2,335 | $ 8,794 |

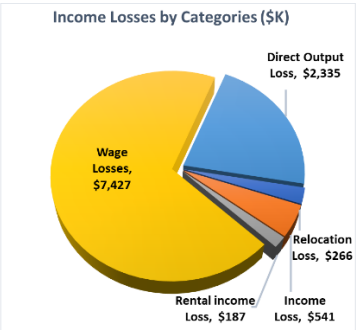
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

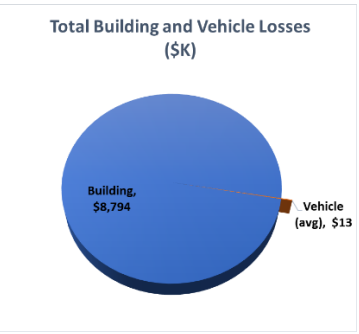
*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 13 | $ 4 | $ 0 | $ 18 |
| Night Time | $ 6 | $ 2 | $ 0 | $ 8 |
| Scenario Total | $ 10 | $ 3 | $ 0 | $ 13 |

| | Total Loss ($K) |
|---|---|
| Building | $ 8,794 |
| Vehicle (avg) | $ 13 |
| Total | $ 8,807 |






# Ranking Summary

Relative to other Problem Areas, Roaches Run PA7 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Roaches Run PA8 (RR_PA8)
# Fact Sheet

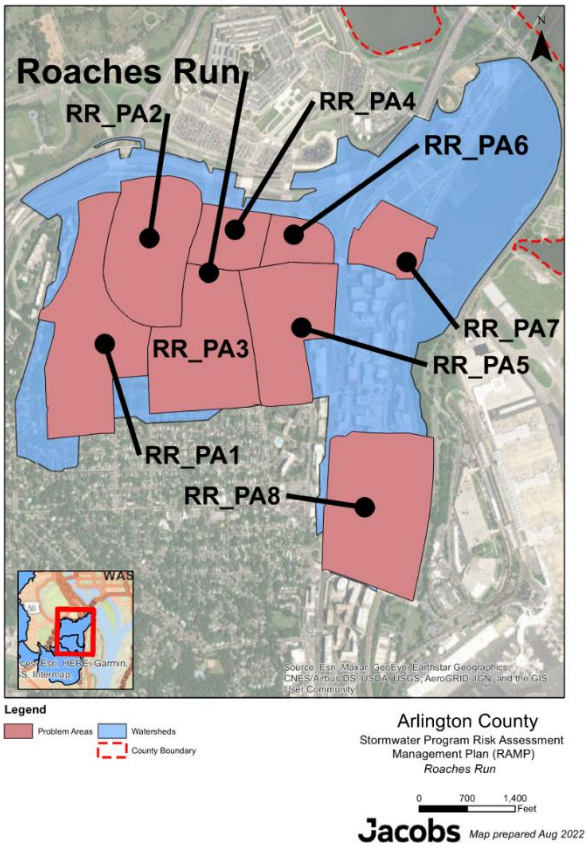
## Description

Area: 76 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.13

Monetary Impact: $13,250

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

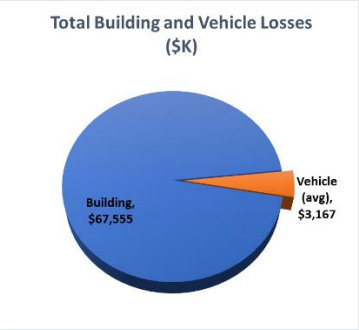
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| RR_PA8 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ 0 | $ - | $ - | $ 0 | $ - | $ 0 | $ 1 | $ 0 |
| Commercial | $ 6,968 | $ 9,927 | $ 6 | $ 5,562 | $ 20,131 | $ 4,273 | $ 7,558 | $ 20,452 | $ 54,426 |
| Education | $ 2 | $ 15 | $ - | $ 8 | $ 36 | $ 0 | $ 87 | $ 709 | $ 148 |
| Government | $ 9 | $ 52 | $ - | $ 70 | $ 27 | $ 18 | $ 3,620 | $ 676 | $ 3,797 |
| Industrial | $ 212 | $ 589 | $ 104 | $ 13 | $ 9 | $ 3 | $ 16 | $ 78 | $ 946 |
| Religious/Non-Profit | $ 6 | $ 55 | $ - | $ 25 | $ 53 | $ 1 | $ 127 | $ 713 | $ 267 |
| Residential | $ 1,281 | $ 760 | $ - | $ 313 | $ 9 | $ 429 | $ 21 | $ 48 | $ 2,813 |
| Scenario Total | $ 8,708 | $ 12,108 | $ 213 | $ 6,109 | $ 20,391 | $ 4,747 | $ 15,280 | $ 24,856 | $ 67,555 |

DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 3,134 | $ 2,028 | $ 97 | $ 5,259 |
| Night Time | $ 597 | $ 376 | $ 102 | $ 1,075 |
| Scenario Total | $ 1,865 | $ 1,202 | $ 100 | $ 3,167 |

| | Total Loss ($K) |
|---|---|
| Building | $ 67,555 |
| Vehicle (avg) | $ 3,167 |
| Total | $ 70,722 |




# Ranking Summary

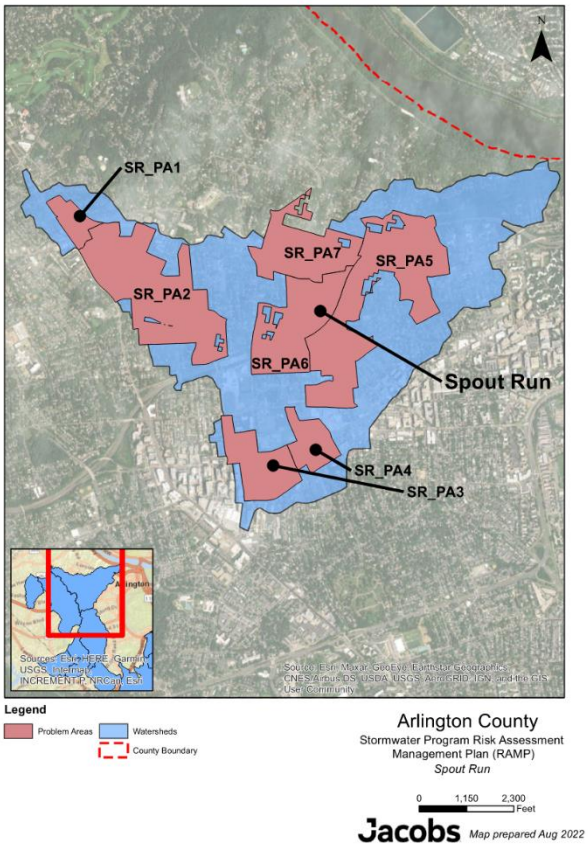
Relative to other Problem Areas, Roaches Run PA8 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Spout Run PA1 (SR_PA1)
# Fact Sheet

## Description

Area: 17 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.01

Monetary Impact: $12,135

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

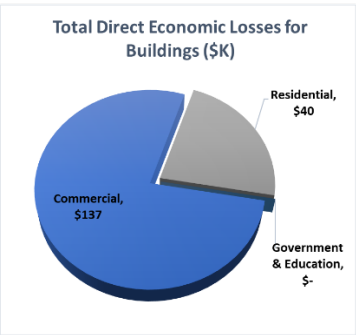
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA1 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 6 | $ 34 | $ 0 | $ 5 | $ 47 | $ 2 | $ 42 | $ 131 | $ 137 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0 | $ 0 | $ - | $ 0 | $ 0 | $ - | $ 0 | $ 0 | $ 0 |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 21 | $ 11 | $ - | $ 7 | $ - | $ 2 | $ - | $ - | $ 40 |
| Scenario Total | $ 27 | $ 45 | $ 0 | $ 12 | $ 47 | $ 4 | $ 42 | $ 131 | $ 177 |

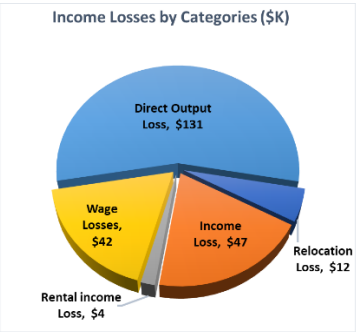
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

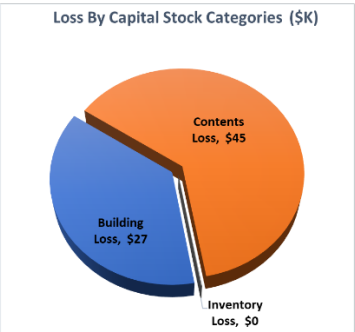
*All values are in thousand of dollars ($K)*

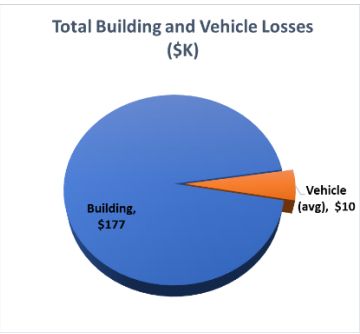
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 9 | $ 3 | $ 0 | $ 12 |
| Night Time | $ 5 | $ 2 | $ 0 | $ 7 |
| Scenario Total | $ 7 | $ 2 | $ 0 | $ 10 |

| | Total Loss ($K) |
|---|---|
| Building | $ 177 |
| Vehicle (avg) | $ 10 |
| Total | $ 187 |




# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 1 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Low

# Spout Run PA2 (SR_PA2)
# Fact Sheet

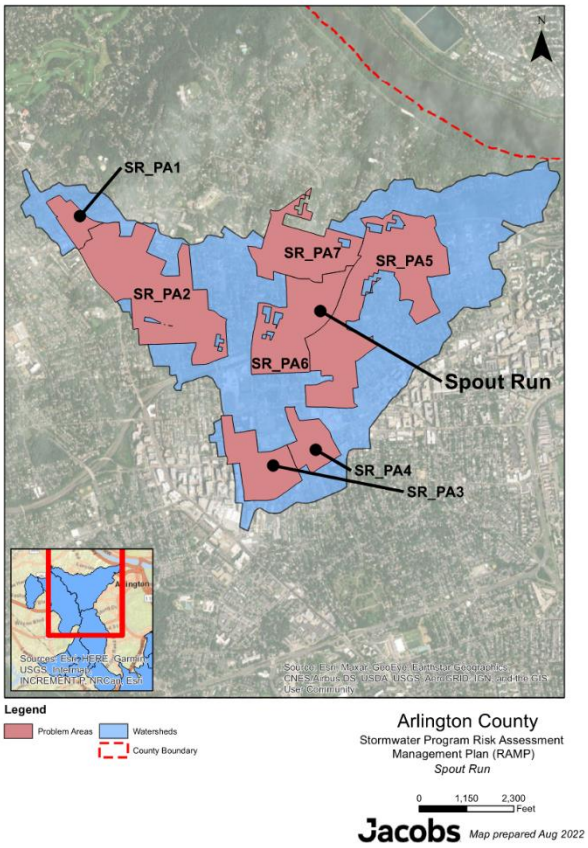
## Description

Area: 140 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.22

Monetary Impact: $14,179

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

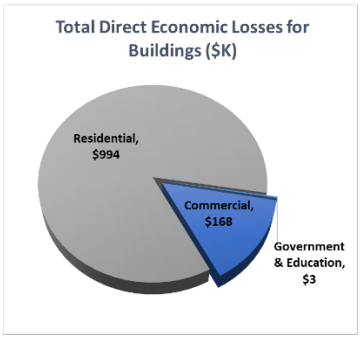
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA2 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 | $ - |
| Commercial | $ 3 | $ 10 | $ - | $ 9 | $ 93 | $ 6 | $ 47 | $ 132 | $ 168 |
| Education | $ - | $ 0 | $ - | $ - | $ 1 | $ - | $ 2 | $ 22 | $ 3 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0 | $ 0 | $ - | $ - | $ - | $ - | $ - | $ 0 | $ 0 |
| Religious/Non-Profit | $ 2 | $ 14 | $ - | $ 2 | $ 13 | $ - | $ 31 | $ 179 | $ 61 |
| Residential | $ 389 | $ 208 | $ - | $ 279 | $ - | $ 118 | $ - | $ - | $ 994 |
| Scenario Total | $ 395 | $ 247 | $ - | $ 291 | $ 119 | $ 124 | $ 113 | $ 535 | $ 1,289 |

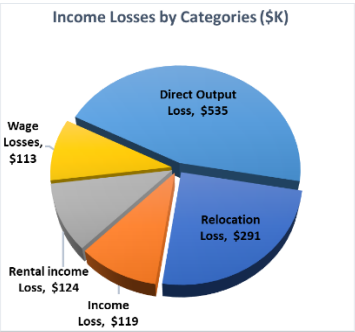
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

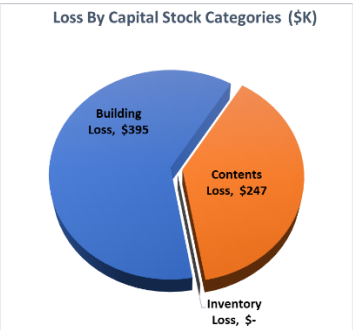
*All values are in thousand of dollars ($K)*

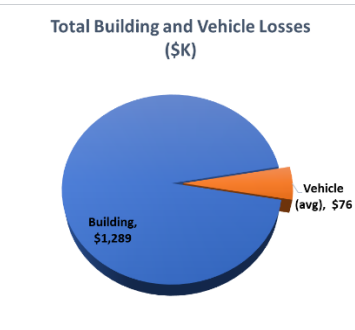
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 40 | $ 12 | $ 1 | $ 53 |
| Night Time | $ 76 | $ 23 | $ 1 | $ 100 |
| Scenario Total | $ 58 | $ 17 | $ 1 | $ 76 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,289 |
| Vehicle (avg) | $ 76 |
| Total | $ 1,366 |




# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 2 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Spout Run PA3 (SR_PA3)
# Fact Sheet

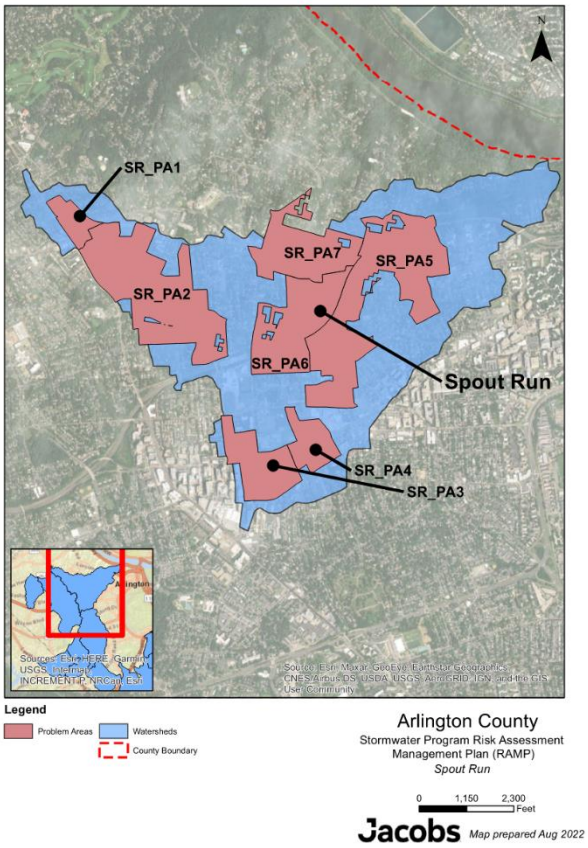
## Description

Area: 61 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.09

Monetary Impact: $12,931

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

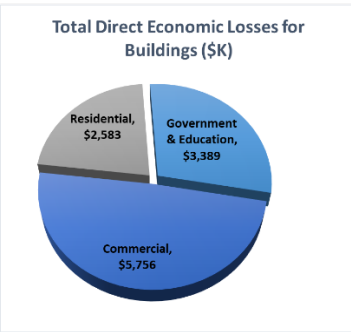
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA3 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 229 | $ 612 | $ 1 | $ 501 | $ 1,969 | $ 339 | $ 2,106 | $ 4,937 | $ 5,756 |
| Education | $ 0 | $ 2 | $ - | $ 11 | $ 26 | $ 0 | $ 63 | $ 546 | $ 102 |
| Government | $ 20 | $ 125 | $ - | $ 169 | $ 101 | $ 68 | $ 2,803 | $ 650 | $ 3,287 |
| Industrial | $ 0 | $ 1 | $ - | $ 0 | $ - | $ - | $ 0 | $ 1 | $ 1 |
| Religious/Non-Profit | $ 10 | $ 84 | $ - | $ 74 | $ 131 | $ 7 | $ 308 | $ 1,725 | $ 614 |
| Residential | $ 821 | $ 444 | $ - | $ 505 | $ 42 | $ 670 | $ 100 | $ 223 | $ 2,583 |
| Scenario Total | $ 1,111 | $ 1,480 | $ 1 | $ 1,517 | $ 2,526 | $ 1,159 | $ 8,553 | $ 11,003 | $ 16,347 |

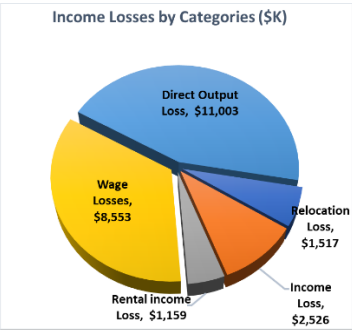
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

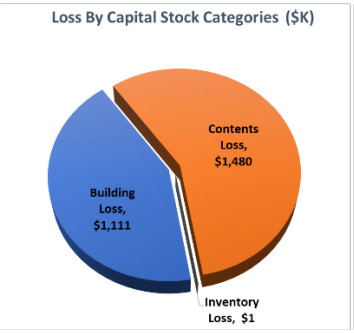
*All values are in thousand of dollars ($K)*

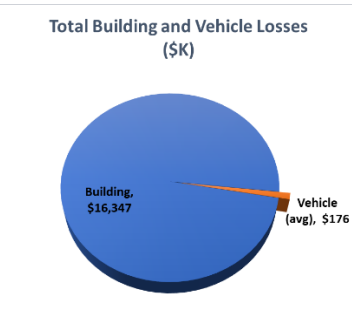
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 171 | $ 65 | $ 3 | $ 239 |
| Night Time | $ 77 | $ 33 | $ 3 | $ 112 |
| Scenario Total | $ 124 | $ 49 | $ 3 | $ 176 |

| | Total Loss ($K) |
|---|---|
| Building | $ 16,347 |
| Vehicle (avg) | $ 176 |
| Total | $ 16,523 |




# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 3 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Spout Run PA4 (SR_PA4)
# Fact Sheet

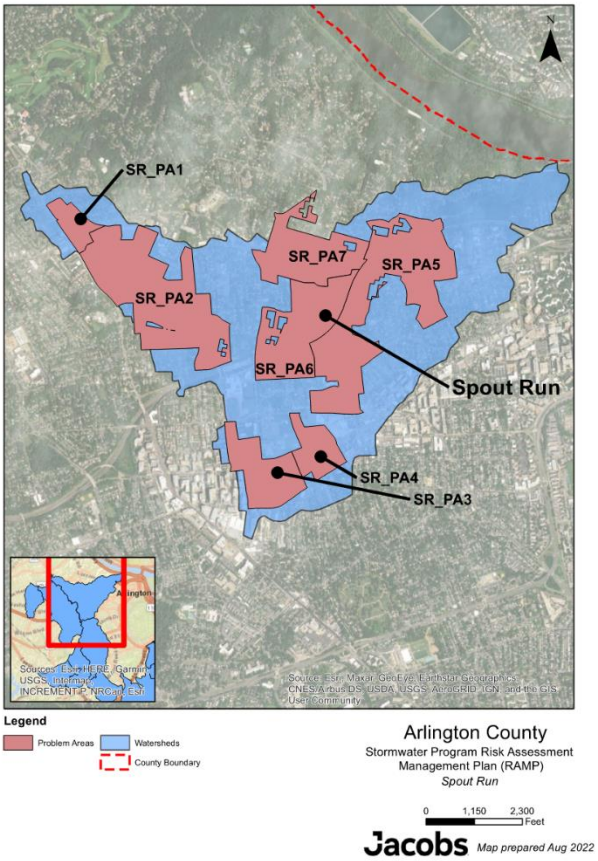
## Description

Area: 28 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.18

Monetary Impact: $13,761

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

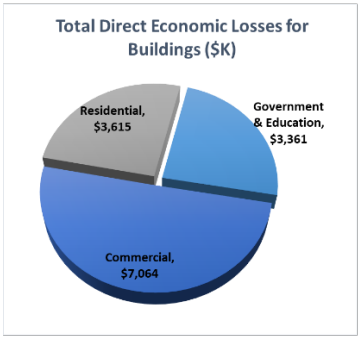
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | Total Loss |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA4 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 335 | $ 920 | $ 5 | $ 661 | $ 2,288 | $ 452 | $ 2,403 | $ 5,757 | $ 7,064 |
| Education | $ 8 | $ 49 | $ - | $ 120 | $ 285 | $ 9 | $ 672 | $ 5,089 | $ 1,142 |
| Government | $ 20 | $ 121 | $ - | $ 113 | $ 67 | $ 46 | $ 1,853 | $ 430 | $ 2,219 |
| Industrial | $ 7 | $ 10 | $ 1 | $ 0 | $ 0 | $ - | $ 1 | $ 5 | $ 20 |
| Religious/Non-Profit | $ 9 | $ 79 | $ - | $ 72 | $ 125 | $ 7 | $ 293 | $ 1,636 | $ 585 |
| Residential | $ 966 | $ 636 | $ - | $ 405 | $ 257 | $ 745 | $ 606 | $ 1,349 | $ 3,615 |
| Scenario Total | $ 1,388 | $ 2,076 | $ 7 | $ 1,677 | $ 3,499 | $ 1,321 | $ 8,647 | $ 21,425 | $ 18,614 |

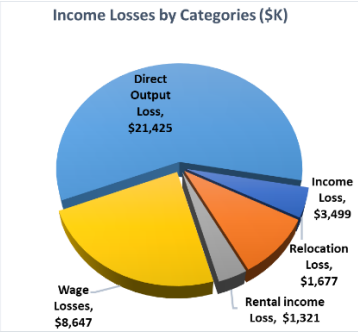
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

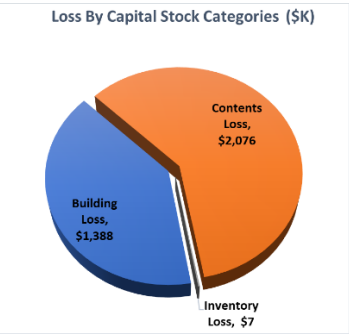
*All values are in thousand of dollars ($K)*

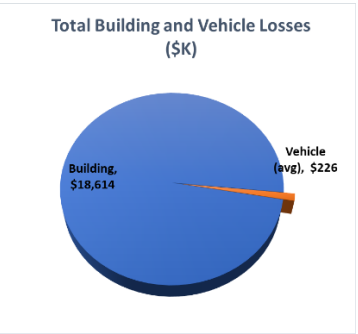
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 225 | $ 82 | $ 4 | $ 311 |
| Night Time | $ 102 | $ 34 | $ 5 | $ 140 |
| Scenario Total | $ 164 | $ 58 | $ 4 | $ 226 |

| | Total Loss ($K) |
|---|---|
| Building | $ 18,614 |
| Vehicle (avg) | $ 226 |
| Total | $ 18,840 |




# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 4 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: High

# Spout Run PA5 (SR_PA5)
# Fact Sheet

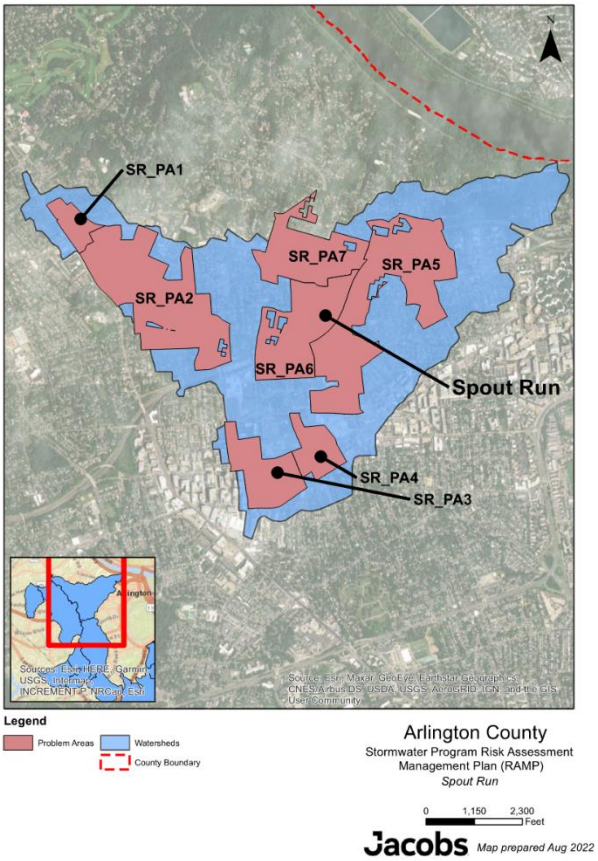
## Description

Area: 149 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 88,223 |
| 100yr Baseline | 155,180 |
| 500yr Baseline | 226,141 |
| 10yr 2070 | 98,243 |
| 100yr 2070 | 183,758 |
| 500yr 2070 | 245,702 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.79

Monetary Impact: $19,854

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

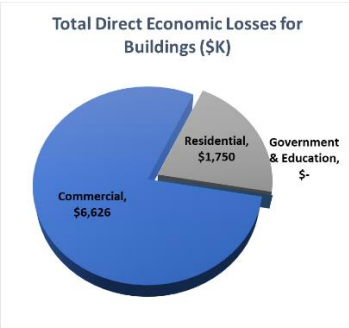
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA5 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ 0 | $ 2 | $ 0 | $ 0 | $ 1 | $ - | $ 0 | $ 6 | $ 4 |
| Commercial | $ 228 | $ 1,039 | $ 3 | $ 467 | $ 2,594 | $ 362 | $ 1,933 | $ 4,523 | $ 6,626 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 1 | $ 2 | $ 0 | $ - | $ - | $ - | $ 0 | $ 1 | $ 2 |
| Religious/Non-Profit | $ 14 | $ 88 | $ - | $ 20 | $ 42 | $ 2 | $ 100 | $ 563 | $ 265 |
| Residential | $ 720 | $ 388 | $ - | $ 455 | $ 0 | $ 186 | $ 0 | $ 2 | $ 1,750 |
| Scenario Total | $ 978 | $ 1,611 | $ 3 | $ 962 | $ 2,680 | $ 552 | $ 2,134 | $ 5,664 | $ 8,919 |

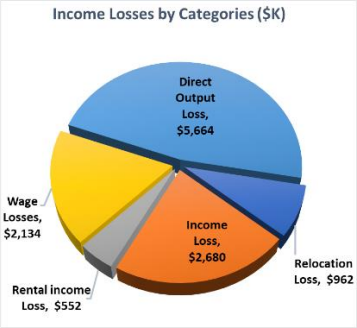
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

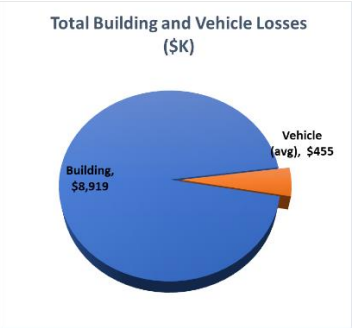
*All values are in thousand of dollars ($K)*

| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 449 | $ 151 | $ 5 | $ 605 |
| Night Time | $ 226 | $ 73 | $ 5 | $ 305 |
| Scenario Total | $ 338 | $ 112 | $ 5 | $ 455 |

| | Total Loss ($K) |
|---|---|
| Building | $ 8,919 |
| Vehicle (avg) | $ 455 |
| Total | $ 9,374 |






# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 5 generally ranks as follows:

Social Vulnerability: Low
Environmental: High
Economic Risk: High

# Spout Run PA6 (SR_PA6)
# Fact Sheet

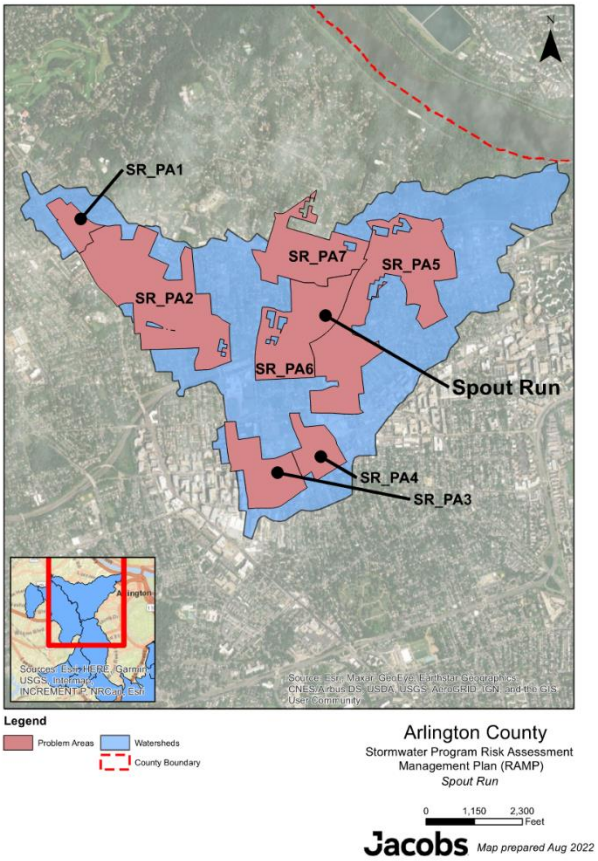
## Description

Area: 77 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 38,027 |
| 500yr Baseline | 42,143 |
| 10yr 2070 | 2,585 |
| 100yr 2070 | 40,039 |
| 500yr 2070 | 43,117 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.09

Monetary Impact: $12,915

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

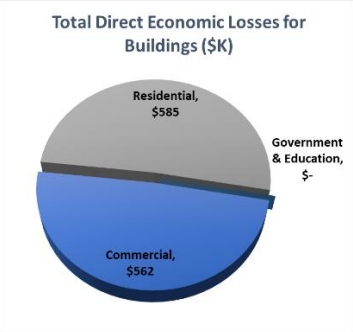
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA6 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ 0 | $ - | $ - | $ - | $ - | $ - | $ 0 | $ 0 |
| Commercial | $ 18 | $ 29 | $ 0 | $ 64 | $ 269 | $ 49 | $ 133 | $ 348 | $ 562 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0 | $ - |
| Religious/Non-Profit | $ - | $ 0 | $ - | $ - | $ 1 | $ - | $ 2 | $ 14 | $ 3 |
| Residential | $ 182 | $ 97 | $ - | $ 209 | $ - | $ 96 | $ - | $ - | $ 585 |
| Scenario Total | $ 200 | $ 126 | $ 0 | $ 273 | $ 270 | $ 145 | $ 137 | $ 376 | $ 1,153 |

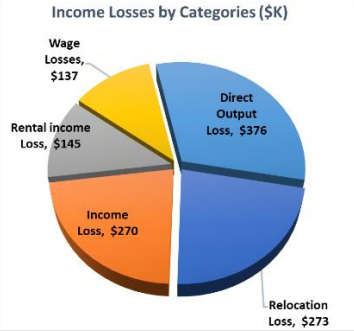
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

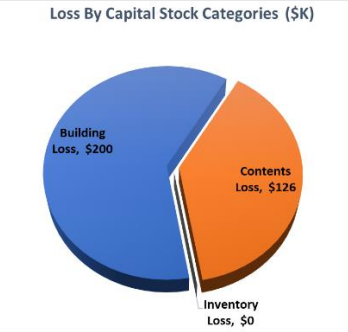
*All values are in thousand of dollars ($K)*

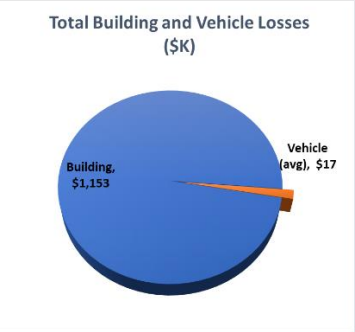
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 14 | $ 5 | $ 0 | $ 19 |
| Night Time | $ 11 | $ 4 | $ 0 | $ 16 |
| Scenario Total | $ 12 | $ 5 | $ 0 | $ 17 |

| | Total Loss ($K) |
|---|---|
| Building | $ 1,153 |
| Vehicle (avg) | $ 17 |
| Total | $ 1,170 |




# Ranking Summary

Relative to other Problem Areas, Spout Run Problem Area 6 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Spout Run PA7 (SR_PA7)
# Fact Sheet

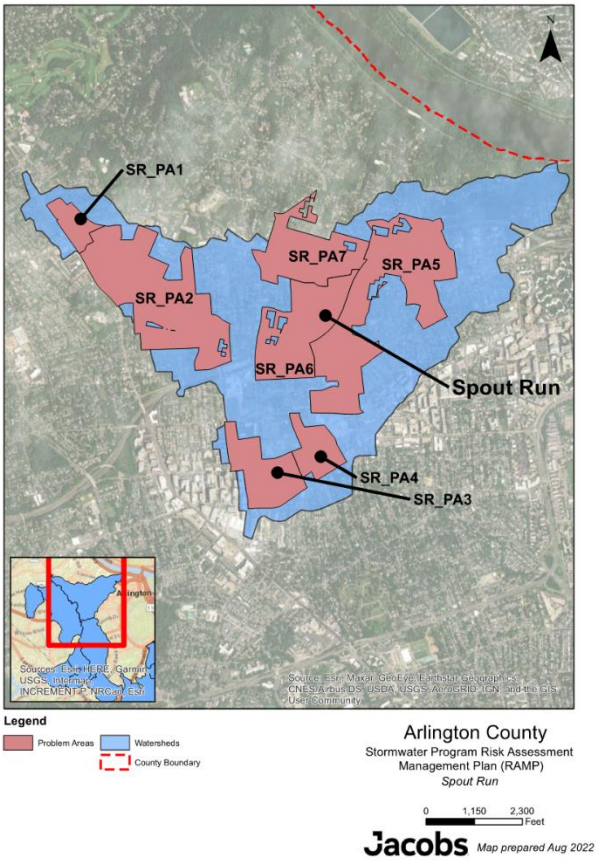
## Description

Area: 68 Acres

## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |




## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.24

Monetary Impact: $14,413

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

DIRECT ECONOMIC LOSSES FOR BUILDINGS

*All values are in thousand of dollars ($K)*

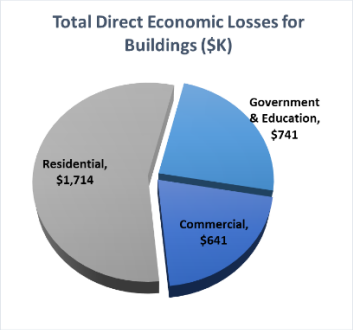
| Problem Area | Capital Stock Losses | | | Income Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SR_PA7 | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Direct Output Loss | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 19 | $ 29 | $ 0 | $ 72 | $ 300 | $ 54 | $ 168 | $ 436 | $ 641 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 1 | $ 3 | $ - | $ 6 | $ - | $ 0 | $ 730 | $ 128 | $ 741 |
| Industrial | $ 3 | $ 3 | $ 0 | $ 0 | $ - | $ - | $ 0 | $ 1 | $ 6 |
| Religious/Non-Profit | $ - | $ 0 | $ - | $ 1 | $ 2 | $ - | $ 6 | $ 36 | $ 9 |
| Residential | $ 443 | $ 441 | $ - | $ 321 | $ 82 | $ 233 | $ 195 | $ 435 | $ 1,714 |
| Scenario Total | $ 469 | $ 484 | $ 1 | $ 406 | $ 386 | $ 287 | $ 1,837 | $ 1,199 | $ 3,869 |

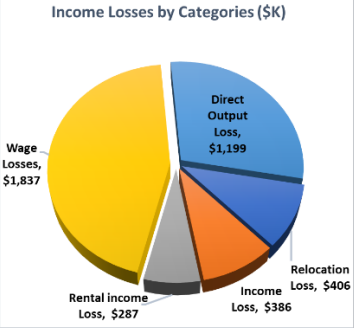
DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)

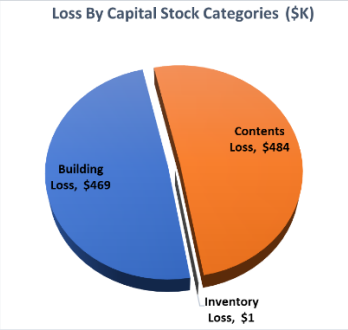
*All values are in thousand of dollars ($K)*

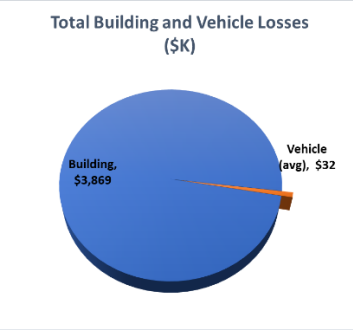
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 23 | $ 11 | $ 1 | $ 36 |
| Night Time | $ 18 | $ 8 | $ 1 | $ 27 |
| Scenario Total | $ 20 | $ 10 | $ 1 | $ 32 |

| | Total Loss ($K) |
|---|---|
| Building | $ 3,869 |
| Vehicle (avg) | $ 32 |
| Total | $ 3,900 |




# Ranking Summary

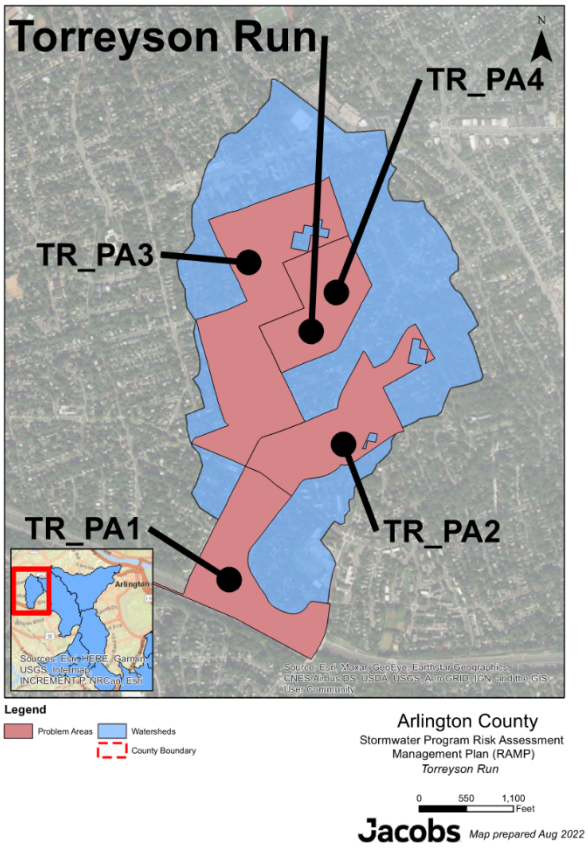
Relative to other Problem Areas, Spout Run Problem Area 7 generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Torreyson Run PA1 (TR_PA1)
# Fact Sheet

## Description

Area: 34 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 460 |
| 100yr Baseline | 6,222 |
| 500yr Baseline | 8,458 |
| 10yr 2070 | 1,651 |
| 100yr 2070 | 7,324 |
| 500yr 2070 | 11,627 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 9,708 |
| 500yr Baseline | 17,819 |
| 10yr 2070 | 1,650 |
| 100yr 2070 | 13,886 |
| 500yr 2070 | 24,939 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.06

Monetary Impact: $12,644

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

**DIRECT ECONOMIC LOSSES FOR BUILDINGS**

*All values are in thousand of dollars ($K)*

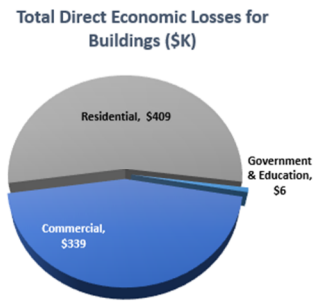
| Problem Area | Capital Stock Losses | | | Income Losses | | | | |
|---|---|---|---|---|---|---|---|---|
| **TR_PA1** | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 12.4 | $ 47.5 | $ 0.4 | $ 19.9 | $ 129.6 | $ 15.3 | $ 113.4 | $ 338.6 |
| Education | $ 0.0 | $ 0.5 | $ - | $ - | $ 1.3 | $ - | $ 3.6 | $ 5.5 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 4.2 | $ 4.5 | $ 0.5 | $ 0.1 | $ 0.4 | $ - | $ 0.5 | $ 10.1 |
| Religious/Non-Profit | $ 0.9 | $ 8.3 | $ - | $ 2.6 | $ 6.9 | $ 0.1 | $ 16.6 | $ 35.3 |
| Residential | $ 168.5 | $ 92.7 | $ - | $ 103.8 | $ - | $ 43.7 | $ - | $ 408.8 |
| **Scenario Total** | **$ 186.1** | **$ 153.5** | **$ 0.9** | **$ 126.4** | **$ 138.2** | **$ 59.0** | **$ 134.1** | **$ 803.8** |

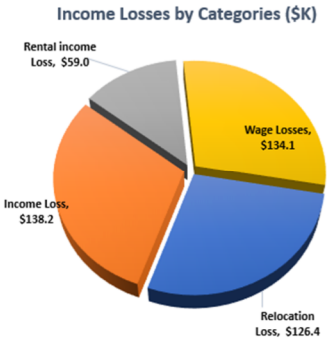
**DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)**

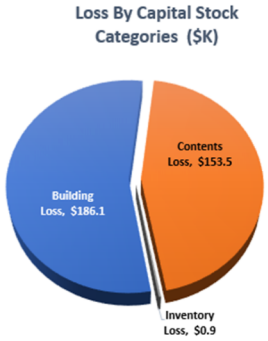
*All values are in thousand of dollars ($K)*

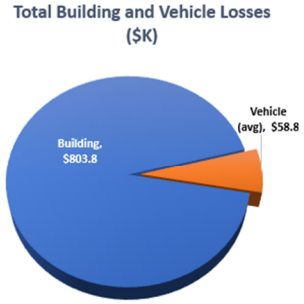
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 40.1 | $ 11.9 | $ 0.9 | $ 52.9 |
| Night Time | $ 48.9 | $ 14.9 | $ 0.9 | $ 64.7 |
| **Scenario Total** | **$ 44.5** | **$ 13.4** | **$ 0.9** | **$ 58.8** |

| | Total Loss ($K) |
|---|---|
| Building | **$ 803.8** |
| Vehicle (avg) | **$ 58.8** |
| **Total** | **$ 862.6** |




# Ranking Summary

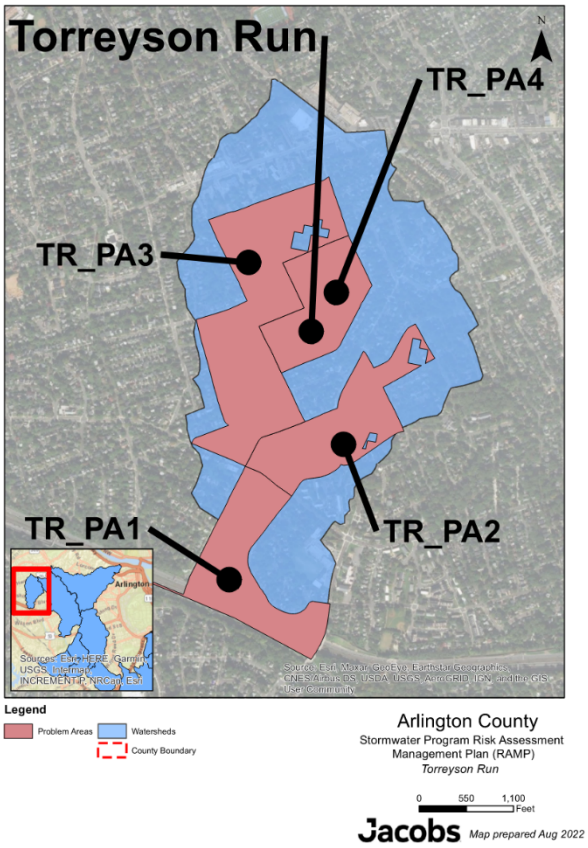
Relative to other Problem Areas, **Torreyson Run Problem Area 1** generally ranks as follows:

Social Vulnerability: Medium
Environmental: Low
Economic Risk: Low

# Torreyson Run PA2 (TR_PA2)
# Fact Sheet

## Description

Area: 32 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.02

Monetary Impact: $12,212

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

**DIRECT ECONOMIC LOSSES FOR BUILDINGS**

*All values are in thousand of dollars ($K)*

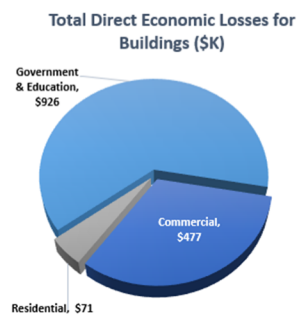
| Problem Area | Capital Stock Losses | | | Income Losses | | | | |
|---|---|---|---|---|---|---|---|---|
| **TR_PA2** | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 22.9 | $ 108.3 | $ 1.9 | $ 42.2 | $ 150.5 | $ 24.1 | $ 127.2 | $ 477.2 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ 9.0 | $ 61.1 | $ - | $ 45.9 | $ 27.5 | $ 18.4 | $ 764.3 | $ 926.3 |
| Industrial | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 23.9 | $ 12.2 | $ - | $ 27.0 | $ - | $ 7.5 | $ - | $ 70.6 |
| **Scenario Total** | **$ 55.8** | **$ 181.7** | **$ 1.9** | **$ 115.1** | **$ 178.0** | **$ 50.0** | **$ 891.5** | **$ 2,400.4** |

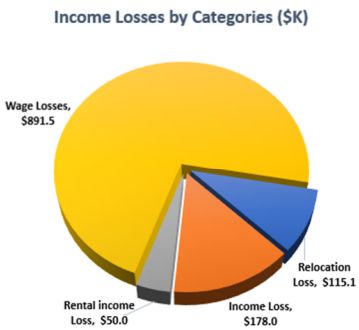
**DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)**

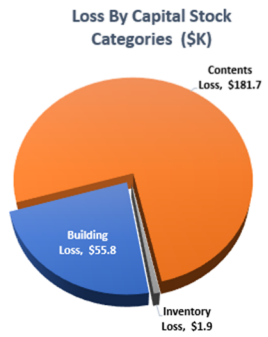
*All values are in thousand of dollars ($K)*

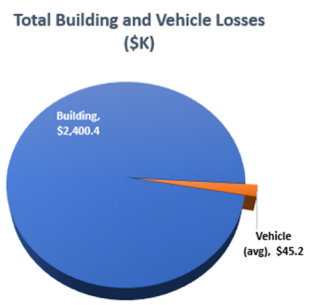
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 53.3 | $ 14.0 | $ 1.0 | $ 68.3 |
| Night Time | $ 16.5 | $ 4.2 | $ 1.4 | $ 22.0 |
| **Scenario Total** | **$ 34.9** | **$ 9.1** | **$ 1.2** | **$ 45.2** |

| | Total Loss ($K) |
|---|---|
| Building | **$ 2,400.4** |
| Vehicle (avg) | **$ 45.2** |
| **Total** | **$ 2,445.5** |




# Ranking Summary

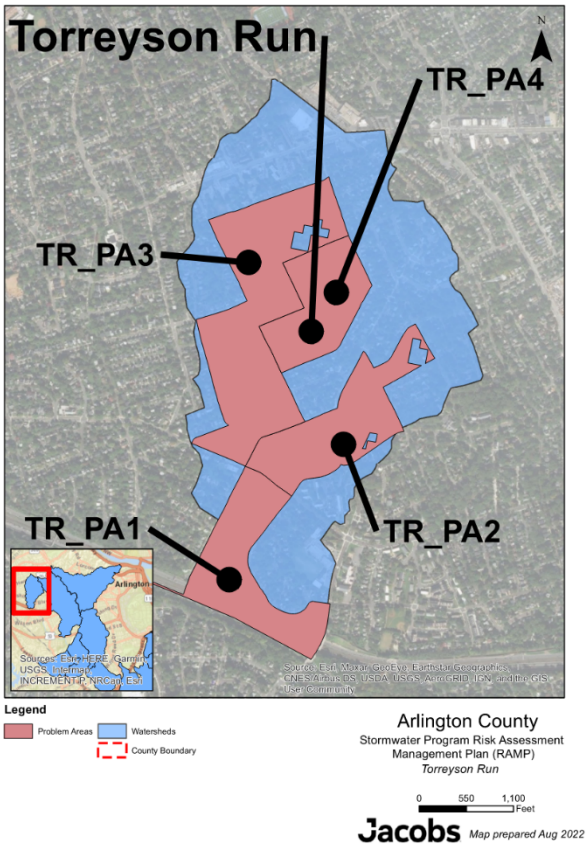
Relative to other Problem Areas, **Torreyson Run Problem Area 2** generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Medium

# Torreyson Run PA3 (TR_PA3)
# Fact Sheet

## Description

Area: 62 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.08

Monetary Impact: $12,790

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

**DIRECT ECONOMIC LOSSES FOR BUILDINGS**

*All values are in thousand of dollars ($K)*

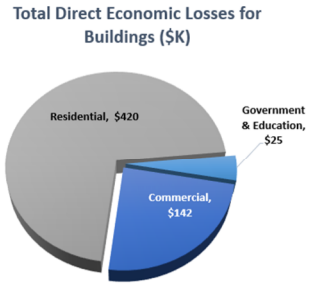
| Problem Area | Capital Stock Losses | | | Income Losses | | | | |
|---|---|---|---|---|---|---|---|---|
| **TR_PA3** | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Total Loss |
| Agriculture | $ - | $ 0.1 | $ - | $ - | $ 0.1 | $ - | $ - | $ 0.1 |
| Commercial | $ 3.5 | $ 12.0 | $ - | $ 12.5 | $ 52.4 | $ 9.5 | $ 52.6 | $ 142.4 |
| Education | $ 0.4 | $ 2.5 | $ - | $ 1.1 | $ 6.2 | $ 0.0 | $ 15.2 | $ 25.4 |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ 0.0 | $ 0.0 | $ - | $ - | $ - | $ - | $ - | $ 0.0 |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 134.4 | $ 73.0 | $ - | $ 126.4 | $ 10.1 | $ 52.0 | $ 23.8 | $ 419.6 |
| **Scenario Total** | **$ 138.3** | **$ 87.5** | **$ -** | **$ 140.0** | **$ 68.7** | **$ 61.4** | **$ 91.6** | **$ 613.0** |

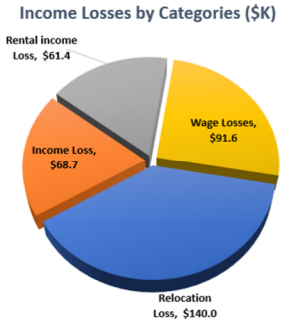
**DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)**

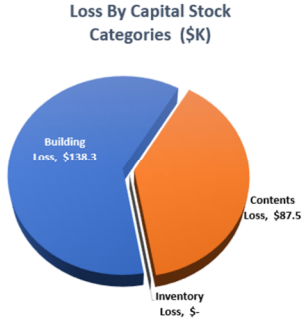
*All values are in thousand of dollars ($K)*

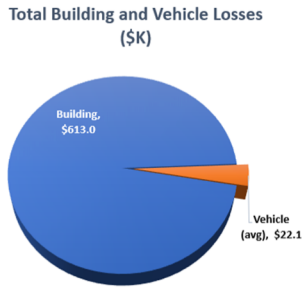
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 14.8 | $ 4.3 | $ 0.3 | $ 19.3 |
| Night Time | $ 18.8 | $ 5.7 | $ 0.3 | $ 24.8 |
| **Scenario Total** | **$ 16.8** | **$ 5.0** | **$ 0.3** | **$ 22.1** |

| | Total Loss ($K) |
|---|---|
| Building | **$ 613.0** |
| Vehicle (avg) | **$ 22.1** |
| **Total** | **$ 635.0** |




# Ranking Summary

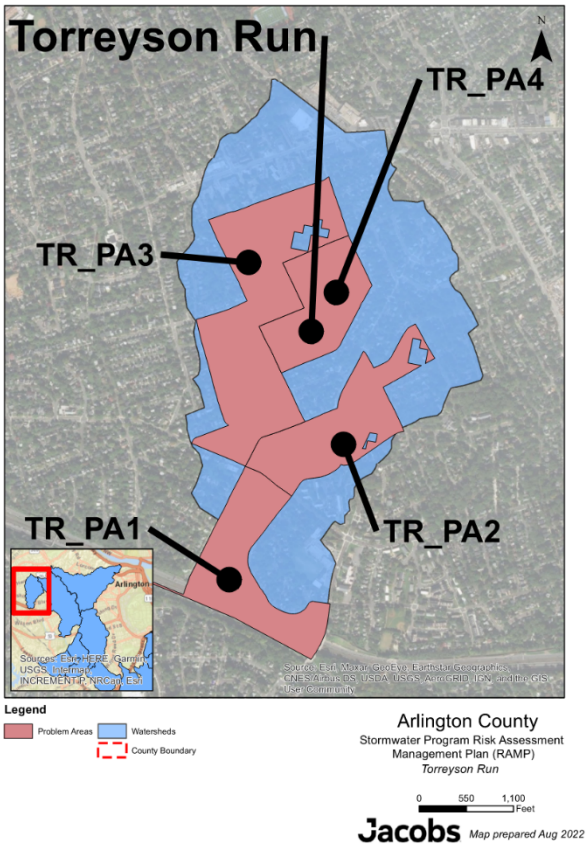
Relative to other Problem Areas, **Torreyson Run Problem Area 3** generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Low

# Torreyson Run PA4 (TR_PA4)
# Fact Sheet

## Description

Area: 26 Acres




## Socially Vulnerable Flooded Areas

| Medium to High SVI (0.50-0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

| High SVI (>0.75)(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Resource Protection Areas Flooded (Environmental Areas)

| RPA Flooded Areas(sq.ft.) | |
|---|---|
| 10yr Baseline | 0 |
| 100yr Baseline | 0 |
| 500yr Baseline | 0 |
| 10yr 2070 | 0 |
| 100yr 2070 | 0 |
| 500yr 2070 | 0 |

## Roads

Total Miles Flooded (Weighted Annualized Average): 0.05

Monetary Impact: $12,511

Note: Monetary Impact is equivalent to $10,000 per mile of flooded roadway plus cost of crew for 80 hours at a rate of $150 per hour

# Risk of Economic Losses (Monetized Risk)

**DIRECT ECONOMIC LOSSES FOR BUILDINGS**

*All values are in thousand of dollars ($K)*

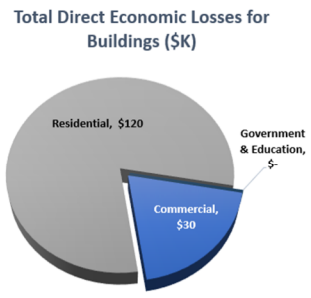
| Problem Area | Capital Stock Losses | | | Income Losses | | | | |
|---|---|---|---|---|---|---|---|---|
| **TR_PA4** | Building Loss | Contents Loss | Inventory Loss | Relocation Loss | Income Loss | Rental income Loss | Wage Losses | Total Loss |
| Agriculture | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Commercial | $ 0.0 | $ 0.0 | $ - | $ 2.5 | $ 16.7 | $ 1.8 | $ 8.6 | $ 29.7 |
| Education | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Government | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Industrial | $ - | $ 0.0 | $ - | $ - | $ - | $ - | $ - | $ 0.0 |
| Religious/Non-Profit | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Residential | $ 32.2 | $ 17.7 | $ - | $ 54.7 | $ - | $ 15.5 | $ - | $ 120.1 |
| **Scenario Total** | **$ 32.3** | **$ 17.8** | **$ -** | **$ 57.1** | **$ 16.7** | **$ 17.3** | **$ 8.6** | **$ 149.8** |

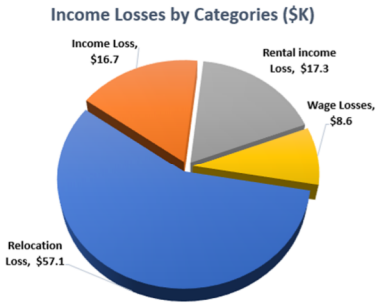
**DIRECT ECONOMIC LOSSES FOR VEHICLES (Annual)**

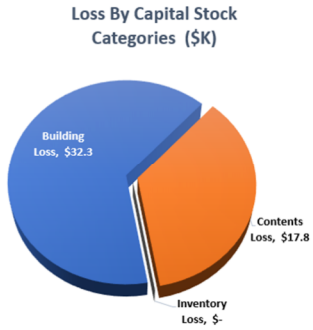
*All values are in thousand of dollars ($K)*

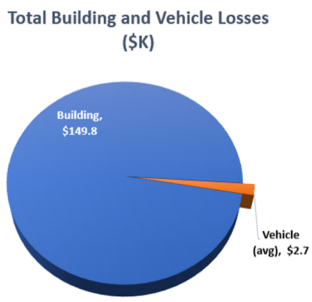
| | Car Loss | Light Truck | Heavy Truck | Total Vehicle Loss |
|---|---|---|---|---|
| Day Time | $ 1.5 | $ 0.4 | $ 0.1 | $ 1.9 |
| Night Time | $ 2.6 | $ 0.7 | $ 0.1 | $ 3.4 |
| **Scenario Total** | **$ 2.0** | **$ 0.6** | **$ 0.1** | **$ 2.7** |

| | Total Loss ($K) |
|---|---|
| Building | **$ 149.8** |
| Vehicle (avg) | **$ 2.7** |
| **Total** | **$ 152.5** |




# Ranking Summary

Relative to other Problem Areas, **Torreyson Run PA4** generally ranks as follows:

Social Vulnerability: Low
Environmental: Low
Economic Risk: Low

# Appendix F
# Criteria Weight Sensitivity for Problem Area Ranking

The sensitivity of the ranking of Problem Areas (PAs) was tested by changing the criteria weights for economic, social and environmental criteria in the risk analysis. Results presented in Section 5 correspond to the following equation:

Total Risk Score = (Economic Risk Normalized Score * 0.5) +
+ (Social Vulnerability Normalized Score * 0.4)
+ (Environmental Areas Normalized Score * 0.1)

The following sensitivity weight factors were tested

| **Theme** | **Economic** Weight | **Social** Weight | **Environmental** Weight |
|---|---|---|---|
| Largely Economic | 0.7 | 0.2 | 0.1 |
| Economic Importance | 0.5 | 0.4 | 0.1 |
| Equal weights | 0.33 | 0.33 | 0.33 |
| Social Importance | 0.4 | 0.5 | 0.1 |
| Largely Social | 0.2 | 0.7 | 0.1 |

The environmental criterion was not assigned a high importance due to the relatively limited information associated with it (only Resource Protection Area [RPA] area is included) and the fact that some RPAs are in fact in the floodplain and are prone and not entirely sensitive to flooding.

The objective of the sensitivity analysis is to identify PAs that can move significantly higher or lower in the prioritization when the criteria weights change. A summary of those observations is included below.

Top 5 and Bottom 5 PAs Under Each Theme

| **Theme** | **Large**ly Economic | **Economic Importan**ce | **Equal Weight** | **Social Importance** | **Largely Social** |
|---|---|---|---|---|---|
| Top 5 PAs | RR PA8<br>LR PA3<br>RR PA2<br>DB PA1<br>SR PA4 | RR PA8<br>DB PA1<br>LR PA3<br>RR PA2<br>FMRLM PA4 | DB PA1<br>FMRLM PA4<br>RR PA8<br>LR PA3<br>RR PA2 | DB PA1<br>RR PA8<br>LR PA3<br>RR PA2<br>DB PA5 | DB PA1<br>DB PA5<br>RR PA8<br>FMRLM PA4<br>DB PA2 |
| Bottom 5 PAs | RR PA6<br>LR PA4<br>RR PA4<br>TR PA4<br>SR PA1 | SR PA1<br>TR PA4<br>RR PA4<br>RR PA6<br>LR PA4 | TR PA3<br>RR PA6<br>RR PA4<br>TR PA4<br>SR PA1 | DB PA1<br>FMRLM PA4<br>RR PA8<br>LR PA3<br>RR PA2 | LR PA4<br>RR PA6<br>RR PA4<br>TR PA4<br>SR PA1 |

Some highlights of the sensitivity analysis include:

- Some PAs are consistently top-ranking: DBPA1, RRPA8, LRPA3 and RRPA2.
- Doctor's Branch PAs will do better with high social criteria weight. More DB PAs come into the picture of top ranked PAs as the weight of the social criterion is elevated.
- DB1 is consistently a top tier PA.
- RR P8 is consistently a top tier unless the economic weight factor goes significantly lower

- FMRPA4 is sensitive in ranking, doing really well when the sum of social and environmental criteria weights is at least 66%. Not otherwise.
- The general movement of PAs into and out of the top tier seems to be between Roaches Run PAs and Doctor's Branch PAs as we move from high economic to low economic and high social criteria weights.

# Appendix G
# Public Facilities Results

## Table G-1. Cumulative Risk for All Facilities at Building/Location Level

| Facility and Building | Total Number of Ass | Asset Replacen | Total Cumulative Risk |
|---|---|---|---|
| ART - BUS PARKING LOT | 59 | $ 39,825,000 | $ 265 |
| ART - O&M CENTER | 21 | $ 385,304 | $ - |
| ART - PARKING STRUCTURE | 7 | $ 29,178 | $ - |
| CARDINAL ELEMENTARY SCHOOL | 73 | $ 2,427,454 | $ - |
| CARDINAL ELEMENTARY SCHOOL - EG | 1 | $ 278,193 | $ - |
| CARDINAL ELEMENTARY SCHOOL - PARKING | 20 | $ 450,000 | $ 323 |
| CHERRYDALE - GENERATOR ROOM | 4 | $ 344,983 | $ - |
| CHERRYDALE HEALTH & REHAB CENTER | 64 | $ 2,997,647 | $ 1,563 |
| GUNSTON - DETACHED MECHANICAL ROOM | 23 | $ 1,417,591 | $ - |
| GUNSTON - SCHOOL & EG | 106 | $ 2,001,866 | $ 75,641 |
| LITTLE FALLS BOOSTER STATION | 30 | $ 3,532,463 | $ 126,726 |
| TJ MIDDLE SCHOOL - SITE EG | 3 | $ 950,435 | $ - |
| TJ MIDDLE SCHOOL AND COMMUNITY CENTER | 89 | $ 7,773,764 | $ 2,281,718 |
| TRADESCENTER-NOCII | 100 | $ 1,684,065 | $ - |
| TRADESCENTER-NOCII-SITEEG | 1 | $ 871,242 | $ - |
| TRADESCENTER-NOCII-SITETRANSFORMER | 1 | $ 344,559 | $ - |
| VA HOSPITAL CENTER - FOOT AND ANKLE BLDG | 7 | $ 2,149,189 | $ 8,754,269 |
| VA HOSPITAL CENTER - MAIN MECHANICAL BLDG | 43 | $ 16,075,270 | $ 139,351 |
| VA HOSPITAL CENTER - NEW PARKING STRUCTURE | 18 | $ 1,657,902 | $ 1,506,618 |
| WPCP - 03 - PIBS/PBFDS | 8 | $ 654,378 | $ 3,733 |
| WPCP - 04 - DAFT | 39 | $ 4,563,590 | $ 2,984 |
| WPCP - 05 - PGTB | 22 | $ 1,414,619 | $ 3,517 |
| WPCP - 06 - SST | 29 | $ 3,919,785 | $ 51,049 |
| WPCP - 09 - PTB | 50 | $ 4,783,239 | $ 128,953 |
| WPCP - 10 - PCL | 22 | $ 1,036,101 | $ 206,223 |
| WPCP - 11 - FET - 1AND2 | 7 | $ 465,577 | $ 1,411,720 |
| WPCP - 11 - FET - 3 | 6 | $ 463,947 | $ 1,597,873 |
| WPCP - 12 - OCB | 34 | $ 1,574,653 | $ 946,848 |
| WPCP - 13 - SBB - LL | 78 | $ 7,336,628 | $ 1,569,855 |
| WPCP - 13 - SBB - TRANSFORMER | 2 | $ 102,432 | $ 60,332 |
| WPCP - 13 - SBB - UL | 6 | $ 3,140,576 | $ 436,544 |
| WPCP - 14 - SAT - HEL | 36 | $ 1,968,464 | $ 1,124,992 |
| WPCP - 14 - SAT - LEL | 36 | $ 1,968,464 | $ 2,654,585 |
| WPCP - 15 - SC-1TO6 | 30 | $ 1,715,476 | $ 1,826,038 |
| WPCP - 15 - SC-7TO9 | 18 | $ 390,897 | $ 208,640 |
| WPCP - 16 - SPSB | 41 | $ 7,839,003 | $ 3,421,615 |
| WPCP - 17 - WSPSB | 51 | $ 6,318,344 | $ 3,687,304 |
| WPCP - 17 - WSPSB - OUTSIDE | 7 | $ 1,558,425 | $ 567,452 |
| WPCP - 18 - WMLFDS | 2 | $ 81,603 | $ 67,883 |
| WPCP - 19 - WWFF | 19 | $ 6,836,459 | $ 840,645 |
| WPCP - 20 - FADF | 71 | $ 6,725,516 | $ 800,420 |
| WPCP - 21 - ABWB | 3 | $ 85,882 | $ 20,331 |
| WPCP - 22 - PEWF | 9 | $ 4,644,123 | $ 1,006 |
| WPCP - 24 - PAF | 56 | $ 6,702,776 | $ 52,972 |
| WPCP - 24 - PAF - TRANSFORMER | 1 | $ 712,664 | $ 56,234 |
| WPCP - 25 - MFF | 50 | $ 2,693,147 | $ 74,657 |
| WPCP - 26 - NFF | 56 | $ 3,409,354 | $ 3,026,811 |
| WPCP - 27 - SFF | 8 | $ 331,673 | $ 372,433 |
| WPCP - 28 - DC3 | 11 | $ 2,910,634 | $ 1,096,488 |
| WPCP - 28 - DC5 | 9 | $ 2,288,014 | $ 293,709 |
| WPCP - 28 - DC5 - TRANSFORMER | 2 | $ 1,425,327 | $ 104,520 |
| WPCP - 29 - SGF | 73 | $ 6,524,629 | $ 5,166,916 |
| WPCP - 30 - PEF | 1 | $ 40,986 | $ 105,657 |
| WPCP - 32 - EMLFDS | 4 | $ 78,287 | $ 29,452 |
| WPCP - 33 - FCPS | 30 | $ 3,282,802 | $ 3,727,495 |
| WPCP - 34 - SWPS | 22 | $ 2,822,317 | $ 7,228,901 |
| WPCP - 35 - SHF | 41 | $ 3,342,112 | $ 1,706,278 |
| WPCP - 35 - SHF - FILLSTATION | 3 | $ 199,198 | $ 10,347 |
| WPCP - 37 - ASE1 | 9 | $ 1,704,903 | $ 28,523 |
| WPCP - 37 - ASE1 - OUTSIDE | 6 | $ 897,058 | $ 1,033,138 |
| WPCP - 38 - ASE2 | 14 | $ 6,163,971 | $ 313,970 |
| WPCP - 39 - WFF | 9 | $ 337,300 | $ 44,070 |
| WPCP - 39 - WFF - OUTSIDE | 2 | $ 121,874 | $ 12,517 |
| WPCP - 40 - FEPS | 8 | $ 2,553,406 | $ 671,453 |
| WPCP - 40 - FEPS - GROUND | 2 | $ 3,261 | $ 1,581 |
| WPCP - 40 - FEPS - PCL | 24 | $ 2,349,163 | $ 431,550 |
| WPCP - 43 - LLPS | 1 | $ 77,324 | $ 291,507 |
| WPCP - 44 - SATPG | 35 | $ 1,742,841 | $ 2,228,830 |
| WPCP - FA | 1 | $ 77,324 | $ 181,185 |
| WPCP - SECURITY GATES | 14 | $ 1,082,542 | $ 3,990,536 |
| **Grand Total** | **1788** | **$ 208,659,174** | **$ 66,808,745** |

Table G-2. Asset Replacement Costs for Facilities Visited

| Form AssetID | Facility | Facility Type | Site Asset | Quantity | Capacity | Unit Replacement Cost ($) |
|---|---|---|---|---|---|---|
| 1 | ART - O&M CENTER | O&M Center | Switchgear | 1 | 2000 amp | $ 112,437.0 |
| 2 | ART - O&M CENTER | O&M Center | Transformer | 1 | 1600 kva | $ 51,216.0 |
| 3 | ART - O&M CENTER | O&M Center | Air compresor | 1 | 20hp, 250 gal | $ 72,888.4 |
| 4 | ART - O&M CENTER | O&M Center | Hydraulic press | 1 | 50 ton | $ 12,500.0 |
| 5 | ART - O&M CENTER | O&M Center | Panel Board | 1 | 100 amp, 120/208Vac, 3Ph | $ 2,934.5 |
| 6 | ART - O&M CENTER | O&M Center | Panel Board | 2 | 200 amp, 277/480Vac, 3Ph | $ 2,622.0 |
| 7 | ART - O&M CENTER | O&M Center | Panel Board | 3 | 600 amp, 277/480Vac, 3Ph | $ 6,129.6 |
| 8 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 1 | 200 cfm | $ 1,290.0 |
| 9 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 1 | 500 cfm | $ 1,480.0 |
| 10 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 2 | 250 cfm | $ 1,290.0 |
| 11 | ART - O&M CENTER | O&M Center | El. Unit Heatter | 1 | 400 cfm | $ 1,396.0 |
| 12 | ART - O&M CENTER | O&M Center | Blower | 1 | 2200 cfm | $ 771.0 |
| 13 | ART - O&M CENTER | O&M Center | Boilers | 4 | 426 mbh | $ 24,737.0 |
| 14 | ART - O&M CENTER | O&M Center | AC unit | 1 | 400 cfm | $ 3,230.0 |
| 15 | ART - PARKING STRUCTURE | Parking Structure | Transformer | 1 | 75 kva, 480-120/208Vac | $ 8,494.6 |
| 16 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 1 | 100 amp, 120/208Vac, 3Ph | $ 2,934.5 |
| 17 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 1 | 100 amp, 120/208Vac, 3Ph | $ 2,934.5 |
| 18 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 2 | 600 amp, 277/480Vac, 3Ph | $ 6,129.6 |
| 19 | ART - PARKING STRUCTURE | Parking Structure | El Unit Heater | 1 | 400 cfm | $ 1,396.0 |
| 20 | ART - PARKING STRUCTURE | Parking Structure | Fan | 1 | 200 cfm | $ 1,159.0 |
| 21 | ART - BUS PARKING LOT | Bus Parking Lot | Busses | 59 | | $ 675,000.0 |
| 22 | CARDINAL ELEMENTARY SCHOOL | School | BAS Controls | 2 | | $ 3,900.0 |
| 23 | CARDINAL ELEMENTARY SCHOOL | School | Water Source Heat Pump | 6 | 0.75 HP | $ 40,567.8 |
| 24 | CARDINAL ELEMENTARY SCHOOL | School | Panel Boards | 3 | | $ 2,934.5 |
| 25 | CARDINAL ELEMENTARY SCHOOL | School | Sump Pump Control Panel | 1 | | $ 2,500.0 |
| 26 | CARDINAL ELEMENTARY SCHOOL | School | Router/Modem | 1 | | $ 2,250.0 |
| 27 | CARDINAL ELEMENTARY SCHOOL | School | Heatstack Water Heaters | 2 | 5 kA (254 MBH) | $ 20,669.2 |
| 28 | CARDINAL ELEMENTARY SCHOOL | School | Modular Chiller System Assembly | 1 | | $ 29,304.0 |
| 29 | CARDINAL ELEMENTARY SCHOOL | School | Pump | 4 | 15 HP | $ 170,683.4 |
| 30 | CARDINAL ELEMENTARY SCHOOL | School | Pump controls | 4 | | $ 10,581.4 |
| 31 | CARDINAL ELEMENTARY SCHOOL | School | Super Changer (Heat Exchanger) | 1 | Assuming 150 PSIG | $ 3,500.0 |
| 32 | CARDINAL ELEMENTARY SCHOOL | School | Geothermal system panel | 1 | | $ 9,128.7 |
| 33 | CARDINAL ELEMENTARY SCHOOL | School | Water circulating pump | 1 | 400-460Vac, 4A; 175 psi | $ 6,500.0 |
| 34 | CARDINAL ELEMENTARY SCHOOL | School | Condensing unit | 3 | 208-230 volts; assuming 8 ton | $ 4,620.0 |
| 35 | CARDINAL ELEMENTARY SCHOOL | School | Outside air unit panel | 1 | | $ 77,324.4 |
| 36 | CARDINAL ELEMENTARY SCHOOL | School | Control panel - Makeup air unit kitch | 2 | | $ 77,324.4 |
| 37 | CARDINAL ELEMENTARY SCHOOL | School | HVAC Drives | 2 | 3 HP | $ 7,237.1 |
| 38 | CARDINAL ELEMENTARY SCHOOL | School | Water Source Heat Pump | 1 | 0.5 HP | $ 40,567.8 |
| 39 | CARDINAL ELEMENTARY SCHOOL | School | Water Source Heat Pump | 1 | 0.75 HP | $ 40,567.8 |
| 40 | CARDINAL ELEMENTARY SCHOOL | School | Router/Modem | 1 | | $ 2,250.0 |
| 41 | CARDINAL ELEMENTARY SCHOOL | School | Transfer switch | 2 | | $ 4,777.0 |
| 42 | CARDINAL ELEMENTARY SCHOOL | School | Panel Boards | 5 | | $ 4,278.9 |
| 43 | CARDINAL ELEMENTARY SCHOOL | School | Panel Boards | 2 | | $ 6,394.7 |
| 44 | CARDINAL ELEMENTARY SCHOOL | School | Advanced metering data acquisition | 1 | | $ 9,128.7 |
| 45 | CARDINAL ELEMENTARY SCHOOL | School | Comba critical point | 1 | | $ 9,128.7 |
| 46 | CARDINAL ELEMENTARY SCHOOL | School | Main service distribution MDP Switch | 1 | 277/480 Vac, 800 Amps | $ 14,109.3 |
| 47 | CARDINAL ELEMENTARY SCHOOL | School | Heavy duty safety switch | 1 | 600 amps, 600Vac, NEMA1 | $ 4,590.5 |
| 48 | CARDINAL ELEMENTARY SCHOOL | School | Transformer | 1 | 150 kVA, 480-120/208Vac | $ 13,571.1 |
| 49 | CARDINAL ELEMENTARY SCHOOL | School | Electrical cabinet (not pictured) | 3 | | $ 77,324.4 |
| 50 | CARDINAL ELEMENTARY SCHOOL | School | Panel Boards | 2 | | $ 4,278.9 |
| 51 | CARDINAL ELEMENTARY SCHOOL | School | Meters | 3 | | $ 105,064.2 |
| 52 | CARDINAL ELEMENTARY SCHOOL | School | Transformer | 2 | 30 kVA, 480-120/208 Vac | $ 9,546.2 |
| 53 | CARDINAL ELEMENTARY SCHOOL | School | Water Source Heat Pump | 2 | 0.5 HP | $ 40,567.8 |
| 54 | CARDINAL ELEMENTARY SCHOOL | School | BAS Controls | 3 | | $ 3,900.0 |
| 55 | CARDINAL ELEMENTARY SCHOOL | School | Water Source Heat Pump | 2 | 0.5 HP | $ 40,567.8 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 56 | CARDINAL ELEMENTARY SCHOOL | School | HD Safety Switch (Elevator) | 1 | 200Amps, 600Vac, NEMA1 | $ | 1,292.6 |
| 57 | CARDINAL ELEMENTARY SCHOOL | School | Elevator Control Panel | 1 | | $ | 77,324.4 |
| 58 | CARDINAL ELEMENTARY SCHOOL | School | AC unit | 1 | | $ | 2,000.0 |
| 59 | CARDINAL ELEMENTARY SCHOOL | School | GYM | 1 | | $ | 80,500.0 |
| 60 | CARDINAL ELEMENTARY SCHOOL - EG | Emergency Generator | Generator | 1 | Assuming 1000 kva | $ | 278,192.5 |
| 61 | CARDINAL ELEMENTARY SCHOOL - PARKING | Parking Lot | Car | 10 | | $ | 20,000.0 |
| 62 | CARDINAL ELEMENTARY SCHOOL - PARKING | Parking Lot | Lt Trk | 10 | | $ | 25,000.0 |
| 63 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Communication network | 1 | | $ | 3,968.0 |
| 64 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Ethernet box | 1 | | $ | 342.0 |
| 65 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Ethernet Switch | 1 | | $ | 350.0 |
| 66 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Security control panel | 3 | | $ | 4,621.0 |
| 67 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Communication network Rack (floor | 1 | | $ | 10,263.0 |
| 68 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Water Heater | 1 | | $ | 2,204.7 |
| 69 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Water Heater Motors | 2 | 0.17 HP | $ | 1,379.0 |
| 70 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Domestic Potable Water Booster Pur | 2 | 10 Hp | $ | 170,683.0 |
| 71 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Domestic Potable water booster pun | 1 | | $ | 77,324.4 |
| 72 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | HVAC System (blower motor) | 2 | 1.5 Hp | $ | 4,881.0 |
| 73 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Heat Exchanger | 2 | 150 PSIG | $ | 3,500.0 |
| 74 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Cooling Tower Pumps and Motors | 2 | 2 Hp | $ | 40,568.0 |
| 75 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Condensation Pumps and Motors | 2 | 25 Hp | $ | 170,683.0 |
| 76 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Cooling Tower Controls | 1 | | $ | 77,324.4 |
| 77 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Utility Meter | 1 | | $ | 1,267.3 |
| 78 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Boilers | 2 | 100 HP (~254 MBH) | $ | 12,575.0 |
| 79 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Boiler Fuel Motor | 2 | 3 Hp (Burner Blower Motor) | $ | 5,250.0 |
| 80 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Switchgear | 1 | | $ | 950,000.0 |
| 81 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Disconnect Switch | 4 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |
| 82 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Disconnect Switch | 1 | 1200A, 600Vac, Nonfused, NEMA1 | $ | 7,648.9 |
| 83 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Automatic Transfer Switch | 1 | 1,200 Amps, 480Vac, 3P, ATS | $ | 30,573.5 |
| 84 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Fire Control Pump and Motor | 1 | 60 Hp | $ | 248,760.0 |
| 85 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Fire Control Panel | 1 | | $ | 4,621.0 |
| 86 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Disconnect Switch | 1 | 800A, 600Vac, Nonfused, NEMA1 | $ | 5,677.0 |
| 87 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Discharge water motor | 1 | 1.5 Hp | $ | 8,746.8 |
| 88 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Discharge water motor controller | 1 | | $ | 77,324.4 |
| 89 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Disconnect Switch | 1 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |
| 90 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Fire Alarm Control Panel | 2 | | $ | 4,621.0 |
| 91 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Fire Alarm Panel Batteries | 1 | | $ | 1,700.0 |
| 92 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 2 | Panelboards, 3 phase 4 wire, main lu | $ | 4,278.9 |
| 93 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Industrial Hot water Tank Sensor | 1 | | $ | 40,986.0 |
| 94 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Steam Condensate/Make-up Water | 2 | 1.5 Hp | $ | 4,881.0 |
| 95 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Steam Condesate/make-up pump c | 1 | | $ | 77,324.4 |
| 96 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 2 | | $ | 5,269.0 |
| 97 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 1 | | $ | 4,278.9 |
| 98 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 2 | | $ | 4,278.9 |
| 99 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Communication network | 2 | | $ | 2,737.0 |
| 100 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 2 | | $ | 5,269.0 |
| 101 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Panelboards | 2 | | $ | 4,278.9 |
| 102 | CHERRYDALE HEALTH & REHAB CENTER | Cooling Towers | Cooling Tower | 1 | tonnage? Typically $120-$200 per To | $ | 30,000.0 |
| 103 | CHERRYDALE HEALTH & REHAB CENTER | Cooling Towers | Cooling Tower Breaker Panel Board | 1 | | $ | 7,278.0 |
| 104 | CHERRYDALE HEALTH & REHAB CENTER | Cooling Towers | Transformer | 1 | 500 kVa | $ | 344,559.3 |
| 105 | CHERRYDALE HEALTH & REHAB CENTER | Cooling Towers | Cooling Tower Control Panel | 1 | | $ | 77,324.4 |
| 106 | CHERRYDALE - GENERATOR ROOM | Emergency Generator | Diesel Engine Generator | 1 | 300 kVa | $ | 342,866.3 |
| 107 | CHERRYDALE - GENERATOR ROOM | Emergency Generator | Fuel motor | 1 | 0.33 hP | $ | 1,116.6 |
| 108 | CHERRYDALE - GENERATOR ROOM | Emergency Generator | Generator Batteries | 2 | | $ | 500.0 |
| 109 | GUNSTON - SCHOOL & EG | School | Panelboards | 4 | | $ | 2,934.5 |
| 110 | GUNSTON - SCHOOL & EG | School | Nac Extender | 1 | | $ | 2,052.6 |
| 111 | GUNSTON - SCHOOL & EG | School | Panelboards | 4 | | $ | 11,976.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 112 | GUNSTON - SCHOOL & EG | School | Panelboards | 3 | | $ 2,934.5 |
| 113 | GUNSTON - SCHOOL & EG | School | Switchboard | 2 | | $ 27,701.9 |
| 114 | GUNSTON - SCHOOL & EG | School | Patch panel | 1 | | $ 4,278.9 |
| 115 | GUNSTON - SCHOOL & EG | School | Nac Extender | 2 | | $ 2,052.6 |
| 116 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 2,765.1 |
| 117 | GUNSTON - SCHOOL & EG | School | Panelboards | 2 | | $ 6,394.7 |
| 118 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 10,371.0 |
| 119 | GUNSTON - SCHOOL & EG | School | Elevator Controller | 1 | | $ 77,324.4 |
| 120 | GUNSTON - SCHOOL & EG | School | AC Unit | 1 | | $ 3,785.0 |
| 121 | GUNSTON - SCHOOL & EG | School | Panelboards | 2 | | $ 2,765.1 |
| 122 | GUNSTON - SCHOOL & EG | School | Electrical Panel | 1 | | $ 4,278.9 |
| 123 | GUNSTON - SCHOOL & EG | School | Nac Extender | 1 | | $ 2,052.6 |
| 124 | GUNSTON - SCHOOL & EG | School | Sump pump control panel | 1 | | $ 2,737.0 |
| 125 | GUNSTON - SCHOOL & EG | School | Boiler Pumps | 2 | 25 HP | $ 170,683.4 |
| 126 | GUNSTON - SCHOOL & EG | School | Boiler pump VFDs | 2 | 25HP, 460Vac | $ 12,572.8 |
| 127 | GUNSTON - SCHOOL & EG | School | Tank Motor (Domestic Hot Water Re | 1 | 1.75 HP | $ 5,363.0 |
| 128 | GUNSTON - SCHOOL & EG | School | ALC Controls | 6 | | $ 2,736.8 |
| 129 | GUNSTON - SCHOOL & EG | School | ALC Controls (fiber optic) | 1 | | $ 3,968.3 |
| 130 | GUNSTON - SCHOOL & EG | School | Switchboard | 1 | | $ 20,376.6 |
| 131 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 2,765.1 |
| 132 | GUNSTON - SCHOOL & EG | School | HVAC Pump drives VFD | 2 | | $ 7,324.1 |
| 133 | GUNSTON - SCHOOL & EG | School | Boilers | 5 | 88 MAWP | $ 37,950.0 |
| 134 | GUNSTON - SCHOOL & EG | School | VFD for chimney fan | 1 | | $ 14,099.3 |
| 135 | GUNSTON - SCHOOL & EG | School | Natural gas water heater | 2 | 160 psi | $ 7,521.0 |
| 136 | GUNSTON - SCHOOL & EG | School | Hot water circulation pump | 2 | 0.08 HP | $ 40,567.8 |
| 137 | GUNSTON - SCHOOL & EG | School | Remote control switch panel | 1 | | $ 4,278.9 |
| 138 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 2,765.1 |
| 139 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 4,278.9 |
| 140 | GUNSTON - SCHOOL & EG | School | Utility meter | 1 | | $ 1,070.0 |
| 141 | GUNSTON - SCHOOL & EG | School | Switchboard | 1 | | $ 350,000.0 |
| 142 | GUNSTON - SCHOOL & EG | School | ATS | 1 | | $ 4,777.0 |
| 143 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 2,765.1 |
| 144 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 11,976.0 |
| 145 | GUNSTON - SCHOOL & EG | School | Electrical panels | 2 | | $ 4,278.9 |
| 146 | GUNSTON - SCHOOL & EG | School | ALC Controls | 2 | | $ 4,278.9 |
| 147 | GUNSTON - SCHOOL & EG | School | Nac Extender | 4 | | $ 2,052.6 |
| 148 | GUNSTON - SCHOOL & EG | School | Fire Safety Operator interface panel | 1 | | $ 9,128.7 |
| 149 | GUNSTON - SCHOOL & EG | School | Disconnect Switch | 3 | 30 Amps | $ 321.0 |
| 150 | GUNSTON - SCHOOL & EG | School | Heavy duty safety switch | 1 | 1200 Amps | $ 11,010.0 |
| 151 | GUNSTON - SCHOOL & EG | School | Security control panel | 1 | | $ 9,128.7 |
| 152 | GUNSTON - SCHOOL & EG | School | Security panel | 2 | | $ 9,128.7 |
| 153 | GUNSTON - SCHOOL & EG | School | Ethernet box | 2 | | $ 342.1 |
| 154 | GUNSTON - SCHOOL & EG | School | AC Unit | 1 | | $ 3,785.0 |
| 155 | GUNSTON - SCHOOL & EG | School | Communications Network | 1 | | $ 3,968.3 |
| 156 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 2,934.5 |
| 157 | GUNSTON - SCHOOL & EG | School | Panelboards | 1 | | $ 17,777.4 |
| 158 | GUNSTON - SCHOOL & EG | School | Transformer | 1 | 30 kva | $ 9,546.2 |
| 159 | GUNSTON - SCHOOL & EG | School | Breaker cabinet (Switchboard) | 1 | | $ 27,701.9 |
| 160 | GUNSTON - SCHOOL & EG | School | Switchboard | 2 | | $ 150,000.0 |
| 161 | GUNSTON - SCHOOL & EG | School | Ethernet box | 1 | | $ 342.1 |
| 162 | GUNSTON - SCHOOL & EG | School | Communications Network | 1 | | $ 3,968.3 |
| 163 | GUNSTON - SCHOOL & EG | School | Sump pump control panel | 1 | | $ 7,500.0 |
| 164 | GUNSTON - SCHOOL & EG | School | Panelboards | 4 | | $ 4,278.9 |
| 165 | GUNSTON - SCHOOL & EG | School | Panelboards | 3 | | $ 4,278.9 |
| 166 | GUNSTON - SCHOOL & EG | School | Building power phase monitor | 1 | | $ 1,500.0 |
| 167 | GUNSTON - SCHOOL & EG | School | Switchboard | 1 | | $ 46,989.5 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 168 | GUNSTON - SCHOOL & EG | School | Nac Extender | 2 | | $ | 2,052.6 |
| 169 | GUNSTON - SCHOOL & EG | School | Panelboards | 3 | | $ | 2,765.1 |
| 170 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling Tower | 2 | tonnage? Typically $120-$200 per Te | $ | 30,000.0 |
| 171 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Condensor Panel | 2 | | $ | 77,324.4 |
| 172 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Chill water pumps | 2 | 125 HP | $ | 273,357.6 |
| 173 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Chill water variable speed drive | 2 | | $ | 40,094.1 |
| 174 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling Tower Pumps | 2 | 30 HP | $ | 170,683.4 |
| 175 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling tower pumps variable speed | 2 | | $ | 14,079.5 |
| 176 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Pressure gauge | 1 | | $ | 40,986.0 |
| 177 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Flow monitor | 1 | | $ | 40,986.0 |
| 178 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Pump for ozone generator | 1 | 5 HP | $ | 7,590.0 |
| 179 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling tower pump (for water treat | 1 | 2 Hp | $ | 40,567.8 |
| 180 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | ALC Controls | 2 | | $ | 4,278.9 |
| 181 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | HVAC Drive | 2 | | $ | 15,000.0 |
| 182 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Panelboards | 1 | | $ | 24,000.0 |
| 183 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Transformer | 1 | 30 kva | $ | 9,546.2 |
| 184 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Panelboards | 1 | | $ | 4,278.9 |
| 185 | GUNSTON - SCHOOL & EG | Emergency Generator | Generator | 1 | | $ | 91,091.2 |
| 186 | LITTLE FALLS BOOSTER STATION | Booster Station | PLC-RTU | 1 | | $ | 31,106.4 |
| 187 | LITTLE FALLS BOOSTER STATION | Booster Station | Battery | 12 | | $ | 304.1 |
| 188 | LITTLE FALLS BOOSTER STATION | Booster Station | Battery Charger | 1 | | $ | 3,500.0 |
| 189 | LITTLE FALLS BOOSTER STATION | Booster Station | SCADA Panel | 1 | | $ | 35,000.0 |
| 190 | LITTLE FALLS BOOSTER STATION | Booster Station | VFD | 2 | 460 volts | $ | 151,335.2 |
| 191 | LITTLE FALLS BOOSTER STATION | Booster Station | Pump Control Disconnect | 2 | 480 volts/600 amps | $ | 20,167.0 |
| 192 | LITTLE FALLS BOOSTER STATION | Booster Station | Fan and Motor | 1 | 1.5 hp | $ | 21,207.2 |
| 193 | LITTLE FALLS BOOSTER STATION | Booster Station | Motor Control Center | 1 | 480 volts | $ | 1,520,723.1 |
| 194 | LITTLE FALLS BOOSTER STATION | Booster Station | Utility Charger (Battery Charger) | 1 | 120 volts | $ | 5,500.0 |
| 195 | LITTLE FALLS BOOSTER STATION | Booster Station | Utility Meter | 1 | | $ | 1,267.3 |
| 196 | LITTLE FALLS BOOSTER STATION | Booster Station | High Service Pump | 2 | 150 hp | $ | 760,498.4 |
| 197 | LITTLE FALLS BOOSTER STATION | Booster Station | Fan and Motor | 1 | 3 hp | $ | 4,458.0 |
| 198 | LITTLE FALLS BOOSTER STATION | Booster Station | Fan and Motor | 1 | 3 hp | $ | 4,458.0 |
| 199 | LITTLE FALLS BOOSTER STATION | Booster Station | Chlorine Analyser | 1 | 120 VAC | $ | 24,212.0 |
| 200 | LITTLE FALLS BOOSTER STATION | Booster Station | Disconnect Switch | 2 | 600Vac, | $ | 6,690.0 |
| 201 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Panelboards | 4 | | $ | 2,934.5 |
| 202 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Transformer | 1 | 30 kVa | $ | 9,546.2 |
| 203 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Computing Device | 1 | | $ | 2,736.8 |
| 204 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Nac Extender | 1 | | $ | 2,052.6 |
| 205 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker | 1 | | $ | 2,765.1 |
| 206 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Telecom board | 1 | | $ | 3,968.3 |
| 207 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Panelboard (Switchboard) | 1 | | $ | 300,000.0 |
| 208 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Sensor Dimming System | 3 | | $ | 10,262.9 |
| 209 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Transformer | 1 | 300 kVa | $ | 56,667.0 |
| 210 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Nac Extender | 2 | | $ | 2,052.6 |
| 211 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | AHU Control Panel | 1 | | $ | 3,000.0 |
| 212 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Air Handling unit | 1 | Assuming product 1,800 to 15,000 cf | $ | 318,370.7 |
| 213 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | AHU Control Panel | 1 | | $ | 5,000.0 |
| 214 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | AHU Control Panel | 1 | | $ | 5,000.0 |
| 215 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | AHU Control Panel | 1 | | $ | 5,000.0 |
| 216 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Air Handling unit | 1 | Assuming product 1,800 to 15,000 cf | $ | 318,370.7 |
| 217 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breakers | 2 | | $ | 4,278.9 |
| 218 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker | 1 | | $ | 4,278.9 |
| 219 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Security Fire Panel | 1 | | $ | 9,128.7 |
| 220 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Panelboard (Switchboard) | 6 | | $ | 800,000.0 |
| 221 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Signal Generator Output Disc. Switc | 1 | 100A | $ | 641.6 |
| 222 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Electrical Cabinet | 1 | | $ | 4,278.9 |
| 223 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Electrical equipment | 3 | | $ | 4,278.9 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | |
|---|---|---|---|---|---|---|
| 224 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Utility meter | 1 | | $ 5,000.0 |
| 225 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Fire Panel | 1 | | $ 9,128.7 |
| 226 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Cooling Tower Fan Controls | 2 | | $ 16,000.0 |
| 227 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | HWS Pumps and motors | 4 | 1775 RPM | $ 4,850.0 |
| 228 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Boilers | 5 | | $ 37,950.0 |
| 229 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Cooling water pumps | 4 | 1750 Rpm | $ 4,775.0 |
| 230 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | MCC | 1 | | $ 92,443.5 |
| 231 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | VFDs | 2 | Assuming 30 hp | $ 12,572.0 |
| 232 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Condensation pumps | 2 | 1260 gpm | $ 6,682.5 |
| 233 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Chiller 1 | 1 | 225 mawp | $ 165,550.0 |
| 234 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Chiller 2 | 1 | 200 mawp | $ 165,550.0 |
| 235 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Transformer | 1 | 45 kva | $ 12,168.7 |
| 236 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker | 1 | | $ 8,418.5 |
| 237 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Hot water control panel | 1 | | $ 18,000.0 |
| 238 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Air Handling unit | 1 | | $ 230,750.0 |
| 239 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Air Handling unit | 1 | | $ 230,750.0 |
| 240 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker (small) | 2 | | $ 4,278.9 |
| 241 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker (large) | 2 | | $ 5,268.6 |
| 242 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Fuse boxes (Disc. Switch) | 2 | | $ 642.0 |
| 243 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Panelboards | 1 | | $ 2,934.5 |
| 244 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Panelboards | 1 | | $ 2,934.5 |
| 245 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Light control panel | 1 | | $ 3,500.0 |
| 246 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Master control panel | 1 | | $ 6,000.0 |
| 247 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Transformer | 1 | Assuming 75 kva | $ 8,495.0 |
| 248 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Swichboard | 1 | | $ 300,000.0 |
| 249 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker | 2 | | $ 4,278.9 |
| 250 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Finned-Tube Terminal Radiator | 5 | | $ 6,250.0 |
| 251 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Swichboard | 1 | | $ 220,000.0 |
| 252 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Breaker | 2 | | $ 2,934.5 |
| 253 | TJ MIDDLE SCHOOL AND COMMUNITY CENT | School and Community Center | Transformer | 1 | Assuming 75 kva | $ 8,495.0 |
| 254 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | Diesel Engine Generator | 1 | Assuming 1000 kva | $ 278,192.5 |
| 255 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | ATS | 1 | 1,200 Amps | $ 60,000.0 |
| 256 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | Transformer | 1 | 2000 kva | $ 612,242.9 |
| 257 | TRADESCENTER-NOCII | Network Operations Center | Circuit Breaker | 4 | | $ 6,395.0 |
| 258 | TRADESCENTER-NOCII | Network Operations Center | Transformer | 1 | 30 kVa | $ 9,546.2 |
| 259 | TRADESCENTER-NOCII | Network Operations Center | Air Handling Unit | 2 | | $ 122,711.3 |
| 260 | TRADESCENTER-NOCII | Network Operations Center | ATS | 1 | | $ 49,142.0 |
| 261 | TRADESCENTER-NOCII | Network Operations Center | Switchboard | 1 | 400 amps | $ 21,048.1 |
| 262 | TRADESCENTER-NOCII | Network Operations Center | Power Supply Cabinet | 6 | | $ 10,262.9 |
| 263 | TRADESCENTER-NOCII | Network Operations Center | Fire Alarm Panel | 1 | | $ 4,621.2 |
| 264 | TRADESCENTER-NOCII | Network Operations Center | Power Monitoring System | 2 | | $ 10,262.9 |
| 265 | TRADESCENTER-NOCII | Network Operations Center | Air Handling Unit | 6 | | $ 154,072.5 |
| 266 | TRADESCENTER-NOCII | Network Operations Center | Data/Comm Panels | 2 | | $ 3,968.3 |
| 267 | TRADESCENTER-NOCII | Network Operations Center | Leak Alert System | 1 | | $ 2,736.8 |
| 268 | TRADESCENTER-NOCII | Network Operations Center | Heavy Duty Safety Switch | 1 | 1200 amps, 600 VAC | $ 25,776.3 |
| 269 | TRADESCENTER-NOCII | Network Operations Center | Server Cabinets | 72 | | $ 3,968.3 |
| 270 | TRADESCENTER-NOCII-SITETRANSFORMER | Outside Transformer | Transformer | 1 | 500 kVa | $ 344,559.3 |
| 271 | TRADESCENTER-NOCII-SITEEG | Outside Emergency Generator | Diesel Engine Generator | 1 | 750 kVa | $ 871,242.1 |
| 272 | VAHOSPITAL CENTER - FOOT AND ANKLE BLD | Foot and Ankle Bldg | cooling and heating pumps | 3 | 20 HP | $ 170,683.4 |
| 273 | VAHOSPITAL CENTER - FOOT AND ANKLE BLD | Foot and Ankle Bldg | Heat Exchange | 1 | | $ 34,581.0 |
| 274 | VAHOSPITAL CENTER - FOOT AND ANKLE BLD | Foot and Ankle Bldg | Water Filtration system Control Pane | 1 | | $ 77,324.4 |
| 275 | VAHOSPITAL CENTER - FOOT AND ANKLE BLD | Foot and Ankle Bldg | Electric Water Heater | 1 | 120 Gallons | $ 4,510.0 |
| 276 | VAHOSPITAL CENTER - FOOT AND ANKLE BLD | Foot and Ankle Bldg | MCC | 1 | | $ 1,520,723.1 |
| 277 | VAHOSPITAL CENTER - MAIN MECHANICAL BI | Main Mechanical Bldg | Generator | 1 | 750 kVA | $ 871,242.1 |
| 278 | VAHOSPITAL CENTER - MAIN MECHANICAL BI | Main Mechanical Bldg | Transformer | 1 | 45 kVA | $ 12,168.7 |
| 279 | VAHOSPITAL CENTER - MAIN MECHANICAL BI | Main Mechanical Bldg | Pumps | 3 | 20 HP | $ 170,683.4 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 280 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Boiler (Version 1) | 1 | 20 HP | $ | 120,351.0 |
| 281 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Boiler (Version 2) | 2 | 20 HP | $ | 120,351.0 |
| 282 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | MCC | 2 | | $ | 2,027,630.8 |
| 283 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | MCC | 1 | | $ | 2,027,630.8 |
| 284 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Transformer | 2 | 30 kVA | $ | 9,546.2 |
| 285 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Transformer | 1 | 75 kVA | $ | 8,495.0 |
| 286 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Condensor Return System | 3 | 3 HP | $ | 5,830.0 |
| 287 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Air Compressor Unit | 1 | 25 HP | $ | 72,888.4 |
| 288 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Air Compressor Unit | 1 | 25 HP | $ | 72,888.4 |
| 289 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | MCC | 1 | | $ | 2,027,630.8 |
| 290 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | ACH580-01 drives | 2 | | $ | 51,652.0 |
| 291 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Secondary Chiller Pumps | 2 | 200 HP | $ | 472,341.7 |
| 292 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | VFD | 2 | | $ | 67,476.2 |
| 293 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Primary Chiller Pumps | 6 | 40 HP | $ | 170,683.4 |
| 294 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Water Filtration System | 3 | | $ | 845,000.0 |
| 295 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Chiller (Version 1) | 1 | 500 HP | $ | 165,550.0 |
| 296 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Chiller (Version 2) | 2 | 750 HP | $ | 165,550.0 |
| 297 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Control Panels | 1 | | $ | 77,324.4 |
| 298 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Condensor Water Pump Panel | 2 | | $ | 77,324.4 |
| 299 | VAHOSPITAL CENTER - MAIN MECHANICAL BU | Main Mechanical Bldg | Simens Control Panel | 2 | | $ | 273,357.6 |
| 300 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Garage Fan System Motor | 1 | 5 or less HP | $ | 2,503.0 |
| 301 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Sump Pump | 1 | | $ | 650.0 |
| 302 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Sump Pump Control Panel | 1 | | $ | 44,549.6 |
| 303 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Transformer | 1 | 30 kVA | $ | 9,546.2 |
| 304 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Transformer | 1 | 45 kVA | $ | 12,168.7 |
| 305 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Control Panels (Large) | 2 | | $ | 77,324.4 |
| 306 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Control Panels (Small) | 3 | | $ | 77,324.4 |
| 307 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Panelboards | 2 | | $ | 17,800.0 |
| 308 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Panelboards | 2 | | $ | 5,186.0 |
| 309 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Communication Asset Panel (Comba | 1 | | $ | 77,324.4 |
| 310 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Swichboard | 1 | | $ | 130,000.0 |
| 311 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Generator | 1 | | $ | 871,242.1 |
| 312 | VAHOSPITAL CENTER - NEW PARKING STRUC | New Parking Structure | Electric panel for Fuel Tank (Day Tar | 1 | | $ | 77,324.4 |
| 313 | WPCP - SECURITY GATES | Security Gates | Security gate panels | 14 | | $ | 77,324.4 |
| 314 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup St | Flow Meters | 2 | | $ | 105,064.2 |
| 315 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup St | Control Panel - Closed | 3 | | $ | 77,324.4 |
| 316 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup St | VFD | 2 | | $ | 67,476.2 |
| 317 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup St | Processor Panel | 1 | | $ | 77,324.4 |
| 318 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | MCC | 1 | | $ | 2,027,630.8 |
| 319 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | VFD | 4 | | $ | 67,476.2 |
| 320 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Processor Panel | 1 | | $ | 77,324.4 |
| 321 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | | 1 | | $ | 40,986.0 |
| 322 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Fan control panel | 1 | | $ | 77,324.4 |
| 323 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Fiber Box | 1 | | $ | 25,000.0 |
| 324 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Control Panel - HOR | 1 | | $ | 77,324.4 |
| 325 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Breaker | 1 | | $ | 4,278.9 |
| 326 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Transformer | 2 | 15 kVA | $ | 19,492.1 |
| 327 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Switch Disconnect Switch | 8 | 30 Amps | $ | 321.0 |
| 328 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Control Panel | 1 | | $ | 77,324.4 |
| 329 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Control Panel - Closed | 2 | 3 amps | $ | 77,324.4 |
| 330 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Breaker | 1 | | $ | 4,278.9 |
| 331 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Pump and motor | 3 | 7.5 hP | $ | 170,683.4 |
| 332 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Pump and motor | 2 | 40 hP | $ | 170,683.4 |
| 333 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Motor | 2 | 15 HP | $ | 182,418.7 |
| 334 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Relay Panel | 1 | | $ | 77,324.4 |
| 335 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Pump and motor | 2 | 3 hp | $ | 40,567.8 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 336 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Electrical Panel | 1 | | $ | 77,324.4 |
| 337 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Control Panel - Old | 1 | | $ | 77,324.4 |
| 338 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Electrical cabinet | 1 | | $ | 77,324.4 |
| 339 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - | Electrical Panel | 1 | | $ | 77,324.4 |
| 340 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Sludge Pump Control Panels | 4 | | $ | 77,324.4 |
| 341 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Gravity Thickened Sludge Pump Con | 1 | | $ | 77,324.4 |
| 342 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Processor Panel | 1 | | $ | 77,324.4 |
| 343 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Foul Air Blower Control Panel | 1 | | $ | 77,324.4 |
| 344 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Clarifier Control Panel | 1 | | $ | 77,324.4 |
| 345 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Electrical cabinet | 2 | | $ | 77,324.4 |
| 346 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Electrical cabinet | 2 | | $ | 77,324.4 |
| 347 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Ac Unit | 2 | | $ | 2,000.0 |
| 348 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Grinder control panels | 4 | | $ | 77,324.4 |
| 349 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Buildi | Grinders | 4 | 5 Hp | $ | 43,357.1 |
| 350 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | MCC | 1 | | $ | 2,027,630.8 |
| 351 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Sludge Transfer Control Panel | 1 | | $ | 77,324.4 |
| 352 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Relay Panel | 1 | | $ | 77,324.4 |
| 353 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Boiler | 1 | 14.1 gph | $ | 12,575.0 |
| 354 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Junction Box | 2 | | $ | 1,630.7 |
| 355 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Breaker | 2 | | $ | 4,278.9 |
| 356 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Transformer | 1 | 30 kVA | $ | 40,193.2 |
| 357 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Electrical cabinet | 1 | | $ | 77,324.4 |
| 358 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Control panel | 2 | | $ | 77,324.4 |
| 359 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Gas detection sensor | 3 | | $ | 40,986.0 |
| 360 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Ventilation Control Panel | 1 | | $ | 77,324.4 |
| 361 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Switch Disconnect Switch | 1 | 30 Amps | $ | 321.0 |
| 362 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Breaker | 3 | | $ | 4,278.9 |
| 363 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Grinder control panels | 2 | | $ | 77,324.4 |
| 364 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Sump pump control panel | 1 | | $ | 77,324.4 |
| 365 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Grinder | 2 | 20 Hp | $ | 182,418.7 |
| 366 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Sludge Transfer Pumps (small) | 2 | 20 Hp | $ | 170,683.0 |
| 367 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Sludge Transfer Pump (large) | 1 | 60 Hp | $ | 248,759.9 |
| 368 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SS | Small pump | 1 | 1 Hp | $ | 40,567.8 |
| 369 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Primary Sludge Pumps 1-8 | 8 | 7.5 Hp | $ | 170,683.0 |
| 370 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Grit pump control panel | 1 | | $ | 77,324.4 |
| 371 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Clarifier drain pump | 1 | 15 Hp | $ | 170,683.0 |
| 372 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Drain/sludge transfer pump | 1 | 15 Hp | $ | 170,683.0 |
| 373 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Grit Pumps | 4 | 25 Hp | $ | 170,683.0 |
| 374 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Sump pump control panel | 1 | | $ | 77,324.4 |
| 375 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Sealwater pump control panel | 1 | | $ | 77,324.4 |
| 376 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Sump Pump control panel | 1 | | $ | 77,324.4 |
| 377 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Primary Clarifier Panel | 1 | | $ | 77,324.4 |
| 378 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Scum Slurry Pumps | 2 | 10 Hp | $ | 170,683.0 |
| 379 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Grinders | 2 | 7.6 Hp | $ | 43,357.1 |
| 380 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Panels - scum mixer, foul air blower v | 5 | | $ | 77,324.4 |
| 381 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Scum Slurry Pump Control Panel | 1 | | $ | 77,324.4 |
| 382 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Scum Electrical Panels | 2 | | $ | 77,324.4 |
| 383 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Primary Clarifier Scum Collection Con | 1 | | $ | 44,549.6 |
| 384 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Grit Turbine Drive Control Panel | 1 | | $ | 77,324.4 |
| 385 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Ventilation Control Panel | 1 | | $ | 77,324.4 |
| 386 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Polymer Dilution Transfer Control Pa | 1 | | $ | 77,324.4 |
| 387 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Polymer Recirc Pumps | 2 | 3 Hp | $ | 40,567.8 |
| 388 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Grit Turbine and Motor | 3 | 0.75 Hp | $ | 43,357.1 |
| 389 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Hypo Feed/Transfer Pump Control P | 4 | | $ | 77,324.4 |
| 390 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Transfer Pumps | 2 | 0.75 Hp | $ | 40,567.8 |
| 391 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | FIT Junction Box | 3 | | $ | 1,630.7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 392 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - | Local control panel | 1 | | $ 77,324.4 |
| 393 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | PCL Panels | 1 | | $ 77,324.4 |
| 394 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Belt drive motor 1 | 4 | | $ 43,357.1 |
| 395 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Belt drive motor 2 | 4 | | $ 43,357.1 |
| 396 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Sluice Gate Controls/Power | 12 | | $ 44,549.6 |
| 397 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Collector Panel | 1 | | $ 77,324.4 |
| 398 | WPCP - 11 - FET - 1AND2 | 11 - Flow Equalization Tanks 1 and 2 | Flow equalization electrical panel | 6 | | $ 77,324.4 |
| 399 | WPCP - 11 - FET - 1AND2 | 11 - Flow Equalization Tanks 1 and 2 | Junction Box | 1 | | $ 1,630.7 |
| 400 | WPCP - 11 - FET - 3 | 11 - Flow Equalization Tanks 3 | Flow equalization electrical panel | 6 | | $ 77,324.4 |
| 401 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Recirculation Pump and Motor | 2 | 15 Hp | $ 170,683.0 |
| 402 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Recirculation Pump Control Panel | 1 | | $ 77,324.4 |
| 403 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Scrubber Supply Fan Motor | 1 | 100 Hp | $ 292,151.9 |
| 404 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Caustic Pump and Motor | 4 | 25 GPH | $ 1,475.0 |
| 405 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Sodium hypochlorite controls | 4 | | $ 44,549.6 |
| 406 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | NOC Pumps and Motors | 2 | 1 Hp | $ 40,567.8 |
| 407 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 2 | | $ 753.0 |
| 408 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 4 | | $ 335.9 |
| 409 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | NFF Fan Controls | 1 | | $ 44,549.6 |
| 410 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Fire Alarm Control Panel | 1 | | $ 9,128.7 |
| 411 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Ferric Pumps and Motors | 2 | 144 gph | $ 1,550.0 |
| 412 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Water Heater | 1 | | $ 2,204.7 |
| 413 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 7 | | $ 753.0 |
| 414 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Gas Monitor | 3 | | $ 40,986.0 |
| 415 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Pump Controls - Hypo, Ferric, Caustic | 3 | | $ 44,549.6 |
| 416 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | MCC | 1 | | $ 1,520,723.1 |
| 417 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Processor Panel | 2 | | $ 77,324.4 |
| 418 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Electrical cabinet | 4 | | $ 77,324.4 |
| 419 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Hypo Pump Local Control Panel (3-4 | 1 | | $ 77,324.4 |
| 420 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 1 | | $ 335.9 |
| 421 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box (at grade) | 2 | | $ 335.9 |
| 422 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box (below grade) | 6 | | $ 335.9 |
| 423 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Tank Controls | 1 | | $ 44,549.6 |
| 424 | WPCP - 30 - PEF | 30 - Primary Effluent Flume | Level Indicator Transmitter | 1 | | $ 40,986.0 |
| 425 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - | FEQ Pump and Motor | 8 | 75 Hp | $ 248,759.9 |
| 426 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - | FEQ Pump Controls | 8 | | $ 44,549.6 |
| 427 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - | Junction Box | 8 | | $ 335.9 |
| 428 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | MCC | 1 | | $ 2,027,630.8 |
| 429 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | VFD | 2 | | $ 67,476.2 |
| 430 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Power Transfer Switch | 1 | | $ 4,777.0 |
| 431 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Electrical cabinet | 3 | | $ 77,324.4 |
| 432 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Air Handling Unit | 1 | | $ 154,072.5 |
| 433 | WPCP - 40 - FEPS - GROUND | 40 - Flow Equalization Pump Station - | Junction Box | 2 | | $ 1,630.7 |
| 434 | WPCP - 43 - LLPS | 43 - Low Level Pump Station | Electrical cabinet | 1 | | $ 77,324.4 |
| 435 | WPCP - FA | Foul Air | Foul Air Blower Control Panel | 1 | | $ 77,324.4 |
| 436 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Switch | 3 | | $ 1,625.8 |
| 437 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Air Compressors | 2 | 1 hp | $ 54,837.8 |
| 438 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Air Handler | 1 | | $ 154,072.5 |
| 439 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | HVAC VFD | 1 | | $ 7,324.1 |
| 440 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | HVAC Electrical Panel | 1 | | $ 77,324.4 |
| 441 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Boilers | 2 | 508 LB/HR (~64 hp) | $ 12,575.0 |
| 442 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Water Heater | 1 | | $ 2,204.7 |
| 443 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Switch | 4 | | $ 1,625.8 |
| 444 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Breakers (large) | 3 | | $ 4,278.9 |
| 445 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Breakers (small) | 2 | | $ 4,278.9 |
| 446 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Electrical cabinets | 2 | | $ 77,324.4 |
| 447 | WPCP - 12 - OCB | 12 - Operations Control Building - OCB | Switch | 2 | | $ 1,625.8 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | |
|---|---|---|---|---|---|---|
| 448 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Power Transfer Switch | 2 | | $ 4,777.0 |
| 449 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | DoD communication network | 1 | | $ 2,736.8 |
| 450 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 1 | | $ 101,317.6 |
| 451 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 2 | | $ 1,625.8 |
| 452 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 2 | 7.5 hp | $ 170,683.0 |
| 453 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Transformer | 2 | 7500 kVa | $ 275,000.0 |
| 454 | WPCP - 13 - SBB - TRANSFORMER | 13 - Secondary Blower Building - SBB | Transformer | 2 | 1500 kVA | $ 51,216.0 |
| 455 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | NaOH Metering Pumps | 3 | 0.33 Hp | $ 40,567.8 |
| 456 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | NaOCl Metering Pumps | 4 | 0.33 Hp | $ 40,567.8 |
| 457 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Recirc pumps | 4 | 10 Hp | $ 170,683.0 |
| 458 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Water Heater | 1 | | $ 2,204.7 |
| 459 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Flow and level meters | 8 | | $ 105,064.2 |
| 460 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | NaOH Metering Transfer Pumps | 2 | 1 hp | $ 40,567.8 |
| 461 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Fire alarm control panel | 1 | | $ 9,128.7 |
| 462 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Blower switches | 5 | | $ 1,625.8 |
| 463 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Generator Terminal Box | 1 | | $ 8,000.0 |
| 464 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Switch Disconnect Switch | 2 | 30 Amps | $ 321.0 |
| 465 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Power source (Non ventilated transf | 1 | | $ 2,500.0 |
| 466 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Switchboard | 1 | | $ 1,625,279.7 |
| 467 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Odor control panel | 1 | | $ 77,324.4 |
| 468 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | MCC | 1 | | $ 1,520,723.1 |
| 469 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Control panels | 3 | | $ 77,324.4 |
| 470 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Breakers (small) | 4 | | $ 4,278.9 |
| 471 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Transformer | 2 | 30 kVA | $ 9,546.2 |
| 472 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Transformer | 1 | 45 KVa | $ 12,168.7 |
| 473 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Flow meters | 2 | | $ 105,064.2 |
| 474 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Breakers (large) | 1 | | $ 4,278.9 |
| 475 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Switch Disconnect Switch | 1 | 100A, 600Vac, Nonfused, NEMA1 | $ 734.5 |
| 476 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Pull box | 1 | | $ 2,500.0 |
| 477 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB | MCC | 2 | | $ 1,520,723.1 |
| 478 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB | Fire alarm control panel | 1 | | $ 9,128.7 |
| 479 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB | Generator Terminal Box (Bus Duct S | 1 | | $ 7,000.0 |
| 480 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB | Power panel | 1 | | $ 77,324.4 |
| 481 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB | Transfer Switch Disconnect Switch | 1 | 800A, 600Vac, Nonfused, NEMA1 | $ 5,677.0 |
| 482 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Blower motor control panel | 3 | | $ 77,324.4 |
| 483 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Blower Motor | 3 | 600 hp | $ 127,500.0 |
| 484 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Small motor | 3 | 3 hp | $ 43,357.1 |
| 485 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Breaker | 1 | | $ 4,278.9 |
| 486 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Security panel | 1 | | $ 77,324.4 |
| 487 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Network cabinet | 1 | | $ 1,500.0 |
| 488 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Processor Panel | 1 | | $ 77,324.4 |
| 489 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Air handling unit | 1 | | $ 154,072.5 |
| 490 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Blower Motor | 2 | 600 hp | $ 127,500.0 |
| 491 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Blower motor control panel | 2 | | $ 77,324.4 |
| 492 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Small motor | 2 | 3 hp | $ 43,357.1 |
| 493 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Air compressor control | 1 | | $ 44,549.6 |
| 494 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Switch Disconnect Switch | 3 | 30 Amps | $ 321.0 |
| 495 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Breaker (small) | 1 | | $ 4,278.9 |
| 496 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Electrical cabinet | 1 | | $ 77,324.4 |
| 497 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Transformer | 1 | 30 kVA | $ 9,546.2 |
| 498 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB | Breaker (large) | 1 | | $ 4,278.9 |
| 499 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT | Submersible mixer control panel | 12 | | $ 77,324.4 |
| 500 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT | Mixer motor | 12 | 3 hp | $ 43,357.1 |
| 501 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT | Mixer Motor (southern) | 12 | 10 hp | $ 43,357.1 |
| 502 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT | Submersible mixer control panel | 12 | | $ 77,324.4 |
| 503 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT | Mixer motor | 12 | 3 hp | $ 43,357.1 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 504 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT | Mixer Motor (southern) | 12 | 10 hp | $ | 43,357.1 |
| 505 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Motor | 3 | 2 hP | $ | 43,357.1 |
| 506 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Switch Disconnect Switch | 3 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |
| 507 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Level Indicator Transmitter | 3 | | $ | 40,986.0 |
| 508 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Junction box | 6 | | $ | 335.9 |
| 509 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Local controls panel box | 3 | | $ | 44,549.6 |
| 510 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum pump control panel | 6 | | $ | 77,324.4 |
| 511 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum Mixer control panel | 6 | | $ | 77,324.4 |
| 512 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum mixer motor | 6 | 3 hp | $ | 43,357.1 |
| 513 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | SCL Motor | 6 | 1 hp | $ | 43,357.1 |
| 514 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | SCL controls | 6 | | $ | 44,549.6 |
| 515 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Fiber box Terminals box | 1 | | $ | 2,500.0 |
| 516 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Tank sensors/levels | 7 | | $ | 40,986.0 |
| 517 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Control panel | 1 | | $ | 77,324.4 |
| 518 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Pump and motor | 1 | 2 hp | $ | 40,567.8 |
| 519 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Switch | 1 | | $ | 1,625.8 |
| 520 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | MCC | 3 | | $ | 1,520,723.1 |
| 521 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Breakers | 2 | | $ | 4,278.9 |
| 522 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Fiber box Pull Box | 1 | | $ | 6,000.0 |
| 523 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Processor Panel | 1 | | $ | 77,324.4 |
| 524 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Air handling Unit | 1 | | $ | 154,072.5 |
| 525 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | WAS Pump Control Panel | 3 | | $ | 77,324.4 |
| 526 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | SC Collector Control Panel | 6 | | $ | 77,324.4 |
| 527 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Air pump control panel | 1 | | $ | 77,324.4 |
| 528 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | Air pump and motor | 1 | 5 hp | $ | 40,567.8 |
| 529 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | WAS Pumps and Motors | 3 | 15/400 hp/gpm | $ | 170,683.0 |
| 530 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | SPR Pumps and Motors (smaller) | 2 | 25/3400 hp/gpm | $ | 170,683.0 |
| 531 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | SPR Pumps and Motors (bigger) | 5 | 15 hp | $ | 170,683.0 |
| 532 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Static | HVAC Unit | 1 | | $ | 101,317.6 |
| 533 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services | Transformer | 2 | 2500 kVa | $ | 712,663.5 |
| 534 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services | Scum well Motor | 1 | 3 hP | $ | 43,357.1 |
| 535 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services | Scum well controls | 2 | | $ | 44,549.6 |
| 536 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services | Switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |
| 537 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | WAS pump | 1 | 7.5 hP | $ | 170,683.0 |
| 538 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Drain pump | 1 | 25 Hp | $ | 170,683.0 |
| 539 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | RAS Pump | 4 | 100 hp | $ | 248,759.9 |
| 540 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Sump pump Control panel | 1 | | $ | 77,324.4 |
| 541 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Electrical Box | 2 | | $ | 77,324.4 |
| 542 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Junction boxes/controls | 4 | | $ | 335.9 |
| 543 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | MCC | 2 | | $ | 1,520,723.1 |
| 544 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Security/lighting panels | 1 | | $ | 77,324.4 |
| 545 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Breakers | 4 | | $ | 4,278.9 |
| 546 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Transformer | 2 | 45 kva | $ | 12,168.7 |
| 547 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Electrical Box | 1 | | $ | 77,324.4 |
| 548 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Switch Disconnect Switch | 1 | 30 Amps | $ | 321.0 |
| 549 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | HVAC control panels | 2 | | $ | 77,324.4 |
| 550 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | VFD | 10 | | $ | 67,476.2 |
| 551 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | VFD | 4 | | $ | 67,476.2 |
| 552 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Processor Panels | 2 | | $ | 77,324.4 |
| 553 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Breaker | 1 | | $ | 4,278.9 |
| 554 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Switch Disconnect Switch | 1 | 30 Amps | $ | 321.0 |
| 555 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Fiber box | 1 | | $ | 3,500.0 |
| 556 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Pump control panel | 1 | | $ | 77,324.4 |
| 557 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Fire alarm panel control | 1 | | $ | 9,128.7 |
| 558 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Air handling unit | 1 | | $ | 154,072.5 |
| 559 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 560 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services | Water heater power | 1 | | $ | 7,521.0 |
| 561 | WPCP - 18 - WMLFDS | 18 - West Mixed Liquor Flow Distribut | Mixer control panel | 1 | | $ | 77,324.4 |
| 562 | WPCP - 18 - WMLFDS | 18 - West Mixed Liquor Flow Distribut | Breaker | 1 | | $ | 4,278.9 |
| 563 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Electrical Box | 1 | | $ | 77,324.4 |
| 564 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Dryer Control panel | 1 | | $ | 77,324.4 |
| 565 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | WWF Motors | 3 | 300 hp | $ | 1,380,456.6 |
| 566 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Air compressors | 2 | | $ | 54,837.8 |
| 567 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Process panel | 1 | | $ | 77,324.4 |
| 568 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Fan control panel | 1 | | $ | 77,324.4 |
| 569 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Control panel | 1 | | $ | 77,324.4 |
| 570 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | MCC | 1 | | $ | 2,027,630.8 |
| 571 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | VFD | 2 | | $ | 67,476.2 |
| 572 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Breaker (large) | 2 | | $ | 4,278.9 |
| 573 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Breaker (small) | 2 | | $ | 4,278.9 |
| 574 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Transformer | 2 | 30 kva | $ | 9,546.2 |
| 575 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Blower panels | 1 | | $ | 77,324.4 |
| 576 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Blower motors | 2 | 300 hp | $ | 63,750.0 |
| 577 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Breakers | 3 | | $ | 4,278.9 |
| 578 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Breaker cabinet | 1 | | $ | 4,278.9 |
| 579 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Fan control panel | 1 | | $ | 77,324.4 |
| 580 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Pump control panel | 1 | | $ | 77,324.4 |
| 581 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Fire alarm panel control | 1 | | $ | 9,128.7 |
| 582 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Transformer | 2 | 75 kva | $ | 8,494.6 |
| 583 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Lighting contractor panel | 1 | | $ | 77,324.4 |
| 584 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |
| 585 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | MCC | 3 | | $ | 1,520,723.1 |
| 586 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Electrical panels | 2 | | $ | 77,324.4 |
| 587 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Switch Disconnect Switch | 3 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |
| 588 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Air handling unit | 1 | | $ | 154,072.5 |
| 589 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Water heater power control | 1 | | $ | 44,549.6 |
| 590 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Transfer Switch Disconnect Switch | 1 | 800A, 600Vac, Nonfused, NEMA1 | $ | 5,677.0 |
| 591 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Valve box | 1 | | $ | 2,500.0 |
| 592 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | BWS Pump & Motor | 2 | 5430 gpm | $ | 24,297.0 |
| 593 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Seed pump motor | 1 | 7.5 hp | $ | 170,683.0 |
| 594 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Drain pump motor | 1 | 15 hp | $ | 170,683.0 |
| 595 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Drain pump controls | 1 | | $ | 44,549.6 |
| 596 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Sump pump controls | 1 | | $ | 44,549.6 |
| 597 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Sample pump controls | 4 | | $ | 44,549.6 |
| 598 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Sample pump motors | 8 | 0.5 Hp | $ | 40,567.8 |
| 599 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Chemical sensors | 3 | | $ | 40,986.0 |
| 600 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Filter termination boxes | 17 | | $ | 2,500.0 |
| 601 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Breaker cabinet | 4 | | $ | 4,278.9 |
| 602 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facilit | Lighting contractor panel | 2 | | $ | 77,324.4 |
| 603 | WPCP - 21 - ABWB | 21 - Advance Backwash Building - ABV | Electrical panels | 1 | | $ | 77,324.4 |
| 604 | WPCP - 21 - ABWB | 21 - Advance Backwash Building - ABV | Breakers | 2 | | $ | 4,278.9 |
| 605 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PE | Effluent pumps and motors | 4 | 250 hp | $ | 1,116,400.8 |
| 606 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PE | Pump controls | 4 | | $ | 44,549.6 |
| 607 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PE | Sluice gate switch Disconnect Switch | 1 | 30 Amps | $ | 321.0 |
| 608 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Pump control panel | 1 | | $ | 77,324.4 |
| 609 | WPCP - 24 - PAF | 24 - Post Aeration Facility | VFD | 8 | 250 hp | $ | 67,476.2 |
| 610 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fan control panel | 1 | | $ | 77,324.4 |
| 611 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fire alarm panel control | 1 | | $ | 9,128.7 |
| 612 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breakers | 2 | | $ | 4,278.9 |
| 613 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Air handling unit | 1 | | $ | 154,072.5 |
| 614 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Transformer | 1 | 30 kVA | $ | 9,546.2 |
| 615 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fan exhaust switch Disconnect Switc | 1 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 616 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Electrical panel | 1 | | $ | 77,324.4 |
| 617 | WPCP - 24 - PAF | 24 - Post Aeration Facility | MCC | 3 | | $ | 1,520,723.1 |
| 618 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Transformer | 1 | 45 kVA | $ | 12,168.7 |
| 619 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Lighting Contractor | 1 | | $ | 77,324.4 |
| 620 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breaker (large) | 1 | | $ | 4,278.9 |
| 621 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breaker (small) | 1 | | $ | 4,278.9 |
| 622 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Processor Panel | 1 | | $ | 77,324.4 |
| 623 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Switch Disconnect Switch | 3 | 30 Amps | $ | 321.0 |
| 624 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Junction box | 1 | | $ | 1,630.7 |
| 625 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Network box | 1 | | $ | 10,262.9 |
| 626 | WPCP - 24 - PAF | 24 - Post Aeration Facility | NAOS Pumps | 3 | 50 gph | $ | 1,540.0 |
| 627 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Pump controls | 3 | | $ | 44,549.6 |
| 628 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sump pump controls | 1 | | $ | 44,549.6 |
| 629 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pumps and motors | 4 | 0.5 hp | $ | 40,567.8 |
| 630 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump controls | 2 | | $ | 44,549.6 |
| 631 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Tank controls | 2 | | $ | 44,549.6 |
| 632 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sump pump controls | 1 | | $ | 44,549.6 |
| 633 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Blower motors | 3 | 125 Hp | $ | 9,502.5 |
| 634 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Water heater power control | 1 | | $ | 44,549.6 |
| 635 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump controls | 1 | | $ | 44,549.6 |
| 636 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump motors | 2 | 0.5 Hp | $ | 40,567.8 |
| 637 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Blower control panel | 3 | | $ | 77,324.4 |
| 638 | WPCP - 24 - PAF - TRANSFORMER | 24 - Post Aeration Facility - Transform | Transformer | 1 | 2500 kva | $ | 712,663.5 |
| 639 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Flow meters | 7 | | $ | 105,064.2 |
| 640 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Valve actuator | 11 | | $ | 43,357.1 |
| 641 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump and motors | 4 | 151 gph | $ | 1,823.0 |
| 642 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump controls | 4 | | $ | 44,549.6 |
| 643 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Valve actuator | 4 | | $ | 43,357.1 |
| 644 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Tank control panel | 1 | | $ | 77,324.4 |
| 645 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Sump pump control panel | 1 | | $ | 77,324.4 |
| 646 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Foam system control panels | 2 | | $ | 77,324.4 |
| 647 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Fire alarm control panel | 1 | | $ | 9,128.7 |
| 648 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump control panel | 2 | | $ | 77,324.4 |
| 649 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Remote I/O panel | 1 | | $ | 77,324.4 |
| 650 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Processor Panel | 1 | | $ | 77,324.4 |
| 651 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker (large) | 1 | | $ | 4,278.9 |
| 652 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker (small) | 1 | | $ | 4,278.9 |
| 653 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Transformer | 1 | 75 kva | $ | 8,494.6 |
| 654 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker Cabinet | 1 | | $ | 4,278.9 |
| 655 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Power Transfer Switch | 1 | | $ | 4,777.0 |
| 656 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Lighting panel | 1 | | $ | 77,324.4 |
| 657 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Fan control panel | 1 | | $ | 77,324.4 |
| 658 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Electrical panels | 1 | | $ | 77,324.4 |
| 659 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Gas monitors | 2 | | $ | 40,986.0 |
| 660 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Air handling unit | 1 | | $ | 154,072.5 |
| 661 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Chemical pump and motor | 2 | 63 gph | $ | 1,540.0 |
| 662 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Chemical pump controls | 2 | | $ | 44,549.6 |
| 663 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Sump pump control panel | 1 | | $ | 77,324.4 |
| 664 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Water heater power | 1 | | $ | 7,521.0 |
| 665 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Sump pump control panel | 1 | | $ | 77,324.4 |
| 666 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Fill Station Control panel | 1 | | $ | 77,324.4 |
| 667 | WPCP - 28 - DC5 - TRANSFORMER | 28 - Distribution Center No. 5 -DSB-5 | Transformer | 2 | 2500 kVA | $ | 712,663.5 |
| 668 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Fan control panel | 1 | | $ | 77,324.4 |
| 669 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Generator Terminal Box | 1 | | $ | 8,000.0 |
| 670 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Process Panel | 1 | | $ | 77,324.4 |
| 671 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Breaker cabinet | 1 | | $ | 4,278.9 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 672 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Power transfer switch | 1 | | $ | 4,777.0 |
| 673 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Transfer Switch Disconnect Switch | 2 | 800A, 600Vac, Nonfused, NEMA1 | $ | 5,677.0 |
| 674 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | Electrical panel | 1 | | $ | 77,324.4 |
| 675 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 -DSB-5 | MCC | 1 | | $ | 2,027,630.8 |
| 676 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Nox Control Panel | 3 | | $ | 77,324.4 |
| 677 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch | 2 | | $ | 1,625.8 |
| 678 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Supply pump (cooling water) | 3 | 7.5 HP | $ | 170,683.0 |
| 679 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Air compressor control power | 3 | | $ | 44,549.6 |
| 680 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Batteries | 12 | | $ | 304.1 |
| 681 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Supply pump control panel | 3 | | $ | 77,324.4 |
| 682 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Generator | 3 | 3125 kVa | $ | 750,000.0 |
| 683 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Bifuel Control Panel | 3 | | $ | 77,324.4 |
| 684 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Overall control panel | 1 | | $ | 77,324.4 |
| 685 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control power junction box | 1 | | $ | 1,630.7 |
| 686 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Urea Tank Booster Pumps | 3 | 0.09 kW | $ | 1,457.5 |
| 687 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Tank control panel | 1 | | $ | 77,324.4 |
| 688 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Gas detection sensor | 2 | | $ | 40,986.0 |
| 689 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control Switches | 4 | | $ | 1,625.8 |
| 690 | WPCP - 29 - SGF | 29 - Standby Generator Facility | MCC | 1 | | $ | 1,520,723.1 |
| 691 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Air handling unit | 1 | | $ | 154,072.5 |
| 692 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Electrical panel (small) | 2 | | $ | 77,324.4 |
| 693 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Communications network | 1 | | $ | 10,262.9 |
| 694 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Transformer | 1 | 75 kVA | $ | 8,494.6 |
| 695 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire alarm control panel | 1 | | $ | 9,128.7 |
| 696 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Breakers (large) | 1 | | $ | 4,278.9 |
| 697 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Breakers (small) | 2 | | $ | 4,278.9 |
| 698 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fan | 1 | 3 hp | $ | 4,458.0 |
| 699 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control power junction box | 1 | | $ | 1,630.7 |
| 700 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 2 | 100A, 600Vac, Nonfused, NEMA1 | $ | 734.5 |
| 701 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Processor Panel | 1 | | $ | 77,324.4 |
| 702 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control panel (large) | 1 | | $ | 77,324.4 |
| 703 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 3 | 30 Amps | $ | 321.0 |
| 704 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control panel | 2 | | $ | 77,324.4 |
| 705 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fuel pumps | 4 | 2 hp | $ | 40,567.8 |
| 706 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire pump | 1 | 60 hp | $ | 248,759.9 |
| 707 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire pump control panel | 1 | | $ | 77,324.4 |
| 708 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |
| 709 | WPCP - 32 - EMLFDS | 32 - East Mixed Liquor Flow Distribut | Mixer control panel | 1 | | $ | 77,324.4 |
| 710 | WPCP - 32 - EMLFDS | 32 - East Mixed Liquor Flow Distribut | Switch Disconnect Switch | 3 | 30 Amps | $ | 321.0 |
| 711 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Transformer | 1 | 30 kva | $ | 9,546.2 |
| 712 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | VFD | 6 | | $ | 67,476.2 |
| 713 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Lighting control panel | 1 | | $ | 77,324.4 |
| 714 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | MCC | 1 | | $ | 1,520,723.1 |
| 715 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Fan control panel | 1 | | $ | 77,324.4 |
| 716 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Processor Panel | 1 | | $ | 77,324.4 |
| 717 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Breakers | 4 | | $ | 4,278.9 |
| 718 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Fire alarm control panel | 1 | | $ | 9,128.7 |
| 719 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Polymer pump control panel | 3 | | $ | 77,324.4 |
| 720 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Vacuum pump control panel | 1 | | $ | 77,324.4 |
| 721 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Blender Control Panel | 1 | | $ | 77,324.4 |
| 722 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Polymer pump and motor | 3 | 1.5 Hp | $ | 40,567.8 |
| 723 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Water heater power control | 1 | | $ | 44,549.6 |
| 724 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Grinder control panel | 1 | | $ | 77,324.4 |
| 725 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Pumps and motors | 2 | 15 hp | $ | 170,683.0 |
| 726 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Drain pump and motor | 1 | 5 hp | $ | 40,567.8 |
| 727 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Statio | Electrical panel | 1 | | $ | 77,324.4 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 728 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Fire alarm control panel | 1 | | $ | 9,128.7 |
| 729 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Transformer | 1 | 30 kva | $ | 9,546.2 |
| 730 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Breaker | 2 | | $ | 4,278.9 |
| 731 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Fan control panel | 1 | | $ | 77,324.4 |
| 732 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Lighting control panel | 1 | | $ | 77,324.4 |
| 733 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | VFD | 2 | | $ | 67,476.2 |
| 734 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Processor panel | 1 | | $ | 77,324.4 |
| 735 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Fiber box | 1 | | $ | 3,500.0 |
| 736 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | MCC | 1 | | $ | 1,520,723.1 |
| 737 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Air handling unit | 1 | | $ | 154,072.5 |
| 738 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Water heater power control | 1 | | $ | 44,549.6 |
| 739 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Electrical panel | 1 | | $ | 77,324.4 |
| 740 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Grinder Motor | 1 | 5 Hp | $ | 43,357.1 |
| 741 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Grinder control panel | 1 | | $ | 77,324.4 |
| 742 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Pumps and Motors | 2 | 40 hp | $ | 170,683.0 |
| 743 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Fiber box | 1 | | $ | 3,500.0 |
| 744 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Panel box | 1 | | $ | 77,324.4 |
| 745 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Scum mixer | 1 | 5 hp | $ | 40,567.8 |
| 746 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - S | Scum mixer controls | 1 | | $ | 44,549.6 |
| 747 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Transfer Pumps and Motors | 2 | 525 gph | $ | 12,500.0 |
| 748 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Pump panels | 1 | | $ | 120,681.5 |
| 749 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Pump switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |
| 750 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Sample pumps and motors | 4 | 0.5 Hp | $ | 40,567.8 |
| 751 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Sample control panels | 2 | | $ | 77,324.4 |
| 752 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Sodium Hypo Pumps and Motors | 2 | 0.5 Hp | $ | 40,567.8 |
| 753 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Pump panels | 1 | | $ | 120,681.5 |
| 754 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | NAOCl Pumps and Motors | 2 | 182 gph | $ | 5,000.0 |
| 755 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | NAOCl Pumps and Motors | 2 | 397 gph | $ | 9,500.0 |
| 756 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Gas monitor | 1 | | $ | 40,986.0 |
| 757 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Water heater power | 1 | | $ | 7,521.0 |
| 758 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | DSCNT Pumps and motors | 2 | 2 hp | $ | 40,567.8 |
| 759 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | DSCNT Controls | 2 | | $ | 44,549.6 |
| 760 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Tank controls junction box | 8 | | $ | 335.9 |
| 761 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Sump pump control panel | 2 | | $ | 77,324.4 |
| 762 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Hypo recirc pump and motor | 2 | 5 hp | $ | 40,567.8 |
| 763 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - S | Fill panels | 1 | | $ | 77,324.4 |
| 764 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - S | Sump pump control panel | 1 | | $ | 77,324.4 |
| 765 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - S | Fill local control box | 1 | 55 | $ | 44,549.6 |
| 766 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Breaker (small) | 1 | | $ | 4,278.9 |
| 767 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Breaker (large) | 1 | | $ | 4,278.9 |
| 768 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Electrical panel | 1 | | $ | 77,324.4 |
| 769 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | Lighting contractor panel | 1 | | $ | 77,324.4 |
| 770 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - S | MCC | 1 | | $ | 2,027,630.8 |
| 771 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump | Control panels | 2 | | $ | 77,324.4 |
| 772 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump | ASE motors | 3 | 300 hp | $ | 504,817.3 |
| 773 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump | Breakers | 2 | | $ | 4,278.9 |
| 774 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump | Switches | 2 | | $ | 1,625.8 |
| 775 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump | Gate control panels | 1 | | $ | 77,324.4 |
| 776 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump | HVAC FAN | 1 | | $ | 101,317.6 |
| 777 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump | Electrical Box | 1 | | $ | 77,324.4 |
| 778 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump | VFI Switch | 1 | | $ | 1,625.8 |
| 779 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump | Transformer | 1 | 2000 kva | $ | 612,242.9 |
| 780 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump | Transformer | 1 | 1500 kva | $ | 51,216.0 |
| 781 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump | ASE Pumps and Motors | 4 | 300 Hp | $ | 1,380,456.6 |
| 782 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump | Wet well panel box | 2 | | $ | 77,324.4 |
| 783 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump | Flow meter panel box | 4 | | $ | 77,324.4 |

Table G-2. Asset Replacement Costs for Facilities Visited

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 784 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump | Controls Panel box | 4 | | $ | 44,549.6 |
| 785 | WPCP - 39 - WFF - OUTSIDE | 39 - West Ferric Facility - WFF - Outs | Chemical feed control panel | 1 | | $ | 77,324.4 |
| 786 | WPCP - 39 - WFF - OUTSIDE | 39 - West Ferric Facility - WFF - Outs | Sump pump controls | 1 | | $ | 44,549.6 |
| 787 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Switch Disconnect Switch | 2 | 30 Amps | $ | 321.0 |
| 788 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Ferric pump motor | 2 | 1 hP | $ | 40,567.8 |
| 789 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Ferric pump controls | 2 | | $ | 44,549.6 |
| 790 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Drain controls | 2 | | $ | 44,549.6 |
| 791 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Pump control panel | 1 | | $ | 77,324.4 |
| 792 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Supply fan control panel | 3 | | $ | 77,324.4 |
| 793 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Switch Disconnect Switch | 2 | 100A, 600Vac, Nonfused, NEMA 1 | $ | 734.5 |
| 794 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Drain pump and motor | 2 | 20 hp | $ | 170,683.0 |
| 795 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Telephone Box | 4 | | $ | 3,968.3 |
| 796 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | SAT Panel | 2 | | $ | 77,324.4 |
| 797 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Fan control panel | 2 | | $ | 77,324.4 |
| 798 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Exhaust fan control panel | 3 | | $ | 77,324.4 |
| 799 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Breakers | 3 | | $ | 4,278.9 |
| 800 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Sump Pump control panel | 3 | | $ | 77,324.4 |
| 801 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Fire alarm control panel | 1 | | $ | 9,128.7 |
| 802 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Breaker Cabinet | 1 | | $ | 4,278.9 |
| 803 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Lighting control panel | 2 | | $ | 77,324.4 |
| 804 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Gas detection sensor | 2 | | $ | 40,986.0 |
| 805 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Breaker (large) | 2 | | $ | 4,278.9 |
| 806 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | DCU | 1 | | $ | 18,000.0 |
| 807 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Transformer | 1 | 45 kva | $ | 12,168.7 |
| 808 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe G | Relay panel | 1 | | $ | 77,324.4 |
| 809 | WPCP - 28 - DC3 | 28 - DC-3 | Torque motors | 2 | 700 rpm | $ | 182,418.7 |
| 810 | WPCP - 28 - DC3 | 28 - DC-3 | VFD | 3 | | $ | 67,476.2 |
| 811 | WPCP - 28 - DC3 | 28 - DC-3 | Breaker | 1 | | $ | 4,278.9 |
| 812 | WPCP - 28 - DC3 | 28 - DC-3 | Processor panel | 1 | | $ | 77,324.4 |
| 813 | WPCP - 28 - DC3 | 28 - DC-3 | Telephone box | 1 | | $ | 2,736.8 |
| 814 | WPCP - 28 - DC3 | 28 - DC-3 | ASE Pump control panel | 1 | | $ | 77,324.4 |
| 815 | WPCP - 28 - DC3 | 28 - DC-3 | MCC | 1 | | $ | 2,027,630.8 |
| 816 | WPCP - 28 - DC3 | 28 - DC-3 | Air Handling Unit | 1 | | $ | 154,072.5 |

# Table G-3. Asset Flood Analysis and Cumulative Risk

Using 4% Dicount Rate and 20-yr Period to 2042

| Form AssetID | Facility | Facility Type | Site Asset | Asset Elevation (ft) (NAVD88) | Facility Flood Path Elevation (NAVD88) | 2020 Flooding Probability (%) | 2040 Flooding Probability (%) | 2070 Flooding Probability (%) | 2022 Flooding Probability (%) | 2042 Flooding Probability (%) | Cumulative Monetized Risk |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ART - O&M CENTER | O&M Center | Switchgear | 58.03 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 2 | ART - O&M CENTER | O&M Center | Transformer | 58.03 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 3 | ART - O&M CENTER | O&M Center | Air compresor | 57.53 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 4 | ART - O&M CENTER | O&M Center | Hydraulic press | 62.2 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 5 | ART - O&M CENTER | O&M Center | Panel Board | 60.53 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 6 | ART - O&M CENTER | O&M Center | Panel Board | 60.53 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 7 | ART - O&M CENTER | O&M Center | Panel Board | 60.53 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 8 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 61.78 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 9 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 61.78 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 10 | ART - O&M CENTER | O&M Center | HW Unit Heaters | 61.78 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 11 | ART - O&M CENTER | O&M Center | El. Unit Heatter | 61.78 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 12 | ART - O&M CENTER | O&M Center | Blower | 59.7 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 13 | ART - O&M CENTER | O&M Center | Boilers | 58.37 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 14 | ART - O&M CENTER | O&M Center | AC unit | 58.87 | 57.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 15 | ART - PARKING STRUCTURE | Parking Structure | Transformer | 60.5 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 16 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 61.33 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 17 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 61.33 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 18 | ART - PARKING STRUCTURE | Parking Structure | Panel Board | 61.33 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 19 | ART - PARKING STRUCTURE | Parking Structure | El Unit Heater | 62.58 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 20 | ART - PARKING STRUCTURE | Parking Structure | Fan | 64.25 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 21 | ART - BUS PARKING LOT | Bus Parking Lot | Busses | 52.27 | 52.27 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 265 |
| 22 | CARDINAL ELEMENTARY | School | BAS Controls | 278.19 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 23 | CARDINAL ELEMENTARY | School | Water Source Heat Pump | 274.39 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 24 | CARDINAL ELEMENTARY | School | Panel Boards | 276.39 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 25 | CARDINAL ELEMENTARY | School | Sump Pump Control Panel | 275.85 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 26 | CARDINAL ELEMENTARY | School | Router/Modem | 280.35 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 27 | CARDINAL ELEMENTARY | School | Heatstack Water Heaters | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 28 | CARDINAL ELEMENTARY SCHOOL | School | Modular Chiller System Assembly | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 29 | CARDINAL ELEMENTARY | School | Pump | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 30 | CARDINAL ELEMENTARY | School | Pump controls | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 31 | CARDINAL ELEMENTARY SCHOOL | School | Super Changer (Heat Exchanger) | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 32 | CARDINAL ELEMENTARY | School | Geothermal system panel | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 33 | CARDINAL ELEMENTARY | School | Water circulating pump | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 34 | CARDINAL ELEMENTARY | School | Condensing unit | 273.98 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 35 | CARDINAL ELEMENTARY | School | Outside air unit panel | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 36 | CARDINAL ELEMENTARY SCHOOL | School | Control panel - Makeup air unit kitchen exhaust fan & Refrigerator/freezer | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 37 | CARDINAL ELEMENTARY | School | HVAC Drives | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 38 | CARDINAL ELEMENTARY | School | Water Source Heat Pump | 274.39 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 39 | CARDINAL ELEMENTARY | School | Water Source Heat Pump | 273.85 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 40 | CARDINAL ELEMENTARY | School | Router/Modem | 274.39 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 41 | CARDINAL ELEMENTARY | School | Transfer switch | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 42 | CARDINAL ELEMENTARY | School | Panel Boards | 277.81 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 43 | CARDINAL ELEMENTARY | School | Panel Boards | 276.19 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 44 | CARDINAL ELEMENTARY SCHOOL | School | Advanced metering data acquisition system | 274.89 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 45 | CARDINAL ELEMENTARY | School | Comba critical point | 277.52 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | CARDINAL ELEMENTARY SCHOOL | School | Main service distribution MDP Switchboard | 275.94 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 47 | CARDINAL ELEMENTARY | School | Heavy duty safety switch | 273.94 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 48 | CARDINAL ELEMENTARY | School | Transformer | 275.77 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 49 | CARDINAL ELEMENTARY | School | Electrical cabinet (not pictured) | 274.14 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 50 | CARDINAL ELEMENTARY | School | Panel Boards | 273.94 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 51 | CARDINAL ELEMENTARY | School | Meters | 276.77 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 52 | CARDINAL ELEMENTARY | School | Transformer | 278.48 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 53 | CARDINAL ELEMENTARY | School | Water Source Heat Pump | 282.14 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 54 | CARDINAL ELEMENTARY | School | BAS Controls | 274.44 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 55 | CARDINAL ELEMENTARY | School | Water Source Heat Pump | 280.81 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 56 | CARDINAL ELEMENTARY | School | HD Safety Switch (Elevator) | 274.44 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 57 | CARDINAL ELEMENTARY | School | Elevator Control Panel | 277.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 58 | CARDINAL ELEMENTARY | School | AC unit | 275.39 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 59 | CARDINAL ELEMENTARY | School | GYM | 281.06 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 60 | CARDINAL ELEMENTARY | Emergency Generator | Generator | 273.56 | 273.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 61 | CARDINAL ELEMENTARY | Parking Lot | Car | 282.15 | 280.9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 216 |
| 62 | CARDINAL ELEMENTARY | Parking Lot | LtTrk | 268.09 | 268.09 | 0.21 | 0.28 | 0.40 | 0.21 | 0.28 | $ 107 |
| 63 | CHERRYDALE HEALTH & REHAB | Medical Center | Communication network | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 2 |
| 64 | CHERRYDALE HEALTH & REHAB | Medical Center | Ethernet box | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 0 |
| 65 | CHERRYDALE HEALTH & REHAB | Medical Center | Ethernet Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 0 |
| 66 | CHERRYDALE HEALTH & REHAB | Medical Center | Security control panel | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 9 |
| 67 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Communication network Rack (floor rack) | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 6 |
| 68 | CHERRYDALE HEALTH & REHAB | Medical Center | Water Heater | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 1 |
| 69 | CHERRYDALE HEALTH & REHAB | Medical Center | Water Heater Motors | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 2 |
| 70 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Domestic Potable Water Booster Pumps | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 213 |
| 71 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Domestic Potable water booster pump control panel | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 48 |
| 72 | CHERRYDALE HEALTH & REHAB | Medical Center | HVAC System (blower motor) | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 6 |
| 73 | CHERRYDALE HEALTH & REHAB | Medical Center | Heat Exchanger | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 4 |
| 74 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Cooling Tower Pumps and Motors | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 51 |
| 75 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Condensation Pumps and Motors | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 213 |
| 76 | CHERRYDALE HEALTH & REHAB | Medical Center | Cooling Tower Controls | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 48 |
| 77 | CHERRYDALE HEALTH & REHAB | Medical Center | Utility Meter | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 1 |
| 78 | CHERRYDALE HEALTH & REHAB | Medical Center | Boilers | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 16 |
| 79 | CHERRYDALE HEALTH & REHAB | Medical Center | Boiler Fuel Motor | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 7 |
| 80 | CHERRYDALE HEALTH & REHAB | Medical Center | Switchgear | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 593 |
| 81 | CHERRYDALE HEALTH & REHAB | Medical Center | Disconnect Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 2 |
| 82 | CHERRYDALE HEALTH & REHAB | Medical Center | Disconnect Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 5 |
| 83 | CHERRYDALE HEALTH & REHAB | Medical Center | Automatic Transfer Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 19 |
| 84 | CHERRYDALE HEALTH & REHAB | Medical Center | Fire Control Pump and Motor | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 155 |
| 85 | CHERRYDALE HEALTH & REHAB | Medical Center | Fire Control Panel | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 3 |
| 86 | CHERRYDALE HEALTH & REHAB | Medical Center | Disconnect Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 4 |
| 87 | CHERRYDALE HEALTH & REHAB | Medical Center | Discharge water motor | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 5 |
| 88 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Discharge water motor controller | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 48 |
| 89 | CHERRYDALE HEALTH & REHAB | Medical Center | Disconnect Switch | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 0 |
| 90 | CHERRYDALE HEALTH & REHAB | Medical Center | Fire Alarm Control Panel | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 6 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 91 | CHERRYDALE HEALTH & REHAB | Medical Center | Fire Alarm Panel Batteries | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 1 |
| 92 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 5 |
| 93 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Industrial Hot water Tank Sensor | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 26 |
| 94 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Steam Condensate/Make-up Water Pump | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 6 |
| 95 | CHERRYDALE HEALTH & REHAB CENTER | Medical Center | Steam Condesate/make-up pump control panel | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 48 |
| 96 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 7 |
| 97 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 269.16 | 269.16 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 3 |
| 98 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 273.99 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 99 | CHERRYDALE HEALTH & REHAB | Medical Center | Communication network | 271.66 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 100 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 272.99 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 101 | CHERRYDALE HEALTH & REHAB | Medical Center | Panelboards | 273.99 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 102 | CHERRYDALE HEALTH & REHAB | Cooling Towers | Cooling Tower | 272.66 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 103 | CHERRYDALE HEALTH & REHAB CENTER | Cooling Towers | Cooling Tower Breaker Panel Board | 272.74 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 104 | CHERRYDALE HEALTH & REHAB | Cooling Towers | Transformer | 273.49 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 105 | CHERRYDALE HEALTH & REHAB | Cooling Towers | Cooling Tower Control Panel | 270.74 | 269.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 106 | CHERRYDALE - GENERATOR | Emergency Generator | Diesel Engine Generator | 270.49 | 270.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 107 | CHERRYDALE - GENERATOR | Emergency Generator | Fuel motor | 270.49 | 270.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 108 | CHERRYDALE - GENERATOR | Emergency Generator | Generator Batteries | 270.49 | 270.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 109 | GUNSTON - SCHOOL & EG | School | Panelboards | 52.24 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 110 | GUNSTON - SCHOOL & EG | School | Nac Extender | 53.99 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 111 | GUNSTON - SCHOOL & EG | School | Panelboards | 52.24 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 112 | GUNSTON - SCHOOL & EG | School | Panelboards | 52.41 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 113 | GUNSTON - SCHOOL & EG | School | Switchboard | 49.74 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 114 | GUNSTON - SCHOOL & EG | School | Patch panel | 52.99 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 115 | GUNSTON - SCHOOL & EG | School | Nac Extender | 52.49 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 116 | GUNSTON - SCHOOL & EG | School | Panelboards | 52.41 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 117 | GUNSTON - SCHOOL & EG | School | Panelboards | 52.74 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 118 | GUNSTON - SCHOOL & EG | School | Panelboards | 50.08 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 119 | GUNSTON - SCHOOL & EG | School | Elevator Controller | 38.25 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 120 | GUNSTON - SCHOOL & EG | School | AC Unit | 43.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 121 | GUNSTON - SCHOOL & EG | School | Panelboards | 39.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 122 | GUNSTON - SCHOOL & EG | School | Electrical Panel | 40.16 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 123 | GUNSTON - SCHOOL & EG | School | Nac Extender | 41.41 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 124 | GUNSTON - SCHOOL & EG | School | Sump pump control panel | 31.1 | 31.1 | 11.19 | 12.08 | 12.58 | 11.28 | 12.11 | $ 4,648 |
| 125 | GUNSTON - SCHOOL & EG | School | Boiler Pumps | 32.85 | 31.1 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 | $ 1,992 |
| 126 | GUNSTON - SCHOOL & EG | School | Boiler pump VFDs | 33.43 | 31.1 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 22 |
| 127 | GUNSTON - SCHOOL & EG | School | Tank Motor (Domestic Hot Water Recirc. Pump) | 35.52 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 128 | GUNSTON - SCHOOL & EG | School | ALC Controls | 34.18 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 129 | GUNSTON - SCHOOL & EG | School | ALC Controls (fiber optic) | 32.35 | 31.1 | 0.20 | 0.21 | 0.23 | 0.20 | 0.21 | $ 117 |
| 130 | GUNSTON - SCHOOL & EG | School | Switchboard | 32.93 | 31.1 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | $ 92 |
| 131 | GUNSTON - SCHOOL & EG | School | Panelboards | 35.02 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 132 | GUNSTON - SCHOOL & EG | School | HVAC Pump drives VFD | 34.18 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 133 | GUNSTON - SCHOOL & EG | School | Boilers | 32.27 | 31.1 | 0.26 | 0.27 | 0.29 | 0.26 | 0.27 | $ 7,258 |
| 134 | GUNSTON - SCHOOL & EG | School | VFD for chimney fan | 34.68 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 135 | GUNSTON - SCHOOL & EG | School | Natural gas water heater | 31.52 | 31.1 | 2.88 | 3.08 | 3.26 | 2.90 | 3.09 | $ 6,545 |
| 136 | GUNSTON - SCHOOL & EG | School | Hot water circulation pump | 31.52 | 31.1 | 2.88 | 3.08 | 3.26 | 2.90 | 3.09 | $ 35,302 |
| 137 | GUNSTON - SCHOOL & EG | School | Remote control switch panel | 32.27 | 31.1 | 0.26 | 0.27 | 0.29 | 0.26 | 0.27 | $ 164 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 138 | GUNSTON - SCHOOL & EG | School | Panelboards | 35.1 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 139 | GUNSTON - SCHOOL & EG | School | Panelboards | 33.85 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 140 | GUNSTON - SCHOOL & EG | School | Utility meter | 39.75 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 141 | GUNSTON - SCHOOL & EG | School | Switchboard | 36.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 142 | GUNSTON - SCHOOL & EG | School | ATS | 41.08 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 143 | GUNSTON - SCHOOL & EG | School | Panelboards | 40.25 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 144 | GUNSTON - SCHOOL & EG | School | Panelboards | 38.91 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 145 | GUNSTON - SCHOOL & EG | School | Electrical panels | 40.5 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 146 | GUNSTON - SCHOOL & EG | School | ALC Controls | 37.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 147 | GUNSTON - SCHOOL & EG | School | Nac Extender | 39.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 148 | GUNSTON - SCHOOL & EG | School | Fire Safety Operator interface panel | 38 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 149 | GUNSTON - SCHOOL & EG | School | Disconnect Switch | 40.08 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 150 | GUNSTON - SCHOOL & EG | School | Heavy duty safety switch | 38.58 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 151 | GUNSTON - SCHOOL & EG | School | Security control panel | 34.93 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 152 | GUNSTON - SCHOOL & EG | School | Security panel | 33.52 | 31.1 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | $ 12 |
| 153 | GUNSTON - SCHOOL & EG | School | Ethernet box | 35.93 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 154 | GUNSTON - SCHOOL & EG | School | AC Unit | 39.27 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 155 | GUNSTON - SCHOOL & EG | School | Communications Network | 31.1 | 31.1 | 11.19 | 12.08 | 12.58 | 11.28 | 12.11 | $ 6,738 |
| 156 | GUNSTON - SCHOOL & EG | School | Panelboards | 40.66 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 157 | GUNSTON - SCHOOL & EG | School | Panelboards | 40.66 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 158 | GUNSTON - SCHOOL & EG | School | Transformer | 38.58 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 159 | GUNSTON - SCHOOL & EG | School | Breaker cabinet (Switchboard) | 38.41 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 160 | GUNSTON - SCHOOL & EG | School | Switchboard | 36.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 161 | GUNSTON - SCHOOL & EG | School | Ethernet box | 40.41 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 162 | GUNSTON - SCHOOL & EG | School | Communications Network | 36.58 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 163 | GUNSTON - SCHOOL & EG | School | Sump pump control panel | 31.1 | 31.1 | 11.19 | 12.08 | 12.58 | 11.28 | 12.11 | $ 12,735 |
| 164 | GUNSTON - SCHOOL & EG | School | Panelboards | 38.66 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 165 | GUNSTON - SCHOOL & EG | School | Panelboards | 39.75 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 166 | GUNSTON - SCHOOL & EG | School | Building power phase monitor | 39.75 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 167 | GUNSTON - SCHOOL & EG | School | Switchboard | 38.25 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 168 | GUNSTON - SCHOOL & EG | School | Nac Extender | 39.83 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 169 | GUNSTON - SCHOOL & EG | School | Panelboards | 40.08 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 170 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling Tower | 53.32 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 171 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Condensor Panel | 51.82 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 172 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Chill water pumps | 51.74 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 173 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Chill water variable speed drive | 49.99 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 174 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling Tower Pumps | 50.82 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 175 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling tower pumps variable speed drive | 51.91 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 176 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Pressure gauge | 53.49 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 177 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Flow monitor | 53.82 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 178 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Pump for ozone generator | 49.91 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 179 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Cooling tower pump (for water treatment) | 51.07 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 180 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | ALC Controls | 52.24 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 181 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | HVAC Drive | 53.57 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 182 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Panelboards | 50.91 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 183 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Transformer | 51.16 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 184 | GUNSTON - DETACHED MECHANICAL ROOM | Detached Mechanical Room | Panelboards | 52.91 | 49.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 185 | GUNSTON - SCHOOL & EG | Emergency Generator | Generator | 34.02 | 31.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 12 |
| 186 | LITTLE FALLS BOOSTER | Booster Station | PLC-RTU | 306.95 | 304.12 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | $ 137 |
| 187 | LITTLE FALLS BOOSTER | Booster Station | Battery | 305.74 | 304.12 | 0.07 | 0.08 | 0.08 | 0.07 | 0.08 | $ 40 |
| 188 | LITTLE FALLS BOOSTER | Booster Station | Battery Charger | 305.91 | 304.12 | 0.06 | 0.07 | 0.07 | 0.06 | 0.07 | $ 34 |
| 189 | LITTLE FALLS BOOSTER | Booster Station | SCADA Panel | 306.99 | 304.12 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | $ 150 |
| 190 | LITTLE FALLS BOOSTER | Booster Station | VFD | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 11,076 |
| 191 | LITTLE FALLS BOOSTER | Booster Station | Pump Control Disconnect | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 1,476 |
| 192 | LITTLE FALLS BOOSTER | Booster Station | Fan and Motor | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 776 |
| 193 | LITTLE FALLS BOOSTER | Booster Station | Motor Control Center | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 55,652 |
| 194 | LITTLE FALLS BOOSTER STATION | Booster Station | Utility Charger (Battery Charger) | 307.99 | 304.12 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 11 |
| 195 | LITTLE FALLS BOOSTER | Booster Station | Utility Meter | 306.16 | 304.12 | 0.05 | 0.06 | 0.06 | 0.05 | 0.06 | $ 10 |
| 196 | LITTLE FALLS BOOSTER | Booster Station | High Service Pump | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 55,662 |
| 197 | LITTLE FALLS BOOSTER | Booster Station | Fan and Motor | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 163 |
| 198 | LITTLE FALLS BOOSTER | Booster Station | Fan and Motor | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 163 |
| 199 | LITTLE FALLS BOOSTER | Booster Station | Chlorine Analyser | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 886 |
| 200 | LITTLE FALLS BOOSTER | Booster Station | Disconnect Switch | 304.12 | 304.12 | 0.23 | 0.27 | 0.31 | 0.23 | 0.27 | $ 490 |
| 201 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Panelboards | 219.5 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 202 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Transformer | 218.33 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 203 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Computing Device | 220 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 204 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Nac Extender | 219.66 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 205 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker | 220.16 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 206 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Telecom board | 217.83 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 207 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Panelboard (Switchboard) | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 100,993 |
| 208 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Sensor Dimming System | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 10,365 |
| 209 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Transformer | 204.58 | 203.16 | 0.10 | 0.13 | 0.16 | 0.10 | 0.14 | $ 953 |
| 210 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Nac Extender | 205.91 | 203.16 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 4 |
| 211 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | AHU Control Panel | 205.08 | 203.16 | 0.03 | 0.05 | 0.06 | 0.03 | 0.05 | $ 18 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 212 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Air Handling unit | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 107,178 |
| 213 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | AHU Control Panel | 220 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 214 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | AHU Control Panel | 220 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 215 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | AHU Control Panel | 205.08 | 203.16 | 0.03 | 0.05 | 0.06 | 0.03 | 0.05 | $ 29 |
| 216 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Air Handling unit | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 107,178 |
| 217 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breakers | 207.41 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 218 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 1,440 |
| 219 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Security Fire Panel | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 3,073 |
| 220 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Panelboard (Switchboard) | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 1,615,893 |
| 221 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Signal Generator Output Disc. Switch | 204.33 | 203.16 | 0.16 | 0.22 | 0.28 | 0.17 | 0.23 | $ 18 |
| 222 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Electrical Cabinet | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 1,440 |
| 223 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Electrical equipment | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 4,321 |
| 224 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Utility meter | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 1,683 |
| 225 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Fire Panel | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 3,073 |
| 226 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Cooling Tower Fan Controls | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 10,773 |
| 227 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | HWS Pumps and motors | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 6,531 |
| 228 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Boilers | 205.49 | 203.16 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | $ 470 |
| 229 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Cooling water pumps | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 6,430 |
| 230 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | MCC | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 31,121 |
| 231 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | VFDs | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 8,465 |
| 232 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Condensation pumps | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 4,499 |
| 233 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Chiller 1 | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 55,731 |
| 234 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Chiller 2 | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 55,731 |
| 235 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Transformer | 203.24 | 203.16 | 1.77 | 2.09 | 2.91 | 1.80 | 2.15 | $ 3,459 |
| 236 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 2,834 |
| 237 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Hot water control panel | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 6,060 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 238 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Air Handling unit | 203.41 | 203.16 | 1.22 | 1.48 | 2.02 | 1.25 | 1.51 | $ 45,808 |
| 239 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Air Handling unit | 203.16 | 203.16 | 2.10 | 2.46 | 3.46 | 2.14 | 2.53 | $ 77,681 |
| 240 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker (small) | 206.21 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 5 |
| 241 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker (large) | 204.8 | 203.16 | 0.06 | 0.09 | 0.10 | 0.06 | 0.09 | $ 111 |
| 242 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Fuse boxes (Disc. Switch) | 207.88 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 243 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Panelboards | 206.21 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 2 |
| 244 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Panelboards | 206.21 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 2 |
| 245 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Light control panel | 207.71 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 246 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Master control panel | 205.91 | 203.16 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 6 |
| 247 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Transformer | 207.24 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 248 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Swichboard | 204.99 | 203.16 | 0.04 | 0.06 | 0.07 | 0.04 | 0.06 | $ 2,127 |
| 249 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker | 206.21 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 5 |
| 250 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Finned-Tube Terminal Radiator | 203.41 | 203.16 | 1.22 | 1.48 | 2.02 | 1.25 | 1.51 | $ 6,204 |
| 251 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Swichboard | 217.16 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 252 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Breaker | 206.21 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 3 |
| 253 | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | School and Community Center | Transformer | 219.75 | 203.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 254 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | Diesel Engine Generator | 205.69 | 201.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 255 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | ATS | 203.28 | 201.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 256 | TJ MIDDLE SCHOOL - SITE EG | Emergency Generator | Transformer | 203.69 | 201.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 257 | TRADESCENTER-NOCII | Network Operations Center | Circuit Breaker | 87.91 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 258 | TRADESCENTER-NOCII | Network Operations Center | Transformer | 88.5 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 259 | TRADESCENTER-NOCII | Network Operations Center | Air Handling Unit | 88.5 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 260 | TRADESCENTER-NOCII | Network Operations Center | ATS | 87.33 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 261 | TRADESCENTER-NOCII | Network Operations Center | Switchboard | 87.16 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 262 | TRADESCENTER-NOCII | Network Operations Center | Power Supply Cabinet | 86.83 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 263 | TRADESCENTER-NOCII | Network Operations Center | Fire Alarm Panel | 88.83 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 264 | TRADESCENTER-NOCII | Network Operations Center | Power Monitoring System | 86.83 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 265 | TRADESCENTER-NOCII | Network Operations Center | Air Handling Unit | 87.33 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 266 | TRADESCENTER-NOCII | Network Operations Center | Data/Comm Panels | 90.75 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 267 | TRADESCENTER-NOCII | Network Operations Center | Leak Alert System | 90.58 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 268 | TRADESCENTER-NOCII | Network Operations Center | Heavy Duty Safety Switch | 87.16 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 269 | TRADESCENTER-NOCII | Network Operations Center | Server Cabinets | 87.16 | 86.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 270 | TRADESCENTER-NOCII- | Outside Transformer | Transformer | 87.49 | 86.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 271 | TRADESCENTER-NOCII-SITEEG | Outside Emergency Generator | Diesel Engine Generator | 89.41 | 87.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 272 | VAHOSPITAL CENTER - FOOT | Foot and Ankle Bldg | cooling and heating pumps | 317.3 | 317.3 | 21.56 | 33.70 | 49.68 | 22.77 | 34.77 | $ 2,085,729 |
| 273 | VAHOSPITAL CENTER - FOOT | Foot and Ankle Bldg | Heat Exchange | 317.3 | 317.3 | 21.56 | 33.70 | 49.68 | 22.77 | 34.77 | $ 140,858 |
| 274 | VAHOSPITAL CENTER - FOOT AND ANKLE BLDG | Foot and Ankle Bldg | Water Filtration system Control Panel | 317.3 | 317.3 | 21.56 | 33.70 | 49.68 | 22.77 | 34.77 | $ 314,965 |
| 275 | VAHOSPITAL CENTER - FOOT | Foot and Ankle Bldg | Electric Water Heater | 317.3 | 317.3 | 21.56 | 33.70 | 49.68 | 22.77 | 34.77 | $ 18,371 |
| 276 | VAHOSPITAL CENTER - FOOT | Foot and Ankle Bldg | MCC | 317.3 | 317.3 | 21.56 | 33.70 | 49.68 | 22.77 | 34.77 | $ 6,194,346 |
| 277 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Generator | 308.69 | 307.36 | 0.06 | 0.07 | 0.08 | 0.06 | 0.07 | $ 7,972 |
| 278 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Transformer | 310.03 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 279 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Pumps | 309.36 | 307.36 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 487 |
| 280 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Boiler (Version 1) | 308.53 | 307.36 | 0.10 | 0.11 | 0.14 | 0.10 | 0.12 | $ 1,895 |
| 281 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Boiler (Version 2) | 308.53 | 307.36 | 0.10 | 0.11 | 0.14 | 0.10 | 0.12 | $ 3,790 |
| 282 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | MCC | 309.03 | 307.36 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | $ 11,742 |
| 283 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | MCC | 308.61 | 307.36 | 0.08 | 0.09 | 0.10 | 0.08 | 0.09 | $ 24,334 |
| 284 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Transformer | 309.69 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 6 |
| 285 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Transformer | 310.44 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 286 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Condensor Return System | 308.36 | 307.36 | 0.17 | 0.21 | 0.26 | 0.18 | 0.21 | $ 491 |
| 287 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Air Compressor Unit | 308.53 | 307.36 | 0.10 | 0.11 | 0.14 | 0.10 | 0.12 | $ 1,148 |
| 288 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Air Compressor Unit | 309.44 | 307.36 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | $ 53 |
| 289 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | MCC | 308.36 | 307.36 | 0.17 | 0.21 | 0.26 | 0.18 | 0.21 | $ 56,870 |
| 290 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | ACH580-01 drives | 309.03 | 307.36 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | $ 299 |
| 291 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Secondary Chiller Pumps | 309.19 | 307.36 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 1,594 |
| 292 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | VFD | 308.03 | 307.36 | 0.50 | 0.68 | 0.90 | 0.52 | 0.69 | $ 11,641 |
| 293 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Primary Chiller Pumps | 308.69 | 307.36 | 0.06 | 0.07 | 0.08 | 0.06 | 0.07 | $ 9,371 |
| 294 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Water Filtration System | 309.36 | 307.36 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | $ 2,411 |
| 295 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Chiller (Version 1) | 311.78 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 296 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Chiller (Version 2) | 308.53 | 307.36 | 0.10 | 0.11 | 0.14 | 0.10 | 0.12 | $ 5,213 |
| 297 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Control Panels | 309.69 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 24 |
| 298 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Condensor Water Pump Panel | 312.03 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 299 | VAHOSPITAL CENTER - MAIN | Main Mechanical Bldg | Simens Control Panel | 310.53 | 307.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 10 |
| 300 | VAHOSPITAL CENTER - NEW | New Parking Structure | Garage Fan System Motor | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 2,275 |
| 301 | VAHOSPITAL CENTER - NEW | New Parking Structure | Sump Pump | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 591 |
| 302 | VAHOSPITAL CENTER - NEW | New Parking Structure | Sump Pump Control Panel | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 40,484 |
| 303 | VAHOSPITAL CENTER - NEW | New Parking Structure | Transformer | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 8,675 |
| 304 | VAHOSPITAL CENTER - NEW | New Parking Structure | Transformer | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 11,058 |
| 305 | VAHOSPITAL CENTER - NEW | New Parking Structure | Control Panels (Large) | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 140,537 |
| 306 | VAHOSPITAL CENTER - NEW | New Parking Structure | Control Panels (Small) | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 210,806 |
| 307 | VAHOSPITAL CENTER - NEW | New Parking Structure | Panelboards | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 32,351 |
| 308 | VAHOSPITAL CENTER - NEW | New Parking Structure | Panelboards | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ 9,426 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 309 | VAHOSPITAL CENTER - NEW PARKING STRUCTURE | New Parking Structure | Communication Asset Panel (Comba Critical Point) | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ | 70,269 |
| 310 | VAHOSPITAL CENTER - NEW | New Parking Structure | Swichboard | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ | 118,137 |
| 311 | VAHOSPITAL CENTER - NEW | New Parking Structure | Generator | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ | 791,741 |
| 312 | VAHOSPITAL CENTER - NEW PARKING STRUCTURE | New Parking Structure | Electric panel for Fuel Tank (Day Tank Transfer Pump Control) | 318.67 | 318.67 | 5.30 | 7.03 | 10.15 | 5.47 | 7.24 | $ | 70,269 |
| 313 | WPCP - SECURITY GATES | Security Gates | Security gate panels | 11.67 | 10.62 | 15.68 | 32.93 | 75.04 | 17.40 | 35.74 | $ | 3,990,536 |
| 314 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup Structure/PTB Bypass Flow Distribution Structure - PIBS/PBFDS | Flow Meters | 21.99 | 18.66 | 0.00 | 0.01 | 0.04 | 0.00 | 0.01 | $ | 161 |
| 315 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup Structure/PTB Bypass Flow Distribution Structure - PIBS/PBFDS | Control Panel - Closed | 22.33 | 18.66 | 0.00 | 0.01 | 0.03 | 0.00 | 0.01 | $ | 124 |
| 316 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup Structure/PTB Bypass Flow Distribution Structure - PIBS/PBFDS | VFD | 19.33 | 18.66 | 0.03 | 0.15 | 0.45 | 0.04 | 0.17 | $ | 1,875 |
| 317 | WPCP - 03 - PIBS/PBFDS | 03 - Potomac Interceptor Backup Structure/PTB Bypass Flow Distribution Structure - PIBS/PBFDS | Processor Panel | 18.99 | 18.66 | 0.04 | 0.22 | 0.61 | 0.06 | 0.25 | $ | 1,573 |
| 318 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | MCC | 24.74 | 23.66 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | $ | 1,776 |
| 319 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | VFD | 24.66 | 23.66 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | $ | 249 |
| 320 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Processor Panel | 24.74 | 23.66 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | $ | 68 |
| 321 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | | 28.66 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ | 3 |
| 322 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Fan control panel | 25.74 | 23.66 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | $ | 36 |
| 323 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Fiber Box | 27.24 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ | 4 |
| 324 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Control Panel - HOR | 28.49 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ | 6 |
| 325 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Breaker | 27.49 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ | 1 |
| 326 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Transformer | 25.83 | 23.66 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | $ | 17 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 327 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Switch Disconnect Switch | 28.49 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 0 |
| 328 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Control Panel | 27.16 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 14 |
| 329 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Control Panel - Closed | 28.24 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 15 |
| 330 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Breaker | 27.33 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 1 |
| 331 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Pump and motor | 25.58 | 23.66 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | $ 263 |
| 332 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Pump and motor | 26.16 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 121 |
| 333 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Motor | 26.66 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 94 |
| 334 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Relay Panel | 24.66 | 23.66 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | $ 71 |
| 335 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Pump and motor | 24.66 | 23.66 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | $ 75 |
| 336 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Electrical Panel | 28.08 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 8 |
| 337 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Control Panel - Old | 24.66 | 23.66 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | $ 71 |
| 338 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Electrical cabinet | 24.66 | 23.66 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | $ 71 |
| 339 | WPCP - 04 - DAFT | 04 - Dissolved Air Floatation Building - DAFT | Electrical Panel | 26.58 | 23.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 21 |
| 340 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Sludge Pump Control Panels | 25.24 | 22.16 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | $ 197 |
| 341 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Gravity Thickened Sludge Pump Control Panel/Sludge Storage Tanks | 24.24 | 22.16 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | $ 93 |
| 342 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Processor Panel | 23.08 | 22.16 | 0.01 | 0.02 | 0.04 | 0.01 | 0.02 | $ 195 |
| 343 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Foul Air Blower Control Panel | 24.24 | 22.16 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | $ 93 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 344 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Clarifier Control Panel | 25.24 | 22.16 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | $ 49 |
| 345 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Electrical cabinet | 24.91 | 22.16 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | $ 122 |
| 346 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Electrical cabinet | 22.49 | 22.16 | 0.02 | 0.03 | 0.05 | 0.02 | 0.03 | $ 568 |
| 347 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Ac Unit | 23.16 | 22.16 | 0.01 | 0.02 | 0.03 | 0.01 | 0.02 | $ 10 |
| 348 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Grinder control panels | 22.16 | 22.16 | 0.02 | 0.04 | 0.07 | 0.02 | 0.04 | $ 1,403 |
| 349 | WPCP - 05 - PGTB | 05 -Primary Gravity Thickener Building and Tanks - PGTB | Grinders | 22.16 | 22.16 | 0.02 | 0.04 | 0.07 | 0.02 | 0.04 | $ 787 |
| 350 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | MCC | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 26,686 |
| 351 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Sludge Transfer Control Panel | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,018 |
| 352 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Relay Panel | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,018 |
| 353 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Boiler | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 166 |
| 354 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Junction Box | 21.66 | 20.49 | 0.03 | 0.05 | 0.09 | 0.03 | 0.06 | $ 20 |
| 355 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Breaker | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 113 |
| 356 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Transformer | 26.49 | 20.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 12 |
| 357 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Electrical cabinet | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,018 |
| 358 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Control panel | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 2,035 |
| 359 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Gas detection sensor | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,618 |
| 360 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Ventilation Control Panel | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,018 |
| 361 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Switch Disconnect Switch | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 4 |
| 362 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Breaker | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 169 |
| 363 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Grinder control panels | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 2,035 |
| 364 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Sump pump control panel | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 1,018 |
| 365 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Grinder | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 4,802 |
| 366 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Sludge Transfer Pumps (small) | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 4,493 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 367 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Sludge Transfer Pump (large) | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 3,274 |
| 368 | WPCP - 06 - SST | 06 - Sludge Storage Tanks (SST1, SST2) | Small pump | 20.49 | 20.49 | 0.06 | 0.11 | 0.20 | 0.07 | 0.12 | $ 534 |
| 369 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Primary Sludge Pumps 1-8 | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 40,833 |
| 370 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Grit pump control panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 371 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Clarifier drain pump | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 5,104 |
| 372 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Drain/sludge transfer pump | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 5,104 |
| 373 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Grit Pumps | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 20,416 |
| 374 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Sump pump control panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 375 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Seal water pump control panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 376 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Sump Pump control panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 377 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Primary Clarifier Panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 378 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Scum Slurry Pumps | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 10,208 |
| 379 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Grinders | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,593 |
| 380 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Panels - scum mixer, foul air blower ventilation, sump pump, grinders | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 11,562 |
| 381 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Scum Slurry Pump Control Panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 382 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Scum Electrical Panels | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 4,625 |
| 383 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Primary Clarifier Scum Collection Control | 21.5 | 19.16 | 0.02 | 0.05 | 0.13 | 0.02 | 0.06 | $ 234 |
| 384 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Grit Turbine Drive Control Panel | 19.66 | 19.16 | 0.07 | 0.20 | 0.41 | 0.09 | 0.21 | $ 1,591 |
| 385 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Ventilation Control Panel | 21.66 | 19.16 | 0.01 | 0.05 | 0.12 | 0.02 | 0.05 | $ 361 |
| 386 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Polymer Dilution Transfer Control Panel | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,312 |
| 387 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Polymer Recirc Pumps | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,426 |
| 388 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Grit Turbine and Motor | 19.83 | 19.16 | 0.06 | 0.18 | 0.37 | 0.07 | 0.19 | $ 2,357 |
| 389 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Hypo Feed/Transfer Pump Control Panel | 21.5 | 19.16 | 0.02 | 0.05 | 0.13 | 0.02 | 0.06 | $ 1,624 |
| 390 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Transfer Pumps | 19.16 | 19.16 | 0.11 | 0.29 | 0.56 | 0.13 | 0.30 | $ 2,426 |
| 391 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | FIT Junction Box | 20.16 | 19.16 | 0.05 | 0.14 | 0.30 | 0.06 | 0.15 | $ 69 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 392 | WPCP - 09 - PTB | 09 - Preliminary Treatment Building - PTB | Local control panel | 20 | 19.16 | 0.05 | 0.16 | 0.33 | 0.06 | 0.17 | $ 1,234 |
| 393 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | PCL Panels | 19.34 | 15.34 | 0.13 | 0.24 | 0.43 | 0.14 | 0.25 | $ 2,120 |
| 394 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Belt drive motor 1 | 16.34 | 15.34 | 0.85 | 1.62 | 3.26 | 0.93 | 1.73 | $ 32,286 |
| 395 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Belt drive motor 2 | 16.34 | 15.34 | 0.85 | 1.62 | 3.26 | 0.93 | 1.73 | $ 32,286 |
| 396 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Sluice Gate Controls/Power | 15.92 | 15.34 | 1.11 | 2.13 | 4.32 | 1.21 | 2.28 | $ 130,148 |
| 397 | WPCP - 10 - PCL | 10 - Primary Clarifiers - PCL | Collector Panel | 17.01 | 15.34 | 0.56 | 1.06 | 2.08 | 0.61 | 1.12 | $ 9,383 |
| 398 | WPCP - 11 - FET - 1AND2 | 11 - Flow Equalization Tanks 1 and 2 | Flow equalization electrical panel | 11.99 | 10.66 | 12.98 | 26.98 | 61.29 | 14.38 | 29.27 | $ 1,405,616 |
| 399 | WPCP - 11 - FET - 1AND2 | 11 - Flow Equalization Tanks 1 and 2 | Junction Box | 11.66 | 10.66 | 15.95 | 33.38 | 76.53 | 17.69 | 36.26 | $ 6,104 |
| 400 | WPCP - 11 - FET - 3 | 11 - Flow Equalization Tanks 3 | Flow equalization electrical panel | 11.79 | 10.46 | 14.71 | 30.70 | 70.12 | 16.30 | 33.33 | $ 1,597,873 |
| 401 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Recirculation Pump and Motor | 13.99 | 12.66 | 3.70 | 7.42 | 15.82 | 4.07 | 7.98 | $ 286,266 |
| 402 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Recirculation Pump Control Panel | 15.83 | 12.66 | 1.18 | 2.27 | 4.60 | 1.28 | 2.42 | $ 19,992 |
| 403 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Scrubber Supply Fan Motor | 14.33 | 12.66 | 2.99 | 5.96 | 12.59 | 3.29 | 6.40 | $ 197,110 |
| 404 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Caustic Pump and Motor | 14.99 | 12.66 | 1.98 | 3.89 | 8.08 | 2.17 | 4.17 | $ 2,610 |
| 405 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Sodium hypochlorite controls | 14.33 | 12.66 | 2.99 | 5.96 | 12.59 | 3.29 | 6.40 | $ 120,228 |
| 406 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | NOC Pumps and Motors | 14.33 | 12.66 | 2.99 | 5.96 | 12.59 | 3.29 | 6.40 | $ 54,741 |
| 407 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 13.83 | 12.66 | 4.08 | 8.23 | 17.61 | 4.50 | 8.86 | $ 1,399 |
| 408 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 14.99 | 12.66 | 1.98 | 3.89 | 8.08 | 2.17 | 4.17 | $ 594 |
| 409 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | NFF Fan Controls | 14.24 | 12.66 | 3.16 | 6.32 | 13.37 | 3.48 | 6.79 | $ 31,838 |
| 410 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Fire Alarm Control Panel | 14.91 | 12.66 | 2.09 | 4.10 | 8.53 | 2.29 | 4.40 | $ 4,250 |
| 411 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Ferric Pumps and Motors | 15.33 | 12.66 | 1.61 | 3.13 | 6.43 | 1.76 | 3.35 | $ 1,103 |
| 412 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Water Heater | 13.83 | 12.66 | 4.08 | 8.23 | 17.61 | 4.50 | 8.86 | $ 2,048 |
| 413 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 14.49 | 12.66 | 2.71 | 5.38 | 11.31 | 2.97 | 5.77 | $ 3,211 |
| 414 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Gas Monitor | 14.58 | 12.66 | 2.56 | 5.07 | 10.64 | 2.81 | 5.44 | $ 70,700 |
| 415 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Pump Controls - Hypo, Ferric, Caustic | 14.66 | 12.66 | 2.44 | 4.82 | 10.09 | 2.67 | 5.17 | $ 73,014 |
| 416 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | MCC | 13.66 | 12.66 | 4.54 | 9.18 | 19.74 | 5.00 | 9.89 | $ 1,575,000 |
| 417 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Processor Panel | 13.66 | 12.66 | 4.54 | 9.18 | 19.74 | 5.00 | 9.89 | $ 160,168 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 418 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Electrical cabinet | 13.66 | 12.66 | 4.54 | 9.18 | 19.74 | 5.00 | 9.89 | $ 320,337 |
| 419 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Hypo Pump Local Control Panel (3-4) | 14.99 | 12.66 | 1.98 | 3.89 | 8.08 | 2.17 | 4.17 | $ 34,206 |
| 420 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box | 14.91 | 12.66 | 2.09 | 4.10 | 8.53 | 2.29 | 4.40 | $ 156 |
| 421 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box (at grade) | 14.74 | 12.66 | 2.32 | 4.58 | 9.56 | 2.54 | 4.91 | $ 349 |
| 422 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Junction Box (below grade) | 12.66 | 12.66 | 8.46 | 17.51 | 38.63 | 9.36 | 18.91 | $ 3,958 |
| 423 | WPCP - 26 - NFF | 26 - North Ferric Facility (NFF) | Tank Controls | 13.16 | 12.66 | 6.20 | 12.68 | 27.62 | 6.85 | 13.67 | $ 63,533 |
| 424 | WPCP - 30 - PEF | 30 - Primary Effluent Flume | Level Indicator Transmitter | 12.25 | 11.5 | 12.56 | 21.56 | 47.36 | 13.46 | 23.28 | $ 105,657 |
| 425 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - PCL | FEQ Pump and Motor | 16.1 | 13.6 | 0.99 | 1.57 | 2.58 | 1.04 | 1.63 | $ 376,446 |
| 426 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - PCL | FEQ Pump Controls | 16.52 | 13.6 | 0.79 | 1.27 | 2.09 | 0.84 | 1.33 | $ 54,575 |
| 427 | WPCP - 40 - FEPS - PCL | 40 - Flow Equalization Pump Station - PCL | Junction Box | 16.02 | 13.6 | 1.03 | 1.63 | 2.69 | 1.09 | 1.70 | $ 529 |
| 428 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | MCC | 15.35 | 14.1 | 1.45 | 2.27 | 3.76 | 1.53 | 2.37 | $ 559,383 |
| 429 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | VFD | 14.93 | 14.1 | 1.80 | 2.80 | 4.63 | 1.90 | 2.92 | $ 45,992 |
| 430 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Power Transfer Switch | 15.43 | 14.1 | 1.39 | 2.18 | 3.61 | 1.47 | 2.28 | $ 1,266 |
| 431 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Electrical cabinet | 16.18 | 14.1 | 0.95 | 1.50 | 2.48 | 1.00 | 1.57 | $ 42,149 |
| 432 | WPCP - 40 - FEPS | 40 - Flow Equalization Pump Station | Air Handling Unit | 16.6 | 14.1 | 0.76 | 1.22 | 2.01 | 0.81 | 1.27 | $ 22,662 |
| 433 | WPCP - 40 - FEPS - GROUND | 40 - Flow Equalization Pump Station - Ground | Junction Box | 14.23 | 12.9 | 2.57 | 3.96 | 6.58 | 2.71 | 4.14 | $ 1,581 |
| 434 | WPCP - 43 - LLPS | 43 - Low Level Pump Station | Electrical cabinet | 11.64 | 10.56 | 15.96 | 33.77 | 76.57 | 17.74 | 36.62 | $ 291,507 |
| 435 | WPCP - FA | Foul Air | Foul Air Blower Control Panel | 12.39 | 10.06 | 10.03 | 20.91 | 46.88 | 11.12 | 22.64 | $ 181,185 |
| 436 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Switch | 15 | 14.33 | 1.98 | 3.89 | 8.16 | 2.17 | 4.17 | $ 2,156 |
| 437 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Air Compressors | 14.33 | 14.33 | 3.00 | 5.99 | 12.78 | 3.30 | 6.45 | $ 74,410 |
| 438 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Air Handler | 14.33 | 14.33 | 3.00 | 5.99 | 12.78 | 3.30 | 6.45 | $ 104,531 |
| 439 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | HVAC VFD | 15.16 | 14.33 | 1.79 | 3.51 | 7.33 | 1.96 | 3.76 | $ 2,923 |
| 440 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | HVAC Electrical Panel | 15.33 | 14.33 | 1.61 | 3.14 | 6.54 | 1.76 | 3.37 | $ 27,678 |
| 441 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Boilers | 15.58 | 14.33 | 1.38 | 2.68 | 5.53 | 1.51 | 2.87 | $ 7,673 |
| 442 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Water Heater | 18.33 | 14.33 | 0.25 | 0.45 | 0.88 | 0.27 | 0.48 | $ 116 |
| 443 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Switch | 18.5 | 14.33 | 0.22 | 0.41 | 0.78 | 0.24 | 0.43 | $ 307 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 444 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Breakers (large) | 16 | 14.33 | 1.06 | 2.04 | 4.18 | 1.16 | 2.18 | $ 2,994 |
| 445 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Breakers (small) | 17.16 | 14.33 | 0.52 | 0.97 | 1.92 | 0.56 | 1.03 | $ 951 |
| 446 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical cabinets | 14.91 | 14.33 | 2.09 | 4.12 | 8.67 | 2.30 | 4.43 | $ 72,409 |
| 447 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Switch | 17.41 | 14.33 | 0.44 | 0.82 | 1.62 | 0.48 | 0.88 | $ 308 |
| 448 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Power Transfer Switch | 15.16 | 14.33 | 1.79 | 3.51 | 7.33 | 1.96 | 3.76 | $ 3,812 |
| 449 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | DoD communication network | 15.16 | 14.33 | 1.79 | 3.51 | 7.33 | 1.96 | 3.76 | $ 1,092 |
| 450 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 15.16 | 14.33 | 1.79 | 3.51 | 7.33 | 1.96 | 3.76 | $ 40,430 |
| 451 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 17.41 | 14.33 | 0.44 | 0.82 | 1.62 | 0.48 | 0.88 | $ 308 |
| 452 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Electrical Box | 14.33 | 14.33 | 3.00 | 5.99 | 12.78 | 3.30 | 6.45 | $ 231,601 |
| 453 | WPCP - 12 - OCB | 12 -Operations Control Building - OCB | Transformer | 14.33 | 11.33 | 3.00 | 5.99 | 12.78 | 3.30 | 6.45 | $ 373,150 |
| 454 | WPCP - 13 - SBB - TRANSFORMER | 13 - Secondary Blower Building - SBB - Transformer | Transformer | 13.74 | 12.91 | 3.02 | 4.92 | 8.12 | 3.21 | 5.13 | $ 60,332 |
| 455 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | NaOH Metering Pumps | 16.99 | 14.16 | 0.62 | 1.01 | 1.66 | 0.66 | 1.05 | $ 14,716 |
| 456 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | NaOCl Metering Pumps | 16.99 | 14.16 | 0.62 | 1.01 | 1.66 | 0.66 | 1.05 | $ 19,621 |
| 457 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Recirc pumps | 15.74 | 14.16 | 1.14 | 1.86 | 3.06 | 1.21 | 1.94 | $ 151,775 |
| 458 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Water Heater | 14.99 | 14.16 | 1.65 | 2.67 | 4.41 | 1.75 | 2.79 | $ 706 |
| 459 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Flow and level meters | 18.83 | 14.16 | 0.25 | 0.41 | 0.68 | 0.27 | 0.43 | $ 41,468 |
| 460 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | NaOH Metering Transfer Pumps | 16.83 | 14.16 | 0.67 | 1.09 | 1.80 | 0.71 | 1.14 | $ 10,606 |
| 461 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Fire alarm control panel | 18.49 | 14.16 | 0.30 | 0.49 | 0.80 | 0.32 | 0.51 | $ 532 |
| 462 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Blower switches | 15.16 | 14.16 | 1.52 | 2.46 | 4.06 | 1.61 | 2.57 | $ 2,397 |
| 463 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Generator Terminal Box | 16.41 | 14.16 | 0.83 | 1.34 | 2.21 | 0.88 | 1.40 | $ 1,283 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 464 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Switch Disconnect Switch | 18.58 | 14.16 | 0.29 | 0.46 | 0.76 | 0.30 | 0.48 | $ 36 |
| 465 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Power source (Non ventilated transformer) | 19.91 | 14.16 | 0.15 | 0.24 | 0.40 | 0.16 | 0.25 | $ 73 |
| 466 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Switchboard | 14.83 | 14.16 | 1.78 | 2.89 | 4.77 | 1.89 | 3.02 | $ 562,879 |
| 467 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Odor control panel | 15.33 | 14.16 | 1.40 | 2.27 | 3.74 | 1.48 | 2.36 | $ 20,990 |
| 468 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | MCC | 15.16 | 14.16 | 1.52 | 2.46 | 4.06 | 1.61 | 2.57 | $ 448,452 |
| 469 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Control panels | 15.74 | 14.16 | 1.14 | 1.86 | 3.06 | 1.21 | 1.94 | $ 51,569 |
| 470 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Breakers (small) | 17.33 | 14.16 | 0.53 | 0.85 | 1.41 | 0.56 | 0.89 | $ 1,754 |
| 471 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Transformer | 16.16 | 14.16 | 0.93 | 1.51 | 2.49 | 0.99 | 1.58 | $ 3,459 |
| 472 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Transformer | 16.33 | 14.16 | 0.86 | 1.39 | 2.29 | 0.91 | 1.45 | $ 2,029 |
| 473 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Flow meters | 18.99 | 14.16 | 0.24 | 0.38 | 0.63 | 0.25 | 0.40 | $ 9,590 |
| 474 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Breakers (large) | 15.66 | 14.16 | 1.19 | 1.93 | 3.18 | 1.26 | 2.01 | $ 989 |
| 475 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Switch Disconnect Switch | 17.83 | 14.16 | 0.41 | 0.67 | 1.10 | 0.44 | 0.70 | $ 59 |
| 476 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Pull box | 14.99 | 14.16 | 1.65 | 2.67 | 4.41 | 1.75 | 2.79 | $ 801 |
| 477 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB - UpperLevel | MCC | 16.66 | 15.66 | 0.73 | 1.18 | 1.95 | 0.78 | 1.24 | $ 431,893 |
| 478 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB - UpperLevel | Fire alarm control panel | 17.74 | 15.66 | 0.43 | 0.70 | 1.15 | 0.46 | 0.73 | $ 766 |
| 479 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB - UpperLevel | Generator Terminal Box (Bus Duct Stub) | 19.41 | 15.66 | 0.19 | 0.31 | 0.51 | 0.20 | 0.32 | $ 260 |
| 480 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB - UpperLevel | Power panel | 19.08 | 15.66 | 0.23 | 0.36 | 0.60 | 0.24 | 0.38 | $ 3,377 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 481 | WPCP - 13 - SBB - UL | 13 - Secondary Blower Building - SBB - UpperLevel | Transfer Switch Disconnect Switch | 19.08 | 15.66 | 0.23 | 0.36 | 0.60 | 0.24 | 0.38 | $ 248 |
| 482 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Blower motor control panel | 15.16 | 14.16 | 1.52 | 2.46 | 4.06 | 1.61 | 2.57 | $ 68,407 |
| 483 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Blower Motor | 21.83 | 14.16 | 0.06 | 0.10 | 0.16 | 0.06 | 0.10 | $ 4,376 |
| 484 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Small motor | 19.33 | 14.16 | 0.20 | 0.32 | 0.53 | 0.21 | 0.34 | $ 5,030 |
| 485 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Breaker | 16.91 | 14.16 | 0.65 | 1.05 | 1.73 | 0.69 | 1.09 | $ 538 |
| 486 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Security panel | 16.66 | 14.16 | 0.73 | 1.18 | 1.95 | 0.78 | 1.24 | $ 10,980 |
| 487 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Network cabinet | 17.91 | 14.16 | 0.40 | 0.64 | 1.06 | 0.42 | 0.67 | $ 116 |
| 488 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Processor Panel | 15.16 | 14.16 | 1.52 | 2.46 | 4.06 | 1.61 | 2.57 | $ 22,802 |
| 489 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Air handling unit | 16.24 | 14.16 | 0.90 | 1.45 | 2.40 | 0.95 | 1.52 | $ 26,846 |
| 490 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Blower Motor | 21.83 | 14.16 | 0.06 | 0.10 | 0.16 | 0.06 | 0.10 | $ 2,917 |
| 491 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Blower motor control panel | 15.16 | 14.16 | 1.52 | 2.46 | 4.06 | 1.61 | 2.57 | $ 45,605 |
| 492 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Small motor | 19.33 | 14.16 | 0.20 | 0.32 | 0.53 | 0.21 | 0.34 | $ 3,353 |
| 493 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Air compressor control | 18.83 | 14.16 | 0.25 | 0.41 | 0.68 | 0.27 | 0.43 | $ 2,198 |
| 494 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Switch Disconnect Switch | 18.58 | 14.16 | 0.29 | 0.46 | 0.76 | 0.30 | 0.48 | $ 54 |
| 495 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Breaker (small) | 18.49 | 14.16 | 0.30 | 0.49 | 0.80 | 0.32 | 0.51 | $ 249 |
| 496 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Electrical cabinet | 14.74 | 14.16 | 1.86 | 3.02 | 4.99 | 1.98 | 3.15 | $ 27,980 |
| 497 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Transformer | 16.33 | 14.16 | 0.86 | 1.39 | 2.29 | 0.91 | 1.45 | $ 1,592 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 498 | WPCP - 13 - SBB - LL | 13 - Secondary Blower Building - SBB - LowerLevel | Breaker (large) | 15.58 | 14.16 | 1.24 | 2.01 | 3.31 | 1.31 | 2.09 | $ 1,028 |
| 499 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT - LowerEL | Submersible mixer control panel | 12.91 | 10.41 | 4.58 | 7.47 | 12.19 | 4.87 | 7.78 | $ 828,090 |
| 500 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT - LowerEL | Mixer motor | 11.66 | 10.41 | 8.44 | 13.79 | 22.55 | 8.98 | 14.38 | $ 857,315 |
| 501 | WPCP - 14 - SAT - LEL | 14 - Secondary Aeration Tanks - SAT - LowerEL | Mixer Motor (southern) | 11.41 | 10.41 | 9.54 | 15.60 | 25.50 | 10.15 | 16.26 | $ 969,180 |
| 502 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT - HigherEL | Submersible mixer control panel | 14.66 | 12.16 | 1.94 | 3.16 | 5.16 | 2.06 | 3.30 | $ 350,938 |
| 503 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT - HigherEL | Mixer motor | 13.41 | 12.16 | 3.58 | 5.84 | 9.53 | 3.81 | 6.09 | $ 363,323 |
| 504 | WPCP - 14 - SAT - HEL | 14 - Secondary Aeration Tanks - SAT - HigherEL | Mixer Motor (southern) | 13.16 | 12.16 | 4.05 | 6.60 | 10.78 | 4.30 | 6.88 | $ 410,731 |
| 505 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Motor | 13.74 | 13.16 | 4.35 | 8.71 | 18.90 | 4.79 | 9.39 | $ 128,305 |
| 506 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Switch Disconnect Switch | 17.41 | 13.16 | 0.44 | 0.82 | 1.60 | 0.48 | 0.87 | $ 209 |
| 507 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Level Indicator Transmitter | 18.74 | 13.16 | 0.19 | 0.35 | 0.66 | 0.21 | 0.37 | $ 4,988 |
| 508 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Junction box | 13.83 | 13.16 | 4.11 | 8.22 | 17.79 | 4.53 | 8.86 | $ 1,877 |
| 509 | WPCP - 15 - SC-7TO9 | 15 - Secondary Clarifiers 7 to 9 | Local controls panel box | 14.66 | 13.16 | 2.45 | 4.82 | 10.18 | 2.69 | 5.18 | $ 73,262 |
| 510 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum pump control panel | 14.16 | 10.16 | 3.21 | 6.27 | 12.88 | 3.51 | 6.71 | $ 330,615 |
| 511 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum Mixer control panel | 14.16 | 10.16 | 3.21 | 6.27 | 12.88 | 3.51 | 6.71 | $ 330,615 |
| 512 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | Scum mixer motor | 12.83 | 10.16 | 7.18 | 14.42 | 30.57 | 7.90 | 15.50 | $ 423,655 |
| 513 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | SCL Motor | 12.33 | 10.16 | 9.72 | 19.73 | 42.30 | 10.72 | 21.24 | $ 578,076 |
| 514 | WPCP - 15 - SC-1TO6 | 15 - Secondary Clarifiers 1 to 6 | SCL controls | 14.41 | 10.16 | 2.76 | 5.36 | 10.95 | 3.02 | 5.73 | $ 163,077 |
| 515 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Fiber box Terminals box | 19.16 | 14.16 | 0.16 | 0.27 | 0.50 | 0.17 | 0.29 | $ 81 |
| 516 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Tank sensors/levels | 18.83 | 14.16 | 0.19 | 0.34 | 0.62 | 0.21 | 0.36 | $ 11,342 |
| 517 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Control panel | 16.16 | 14.16 | 0.96 | 1.78 | 3.49 | 1.04 | 1.90 | $ 15,898 |
| 518 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Pump and motor | 16.24 | 14.16 | 0.92 | 1.70 | 3.31 | 0.99 | 1.80 | $ 7,939 |
| 519 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Switch | 17.99 | 14.16 | 0.32 | 0.57 | 1.07 | 0.34 | 0.60 | $ 108 |
| 520 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | MCC | 15.16 | 14.16 | 1.76 | 3.33 | 6.65 | 1.91 | 3.55 | $ 1,739,923 |
| 521 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Breakers | 15.83 | 14.16 | 1.17 | 2.19 | 4.32 | 1.27 | 2.33 | $ 2,157 |
| 522 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Fiber box Pull Box | 14.99 | 14.16 | 1.95 | 3.70 | 7.42 | 2.12 | 3.95 | $ 2,542 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 523 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Processor Panel | 15.41 | 14.16 | 1.51 | 2.85 | 5.66 | 1.64 | 3.03 | $ 25,269 |
| 524 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Air handling Unit | 15.16 | 14.16 | 1.76 | 3.33 | 6.65 | 1.91 | 3.55 | $ 58,760 |
| 525 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | WAS Pump Control Panel | 15.66 | 14.16 | 1.30 | 2.44 | 4.82 | 1.41 | 2.59 | $ 64,957 |
| 526 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | SC Collector Control Panel | 15.66 | 14.16 | 1.30 | 2.44 | 4.82 | 1.41 | 2.59 | $ 129,915 |
| 527 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Air pump control panel | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 54,709 |
| 528 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | Air pump and motor | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 28,703 |
| 529 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | WAS Pumps and Motors | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 362,288 |
| 530 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | SPR Pumps and Motors (smaller) | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 241,525 |
| 531 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | SPR Pumps and Motors (bigger) | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 603,813 |
| 532 | WPCP - 16 - SPSB | 16 - Secondary Services Pump Stations - SPSB | HVAC Unit | 14.16 | 14.16 | 3.21 | 6.20 | 12.67 | 3.51 | 6.64 | $ 71,685 |
| 533 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services Building - WSPSB - Outside | Transformer | 14.83 | 12.66 | 2.08 | 3.02 | 5.04 | 2.18 | 3.15 | $ 539,471 |
| 534 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services Building - WSPSB - Outside | Scum well Motor | 14.66 | 12.66 | 2.29 | 3.29 | 5.49 | 2.39 | 3.43 | $ 17,938 |
| 535 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services Building - WSPSB - Outside | Scum well controls | 17.16 | 12.66 | 0.58 | 0.93 | 1.54 | 0.61 | 0.97 | $ 9,971 |
| 536 | WPCP - 17 - WSPSB - OUTSIDE | 17 - West Secondary Pump Services Building - WSPSB - Outside | Switch Disconnect Switch | 17.16 | 12.66 | 0.58 | 0.93 | 1.54 | 0.61 | 0.97 | $ 72 |
| 537 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | WAS pump | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 155,124 |
| 538 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Drain pump | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 155,124 |
| 539 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | RAS Pump | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 904,334 |
| 540 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Sump pump Control panel | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 70,276 |
| 541 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Electrical Box | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 140,551 |
| 542 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Junction boxes/controls | 13.16 | 13.16 | 5.22 | 7.01 | 11.79 | 5.40 | 7.33 | $ 1,221 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 543 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | MCC | 14.16 | 13.16 | 3.01 | 4.23 | 7.09 | 3.13 | 4.42 | $ 1,635,752 |
| 544 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Security/lighting panels | 16.74 | 13.16 | 0.73 | 1.15 | 1.91 | 0.77 | 1.20 | $ 10,768 |
| 545 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Breakers | 15.24 | 13.16 | 1.66 | 2.45 | 4.10 | 1.74 | 2.56 | $ 5,226 |
| 546 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Transformer | 15.58 | 13.16 | 1.38 | 2.07 | 3.45 | 1.44 | 2.16 | $ 6,219 |
| 547 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Electrical Box | 16.91 | 13.16 | 0.66 | 1.06 | 1.75 | 0.70 | 1.10 | $ 9,852 |
| 548 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Switch Disconnect Switch | 17.66 | 13.16 | 0.44 | 0.72 | 1.20 | 0.47 | 0.76 | $ 28 |
| 549 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | HVAC control panels | 15.41 | 13.16 | 1.51 | 2.25 | 3.76 | 1.59 | 2.35 | $ 43,201 |
| 550 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | VFD | 14.16 | 13.16 | 3.01 | 4.23 | 7.09 | 3.13 | 4.42 | $ 362,901 |
| 551 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | VFD | 16.74 | 13.16 | 0.73 | 1.15 | 1.91 | 0.77 | 1.20 | $ 37,587 |
| 552 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Processor Panels | 14.16 | 13.16 | 3.01 | 4.23 | 7.09 | 3.13 | 4.42 | $ 83,173 |
| 553 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Breaker | 14.74 | 13.16 | 2.19 | 3.16 | 5.28 | 2.28 | 3.30 | $ 1,698 |
| 554 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Switch Disconnect Switch | 17.58 | 13.16 | 0.46 | 0.75 | 1.25 | 0.49 | 0.79 | $ 29 |
| 555 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Fiber box | 16.49 | 13.16 | 0.83 | 1.31 | 2.17 | 0.88 | 1.36 | $ 556 |
| 556 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Pump control panel | 14.16 | 13.16 | 3.01 | 4.23 | 7.09 | 3.13 | 4.42 | $ 41,587 |
| 557 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Fire alarm panel control | 14.74 | 13.16 | 2.19 | 3.16 | 5.28 | 2.28 | 3.30 | $ 3,622 |
| 558 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Air handling unit | 17.16 | 13.16 | 0.58 | 0.93 | 1.54 | 0.61 | 0.97 | $ 17,226 |
| 559 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Switch Disconnect Switch | 17.66 | 13.16 | 0.44 | 0.72 | 1.20 | 0.47 | 0.76 | $ 55 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 560 | WPCP - 17 - WSPSB | 17 - West Secondary Pump Services Building - WSPSB | Water heater power | 16.49 | 13.16 | 0.83 | 1.31 | 2.17 | 0.88 | 1.36 | $ 1,194 |
| 561 | WPCP - 18 - WMLFDS | 18 - West Mixed Liquor Flow Distribution Structures-WMLFDS | Mixer control panel | 12.99 | 12.16 | 4.41 | 7.18 | 11.73 | 4.68 | 7.49 | $ 66,394 |
| 562 | WPCP - 18 - WMLFDS | 18 - West Mixed Liquor Flow Distribution Structures-WMLFDS | Breaker | 14.83 | 12.16 | 1.79 | 2.91 | 4.75 | 1.90 | 3.03 | $ 1,489 |
| 563 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Electrical Box | 16.03 | 15.87 | 1.45 | 2.25 | 3.18 | 1.53 | 2.31 | $ 21,039 |
| 564 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Dryer Control panel | 16.45 | 15.87 | 1.06 | 1.72 | 2.51 | 1.12 | 1.77 | $ 15,798 |
| 565 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | WWF Motors | 21.28 | 15.87 | 0.03 | 0.08 | 0.17 | 0.03 | 0.08 | $ 32,742 |
| 566 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Air compressors | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 33,288 |
| 567 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Process panel | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 23,469 |
| 568 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Fan control panel | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 23,469 |
| 569 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Control panel | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 23,469 |
| 570 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | MCC | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 615,420 |
| 571 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | VFD | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 40,960 |
| 572 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Breaker (large) | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 2,597 |
| 573 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Breaker (small) | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 2,597 |
| 574 | WPCP - 19 - WWFF | 19 - Wet Weather Filtration Facility | Transformer | 15.87 | 15.87 | 1.63 | 2.50 | 3.48 | 1.72 | 2.56 | $ 5,795 |
| 575 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Blower panels | 19.33 | 16.16 | 0.20 | 0.32 | 0.52 | 0.21 | 0.33 | $ 2,965 |
| 576 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Blower motors | 19.83 | 16.16 | 0.16 | 0.25 | 0.41 | 0.16 | 0.26 | $ 3,825 |
| 577 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Breakers | 18.16 | 16.16 | 0.35 | 0.57 | 0.93 | 0.37 | 0.59 | $ 875 |
| 578 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Breaker cabinet | 17.16 | 16.16 | 0.57 | 0.93 | 1.52 | 0.61 | 0.97 | $ 477 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 579 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Fan control panel | 18.08 | 16.16 | 0.37 | 0.59 | 0.96 | 0.39 | 0.62 | $ 5,480 |
| 580 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Pump control panel | 17.83 | 16.16 | 0.41 | 0.67 | 1.09 | 0.44 | 0.70 | $ 6,196 |
| 581 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Fire alarm panel control | 18.16 | 16.16 | 0.35 | 0.57 | 0.93 | 0.37 | 0.59 | $ 622 |
| 582 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Transformer | 19.16 | 16.16 | 0.22 | 0.35 | 0.57 | 0.23 | 0.36 | $ 708 |
| 583 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Lighting contractor panel | 20.33 | 16.16 | 0.12 | 0.20 | 0.32 | 0.13 | 0.20 | $ 1,814 |
| 584 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Switch Disconnect Switch | 21.08 | 16.16 | 0.08 | 0.13 | 0.22 | 0.09 | 0.14 | $ 10 |
| 585 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | MCC | 17.16 | 16.16 | 0.57 | 0.93 | 1.52 | 0.61 | 0.97 | $ 508,110 |
| 586 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Electrical panels | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 28,152 |
| 587 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Switch Disconnect Switch | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 401 |
| 588 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Air handling unit | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 28,047 |
| 589 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Water heater power control | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 8,110 |
| 590 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Transfer Switch Disconnect Switch | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 1,033 |
| 591 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Valve box | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 455 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 592 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | BWS Pump & Motor | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 8,846 |
| 593 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Seed pump motor | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 31,071 |
| 594 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Drain pump motor | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 31,071 |
| 595 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Drain pump controls | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 8,110 |
| 596 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Sump pump controls | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 8,110 |
| 597 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Sample pump controls | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 32,439 |
| 598 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Sample pump motors | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 59,079 |
| 599 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Chemical sensors | 16.16 | 16.16 | 0.94 | 1.52 | 2.48 | 1.00 | 1.58 | $ 22,383 |
| 600 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Filter termination boxes | 22.66 | 16.16 | 0.04 | 0.06 | 0.10 | 0.04 | 0.06 | $ 317 |
| 601 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Breaker cabinet | 19.66 | 16.16 | 0.17 | 0.27 | 0.44 | 0.18 | 0.28 | $ 558 |
| 602 | WPCP - 20 - FADF | 20 - Filtration and Disinfection Facility / Sodium Hypochlorite Facility | Lighting contractor panel | 22.66 | 16.16 | 0.04 | 0.06 | 0.10 | 0.04 | 0.06 | $ 1,155 |
| 603 | WPCP - 21 - ABWB | 21 - Advance Backwash Building - ABWB | Electrical panels | 16.16 | 15.16 | 1.32 | 2.23 | 3.17 | 1.42 | 2.30 | $ 20,227 |
| 604 | WPCP - 21 - ABWB | 21 - Advance Backwash Building - ABWB | Breakers | 20.58 | 15.16 | 0.04 | 0.12 | 0.25 | 0.05 | 0.13 | $ 105 |
| 605 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PEWF (ACDB) | Effluent pumps and motors | 28.99 | 20.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | $ 540 |
| 606 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PEWF (ACDB) | Pump controls | 23.66 | 20.66 | 0.01 | 0.03 | 0.05 | 0.01 | 0.03 | $ 465 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 607 | WPCP - 22 - PEWF | 22 - Plant Effluent Water Facility - PEWF (ACDB) | Sluice gate switch Disconnect Switch | 25.66 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 0 |
| 608 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Pump control panel | 21.66 | 20.66 | 0.03 | 0.08 | 0.15 | 0.04 | 0.08 | $ 648 |
| 609 | WPCP - 24 - PAF | 24 - Post Aeration Facility | VFD | 21.66 | 20.66 | 0.03 | 0.08 | 0.15 | 0.04 | 0.08 | $ 4,527 |
| 610 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fan control panel | 22.33 | 20.66 | 0.02 | 0.05 | 0.10 | 0.02 | 0.06 | $ 439 |
| 611 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fire alarm panel control | 22.99 | 20.66 | 0.01 | 0.04 | 0.07 | 0.02 | 0.04 | $ 35 |
| 612 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breakers | 22.83 | 20.66 | 0.02 | 0.04 | 0.08 | 0.02 | 0.04 | $ 36 |
| 613 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Air handling unit | 21.74 | 20.66 | 0.03 | 0.08 | 0.14 | 0.04 | 0.08 | $ 1,233 |
| 614 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Transformer | 22.83 | 20.66 | 0.02 | 0.04 | 0.08 | 0.02 | 0.04 | $ 41 |
| 615 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Fan exhaust switch Disconnect Switch | 25.49 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 1 |
| 616 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Electrical panel | 24.99 | 20.66 | 0.00 | 0.01 | 0.03 | 0.00 | 0.01 | $ 94 |
| 617 | WPCP - 24 - PAF | 24 - Post Aeration Facility | MCC | 21.49 | 20.66 | 0.04 | 0.09 | 0.16 | 0.04 | 0.09 | $ 42,243 |
| 618 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Transformer | 22.99 | 20.66 | 0.01 | 0.04 | 0.07 | 0.02 | 0.04 | $ 47 |
| 619 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Lighting Contractor | 25.66 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 64 |
| 620 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breaker (large) | 21.66 | 20.66 | 0.03 | 0.08 | 0.15 | 0.04 | 0.08 | $ 36 |
| 621 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Breaker (small) | 23.24 | 20.66 | 0.01 | 0.03 | 0.06 | 0.01 | 0.03 | $ 14 |
| 622 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Processor Panel | 21.66 | 20.66 | 0.03 | 0.08 | 0.15 | 0.04 | 0.08 | $ 648 |
| 623 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Switch Disconnect Switch | 25.41 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 1 |
| 624 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Junction box | 22.99 | 20.66 | 0.01 | 0.04 | 0.07 | 0.02 | 0.04 | $ 6 |
| 625 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Network box | 24.66 | 20.66 | 0.00 | 0.01 | 0.03 | 0.01 | 0.02 | $ 15 |
| 626 | WPCP - 24 - PAF | 24 - Post Aeration Facility | NAOS Pumps | 23.99 | 20.66 | 0.01 | 0.02 | 0.04 | 0.01 | 0.02 | $ 10 |
| 627 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Pump controls | 25.58 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 115 |
| 628 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sump pump controls | 25.16 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 49 |
| 629 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pumps and motors | 22.74 | 20.66 | 0.02 | 0.04 | 0.08 | 0.02 | 0.05 | $ 726 |
| 630 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump controls | 24.66 | 20.66 | 0.00 | 0.01 | 0.03 | 0.01 | 0.02 | $ 131 |
| 631 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Tank controls | 22.33 | 20.66 | 0.02 | 0.05 | 0.10 | 0.02 | 0.06 | $ 506 |
| 632 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sump pump controls | 25.66 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 37 |
| 633 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Blower motors | 23.16 | 20.66 | 0.01 | 0.03 | 0.07 | 0.01 | 0.04 | $ 100 |
| 634 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Water heater power control | 22.74 | 20.66 | 0.02 | 0.04 | 0.08 | 0.02 | 0.05 | $ 199 |
| 635 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump controls | 25.16 | 20.66 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | $ 49 |
| 636 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Sample pump motors | 23.16 | 20.66 | 0.01 | 0.03 | 0.07 | 0.01 | 0.04 | $ 284 |
| 637 | WPCP - 24 - PAF | 24 - Post Aeration Facility | Blower control panel | 23.58 | 20.66 | 0.01 | 0.03 | 0.05 | 0.01 | 0.03 | $ 637 |
| 638 | WPCP - 24 - PAF - TRANSFORMER | 24 - Post Aeration Facility - Transformer | Transformer | 17.83 | 15.66 | 0.38 | 0.68 | 1.12 | 0.41 | 0.71 | $ 56,234 |
| 639 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Flow meters | 19.76 | 16.01 | 0.07 | 0.19 | 0.39 | 0.08 | 0.20 | $ 14,524 |
| 640 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Valve actuator | 19.43 | 16.01 | 0.09 | 0.24 | 0.47 | 0.11 | 0.26 | $ 11,971 |
| 641 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump and motors | 18.51 | 16.01 | 0.20 | 0.46 | 0.82 | 0.23 | 0.48 | $ 358 |
| 642 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump controls | 21.01 | 16.01 | 0.03 | 0.08 | 0.18 | 0.03 | 0.09 | $ 1,426 |
| 643 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Valve actuator | 20.84 | 15.51 | 0.03 | 0.09 | 0.20 | 0.04 | 0.10 | $ 1,568 |
| 644 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Tank control panel | 19.18 | 15.51 | 0.12 | 0.29 | 0.55 | 0.13 | 0.30 | $ 2,328 |
| 645 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Sump pump control panel | 20.51 | 15.51 | 0.04 | 0.11 | 0.25 | 0.05 | 0.12 | $ 887 |
| 646 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Foam system control panels | 21.43 | 16.01 | 0.02 | 0.06 | 0.14 | 0.02 | 0.07 | $ 915 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 647 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Fire alarm control panel | 20.01 | 16.01 | 0.06 | 0.16 | 0.33 | 0.07 | 0.17 | $ 150 |
| 648 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Methanol pump control panel | 18.09 | 16.01 | 0.29 | 0.61 | 1.06 | 0.32 | 0.64 | $ 10,334 |
| 649 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Remote I/O panel | 17.68 | 16.01 | 0.40 | 0.82 | 1.35 | 0.44 | 0.85 | $ 6,984 |
| 650 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Processor Panel | 17.01 | 16.01 | 0.70 | 1.31 | 2.03 | 0.76 | 1.35 | $ 11,448 |
| 651 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker (large) | 18.01 | 16.01 | 0.30 | 0.65 | 1.11 | 0.34 | 0.68 | $ 303 |
| 652 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker (small) | 19.09 | 16.01 | 0.12 | 0.31 | 0.58 | 0.14 | 0.32 | $ 138 |
| 653 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Transformer | 19.01 | 16.01 | 0.13 | 0.32 | 0.61 | 0.15 | 0.34 | $ 290 |
| 654 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Breaker Cabinet | 17.34 | 16.01 | 0.53 | 1.04 | 1.66 | 0.58 | 1.08 | $ 496 |
| 655 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Power Transfer Switch | 17.34 | 16.01 | 0.53 | 1.04 | 1.66 | 0.58 | 1.08 | $ 554 |
| 656 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Lighting panel | 19.84 | 16.01 | 0.07 | 0.18 | 0.37 | 0.08 | 0.19 | $ 1,441 |
| 657 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Fan control panel | 18.01 | 16.01 | 0.30 | 0.65 | 1.11 | 0.34 | 0.68 | $ 5,479 |
| 658 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Electrical panels | 19.18 | 16.01 | 0.12 | 0.29 | 0.55 | 0.13 | 0.30 | $ 2,328 |
| 659 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Gas monitors | 21.18 | 16.01 | 0.02 | 0.07 | 0.16 | 0.03 | 0.08 | $ 580 |
| 660 | WPCP - 25 - MFF | 25 - Methanol Feed Facility | Air handling unit | 23.93 | 16.01 | 0.00 | 0.01 | 0.03 | 0.00 | 0.01 | $ 153 |
| 661 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Chemical pump and motor | 13.83 | 10.66 | 3.77 | 7.18 | 14.23 | 4.12 | 7.65 | $ 2,531 |
| 662 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Chemical pump controls | 14.99 | 10.66 | 1.91 | 3.56 | 6.90 | 2.07 | 3.78 | $ 36,457 |
| 663 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Sump pump control panel | 14.24 | 10.66 | 2.96 | 5.60 | 11.01 | 3.23 | 5.96 | $ 49,664 |
| 664 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Water heater power | 12.33 | 10.66 | 9.13 | 17.82 | 36.26 | 10.00 | 19.05 | $ 15,233 |
| 665 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Sump pump control panel | 13.16 | 10.16 | 5.60 | 10.78 | 21.61 | 6.12 | 11.50 | $ 95,074 |
| 666 | WPCP - 27 - SFF | 27 - South Ferric Facility (SFF) | Fill Station Control panel | 12.16 | 10.16 | 10.09 | 19.75 | 40.32 | 11.06 | 21.12 | $ 173,475 |
| 667 | WPCP - 28 - DC5 - TRANSFORMER | 28 - Distribution Center No. 5 - DSB-5 - Transformer | Transformer | 17.99 | 15.66 | 0.32 | 0.67 | 1.15 | 0.35 | 0.70 | $ 104,520 |
| 668 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Fan control panel | 18.33 | 16.16 | 0.24 | 0.53 | 0.94 | 0.27 | 0.56 | $ 4,411 |
| 669 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Generator Terminal Box | 19.91 | 16.16 | 0.06 | 0.17 | 0.36 | 0.07 | 0.19 | $ 143 |
| 670 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Process Panel | 17.16 | 16.16 | 0.63 | 1.20 | 1.90 | 0.69 | 1.25 | $ 10,495 |
| 671 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Breaker cabinet | 17.16 | 16.16 | 0.63 | 1.20 | 1.90 | 0.69 | 1.25 | $ 581 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 672 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Power transfer switch | 18.33 | 16.16 | 0.24 | 0.53 | 0.94 | 0.27 | 0.56 | $ 272 |
| 673 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Transfer Switch Disconnect Switch | 19.91 | 16.16 | 0.06 | 0.17 | 0.36 | 0.07 | 0.19 | $ 203 |
| 674 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | Electrical panel | 19.16 | 16.16 | 0.12 | 0.30 | 0.57 | 0.14 | 0.31 | $ 2,395 |
| 675 | WPCP - 28 - DC5 | 28 - Distribution Center No. 5 - DSB-5 | MCC | 17.16 | 16.16 | 0.63 | 1.20 | 1.90 | 0.69 | 1.25 | $ 275,208 |
| 676 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Nox Control Panel | 15.83 | 12.16 | 1.17 | 2.26 | 4.62 | 1.28 | 2.42 | $ 59,937 |
| 677 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch | 15.91 | 12.16 | 1.12 | 2.15 | 4.38 | 1.22 | 2.30 | $ 798 |
| 678 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Supply pump (cooling water) | 12.99 | 12.16 | 6.90 | 14.11 | 31.09 | 7.62 | 15.24 | $ 813,293 |
| 679 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Air compressor control power | 12.91 | 12.16 | 7.25 | 14.85 | 32.80 | 8.01 | 16.05 | $ 223,422 |
| 680 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Batteries | 14.74 | 12.16 | 2.32 | 4.57 | 9.60 | 2.54 | 4.90 | $ 1,893 |
| 681 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Supply pump control panel | 14.74 | 12.16 | 2.32 | 4.57 | 9.60 | 2.54 | 4.90 | $ 120,314 |
| 682 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Generator | 15.24 | 12.16 | 1.70 | 3.31 | 6.86 | 1.86 | 3.55 | $ 847,683 |
| 683 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Bifuel Control Panel | 18.33 | 12.16 | 0.25 | 0.45 | 0.86 | 0.27 | 0.48 | $ 12,133 |
| 684 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Overall control panel | 13.33 | 12.16 | 5.58 | 11.33 | 24.74 | 6.15 | 12.23 | $ 98,810 |
| 685 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control power junction box | 15.74 | 12.16 | 1.24 | 2.40 | 4.90 | 1.36 | 2.57 | $ 446 |
| 686 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Urea Tank Booster Pumps | 14.99 | 12.16 | 1.98 | 3.89 | 8.12 | 2.17 | 4.17 | $ 1,933 |
| 687 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Tank control panel | 16.91 | 12.16 | 0.60 | 1.13 | 2.24 | 0.65 | 1.20 | $ 10,019 |
| 688 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Gas detection sensor | 16.58 | 12.16 | 0.74 | 1.40 | 2.79 | 0.80 | 1.49 | $ 13,115 |
| 689 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control Switches | 12.74 | 12.16 | 8.06 | 16.57 | 36.77 | 8.91 | 17.92 | $ 12,121 |
| 690 | WPCP - 29 - SGF | 29 - Standby Generator Facility | MCC | 13.16 | 12.16 | 6.20 | 12.64 | 27.73 | 6.85 | 13.65 | $ 2,166,497 |
| 691 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Air handling unit | 13.16 | 12.16 | 6.20 | 12.64 | 27.73 | 6.85 | 13.65 | $ 219,499 |
| 692 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Electrical panel (small) | 16.24 | 12.16 | 0.91 | 1.74 | 3.51 | 0.99 | 1.86 | $ 30,747 |
| 693 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Communications network | 16.33 | 12.16 | 0.86 | 1.64 | 3.30 | 0.94 | 1.75 | $ 1,926 |
| 694 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Transformer | 12.99 | 12.16 | 6.90 | 14.11 | 31.09 | 7.62 | 15.24 | $ 13,492 |
| 695 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire alarm control panel | 16.16 | 12.16 | 0.96 | 1.83 | 3.70 | 1.04 | 1.95 | $ 1,910 |
| 696 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Breakers (large) | 13.74 | 12.16 | 4.32 | 8.70 | 18.79 | 4.76 | 9.37 | $ 4,207 |
| 697 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Breakers (small) | 15.49 | 12.16 | 1.45 | 2.82 | 5.80 | 1.59 | 3.02 | $ 2,748 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 698 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fan | 19.49 | 12.16 | 0.12 | 0.21 | 0.40 | 0.13 | 0.23 | $ 111 |
| 699 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control power junction box | 12.58 | 12.16 | 8.90 | 18.37 | 40.94 | 9.85 | 19.88 | $ 3,367 |
| 700 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 16.83 | 12.16 | 0.63 | 1.19 | 2.36 | 0.69 | 1.27 | $ 200 |
| 701 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Processor Panel | 13.91 | 12.16 | 3.89 | 7.80 | 16.76 | 4.28 | 8.40 | $ 68,186 |
| 702 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control panel (large) | 15.24 | 12.16 | 1.70 | 3.31 | 6.86 | 1.86 | 3.55 | $ 29,132 |
| 703 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 17.16 | 12.16 | 0.51 | 0.96 | 1.89 | 0.56 | 1.02 | $ 106 |
| 704 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Control panel | 15.24 | 12.16 | 1.70 | 3.31 | 6.86 | 1.86 | 3.55 | $ 58,264 |
| 705 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fuel pumps | 13.33 | 12.16 | 5.58 | 11.33 | 24.74 | 6.15 | 12.23 | $ 207,360 |
| 706 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire pump | 16.41 | 12.16 | 0.82 | 1.56 | 3.13 | 0.89 | 1.66 | $ 44,366 |
| 707 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Fire pump control panel | 13.33 | 12.16 | 5.58 | 11.33 | 24.74 | 6.15 | 12.23 | $ 98,810 |
| 708 | WPCP - 29 - SGF | 29 - Standby Generator Facility | Switch Disconnect Switch | 17.16 | 12.16 | 0.51 | 0.96 | 1.89 | 0.56 | 1.02 | $ 71 |
| 709 | WPCP - 32 - EMLFDS | 32 - East Mixed Liquor Flow Distribution Sturcture - EMLFDS | Mixer control panel | 15.16 | 10.16 | 1.74 | 3.28 | 6.45 | 1.90 | 3.49 | $ 29,090 |
| 710 | WPCP - 32 - EMLFDS | 32 - East Mixed Liquor Flow Distribution Sturcture - EMLFDS | Switch Disconnect Switch | 15.16 | 10.16 | 1.74 | 3.28 | 6.45 | 1.90 | 3.49 | $ 362 |
| 711 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Transformer | 13.33 | 11.16 | 3.73 | 6.06 | 9.90 | 3.96 | 6.31 | $ 6,922 |
| 712 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | VFD | 14.49 | 11.16 | 2.11 | 3.43 | 5.59 | 2.25 | 3.57 | $ 166,223 |
| 713 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Lighting control panel | 15.24 | 11.16 | 1.47 | 2.37 | 3.87 | 1.56 | 2.47 | $ 21,980 |
| 714 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | MCC | 12.16 | 11.16 | 6.61 | 10.75 | 17.59 | 7.02 | 11.21 | $ 1,956,758 |
| 715 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Fan control panel | 12.49 | 11.16 | 5.62 | 9.15 | 14.95 | 5.98 | 9.53 | $ 84,633 |
| 716 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Processor Panel | 12.99 | 11.16 | 4.40 | 7.15 | 11.70 | 4.68 | 7.46 | $ 66,234 |
| 717 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Breakers | 13.49 | 11.16 | 3.45 | 5.60 | 9.15 | 3.66 | 5.83 | $ 11,473 |
| 718 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Fire alarm control panel | 12.49 | 11.16 | 5.62 | 9.15 | 14.95 | 5.98 | 9.53 | $ 9,992 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 719 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Polymer pump control panel | 15.83 | 11.16 | 1.10 | 1.77 | 2.89 | 1.17 | 1.85 | $ 49,376 |
| 720 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Vacuum pump control panel | 15.66 | 11.16 | 1.19 | 1.93 | 3.15 | 1.27 | 2.01 | $ 17,889 |
| 721 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Blender Control Panel | 14.83 | 11.16 | 1.79 | 2.90 | 4.73 | 1.90 | 3.02 | $ 26,873 |
| 722 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Polymer pump and motor | 13.33 | 11.16 | 3.73 | 6.06 | 9.90 | 3.96 | 6.31 | $ 88,242 |
| 723 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Water heater power control | 11.16 | 11.16 | 10.78 | 17.57 | 28.76 | 11.46 | 18.31 | $ 93,594 |
| 724 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Grinder control panel | 11.16 | 11.16 | 10.78 | 17.57 | 28.76 | 11.46 | 18.31 | $ 162,451 |
| 725 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Pumps and motors | 11.16 | 11.16 | 10.78 | 17.57 | 28.76 | 11.46 | 18.31 | $ 717,175 |
| 726 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Drain pump and motor | 11.16 | 11.16 | 10.78 | 17.57 | 28.76 | 11.46 | 18.31 | $ 85,229 |
| 727 | WPCP - 33 - FCPS | 33 - Foam Collection Pumping Station Building - FCPS #33 | Electrical panel | 11.16 | 11.16 | 10.78 | 17.57 | 28.76 | 11.46 | 18.31 | $ 162,451 |
| 728 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Fire alarm control panel | 14.16 | 11.16 | 3.20 | 6.20 | 12.67 | 3.50 | 6.64 | $ 6,454 |
| 729 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Transformer | 13.33 | 11.16 | 5.28 | 10.41 | 21.64 | 5.80 | 11.16 | $ 11,276 |
| 730 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Breaker | 13.08 | 11.16 | 6.15 | 12.16 | 25.42 | 6.75 | 13.05 | $ 11,799 |
| 731 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Fan control panel | 12.83 | 11.16 | 7.15 | 14.22 | 29.87 | 7.85 | 15.26 | $ 124,445 |
| 732 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Lighting control panel | 15.24 | 11.16 | 1.67 | 3.16 | 6.32 | 1.82 | 3.37 | $ 28,033 |
| 733 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | VFD | 13.83 | 11.16 | 3.91 | 7.62 | 15.68 | 4.28 | 8.16 | $ 117,006 |
| 734 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Processor panel | 12.16 | 11.16 | 10.71 | 21.59 | 46.01 | 11.80 | 23.21 | $ 188,362 |
| 735 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Fiber box | 13.74 | 11.16 | 4.13 | 8.06 | 16.61 | 4.52 | 8.63 | $ 3,208 |
| 736 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | MCC | 12.16 | 11.16 | 10.71 | 21.59 | 46.01 | 11.80 | 23.21 | $ 3,704,478 |
| 737 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Air handling unit | 14.08 | 11.16 | 3.36 | 6.52 | 13.34 | 3.68 | 6.98 | $ 114,447 |
| 738 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Water heater power control | 14.24 | 11.16 | 3.05 | 5.90 | 12.04 | 3.34 | 6.31 | $ 29,974 |
| 739 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Electrical panel | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 349,724 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 740 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Grinder Motor | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 196,096 |
| 741 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Grinder control panel | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 349,724 |
| 742 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Pumps and Motors | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 1,543,934 |
| 743 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Fiber box | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 15,830 |
| 744 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Panel box | 11.16 | 11.16 | 19.60 | 40.27 | 87.66 | 21.67 | 43.43 | $ 349,724 |
| 745 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Scum mixer | 12.66 | 11.16 | 7.92 | 15.81 | 33.33 | 8.71 | 16.97 | $ 72,530 |
| 746 | WPCP - 34 - SWPS | 34 - Surface Waste Pump Station - SWPS | Scum mixer controls | 15.74 | 11.16 | 1.23 | 2.32 | 4.58 | 1.34 | 2.47 | $ 11,856 |
| 747 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Transfer Pumps and Motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 12,763 |
| 748 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Pump panels | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 61,613 |
| 749 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Pump switch Disconnect Switch | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 328 |
| 750 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Sample pumps and motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 82,846 |
| 751 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Sample control panels | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 78,954 |
| 752 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Sodium Hypo Pumps and Motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 41,423 |
| 753 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Pump panels | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 61,613 |
| 754 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | NAOCl Pumps and Motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 5,105 |
| 755 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | NAOCl Pumps and Motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 9,700 |
| 756 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Gas monitor | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 20,925 |
| 757 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Water heater power | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 3,840 |
| 758 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | DSCNT Pumps and motors | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 41,423 |
| 759 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | DSCNT Controls | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 45,489 |
| 760 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Tank controls junction box | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 1,372 |
| 761 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Sump pump control panel | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 78,954 |
| 762 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Hypo recirc pump and motor | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 41,423 |
| 763 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - SHF - FillStation | Fill panels | 17.91 | 14.16 | 0.34 | 0.68 | 1.12 | 0.38 | 0.71 | $ 5,852 |
| 764 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - SHF - FillStation | Sump pump control panel | 19.16 | 14.16 | 0.13 | 0.30 | 0.55 | 0.15 | 0.32 | $ 2,481 |
| 765 | WPCP - 35 - SHF - FILLSTATION | 35 - Sodium Hypochlorite Facility - SHF - FillStation | Fill local control box | 18.66 | 14.16 | 0.19 | 0.42 | 0.73 | 0.21 | 0.44 | $ 2,013 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 766 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Breaker (small) | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 2,185 |
| 767 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Breaker (large) | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 2,185 |
| 768 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Electrical panel | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 39,477 |
| 769 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | Lighting contractor panel | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 39,477 |
| 770 | WPCP - 35 - SHF | 35 - Sodium Hypochlorite Facility - SHF | MCC | 15.16 | 15.16 | 2.85 | 4.11 | 5.40 | 2.97 | 4.20 | $ 1,035,184 |
| 771 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 - Outside | Control panels | 13.33 | 12.16 | 4.92 | 9.36 | 18.80 | 5.37 | 9.99 | $ 165,793 |
| 772 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 | ASE motors | 22.83 | 16.16 | 0.02 | 0.03 | 0.05 | 0.02 | 0.03 | $ 5,875 |
| 773 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 | Breakers | 17.66 | 16.16 | 0.40 | 0.71 | 1.29 | 0.43 | 0.75 | $ 707 |
| 774 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 | Switches | 17.49 | 16.16 | 0.44 | 0.78 | 1.44 | 0.48 | 0.83 | $ 297 |
| 775 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 | Gate control panels | 20.33 | 16.16 | 0.09 | 0.14 | 0.25 | 0.09 | 0.15 | $ 1,316 |
| 776 | WPCP - 37 - ASE1 | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 | HVAC FAN | 16.16 | 16.16 | 0.96 | 1.73 | 3.27 | 1.03 | 1.83 | $ 20,329 |
| 777 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 - Outside | Electrical Box | 13.41 | 12.16 | 4.70 | 8.92 | 17.89 | 5.12 | 9.52 | $ 79,060 |
| 778 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 - Outside | VFI Switch | 13.41 | 12.16 | 4.70 | 8.92 | 17.89 | 5.12 | 9.52 | $ 1,662 |
| 779 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 - Outside | Transformer | 13.16 | 12.16 | 5.43 | 10.36 | 20.88 | 5.92 | 11.06 | $ 725,898 |
| 780 | WPCP - 37 - ASE1 - OUTSIDE | 37 - Activated Sludge Effluent Pump Station 1 - ASE1 - Outside | Transformer | 13.16 | 12.16 | 5.43 | 10.36 | 20.88 | 5.92 | 11.06 | $ 60,724 |
| 781 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump Station 2 - ASE2 | ASE Pumps and Motors | 21.49 | 13.16 | 0.05 | 0.10 | 0.17 | 0.05 | 0.11 | $ 61,148 |
| 782 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump Station 2 - ASE2 | Wet well panel box | 17.33 | 13.16 | 0.53 | 0.87 | 1.43 | 0.56 | 0.90 | $ 15,996 |
| 783 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump Station 2 - ASE2 | Flow meter panel box | 14.74 | 13.16 | 2.39 | 3.27 | 5.41 | 2.47 | 3.41 | $ 129,820 |
| 784 | WPCP - 38 - ASE2 | 38 - Activated Sludge Effluent Pump Station 2 - ASE2 | Controls Panel box | 14.08 | 13.16 | 3.50 | 4.59 | 7.60 | 3.61 | 4.79 | $ 107,007 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 785 | WPCP - 39 - WFF - OUTSIDE | 39 - West Ferric Facility - WFF - Outside | Chemical feed control panel | 17.33 | 12.66 | 0.53 | 0.86 | 1.42 | 0.56 | 0.90 | $ 7,941 |
| 786 | WPCP - 39 - WFF - OUTSIDE | 39 - West Ferric Facility - WFF - Outside | Sump pump controls | 17.33 | 12.66 | 0.53 | 0.86 | 1.42 | 0.56 | 0.90 | $ 4,575 |
| 787 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Switch Disconnect Switch | 17.66 | 13.16 | 0.44 | 0.73 | 1.20 | 0.47 | 0.76 | $ 56 |
| 788 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Ferric pump motor | 16.16 | 13.16 | 0.98 | 1.55 | 2.55 | 1.04 | 1.61 | $ 15,210 |
| 789 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Ferric pump controls | 17.16 | 13.16 | 0.58 | 0.94 | 1.54 | 0.61 | 0.98 | $ 9,987 |
| 790 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Drain controls | 16.83 | 13.16 | 0.69 | 1.10 | 1.82 | 0.73 | 1.15 | $ 11,834 |
| 791 | WPCP - 39 - WFF | 39 - West Ferric Facility - WFF | Pump control panel | 17.58 | 13.16 | 0.46 | 0.76 | 1.25 | 0.49 | 0.79 | $ 6,984 |
| 792 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Supply fan control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 296,659 |
| 793 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Switch Disconnect Switch | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 1,879 |
| 794 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Drain pump and motor | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 436,555 |
| 795 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Telephone Box | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 20,299 |
| 796 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | SAT Panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 197,772 |
| 797 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Fan control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 197,772 |
| 798 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Exhaust fan control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 296,659 |
| 799 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Breakers | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 16,416 |
| 800 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Sump Pump control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 296,659 |
| 801 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Fire alarm control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 11,674 |
| 802 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Breaker Cabinet | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 5,472 |
| 803 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Lighting control panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 197,772 |
| 804 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Gas detection sensor | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 104,830 |
| 805 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Breaker (large) | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 10,944 |
| 806 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | DCU | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 23,019 |
| 807 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Transformer | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 15,562 |
| 808 | WPCP - 44 - SATPG | 44 - Secondary Aeration Tank Pipe Gallery - SATPG | Relay panel | 12.16 | 12.16 | 6.51 | 10.75 | 17.54 | 6.94 | 11.20 | $ 98,886 |
| 809 | WPCP - 28 - DC3 | 28 - DC-3 | Torque motors | 17.74 | 13.91 | 0.37 | 0.67 | 1.25 | 0.40 | 0.70 | $ 28,354 |
| 810 | WPCP - 28 - DC3 | 28 - DC-3 | VFD | 14.91 | 13.91 | 2.03 | 3.84 | 7.72 | 2.21 | 4.10 | $ 89,269 |
| 811 | WPCP - 28 - DC3 | 28 - DC-3 | Breaker | 15.83 | 13.91 | 1.17 | 2.17 | 4.28 | 1.27 | 2.31 | $ 1,073 |
| 812 | WPCP - 28 - DC3 | 28 - DC-3 | Processor panel | 15.58 | 13.91 | 1.36 | 2.54 | 5.02 | 1.48 | 2.70 | $ 22,605 |

# Table G-3. Asset Flood Analysis and Cumulative Risk

Using 4% Dicount Rate and 20-yr Period to 2042

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 813 | WPCP - 28 - DC3 | 28 - DC-3 | Telephone box | 14.99 | 13.91 | 1.94 | 3.65 | 7.34 | 2.11 | 3.90 | $ 1,149 |
| 814 | WPCP - 28 - DC3 | 28 - DC-3 | ASE Pump control panel | 14.91 | 13.91 | 2.03 | 3.84 | 7.72 | 2.21 | 4.10 | $ 34,099 |
| 815 | WPCP - 28 - DC3 | 28 - DC-3 | MCC | 14.91 | 13.91 | 2.03 | 3.84 | 7.72 | 2.21 | 4.10 | $ 894,164 |
| 816 | WPCP - 28 - DC3 | 28 - DC-3 | Air Handling Unit | 16.49 | 13.91 | 0.79 | 1.44 | 2.80 | 0.86 | 1.53 | $ 25,774 |

# Appendix F
# Arlington Flood Mitigation and Adaptation Strategy Technical Memorandum

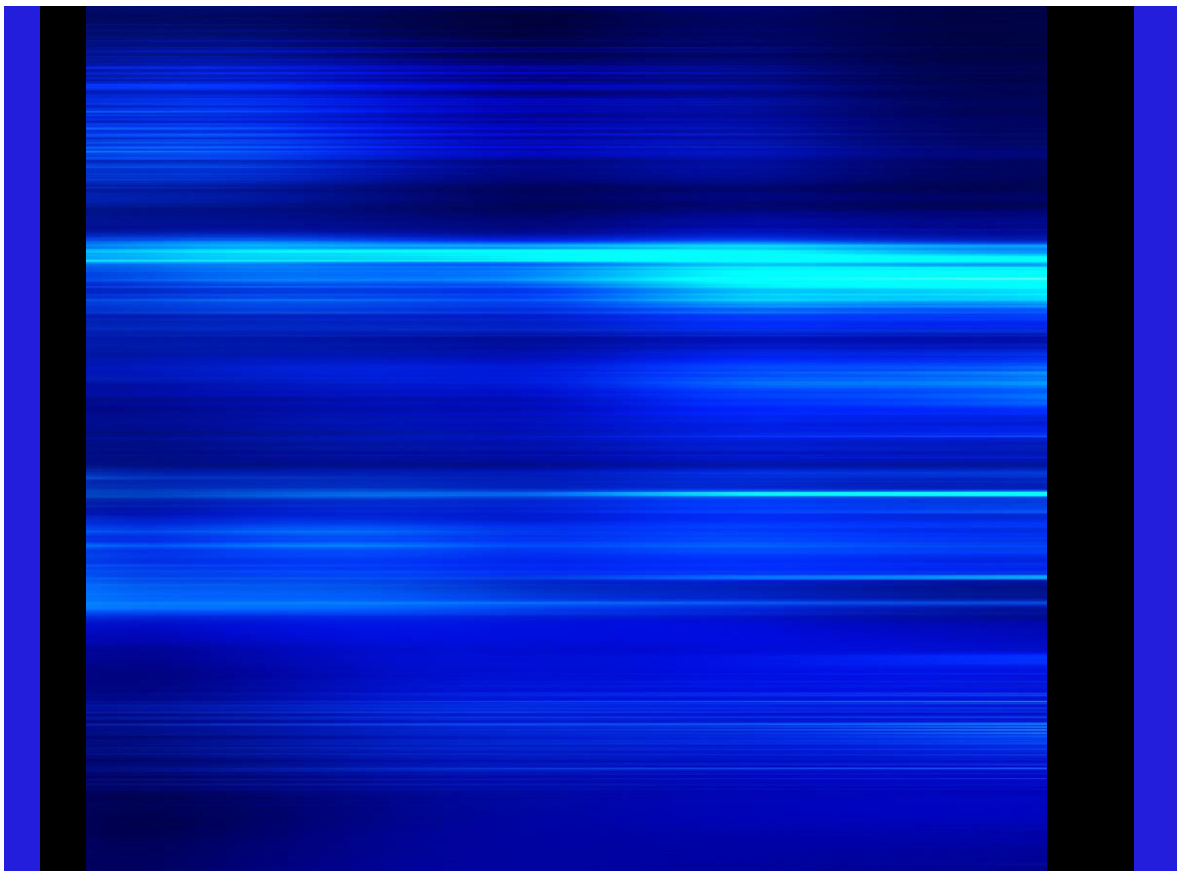
ARLINGTON
VIRGINIA

# Arlington Flood Mitigation and Adaptation Strategy (Task 6) Technical Memorandum

Document No: 230308140714_22959f54
Version: Final

Arlington County, Virginia
Flood Risk Assessment and Management Plan (RAMP)

October 2023



# Arlington Flood Mitigation and Adaptation Strategy (Task 6) Technical Memorandum

| | | | |
|---|---|---|---|
| **Client name:** | Arlington County, Virginia | | |
| **Project name:** | Flood Risk Assessment and Management Plan (RAMP) | | |
| **Client reference:** | County of Arlington, Virginia | **Project No:** | E5X65609 |
| **Document No:** | 230308140714_22959f54 | **Project manager:** | Laurens van der Tak |
| **Version:** | Final | **Prepared by:** | Jacobs |
| **Date:** | October 2023 | **File name:** | RAMP_Task6_TechMemo_ Final_July.2023 |

## Document History and Status

| Version | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| 1 | March 8, 2023 | DRAFT | Jacobs Team | Enrique Lopezcalva | Laurens van der Tak | L. van der Tak |
| 2 | July 14, 2023 | DRAFT FINAL | Jacobs Team | L. van der Tak | Tara Ajello | L. van der Tak |
| 3 | October 6, 2023 | FINAL | Jacobs Team | Enrique Lopezcalva | Enrique Lopezcalva | Tara Ajello |

**Jacobs Engineering Group Inc.**

2551 Dulles View Drive 7th Floor
Herndon, VA 20171 United States

# Executive Summary

Arlington County, Virginia (County) initiated a study to support the Flood Risk Assessment and Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for the Arlington County Department of Environmental Services resulting in a comprehensive RAMP to address the risk of flooding due to current and future climate conditions, and to project and map flood risk in support of a long-term resilience strategy and capital improvement plan.

## Purpose

The purpose of Task 6 was to develop flood mitigation strategies in three main categories as follows:

- Programmatic strategies as a nonstructural approach for flood management in the County, which includes but is not limited to policies for land use planning, re/development, zoning, and sustainable communities
- Conveyance and storage concepts for Problem Areas in the County that were identified and prioritized in previous tasks
- Building-level and asset-level concepts to protect critical assets in Public Facilities that were identified and prioritized in previous tasks

## Geographic Scope: Problem Areas and Public Facilities

The vulnerability assessment during Task 4 was conducted at a watershed scale to select watersheds with vulnerable Problem Areas (abbreviation PA is used in some tables and figures for practical reasons) and Public Facilities. For Task 5 (Risk Assessment) and Task 6 (Mitigation and Adaptation), the analysis is conducted at the sub-watershed scale using 34 Problem Areas and 10 Public Facilities as the receptors of interest, and then aggregated at watershed scale.

In the context of this project, a "Problem Area" is defined as an area exposed to flooding within a County watershed, based on hydrologic/hydraulic modeling and flood complaint calls. The boundary of flooded area included in each Problem Area was delineated approximately based on maximum contiguous extent of flood exposure for the worst case scenario (500-year storm in 2070) and potential location of mitigation alternatives to hydraulic deficiencies for the flooded area. The watersheds that contain Problem Areas analyzed in Task 6 are presented as follows and are shown on Figure ES-1, including the abbreviations used in this Technical Memorandum (TM) for figures and tables:

- Bailey's Branch (BB)[1]
- Doctor's Branch (DB)
- Little Pimmit Run East Branch[2]
- Lubber Run (LR)
- Four Mile Run Lower Mainstem (FMRL)
- Four Mile Run Middle Mainstem[2]
- Roaches Run (RR)
- Spout Run (SP)
- Torreyson Run (TR)

[1] Bailey's Branch modeling included only a small segment of the watershed known to have flooding risk, and incudes a Problem Area in the analysis.

[2] Little Pimmit Run and Four Mile Run Middle Mainstem model results were each used for the analysis of a Public Facility (Little Falls Booster Station and Trades Center – DPR Building/Network Operations Hub) but do not include any Problem Areas. No abbreviation is used (not included in Problem Area analysis tables and figures).

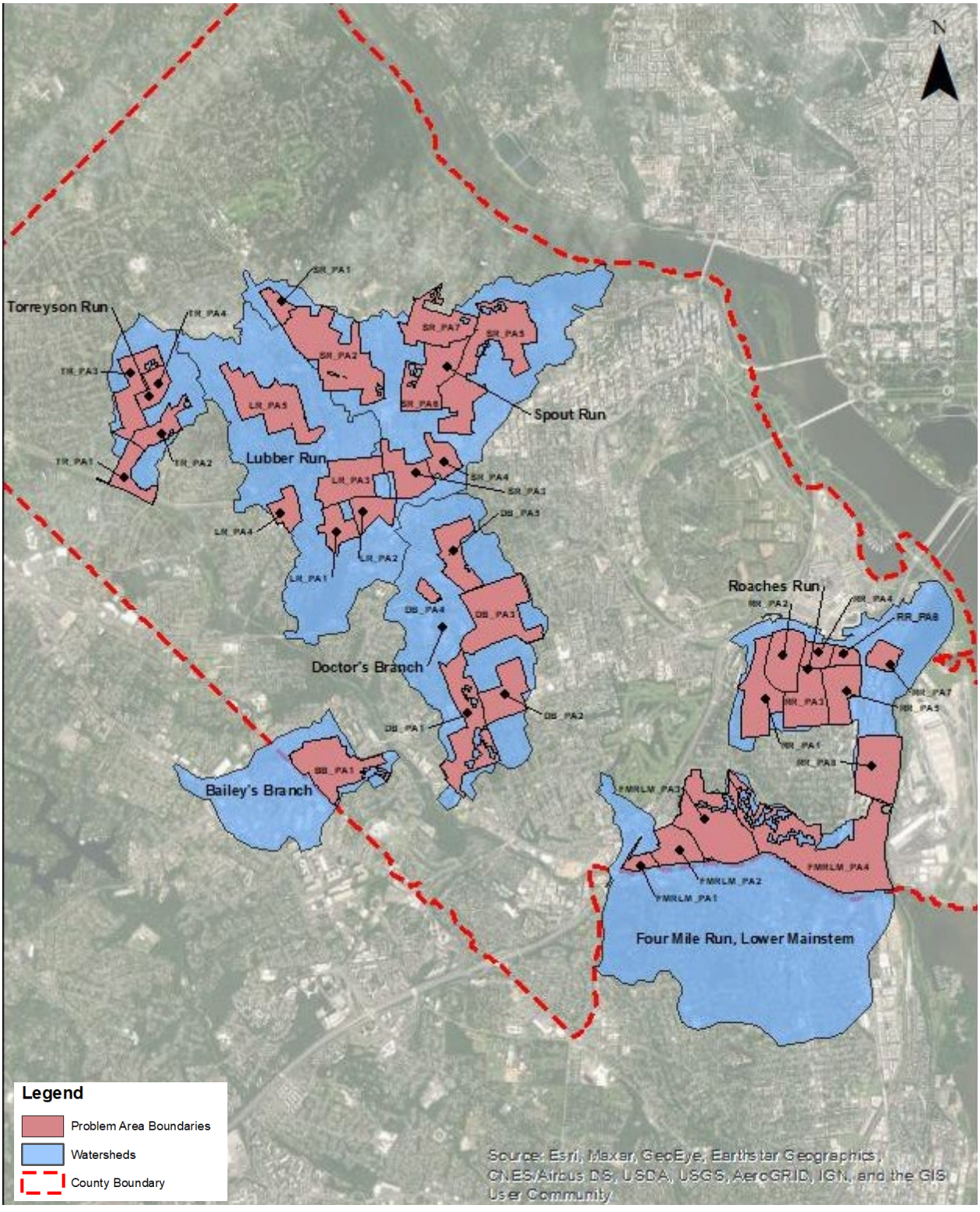



**Figure ES-1. Arlington County Problem Areas Selected for Flood Mitigation Concepts**

With the information on exposure and considerations of criticality of the facilities, a short list of Public Facilities was prioritized during Task 4 for analysis during Tasks 5 and 6. These Public Facilities are depicted on Figure ES-2 and include the following:

- ART Operations and Maintenance (O&M) Facility, located in Four Mile Run Lower Mainstem (with part of it in Nauck Branch watershed)
- Cardinal Elementary School, located in Torreyson Run
- Cherrydale Health and Rehabilitation Center, located in Spout Run
- Gunston Middle School and Community Center, located in Four Mile Run Lower Mainstem
- Little Falls Booster Station, located in Little Pimmit Run East Branch
- Thomas Jefferson Middle School and Community Center, located in Doctor's Branch
- Trades Center – DPR Building/Network Operations Hub, located in Four Mile Run Middle Mainstem
- Trades Center – Equipment Bureau, located in Four Mile Run Middle Mainstem
- Virginia Hospital Center, located in Lubber Run
- Water Pollution Control Plant (WPCP), located in Four Mile Run Lower Mainstem

## Methods

- Problem Areas and Public Facilities (and the buildings and assets inside those facilities that require flood mitigation) were identified and prioritized during Tasks 4 and 5. To define flood mitigation concepts for Problem Areas and Public Facilities, flood inundation depth grids were developed for baseline (no climate change) 2020 design storm event scenarios for the 2-, 10-, 50-, 100- and 500-year storms.
- The 10-year 2020 event was used as the basis of design for Problem Areas based on established guidelines from the County. Storage and conveyance concepts to mitigate flooding were developed for Problem Areas and modeled under the five storm event scenarios listed earlier, generating flood inundation depth grids that result from any residual flooding after the implementation of the flood mitigation concepts. During detailed feasibility study and design, the County should consider the cost benefit of higher levels of protection, such as the projected future 10-year storm in 2070 or greater.
- Storage concepts were developed for a range of vacant properties in the general vicinity of Problem Areas, focusing on publicly owned properties; however, private properties were also considered. Cost estimates were initially developed assuming no land acquisition costs, which were subsequently assessed where private sites were included and found to be within the range of accuracy of the planning level cost estimates for storage. Where possible, the bottom elevation of the storage facilities was selected to allow for gravity drainage to nearby storm drains. However, in two instances the bottom elevation that allowed gravity dewatering did not provide adequate volume to capture the 10-year storm, and a lower depth was assumed with pumping systems to dewater the facility, and pumping facility cost estimates were included. These locations where pumping costs were included were in Doctors Branch and Bailey's Branch.
- Mitigation concepts for flood proofing of Public Facilities were developed to address flooding at specific buildings and assets identified as critical infrastructure. The 100-year storm was the basis for Design Flood Elevations for flood mitigation concepts for Public Facilities (where concepts target specific buildings and assets as opposed to Problem Areas). This is the same standard that would be applied were those facilities located in Federal Emergency Management Agency (FEMA) delineated

floodplain (areas of riverine or coastal flooding), where the FEMA base flood elevation plus 1 foot of freeboard would be the recommended standard[3]. Most of the Public Facilities in this analysis were found to be outside FEMA floodplains but within areas of pluvial/interior flood risk; therefore, a similar standard was applied for development of flood mitigation concepts.

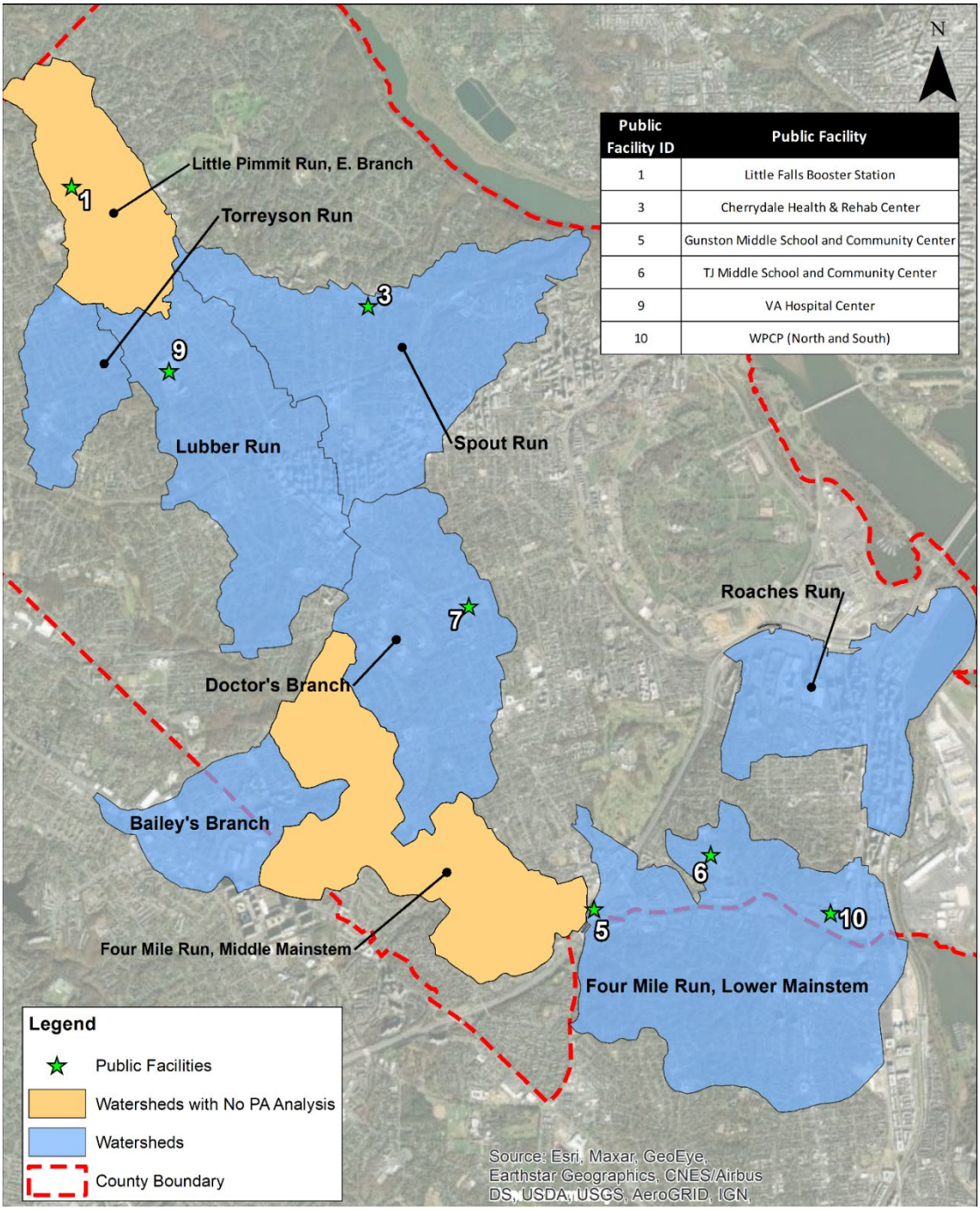



**Figure ES-2. Arlington County Public Facilities and Watersheds Selected for Flood Mitigation Concepts**

[3] Per American Society of Civil Engineers Standard 24-14: *Flood Resistant Design and Construction*.

- Planning-level cost estimates were developed for flood mitigation concepts, which typically have an accuracy range of +100%/-50%[4]. Benefits were estimated as the difference between flood-related losses before mitigation and residual losses after mitigation concepts. The methodology to compute monetized losses was developed and applied originally during Task 5 (Risk Assessment).
- A Benefit-Cost Analysis (BCA) was conducted for Problem Areas and Public Facilities that follows a methodology consistent with FEMA's guidance and tools. This included the use of FEMA's Hazus tool for the assessment of monetized losses driven by flood (also used during Task 5 for Risk Assessment of Problem Areas).

## Limitations and Climate Change Impacts

- This study did not assess the site-specific feasibility of storage and conveyance solutions for Problem Areas that may be impacted by constraints such as utility conflicts, site availability, and contaminated soils.
- The development and analysis of mitigation concepts for Problem Areas did not include consideration of cost of property buyouts and demolition to allow for overland flow during extreme events thus reducing or eliminating repetitive losses in those areas. The analysis of these property acquisition solutions were not part of the scope of this project. Property acquisition is generally considered an alternative of last resort where engineered solutions such as storage or increased conveyance capacity may be deemed infeasible as a result of site-specific studies. Given significant constraints in some areas of the County for the implementation of traditional solutions, property acquisition is currently a tool in the County's toolbox for flood mitigation. The County has undertaken such site-specific feasibility studies in two areas where other solutions were deemed infeasible and results of those analyses have been added to this TM for completeness (parts of Spout Run and Lubber Run).
- The BCA for storage and conveyance flood mitigation concepts in Problem Areas did not consider climate change directly in the calculation of benefits, largely because the Hazus tool requires all five return intervals to accurately assess annualized losses (2-, 10-, 25-, 100- and 500-year storms). The climate change-related scope included modeling with the flood mitigation concepts for only the 10- and 100-year storms under future climate change conditions. However, the change in risk was calculated in the risk assessment in Task 5 and shown to increase on average by 43% for the 10-year storm (with a range of 34% to 74% depending on the watershed) and 14% for the 100-year storm (with a range of 10% to 25% depending on the watershed). Lower Four Mile Run has the highest increase in risk due to climate change. These results suggest that the Benefit-Cost Ratio (BCR) is likely to considerably increase as a result of climate change. In other words, the benefit cost ratio for flood mitigation measures implemented today will only increase as the frequency and severity of storms increases due to climate change.
- The alternatives assessment did not consider the costs and benefits of green stormwater infrastructure (GSI), largely because these alternatives usually are designed at individual property scale and designed for smaller storms, typically 1-inch, and therefore have limited effect on managing large storms that cause flooding. It is recommended that GSI be included as part of comprehensive solutions during site-specific feasibility study and design.

[4] A Class 5 (Planning-Level) cost estimate corresponds to -50% +100% estimates and was performed as defined by the Association for the Advancement of Cost Engineering International, Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06.

# Programmatic Strategies

Programmatic strategies and solutions constitute a valuable approach for flood management in the County. Task 6 included not only the structural flood mitigation concepts for Problem Areas and Public Facilities but also a review of strategies that can enhance the County's administrative, policy, and strategic toolbox related to flooding.

Task 6 included a literature review and interviews to compile programmatic strategies used in other jurisdictions. Task 6 summarizes ongoing strategies as well as existing regulations in the County, and describes novel policy or program approaches to flood management. A matrix was generated to classify relevant policies and programs (refer to Appendix A).

# Concepts for Flood Mitigation

Storage or conveyance solutions were identified conceptually to reduce flooding from the 10-year storm scenario for Problem Areas. These calculations/assessments are to be interpreted on a conceptual basis; no site-specific feasibility assessments were conducted to evaluate utility conflicts, availability of easements, or any other constructability and implementation issues. However, County staff provided information on areas where they have not been successful in developing or implementing conveyance or storage relief because of implementation constraints. This information was taken into consideration during this analysis.

Flood mitigation solutions for Public Facilities looked at solutions in two main mitigation categories related to elevating and/or flood-proofing assets. Specific information on the conveyance and storage solutions for Problem Areas and elevation and flood-proofing of assets at Public Facilities is provided in Section 5.

Task 6 outlines conceptual alternatives. The flood mitigation concepts for Problem Areas and Public Facilities will require additional analysis, including detailed feasibility analyses, before design activities and project implementation can proceed. The concepts, however, inform those pre-design next steps. An additional consideration is that while Task 6 presents conveyance and storage separately as alternatives, projects for flood mitigation can be implemented as a combination of both strategies.

# Flood Risk Mitigation Results

## Costs and Benefits of Mitigation Concepts

### Problem Areas

Benefits of flood mitigation concepts for Problem Areas were estimated based on the flood modeling results and the estimates of flood-related losses from Hazus, as the difference between the losses before and after the implementation of concepts. The analysis of flood reduction and associated reduction of losses was conducted for each Problem Area and can be aggregated at the watershed scale. Figure ES-3 presents the summary of benefits of conveyance and storage concepts at the watershed level, expressed in terms of total annualized risk from Hazus loss, before and after each solution is applied.

The total costs and benefits of the projects are accounted for during the useful life of the infrastructure associated with the flood mitigation concepts. For conveyance and storage infrastructure, a useful life of 50 years is assumed. For BCR computations, the present value of the benefits and costs is computed using a discount rate of 7% consistent with FEMA guidelines. Figure ES-4 shows the net present value (NPV) of costs and benefits for conveyance solutions (which generally have a higher BCR compared with storage solutions) aggregated by watershed.

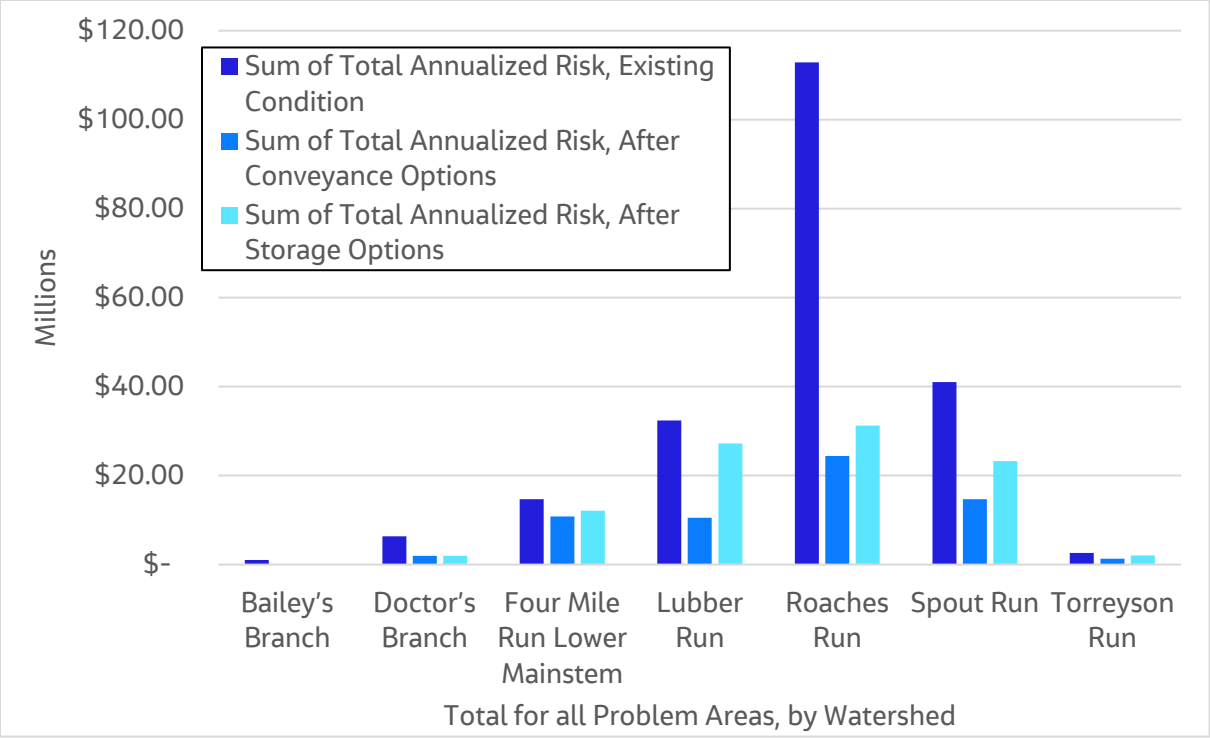



**Figure ES-3. Risk Mitigation (Benefits) from Conveyance and Storage Concepts per Watershed, Based on Total Annualized Risk from Hazus Loss Analysis, Before and After Each Solution is Applied**

**Figure ES-4. Conveyance Flood Mitigation Concepts: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate)**

The NPV of the benefits and costs was used to compute BCRs for each watershed. Ratios were also computed for each Problem Area. Table ES-1 presents the BCRs by watershed. Figure ES-5 and Table ES-1 show that there is a ratio greater than 1.0 for each watershed under at least one of the two concepts explored.

**Table ES-1. Conveyance and Storage Mitigation Solutions Benefit-Cost Results**

| Watershed | Benefit-Cost Ratio Conveyance Concepts | Benefit-Cost Ratio Storage Concepts |
|---|---|---|
| Baileys Branch | 1.4 | 0.9 |
| Doctors Branch | 1.2 | 1.1 |
| Four Mile Run Lower Mainstem[a] | 1.5 | 0.6 |
| Lubber Run | 10.8 | 5.6 |
| Roaches Run | 15.5 | 40.2 |
| Spout Run | 3.9 | 19.6 |
| Torreyson Run[b] | 2.7 | 21.1[b] |

[a] The floodwall project currently under evaluation by the U.S. Army Corps of Engineers (USACE) would have a BCR of 2.0, based on USACE's own modeling and analysis (USACE 2022). That floodwall project or an equivalent project is an additional alternative for the Four Mile Run Lower Mainstem watershed.

[b] The County recently completed construction of 4 MG Cardinal School Vault, which was assumed to be included in baseline scenario. Limited additional opportunities were found for storage, resulting in only small incremental benefits from additional storage. In contrast, there are remaining opportunities for conveyance improvements, thus continuing to add value.

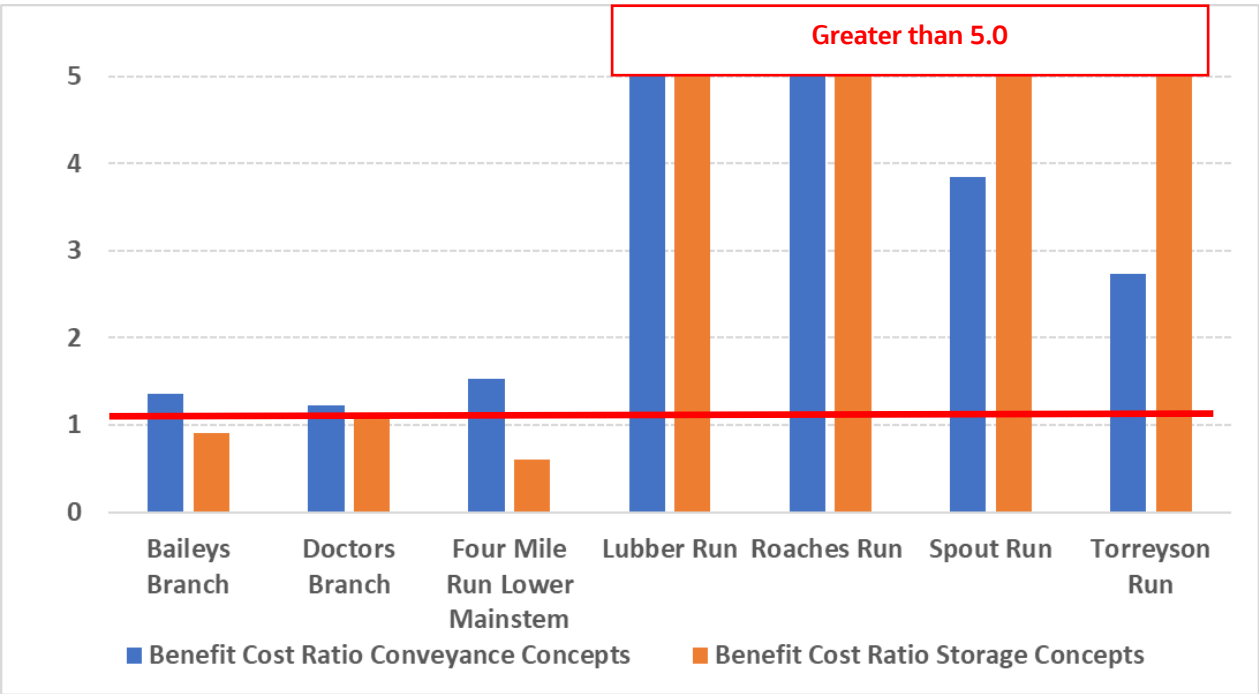



**Figure ES-5. Benefit-Cost Ratios for Conveyance and Storage Flood Mitigation Concepts by Watershed (Y-Axis Ends at 5.0 to Better Visualize the 1.0 Threshold)**

## Public Facilities

Table ES-2 outlines the monetized risk for each facility before flood mitigation and the benefits from implementing flood mitigation concepts (change in cumulative risk for Public Facilities when mitigation strategies are applied from both Alternatives 1 and 2). Alternatives 1 and 2 were developed as combinations of elevating assets and flood-proofing buildings or rooms. Results in Table ES-2, aggregated at the Public Facility level, are derived from the individual building analysis for buildings within a facility.

**Table ES-2. Public Facility Cumulative Monetized Risk and Benefits with Mitigation Strategies, Based on Direct Equipment Damage**

| Facility | Sum of Cumulative Monetized Risk without Strategy (2022-2042) (Thousands $) | Alternative 1 Benefit (Thousands $) | Alternative 2 Benefit (Thousands $) |
|---|---|---|---|
| Cherrydale Center | 1 | 1 | 1 |
| Gunston | 60 | 58 | 58 |
| Little Falls | 100 | 52 | 52 |
| Thomas Jefferson Middle School | 1,798 | 1,764 | 1,770 |
| Virginia Hospital | 5,659 | 5,586 | 5,586 |
| WPCP (North) | 10,137 | 9,401 | Not computed[a] |
| WPCP (South) | 32,270 | 27,368 | Not computed[a] |

[a] The Alternative 2 strategy for the WPCP North and South uses the USACE floodwall. Cumulative monetized risk cannot be accurately calculated with the Task 6 Public Facilities model; however, the floodwall would provide significant protection to both North and South facilities. Table ES-3 outlines the benefits, costs, and BCRs for the two alternative mitigation strategies applied to each Public Facility. Figure ES-6 shows the costs and benefits of the best alternative with the highest BCRs for each facility.

The benefits and BCR values presented in Tables ES-2 and ES-3 include only monetized risk and benefits based on avoided risk from direct damage to equipment and do not include the indirect economic impacts to County residents and businesses should there be a failure of a given facility. Including indirect economic impacts could increase the estimated benefits and BCR for flood mitigation if included. To demonstrate this, the risk and benefits were also calculated to include indirect economic impacts associated with a closure of the WPCP. The results indicate that by accounting for avoided losses from both direct equipment damage and indirect economic losses, the estimated benefits could increase by 19%, from $27.4 million to $32.6 million, with a corresponding increase in the BCR.

Results show that, in all facilities except for Cherrydale Center, there is an alternative with a BCR greater than 1.0, which does not mean that flood mitigation should not be implemented. Other considerations of risk are important in determining the need for flood mitigation at that facility, such as providing safe access roads and parking areas for first responders to support a vulnerable population. The BCR, however, is an indication that additional exploration of concepts may be necessary to maximize cost-effectiveness at Cherrydale Center.

**Table ES-3. Public Facility Capital Costs, Benefits, and Benefit-Cost Ratios Based on Direct Equipment Damage**

| Public Facility | Benefit Alternative 1 (Thousands $) | Benefit Alternative 2 (Thousands $) | Capital Costs, Alternative 1[b] (Thousands $) | Capital Costs, Alternative 2[b] (Thousands $) | Benefit-Cost Ratio Alternative 1 | Benefit-Cost Ratio Alternative 2 |
|---|---|---|---|---|---|---|
| Cherrydale Center | 1 | 1 | 7<br>(5 to 11) | 21<br>(14 to 31) | 0.2 | 0.1 |
| Gunston Middle School | 58 | 58 | 252<br>(177 to 378) | 22<br>(15 to 33) | 0.2 | 2.7 |
| Little Falls | 52 | 52 | 7<br>(5 to 11) | 21<br>(14 to 31) | 7.2 | 2.6 |
| Thomas Jefferson Middle School | 1,764 | 1,770 | 91<br>(64 to 137) | 49<br>(35 to 74) | 19.3 | 35.9 |
| Virginia Hospital Center | 5,586 | 5,586 | 59<br>(41 to 88) | 164<br>(115 to 246) | 95.4 | 34.1 |
| WPCP (North)[a] | 9,401 | N/A | 2,096<br>(1,467 to 3,144) | 3,592<br>(1,347 to 5,388) | 4.5 | 2.0[a] |
| WPCP (South)[a] | 27,368 | N/A | 4,537<br>(3,176 to 6,806) | | 6.0 | 2.0[a] |
| Total | | | 7,049<br>(4,934 to 10,574) | 3,869<br>(2,708 to 5,804) | | |

[a] The Alternative 2 strategy for the WPCP North and South uses the USACE floodwall. Benefits for Alternative 2 could not be determined, thus a BCR cannot be determined with the same methods used in Task 6 of the RAMP. USACE, however, reports a BCR of 2.0 for the project (based on protection of the area beyond the WPCP) (USACE 2022).

[b] Class 4 level (-30% to +50%) estimate was used to develop the costs as defined by the Association for the Advancement of Cost Engineering International (AACEI), Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M. Problem Area cost estimates used Class 5 (-50% to +100%) given the larger uncertainty on implementing projects at neighborhood scale.

For the WPCP, Table ES-3 lists the BCR developed by USACE for their floodwall along Four Mile Run. A project to protect from fluvial flooding in the area, such as the USACE floodwall, would provide flood mitigation benefits and could protect the facility (and vicinity).

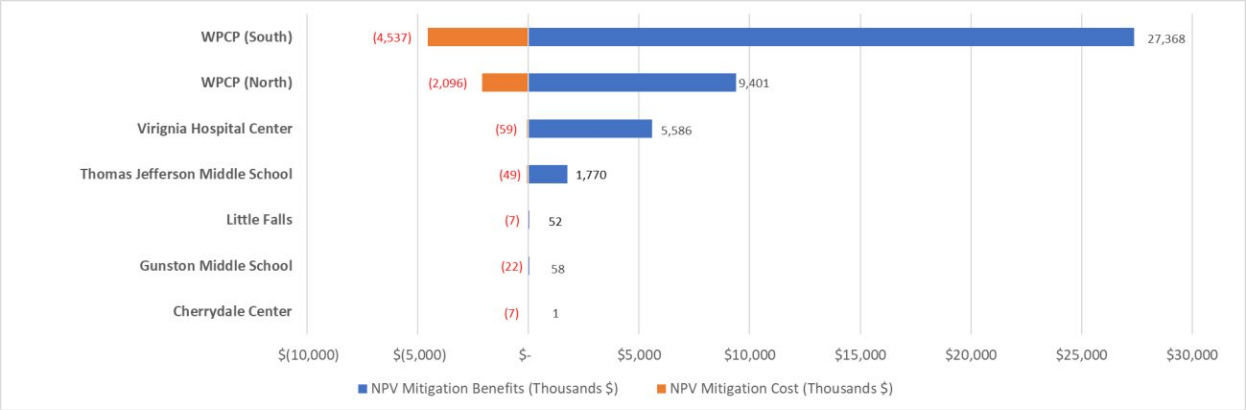



**Figure ES-6. Flood Mitigation at Public Facilities: Net Present Value of Benefits and Costs (Total Capital and O&M) of Best Alternatives for Elevation and Flood-Proofing (20-Year Period and 7% Discount Rate)**

## Next Steps

The RAMP effort included a workshop to present and discuss results of Task 6 to identify mitigation and adaptation strategies that provide flood reduction benefits above the general costs that are expected to be incurred for implementation. A final report will document not only the results of Task 6 analysis but also the outcomes of the workshop as it relates to implementation considerations.

Implementation steps after completion of the RAMP will include feasibility-level studies for project implementation and further analysis to optimize the concepts assessed in this Task 6 at the planning level. Conducting feasibility studies are typically part of the next steps after a planning analysis such as the RAMP. The studies would entail site-specific investigation of siting constraints to identify available space limitations, conflicts with existing underground utility infrastructure, easement and property acquisition requirements, and environmental resource constraints. That information is then used to refine and evaluate alternatives, costs and benefits, and assess permitting requirements. For many Problem Areas, projects are likely to include a combination of conveyance, storage, and possibly overland relief options. For Public Facilities, flood mitigation concepts from Task 6 could proceed with pre-design and design for facilities buildings and assets at risk.

Prioritization of actions for Problem Areas and Public Facilities can be informed by the BCRs developed as part of Task 6. Prioritization of projects for Public Facilities can additionally rely on criteria such as criticality of assets and risk exposure identified in Task 5. For Problem Areas, project prioritization will include additional considerations given that those projects protect not only individual assets and their functions, but larger areas where people live, work, and recreate. Environmental and social vulnerability factors assessed in Tasks 4 and 5, as well as other relevant prioritization criteria, will be taken into consideration. Additional criteria can include public safety, availability of funding opportunities, project-bundling opportunities, legal and regulatory mandates, opportunities for partnerships with other agencies, public support and need, and a number of other key considerations that go beyond the scope of Task 6.

Programmatic solutions are part of the County's portfolio of potential actions, and decisions to enhance existing solutions and add new policies, actions, procedures, and standards can be informed by the review of programmatic solutions provided in this TM. The RAMP tasks, which have included assessments of flood exposure, vulnerability, and risk under historical and climate change conditions, will inform the County's actions in updating design guidance and standards for County facilities.

The final report for the RAMP will be prepared serving as an informed implementation roadmap for successfully guiding risk reduction and resilience in the County's continued stormwater investment.

# Contents

**Executive Summary** ..... **ES-1**
Purpose ..... ES-1
Geographic Scope: Problem Areas and Public Facilities ..... ES-1
Methods ..... ES-3
Limitations and Climate Change Impacts ..... ES-5
Programmatic Strategies ..... ES-6
Concepts for Flood Mitigation ..... ES-6
Flood Risk Mitigation Results ..... ES-6
Costs and Benefits of Mitigation Concepts ..... ES-6
Public Facilities ..... ES-9
Next Steps ..... ES-11
**Acronyms and Abbreviations** ..... **v**
**1. Introduction** ..... **1-1**
1.1 Task Purpose ..... 1-1
1.2 Task Terminology ..... 1-2
1.3 Problem Areas and Public Facilities ..... 1-2
1.4 Geographic Scope ..... 1-3
1.4.1 Problem Areas ..... 1-3
1.4.2 Public Facilities ..... 1-3
**2. Data and Information Sources** ..... **2-1**
2.1 Exposure and Scenarios ..... 2-1
2.2 Problem Areas Data ..... 2-1
2.3 Public Facilities Data ..... 2-2
**3. Programmatic Strategies for Flood Management** ..... **3-1**
**4. Analysis Methodology** ..... **4-1**
4.1 Problem Areas ..... 4-1
4.1.1 Concept Definition ..... 4-1
4.1.2 Modeling Methodology ..... 4-1
4.1.3 Hazus – Economic Analysis ..... 4-2
4.1.4 Cost Estimates ..... 4-3
4.1.5 Benefit-Cost Analysis ..... 4-4
4.2 Public Facilities ..... 4-5
4.2.1 Mitigation Strategy Methods ..... 4-5
4.2.2 Mitigation Strategies for Assets Selection ..... 4-6
4.2.3 Mitigation Concepts Cost Estimates ..... 4-6

4.2.4 Benefit-Cost Analysis for Public Facilities ..... 4-6
**5. Flood Mitigation Concepts ..... 5-1**
5.1 Background and Considerations ..... 5-1
5.2 Conceptual Conveyance and Storage Solutions for Problem Areas ..... 5-1
5.2.1 Conveyance and Storage Flood Mitigation Concepts for Areas of Pluvial Flooding ..... 5-1
5.2.2 Levee Flood Mitigation Concepts for Areas of Four Mile Run Lower Mainstem with Riverine and Coastal Flooding ..... 5-3
5.2.3 Cost Estimate Results ..... 5-5
5.3 Conceptual Flood Mitigation Solutions for Public Facilities ..... 5-8
5.3.1 Concepts Chosen to Protect Assets ..... 5-13
5.3.2 Cost Estimates ..... 5-14
**6. Analysis Results ..... 6-1**
6.1 Problem Areas ..... 6-1
6.1.1 Model Results ..... 6-1
6.1.2 Reduction in Flood Risk ..... 6-1
6.1.3 Benefit-Cost Ratio Results ..... 6-12
6.2 Public Facilities ..... 6-13
6.2.1 Cumulative Risk Comparison Based on Direct Damages ..... 6-14
6.2.2 Cumulative Risk from Indirect Impacts of a Potential Service Interruption at the WPCP ..... 6-16
6.2.3 Benefit-Cost Analysis for Public Facilities ..... 6-17
**7. Conclusions and Next Steps ..... 7-1**
7.1 Conclusions ..... 7-1
7.2 Next Steps ..... 7-1
**8. References ..... 8-1**

## Appendices

A Programmatic Strategies for Flood Management
B Hazus Overview
C Detailed Concepts per Watershed Problem Areas
D Analysis of Land Acquisition Costs on Storage Capital Costs by Problem Area
E Conveyance and Storage Solution Cost Estimate and Benefits Details per Problem Area
F Inundated SVI Area Pre versus Post Mitigation Solutions per Problem Area
G Cost Estimate Details and Benefits for Public Facilities
H Economic Impacts of Natural Hazards on Water Pollution Control Plant

## Tables

Table ES-1. Conveyance and Storage Mitigation Solutions Benefit-Cost Results ..... ES-8

Table ES-2. Public Facility Cumulative Monetized Risk and Benefits with Mitigation Strategies, Based on Direct Equipment Damage ..... ES-9

Table ES-3. Public Facility Capital Costs, Benefits, and Benefit-Cost Ratios Based on Direct Equipment Damage ..... ES-10

Table 3-1. Summary of Flood Management Programmatic Strategies Recommendations ..... 3-2

Table 5-1. Aggregate Estimated Capital Cost of Conveyance and Storage Solutions per Watershed ..... 5-7

Table 5-2. Public Facility Flood Scenarios and Mitigation Strategies ..... 5-13

Table 5-3. Public Facility Cost of Alternatives 1 and 2 Mitigation Strategies ..... 5-14

Table 6-1. Conveyance Solutions Hazus Risk (Losses) and Benefits Comparison per Watershed ..... 6-10

Table 6-2. Storage Solutions Hazus Risk (Losses) and Benefits Comparison per Watershed ..... 6-10

Table 6-3. Conveyance Solutions Reduction in SVI Flood Impacts per Watershed for 100-year 2020 Storm ..... 6-11

Table 6-4. Storage Solutions Reduction in SVI Flood Impacts per Watershed for 100-year 2020 Storm ..... 6-11

Table 6-5. Conveyance Mitigation Solutions Benefit-Cost Analysis Results ..... 6-12

Table 6-6. Storage Mitigation Solutions Benefit-Cost Analysis Results ..... 6-12

Table 6-7. Public Facility Cumulative Monetized Risk from Direct Equipment Damage, without and with Mitigation Strategies ..... 6-15

Table 6-8. Public Facility Benefits of Mitigation Strategies Based on Cumulative Monetized Risk Avoided for Direct Equipment Damage ..... 6-15

Table 6-9. Facilities not Requiring Mitigation ..... 6-16

Table 6-10. Summary of WPCP Service Interruption Scenarios and Economic Impact Estimates ..... 6-16

Table 6-11. Cumulative Monetized Risks and Benefits for Mitigation Strategy 1 at WPCP, with Both Direct Damage to Equipment and Indirect Economic Risk ..... 6-17

Table 6-12. Public Facility Costs, Benefits, and Benefit-Cost Ratios Based on Direct Equipment Damage ..... 6-18

## Figures

Figure ES-1. Arlington County Problem Areas Selected for Flood Mitigation Concepts ..... ES-2

Figure ES-2. Arlington County Public Facilities and Watersheds Selected for Flood Mitigation Concepts ..... ES-4

Figure ES-3. Risk Mitigation (Benefits) from Conveyance and Storage Concepts per Watershed, Based on Total Annualized Risk from Hazus Loss Analysis, Before and After Each Solution is Applied ..... ES-7

Figure ES-4. Conveyance Flood Mitigation Concepts: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate) ..... ES-7

Figure ES-5. Benefit-Cost Ratios for Conveyance and Storage Flood Mitigation Concepts by Watershed (Y-Axis Ends at 5.0 to Better Visualize the 1.0 Threshold) ..... ES-8

Figure ES-6. Flood Mitigation at Public Facilities: Net Present Value of Benefits and Costs (Total Capital and O&M) of Best Alternatives for Elevation and Flood-Proofing (20-Year Period and 7% Discount Rate) ..... ES-11
Figure 1-1. Arlington County Problem Areas Selected for Flood Mitigation Concepts ..... 1-4
Figure 1-2. Arlington County Public Facilities and Watersheds Selected for Flood Mitigation Concepts ..... 1-6
Figure 5-1. Example Conveyance Concept Map in the Doctor's Branch Watershed ..... 5-2
Figure 5-2. Example Storage Concept Map in the Doctor's Branch Watershed ..... 5-4
Figure 5-3. USACE Floodwall Project Highlights (USACE 2022) ..... 5-6
Figure 5-4. Elevating Flood Strategy within a Building ..... 5-9
Figure 5-5. Elevating Flood Strategy outside a Building ..... 5-10
Figure 5-6. Hardening Flood Strategy – Operable Flood Barriers (Can be Manual and Automatic) ..... 5-11
Figure 5-7. Hardening Flood Strategy – Perimeter Wall with Gate ..... 5-12
Figure 6-1. Bailey's Branch Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-2
Figure 6-2. Doctors Branch Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-3
Figure 6-3. Lubber Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-4
Figure 6-4. Roaches Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-5
Figure 6-5. Spout Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-6
Figure 6-6. Torreyson Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-7
Figure 6-7. Four Mile Run Middle Mainstem Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions ..... 6-8
Figure 6-8. Four Mile Run Middle Mainstem Current (Year 2020) ..... 6-9
Figure 6-9. Conveyance Flood Mitigation Concepts: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate) ..... 6-13
Figure 6-10. Flood Exposure for Flood Scenario 1 (Climate Change in 2040) 100-year Storm at the WPCP ..... 6-14
Figure 6-11. Alternative 1 Mitigation Strategies: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate) ..... 6-19
Figure 6-12. Alternative 2 Mitigation Strategies: Net Present Value of Benefits and Costs (Total Capital and O&M) (50- Year Period and 7% Discount Rate) ..... 6-19

# Acronyms and Abbreviations

| | |
|---|---|
| 1D | one-dimensional |
| 2D | two-dimensional |
| AACEI | Association for the Advancement of Cost Engineering International |
| ac. | acre(s) |
| BB | Bailey's Branch |
| BCA | Benefit-Cost Analysis |
| BCR | Benefit-Cost Ratio |
| BFE | base flood elevation |
| County | Arlington County, Virginia |
| DB | Doctor's Branch |
| FEMA | Federal Emergency Management Agency |
| FMRL | Four Mile Run Lower Mainstem |
| GIS | geographic information system |
| IDF | intensity-duration-frequency |
| LOS | level of service |
| LR | Lubber Run |
| NAVD88 | North American Vertical Datum of 1988 |
| NFIP | National Flood Insurance Program |
| NPV | net present value |
| O&M | Operations and Maintenance |
| PA | Problem Area |
| PUL | Project Useful Life |
| RAMP | Risk Assessment and Management Plan |
| RPA | Resource Protection Area |
| RR | Roaches Run |
| SLR | sea level rise |
| SP | Spout Run |
| SVI | social vulnerability index |

| | |
|---|---|
| TM | Technical Memorandum |
| TR | Torreyson Run |
| USACE | U.S. Army Corps of Engineers |
| WPCP | Water Pollution Control Plant |

# 1. Introduction

Arlington County, Virginia (County) initiated a study to support the Stormwater Program Risk Assessment and Management Plan (RAMP) in May 2020. The intent of this project is to conduct analyses for the Arlington County Department of Environmental Services resulting in a comprehensive RAMP; specifically a full strategic portfolio to address the risk of flooding due to current and future climate conditions, and to project and map risk and consequential impacts in support of long-term resilience. In addition, the RAMP will inform a prioritized capital improvement plan, with enhanced design standards and forward-looking adaptation strategies that will allow the County to maintain a responsive level of service (LOS) and a pathway for long-term adaptive design and functionality of the stormwater conveyance systems.

Previous tasks in the RAMP identified flood exposure in the County and conducted analyses to assess flood risk in specific Problem Areas and selected Public Facilities in the project area. This task, Task 6 of the RAMP, includes the development of conceptual flood mitigation strategies to address each Problem Area. Site-specific mitigation strategies were also developed for at-risk Public Facilities, focusing on protection of specific assets within those facilities. This Technical Memorandum (TM) documents Task 6.

## 1.1 Task Purpose

The purpose of Task 6 was to develop flood mitigation strategies in three main categories as follows:

- Programmatic strategies as a nonstructural approach for management of flooding in the County
- Conveyance and storage concepts for Problem Areas in the County identified and prioritized in previous tasks
- Building-level and asset-level concepts to protect critical assets in Public Facilities identified and prioritized in previous tasks

Additionally, Task 6 calculates the monetized residual risk after implementation of the flood mitigation concepts. The difference between the risk under no action (estimated in Task 5) and any residual risk after implementation of the flood mitigation concepts is the benefit associated with those concepts. Planning- level cost estimates for the flood mitigation concepts were used to conduct a Benefit-Cost Analysis (BCA) that can inform future actions by the County in Capital Improvement Program development and prioritization.

Task 6 does not include project recommendations. *The flood mitigation concepts for Problem Areas and Public Facilities will require additional analysis, including detailed feasibility analyses, before design activities and project implementation can proceed.* The flood mitigation concepts, however, inform those pre-design next steps, which include feasibility-level studies for project implementation and further analysis to optimize the concepts assessed in this Task 6 at the planning level. Conducting feasibility studies typically would entail site-specific investigation of siting constraints to identify available space limitations, conflicts with existing underground utility infrastructure, easement and property acquisition requirements, and environmental resource constraints. That information is then used to refine and evaluate alternatives, costs and benefits, and assess permitting requirements. For many Problem Areas, projects are likely to include a combination of conveyance and storage, and possibly overland relief options. For Public Facilities, flood mitigation concepts from Task 6 could proceed with pre-design and design for facilities buildings and assets at risk.

## 1.2 Task Terminology

The following are some key terms and definitions for this task and past and future RAMP tasks:

- **Asset**: Piece of equipment or equipment sets within a facility – example: electrical panel in a pump station building.
- **Flood Mitigation Concept**: Conceptual-level projects to address flood risk. In this task, projects include conveyance, storage, structures to elevate assets, deployable flood gates, and perimeter walls.
- **Problem Area**: A geographic area containing many receptors (refer to the definition of "receptor" in this section) that are at high risk (abbreviated in this document as PA).
- **Programmatic Strategies**: Nonstructural actions for management of flooding in the County. These include policies, programs, administrative actions, ordinances, design and construction standards, and operational procedures with tangible flood management benefits.
- **Public Facility**: A specific facility selected for risk analysis under this Task 6.
- **Receptor**: Any entity of interest that can be exposed to flooding – examples: a facility, an asset, a public building providing critical services, a resource protection area (RPA). Receptors used in the vulnerability analysis documented in this TM come primarily from the work in Task 2, Data Collection, which compiled a list of "critical facilities." The term "receptor" in this TM refers primarily to the elements in that list, with some additions such as environmentally relevant locations and private electric and gas utility facilities.
- **Risk**: Risk is generally estimated as the product of likelihood (probability of occurrence, such as 10% annual chance from a 10-year storm) times consequence (such as physical damages). Two additional risk terms are used in Task 6 as follows:
  - **Annualized Risk** is the monetary risk that accounts for the probability of events of different magnitudes occurring in a single year, and the consequences of those events.
  - **Cumulative Risk** is the aggregate of the annualized risk over the planning period, using a discount rate.

## 1.3 Problem Areas and Public Facilities

A key feature of Task 6 (and Task 5, previously) is the distinction between two types of receptors (areas or locations impacted by flood that are of special interest for the analysis): Public Facilities and Problem Areas. Task 5 included risk analysis for the following:

- Thirty-four Problem Areas (referred to in this TM as Problem Areas and abbreviated as PA in some instances): These areas correspond to areas where flooding is anticipated based on flood modeling results in watersheds prioritized during Task 4 (Vulnerability Assessment) and can include any type of public or private building with residential, commercial, governmental, educational, and other uses, as well as emergency response or utility facilities. The Problem Areas are described in Section 1.4.1.
- Ten Public Facilities (referred to in this TM as Public Facilities, capitalized): Identified as a result of the Vulnerability Assessment in Task 4, these Public Facilities were identified as potentially vulnerable to flood impacts and are critical for different public functions. The list, location, and description of Public Facilities is included in Section 1.4.2.

Task 6 develops flood mitigation concepts for the same Problem Areas and Public Facilities analyzed in Task 5. The Programmatic Strategies that are also part of the County's toolbox to manage flood risk and described in this TM can be (and likely will be) applied County-wide.

While the framework of the Task 6 analysis in terms of risk, cost, and benefits, is the same for Problem Areas and Public Facilities, the specific flood mitigation concepts are different. In both cases, the key desired outcome is the reduction of flood risk but the scale of analysis is different, with Problem Areas at the scale of neighborhood(s) and Public Facilities at building- and even asset-level scale.

## 1.4 Geographic Scope

### 1.4.1 Problem Areas

A total of 34 Problem Areas were identified for the analysis in the priority watersheds. These areas do not comprise a full list of potential flooding Problem Areas in the County, just those in the priority watersheds selected by the County based on the Vulnerability Assessment in Task 4. Figure 1-1 includes the Problem Areas analyzed for mitigation solutions and their respective watersheds. Watersheds prioritized in previous tasks (Jacobs 2021a) are listed as follows, including the abbreviation used in this TM for figures and tables):

- Bailey's Branch (BB)
- Doctor's Branch (DB)
- Lubber Run (LR)
- Four Mile Run Lower Mainstem (FMRL)
- Roaches Run (RR)
- Spout Run (SP)
- Torreyson Run (TR)

In the context of this project, a "Problem Area" is defined as an area exposed to flooding within a County watershed, based on hydrologic/hydraulic modeling, historic data, and flood complaint calls. The boundary of flooded area included in each Problem Area was delineated approximately based on maximum contiguous extent of flood exposure and potential location of mitigation alternatives (conveyance or storage improvements) to hydraulic deficiencies for the flooded area. Additional detail in the definition of Problem Areas is included in the TM developed for the Task 5 analysis (Jacobs 2022).

### 1.4.2 Public Facilities

As part of Task 4, a large set of County critical facilities was included in the analysis of exposure under multiple scenarios. With the information on exposure and considerations of criticality of the facilities, a short list of Public Facilities was prioritized for detailed analysis of risk under Task 5 and for flood mitigation concepts under Task 6. These Public Facilities include the following:

- Little Falls Booster Station, located in Little Pimmit Run East Branch
- Cardinal Elementary School, located in Torreyson Run
- Water Pollution Control Plant (WPCP) North Area, located in Four Mile Run Lower Mainstem
- WPCP South Area, located in Four Mile Run Lower Mainstem
- Trades Center – Equipment Bureau, and DPR Building/Network Operations Hub, located in Four Mile Run Middle Mainstem
- Virginia Hospital Center, located in Lubber Run
- Thomas Jefferson Middle School and Community Center, located in Doctor's Branch
- Gunston Middle School and Community Center, located in Four Mile Run Lower Mainstem
- Cherrydale Health and Rehabilitation Center, located in Spout Run
- ART Operations and Maintenance (O&M) Facility, located in Four Mile Run Lower Mainstem (with a part of it in Nauck Branch watershed)

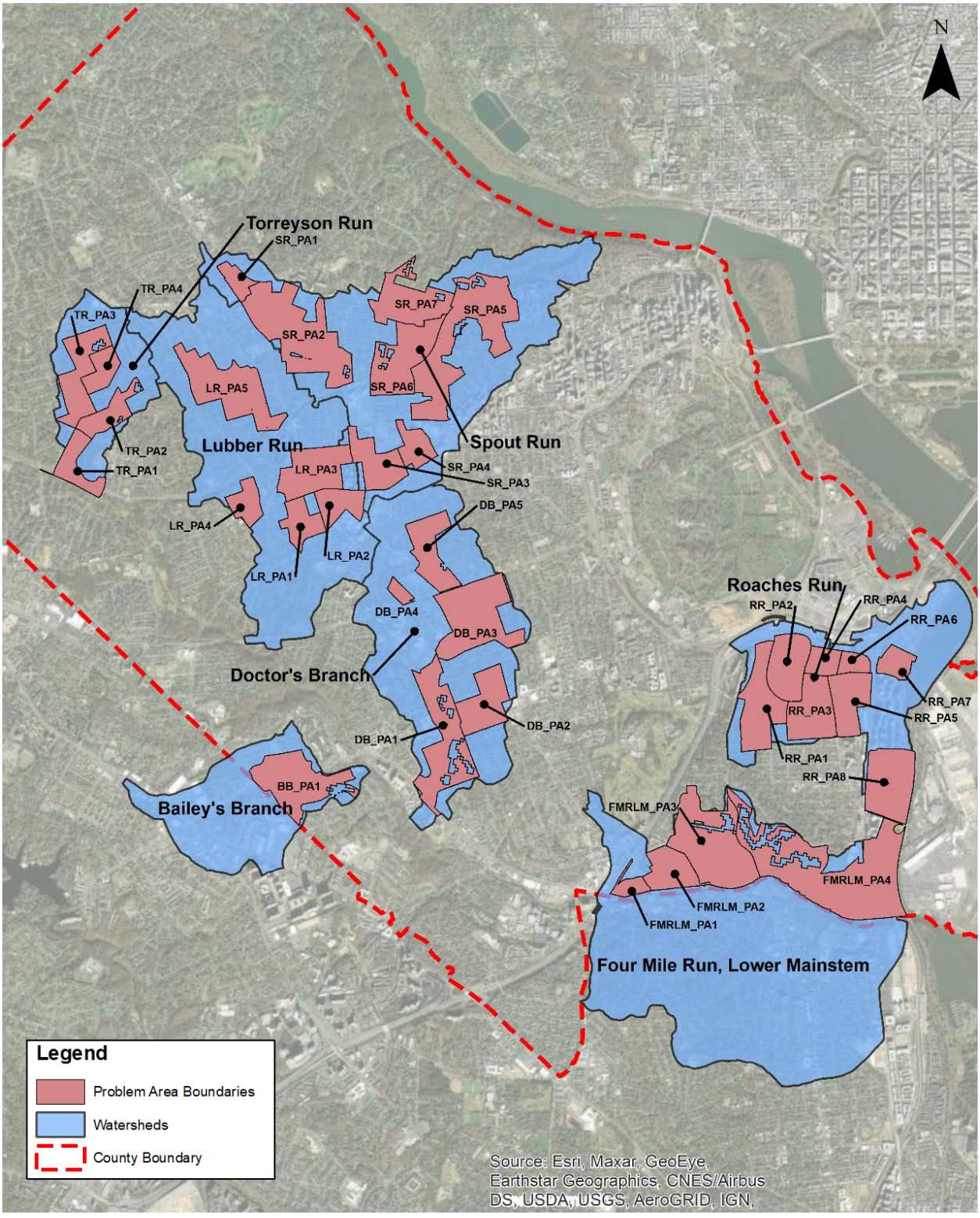



**Figure 1-1. Arlington County Problem Areas Selected for Flood Mitigation Concepts**

Figure 1-2 presents the watersheds and Public Facilities included in Tasks 5 and 6. Of the 10 Public Facilities, the risk analysis under Task 5 identified limited risk for three facilities: Trades Center, ART O&M Facility, and Cardinal Elementary School. While these three facilities are in areas where flooding does occur and is projected to occur, results of the flood modeling analysis show very limited risk to the assets in those facilities that could be vulnerable to flood. Flood in the vicinity and inside those facilities could still be disruptive for access and general operations, but no flood mitigation concepts were developed as part of Task 6.[5]

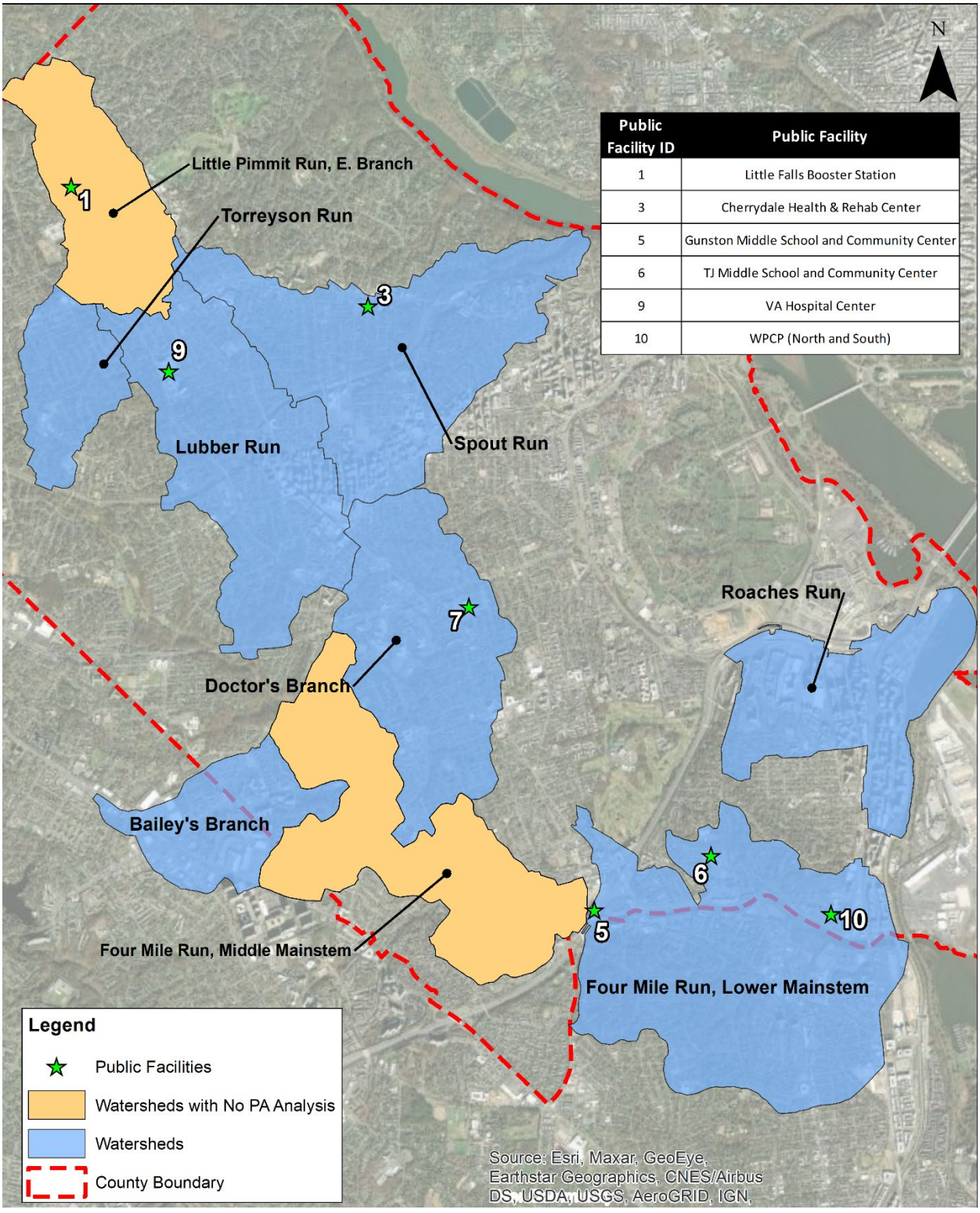



**Figure 1-2. Arlington County Public Facilities and Watersheds Selected for Flood Mitigation Concepts**

# 2. Data and Information Sources

Given that the mitigation solutions for storage and conveyance are followed by a risk analysis based on the overlay of the flood hazard and receptors of interest, the critical data relate to both the modeled flood exposure and the inventory of assets included in the receptors of interest.

For Task 6, the receptors are Problem Areas and Public Facilities. Relevant assets for the analyzed Problem Areas are the building stock and the vehicle stock in each Problem Area (which are sensitive to flood in different degrees). For Public Facilities, specific assets sensitive to flood were surveyed. Data sources and collection are described in the following sections.

## 2.1 Exposure and Scenarios

Analysis of Problem Areas was based on selected storm events with varying return periods modeled during this task, matching the return periods used during Task 5: 2-, 10-, 50-, 100-, and 500-year return periods under historical climate conditions (no climate change). While the analysis in Task 6 does not include climate change scenarios, significant assessment of flood exposure vulnerability and risk under climate change has been included in the RAMP in earlier tasks. In addition to urban flood (interior flood) exposure from rainfall, results of exposure from the Four Mile Run riverine flood model in Task 3 were used. The Public Facilities analysis did not require additional flood modeling.

## 2.2 Problem Areas Data

The existing condition models developed in PCSWMM for Task 3.3, Arlington Interior and Riverine Flooding Report Task (Jacobs 2021b) of the Arlington RAMP was used as the basis for the Problem Area flood mitigation analysis.

Results of the Task 4 Vulnerability Assessment and Task 5 Risk Assessment were used to inform locations to target for flood mitigation solutions. Two conceptual flood mitigation strategies including conveyance relief and underground storage were developed to address each Problem Area as a whole to the extent practicable.

Criteria used to the extent practicable include the following:

- Baseline 2020 10-year event with updated intensity-duration-frequency (IDF) developed in Task 3.1, Climate Change Projections and Definition of Climate Change Scenarios. The 10-year event used corresponds to historical conditions (no climate change) and the updated IDF for the RAMP corresponds to 5.16-inch 24-hour volume and a 60-minute maximum intensity of 2.29 inches per hour.
- To the extent practicable, limit sewer surcharges up to 1-foot freeboard below ground elevation.

Based on the data and information presented earlier, conceptual flood mitigation solution projects and cost estimates were developed to alleviate flooding in the Problem Areas.

To calculate the benefits of flood mitigation alternatives, the Federal Emergency Management Agency's (FEMA's) Hazus tool was applied to estimate residual risk that remains after implementation of a given mitigation alternative. Benefits for each problem area were calculated as damages avoided by subtracting the residual risk after a given set of solutions were identified, from the current flood risks monetized in Task 5 (the risk with no action). The data required for the monetary risk analysis are included in the database of the tool applied for the analysis. The tool, Hazus, was developed by FEMA and uses baseline databases in the software for building area and value, population characteristics, costs of building repair, and certain basic economic data.

Hazard data are uniformly applied or generated from minimal input data and applied to the baseline inventory data with little to no user modification. Direct economic and social losses associated with the general building stock and critical facilities are computed. Baseline data for transportation and utility systems are also included in Hazus databases. A disadvantage of Hazus is that data in its most recent datasets correspond to 2010 Census and 2018 property valuations and loss unit costs. **These dated inputs can result in underestimated total losses and benefits in Task 6.** This will be further discussed in Section 6. Appendix B includes a description of Hazus.

## 2.3 Public Facilities Data

Data for the 10 Public Facilities were collected as part of Task 5 by means of County-provided as-builts, site visits, and survey results. In addition, one facility required additional collaboration with the County because of the proposed design and reconstruction of the ART O&M Facility. A detailed description of the data collection process for Task 5 for Public Facilities can be reviewed in the TM for that task (Jacobs 2022). Critical inputs from Task 5 used for Task 6 include the following:

- Asset elevation for assets vulnerable to flood, for exposed buildings in critical facilities.
- Nonmitigated monetized risk, which is the monetary losses associated with assets flooding and being damaged. This information is available as an annualized risk (accounts for events of different magnitude and probability in an annualized basis) and cumulative risk (annualized risk aggregated over 20 years, which is assumed as the average useful life for the assets analyzed).

Additional key data for Task 6 are the cost of the flood mitigation concepts. Unit costs were obtained from previous similar projects and escalated to year 2023 and adjusted for geographic cost index.

A key difference between the Problem Area analysis and the Public Facilities analysis in Task 6 is that Public Facilities do not require new flood model runs to evaluate the flood mitigation. The water surface elevations from the Task 5 analysis are used as base flood elevations (BFEs) in Task 6 to establish the dimensions and elevations of the flood mitigation concepts.

# 3. Programmatic Strategies for Flood Management

Programmatic strategies and solutions constitute a valuable approach for management of flooding in the County. Task 6 included not only the structural flood mitigation concepts for Problem Areas and Public Facilities but also a review of strategies that can enhance the County's administrative and policy toolbox related to flooding.

A multitude of policy and program offerings are used by jurisdictions nationally that should be considered for management of flood risk on a County-wide scale and potentially applied on a site-specific basis in the County. As part of Task 6, a TM has been developed that summarizes ongoing strategies as well as existing regulations in the County but also describes novel policy or program approaches to flood management implemented in other jurisdictions. A matrix was generated to classify relevant policies and programs (for example, freeboard, public flood risk information tools, flood overlay zoning) and identify jurisdictions that may have experience with these. Two primary methods were used to understand the ways other jurisdictions have addressed flood management in their localities: a desktop study and an informal interview with representatives from select jurisdictions. Interviews were conducted virtually using a prepared questionnaire.

A discussion of strategies is included in the Programmatic Strategies TM (Appendix A). Because strategies cover a wide range of activities, they have been summarized according to the following categories:

- Governance considerations
- Public information
- Information supporting County flood risk activities
- Equity considerations
- Flood risk mitigation
- Integrating flood risk information into land use planning
- Updating regulations based on flood risk information
- Flood management finance and funding
- Storm drainage asset management

Appendix A provides the full TM on Programmatic Strategies with a discussion of strategies that may be considered by the County to improve management of flooding. It is important to consider that the projects that may result from the concepts discussed in Section 5 of this TM, will be implemented in the context of programmatic solutions both new and currently in place in the County. Table 3-1 presents a summary of recommendations from the review and surveys documented in Appendix A.

**Table 3-1. Summary of Flood Management Programmatic Strategies Recommendations**

| Subject | Recommendations |
|---|---|
| Governance | Explore methods to formalize communication and data sharing among relevant agencies for the specific goal of ongoing flood management. |
| Public Information | Consider whether existing flood hazard information, available via FEMA, can be made more accessible to the public using an available mapping tool, or whether development of a targeted flood risk tool may be helpful to also provide information on pluvial/urban flooding risk, when available, that are not addressed by FEMA National Flood Insurance Program (NFIP) flood maps.<br>Consider assessing whether National Weather Service notifications or more location-specific real-time alerts would be helpful in avoiding damages or life-safety issues in flood-prone areas.<br>Consider development of coordinated and ongoing community engagement programs that will provide public education on flood risk and flood risk mitigation options. Consider outreach techniques targeted at socially disadvantaged communities.<br>Consider whether more stringent disclosures may be warranted in areas of chronic flooding. |
| Information Supporting County Flood Risk Management Activities | Explore the benefits of installing real-time rainfall, tide, or stream gauges to inform County operations.<br>Consider whether drainage-focused building permit reviews could be an opportunity to address conditions that may exacerbate lot-to-lot flooding.<br>Identify available records that can be used to assess historical flood impacts, recognize limitations the records may have, and determine whether the data may inform ongoing flood management activities. |
| Equity Considerations | Ensure that flood management activities are carried out with appropriate consideration of the County's equity goals. |
| Flood Risk Mitigation | Understand how the following activities may encourage property owners to purchase flood insurance and/or flood proof their facilities by tracking flood insurance coverage statistics: current efforts to expand flood hazard and flood risk information, making this information available to the public, and using the information to manage flooding.<br>Understand how the following activities may help increase flood insurance coverage for County residents: parametric microinsurance, premium reductions for low-cost flood mitigation, local flood insurance affordability programs, community assistance combined with a high-deductible NFIP policy, community-based insurance, and right-sizing coverage (Kousky and Wiley 2021).<br>Consider whether a technical support program may be helpful in addressing resident flooding or drainage issues. Consider whether the goal of such a program might be limited to storm drain improvement or to assisting low-income residents in addressing floodproofing and other private property mitigations.<br>As part of repetitive loss plan, consider whether property acquisition or buyouts should be planned for. |

| Subject | Recommendations |
|---|---|
| Integrating Flood Risk Information with Land Use Planning | Consider what process will be used to integrate flood risk into land use planning, subdivision, and development review. |
| Updating Regulations and Design Standards Based on Flood Risk Information and Climate Change | Proceed with the planned review of regulations and standards to ensure that they are consistent with the resilience and flood management goals of the County. |
| Flood Management Finance and Funding | Consider development of a strategy for funding and finance of flood management programmatic strategies and capital projects. |
| Storm Drainage Asset Management | Prioritize identification of the location, condition, remaining service life, and LOS of existing assets to better assess the capital investment needed to maintain that LOS in the future. |

# 4. Analysis Methodology

This section describes the general approach to develop concepts for Problem Areas and Public Facilities as well as the methodology to assess their flood reduction benefits. The section also describes the method to quantify and monetize any remaining flood risk after the implementation of the flood mitigation concepts and how that monetary benefit is used in the BCA.

## 4.1 Problem Areas

### 4.1.1 Concept Definition

Jacobs was tasked with identifying the feasibility of two types of mitigation solutions per Problem Areas: one that uses only storage opportunities to reduce peak flows downstream and another that only uses conveyance improvements to increase the capacity of existing stormwater systems, thereby reducing surface flooding.

Storage solutions were developed based on the presence of public or privately owned open space to site a belowground storage facility. Diversions at stormwater manholes would divert peak flows to and from storage to the extent practicable by gravity flow. Pumping out of storage was considered as a viable option only where open space was limited and storage depth that would allow for gravity dewatering was constrained by downstream pipe elevations.

Conveyance solutions were defined by identifying limitations in the storm systems causing backups and flooding in the identified Problem Areas. The extent and size of each solution was determined through an iterative process of replacing the restricted sewers with larger pipes that could pass the predicted peak flows of the design storm event, further increasing pipe sizes and extending the projects as needed until flooding was eliminated.

Conveyance concepts assume replacement of existing infrastructure within an existing drainage easement. That is an adequate assumption for most Problem Areas. However, County staff provided information on areas where they have not been successful in implementing conveyance relief because of implementation constraints. This information was taken into consideration during this analysis. These areas have been annotated with suggestions to consider other mitigation strategies such as overland relief. Additional information on these areas with significant constraints is included in Section 6 and Appendix C.

### 4.1.2 Modeling Methodology

The flood mitigation was focused on the 34 Problem Areas, identified in Task 4 (Vulnerability Assessment) and presented in Section 1.4 of this TM. The hydraulic models indicate the storm system pipes draining the Problem Areas are undersized for the 10-year, 24-hour design storm peak flows (design peak flows), resulting in substantial overland flooding. Two basic types of mitigation were considered during the optimization as follows:

- Storage Solution – Divert surcharged flows by weirs into storage to reduce peak flows downstream and return the stored flows to the storm system by gravity flow after the peak subsides. This option is limited by available open space to site a storage facility and the difference in invert elevations (height) of the diversion weir and the flow return maintenance hole to maintain gravity flow into and out of the

facility. Belowground storage options are assumed as these allow for multipurpose use of the site with potential other uses on the surface such as parking, parks, and recreation facilities.[6]

- Conveyance Solution – Replacement of existing pipes where there are restrictions in the collection system. A spreadsheet tool was developed and used to evaluate alternatives and identify the minimum pipe size required to pass the predicted design peak flows, considering the design criteria set for the analysis (refer to Section 2.2). Replacement of existing storm sewers with larger pipes was the mitigation strategy initially identified. However, the implementation of a parallel pipe system alongside existing sewers, for additional capacity, was used where larger pipes could not be feasibly implemented.

In addition to the design storm and freeboard criteria used, certain assumptions were made because site-specific surveys for detailed design of mitigation projects are beyond the scope of this task.

Assumptions made for conceptual design and modeling of mitigation solutions are as follows:

- Slopes of existing sewers were maintained when recommending replacement or parallel system pipes.
- Utility conflicts were not considered in concept development.
- Inflow and outflow of proposed storage mitigation were limited to gravity flow configurations, unless surface area and downstream pipe elevations did not allow for sufficient storage to meet design storm requirements. In those instances, the bottom elevation was lowered until sufficient storage was provided, and pumping facilities were assumed necessary to dewater storage after each storm. Within this analysis, select storage solutions within problem areas DBPA1 and BBPA1 have been identified as requiring pumping facilities.
- Construction constraints were not considered for most locations, but County staff provided information on areas where they have not been successful in implementing conveyance relief or finding feasible options to implement it because of construction constraints. This information was taken into consideration and mitigation projects were duly annotated to reflect this information.

Through an iterative process of one-dimensional (1D) modeling of the mitigation solutions, the preferred solution was selected and validated with two-dimensional (2D) modeling to quantify residual flooding after implementation of the proposed solution and moved into conceptual design and costing.

### 4.1.3 Hazus – Economic Analysis[7]

Hazus was used to estimate risk of losses due to potential flooding within the Problem Areas. It was used to quantify and map potential annualized expected value of economic risk of building and vehicle damage by applying depth-damage curves to the range of storm events and likelihoods for the five flood recurrence intervals (2- through 500-year). The Hazus flood model calculates physical damage and economic loss due to inundation from flood events. Losses are calculated using functions that relate the depth and type of flooding to the degree of damage for various categories of buildings and vehicles (Hazus 5.1) (FEMA 2022). Basic ("Level 2," refer to Appendix B for a description of levels of analysis in Hazus) analysis was done based on the generalized national databases and best available information to estimate flood losses, combined with specific flood modeling results from this task.

[6] In February 2023, the County completed a large-scale detention vault under the athletic fields at Cardinal School. This is the first multipurpose flood storage project under Flood Resilient Arlington.

[7] Social and environmental loss methodology and analysis was outlined in Task 5. The economic and social benefits of conveyance or storage alternatives are presented in Section 6. Environmental impacts were not included in Task 6 because it was determined that while RPAs are areas of significant environmental value, a significant extent of the total RPA area in the county is in the floodplain and are supposed to flood and can help with flood attenuation.

As a result of the proposed mitigation solutions, alternative-specific flood inundation depth grids were developed for the baseline 2020 design storm event scenarios, including the 2-, 10-, 50-, 100-, and 500- year storms. The Hazus analysis does not include climate change scenarios, but significant assessment of flood exposure vulnerability and risk under climate change has been included in the RAMP in earlier tasks.

The mitigation-influenced flood inundation depth grids were used in conjunction with damage and economic risk profiles included in Hazus database for the County by Census block to calculate annualized economic losses for buildings and vehicles. The economic losses due to risk to building and vehicle were calculated by the following categories (refer to Appendix B for a definition of losses items):

- Economic losses for building stock
  - Capital Stock Losses: correspond to direct impacts from flood to buildings and their contents
    - Building Loss: resulting from direct damage to the actual building
    - Contents Loss: resulting from direct damage to contents in the building, excluding inventory for commercial and industrial buildings
    - Inventory Loss: resulting from direct damage to inventory for commercial and industrial buildings
  - Income Losses: indirect impacts of flood resulting from the temporary displacement of residents or disruption of economic activity
    - Relocation Loss: impacts associated with displacement of population
    - Income Loss: impacts associated with loss of economic activity, excluding wages, direct sales, or output and rental income, which are computed separately
    - Rental income Loss: impacts associated with loss of rental revenue due to damage of rental property
    - Wage Losses: impact to wage income for employees
    - Direct Output Loss: impact on sales and direct economic output from a building
- Direct Economic Losses for vehicles (computed for day and night because the stock in a given area has diurnal variability and the time of the flood event can thus have different consequences related to vehicle loss): includes direct impacts to cars, light trucks, and heavy trucks

Because a spatial grid for analysis corresponds to Census blocks within Hazus, Task 6 required an additional step allocating the Hazus results to each Problem Area, using the Problem Area polygons and Hazus results in a geographic information system (GIS) exercise. Losses from Hazus are then reported at a Problem Area level.

### 4.1.4 Cost Estimates

A Class 5 (Planning-Level) cost estimate was developed per Problem Area (those with solutions) and ultimately added up to the watershed level as well. The Class 5 cost estimate corresponds to -50% +100% estimates and was performed as defined by the Association for the Advancement of Cost Engineering International (AACEI), Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M. Class 4 was used for cost estimates in Public Facilities (Section 4.2) due to less uncertainty associated with the projects to protect specific assets (as opposed to neighborhood-scale projects in Problem Areas).

The following key assumptions are used for O&M costs:

- O&M costs for existing collection system assets (before and after implementation of storage or conveyance solutions) will be the same and are thus not included in the analysis (equal for all alternatives).
- Storage solution vault inspections and cleaning are required.
- Conveyance solutions will require the following:
  - Pipeline CCTV inspection and pipeline cleaning
  - Maintenance hole inspections
- Estimate of 0.5% of the Total Capital Costs per mitigation solution was used for annual O&M costs for both storage and conveyance.

The mitigation costs are meant to be used only for relative risk comparisons based on the aggregate results for monetized risk. The mitigation capital costs should not be used for budgeting purposes within any Problem Area.

### 4.1.5 Benefit-Cost Analysis

A BCA is the process of quantifying the advantages (benefits) of an action and comparing it with its costs. During Task 6, the BCA methodology is based on the methods used and recommended by FEMA for Hazard Mitigation projects and grants which include the following key parameters:

- Project Cost Estimates – Capital costs
- Project Cost Estimates – O&M Costs
- Discount Rate
- Project Useful Life (PUL)
- Project Design/Recurrence Interval (the design storm or storms associated with the measured risk)

The ultimate outcome of a BCA for FEMA projects and grants is the Benefit-Cost Ratio (BCR). If the BCR is greater than or equal to 1.0, then the action is "cost-effective" (the term used by FEMA for BCR ≥1.0). The BCR is a simple ratio of the net present value (NPV) of benefits divided by the NPV of the costs. NPV is a financial concept that takes into account the time value of money by discounting the expected future annual costs/benefits of a mitigation recommendation back to their present value using a discount rate.

*BCR = NPV of Total Annual Benefits (in $K) ÷ NPV of Total Annual Project Cost Estimates (in $K)*

For flood mitigation projects, benefits are any future costs or losses that can be avoided by completing a mitigation project and correspond to:

*Benefits = Losses Before Mitigation – Losses After Mitigation*

For this task, losses before mitigation correspond to the Hazus outcome on losses (annualized for five return period scenarios) under the existing conditions (year 2020), which were assessed during Task 5. Losses after mitigation correspond to the Hazus outcome on losses (annualized for five return period scenarios) for each conveyance and storage solution, which results in two different BCRs per watershed described later in this document. Because each Problem Area does not have both solutions, a BCR may just be defined for one alternative. Results of this BCA can be found in Section 6.1.4.

For the purposes of BCR computation, the FEMA BCA toolkit 6.0 (2022) was consulted to align the methodology used in this analysis to the FEMA tool. Equivalent methodology and the same general assumptions recommended by FEMA for the use of their tool were applied in the Task 6 analysis.

#### 4.1.5.1 Discount Rate

The discount rate used for the analysis is 7%, consistent with FEMA requirements (which is in turn consistent with Office of Management and Budget requirements for federal project analysis). The discount rate is subjective and varies considerably for different agencies. Generally, for this project in which benefits are accrued over time for multiple years, a higher discount rate will reduce the BCR. This project is not a federal project and is thus not subject to the federal guidance for a 7% discount rate for BCA; however, the County could pursue federal grants that would require the use of 7%. In some cases involving FEMA grants, FEMA does allow the use of a 3% discount rate for comparison and reference. The use of a 3% discount rate should be considered if FEMA grants are pursued.

#### 4.1.5.2 Project Useful Life

All infrastructure components of the mitigation solutions are assumed to have a PUL of 50 years for this analysis.

#### 4.1.5.3 Project Design/Recurrence Interval

The analysis includes five different scenarios with 2-, 10-, 25-, 100-, and 500-year recurrence intervals. Hazus requires five recurrence intervals to compute an annualized risk which considers the combined probabilities of these storms and provides the "expected value" of losses in any given year. This annualized risk can then be applied in every year during the PUL for the cumulative benefits.

## 4.2 Public Facilities

### 4.2.1 Mitigation Strategy Methods

The data collected and developed during Task 5 were reviewed to identify which assets within each Public Facility would benefit from mitigation strategies. This process used the asset's height at failure, flood path, and total cumulative monetized risk.

First, assets were assessed for significant cumulative monetized risk to identify those that would provide the highest benefits from flood mitigation, and likely the highest BCR. Then, each asset's flood path elevation and height at failure were compared with the design flood elevation plus 1 foot of freeboard to determine if the asset required mitigation.

If a high cumulative monetized risk asset did not require mitigation, it was due to the low probability of flooding.

Most Public Facilities used the 2040 100-year storm event to apply mitigation strategies. Flood scenarios were changed from 2040 100-year storm to 2040 500-year storm for two facilities (Cherrydale Health and Rehabilitation Center and the Little Falls Booster Station) that had flood path elevations higher than the design flood elevation for 2040 100-year storms.

For a more robust analysis, two alternatives were developed. Both alternatives used the same flooding event selected for the Public Facility. Two alternatives allowed for a comparison of the BCR.

### 4.2.2 Mitigation Strategies for Assets Selection

Numerous strategies were evaluated for flood risk mitigation in the buildings with vulnerable assets in each Public Facility. Selection of a strategy for specific buildings or assets was based on the information collected during the site visits and on the flood depth data for different scenarios (from Task 3, as documented in the Task 3 TM [Jacobs 2021b]).

Estimates of flood risk after implementation of mitigation concepts were developed using a risk assessment model[8]. The flood scenario used to establish the design flood elevation corresponds to the 100-year event. One foot of freeboard was also assumed as part of the conceptual dimensioning of the concepts. The 100-year flood event and 1 foot of freeboard correspond to American Society of Civil Engineers guidelines for utilities (ASCE 24-14 Flood Resistant Design and Construction).

The menu of flood mitigation strategies included the following two general categories:

- Elevating – Elevate a specific asset using different strategies (refer to Section 5).
- Hardening – The hardening strategy includes watertight sealing to change the flood path elevation of an asset. Hardening strategies are described in Section 5.

A key difference between the analysis of Problem Areas and Public Facilities as part of Task 6 is that Public Facilities include information at asset-level, including asset replacement costs. As part of Task 5, a methodology was developed to assess the monetized risk of flooding based on the asset replacement costs (Jacobs 2022). The same methodology and equations were used during Task 6 to estimate the monetized risk remaining after the implementation of the flood mitigation concepts. The benefits are thus computed as the difference between monetized risk before implementation and monetized risk after implementation.

### 4.2.3 Mitigation Concepts Cost Estimates

Two approaches were used to determine the mitigation costs as follows:

- Comparable project's values and applied adjusted inflation and location rates
- Cost estimation tool (RSMeans) for material costs and applied installation rates[9]

Class 4 level (-30% to +50%) estimate was used to develop the costs as defined by AACEI, International Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M. Indirect costs were applied uniformly to each mitigation strategy, which included material sales and use tax, general conditions, mobilization and demobilization, overhead and profit, bonds and insurance, contingency, and engineering. The mitigation costs are meant to be used only for relative risk comparisons based on the aggregate results for monetized risk, by facility. The mitigation costs should not be used for budgeting purposes on any facility.

### 4.2.4 Benefit-Cost Analysis for Public Facilities

The BCA method for Public Facilities is the same as Problem Areas. Refer to Section 4.1.5 for a description.

[8] A spreadsheet model was developed during Task 5 that monetizes flood risk at Public Facilities based on impacts to assets. It thus performs a similar function to Hazus for Problem Areas (monetization of flood impacts). The Task 5 model was used in Task 6 to estimate residual risk after implementation of flood mitigation concepts.

[9] RSMeans is a widely used source of construction cost estimating data. https://www.rsmeans.com/

# 5. Flood Mitigation Concepts

This section describes the flood mitigation concepts identified for each Problem Area and for each Public Facility. The main categories of concepts include the following:

- Conveyance and storage concepts for Problem Areas in the County identified and prioritized in previous tasks
- Building-level and asset-level concepts to protect critical assets in Public Facilities identified and prioritized in previous tasks

## 5.1 Background and Considerations

Task 6 does not include detailed project development. The flood mitigation concepts for Problem Areas and Public Facilities will require additional analysis, including detailed feasibility analyses, before design activities and project implementation can proceed. Additionally, in almost every case, flood mitigation solutions for a Problem Area or building within a Public Facility result from the implementation of more than one individual project. The Programmatic Strategies described in Appendix A will also contribute to flood management solutions.

A key consideration in reviewing the concepts presented further in this section for the Problem Areas is the feasibility of implementing the conveyance and storage projects that could result from these concepts. The conveyance and storage elements presented next are based on desktop analysis with the hydraulic model developed for the RAMP. No detailed analysis has been conducted assessing right-of-way, utility conflicts, other space constraints such as tree canopy, structures in the area not visible from aerial imagery (homes, and other buildings and facilities), known public opposition, etc. In the life of a project, those factors are typically addressed in the feasibility study phase, which in this case would be conducted after the RAMP. Task 6, however, did include discussions with County staff and vetting of the general concepts by staff with knowledge in the Problem Areas.

County staff is continuously evaluating flood mitigation alternatives for known problems in the County, and Task 6 has incorporated their feedback on some of the most challenging areas in terms of implementability. That feedback is discussed in the following section in the description of concepts by watershed.

## 5.2 Conceptual Conveyance and Storage Solutions for Problem Areas

### 5.2.1 Conveyance and Storage Flood Mitigation Concepts for Areas of Pluvial Flooding

Mitigation concepts were developed and assessed in generalized groupings for all Problem Areas based on location, type, and size of structures. Although storage solutions could be more costly based on availability of open space, upstream storage may provide the County additional resilience and flexibility to meet flood reduction goals. This approach has been modeled to reduce some upstream residual flooding, especially in the Roaches Run watershed. Figure 5-1 presents an example conveyance concept mitigation project plan for the Doctor's Branch watershed. A project identifier and some project attributes are included in each figure (red text) in addition to the pipeline segments on the map.

Refer to Appendix C for fully detailed concept information for storage and conveyance solutions per each watershed analyzed. Figure 5-2 presents an example of the storage concept maps for the Doctor's Branch watershed. For storage areas, given that detailed site-specific feasibility of projects is not included in Task 6, a general area for storage tanks has been identified as opposed to specific locations for specific tanks.

A consideration in the analysis of these mitigation concepts is that specific projects for each Problem Area may be more cost-effective or provide larger flood mitigation benefits when conveyance and storage options are combined in a single project. The Task 6 planning-level analysis did not explore combined concepts.

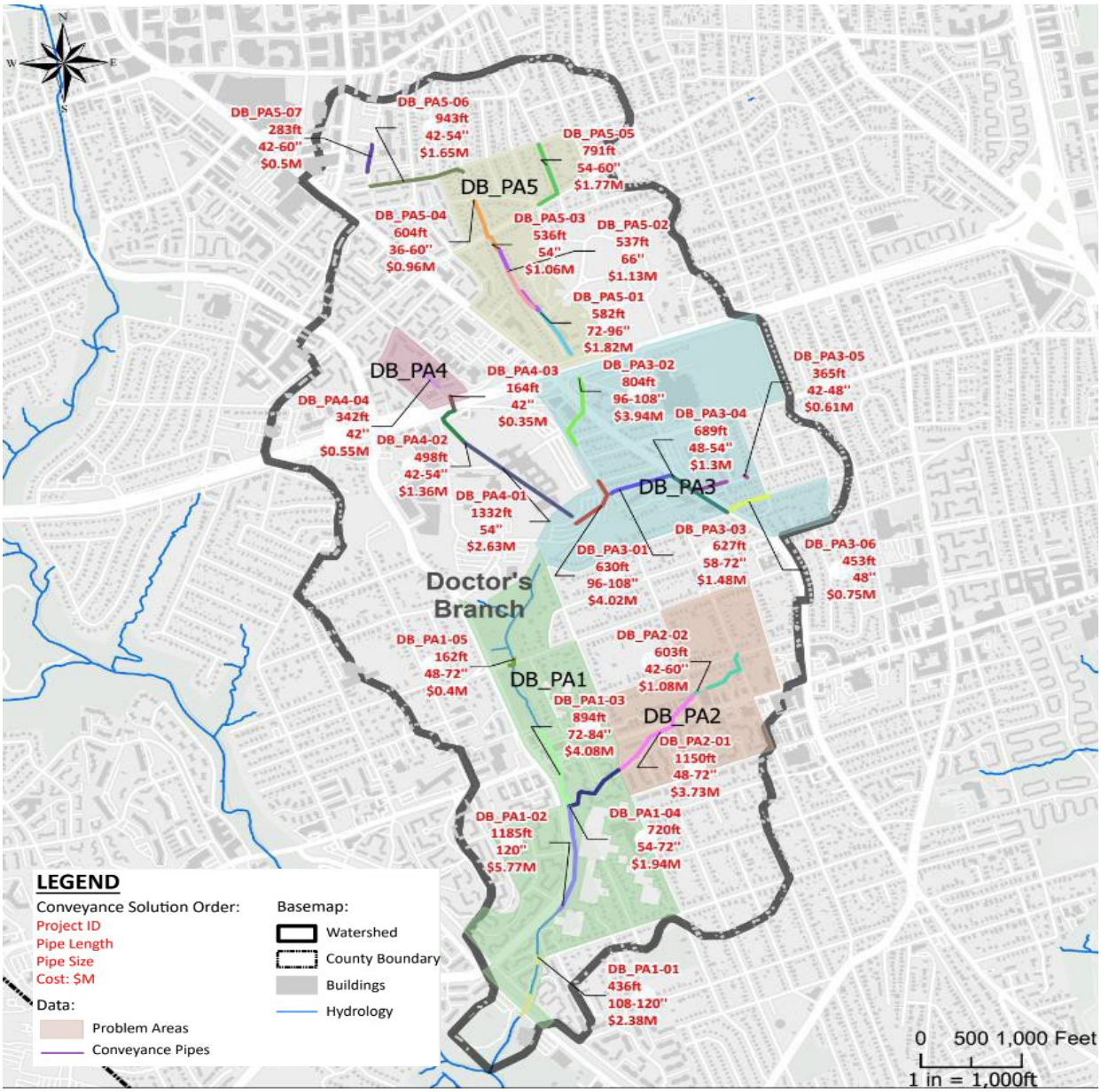



**Figure 5-1. Example Conveyance Concept Map in the Doctor's Branch Watershed**

### 5.2.2 Levee Flood Mitigation Concepts for Areas of Four Mile Run Lower Mainstem with Riverine and Coastal Flooding

An additional alternative was considered in the Four Mile Run Lower Mainstem watershed, in addition to conveyance and storage. Some of the flooding observed in this watershed is the result of flood stage in Four Mile Run from riverine and/or coastal flooding from storm surge and future sea level rise (and, in fact, a significant percentage of the total flooded area occurs within the FEMA 100-year floodplain). This points to an additional alternative to protect the Problem Areas in the watershed with a fluvial flood protection project. The U.S. Army Corps of Engineers (USACE) is conducting planning activities to implement a floodwall project in the area to address this fluvial flood risk. The concept by USACE in its Draft Integrated Feasibility Report and Environmental Assessment (USACE 2022) was evaluated as part of Task 6 in terms of flood reduction benefits. Given that the assumptions, scenarios, and analysis tools and objectives are different in the USACE study and the County's RAMP, the results of the analysis of the floodwall along Four Mile Run should not be seen as conflicting or supportive of USACE's assessment. Figure 5-3 presents some highlights of the USACE project.

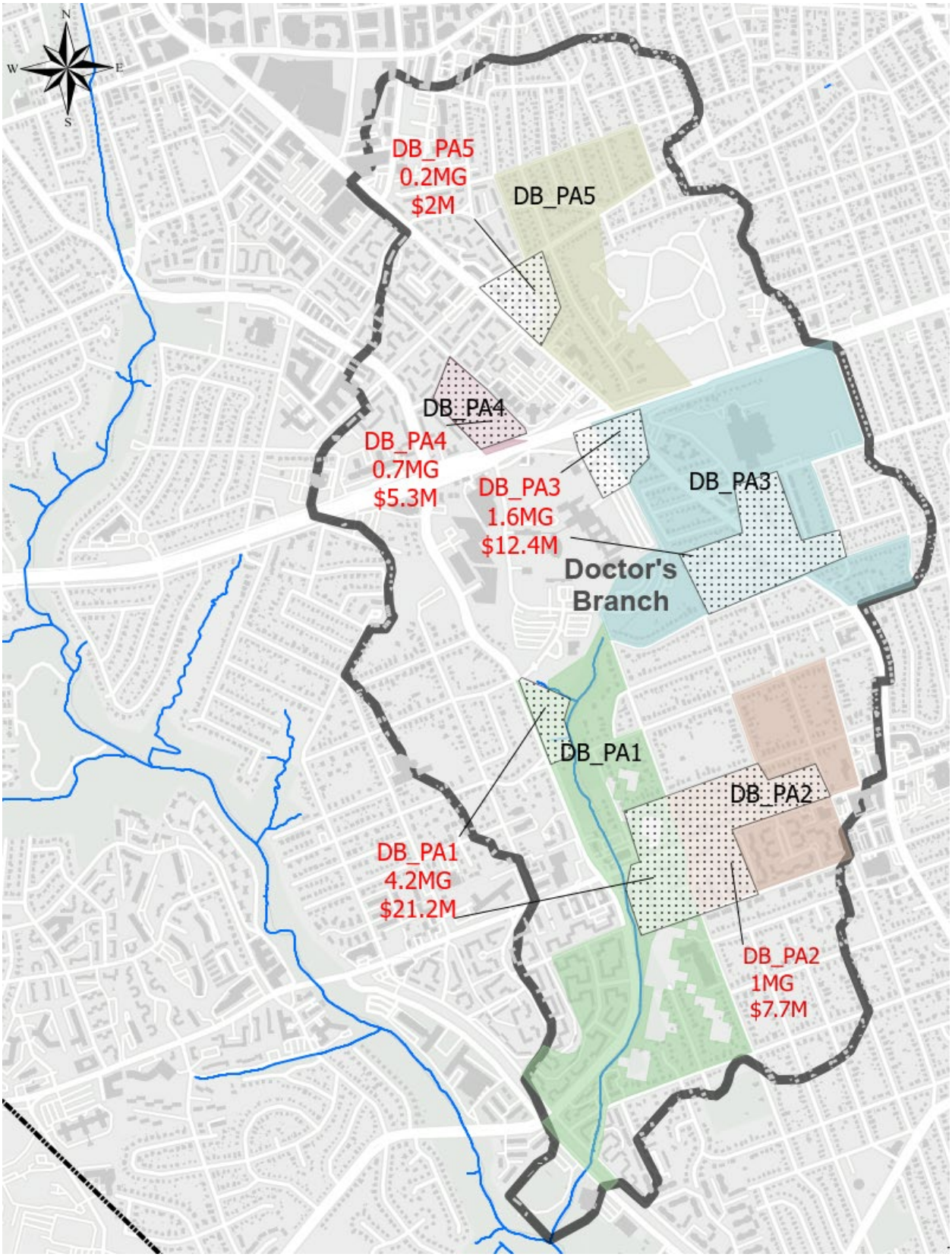



**Figure 5-2. Example Storage Concept Map in the Doctor's Branch Watershed**

The following are the key factors that differentiates the USACE and the RAMP analysis making the RAMP analysis more conservative:

- Levee Height – USACE's analysis resulted in recommendation of a levee with top elevation of 14.3 feet North American Vertical Datum of 1988 (NAVD88). The RAMP analysis of Four Mile Run lower mainstem used predicted maximum costal surge elevation of 16.7 feet (NAVD88) as boundary condition at the mouth of Four Mile Run with the assumption that the river peak flow could coincide with maximum coastal surge. This resulted in flood levels at the Arlington WPCP of 16.7 feet (NAVD88) for the future 2070, 500-year Intermediate-High sea level rise (SLR), which exceeds USACE's recommended levee height.
- Flood Scenarios (Current and Future) – USACE considered up to 500-year Coastal Storms + Sea Level Change at 95% confidence level and intermediate SLR curve through 2080 (1.75 feet). RAMP considered up to 500-year, with National Oceanic and Atmospheric Administration Intermediate-High SLR curve through 2070 (3.73 feet).
- Models Used (Coastal and Riverine flooding) – USACE used Probabilistic Coastal Hazard Analysis Framework (StormSim-SST for XC Induced Responses). The analysis uses simulation of Still Water Levels (coastal surge plus astronomical tide) but does not include coincidence of riverine flooding and flooding from overland runoff.
- RAMP Analysis Used – MIKE 21 for coastal flood modeling to determine coastal flood levels which were used as boundary condition inputs to riverine and inland flood modeling in PCSWMM.
- Tools Used for the BCA – USACE's project benefits represent damages reduced (National Economic Development) from coastal storm surge inundation with the combination of sea level rise for each alternative. For comparison, the Problem Area Analysis in the RAMP converts Present Value damages to average annual damages basis and the costs are annualized using the FY22 discount rate of 7.00% and a 50-year period of analysis for the purpose of the comparison.

### 5.2.3 Cost Estimate Results

The conceptual cost estimate described in Section 4 was developed for the conveyance and storage mitigation solution concepts and presented here at the watershed level. The cost estimate was used in the BCA of proposed mitigation solutions. Table 5-1 lists the aggregate estimated capital cost of projects by watersheds for conveyance and storage solutions. The total capital costs shown are a result of a Class 5 cost estimate, which corresponds to a range of -50% to +100% in estimation. Class 5 Cost Estimates are classified as defined by the AAACEI, Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M costs. O&M costs have been included in the BCA.

**Goal**: determine whether the implementation of coastal storm risk management measures would reduce coastal flood risk.

**Purpose**: to evaluate the feasibility of federal participation in the implementation of solutions to reduce long-term coastal flood risk, considering future climate and sea level change scenarios to support resilient communities in Northern Virginia within the Middle Potomac River watershed.

**Plan**: includes a floodwall at the Arlington WPCP among other components and alternatives.

At the Arlington WPCP, a floodwall would be constructed along the left bank of Four Mile Run between Four Mile Run and the Arlington WPCP with a closure structure on the east side of the structure. The new floodwall would tie into the bank to the east just past South Eads Street. The floodwall would wrap around the Arlington WPCP to the west where the stop log closure structure is located along South Glebe Road.

**Criteria**: based up to 500-year Coastal Storms + Sea Level Change at 95% confidence level and intermediate SLR curve through 2080 (1.75 feet). Top of Wall, Level of Performance at Elevation 14.3 feet NAVD88

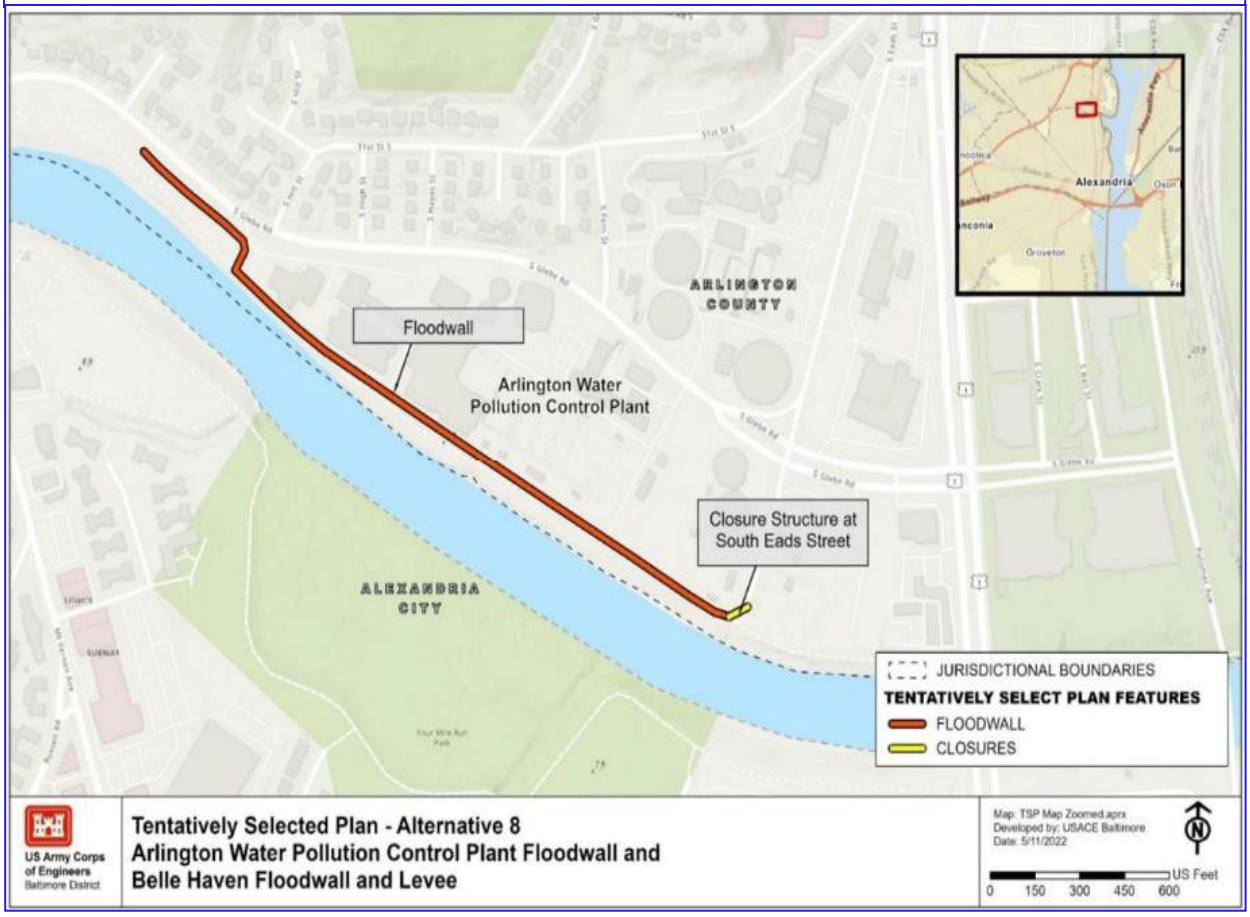



**Figure 5-3. USACE Floodwall Project Highlights (USACE 2022)**

**Table 5-1. Aggregate Estimated Capital Cost of Conveyance and Storage Solutions per Watershed**

| Watershed | Total Length of Conveyance Projects (LF) | Total Capital Cost of Conveyance Solution (Millions $)[a] | Total Estimated Storage Volume Provided (MG) | Total Capital Cost of Storage Solution (Millions $)[a] |
|---|---|---|---|---|
| Bailey's Branch[b] | 2,599 | 8.52 (4.26 to 17.05) | 1.80 | 12.56 (6.28 to 25.11) |
| Doctor's Branch[b] | 15,333 | 45.23 (22.62 to 90.46) | 7.70 | 48.45 (24.23 to 96.90) |
| Four Mile Run Lower Mainstem | 12,276 | 32.11 (16.05 to 64.21) | 9.28 | 54.06 (27.03 to 108.11) |
| Lubber Run | 9,882 | 9.22 (4.61 to 18.44) | 1.67 | 2.53 (1.26 to 5.05) |
| Roaches Run | 16,254 | 71.91 (35.96 to 143.82) | 3.79 | 25.60 (12.80 to 51.21) |
| Spout Run | 25,589 | 49.04 (27.02 to 108.08) | 2.03 | 11.42 (5.71 to 22.83) |
| Torreyson Run | 2,709 | 5.99 (2.99 to 11.99) | 0.05 | 0.75 (0.38 to 1.50)[c] |
| Total (Millions $) | | 222.02 (113.51 to 444.04) | | 155.37 (77.69 to 310.74) |

[a] Class 5 level (-50% to +100%) estimate was used to develop the costs as defined by the AACEI Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M.

[b] Watersheds where pumping due to lack of feasible gravity flow connections were identified within a Problem Area; Capital Costs therefore include an estimate of costs associated with pumping.

[c] Capital costs in Torreyson Run are for potential new storage options, and do not include the recently completed Cardinal School Detention Vault, which cost $16M.

LF = linear feet
MG = million gallon(s)

For the analysis presented in Table 5-1, the capital costs for storage options did not consider cost of land acquisition, given that the goal was to avoid using private property to site storage facilities, even if they could be dual-purpose facilities. However, in some locations it is anticipated that some land acquisition may be needed if a solution based only on storage is considered, versus a hybrid solution of storage and conveyance. As summarized in Appendix D, an analysis was conducted to evaluate the potential impact of land acquisition costs on total storage capital costs, and compared with the likely range of capital costs for a Class 5 cost estimate shown in Table 5-1.

At a watershed level, adding land acquisition costs increased storage capital costs between 0% and 32%, well within the range of accuracy of the Class 5 cost estimate. At a Problem Area level, the addition of capital costs for all but one problem area were also within the range of accuracy of Class 5 estimate; RR_PA8 in Roaches Run has an increase in capital cost of 126% when land acquisition was included. For all other Problem Areas, the increase with land acquisition ranged from 0% to 63%.

## 5.3 Conceptual Flood Mitigation Solutions for Public Facilities

The flood mitigation strategies and their application to the assets are outlined as follows:

- Elevating – Elevate flood strategy consists of elevating a specific asset within or outside of a building. The choice to elevate a singular asset was practical where other assets in a given space were not impacted by the flood scenario. If multiple assets were impacted in that specific space, elevation became less practical. Limitations on vertical clearance within a building also limited the use of elevating as a mitigation strategy. Refer to Figures 5-4 and 5-5 for general examples of this type of solution.
- Hardening – The hardening strategy includes watertight sealing of assets, preventing flood waters from entering the rooms, buildings, or outdoor locations of assets. Hardening strategies are categorized and outlined as follows:
  - Operable Flood Barriers – Manual – Barriers that change the flood path elevation of a specific space within a facility. These barriers include watertight sealing of openings such as doors and windows. Barriers were chosen to be added within rooms of a building (such as schools) so that not all doors to the outside had to be flood-protected. Manual barriers must be deployed by facility staff before predicted flooding events. Refer to Figure 5-6 for general examples of this type of solution.
  - Operable Flood Barrier – Automatic – Similar application to manual operable flood barriers that are instead automatically deployed when flooding will occur. Refer to Figure 5-6 for general examples of this type of solution.
  - Curb – Curbs were added to assets located inside a building where elevating the asset was not feasible. Adding a curb around an asset changed the flood path elevation of the asset.
  - Perimeter Wall with Gate – A perimeter wall was used for assets located outside of a building to change the flood path elevation. Refer to Figure 5-7 for general examples of this type of solution.
- The USACE floodwall described in Section 5.2 and shown on Figure 5-3, or a similar fluvial flooding mitigation project, could potentially bring significant protection. For WPCP North and South, only one alternative was considered in Task 6 assuming that a second alternative could be the USACE levee project or equivalent.

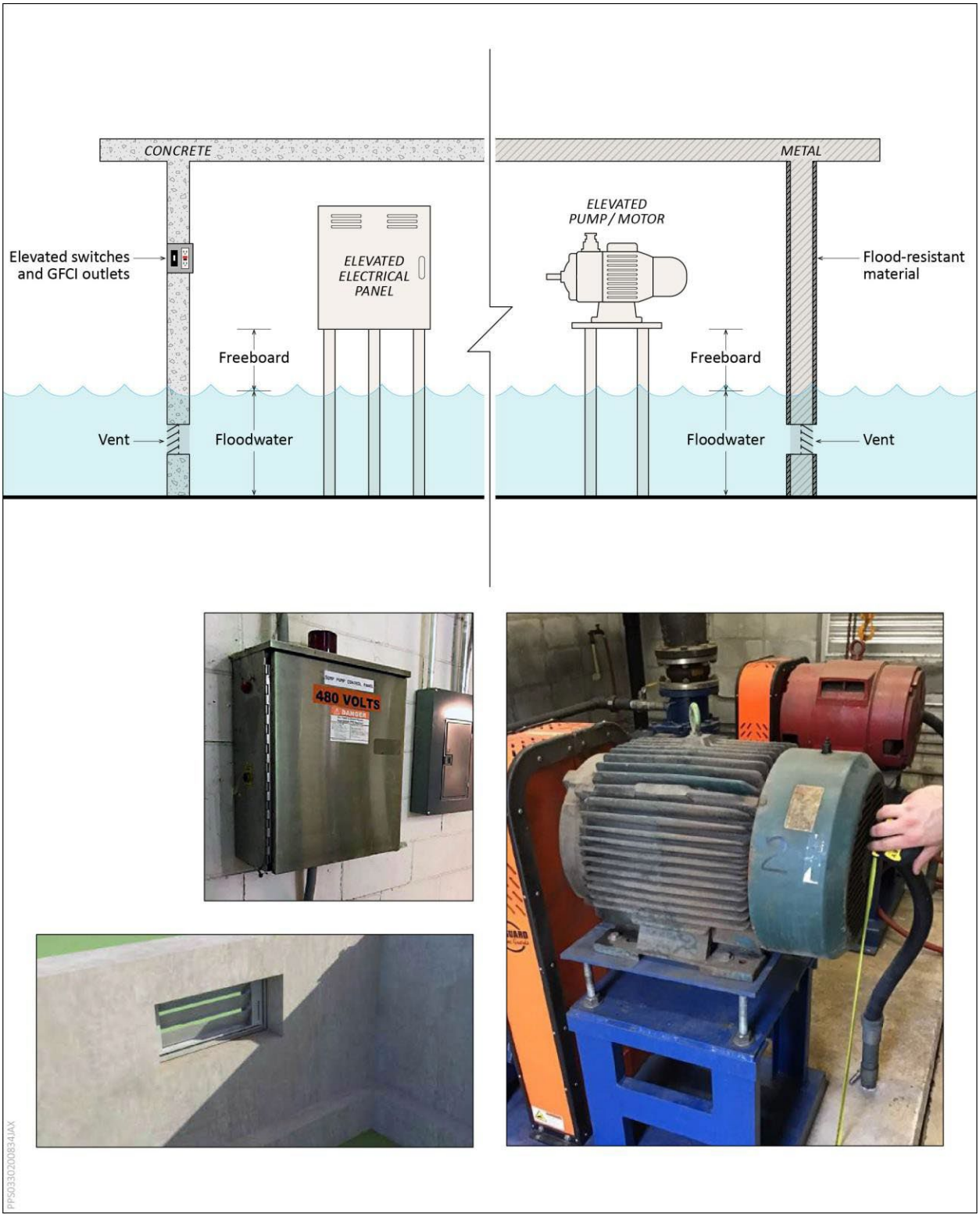



**Figure 5-4. Elevating Flood Strategy within a Building**

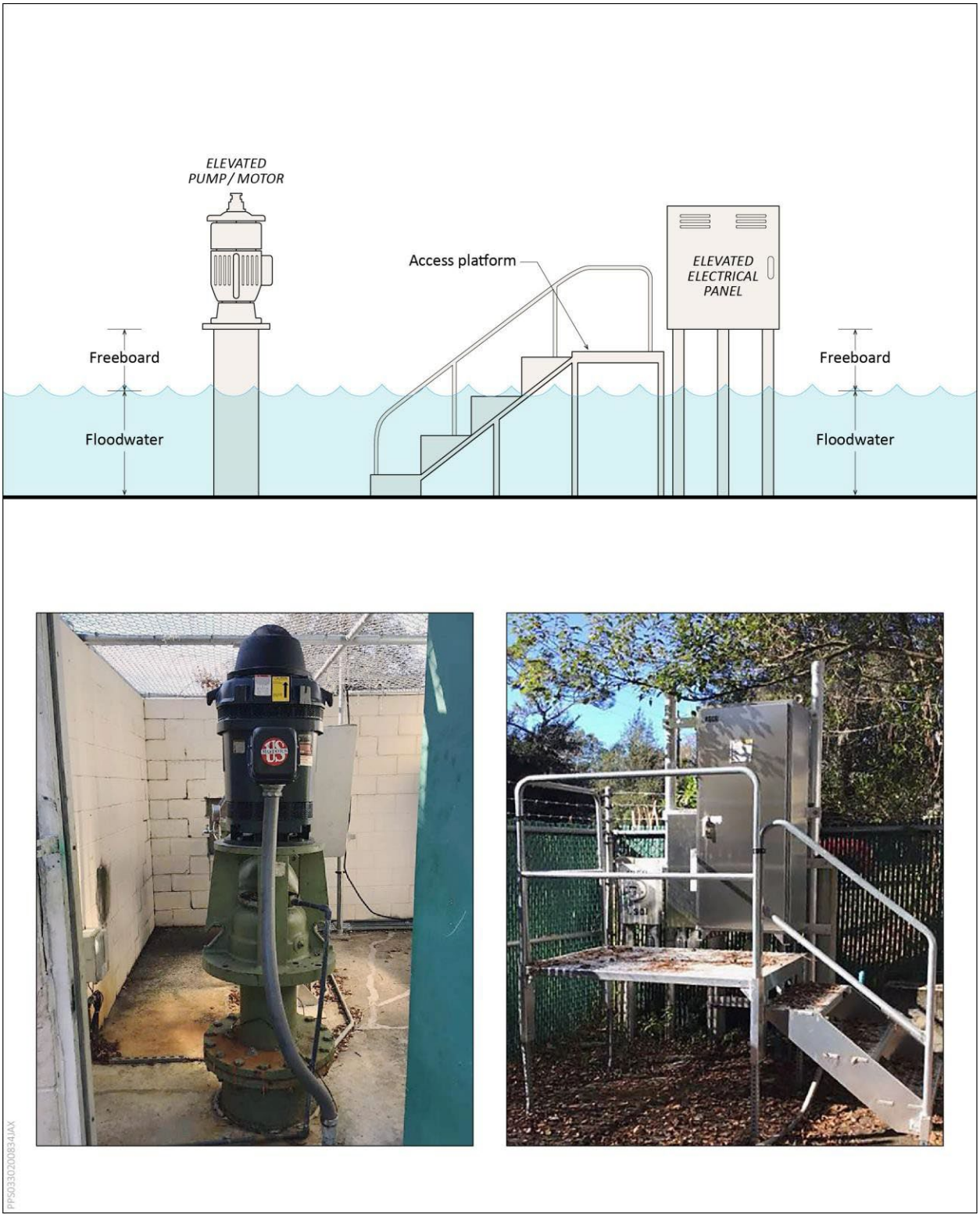



**Figure 5-5. Elevating Flood Strategy outside a Building**

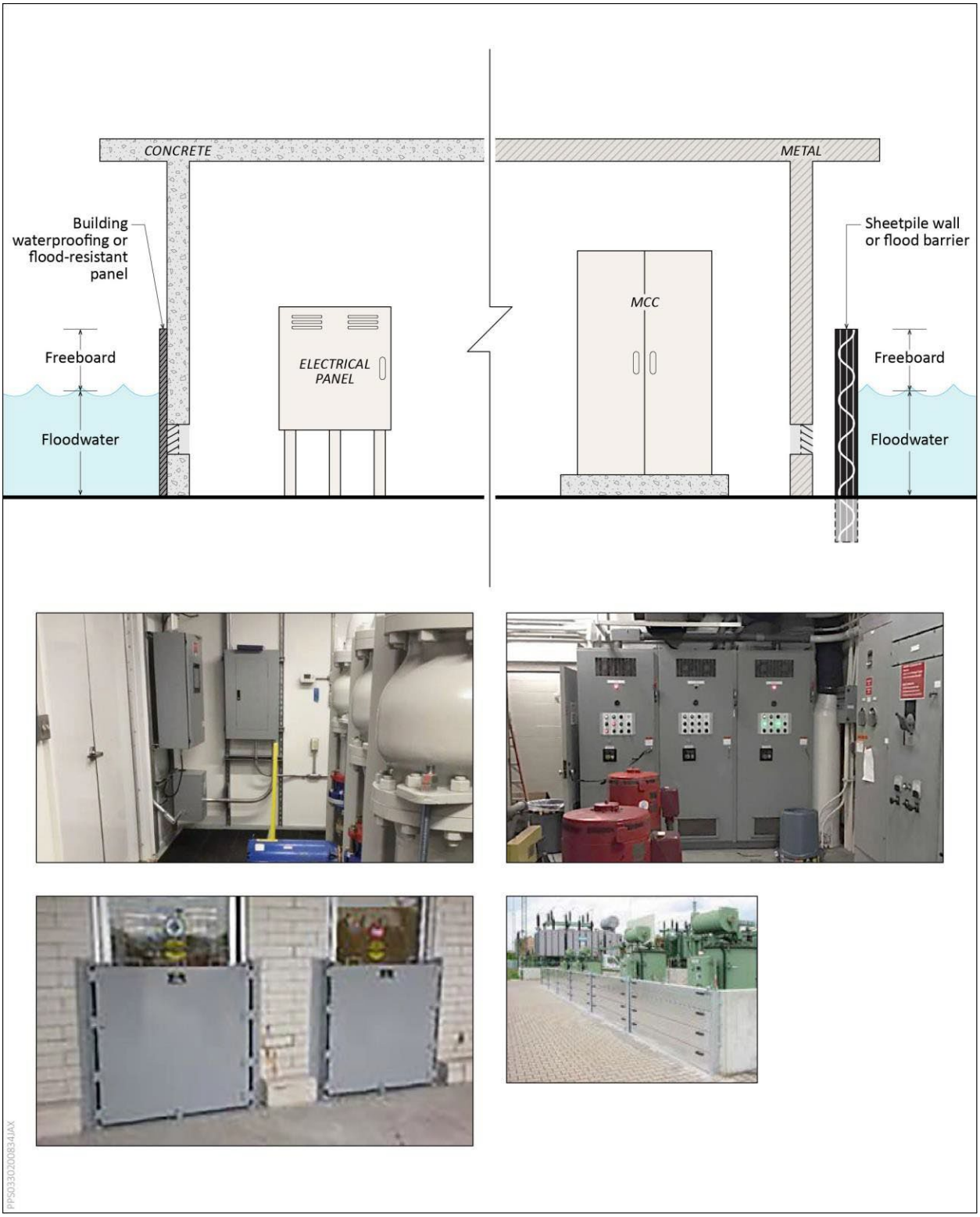



**Figure 5-6. Hardening Flood Strategy – Operable Flood Barriers (Can be Manual and Automatic)**

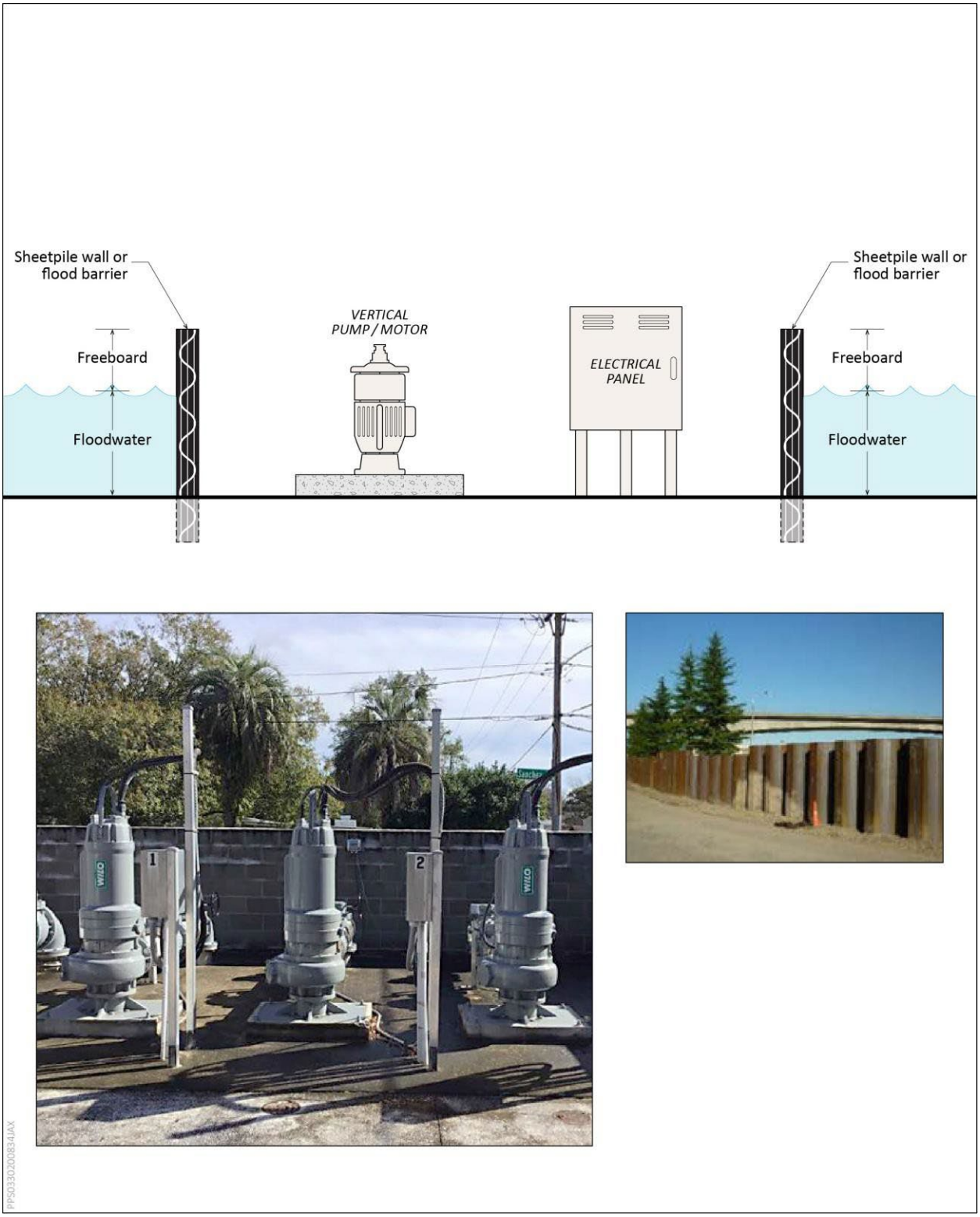



**Figure 5-7. Hardening Flood Strategy – Perimeter Wall with Gate**

### 5.3.1 Concepts Chosen to Protect Assets

The different flood scenarios selected for concept definition and the types of mitigation strategies assessed for each Public Facility are presented in Table 5-2. Even though the principal criterion for BFE is the year 2040 100-year storm, two facilities were modified to use the year 2040 500-year storm to protect some of the main assets. The decision was made to use a more conservative BFE and evaluate if the Benefit-Cost would still be favorable. BCR results are presented in Section 6.

**Table 5-2. Public Facility Flood Scenarios and Mitigation Strategies**

| Public Facility[a] | Flood Scenario | Alternative 1 Strategies | Alternative 2 Strategies |
|---|---|---|---|
| Cherrydale Health and Rehabilitation Center | Flood Scenario 2 (500-year 2040) | Hardening – Manual operable flood barriers | Hardening – Automatic operable flood barriers |
| Gunston Middle School | Flood Scenario 1 (100-year 2040) | Elevating and Hardening – Curb | Hardening – Manual operable flood barriers |
| Little Falls Pump Station | Flood Scenario 2 (500-year 2040) | Hardening – Manual operable flood barriers | Hardening – Automatic operable flood barriers |
| Thomas Jefferson Middle School | Flood Scenario 1 (100-year 2040) | Elevating and Hardening – Manual operable flood barriers | Hardening – Manual operable flood barriers and curbs |
| Virginia Hospital Center | Flood Scenario 1 (100-year 2040) | Hardening – Manual operable flood barriers | Hardening – Automatic operable flood barriers |
| WPCP (North) | Flood Scenario 1 (100-year 2040) | Elevating and Hardening – Automatic operable flood barriers and perimeter walls | USACE Floodwall |
| WPCP (South) | Flood Scenario 1 (100-year 2040) | Elevating and Hardening – Automatic operable flood barriers, perimeter walls, and curbs | |

[a] The Trades Center NOCII & Equipment Bureau facilities are excluded from this table given that no asset damage was predicted. These facilities do observe flooding in access roads which could represent indirect losses that are not accounted for in our analysis, which is based on direct damages.

### 5.3.2 Cost Estimates

Table 5-3 outlines the total cost of mitigation strategies for each Public Facility for Alternatives 1 and 2.

**Table 5-3. Public Facility Cost of Alternatives 1 and 2 Mitigation Strategies**

| Public Facility[c] | Mitigation Costs, Alternative 1[a] (Thousands $) | Mitigation Costs, Alternative 2[a] (Thousands $) |
|---|---|---|
| Cherrydale Health and Rehabilitation Center | 7<br>(5 to 11) | 21<br>(14 to 31) |
| Gunston Middle School | 252<br>(177 to 378) | 22<br>(15 to 33) |
| Little Falls Pump Station | 7<br>(5 to 11) | 21<br>(14 to 31) |
| Thomas Jefferson Middle School | 91<br>(64 to 137) | 49<br>(35 to 74) |
| Virginia Hospital Center | 59<br>(41 to 88) | 164<br>(115 to 246) |
| WPCP (North) | 2,096<br>(1,467 to 3,144) | 3,592<br>(1,347 to 5,388)[b] |
| WPCP (South) | 4,537<br>(3,176 to 6,806) | |
| Total | 7,049<br>(4,934 to 10,574) | 3,869<br>(2,708 to 5,804) |

[a] Class 4 level (-30% to +50%) estimate was used to develop the costs as defined by the AACEI, Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both Capital Costs and O&M.

[b] Based on USACE's estimates (USACE 2022).

[c] The ART O&M Center, Cardinal Elementary School, and Trades Center NOCII & Equipment Bureau facilities are excluded from this table given that minimal asset damage was predicted. These facilities do observe flooding in access roads and parking lots which could represent indirect losses that are not accounted for in our analysis, which is based on direct damages.

# 6. Analysis Results

The following sections describe results of the Problem Areas and Public Facilities analysis.

## 6.1 Problem Areas

The Problem Area results include multiple tables and graphics where abbreviations of the areas are used. Section 1.3.1 included the abbreviation used for the watersheds in which the Problem Areas are located, as follows:

- Bailey's Branch (BB)
- Doctor's Branch (DB)
- Lubber Run (LR)
- Four Mile Run Lower Mainstem (FMRL)
- Roaches Run (RR)
- Spout Run (SP)
- Torreyson Run (TR)

### 6.1.1 Model Results

After iterative process of 1D modeling of the mitigation solutions, the preferred solution was selected and validated with 2D modeling to quantify residual flooding after implementation of the flood mitigation concept. This process was conducted for conveyance and storage concepts. Results of current 10-year design storm flood exposure before and after implementation are presented on Figures 6-1 to 6-7 for each watershed. The analysis in Task 6 does not include climate change scenarios but significant assessment of flood exposure vulnerability and risk under climate change has been included in the RAMP in earlier tasks.

Jacobs also modeled the flood wall proposed by USACE (Section 5.2) in their coastal storm risk management feasibility studies for the Washington, D.C. metropolitan area (USACE 2022). The RAMP Storm Water Management Model predicts the floodwall, as proposed, to provide some flooding mitigation benefits to the Arlington WPCP and the general Four Mile Run Lower Mainstem up to the current 10-year event as defined in the RAMP (with the combination of rainfall and tailwater conditions selected for that watershed (Jacobs 2021b). Figure 6-8 presents the before-and-after inundation maps for the USACE project for the 10-year storm condition. The floodwall does not provide significant benefits for the 100-year design event as defined by the RAMP because of potential coincidence for interior and riverine high stormwater flows (Jacobs 2021b).

### 6.1.2 Reduction in Flood Risk

As the basis of comparison for the flood mitigation solutions, reductions in flood risk were quantified at the Problem Area scale based on two metrics: (1) total monetary risk, based on the expected value of annualized losses as calculated with the Hazus tool, and (2) reductions in flooded area of vulnerable groups, based medium and high social vulnerability index (SVI). These results are presented for each problem area in Appendix E and Appendix F, respectively. The results are summarized as follows at watershed scale.

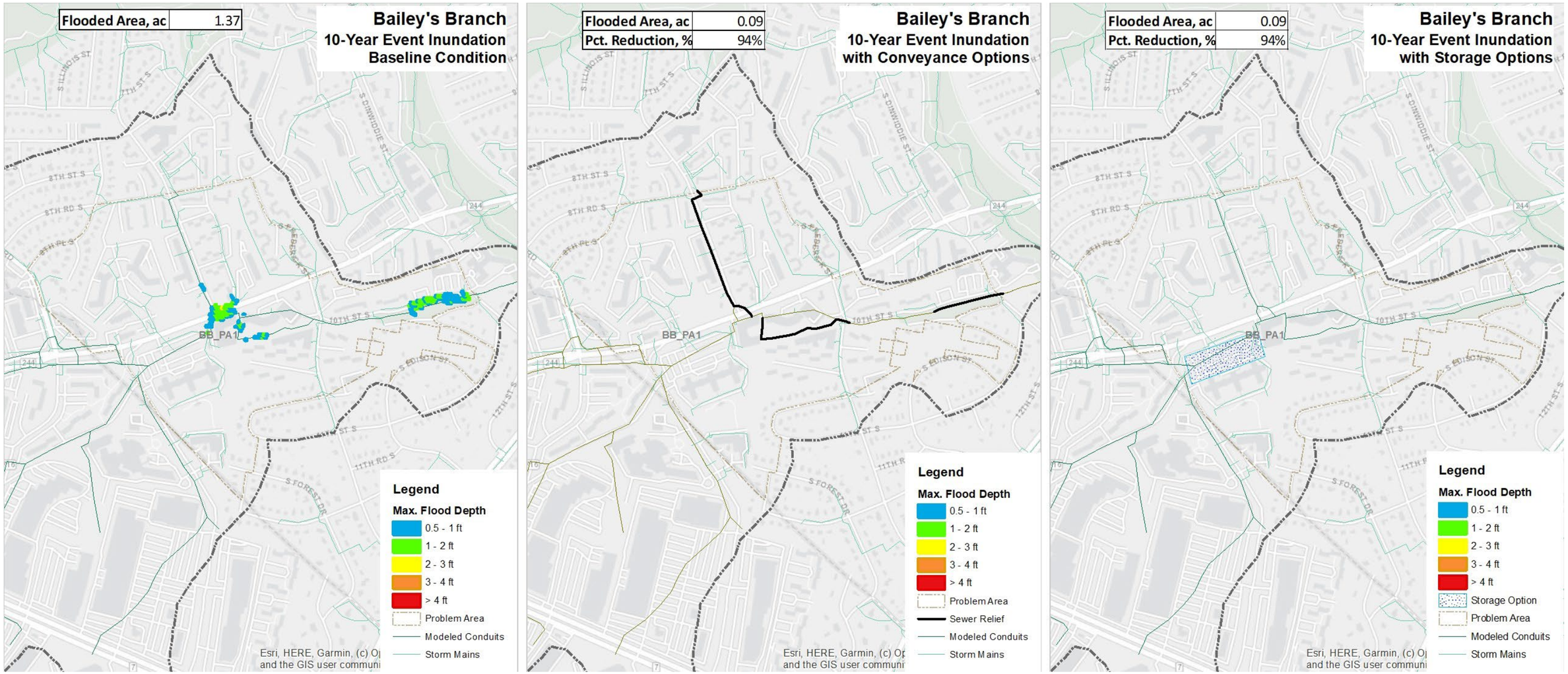



**Figure 6-1. Bailey's Branch Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**

(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).

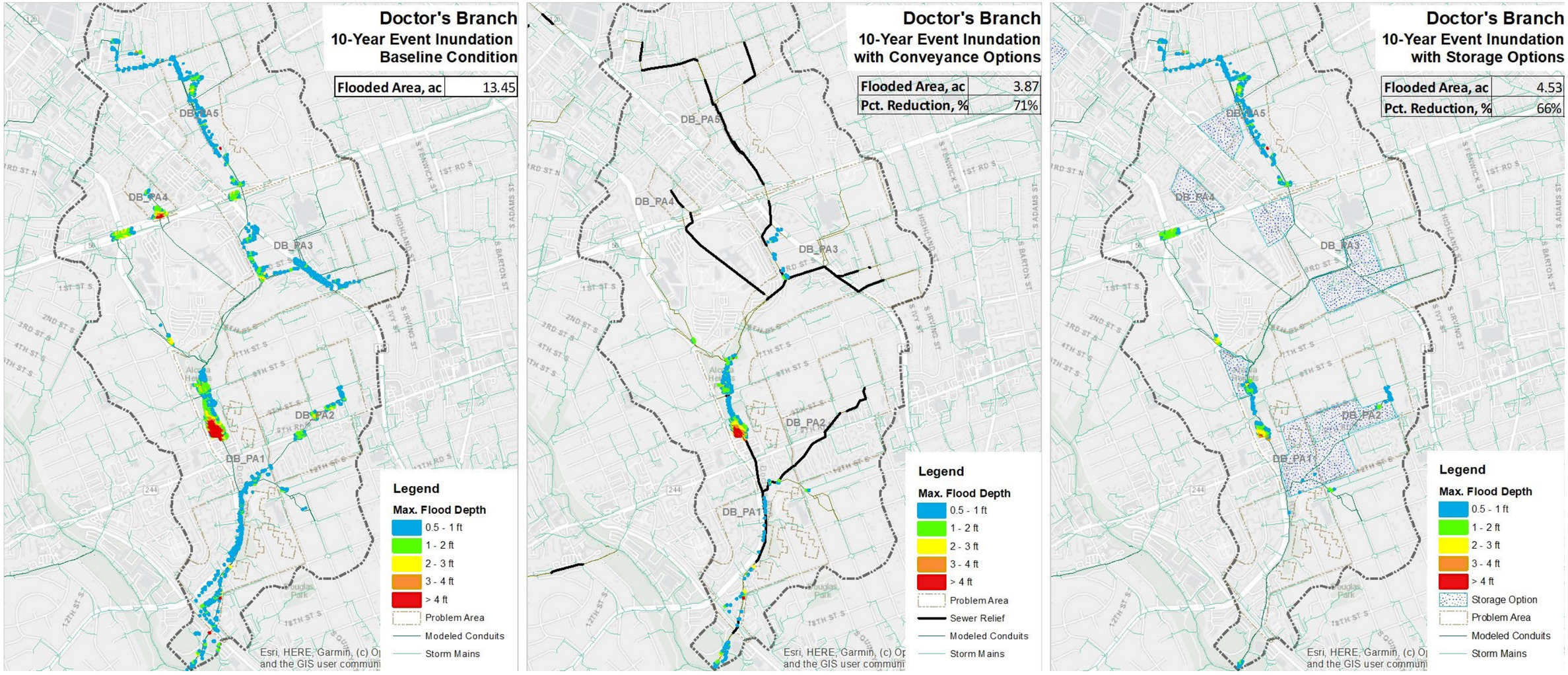
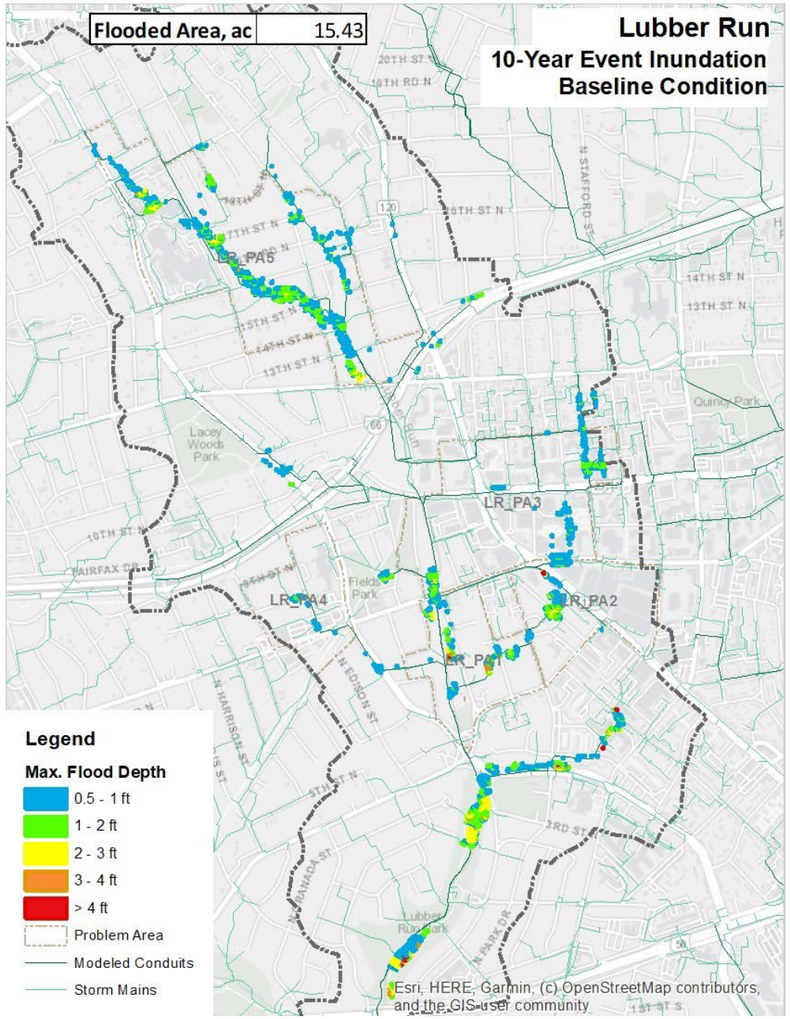
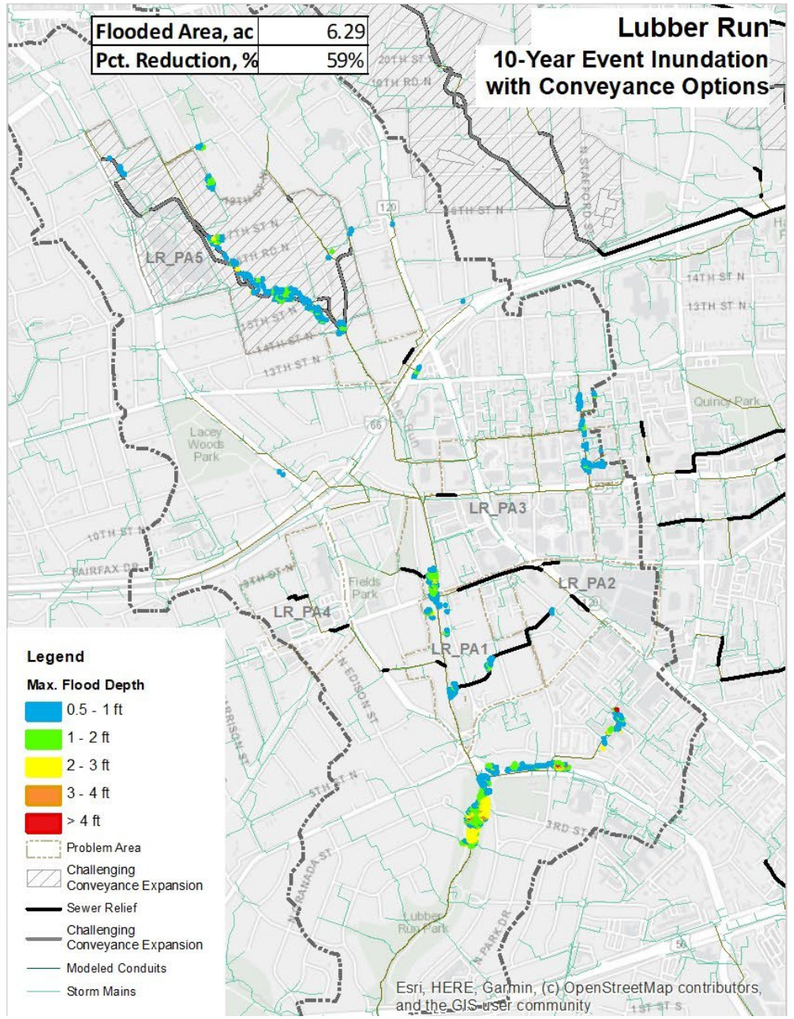



**Figure 6-2. Doctors Branch Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**

(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).



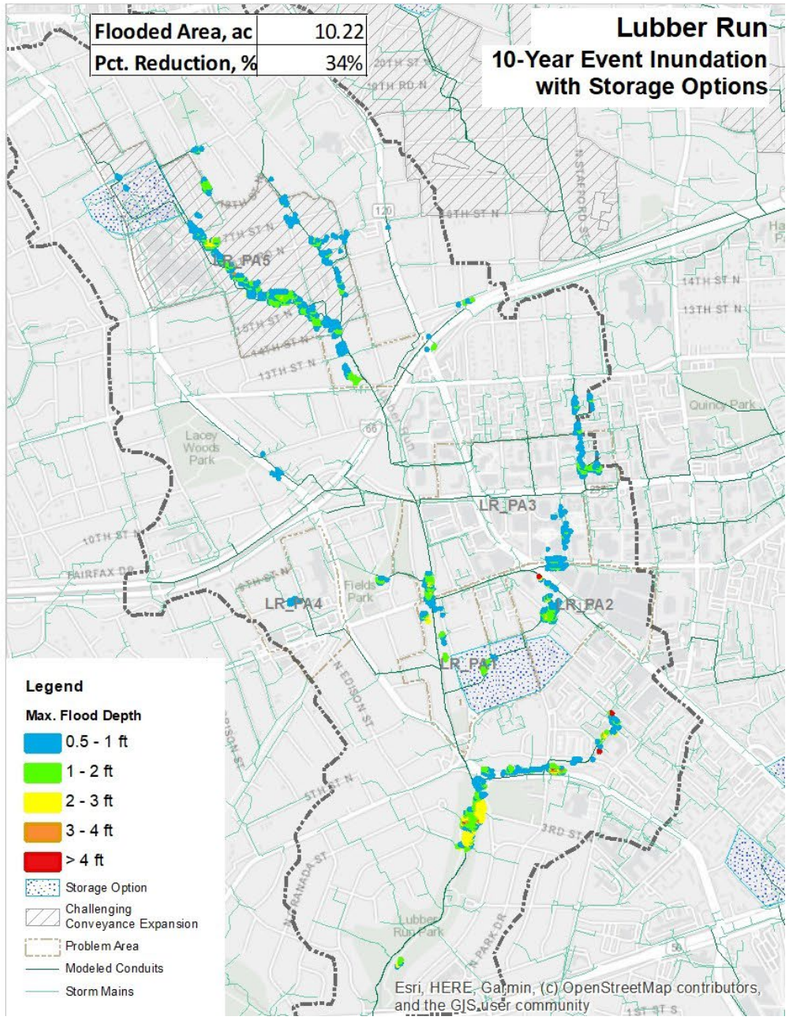




**Figure 6-3. Lubber Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**

(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).

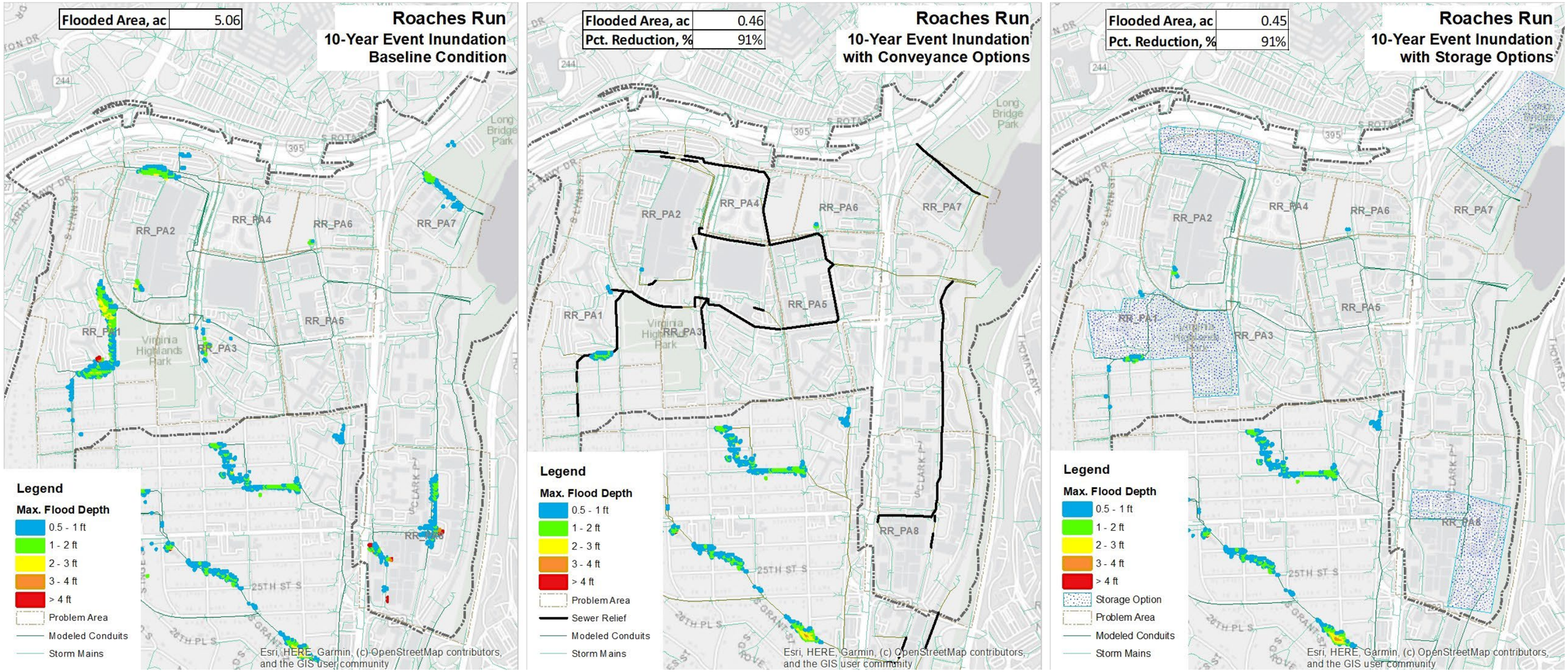



**Figure 6-4. Roaches Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**

(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).

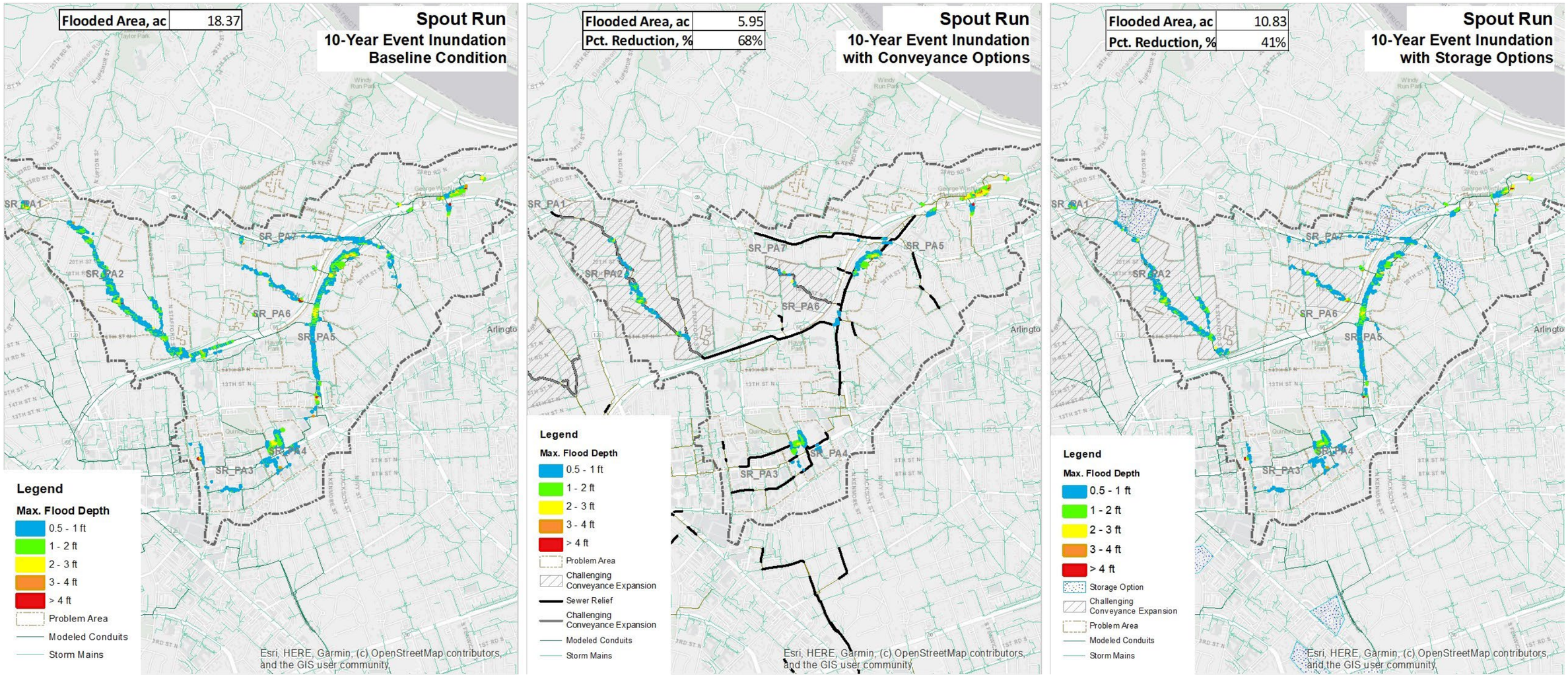



**Figure 6-5. Spout Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**
(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).

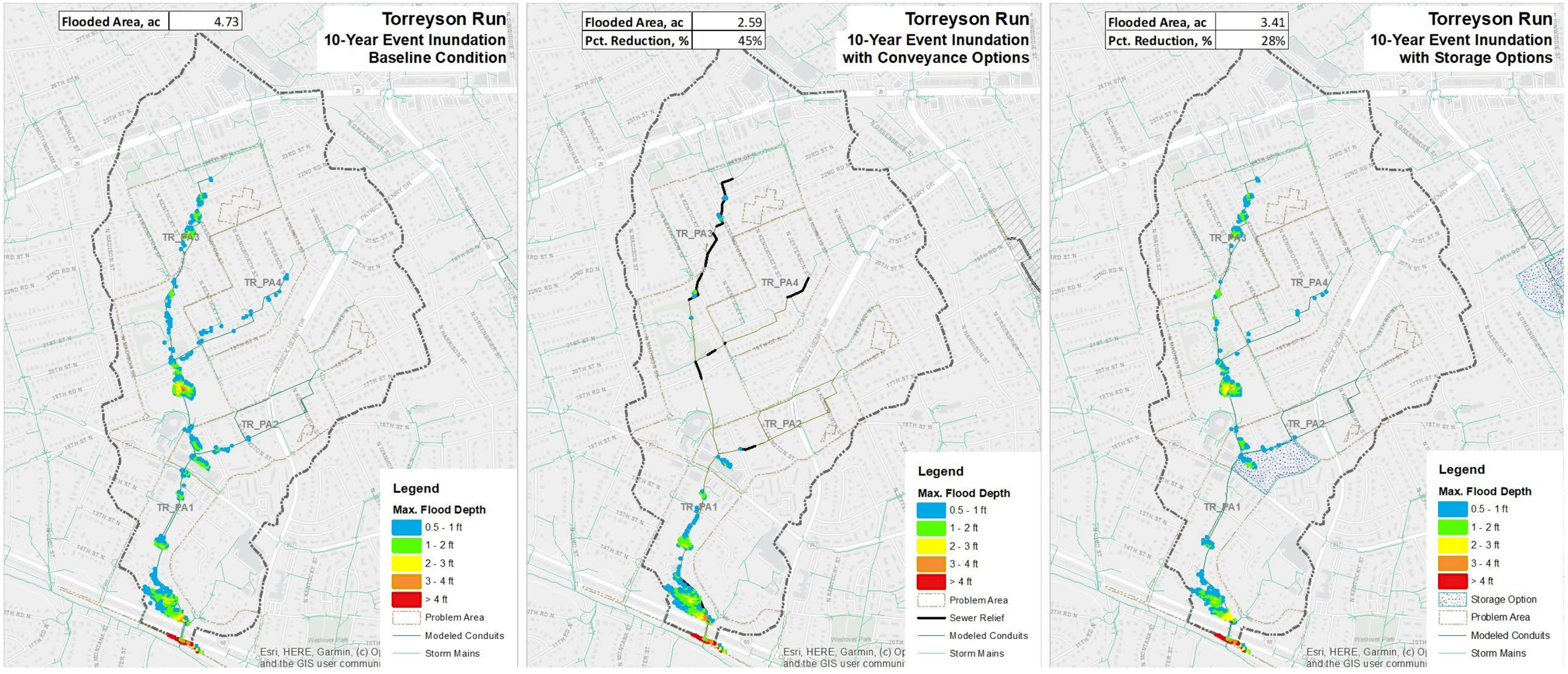



**Figure 6-6. Torreyson Run Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**
(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed). B

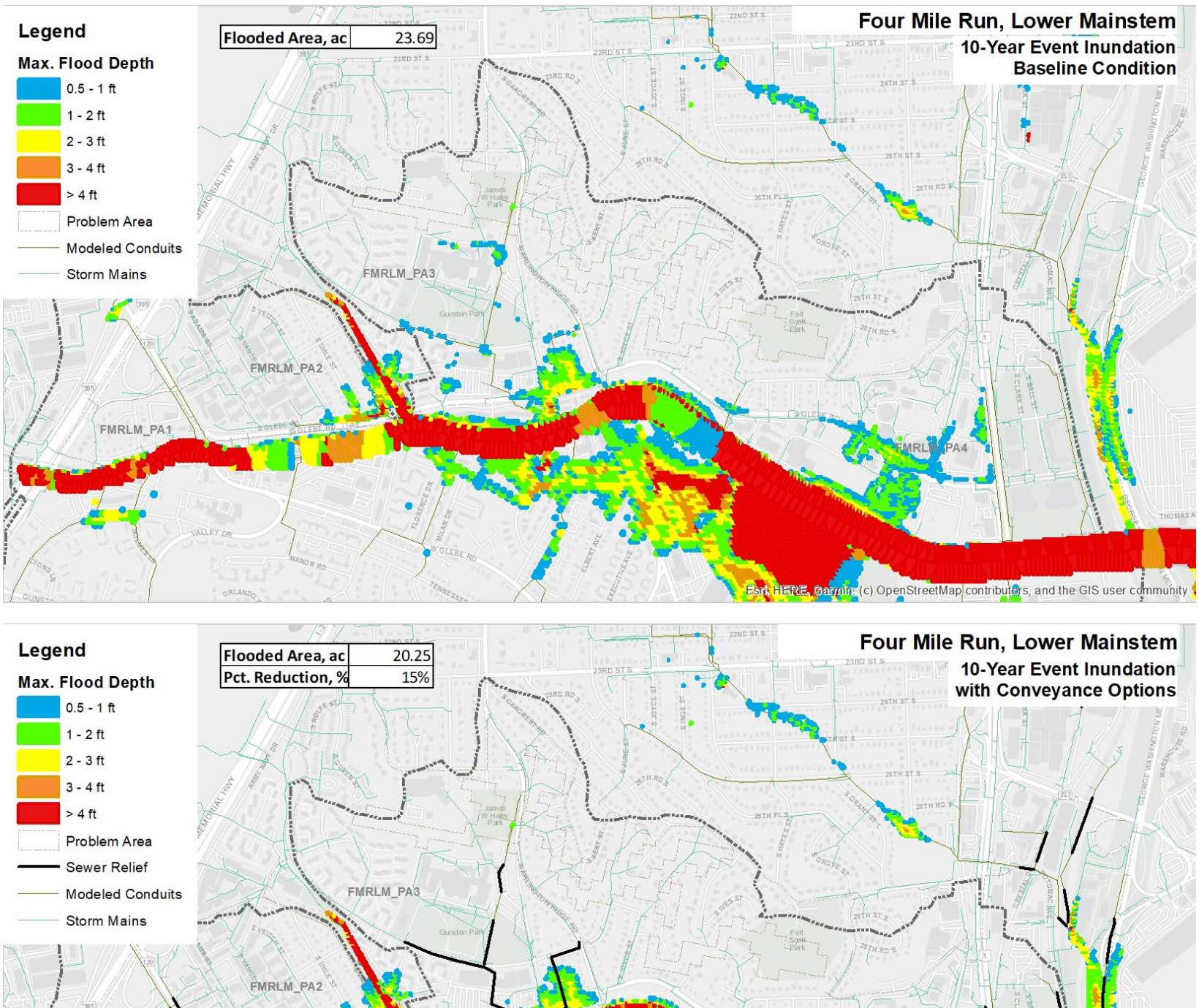



**Figure 6-7. Four Mile Run Middle Mainstem Current (Year 2020) 10-year Storm Predicted Flood Inundation under Current Conditions and Conveyance and Storage Mitigation Solutions**

(Note: "Storage Option" Areas do not depict a specific site. Areas depicted represent a large general location where a specific tank or tanks could be constructed).

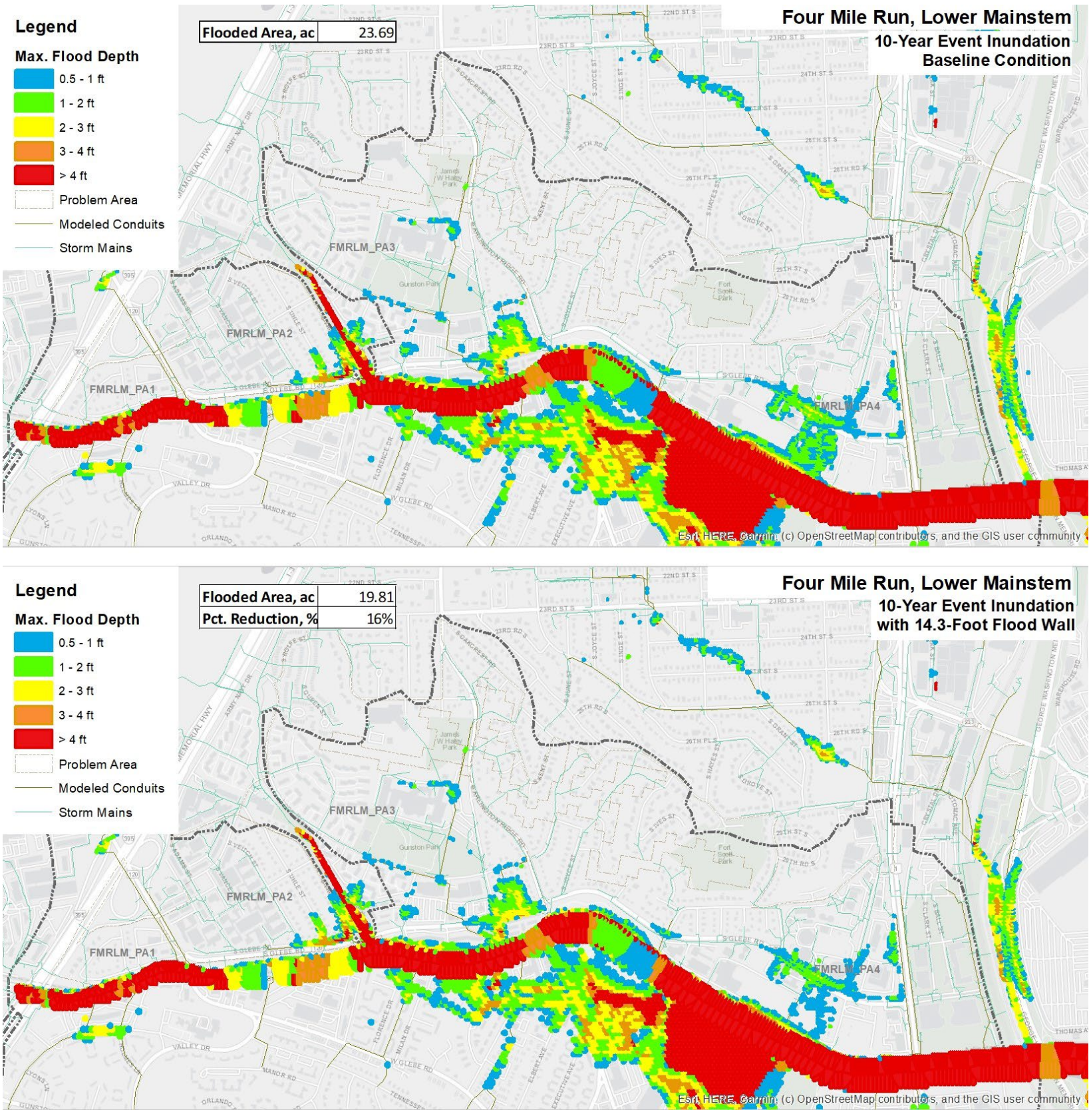



**Figure 6-8. Four Mile Run Middle Mainstem Current (Year 2020)**

10-year Storm Predicted Flood Inundation under Current Conditions and USACE Floodwall Project (approximate location of floodwall shown in yellow rectangle)

#### 6.1.2.1 Reduction in Expected Value of Flood Losses

To understand the benefits of each conceptual conveyance or storage solution, the total annualized losses were calculated based on flood modeling results and application of Hazus for each Problem Area with the solution included, and then compared with the previously determined existing condition losses from Task 5 Area. The results at a Problem Area scale are available in Appendix E, and summarized at a watershed scale in Tables 6-1 and 6-2 for conveyance solutions and storage solutions, respectively.

These results feed directly into the BCR results in the following sections. Watersheds with higher existing condition losses had higher benefits than those with lower initial risk.

For Problem Areas where property acquisition is considered the only viable solution, a BCA was not performed. While a theoretical benefit could be assumed based on eliminating the total annualized risk in existing conditions calculated with Hazus, which assumes that all structures and vehicles in flood zones were acquired and removed; that value would significantly underestimate the potential benefits because it would not reflect potential and difficult to quantify benefits from externalities such as improvements to public health and safety, and increases in property values and property tax revenue for nearby properties.

**Table 6-1. Conveyance Solutions Hazus Risk (Losses) and Benefits Comparison per Watershed**

| Watershed | Total Annualized Risk, Existing Condition (Thousands $) | Total Annualized Risk with Conveyance Solution (Thousands $) | Benefits (Annualized Losses Avoided) (Thousands $) |
|---|---|---|---|
| Bailey's Branch | 1,022 | 100 | 922 |
| Doctor's Branch | 6,363 | 1,970 | 4,392 |
| Four Mile Run Lower Mainstem | 14,689 | 10,792 | 3,897 |
| Lubber Run | 32,422 | 10,557 | 21,865 |
| Roaches Run | 112,845 | 24,438 | 88,407 |
| Spout Run | 40,992 | 14,673 | 25,349 |
| Torreyson Run | 2,628 | 1,326 | 1,302 |

**Table 6-2. Storage Solutions Hazus Risk (Losses) and Benefits Comparison per Watershed**

| Watershed | Total Annualized Risk, Existing Condition (Thousands $) | Total Annualized Risk with Storage Solution (Thousands $) | Benefits (Annualized Losses Avoided) (Thousands $) |
|---|---|---|---|
| Bailey's Branch | 1,022 | 111 | 911 |
| Doctor's Branch | 6,363 | 1,998 | 4,365 |
| Four Mile Run Lower Mainstem | 14,689 | 12,131 | 2,559 |
| Lubber Run | 32,422 | 27,196 | 5,226 |
| Roaches Run | 112,845 | 31,211 | 81,634 |
| Spout Run | 40,992 | 23,273 | 17,719 |
| Torreyson Run | 2,628 | 2,059 | 569 |

### 6.1.2.2 Reduction in Flood Impacts to Socially Vulnerable Areas

To understand the benefits of each conceptual conveyance or storage solution for vulnerable communities, the total flooded area before and after was determined using the areas with mid to high SVI, are areas with high SVI within each Problem Area. The analysis was conducted for all storm return intervals models (10, 100, and 500). The results at a Problem Area scale are available in Appendix F for all storms, and summarized for the 100-year storm at a watershed scale in Tables 6-3 and 6-4 for conveyance solutions and storage solutions, respectively.

**Table 6-3. Conveyance Solutions Reduction in SVI Flood Impacts per Watershed for 100-year 2020 Storm**

| Watershed | Existing Mid High SVI Flooded Area (ac.) | Mid High SVI Flooded Area (ac.) | Reduction in Mid High SVI Flooded Area (ac.) | Existing High SVI Flooded Area (ac.) | High SVI Flooded Area (ac.) | Reduction in High SVI Flooded Area (ac.) |
|---|---|---|---|---|---|---|
| Bailey's Branch | 5.2 | 0.0 | 5.2 | 0.8 | 0.7 | 0.1 |
| Doctor's Branch | 15.4 | 10.9 | 4.5 | 18.6 | 12.2 | 6.4 |
| Four Mile Run Lower Mainstem | 0 | 0 | 0 | 0 | 0 | 0 |
| Lubber Run | 0.003 | 0 | 0.003 | 0 | 0 | 0 |
| Roaches Run | 0 | 0 | 0 | 0 | 0 | 0 |
| Spout Run | 0 | 0 | 0 | 0 | 0 | 0 |
| Torreyson Run | 0.1 | 0.1 | 0 | 0 | 0 | 0 |

Note:

Mid to High SVI refers to areas with SVI values ranging from 0.5 to 0.75.

High SVI refers to areas with SVI values greater than 0.75.

ac. = acre(s)

**Table 6-4. Storage Solutions Reduction in SVI Flood Impacts per Watershed for 100-year 2020 Storm**

| Watershed | Existing Mid High SVI Flooded Area (ac.) | Mid High SVI Flooded Area (ac.) | Reduction in Mid High SVI Flooded Area (ac.) | Existing High SVI Flooded Area (ac.) | High SVI Flooded Area (ac.) | Reduction in High SVI Flooded Area (ac.) |
|---|---|---|---|---|---|---|
| Bailey's Branch | 5 | 1.3 | 3.9 | 0.8 | 0 | 0.8 |
| Doctor's Branch | 15 | 8.7 | 6.7 | 18.6 | 2.8 | 15.8 |
| Four Mile Run Lower Mainstem | 0 | 0 | 0 | 0 | 0 | 0 |
| Lubber Run | 0.003 | 0.003 | 0 | 0 | 0 | 0 |
| Roaches Run | 0 | 0 | 0 | 0 | 0 | 0 |
| Spout Run | 0 | 0 | 0 | 0 | 0 | 0 |
| Torreyson Run | 0.1 | 0.1 | 0 | 0 | 0 | 0 |

Note:

Mid to High SVI refers to areas with SVI values ranging from 0.5 to 0.75.

High SVI refers to areas with SVI values greater than 0.75.

### 6.1.3 Benefit-Cost Ratio Results

A BCA was performed for each Problem Area that contained a mitigation solution. This section briefly discusses the results of the BCA on a watershed scale; however, results per Problem Area can be reviewed in Appendix E. Tables 6-5 and 6-6 include the BCR for conveyance and storage, respectively. Tables 6-5 and 6-6 indicate that all mitigation solutions are cost-effective (BCR >1), on a watershed basis, with the exception of the use of storage alone in Four Mile Run Lower Mainstem and Bailey's Branch. Implementation of storage in Roaches Run and Spout Run and conveyance improvements in Lubber Run provide the greatest project value (highest BCR). The total capital and annual O&M costs shown are a result of a Class 5 cost estimate, which corresponds to a range of -50% to +100% in estimation.

**Table 6-5. Conveyance Mitigation Solutions Benefit-Cost Analysis Results**

| Watershed | Net Present Value of Total Annual Benefits (Thousands $) | Net Present Value of Total Capital and Annual O&M Costs (Thousands $) [a] | Benefit-Cost Ratio |
|---|---|---|---|
| Bailey's Branch | 10,332 | 7,584 | 1.4 |
| Doctor's Branch | 49,232 | 40,250 | 1.2 |
| Four Mile Run Lower Mainstem | 43,679 | 28,570 | 1.5 |
| Lubber Run | 245,066 | 22,712 | 10.8 |
| Roaches Run | 990,879 | 63,992 | 15.5 |
| Spout Run | 284,112 | 76,606 | 3.9 |
| Torreyson Run | 14,594 | 5,334 | 2.7 |

[a] Class 5 level (-50% to +100%) estimate was used to develop the costs as defined by the AACEI Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M.

**Table 6-6. Storage Mitigation Solutions Benefit-Cost Analysis Results**

| Watershed | Net Present Value of Total Annual Benefits (Thousands $) | Net Present Value of Total Capital and Annual O&M Costs (Thousands $)[a] | Benefit-Cost Ratio |
|---|---|---|---|
| Bailey's Branch | 10,210 | 11,174 | 0.9 |
| Doctor's Branch | 48,928 | 43,114 | 1.1 |
| Four Mile Run Lower Mainstem | 28,677 | 48,104 | 0.6 |
| Lubber Run | 58,573 | 10,559 | 5.6 |
| Roaches Run | 914,970 | 22,785 | 40.2 |
| Spout Run | 198,598 | 10,158 | 19.6 |
| Torreyson Run | 6,377 | 302 | 21.1 |

[a] Class 5 level (-50% to +100%) estimate was used to develop the costs as defined by the AACEI Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M.

Figure 6-9 presents the expected NPV of the conveyance solutions in a tornado graphic format, which aligns with the watershed-wide BCR results presented earlier.

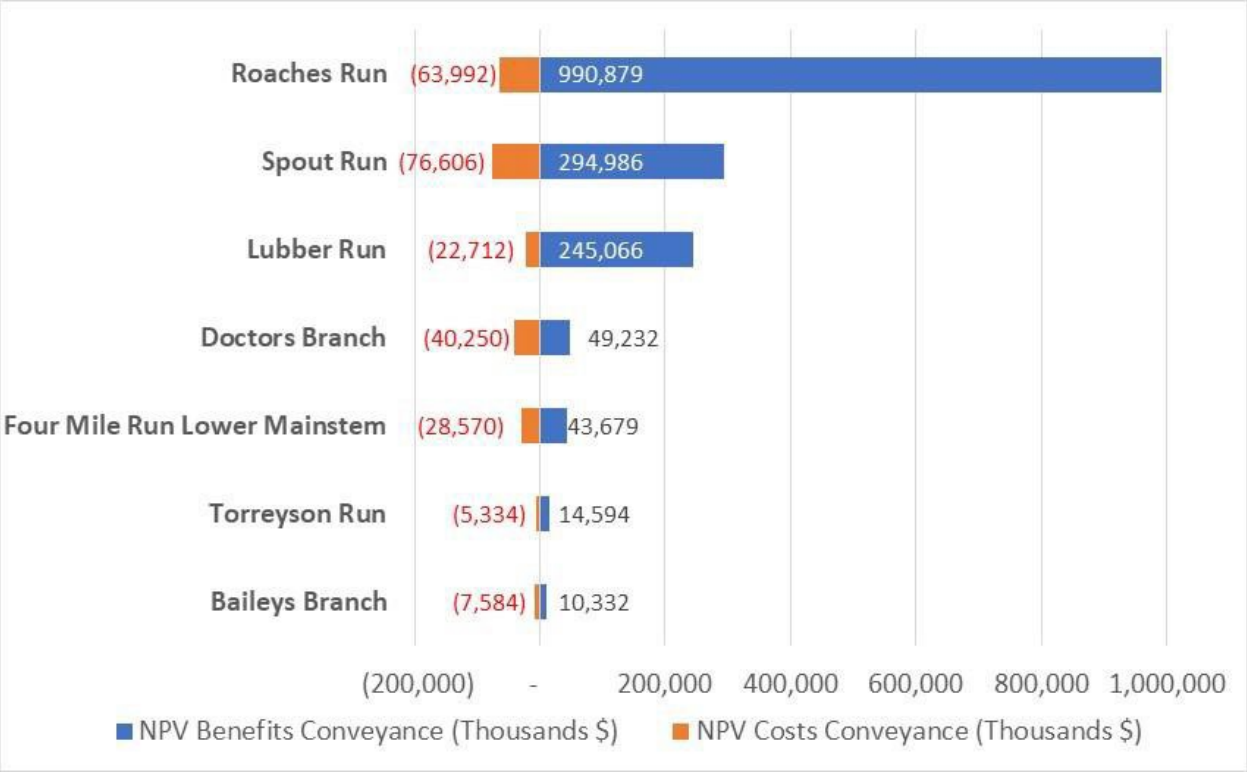



**Figure 6-9. Conveyance Flood Mitigation Concepts: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate)**

## 6.2 Public Facilities

A total of 10 Public Facilities were included in the analysis, seven required mitigation concepts and three were determined to have low risk without the need for mitigation concepts (ART O&M Facility, Cardinal Elementary School, Trade Center – Equipment Bureau/Trade Center NOCII). WPCP North included 10 buildings/sub-facilities with assets not at risk of flooding within the chosen flood scenario (2040, 100-year storm). Figure 6-10 shows the 2040, 100-year flood scenario overlaid on the WPCP North and South and highlights the buildings/sub-facilities omitted from mitigation strategies.

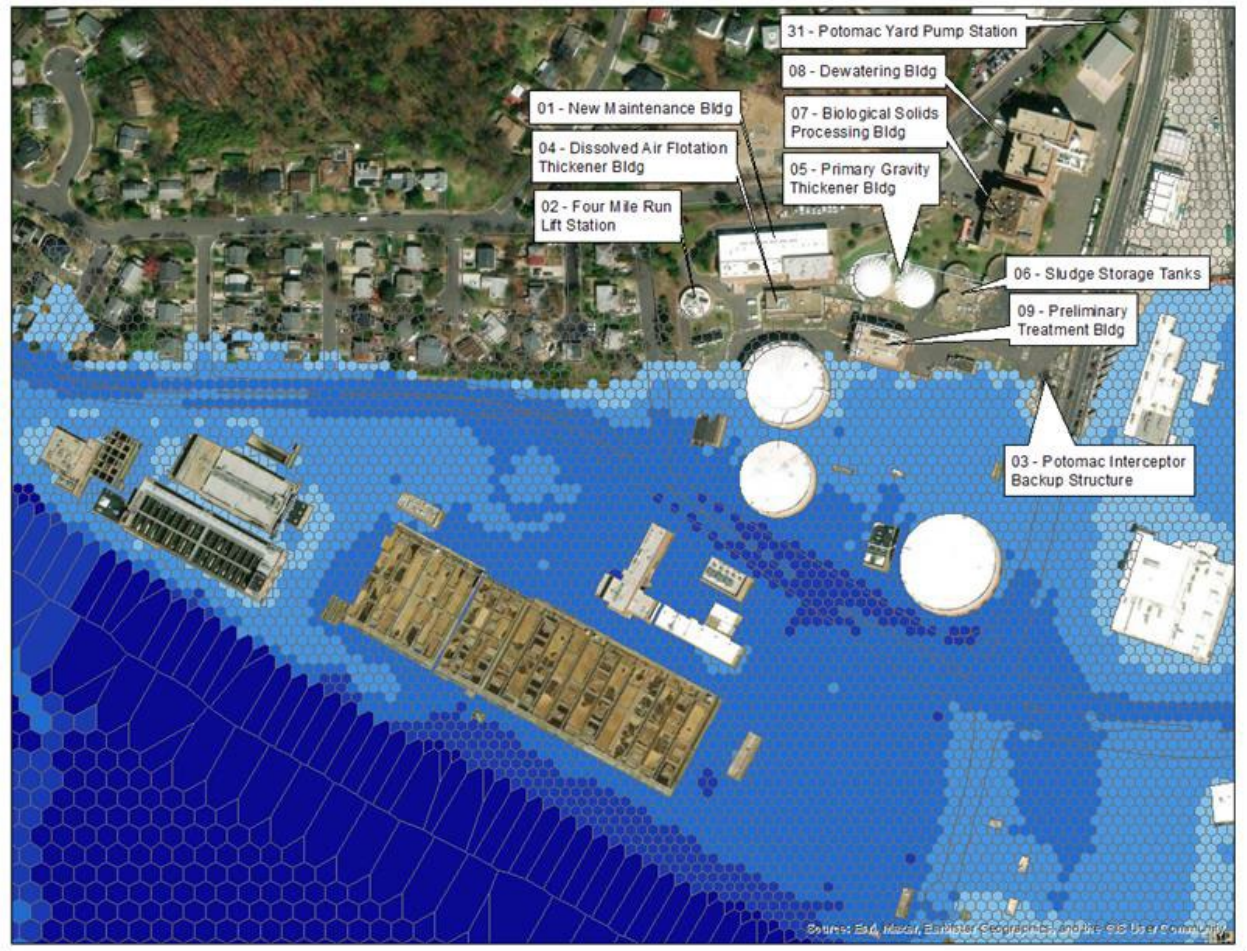



**Figure 6-10. Flood Exposure for Flood Scenario 1 (Climate Change in 2040) 100-year Storm at the WPCP**

## 6.2.1 Cumulative Risk Comparison Based on Direct Damages

Table 6-7 outlines the change in cumulative risk for Public Facilities when mitigation strategies are applied from Alternatives 1 and 2. These results aggregated at Public Facility level are derived from the individual building analysis for buildings within a facility. For a cumulative risk comparison of each building at each facility, refer to Appendix G.

The approach of monetizing risk assesses only the potential direct damage to equipment that might fail in the event of a flood, but does not imply that there's no nonmonetary risks, such as nuisance flooding in access roads that might impede access for first responders. For example, vulnerable populations in Cherrydale might be impacted by flooding in the vicinity even if direct damages are not expected for the range of scenarios modeled. In addition to the nonmonetary risks, the values in Table 6-7 do not include the indirect economic impacts to County residents and businesses should there be a failure of a given facility. Section 6.2.2 provides an example of how those indirect impacts could be calculated, using the case of the WPCP.

**Table 6-7. Public Facility Cumulative Monetized Risk from Direct Equipment Damage, without and with Mitigation Strategies**

| Facility | Sum of Cumulative Monetized Risk without Strategy (2022-2042) (Thousands $) | Sum of Alternative 1 – Cumulative Risk Remaining With Strategy (Thousands $) | Sum of Alternative 2 – Cumulative Risk Remaining With Strategy (Thousands $) |
|---|---|---|---|
| Cherrydale Center | 1 | < 1 | < 1 |
| Gunston | 60 | 2 | 2 |
| Little Falls | 100 | 48 | 48 |
| TJ Middle School | 1,798 | 34 | 28 |
| Virginia Hospital | 5,659 | 74 | 74 |
| WPCP – North | 10,137 | 736 | Not computed [a] |
| WPCP – South | 32,270 | 4,726 | Not computed [a] |

[a] Alternative 2 strategy for the WPCP North and South uses the USACE floodwall. Cumulative monetized risk cannot be accurately calculated with the Task 6 Public Facilities model, but the floodwall would provide significant protection to both North and South facilities.

The initial monetized risk before mitigation reduced by the flood mitigation concepts constitutes the monetized benefit for the BCA. Table 6-8 outlines the benefit when mitigation strategies are applied from both Alternatives 1 and 2.

**Table 6-8. Public Facility Benefits of Mitigation Strategies Based on Cumulative Monetized Risk Avoided for Direct Equipment Damage**

| Facility | Cumulative Monetized Risk Avoided, Alternative 1 Benefit (Thousands $) | Cumulative Monetized Risk Avoided, Alternative 2 Benefit (Thousands $) |
|---|---|---|
| Cherrydale Center | 1 | 1 |
| Gunston Middle School | 58 | 58 |
| Little Falls | 52 | 52 |
| Thomas Jefferson Middle School | 1,764 | 1,770 |
| Virginia Hospital Center | 5,586 | 5,586 |
| WPCP – North[a] | 9,401 | - |
| WPCP – South[a] | 27,368 | - |

[a] Alternative 2 strategy for the WPCP North and South uses the USACE floodwall. Cumulative monetized risk cannot be calculated within the model as the floodwall will provide protection to both North and South facilities.

As mentioned earlier, the ART O&M Facility, Cardinal Elementary School, Trade Center – Equipment Bureau, and Trade Center NOCII did not require mitigation strategies. They were evaluated and determined to not need mitigation strategies due to low cumulative monetized risk as estimated in Task 5 (Jacobs 2022). While these three facilities are in areas where flooding does occur and is projected to occur, results of the flood modeling analysis show very limited risk to the assets in those facilities that could be vulnerable to flood. Flood in the vicinity and inside those facilities could still be disruptive for access and general operations, but no flood mitigation concepts were developed as part of Task 6[10]. Table 6-9 outlines each facility's cumulative monetized risk. The Trade Center – Equipment Bureau was excluded during Task 5 given that no asset damage was predicted; therefore, no cumulative monetized risk was evaluated.

[10] A flood mitigation concept was developed for the Cardinal Elementary School parking area, which is exposed to flooding but is not recommended for implementation due to high costs to protect vehicles that could be moved away from harm.

**Table 6-9. Facilities not Requiring Mitigation**

| Facility | Sum of Cumulative Monetized Risk without Strategy (2022- 2042) (Thousands $) |
|---|---|
| ART | <1 |
| Cardinal Elementary School | <1 |
| Trade Center – NOCII | <1 |

### 6.2.2 Cumulative Risk from Indirect Impacts of a Potential Service Interruption at the WPCP

As noted earlier, the benefits of flood mitigation can be expressed in terms of avoided damages to a given facility for different flood events, where risk is calculated as the probability of flooding times the damages, summed over all events in a given year, and over all years in the service life of each asset within a facility. The analysis presented in Section 6.2.1 and previously in the Task 5 TM was based entirely on direct damages to equipment, as determined by asset replacement costs. To illustrate how benefits will increase if indirect damages were included, an analysis was conducted to estimate the potential economic impacts associated with the risk of natural hazards at the County's WPCP.

To carry out this analysis, three hazard scenarios were developed based on the three most likely impacts that flood, storm, and electrical outage could have on the facility. Economic impacts considered in the analysis include: loss of local economic activity, loss of local income, and loss of function of the Four Mile Run recreation trail adjacent to the WPCP.

The details of the analysis are presented in Appendix H. The three hazard scenarios are as described in Table 6-10. Results indicate that under this set of hazard scenarios, potential economic impacts range from $1.3 million to nearly $590 million. An alternative calculation of the economic impact of loss of wastewater service according to FEMA standard values range from $170,000 to $42 million.

**Table 6-10. Summary of WPCP Service Interruption Scenarios and Economic Impact Estimates**

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Scenario Summary | 3-day countywide minimal water use restriction | 8-hour wastewater outage in the lower sewershed and Potomac Yard sewershed | No service outage; 180-day recreation trail closure and additional operational costs |
| Duration | 3 days | 8 hours | 6 months |
| Failure Mode/Hazard | Wind and Regionwide Power Outage | Wind, local power outage, local flooding of access roads | Flood damage to secondary or tertiary treatment at the WPCP |
| Operational Costs (Arlington estimate) | | | $850,000 |
| Loss of Income (IMPLAN) | $225,970,486 | $1,011,603 | |
| Loss of Economic Activity (IMPLAN) | $363,639,939 | $2,269,021 | |
| Loss of Recreation Trail Use (DOT standard values) | | | $475,437 |
| **Total** | **$589,610,424** | **$3,280,624** | **$1,325,437** |

The economic loss estimates in Table 6-10 represent the one-time losses that would occur if the WPCP were to fail under each of the three scenarios described. Cumulative losses were also calculated for Scenario 2 using the same approach as described earlier for Tables 6-1 and 6-2. The values in Tables 6-1 and 6-2 include only cumulative monetized risk due to direct damage to equipment and do not include the indirect economic impacts to County residents and businesses should there be a failure of a given facility, as presented in Table 6-10. As an example, the cumulative monetized risk of indirect economic impacts was also calculated for the WPCP. The method is similar to that applied to derive the values in Tables 6-1 and 6-2 but is based on finding the one asset that may cause the plant to fail and therefore result in the damages indicated in Table 6-10. The probability of each flood event reaching that elevation times the damages is summed over all events in a given year, and over all years during the useful life of the asset. The asset assumed to cause that outage was the SCL motor for secondary clarifiers. This calculation is then repeated to calculate residual risk for Flood Mitigation Alternative 1 (flood proofing to 100-year flood elevation in 2040). Table 6-11 presents the results of that calculation of benefits, inclusive of both direct and indirect damages. The results in Table 6-11 indicate that by accounting for avoided losses from both direct equipment damage and indirect economic losses, the estimated benefits could increase by 19%, from $27.4 million to $32.6 million.

**Table 6-11. Cumulative Monetized Risks and Benefits for Mitigation Strategy 1 at WPCP, with Both Direct Damage to Equipment and Indirect Economic Risk**

| Facility | Sum of Cumulative Monetized Risk without Strategy (2022-2042) (Thousands $) | | Sum of Alternative 1 – Cumulative Risk Remaining With Strategy (Thousands $) | | Benefits Based on Cumulative Monetized Risk Avoided | |
|---|---|---|---|---|---|---|
| | Direct Risk to Equipment | Indirect Risk of Economic Losses | Direct Risk to Equipment | Indirect Risk of Economic Losses | For Direct Equipment Losses | For both Equipment and Economic Losses |
| WPCP – South | 32,270 | 5,597 | 4,726 | 520 | 27,368 | 32,621 |

These economic impacts can provide the basis for a BCA. If impacts are completely avoided through hazard mitigation measures at the WPCP, they can be considered the economic benefits associated with increased resilience.

### 6.2.3 Benefit-Cost Analysis for Public Facilities

The costs to implement the flood mitigation concepts at Public Facilities described in Section 5 (Table 5- 2) were used to compute BCRs. Table 6-12 outlines the benefits, costs, and BCRs for the two alternative mitigation strategies applied to each Public Facility. Figure 6-11 and Figure 6-12 show the costs and benefits of Alternative 1 and Alternative 2 for each facility. Results show that, in all facilities except for Cherrydale Center, there is an alternative with a BCR greater than 1.0, which does not mean that flood mitigation should not be implemented. For the benefits, costs, and BCRs of each building within each facility, refer to Appendix G.

Other considerations of risk are important in determining the need for flood mitigation at that facility. For example, as noted in Section 6.2.1, the benefits in Table 6-12 do not include the indirect economic impacts to County residents and businesses should there be a failure of a given facility. Section 6.2.2 illustrates how including those indirect economic impacts could increase the benefits of flood mitigation a the WPCP-South by 19%, which would increase the BCR in Table 6-12 from 6.0 to 7.2. In addition, the benefits shown in Table 6-12 do not include nonmonetary risks. For example, as previously noted, benefits for Cherrydale only consider direct monetary risk, and not indirect monetary risk or limitations on access to the vulnerable occupants. In addition, a site-specific investigation may suggest other, lower cost mitigation strategies, such as simple surface diversions or curbs if local topography allows.

**Table 6-12. Public Facility Costs, Benefits, and Benefit-Cost Ratios Based on Direct Equipment Damage**

| Public Facility | Benefit Alternative 1 (Thousands $) | Benefit Alternative 2 (Thousands $) | Mitigation Costs, Alternative 1[b] (Thousands $) | Mitigation Costs, Alternative 2[b] (Thousands $) | Benefit- Cost Ratio Alternative 1 | Benefit- Cost Ratio Alternative 2 |
|---|---|---|---|---|---|---|
| Cherrydale Center | 1 | 1 | 7 (5 to 11) | 21 (14 to 31) | 0.2 | 0.1 |
| Gunston Middle School | 58 | 58 | 252 (177 to 378) | 22 (15 to 33) | 0.2 | 2.7 |
| Little Falls | 52 | 52 | 7 (5 to 11) | 21 (14 to 31) | 7.2 | 2.6 |
| Thomas Jefferson Middle School | 1,764 | 1,770 | 91 (64 to 137) | 49 (35 to 74) | 19.3 | 35.9 |
| Virginia Hospital Center | 5,586 | 5,586 | 59 (41 to 88) | 164 (115 to 246) | 95.4 | 34.1 |
| WPCP (North)[a] | 9,401 | N/A | 2,096 (1,467 to 3,144) | 3,592 (1,347 to 5,388) | 4.5 | 2.0[a] |
| WPCP (South)[a] | 27,368 | N/A | 4,537 (3,176 to 6,806) | N/A | 6.0 | 2.0[a] |
| Total | | | 7,049 (4,934 to 10,574) | 3,869 (2,708 to 5,804) | | |

[a] Alternative 2 strategy for the WPCP North and South uses the USACE floodwall. Cost allocation is not set and therefore a BCR cannot be determined with the same methods used in Task 6 of the RAMP. USACE, however, reports a BCR of 2.0 for the project (based on protection of the area beyond the WPCP) (USACE 2022).

[b] Class 4 level (-30% to +50%) estimate was used to develop the costs as defined by the AACEI Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. Cost estimates of this class account for both capital costs and O&M.

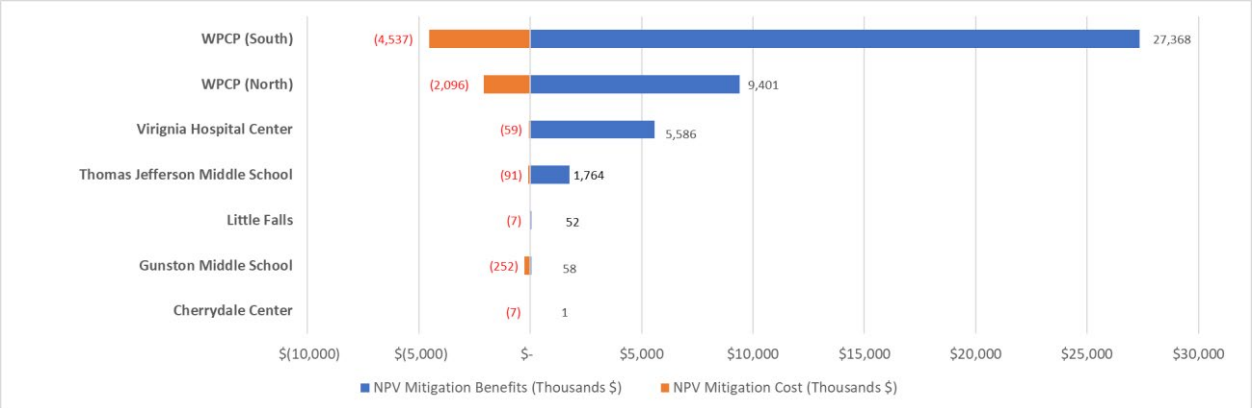



**Figure 6-11. Alternative 1 Mitigation Strategies: Net Present Value of Benefits and Costs (Total Capital and O&M) (50-Year Period and 7% Discount Rate)**

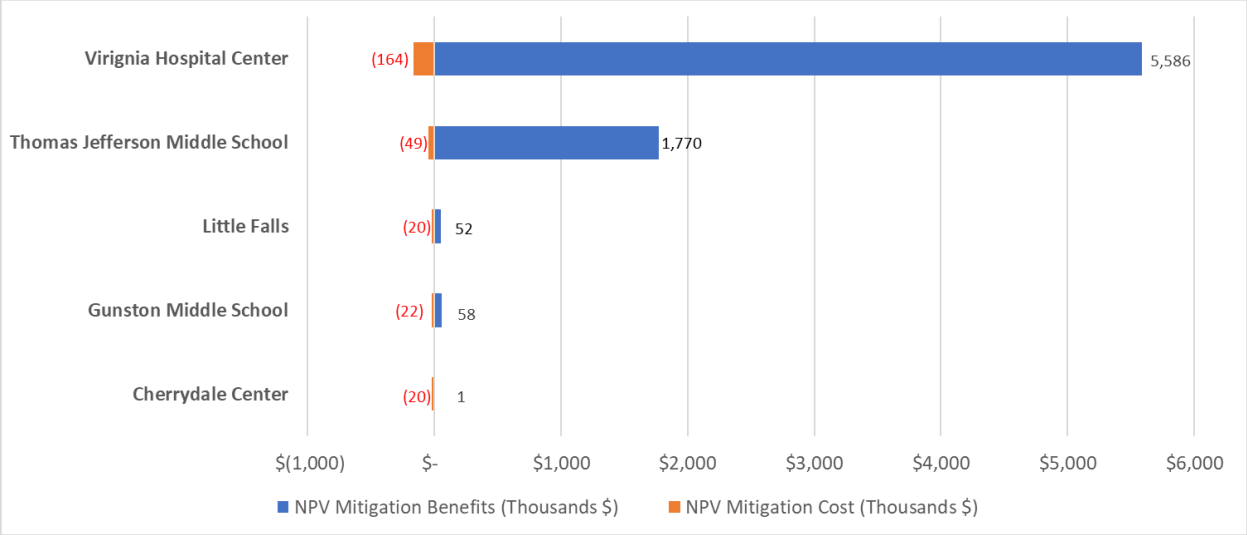



**Figure 6-12. Alternative 2 Mitigation Strategies: Net Present Value of Benefits and Costs (Total Capital and O&M) (50- Year Period and 7% Discount Rate)**

# 7. Conclusions and Next Steps

## 7.1 Conclusions

The flood mitigation concepts for Problem Areas developed and evaluated in Task 6 reduce flooding and at the watershed level are estimated to have a BCR above 1.0 (at least one alternative exists for each watershed for which the ratio is greater than 1.0). For a few individual Problem Areas, some significant challenges for project implementation do exist that require additional analysis.

Programmatic solutions, many of which the County currently has in its menu of flood management strategies, can serve as an important tool to address flooding County-wide and in localized areas. Additional programmatic solutions are available that other jurisdictions are applying that can be considered for exploration and potential adoption.

For the Public Facilities where flood mitigation alternatives were developed and assessed, all but one are estimated to have a BCR above 1.0. Further exploration of detailed alternatives for the Cherrydale Health and Rehabilitation Center is recommended to potentially find more cost-effective options.

The WPCP alternatives provide significant flood risk reduction and have large BCRs driven by both the asset replacement costs of vulnerable assets and the significant flood exposure in the facility. There is significant merit in exploring a watershed-level alternative that could protect the WPCP and the neighborhoods in the Four Mile Run flood risk area (as identified in Task 5, which includes some areas outside the FEMA 100-year floodplain). The USACE levee alternative (USACE 2022) is an alternative to consider for enhancement through collaboration.

## 7.2 Next Steps

The next steps within the RAMP effort include a workshop to present and discuss results of Task 6 to identify mitigation and adaptation strategies that provide flood reduction benefits above the costs that are expected to be incurred for implementation. A final report will document not only the results of Task 6 analysis but also the outcomes of the workshop as it relates to implementation considerations.

Implementation steps after completion of the RAMP project will include feasibility-level studies for project implementation and further analysis to optimize the concepts assessed in this Task 6 at the planning level. For many Problem Areas, projects are likely to include a combination of conveyance and storage options. For Public Facilities, flood mitigation concepts from Task 6 could proceed with pre-design and design for facilities buildings and assets at risk.

Prioritization of actions for Problem Areas and Public Facilities can be informed by the BCRs developed as part of Task 6. Prioritization of projects for Public Facilities can additionally rely on criteria such as criticality of assets and risk exposure identified in Task 5. For Problem Areas, project prioritization will include additional considerations given that those projects protect not only individual assets and their function, but larger areas where people live work and recreate. Environmental and social vulnerability factors assessed in Tasks 4 and 5, as well as other relevant prioritization criteria, will be taken into consideration. Additional criteria can include public safety, availability of funding opportunities, project-bundling opportunities, legal and regulatory mandates, opportunities for partnerships with other agencies, public support and need, and a number of other key considerations that go beyond the scope of Task 6.

Programmatic solutions are part of the County's portfolio of potential actions and decisions to enhance existing solutions and add new policies, actions, procedures, and standards can be informed by the review of programmatic solutions provided in this TM. The RAMP tasks, which have included assessments of flood exposure, vulnerability, and risk under historical and climate change conditions, will inform the County's actions in updating design guidance and standards for County facilities. The final report for the RAMP will be prepared serving as an informed implementation roadmap for successfully guiding risk reduction and resilience in the County's continued stormwater investment.

# 8. References

American Society of Civil Engineers (ASCE). 2014. Flood Resistant Design and Construction, ASCE/SEI 24-14. October.

Kousky, C. and H. Wiley. 2021. *Improving the Post-Flood Financial Resilience of Lower-Income Households through Insurance.* Wharton Risk Center, University of Pennsylvania: Philadelphia, PA. January.

Federal Emergency Management Agency (FEMA). 2022. Hazus Flood Model User Guidance, Hazus 5.1. April.

Jacobs. 2021a. *Task 4 Technical Memorandum: Watershed Vulnerability Assessment (Task 4).* August.

Jacobs. 2021b. *Task 3.3 Technical Memorandum: Arlington Interior and Riverine Flooding Report (Task 3.3)*. July.

Jacobs. 2022. *Task 5 Technical Memorandum: Arlington Flood Risk Assessment (Task 5)*. September.

U.S. Army Corps of Engineers (USACE). 2022. *Draft Integrated Feasibility Report and Environmental Assessment, Metropolitan Washington District of Columbia Coastal Storm Risk Management Feasibility Study*. Prepared by the USACE Baltimore District. May.

# Appendix A
# Programmatic Strategies for Flood Management

# Appendix A. Programmatic Strategies for Flood Management

Refer to Appendix G of the Flood Risk Assessment and Management Plan.

# Appendix B
# Hazus Overview

# Hazus Software Background

This appendix presents some basic information about Hazus software, including excerpts from its technical user's manual which can be accessed in the following link: Hazus 5.1 Flood Model User Guidance (fema.gov).

The Hazus Flood Loss Estimation Methodology provides officials and analysts with a decision support software for estimating potential losses from flood events. This loss estimation capability enables users to anticipate the consequences of floods and develop plans and strategies for reducing risk. The Geographic Information System (GIS)-based software can be applied to study geographic areas of varying scale with diverse population characteristics and can be implemented by users with a wide range of technical and subject matter expertise.

This methodology has been developed, enhanced, and maintained by the Federal Emergency Management Agency (FEMA) to provide a tool for developing flood loss estimates. While the tool can be used in preparedness and recovery, Hazus has been used in this Arlington County Risk Assessment Management Program (RAMP) as a planning tool to quantify potential building and vehicle impacts and losses. Hazus can analyze flood hazards from a variety of inputs. For Task 5, the flood exposure information was generated by RAMP modeling as part of Task 3 under multiple scenarios with different probabilities.

Hazus flood methodology was developed by FEMA in the early 2000s and is updated with ongoing modifications based on newer methodology or software development. It is intended to help guide the allocation of federal resources to stimulate risk mitigation efforts and to plan for a flood-related disaster response at all levels of government.

The Hazus Flood Model Technical Manual (link provided above) documents the methods used in calculating losses. A companion document, the Hazus Inventory Technical Manual provides more detailed methodology and data descriptions for the inventory shared by each hazard model. Technical Memorandum 5 for the RAMP includes a description of Hazus, including an excerpt of Section 2 of the Hazus 5.1 User Guidance.

## Definitions Used in the Arlington RAMP Task 5 and Task 6 Analysis

Losses computed by Hazus are divided in multiple categories that align with direct losses (direct damages to an asset from flooding) and indirect losses (consequences of the physical damage or activity disruption due to flood). The following categories were used in Task 5 and are used again in Task 6:

- Capital Stock Losses: Include losses related to physical damage to the building (structural and nonstructural) as well as the building contents and contents related to economic activity (inventory) for building categories that observe economic activity with inventory.

Under Capital Stock Losses, the following categories are relevant:

- Building Loss: building loss is the losses associated with direct damages to the building and are thus specific to building typology, accounted for in Hazus (multiple building types and materials are included in the database).
- Content Loss: Building contents are defined as furniture, equipment that is not integral with the structure, computers and other supplies. Contents do not include inventory or nonstructural components such as lighting, ceilings, mechanical and electrical equipment and other fixtures. Contents damage functions are applied in the same manner as building damage functions.
- Inventory Loss: Inventory losses in the flood module are determined in a manner consistent with the other building losses, as well as the methodology currently utilized in the Hazus earthquake module. For occupancies with inventory considerations (COM1– COM2, IND1 – IND6 and AGR1, as defined in the Hazus99 Earthquake Technical Manual), inventory losses are estimated using USACE-based depth-damage functions, in conjunction with Hazus default inventory values determined as a percentage of annual sales per square foot.

Income Losses: Income losses are related to the disrupted economic activity associated with the flood event. Their estimates require an estimation of building restoration time or outage time (they are time-dependent).

Under Income Losses, the following categories are relevant:

- Relocation Loss: losses incurred by occupants of a building after damages reach a certain threshold. Relocation expenses represent disruption costs to building owners for selected occupancies. Expenses include "… disruption costs that include the cost of shifting and transferring, and the rental of temporary space."
- Income Loss: Income losses account for temporary loss of income due to flooding and exclude wage loss (associated with employees) and sales output loss (for owners), which are accounted for separately.
- Wage Losses: includes the temporary loss of wages for employee occupants of a building after damages reach a certain threshold.
- Direct Output Loss: includes temporary loss of sales and other direct output loss for incurred by business owners after damages in a building reach a certain threshold.
- Rental Income Loss: includes the temporary loss of rental income associated with relocation triggered by the flood event.

The Hazus Technical Manual includes the specific methodologies, data, assumptions, and equations to compute these losses.

## References

Hazus 5.1 User Guidance

Jacobs Engineering Group Inc. (Jacobs). Task 5 Technical Memorandum: Arlington Flood Risk Assessment (Task 5). September.

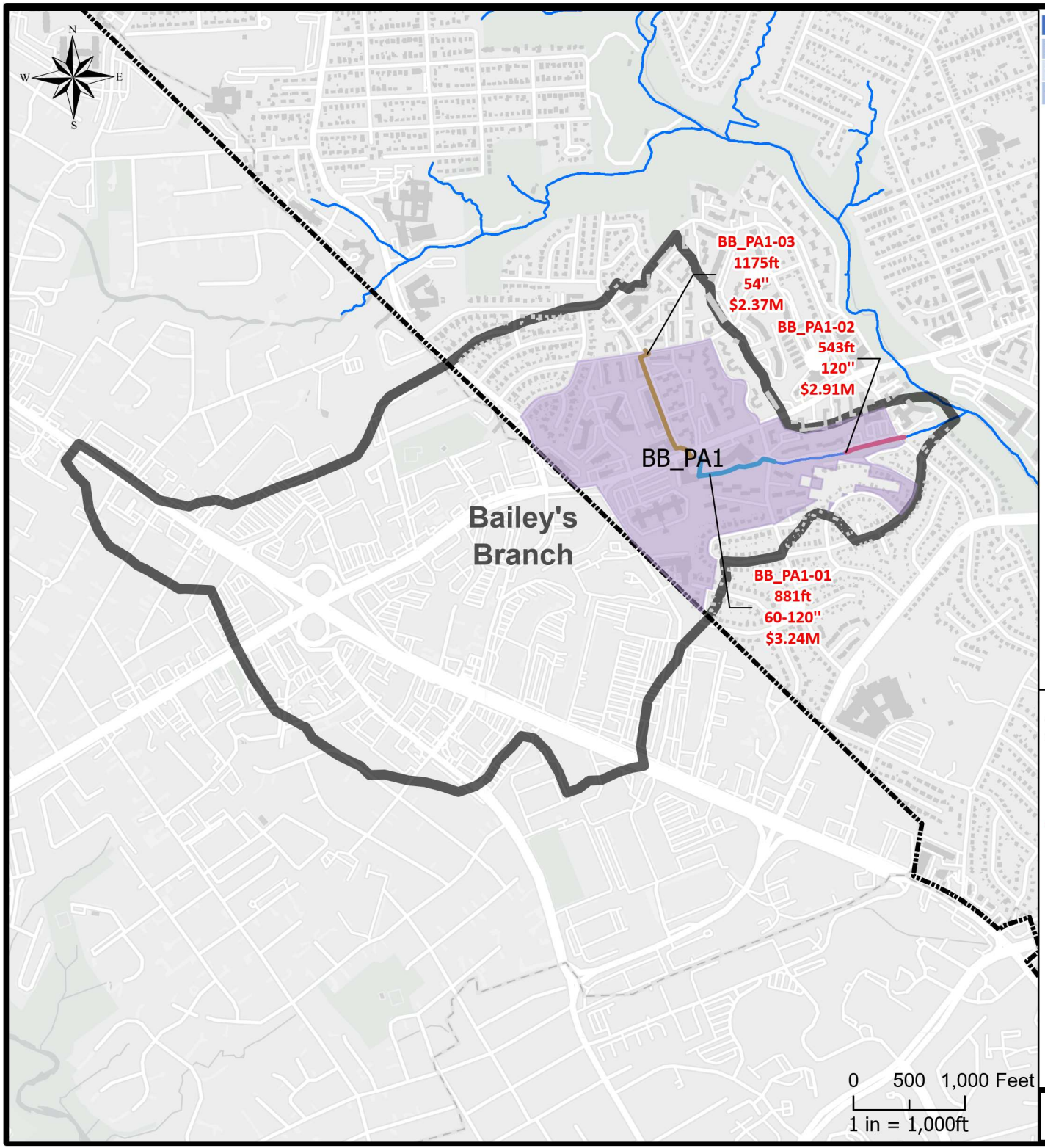
# Appendix C
# Detailed Concepts per Watershed Problem Areas

Appendix C provides detailed concept information for storage and conveyance solutions for each watershed analyzed.

The storage areas depicted in the maps are general areas where one or multiple dispersed underground storage tanks would be built for the total storage specified for the project area. These areas are presented as general areas because Task 6 did not conduct detailed feasibility of any specific site. The areas were identified based on locations where storage relief would benefit the system and where there is apparent availability of sites in public or private parcels where implementation would be less complex than in areas with high density and/or parcels with buildings.

The conveyance concepts maps include some areas -in two watersheds- that are noted as “Challenging Conveyance Expansion” with sewer lines that are labeled as “Challenging Conveyance Projects”. From modeling and desktop analyses, these areas would significantly benefit from conveyance expansion. They are, however, areas known to have significant constraints in terms of easements and general space to implement conventional sewer projects. The County has explored opportunities for projects in these areas and conventional storm sewer projects have been ruled out. Overland relief alternatives are being analyzed and further technical and financial feasibility of deep sewers with tunneling options could be analyzed in phases following the RAMP.

The costs, benefits and Cost-Benefit ratios of each problem area in the watersheds analyzed in Task 6 are included in Appendix E. Appendix E includes the project areas with challenging implementation in results tables but benefits and benefit cost ratios have not been included given that implementation of conveyance projects in these areas are highly unlikely. Tables with cost, benefits and Benefit-Cost ratios by watershed in Section 6 exclude the areas with implementation challenges.




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| BB_PA1-01 | 881ft | 60-120" | $3.24 |
| BB_PA1-02 | 543ft | 120" | $2.91 |
| BB_PA1-03 | 1175ft | 54" | $2.37 |

## LEGEND

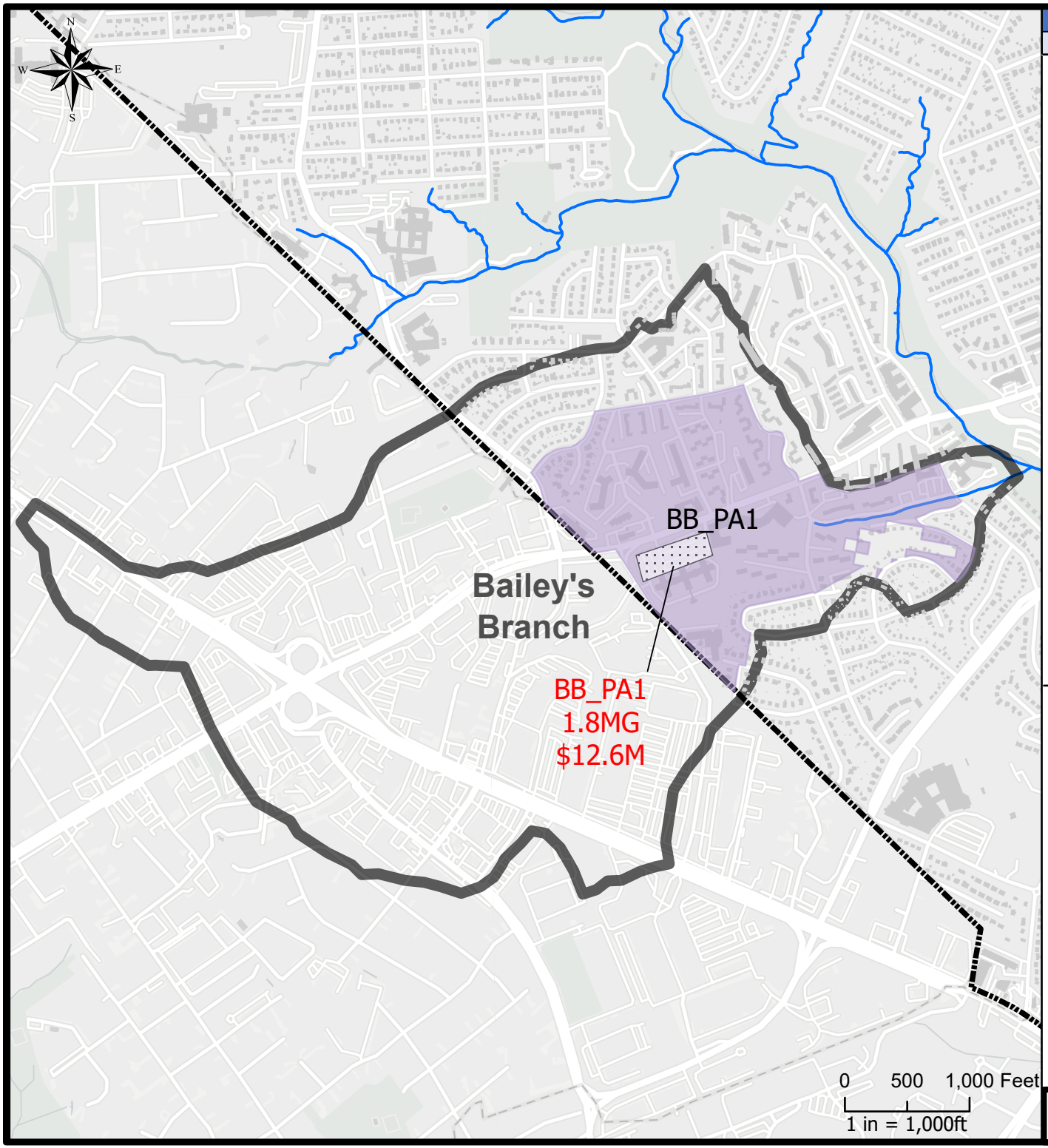
Conveyance Solution Order:
- Project ID
- Pipe Length
- Pipe Size
- Cost: $M

Data:
- Problem Areas
- Conveyance Pipes

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

# Conveyance Concepts: Baileys Branch




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| BB_PA1 | 1.8 | Mixed | 12.6 |

## LEGEND

Storage Solution:

Project Area ID

Storage Volume: MG

Capital Cost: $M

Data:

Problem Areas

General Area for Storage Projects

Basemap:

Watershed

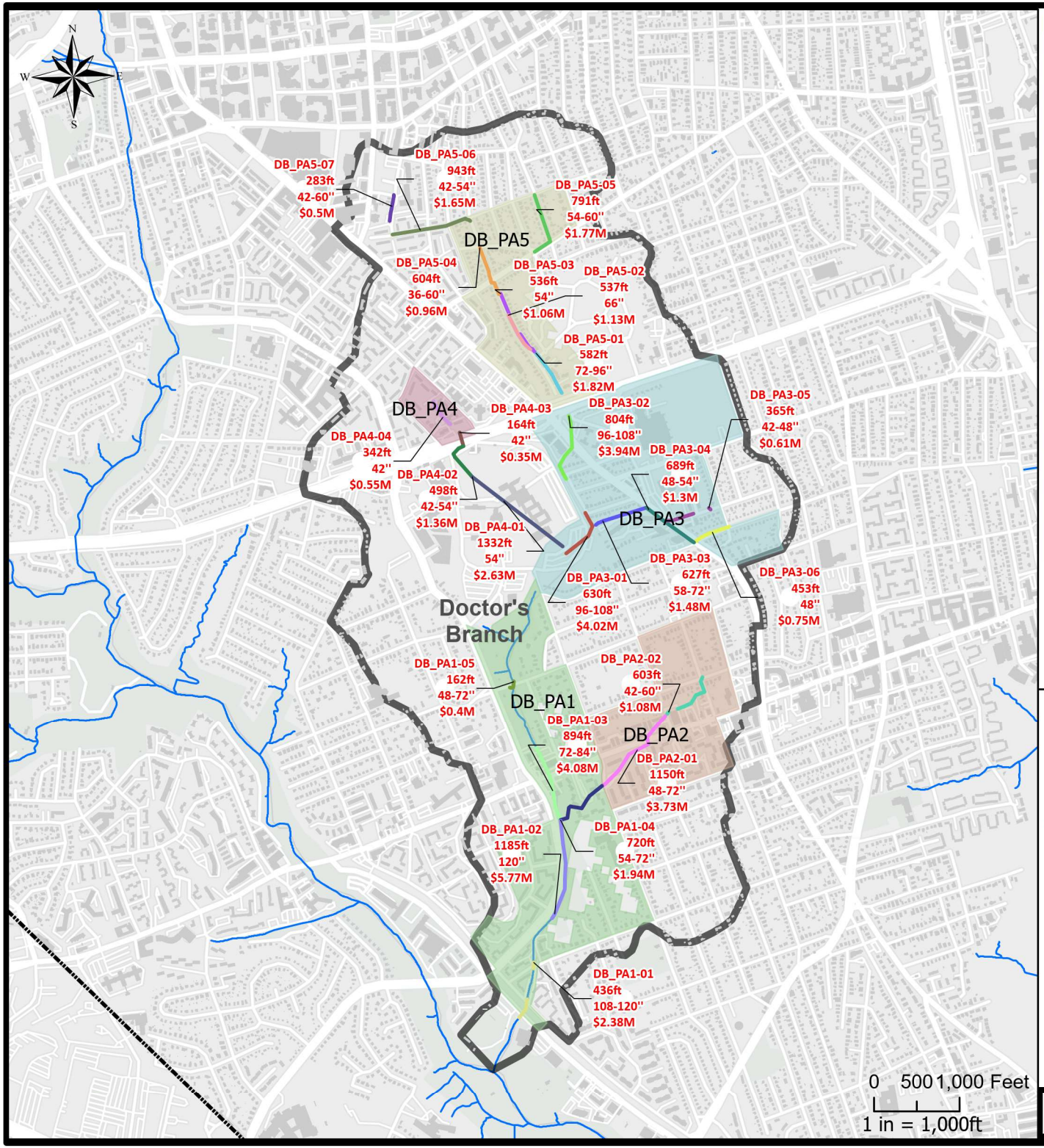
County Boundary

Buildings

Hydrology

ARLINGTON
VIRGINIA

# Storage Concepts: Bailey's Branch




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| DB_PA1-01 | 436ft | 108-120'' | $2.38 |
| DB_PA1-02 | 1185ft | 120'' | $5.77 |
| DB_PA1-03 | 894ft | 72-84'' | $4.08 |
| DB_PA1-04 | 720ft | 54-72'' | $1.94 |
| DB_PA1-05 | 162ft | 48-72'' | $0.40 |
| DB_PA2-01 | 1150ft | 48-72'' | $3.73 |
| DB_PA2-02 | 603ft | 42-60'' | $1.08 |
| DB_PA3-01 | 630ft | 96-108'' | $4.02 |
| DB_PA3-02 | 804ft | 96-108'' | $3.94 |
| DB_PA3-03 | 627ft | 58-72'' | $1.48 |
| DB_PA3-04 | 689ft | 48-54'' | $1.30 |
| DB_PA3-05 | 365ft | 42-48'' | $0.61 |
| DB_PA3-06 | 453ft | 48'' | $0.75 |
| DB_PA4-01 | 1332ft | 54'' | $2.63 |
| DB_PA4-02 | 498ft | 42-54'' | $1.36 |
| DB_PA4-03 | 164ft | 42'' | $0.35 |
| DB_PA4-04 | 342ft | 42'' | $0.55 |
| DB_PA5-01 | 582ft | 72-96'' | $1.82 |
| DB_PA5-02 | 537ft | 66'' | $1.13 |
| DB_PA5-03 | 536ft | 54'' | $1.06 |
| DB_PA5-04 | 604ft | 36-60'' | $0.96 |
| DB_PA5-05 | 791ft | 54-60'' | $1.77 |
| DB_PA5-06 | 943ft | 42-54'' | $1.65 |
| DB_PA5-07 | 283ft | 42-60'' | $0.50 |

## LEGEND

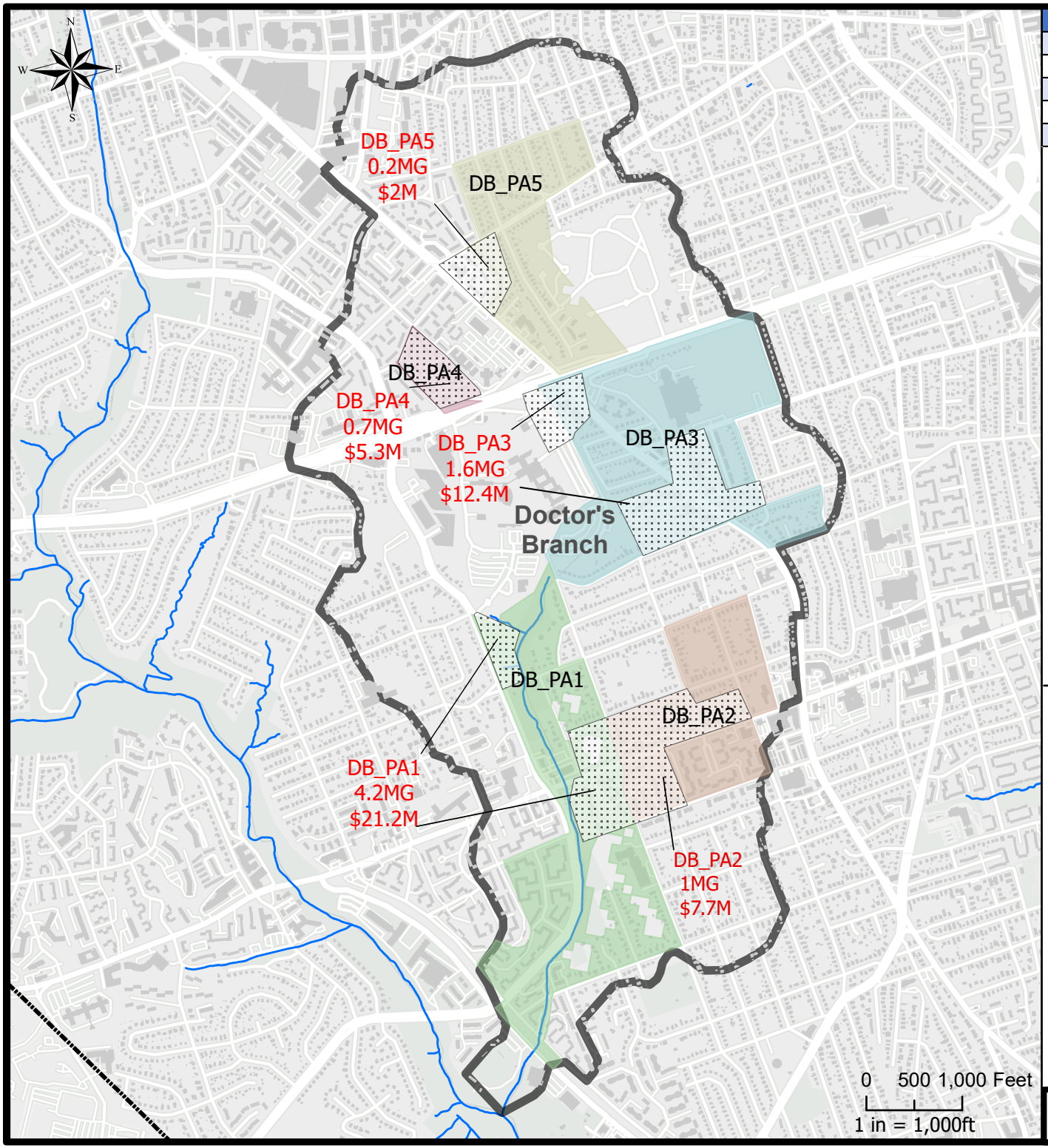
Conveyance Solution Order:
- Project ID
- Pipe Length
- Pipe Size
- Cost: $M

Data:
- Problem Areas
- Conveyance Pipes

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

**Conveyance Concepts: Doctors Branch**




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| DB_PA1 | 4.2 | Mixed | 21.2 |
| DB_PA2 | 1 | Mixed | 7.7 |
| DB_PA3 | 1.6 | Mixed | 12.4 |
| DB_PA4 | 0.7 | Mixed | 5.3 |
| DB_PA5 | 0.2 | Mixed | 2 |

## LEGEND

Storage Solution:

Project Area ID
Storage Volume: MG
Capital Cost: $M

Data:

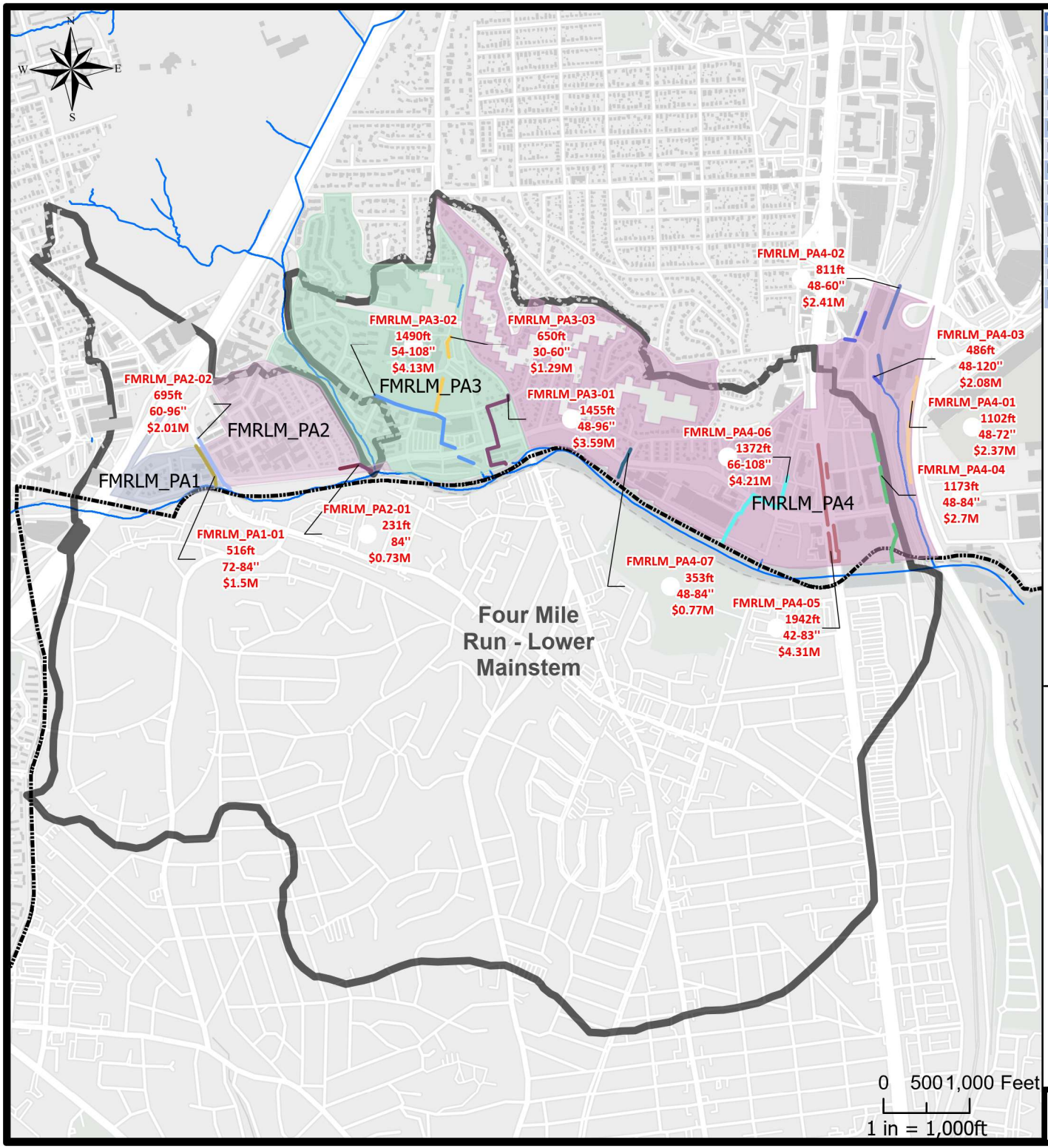
- Problem Areas
- General Area for Storage Projects

Basemap:

- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON
VIRGINIA

# Storage Concepts: Doctor's Branch




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| FMRLM_PA1-01 | 516ft | 72-84" | $1.50 |
| FMRLM_PA2-01 | 231ft | 84" | $0.73 |
| FMRLM_PA2-02 | 695ft | 60-96" | $2.01 |
| FMRLM_PA3-01 | 1455ft | 48-96" | $3.59 |
| FMRLM_PA3-02 | 1490ft | 54-108" | $4.13 |
| FMRLM_PA3-03 | 650ft | 30-60" | $1.29 |
| FMRLM_PA4-01 | 1102ft | 48-72" | $2.37 |
| FMRLM_PA4-02 | 811ft | 48-60" | $2.41 |
| FMRLM_PA4-03 | 486ft | 48-120" | $2.08 |
| FMRLM_PA4-04 | 1173ft | 48-84" | $2.70 |
| FMRLM_PA4-05 | 1942ft | 42-83" | $4.31 |
| FMRLM_PA4-06 | 1372ft | 66-108" | $4.21 |
| FMRLM_PA4-07 | 353ft | 48-84" | $0.77 |

## LEGEND

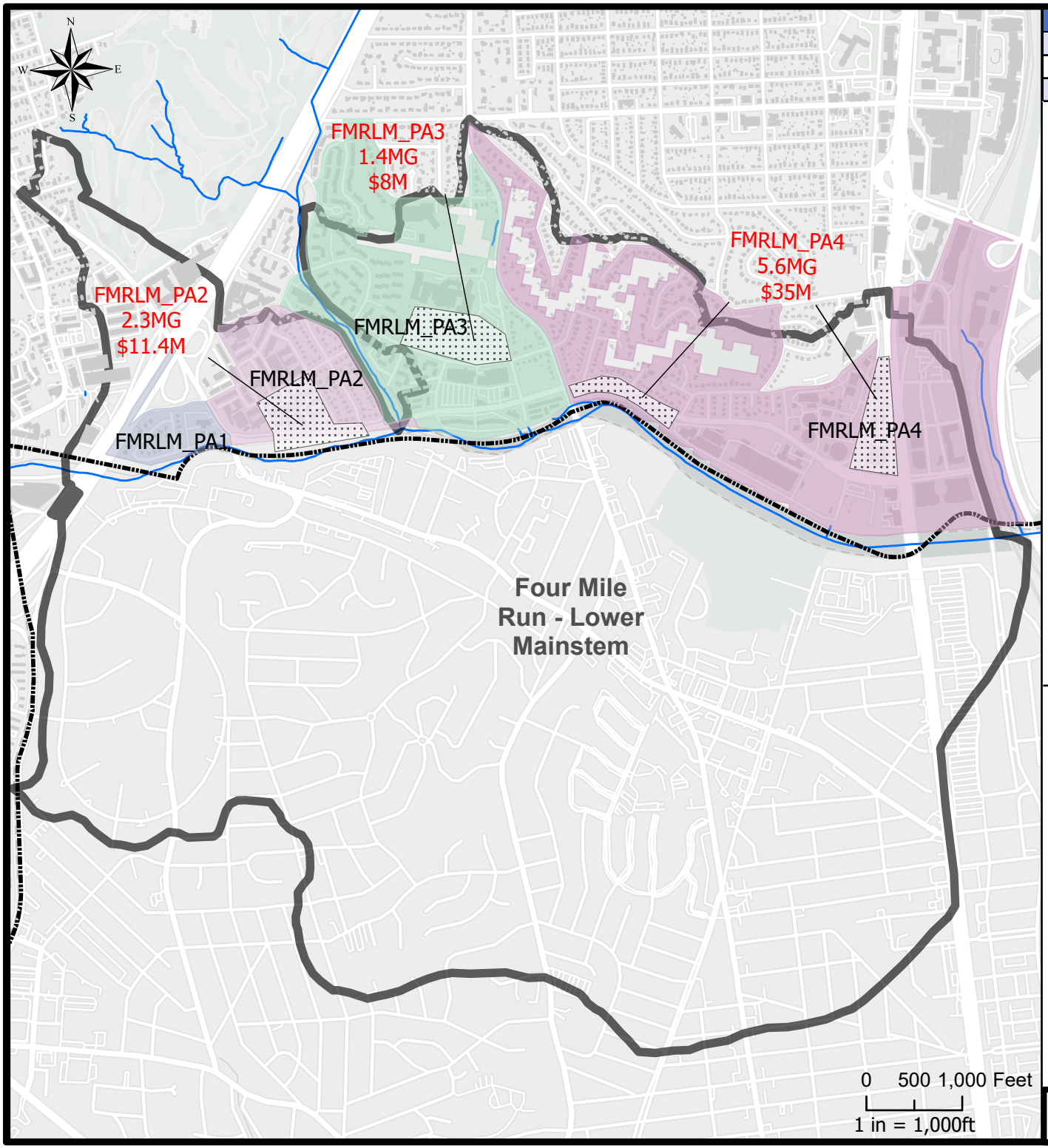
Conveyance Solution Order:
- Project ID
- Pipe Length
- Pipe Size
- Cost: $M

Data:
- Problem Areas
- Conveyance Pipes

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

**Conveyance Concepts:**
**Four Mile Run, Lower Mainstem**




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| FMRLM_PA2 | 2.3 | Mixed | 11.4 |
| FMRLM_PA3 | 1.4 | Mixed | 8 |
| FMRLM_PA4 | 5.6 | Mixed | 35 |

## LEGEND

Storage Solution:

Project Area ID
Storage Volume: MG
Capital Cost: $M

Data:

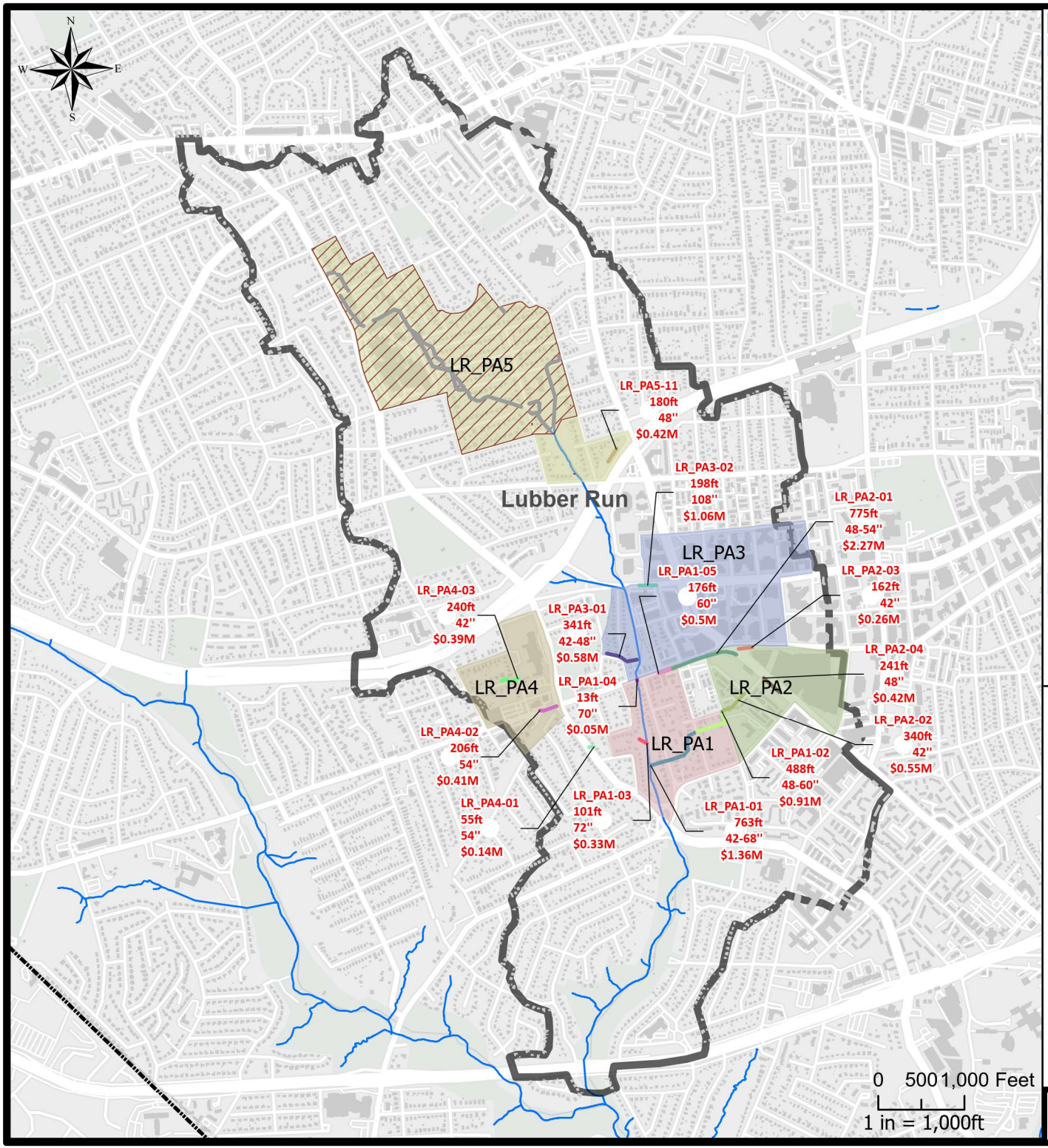
- Problem Areas
- General Area for Storage Projects

Basemap:

- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON
VIRGINIA

**Storage Concepts: Four Mile Run Lower Mainstem**




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| LR_PA1-01 | 763ft | 42-68" | $1.36 |
| LR_PA1-02 | 488ft | 48-60" | $0.91 |
| LR_PA1-03 | 101ft | 72" | $0.33 |
| LR_PA1-04 | 13ft | 70" | $0.05 |
| LR_PA1-05 | 176ft | 60" | $0.50 |
| LR_PA2-01 | 775ft | 48-54" | $2.27 |
| LR_PA2-02 | 340ft | 42" | $0.55 |
| LR_PA2-03 | 162ft | 42" | $0.26 |
| LR_PA2-04 | 241ft | 48" | $0.42 |
| LR_PA3-01 | 341ft | 42-48" | $0.58 |
| LR_PA3-02 | 198ft | 108" | $1.06 |
| LR_PA4-01 | 55ft | 54" | $0.14 |
| LR_PA4-02 | 206ft | 54" | $0.41 |
| LR_PA4-03 | 240ft | 42" | $0.41 |
| LR_PA5-01 | 349ft | 84" | $1.10 |
| LR_PA5-02 | 242ft | 60" | $0.51 |
| LR_PA5-03 | 747ft | 106-121" | $3.14 |
| LR_PA5-04 | 1001ft | 66-78" | $2.64 |
| LR_PA5-05 | 959ft | 54-66" | $2 |
| LR_PA5-06 | 590ft | 66-72" | $1.91 |
| LR_PA5-07 | 456ft | 72" | $2.13 |
| LR_PA5-08 | 289ft | 48-66" | $0.52 |
| LR_PA5-09 | 702ft | 66" | $1.48 |
| LR_PA5-10 | 203ft | 42" | $0.33 |
| LR_PA5-11 | 180ft | 48" | $0.42 |
| LR_PA5-12 | 65ft | 48-54" | $0.12 |

## LEGEND

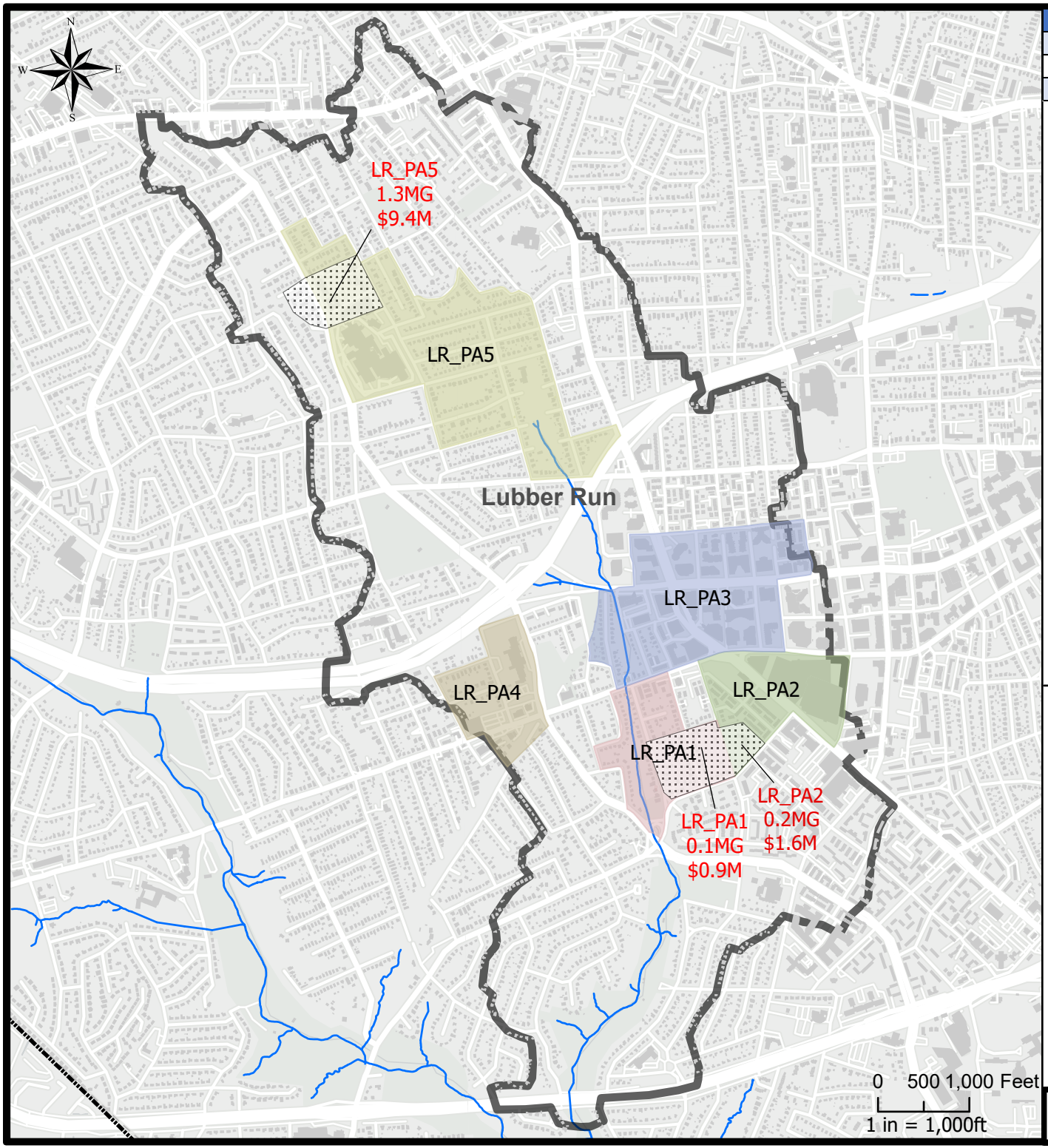
Conveyance Solution Order:
Project ID
Pipe Length
Pipe Size
Cost: $M

Data:
- Problem Areas
- Conveyance Pipes
- Challenging Conveyance Expansion
- Challenging Conveyance Project

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

# Conveyance Concepts: Lubber Run




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| LR_PA1 | 0.1 | Mixed | 0.9 |
| LR_PA2 | 0.2 | Mixed | 1.6 |
| LR_PA5 | 1.3 | Mixed | 9.4 |

## LEGEND

Storage Solution:

Project Area ID

Storage Volume: MG

Capital Cost: $M

Data:

Problem Areas

General Area for Storage Projects

Basemap:

Watershed

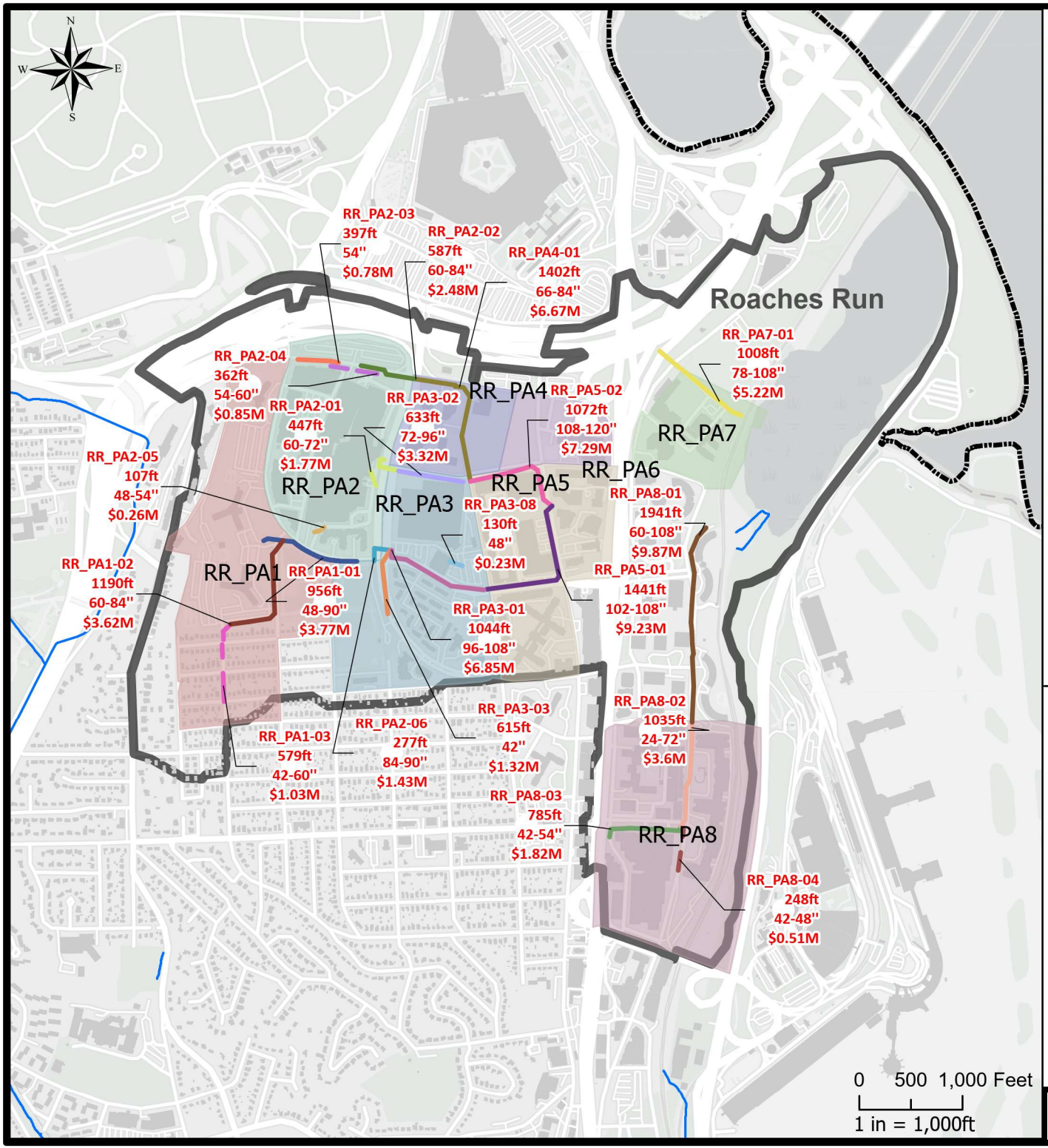
County Boundary

Buildings

Hydrology

ARLINGTON VIRGINIA

# Storage Concepts: Lubber Run




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| RR_PA1-01 | 956ft | 48-90" | $3.77 |
| RR_PA1-02 | 1190ft | 60-84" | $3.62 |
| RR_PA1-03 | 579ft | 42-60" | $1.03 |
| RR_PA2-01 | 447ft | 60-72" | $1.77 |
| RR_PA2-02 | 587ft | 60-84" | $2.48 |
| RR_PA2-03 | 397ft | 54" | $0.78 |
| RR_PA2-04 | 362ft | 54-60" | $0.85 |
| RR_PA2-05 | 107ft | 48-54" | $0.26 |
| RR_PA2-06 | 277ft | 84-90" | $1.43 |
| RR_PA3-01 | 1044ft | 96-108" | $6.85 |
| RR_PA3-02 | 633ft | 72-96" | $3.32 |
| RR_PA3-03 | 615ft | 42" | $1.32 |
| RR_PA3-08 | 130ft | 48" | $0.23 |
| RR_PA4-01 | 1402ft | 66-84" | $6.67 |
| RR_PA5-01 | 1441ft | 102-108" | $9.23 |
| RR_PA5-02 | 1072ft | 108-120" | $7.29 |
| RR_PA7-01 | 1008ft | 78-108" | $5.22 |
| RR_PA8-01 | 1941ft | 60-108" | $9.87 |
| RR_PA8-02 | 1035ft | 24-72" | $3.60 |
| RR_PA8-03 | 785ft | 42-54" | $1.82 |
| RR_PA8-04 | 248ft | 42-48" | $0.51 |

## LEGEND

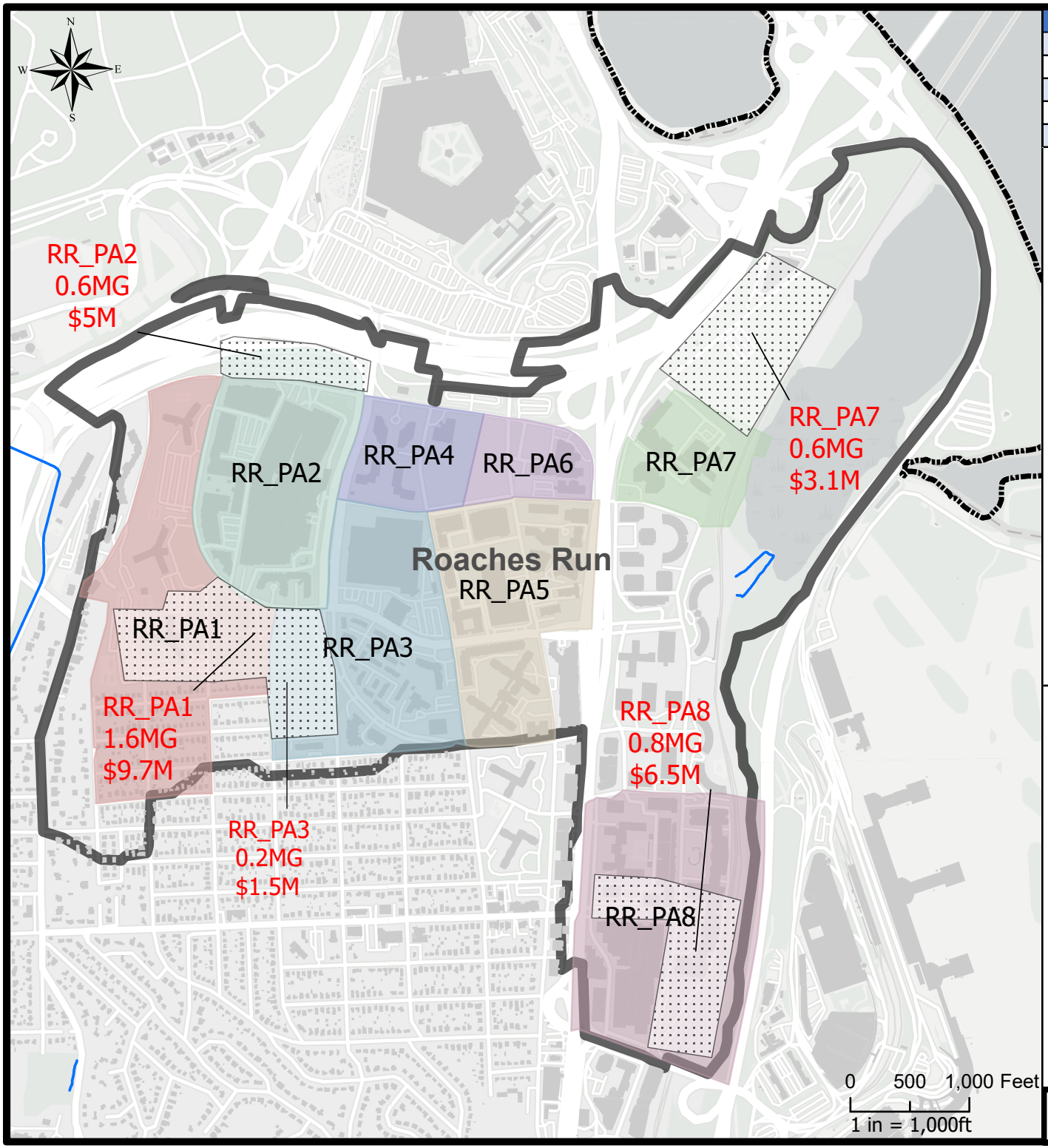
Conveyance Solution Order:
- Project ID
- Pipe Length
- Pipe Size
- Cost: $M

Data:
- Problem Areas
- Conveyance Pipes

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

# Conveyance Concepts: Roaches Run




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| RR_PA1 | 1.6 | Mixed | 9.7 |
| RR_PA2 | 0.6 | Mixed | 5 |
| RR_PA3 | 0.2 | Mixed | 1.5 |
| RR_PA7 | 0.6 | Mixed | 3.1 |
| RR_PA8 | 0.8 | Mixed | 6.5 |

## LEGEND

Storage Solution:

Project Area ID

Storage Volume: MG

Capital Cost: $M

Data:

Problem Areas

General Area for Storage Projects

Basemap:

Watershed

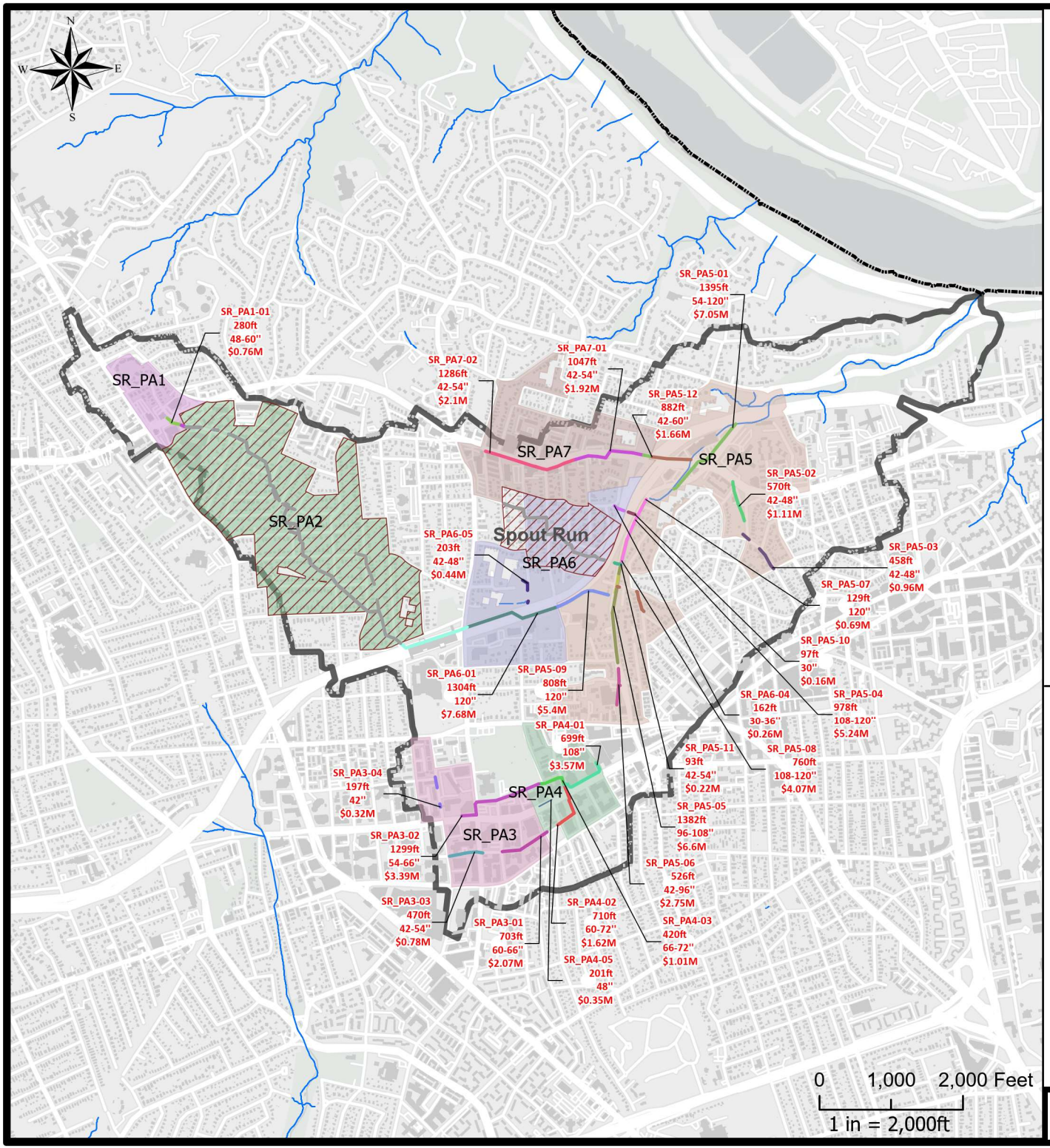
County Boundary

Buildings

Hydrology

ARLINGTON VIRGINIA

# Storage Concepts: Roaches Run




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| SR_PA1-01 | 280ft | 48-60" | $0.76 |
| SR_PA2-01 | 1587ft | 96-108" | $7.84 |
| SR_PA2-02 | 1394ft | 84-113" | $4.73 |
| SR_PA2-03 | 319ft | 48-54" | $0.58 |
| SR_PA2-04 | 238ft | 72" | $0.61 |
| SR_PA2-05 | 219ft | 54" | $0.43 |
| SR_PA2-06 | 516ft | 60-72" | $1.13 |
| SR_PA2-07 | 172ft | 54-72" | $0.36 |
| SR_PA2-08 | 1278ft | 54-84" | $3.04 |
| SR_PA2-09 | 287ft | 48-72" | $0.61 |
| SR_PA2-10 | 696ft | 42-54" | $1.22 |
| SR_PA3-01 | 703ft | 60-66" | $2.07 |
| SR_PA3-02 | 1299ft | 54-66" | $3.39 |
| SR_PA3-03 | 470ft | 42-54" | $0.78 |
| SR_PA3-04 | 197ft | 42" | $0.32 |
| SR_PA4-01 | 699ft | 108" | $3.57 |
| SR_PA4-02 | 710ft | 60-72" | $1.62 |
| SR_PA4-03 | 420ft | 66-72" | $1.01 |
| SR_PA4-05 | 201ft | 48" | $0.35 |
| SR_PA5-01 | 1395ft | 54-120" | $7.05 |
| SR_PA5-02 | 570ft | 42-48" | $1.11 |
| SR_PA5-03 | 458ft | 42-48" | $0.96 |
| SR_PA5-04 | 978ft | 108-120" | $5.24 |
| SR_PA5-05 | 1382ft | 96-108" | $6.60 |
| SR_PA5-06 | 526ft | 42-96" | $2.75 |
| SR_PA5-07 | 129ft | 120" | $0.69 |
| SR_PA5-08 | 760ft | 108-120" | $4.07 |
| SR_PA5-09 | 808ft | 120" | $5.40 |
| SR_PA5-10 | 97ft | 30" | $0.16 |
| SR_PA5-11 | 93ft | 42-54" | $0.22 |
| SR_PA5-12 | 882ft | 42-60" | $1.66 |
| SR_PA6-01 | 1304ft | 120" | $7.68 |
| SR_PA6-02 | 948ft | 42-54" | $1.87 |
| SR_PA6-03 | 738ft | 42" | $1.24 |
| SR_PA6-04 | 162ft | 30-36" | $0.26 |
| SR_PA6-05 | 203ft | 42-48" | $0.44 |
| SR_PA7-01 | 1047ft | 42-54" | $1.92 |
| SR_PA7-02 | 1286ft | 42-54" | $2.10 |
| SR_PA7-03 | 136ft | 42" | $0.22 |

## LEGEND

Conveyance Solution Order:

Project ID

Pipe Length

Pipe Size

Cost: $M

Data:

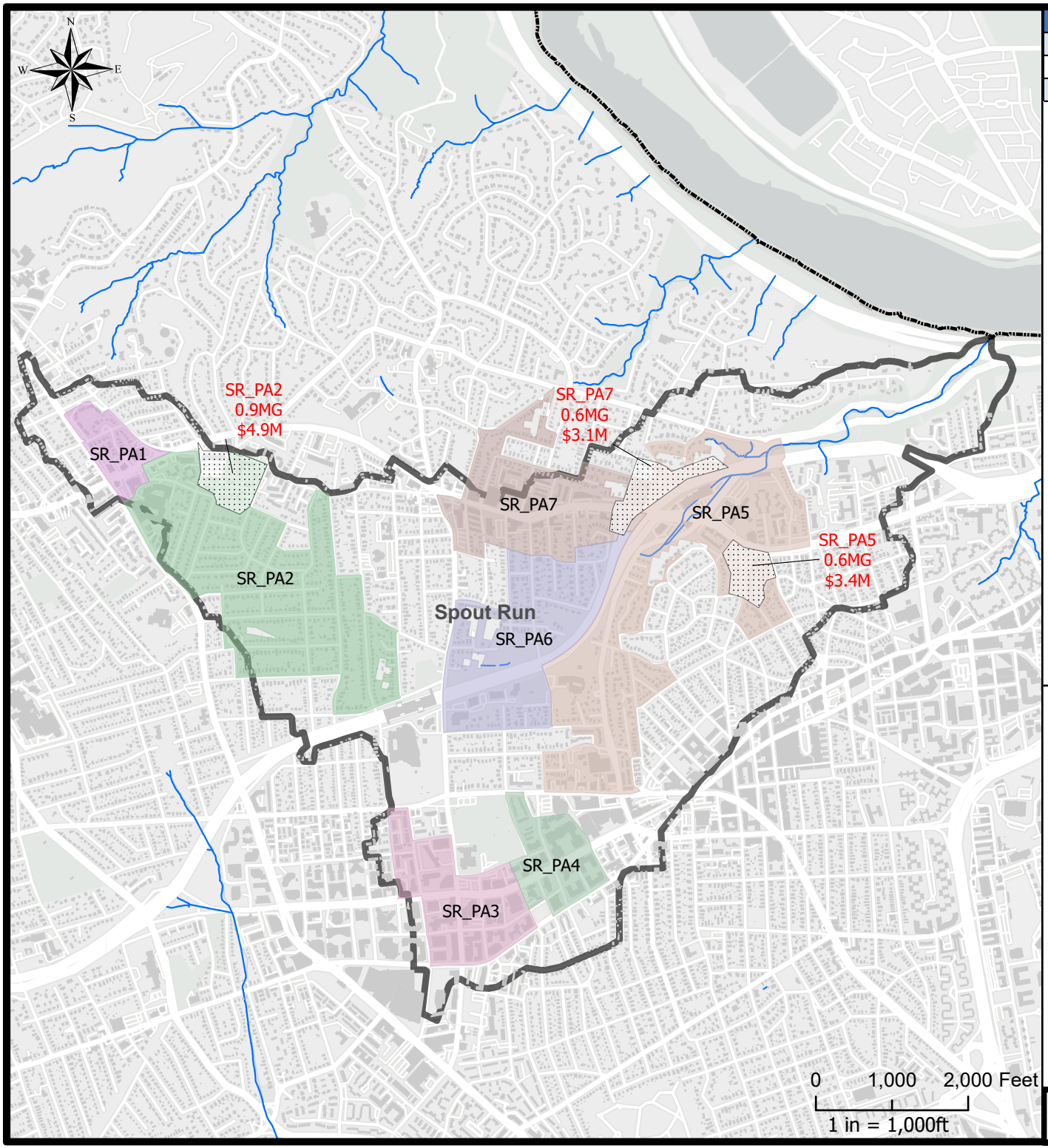
- Problem Areas
- Conveyance Pipes
- Challenging Conveyance Expansion
- Challenging Conveyance Project

Basemap:

- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

# Conveyance Concepts: Spouts Run




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| SR_PA2 | 0.9 | Mixed | 4.9 |
| SR_PA7 | 0.6 | Mixed | 3.1 |
| SR_PA5 | 0.6 | Mixed | 3.4 |

## LEGEND

Storage Solution:

Project Area ID
Storage Volume: MG
Capital Cost: $M

Data:

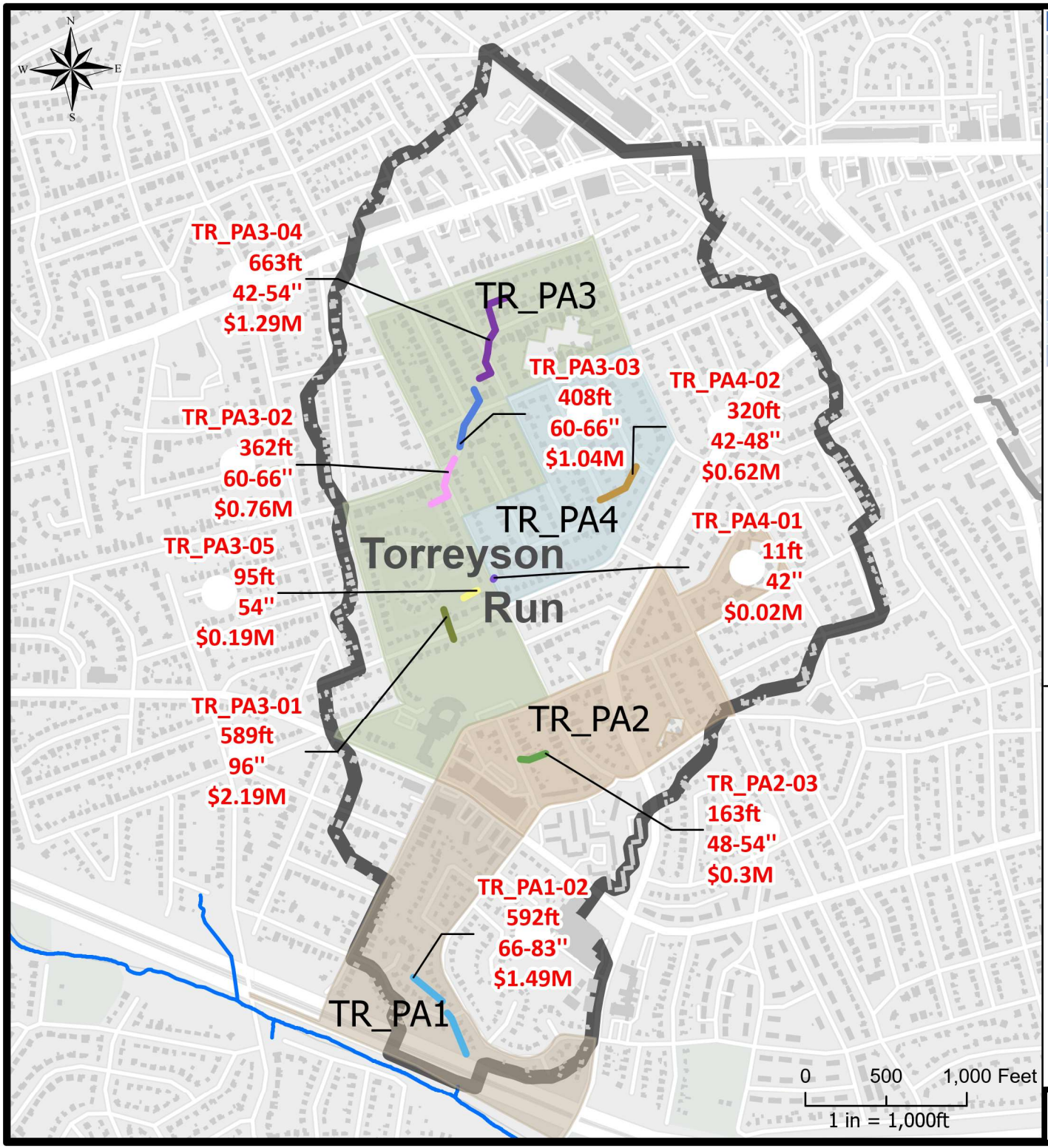
- Problem Areas
- General Area for Storage Projects

Basemap:

- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

# Storage Concepts: Spout Run




| Proj_ID | Total Lengh, ft | Project Size | Capital Cost, $M |
|---|---|---|---|
| TR_PA1-01 | 216ft | 96" | $0.93 |
| TR_PA1-02 | 592ft | 66-83" | $1.49 |
| TR_PA1-03 | 444ft | 60-72" | $1.12 |
| TR_PA1-04 | 272ft | 96" | $1.01 |
| TR_PA1-05 | 105ft | 48-54" | $0.19 |
| TR_PA2-01 | 65ft | 66-84" | $0.17 |
| TR_PA2-02 | 295ft | 96-108" | $1.19 |
| TR_PA2-03 | 163ft | 48-54" | $0.30 |
| TR_PA3-01 | 589ft | 96" | $2.19 |
| TR_PA3-02 | 362ft | 60-66" | $0.76 |
| TR_PA3-03 | 408ft | 60-66" | $1.04 |
| TR_PA3-04 | 663ft | 42-54" | $1.29 |
| TR_PA3-05 | 95ft | 54" | $0.19 |
| TR_PA4-01 | 11ft | 42" | $0.02 |
| TR_PA4-02 | 320ft | 42-48" | $0.62 |

## LEGEND

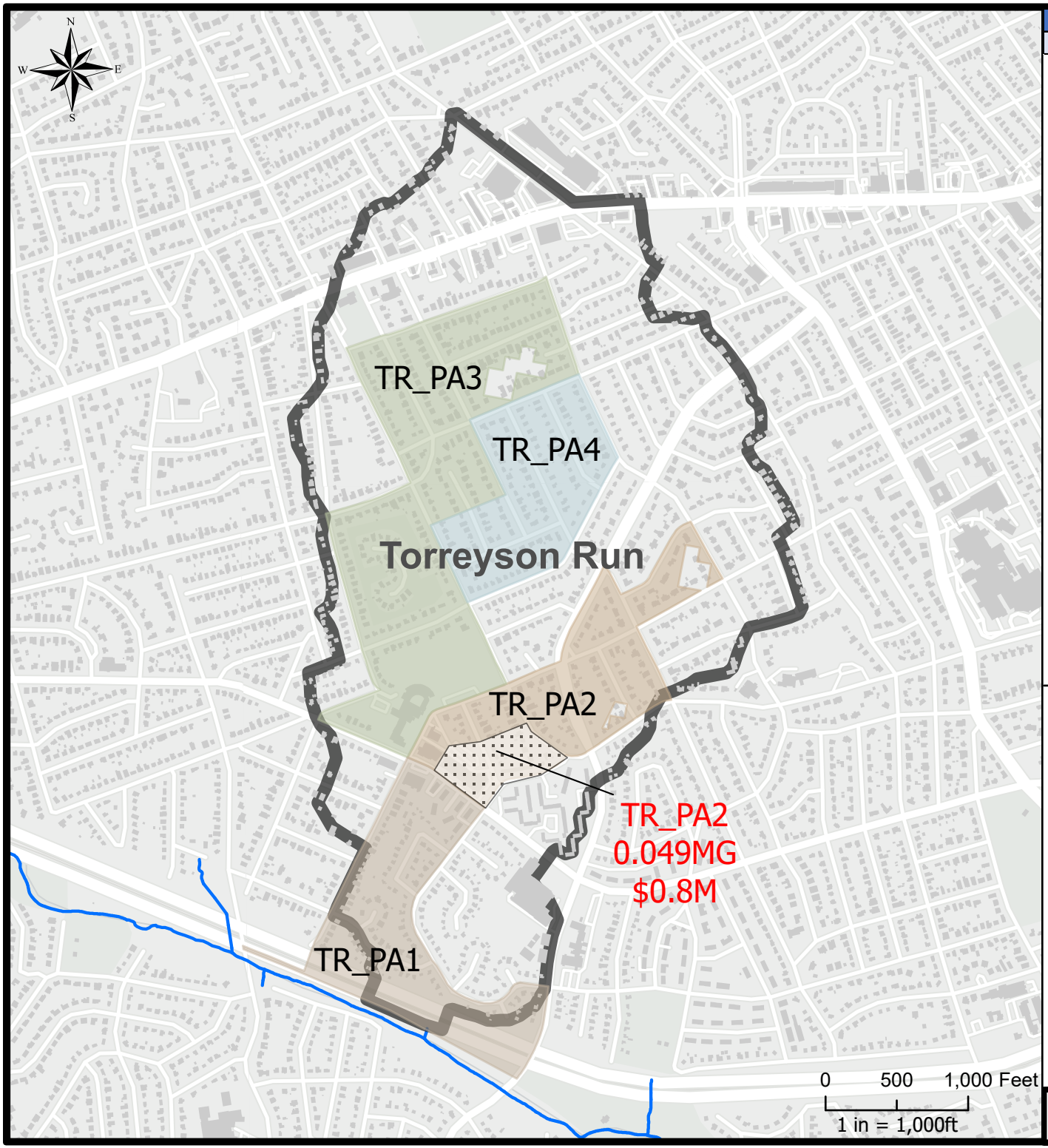
Conveyance Solution Order:
- Project ID
- Pipe Length
- Pipe Size
- Cost: $M

Data:
- Problem Areas
- Conveyance Pipes

Basemap:
- Watershed
- County Boundary
- Buildings
- Hydrology

ARLINGTON VIRGINIA

**Conveyance Concepts: Torreyson Run**




| ProAreaID | Storage Volume, MG | Ownership | Capital Cost, $M |
|---|---|---|---|
| TR_PA2 | 0.05 | Mixed | 0.8 |

## LEGEND

Storage Solution:

Project Area ID

Storage Volume: MG

Capital Cost: $M

Data:

Problem Areas

General Area for Storage Projects

Basemap:

Watershed

County Boundary

Buildings

Hydrology

ARLINGTON VIRGINIA

# Storage Concepts: Torreyson Run

# Appendix D
# Analysis of Land Acquisition Costs on Storage Capital Costs by Problem Area

For the analysis presented in Table D-1, the capital costs for storage options did not consider cost of land acquisition, given that the goal was to avoid using private property to site storage facilities, as much as possible. As summarized in Table F-1, an analysis was conducted of the potential impact of land acquisition costs on total storage capital costs, and compared to the likely range of capital costs for a class 5 cost estimate shown in Table D-1.

The assessed value of privately owned land for potential storage sites was determined for each problem area, scaled up to reflect likely market value, and prorated based on likely surface area needed for storage.

Table D-1 shows that at a watershed level, adding land acquisition costs increased storage capital costs between 0% and 32%, well within the range of accuracy of the class 5 cost estimate. At a Problem Area level, the addition of capital costs for all but one problem area were also within the range of accuracy of class 5 estimate; RR_PA8 in Roaches Run has an increase in capital cost of 126% when land acquisition was included. For all other PAs, the increase with land acquisition ranged from 0% to 63%.

**Table D-1. Analysis of Land Acquisition Costs on Storage Capital Costs by Problem Area**

| Watershed | PA Number | Cost Estimate without Land Costs $M | Range of Costs given Cost Level (-50%) | Range of Costs \|given Cost Level (+100%) | Land Costs for Private Facilities $M | Total Costs Assuming Land Acquisition $M | % Change in Costs with Land Acquisition Included |
|---|---|---|---|---|---|---|---|
| Bailey's Branch | BB_PA1 | $12.6 | $6.3 | $25.3 | $3.95 | $16.6 | 31% |
| | *Subtotal* | *$12.6* | *$ 6.3* | *$25.3* | *$3.95* | *$16.6* | *31%* |
| Doctor's Branch | DB_PA1 | $21.2 | $10.6 | $42.4 | $0.94 | $22.2 | 4% |
| | DB_PA2 | $7.7 | $3.9 | $15.5 | $1.56 | $9.3 | 20% |
| | DB_PA3 | $12.4 | $6.2 | $24.8 | $2.82 | $15.2 | 23% |
| | DB_PA4 | $5.3 | $2.7 | $10.7 | $ - | $5.3 | 0% |
| | DB_PA5 | $2.0 | $1.0 | $4.1 | $0.34 | $2.4 | 17% |
| | *Subtotal* | *$48.7* | *$24.4* | *$97.5* | *$5.66* | *$54.4* | *12%* |
| FMR Lower Mainstem | FMRLM_PA2 | $11.4 | $5.7 | $22.7 | $ - | $11.4 | 0% |
| | FMRLM_PA3 | $8.0 | $4.0 | $16.0 | $ - | $8.0 | 0% |
| | FMRLM_PA4 | $35.0 | $17.5 | $70.1 | $8.26 | $43.3 | 24% |
| | *Subtotal* | *$54.4* | *$27.2* | *$108.8* | *$8.26* | *$62.6* | *15%* |
| Lubber Run | LR_PA1 | $0.9 | $0.5 | $1.8 | $0.00 | $0.9 | 0% |
| | LR_PA2 | $1.6 | $0.8 | $3.2 | $1.03 | $2.6 | 63% |
| | LR_PA5 | $9.4 | $4.7 | $18.8 | $0.00 | $9.4 | 0% |
| | *Subtotal* | *$11.9* | *$ 6.0* | *$23.9* | *$1.03* | *$13.0* | *9%* |
| Roaches Run | RR_PA1 | $9.7 | $4.8 | $19.4 | $ - | $9.7 | 0% |
| | RR_PA2 | $5.0 | $2.5 | $10.0 | $0.16 | $5.2 | 3% |
| | RR_PA3 | $1.5 | $0.7 | $2.9 | $ - | $1.5 | 0% |
| | RR_PA7 | $3.1 | $1.6 | $6.2 | $ - | $3.1 | 0% |
| | RR_PA8 | $6.5 | $3.2 | $13.0 | $8.20 | $14.7 | 126% |
| | *Subtotal* | *$25.8* | *$12.9* | *$51.5* | *$8.35* | *$34.1* | *32%* |
| Spout Run | SR_PA2 | $4.9 | $2.5 | $9.8 | $ - | $4.9 | 0% |
| | SR_PA5 | $3.4 | $1.7 | $6.9 | $ - | $3.4 | 0% |
| | SR_PA7 | $3.1 | $1.6 | $6.3 | $ - | $3.1 | 0% |
| | *Subtotal* | *$11.5* | *$ 5.7* | *$23.0* | *$-* | *$11.5* | *0%* |

| Watershed | PA Number | Cost Estimate without Land Costs $M | Range of Costs given Cost Level (-50%) | Range of Costs \|given Cost Level (+100%) | Land Costs for Private Facilities $M | Total Costs Assuming Land Acquisition $M | % Change in Costs with Land Acquisition Included |
|---|---|---|---|---|---|---|---|
| Torreyson Run | TR_PA2 | $2.1 | $1.1 | $4.3 | $0.24 | $2.4 | 11% |
| | TR_PA3 | $2.3 | $1.1 | $4.6 | $0.01 | $2.3 | 0% |
| | *Subtotal* | *$ 4.4* | *$ 2.2* | *$ 8.8* | *$0.25* | *$4.7* | *6%* |
| Grand Total | | $ 169.3 | $84.7 | $ 338.6 | $ 27.50 | $196.8 | 16% |

# Appendix E
# Conveyance and Storage Solution Cost Estimate and Benefits Details per Problem Area

**Table E-1. Conveyance Solution Hazus Losses Comparison plus Capital Costs and Benefit-Cost Ratio Results per Problem Area**

| Problem Area | Sum of Total Annualized Risk, Existing Condition (in $K) | Sum of Total Annualized Risk with Conveyance Solutions (in $K) | Sum of Benefits (Annualized Losses Avoided) (in $K) | Total Capital Costs of Conveyance Solutions (in $K)[a] | Net Present Value of Total Annual Benefits (in $K) | Net Present Value of Total Capital and Annual O&M Costs (in $K) | Benefit- Cost Ratio |
|---|---|---|---|---|---|---|---|
| BB_PA1 | 1,022 | 100 | 922 | 8,523 | 10,210 | 8,200 | 1.36 |
| DB_PA1 | 2,467 | 1,049 | 1,418 | 14,562 | 21,579 | 17,405 | 1.23 |
| DB_PA2 | 963 | 178 | 784 | 4,808 | 8,509 | 5,524 | 2.05 |
| DB_PA3 | 1,617 | 526 | 1,091 | 12,085 | 14,488 | 7,074 | 1.14 |
| DB_PA4 | 264 | 34 | 229 | 4,891 | 2,875 | 2,758 | 0.59 |
| DB_PA5 | 1,053 | 182 | 870 | 8,885 | 1,476 | 1,036 | 1.23 |
| FMRLM_PA1 | 176 | 157 | 19 | 1,501 | 227 | 0 | 0.16 |
| FMRLM_PA2 | 1,249 | 1,176 | 73 | 2,740 | 1,122 | 8,317 | 0.34 |
| FMRLM_PA3 | 8,834 | 5,772 | 3,062 | 9,009 | 18,862 | 10,969 | 4.28 |
| FMRLM_PA4 | 4,430 | 3,687 | 743 | 18,856 | 8,467 | 30,366 | 0.50 |
| LR_PA1 | 516 | 158 | 357 | 3,149 | 3,256 | 605 | 1.43 |
| LR_PA2 | 5,301 | 1,064 | 4,237 | 3,502 | 6,525 | 2,146 | 15.24 |
| LR_PA3 | 26,424 | 9,277 | 17,147 | 1,638 | 47,987 | 0 | 131.83 |
| LR_PA4 | 182 | 58 | 124 | 932 | 806 | 0 | 1.68 LR_PA5[b] |
| RR_PA1 | 2,393 | 523 | 1,870 | 8,415 | 22,050 | 7,270 | 2.80 |
| RR_PA2 | 35,967 | 13,026 | 22,941 | 7,574 | 172,084 | 3,368 | 38.15 |
| RR_PA3 | 1,462 | 210 | 1,251 | 11,718 | 14,421 | 1,274 | 1.35 |
| RR_PA4 | 264 | 15 | 250 | 6,672 | 2,744 | 0 | 0.47 |
| RR_PA5 | 1,781 | 271 | 1,510 | 16,526 | 14,217 | 0 | 1.15 |
| RR_PA6 | 308 | 33 | 276 | 0 | 3,109 | 0 | N/A |
| RR_PA7 | 5,106 | 222 | 4,885 | 5,220 | 55,836 | 2,2 | 11.79 |
| RR_PA8 | 65,564 | 10,140 | 55,425 | 15,786 | 630,509 | 7,851 | 44.22 |
| SR_PA1 | 187 | 31 | 156 | 760 | 649 | 0 | 2.58 SR_PA2[c] |
| SR_PA3 | 12,519 | 4,715 | 7,804 | 6,558 | 48,093 | 0 | 14.99 |
| SR_PA4 | 14,873 | 7,331 | 7,542 | 6,549 | 87,351 | 0 | 14.50 |
| SR_PA5 | 9,102 | 1,990 | 7,112 | 35,932 | 35,604 | 2,188 | 2.49 |
| SR_PA68 | | | | | | | |
| SR_PA7 | 3,144 | 408 | 2,736 | 4,238 | 18,978 | 1,023 | 8.13 |
| TR_PA1 | 498 | 396 | 102 | 1,101 | 1,739 | 0 | 1.17 |
| TR_PA2 | 1,201 | 694 | 506 | 297 | 2,846 | 575 | 21.47 |
| TR_PA3 | 777 | 199 | 578 | 3,966 | 1,359 | 9,028 | 1.84 |
| TR_PA4 | 152 | 36 | 116 | 631 | 433 | 0 | 2.31 |

[a] Problem Areas with Total Capital Costs of 0 dollars means that no storage solution was feasible within these areas.

[b] On guidance from Arlington County, these problem areas were identified as being infeasible for conveyance solution mitigation.

[c] On guidance from Arlington County, these Problem Areas were identified as being infeasible for conveyance solution mitigation.

**Table E-2. Storage Solution Hazus Losses Comparison plus Capital Costs and Benefit-Cost Results per Problem Area**

| | Sum of Total Annualized Risk, Existing Condition (in $K) | Sum of Total Annualized Risk with Storage Solution (in $K) | Sum of Benefits (Annualized Losses Avoided) (in $K) | Total Capital Costs of Storage Solutions (in $K)[a] | Net Present Value of Total Annual Benefits (in $K) | Net Present Value of Total Capital and Annual O&M Costs (in $K) | Benefit- Cost Ratio |
|---|---|---|---|---|---|---|---|
| | 1,022 | 111 | 911 | 12,557 | 10,210 | 11,174 | 0.91 |
| | 2,467 | 542 | 1,925 | 21,091 | 21,579 | 18,769 | 1.15 |
| | 963 | 203 | 759 | 7,694 | 8,509 | 6,847 | 1.24 |
| DB_PA3 | 1,617 | 325 | 1,293 | *12,330* | 14,488 | 10,972 | 1.32 |
| DB_PA4 | 264 | 7 | 256 | 5,310 | 2,875 | 4,725 | 0.61 |
| DB_PA5 | 1,053 | 921 | 132 | 2,025 | 1,476 | 1,802 | 0.82 |
| FMRLM_PA1 | 176 | 156 | 20 | 0 | 227 | 0 | N/A |
| FMRLM_PA2 | 1,249 | 1,149 | 100 | 11,285 | 1,122 | 10,042 | 0.11 |
| FMRLM_PA3 | 8,834 | 7,151 | 1,683 | 7,948 | 18,862 | 7,073 | 2.67 |
| FMRLM_PA4 | 4,430 | 3,674 | 755 | 34,824 | 8,467 | 30,989 | 0.27 |
| LR_PA1 | 516 | 225 | 291 | 918 | 3,256 | 816 | 3.99 |
| LR_PA2 | 5,301 | 4,718 | 582 | 1,609 | 6,525 | 1,432 | 4.56 |
| LR_PA3 | 26,424 | 22,142 | 4,281 | 0 | 47,987 | 0 | N/A |
| LR_PA4 | 182 | 110 | 72 | 0 | 806 | 0 | N/A LR_PA5[b] |
| RR_PA1 | 2,393 | 425 | 1,967 | 9,641 | 22,050 | 8,579 | 2.57 |
| RR_PA2 | 35,967 | 20,613 | 15,353 | 4,978 | 172,084 | 4,430 | 38.85 |
| RR_PA3 | 1,462 | 175 | 1,287 | 1,441 | 14,421 | 1,282 | 11.25 |
| RR_PA4 | 264 | 19 | 245 | 0 | 2,744 | 0 | N/A |
| RR_PA5 | 1,781 | 512 | 1,268 | 0 | 14,217 | 0 | N/A |
| RR_PA6 | 308 | 31 | 277 | 0 | 3,109 | 0 | N/A |
| RR_PA7 | 5,106 | 124 | 4,982 | 3,098 | 55,836 | 2,756 | 20.26 |
| RR_PA8 | 65,564 | 9,310 | 56,254 | 6,447 | 630,509 | 5,737 | 109.89 |
| SR_PA1 | 187 | 129 | 58 | 0 | 649 | 0 | N/A SR_PA2[c] |
| SR_PA3 | 12,519 | 8,228 | 4,291 | 0 | 48,093 | 0 | N/A |
| SR_PA4 | 14,873 | 7,079 | 7,794 | 0 | 87,351 | 0 | N/A |
| SR_PA5 | 9,102 | 5,926 | 3,177 | 3,410 | 35,604 | 3,034 | 11.73 |
| SR_PA6 | 1,167 | 460 | 707 | 0 | 7,924 | 0 | N/A |
| SR_PA7 | 3,144 | 1,450 | 1,693 | 3,117 | 18,978 | 2,774 | 6.84 |
| TR_PA1 | 498 | 343 | 155 | 0 | 1,739 | 0 | N/A |
| TR_PA2 | 1,201 | 947 | 254 | 339 | 2,846 | 302 | 9.42 |
| TR_PA3 | 777 | 656 | 121 | 0 | 1,359 | 0 | N/A |
| TR_PA4 | 152 | 113 | 39 | 0 | 433 | 0 | N/A |

[a] Problem Areas with Total Capital Costs of 0 dollars means that no storage solution was feasible within these areas.

[b] On guidance from Arlington County, these problem areas were identified as being infeasible for conveyance solution mitigation.

[c] On guidance from Arlington County, these Problem Areas were identified as being infeasible for conveyance solution mitigation.

# Appendix F
# Inundated SVI Area Pre versus Post Mitigation Solutions per Problem Area

**Table F-1. Mid to High SVI Flooded Area Results per Problem Area with Mitigation Solutions (in acres)**

| | | Existing Conditions | | | Post Storage Mitigation | | | Post Conveyance Mitigation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Problem Area ID | Total Mid High SVI Area (ac.) | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 |
| FMRLM_PA1 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA2 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA3 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA4 | - | - | - | - | - | - | - | - | - | - |
| TR_PA1 | 0.3 | 0.01 | 0.1 | 0.2 | 0.01 | 0.1 | 0.2 | 0.01 | 0.1 | 0.2 |
| TR_PA2 | - | - | - | - | - | - | - | - | - | - |
| TR_PA3 | - | - | - | - | - | - | - | - | - | - |
| TR_PA4 | - | - | - | - | - | - | - | - | - | - |
| RR_PA1 | - | - | - | - | - | - | - | - | - | - |
| RR_PA2 | - | - | - | - | - | - | - | - | - | - |
| RR_PA3 | - | - | - | - | - | - | - | - | - | - |
| RR_PA4 | - | - | - | - | - | - | - | - | - | - |
| RR_PA5 | - | - | - | - | - | - | - | - | - | - |
| RR_PA6 | - | - | - | - | - | - | - | - | - | - |
| RR_PA7 | - | - | - | - | - | - | - | - | - | - |
| RR_PA8 | - | - | - | - | - | - | - | - | - | - |
| SR_PA1 | - | - | - | - | - | - | - | - | - | - |
| SR_PA2 | - | - | - | - | - | - | - | - | - | - |
| SR_PA3 | - | - | - | - | - | - | - | - | - | - |
| SR_PA4 | - | - | - | - | - | - | - | - | - | - |
| SR_PA5 | - | - | - | - | - | - | - | - | - | - |
| SR_PA6 | - | - | - | - | - | - | - | - | - | - |
| SR_PA7 | - | - | - | - | - | - | - | - | - | - |
| DB_PA1 | 36.0 | 4.9 | 10.0 | 12.7 | 2.5 | 6.8 | 9.6 | 3.9 | 7.9 | 11.4 |
| DB_PA2 | 55.3 | 2.2 | 5.4 | 6.0 | 0.6 | 1.9 | 4.0 | - | 3.1 | 4.4 |
| DB_PA3 | 0.1 | 0.004 | 0.01 | 0.01 | - | - | 0.01 | - | - | 0.01 |
| DB_PA4 | - | - | - | - | - | - | - | - | - | - |
| DB_PA5 | - | - | - | - | - | - | - | - | - | - |
| LR_PA1 | - | - | - | - | - | - | - | - | - | - |
| LR_PA2 | 0.9 | - | 0.003 | 0.02 | - | 0.003 | 0.01 | - | - | 0.003 |
| LR_PA3 | - | - | - | - | - | - | - | - | - | - |
| LR_PA4 | - | - | - | - | - | - | - | - | - | - |
| LR_PA5 | - | - | - | - | - | - | - | - | - | - |
| BB_PA1 | 46.4 | 2.1 | 5.2 | 6.0 | - | 1.3 | 4.3 | - | - | 5.1 |

Note:

Mid High SVI value refers to SVI values ranging from 0.5 to 0.75

High SVI value refers to SVI values greater than 0.75

**Table F-1. High SVI Flooded Area Results per Problem Area with Mitigation Solutions (in acres)**

| | | Existing Conditions | | | Post Storage Mitigation | | | Post Conveyance Mitigation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Problem Area ID | Total High SVI Area (ac.) | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 | 10 yr 2020 | 100 yr 2020 | 500 yr 2020 |
| FMRLM_PA1 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA2 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA3 | - | - | - | - | - | - | - | - | - | - |
| FMRLM_PA4 | - | - | - | - | - | - | - | - | - | - |
| TR_PA1 | - | - | - | - | - | - | - | - | - | - |
| TR_PA2 | - | - | - | - | - | - | - | - | - | - |
| TR_PA3 | - | - | - | - | - | - | - | - | - | - |
| TR_PA4 | - | - | - | - | - | - | - | - | - | - |
| RR_PA1 | - | - | - | - | - | - | - | - | - | - |
| RR_PA2 | - | - | - | - | - | - | - | - | - | - |
| RR_PA3 | - | - | - | - | - | - | - | - | - | - |
| RR_PA4 | - | - | - | - | - | - | - | - | - | - |
| RR_PA5 | - | - | - | - | - | - | - | - | - | - |
| RR_PA6 | - | - | - | - | - | - | - | - | - | - |
| RR_PA7 | - | - | - | - | - | - | - | - | - | - |
| RR_PA8 | - | - | - | - | - | - | - | - | - | - |
| SR_PA1 | - | - | - | - | - | - | - | - | - | - |
| SR_PA2 | - | - | - | - | - | - | - | - | - | - |
| SR_PA3 | - | - | - | - | - | - | - | - | - | - |
| SR_PA4 | - | - | - | - | - | - | - | - | - | - |
| SR_PA5 | - | - | - | - | - | - | - | - | - | - |
| SR_PA6 | - | - | - | - | - | - | - | - | - | - |
| SR_PA7 | - | - | - | - | - | - | - | - | - | - |
| DB_PA1 | 56.3 | 7.5 | 12.6 | 15.3 | 0.2 | 0.2 | 9.7 | 3.1 | 8.0 | 11.1 |
| DB_PA2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.01 | 0.01 | 0.1 | | 0.1 | 0.1 |
| DB_PA3 | - | - | - | - | - | - | - | - | - | - |
| DB_PA4 | 8.6 | 1.2 | 1.6 | 1.7 | - | - | 0.9 | - | 1.0 | 1.2 |
| DB_PA5 | 19.9 | 3.1 | 4.3 | 4.6 | 2.6 | 2.6 | 4.0 | - | 3.2 | 3.8 |
| LR_PA1 | - | - | - | - | - | - | - | - | - | - |
| LR_PA2 | - | - | - | - | - | - | - | - | - | - |
| LR_PA3 | - | - | - | - | - | - | - | - | - | - |
| LR_PA4 | - | - | - | - | - | - | - | - | - | - |
| LR_PA5 | - | - | - | - | - | - | - | - | - | - |
| BB_PA1 | 39.5 | 0.6 | 0.8 | 0.9 | - | - | 0.9 | - | 0.7 | 0.9 |

Note:

Mid High SVI value refers to SVI values ranging from 0.5 to 0.75

High SVI value refers to SVI values greater than 0.7

# Appendix G
# Cost Estimate Details and Benefits for Public Facilities

**Appendix G: Cost Estimate Details and Benefits for Public Facilities**

| Facility - Site | Facility - Building | Sum of Total Asset Replacement Cost ($) | Sum of Cumulative Monetized Risk without Strategy (2022 - 2042) ($) | Sum of Alternative 1 - Cumulative Risk Remaining With Strategy ($) | Sum of Alternative 2 - Cumulative Risk Remaining With Strategy ($) | Alternative 1 - Benefit (Risk Avoided in $) | Alternative 2 - Benefit (Risk Avoided in $) | Alternative 1 - Mitigation Cost Before Indirect Costs ($) | Alternative 2 - Mitigation Cost Before Indirect Costs ($) | Alternative 1 - Mitigation Cost ($) | Alternative 2 - Mitigation Cost ($) | Alternative 1 - Benefit Cost Ratio | Alternative 2 - Benefit Cost Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ART | ART - BUS PARKING LOT | 39,825,000 | 205 | 205 | 205 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ART | ART - O&M CENTER | 385,304 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ART | ART - PARKING STRUCTURE | 29,178 | 1 | 1 | 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Cardinal | CARDINAL ELEMENTARY SCHOOL | 2,427,454 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Cardinal | CARDINAL ELEMENTARY SCHOOL - EG | 278,193 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Cardinal | CARDINAL ELEMENTARY SCHOOL - PARKING | 450,000 | 255 | 255 | 255 | N/A | N/A | 388,822 | 388,822 | 769,023 | 769,023 | N/A | N/A |
| Cherrydale | CHERRYDALE - GENERATOR ROOM | 344,983 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Cherrydale | CHERRYDALE HEALTH & REHAB CENTER | 2,997,647 | 1,276 | 13 | 13 | 1,264 | 1,264 | 3,701 | 10,364 | 7,320 | 20,498 | 0.17 | 0.06 |
| Gunston | GUNSTON - DETACHED MECHANICAL ROOM | 1,417,591 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Gunston | GUNSTON - SCHOOL & EG | 2,001,866 | 59,924 | 2,362 | 1,541 | 57,562 | 58,383 | 127,474 | 11,104 | 252,122 | 21,962 | 0.23 | 2.66 |
| Little Falls | LITTLE FALLS BOOSTER STATION | 3,532,463 | 99,976 | 47,536 | 47,536 | 52,440 | 52,440 | 3,701 | 10,364 | 7,320 | 20,498 | 7.16 | 2.56 |
| TJ Middle School | TJ MIDDLE SCHOOL - SITE EG | 950,435 | 1 | 1 | 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| TJ Middle School | TJ MIDDLE SCHOOL AND COMMUNITY CENTER | 7,773,764 | 1,798,041 | 34,135 | 28,423 | 1,763,906 | 1,769,618 | 46,160 | 24,931 | 91,297 | 49,309 | 19.32 | 35.89 |
| Trade Center - NOCII | TRADESCENTER-NOCII | 1,684,065 | 1 | 1 | 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Trade Center - NOCII | TRADESCENTER-NOCII-SITEEG | 871,242 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Trade Center - NOCII | TRADESCENTER-NOCII-SITETRANSFORMER | 344,559 | 0 | 0 | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| VA Hospital | VA HOSPITAL CENTER - FOOT AND ANKLE BLDG | 2,149,189 | 4,884,319 | 47,351 | 47,351 | 4,836,968 | 4,836,968 | 14,806 | 41,456 | 29,284 | 81,994 | 165.18 | 58.99 |
| VA Hospital | VA HOSPITAL CENTER - MAIN MECHANICAL BLDG | 16,075,270 | 109,960 | 11,490 | 11,490 | 98,471 | 98,471 | 3,701 | 10,364 | 7,321 | 20,498 | 13.45 | 4.80 |
| VA Hospital | VA HOSPITAL CENTER - NEW PARKING STRUCTURE | 1,657,902 | 665,204 | 14,888 | 14,888 | 650,316 | 650,316 | 11,104 | 31,092 | 21,963 | 61,495 | 29.61 | 10.58 |
| WPCP - North | WPCP - 03 - PIBS/PBFDS | 654,378 | 2,762 | 2,762 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - North | WPCP - 04 - DAFT | 4,563,590 | 2,320 | 2,320 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - North | WPCP - 05 - PGTB | 1,414,619 | 2,727 | 2,727 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - North | WPCP - 06 - SST | 3,919,785 | 39,494 | 39,494 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - North | WPCP - 09 - PTB | 4,783,239 | 98,153 | 98,153 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - North | WPCP - 10 - PCL | 1,036,101 | 158,797 | 40,050 | N/A | 118,747 | N/A | 133,253 | N/A | 263,552 | N/A | 0.45 | N/A |
| WPCP - North | WPCP - 11 - FET - 1AND2 | 465,577 | 1,082,427 | 54,568 | N/A | 1,027,859 | N/A | 245,186 | N/A | 484,936 | N/A | 2.12 | N/A |
| WPCP - North | WPCP - 11 - FET - 3 | 463,947 | 1,224,914 | 61,792 | N/A | 1,163,122 | N/A | 159,904 | N/A | 316,263 | N/A | 3.68 | N/A |
| WPCP - South | WPCP - 12 - OCB | 1,574,653 | 727,614 | 83,846 | N/A | 643,768 | N/A | 54,486 | N/A | 107,764 | N/A | 5.97 | N/A |
| WPCP - South | WPCP - 13 - SBB - LL | 10,477,204 | 1,557,422 | 504,264 | N/A | 1,053,158 | N/A | 82,913 | N/A | 163,988 | N/A | 6.42 | N/A |
| WPCP - South | WPCP - 13 - SBB - TRANSFORMER | 102,432 | 46,826 | 3,774 | N/A | 43,052 | N/A | 26,651 | N/A | 52,711 | N/A | 0.82 | N/A |
| WPCP - South | WPCP - 14 - SAT - LEL | 3,936,928 | 2,933,229 | 489,817 | N/A | 2,443,411 | N/A | 466,385 | N/A | 922,429 | N/A | 2.65 | N/A |
| WPCP - South | WPCP - 15 - SC-1TO6 | 1,715,476 | 1,403,335 | 272,006 | N/A | 1,131,329 | N/A | 639,614 | N/A | 1,265,046 | N/A | 0.89 | N/A |
| WPCP - South | WPCP - 15 - SC-7TO9 | 390,897 | 160,345 | 15,995 | N/A | 144,350 | N/A | 333,132 | N/A | 658,878 | N/A | 0.22 | N/A |
| WPCP - South | WPCP - 16 - SPSB | 7,839,003 | 2,634,811 | 357,544 | N/A | 2,277,267 | N/A | 41,456 | N/A | 81,993 | N/A | 27.77 | N/A |
| WPCP - South | WPCP - 17 - WSPSB | 6,318,344 | 2,881,645 | 324,541 | N/A | 2,557,104 | N/A | 41,456 | N/A | 81,993 | N/A | 31.19 | N/A |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WPCP - South | WPCP - 17 - WSPSB - OUTSIDE | 1,558,425 | 442,581 | 61,702 | N/A | 380,878 | N/A | 47,971 | N/A | 94,878 | N/A | 4.01 | N/A |
| WPCP - South | WPCP - 18 - WMLFDS | 4,279 | 1,156 | 225 | N/A | 930 | N/A | 7,995 | N/A | 15,813 | N/A | 0.06 | N/A |
| WPCP - South | WPCP - 19 - WWFF | 6,836,459 | 654,032 | 106,901 | N/A | 547,131 | N/A | 31,092 | N/A | 61,495 | N/A | 8.90 | N/A |
| WPCP - South | WPCP - 20 - FADF | 6,725,516 | 621,478 | 337,479 | N/A | 283,999 | N/A | 62,185 | N/A | 122,991 | N/A | 2.31 | N/A |
| WPCP - South | WPCP - 21 - ABWB | 85,882 | 15,766 | 3,935 | N/A | 11,831 | N/A | 4,627 | N/A | 9,151 | N/A | 1.29 | N/A |
| WPCP - South | WPCP - 22 - PEWF | 4,644,123 | 756 | 756 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - South | WPCP - 24 - PAF | 6,702,776 | 40,427 | 40,427 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| WPCP - South | WPCP - 24 - PAF - TRANSFORMER | 712,664 | 43,480 | 26,571 | N/A | 16,909 | N/A | 5,996 | N/A | 11,859 | N/A | 1.43 | N/A |
| WPCP - South | WPCP - 25 - MFF | 2,693,147 | 57,053 | 39,992 | N/A | 17,061 | N/A | 24,059 | N/A | 47,585 | N/A | 0.36 | N/A |
| WPCP - North | WPCP - 26 - NFF | 3,409,354 | 2,324,708 | 111,551 | N/A | 2,213,157 | N/A | 103,641 | N/A | 204,984 | N/A | 10.80 | N/A |
| WPCP - South | WPCP - 27 - SFF | 331,673 | 286,658 | 44,661 | N/A | 241,998 | N/A | 58,484 | N/A | 115,671 | N/A | 2.09 | N/A |
| WPCP - South | WPCP - 28 - DC3 | 2,910,634 | 844,846 | 85,401 | N/A | 759,445 | N/A | 20,728 | N/A | 40,996 | N/A | 18.52 | N/A |
| WPCP - South | WPCP - 28 - DC5 | 2,288,014 | 226,487 | 53,820 | N/A | 172,667 | N/A | 31,092 | N/A | 61,495 | N/A | 2.81 | N/A |
| WPCP - South | WPCP - 28 - DC5 - TRANSFORMER | 1,425,327 | 80,213 | 48,731 | N/A | 31,481 | N/A | 5,996 | N/A | 11,859 | N/A | 2.65 | N/A |
| WPCP - South | WPCP - 29 - SGF | 6,524,629 | 3,967,908 | 292,321 | N/A | 3,675,586 | N/A | 41,456 | N/A | 81,993 | N/A | 44.83 | N/A |
| WPCP - North | WPCP - 30 - PEF | 40,986 | 81,674 | 1,917 | N/A | 79,758 | N/A | 1,851 | N/A | 3,661 | N/A | 21.79 | N/A |
| WPCP - South | WPCP - 32 - EMLFDS | 78,287 | 22,696 | 3,975 | N/A | 18,721 | N/A | 4,627 | N/A | 9,151 | N/A | 2.05 | N/A |
| WPCP - South | WPCP - 33 - FCPS | 3,282,802 | 2,893,189 | 282,671 | N/A | 2,610,518 | N/A | 51,821 | N/A | 102,493 | N/A | 25.47 | N/A |
| WPCP - South | WPCP - 34 - SWPS | 2,822,317 | 5,550,688 | 235,170 | N/A | 5,315,517 | N/A | 33,757 | N/A | 66,766 | N/A | 79.61 | N/A |
| WPCP - South | WPCP - 35 - SHF | 3,342,112 | 1,332,587 | 929,929 | N/A | 402,658 | N/A | 41,456 | N/A | 81,993 | N/A | 4.91 | N/A |
| WPCP - South | WPCP - 35 - SHF - FILLSTATION | 199,198 | 7,945 | 7,228 | N/A | 717 | N/A | 3,553 | N/A | 7,027 | N/A | 0.10 | N/A |
| WPCP - South | WPCP - 37 - ASE1 | 1,704,903 | 22,053 | 10,956 | N/A | 11,097 | N/A | 28,350 | N/A | 56,071 | N/A | 0.20 | N/A |
| WPCP - South | WPCP - 37 - ASE1 - OUTSIDE | 897,058 | 795,606 | 42,837 | N/A | 752,769 | N/A | 50,488 | N/A | 99,857 | N/A | 7.54 | N/A |
| WPCP - South | WPCP - 38 - ASE2 | 6,163,971 | 244,662 | 79,763 | N/A | 164,899 | N/A | 6,663 | N/A | 13,178 | N/A | 12.51 | N/A |
| WPCP - South | WPCP - 39 - WFF | 337,300 | 34,222 | 17,524 | N/A | 16,699 | N/A | 10,364 | N/A | 20,498 | N/A | 0.81 | N/A |
| WPCP - South | WPCP - 39 - WFF - OUTSIDE | 121,874 | 9,712 | 4,894 | N/A | 4,819 | N/A | 3,998 | N/A | 7,907 | N/A | 0.61 | N/A |
| WPCP - North | WPCP - 40 - FEPS | 2,553,406 | 521,911 | 137,016 | N/A | 384,895 | N/A | 20,728 | N/A | 40,996 | N/A | 9.39 | N/A |
| WPCP - North | WPCP - 40 - FEPS - GROUND | 3,261 | 1,230 | 175 | N/A | 1,055 | N/A | 2,961 | N/A | 5,856 | N/A | 0.18 | N/A |
| WPCP - North | WPCP - 40 - FEPS - PCL | 2,349,163 | 335,268 | 126,323 | N/A | 208,944 | N/A | 244,297 | N/A | 483,177 | N/A | 0.43 | N/A |
| WPCP - North | WPCP - 43 - LLPS | 77,324 | 223,359 | 3,598 | N/A | 219,761 | N/A | 9,254 | N/A | 18,303 | N/A | 12.01 | N/A |
| WPCP - South | WPCP - 44 - SATPG | 1,742,841 | 1,728,952 | 92,517 | N/A | 1,636,435 | N/A | 31,092 | N/A | 61,495 | N/A | 26.61 | N/A |
| WPCP - North | WPCP - FA | 77,324 | 138,922 | 3,596 | N/A | 135,326 | N/A | 9,254 | N/A | 18,303 | N/A | 7.39 | N/A |
| WPCP - North | WPCP - SECURITY GATES | 1,082,542 | 3,898,255 | 50,293 | N/A | 3,847,963 | N/A | 129,552 | N/A | 256,232 | N/A | 15.02 | N/A |

# Appendix H
# Economic Impacts of Natural Hazards on Water Pollution Control Plant

# Overview

The goal of this analysis is to estimate the potential economic impacts associated with the risk of natural hazards at Arlington County's Water Pollution Control Plant (WPCP). To carry out this analysis, three hazard scenarios were developed based on the three most likely impacts that flood, storm, and electrical outage could have on the facility. Economic impacts considered in the analysis include: loss of local economic activity, loss of local income, and loss of function of the Four Mile Run recreation trail adjacent to the WPCP. Results indicate that under a range of hazard scenarios, potential economic impacts range from $1.3 million to nearly $590 million. An alternative calculation of economic impact of loss of wastewater service according to FEMA standard values range from $170,000 to $42 million.

These economic impacts can provide the basis for a benefit cost analysis. If impacts are completely avoided through hazard mitigation measures at the WPCP, they can be considered the economic benefits associated with increased resilience.

## Scenarios

Based on input from Arlington County staff, three hazard scenarios were developed based on the three most likely impacts that flood, storm, and electrical outage events could have on the WPCP. The WPCP, located in South Arlington County, currently processes wastewater for the entire county.

The three scenarios considered in this analysis include:

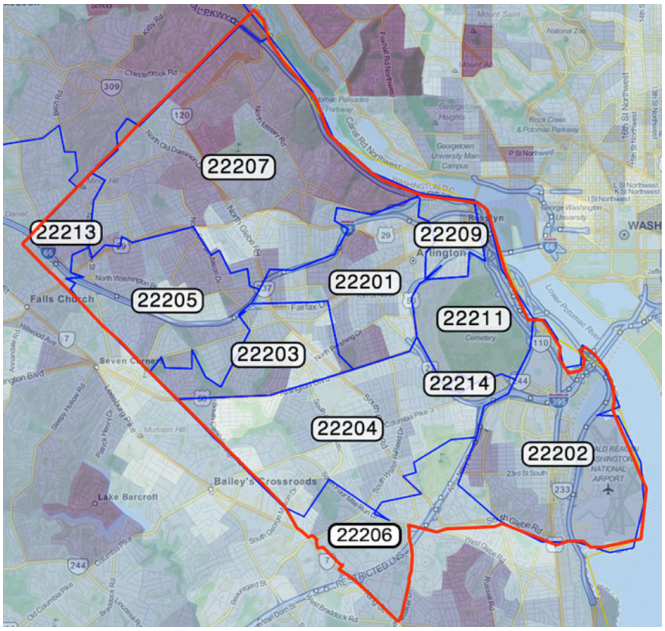
### Scenario 1.

Scenario 1 is the worst-case scenario, where the WCPC is unable to treat wastewater at all due to an extended power outage and failure of backup power. Under this scenario, Arlington County would most likely ask customers to stop using any non-essential water and may ask businesses to close.

Specific assumptions under this scenario include:

- Failure mechanism: Electric grid shutdown down for an extended period due to hurricane or extreme wind or storm (parallel to the historic derecho storm that impacted the D.C. area in 2012, coupled with an extreme flood event)
- Area of influence: Countywide, assuming an emergency declaration with request to limit water and wastewater use. The area of influence, including the zip codes encompassed by the county is shown in Figure H-1.
- Duration: 3 days, considering the potential for fuel shortage to supply backup power systems

**Figure H-1. Map of Scenario 1 Area of Influence**



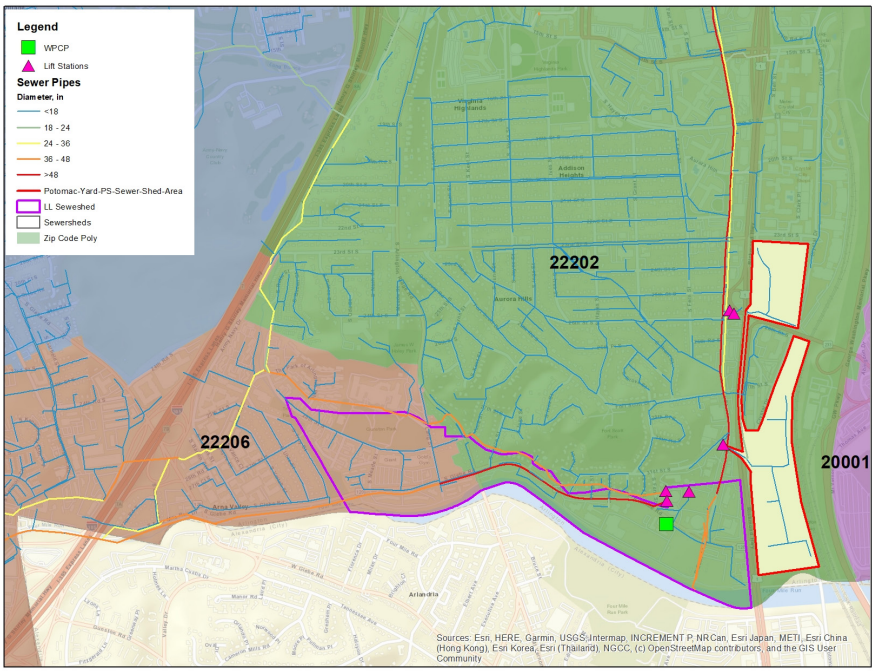

## Scenario 2.

Scenario 2 covers a less extreme case where the facility is still able to treat wastewater but loses power to the two onsite pump stations that bring in the raw wastewater. Impacts would be more localized to the areas neighboring the plant.

Specific assumptions under this scenario include:

- Failure mechanism: Electric grid shutdown due to extreme wind or storm, but not flooding.
- Area of influence: Two areas just west and east of the plant. These include the Potomac Yard sewershed and the lower sewershed, outlined in Figure H-2.
- Duration: 8 hours. Onsite backup power would be used, requiring approximately 8 hours to bring online.

**Figure H-2. Map of Scenario 2 Area of Influence**




## Scenario 3.

In a scenario with more limited impacts to the facility, Scenario 3 is defined by what would happen if the southern half of the plant flooded and there was damage to the electrical gear at the on-site pump stations that take flow from the secondary to the tertiary process. Once the floodwaters receded, a temporary operation would likely be set up to treat only to secondary standards, disinfect and discharge the effluent to Four Mile Run Stream.

Specific assumptions under this scenario include:

- Failure mechanism: hydraulic throughput would be maintained since the two raw wastewater pump stations are outside flood zone in this scenario, but significant damage to primary or secondary treatment would require new equipment purchases and would be lengthy to fully repair. It is assumed that access to Four Mile Run and the bike path would be closed.
- Operational costs: temporary pumping would require an additional cost of $850K/6 months
- Area of influence: The Four Mile Run bike and pedestrian trail would be closed for a 1.1-mile stretch from Mt Vernon Avenue to the George Washington Memorial Parkway.
- Duration: 6 months

## Approach

There are three main benefits estimated for each of the three hazard scenarios, including economic activity (or economic output), income, and losses associated with loss of recreation trail access, in addition to operating costs that would be incurred by Arlington County. Economic activity and income are estimated using the Impact Analysis for Planning (IMPLAN) model. An alternative estimate of the economic value of a loss of service is estimated using standard values developed by U.S. Federal Emergency Management Agency (FEMA). The approach for making each of these estimates is outlined in the sections below.

All values are adjusted to common 2022 dollars using a GDP Implicit Price Deflator.[4]

[4] Organization for Economic Co-operation and Development, GDP Implicit Price Deflator in United States [USAGDPDEFAISMEI], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/USAGDPDEFAISMEI, June 28, 2023.

## Economic Impacts

The economic impacts of a loss of function at the WPCP include both a loss of economic activity if local businesses and public buildings served by the project are asked to close, and a loss of income to local workers if they are not able to work that day or are required to stay home to attend school-aged children.

The data used to estimate economic output and income are embedded in the IMPLAN model for Arlington County. IMPLAN is an industry standard model used to estimate local and regional economic impacts based on an input-output model. The IMPLAN model is built upon industry, wage, price, and other economic data compiled by the Bureau of Economic Analysis (BEA), Bureau of Labor Statistics (BLS), and the U.S. Census. Data in the model is estimated and made consistent down to the zip-code level.

Total economic activity or economic output and total income are estimated according to the assumptions outlined in the scenario descriptions above. For scenario 1, the area of impact is Arlington County. For scenario 2, the area of impact is two areas just east and west of the WPCP shown in Figure H-2. GIS analysis was used to allocate a share of total economic activity at the zip code level to the specific areas that are likely to experience a loss of service. Scenario 3 has no direct impacts to local economic output or income.

Economic data is provided in the IMPLAN model on an annual basis. Expected daily economic values are estimated by dividing annual activity by 365 days in the year. Business service interruptions durations are based on information from Arlington County, as summarized in the 3 scenarios, and range from 8-hours in scenario 2 to 3 days in scenario 1. It is assumed that under an 8-hour loss of service in Scenario 2, businesses would be asked to close for one business day.

The most recent year of IMPLAN data available is 2021. These values are adjusted to 2022 dollars using the GDP Implicit Price Deflator.

## Recreation/Transportation Impacts

Scenario 3 includes a closure of the Four Mile Run recreation trail that runs along Four Mile Run Creek. To estimate the value of the loss of use of this public resource, this analysis relies on standard values from the U.S. Department of Transportation's (USDOT) Benefit Cost Analysis Guidance5 and estimates of average trail use from the Arlington County Division of Transportation.

The USDOT provides standard values for the public use of a cycling path with at-grade crossings on a dollar per person per mile basis. This value of $2.00 per person per mile includes the value of travel time savings, and journey quality, based on revealed preference values. This value is adjusted from 2021 dollars as provided in the USDOT guidance, to 2022 dollars using the GDP Implicit Price Deflator.

The Arlington County Division of Transportation provided historic use counts for the Four Mile Run bike trail. Over 8 years of traffic counts, trail use has averaged 900 bike trips per day. Based on the 4 years of traffic counts available for pedestrian traffic, trail use has averaged 300 pedestrian trips per day.

It is estimated that closure of the trail near the WPCP would impact approximately 1.1 miles from the intersection with Mt Vernon Avenue to the George Washington Memorial Parkway

## Alternative Water Use Impacts

An alternative approach to estimating the economic value of a loss of function at the WPCP is based on standard values used in FEMA benefit cost analysis to estimate loss of water and wastewater function. These values are provided in FEMA's BCA Reference Guide[6] and in the FEMA BCA Toolkit version 6.0 on a per capita basis at $60 per person per day for the loss of wastewater service, and $116 per person per day for the loss of water service, in 2022 dollars. There are no standard values associated with minimal use restrictions. For this analysis Scenario 1, which includes a 3-day minimal use restriction, is estimated as a

[5] U.S. Department of Transportation. 2023. Benefit-Cost Analysis Guidance for Discretionary Grant Programs. January 2023. Benefit Cost Analysis Guidance 2023 Update.pdf (transportation.gov)

[6] Federal Emergency Management Agency. 2009. BCA Reference Guide: Final. June 2009. BCA Reference Guide (fema.gov)

full loss of wastewater services. Scenario 2 is estimated as a full loss of both water and wastewater services.

Population estimates used to calculate the total value of service interruption according to per capita FEMA standard values, were gathered from the IMPLAN model for the county as a whole and the portions of impacted zip codes, according to GIS analysis.

## Results

Based on the assumptions outlined in the previous sections, total estimates of the potential economic impacts of the three natural hazard scenarios are presented in **Table H-1**. Total impacts range from $1.3 million under Scenario 3 to nearly $590 million in Scenario 1. The alternative estimates of the loss of function of the WPCP according to FEMA standard values range from $169,000 in Scenario 2 to nearly $42 million in Scenario 1. It should be noted that the FEMA values and the IMPLAN values are estimating the same benefit in two different ways and therefore should not be considered additive. Instead, they provide valuable bookend estimates for the economic value of a loss of function. If pursuing future grant funding from FEMA, the FEMA values should be used, but for internal decision making, the IMPLAN values may better represent impacts to the local economy.

**Table H-2. Summary of Economic Impact Estimates**

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Scenario summary | 3-day countywide minimal water use restriction | 8-hour wastewater outage in the lower sewershed and Potomac Yard sewershed | no service outage; 180-day recreation trail closure and additional operational costs |
| Operational Costs (Arlington estimate) | | | $850,000 |
| Loss of Income (IMPLAN) | $225,970,486 | $1,011,603 | |
| Loss of Economic Activity (IMPLAN) | $363,639,939 | $2,269,021 | |
| Loss of Recreation Trail Use (DOT standard values) | | | $475,437 |
| **Total** | **$589,610,424** | **$3,280,624** | **$1,325,437** |
| Alternative Loss of Function Estimates (FEMA standard values) | $41,933,700 | $169,272 | |

# Appendix G
# Programmatic Strategies for Flood Management Technical Memorandum

ARLINGTON
VIRGINIA

# Programmatic Strategies for Flood Management

| | |
|---|---|
| **Date:** | October 6, 2023 |
| **Project name:** | Flood Risk Assessment and Management Plan (RAMP) |
| **Project no:** | E5X69605 |
| **Attention:** | County of Arlington, Virginia |
| **Company:** | Jacobs |
| **Prepared by:** | Miranda Santucci |

**Jacobs Engineering Group Inc.**
2551 Dulles View Drive
7th Floor
Herndon, VA 20171
United States
T +1.703.376.5000
www.jacobs.com

# 1. Purpose

The purpose of this technical memorandum (TM) is to summarize potential programmatic approaches for management of flooding in Arlington County. This TM has been produced as part of Task 6 activities of the Arlington County Risk Assessment and Management Plan (RAMP).

# 2. Background

Arlington County (the County) has initiated the Flood Risk Assessment and Management Plan (RAMP) work to generate detailed flood hazard information (Task 3), flood vulnerability (Task 4) and risk (Task 5) information, and concept-level capital projects (Task 6) that may be implemented to mitigate flood risk. It is understood, however, that many policy and program offerings (programmatic strategies) should also be considered for management of flood risk on a County-wide scale. A summary of ongoing strategies and existing regulations is included in this section.

## 2.1 Definitions: Stormwater Management, Flood Risk Management, and FEMA Floodplains

The County has experienced an increase in flooding events, causing impacts on property and people. The following significant factors have contributed to the increase in local flooding:

- Increased precipitation and change in the nature of that precipitation
- Increased impervious surface areas from new development
- Infill development
- Redevelopment
- Aging stormwater drainage and management infrastructure built to older design standards is unable to handle the large volumes of water associated with higher levels of imperviousness and more intense precipitation events

The County is subject to flooding from intense rainfall producing local flooding (referred to as urban flooding, interior flooding, or pluvial flooding) and from streams and rivers overtopping their banks (referred to as riverine flooding or fluvial flooding). The County is also subject to high tides and surge flooding, potentially compounded by sea level rise (referred to as coastal flooding, surge flooding tidal flooding, or sea level rise flooding). The spectrum of impacts from flooding within the County varies from nuisance to significant flooding events.

Historically, the County defined areas of flood hazard based solely on Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) produced as part of a Flood Insurance Study.

This mapping provides a delineation of a special flood hazard area (SFHA) defined as the 100-year annual recurrence storm event inundation area. Studies and associated FIRMs typically focus on areas of historical impact and include coastal areas as well as larger river and stream channels. This mapping, however, leaves out areas of urban flood risk, where flooding may occur far from a mapped river. Through the work of the RAMP, the County has initiated defining areas of urban flooding (Figure 1).

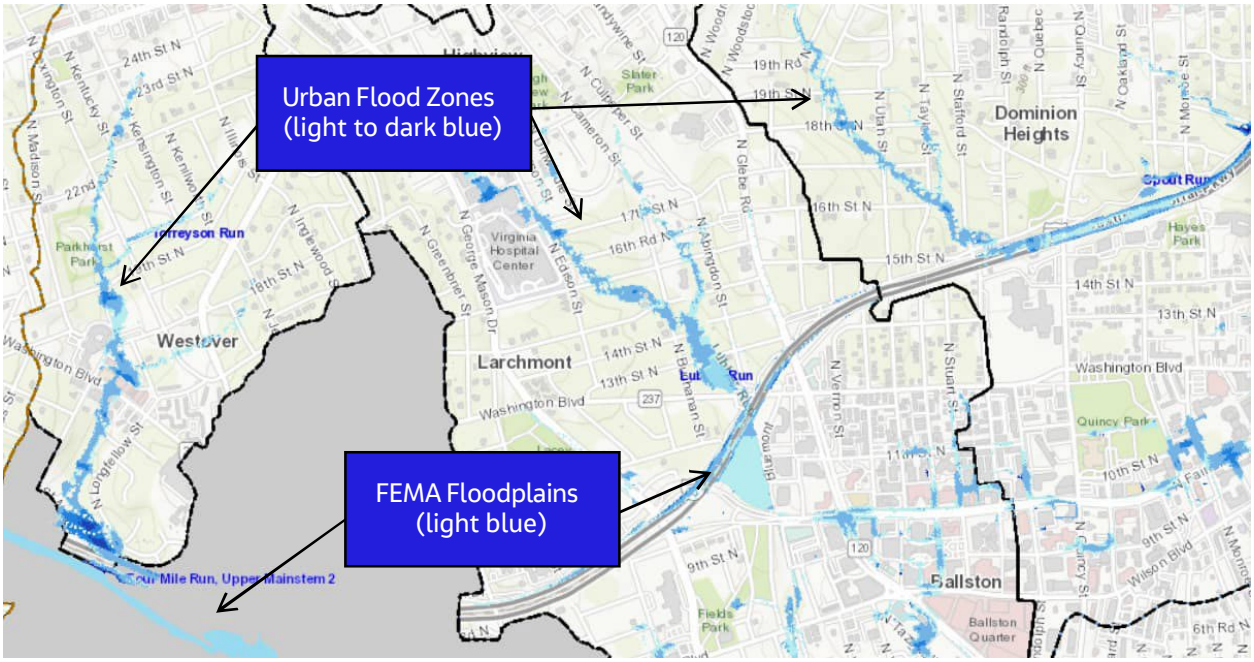



**Figure 1. Flood Zones and Floodplains**

Flood risk management programmatic measures are intended to address both FEMA floodplains and urban flood zones (shown on Figure 1, which is based on modeling of 100-year storm). But historically, only stormwater management measures that manage smaller storms (2- and 10-year) have been provided in areas at risk of urban flooding, while FEMA flood zones have flood mitigation requirements for 100-year storms.

Various laws, regulations, policies, and procedures govern the development of the built environment that contributes to stormwater runoff and the infrastructure that is designed to handle this runoff.

Infrastructure related to stormwater runoff management, and regulations related to them, fall into roughly three categories:

- Infrastructure that focuses on management of comparatively small volumes of stormwater runoff to improve water quality is typically called stormwater management infrastructure.
- Infrastructure designed for conveyance of larger volumes of water for drainage of roadways is typically called stormwater drainage or storm drain infrastructure.
- Infrastructure related to management of extreme storm events is typically described as flood management or flood mitigation infrastructure.

Within this document, the term “stormwater and flood mitigation infrastructure” is used to describe infrastructure that may serve any of these purposes. Figure 2 further illustrates the nomenclature.

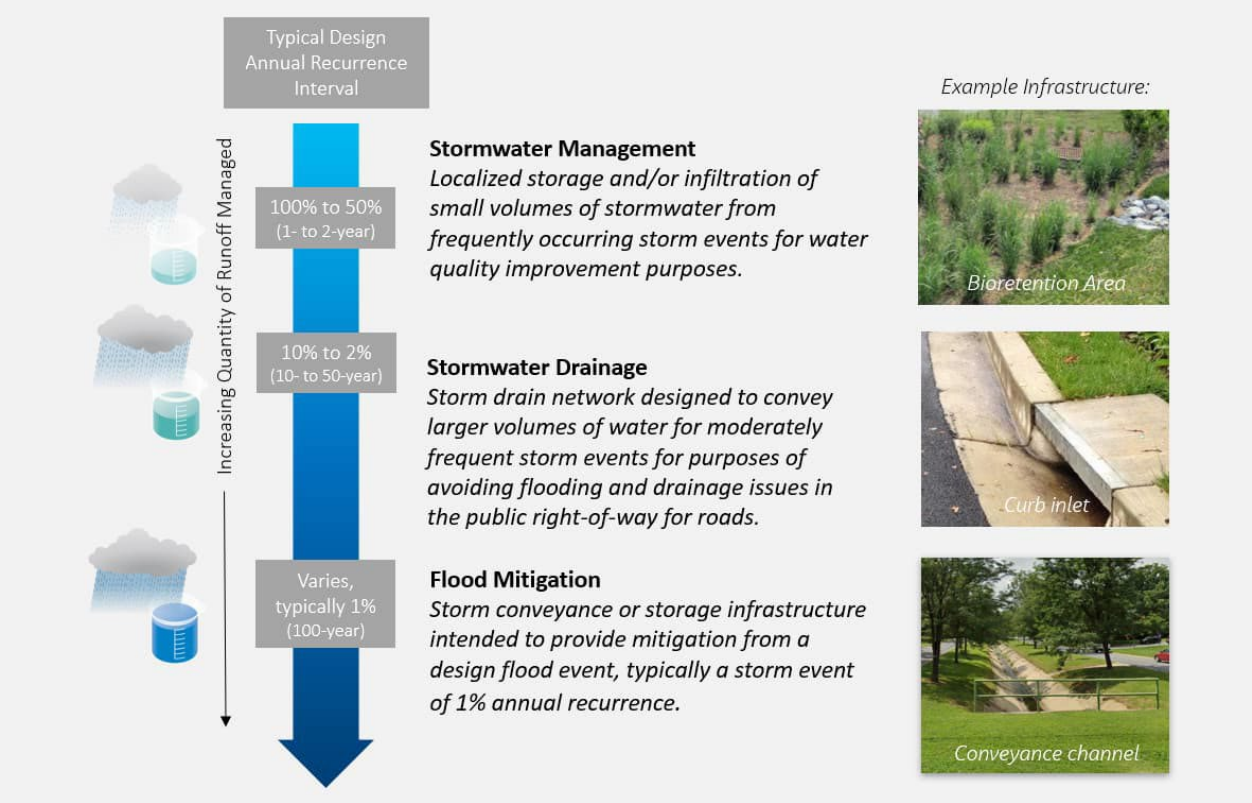



**Figure 2. Typical Design Storm Sizing for Stormwater Management, Stormwater Drainage, and Flood Mitigation Infrastructure Design**

Annual Recurrent Interval refers to the statistical occurrence of a storm event in a given year. For example,. the 100 percent storm can also be referred to as the 1-year storm, which is the storm event that has 100 percent likelihood of happening in any given year.

Flood risk management programmatic measures intended to address both riverine and urban/pluvial flooding are needed. However, historically, flood mitigation requirements and programs have focused on the riverine or coastal flood areas only. For those areas at risk of urban/pluvial flooding, only stormwater management measures that manage smaller storms (2- and 10-year) have been provided. An overview of existing policies, programs, and standards is provided in Sections 2.2 and 2.3.

## 2.2 Current Policies and Programs Addressing Flood Management

The County has participated in FEMA's National Flood Insurance Program (NFIP) since 1976. The County entered the Community Rating System (CRS) program in 1992 and is currently listed as a Class 8 community. Classes vary from Class 10 to Class 1 and qualify a community for flood insurance premium reductions based on verification of eligible flood mitigation activities (from 0 to 45 percent premium reduction within the SFHA and 0 to 10 percent outside). Classes are associated with increasing levels of discounts on flood insurance premiums. Class 8 provides a 10 percent discount on flood insurance premiums for residents within the SFHA and 5 percent discount for residents outside the SFHA.[1]

[1] The CRS Coordinator's Manual, originally published in 2017, has been amended in 2021. The addendum includes a new prerequisite for achieving Class 8, requiring communities to adopt and enforce freeboard for residential buildings in their SFHAs.

Arlington County's Inter-departmental Workgroup on Stormwater Management and Resilience is tasked with addressing stormwater management and resilience. As noted on the "Flood Resilient Arlington" webpage, the group focuses on the following key topics:

- Emergency response/life-safety notification
- Development and regulations
- Strategic improvements and policy changes
- Communications and engagement

In addition to the workgroup, the County is actively investigating enhancements to programs and policies for flood risk management. Other ongoing, activities include the following:

- Development of comprehensive flood hazard mapping, and vulnerability and flood risk assessments for current and future climate conditions. The output of the flood hazard mapping, and the vulnerability and risk assessments are documented in a series of reports, some still in development at the time this TM was written.
- Investigation into options for expanding flood insurance coverage.
- Small scale implementation of site/property acquisition and repurposing for flood-prone properties.

## 2.3 Summary of Regulations Relevant to Flood Management

Table 1 provides a brief overview of existing regulations and policies that have an impact on various aspects of flood management. Table 2 provides relevant design criteria, standards, and guidelines.

**Table 1. Summary of Relevant Regulations**

| Topic | Reference | Description |
|---|---|---|
| Stormwater Management Ordinance | Arlington County Code Chapter 60 | References the *Arlington County Department of Environmental Services Manual* for technical requirements. Requires submittal of a stormwater pollution prevention plan, stormwater management plan, and/or pollution prevention plan for land disturbing activity (LDA) > 2,500 square feet. |
| E&SC Ordinance | Arlington County Code Chapter 57 | E&SC Ordinance. Requires submittal of an E&SC Plan for LDA > 2,500 square feet. |
| Chesapeake Bay Preservation Ordinance | Arlington County Code Chapter 61 | Chesapeake Bay Preservation Ordinance. Requires submittal of a landscape conservation plan for LDA > 2,500 square feet within Resource Protection Areas. |
| Building Code | Arlington County Code Chapter 3 | Arlington County follows the 2018 Virginia Uniform Statewide Building Code. |
| Land Development Standards | Arlington County Zoning Ordinance | Code of Virginia §15.2 Chapter 22 grants localities in the Commonwealth the legislative authority to classify and regulate development on the land under its jurisdiction. The Arlington County Zoning Ordinance, last updated in 2023, sets development standards for land use in the County. |
| Development Review | Administration Regulation 4.1 | The Site Plan Review process is one pathway through which development occurs in the County, and it focuses on larger developments. |
| Subdivision Ordinance | Arlington County Code Chapter 23 | Regulates subdivision of land within the County, referencing the need to provide adequate E&SC, stormwater drainage, and flood control. |
| Floodplain Management Ordinance | Arlington County Code Chapter 48 | Defines the County Floodplain District based on the FIRM SFHA. Regulates development within the County floodplain. Elevation requirement is that lowest floor be 1 foot above base flood elevation. |

Notes:

E&SC = erosion and sediment control
LDA = land disturbing activity

**Table 2. Summary of Relevant Design Criteria, Standards, and Guidelines**

| Topic | Reference | Owner | Description |
|---|---|---|---|
| Stormwater Management and E&SC Design Guide | Arlington County Department of Environmental Services Manual | Arlington County Department of Environmental Services | Last updated July 2021. Provides technical guidance for Stormwater Management Ordinance (Chapter 60) and E&SC Ordinance (Chapter 57). It also provides guidance for Chesapeake Bay Preservation Ordinance, applicable within the Resource Protection Areas (Chapter 61). |
| Storm Sewer Construction Standards and Specifications. | Arlington County Department of Environmental Services Construction Standards and Specifications | Arlington County Department of Environmental Services | Last updated in September 2020. Provides design requirements for storm sewers (Section 02505 3.3). |
| Storm Drainage Design | Drainage Manual | Virginia Department of Transportation | Last updated January 2021. Provides technical guidance for design of public storm drain facilities. |

# 3. Methods/Approach

A brief literature review was conducted to identify jurisdictions with novel policy or program approaches to flood management. A matrix was generated to classify relevant policies and programs (freeboard, public flood risk information tools, flood overlay zoning, etc.) and identify jurisdictions that may have experience with these tools and programs. Two primary methods were used to identify the ways other jurisdictions have addressed flood management in their localities: a desktop study and an informal interview with representatives from selected jurisdictions. Interviews were conducted virtually using a prepared questionnaire (Attachment 2). Other examples were added from Jacobs staff experience. Table 3 lists jurisdictions with novel strategies for flood management.

**Table 3. Jurisdictions with Novel Programmatic Strategies for Flood Management**

| Jurisdiction | State | Desktop Review | Interview |
|---|---|---|---|
| Anne Arundel County | Maryland | | X |
| Charlotte-Mecklenburg Stormwater | North Carolina | | X |
| City of Baltimore | Maryland | | X |
| City of Boston | Massachusetts | X | |
| Metropolitan Water Reclamation District of Greater Chicago | Illinois | | X |
| City of Denver and Mile High Flood District | Colorado | | X |
| District of Columbia (DOEE/DDOT) | District of Columbia | | X |
| City of Fort Worth (Stormwater Management Division) | Texas | | X |
| City of Houston/Harris County Flood Control District | Texas | X | |
| New York City | New York | X | |
| Pittsburgh Water and Sewer Authority | Pennsylvania | | X |

Notes:

DDOT = District Department of Transportation
DOEE = Department of Energy and Environment

A discussion of strategies is included in this document. Because strategies cover a wide range of activities, they have been categorized as follows:

- Governance considerations
- Public information
- Information supporting County flood risk activities
- Equity considerations
- Flood risk mitigation
- Integrating flood risk information into land use planning
- Updating regulations and design standards based on flood risk information
- Flood management finance and funding
- Storm drainage asset management

The categories are addressed in Sections 4.1 through 4.9. Section 4 provides a discussion of strategies that may be considered by the County to improve management of flooding.

# 4. Summary of Programmatic Flood Management Strategies

## 4.1 Governance Considerations

Flood management is a complex activity that requires both cross-departmental and interdisciplinary communication. Flood management can include land use planning, engineering, permitting, construction, operations, maintenance, preparedness, and response. These activities touch diverse functions of local government, which may be siloed (do not typically communicate or share data with one another).

Similarly, because flood management often crosses jurisdictional boundaries and can be directly affected by neighboring jurisdictions, management activities, including policy development, must be carried out in a collaborative manner.

Common to several jurisdictions included in the review was implementation of a cross-departmental organization for management of flooding to bring flooding-centric issues to a group of decision makers on a regular basis. Although the format of such groups differs, they all operate to facilitate cross-agency/ cross-departmental communication on the subject. The challenge is empowering the group with sufficient authority to bind each organization to the actions and budget allocations generated through the deliberations.

Other local entities, such as the **City of Baltimore; Montgomery County, Maryland**; and the **District of Columbia (DC or District)** have initiated organizational reviews related to flood management and identified actions to address organizational approaches to management of flooding.

Following an organizational review, but not strictly following recommendations provided therein, the **District of Columbia** formed a Flood Task Force (FTF) [link]. The FTF is jointly administered by DOEE and DC Water. Monthly meetings are held to advance Action Plans generated by the FTF members. The FTF reports directly to the Mayor's office. The FTF has reportedly worked well in facilitating communication and bringing together District and federal partners. But a challenge with this specific model is the difficulty in binding member organizations to the actions delegated in the Action Plans. The District also has had an established U.S. Army Corps of Engineers-supported Silver Jackets group [link] that brings together federal, local, academic, and District stakeholders to discuss flood management issues.

The mayor of the **City of Baltimore** formed the Baltimore Flood Infrastructure Working Group that includes representatives from Planning, Department of Public Works, Department of Transportation, Parks and Recreation, and Department of General Services. The group meets regularly and is tasked with coming up with joint solutions for flooding issues.

***Recommendation:*** *Explore methods to formalize communication and data sharing among relevant agencies for the specific goal of ongoing flood management.*

## 4.2 Public Information

### 4.2.1 Coordinated Flood Risk Community Outreach

Increasing public awareness of flood risk is a key means of empowering residents to mitigate their own risk. Typically, public outreach for flooding-related matters is associated with a specific project and therefore has a defined geographic audience and timeline.

The District of Columbia's DOEE is moving away from "swoop in" types of engagement in areas with an equity focus. Wards 7 and 8 house much of the District's floodplain and are also areas of high social vulnerability. DOEE has established a relationship with a local community center as an initial step in improving engagement. The community center provides a monthly 1.5-hour programming slot that DOEE fills with flood education. DOEE is working on composing a three-module education series (Flood 101, Flood Insurance, DC's FloodSmart homes program) that will be continually offered at the center.

DOEE is working to identify specific federal grants that can be used to increase community center programming and outreach. The grants can be provided with some metric to measure the success of engagement (number of engagements) and success in using the existing community center connections to get information out. Of additional note, successful methods for outreach include radio stations, the *Washington Informer* (a local Black-owned newspaper), retirement centers, and "hang outs" for those without internet access.

Likewise, **Anne Arundel County** undertook efforts to pursue FEMA grant funding to organize dedicated public outreach to an area with chronic tidal and urban flooding issues.

In partnership with FEMA, **New York City's** Center for New York City Neighborhoods has developed an online educational outreach tool about flooding that is targeted to low- and middle-income homeowners [link]. The tool provides approachable education on flood risk, a discussion of flood insurance, and mitigation strategies, and the tool links residents to flood hazard mapping. A Flood Action Toolkit is also provided in several languages [link].

***Recommendation:*** *Consider development of coordinated and ongoing community engagement programs that will provide public education on flood risk and flood risk mitigation options. Consider outreach techniques targeted at socially disadvantaged communities.*

### 4.2.2 Flooding Hazard Alert System

Depending on the severity of past flood events, some jurisdictions have initiated flash flood alerting systems for residents. These systems can vary from a National Weather Service (NWS) notification system to a local sensor network.

**Montgomery County** Office of Emergency Management and Homeland Security has a voluntary program for public alerts that is currently the largest in Maryland (more than 230,000 subscribers). Its "Alert Montgomery" system relays NWS notifications to individuals who have subscribed to receive the classification of alert. The **District of Columbia** Homeland Security and Emergency Management Agency hosts a similar system, "AlertDC," which relays notifications to subscribers. These systems are similar in nature to the Arlington Alert system, providing broad notifications of emergency alerts to subscribers.

Some countries have begun using "blue-green" infrastructure, which is designed to operate as flood storage or conveyance during extreme rainfall events. This presents a flood alerting challenge because the infrastructure must be vacated to allow for safe use during such an event. An example of a highly local flood hazard alerting system is the **City of Singapore's** Bishan Park. It is a blue-green park used for flood storage during extreme flood events. The park is equipped with a flood warning system linked to a national weather monitoring system that tracks local rainfall forecasts and conditions. The alerts include audio announcements to enable safe evacuation of the area.

***Recommendation:*** *Consider assessing whether NWS notifications or more location-specific real-time alerts would be helpful in avoiding damage or life-safety issues in flood-prone areas.*

### 4.2.3 Making Flood Hazard Information Available

One way in which many jurisdictions are increasing public awareness of local flood hazards is by making this information readily available online. While it is understood that some residents, particularly those in disadvantaged populations or rural areas, may have issues accessing online resources, this is a powerful way to make such information readily accessible.

Most jurisdictions have moved toward offering online flood risk mapping in addition to general flood risk mitigation information (insurance information or FEMA links for mitigation techniques and considerations). Some entities, such as Charlotte-Mecklenburg Stormwater Services (a stormwater utility serving the City of Charlotte and Mecklenburg County), have developed flood viewer tools enabling residents to view FEMA mapping [link] and other information, in this case flood depth and structure locations. Disclaimer language is a consideration for ensuring that viewers are aware that the information has its limitations.

The **District of Columbia** has developed a tool that enables residents to learn about flood risk, view forecasted risk, and view flood stories (twitter reports and optional user stories submitted via the website) [link].

The **City of Fort Worth** provides flood risk mapping that includes detailed "City Flood Risk Areas" in addition to the FEMA SFHA [link]. The **Harris County Flood Control District** provides mapped riverine floodplains for the 100-year and 500-year events as well as a ponding layer that allows residents to view areas that may have drainage issues because of the lack of an outlet [link].

**New York City** has developed a tool that includes consideration of climate change impacts (sea level rise) [link].

The **City of Boston** has two different flood viewers. The first, developed by the Boston Environment Department as part of the Climate Ready Boston initiative, includes viewing of Climate Ready Boston data (temperature, coastal and urban stormwater flooding) [link]. The second, developed by the Boston Water and Sewer Commission, includes interior, riverine, and coastal impacts, including the extent of impacts and the number of critical facilities affected [link] Figure 3). Considerations of different types of storm events (tropical storm versus nor'easter, for example) has been included.

**Figure 3. Example Flood Hazard Viewer: Boston Water and Sewer Commission Inundation Model Viewer**

Source: BW&SC 2023

***Recommendation:*** *Consider whether existing flood hazard information, available via FEMA, can be made more accessible to the public using an available mapping tool, or whether development of a targeted flood risk tool might be helpful to also provide information on pluvial/urban flooding risk, when available, that are not addressed by FEMA NFIP flood maps.*

### 4.2.4 Flood Hazard Disclosure

Another means through which information on flood hazards can be conveyed to the public is through real estate disclosures required for the transfer or sale of a property.

There is no federal requirement for home sellers to disclose information about a property's flood risk or prior damage to a prospective buyer. States vary on flood disclosure requirements. Virginia state code lists required disclosures, which include a disclosure requirement if "the owner of a residential property has actual knowledge that the dwelling unit is a repetitive loss property" (two or more claims greater than $1,000 within a 10-year period).[2]

Several states have more rigorous flood disclosure statutes, namely Louisiana, Texas, South Carolina, Mississippi, and Delaware (FEMA, NRDC, 2022). However, at the local level, jurisdictions moving toward more stringent real estate hazard disclosure requirements are doing so in coordination with flood overlay zones. **The City of Burlingame,** within **San Mateo County, California**, has updated their zoning ordinance to include a requirement of additional disclosure of hazards for properties within their defined Sea Level Rise Overlay Area.

***Recommendation:*** *Consider whether more stringent disclosure requirements may be warranted in areas of chronic flooding.*

[2] Title 55.1 Subtitle II. Chapter 7. Residential Property Disclosure Act

## 4.3 Information Supporting County Flood Risk Management Functions

Sections 4.3.1 through 4.3.3 discuss several strategies that involve jurisdictions making climate or flood hazard information available to staff and building processes around that data.

### 4.3.1 Real-time Climate and Forecasting Data

The U.S. Geological Survey (USGS) National Water Information System has a network of real-time climate data. But some jurisdictions that have dealt with impacts from fast-moving high-intensity and highly localized rainfall events have sought to build their own climate data collection networks to supplement that of the USGS. Developing a network of real-time rainfall data can be beneficial for environmental monitoring (stream or sensitive area monitoring) and for operational responses (road closures).

**Montgomery County, Maryland,** Office of Emergency Management and Homeland Security in concert with the federal Department of Homeland Security, has installed real-time stream gauges throughout the County. The gauges collect up to 5-minute stage data and log it for a short period. The gauges can be outfitted with other sensors (e.g., rainfall gauge). While not coordinated with the flood gauge installation, Montgomery County's Fire and Rescue Services regularly use NWS meteorological forecasts, real-time river gauge data, and staff monitoring of known flooding points to both gauge local staffing levels and alert staff to road hazards.

The **City of San Mateo** has developed a tool that sends an automated daily two-part report of area rain gauge data (past 5 days) and NWS forecast data (7-day forecast) to City stormwater managers.

**Charlotte-Mecklenburg Storm Water Services (City of Charlotte and Mecklenburg County, North Carolina)**, in partnership with the USGS, has developed the Flood Information and Notification System (FINS) [link]. The regional network includes 52 stream gauges and 72 rainfall gauges, most of which are telemetry-enabled and report at 5-minute increments (when site thresholds are exceeded) (Figure 4). The network provides data directly to emergency managers and to the USGS National Water Information System. This data are used for operations purposes such as road closure responses from police and fire departments. Distribution of this information among staff is reportedly helpful in responding to resident inquiries. For example, Department of Transportation staff can communicate with residents regarding the statistical recurrence of an observed event or impact.

The **City of Newport News**, Virginia, through partnership with the Virginia Institute for Marine Science, is carrying out its StormSense research project, using low-cost low-energy water level sensors to aid the response to king tides and storm surges [link].

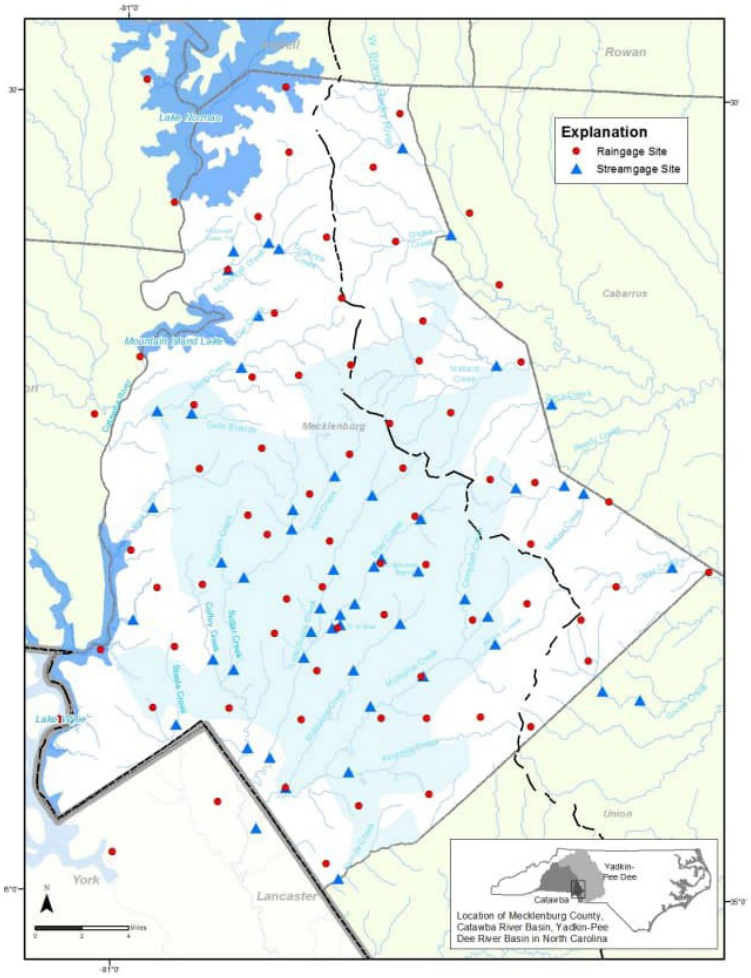



**Figure 4. City of Charlotte and Mecklenburg County, North Carolina, FINS Network Rain and Stream Gauges**

**Recommendation:** Assess the availability of real-time data throughout the County to understand what information is available now. Consider whether such information would be useful for staff, and investigate whether tools, such as those developed for San Mateo, may be helpful.

***Recommendation:*** *Explore the benefits of installing real-time rainfall, tide, or stream gauges to inform County operations.*

## 4.3.2 Integrating Knowledge of Known Flood Risk Areas

Several of the jurisdictions interviewed noted efforts to conduct drainage-specific reviews of building permit applications. In most jurisdictions, building permit reviews are done separately from drainage or floodplain reviews. Building reviewers are, therefore, less familiar with conditions that may exacerbate a drainage issue. Some jurisdictions are approaching the building permit review as an opportunity to catch likely site-level drainage issues before equipment is installed. Once equipment is installed, drainage issues originating from a private lot (i.e. lot-to-lot flooding) are outside the authority of the jurisdiction and must typically be addressed between neighbors.

The **Anne Arundel County** Department of Public Works created a Stormwater Strike Force that functions like "eyes on the ground" for review staff, inspectors, and project-level and senior engineers looking at downstream stability. The Stormwater Strike Force staff can spot potential issues during the plan review approval process, be a liaison with County staff, and provide technical assistance during construction.

The **City of Charlotte** is working to expand their plan review division to support reviews associated with a new Drainage Article. The new staff will perform drainage reviews on construction, expansion, or land disturbance. The perception is that most permit projects will not be affected by this, but even minimal interventions or just the notification of potential problems on a project may result in addressing a potential issue before it occurs.

The **City of San Mateo's** OneShoreline initiative provided planning reviews of shoreline projects. The review comments are being used to develop the OneShoreline's Planning Guidance Policy, intended to be made available for jurisdictions to refer to in developing planning documents and processes [link].

***Recommendation:*** *Consider whether drainage-focused building permit reviews could be an opportunity to address conditions that may exacerbate lot-to-lot flooding.*

### 4.3.3 Collating Flooding or Drainage Calls

Several jurisdictions have found value in collating and analyzing public complaint and service call information. Call databases such as 311 can be useful in validating results of engineering studies. **Baltimore County**, for their Storm Drain Asset Management Program, looked at flooding and drainage complaints in the context of storm drain level of service (LOS). However, the information gathered from a 311 call interaction can be highly varied. Furthermore, there can be concerns that such records do not represent impacts on socially vulnerable communities that may not know about public services or may have language or technology barriers that inhibit calls. Therefore, call data need to be used with an understanding of the data's limitations.

Some jurisdictions have solicited public input and comment directly related to flooding through surveys or web mapping services. Both **Montgomery County** [link] and the **City of Gaithersburg** [link] (a jurisdiction within Montgomery County) have launched public surveys to gain input specifically on resident flooding and drainage impacts. These surveys contain detailed questions on resident demographics and the type and severity of flood impacts. The **District of Columbia** recently launched the DC Flood Risk Map [ link]. This tool provides the opportunity to submit user stories related to flooding and twitter stories.

Arlington County has detailed flood complaint call information from specific storms that has been reviewed by agencies to understand flood impacts. Gathering and reviewing information as a regular part of flood management activities can help managers stay up to date on local impacts. Given the limitations of 311 type calls for illustrating impacts on socially vulnerable populations, it may be necessary to target outreach at a neighborhood level to understand impacts.

***Recommendation:*** *Identify available records that can be used to assess historical flood impacts, recognize limitations the records may have, and determine whether the data may inform ongoing flood management activities.*

## 4.4 Equity Considerations

While not necessarily a formal component of a flood management program, equity is being considered by many jurisdictions as they implement flood management policies and programs. The following are some examples:

- The **City of Baltimore** conducted a flooding equity assessment as part of their Nuisance Flood Plan 2020.
- The **City of Boston** has developed the "Greenovate Leaders Program" through which Bostonians can be trained to lead climate equity discussions in their communities [link]. The program hosts roundtables and workshops for socially vulnerable groups to address equity concerns and improve resiliency in disadvantaged areas.

- The **District of Columbia** has pursued use of local advocacy groups, such as the Far Northeast Ward 7 Equity Advisory Group (EAG), to engage citizens and communities in climate change discussions, including flooding [link]. The EAG was formed via a partnership between the Georgetown Climate Center (part of Georgetown University Law School) and DOEE.
- The **Pittsburgh Water and Sewer Authority**, along with the **City of Pittsburgh**, are revising the Stormwater Code for resiliency purposes. The process was designed to make sure revisions would not be overly burdensome on small developers and property owners in communities with a high social vulnerability index (ATSDR 2022). Multiple stakeholder working groups were formed, one including neighborhood organizations and advocacy groups for high social vulnerability index neighborhoods, to stimulate economic development. Stipulations were written into the code that certain areas had limitations because of economic variables.
- The **Harris County Flood Control District** (the flood management authority in Harris County, which is in the vicinity of Houston, Texas) has initiatives to redirect flood mitigation projects and funds to communities with historical social vulnerability. Harris County Flood Control District's Community Flood Resilience Task Force influences policy with an equity focus.

***Recommendation:*** *Ensure that flood management activities are carried out with appropriate consideration of the County's equity goals.*

## 4.5 Flood Risk Mitigation

### 4.5.1 Insurance Premium Reduction/Coverage Increase

While not a means of reducing risk, increasing flood insurance coverage can reduce exposure of residents to financial losses from flood damage. Several communities interviewed were participants in the FEMA CRS and were benefiting from reduction in insurance premium rates. Reductions in rates can lead to an increase in the number of residents with coverage.

While reductions in premiums can help higher and middle-income residents afford flood insurance, these programs may do little to make flood insurance affordable for low-income residents, particularly low-income renters. For this reason, alternative programs, such as local flood insurance affordability programs, community assistance, or community-based insurance, are being considered, but they are not yet implemented by jurisdictions. The University of Pennsylvania's Wharton School has provided some commentary on potential insurance policy options in the linked brief [link], including: parametric microinsurance, premium reductions for low-cost flood mitigation, local flood insurance affordability programs, community assistance combined with a high-deductible NFIP policy, community-based insurance, and right-sizing coverage (Kousky and Wiley, 2021).

***Recommendation:***

*Understand how the following activities may encourage property owners to purchase flood insurance and/or flood-proof their facilities by tracking flood insurance coverage statistics: current efforts to expand flood hazard and flood risk information, making this information available to the public, and using the information to manage flooding.*

*Understand how the following activities may help increase flood insurance coverage for County residents and implement appropriate activities: parametric microinsurance, premium reductions for low-cost flood mitigation, local flood insurance affordability programs, community assistance combined with a high-deductible NFIP policy, community-based insurance, and right-sizing coverage.*

### 4.5.2 Community Technical Support Program

Several jurisdictions used technical support programs to address local flooding or drainage issues. Some jurisdictions, such as **Montgomery County**, have programs focused on issues within the public right-of-way (i.e., County-owned facilities). Montgomery County's Storm Drain Request Program provides residents with technical assistance for drainage issues associated with the public storm drain system. When a request is made, the County conducts a site visit and evaluation that can include recommendations to the resident. Those issues resulting from public assets that are performing at less than the design LOS are addressed. Issues originating from a resident's or neighbor's property are not within the purview of the program.

Other jurisdictions have developed programs to allow assistance outside the public right-of-way. The **District of Columbia** is piloting the "FloodSmart Homes" program – a joint District- and FEMA-funded technical assistance program aimed at helping residents address flooding issues on private property. The program will provide a free home assessment, technical consultation, and, potentially, free flood-proofing and resilience upgrades. The **City of Baltimore** reportedly uses a Department of Housing and Community Development Weatherization Program to help residents with home floodproofing where it is warranted. This program is income-qualifying, so is intended to serve socially vulnerable residents.

***Recommendation:*** *Consider whether a technical support program may be helpful in addressing residential flooding or drainage issues. Consider whether the goal of such a program might be limited to storm drain improvement or to assisting low-income residents in addressing floodproofing and other private property mitigations.*

### 4.5.3 Property Acquisition and Buyout Programs

Acquisition or buyout[3] programs can be a viable means for communities to remove high flood risk properties from continued use. However, this strategy can be controversial and must be only one facet of a broad flood management program that includes a range of risk identification, outreach, and mitigation activities. The **District of Columbia** indicated concerns surrounding gentrification and optics around buyouts. Casey Trees, a nonprofit, will buy property and convert it to open preservation land.

The Casey Trees nonprofit is able to purchase the house and allow the resident to remain there as long as they wish. This helps mitigate gentrification concerns in some cases.

In **Anne Arundel County, Maryland**, much of the higher elevation, less flood-prone property has already been developed and there is pressure to develop flood-prone infill lots. The County has identified flood-prone infill lots and targeted them for buyout to avoid conflict with development.

**Harris County, Texas**, has a Harris County Flood Control District Property Acquisition Program, Harris County Home Buyout Program, and Harvey Buyout Program (multi-family buildings). **New York City** participates in the New York State Governor's Office of Storm Recovery – Buyout & Acquisition Programs, which were designed to purchase properties damaged by Superstorm Sandy, Hurricane Irene, or Tropical Storm Lee. Similarly, the **City of Fort Worth** has done voluntary acquisitions of properties in the most flood-prone Arlington Heights neighborhoods [link].

***Recommendation:*** *As part of a repetitive loss plan and allowance for overland relief, consider whether property acquisition or buyouts should be planned for.*

[3] The County defines Property Acquisition and Buyout in the following manner: "Property Acquisition" allows for risk mitigation, with the benefit of allowing for overland relief and possible infrastructure improvements, i.e., acquiring these properties provides a strategic benefit to the County to reduce easement negotiations related to infrastructure improvements. Whereas "buyouts" are focused on removing individual properties with repetitive losses, mostly in FEMA floodplains that are already in recognized flood zones.

## 4.6 Integrating Flood Risk Information into Land Use Planning

### 4.6.1 Integrating Flood Risk into the Comprehensive Planning Process

The amount of stormwater runoff is influenced by several conditions, but impervious surfaces are the most pronounced contributors to increasing runoff in urban areas. Although it does not set zoning or associated development standards, a comprehensive plan is the tool through which planners establish a long-term land use scheme. Comprehensive planning has traditionally focused on achieving growth targets while preserving sensitive environmental, historic, and cultural resources. While preservation of a regulatory floodplain, and potentially sensitive stream bank or flood fringe areas, is typically a goal of comprehensive planning, integrating urban and pluvial flood risk has not typically been part of the comprehensive plan or sector master plan update processes. Guidance is available, in particular the Maryland Department of Planning's Water Resources Element Guidance Update for Integrating Water-related Climate Change Adaptation into Local Comprehensive Plans and for Considering Planned Growth and Development Impacts on Water Resources through an Equity Lens [link] (MDP, 2022).

### 4.6.2 Implementation of Flood Overlay Zones

Flood overlay zones are a means of introducing more restrictive development standards or regulations in areas known to be at high current and future flood risk. An overlay zone allows planners and regulators to specify zoning restrictions or more stringent development requirements specific to that zone. The following examples are not overlay zones (not zoning code overlays) but are regulatory zones based on flood hazard boundaries.

The **City of Fort Worth** has established a City Flood Risk Area that supplements the regulatory FEMA-derived floodplain. The **City of Charlotte** has established a similar Community Floodplain that includes a detailed study of floodplains that expand from the FEMA-derived regulatory floodplain. Through its Floodplain Regulations, **Montgomery County** has established a Floodplain District that includes the 100-year floodplain resulting from any drainage area of 30 acres or greater. Properties that fall within these expanded floodplain or flood district areas are subject to local regulations.

### 4.6.3 Adequate Public Facilities Ordinance

One way jurisdictions can ensure that infrastructure planning is adequate for planned development is through an Adequate Public Facilities Ordinance. These ordinances can be used to stipulate infrastructure capacity analyses required for development. While traditionally focused on transportation, public schools, police, and fire services, some jurisdictions include storm drainage in the ordinance language. **Anne Arundel County** and the **City of Annapolis**, for example, include a provision for adequacy of stormwater management facilities (MDP, 2012).

***Recommendation:*** *Consider what process will be used to integrate flood risk into land use planning, subdivision, and development review.*

## 4.7 Updating Regulations and Design Standards based on Flood Risk Information and Climate Change

Update of stormwater management, stormwater drainage, and building codes may be warranted as current and future flood hazards, and the potential impact of development on these hazards, are better understood. Several jurisdictions are moving forward with exploring appropriate regulation and standard updates that incorporate climate resiliency. The **Pittsburgh Water & Sewer Authority,** along with the **City of Pittsburgh**, is undergoing a stormwater code and ordinance review. The review process has included convening several stakeholder groups to address potential concerns and impacts on each group (developers, residents, etc.) and quantify cost impacts. Variance language that allows the reviewing

authority to deviate from standards due to site specific conditions can be key to ensuring such updates do not cause adverse conditions or undue hardship. Arlington County is considering completing a similar review of stormwater management and storm drain regulations and standards.

Likewise, the **City of Fort Worth**, is moving toward implementing a more stringent building code for areas of known urban flood risk. The City is an NFIP community and therefore currently has floodplain regulations requiring freeboard for buildings within the SFHA. The revisions will define City Flood Risk Areas based on detailed modeling and will expand building freeboard requirements to those areas as well. To better protect property owners in City Flood Risk Areas, the City is revising the existing Floodplain Provisions Ordinance and Updating the Stormwater Criteria Manual.

The **City of Charlotte** has passed a Drainage Article that requires a storm drainage plan and permit for any construction or expansion project, modification of the public storm drain system, or land disturbance affecting drainage features or patterns.

***Recommendation:*** *Proceed with the planned a review of regulations and standards to ensure that they are consistent with the resilience and flood management goals of the County.*

## 4.8 Flood Management Finance and Funding

Flood resilience, including both flood mitigation and programmatic management strategies, can be costly. This cost challenge has been addressed in different ways.

Several local jurisdictions use a stormwater management fee to help finance stormwater management (i.e., water quality regulation) activities. The following jurisdictions collect a stormwater fee:

**City of Alexandria**, **Prince William County**; the **City of Richmond** among others in Virginia; **Montgomery County**; **Anne Arundel County**; and the **City of Baltimore**. These revenue sources, while potentially limited to funding certain types of infrastructure that will have quality-related benefits, may be viable funding mechanisms for infrastructure that has a co-benefit of flood mitigation.

Following passage of Resilience Authority legislation in Maryland, **Anne Arundel County**, in partnership with the **City of Annapolis**, has established a Resilience Authority through which it intends to fund capital projects related to resilience, particularly transportation resilience.

The **City of Baltimore** is considering making elevation certificates free for residents (typically a cost of $1,000) to improve awareness for home renovation projects. The **District of Columbia** is piloting a "FloodSmart Homes" program to provide free home assessment, technical consultation, and potentially free installation of flood-proofing and resilience upgrades. The program is jointly funded through FEMA and District capital funding.

***Recommendation****: Consider development of a strategy for funding and finance of flood management programmatic strategies and capital projects.*

## 4.9 Storm Drainage Asset Management

While more of a maintenance strategy than flood management strategy, storm drainage asset management is critical to understanding the existing LOS and communicating the replacement and rehabilitation needs of a storm drainage network. These networks are often old and have a large number of unknown assets (potentially private) contributing to the network.

**Montgomery County** has made significant improvements by conducting a many-years-long campaign to improve the geospatial database of assets. The County prioritized those assets causing the most problems and are continually improving their database using field surveys. The County Department of Transportation, responsible for storm drain assets in the public right-of-way, maintains the data and works with other

agencies to merge new-build asset updates (from Department of Permitting Services) and share information with other agencies. The County has developed a geographic information system (GIS) tool that enables this progress (tools for field staff and for merging of geometry corrections), provides this information online to all residents [link], and shows status using a series of automated dashboards.

Identifying the number of assets in the ground and being able to communicate the need for improvement are the best ways of ensuring that budget requests for rehabilitation and replacement are prioritized.

**Baltimore County** has initiated an extensive Storm Drain Asset Management Program. The program began with moving mylar and paper plans into a GIS geodatabase and then building an accurate and comprehensive database. The program is conducting storm drain network hydrologic and hydraulic modeling to establish the LOS and compare the LOS against asset life span to help prioritize capital investment.

***Recommendation:*** *Prioritize identification of the location, condition, remaining service life, and LOS of existing assets to better assess the capital investment needed to maintain that LOS in the future.*

# 5. Recommendations

The programmatic strategies discussed in this TM will be reviewed with the County. This TM will be incorporated into the Task 6 TM, which will also include recommended strategies for the near- and long-term. Table 4 presents a summary of recommendations by subject area.

**Table 4. Summary of Flood Management Programmatic Strategies Recommendations**

| Subject | Recommendations |
|---|---|
| Governance Considerations | Explore methods to formalize communication and data sharing among relevant agencies for the specific goal of ongoing flood management. |
| Public Information | Consider whether existing flood hazard information, available via FEMA, can be made more accessible to the public using an available mapping tool, or whether development of a targeted flood risk tool might be helpful to also provide information on pluvial/urban flooding risk, when available, that are not addressed by FEMA NFIP flood maps.<br>Consider assessing whether NWS notifications or more location-specific real-time alerts would be helpful in avoiding damages or life-safety issues in flood-prone areas.<br>Consider development of coordinated and ongoing community engagement programs that will provide public education on flood risk and flood risk mitigation options. Consider outreach techniques targeted at socially disadvantaged communities.<br>Consider whether more stringent disclosures may be warranted in areas of chronic flooding. |
| Information Supporting County Flood Risk Management Functions | Explore the benefits of installing real-time rainfall, tide, or stream gauges to inform County operations. Consider whether drainage-focused building permit reviews could be an opportunity to address conditions that may exacerbate lot-to-lot flooding.<br>Identify available records that can be used to assess historical flood impacts, recognize limitations the records may have, and determine whether the data may inform ongoing flood management activities. |
| Equity Considerations | Ensure that flood management activities are carried out with appropriate consideration of the County's equity goals. |
| Flood Risk Mitigation | Understand how the following activities may encourage property owners to purchase flood insurance and/or flood-proof their facilities by tracking flood insurance coverage statistics: current efforts to expand flood hazard and flood risk information, making this information available to the public, and using the information to manage flooding.<br>Understand how the following activities may help increase flood insurance coverage for County residents: parametric microinsurance, premium reductions for low-cost flood mitigation, local flood insurance affordability programs, community assistance combined with a high-deductible NFIP policy, community-based insurance, and right-sizing coverage. |

| Subject | Recommendations |
|---|---|
| Flood Risk Mitigation (cont.) | Consider whether a technical support program may be helpful in addressing resident flooding or drainage issues. Consider whether the goal of such a program might be limited to storm drain improvement or to assisting low-income residents in addressing floodproofing and other private property mitigations.<br>As part of a repetitive loss plan and allowance for overland relief, consider whether property acquisition or buyouts should be planned for. |
| Integrating Flood Risk Information into Land Use Planning | Consider what process will be used to integrate flood risk into land use planning, subdivision, and development review. |
| Updating Regulations and Design Standards based on Flood Risk Information and Climate Change | Proceed with the planned review of regulations and standards to ensure that they are consistent with the resilience and flood management goals of the County. |
| Flood Management Finance and Funding | Consider development of a strategy for funding and finance of flood management programmatic strategies and capital projects. |
| Storm Drainage Asset Management | Prioritize identification of the location, condition, remaining service life, and LOS of existing assets to better assess the capital investment needed to maintain that LOS in the future. |

# 6. References

Agency for Toxic Substances Disease Registry (ATSDR). 2022. CDC/ATSDR Social Vulnerability Index. November 16. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html.

Boston Water and Sewer Commission (BW&SC). 2023. *City of Boston Inundation Model*. Accessed February 14, 2023. https://www.bwscstormviewer.com/index.html

Federal Emergency Management Agency (FEMA). 2022. *Flood Risk Disclosure Model State Requirements for Disclosing Flood Risk During Real Estate Transaction.* July 11, 2022.

Kousky, Caroline and Helen Wiley. 2021. *Improving the Post-Flood Resilience of Lower-Income Households through Insurance.* University of Pennsylvania Wharton School Risk Management and Decision Process Center. Accessed February 14, 2023. https://riskcenter.wharton.upenn.edu/wp-content/uploads/2022/04/Improving-LMI-Household-Flood-Insurance-Options_Issue-Brief.pdf

Maryland Department of Planning (MDP). 2022. 2022 Water Resources Element (WRE) Guidance Update: Best Practices for Integrating Climate Change, Identifying Suitable Receiving Waters. https://planning.maryland.gov/Pages/OurWork/envr-planning/water-resources-mg/2022/2022-guidance-update.aspx

Maryland Department of Planning (MDP). 2012. Adequate Public Facilities Ordinances in Maryland. https://planning.maryland.gov/Documents/YourPart/773/2013/APFO-WorkgroupReport072213.pdf

National Resource Defense Council (NRDC). 2022. *How States Stack Up on Flood Disclosure.* https://www.nrdc.org/flood-disclosure-map

# Appendix A
# Desktop Review and Interview Summary

# Desktop Review and Interview Summary

## A.1 Approach

### A.1.1 Methods

Two primary methods were used to identify the ways other jurisdictions have addressed flood management in their localities: a desktop study and an informal interview with representatives from selected jurisdictions. Interviews were conducted virtually using a prepared questionnaire (Attachment 2). Table A1-1 lists jurisdictions with novel strategies for flood management.

**Table A1-1. Jurisdictions with Novel Programmatic Strategies for Flood Management**

| Jurisdiction | State | Desktop Review | Interview |
|---|---|---|---|
| Anne Arundel County | Maryland | | X |
| Charlotte-Mecklenburg Stormwater | North Carolina | | X |
| City of Baltimore | Maryland | | X |
| City of Boston | Massachusetts | X | |
| MWRD | Illinois | | X |
| City of Denver and Mile High Flood District | Colorado | | X |
| District of Columbia (DOEE/DDOT) | District of Columbia | | X |
| City of Fort Worth (Stormwater Management Division) | Texas | | X |
| City of Houston/Harris County Flood Control District | Texas | X | |
| New York City | New York | X | |
| Pittsburgh Water and Sewer Authority | Pennsylvania | | X |

DDOT = District Department of Transportation
DOEE = Department of Energy and Environment
MWRD = Metropolitan Water Reclamation District of Greater Chicago

## A.2 Topics of Review

Table A1-2 presents policy topics reviewed.

**Table A1-2. Policy Topics Reviewed**

| Policy Topic | Elements Relevant to Urban Flooding | Key Considerations |
|---|---|---|
| O&M-Public | Maintain pipes, channels, green infrastructure. Keep catch basins/inlets clear of debris. | ▪ Which elements currently require public maintenance as part of O&M programs, and should any be added? (i.e., size threshold for open channels and ownership considerations vs. right-of-way).<br>▪ When infrastructure is slated for an upgrade, is urban flood mitigation encouraged (or required) in partnership with other activities (i.e., build a new school; can we over-mitigate detention or green infrastructure)? |

| Policy Topic | Elements Relevant to Urban Flooding | Key Considerations |
|---|---|---|
| O&M-Private | Green infrastructure, downspouts, maintenance agreements. Temporary floodproofing until more permanent mitigation is installed. Technical assistance and funding. | ▪ New development or retroactive? Include private homeowners? Requirement maintenance schedule?<br>▪ What steps can private homeowners take (i.e., backflow valves, floodgates, sandbag readiness) to protect themselves and their property until more permanent measures can be installed? Is technical assistance or funding available? |
| Urban Flood Zones/Floodplain Definition | Designated risk areas, i.e., local (non-FEMA) floodplains, historic creek beds, storm sewer areas with low capacity,<br>FirstStreet flood layers (i.e., Redfin). | ▪ Does the community have designated risk areas? Are these advisory or regulatory? Are they property or roads?<br>▪ Do localized standards require an urban floodplain development permit?<br>▪ How has the community addressed potential impacts on real estate property values? Disclaimer on data (i.e., Boston viewer, not for detailed analysis, etc.). |
| Redevelopment Quantity Standards; Differential Runoff Requirements; Land Use Planning | Private infill and redevelopment. Differential runoff, compensatory floodplain or detention storage, mitigation requirements, climate escalation, storm sewer design standards. Use building codes to eliminate increases in runoff from newly constructed properties. | ▪ Thresholds. Required if contributing urban drainage area is greater than 1 acre.<br>▪ Timeframe. Include climate escalated precipitation.<br>▪ Defined LOS and climate integration.<br>▪ Integrate flood with MS4/water quality requirements/policy. |
| Freeboard | NFIP floodway compliance. Exceed NFIP or State Department of Transportation criteria. | ▪ Pure freeboard (i.e., 2 feet over the 100-year) or include climate escalation parameters?<br>▪ What type of development or infrastructure has a freeboard requirement? |
| New Development Setback/Fringe Requirements | Locational restrictions (i.e., mapped urban flood<br>zones, coastal hazard/sea level rise zones, or contributing drainage area). Similar elements to redevelopment. | ▪ Thresholds. Required if contributing urban drainage area is greater than 1 acre; timeframe; process.<br>▪ Does the community follow No Adverse Impact approach/principles? |
| Grading/Drainage Provisions | Require no adverse flood impact or improve the situation when a certain level of redevelopment is met. Require city-funded projects to consider whether neighborhood-scale nuisance/urban flooding can be improved in project right-of-way; climate escalation. | ▪ Thresholds. Required if contributing urban drainage area is greater than 1 acre; timeframe;<br>▪ Requiring a simple evaluation of potential may open up opportunities for grants or loans (partnerships or opportunities). Include climate escalated standards and LOS? Consider incorporating Design for Exceedance principles (UK-CIRIA). |
| Gutters and Downspouts; Overflow Pipes | Direct away from structures and into receiving sewers and green infrastructure. | Required for all new and redevelopment or just at a threshold point? |
| Site-level Building Standards | Elevation of first floor. Basements (allowed?), enclosures with flood vents, elevated mechanical/ electrical/plumbing. | What thresholds/standards must mitigation measures meet? (i.e., standard elevation difference, climate standard, freeboard, FEMA vs. urban flood map elevations, different standards for CSO vs. MS4 areas). See also freeboard item often executed as a building standard. |

| Policy Topic | Elements Relevant to Urban Flooding | Key Considerations |
|---|---|---|
| Hazard Mitigation | Restoring natural floodplains, non-governmental organization partnerships for floodproofing, BMPs for urban drainage, design for exceedance (CIRIA), managed retreat (buyouts). Policies that ensure fair processes and compensation for mitigation and managed retreat. "Worst First" type prioritization for capital improvement spending in mitigation. | Policy can enable or set requirements for what to do in redevelopment and/ or buyouts as related to mitigation. Managed retreat, buyouts, local programs—encourage or require acquired property to be used for mitigation measures/community amenities? Staged mitigation—what can we fix now and what is the long-term plan? Ensure that stormwater and mitigation infrastructure is equitably and adequately funded. Should State Revolving Funds be used for flood mitigation as well as other infrastructure and that coded in policy? Prioritize repetitive loss properties, and if so, define as FEMA zones (insured only) or all properties (how to define without data)? |
| Diversity and Inclusion/ Equity | Fully incorporate equity into resilience planning process and policy. Integrate social data into policy evaluation. Overlay social vulnerability mapping data to inform urban flood policy.<br>Pairing of social and technical information. Stormwater Management Advisory Committee and Community Benefits Assessment requirement. Remove any legal barriers to rate structures that enable billing/ assistance options so that mitigation costs do not disproportionately impact disadvantaged communities. | Use policy to enable and/ or require neighborhood-level reduction strategies and target BMPs on individual lots. Evaluate policies to see if they can be changed to make a difference in urban/nuisance flooding at the small scale. Engage community groups when determining design issues and policies (threshold for requiring engagement?).<br>Maximize sewer system improvements by considering climate resilience, flooding, and equity goals together (threshold to consider or require in policy?). Require equity reports for mitigation and infrastructure measures. |
| Vacant Lots/Land Acquisition | Repurpose for urban flood mitigation. | ▪ Are vacant lot programs integrated with local land reclamation efforts?<br>▪ Is a green infrastructure analysis required before sending tax properties to auction?<br>▪ Are properties in floodplain put in a conservation set-aside? |

BMP = best management practice
CSO = combined sewer overflow
FEMA = Federal Emergency Management Agency
LOS = level of service
MS4 = municipal separate storm sewer system
NFIP = National Flood Insurance Program
O&M = operations and maintenance

# A.3 Jurisdictions

## A.3.1 Anne Arundel County and Anne Arundel and Annapolis Resilience Authority

### A.3.1.1 Overview

Anne Arundel County is a coastal Maryland county located to the northeast of Arlington. The County was selected for research because of the newly established Anne Arundel County/City of Annapolis Resilience Authority (Throw Environmental) as well as a number of vulnerability assessments undertaken by the Anne Arundel County (AACo) Department of Public Works Water Resource Division.

Key highlights:

- Stormwater Strike Force to look at downstream stability.
- Newly established Resilience Authority.
- Lot-to-lot flooding: AACo offers technical assistance but considers lot-to-lot a private property issue to sort out through legal means.
- AACo has restoration Grant Program through Chesapeake Bay Trust, which is water quality focused but, thinking creatively, also an opportunity to blend conveyance (water quantity) into water quality practice and take advantage of program as cost share. AACo has worked with several churches with ongoing flood problems and has been able to help them. Program is not targeted at homeowners but can be used at private properties.
- Any infill lots that remain have environmental challenges: many act as de facto stormwater management for conveyance or stormwater quality. When lots get developed, it creates problems for residents in the lot and surrounding neighborhoods. Office of Planning and Zoning, for first time in history, denied development of a lot because it was incumbered by nature. AACo has endeavored to acquire lots and take them off the tax roll/ development docket so there is no need to be at odds with developers.

### A.3.1.2 Land Use Planning and Permitting

- AACo created a Stormwater Strike Force, the "eyes on the ground" for review staff, inspectors, and project-level and senior engineers looking at downstream stability. The County has an outfall adequacy requirement; if there is an instability with an existing outfall, the developer may be required to design, permit, and construct an outfall stabilization for their project in addition to stormwater regulatory requirements. The Stormwater Strike Force is able to spot potential issues during the plan review approval process, be a liaison with County staff, and provide technical assistance during construction. There is an opportunity to get plan reviewers invested in real world context of the plan and ask, "Are there problems we should be aware of? Let's put our heads together to mitigate."
- AACo has less redevelopment and more greenfield development than Arlington County. In discussions about requiring developer to purchase floodplain easement on downstream property or to move existing infrastructure on downstream property in order to move forward with a project, it gets expensive. Depending on political winds, may not be feasible. At a minimum, County can require over-management in terms of quantity. County wants to be careful not to disincentivize redevelopment, but if redevelopment is heavy, County considers upping the ante.
- Big fan of carrot-based approach. As an example: the County has funds to entice redevelopers to go above and beyond or it can create a trading program like the District of Columbia (DC) has.
- Resilience Authority (RA) – newly established. Resilience *financing* authority. RA is not a planning agency but works in partnership with Planning and Public Works in the County and City. They will be part of the plan's implementation. RA tasked with making County's processes efficient and identifying sources of revenue, how to pay for capital improvement project (CIP) on ground. Project portfolio will be based on the planning from County and City. RA works in green bank issue of financing.
- Historically, AACo had been looking at 24-hour window but is now seeing more intense, shorter duration storms causing problems: 3 inches in an hour is worse than 5 inches in a day. AACo does not have good engineering solutions yet nor good data at hourly intervals. RA is necessary to help with thinking more proactively.

### A.3.1.3 Urban Flood Zone Identification and Mapping

- AACo delineates riverine floodplain to an extent.

#### A.3.1.4 Hazard Mitigation

- Floodplain Acquisition program example: $423,000 spent for a house with repetitive floodplain-driven flooding that was developed 15 years ago. Expensive but engineering solution to make more viable would have been more expensive. Primary metric: "Is there revenue to support it?" There are opportunities in existing communities where parcels are flooding for an authority to step in and purchase, and if used as flood mitigation, parcel adds value to community that could be leveraged to pay for costs. Fee simple purchase with not a lot of political sensitivity. Problem to avoid is condemning properties and then turning them into flood mitigation means.

#### A.3.1.5 Equity and Community Engagement

- AACo has applied for a FEMA grant for assessment of Shady Side area, south of Annapolis, which is fairly flood-prone. If successful, part of the grant will be dedicated to outreach.

#### A.3.1.6 Flood Warning, Emergency Response, and Recovery

- Monitor high hazard facility, regulated by Maryland Department of the Environment.
- Their sense of road flooding is based on experience. Highways group is working with consultant to put out 20 to 30 stage gauging stations at road crossings to trigger response, given a flood elevation. A couple of gauges are tied to controlled gates that come down to prevent drivers from entering into floodwaters. They also have remote sensing tools and emergency alerts. Goal is to marry stage gauging with near term precipitation data so they are prepared, ready, and responding 3 hours, rather than 15 minutes, before a road overtops. County highway department funds most of the effort.

#### A.3.1.7 Funding and Finance

- Transportation flooding revenue is limited (no tolling system). Fee systems in place for water quality. Trying to work with State to make it more competitive in federal transportation money. RA looks at onsite and offsite funding. Onsite: County assets and developing revenues. Offsite: assets that can be leveraged and redirected to flooding exercises. Stormwater utility is well funded. RA is in conversation to leverage revenues from water quality with water quantity program.

### A.3.2 City of Baltimore

#### A1.1.1.1 Overview

Baltimore was one of the primary cities chosen for this screening study because of its recurrent urban flooding issues, proposed/implemented policy updates to address flooding, and equity considerations.

Key highlights are as follows:

- Baltimore is a Class 5 Community Rating System (CRS) community. In partnership with the University of Maryland, they have mapped common flood areas based on statistical analysis, including urban areas and heavy storm events.
- Found in Article 7, Floodplain Management, Baltimore regulates according to the geographic extent of the 0.2 percent or 500-year floodplain. Baltimore is the only county in Maryland that does this.
- For O&M, the Department of Public Works protects, enhances, and restores waterways. The city implements a Stormwater Fee (calculated by amount of impervious surface on a property) and Guidelines/incentives for private property owners to install green infrastructure or stormwater management methods.

### A.3.2.1 Land Use Planning and Permitting

- Lot-to-lot flooding: Planning does annual publicity to let owners know that they are in the FEMA floodplain. Planning connects with Department of Public Works (DPW) for stormwater management and sediment and erosion control. DPW sends inspectors to identify source. There are instances when owners are responsible (e.g., fixing grading of private property).
- DPW requires either redevelopment or new development to manage and retain the volume of a 10-year storm. See Article 7, Natural Resources Code, Division II Stormwater Management.
- Redevelopment is detailed in the City Code (Article 7, Section 23-7).
- Planning needs to identify locations of flood hazards outside of FEMA floodplain; map would be needed as first step to understand cause of flooding and could mean a CIP. Next step would be to regulate construction in those areas in the same way it is regulated in a FEMA floodplain, which would require legislative staff because they anticipate pushback from developers. Next step after mapping: watershed master plans will be needed to identify flooding hotspots and suggest CIP. For Class 4 upgrade, City needs watershed master plans.
- A 2-foot elevation is needed for mechanical equipment if new system installed. If non-tidal, 2 feet over base flood elevation. If in tidal system, elevation of 0.2 percent annual flood.
- For New Development Setback/Fringe requirements – "A minimum 25-foot flood protection setback must be maintained from the edge of the banks of any watercourse delineated on the floodplain map or FIRM as having a floodplain" (Article 7, Section 3-16). Also, vegetation should be planted along watercourse banks to reduce erosion.
- For Grading/Drainage Provisions in Baltimore, a grading permit is required:
  - If the proposed work disturbs more than 5,000 square feet of surface area or more than 100 cubic yards of earth.
  - For any grading activities in any watercourse, floodplain, wetland area, buffers (stream and within 100 feet of tidal water), habitat protection areas, or forest buffer areas, including forest conservation areas.
- For gutters in the city, Baltimore Code states that Building drains are to be no less than 4 inches.
- The site-level building standards follow the City Floodplain Code.
- When a building is designated as historic, it does not have to meet the full force of the floodplain code; however, some level of floodproofing is required. Baltimore's Commission for Historical and Architectural Preservation works closely with the Floodplain Office to determine appropriate level of floodproofing and oversees flood mitigation project reviews and criteria for Baltimore's historic areas and properties.
- Flood Infrastructure Working Group formed by the mayor meets monthly and includes Planning, DPW, Department of Transportation (DOT), Rec and Parks, and Department of General Services (above ground infrastructure maintenance). Purpose of the working group is to come up with joint solutions.

### A.3.2.2 Urban Flood Zone Identification and Mapping

- Initial efforts are underway to delineate commonly flooded areas (have data but not centralized).
  - Planning is required by FEMA to collect data on floods within FEMA's floodplain. DPW has data on flooding because of burst pipes, pluvial flooding, and areas with poor stormwater systems. DOT has another set of data on the deployment of crews during flooding. Office of Emergency Management deploys crews for rescues, and there is 311 data for basement and street flooding.
  - Recognize the need to consolidate data; the models do not reflect reality. Details of stormwater pipe systems are unknown. DPW is undertaking a hydrologic and hydraulic (H&H) model to identify locations and capacity of pipes, looking at three watersheds with pilot projects, which will expand to citywide to 2025. They will include projected rainfall events when conducting study.
- The urban Flood Zones/FEMA Floodplain are defined in the Baltimore CoDe Map.

- Planning, Designing, Operating, and Maintaining Local Infrastructure in a Changing Climate
  - "Senate Bill 457 (2020) authorizes local governments to establish a Resilience Authority to fund large-scale infrastructure projects aimed at addressing the impacts from climate change" (page 39).
  - "Baltimore County's codes currently exceed the National Flood Insurance Program requirements and further mitigate vulnerability to flooding" (page 42).

#### A.3.2.3 Hazard Mitigation

- Regarding hazard mitigation, the Disaster Preparedness and Planning Project (DP3), which the city adopted in 2018, fulfills the FEMA requirements to update the city's formal plans. For stream restoration, the city implements stream restoration and stabilization projects.
- Baltimore also has done a few property acquisitions of flood-prone properties in Towson.

#### A.3.2.4 Equity and Community Engagement

- The Baltimore Urban Waters Partnership held workshops in 2020 with participants of experts and stakeholders to produce the Baltimore Urban Waters Flood Science and Policy Action Report to address urban flooding.
- Baltimore also conducts flooding equity assessments according to their Nuisance Flood Plan 2020 (see page 68).
- Regional flood-focused partnerships with Maryland Silver Jackets.
- No designated person in the Office or City for public outreach. Staff members will pass out resources through tabling and post information on social media. There is also a tool, MyCoast Maryland application, that is available for users to identify nuisance flooding.

#### A.3.2.5 Flood Warning, Emergency Response and Recovery

- Emergency Management Alert System: BMore Alert.

#### A.3.2.6 Funding and Finance

- Currently, Baltimore receives funding for several flood mitigation projects from the Maryland Comprehensive Flood Management Grant Program.
- The Maryland Department of the Environment is funding an H&H study for Frederick Avenue, the Maryland Department of Natural Resources Grants Gateway: six different outcomes from the National Oceanic and Atmospheric Administration (NOAA) to address flooding.
- City wants to provide, for free, elevation certificates for residents (costs an average $1,000) to have better understanding of compliance when doing home improvement.
- Department of Housing and Community Development has Weatherization Program, funded by federal Housing and Urban Development (HUD).

### A.3.3 City of Boston

#### A.3.3.1 Overview

Boston was chosen as a key city to screen because of its recurrent urban flooding issues, proposed/ implemented policy updates to address this, and equity considerations as well.

Key highlights are the following:

- The Resiliency Policy "requires that all projects consider present and future climate conditions in assessing project environmental impacts, including carbon emissions, extreme precipitation, extreme heat, and sea level rise. Projects must identify building strategies that eliminate, reduce, and mitigate adverse impacts including those due to changing climate conditions".
- Boston Redevelopment Authority Article 80: Development Review and Approval.
- Boston has an Online hazard mapper with urban hazards, including heat and flooding maps. The mapper overlays these with social equity mapping.

### A.3.3.2 Land Use Planning and Permitting

- City of Boston requires all construction and re-construction projects to retain stormwater onsite. Projects less than 100,000 square feet must infiltrate the volume of runoff equal to 1 inch of rainfall times the total impervious area prior to discharge. Projects greater than 100,000 square feet must infiltrate volume of runoff equal to 1.25 inches of rainfall times the total impervious area on site. These requirements are documented in the Massachusetts Stormwater Handbook (see also Smart Utilities Policy).
- See Article 25 for Flood Hazard Districts. Building codes are referenced to the Massachusetts State Building Code.
- Article 25A provides specific requirements for the Coastal Flood Resilience Overlay District. Article 25A requires a minimum sea level rise assumption of at least 2 feet [25A-6(1)(a)]. The Boston Planning and Development Agency has also published Coastal Flood Resilience Design Guidelines for redevelopment and new construction projects.
- The Boston Environment Department provides recommendations for improving flood resiliency to individual homeowners as part of the Climate Ready Boston Program. The Boston Planning Department has also published potential strategies on increasing flood resiliency for building retrofits. The State of Massachusetts Department of Housing and Community Development publishes guidelines for gutters and downspouts. Section 10.17 of Unified State Plumbing Code sets out requirements for storm drain design. See also DHCD CHARM Rapid RVA Design Guidelines.
- Climate Resilient Design Standards and Guidelines for Protection of Public Rights-of-Way.

### A.3.3.3 Urban Flood Zone Identification and Mapping

- The City of Boston has an online map viewer application that displays social vulnerability data, stormwater and coastal flooding, temperature data from the heat resiliency study, and Urban Heat Island Intensity analysis presented in the 2021 Natural Hazard Mitigation Plan Update.

### A.3.3.4 Equity and Community Engagement

- Green infrastructure integrated in Boston public schools science curriculum.
- StormSmart Coasts Program. A catalogue of publications on coastal zone management developed by the Massachusetts Office of Coastal Zone Management.
- The City of Boston has developed the Greenovate Leaders Program through which Bostonians can be trained to lead climate equity discussions in their communities. The program hosts roundtables and workshops for socially vulnerable groups to address equity concerns and improve resiliency in disadvantaged areas.

### A.3.3.5 Funding and Finance

- Boston is one of 78 municipalities participating in the Massachusetts Coastal Resilience Grant Program, which provides financial and technical support for resilience and adaptation. Grants are available for planning, outreach, assessment, design, and construction activities.

- Boston has a Climate Resiliency Fund established "to " help finance the berms, seawalls, and natural systems restoration that will help protect real estate in the vulnerable Seaport district". Developers pay into the fund to offset state, local, and federal expenditures on flood infrastructure.

#### A.3.3.6 Other Policy Topics

- BW&SC manages most municipal storm drains. In 2013, BW&SC established memorandums of understanding under a Consent Decree which requires the following:
  - Perform annual wet and dry weather field screening of its storm drain outfalls, CSO outfalls, and storm rain manholes that discharge to (interconnect with) other MS4 drain systems.
  - Establish priorities and schedules for investigating sub-catchment areas that demonstrate contamination.
  - Implement a sub-catchment investigation program based on the priorities and schedules established.
  - Correct or repair illicit discharges within deadlines established in the Consent Decree.
  - Coordinate efforts with other city agencies, state agencies, and surrounding cities to implement green infrastructure solutions.
- These policies are summarized in the most recent BW&SC Annual Stormwater Management Report (BW&SC 2022).

#### A.3.3.7 Mitigation Projects of Note

- Climate Ready Boston helps Boston plan for the impacts of climate change and build a resilient future.
- Multiple projects, including Climate Ready Dorchester, Climate Ready South Boston.

### A.3.4 City of Fort Worth

#### A.3.4.1 Overview

Fort Worth was selected as a key city to be screened because of its modeled/mapped local flood risks that are tied to policy. The City of Fort Worth Interim Assistant Director of Transportation and Public Works Department and City Floodplain Manager were interviewed as part of the research.

Key highlights are the following:

- Fort Worth is equipped with an integrated stormwater management community program to assist their counties in meeting their state stormwater permits during construction and post-construction.
- The City of Fort Worth developed a local floodplain management policy designed to amend the city's existing Floodplain Provisions Ordinance, Subdivision Ordinance, Stormwater Criteria Manual, Comprehensive Plan, and other applicable city codes. The policy establishes a consistent method for reducing flood damage that occurs in areas outside of current city regulatory floodplains, specifically urban flood hazard areas.
- The City produced the Informal Report: Update on Non-FEMA Flood Risk Initiative (August 2022), proposing to amend the Comprehensive Plan to include both FEMA and City flood risk mapping areas.
- The City of Fort Worth provided the Cumulative Impacts of Development on Flood Risk (October 2022) report to the mayor and City Council. The report included an analysis of potential options for City Code revisions related to impervious surfaces.
- The stakeholder group was involved at the beginning (for non-FEMA flood risk areas) and volunteered after awareness of flood risk was not mapped or communicated well. More support was garnered after unintended consequences were realized. Surveys reflected locals were in favor of getting maps updated at the end of the day. City promotes transparency to help property owners in decision-making.

### A.3.4.2 Land Use Planning and Permitting

- The City of Fort Worth Public Works manages most stormwater projects.
- Fort Worth reviews development if the area is greater than 1 acre. They require developers to fill out a certificate of compliance, floodproof, and consider flow paths and adverse impacts. The engineer is held responsible. The City does not provide a detailed review.
- Regulations are focused on building protections and are based on the 100-year storm event. City has adopted 2 feet of freeboard standard, local areas included.
- The City adopted a Grading Ordinance in June 2012, which includes requirements of an integrated Stormwater Management Plan grading permit for land alterations in excess of 1 acre, and lot grading patterns for single family and building permit applicants.
- Two Case studies on cumulative impervious areas were conducted:
  - Increases in impervious cover
  - Loss of flood/valley storage within natural creeks that have been encroached upon
- Goal of case studies is to verify standards are accurate; areas were identified that already exceed the amount of impervious cover anticipated. The City does not regulate impervious cover in backyards. About to kick-start stakeholder engagement. Interestingly, basins with detention ponds performed well for low-frequency (100- and 500-year) storm events. But 1-, 2-, 5-, and 10-year storm flows were increasing significantly. City does not look at smaller storms typically.
- Case studies provide evidence necessary to help planners change standards.
- On valley storage side, a typical development process is as follows: There is a natural stream through a pasture with a wide floodplain with X amount of storage, and in typical FEMA fashion, will allow encroachment up to a certain point to create channelized stream. This leads to a more efficient channel with increased velocity (development engineers improve conveyance) but can sometimes increase velocity and flows downstream. The Study found that this increased velocity is occurring.
- Through the case study areas, Fort Worth can adjust standards and reflect reality (impervious cover will increase runoff or the City can limit impervious cover or offset mitigation measures, the latter of which is currently not allowed). Standards will be rolled out to whole city. Not intending to look basin-by-basin.
- Regarding infill, Council members want a development moratorium. They and politicians create policy.

### A.3.4.3 Urban Flood Zone Identification and Mapping

- Fort Worth is in the process of updating their citywide map (which is currently in low-level in detail) to include pipe sizes, have a more specific drainage basin to better map flood risk, and help regulate where there is a high degree of data. Planning to take updated map to Council to update floodplain ordinance and stormwater management criteria regulations.

### A.3.4.4 Equity and Community Engagement

- Development-focused stakeholder group (the real estate council) for non-FEMA areas was involved early on. They got on board once they realized how extensive the problem was. Community wants flood information reflected on maps. Concern was expressed at kickoff because of the potential impacts on property values. However, it was concluded that there is no downside in having more information. The City wants to be transparent to help owners with their decision-making.

### A.3.4.5 Funding and Finance

- The City of Fort Worth received funding of $403 million from the U.S. Army Corps of Engineers for the Trinity River Vision/Central City flood control project.
- The City also collects a stormwater utility fee.

#### A.3.4.6 Other Policy Topics/Building-related Policies

- Article VIII contains specific requirements for floodplain provisions.
- The Texas minimum Construction Standards (page 32) requires all gutters and downspouts to be installed or replaced on all rehabilitations, along with minimum requirements for slope, distance from foundation, screens, and other guidelines.
- The City has also done voluntary acquisitions of properties in the most flood-prone Arlington Heights neighborhoods.

#### A.3.4.7 Mitigation Projects of Note

- The Native Grass Program helps the City of Fort Worth to reduce flooding risks by planting native grasses and flowers around reconstructed drainage channels; these plantings reduce erosion.

### A.3.5 City of Houston

#### A.3.5.1 Overview

Houston was chosen as a key city to screen because of its recurrent urban flooding issues, proposed/ implemented policy updates to address this, equity considerations, flood easements to restrict development in known flooding areas, urban flood mapping, and increased building requirements.

Houston was also noted to have a mapping tool that has regulatory and "ponding" layers. The City has also tied funding to equity through policy, climate accounted for with increased freeboard but not with climate science, and coastal barrier projects in planning stages in response to sea level rise.

#### A.3.5.2 Land Use Planning and Permitting

- The Code of Ordinances Chapter 19 provides regulations and standards in Houston for special flood hazard areas (SFHAs).
- Chapter 9 of the Infrastructure Design Manual: Stormwater Design Requirements (and supplemental revision to storm detention requirements) of the City of Houston include drainage criteria, storm sewer design, and maximum ponding elevation. The City also has incentives for green stormwater infrastructure, including an expedited permitting pilot program and tax abatement program.
- Chapter 19 of the Houston Code of Ordinances lays out the definitions and regulations of the City for floodplains.
- The Houston/Harris County freeboard updates state that all new construction in floodplains is to be built up 2 feet above the water level of a 500-year storm.
- The City of Houston also added measures of fringe/setback requirements after Hurricane Harvey.
- See The Houston Construction Code for minimum standards for the construction, alteration, maintenance, repair, and demolition of buildings and other structures. The city also published a more visionary document of the Houston Incentives for Green development, which could potentially lead to further regulation in the near future.
- The City's ordinances and building codes also guide and regulate construction in the floodplain in order to align with NFIP standards. This includes limited development in 1% and 0.2% percent annual flood chance floodplains, requirements for buildings to be 2 feet above 500-year elevation, and flood studies required for developments adjacent to a creek.

#### A.3.5.3 Urban Flood Zone Identification and Mapping

- The City of Houston has an interactive ArcGIS Pro web map (GeoLink Floodplain) that displays urban floodplains or FEMA floodplains.

#### A.3.5.4 Hazard Mitigation

- In terms of flood risk property acquisition, the City has a Harris County Flood Control District Property Acquisition Program, Harris County Home Buyout Program, and Harvey Buyout Program (multi-family buildings).

#### A.3.5.5 Equity and Community Engagement

- Harris County MAAPNext is an interactive tool with resources and educational information for community members to understand their flood risks.
- The Harris County Flood Control District has held more than 150 Bond Program Community Engagement Meetings, which saw 12,000+ registered attendees, and 8,000+ bond program comments were received.
- Houston has initiatives to redirect flood mitigation projects/funds to historically high social vulnerability index (SVI) and lower income communities. They have Citizens Advisory Committees that provide guidance on flood mitigation projects/resource distribution. The Harris County Flood Control District's Community Flood Resilience Task Force influences policy with an equity focus.

#### A.3.5.6 Funding and Finance

- The City of Houston/Harris County is actively receiving bond funding with a total received amount of $2.5 billion and $578 million in bond funding authorized.
- Harris County has also received in Partnership Funding.
- The unprecedented Houston/Harris County "worst first" formula (eight criteria) was set in policy for a $2.5 million flooding bond, "Harris Thrives." This policy included a community-based oversight committee for diversity, equity, and inclusion in implementation. The Flood Control District has also developed written guidelines adopted by Commissioners Court on August 27, 2019, to assist with the prioritization of the 2018 bond projects that have not started.

#### A.3.5.7 Other Policy

- Stormwater Operations Branch of Public Works manages storm sewer systems, roadside and off-road ditches, detention basins, and stormwater pump stations. They also implement green infrastructure projects.

#### A.3.5.8 Mitigation Projects of Note

- Houston invests in incentives for nature based infrastructure to mitigate against water pollution and flooding effects in the future.
- The County projects interactive map gives an overview of capital and maintenance projects the City is undertaking to reduce flooding risks.

### A.3.6 City of New York

#### A.3.6.1 Overview

New York City was selected because of their planned pilot Cloudburst and Bluebelt Programs as well as their Harbor Protection Program. These programs are explained as follows:

- Cloudburst program – a pilot program to address flood impacts of intense rainfall events.
- Bluebelt program – "Ecologically rich and cost-effective drainage systems that naturally handle the precipitation runoff from […] streets and sidewalks by preserving natural drainage corridors […]".
- Harbor Protectors Program – a program to enlist residents as volunteers to maintain green infrastructure and improve functionality of the piped stormwater system.

### A.3.6.2 Land Use Planning and Permitting

- New York City Department of Environmental Protection (NYCDEP) developed a Unified Stormwater Rule, which changes requirements related to how stormwater is managed on new and redevelopment properties across New York City. The rule requires updated stormwater quantity and flow rates for site and house connection proposals and a retention-first approach for projects that need MS4 Construction Permits.
- NYCDEP has developed the Guidelines for the Design and Construction of Stormwater Management Systems to "provide guidance to New York City's development community and licensed professionals for the planning, design and construction of onsite source controls that comply with NYCDEP's stormwater performance standard ".
- New York City requires 1 foot of freeboard for commercial and multi-family buildings, and 2 feet for single- and two-family buildings in Zone A SFHAs (New York City Administrative Code, Title 28, Chapter 7, Appendix G, Section BC G501). Chapter 4 of the New York Zoning Resolution lists setback requirements for flood zones. Chapter 11 of the New York City plumbing code sets standards for grading and storm drainage design, including sizing of gutters and downspouts (sized for 100-year rainfall rate of 3 inches per hour). The code also requires backflow preventers in SFHAs.
- As part of the New York City Climate Mobilization Act passed in 2019, New York City Council passed Local Laws 92 and 97, which require new and substantially renovated or enlarged rooftops to incorporate sustainable (green) roofing on all available roof space. The City anticipates that these laws will help buildings manage up to 1 million additional gallons of stormwater per year and help manage water quality and urban flooding. The City provides financial incentives through a grant program for residents to install green infrastructure (green roofs in particular) on their private property.
- New York City Planning Department: Coastal Climate Resilience – Designing for Flood Risk.
- New York City Planning Department: Retrofitting Buildings for Flood Risk.

### A.3.6.3 Urban Flood Zone Identification and Mapping

- New York City has published its Stormwater Resiliency Plan to address climate change resiliency. Page 10 provides a citywide map of two scenarios: 1) moderate stormwater, rain-driven flooding under future conditions, and 2) extreme stormwater, rain-driven flooding under future conditions.
- The NYC Flood Hazard Mapper tool shows the flood hazard areas from the FEMA Flood Insurance Rate Map (FIRM).

### A.3.6.4 Hazard Mitigation

- Emergency preparedness for New Yorkers
- New York City seeks to get residents involved in resiliency and environmental stewardship through its Harbor Protectors program. The program enlists residents to clean and stencil catch basins and care for rain gardens. A 311 program encourages residents to report sewer grates that are blocked with leafy debris.
- New York City has adopted an Interim Flood Protection Measures Program, which is used to protect critical infrastructure from hurricane flooding. Measures to preserve natural drainage flow paths that improve drainage during major storm events are included in the Bluebelt program.

### A.3.6.5 Equity and Community Engagement

Engagement programs by New York City include the following:

- The Special Initiative for Rebuilding and Resiliency conducted ongoing briefings with community leaders/key stakeholders.

- NYCDEP: Comprehensive Waterfront Plan – Climate Resiliency and Adaptation. The plan includes measures to promote social equity and access to water recreation.

#### A.3.6.6 Flood Warning, Emergency Response, and Recovery

- New York City participates in the New York State Governor's Office of Storm Recovery – Buyout & Acquisition Programs, which were designed to purchase properties damaged by Superstorm Sandy, Hurricane Irene, or Tropical Storm Lee.

#### A.3.6.7 Funding and Finance

- New York City participates in the New York Governor's Storm Recovery effort, which funds resiliency and recovery projects. The State provides a portal that includes a dashboard of funding by County that lists initiatives and summarizes expenditure. New York City funding and grant programs listed in the portal include the HUD Rebuild by Design grant and Community Development Block Grant Disaster Recovery funding program. A specific project listed under the program is the Living Breakwaters program, which is enhancing the shoreline protection of Staten Island.

#### A.3.6.8 Other Policy

- NYCDEP has developed design guidelines, standards and specifications for green infrastructure built in city streets and sidewalks, right-of-way, and green infrastructure built within the property line of a City-owned site such as parklands and schools (public onsite). The City has a mapping tool that identifies the location of all green infrastructure projects in New York, and provides details on those projects.

#### A.3.6.9 Mitigation Projects of Note

- High level storm sewers (sewers designed to provide combined sewer relief during wet-weather conditions) are designed specifically for stormwater and help reduce street flooding, improve the health of surrounding water bodies, ensure the reliability of the drinking water delivery system, and make neighborhood roadways safer for all users. In 2018, NYCDEP completed the first phase of installing high level storm sewers along 3rd Avenue in the Gowanus neighborhood, with Phase II anticipated to be completed by 2021. This $53 million project, which will increase capacity in the neighborhood's drainage system, is helping to reduce roadway flooding and the amount of pollution that may be discharged into the Gowanus Canal during heavy rainstorms.
- Living Breakwaters Project – nearshore breakwaters that promote risk reduction and ecological enhancement, and foster social resilience
- Living with the Bay – promotes flood defenses, ecological restoration, access and urban quality, and social resiliency along the Mill River and around the South Shore's bays in Nassau County, Long Island
- Lower Manhattan Coastal Resiliency – making lower Manhattan flood-resilient

### A.3.7 District of Columbia

#### A.3.7.1 Overview

DC was selected as a key city to be screened because of its recurrent urban flooding issues, proposed/ implemented policy updates to address this, flood zone overlay considerations, and equity considerations. DOEE is responsible for managing the floodplain, administering outreach, and coordinating the Flood Task Force (FTF). DDOT is responsible for stormwater design in the public right-of-way.

Key highlights:

- DOEE's Proposed Floodplain Regulation Updates
- In the of process of developing a heat map that will flag a permit going through erosion and sediment control review that is in an area prone to flooding (1 percent annual chance flooding).

- On-going Flood Task Force (FTF) to organize flood management activities between multiple City and federal stakeholders.

### A.3.7.2 Land Use Planning and Permitting

- Regarding lot-to-lot flooding, the District responds to complaints through inspection enforcement. If water goes into the street and into a neighbor's property, DDOT gets involved. There is a matrix of cause/effect and the agency responsible. The District is working on a flowchart. Some issues are the resident's responsibility.
- The Building Code Appendix G (page 449) lays out the building standards, which include the minimum elevation of 2 feet above base flood elevation for 500-year floodplains.
- The District Department of the Environment amended its code of Flood Hazard Rules in 2006 to include a freeboard safety factor of 1.5 feet above base flood elevation. It also defines three zones of SFHAs, the area within a floodplain subject to a 1 percent or greater chance of flooding in any year, and designates that building permits or special regulations be required for proposals in the SFHAs. In 2021, DOEE's Proposed Floodplain Regulation Updates proposed changes to the Flood Hazard Rule, that all new and substantially improved buildings must be elevated or floodproofed to the higher value of either the base flood elevation plus 2 feet or the high flood elevation.
- The 2020 Stormwater Management Guidebook provides guidance and minimum requirements to comply with the District's stormwater management regulations, including the use of BMPs. According to the Guidebook, sites must have detention to accommodate for the post-project peak discharge rate for the 2-year, 24-hour storm event (except for areas with exceptions), the 15-year, 24-hour storm event, and the extreme flood requirement (detention to accommodate the 100-year storm). Requirements for grading/drainage provisions, gutters, and downspouts are also outlined in the guidebook.
- Long-term goals include interior flood management with neighborhood residential plans that identify flood problems and incorporate use of blue-green infrastructure as well as setting aside funding and applying for FEMA grants.

Medium-term goals: Until infrastructure is in place, provide help from an insurance angle (FloodSmart Homes) where DC pays for the home assessment and a contractor will make the necessary improvements for free. Money available from the local budget for fiscal year 2023 is $2.3 million. DC will also make sandbags available and offer rebates for fixes homeowners make.

### A.3.7.3 Urban Flood Zone Identification and Mapping

- In the process of developing a heat map that will flag a permit going through erosion and sediment control review that is in an area prone to flooding (1 percent annual chance flooding). Nothing is enforced; the map is intended to be advisory, reliable, and as legitimate as FEMA flood maps but for interior (urban) flooding.
- The District has developed several tools accessible to the public, including an interactive flood map with FEMA floodplains, forecasted risk, and socioeconomic values, as well as a Flood Inundation Mapping Tool for the Potomac and Anacostia Rivers.

### A.3.7.4 Hazard Mitigation

- The means of improving flood management are at a more tactical level (in contrast to centralized authority). Small procedural changes have a strong impact. For example, while working through a TetraTech report, the National Capital Planning Commission made small changes to monthly meeting invites to address a federal communications issue (one of the core organizational recommendations). Currently, DOEE houses most of the programmatic responses.
- The FTF is a shared responsibility between DC Water and DOEE. DC Water has a consultant facilitator to assist. Weekly DC Water/DOEE/Consultant meetings are held to prepare for monthly FTF meetings. Consultant prepares and revises presentations. DOEE does much of the interagency coordination.

  - The FTF was formed to elevate request for separate agencies to implement actions, allowing the agencies to point to the FTF to justify the budget request. In practice, this is still difficult to implement.

- The FTF has 30 different Action Plans that are 3 to 5 pages each, which will be aggregated into an annual report that will include budget information. The FTF does not make budget recommendations; rather, the individual agencies are responsible for placing the budget items into their annual budget requests. To mitigate hazards, the District is also engaged in wetland restoration work and conservation projects.

### A.3.7.5 Equity and Community Engagement

- The DC Silver Jackets is an interagency team of federal, DC, and regional agencies and academia that facilitates collaborative solutions to State Flood Risk Priorities.
- DC also has taken initiative to address equity, including the Far Northeast Ward 7 Equity Advisory Group (EAG) that engaged citizens and communities in discussion on climate change.
- The District has developed the Watts Branch Flood Risk Management Plan to work toward protecting the Watts Branch area, which is in a designated FEMA SFHA from flooding risks.
- Flooding in the District E-Learning Series is a resource made available for public access to raise awareness of flooding risks.
- There are concerns about gentrification and optics around buyouts. Casey Trees, a nonprofit, will buy property and convert it to open preservation land. They are able to purchase the house and allow the residents to remain as long as they wish. This helps mitigate the concern, but not entirely.
- DOEE is moving away from "swoop in" types of engagement in areas with an equity focus. Wards 7 and 8 house much of the District's floodplain and are also areas of high SVI. DOEE has established a relationship with a local community center as an initial step in improving engagement.
- The community center provides a monthly 1.5-hour programming slot that DOEE fills with flood education. They are working on composing a three-module education series (Flood 101, Flood Insurance, DC's FloodSmart homes program) that will be continually offered at the center.
- DOEE has identified specific federal grants that can increase community center
- programming/outreach. The grants can be provided with some metric to measure the success of engagement (number of engagements) and success in using the existing community center connections to get information out.
- Outreach outlets include a radio station, the Washington Informer (Black-owned newspaper), retirement centers, and "hang outs" for those without internet access.

### A.3.7.6 Funding and Finance

- DC secured a FEMA Building Resilient Infrastructure and Communities grant for $20 million to support resilience efforts.
- DC applies for funding from the Flood Mitigation Assistance Program.
- NFIP is not the best program for interior flooding; it does not cover backflow valve flooding. Under the NFIP, to be defined as flooding requires crossing two or more properties.
- Riversmart Rewards is a stormwater fee discount program developed by the District to give discounts on water treatment bills if residents, property owners, or businesses install green infrastructure.
- The District is piloting it's "FloodSmart Homes" program that will provide free home assessment, technical consultation, and, potentially, free flood proofing and resilience upgrades. The program is jointly funded through FEMA and District capital funds. FEMA funds are applicable for properties within the SFHA. District funds can be used to address areas of known pluvial impact (not mapped by FEMA).

### A.3.7.7 Other Policy

- DOEE has worked with DC to explore the potential applications of Blue-green infrastructure and cloudburst management strategies and conduct workshops with district agencies and stakeholders.

### A.3.7.8 Mitigation Projects of Note

- Rock Creek Green Infrastructure Project B, the second project of DC Water's Clean Water Green Infrastructure projects, will be completed by 2024 and includes the construction of permeable pavement and bioretention sites in the Rock Creek sewershed to reduce flood risks.
- To protect the Blue Plains Advanced Treatment Plant, DC water is constructing a Blue Plains Floodwall to mitigate against a 500-year flood event.

## A.3.8 Chicago – Metropolitan Water Reclamation District of Greater Chicago

### A.3.8.1 Overview

- The MWRD manages wastewater treatment and stormwater for residents and businesses in Chicago and 128 suburban communities throughout Cook County.

### A.3.8.2 Land Use Planning and Permitting

- Adopted watershed management ordinance for suburban, regional ordinance. Anything over 0.5 acre has requirements to fall under ordinance. City of Chicago has their own that mirrors MWRD's ordinance. MWRD does not get involved in single-family home requirements but looks more at multi-family development or redevelopment (City of Chicago is the same).
- City of Chicago, in general, is structurally a different organization. Their permit review section is a bit smaller; they have 50 percent of land area, but enforcement is shared among the departments. Department of Water Management leads their stormwater management permitting, but they also enlist people from the Building Department to do inspections and some of the permitting.
- Have freeboard with detention; pond detention requirements in Technical Guidance Manual. Zero release required in developments in floodplain.
- Full-time staff of 25 people in permit review and about 20 in enforcement section. Personnel inspect every permit and look into violations and notices; sometimes hearings are held to get people back in compliance.
- Communities are co-permittees; communities are aware that they have a role.

### A.3.8.3 Urban Flood Zone Identification and Mapping

- The City of Chicago has modeled its entire sewer system, all sizes of service lines, so there is good model data; City knows where stress points are and can look at many factors, such as other infrastructure projects and how they can work on sewer when a roadway project is underway.
- MWRD has a tunnel system for CSO relief to City sewers and other combined sewer communities, which have been modeled.
- MWRD is careful about mapping; this can be seen as negative. There is reliance on local data sets to identify what an area's flood susceptibility is and not necessarily an urban flood zone. It is difficult to pinpoint specific locations, but there are indicators MWRD has used and has access to.
- Flood Susceptibility Index has been developed by the metro planning organization to indicate which areas might be more susceptible to flooding.
- Riverine (FEMA data) but also Urban flooding index: indicates where communities may be more likely to see urban flooding based on factors in the index. It is currently being updated.

- MWRD is also doing master planning to look at the subwatershed level, where there are known flooding problems based on local communities. Looking at flooding locations in high SVI communities; there has been turnover in those communities and thus, less historical knowledge and data are readily available.
- MWRD has done studies using many geographic information system (GIS) tools to see where there is a lack of stormwater storage (an indicator of risk) and where they have information about the system (i.e., a model used to help pinpoint risks and solutions). Volumetrics approach to stormwater management, overland flow routing, other GIS data/tools; metrics to help focus attention in the future on where volume is needed.

#### A.3.8.4 Equity and Community Engagement

- More high SVI communities have more violations; it is a challenge to make sure people seek out a permit and that their property is properly maintained after the permit is issued and construction is completed.

#### A.3.8.5 Funding and Finance

- MWRD has a capital program for urban flooding problems and floodplain. About half of communities outside Chicago have combined sewers and programs to help fund green infrastructure and more traditional flood control/stormwater projects. In high SVI areas. MWRD tries to encourage those with permit violations to get them fixed, but MWRD also uses the carrot stick approach: address violations but if not, they might not be able to partner on flood control funding. On the flip side, trying to encourage those communities to take advantage of what is available poses a challenge because MWRD does not want to reward those in violation. Looking for projects that are for the greater good.
- About $50 to 75 million per year capital improvements. MWRD has some long-term programs, including Department of Water Management and school system-space to grow. Schoolyards convert to green infrastructure, playgrounds, etc., to help flooding in neighborhoods. Partner with other larger agencies, like Forest Preserve District, where MWRD adds on volume or green infrastructure that agencies are already providing.
- Three programs with open calls for projects from any community, township, agency in jurisdiction that want to take on a stormwater project, which can be green infrastructure, traditional stormwater, pipes and storage, buyout program. Usually budget about $5 million per project but can vary. Much of budget is set aside to help communities move projects forward with construction money. MWRD has helped high SVI communities with design and construction. Can also partner with U.S. Army Corps of Engineers. For some communities, money for construction is not sufficient. Cook County is mirroring their program, working to get MWRD to fund directly. Exciting opportunity; do not want to just be provider of services but want to help communities build capacity.
- Call for projects: application period is 2 to 3 months. Do outreach on the application process, and have a basic pre-application process so MWRD can help them with the full application, if it is promising.

### A.3.9 Mile High Flood District – Denver

#### A.3.9.1 Overview

Mile High Flood District (MHFD) was selected because of their work integrating local flood maps with FEMA mapping and updating policy based on mapping. The Planning and Floodplain Management Director for MHFD was interviewed as part of the research.

Key highlights:

- MHFD has in-depth technical criteria for stormwater management, which all the local governments have voluntarily adopted.

- Currently, their approach is to build in freeboard factor of safety, discourage new pipe systems, and try to keep open channel design; design with flexibility and freeboard resilience, rather than taking the approach of modeling with future projections.
- MHFD has a number of rainfall and streamflow gauges throughout the district that help communicate in real-time the risk to local governments.

### A.3.9.2 Land Use Planning and Permitting

- MHFD does not do land use planning nor get involved in areas less than 130 acres unless local government requests it of them. The 130-acre figure is the amount where development with a minor storm drain and surface conveyance through streets would not be enough and thus would require a major drainpipe. Their role is to help influence but not set zoning or land use regulations, working with local government to make sure zoning makes sense with underlying drainage system.
- If local flood risk on map becomes part of a regulatory requirement, it would be a considerable challenge from a revisions-standpoint; updating through FEMA's process would require extensive work and slow processes down.
- The details of a storm sewer network, onsite detention ponds, gutters, inlets, etc., would make a significant difference to what the homeowner would see in terms of actual flooding. Models that FEMA put together are calibrated to major drainage; they may not fully reflect the impacts the homeowner will see. Prefers keeping in local government hands rather than making flood risk map regulatory.
- MHFD has in-depth technical criteria for stormwater management, which all the local governments have adopted and use even though not required to do so.

### A.3.9.3 Urban Flood Zone Identification and Mapping

- MHFD has begun working on two-dimensional (2D) rain-on-mesh modeling (HEC-RAS 2D, latest version) for the District. Colorado Water Conservation Board (CWCB) provides 2D mapping. MHFD hires consultants to take CWCB's data/map to a level of detail appropriate for the urban area. For Denver,
- 2D mapping results with GIS mapping interface; potential inundation areas or urban flooding areas not on FEMA maps. Apply 1 foot of freeboard.
- Confluence is an online platform. Plan is to take it and combine with FEMA regulatory data to develop understanding of risk to prioritize projects.
- MHFD has a specific agreement with FEMA for their FEMA-regulated mapping that allows them to consider future land use and projected zoning. Rainfall is trickier without NOAA Atlas 15.
- Their approach is to build in freeboard factor of safety, discourage new pipe systems, and try to keep open channel design; design with flexibility plus freeboard resilience, rather than taking the approach of modeling with future projections. After obtaining better projections, a combined approach can be taken. Map what is best available/known today regarding what may happen in the future, i.e., what is zoned today plus any development and planning tools that are currently available from local government will be incorporated.

### A.3.9.4 Equity and Community Engagement

- Local governments take the lead in engaging their communities because they know them best.
- The City/County of Denver set aside $200,000 for a master plan study, $400,000 (double the study budget) for outreach and engagement. Robust engagement targeting socially vulnerable communities.

### A.3.9.5 Flood Warning Emergency Response and Recovery

- Works with Office of Emergency Management of local governments; their role is in prediction side, working with NWS. MHFD has rainfall and streamflow gauges throughout the district that they use to communicate the risk in real-time to the local government. Local government makes the calls for evacuation.

- Main role is to make necessary improvements to be as prepared as possible for flood events.
- Recovery efforts after flooding include partnering with local government for repair to major drainage ways (rebuild a culvert that blew out, fix erosion, etc.).

#### A.3.9.6 Financing

- Available as a technical resource. If there is a new capital project greater than 130 acres, MHFD funds 50 percent and looks for local government to provide a 50 percent match. Maintenance can be funded 100 percent but has to be requested by local government.
- To spend maintenance dollars in future, MHFD must review developer-led projects for approval. Local governments must have easement/right-of-way, and MHFD will maintain it in future.

### A.3.10 Charlotte-Mecklenburg, North Carolina

#### A.3.10.1 Overview

In 2000, Charlotte-Mecklenburg became the first community in the nation to show both current and future floodplains on its official maps. Charlotte-Mecklenburg Stormwater Services (CMSWS) consists of Mecklenburg County Stormwater and City of Charlotte Stormwater. City of Charlotte Stormwater was interviewed to find out about their urban flood mitigation approaches.

Key highlights are the following:

- Charlotte's Unified Development Ordinance, as described on their website, "will simplify, consolidate and update the regulations that guide development into a single document. In addition, the draft Unified Development Ordinance will align these standards with the vision of the Charlotte Future 2040 Comprehensive Plan and other adopted City policies. This effort will also make development standards easier to understand through the increased use of common language and graphics".
- Summary of changes to Stormwater Ordinance
- They are a CRS Class 3 with good flood protection measures. They do not prohibit building in floodplain but require building responsibly and mitigating the risk. They are active in removing existing problems in the floodplain, with the acknowledgment that their landscape may be different from that of others (they have steep valleys and the floodplain is confined).
- The FEMA floodplain shows where flooding is likely to occur now. Their Community Floodplain shows where flooding is likely to occur in the future, based on expected development upstream.
- Three dimensional (3D) Interactive Flood Zone Mapping

#### A.3.10.2 Land Use Planning and Permitting

- The City of Charlotte and Mecklenburg County split responsibilities. They have an inter-local agreement; for Charlotte City, "turf" is everything that drains less than 1 square mile, and for County, everything that drains more than 1 square mile. The County is mostly responsible for their floodplain mapping and ordinances; they draft them and go through the City of Charlotte, Stormwater Management Storm Water Services Department for approval to City Council.
- Both City and County collaborate in outreach/communications. They incorporate flood awareness campaigns together. The County is seeking to satisfy requirements for FEMA process and CRS, and the City is trying to reach those experiencing flooding in basements and crawl spaces.
- Substantial improvement rule: if adding onto a house in a FEMA floodplain and enhancing to more than 50 percent of the value, there are standards to be met. See Drainage Article. Building Code Department is not involved in preventing flooding problems. The County is focused on the Community Floodplain, going above and beyond, and adding flood depth. Development and the building industry collaborate in terms of ordinance requirements.

- Drainage Article will be in effect in June 2023. Cursory reviews are forthcoming; for instance, checking to see if a new bathroom is near a ditch or over a pipe. However, 70 to 80 percent of these reviews will be pass-throughs. Number of staff required will be about 6 or 7: supervisor and plan review engineers. They will likely charge a $50 to $100 fee for short 15-minute reviews. No calculation reviews but they will make sure that what is being built is not in harm's way, that it will not damage city infrastructure in the right-of-way, or cause a flooding problem for someone else.
- CMSWS standards: If building a house with the drainage area threshold of 100 cubic feet per second for 100-year storm, a study/analysis is required before siting a home and the home must be elevated to 1-foot above the 100-year base flood elevation. Crawl spaces and basements are included in this requirement. This has been a longstanding standard for 30 to 40 years.
- Lot-to-lot issues: Charlotte is experiencing a great deal of growth, infill development, and redevelopment. Spending 3 years to work on Charlotte's Unified Development Ordinance, drawing the line between developer and homeowner responsibility. See Drainage Article; CMSWS staff will review smaller infill sites, smaller additions to homes, etc., but CMSWS is not taking responsibility for lot-to-lot drainage. Instead, they seek to prevent nuisance problems from happening. When citizens experience lot-to-lot issues, they call 311, and CMSWS inspects and determines whether they can provide services. There is no direct campaign toward lot-to-lot issues. Information on their website specifies what they will provide.
- Because of the degree of infill development, small site development is dominating, so CMSWS has lowered the threshold to require stormwater control measures from 20,000 square feet. down to 5,000 square feet. New impervious surfaces of 5,000 square feet or more will require control measures, such as an infiltration basin or a rain garden for a single-family home.

### A.3.10.3 Urban Flood Zone Identification and Mapping

- The Stormwater Utility Department was created because of urban pluvial flooding. CMSWS has spent 20 to 30 years addressing witnessed and known flooding locations (did not need to do modeling for this). Invested $1 billion since 1993 for capacity improvements. Now, focus is on inspection and modeling of drainage systems and asset management. Not sure how extensive modeling will be or if it will be used for land development requirements because developers are required to conduct a study when building onsite.
- 3D Flood Zone Map Tool: No pluvial mapping done upstream of FEMA floodplain and 1 square mile point, but discussions underway with County.
- The 311 database has been in existence since 1993. Inspector/drainage investigator would go out for each call to determine the nature of problem and whether it qualifies for public service. More thorough data collection is now supported for the first site visit from homeowner and observer. The database provides a reliable historical reference for CMSWS.
- Modeling used existing zoning records, considering what is likely the maximum intensity based on that zoning category. Stormwater control measures were installed intensely starting in 2008. An internal source of debate is on how to map them; the attenuation in the system is not included in the model.
- Flood zone maps are available for the City and Planning Dept to review. The County has been active over the last 20 years, acquiring flood-prone properties that provide right of way for new greenways and trails. CMSWS has funneled money to the same projects to build stormwater control measures and stream restoration projects to reclaim beneficial uses. Have not used floodplain modeling to rezone property or prohibit how it is used.

### A.3.10.4 Hazard Mitigation

- If there is a major systemic problem, CMSWS logs, categorizes, and prioritizes the problem in the system. No other cost to citizens other than their monthly stormwater fees. If it does not qualify for public program, CMSWS does not have a cost share program to offer.

### A.3.10.5 Equity and Community Engagement

- Looking at a map of the thousands of projects in the last 30 years, there is no evidence of economic disparities in service delivery.
- Website has been useful. TV media broadcast and commercials are used (pay for 15 to 30 seconds of ad time on local TV stations). It is expensive, but the number of people who see the ad is high, so it is a good value. Partner with neighboring cities to pull resources together. Using social media more and more, Twitter and Facebook weekly. If it is a regional message, for National Pollutant Discharge Elimination System (NPDES) permits, localities will help buy ad/ air time collectively with a universal message and that will meet regulatory requirement for permits.

### A.3.10.6 Flood Warning Emergency Response and Recovery

- Staff has a dense network of 74 automated rain gauges that provide live, real-time data available for anyone to see online. Helps with erosion control violations and in understanding whether the CMSWS could have expected the system to fail in that kind of event.
- Flood Information Notification System (FINS). County works closely with Charlotte Fire Department. When rain gauges hit certain levels, a message is sent to Fire and staff about the location where it is raining heavily.
- Failing, small old earth dams originally from 75 years ago. Staff met with Emergency Management.
- State regulates dams (safety/inspection) but City's/County's local emergency responders would be called into action if there are dam failures. Dam owner is responsible for repairs. The State sets the pace and interest level in updating dam emergency plans. Owner must keep an updated Emergency Action Plan. CMSWS maintains and owns some dams; they try to be leaders in City.

### A.3.10.7 Financing

- As federal initiatives come down, CMSWS has been active on grants. Focus is on having adequate stormwater utility rates, paying close attention to bond ratings, and keeping elected officials aware of what CMSWS is doing.
- 70 percent of their revenue is funded through fees. CMSWS leverages some revenue from debt funding. They are a fee-funded program and do not get any general or tax funds; it is all stormwater utility fees.

### A.3.10.8 Other Policy

- RetroFIT shows how the CMSWS prioritizes/assists with existing buildings that are prone to flood damage in the FEMA floodplain. CMSWS is willing to accept some level of street and house flooding that they previously would not tolerate. More focused on making sure the infrastructure will not fall apart.
- Strategic Plan. Comprehensive big picture planning with a focus on aging infrastructure. Prioritizing keeping what they have functioning and worrying about Tier 2 flooding problems later on.
- They do less private property work, more asset management and preventative maintenance work. Their program grows, 200 or more staff members; no construction crew members, just professional staff. Rally workforce around mission and move in same direction.
- Report on metrics. A work to be completed. Trying to tie staff's work plan to the strategic plan is becoming burdensome. They have five core metrics that they report to Strategy and Budget, Finance, and City Management Office every year; two metrics are related to surface water quality improvement, retrofitting impervious and stream restoration, and the number of miles of pipe rehabilitated in a year. Trying to measure infrastructure provision, which is the main metric they push up to Citywide organization.
- Pond Retrofitting Program. About 15 years ago, CMSWS recognized that old farm ponds were having subdivisions built around them and were failing. They also had an NPDES permit requirement to capture and treat impervious surfaces. Homeowners wanted dams to look nice, and CMSWS needed

BMPs and stormwater control measures in areas that did not have them. CMSWS started the Pond Retrofitting Program, where the public invests in retrofitting BMPs. CMSWS will put multi-stage outlet control structures on them, permit them to function at much higher level to meet NPDES permit goals, and give residents a place to row boats and fish. Public gives them the protective easement they need. Good partnership. Raleigh recently jumped on board. BMPs are still private, but CMSWS has permanent storm drainage easement on property; public cannot alter it or remove it but can enjoy it and CMSWS maintains it.

## A.3.11 Pittsburgh Water and Sewer Authority

### A.3.11.1 Overview

Pittsburgh Water and Sewer Authority (PWSA) was selected because it is undergoing a policy update to incorporate climate change. Pittsburgh is different in that PWSA is an authority of the City of Pittsburgh, a quasi-governmental agency; technically, PWSA is a nonprofit that operates the City's sewer and water systems, with board members appointed by the mayor. They manage the drinking water system from Allegheny River to the tap and sewer conveyance system; however, they do not manage treatment.

Key highlights are the following:

- PWSA worked closely with the City in drafting a stormwater agreement, acknowledging that it will be cost prohibitive if they do not find a way to change land use regulations to increase the level of participation from private development.
- PWSA considered stormwater management a land use issue and that there was the need to change land use codes. PWSA does not control land use or planning codes. They work with Planning regularly but needed an agreement to hold them to.
- RAND Corporation and Carnegie Mellon provided studies on climate change effects and projection models for the local region, which added a layer of justification for PWSA's work; they recommend incorporating local researchers and universities, if possible.
- Watershed analysis was done as a CSO study, where water quality was a benefit from the water quantity analysis.

### A.3.11.2 Land Use Planning and Permitting

- Until about 10 years ago, there was no stormwater agency, just a combined sewer system. Some of the newer portions (20 to 25 percent) are separated because of changes in the Code (1970s Clean Water Act) and NPDES permitting. However, the Code is lacking in control measures.
- The City sets code for land use and building construction. PWSA manages the stormwater itself. It was an unwritten agreement in the past that the City would manage water on the surface, but once it penetrated to a storm drain or inlet, it came under the purview of PWSA. Surface plane was delineation, but it left gray areas: back-up of flooding, overflowing banks of streams. Took time to sort out.
- Last decade, they saw an increase in rainfall amounts (intensity, duration, and frequency were off the charts). Systems were not designed for heavy downpours and cloudburst events. It was asked: "What is LOS as a sewer system?" "What should City be doing to get water to system?" City would have a paving plan but it would not include stormwater acknowledgment. The situation came to a head, and everyone came to the table to figure out a solution; there was not enough space in the right-of-way to build enough stormwater management systems into which everyone could offload their water.
- In terms of quantifying runoff, it was gut-feeling, anecdotal evidence from years of experience. There was too much water coming in from private properties.
- County 167 Stormwater ordinance required the City to change laws to implement code to meet a minimum; thresholds were low. PWSA was footing the bill and able to get land grants from local foundations for an initial study on how the code could change stormwater impacts. It is cost-effective

to change code to put the burden back on private development. PWSA paid for legal updates to change the City's code correctly. They consider themselves the subject matter experts and wrote up and presented to City Council the reasons why changes were necessary.

- County Conservation District (CCD) approves stormwater plans over an acre. Erosion and sedimentation enforcement is in their wheelhouse.
- Multiple meetings with City Departments and agencies, CCD, and State Department of Environmental Protection were held to ensure they were heard and that their recommendations would be taken into consideration. Shared pinch points with the Code as it exists currently. Then PWSA reached out to stakeholders, engineers, developers, landowners, and asked what their pinch points were with existing Code. It gave PWSA a reality check on how much work it was going to require. The meetings provided abundant transparency for the stakeholder group, who does not like surprises. It helped to have them at the table from beginning. The buy-in was there; less push back when changes were launched. PWSA did much to streamline the process. The carrot stick approach: If developers go above and beyond, they could get density credits. Outreach was paramount to their success.
- Trying to get neighboring counties/municipalities to change their codes as well. There are 167 municipalities with different codes.
- Code changes are targeting development/redevelopment over a certain threshold. For those properties not going through large development projects, establishing LOS is still an ongoing conversation; it changes for every street, neighborhood, block. System was not built comprehensively. Trying to change narrative on how people talk about LOS and trying to understand what PWSA can feasibly provide. Still designing to the 10-year storm, but no one has been willing to commit to a higher level yet.
- Lot-to-lot issues. Code writes those as a private property matter. However, also in Code, no property can redirect runoff that detrimentally affects neighboring property. PWSA has its own credit program with stormwater fee. They offer guidance on how to manage property better to limit the stormwater fee. PWSA handles lot-to-lot issue once they have reached out to the neighborhood to let them know they can disconnect downspouts. Code enforcement gives violations when appropriate.
- PWSA has some oversight by the PA Public Utility Commission, a statewide organization and consumer advocacy group that oversees private company utilities.
- 3 Rivers Wet Weather, a nonprofit of 20 or more years. Established/funded by Allegheny County Sanitary Authority (regional treatment facility). Information sharing, strategic planning, comprehensive strategies. Twelve out of 83 municipalities participate. Cordial but in the end, municipalities are still going to operate according to their preference.

### A.3.11.3 Urban Flood Zone Identification and Mapping

- Act 167 Countywide Model Ordinance, mandated by the State. Certain watersheds were selected for having impaired waterways and would be required to have restricted release rates in place. Watershed analysis was done as a CSO study, where water quality was a benefit from the water quantity analysis (latter was the focus; volume-centric). After obtaining detailed model, they identified 20 or so watersheds to further analyze, focusing on problem areas, and modeling at the granular level, some to every single inlet.
- Looked at infill, land use projections, etc. PWSA was fortunate that RAND Corporation and Carnegie Mellon were already performing studies on climate change effects and projection models for the local region. Serendipitous that they were downscaling large climate models to the city and local level. PWSA could use rainfall data/projections and expected land use change, population shifts, and economic parameters. It added a layer of justification for what they were going to do and would require, to answer, "What can we manage to the year 2100?" PWSA recommends incorporating local researchers and universities, if possible.

### A.3.11.4 Equity and Community Engagement

- Engage.pittsburghpa.gov. With the Code update project, one of the key things in the request for proposals was to implement public engagement to address equity issues as well as high-dollar developers who will likely complain to the mayor's office. Wanted to make sure their writing of the Code would not be overly burdensome on small developers and property owners in high SVI communities. Address certain comment periods before getting codified. On stakeholder working group, they had neighborhood organizations and advocacy groups for high SVI neighborhoods to stimulate economic development. Stipulations were written into Code that certain areas had limitations because of economic variables.

### A.3.11.5 Flood Warning, Emergency Response and Recovery

- Look at light detection and ranging rainfall data to see where heavy spots were and how the data correlate with what was seen in the system. Long-term, looking closely at real-time controls within sewer system and using rain gauge data to see how runoff/flood progresses. Use data to prevent more flooding downstream.

### A.3.11.6 Funding and Finance

- PWSA has a stormwater fee based on impervious area. Relatively low initially but allows them to familiarize residents with the notion of paying a fee. They will be able to use that as an incentive to limit runoff. The plan is to gradually increase the rate over several rate cycles until it becomes more cost-effective to manage the water well than pay the fee.

## Sample Interview Questionnaire

1. Land Use Planning and Permitting
    a. How would you briefly characterize the organizational structure around urban flooding for your community?
    b. What stormwater management and building code requirements do you include for redevelopment projects to minimize urban flood risk? New development projects?
    c. How does your community address lot-to-lot flooding issues?
    d. How have your building standards been adjusted for development in urban flood zones or areas with known urban flooding issues?
2. Urban Flood Zone Identification and Mapping
    a. Has your community mapped urban flooding areas outside of the FEMA zones, and if so, how did you develop them?
    b. Does your urban flooding analysis approach include climate change effects?
3. Hazard Mitigation
    a. What kind of programs does your community have to help homeowners mitigate flood risk?
4. Equity and Community Engagement
    a. How does your community approach social equity when it comes to urban flooding?
    b. What is the most successful outreach method employed by your community? What methods have been unsuccessful?
5. Flood Warning Emergency Response and Recovery
    a. Has your community identified areas that are likely to flood or areas that flood repeatedly during large storm events?

6. Financing
    a. What current actions are you pursuing to generate funding for urban flood planning mitigation and related activities?

# Appendix H
# Market Analysis on Climate Risk Technical Memorandum

ARLINGTON
VIRGINIA

# Market Analysis on Climate Risk (Task 10.1)

Document no: 231004135735_aab66d09
Revision no: 1

Arlington County

Flood Risk Assessment and Management Plan (RAMP)
January 26, 2023

# Market Analysis on Climate Risk (Task 10.1)

| | | | |
|---|---|---|---|
| **Client name:** | Arlington County | | |
| **Project name:** | Flood Risk Assessment and Management Plan (RAMP) | | |
| **Project no:** | E5X69605 | | |
| **Document no:** | 231004135735_aab66d09 | **Project manager:** | Laurens van der Tak |
| **Revision no:** | 1 | **Prepared by:** | Praveen Sridharan and Veronika Vazhnik |
| **Date:** | January 26, 2023 | **File name:** | RAMP_Task10.1_MarketAnalysisClimateRisk |
| **Doc status:** | Final | | |

## Document History and Status

| Revision | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| 0 | 6/20/2022 | Draft Submission | PS/VV | EL | TA | TA |
| 1 | 01/26/2023 | Revised submission | PS/VV | | TA | TA |

**Jacobs Engineering Inc.**

2551 Dulles View Drive
Herndon, VA 20171
United States

T +1.703.376.5000
www.jacobs.com

# Executive Summary

The world's collective understanding of climate change, how it will impact all parts of society, and what must be done to respond to current and future threats has developed enormously. In recent years, we have experienced a real impact on aging infrastructure from a large diversity of extreme events, with adverse effects on people's lives and livelihoods.

The exacerbating frequency and the impact of natural disasters are causing devastation to most regions in the United States and across the world. These impacts take two general forms: 1) degradation and damage to all forms of civil infrastructure, resulting in higher life-cycle costs prompted by accelerated repair and replacement, as well as increased costs of operations and maintenance; and 2) extreme and repetitive climate events, such as flooding and extreme heat events stress and exceed the capacity of existing infrastructure with cascading impacts. The impact is measured in billions of dollars and hundreds of lives lost, meaning that investing in resilience to mitigate such impacts of climate change is becoming a critical mission of governments.

Increasing frequency and intensity of extreme weather events have also produced challenges to private property and property ownership, for example, through the limited availability and sufficiency of insurance and secondary impacts on bankability and marketability. This extends to federal disaster insurance safety nets such as Federal Emergency Management Agency (FEMA). In 2021, NOAA recorded 22 "Billion Dollar Loss" events, exceeding the prior record of 16 such events in 2020.[1] Climate change is formally recognized as both a driver and multiplier of risk.[2]

There is recognition that local governments, through effective collaboration, can play an important role in addressing climate change and other issues such as equity and decarbonization priorities. With the increased likelihood and severity of climate-related risks, municipalities and local governments should consider how, in addition to direct physical damages to assets an infrastructure, these risks pose a threat to their tax bases, their insurance policies, and the impact on financing capital projects. Through increased awareness, Arlington County, Virginia, can preserve currently planned economic growth by investing in more resilient, inclusive, and healthy communities, and attracting new businesses that share these values.

This white paper outlines emerging issues around the consequences of climate change and its associated social and economic risks, and opportunities for comprehensive investment in resilience planning and infrastructure to ensure sustainable growth. This paper discusses relevant financial markets and economic trends related to climate change that can have a direct impact on future investment decisions. The following key developments are addressed herein:

- The impacts of climate change considerations are beginning to impact policy and regulations within financial markets.
- New regulations are designed to aid investment decisions to take into consideration the opportunities and threats through additional climate change disclosures and assess the detrimental impacts of recurring and acute climate events. The new disclosures are anticipated to create increased investor awareness and inform business decisions related to climate impact and sustainability and instill new risk considerations when borrowing funds or acquiring property insurance.

[1] Department of Homeland Security. 2021. *National Preparedness Report.*
[2] Arlington VA. 2020. *Flood Insurance Rate Map Public Meeting.*

- Bond rating agencies are beginning to evaluate the risks from climate-related impacts and will increasingly evaluate those risks in ratings. The disruption of revenue generation due to climate impacts could increase uncertainty and lower ratings, leading to a detrimental effect on communities' cost of capital and ability to borrow funds.
- Insurance premiums are projected to grow because of increased information available on climate vulnerabilities. These premium increases may be mitigated with investment in resilience measures that will reduce the impact of climate-related risks.
- New forecast, impact, and property valuation tools are being developed and used by markets (e.g., real estate) and the public. These analytical tools equip investors with increased awareness by more closely aligning climate change impacts with commercial, financial, and socio-economic interests.
- New pathways to financing resilience investments are under development, such as local revenue generation through taxes or stormwater fees, climate or resilience bonds, public-private partnerships including partnerships with businesses or land trusts and landowner engagement, and competitive grants at both the federal and state levels.
- Investment in resilience can further spark local economic development through supporting a diverse economy, fostering environmental justice, building local supply chains, and improving the health of local communities.

# Contents

**Executive Summary** ..... i

**Acronyms and Abbreviations** ..... iv

**1. Introduction** ..... 1-1

**2. Key Climate Risks and Financial Market Trends** ..... 2-1

2.1 Bond Ratings and Municipal Borrowing Costs ..... 2-1

2.2 Insurance Responses to Climate Risks ..... 2-3

2.3 Urban Area and Real Estate Trends ..... 2-5

2.4 Climate-Related Financial Disclosures ..... 2-6

2.5 Climate-Related Analytical Tools ..... 2-7

**3. Environmental, Social, and Governance Impacts** ..... 3-1

3.1 Building Urban Resiliency and Adaptive Capacity ..... 3-1

3.2 Social Vulnerability, Health, and Safety ..... 3-2

**4. Economic Impacts and Opportunities** ..... 4-1

4.1 Jobs, Tourism, and Preservation of the Diverse Economy ..... 4-1

4.2 Low-Carbon Economy Transition and Circular Economy ..... 4-2

**5. Emerging Solutions** ..... 5-1

**6. Conclusion** ..... 6-1

**7. References** ..... 7-1

# Tables

Table 1. Financial and Insurance Risks Related to Climate Change ..... 2-5

Table 2. Resiliency Funding Pathways with U.S. Municipality Examples ..... 5-2

# Figures

Figure 1. Projected climate impacts in Arlington: Sea level rise (top left), heat vulnerability (top right), and inland flood risk (bottom left) ..... 1-2

Figure 2. Influence of climate trends and shocks on bond ratings ..... 2-3

Figure 3. Social metrics for consideration in Arlington climate investments – Social Vulnerability Index and Disadvantaged Communities Map ..... 3-3

# Acronyms and Abbreviations

| | |
|---|---|
| % | percent |
| °F | degree(s) Fahrenheit |
| Amazon | Amazon.com, Inc. |
| ASCE | American Society of Civil Engineers |
| CIP | Capital Improvement Plan |
| CRS | Community Rating System |
| DMV | District of Columbia, Maryland, and Virginia |
| EPA | U.S. Environmental Protection Agency |
| ESG | Environmental, Social, & Governance |
| FEMA | Federal Emergency Management Agency |
| FY | fiscal year |
| IPCC | Intergovernmental Panel on Climate Change |
| LEED | Leadership in Energy and Environmental |
| MFDA | The Metro Flood Diversion Authority |
| MSCI | Morgan Stanley Capital International |
| NFIP | National Flood Insurance Program |
| NOAA | National Oceanic and Atmospheric Administration |
| PAYG | Pay-As-You-Go |
| RAMP | Flood Risk Assessment and Management Plan |
| RCP | Representative Concentration Pathway |
| RRVA | Red River Valley Alliance |
| SEC | Securities and Exchange Board |
| SFHA | Special Flood Hazard Area |
| TCFD | Task Force on Climate-Related Financial Disclosures |
| TIF | Tax Increment Financing |

# 1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicts that natural catastrophes such as flooding, extreme heat, fires, and tropical storms will increase in North America because of climate change. The impacts include a decrease in the quality of life, severe economic losses because of heat stress, sea level rise, damaged infrastructure, increased costs and threats to service/external workers, an increase in health issues amongst the population, and economic pressure on key sectors, such as agriculture and tourism.

Deloitte's recent report, *The Turning Point: A Global Summary*, estimated $178 trillion in global economic losses as a result of inaction, and that the United States could directly experience $14.5 trillion in economic losses because of climate change by 2070, which is a lifetime loss of nearly $70,000 for each working American[3]. The report also lays out the positive opportunity for investments in resilience and net-zero carbon that could boost the U.S. economy by $885 billion.

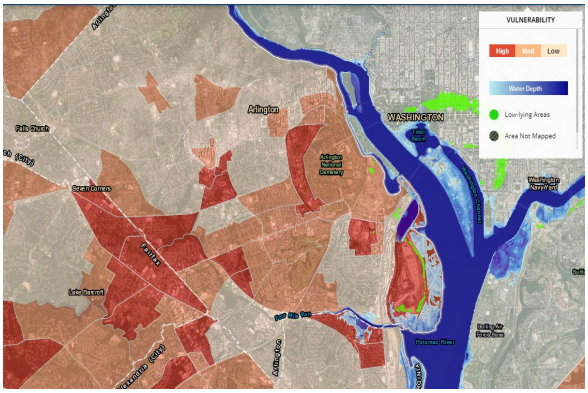
These climate change risks can be divided into two categories: physical, and transition risks. The physical risks result from climatic events, such as wildfires, heat waves, storms, and floods, whereas transition risks result from policy action taken to transition the economy off of fossil fuels towards net-zero emissions. The acute physical effects of extreme weather has socio-economic impacts on business, health, food, and water insecurity. At the same time, decarbonization efforts will present opportunities for renewed investment in communities and emerging industries.

Arlington County, Virginia, is projected to experience the physical impacts of climate change in a variety of ways. Figure 1 maps forecasted impacts from the Climate Explorer[4] and National Risk Index for Natural Hazards[5]. The main effects that can be expected in Arlington include increased flooding, increased risk, and frequency of hail, hurricanes, ice storms, strong winds, and other winter weather events. The area will also experience a significant increase of days when temperatures rise to over 95 degrees Fahrenheit ($^0$F), which can pose a threat to human health, the number of outdoor working hours, and infrastructures such as heating, ventilation, and air-conditioning systems and electrical equipment. The maps in Figure 1 are an example of the projected climate change effects on the County.

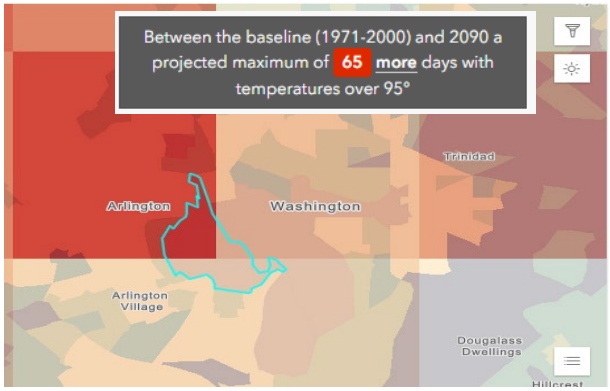
Globally there is a convergence on identifying solution-focused information that may be used to improve the understanding of climate change impacts and policies; assessing climate risk in terms of other economic and societal risks; assessing the risk profile of new technologies; and assessing these risks from an investor standpoint. Climate policy continues to evolve as new information becomes available to measure risks and uncertainties that are most relevant and assess the decision-making priorities and processes in the private and public sectors.

The shift in credit ratings and interest rates for not acting on climate readiness or resilience may create new challenges in bondability or potential barriers to accessing the bond market because of unmanaged climate-related effects on local government authorities. Private corporations in jurisdictions that don't proactively address climate change risks with meaningful adaptation strategies are likely to find themselves increasingly paying more for their corporate debt and, in some situations, unable to secure debt due to risks that climate events may compromise the assets being financed.

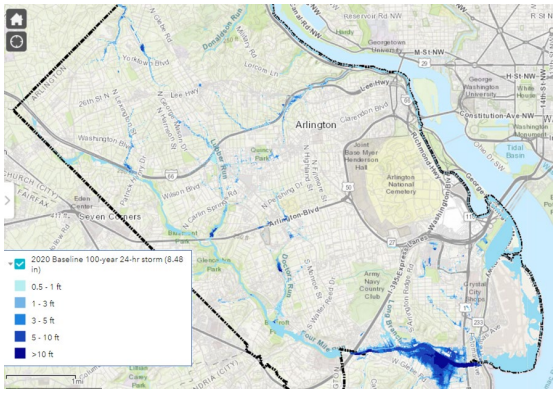
[3] Deloitte. 2022. *The Turning Point: A Global Summary.*
[4] National Oceanic and Atmospheric Administration. 2022. *U.S. Climate Resilience Toolkit Climate Explorer (version 3.1).*
[5] U.S. Department of Energy Federal Energy Management Program. 2022. *Technical Resilience Navigator.*




Vulnerability to sea level rise[6] by 2090 with vulnerability for Ronald Reagan Washington National Airport, Fort Myer, and many other parts of Arlington County, and medium vulnerability for the Pentagon.




Heat vulnerability mapping[7] by 2090 with predicted 65 more days over 95°F in Arlington County.




Arlington Flood Risk[8], as interior flooding on 100 Year Baseline for 24-hr Storm.

**Figure 1. Projected climate impacts in Arlington: Sea level rise (top left), heat vulnerability (top right), and inland flood risk (bottom left)**

Local governments across the world face increasingly complex decisions that balance immediate economic priorities with addressing long-term funding for resilience measures. Creating community awareness is key to informing future decisions and how investments in infrastructure can mitigate climate risks to ensure vibrant and sustainable economic growth. Equally important, understanding the financial implications of climate-related inaction can help justify community investments and timely action in resilience. Through careful research, planning, and execution of resilience actions, Arlington County can be a leader in physical risk mitigation and minimize the acute and chronic impacts of climate change.

This white paper discusses relevant topics on the financial impacts that climate change can have on a community—from the ability to borrow money given the climate-related risks, to the risks to infrastructure and business retention and economic development opportunities. The sections that follow cover the evolution of financial markets and trends in long-term infrastructure investment, as well as emerging trends in private and public sector guidance.

[6] NOAA. 2022. Sea Level Rise Viewer.
[7] National Integrated Heat Health Information System. 2018. Future Heat Events and Social Vulnerability 2018.
[8] Arlington County Flood Risk Tool, 2022

# 2. Key Climate Risks and Financial Market Trends

A growing number of businesses, financial institutions, and institutional investors are making increased efforts to assess physical and transition risks. These efforts have resulted in a wave of climate transition plans to achieve carbon neutrality. In turn, financial markets are beginning to integrate climate transition risks and opportunities into investment decision-making.

One of the major impacts that climate change will have on the financial market is the understanding and incorporation of climate-related risk in financing future capital programs. The bankability of future projects or their ability to attract favorable financing has traditionally been determined by a project's alignment with local priorities, and whether it provides services and/or stable revenue sufficient to repay borrowed funds and can provide attractive financial or performance returns. Increasingly, factors that demonstrate investments aligning with rapidly developing sustainability metrics are becoming more important in these investment decisions[9]. With the increased attention to climate change risks by credit ratings and insurance companies, the ability for projects to be considered attractive in the future may depend on their local implementation of resilience measures.

Arlington will be impacted by those market trends both through its ability to finance future projects and also through the difficult choices that local businesses and individuals will need to make when considering their real property and other assets.

This section discusses emerging trends in climate-related risks that are impacting borrowing, insurance, and other financing decisions, including climate-related financial disclosures.

## 2.1 Bond Ratings and Municipal Borrowing Costs

The impacts of climate change will amplify the financial burden on organizations and their ability to manage their debt policies. Arlington's current Fiscal Year (FY) 2023 – FY 2032 Capital Improvement Plan (CIP) details the requirements for managing the growth of debt service. Therefore, it will be crucial to understand the impacts of climate change on bond ratings and municipality costs so that the County's debt policies are sustainable and support their goal to maintain a strong bond rating to support low-cost borrowing for County citizens and property owners.

Bond issuance plays an important role for many government organizations as a source of raising financing capital for projects, such as those related to infrastructure. For the past 21 years, Arlington County has maintained a top AAA rating with the three major bond rating organizations, Moody's, Fitch, and the S&P. While the current 10-year debt service growth is calculated at 3.7 percent (%) by the adopted Arlington County CIP, maintaining the AAA will be a priority goal for the County as the cost of capital and the demand for major infrastructure projects increase.

The higher a bond rating, the more confidence investors have, meaning the bond is more likely to be purchased and can yield a lower interest rate for the County. AAA ratings are the rarest bond rating and the best achievable across all three major rating indices, with only 48 counties in the United States able to claim such a distinction[10]. Traditional bond ratings are influenced by several qualitative and quantitative factors, such as organization management, budgetary flexibility, budgetary performance, liquidity, debt and contingent liabilities, and institutional framework[11].

[9] Ellis C., and K. Pillay. 2017. *Understanding "bankability" and unlocking climate finance for climate compatible development.*
[10] Arlington County, Virginia. 2022. *Bonds.*
[11] OpenGov. 2019. *5 Steps to Maintain or Improve Your Municipal Bond Rating.*

Major bond rating agencies are beginning to consider how climate change affects a municipality's operations and revenue generation capability. A bond rating may be affected based on the frequency and likely severity of the impact of extreme weather events. Both Moody's and S&P Global, have made recent climate-focused acquisitions in the industry, setting a precedent that climate impacts will be considered an increasingly important factor in future investment decisions; Moody's acquired Four Twenty Seven and RMS and S&P Global acquired The Climate Service.

As climate change impacts nature, built infrastructure, and operations, it will also shift the way investors and rating agencies evaluate organizations. A recent study by Morgan Stanley Capital International (MSCI) simulated the impacts on bond ratings against several climate change and transitional scenarios across industrial sectors. The outcome of the analysis showed that 16% to 27% of bond issuers could be at risk of being downgraded[12]. The analysis concluded investors are increasingly interested in including climate change in their risk management.

Climate risks that the S&P claimed to account for in modern bond ratings include heat waves, cold waves, wildfires, hurricanes, floods, droughts, and more, but the ways these risks will affect municipalities are qualitative and not quantitative, ultimately leaving the rating up to the discretion of the lead analyst who will assess how or whether these risks will be felt in a geographic location[13].

Charles Schwab cited the following examples in its recommendation to bond investors to focus investments on higher-rated bond issuers:

*New Orleans had already been struggling financially and was rated BBB+ by S&P before Hurricane Katrina. When the Hurricane hit New Orleans in 2005, it took a tremendous toll on the city. S&P downgraded many of New Orleans issuers to B-, or "Junk" status. It has taken the city 8 years to recover to a AA- rating.*

*By comparison, when Hurricane Sandy hit the coast of New York City in 2012, it was the 4th costliest storm in the history of the United States and wreaked havoc on coastal communities, however, the bond rating was not downgraded or changed. This is attributed to the economic strength of New York City, reflected in its AA bond rating at that time.*

A McKinsey report highlights some key climate impacts, such as habitability considering physical assets at risk of flooding or wildfires, heat stress, drought possibilities on food systems, heat stress from extreme temperatures, and infrastructure strength and resilience[14]. The frequency of strong storms and other acute impacts, together with investment resilience measures will be relevant in the evaluation of stronger municipality's bond rating,—a phenomenon made more frequent by climate change.

In its recommendations to investors, Charles Schwab emphasized more scrutiny on a bond issuer's financial flexibility when determining investment decisions—a quality that is often associated with higher credit ratings. This enables a better ability to manage the financial disruption of climate vulnerabilities as highlighted in the example box[15]. Although current pricing of climate change has been limited to long-term municipal bonds, there is a precedent of historic investor attention as a driving factor in issuance costs on bonds issued by climate- and non-climate-affected counties. This change was recorded historically with the example of the 2006 Stern Review on climate change that resulted in the upward revision in sea level rise projections which led to municipal bond markets price increase for sea level rise exposure. Long-term bonds remain a preference for long-term borrowing and it is worth noting that in the first half of 2022, 66% of municipal bonds traded had 10+ year maturity horizons[16].

[12] Janosik R., and T. Verbraken. 2021. How Climate Change Could Impact Credit Risk. *MSCI.*
[13] S&P Global Ratings. 2017. *How Does S&P Global Ratings Incorporate Environmental, Social, And Governance Risks Into Its Ratings Analysis.*
[14] Woetzel J., D. Pinner, H. Samandari, H. Engel, M. Krishnan, B. Boland, and C. Powis. 2020. *Climate risk and response: Physical Hazards and Socioeconomic Impacts.*
[15] Howard C. 2020. Charles Schwab. *Should Muni Bond Investors Be Concerned About Climate Shocks?*
[16] Electronic Municipal Market Access. 2022. Municipal Trade Statistics filter January 1 to June 1 2022.

The flowchart on the following page from Moody's shows how environmental risks are incorporated into credit ratings from both climate trends, and how climate shocks are considered in the final bond rating through the potential socioeconomic impacts felt downstream.

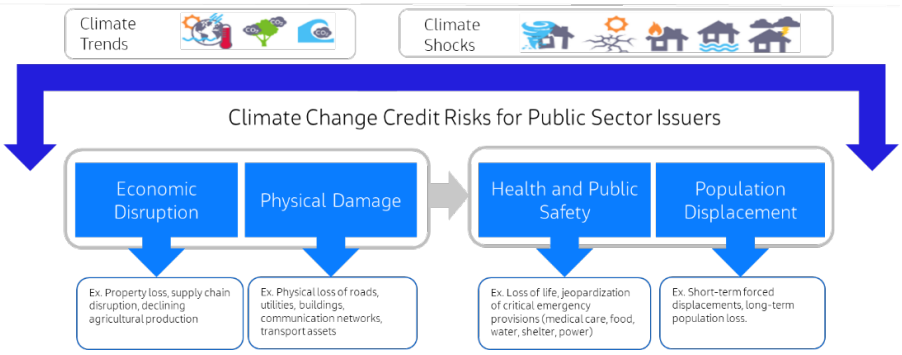



**Figure 2. Influence of climate trends and shocks on bond ratings[17]**

Local governments are increasingly seeking green bonds, a type of fixed-income instrument that is specifically earmarked to raise money for climate and environmental projects. Climate or green bonds are specifically issued to address projects related to climate change mitigation or adaptation measures or other forms of environmental sustainability. These bonds form emerging financing sources to advance mitigation measures, as well as update infrastructure to withstand the projected effects of climate change. Green bonds raise capital directly for this purpose, and the growth of the green bond market has undergone an annual growth rate of 95% since 2007 when the very first green bond was issued by the European Investment Bank[18]. As of 2020, the green bond market hit a market value milestone of $1 trillion[19] and is still growing. As the green bond market grows, so do the oversight and adopted standards. The Climate Bonds Standard V3, released by the Climate Bonds Initiative, presents a new standard of climate bond rules and regulations. This includes setting standards for guidance, ongoing reporting, improved disclosure, verification, and definitions of proceeds and expenditures[20]. It is this kind of universally adopted standard that further instills trustworthiness by investors in an issuing organization.

## 2.2 Insurance Responses to Climate Risks

Globally, during the first half of 2021, insured losses from natural disasters were at $42 billion, a 10-year high[21]. Insurers and regulators are experiencing more claims and higher losses and, as a result, are focusing more on the physical, systemic, and transitional risks that climate change poses to the pricing of insurance products and investment portfolios. Chronic and acute weather-related events result in physical risks, while the advancement of technology, regulations, and changing consumer sentiment create transition risks for entities. With urbanization fueling population growth and property values rising in the District of Columbia, Maryland, and Virginia (DMV) region, the value at risk for insurers is also growing.

Insurance regulators are also taking note of climate risks, as described in the recent Insurance Regulator State of Climate Risks Survey[22] conducted by Deloitte. It shows that U.S. state insurance regulators are bracing for increasing climate-related risks to insurers over the next 5 to 10 years. These risks will impact insurers' ability and willingness to underwrite and invest in infrastructure projects, as well as provide affordable insurance premiums to businesses and homeowners.

[17] Jones L. 2018. Incorporating Environmental Risks in Credit Ratings.
[18] Climate Bonds Initiative. 2020. Explaining Green Bonds.
[19] Climate Bonds Initiative. 2020. Explaining Green Bonds.
[20] Climate Bonds Initiative. 2020. Climate Bonds Standard V3.0.
[21] Reuters. 2021. Natural Disaster H1 Insured Losses Hit 10-year High-Aon.
[22] Deloitte. 2019. *Climate Risk: Regulators Sharpen Their Focus.*

The National Association of Insurance Commissioners has studied the potential impacts of climate risks on insurance regulation and policy premiums. One of their main concerns is the risk of solvency that natural disasters pose to their investment portfolios, which strengthens their financial stability and their ability to pay out claims. They also note that their risks to weather-related losses include declining asset values in disaster-prone areas, costs of resiliency and fortification, physical damage to structures, and disruptions in business operations[23]. Therefore, insurers are reevaluating their catastrophe models, investment frameworks, product lines, and public policy measures to assist all stakeholders—insurers, regulators, and policyholders—in mitigating the financial and physical dangers of climate change. However, these mitigation measures by the insurance industry carry additional costs to businesses and policyholders and affect the public and private sectors differently.

Furthermore, reinsurance companies are analyzing climate change on a global scale and assessing their ability to provide capital backing to regional insurers and infrastructure assets. The reinsurance giant Swiss Re Institute estimates that the world economy could suffer losses of up to 18% of GDP by 2050 if no action is taken against climate change[24]. Already many reinsurers are witnessing strains on their financial investments through increased claims from climate-related events. Reinsurers will be more stringent on investment opportunities and pricing their premiums to include aggregated risks from various climate impacts that are country- or location-specific, including future catastrophe models and considering Environmental, Social, & Governance (ESG) metrics in their underwriting criteria. The failure of businesses and governments to improve their resiliency efforts could result in increased carrying costs or loss of coverage for their infrastructure needs[25].

The most direct insurance-related impact on Arlington County is the change to the Federal Emergency Management Agency (FEMA)-administered National Flood Insurance Program (NFIP). In 2020, the average flood insurance premium in Arlington County was $568 and 2% of the population resided in a "preliminary flood high hazard area" according to the FEMA Flood Insurance Rate Map[26]. However, with the increased risks from climate change and the growing paid losses and claims, FEMA is making some changes that could increase rates for policyholders. As of October 1, 2021, the NFIP has implemented a new methodology called Risk Rating 2.0 for providing insurance premiums. Previously, insurance premiums were calculated by a property's elevation within a 100-year flood zone map or a Flood Insurance Rate Map. However, with the increased risks to property because of climate change and the NFIP's current debt issues[27], FEMA has developed software to analyze more property considerations and motivate insurance holders to be more proactive in their resilience efforts[28]. This new rating system is causing flood insurance premiums to rise for many businesses and homeowners as they begin to price in climate risk impacts of recurring events[29].

All these trends indicate a higher risk and cost burden for insurance, as shown in Table 1. Already, policyholders are seeing premium increases, business closures, and higher claims. If residents and businesses decide to relocate in search of a safer and lower cost of living, this could reduce the Arlington County tax revenue base. Based on Arlington County's Adopted FY 2022 – FY 2024 CIP[30], the County uses Pay-As-You-Go (PAYG) funds that are derived from the County's local tax dollars to finance capital projects. A reduced tax base could limit the ability of the PAYG funds to finance Arlington County's maintenance capital program, utility fund, and regional partnerships[31].

[23] National Association of Insurance Commissioners. 2008. *The Potential Impact of Climate Change on Insurance Regulation.*
[24] Swiss Re Institute. 2021. *The Economics of Climate Change: No Action Not an Option.*
[25] S&P Global. 2021. *Global Reinsurers Grapple with Climate Change Risks.*
[26] Arlington VA. 2020. *Flood Insurance Rate Map Public Meeting.*
[27] Congressional Research Service. 2021. *Introduction to the National Flood Insurance Program (NFIP).*
[28] FEMA. 2022. *Risk Rating 2.0: Equity in Action.*
[29] The New York Times. 2021 *The Cost of Insuring Expensive Waterfront Homes Is About to Skyrocket*
[30] Arlington VA. 2022. Adopted Capital Improvement Plan.
[31] Arlington VA. Pay-As-You-Go Capital General Capital Projects Fund.

**Table 1. Financial and Insurance Risks Related to Climate Change**

| Risk | Public Sector Impact | Private Sector Impact |
|---|---|---|
| Property and flood insurance premiums rise | Insurance premium impact to County-owned assets* | Homeowners and businesses leave in search of lower costs, unwilling to pay the higher insurance premium |
| Disruption to the tax revenue base | Decreased tax revenue and availability of PAYG funds for capital improvement projects and to address debt service | Disruption to regular business operations, leading to revenue loss |
| Lower bond rating from climate impact increases the cost of capital | Higher financing costs for capital projects | Higher costs to the community from increased taxes and levies to cover increased financing costs |

*The County has a deductible property insurance program that covers the County's building and assets and business interruptions as applicable to the peril. The premiums for property coverage for the County can be affected due to national and international high-risk perils, e.g., natural disasters, which at times can cause a rise in property premiums.

There are ways to improve the resilience of communities and lower insurance premiums. The Community Rating System (CRS) provides insurance holders with premium discounts for communities that exceed the NFIP minimum floodplain management criteria. The three goals of the program are to reduce and avoid flood damage to insurable property, to strengthen and support the insurance aspects of the NFIP, and to foster comprehensive floodplain management. Arlington County currently holds a Class 8 CRS rating that qualifies insurance holders for a 10% discount in a Special Flood Hazard Area (SFHA) and a 5% discount in a non-SFHA[32].If the County were to incorporate additional flood mitigation efforts from the CRS manual[33], they would be eligible for increased premium discounts. Due to the current constraints that Arlington County faces, codes and standards offer the primary opportunity to increase County's ratings and appropriate discounts.

## 2.3 Urban Area and Real Estate Trends

Several urban trends, such as aging or under-capacity infrastructure and continued urbanization, can make counties like Arlington progressively more susceptible to the impacts of climate change. The migration of people to cities has been a growing trend that creates pressure on the infrastructure and systems in an urban area. While a reverse migration out to the suburbs and smaller cities was hypothesized at the height of the pandemic, many large cities are seeing a restoration, or growth, of their urban population as the world learns to live with the COVID–19 pandemic. The DMV is the 6th largest metropolitan area in the United States[34] and is projected to grow nearly 14% by 2030 to 7.4 million residents. A more condensed population is a larger risk for localized natural disasters.

Beyond the population density, the American Society of Civil Engineers (ASCE) Infrastructure Report Card illustrates that Virginia's infrastructure, including roads, bridges, and water systems, is deteriorating, which can exacerbate the impacts of climate change. The ASCE estimates that 4.4% of bridges are rated structurally deficient, 14% of roads are in poor condition and the state's schools have an estimated capital expenditure gap of $973 million[35]. Some assistance is coming due to the signing of the Bipartisan Infrastructure Law, as Virginia is expected to get $9.8 billion in funding over the next 5 years[36]. An increase in heavy infrastructure projects will require expert land planning and resource management use to mitigate climate change exposures.

[32] FEMA. 2022. Community Rating Systems.
[33] CRS Resources. 2021. The CRS Coordinator's Manual.
[34] Statista. 2022. Population of the Largest Metropolitan Areas in the US as of 2021.
[35] ASCE. 2021. *Virginia Infrastructure Overview.*
[36] The White House. 2020. *Building a Better America.*

With businesses and governments continually adopting carbon emissions goals, many industries will have to undergo transformations to achieve carbon reductions. According to the U.S. Environmental Protection Agency (EPA), 13% of greenhouse gas emissions come from commercial and residential operations, while 27% are a result of the transportation industry and 25% result from the use of electricity. A major concern for governments will be the ability to find the capital to fund these decarbonization projects, such as building retrofits and low-to-zero tailpipe emissions bus fleets, to achieve their carbon emissions goals.

## 2.4 Climate-Related Financial Disclosures

The Financial Stability Board created the Task Force on Climate-Related Financial Disclosures (TCFD)[37] to improve and increase reporting of climate-related financial information. The goal of the TCFD was to provide financial markets with concise guidance for climate change impacts, including the risks and opportunities presented by rising temperatures, climate-related policy, and emerging technologies. Recent guidance on metrics and targets was designed to support plans for transitioning, including climate-related metric categories that all organizations can disclose[38].

In the United States, regulations are converging to consider the guidance provided by the TCFD framework, which includes four pillars of governance, strategy, risk management, and metrics and targets. The additional disclosure has many benefits for public sector organizations beyond just attracting investors, it could also put climate concerns into an organization's top budget considerations and help to accelerate finance towards resilience and future-proofing projects.

President Biden's Executive Order 14040[39] presented a roadmap for measuring, disclosing, managing, and mitigating climate-related financial risk across the economy, including to the federal government, while also catalyzing public and private investment to seize the opportunity of a net-zero, clean energy future. The climate risk accountability framework outlines core principles for addressing climate-related financial risk. A recent discussion paper outlined the development changes required for financial accounting standards and reporting climate-related financial risks[40] for federal government agencies. This is the first step toward working deliberation before considering changes or modifications to the Federal Accounting Standards guidance, which facilitates how federal agencies report financial disclosures and is expected to inform future investment decisions for federal government organizations.

As a major milestone in March 2022, the Securities and Exchange Board (SEC) proposed rule changes that would require registrants to include certain climate-related disclosures in their statements and periodic reports[41]. Such information will enable investors to appropriately assess their investment and lending risks. The new guidance would create requirements for the disclosure of climate-related risks and impacts based on the TCFD disclosure framework, including information about material impacts of climate risk on a company's business, and information about a company's governance, risk management, and strategy related to climate risk. The guidelines are designed to improve transparent reporting to investors on climate impacts and mitigation measures. The objective is to instill behavioral change in companies, such as identifying how a company's investment decisions are addressing a transition towards greenhouse gas emission reduction, or reducing climate risk vulnerability in the future. Even though the proposed rules have yet to be adopted, and face all but certain legal challenges thereafter, the SEC climate-related disclosure rules represent a growing global business push for more consistent, transparent ESG reporting standards by companies.

[37] TCFD. 2017. *Final Report.*
[38] TCFD. 2021. *Implementing the Recommendations on the TCFD.*
[39] U.S. Climate-Related Financial Risk Executive Order 14030. 2021. *A Roadmap to Build a Climate-Resilient Economy.*
[40] Federal Accounting Standards Advisory Board (FASAB). 2022. *Statements of Federal Financial Accounting Standards That May Be Relevant to Climate-Related Financial Reporting.*
[41] U.S. Securities and Exchange Commission. 2022. *Shelter from the Storm: Helping Investors Navigate Climate Change Risk.*

The context for Arlington County can be related to cities in Canada, which are an example of mainstream adoption of the TCFD guiding principles by a local authority[42] into the budgetary processes, building an understanding of incorporating climate risk into financial plans, budgets, and capital investments. Areas for consideration include:

- Potential risks of climate change to the city's operations and assets, including its financial status, such as its credit rating.
- Estimated financial impacts of climate risks and opportunities, such as present and future costs from climate hazards and potential savings from adaptation or mitigation efforts.
- Embedding the useful life of capital assets and critical infrastructure upgrade plans, and how climate is currently included in capital planning.
- The locations of climate expertise in the city and which departments are integrating climate into their decisions[43].

## 2.5 Climate-Related Analytical Tools

The demand for analyzing the impacts of climate change has resulted in a growing industry of customized climate-related analytical tools that capture the full complexity of economic, environmental, and societal interactions. These tools range in scope, purpose, and capabilities, from improving climate-related awareness to specialized tools that use AI to inform future targeted investment[44] and mitigation measures. Climate analytics tools offer the ability to translate complex climate science impacts at an asset or portfolio to a broader stakeholder audience, including end users, investors and/or regulators.

Similar to real estate market-driven trends, decision-makers now have the ability to integrate this knowledge to better identify physical risks from climate change, and the probability of exposure and severity of those physical risks at a site-specific scale. As consumer awareness increases, climate impact models are being embedded into popular web portals, such as Realtor, Zillow, and Redfin; all have flood risk map layers within their real estate listing maps to better inform buyers and renters.

The synthesis of scientific knowledge in the area of climate change creates a range of capabilities to inform scenario analysis, time, and baseline assumptions[45]. In addition, federal agencies such as NOAA offer data and mapping tools to help the public understand underlying climate science and add value by enhancing the discoverability, accessibility, and utility of commonly requested data.[46] Depending on the approach each tool utilizes for scenario development, there may be variations in the demonstrated likelihood of damage from certain risks increases over time, for example, climate-risk assessment output may differ if the assumption is a 10-, 20-, or 50-year horizon or depending on the Representative Concentration Pathway (RCP) trajectory adopted.

[42] C40 Knowledge Hub. 2019. *Enhancing climate-related disclosure by cities: A guide to adopting the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD).*
[43] C40 Knowledge Hub. 2019. *Enhancing climate-related disclosure by cities: A guide to adopting the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD).*
[44] Climate Alpha Tool. 2022. *AI Powered Analytics Platform.*
[45] Climate Analytics. 2022. *Main Page: Latest Tools, Briefings, Blog, Media Coverage, & Publications.*
[46] NOAA. 2022. *About Us Page.*

In order to manage climate-related risks and opportunities, businesses are choosing to align with vendor tools that offer the ability to analyze physical-risk climate science data to specific needs, such as real-estate life-cycle, supply chain, and operational decisions. To aid in investment decisions, certain providers offer value at risk as an additional consideration, where the likelihood that a physical asset suffers damage from an acute weather event or is subject to gradual stress of chronic weather conditions like heat stress is translated into a probabilistic estimate of the financial loss suffered if an event occurs.[47] A small share of these tools is considering localized mitigation measures such as building codes and action in the form of upgraded infrastructure to address future risks.

The availability of climate-related data and mapping tools is expected to stimulate dialogue to ensure stakeholders understand the constantly evolving nature of climate science and its nuances as well as limits such as the scale, precision, complexity, and how these results are translated into value and value-at-risk metrics. New standards continue to evolve the link between scientific and policy analysis, to support the adaptive nature of producer, consumer, and government stakeholders to inform future business and policy decisions.

[47] Urban Land Institute. 2022. *How to Choose, Use, and Better Understand Climate-Risk Analytics.*

# 3. Environmental, Social, and Governance Impacts

A recent IPCC report[48] outlined that to enable mutual climate-resilient pathways and sustainable development, effective implementation requires cross-sectoral cooperative action at all levels, through a holistic integrated approach to future investment decisions that link adaptation, mitigation, resilience, with other objectives. Beyond the direct impact on damages and financial markets, climate change will impact urban systems socially and environmentally. Building infrastructural resilience can support sustainable urban development if those factors are considered.

The increased importance of ESG is an approach to assess the performance of organizations' works on behalf of social goals that go beyond the role of a corporation to maximize profits on behalf of shareholders. The three domains of social, environmental, and corporate governance are linked to the concept of responsible investment. Typically, the social goals advocated within an ESG perspective include working to achieve a certain set of environmental priorities, supporting certain social objectives, and establishing a governance framework that instills accountability and reporting on relevant issues such as diversity, equity, and inclusion. The ESG movement has grown in importance due to the general adoption within TCFD guidelines and draws parallels to historic Equator Principles for large infrastructure and industrial projects.

Arlington is at the forefront of climate change impacts, stressing the need for infrastructure and other investments and policies that reduce exposure and amplify adaptive capacity to natural disasters, but also for taking care of those citizen groups that have historically been underserved and are most vulnerable to the impacts of climate change. The following subsection describes some key concepts that are not directly impacting urban financing but are crucial for potential future funding and sustainable development of the County.

## 3.1 Building Urban Resiliency and Adaptive Capacity

Arlington County's infrastructure is crucial to supplying services to many of the key organizations of the U.S. government, businesses, and residents within its borders. As the area is threatened by changes in the climate, it must adapt and build resilience. First, an assessment of the municipality's infrastructure would grade the health of key structures, followed by a present and future assessment of material health and ability to handle extreme events. Currently, the Flood Risk Assessment and Management Plan (RAMP) serves part of that purpose, as it relates to inland flooding, sea level rise, and storm surge risks. Both prolonged natural events and flash natural events must be anticipated and planned for if Arlington is to be truly resilient and adaptive. Arlington constitutes only 26 square miles and the County experienced rapid development between the 1940s and 1970s, prior to the emergence of strong stormwater and overland relief regulation. The dense development was achieved through undergrounding 2/3 of the County's 93 miles of streams, and these pipes were used to establish the stormwater infrastructure, but without meaningful tertiary infrastructure or design consideration of Arlington's acute elevation changes (which create flood "bowls" and back-flows). While inland flooding pose a serious issue, it can be mitigated with proper planning. The structural constraints and physical multipliers that produce inland flooding have been amplified by climate volatility and increasing frequency, intensity and duration of extreme storms. In response to repetitive flooding and loss (including the historic storm of July 8, 2019), the County re-visioned its stormwater program to become Flood Resilient Arlington, which provides for increased operations and maintenance budgets, and substantially increased capital investments in innovative infrastructure upgrades, including tertiary infrastructure, underground detention, and property acquisition for the purpose of overland relief and future climate elasticity.[49]

[48] IPCC. 202. *AR6 Synthesis Report: Climate Change 2022.*
[49] Arlington County, VA. 2022. *Flood Resilient Arlington*

Arlington County has already begun to implement policies and initiatives to improve urban sustainability, resilience and adaptive capacity, under the multi-disciplinary rubric of its Community Energy Plan (CEP) and multi-sector CEP Roadmap[50]. E.g., by incentivizing builders to implement U.S. Green Building Council Leadership in Energy and Environmental (LEED) principles, buildings can be instruments to combat urban heat island effects, control stormwater runoff, and decrease carbon dioxide emissions. The County already contains more than 17 LEED-certified buildings[51] as of 2019 and promotes the use of LEED and other performance standards in its *2020 Green Building Incentive Policy*[52]. Furthermore, the County implements its own Sustainable Facilities Standards and County Operations Energy Plan to meet its carbon neutrality goals by 2050[53]. The County's prior transportation programs and policies have reduced private car ownership and annual vehicle miles traveled, despite progressively increasing population; and presently the County is conducting studies and developing a master plan to attain low-to-zero carbon targets in transportation. These guides aim to reduce greenhouse gas emissions, increase the use of renewable energy, and improve energy resilience systems. Committing more capital funding and fulfilling these initiatives will be crucial to fortifying the County from future climate change impacts. Arlington has already recognized climate change impacts related to flood by examining climate change impacts on stormwater capacity during the prior Stormwater Capacity project, undertaking the current Risk Assessment Management Plan (RAMP) project to address the risk and uncertainty of flooding due to current and future climate, and by projecting and mapping risk and consequential impacts in support of a long-term resiliency strategy.

## 3.2 Social Vulnerability, Health, and Safety

Climate change can pose severe risks to human health and disproportionately affects underserved communities. An EPA report highlights that the primary climate change impacts on the underserved populations in Arlington include air quality and chronic conditions concerns, extreme temperature and the related labor and health concerns, coastal and inland flooding, and impact on traffic and property[54]. Furthermore, other climate change-related risks may affect the area, such as the moderate to a high potential abundance of disease-carrying mosquitoes[55] and invasive species, as well as a reduction in work hours by 3% to 3.9% in the construction, manufacturing, transportation, and utility industries. Resilience investments that are centered on socially vulnerable communities (Figure 3) can help mitigate climate-related health and justice concerns.

Although Arlington County has a low climate risk index[56] for social vulnerability (3.78 compared to a national average of 38.35), localized areas of high social vulnerability do exist. The current RAMP efforts and future implementation of its recommendations create an opportunity for Arlington to maintain and further support climate equity through its climate actions to address community resilience. The RAMP directly assesses mitigation of flood impacts that include high social vulnerability areas that can be protected through targeted investments. Some funding sources require an environmental justice consideration, such as the Virginia Community Flood Preparedness Fund, which requires that no less than 25% of the funds each year should be used for projects in low-income areas[57]. Fulfilling those requirements could further support environmental justice efforts in the County.

[50] Arlington County, VA. 2022. Community Energy Plan (CEP). https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Energy/Community-Energy-Plan
[51] Arlington County, VA. 2019. *Arlington County LEED Certified Projects.*
[52] Arlington County, VA. 2020. *Updates to the Green Building Incentive Policy for Site Plan Projects.*
[53] Arlington County, VA. 2022. *County Operations.*
[54] US EPA. 2021. *Climate Change and the Social Vulnerability in the United States.*
[55] Southeast | Fourth National Climate Assessment. 2018. *Impacts, Risk, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.*
[56] FEMA. 2022. *National Risk Index Map.*
[57] Virginia Department of Conservation and Recreation. 2022. *Community Flood Preparedness Fund Grands and Loans.*

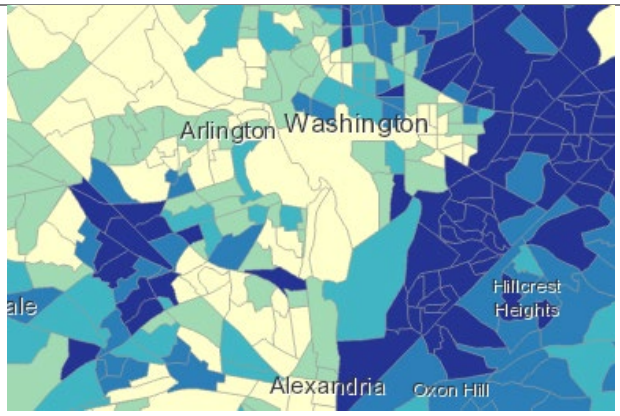
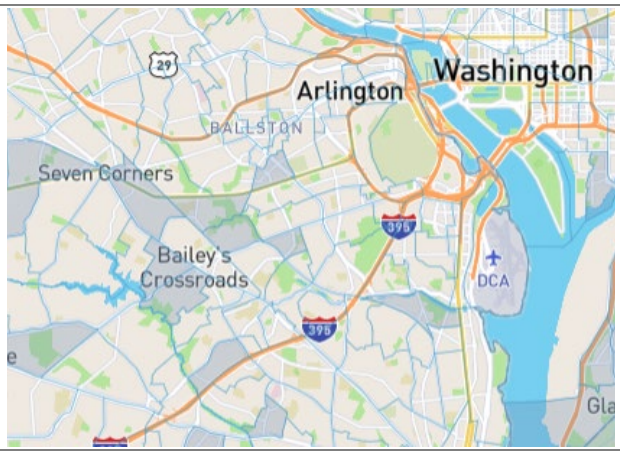
| | | |
|---|---|---|
| **Aggregate Social Vulnerability Index** [58] |  | **Composite Social Vulnerability**<br>Social Vulnerability Index 2018<br>> 0.8 – 1.0<br>> 0.6 – 0.8<br>> 0.4 – 0.6<br>> 0.2 – 0.4<br>0 - 0.2<br>**Note: The composite Social Vulnerability Index comprises four categories of factors: socioeconomic status, household composition and disability, minority status and language, and housing and transportation.** |
| **Highlighted Disadvantaged Communities in Arlington**[59] |  | Note: Disadvantaged communities are identified as such if the census tract is above threshold for one or more environmental or climate indicators, and the census tract is above the threshold for the socioeconomic indicators. Those indicators include climate change, clean energy and energy efficiency, clean transit, affordable and sustainable housing, reduction and remediation of legacy pollution, critical clean water and wastewater infrastructure, health burdens, and training and workforce development. |

**Figure 3. Social metrics for consideration in Arlington climate investments – Social Vulnerability Index and Disadvantaged Communities Map**

[58] Chesapeake Bay Environmental Justice and Equity Dashboard. 2021. *Dashboard Overview*.
[59] Executive Office of the President of the United States. 2022. *Climate and Economic Justice Screening Tool*.

# 4. Economic Impacts and Opportunities

Arlington's property tax base consists of 46% commercial and 54% residential. Various business types might be affected by climate in different ways. To continue attracting forward-thinking and innovative businesses, retaining, and attracting talent to the area, the County needs to maintain its attractiveness for investment. This section outlines the ways businesses might be affected and reviews some new approaches to growing Arlington's economy to future-proof the investments in the County.

## 4.1 Jobs, Tourism, and Preservation of the Diverse Economy

In recent years, Arlington has been facing intense flash floods due to severe rainfall[60]. These periods of inundation have highlighted the need for mitigation and relief planning. Arlington is a community that houses federal agencies, major corporate headquarters and business hubs, Washington DC workers, and has many residents that live and work inside the County. As such, the need for housing is consistently rising. Old and new housing alike is susceptible to more frequent and severe storms which can and have caused devastating property damage, often displacing the local population. If the residents are displaced, local jobs will also take a hit as commuting may no longer be feasible.

Tourism is another large draw to Arlington and the surrounding area, and the same issues that will affect housing will have a very similar impact on the ability of tourists to visit and feed the local economy. Flash floods, frequent intense storms, severe heat waves, and more will make the local area less attractive to potential tourists. This would be a severe loss in income, as pre-COVID–19 Arlington recorded $3.3 billion in tourism revenue in 2017[61]. The solution to this is planned mitigation and resilience planning so that foreseeable issues can be avoided as much as possible. Arlington has a uniquely diverse economy, hosting everyone from top government officials to entry-level municipal employees to a wide array of private industry employees; ensuring access to work and housing among those workers is critical to keep the economy functioning.

In a case study by the Pew Research Center, it was found that climate change would shift patterns of tourism towards higher altitudes and latitudes. Warm areas which may be comfortable now will become unbearably hot and stormier in the warmer months when tourism is most prevalent. The northern United States will see a rise in tourism, while the mid-latitude and lower latitude states will see a drop in tourism[62]. With proper resiliency and mitigation measures, Arlington will hopefully be able to retain or even grow its attractiveness to tourists.

The decision by Amazon.com, Inc. (Amazon) to locate its second headquarters facility at National Landing within Arlington County will increase both the demand for and expected supply of condominium and apartment buildings within the County, accelerating the existing movement toward more development therein. Projected new development in the National Landing corridor for 2022 is estimated at more than 10 million square feet of majority multifamily high-rises, nearly half of which have applied for bonus density under the County Green Building Bonus Density Incentive Program. In addition, this project, which is expected to include 25,000 employees when fully staffed, will support additional growth in supplying industries such as restaurants and other elements of the hospitality industry. One of the reasons Amazon selected Arlington County for its Headquarters is the forward-thinking climate and resilience planning by the County, as the nation's first recipient of LEED Platinum Community certification (2017). Continued recognition of climate-related risks can attract other businesses of similar scale to the region, and keep the development that Amazon and others are bringing.

[60] Arlington, VA. 2019. *A Flood Resistant Arlington.*
[61] Arlington, VA. 2018. *Arlington Tourism Revenue Hits Record $3.3 Billion in 2017.*
[62] Pew Research Center. 2006. *The Surprising Impact of Global Warming on Tourism.*

## 4.2 Low-Carbon Economy Transition and Circular Economy

Investing in resilience is not only an approach to adapt to climate change, but it is also an opportunity to support the low-carbon and circular economy. The circular economy is a system that changes the linear approach of raw materials extraction to make a product and eventually disposing of them as waste, elimination of waste and pollution, reuse of materials and products at their highest value, and regeneration of resources and nature[63].

Decreasing the carbon footprint or transitioning to a low-carbon economy can also help foster a region's economic growth. Currently, over 60% of Fortune 500 companies have established climate goals[64], meaning that they will be considering the footprint of their headquarters, manufacturing, and supporting services. Cities that have a smaller footprint can not only attract emissions-conscious businesses but also form mutually beneficial partnerships like the City-Business Climate Alliance[65]. For example, London formed the London Business Climate Leaders Initiative, which established shared climate priorities and stakeholder buy-in. Currently, businesses in London are helping to get the city to a resilient decarbonized future. Arlington County's Community Energy Plan with the 2050 decarbonization goal is a great step in supporting a low-carbon economy and fostering partnerships with businesses. Local initiatives such as the Climate Change, Energy and Environment Commission, and the Arlington Initiative to Rethink Energy, can continue providing and expanding the opportunities for partnering with local businesses in decarbonization.

Other countries – especially in Europe – have used building energy and environmental benchmarking and "report cards", first to establish and institutionalize ranking systems for these attributes in buildings[66]. Overall, the Energy Performance of Buildings Directive policy framework laid down the foundation for setting minimum standards in new construction and for existing buildings under major renovations, elevating public awareness and influencing decision-making among renters and buyers, and converting market priorities for energy and environmental performance in buildings into higher valuations for such buildings by investors, banks/lenders, and mortgage agencies.

The principles of circular economy can be used by municipalities to increase climate resilience[67.] Municipalities are often thought of as consumers68, with most of their resources being imported, even if they originate from the same region. For example, many cities do not produce food or products that can meet the needs of their population. This means that when an emergency occurs that cuts the supply of a city, that city may not be resilient to that stress. Investing in resilience through closed-loop/circular principles, on the other hand, can mean investment in local businesses and new local supply chains[69] that can carry the city through a crisis and encourage local economic growth. Another way to characterize such a municipality is as being resource-efficient. This concept highlights that the more resource-efficient a municipality is, the less vulnerable it is to external shortages, and it may require less cost to recover[70]. Combining the circular economy and resilience mindsets can result in a more flourishing community that requires fewer resources in the future. Transitioning to a low-carbon, sustainable approach to government should be a win for all parties if properly implemented. Cost savings in the short- and long-term, decreased carbon footprint, self-reliance and resilience, and attraction and retention of top talent residents can foster local environmental, social, and economic resilience.

[63] Ellen Macarthur Foundation. 2022. *What is a Circular Economy?*
[64] WWF. 2021. *Power Forward 4.0: A Progress Report of the Fortune 500's Transition to a Net-Zero Economy.*
[65] CDP. 2019. *City-Business Climate Alliances: A Step-by-Step Guide for Developing Successful Collaborations.*
[66] EU. 2010. *EU Directive on the Energy Performance of Buildings.*
[67] Enel. 2021. *Circular Cities: Impacts on Decarbonization and Beyond.*
[68] World Economic Forum. 2022. *This Chart Shows the Impact Rising Urbanization will have on the World.*
[69] Enel. 2021. *Circular Cities: Impacts on Decarbonization and Beyond.*
[70] U.N. Environment Programme. 2017. *Resilience and Resource Efficiency.*

# 5. Emerging Solutions

Resilient solutions are needed to avoid or decrease the intensity of climate impacts but can require significant funding. Climate financing pathways that municipalities are currently using are, in general, existing techniques repurposed for resilience investments. This section covers three types of typical financing that have been used to raise funds for climate adaptation: local revenue, private or philanthropic funding, and competitive state and federal grants. Overall, most cities and districts use a portfolio approach of combining these sources of funding to invest in more resilience and climate-ready assets.

The first category mentioned above is local revenue. Municipalities have used fees, taxes, credits and rebates, or other collections to fund resilience investments (Table 2). Many of the examples tackle the "symptoms" of climate change, such as flooding, without directly talking about emissions but can justify such vast infrastructural investments often due to past natural disasters. Many of the solutions like additional property taxes or higher stormwater fees require the support of the legislature and could be challenging to initiate but can be a stable source of funding.

Public-private partnership is an alternative source of funding for resilience investment and takes many forms. An example of a small-scale, but important public-private partnership, is the engagement of the local citizens in New Orleans to change their front yard to be flood-ready. Another example is DC's Stormwater Retention Credit program facilitate funds between landowner-installed stormwater infrastructure and incentivize development of facilities that reduce stormwater runoff. Such steps from individuals could result in significant improvements both to the resilience of the city or county, and the community's wellbeing. Beyond the City-Business Climate Alliances mentioned earlier in the paper, partnerships can look like city-land trust partnerships that can support local communities.

Environmental impact bonds, a form of private finance in which private investors agree to take a lower-than-typical return if emerging green technologies under-perform but reap a higher-than-typical return if they over-perform has become an emerging form of finance for sustainable solutions. DC Water was a pioneer in issuing environmental impact bonds, as profiled in the American Water Works Association Journal. Other examples of environmental or green bonds, is the Miami's Forever Bond (Table 2) is an example of such a fundraising tool, and it can help raise large amounts of investment dollars; in the case of Miami, such bonds have raised $198 million for resilience purposes. Nonetheless, municipal green bonds constitute only 2.1%[71] of all municipal bonds issued and could point to the use of other sources of funding, like philanthropic grants.

Competitive grant funding can originate from various state and federal sourcing and could be a significant additional source for resilience investments. Examples are the following:

- FEMA has provided funding to those communities that are most severely impacted by climate change, such as New Orleans, New York, and Miami. In addition, other federal agencies provide grant funding for specific infrastructure improvements such as the U.S. Department of Transportation or U.S. Department of Housing and Urban Development's Community Development Block Grant-Disaster Recovery[72]. which will award $3 billion in funds for disaster recovery and building inclusive resilience. Future funding will be available from the Bipartisan Infrastructure Framework dedicated to resilience infrastructure. Those funds will be coordinated through various agencies, including U.S. Army Corps of Engineers for aquatic ecosystem restoration and inland flood risk management, FEMA for flood and other hazard mitigation, NOAA for ecosystem restoration and coastal resilience, and U.S. Department of Transportation for coastal infrastructure and carbon reduction.

[71] Brookings Institute. 2021. *Rethinking Climate Finance to Improve Infrastructure Resilience.*

[72] U.S. Department of Housing and Urban Development. 2022. *HUD Announces $3 Billion to Advance Equitable Disaster Recovery, Build Climate Resilience.*

- Other resilience funding sources are region-specific, such as Florida's Resilient Grants program that supports municipalities across the state. Virginia-specific funds exist and include Virginia Community Flood Preparedness Fund[73], which is based on the money from auctioning carbon allowances through the Regional Greenhouse Gas Initiative funded programs until 2022 that prioritized projects that align with Virginia Coastal Resilience Master Plan . Other funding pathways are Resilience Virginia Revolving Loan Fund[74], Infrastructure Investment and Jobs Acts for resilience infrastructure, and EPA's Chesapeake Bay Program[75].
- The U.S. Army Corps of Engineers is engaging public-private partnerships on the $2.48 billion Fargo-Moorhead Metropolitan Area Flood Risk Management Project to be delivered as Design, Build, Finance, Operate, and Maintain. The project is designed to protect the Fargo-Moorhead-West Fargo metro area during times of extreme flooding using river control structures, floodwalls, levees, and other flood protection measures.

The list of possible resilience funding solutions in Table 2 does not provide an exhaustive list of examples, but rather provides examples of funding sources that are used for resilience investments and are currently used to address economic and climate vulnerabilities.

**Table 2. Resiliency Funding Pathways with U.S. Municipality Examples**

| City | Funding Method | Amount of Funding | Purpose | Source |
|---|---|---|---|---|
| **Local Revenue** | | | | |
| **Lancaster, PA** | Stormwater fee | The base rate is $52 per 1,000 square feet, but is tiered based on the total impervious area on the property. | The stormwater fees are based on the measurement of impervious surface for all property owners, and are used for implementation, management, construction and other fees related to stormwater infrastructure and facilities. Property owners are able to receive stormwater credits reducing their stormwater fees by up to 50% if they install green infrastructure. | [76] |
| **Austin, MN** | 20-year local option sales tax | $.005 tax (approximately $1.4 million per year that generated $7.5 million in state funding and $5 million in federal funding) | The local sales tax dollars are used for flood mitigation projects as local match funds for state and federal grants, and property buy-outs. | [77] [78] |
| **Chicago, IL** | Tax Increment Financing (TIF) | With over 120 TIF districts, funds were leveraged to attract $6 billion in private capital investments. | Chicago has established over 120 TIF districts, that are intended for the redevelopment of distressed areas. The money was used for a Green Roof Improvement Fund for commercial buildings to manage stormwater. | [79] |

[73] Virginia Department of Conservation & Recreation. 2022. *Community Flood Preparedness Fund Grants and Loans.*
[74] Virginia's Legislative Information System. 2022. *SB 756 Resilient Virginia Revolving Loan Fund; created*
[75] US EPA. 2022. *EPA Announces $40 Million from Infrastructure Law for Chesapeake Bay Restoration*
[76] City of Lancaster. 2002. *Stormwater*
[77] Headwaters Economics. 2021. *Building Community Support for Flood Mitigation*
[78] Short Elliot Hendrickson Inc. 2022. *How One City Continues to Rise Above the Floodwaters*
[79] Adaptation Clearinghouse. 2011. *Chicago, Illinois Central Loop Tax Increment Financing*

| City | Funding Method | Amount of Funding | Purpose | Source |
|---|---|---|---|---|
| **Norfolk, VA** | Property tax increase | $0.01 tax increase per $100 of asset value, which generates $1.8 million per year. | Termed a "resilience penny," dedicated to resilience efforts and can be later used for bond repayment. | |
| **Miami, FL** | General obligation green and resilience bonds | $198 million (out of a total $400 million bond). | The Miami Forever Bond provides funding for many resilience projects like sea level rise and flood prevention, along with other investments in the city's infrastructure. | 80, 81 |
| **Public-private Partnership** | | | | |
| **City of Fargo, ND and City of Moorhead, MN** | Proof of Concept for Alternative Financing U.S. Army Corps of Engineers | Red River Valley Alliance was selected as the P3 partner to construct the 30-mile diversion on behalf of the non-federal share. | MFDA and the City of Fargo and the City of Moorhead hold the Project Agreement (P3 Agreement) with the P3 Developer. RRVA, the private-sector partner, delivers innovative solutions that align with the MFDA's technical requirements. RRVA assumes the risks of delays and costs escalation. | 82 |
| **New Orleans, LA** | Citizen engagement for flood-ready landscaping | Urban Conservancy Front Yard Initiative reimburses homeowners $2.5 per square foot of paving removed, funded by grant money. | The effort is one of the pathways to engage private citizens in resilience efforts that combines private funds from homeowners and grants that reimburse their payments. | 83 |
| **Boston, MA** | City-land trust partnership (Dudley Street Neighborhood Initiative) | NA (funded by grants, donations, and Community Investment Tax Credits). | While not a source of direct revenue, the land trust was a way to provide resilience improvement without displacing local citizens, preserving affordable housing, alongside other amenities. Related to climate vulnerabilities, the land trust created green spaces to prevent urban heat islands. | 84 |
| **State and Federal Grants** | | | | |
| **New York, NY** | Federal funds with FEMA support | $3 billion to the public housing authority, $1.8 billion for the resiliency of hospitals and care centers from FEMA. | Using the Section FEMA 428 for the alternative public assistance program for resilience investments in 33 impacted developments. | 85 |

[80] Innovation Network for Communities. 2019. *Playbook 1.0: How Cities are Paying for Climate Resilience.*
[81] City of Miami. 2022. *Miami Forever Bond.*
[82] U.S. Army Corps of Engineers. 2021. *Fargo-Moorhead Diversion, Alternative Financing (P3) Proof of Concept.*
[83] Urban Conservancy. 2022. *Front Yard Initiative.*
[84] Adaptation Clearinghouse. 2011. *Dudley Street Neighborhood Initiative, Boston, Massachusetts.*
[85] Innovation Network for Communities. 2019. *Playbook 1.0: How Cities are Paying for Climate Resilience.*

| City | Funding Method | Amount of Funding | Purpose | Source |
|---|---|---|---|---|
| **Miami Beach, FL** | Resilient Florida Grants | $40 million as part of the Resilience Florida Grants. | | 86 |
| **Federal Allocations for Urban and Rural Development** | Infrastructure Investment and Jobs Act | ~$50 billion in resilience infrastructure funding. | The resilience infrastructure funding that is available within the Infrastructure Investment and Jobs Act includes: $7B flood mitigation funding through U.S. Army Corps of Engineers, a $500M FEMA capitalization grant program, $2B for National Oceanic and Atmospheric Administration (NOAA) projects for coastal resiliency and other restoration projects, $3.5B in FEMA Flood Mitigation Assistance grants. . | 87, 88 |
| **Other** | | | | |
| **Central Valley, CA** | Portfolio approach (Central Valley Flood Protection Plan Investment Strategy; with a 2022 update) | Based on the estimated $17 billion to $21 billion investments over 30 years. | This example is more state-level than municipal level, it suggests a strategy of using a portfolio approach from the onset. There are hardly any resilience initiatives that can be based on a single source of funding and having a portfolio strategy up-front can make prioritization of investments easier. | 89,90 |
| **Projects in Boise, ID, Austin, TX, and others** | Carbon offset market | Benefits can be estimated at $18.3 billion per year from city forests, where carbon credits cover planting costs. | An approach that can be used with nature-based solutions like city forests, mangrove restoration, or forested riparian buffers, where natural plantings not only help with flooding or heat island issues but also generate carbon credits. | 91, 92 |

MFDA = The Metro Flood Diversion Authority
TIF = Tax Increment Financing
RRVA = Red River Valley Alliance

[86] Florida Department of Environmental Protection. 2022. *Resilient Florida Grants*.
[87] BGR Group. 2022. *Infrastructure Investment and Jobs Act – Resiliency and Environmental Remediation*
[88] 117th United States Congress. 2021. *Infrastructure Investment and Jobs Act*
[89] California Natural Resources Agency. 2017. *Central Valley Flood Protection Plan Investment Strategy*
[90] California Department of Water Resources. 2022. *Central Valley Flood Protection Plan.*
[91] City Forest Credits. 2022. *Local Climate Action*
[92] American Forests. 2021. *Innovative Financing Bring Carbon Markets to Cities*

# 6. Conclusion

Climate change will impact how governments plan, prepare, fund, and manage their capital assets and infrastructure. These impacts will have a cascading impact on all the County's stakeholders that benefit from the County's operations, such as residents, businesses, developers, and financial institutions. Failure to identify and plan for the risks associated with climate change will amplify their financial impact for years to come. As discussed, inaction around climate change could result in lower than necessary bond ratings, even though the institutions are still processing the implications of the upcoming climate-related disclosures. Similarly, insurance rates are likely to be affected as more assets are subject to climate risks. Insurance premiums are projected to grow but implementing more resilience approaches can provide discounts and mitigate the expected increases in future insurance costs. In brief, climate adaptation and resiliency planning and active implementation of programs, projects and policies, will secure the fiscal stability of local governments, contain costs to individuals and businesses, and sustain property valuation and marketability.

Beyond financial risks, climate considerations offer opportunities to build more resilient communities and to ensure long-term competitiveness, desirability, economic vibrancy, and high quality-of-life indicators. Various funding mechanisms can be used for supporting resilience investments, such as local revenue generation, public-private partnerships, and state or federal grants. These funding pathways can foster an equitable, healthy, and economically flourishing County. Extolling virtue and the need for resilience is the beginning of change, but the onus of palpable resilience falls to the municipality. For Arlington County to retain its financial and economic position and environmental as a desirable place to live and work in future years, it will require the desire and proactive planning and action to fortify against the growing effects of climate change.

# 7. References

[1] Department of Homeland Security. 2021. National Preparedness Report https://www.fema.gov/sites/default/files/documents/fema_2021-national-preparedness-report.pdf

[2] Arlington VA. 2020. Flood Insurance Rate Map Public Meeting. https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Stormwater/Flood-Insurance-Rate-Maps

[3] Deloitte. 2022. The turning point: A global summary https://www2.deloitte.com/content/dam/Deloitte/global/Documents/gx-global-turning-point-report.pdf

[4] NOAA. 2022. U.S. Climate Resilience Toolkit Climate Explorer (version 3.1) https://crt-climate-explorer.nemac.org/climate_maps/?city=Arlington%2C+VA&county=Arlington%2BCounty&area-id=51013&fips=51013&zoom=7&lat=38.8799697&lon=-77.1067698&id=days_tmax_gt_90f

[5] U.S. Department of Energy Federal Energy Management Program. 2022. Technical Resilience Navigator https://trn.pnnl.gov/potential-hazards

[6] NOAA. 2022. Sea Level Rise Viewer https://coast.noaa.gov/slr/#/layer/vul-soc/10/-8583924.259890256/4702345.244449838/13/satellite/152/0.8/2050/interHigh/midAccretion

[7] National Integrated Heat Health Information System. 2018. Future Heat Events and Social Vulnerability 2018 https://nihhis.cpo.noaa.gov/vulnerability-mapping

[8] Arlington County Flood Risk Tool, 2022 https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Stormwater/Flood-Insurance-Rate-Maps

[9] Ellis C., and K. Pillay. 2017. Understanding 'bankability' and unlocking climate finance for climate compatible development. https://cdkn.org/sites/default/files/files/CDKN_unlocking-climate-finance.pdf

[10] Arlington County, Virginia 2022. Bonds https://www.arlingtonva.us/Government/Programs/Budget-Finance/Bonds

[11] OpenGov. 2019. 5 Steps to Maintain or Improve Your Municipal Bond Rating https://www.governing.com/archive/5-steps-to-maintain-or-improve-your-municipal-bond-rating.html

[12] Janosik R., and T. Verbraken. 2021. How Climate Change Could Impact Credit Risk. MSCI. https://www.msci.com/www/blog-posts/how-climate-change-could-impact/02803746523

[13] S&P Global Ratings. 2017. How Does S&P Global Ratings Incorporate Environmental, Social, And Governance Risks Into Its Ratings Analysis https://www.brookings.edu/wp-content/uploads/2018/01/epdf_spg-esg-risks-into-ratings-analysis_final.pdf

[14] Woetzel J., D. Pinner, H. Samandari, H. Engel, M. Krishnan, B. Boland, and C. Powis. 2020. Climate risk and response: Physical Hazards and Socioeconomic Impacts. https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts how

[15] Howard C. 2020. Charles Schwab. Should Muni Bond Investors Be Concerned About Climate Shocks? https://www.schwab.com/learn/story/should-muni-bond-investors-be-concerned-about-climate-shocks

[16] Electronic Municipal Market Access. 2022. Municipal Trade Statistics https://emma.msrb.org/MunicipalTradeStatistics/ByTradeCharacteristic.aspx

[17] Jones L. 2018. Incorporating Environmental Risks in Credit Ratings. https://opr.ca.gov/meetings/tac/2018-06-29/docs/7_California_Governors_Moodys_Investors_Service_June_2018.pdf

[18] Climate Bonds Initiative. 2020. Explaining Green Bonds https://www.climatebonds.net/market/explaining-green-bonds#:~:text=Green%20bonds%20were%20created%20to,the%20issuer%27s%20entire%20balance%20sheet.

[19] Climate Bonds Initiative. 2020. Explaining Green Bonds https://www.climatebonds.net/market/explaining-green-bonds#:~:text=Green%20bonds%20were%20created%20to,the%20issuer%27s%20entire%20balance%20sheet.

[20] Climate Bonds Initiative. 2020. Climate Bonds Standard V3.0 https://www.climatebonds.net/climate-bonds-standard-v3

[21] Reuters. 2021. Natural Disaster H1 Insured Losses Hit 10-year High-Aon https://www.reuters.com/business/finance/natural-disaster-h1-insured-losses-hit-10-year-high-aon-2021-07-21/

[22] Deloitte. 2019. Climate Risk: Regulators Sharpen Their Focus. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/financial-services/us-fsi-climate-risk-regulators-sharpen-their-focus.pdf

[23] National Association of Insurance Commissioners. 2008. The Potential Impact of Climate Change on Insurance Regulation. https://content.naic.org/sites/default/files/inline-files/cipr_potential_impact_climate_change.pdf

[24] Swiss Re Institute. 2021. The Economics of Climate Change: No Action Not an Option. https://www.swissre.com/dam/jcr:e73ee7c3-7f83-4c17-a2b8-8ef23a8d3312/swiss-re-institute-expertise-publication-economics-of-climate-change.pdf

[25] S&P Global. 2021. Global Reinsurers Grapple with Climate Change Risks https://www.spglobal.com/ratings/en/research/articles/210923-global-reinsurers-grapple-with-climate-change-risks-12116706

[26] Arlington County, Virginia. 2020. Flood Insurance Rate Map Public Meeting https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2020/11/FIRM-presentation-2020.pdf

[27] Congressional Research Service. 2021. Introduction to the National Flood Insurance Program (NFIP) https://sgp.fas.org/crs/homesec/R44593.pdf

[28] FEMA. 2022. Risk Rating 2.0: Equity in Action https://www.fema.gov/flood-insurance/risk-rating

[29] The New York Times, 2021. The Cost of Insuring Expensive Waterfront Homes Is About to Skyrocket https://www.nytimes.com/2021/09/24/climate/federal-flood-insurance-cost.html

[30] Arlington VA. 2022. Adopted Capital Improvement Plan https://www.arlingtonva.us/files/sharedassets/public/budget/documents/adopted-fy-2022-2024-capital-improvement-plan_v3.pdf

[31] Arlington VA. Pay-As-You-Go Capital General Capital Projects Fund https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/18/2019/08/11-PAYG-GO-ST.pdf

[32] FEMA. 2022. Community Rating Systems https://www.fema.gov/floodplain-management/community-rating-system#participating

[33] CRS Resources. 2021. The CRS Coordinator's Manual https://crsresources.org/manual/

[34] Statista. 2022. Population of the Largest Metropolitan Areas in the US as of 2021 https://www.statista.com/statistics/183600/population-of-metropolitan-areas-in-the-us/

[35] ASCE. 2021. Virginia Infrastructure Overview https://infrastructurereportcard.org/state-item/virginia/

[36] The White House. 2020. Building a Better America https://www.whitehouse.gov/wp-content/uploads/2022/01/BUILDING-A-BETTER-AMERICA_FINAL.pdf

[37] Task Force on Climate-Related Financial Disclosures. 2017. *Final Report* https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf

[38] Task Force on Climate-Related Financial Disclosures. 2021. Implementing the Recommendations on the TCFD https://assets.bbhub.io/company/sites/60/2021/07/2021-TCFD-Implementing_Guidance.pdf

[39] U.S. Climate-Related Financial Risk Executive Order 14030. 2021. A Roadmap to Build a Climate-Resilient Economy https://www.whitehouse.gov/wp-content/uploads/2021/10/Climate-Finance-Report.pdf

[40] FASAB, 2022, Statements of Federal Financial Accounting Standards That May Be Relevant to Climate-Related Financial Reporting https://files.fasab.gov/pdffiles/climate_related_fin_reporting_staff_paper_2022.pdf

[41] U.S. Securities and Exchange Commission. 2022. Shelter from the Strom: Helping Investors Navigate Climate Change Risk https://www.sec.gov/news/statement/lee-climate-disclosure-20220321

[42] C40 Knowledge Hub. 2019. Enhancing climate-related disclosure by cities: A guide to adopting the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) https://www.c40knowledgehub.org/s/article/Enhancing-climate-related-disclosure-by-cities-A-guide-to-adopting-TCFD-recommendations?language=en_US

[43] C40 Knowledge Hub. 2019. Enhancing climate-related disclosure by cities: A guide to adopting the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) https://www.c40knowledgehub.org/s/article/Enhancing-climate-related-disclosure-by-cities-A-guide-to-adopting-TCFD-recommendations?language=en_US

[44] Climate Alpha Tool. 2022. *AI Powered Analytics Platform.* https://climatealpha.ai/

[45] Climate Analytics. 2022. *Main Page: Latest Tools, Briefings, Blog, Media Coverage, & Publications.* https://climateanalytics.org/

[46] NOAA. 2022. *About Us Page.* https://www.climate.gov/about

[47] Urban Land Institute. 2022. *How to Choose, Use, and Better Understand Climate-Risk Analytics.* https://knowledge.uli.org/-/media/files/research-reports/2022/uli-lasalle-report_final.pdf?rev=c19c836b5d1d4358bfcad5cc2cbc4a46&hash=5F84D14ED11CDB75B89DBFB0193F309D

[48] IPCC. 202. *AR6 Synthesis Report: Climate Change 2022* https://www.ipcc.ch/report/sixth-assessment-report-cycle/

[49] Arlington County, VA. 2022. *Flood Resilient Arlington*. https://www.arlingtonva.us/Government/Programs/Flooding

[50] Arlington County, VA. 2022. Community Energy Plan (CEP). https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Energy/Community-Energy-Plan

[51] Arlington, VA. 2019. Arlington County LEED Certified Projects https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Energy/Green-Building/Government-Green-Building

[52] Arlington County, VA. 2020. Updates to the Green Building Incentive Policy for Site Plan Projects https://www.arlingtonva.us/files/sharedassets/public/Environment/Documents/Board_Report_35-FINAL.pdf

[53] Arlington, VA. 2022. County Operations https://www.arlingtonva.us/Government/Programs/Sustainability-and-Environment/Energy/County-Operations

[54] US EPA. 2021. Climate Change and the Social Vulnerability in the United States https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf

[55] Southeast | Fourth National Climate Assessment. 2018. Impacts, Risk, and Adaptation in the United States: Fourth National Climate Assessment, Volume II https://nca2018.globalchange.gov/downloads/NCA4_Ch19_Southeast_Full.pdf

[56] FEMA. 2022. National Risk Index Map https://hazards.fema.gov/nri/map

[57] Virginia Department of Conservation and Recreation. 2022. Community Flood Preparedness Fund Grands and Loans https://www.dcr.virginia.gov/dam-safety-and-floodplains/dsfpm-cfpf

[58] Chesapeake Bay Environmental Justice and Equity Dashboard. 2021. Dashboard Overview. https://chesapeake-deij2-chesbay.hub.arcgis.com/

[59] Executive Office of the President of the United States. 2022. Climate and Economic Justice Screening Tool. https://screeningtool.geoplatform.gov/en/#10.71/38.845/-77.1261

[60] Arlington, VA. 2019. A Flood Resistant Arlington. https://storymaps.arcgis.com/stories/d0bb906589d144e5939281b60160b583

[61] Arlington, VA. 2018. Arlington Tourism Revenue Hits Record $3.3 Billion in 2017. https://www.arlingtonva.us/About-Arlington/News/Articles/2018/Arlington-Tourism-Revenue-Hits-Record-3.3-Billion-in-2017

[62] Pew Research Center. 2006. The Surprising Impact of Global Warming on Tourism https://www.pewresearch.org/2006/08/17/the-surprising-impact-of-global-warming-on-tourism/#:~:text=%E2%80%9CClimate%20change%20would%20shift%20patterns,may%20be%20cut%20in%20half.%E2%80%9D

[63] Ellen Macarthur Foundation. 2022. What is a Circular Economy? https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview#:~:text=A%20circular%20economy%20decouples%20economic,loss%2C%20waste%2C%20and%20pollution.

[64] WWF. 2021. *Power Forward 4.0: A Progress Report of the Fortune 500's Transition to a Net-Zero Economy* https://www.worldwildlife.org/publications/power-forward-4-0-a-progress-report-of-the-fortune-500-s-transition-to-a-net-zero-economy

[65] CDP. 2019. City-Business Climate Alliances: A Step-by-Step Guide for Developing Successful Collaborations https://www.c40.org/wp-content/uploads/2021/09/City-Business-Climate-Alliances.pdf

[66] EU. 2010. EU Directive on the Energy Performance of Buildings. https://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031

[67] Enel. 2021. Circular Cities: Impacts on Decarbonization and Beyond https://www.enel.com/content/dam/enel-com/documenti/media/circular-cities_october2021.pdf

[68] World Economic Forum. 2022. This Chart Shows the Impact Rising Urbanization will have on the World. https://www.weforum.org/agenda/2022/04/global-urbanization-material-consumption/

[69] Enel. 2021. Circular Cities: Impacts on Decarbonization and Beyond https://www.enel.com/content/dam/enel-com/documenti/media/circular-cities_october2021.pdf

[70] U.N. Environment Programme. 2017. Resilience and Resource Efficiency *https://wedocs.unep.org/bitstream/handle/20.500.11822/20629/Resilience_resource_efficiency_cities.pdf?sequence=1&amp%3BisAllowed=*

[71] Brookings Institute. 2021. Rethinking Climate Finance to Improve Infrastructure Resilience https://www.brookings.edu/research/rethinking-climate-finance-to-improve-infrastructure-resilience/

[72] US Department of Housing and Urban Development. 2022. HUD Announces $3 Billion to Advance Equitable Disaster Recovery, Build Climate Resilience https://www.hud.gov/press/press_releases_media_advisories/hud_no_22_049

[73] Virginia Department of Conservation & Recreation. 2022. Community Flood Preparedness Fund Grants and Loans. https://www.dcr.virginia.gov/dam-safety-and-floodplains/dsfpm-cfpf

[74] Virginia's Legislative Information System. 2022. SB 756 Resilient Virginia Revolving Loan Fund; created. https://lis.virginia.gov/cgi-bin/legp604.exe?221+sum+SB756

[75] US EPA. 2022. EPA Announces $40 Million from Infrastructure Law for Chesapeake Bay Restoration https://www.epa.gov/newsreleases/epa-announces-40-million-infrastructure-law-chesapeake-bay-restoration#:~:text=BALTIMORE%20(May%202%2C%202022),justice%20and%20counter%20climate%20change.

[76] City of Lancaster. 2002. Stormwater https://cityoflancasterpa.com/stormwater-information/

[77] Headwaters Economics. 2021. Building Community Support for Flood Mitigation https://headwaterseconomics.org/wp-content/uploads/Austin-Report-R5.pdf

[78] Short Elliot Hendrickson Inc. 2022. How One City Continues to Rise Above the Floodwaters. https://www.sehinc.com/news/how-one-city-continues-rise-above-floodwaters

[79] Adaptation Clearinghouse. 2011. Chicago, Illinois Central Loop Tax Increment Financing. https://www.adaptationclearinghouse.org/resources/chicago-illinois-central-loop-tax-increment-financing.html

[80] Innovation Network for Communities. 2019. Playbook 1.0: How Cities are Paying for Climate Resilience https://abag.ca.gov/sites/default/files/playbook1.0howcitiesarepayingforclimateresiliencejuly2019.pdf

[81] City of Miami. 2022. Miami Forever Bond https://www.miamigov.com/My-Government/Departments/Office-of-Capital-Improvements/Miami-Forever-Bond

[82] Urban Conservancy. 2022. Front Yard Initiative https://www.urbanconservancy.org/project/fyi/

[83] Adaptation Clearinghouse. 2011. Dudley Street Neighborhood Initiative, Boston, Massachusetts. https://www.adaptationclearinghouse.org/resources/dudley-street-neighborhood-initiative-boston-massachusetts.html

[84] US Army Corps of Engineers. 2021. Fargo-Moorhead Diversion, Alternative Financing (P3) Proof of Concept https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll11/id/5263

[85] Innovation Network for Communities. 2019. Playbook 1.0: How Cities are Paying for Climate Resilience https://abag.ca.gov/sites/default/files/playbook1.0howcitiesarepayingforclimateresiliencejuly2019.pdf

[86] Florida Department of Environmental Protection. 2022. Resilient Florida Grants https://floridadep.gov/Resilient-Florida-Program/Grants

[87] BGR Group. 2022. *Infrastructure Investment and Jobs Act – Resiliency and Environmental Remediation* https://bgrdc.com/infrastructure-investment-and-jobs-act-resiliency-and-environmental-remediation/

[88] 117th United States Congress. 2021. *Infrastructure Investment and Jobs Act* https://www.congress.gov/bill/117th-congress/house-bill/3684/text

[89] California Natural Resources Agency. 2017. Central Valley Flood Protection Plan Investment Strategy *http://cvfpb.ca.gov/wp-content/uploads/2018/01/CVFPP_InvestStrat-TM_Draft_201708-1.pdf*

[90] California Department of Water Resources. 2022. Central Valley Flood Protection Plan. https://deltacouncil.ca.gov/pdf/council-meeting/meeting-materials/2020-07-23-item-10-attachment-1-cvfpp-fact-sheet.pdf

[91] City Forest Credits. 2022. Local Climate Action *https://www.cityforestcredits.org/*

[92] American Forests. 2021. Innovative Financing Bring Carbon Markets to Cities *https://www.americanforests.org/article/innovation-innovative-financing-brings-carbon-markets-to-cities/*

# ARLINGTON
## VIRGINIA

Jacobs

Jacobs Engineering Group Inc.
1100 N Glebe Road, Suite 500
Arlington, VA 22201