Chapter 4: Regional Hazard Identification and Risk Assessment (HIRA)

Requirement §*201.6(c)(2): (The plan shall include) …a risk assessment that provides the factual basis for activities proposed in the strategy to reduce losses from identified hazards. Local risk assessments must provide sufficient information to enable the jurisdiction to identify and prioritize appropriate mitigation actions to reduce losses from identified hazards. The risk assessment shall include:*

(i) A description of the type, location, and extent of all natural hazards that can affect the jurisdiction. The plan shall include information on previous occurrences of hazard events and on the probability of future hazard events.

(ii) A description of the jurisdiction's vulnerability to the hazards described in paragraph (c)(2)(i) of this section. This description shall include an overall summary of each hazard and its impact on the community. All plans approved after October 1, 2008 must also address NFIP insured structures that have been repetitively damaged by floods. The plan should describe vulnerability in terms of:

a. The types and numbers of existing and future buildings, infrastructure, and critical facilities located in the identified hazard areas;

b. An estimate of the potential dollar losses to vulnerable structures identified in paragraph (c)(2)(ii)(A) of this section and a description of the methodology used to prepare the estimate;

c. Providing a general description of land uses and development trends within the community so that mitigation options can be considered in future land use decisions.

(iii) For multi-jurisdictional plans, the risk assessment must assess each jurisdiction's risks where they vary from the risks facing the entire planning area.

I. Introduction

The 2016 update to the Northern Virginia Hazard Mitigation Plan includes the following participating jurisdictions:

Counties

Arlington County
Fairfax County
Loudoun County
Prince William County

Cities

City of Alexandria
City of Fairfax
City of Falls Church
City of Manassas
City of Manassas Park

Towns

Town of Clifton
Town of Dumfries
Town of Haymarket
Town of Herndon
Town of Leesburg
Town of Lovettsville
Town of Middleburg
Town of Purcellville
Town of Occoquan
Town of Quantico
Town of Round Hill
Town of Vienna

Although some anecdotal information may be included regarding the towns located within these counties, these areas may not be fully included in this assessment due to the lack of data available. Where available, location-specific data is incorporated into the 2016 update. Where it was not available, it is assumed that adjacent county or municipal data includes or otherwise accounts for the town. For the purpose of simplicity, the study area will be referred to as the Northern Virginia planning area throughout the remainder of this chapter.

Efforts to involve county, city, and town departments and community organizations that might have a role in the implementation of mitigation actions or policies included invitations to attend meetings and assist with the development process, e-mails of minutes and updates, and opportunities for input and comment on all draft deliverables. Additional information on how this chapter was developed is available in the Planning Process Chapter.

The purpose of this section of the plan is to:

1) Identify the natural hazards that could affect the Northern Virginia planning area;
2) Assess the extent to which the area is vulnerable to the effects of these hazards; and
3) Prioritize the potential risks to the planning area.

The first step, identifying hazards, assessed and ranked all the potential natural hazards in terms of probability of occurrence and potential impacts. It also identified those hazards with the highest likelihood of significantly impacting the community. This section was completed based on a detailed review of the planning area hazard history. The 2010 update evaluated and reviewed the 2006 ranking and it was determined by the steering committee to expand the ranking and better align it with the Commonwealth of Virginia's methodologies. For the 2016 update, it was determined to continue the same methodology and hazards, with one minor change – rather than include extreme temperatures with other hazards, extreme temperatures is included in the 2016 update as an independent hazard.

Prior to the beginning of work to update the HIRA, the planning committee determined that the 2016 plan update would focus on natural hazards, and that no man-made or technological hazards would be included in this update, even in a redacted appendix.

The hazards determined to be of the highest risk were analyzed further to determine the magnitude of potential events, and to characterize the location, type, and extent of potential impacts. This included an assessment of what types of development are at risk, including critical facilities and community infrastructure. Finally, a prioritization of the risk to the planning area was compiled, to serve as an overall guide for the communities when planning development, implementing policy, and identifying potential mitigation measures.

II. Data Availability and Limitations

This study includes data collected from a variety of resources including local, state, and national datasets. Whenever possible and practical, data has been incorporated into GIS products to aid in analysis and to develop area-wide maps for depicting historical hazard events, hazard areas, and vulnerable infrastructure. Critical facility data has been collected from the FEMA loss-estimating

module, Hazards U.S. (HAZUS^{MH}), and has been supplemented, to the extent possible, by local data. The local data provided is summarized below in the Building Inventory & Local Critical Facility Data section. In accordance with FEMA mitigation planning guidance, the results of this study are based on the best available data. In most cases, detailed data regarding the structural characteristics of facilities does not exist in a usable format at the local level.

Local Critical Facility and Building Data

Building inventories were provided by the jurisdictions participating in this plan. In most cases, the building inventory captures only the location and estimated value of structures. Characteristics such as structure and construction type, (i.e., residential wood frame home) are not always recorded. This data was utilized to determine the risk to buildings based on the extent of known hazard areas that can be spatially defined through GIS technology. Hazards without known recurrence probabilities or mapped hazard extents are not deemed unique enough to make definitive risk and vulnerability assessments for potentially at-risk buildings or facilities that differentiate them from other areas of the region. The hazard-specific sections provide the analysis, if relevant, for the critical facilities, historic structures, and buildings at risk. Table 4.1 summarizes estimated building inventories per jurisdiction, estimated from both local inventories and HAZUS^{MH}.

Table 4.1. Local Building Inventory per Jurisdiction, from Local Inventories and HAZUS^{MH}

Jurisdiction	Estimated Number of Buildings per HAZUS^{MH}	Jurisdiction Estimated Number of Critical and Historic Assets
Arlington County	40,847	380
Fairfax County	328,867	448
Town of Clifton	*included*	58
Town of Herndon	*included*	37
Town of Vienna	*included*	19
Loudoun County	99,182	176
Town of Leesburg	*included*	171
Town of Lovettsville	*included*	7
Town of Purcellville	*included*	7
Town of Middleburg	*included*	6
Town of Round Hill	*included*	5
Prince William County	128,867	171
Town of Dumfries	*included*	NA
Town of Haymarket	*included*	8
Town of Occoquan	*included*	11
Town of Quantico	*included*	NA
City of Alexandria	41,158	21
City of Fairfax	7,986	16
City of Falls Church	4,602	9
City of Manassas	8,024	85

Table 4.1. Local Building Inventory per Jurisdiction, from Local Inventories and HAZUS^{MH}		
Jurisdiction	**Estimated Number of Buildings per HAZUS^{MH}**	**Jurisdiction Estimated Number of Critical and Historic Assets**
City of Manassas Park	4,152	19

Local historic asset, critical facility, and infrastructure data were provided in some form by most jurisdictions. However, a comprehensive inventory consistent across jurisdictions does not exist because there is no universally accepted definition of what constitutes critical facilities and infrastructure, nor is one associated with FEMA and DMA 2000 planning requirements. For purposes of this plan, critical facilities and infrastructure are identified as "*those facilities or systems that are owned/operated/maintained by the jurisdiction whose incapacity or destruction would present an immediate threat to life, public health, and safety, or have a debilitating effect on the economic security of the region*." This includes the following facilities and systems based on their high relative importance for the delivery of vital services, the protection of special populations, and other important functions in the Northern Virginia region:

- Emergency Operations Centers (EOCs);
- Hospitals and medical care facilities;
- Police stations;
- Fire stations;
- Schools (particularly those designated as shelters);
- Hazardous material facilities;
- Potable water facilities;
- Wastewater facilities;
- Energy facilities (electric, oil, and natural gas); and
- Communication facilities.

Because of their significance to many of the participating jurisdictions, historic assets were also included in this critical asset inventory for many jurisdictions.

In preparing the inventory of critical facilities for the Northern Virginia region, each participating jurisdiction was asked to submit best available GIS data for their primary critical facilities to be used in combination with HAZUS^{MH} inventory data. This resulted in the identification of hundreds of critical facilities for the Northern Virginia region. It is understood that this listing is incomplete due to data limitations associated with both the local GIS and HAZUS^{MH} inventories, but that further enhancements to the data will be made over time and incorporated during future plan updates. When analysis for critical facilities was performed, both the local and HAZUS^{MH} summary results are presented in the hazard specific sections, with clear notations as to which data set was utilized for that particular portion of the assessment.

During the 2016 update, each of the localities was provided a data matrix to assist them in compiling local data. The Data Matrix found in Appendix D contains the populated data matrices for localities that provided data during the data collection phase of this update. Figures 4.1

through 4.19 show the provided critical facility and historic asset locations within each of the participating jurisdictions.

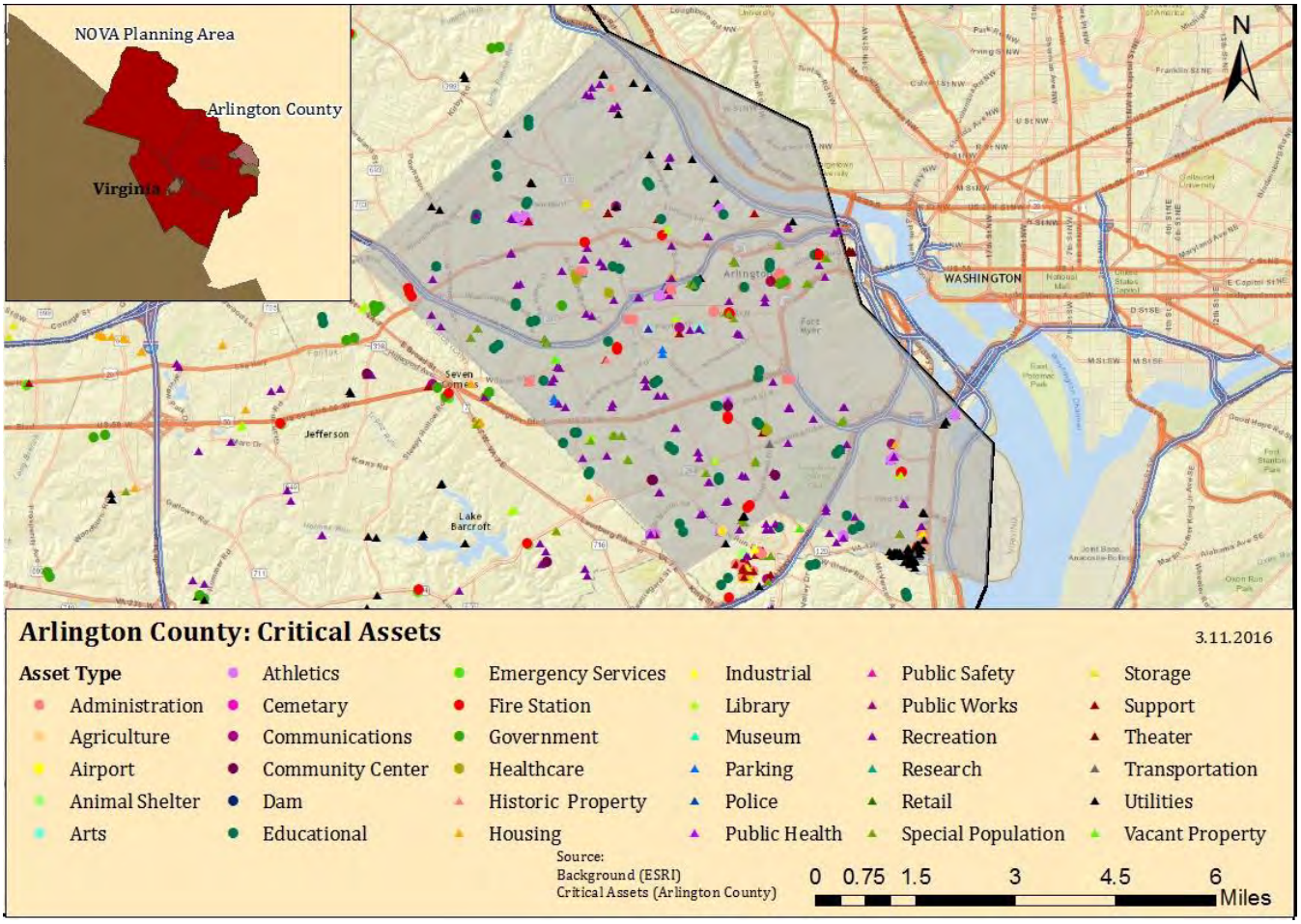

Figure 4.1. Arlington County local critical assets and historic structures.

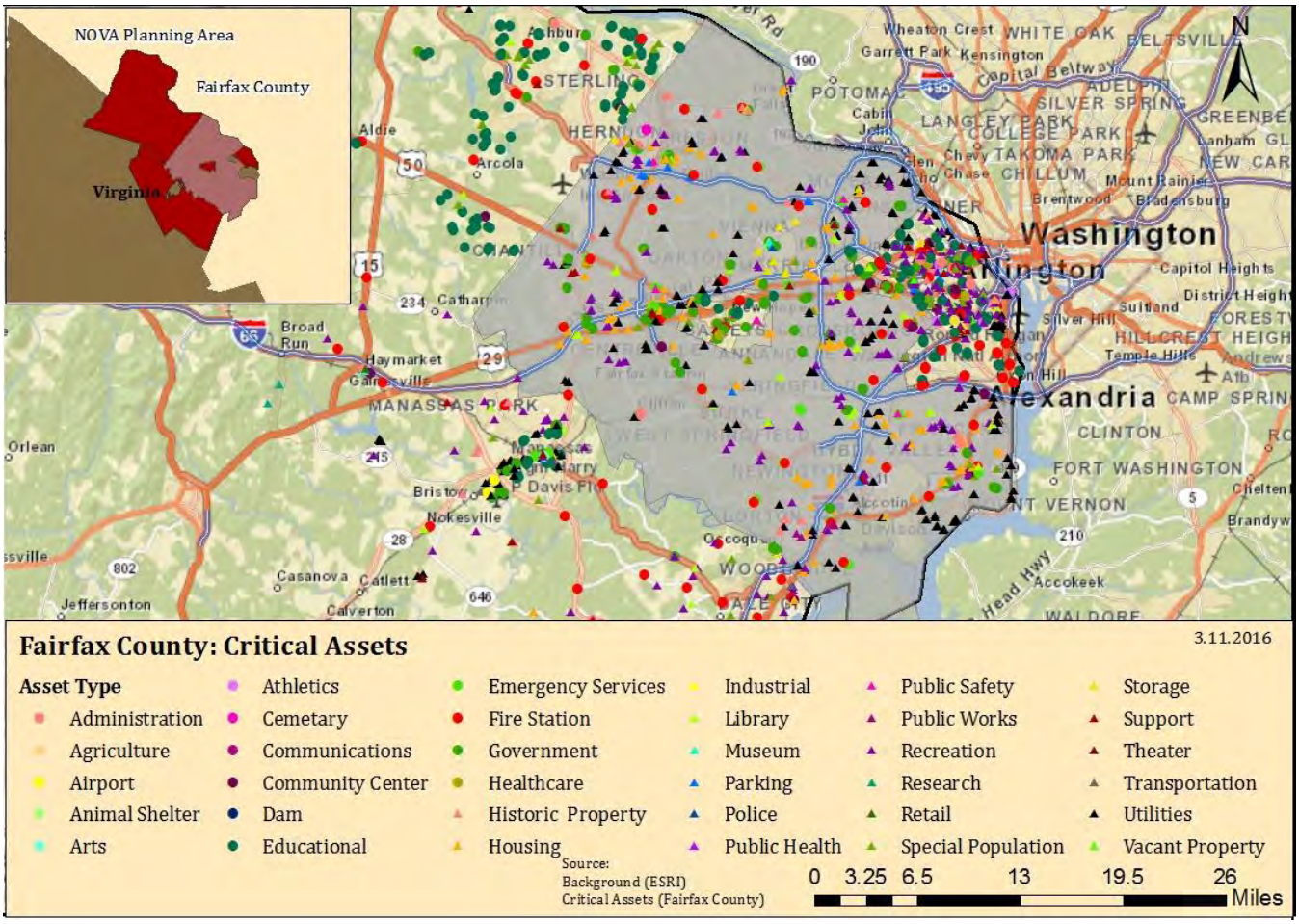

Figure 4.2. Fairfax County local critical assets and historic structures.

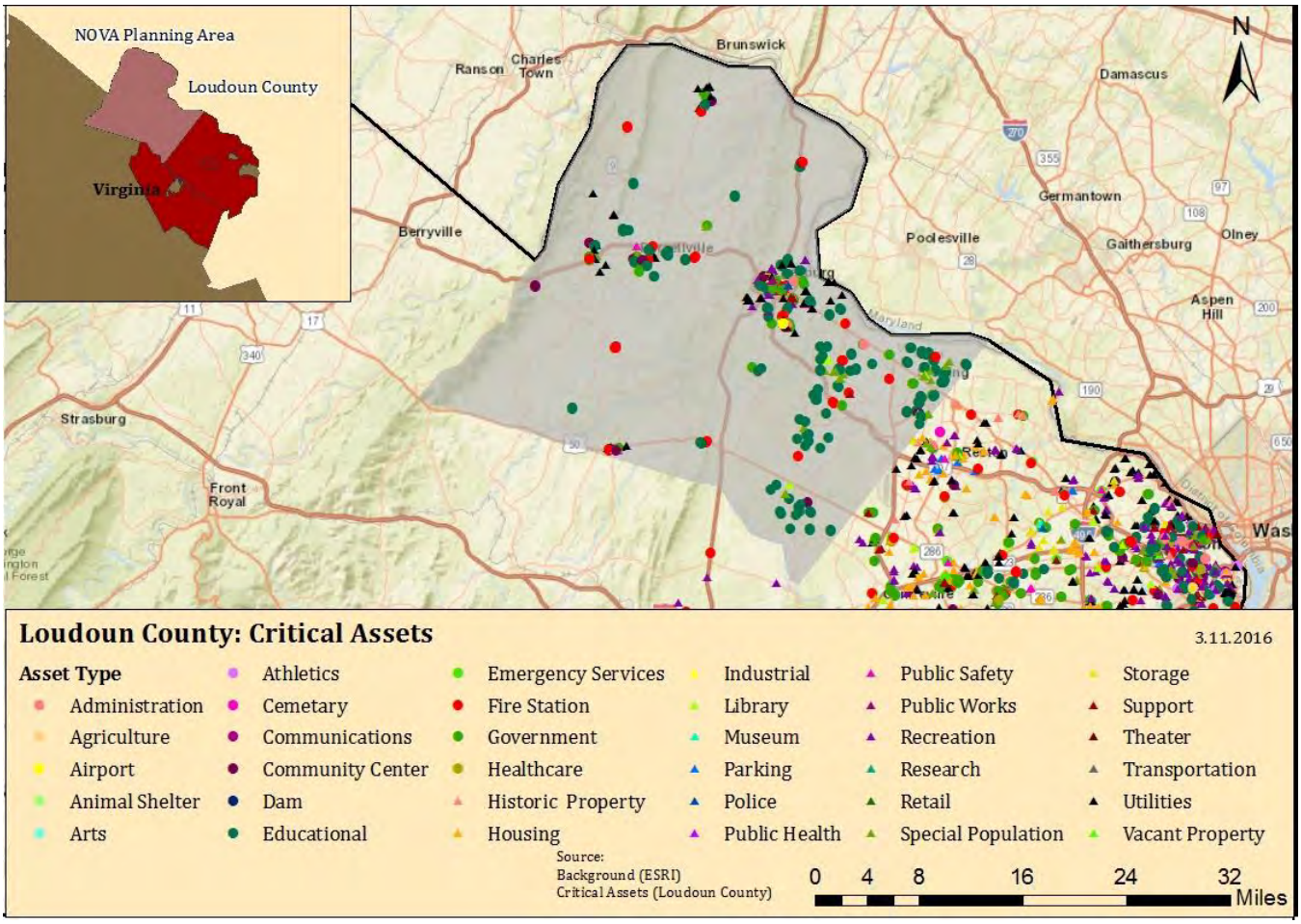

Figure 4.3. Loudoun County local critical assets and historic structures.

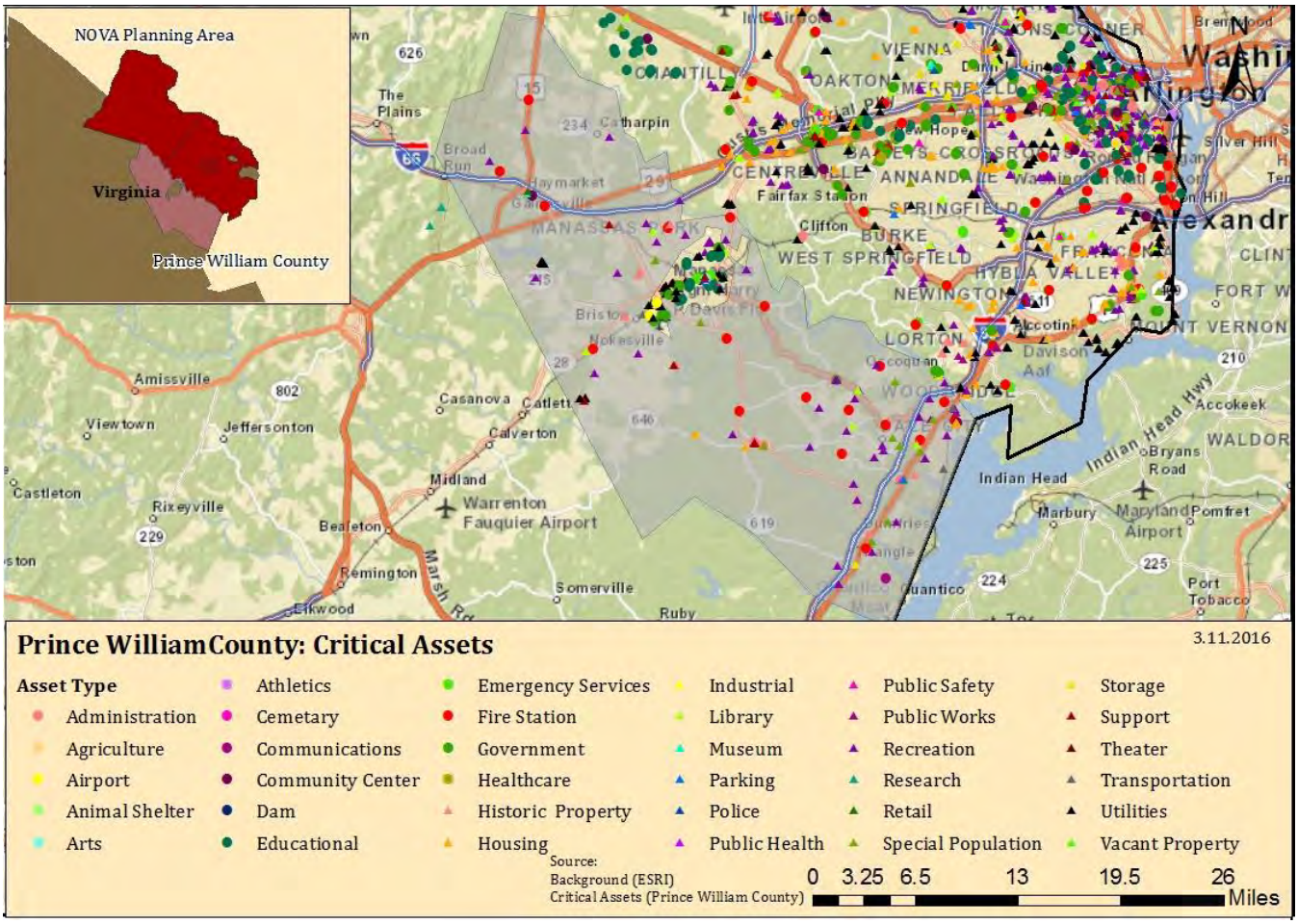

Figure 4.4. Prince William County local critical assets and historic structures.

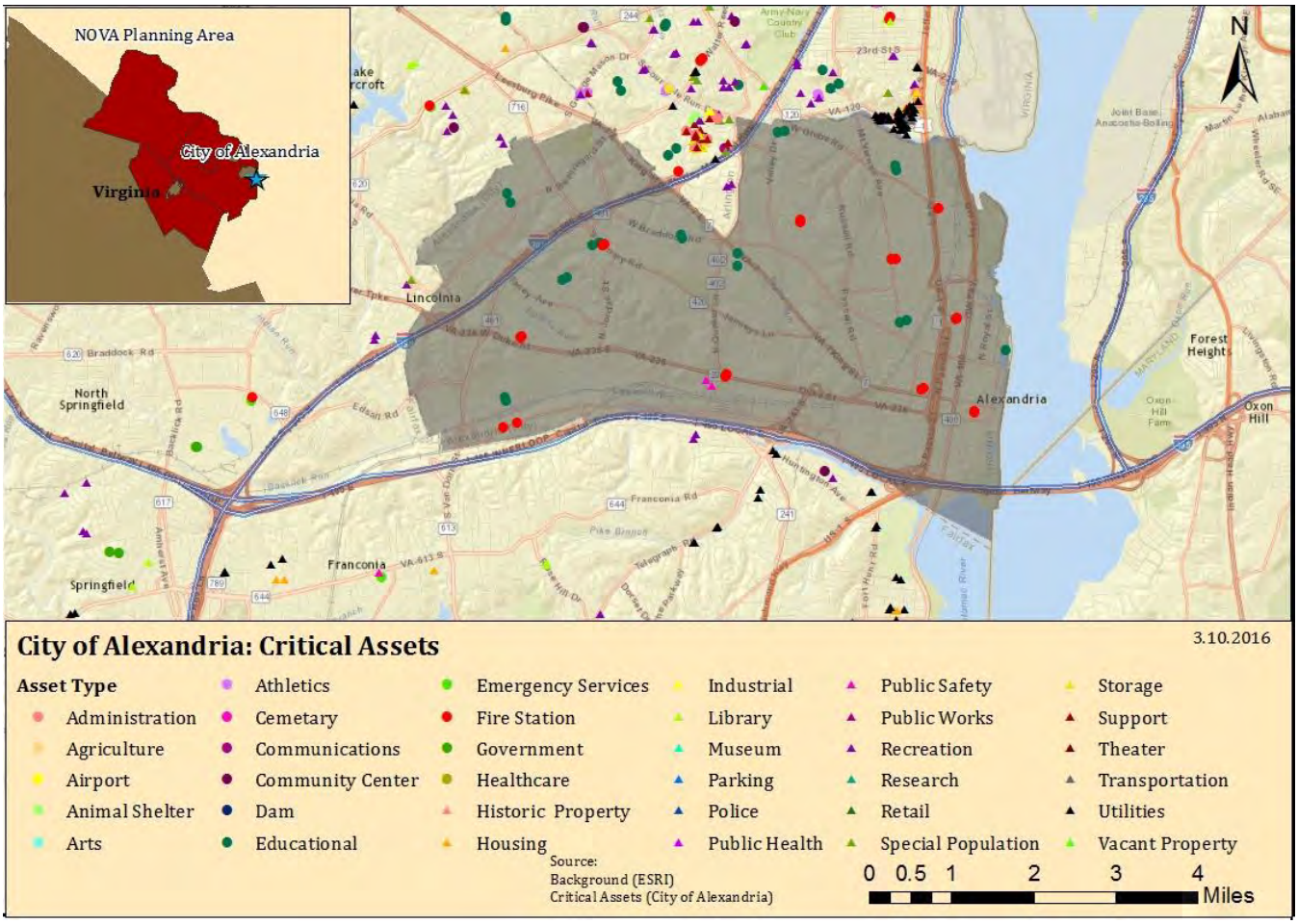

Figure 4.5. City of Alexandria local critical assets and historic structures.

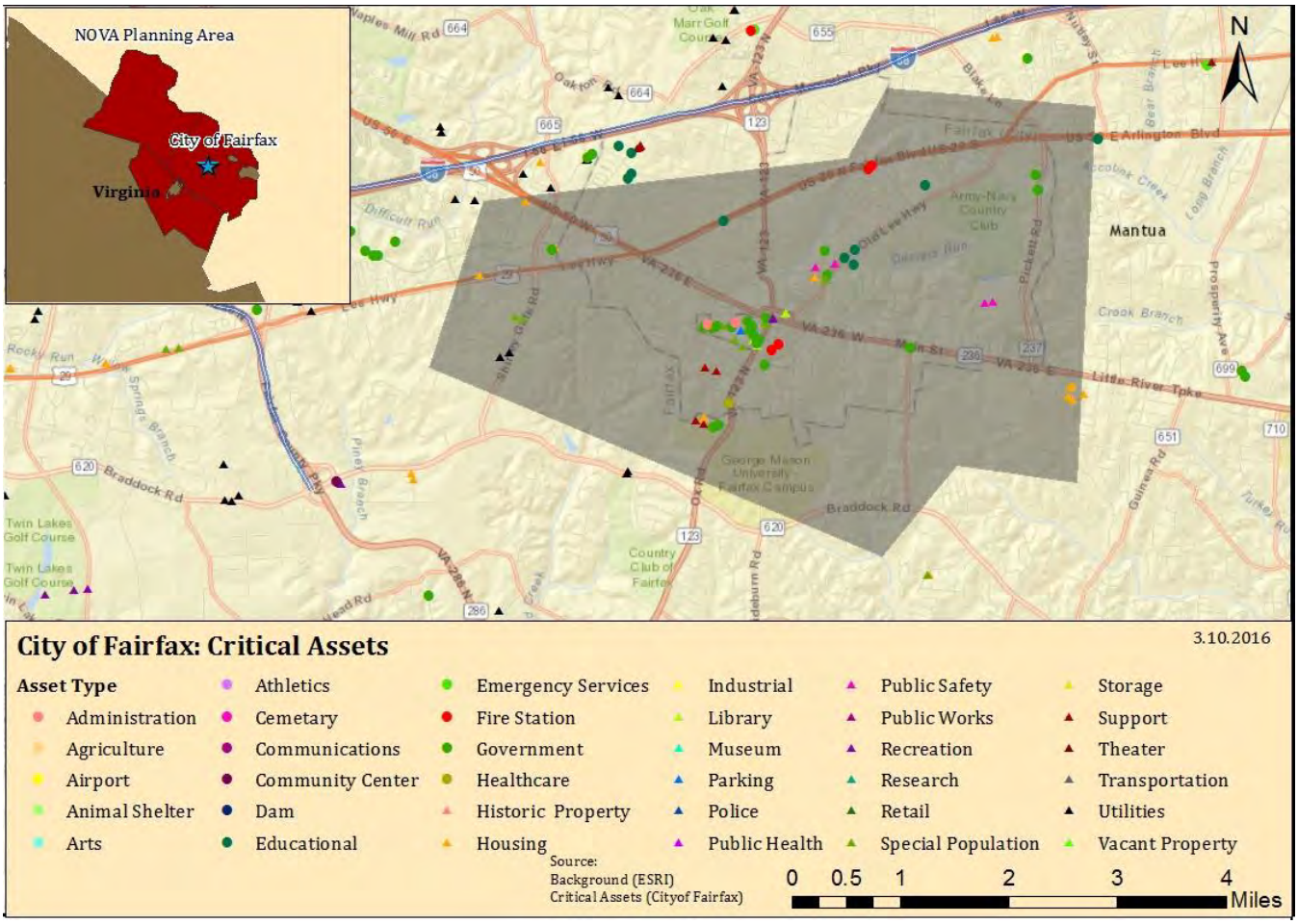

Figure 4.6. City of Fairfax local critical assets and historic structures.

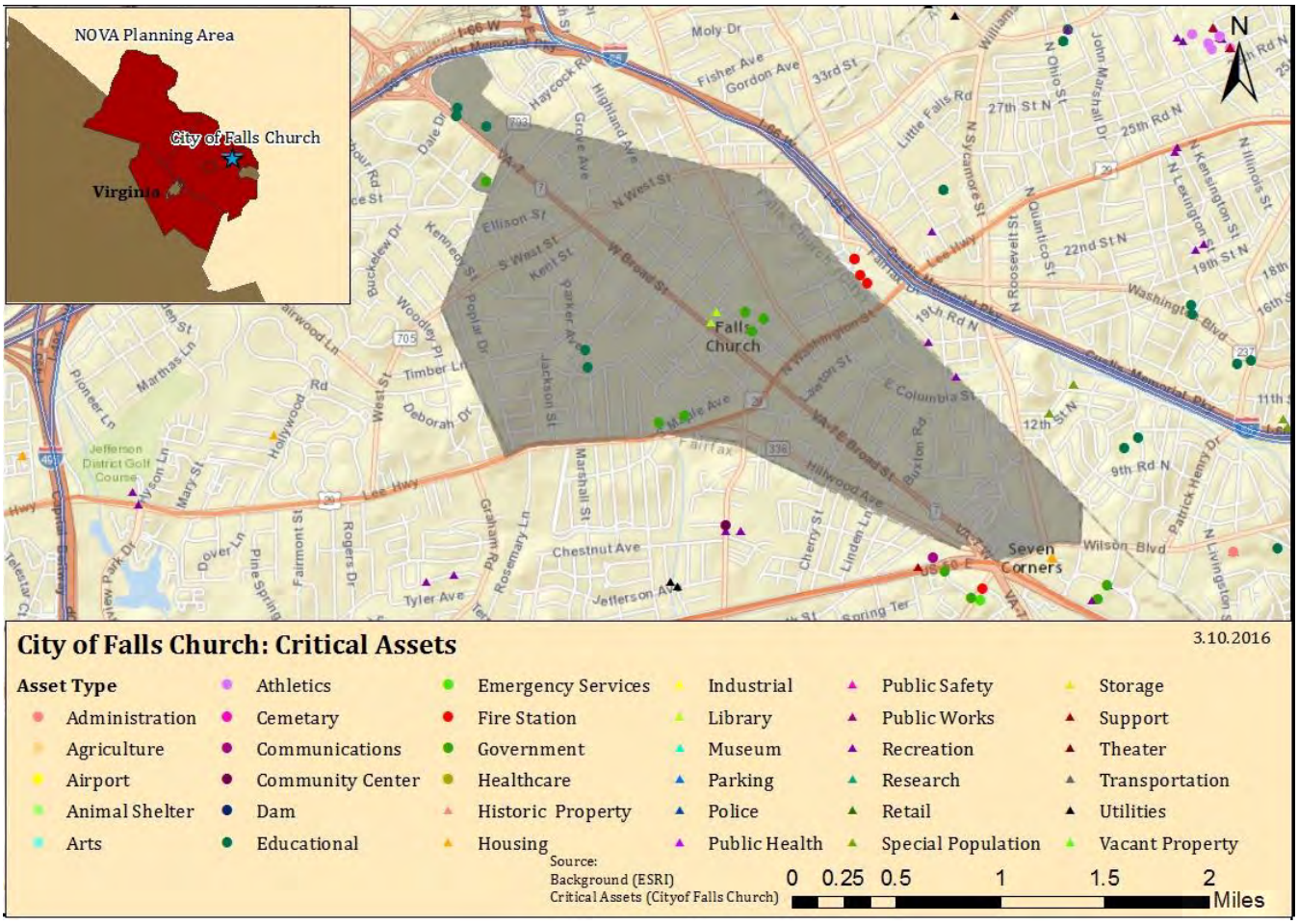

Figure 4.7. City of Falls Church local critical assets and historic structures.

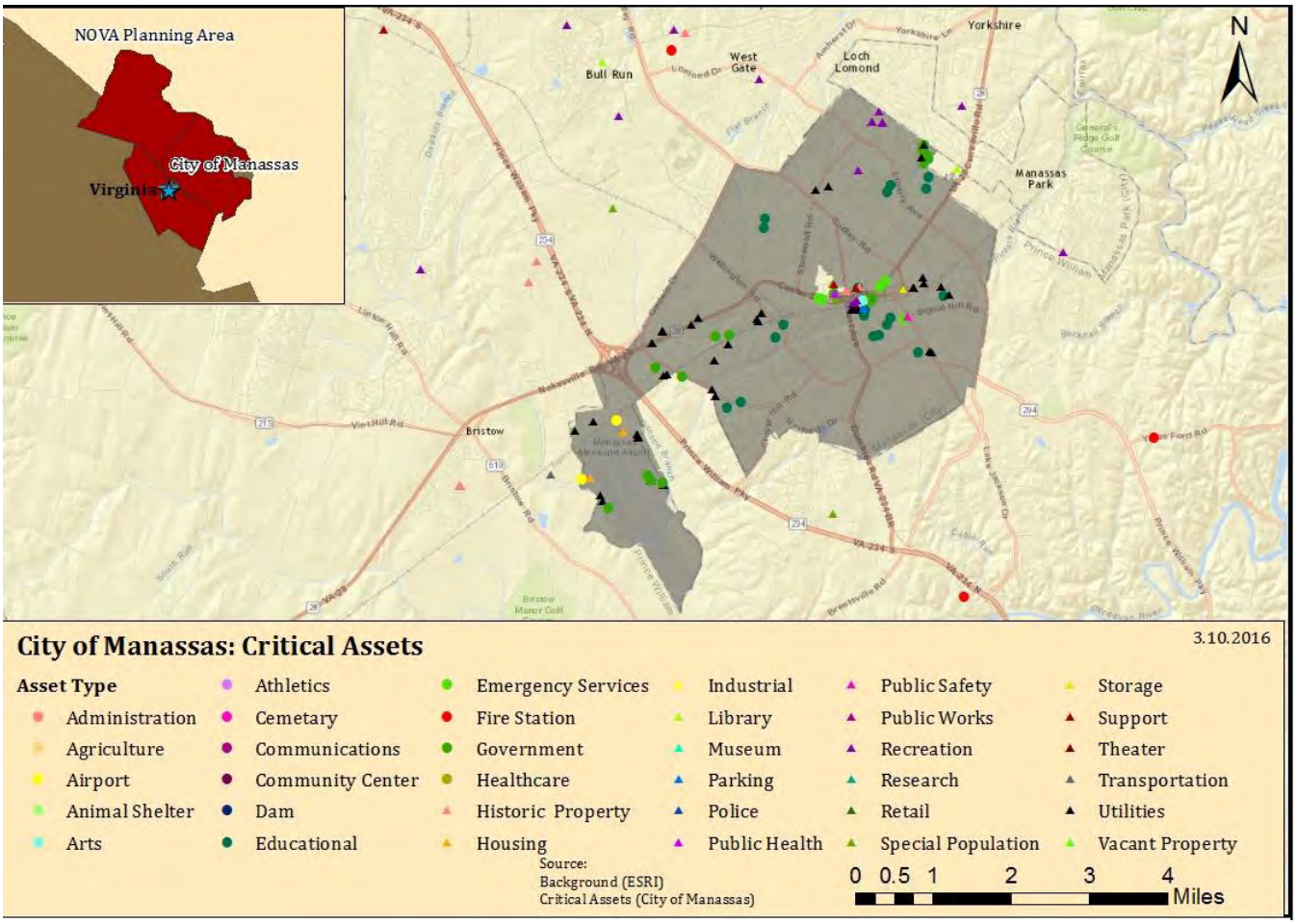

Figure 4.8. City of Manassas local critical assets and historic structures.

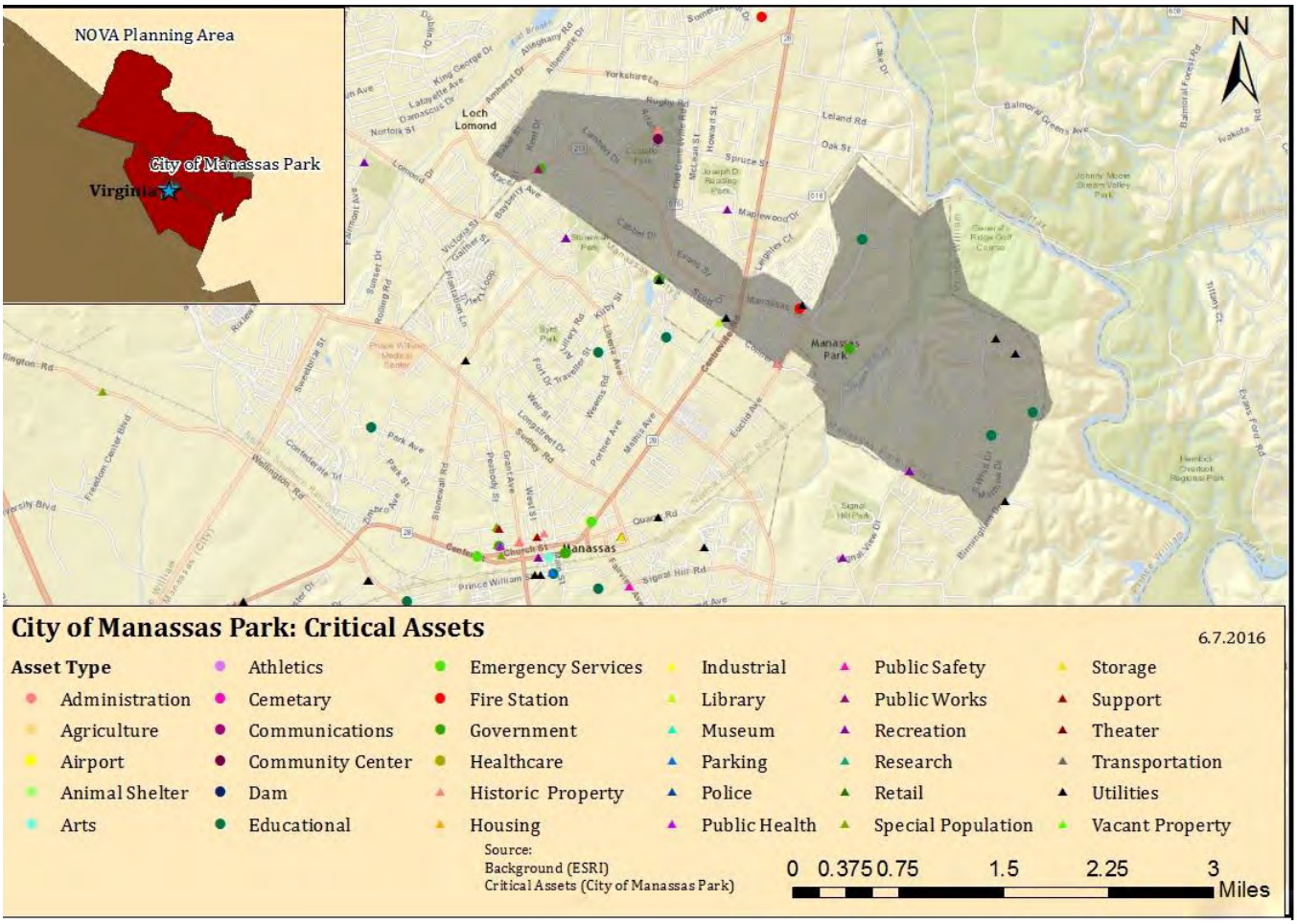

Figure 4.9. City of Manassas Park local critical assets and historic structures.

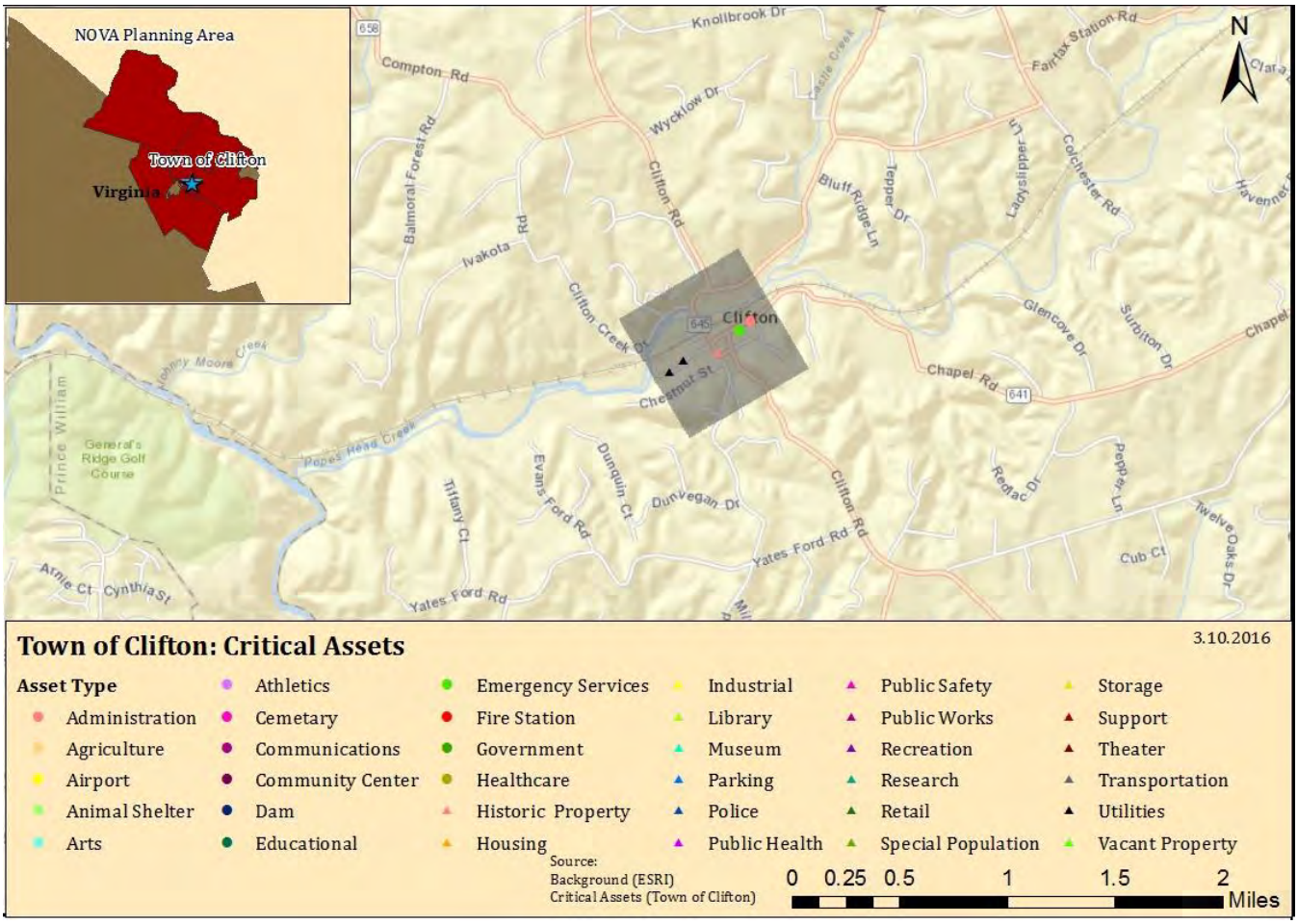

Figure 4.10. Town of Clifton local critical assets and historic structures.

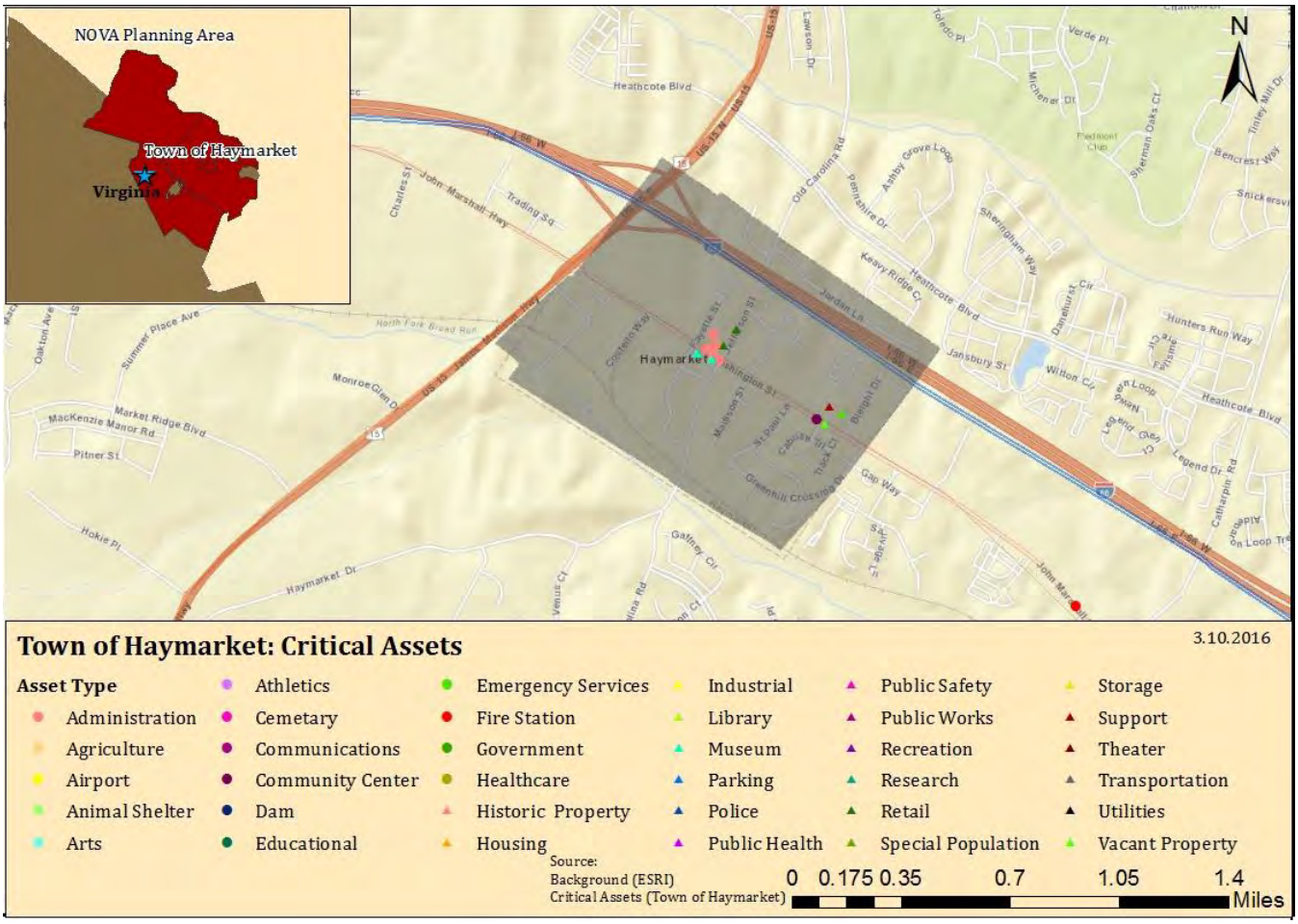

Figure 4.11. Town of Haymarket local critical assets and historic structures.

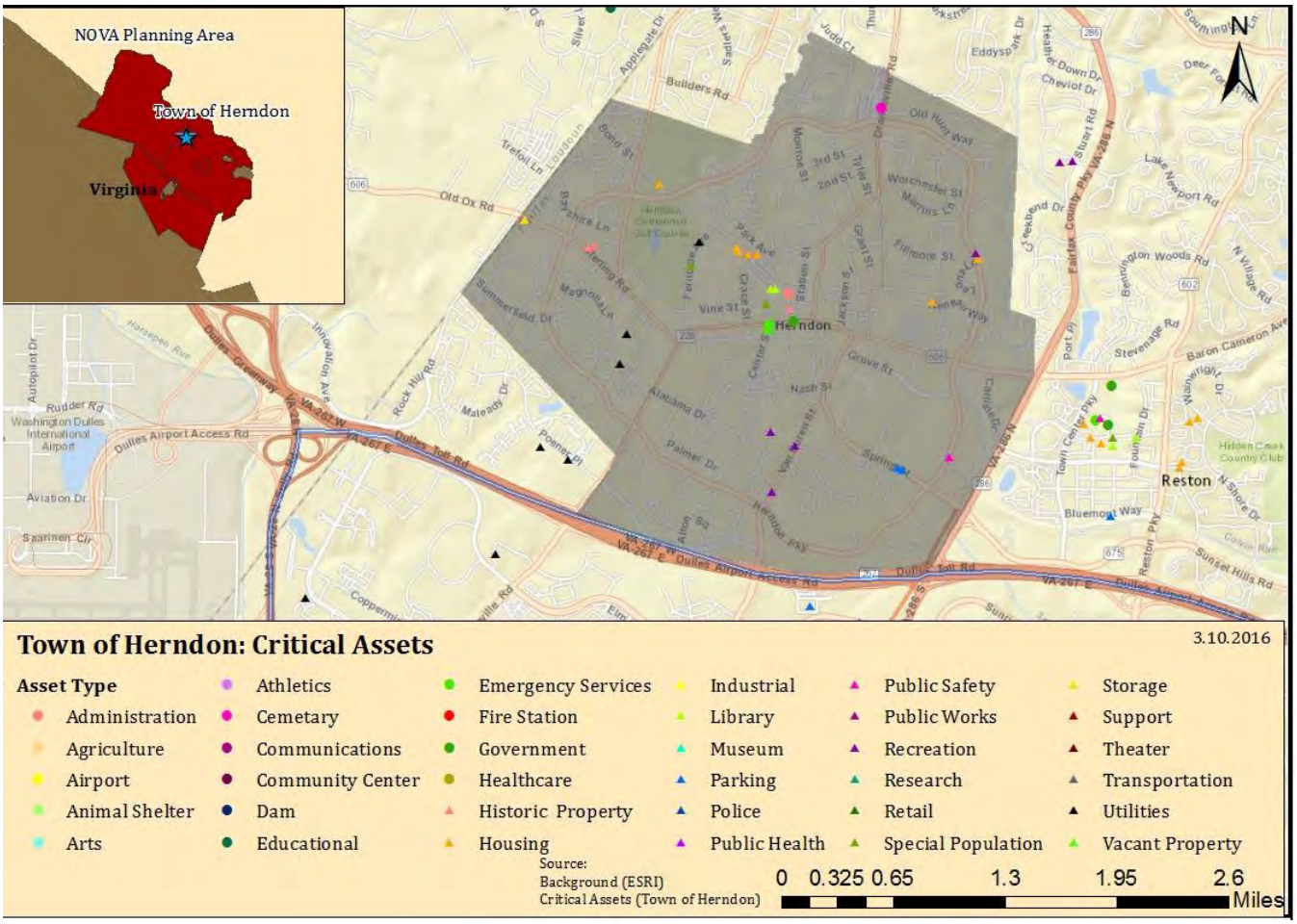

Figure 4.12. Town of Herndon local critical assets and historic structures.

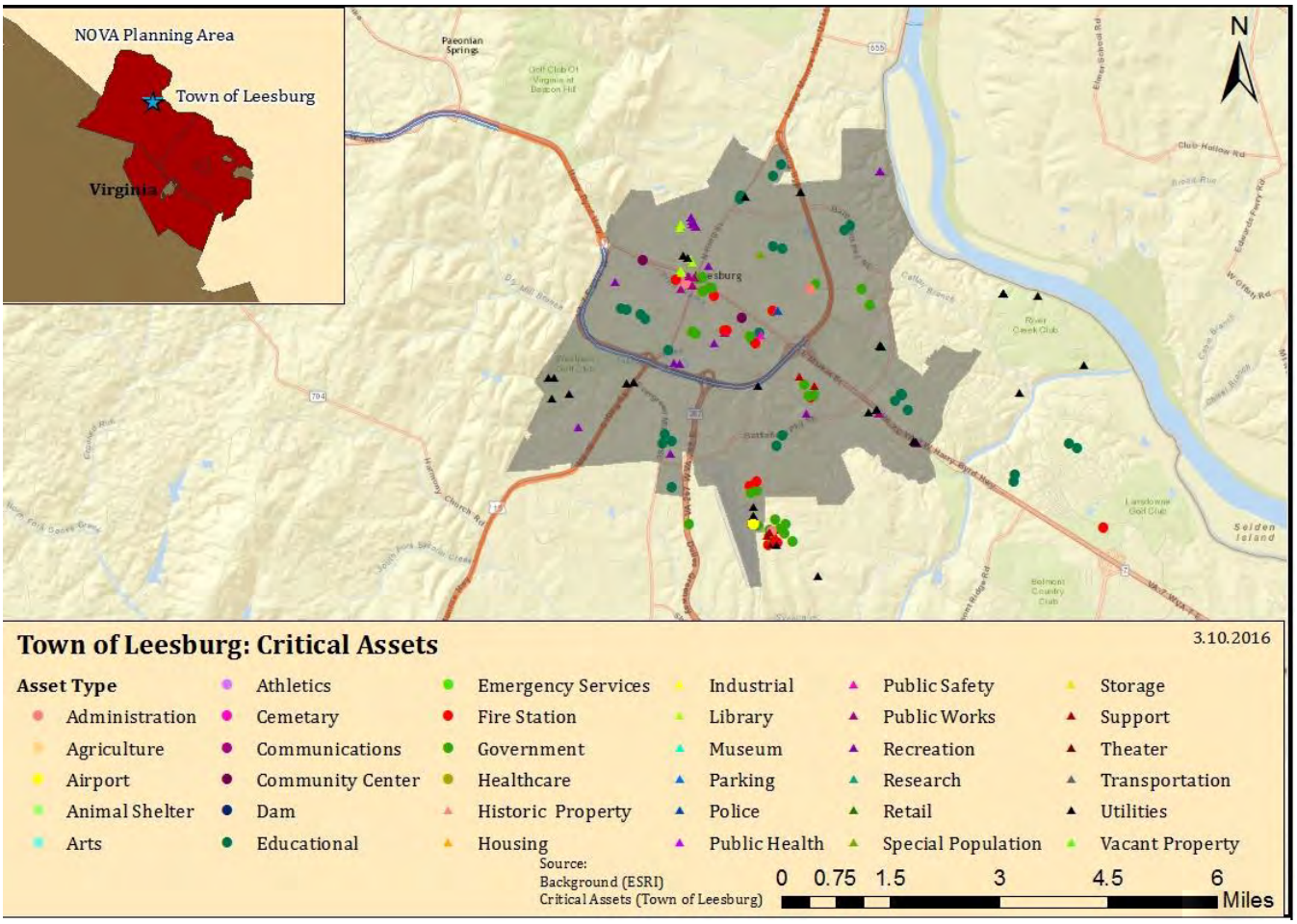

Figure 4.13. Town of Leesburg local critical assets and historic structures.

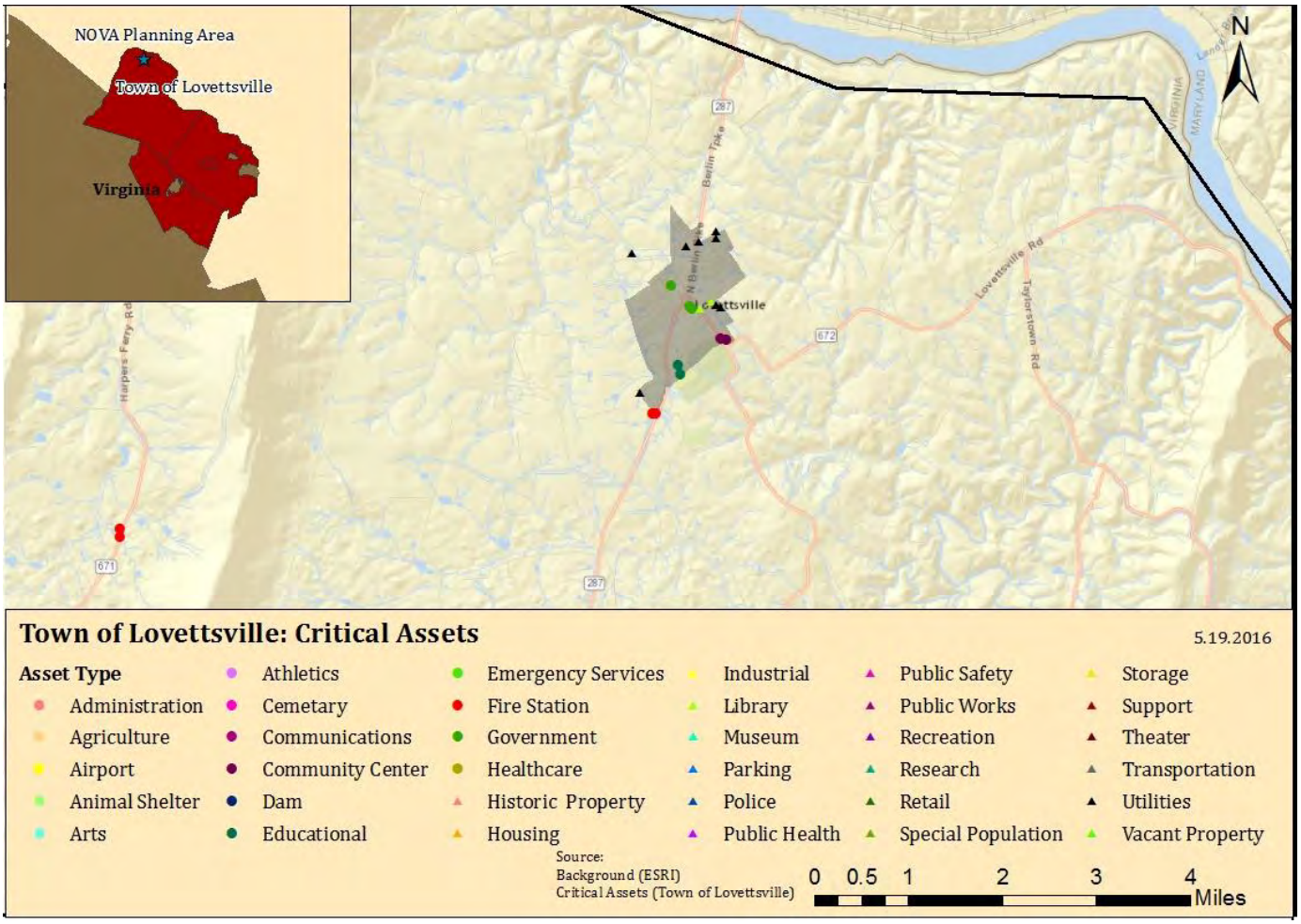

Figure 4.14. Town of Lovettsville local critical assets and historic structures.

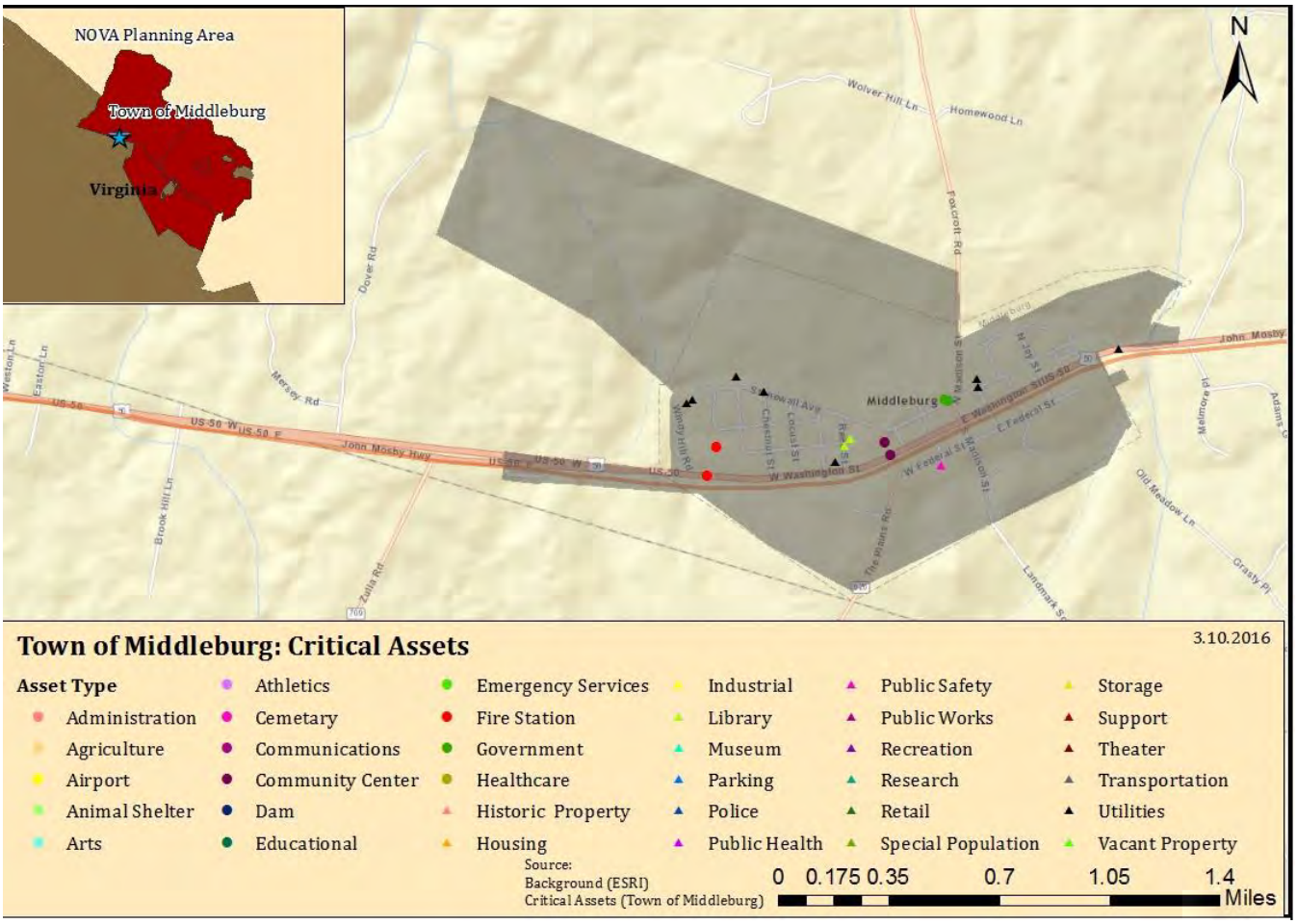

Figure 4.15. Town of Middleburg local critical assets and historic structures.

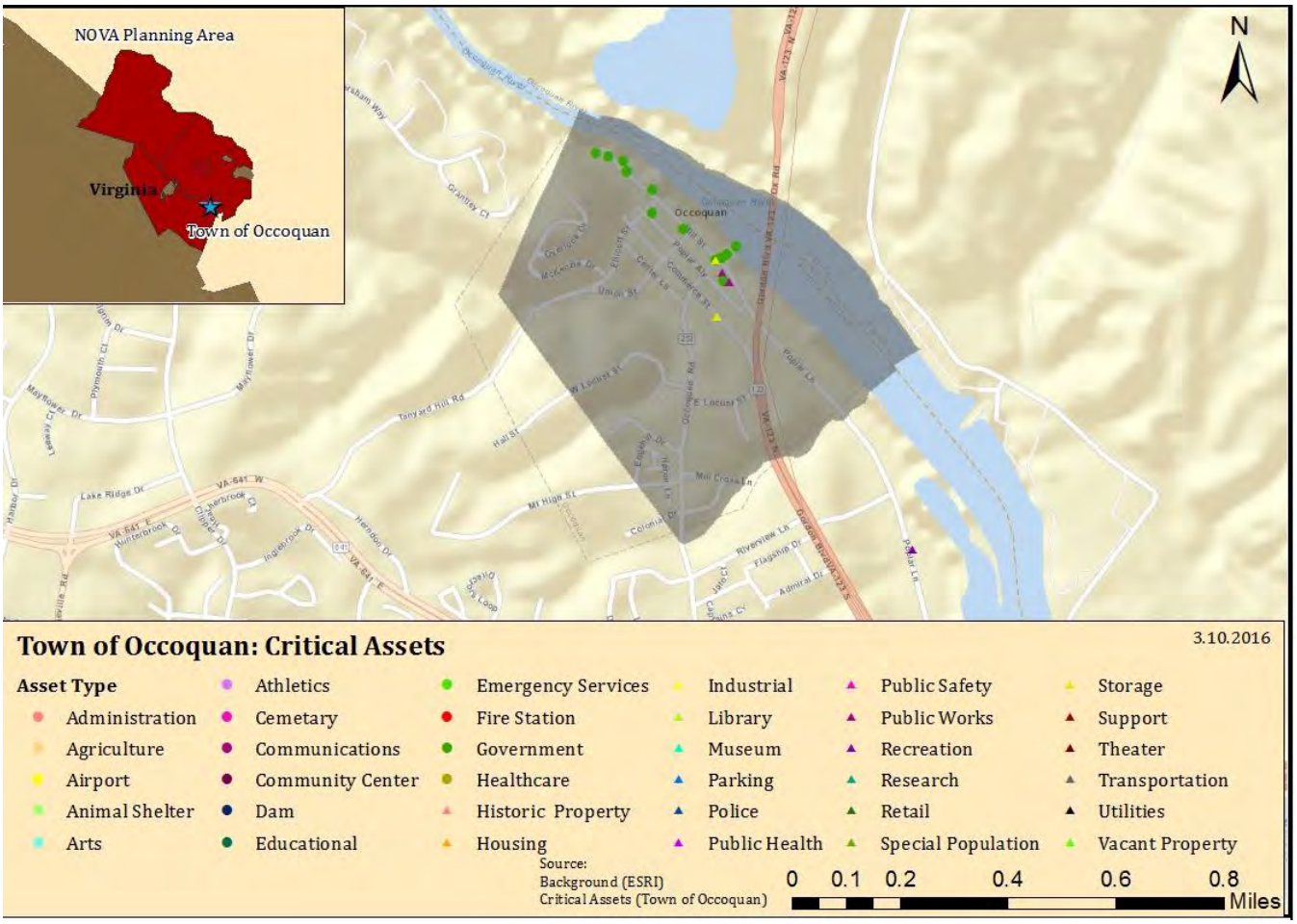

Figure 4.16. Town of Occoquan local critical assets and historic structures.

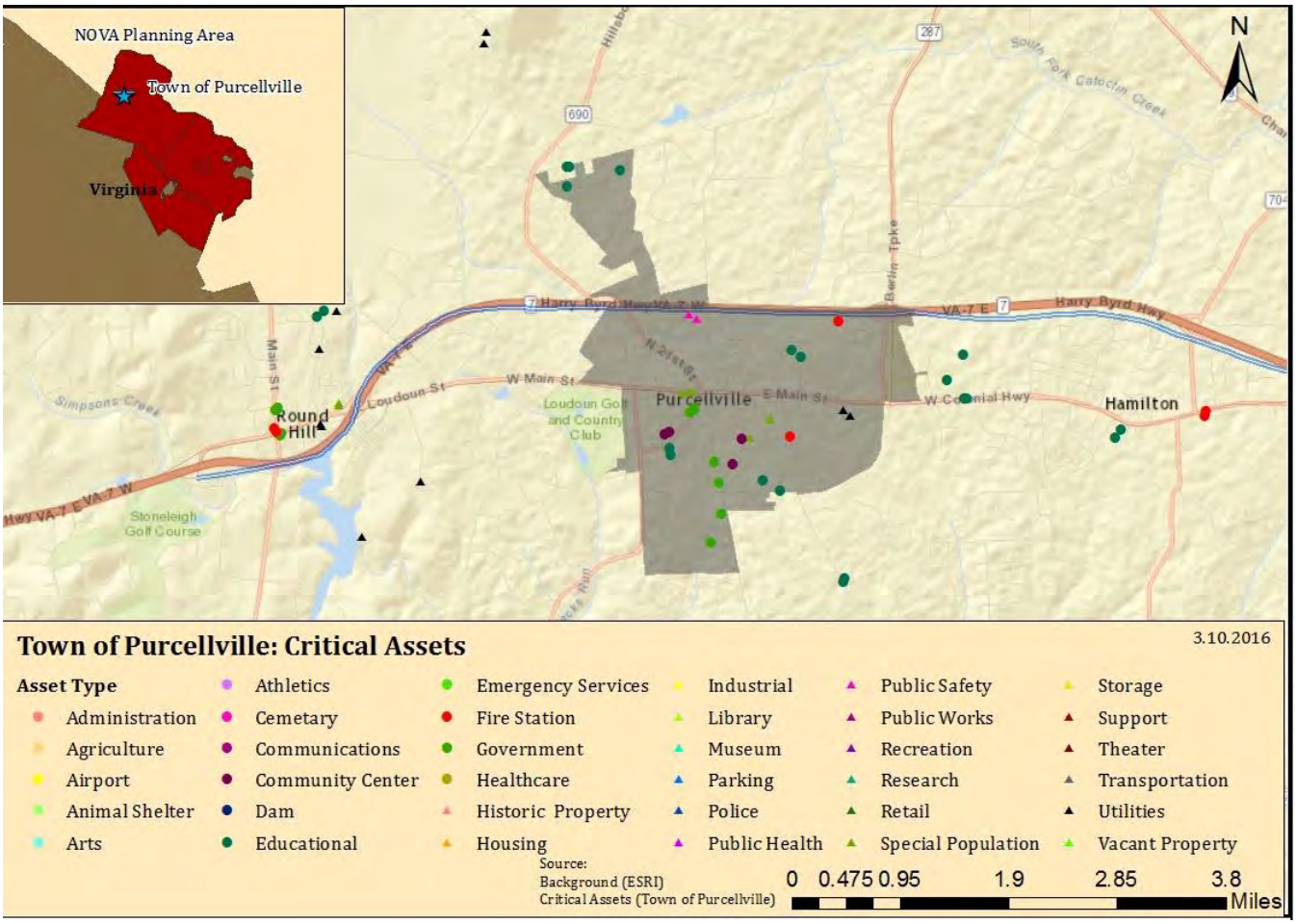

Figure 4.17. Town of Purcellville local critical assets and historic structures.

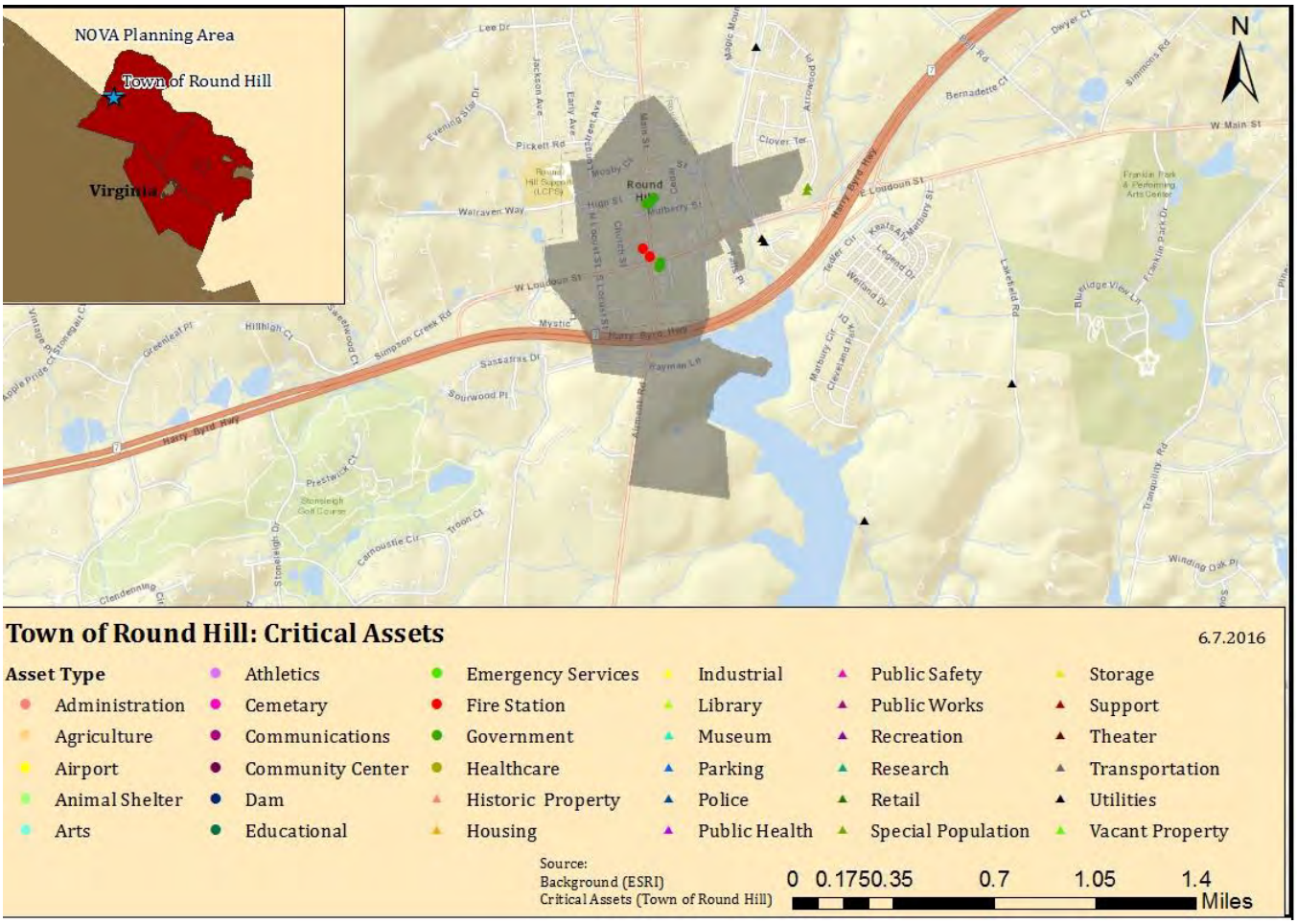

Figure 4.18. Town of Round Hill local critical assets and historic structures.

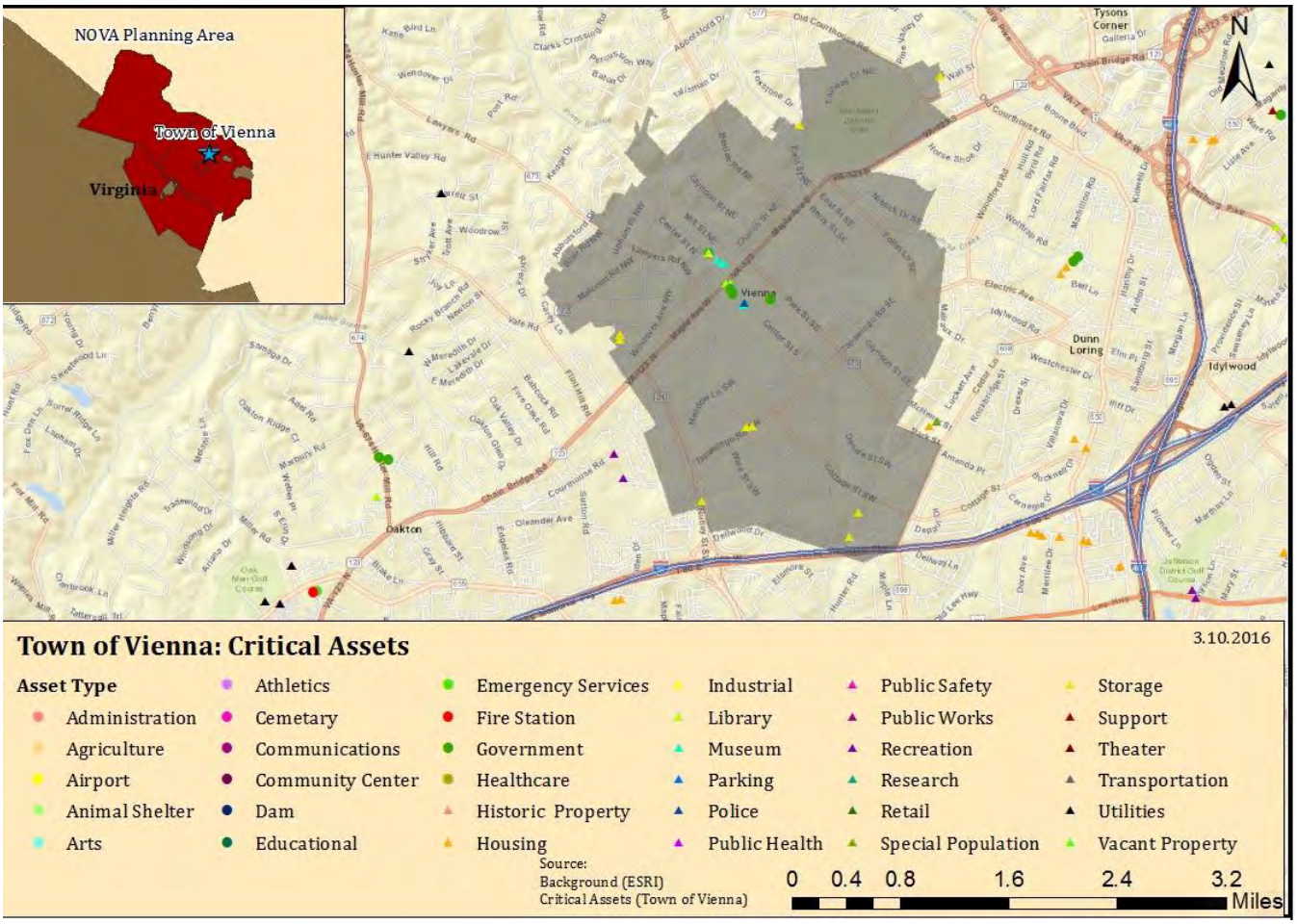

Figure 4.19. Town of Vienna local critical assets and historic structures.

No local critical assets were identified for the towns of Dumfries or Quantico; therefore, no maps were created for these jurisdictions, and no locally-identified assets were included in any risk assessment for these jurisdictions.

HAZUS^{MH} Version 3.1

HAZUS^{MH} facilities data was used to supplement the hazard-specific analysis. The HAZUS^{MH} inventory serves as the default when a user does not have better data available. This data provides a uniform look at building stock in the region. There are approximately 663,685 buildings in the region as estimated by HAZUS, categorized as residential, commercial, industrial, agricultural, religious, government, and education.

HAZUS^{MH} essential facilities are facilities vital to emergency response and recovery following a disaster, including medical care facilities, emergency response facilities, and schools. School buildings are included in this category because of the key role they often play in housing people displaced from damaged homes. With the Northern Virginia planning area, HAZUS^{MH} estimates there are approximately 762 essential facilities.

Note: For estimation purposes, building stock and essential facilities data from HAZUS^{MH} was obtained through the hurricane module. Runs for this module were completed at a smaller

regional level. HAZUS^{MH} outputs do not easily differentiate counties from independent cities, and so will often combine independent cities into county data, and cannot always distinguish the boundaries of towns and villages from counties. In most cases, aggregate building stock and essential facilities counts are provided at a 'county' level, and incorporate municipal and other entity building counts.

Fairfax County and the City of Fairfax have the largest number of essential facilities, 401, with almost 85% of those facilities labeled as schools. Table 4.2 below shows the number of facilities in each of the HAZUS^{MH} essential facility classes. With many national datasets, accuracy and completeness leave much to be desired.

Table 4.2 HAZUS-MH Essential Facilities for Northern Virginia planning area.

Jurisdiction	EOC	Fire Station	Hospitals	Police Stations	Schools	Total
Arlington County, The City of Alexandria, and The City of Falls Church	-	4	4	4	79	**91**
Fairfax County and The City of Fairfax	-	42	8	15	336	**401**
Town of Herndon	Included in Fairfax County essential facilities count					
Town of Vienna						
Town of Clifton						
Loudoun County	1	11	3	7	83	**105**
Town of Leesburg	Included in Loudoun County essential facilities count					
Town of Lovettsville						
Town of Purcellville						
Town of Middleburg						
Town of Round Hill						
Prince William County, The City of Manassas, and The City of Manassas Park	-	11	2	14	138	**165**
Town of Dumfries	Included in Prince William County essential facilities count					
Town of Haymarket						
Town of Occoquan						
Town of Quantico						
Total	**1**	**68**	**17**	**40**	**636**	**762**

The HAZUS^{MH} stock inventory for the jurisdiction often differs from reality. The table above reflects only those structures contained within the HAZUS dataset, and may not accurately reflect actual assets for each jurisdiction.

Data

The HAZUS^{MH} building stock for Northern Virginia contains 663,685 structures with an estimated exposure value of approximately $384 million (2015 dollars). HAZUS^{MH} estimates 84% of the region's general occupancy is categorized as residential, which represents 83.62% of the building value for the region. Fairfax County and the City of Fairfax represent approximately 50% of the region's total building value summarized in Table 4.3.

Table 4.3 Total Building Value per HAZUS^{MH} area (2015 dollars).

Jurisdiction	Residential	Non-Residential	Total	% Total
Arlington County, the City of Alexandria, and the City of Falls Church	$54,402,048,000	$14,354,494,000	$68,756,542,000	**17.89%**
Fairfax County and the City of Fairfax	$161,437,502,000	$32,603,535,000	$194,041,037,000	**50.49%**
Loudoun County	$46,169,251,000	$7,131,665,000	$53,300,916,000	**13.87%**
Prince William County	$59,393,279,000	$8,845,863,000	$68,239,142,000	**17.75%**
Total	**$321,402,080,000**	**$62,935,557,000**	**$384,337,637,000**	**100%**

Table 4.4 shows the estimated total exposure values by jurisdiction. Residential housing represents 84% of the building value in the region, followed by commercial properties representing 11.5%. The remaining occupancy types account for the remaining 4.5% of the region.

Table 4.4. Building stock exposure for general occupancy type by jurisdiction (2015 dollars).

Jurisdiction	Residential	Commercial	Industrial	Agriculture	Religious	Government	Education	Total
Arlington County, the City of Alexandria, & the City of Falls Church	$54,402,048,000	$10,027,368,000	$786,596,000	$57,929,000	$1,408,243,000	$565,297,000	$1,509,061,000	**$68,756,542,000**
Fairfax County, the City of Fairfax, the Town of Clifton, the Town of Herndon, & the Town of Vienna	$161,437,502,000	$25,013,495,000	$2,930,598,000	$302,667,000	$2,189,134,000	$653,199,000	$1,514,442,000	**$194,041,037,000**

Table 4.4. Building stock exposure for general occupancy type by jurisdiction (2015 dollars).								
Jurisdiction	**Residential**	**Commercial**	**Industrial**	**Agriculture**	**Religious**	**Government**	**Education**	**Total**
Loudoun County, the Town of Leesburg, the Town of Lovettsville, the Town of Middleburg, & the Town of Round Hill	$49,169,251,000	$5,027,525,000	$1,021,465,000	$172,981,000	$440,995,000	$151,487,000	$317,212,000	**$53,300,916,000**
Prince William County, the City of Manassas, the City of Manassas Park, the Town of Dumfries, the Town of Haymarket, the Town of Occoquan, & the Town of Quantico	$59,393,279,000	$6,248,644,000	$1,223,616,000	$209,192,000	$540,415,000	$182663,000	$441,333,000	**$68,239,142,000**
Total	**$321,402,080,000**	**$46,317,032,000**	**$5,962,275,000**	**$742,769,000**	**$4,578,787,000**	**$1,552,646,000**	**$3,72,048,000**	**$384,337,637,000**

Building stock exposure is also classified by building type. General Building Types have been developed as a means to classify different building construction types. This provides an ability to differentiate between buildings with substantially different damage and loss characteristics. Model building types represent the average characteristics of buildings in a class. The damage and loss prediction models are developed for model building types and the estimated performance is based upon the "average characteristics" of the total population of buildings within each class. Five general classifications have been established, including wood, masonry, concrete, steel, and manufactured homes (MH). A brief description of the building types is available in Table 4.5.

Table 4.5. HAZUS-MH General Building Type Classes.	
General Building Type	**Description**
Wood	Wood frame construction
Masonry	Reinforced or unreinforced masonry construction
Steel	Steel frame construction
Concrete	Cast-in-place or pre-cast reinforced concrete construction
MH	Factory-built residential construction

Wood construction represents the majority (60%) of building types in the region, followed by masonry, which represents 27% of building stock exposure. The remaining percentage is distributed among other building types. Table 4.6 below provides building stock exposure for

the five main building types. The differences in the building stock tables are a result of aggregation by HAZUS^{MH} and rounding. HAZUS^{MH} only provides building stock for the counties and cities in Northern Virginia. Towns participating in this plan are represented in their respective county totals.

Table 4.6: Building stock exposure for general building type by jurisdiction (2015 dollars).

Jurisdiction	Wood	Masonry	Concrete	Steel	MH	Total
City of Alexandria	$15,742,702,000	$7,883,135,000	$1,177,964,000	$2,953,902,000	$10,899,000	**$27,768,602,000**
Arlington County	$22,903,960,000	$10,739,683,000	$1,393,360,000	$3,269,160,000	$20,238,000	**$38,326,401,000**
Fairfax County and The City of Fairfax	$123,744,041,000	$51,405,986,000	$4,412,824,000	$14,332,720,000	$145,461,000	**$194,041,032,000**
City of Falls Church	$1,561,833,000	$724,271,000	$78,296,000	$297,211,000	$0	**$2,661,611,000**
Loudoun County	$25,465,190,000	$13,776,791,000	$866,772,000	$3,170,583,000	$21,457,000	**$53,500,916,000**
City of Manassas	$3,363,297,000	$1,516,280,000	$189,293,000	$705,525,000	$11,970,000	**$5,786,365,000**
City of Manassas Park	$1,182,103,000	$475,657,000	$34,789,000	$145,600,000	$428,000	**$1,838,586,000**
Prince William County	$40,804,413,000	$15,628,024,000	$916,267,000	$3,200,275,000	$65,208,000	**$60,614,187,000**
Total	**$244,767,539,000**	**$102,149,827,000**	**$9,069,574,000**	**$28,074,976,000**	**$275,662,000**	**$384,337,577,000**

III. Hazard Identification

While there are many different natural hazards that could potentially affect the Northern Virginia planning area, some hazards are more likely to cause significant impacts and damages than others. This analysis will quantify these potential impacts and identify the hazards that pose the greatest possible risk.

The potential hazards that could affect the Northern Virginia planning area include: flooding, winter storms, high winds, tornadoes, droughts, earthquakes, landslides, wildfires, landslides, dam failures, and extreme temperatures. Some of these hazards are interrelated (i.e., hurricanes can cause flooding and tornadoes), and some consist of hazardous elements that are not listed separately (i.e., severe thunderstorms can cause lightning; hurricanes can cause coastal erosion). Some hazards, such as severe winter storms, may impact a large area yet cause little damage; other hazards, such as a tornado, may impact a small area yet cause extensive damage. Several of these hazards have been included together (i.e. high winds/thunderstorms/hurricane winds). The hazard description in each hazard section provides a general description for each of the hazards listed above, along with their hazardous elements.

Depending on the severity, location, and timing of the specific events, each of these hazards could have devastating effects on houses, businesses, agricultural lands, infrastructure, and ultimately residents of the planning area. In order to gain a full understanding of the history of these hazards in the planning area, detailed data related to the hazard history was compiled and available in each of the hazard sections. Appendix D contains the National Climactic Data Center (NCDC) storm events database used in the 2016 analysis.

Information was collected from meetings with local community officials, existing reports and studies, state and national data sets, and local newspaper clippings, among others sources; the assessment is largely based on the NCDC databased whenever possible and practical.

The historical data collected includes accounts of all the hazard types listed above. However, some have occurred much more frequently than others with a wide range of impacts. By analyzing the historical frequency of each hazard, along with the associated impacts, the hazards that pose the most significant risks to the Northern Virginia planning area can be identified. This analysis will allow the jurisdictions included in this study to focus their hazard mitigation plans on those hazards that are most likely to cause significant impacts to their community.

To a large extent, historical records are used to identify the level of risk within the Northern Virginia region with the assumption that the data sources cited are reliable and accurate. Unless otherwise cited, all data on historical weather-related events is based on information made available through the Storm Event Database by the NWS NCDC[1]. From a regional planning perspective, it is important to use a consistent source for hazard-related data such as the NCDC. That being said, descriptions of historical hazard events and numerical damage data are based on the collection of information reported by local offices of the NWS and other local users, such as emergency management officials, and should only be considered approximate figures for general analysis and planning purposes.

To complete the risk assessment, best available data was collected from a variety of sources, including local, state and federal agencies, and multiple analyses were performed qualitatively and quantitatively (further described below). Additional work will be done on an ongoing basis to enhance, expand, and further improve the accuracy of the baseline established here, and it is expected that this assessment will continue to be refined through future plan updates as new data and loss estimation methods or tools become available to the participating jurisdictions.

The findings presented in the hazard risk assessments and in the overall results were developed using best available data, and the methodologies applied have resulted in an approximation of risk. These estimates should be used to understand relative risk from hazards and the potential losses that may be incurred. However, uncertainties are inherent in any loss estimation methodology, arising in part from incomplete scientific knowledge concerning specific hazards and their effects on the built environment, as well as incomplete data sets and approximations and simplifications that are necessary in order to provide a meaningful analysis. Further, most data sets used in this assessment contain relatively short periods of records which increases the uncertainty of any statistically-based analysis.

Federally Declared Disasters

Presidential Disaster Declarations are issued for county (including towns) or independent city jurisdictions when an event has been determined to be beyond the capabilities of State and local governments to respond. There have been a total of 62 declared disasters in Virginia, and 17 of those disasters have been declared in at least one community in the Northern Virginia planning area since 1965. The City of Alexandria has been declared in 13 of these events, and Arlington and Fairfax Counties have been declared in 10 and 11 of the disasters, respectively. Prior to January 1, 1965, presidential disaster declarations did not have county or independent city designations. The region has also experienced a significant number of additional emergencies and disasters that were not severe enough to require Federal disaster relief through a presidential declaration. Table 4.7 summarizes the disasters and the localities that were included in the declaration.

Wind-related events (severe storms, tornados, and flooding) dominate the Northern Virginia declared hazards, followed by winter storms events.

Table 4.7. Major disaster declarations for Northern Virginia planning area (1965-December 2015), based on FEMA records.

Date of Declaration	Disaster	Declared Jurisdiction								
		Arlington County	Fairfax County	Loudoun County	Prince William County	Alexandria, City of	Fairfax, City of	Falls Church, City of	Manassas, City of	Manassas Park, City of
7/27/2012	Severe Storms and Straight-line Winds	✓	✓				✓	✓		✓
11/17/11	Remnants of Tropical Storm Lee		✓		✓	✓				
9/3/2011	Hurricane Irene					✓				
4/27/2010	Severe Winter Storms and Snowstorms	✓	✓	✓	✓	✓	✓	✓	✓	✓
2/16/2010	Severe Winter Storm and Snowstorm	✓	✓		✓	✓	✓	✓	✓	✓
7/13/2006	Severe Storms, Tornadoes, and Flooding	✓	✓			✓				
9/18/2003	Hurricane Isabel	✓	✓	✓	✓	✓	✓	✓	✓	✓
3/27/2003	Severe Winter Storm	✓	✓	✓	✓	✓	✓	✓	✓	✓
9/11/2001	Terrorism	✓								
2/28/2000	Severe Winter Storm	✓	✓	✓	✓	✓	✓		✓	
10/12/1999	Hurricane Floyd		✓				✓			
10/23/1996	Hurricane Fran				✓					
2/2/1996	Blizzard of 1996	✓	✓	✓	✓	✓	✓	✓	✓	✓
11/10/1985	Severe Storms & Flooding					✓				
10/10/1972	Severe Storms & Flooding					✓				
10/7/1972	Severe Storms & Flooding					✓				
6/29/1972	Tropical Storm Agnes	✓	✓	✓	✓	✓	✓	✓		

NCDC Storm Events Database

NCDC Storm Data is published by the National Oceanic and Atmospheric Administration (NOAA), part of the U.S. Department of Commerce. The Storm Events Database contains information on storms and weather phenomena that have caused loss of life, injuries, significant property damage, and/or disruption to commerce. Efforts are made to collect the best available information, but because of time and resource constraints, information may be unverified by the NWS. The NWS does not guarantee the accuracy or validity of the information. Although the historical records in the database often vary widely in their level of detail, the NWS does have a set of guidelines used in the preparation of event descriptions.[2]

The NCDC is well known for having limited records of geological hazards (i.e., earthquake, landslide, and karst). In the absence of better data it was decided to proceed with the records available in NCDC for these events, in all cases. NCDC records for these events are severe under-representations of what has happened in Northern Virginia's history. To date, no comprehensive digital databases exist for these hazards[3].

In 2012, shortly after the completion of the previous plan update, major changes were made to the records in the NCDC database. These changes resulted in revisions to historic records in the database, as well as additional data being added to the database. Since this 2012 change, periodic additions of new data and revisions of existing data have been accomplished by NOAA, all with the goal of creating a better data set for general use. Because of these changes, however, the data set available from NCDC during the development of the 2016 plan update was significantly different from the data set available during previous plan activities. As a result, all previous NCDC data has been removed from the 2016 plan update, and has been replaced with the data available during the plan update process. This has resulted in different calculations and findings – in some cases significantly different – than were contained in previous versions of this plan. However, the NCDC data contained in the 2016 plan update is the best available version of the best available data.

Event records from January 1, 1950, through December 31, 2015, have been used for the HIRA analysis. There are approximately 6,101 events recorded in the NCDC storm events database for the Northern Virginia planning area spanning 1950 through 2015; approximately 2,153 of those events have not been included in the analysis – comprised of drought, winter storm, and extreme temperature events – as it is assumed the records are duplicative, as records for towns cannot be reliably separated from records for the corresponding county. Given the widespread spatial nature of those three hazards, it is reasonable to assume that a winter storm event that impacts a county would also impact the towns within the county; the same is true for extreme temperature events and drought events.

Table 4.8 shows the number of NCDC events for each county, city, and town by hazard type.

Table 4.8. Number of Storm Events in the NCDC database (1950-2015).

Jurisdiction	Drought	Flood	High Wind	Tornado	Winter Storm	Extreme Temperatures	Total
Arlington County	9	45	144	2	97	59	**356**
Fairfax County	10	34	63	0	123	67	**297**
Loudoun County	12	130	434	25	131	66	**798**
Prince William County	12	84	191	17	110	74	**488**
City of Alexandria	9	33	90	2	97	59	**290**
City of Fairfax	10	34	63	0	123	67	**297**

Table 4.8. Number of Storm Events in the NCDC database (1950-2015).							
Jurisdiction	**Drought**	**Flood**	**High Wind**	**Tornado**	**Winter Storm**	**Extreme Temperatures**	**Total**
City of Falls Church	9	36	54	1	97	9	**206**
City of Manassas	12	28	52	2	110	74	**278**
City of Manassas Park	12	18	31	1	110	74	**246**
Town of Clifton	10	0	1	0	123	67	**201**
Town of Dumfries	12	7	27	2	110	74	**232**
Town of Haymarket	12	9	26	0	110	74	**231**
Town of Herndon	10	9	12	0	123	67	**221**
Town of Leesburg	12	38	70	5	131	66	**322**
Town of Lovettsville	12	1	33	6	131	66	**249**
Town of Middleburg	12	13	29	3	131	66	**254**
Town of Occoquan	12	1	1	0	110	74	**198**
Town of Purcellville	12	16	38	0	131	66	**263**
Town of Quantico	12	6	17	3	110	74	**222**
Town of Round Hill	12	4	21	1	131	66	**235**
Town of Vienna	10	7	10	0	123	67	**217**
Total	**233**	**553**	**1,407**	**70**	**2,462**	**1,376**	**6,101**

To use the NCDC data in the same fashion as it was used in the *Commonwealth of Virginia Hazard Mitigation Plan* Risk Assessment, the data had to be processed. The following excerpt on processing the NCDC data has been taken from Virginia's hazard mitigation plan.

NCDC Normalizing Data

Information for specific hazard events is sometimes reported by the NWS and found in the NCDC database only at a zonal level. This is particularly true for events that impact a wide area, such as winter storm and drought events. Each zone may contain one or many political jurisdictions. These zonal events may include information regarding deaths, injuries, and damages caused by the event, but may not break these down by individual jurisdiction. To accurately count the number of events occurring in a single county or city, the zonal data records were expanded into a set of individual city/county records, based on NCDC records. To the

extent possible, determinations were made as to if a specific event impacted a particular town or jurisdiction. Those records that could be reliably tied to a particular jurisdiction remained in the assessment. Other records were excluded. The exceptions to this are records for winter weather, drought, and extreme temperatures. Given the widespread spatial nature of these three hazards, it can be reliably assumed that reports of incidents that impacted the greater county also impacted the towns. Therefore, only reports for the counties and cities were included in the final assessment for droughts, winter weather, and extreme temperatures.

Injuries and fatalities are counted exactly as recorded from those reports that remain in the assessment.

For most hazards for which NCDC data was utilized, the period of record used for the assessment was 1950 through 2015, a total of 65 years. The exceptions are winter weather and extreme temperatures. NCDC began maintaining separate records for these hazards in 1996. Therefore, the period of record for these hazards used for the assessment was 1996 to 2015, a total of 19 years.

NCDC Damages

The damages entered into the NCDC Storm Events database portray how much damage was incurred in the year of the event. These damages are approximations or estimates only, and may not reflect the actual or final calculations of damages from other sources.

NCDC Annualizing Data

After the data was normalized, the data was annualized in order to be able to compare the results on a common system (i.e., ranking the hazards). In general, this was completed by taking the parameter of interest and dividing by the length of record for each hazard. The annualized value should only be utilized as an estimate of what can be expected in a given year. Deaths/injuries, property and crop damage, and events were all annualized in this fashion, on a per-jurisdiction basis, where data was available.

NCDC Data Compilation

The NCDC Storm Events database uses very detailed event categories. The reported storm events were summarized in simplified classifications to correspond to the major hazard types considered in this plan. Table 4.9 shows how the NCDC categories were grouped into the HIRA hazard categories. The ranking methodologies, explained later in this section, summarize how the NCDC data was used in ranking the hazards.

Table 4.9. HIRA and NCDC Event Category Classifications	
HIRA Category	**NCDC Event Categories**
Drought	Drought
Flood	Coastal flood
	Flash Flood
	Flood
	Heavy Rain
	High Surf
	Lakeshore Flood
	Storm Surge/Tide
High Wind	Hurricane (Typhoon)
	Marine High Wind
	Marine Strong Wind
	Marine Thunderstorm Wind
	Strong Wind
	Thunderstorm Wind
	Tropical Depression
	Tropical Storm
	Thunderstorm Wind
Tornado	Funnel Cloud
	Tornado
	Water Spout
Winter Storm	Blizzard
	Heavy Snow
	Ice Storm
	Sleet
	Winter Storm
	Winter Weather
Extreme Temperatures	Cold/Wind Chill
	Extreme Cold/Wind Chill
	Excessive Heat
	Frost/Freeze
	Heat
Not Included	Agricultural Freeze
	Avalanche
	Black Ice
	Dense Fog
	Dust Devil

Table 4.9. HIRA and NCDC Event Category Classifications	
HIRA Category	**NCDC Event Categories**
	Freezing Fog
	Hail
	Lake-effect Snow
	Rip Current
	Lightning

IV. Ranking and Analysis Methodologies

HAZUS^{MH} Methodology

HAZUS^{MH} is FEMA's nationwide standardized loss estimation software package, built upon an integrated GIS platform with a national inventory of baseline geographic data (including information on the Northern Virginia region's general building stock and dollar exposure). Originally designed for the analysis of earthquake risks, FEMA has expanded the program to allow for the analysis of multiple hazards including flood and wind events. By providing estimates on potential losses, HAZUS^{MH} facilitates quantitative comparisons among hazards and may assist in the prioritization of hazard mitigation activities.

HAZUS^{MH} uses a statistical approach and mathematical modeling of risk to predict a hazard's frequency of occurrence and estimated impacts based on recorded or historic damage information. The HAZUS^{MH} risk assessment methodology includes distinct hazard and inventory parameters. For example, wind speed and building type were modeled using the HAZUS^{MH} software to determine the impact (damages and losses) on structures. Figure 4.20 shows a conceptual model of HAZUS^{MH} methodology.

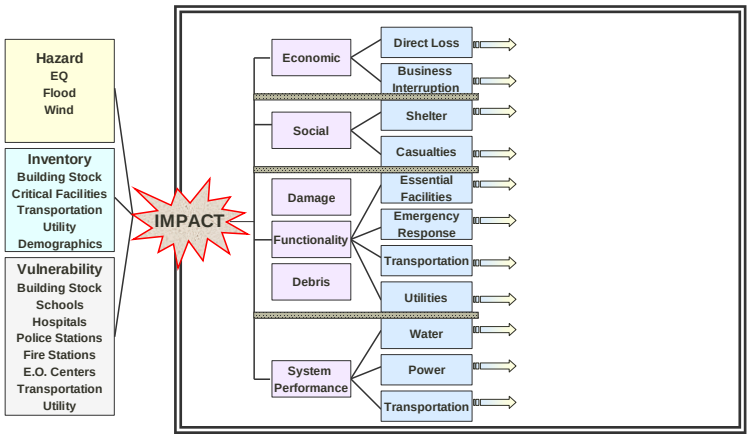

Figure 4.20. Conceptual Model of HAZUS^{MH} Methodology

As with the 2006 and 2010 update of the risk assessment, the 2016 update utilized HAZUS^{MH} to produce regional profiles and estimated losses for hazards addressed in this section: hurricane winds, earthquake, and flood. For each of these hazards, HAZUS^{MH} was used to generate probabilistic "worst case scenario" events to show the maximum potential extent of damages. It is understood that those events of less severe magnitude which could occur would likely result in fewer losses than those calculated here. During the update additional scenarios were completed for flood and earthquake to further define the region's risk.

Supplemental Annualized Loss Estimate Methodology

The first step in conducting supplemental annualized loss calculations and risk assessment included the collection of relevant GIS data from local, state, and national sources. This began with the collection of local data from each participating jurisdiction, then continued up to best available data at the national inventory level (considered least accurate). The data determined to be "best available" was then used for purposes of this assessment. Data matrices were compiled based on the data provided by each of the localities; these may be found in Appendix D.

In order to generate hazard loss estimates beyond hurricane wind, flood, and earthquake, the following steps were conducted independent of the HAZUS^{MH} analysis:

- For the drought, severe storm, tornado, wildfire, and winter storm hazards, best available data on historical hazard occurrences (limited to NOAA NCDC and Virginia Department of Forestry [VDOF] records) was used to produce estimate of potential damages. Using this data, loss estimates were generated by totaling the amount of property damage over the period of time for which records were available, and calculating the average annual loss. In addition, for appropriate hazards, scenarios were also created to allow for additional estimation of potential losses.
- For the hazards of extreme temperatures, erosion, sinkholes, landslides, and dam failure, meaningful historical data (meaning data which would have included past property damages and other essential indicators) was virtually non-existent, and therefore potential losses for these hazards could not be calculated. For these hazard, a qualitative analysis was performed based on what limited data is available for the participating jurisdictions.

All conclusions of the HIRA completed for the Northern Virginia region are presented at the end of each of the hazard specific sections.

Critical Facility and Building Risk

In addition to generating loss estimates for particular hazards, GIS technology was further utilized to identify, quantify, and analyze potentially at-risk community assets such as public buildings, critical facilities, and infrastructure. This analysis was completed for hazards that can be spatially defined in a meaningful manner (i.e., hazards with a determined geographic extent) and for which digital GIS data layers are readily available. The analysis resulted in the identification of potentially at-risk community assets based upon their location in relation to identified hazard areas. Results of this analysis are contained within each of the hazard specific sections; the actual GIS products are found in Appendix D.

For the flood hazard, GIS was used to further assess risk utilizing the FEMA Digital Flood Insurance Risk Maps (DFIRMs) in combination with locally-available GIS data layers. Primary

data layers used include local building footprints and tax parcel data. Exposure values do not include any estimated values for building contents.

Ranking Methodology

During the 2010 HIRA update kick-off meeting, committee members liked the NCDC ranking methods developed for the Commonwealth of Virginia's HIRA. It was agreed that this approach would be used in the update to the Northern Virginia plan update. During the January 2016 HIRA update kick-off meeting, committee members determined that the same methodologies used in the 2010 update should be applied to the 2016 update, to the extent possible and practicable, to ensure that there was a means of comparison across plans, and that progress could be measured over time.

Since the methodology for the update was to mirror the State plan, with updated storm event records, the following has been taken from the Commonwealth of Virginia Emergency Operations Plan Annex 3 (Volume II) of the Standard and Enhanced Hazard Mitigation Plan Ranking Methodology.

To compare the risk of different hazards, and prioritize which are more significant, requires a system for equalizing the units of analysis. Under ideal conditions, this common unit of analysis would be "annualized dollars." However, such an analysis requires reliable probability and impact data for all the hazards to be compared. As this is often not the case, many hazard prioritization methods are based on scoring systems, which allow greater flexibility and more room for expert judgment.

The Virginia Tech Center for Geospatial Information and Technology's (CGIT) and VDEM have developed a standardized methodology to compare different hazard's risk on a jurisdictional basis. As some of the hazards assessed in this plan did not have precisely quantifiable probability or impact data, a semi-quantitative scoring system was used to compare all of the hazards. This method prioritizes hazard risk based on a blend of quantitative factors from the available data. A number of parameters have been considered in this methodology, all of which could be derived from the NCDC database:

- History of occurrence;
- Vulnerability of people in the hazard area;
- Probable geographic extent of the hazard area; and
- Historical impact, in terms of human lives and property.

The ranking methodology tries to balance these factors, whose reliability varies from hazard to hazard due to the nature of the underlying data. Each parameter was rated on a scale of one (1) through four (4). The exact weights were highly debated, but the final conclusion was that the population vulnerability and density would each be weighted at 0.5 with a geographic extent at 1.5, relative to the other parameters. These scores are summed at a jurisdictional level for each hazard separately, permitting comparison between jurisdictions for each hazard type. A summation of all the scores from all hazards in each jurisdiction provides an overall "all-hazards" risk prioritization. The following sections provide an overview of the six parameters that were used in ranking the hazards that impact Virginia.

The NCDC data, as described above, is far from a complete data source. This data was used for the ranking because of its standardized collection of many of the hazards of interest. The data only partially represents the geological hazards, and as a result, the ranking can only characterize the current form of the data. As other data sources become available, the ranking will need to be reassessed to make sure the parameters are still valid for ranking the hazards.

Population Vulnerability and Density

Population vulnerability and density are simple, yet important factors in the risk ranking assigned to a jurisdiction. In general, a hazard event that occurs in a highly populated area has a much higher impact than a comparable event that occurs in a remote, unpopulated area. Two population parameters were used, accounting for jurisdictions with high populations and jurisdictions with densely populated areas. Each parameter was given a weighting of 0.5 in an effort to avoid overwhelming the overall ranking methodology with pure population data.

Population vulnerability was calculated as a percent of the total population of Virginia present in each jurisdiction. The 2010 U.S. Census population calculation for each jurisdiction were divided by the total population for the State and a value between one and four was assigned based on a geometric breaks pattern. By ranking jurisdictions this way, those cities and counties with significantly larger populations have effectively been given extra weight. Table 4.10 describes the breaks and assigned scores for population vulnerability.

Table 4.10. Population Vulnerability as the percentage of people that will be affected by the occurrence of the hazard.

Population Vulnerability	
Rank	***Definition***
1	<= 0.229 % of the total population of the State
2	0.230% - 0.749% of the total population of the State
3	0.750% - 2.099% of the total population of the State
4	> = 2.100% of the total population of the State

Population density was based on the population per square mile for each jurisdiction. The 2010 Census population calculation for each jurisdiction were divided by the total area for the jurisdiction; a value between one and four was assigned based on geometric intervals. By ranking jurisdictions this way, those cities and counties with densely populated areas have effectively been given extra weight. Table 4.11 describes the breaks and assigned scores for population density.

Table 4.11. Population Density as the number of people per square mile that will be affected by the occurrence of the hazard.	
Population Density	
Rank	***Definition***
1	<= 60.92 people/sq mi
2	60.93 – 339.10 people/sq mi
3	339.11 - 1,743.35 people/sq mi
4	>= 1,743.36 people/sq mi

Geographic Extent

Probable geographic extent (GE) would ideally be measured consistently for each hazard; however, the available data sources vary widely in their depiction of hazard geography. As a result, one uniform ranking system could not be accomplished at this time. In this version of the plan each hazard has been assigned individual category break points based on the available hazard data. In the overall scoring system, geographic extent was given a 1.5 weighting relative to the other parameters, as geographic extent was deemed to be critically important, and more reliable than some of the other parameters. GE data sources, ranking criteria, and category breaks are summarized in Table 4.12.

Table 4.12. Geographic Extent as the percentage of a jurisdiction impacted by the hazard.			
Geographic Extent			
Hazard	***Description***	***Category Breaks***	
		Rank	*Definition*
Flood	Percent of a jurisdiction that falls within FEMA Special Flood Hazard Area (SFHA). Data: FEMA Floodplains (DFIRMs)	*1*	*<=2.99%*
		2	*3.00-4.99%*
		3	*5.00 -9.99%*
		4	*>=10.00%*
High Wind	Average maximum wind speed throughout the entire jurisdiction. Data: HAZUS^{MH} 3-second Peak Gust Wind Speeds	*1*	*<= 59.9*
		2	*60.0 - 73.9*
		3	*74.0 - 94.9*
		4	*>= 95.0*
Wildfire	Percent of jurisdiction that falls within a "high" risk. Data: VDOF Wildfire Risk Assessment	*1*	*<= 9.9%*
		2	*10.0% - 19.9%*
		3	*20.0% - 49.9%*
		4	*>= 50.0%*
Karst	Percent of jurisdiction where the risk is "high" for karst related events. Data: USGS Engineering Aspects of Karst	*1*	*<= 24.9%*
		2	*25.0% - 49.9%*
		3	*50.0% - 74.9%*
		4	*>= 75.0%*
Landslide	Percent of jurisdiction where a high	*1*	*<= 24.9%*

Table 4.12. Geographic Extent as the percentage of a jurisdiction impacted by the hazard.			
Geographic Extent			
Hazard	*Description*	*Category Breaks*	
		Rank	*Definition*
	landslide risk exists.	*2*	*25.0% - 49.9%*
	Data: USGS Landslide Incidence & Susceptibility	*3*	*50.0% - 74.9%*
		4	*>= 75.0%*
Earthquake	Average 2,500-year return period max percent of gravitational acceleration (PGA).	*1*	*<= 0.069*
		2	*0.070 - 0.159*
		3	*0.160 - 0.299*
	Data: HAZUS^{MH} 2,500-year PGA	*4*	*>= 0.300*
Winter Storm	Average annual number of days receiving at least 3 inches of snow, calculated as an area-weighted average for each jurisdiction.	*1*	*<= 1.49*
		2	*1.50 - 1.99*
		3	*2.00 - 2.99*
	Data: NWS snowfall statistics	*4*	*>= 3.0*
Tornado	Annual tornado hazard frequency (times 1 million), calculated as an area-weighted average for each jurisdiction.	*1*	*<= 1.24*
		2	*1.25 - 9.99*
		3	*10.00 - 99.9*
	Data: NCDC tornado frequency statistics	*4*	*>= 100.00*

Annualizing the Data for Analysis

Data from the NCDC database was annualized in order to compare the results on a common system. In general, this was completed by taking the parameter of interest and dividing by the length of record for each hazard. The annualized value should only be utilized as an estimate of what can be expected in a given year.

Annualized Deaths and Injuries

Deaths and injuries are also an important factor to evaluate when determining risk ranking. Using NCDC data, past deaths and injuries were computed for drought, flood, high wind, tornado, wildfire, and winter storm. The remaining hazards have no reported deaths or injuries in this database and as a result were assigned a ranking of one (1).

Table 4.13. Annualized Deaths and Injuries as the number of deaths or injuries that a hazard event would likely cause in a given year.	
Annualized Deaths and Injuries	
Rank	*Definition*
1	<= 1.019 deaths and/or injuries per year
2	1.020 – 6.279 deaths and/or injuries per year
3	6.280 – 13.199 deaths and/or injuries per year

Table 4.13. Annualized Deaths and Injuries as the number of deaths or injuries that a hazard event would likely cause in a given year.	
Annualized Deaths and Injuries	
Rank	*Definition*
4	>= 13.200 deaths and/or injuries per year

Annualized Crop and Property Damage

Crop damage and property damage were also analyzed separately in order to give each jurisdiction a score of one (1) to four (4). This data was obtained from the NCDC storm events database and annualized according to the period of record for each event category (Table 4.14).

Table 4.14. Annualized Crop and Property Damage as the estimated damages that a hazard event will likely cause in a given year.		
Annualized Crop and Property Damage		
Rank	*Definition: Crop Damage*	*Definition: Property Damage*
1	*<= $25,711 per year*	*<= $ 136,129 per year*
2	*$25,712 – $100,270 per year*	*$136,130 - $432,555 per year*
3	*$100,271 - $291,384 per year*	*$432,556 - $1,111,067 per year*
4	*>= $291,385 per year*	*>= $1,111,068 per year*

Annualized Events

While each hazard may not have a comprehensive database of past historical occurrences, the record of historical occurrences is still an important factor in determining where hazards are likely to occur in the future. Annualizing the NCDC storm events data yields a rough estimate of the number of times a jurisdiction might experience a similar hazard event in any given year. To do this, the total number of events in the NCDC database, for each specific hazard in each jurisdiction, was divided by the total years of record for that hazard to calculate an "annualized events" value.

There were no significant events reported for land subsidence (karst), earthquake, and landslide in NCDC; as a result, the events for these hazards all received a rank of one (1). Table 4.15 describes the annual frequency breaks for events.

Table 4.15. Annualized Events as the number of times that a hazard event would likely happen in a given year.	
Annualized Events	
Rank	***Definition***
1	<= 0.09 events per year
2	0.10 – 0.99 events per year
3	1.00 – 4.99 events per year
4	>= 5.00 events per year

Overall Hazard Ranking

The scores from each of these categories were added together for each hazard to estimate the total jurisdictional risk due to that hazard. As discussed previously, the population parameters were each given a weighting of 0.5 (for a total of 1.0 for all population parameters), and Geographic Extent was given a weighting of 1.5 relative to the other factors. The total scores were broken into five categories to better illustrate the distribution of risk scores. Those jurisdictions with scores from 0 to 8.49 were determined to have a low risk in that hazard category; scores 8.50 through 9.99 were considered medium-low risk; between 10.0 and 11.49, medium risk; between 11.50 and 12.99 were considered medium-high risk; and jurisdictional hazard scores greater than 13.00 were given a high rating.

In order to assess the total risk of a county or city across all hazard categories, each of the previous categories were summed across the different hazard types. Overall, all-hazards ranking counties with a low risk have a score less than 86.00; those with a medium-low risk between 86.01 and 93.50; medium risk between 95.51 and 100.00; medium-high risk between 100.01 and 108.00; and those with a high risk have a score greater than or equal to 108.01.

Comparison of Methodologies

Differences in 2010 and 2016 annualized loss estimates can be attributed to several factors:

- Time frame of storm events database and/or data sources;
- Inflation of storm events database;
- Methodologies used for analysis (i.e., HAZUS^{MH}); and
- Differences in versions of HAZUS available for use.

Additional Risk Assessments Completed for the Northern Virginia Region

The Northern Virginia Planning region, as discussed in other sections of this plan, has numerous plans that document different aspects of the risk to natural and man-made hazards. Some of these plans are briefly outlined below:

December 2015 National Capital Region THIRA *National Capital Region Threat and Hazard Identification and Risk Assessment:* This THIRA discusses natural and human-caused hazards and provides risk summaries for each of the hazards. Threats and hazards were identified based on the likelihood of an incident and the significance of the threat/hazard's effects to the area.

Threats/Hazards considered in the THIRA:

- Pandemic
- Severe Weather Event (hurricane/winter weather)
- CBRNE
- Cyber attack
- Terrorism
- Earthquake

Limitations of Data

The data sources used in the hazard ranking and loss estimation are varied in their degree of completeness, accuracy, and precision as the ability to accurately prioritize some of the hazards

would be improved by better information (e.g., landslide, karst, etc.). The participating jurisdictions should consider their internal and cooperative abilities to gather and maintain additional data for future updates to this plan.

V. Overall Hazard Results

The preceding sub-sections discuss the probability, impacts, vulnerability, and risks for each of the natural hazards that have been determined to have a significant impact on the Northern Virginia planning region. The final section of the HIRA provides an overall assessment, summary, and comparison of the overall hazard ranking and estimated losses. Risk to critical facilities has been discussed, to the extent possible, in each of the hazard sub-sections. These sections highlight the results of the analysis completed during the 2010 and 2016 plan updates. Refer to the tables in these sections to determine what facilities or facility types are at greater risk for each hazard. This information is ideal for determining structural mitigation strategies. The names and information for the HAZUS^{MH} and local critical facilities in the assessments are available in Appendix D.

Refer to the Risk Assessment Methodology section of the HIRA for a full description of the methodology and the limitations of the data used for ranking the hazards and loss estimation. For most natural hazards, the NCDC data, although somewhat limited, provides the most comprehensive historical record of events and damages available. This analysis is only representative of the NCDC data and other data that was used. It is known that the time period of this data is small in comparison to the known historical events. The data does not fully represent geological hazards, but in the absence of better data, NCDC was used to represent the risk.

Comparison of 2010 and 2016 Results

Table 4.16 provides a comparison of the 2010 and 2016 hazard rankings, by jurisdiction. Note that the list of jurisdictions that participated in the plan in 2010 is slightly different from the list of jurisdictions that participated in 2016; therefore, the rankings do not line up exactly. In addition, the configuration of the hazards included, while substantively the same, is slightly different between the 2010 and 2016 plans.

Following Table 4.16, tables are provided that show select results from the HIRA for the most probable hazards likely to impact the Northern Virginia planning area – floods, high wind, earthquake, and winter weather – by participating jurisdiction.

Table 4.16. Hazard Vulnerability Comparison, 2010 and 2016 Plans, by Jurisdiction and Hazard.

Jurisdiction	Flood		Winter Storm		High Wind		Tornado		Drought		Earthquake		Landslide		Wildfire		Geologic		Extreme Temperatures	
	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016	2010	2016
Arlington County	H	H	H	H	H	H	H	H	MH	L	M	M	M	L	ML	L	ML	L		H
Fairfax County	H	H	H	H	H	H	H	H	MH	L	M	M	ML	L	M	L	ML	L		H
Loudoun County	H	H	H	H	H	H	H	H	H	M	M	M	MH	L	ML	M	ML	M		H
Prince William County	H	H	H	H	H	H	H	H	H	M	M	M	ML	L	M	M	ML	L		H
City of Alexandria	H	H	H	H	H	H	H	H	MH	L	M	M	M	L	L	L	ML	L		H
City of Fairfax	H	H	H	H	H	H	H	H	MH	L	M	M	M	L	ML	L	L	L		H
City of Falls Church	H	H	H	H	H	H	MH	H	M	L	ML	M	ML	L	L	L	ML	L		H
City of Manassas	H	H	H	H	H	H	H	H	MH	L	M	M	M	L	ML	L	ML	L		H
City of Manassas Park	H	M	H	H	H	H	MH	H	L	L	ML	M	ML	L	L	L	L	L		H
Town of Clifton	H	L	H	H	H	H	H	H	MH	L	M	M	ML	L	M	L	ML	L		H
Town of Dumfries	H	M	H	H	H	H	H	H	H	M	M	M	ML	L	M	M	ML	L		H
Town of Haymarket	H	M	H	H	H	H	H	H	H	M	M	M	ML	L	M	M	ML	L		H
Town of Herndon	H	M	H	H	H	H	H	H	MH	L	M	M	ML	L	M	L	ML	L		H
Town of Leesburg	H	H	H	H	H	H	H	H	H	M	M	M	MH	L	ML	M	ML	M		H
Town of Lovettsville		L		H		H		H		M		M		L		M		L		H
Town of Middleburg	H	H	H	H	H	H	H	H	H	M	M	M	MH	L	ML	M	ML	L		H
Town of Occoquan	H	L	H	H	H	H	H	H	H	M	M	M	ML	L	M	M	ML	L		H
Town of Purcellville	H	H	H	H	H	H	H	H	H	M	M	M	MH	L	ML	M	ML	L		H
Town of Quantico	H	M	H	H	H	H	H	H	H	M	M	M	ML	L	M	M	ML	L		H
Town of Round Hill	H	M	H	H	H	H	H	H	H	M	M	M	MH	L	ML	M	ML	L		H
Town of Vienna	H	M	H	H	H	H	H	H	MH	L	M	M	ML	L	M	L	ML	L		H

Table 4.17. Flood Events and Damages in the Northern Virginia Region, 1950–2015.				
Jurisdiction	**# of Flood Events**	**Property Damage**	**Crop Damage**	**Total**
Arlington County	45	$4,123,000	$0	$4,123,000
Fairfax County	34	$2,506,000	$0	$2,506,000
Loudoun County	130	$2,138,000	$180,000	$2,318,000
Prince William County	84	$775,000	$50,000	$825,000
City of Alexandria	33	$718,000	$0	$718,000
City of Fairfax	34	$2,506,000	$0	$2,506,000
City of Falls Church	36	$620,000	$0	$620,000
City of Manassas	28	$31,000	$0	$31,000
City of Manassas Park	18	$11,000	$0	$11,000
Town of Clifton	0	$0	$0	$0
Town of Dumfries	7	$500,000	$0	$500,000
Town of Haymarket	9	$173,000	$50,000	$223,000
Town of Herndon	9	$0	$0	$0
Town of Leesburg	38	$718,000	$0	$718,000
Town of Lovettsville	1	$0	$0	$0
Town of Middleburg	13	$500,000	$0	$500,000
Town of Occoquan	1	$0	$0	$0
Town of Purcellville	16	$500,000	$0	$500,000
Town of Quantico	6	$507,000	$0	$507,000
Town of Round Hill	4	$0	$0	$0
Town of Vienna	7	$0	$0	$0
Total	**553**	**$16,326,000**	**$280,000**	**$16,606,000**

Based on the data in the table above, the planning area should expect to experience flood damages in the amount of $255,477 annually.

Table 4.18. Annualized Loss Estimates Due to Severe Storms and High Winds, 1950-2015.

Jurisdiction(s)	Annualized Property and Crop Damage	Total Property and Crop Damage
Arlington County	$158,827	$10,323,750
Fairfax County & the City of Fairfax (including Town of Clifton, Town of Herndon, and Town of Vienna)	$315,508	$20,508,000
Loudoun County (including Town of Leesburg, Town of Lovettsville, Town of Middleburg, Town of Purcellville, and Town of Round Hill)	$49,732	$3,232,600
Prince William County (including Town of Dumfries, Town of Haymarket, Town of Occoquan, and Town of Quantico)	$268,412	$17,446,750
City of Alexandria	$149,538	$9,720,000
City of Fairfax	--	--
City of Falls Church	$149,692	$9,730,000
City of Manassas	240,538	$15,635,000
City of Manassas Park	$231,261	$15,032,000
Total	**$1,563,509**	**$101,628,100**

Table 4.19. HAZUS^{MH} Estimated Damages from Probabilistic Scenario 2500-year Return Interval.				
Jurisdiction	**Building Stock**	**Transportation Infrastructure**	**Utility Infrastructure**	**Total**
Arlington County	$343,903,000	$4,726,000	$3,172,000	$347,551,000
Fairfax County	$1,794,989,000	$12,702,000	$20,528,000	$1,828,219,000
Loudoun County	$430,261,000	$1,985,000	$8,280,000	$440,526,000
Prince William County	$679,957,000	$4,027,000	$15,648,000	$699,632,000
City of Alexandria	$274,089,000	$3,011,000	$4,038,000	$281,238,000
City of Fairfax	$63,431,000	$28,000	$286,000	$63,745,000
City of Falls Church	$274,089,000	$0	$154,000	$274,243,000
City of Manassas	$74,521,000	$854,000	$5,412,000	$80,787,000
City of Manassas Park	$20,296,000	$131,000	$165,000	$20,592,000
Total	**$3,708,422,000**	**$27,464,000**	**$57,684,000**	**$3,793,570,000**

Table 4.20. Winter Storm Events and Damages in the Northern Virginia Region, 1996–2015.				
Jurisdiction	**# of Winter Storm Events**	**Property Damage**	**Crop Damage**	**Total**
Arlington County (includes the Cities of Alexandria and Falls Church)	97	$460,000	$0	$460,000
Fairfax County (includes the City of Fairfax and the Towns of Clifton, Herndon, and Vienna)	123	$335,000	$0	$335,000
Loudoun County (includes the Towns of Leesburg, Lovettsville, Middleburg, Purcellville, and Round Hill)	131	$135,000	$100,000	$235,000
Prince William County (includes the Cities of Manassas and Manassas Park and the Towns of Dumfries, Haymarket,	110	$55,000	$0	$55,000

Table 4.20. Winter Storm Events and Damages in the Northern Virginia Region, 1996–2015.				
Jurisdiction	**# of Winter Storm Events**	**Property Damage**	**Crop Damage**	**Total**
Occoquan, and Quantico)				
Total	**461**	**$985,000**	**$100,000**	**$1,085,000**

Based on the data in the table above, the planning area should expect to experience winter storm damages in the amount of $57,105 annually.

VI. Flood

NOTE: As part of the 2016 plan update, the flood hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in the HIRA Introduction section. In addition, each section of the plan was also reformatted to improve clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Flooding - Flooding is the most frequent and costly natural hazard in the United States; a hazard that has caused more than 10,000 fatalities since 1900. Nearly 90% of presidential disaster declarations result from natural events where flooding was a major component.

Floods are the result of excessive precipitation, and can be classified under two categories: general floods, precipitation over a given river basin for a long period of time; and flash floods, the product of heavy, localized precipitation in a short time period over a given location. The severity of a flooding event is determined by the following: 1) a combination of stream and river basin topography and physiography; 2) precipitation and weather patterns; 3) recent soil moisture conditions; and 4) the degree of vegetative clearing.

Floods are events that may last for several days. The primary types of flooding include riverine, coastal, and urban. Riverine flooding is a function of excessive precipitation levels and water runoff volumes within the watershed of a stream or river. Coastal flooding is typically a result of storm surge, wind-driven waves, and heavy rainfall produced by hurricanes, tropical storms, nor'easters, and other large coastal storms. Urban flooding occurs where man-made development has obstructed the natural flow of water and decreased the ability of natural groundcover to absorb and retain surface water runoff.

Flash Flooding - Flash flooding events can occur from a dam or levee failure within minutes or hours of heavy amounts of rainfall, or from a sudden release of water held by an ice jam. Most flash flooding is caused by slow-moving thunderstorms in a local area or by heavy rains associated with hurricanes and tropical storms. Although flash flooding occurs often along mountain streams, it is also common in urbanized areas where much of the ground is covered by impervious surfaces. Flash flood waters move at very high speeds—"walls" of water can reach heights of 10 to 20 feet. Flash flood waters and the accompanying debris can uproot trees, roll boulders, and damage or destroy buildings, bridges, and roads.

The average global sea level has been rising at the rate of about 3.1 mm per year (data from 1993 to 2003)[4]. This same trend is apparent in the historical gage records for Washington, DC, (Station 8594900) along the tidally-influenced Potomac River where rates have averaged about 3.2 mm/year.

Sea Level Rise

Sea level rise is expected to continue and possibly accelerate as the planet warms. Based on output from multiple computer models, a low sea level rise scenario is one with a sea level rise of 7 to 15 inches by 2100. A high scenario would include a sea level rise of 10 to 23 inches by 2100. Neither scenario includes the possibility of ice sheet melting contributing to sea level rise. Some scientists suggest that should the Greenland and West Antarctic ice sheets collapse; sea level rise will be on the order of several feet higher than the high scenario shown here. [5]

Using the high Intergovernmental Panel on Climate Change (IPCC) emissions growth scenario and overlaying corresponding projected sea levels expected with that scenario, it is anticipated that significant portions of the eastern sections of Old Town Alexandria, including the eastern portions of King Street will be at risk of inundation (Figure 4.21). A study being conducted by NVRC as part of Sustainable Shorelines & Community Management indicates that approximately 49 buildings may be inundated under a high sea-level rise scenario.

Also at risk of inundation under projected rises in sea-level is Ronald Reagan Washington National Airport. Situated along the banks of the Potomac, the airport opened in 1941. The site had originally been mostly underwater and was built up by sand and gravel fill. Approximately 200 acres of the airport are within the 100-year floodplain which is 11.4 feet above mean sea level. Under the high emissions scenario, permanent inundation of portions of taxiways and access roadways is possible (See Figure 4.22).

Other low-lying areas in Northern Virginia are also at risk for sea level rise inundation. Portions of Four Mile Run in Arlington and Alexandria, Dangerfield Island, Jones Point, Huntington, Belle Haven/New Alexandria, Dyke Marsh, Hallowing Point, Occoquan NWR, Town of Quantico, the Occoquan River and various tidal embayments may be impacted.

In addition to producing high resolution sea level rise and storm surge inundation mapping for Northern Virginia, the NVRC study, completed in late 2010, also quantified specific elements

vulnerable for both the built and natural environments and developed strategies to protect, adapt or retreat communities located in areas at risk.

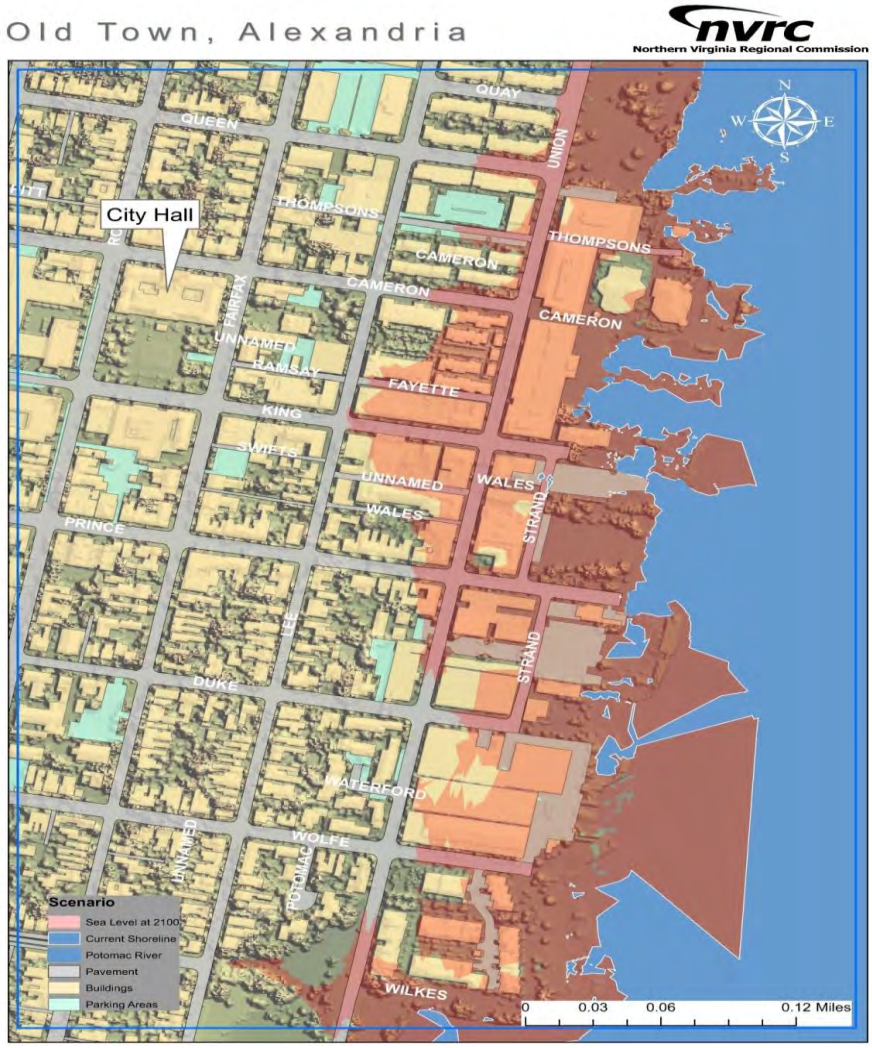

Figure 4.21. Projected 'high scenario' sea level rise for Old Town, Alexandria, 2100. *Source: NVRC, 2010.*

Figure 4.22. Projected "high-scenario" sea-level rise for Ronald Reagan Washington National Airport Year 2100.
Source: NVRC, 2010

Erosion

Erosion is the gradual breakdown and movement of land due to both physical and chemical processes of water, wind, and general meteorological conditions. Natural, or geologic, erosion has occurred since the Earth's formation and continues at a very slow and uniform rate each year.

There are two general causes of soil erosion: wind and water. Both can cause significant soil loss. Winds blowing across sparsely vegetated or disturbed land can pick up soil particles and transport them to another location. Water flowing over land also transports soil particles to other locations. Wind erosion generally impacts wider, less well defined areas than water erosion, but water erosion is capable of transporting larger particles than wind. Major storms such as hurricanes may cause significant erosion by combining the impacts of high winds and high

velocity water flow over large flood areas, including storm surges that significantly impact the shoreline.

Wind erosion is the result of lateral and uplift wind forces separating individual soil particles from the soil mass and transporting them until the wind speed and resulting forces decrease to where they are insufficient to support and transport the particles. Generally, individual wind erosion events in areas of exposed silt and clay are relatively minor. However, if the exposed soil consists of sand, and the sand becomes airborne, the rate of erosion can increase by a factor of 10. Airborne sand acts as an abrasive as it is blown across the surface, which acts to dislodge significantly more soil that the wind alone.

The main causes of water erosion are stream or overland flow, and wave action. Stream or overland flow erosion is the result of mechanical or chemical removal, and transportation of soil particles to a new location. Mechanical erosion is caused by hydrodynamic forces pushing particles down-gradient; hydraulic drag forces pulling particles down-gradient, and/or hydraulic uplift. Susceptibility of an area to stream or overland flow erosion is a function of soil characteristics, vegetative cover, water quality, topography, and climate. Soils weathered from calcareous carbonate rock (i.e., limestone and dolomite), are more susceptible to chemical erosion by dissolution than other soils. Vegetative cover can be very helpful in controlling erosion by shielding the soil surface from direct water contact and reinforcing the soil, with the foliage serving as an energy dissipater and the root mat reinforcing the near surface soils. Water quality impacts both chemical and mechanical erosion; water with relatively a high concentration of carbon dioxide, oxygen, and organic acids accelerates dissolving minerals from calcareous carbonate soils. Sand and gravel that are transported during periods of high velocity flow increase mechanical erosion through abrasion of the flow bed. Topography of the area, including size, shape, and slope is a key variable in determining water flow velocity which in turn is a key variable in the magnitude of the hydraulic forces producing erosion. The greater the slope length and gradient, the more potential an area has for erosion. Climate can also affect the amount of runoff, especially the frequency, intensity, and duration of rainfall and storms. When rainstorms are frequent, intense, or of long duration, erosion risks are high. Seasonal changes in temperature and rainfall amounts define the period of highest erosion risk for the year.

During the mid to late 1960s, the importance of erosion control gained increased public attention. Implementation of erosion control measures consistent with sound agricultural and construction operations was needed to minimize the adverse effects associated with increasing settling out of the soil particles due to water or wind. The increase in government regulatory programs and public concern has resulted in a wide range of erosion control products, techniques, and analytical methodologies in the United States. The preferred method of erosion control in recent years has been the restoration of vegetation. These measures are addressed in the Northern Virginia region through local sedimentation and erosion control programs. While local erosion hazard areas are not identified, the areas of greatest concern are typically those areas consisting of steep slopes and fast running stream channels, as well as large construction sites involved in the excavation and disturbance of their natural state.

There is no known database of historic erosion events in the Northern Virginia region. Erosion events are often extremely localized in nature and often go unreported unless they damage infrastructure or the resulting topography presents a new hazard.

As far as coastal and tidal erosion, Prince William, Fairfax, and Arlington Counties and the City of Alexandria all have tidal shorelines along the Potomac River and its associated embayments and tributaries. The accretion and erosion of these shorelines are greatly influenced by wind-induced waves, littoral currents, tidal currents, sea-level rise, boat wake, and storm water runoff. Other contributing factors include the physical characteristics of the shoreline (e.g., topography, soil), as well as human activities (e.g., land use, dredging, and shoreline stabilization).

In September 1992, NVRC prepared a study entitled "Tidal Shoreline Erosion in Northern Virginia" which discusses the erosion situation for various segments of the shoreline in the Northern Virginia region, as well as identifies the locations of "priority" erosion concern. The report is intended to serve as a valuable resource document for State and local officials to assist them in planning for shoreline and erosion control throughout Northern Virginia, and is hereby incorporated by reference. In addition, the report augments a DBase IV computer data file also created by NVRC that contains the names, mailing addresses, and tax parcel numbers of tidal Potomac shoreline property owners. This data is distributed to the Shoreline Erosion Advisory Service and Northern Virginia local governments. Combined with the set of approximately 360 low altitude aerial photographs, these work products serve as an excellent historical record for current planning efforts, and also future research.

According to the report, 20% of the Northern Virginia shoreline has been artificially stabilized with 32 miles of hard structures. Prince William County has approximately 48 miles of shoreline with 8.7 miles of artificial shoreline stabilization structures. Fairfax has the most tidal shoreline in Northern Virginia (87 miles), and the most artificial stabilization (13.3 miles), but the smallest percent of stabilized shoreline (15%). The City of Alexandria has the shortest shoreline length (8.8 miles), with the largest percent stabilized (58%, or 5.1 miles). Arlington County has 13.3 miles of tidal shoreline, with 4.9 miles of hardened shoreline (37%). This information has not been updated since the 2006 plan creation, and remains the best available data for the 2016 update to this plan.

The probability of future erosion events remains likely in localized areas throughout the Northern Virginia region. According to projects researching the changing climate, including sea-level risk and increased storm events, erosion would be expected to increase.

Erosion vulnerability for the region is difficult to determine because there are no historical records for previous occurrences of erosion events. The Northern Virginia region's vulnerability to erosion is limited to those immediate areas along rivers, creeks, and streams and to areas of loose soils with steep slopes. In most cases where erosion poses an imminent threat to property, erosion control techniques are typically applied before damages occur. Therefore, future structural damages caused by long-term erosion and associated dollar losses are expected to be negligible.

As discussed in the Hazard Analysis section, NVRC prepared a study titled "Tidal Shoreline Erosion in Northern Virginia," which discusses the erosion situation for various segments of the shoreline in the Northern Virginia region, as well as identifies the locations of "priority" erosion concern. This publication is hereby incorporated by reference, as will be future updates to shoreline erosion studies in the Northern Virginia region.

2. Geographic Location/Extent

There are numerous rivers and streams flowing through the Northern Virginia region. When heavy or prolonged rainfall events occur, these rivers and streams are susceptible to some degree of flooding. The most notable of these water bodies is the Potomac River, which in the past has been the source for significant storm surge and tidal flooding – particularly in waterfront communities such as Arlington and Alexandria.

The entire Northern Virginia region falls within the Potomac River Basin, which serves as the border between Maryland and Virginia and flows in a southeasterly direction. The topography of the upper reaches of the basin is characterized by gently sloping hills and valleys.

At Great Falls in Maryland, the Potomac River starts its rapid descent to sea level by plunging 76 feet through a deep gorge in less than one mile. Eastward of Great Falls, the Potomac flows between Washington, DC, Arlington, and Alexandria. Here the river dramatically broadens and is flanked by low marshes in many places along the eastern side of Prince William County, where tides further influence the river. The Potomac then continues on through the coastal plain and eventually grows to more than 11 miles wide as it reaches the Chesapeake Bay.

While some of the most dramatic flooding events in Northern Virginia are associated with the tidal flooding of the Potomac River during hurricanes or tropical storms, other more frequent inland flood hazards exist throughout the region. Too much rainfall or snowmelt in too little time causes serious flooding problems along even the smallest of tributaries or storm drainage systems. The low-lying areas prone to this type of flooding are known as floodplains or SFHAs. These locations, which are more commonly referred to as the "100-year floodplain" (areas with a one-percent-annual-chance of flooding), are routinely surveyed and mapped by FEMA as part of a Flood Insurance Study (FIS) sponsored by the NFIP. These studies and associated maps are then provided to local communities in order to regulate the development of land within these hazard areas.

Figure 4.23 shows the potential flood hazard areas throughout the Northern Virginia region based on the FEMA National Flood Hazard Layer (NFHL). Jurisdiction-specific flood maps that show the FEMA floodplain in relation to boundaries and assets in the region can be found in Appendix D.

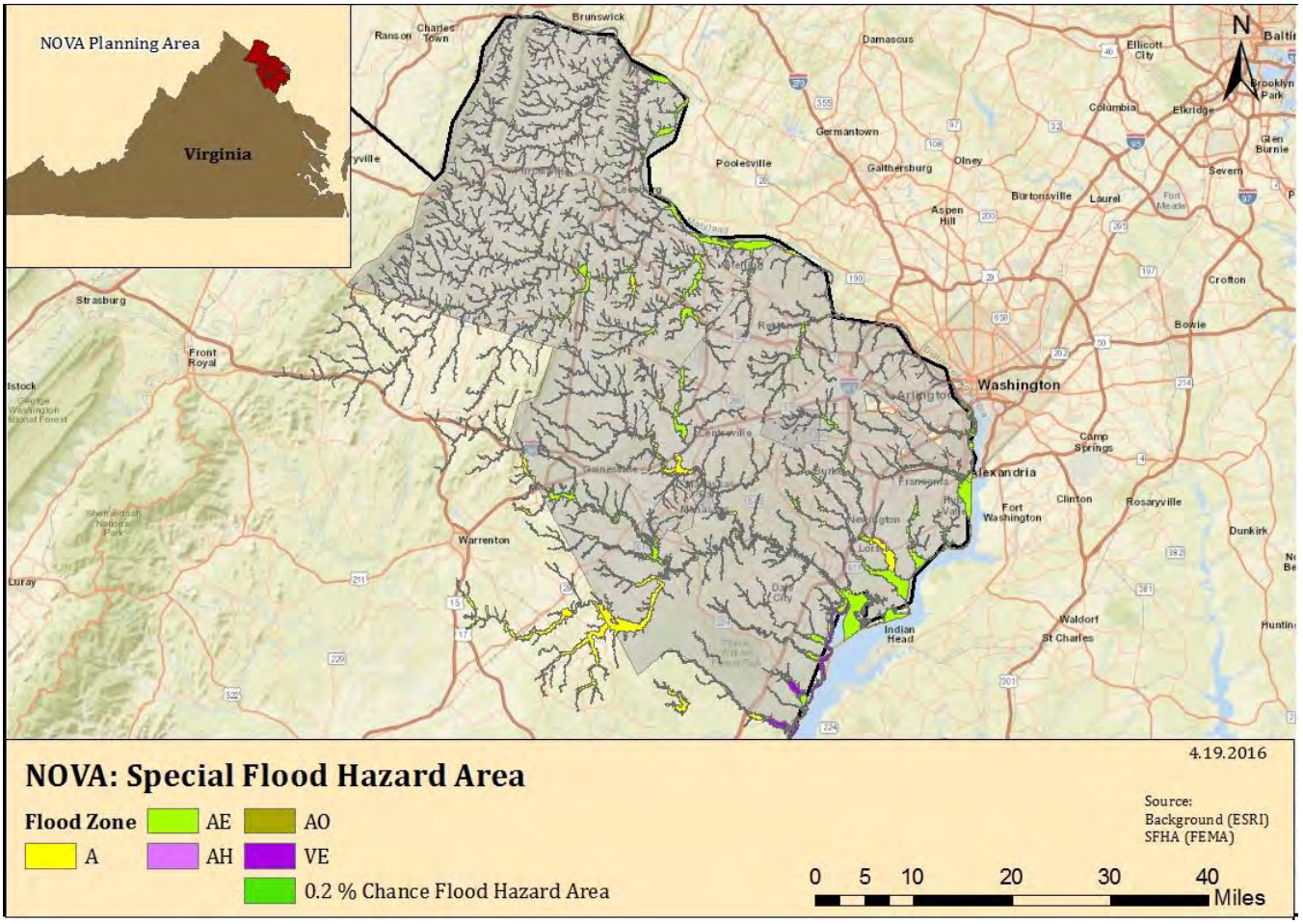

Figure 4.23 FEMA Special Flood Hazard Area Map (National Flood Hazard Layer data).

There have been a number of past flooding events throughout the region, ranging widely in terms of location, magnitude, and impact. The most frequent flooding events are quite localized in nature, resulting from heavy rains in a short period of time over urbanized areas that are not able to appropriately handle storm water runoff. These events typically do not threaten lives or property and will not result in emergency or disaster declarations, thus historical data is difficult to obtain. Table 4.21 summarizes the number of flood events (by participating jurisdiction) since 1950 which have caused a notable impact on the Northern Virginia region as recorded by the NCDC. This includes 553 flood events that have caused approximately $16.6 million in property and crop damages.

Table 4.21. Flood Events in the Northern Virginia Region, 1950–2015 based on NCDC data.

Jurisdiction	# of Flood Events	Property Damage	Crop Damage	Total
Arlington County	45	$4,123,000	$0	**$4,123,000**
Fairfax County	34	$2,506,000	$0	**$2,506,000**
Loudoun County	130	$2,138,000	$180,000	**$2,318,000**

Table 4.21. Flood Events in the Northern Virginia Region, 1950–2015 based on NCDC data.				
Jurisdiction	**# of Flood Events**	**Property Damage**	**Crop Damage**	**Total**
Prince William County	84	$775,000	$50,000	**$825,000**
City of Alexandria	33	$718,000	$0	**$718,000**
City of Fairfax	34	$2,506,000	$0	**$2,506,000**
City of Falls Church	36	$620,000	$0	**$620,000**
City of Manassas	28	$31,000	$0	**$31,000**
City of Manassas Park	18	$11,000	$0	**$11,000**
Town of Clifton	0	$0	$0	**$0**
Town of Dumfries	7	$500,000	$0	**$500,000**
Town of Haymarket	9	$173,000	$50,000	**$223,000**
Town of Herndon	9	$0	$0	**$0**
Town of Leesburg	38	$718,000	$0	**$718,000**
Town of Lovettsville	1	$0	$0	**$0**
Town of Middleburg	13	$500,000	$0	**$500,000**
Town of Occoquan	1	$0	$0	**$0**
Town of Purcellville	16	$500,000	$0	**$500,000**
Town of Quantico	6	$507,000	$0	**$507,000**
Town of Round Hill	4	$0	$0	**$0**
Town of Vienna	7	$0	$0	**$0**
Total	**553**	**$16,326,000**	**$280,000**	**$16,606,000**

*Prior to the 2016 Plan Update, previous damages were inflated to current values. As of the 2016 plan update, damages are presented in year of occurrence values, as reported by the NCDC.

3. Magnitude or Severity

Flooding only impacts a community to the degree that it affects the lives of its citizens and the community functions overall. Therefore, the most vulnerable areas of a community will be those most affected by floodwaters in terms of potential loss of life, damages to homes and businesses, and disruption of community services and utilities. For example, an area with a highly developed floodplain is significantly more vulnerable to the impacts of flooding than a rural or undeveloped floodplain where potential floodwaters would have little impact on the community.

The severity of a flood on a community can be magnified to the degree floodwaters affect special needs populations and critical facilities. Special needs populations are those that may require special assistance during a flood event, may not be able to protect themselves prior to an event, or may not be able to understand potential risks. These can include non-English speaking populations, elderly populations, or those in a lower socioeconomic group. Tourists and visitors to the area also have increased vulnerability, as they are less familiar with the geography of the area and the typical means of warning residents regarding dangerous conditions.

The impacts of floodwaters on critical facilities, such as police and fire stations, hospitals, and water or wastewater treatment facilities can greatly increase the overall effect of a flood event on a community. In general, relatively few of these facilities are located in areas with a high risk from flooding.

As discussed above, relative sea-level rise due to land subsidence and global sea level changes that are projected to occur in association with climate change and the possibility of more intense precipitation events, which may translate into greater storm water run-off into the future, are expected to exacerbate flooding hazards.

4. Previous Occurrences

Arlington County

From 1950 through 2015, NCDC recorded 45 flood events in Arlington County. Of these events, 11 were designated as coastal flood/storm surge, 12 were coded as flash floods, 11 were attributed to heavy rain, and the remaining were categorized as flood.

Arlington County was included in DR 1655, which occurred June 23-July 6, 2006. A nearly stationary front draped across the area combined with several low pressure systems and produced several waves of heavy rainfall across Northern Virginia over this 5-day stretch. Rainfall totals over this period were in the double digits at several locations. The pinnacle of the flooding occurred on June 26th. The VRE commuter line ceased operations and flooding in underground tunnels forced much of the Washington Metro rail service to close. Numerous roadways across the region were also underwater. Water rescues were needed for motorists that became trapped in floodwaters. In Huntington, flooding-related damages lead to 158 homes being declared uninhabitable due to contamination and lack of utilities.

On August 11, 2001, showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. In Arlington County, heavy rainfall washed out a culvert and created a sinkhole. Trees were downed along streams when the waterways overflowed their banks. Flooded roads and downed power lines were reported in North Arlington where a total of 5½ inches of rain was recorded.

Fairfax County

From 1950 through 2015, NCDC received reports of 34 flood events in Fairfax County. Of these events, two were categorized as coastal flood/storm surge events, six as flash flood events, 11 were attributed to heavy rain, and the remaining 15 as flood.

Fairfax County was included in DR 1655, which occurred June 23-July 6, 2006. A nearly stationary front draped across the area combined with several low pressure systems and produced several waves of heavy rainfall across Northern Virginia over this 5-day stretch. Rainfall totals over this period were in the double digits at several locations. The pinnacle of the flooding occurred on June 26th. The VRE commuter line ceased operations and flooding in underground tunnels forced much of the Washington Metro rail service to close. Numerous roadways across the region were also underwater. Water rescues were needed for motorists that became trapped in

floodwaters. In Huntington, flooding-related damages lead to 158 homes being declared uninhabitable due to contamination and lack of utilities.

On June 21-24, 1972, Hurricane Agnes entered Virginia as a tropical depression that produced widespread severe flooding. Sixteen inches of rain were recorded in Chantilly in Fairfax County resulting in major flooding of the Potomac River. Peak flows in the Potomac River basin ranged from two to six times previously known maximums. The Potomac River crested at 15.5 feet, 8.5 feet above flood stage.

Loudoun County
From 1950 through 2015, NCDC recorded 130 flood events in Loudoun County. Of the recorded events, 57 were categorized as flash flood events, 16 were attributed to heavy rain, and the remaining 57 as flood events.

On September 23, 2003, six inches of rain in four hours caused major flooding across the region, but particularly in Loudoun County. During the morning of the 23rd, heavy rain fell on top of already saturated ground from Hurricane Isabel, which struck a few days before. This led to widespread flooding of roads, waterways, and other low lying areas. Widespread flooding was reported, especially in the Leesburg, Purcellville, Bluemont, Aldie, and Middleburg areas. Across the county, over 50 roads were affected by flooding. Lime Kiln Road, Evergreen Mills Road, and Route 15 were underwater for over 24 hours after Goose Creek surged nearly 11 feet above bank full stage. The Little River flooded the Oatlands Mill area and five people had to be rescued from their homes by boat. One farmhouse along Oatlands Mills Road had water up to its second story, and in Aldie the local firehouse sustained significant flood damage. St. Louis Road was completely washed away. In Leesburg, Tuscarora Creek and Town Branch overflowed into yards, basements, and parking lots. Two vans in a parking lot along Town Branch were washed downstream and residents along Shenandoah Street had to be evacuated. The Sheriff's Office administrative building was heavily damaged after the heavy rain collecting on the roof caused the ceiling to collapse. Across the county, 60 basements were flooded.

On August 11, 2001, showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. In Loudoun County, high water stranded motorists in Sterling and the bridge at Lawson Road in Leesburg was impassible after a stream overflowed its banks.

Loudoun County was included in DR 1098, which occurred January 19-February 1, 1996. Snowmelt, combined with one to three inches of rain (some locations received nearly five inches), caused the worst regional flooding in over 10 years. Warming temperatures melted most of the snow on the ground within 12 hours. The snow pack had a liquid equivalent of between two to three inches. River flooding began along the headwaters of all basins and continued downstream through the 22nd, with crests ranging from three to 21 feet above flood stage. High water caused millions of dollars in damage, closed roads, destroyed homes and businesses, and forced the evacuation of several towns.

Prince William County
From 1950 to 2015, NCDC recorded 84 flood events in Prince William County. Of these events, two were recorded as storm surge, 59 were categorized as flash floods, and the remaining 23 as flood events.

On August 11, 2001, showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. In Prince William County, side roads were flooded by heavy downpours in Manassas. Four homes and two cars were damaged by flood waters.

City of Alexandria
From 1950 through 2015, NCDC recorded 33 flood events as impacting the City of Alexandria. Of these events, 13 were attributed to coastal flooding/storm surge, nine were categorized as flash floods, and 11 as floods.

Alexandria was included in DR 1655, which occurred June 23-July 6, 2006. A nearly stationary front draped across the area combined with several low pressure systems and produced several waves of heavy rainfall across Northern Virginia over this 5-day stretch. Rainfall totals over this period were in the double digits at several locations. The pinnacle of the flooding occurred on June 26. The VRE commuter line ceased operations and flooding in underground tunnels forced much of the Washington Metro rail service to close. Numerous roadways across the region were also underwater. Water rescues were needed for motorists that became trapped in floodwaters. In Huntington, flooding-related damages lead to 158 homes being declared uninhabitable due to contamination and lack of utilities.

On January 19-February 1, 1996, Alexandria was affected by snowmelt, combined with one to three inches of rain (some locations received nearly five inches), caused the worst regional flooding in over 10 years. Warming temperatures melted most of the snow on the ground within 12 hours. The snow pack had a liquid equivalent of between two to three inches. River flooding began along the headwaters of all basins and continued downstream through the 22nd, with crests ranging from three to 21 feet above flood stage. High water caused millions of dollars in damage, closed roads, destroyed homes and businesses, and forced the evacuation of several towns. Several kayakers were also rescued while trying to navigate the rough waters. Flood waters covered Union Street and the lower part of King Street along the river in Old Town Alexandria, and affected Washington National Airport, but not the runways.

City of Fairfax
From 1950 through 2015, NCDC recorded 34 flood events for the City of Fairfax. Five events were categorized as flash floods, three as coastal flood/storm surge, 11 were attributed to heavy rain, and the remaining 15 events were flood events.

On August 11, 2001, showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. Water covered roads in the City of Fairfax.

City of Falls Church
NCDC recorded 36 flood events as impacting the City of Falls Church from 1950 through 2015. Ten of these events were categorized as coastal flood/storm surge, 13 were attributed to heavy rain, six were noted as flash floods, and the remaining seven were described as flood events.

On August 11, 2001, showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. In Falls Church, more than three inches of rain fell in two to three hours. The Red Cross Chapter Headquarters was damaged when water flooded a portion of the building.

City of Manassas
NCDC recorded 28 flood events for the City of Manassas from 1950 through 2015. Of these, eight were recorded as flash floods, one was attributed to storm surge, nine were described as heavy rain, and the remaining 10 were described as flood events.

In July 2013, the City experienced torrential rain that resulted in significant flooding at the corner or Portner and Battle Streets. Several private residences were flooded. The City's storm water system was also damaged, resulting in cleanup costs estimated at $1.2 million, some of which was due to the age of the storm water system.

City of Manassas Park
From 1950 through 2015, NCDC recorded 18 flood events for the City of Manassas Park. Of these events, one was storm surge, two were flash floods, eight were attributed to heavy rain, and the remaining seven were described as flood events.

Town of Clifton
The Town of Clifton reported no events or damages from flooding, and none were recorded by NCDC from 1950 through 2015.

Town of Dumfries
NCDC recorded seven flood events for the Town of Dumfries from 1950 through 2015. Of these, one was recorded as storm surge, two were flood events, and the remaining four were described as flood events.

Town of Haymarket
NCDC recorded nine flood events for the Town of Haymarket from 1950 through 2015. Of these, two were flood events, and the remaining seven were described as flash flood events.

Town of Herndon
NCDC recorded nine flood events for the Town of Herndon from 1950 through 2015. Of these, three were flood events, three were heavy rain events, and the remaining three were described as flash flood events.

Town of Leesburg
NCDC recorded 38 flood events for the Town of Leesburg from 1950 through 2015. 17 events were described as flash floods, six were attributed to heavy rain, and the remaining 15 were recorded as flood events.

Town of Lovettsville
NCDC recorded one flood event impacting the Town of Lovettsville from 1950 through 2015. This event was recorded as a flash flood event in 1996.

Town of Middleburg
NCDC recorded 13 flood events for the Town of Middleburg from 1950 through 2015. Seven events were described as flash floods, two were attributed to heavy rain, and the remaining four were recorded as flood events.

Town of Occoquan
NCDC recorded one flood event impacting the Town of Occoquan from 1950 through 2015. This event was recorded as a flash flood event in 1996.

Town of Purcellville
NCDC recorded 16 flood events for the Town of Purcellville from 1950 through 2015. Nine events were described as flash floods, and the remaining seven were recorded as flood events.

Town of Quantico
NCDC recorded six flood events for the Town of Quantico from 1950 through 2015. Of these, two were flood events, one was attributed to storm surge, and the other three were described as flash flood events.

Town of Round Hill
NCDC recorded four flood events for the Town of Round Hill from 1950 through 2015 – two flash floods and two flood events.

Town of Vienna
NCDC recorded seven flood events for the Town of Vienna from 1950 through 2015. Two events were described as flash floods, three were attributed to heavy rain, and the remaining two were recorded as flood events.

National Flood Insurance Program (NFIP)
The Flood Insurance and Mitigation Administration, a component of FEMA, manages the NFIP. The three components of the NFIP are:

1. Flood Insurance;
2. Floodplain Management; and
3. Flood Hazard Mapping.

Nearly 20,000 communities across the United States and its territories participate in the NFIP by adopting and enforcing floodplain management ordinances to reduce future flood damage. In

exchange, the NFIP makes federally backed flood insurance available to homeowners, renters, and business owners in these communities. Community participation in the NFIP is voluntary.

Flood insurance is designed to provide an alternative to disaster assistance to reduce the escalating costs of repairing damage to buildings and their contents caused by floods. Flood damage is reduced by nearly $1 billion a year through communities implementing sound floodplain management requirements and property owners purchasing flood insurance. Additionally, buildings constructed in compliance with NFIP building standards suffer approximately 80% less damage annually than those not built in compliance.

In addition to providing flood insurance and reducing flood damages through floodplain management regulations, the NFIP identifies and maps the Nation's floodplains. Mapping flood hazards creates broad-based awareness of flood hazards, and provides the data needed for floodplain management programs and to actuarially rate new construction for flood insurance.

Table 4.22 shows the dates each of the jurisdictions were identified with Flood Hazard Boundary Maps (FHBMs), when the first FIRM became effective, the date of the current FIRMs used for insurance purposes, and the date the community entered into the NFIP.

Table 4.22. Communities Participating in the NFIP.

Community Name	Init FHBM Identified	Init FIRM Identified	Current Effective Map Date	Reg-Emer Date
Arlington County	--	10/1/1969	8/19/13	12/31/1976
Fairfax County	5/5/1970	3/5/1990	9/17/2010	1/7/1972
Town of Herndon	6/14/1974	8/1/1979	9/17/2010	8/1/1979
Town of Vienna	8/2/1974	2/3/1982	9/17/2010	2/3/1982
Town of Clifton	3/28/1975	5/2/1977	9/17/2010	5/2/1977
Loudoun County[1]	4/25/1975	1/5/1978	7/5/2001	1/5/1978
Town of Leesburg	8/30/1974	9/30/1982	7/5/2001	9/30/1982
Town of Purcellville	7/11/1975	11/15/1989	7/5/2001	11/15/1989
Town of Middleburg	--	7/5/2001	7/5/2001	7/31/2001
Town of Round Hill	5/13/1977	7/5/2001	7/5/2001	1/10/2006
Prince William County	1/10/1975	12/1/1981	8/3/2015	12/1/1981
Town of Dumfries	6/18/1976	5/15/1980	8/3/2015	5/15/1980
Town of Haymarket	8/9/1974	1/17/1990	1/5/1995	1/31/1990
Town of Occoquan	7/19/1974	9/1/1978	1/5/1995	9/1/1978
Town of Quantico	11/1/1974	8/15/1978	8/3/2015	8/15/1978
City of Alexandria	8/22/1969	8/22/1969	6/16/2011	5/8/1970

[1] Loudoun County is currently participating in RiskMAP; map effective dates are expected to change during the lifecycle of the 2016 plan update.

Table 4.22. Communities Participating in the NFIP.				
Community Name	**Init FHBM Identified**	**Init FIRM Identified**	**Current Effective Map Date**	**Reg-Emer Date**
City of Fairfax	5/5/1970	12/23/1971	6/2/2006	12/17/1971
City of Falls Church	9/6/1974	2/3/1982	7/16/2004	2/3/1982
City of Manassas	5/31/1974	1/3/1979	1/5/1995	1/3/1979
City of Manassas Park	3/11/1977	9/29/1978	1/5/1995	9/29/1978

as of 3/29/16 http://www.fema.gov/cis/VA.html

As of October 31, 2015, there was a total of 9,626 flood insurance policies in-force in the Northern Virginia region. These policies amounted to more than $6.6 million in flood insurance premiums paid in the region. Approximately 2,058 claims have been filed, accounting for more than $23 million in payments. Table 4.23 shows the NFIP policy statistics for each of the participating jurisdictions of the Northern Virginia region.

Table 4.23. NFIP policy and claim statistics.					
		Policy Statistics (as of 10/31/2015)		**Claim Statistics 1/1/1978 – 10/31/2015**	
County	**Community Name**	**Policies In-Force**	**Premiums Paid**	**Total Claims**	**Total Payment**
Arlington County	Arlington County	650	$346,450	129	$372,316
	Total	*650*	*$346,450*	*129*	*$372,316*
Fairfax County	Fairfax County	4,849	$3,060,806	1,028	$10,554,103
	Town of Herndon	80	$55,705	12	$19,356
	Town of Vienna	120	$82,120	19	$222,630
	Town of Clifton	8	$8,176	3	$48,969
	Total	*5,057*	*$3,206,807*	*1,062*	*$10,835,058*
Loudoun County	Loudoun County	741	$402,773	129	$1,659,242
	Town of Leesburg	124	$90,571	8	$140,160
	Town of Lovettsville	6	$2,497	-	-
	Town of Purcellville	9	$3,283	-	-
	Town of Middleburg	19	$4,691	-	-

Table 4.23. NFIP policy and claim statistics.					
		Policy Statistics (as of 10/31/2015)		Claim Statistics 1/1/1978 – 10/31/2015	
County	Community Name	Policies In-Force	Premiums Paid	Total Claims	Total Payment
	Town of Round Hill	2	$872	-	-
	Total	*901*	*$504,687*	*137*	*$1799,402*
Prince William County	Prince William County	1,351	$856,788	150	$4,630,540
	Town of Dumfries	16	$20,703	9	$34,842
	Town of Haymarket	4	$1,803	1	$0
	Town of Occoquan	34	$57,025	19	$65,187
	Town of Quantico	4	$2,364	-	-
	Total	*1,409*	*$1,877,366*	*179*	*$4,730,569*
City of Alexandria	City of Alexandria	1,155	$1,112,202	266	$3,762,441
	Total	1,155	$1,112,202	266	$3,762,441
City of Fairfax	City of Fairfax	172	$301,415	50	$885,955
	Total	172	$301,415	50	$885,955
City of Falls Church	City of Falls Church	172	$181,571	45	$399.413
	Total	172	$181,571	45	$399413
City of Manassas	City of Manassas	90	$64,445	30	$215,536
	Total	90	$64,445	30	$215,536
City of Manassas Park	City of Manassas Park	20	$17,927	7	$94,804
	Total	20	$17,927	7	$94,804
NOVA Total:		9,626	$6,674,187	2,057	$23,105,494

Floodplain management regulations are the cornerstone of NFIP participation. Communities that participate in the NFIP are expected to adopt and enforce floodplain management regulations. These regulations apply to all types of floodplain development and ensure that development activities will not cause an increase in future flood damages. Buildings are required to be elevated at or above the BFE.

Repetitive Loss Properties

A Repetitive Loss Property is a property that is insured under the NFIP and has filed two or more claims in excess of $1,000 each, within a 10-year period. Nationwide, Repetitive Loss properties constitute 2% of all NFIP insured properties, but are responsible for 40% of all NFIP claims. Mitigation for Repetitive Loss properties is a high priority for FEMA, and the areas in which these properties are located typically represent the most flood prone areas of a community.

The identification of Repetitive Loss properties is an important element to conducting a local flood risk assessment, as the inherent characteristics of properties with multiple flood losses strongly suggest that they will be threatened by continual losses. Repetitive Loss properties are also important to the NFIP, since structures that flood frequently put a strain on the National Flood Insurance Fund. Under the NFIP, FEMA defines a Repetitive Loss property as "any NFIP-insured property that, since 1978 and regardless of any change(s) of ownership during that period, has experienced: a) four or more paid flood losses; or b) two paid flood losses within a 10-year period that equal or exceed the current value of the insured property; or c) three or more paid losses that equal or exceed the current value of the insured property."

A second category of Repetitive Loss properties has been identified, for those properties that have sustained the highest levels of damages and claims; these are known as Severe Repetitive Loss properties. Severe Repetitive Loss properties are defined as any building that is covered under a Standard Flood Insurance Policy (SFIP) and has sustained flood damage for which: (a) four or more separate claim payments have been made under a SFIP, with the amount of each claim exceeds $5,000, and with the cumulative amount of such claims exceeding $20,000; or (b) at least two separate claims payments have been main under a SFIP, with the cumulative amount of those payments exceeding the fair market value of the insured structure as of the day before the loss.

A primary goal of FEMA is to reduce the number of structures that meet these criteria, whether through elevation, acquisition, relocation, or a flood-control project that lessens the potential for continual losses.

According to FEMA, there are currently 135 Repetitive Loss properties and three Severe Repetitive Loss properties within the Northern Virginia region. The specific addresses of the properties are maintained by FEMA, VDEM, and local jurisdictions, but are deliberately not included in this Plan as required by law.[6] All of these properties are unmitigated; 35 of them are also uninsured. The insured properties have been paid more than $9.3 million from 332 payable claims. Table 4.24 shows the total number of properties, total number of losses experienced, and losses paid for all of the communities within the planning region that have Repetitive Loss or Severe Repetitive Loss properties, according to data obtained from the NFIP through the State Floodplain Coordinator.

Table 4.24 Repetitive Loss and Severe Repetitive Loss Properties, as of October 2015.							
Jurisdiction	Number of Repetitive Loss Properties			Total Number of Losses	Total Building Payment	Total Contents Payment	Total Payment
	Residential	Non-Residential	Total				
Arlington County	2	0	2	4	$102,468	$16,827	$119,295
Fairfax County	76	1	77	160	$3,015,231	$200,340	$3,215,571
Town of Herndon	1	0	1	2	$5,928	$0	$5,928
Town of Clifton	1	0	1	2	$18,983	$24,750	$42,733
Loudoun County	13	1	14	46	$1,097,410	$336,513	$1,433,922
Prince William County	17	1	18	61	$1,478,608	$285,097	$1,763,705
City of Alexandria	6	6	12	30	$1,312,222	$559,065	$1,871,287
City of Fairfax	5	0	5	12	$519,284	$71,864	$591,148
City of Falls Church	1	0	1	3	$166,432	$13,836	$180,268
City of Manassas	3	1	4	10	$46,664	$23,845	$70,509
City of Manassas Park	1	0	1	2	$78,647	$9,654	$88,301
TOTAL	125	10	138	332	$7,841,875	$1,541,792	$9,383,667

B. Risk Assessment

1. Probability of Future Occurrences

Periodic flooding of lands adjacent to rivers, streams, and shorelines (land known as floodplain) is a natural occurrence that can be expected to take place based upon established recurrence intervals. The recurrence interval of a flood is defined as the average time interval, in years, expected between a flood event of a particular magnitude and an equal or larger flood. Flood magnitude increases with increasing recurrence interval.

A 100-year flood is not a flood that occurs every 100 years. In fact, the 100-year flood has a 26 percent chance of occurring during a 30-year period, the typical length of many mortgages. The 100-year flood is a regulatory standard used by Federal agencies, States, and NFIP-participating communities to administer and enforce floodplain management programs. The 100-year flood is also used by the NFIP as the basis for insurance requirements nationwide[7]. The main recurrence intervals used on the FIRMs are shown in the table below (Table 4.25).

Table 4.25. Annual probability based on flood recurrence intervals.

Flood Recurrence Interval	Annual Chance of Occurrence
10 –year	10.0%
50–year	2.0%
100–year	1.0%
500–year	0.2%

Flooding remains a highly likely occurrence throughout the identified flood hazard areas of the Northern Virginia region. Smaller floods caused by heavy rains and inadequate drainage capacity in urbanized areas will be more frequent, but not as costly as the large-scale floods which may occur at much less frequent intervals.

2. Impact & Vulnerability

A number of factors contribute to the relative vulnerabilities of certain areas in the floodplain. Development, or the presence of people and property in the hazardous areas, is a critical factor in determining vulnerability to flooding. Additional factors that contribute to flood vulnerability range from specific characteristics of the floodplain to characteristics of the structures located within the floodplain.

The following is a brief discussion of some of these factors and how they may relate to the Northern Virginia planning region.

- Flood depth: The greater the depth of flooding, the higher the potential for significant damages.
- Flood duration: The longer duration of time that floodwaters are in contact with building components, such as structural members, interior finishes, and mechanical equipment, the greater the potential for damage.
- Velocity: Flowing water exerts forces on the structural members of a building, increasing the likelihood of significant damage.

- Elevation: The lowest possible point where floodwaters may enter a structure is the most significant factor contributing to its vulnerability to damage due to flooding.
- Construction Type: Certain types of construction are more resistant to the effects of floodwaters than others. Typically masonry buildings, constructed of brick or concrete blocks, are the most resistant to damages simply because masonry materials can be in contact with limited depths of flooding without sustaining significant damage. Wood frame structures are more susceptible to damage because the construction materials used are easily damaged when inundated with water.

3. Risk

Riverine HAZUS^{MH} analysis was completed for the 2016 revision using 100-year scenarios. The following section summarizes the module and highlights the results and differences of the HAZUS^{MH} runs. The detailed reports of the HAZUS^{MH} run results can be found in Appendix D.

HAZUS^{MH} is a regional multi-hazard loss estimation model that was developed by FEMA and the National Institute of Building Sciences. he primary purpose of HAZUS^{MH} is to provide methodology and software application to develop multi-hazard losses at a regional scale. The loss estimates are used primarily by local, State, and regional officials to plan and stimulate efforts to reduce risk from multi-hazards and prepare for emergency response and recovery[8].

Potential loss estimates analyzed in HAZUS^{MH} include:

- Physical damage to residential and commercial buildings, schools, essential facilities, and infrastructure; and
- Economic loss including lost jobs, business interruptions, repair and reconstruction costs.

The HAZUS^{MH} Flood Model analyzes both riverine and coastal flood hazards. Flood hazard is defined by a relationship between depth of flooding and the annual chance of inundation to that depth. Hazard analysis of the 100-year return interval was performed in order to assess risk to essential facilities.

Depth, duration, and velocity of water in the floodplain are the primary factors contributing to flood losses. Other hazards associated with flooding that contribute to flood losses include channel erosion and migration, sediment deposition, bridge scour and the impact of flood-born debris. The HAZUS^{MH} Flood Model allows users to estimate flood losses due to flood velocity to the general building stock. The agricultural component will allow the user to estimate a range of losses to account for flood duration. The flood model does not estimate losses due to high velocity flash floods at this time. Building stock exposure is discussed in detail in the HAZUS^{MH} building stock portion of the HIRA.

The flood analysis for the HIRA was completed using the FEMA HAZUS^{MH} software for riverine flood hazards. This assessment has been completed for streams and reaches within the identified study region with a drainage area of ten square miles. The flood depth grid was developed for the 100-year return period.

Loss estimation for this HAZUS^{MH} module is based on specific input data. The first type of data includes square footage of buildings for specified types or population. The second type of data

includes information on the local economy that is used in estimating losses. Table 4.26 displays the economic loss categories used to calculate annualized losses by HAZUS^{MH}. Data for this analysis has been provided at the census block level.

Table 4.26. HAZUS^{MH} direct economic loss categories and descriptions.

Category Name	Description of Data Input into Model	HAZUS Output
Building	Cost per sq ft to repair damage by structural type and occupancy for each level of damage	Cost of building repair or replacement of damaged and destroyed buildings
Contents	Replacement value by occupancy	Cost of damage to building contents
Inventory	Annual gross sales in $ per sq ft	Loss of building inventory as contents related to business activities
Relocation	Rental costs per month per sq ft by occupancy	Relocation expenses (for businesses and institutions)
Income	Income in $ per sq ft per month by occupancy	Capital-related incomes losses as a measure of the loss of productivity, services, or sales
Rental	Rental costs per month per sq ft by occupancy	Loss of rental income to building owners
Wage	Wages in $ per sq ft per month by occupancy	Employee wage loss as described in income loss

Annualized loss is one way to determine the maximum potential annual loss. This is useful for creating a common denominator by which different types of hazards can be compared. Annualized losses are the summation of losses over all return periods multiplied by the probability of occurrence.

The HAZUS^{MH} flood analysis predicts that the Northern Virginia region can expect, annually, $1,061,851,000 in damages due to flood events. Property or "capital stock" losses make up about $1,059,291,000 of the damages 99.7%. This includes the values for building, content, and inventory. Business interruption accounts for 0.3% of the annualized losses and includes income, rental, wage, and relocation costs.

Table 4.27 illustrates the expected annualized losses. The majority of the expected damages for all jurisdictions can be attributed to building and content value. The flood model incorporates NFIP entry dates to distinguish pre-FIRM and post-FIRM census blocks.

The stream threshold used to delineate stream reaches included a 10 mi^2 threshold. The stream threshold influenced a lack of stream delineation within two communities: the City of Fairfax and City of Falls Church. This does not mean streams or floodplains do not exist in these communities, however it does mean that the automated, GIS-based method used to define a sub-watershed and the number of grid cells flowing through the community was less than the 10 mi^2 threshold. In order to try and compensate for the lack of data for these two communities,

coupled with the need to quantify other flood-related loss estimates, additional flood model work was performed using the 100-year scenario.

For the flood scenario models, the built-in default inventory of assets - known as the Comprehensive Data Management System (CDMS) - was utilized. No adjustments were made to the inventory to account for any locally-reporting critical assets. Therefore, discrepancies may appear related to critical assets between self-reported data, such as historic occurrences, and HAZUS-generated data, such as the data in this section. See Appendix D for a description of the methodology used for the flood scenarios described in this section, and the grouping of counties, cities, and towns in each model.

Table 4.27. HAZUS^{MH} Flood Module Annualized Building Loss (2015 dollars)								
Jurisdiction	**Building Loss**	**Content Loss**	**Inventory Loss**	**Relocation Loss**	**Income Loss**	**Rental Loss**	**Wage Loss**	**Total Loss**
Arlington County & the City of Falls Church	$60,000	$70,000	$34,000	$0	$0	$0	$0	$131,000
Fairfax County, the City of Fairfax, & the Towns of Clifton, Herndon, & Vienna	$163,482,000	$116,257,000	$1,802,000	$179,000	$115,000	$30,000	$239,000	$282,104,000
Loudoun County & the Towns of Leesburg, Lovettsville, Purcellville, Middleburg, & Round Hill	$216,864,000	$150,661,000	$1,089,000	$284,000	$181,000	$92,000	$448,000	$369,619,000
Prince William County, the City of Manassas Park, & the Towns of Dumfries, Haymarket, Occoquan, & Quantico	$216,772,000	$160,654,000	$2,953,000	$227,000	$256,000	$60,000	$343,000	$380,893,000
City of Alexandria	$12,895,000	$9,852,000	$33,000	$18,000	$12,000	$6,000	$9,000	$22,825,000
City of Manassas	$2,362,000	$3,846,000	$10,000	$7,000	$37,000	$5,000	$12,000	$6,279,000
Total	$612,435,000	$441,340,000	$5,921,000	$715,000	$601,000	$193,000	$1,051,000	$1,061,851,000

Essential Facilities Risk

The vulnerability of the region's building stock was assessed using GIS analysis by comparing the physical location with the extent of known hazard areas that can be spatially defined through GIS technology. Tables 4.28 and 4.29 summarize the number of potentially at-risk essential facilities in the region to flood by jurisdiction and facility type. These determinations are based solely on best available data for critical facility locations and delineable hazard areas for. The actual level of risk for each facility may only be determined by further on-site assessments.

Table 4.28. Number of HAZUS^{MH} Critical Facilities Potentially At-Risk to Flood.

Jurisdiction	Fire Stations	Hospitals	Police Stations	Schools	EOCs
Arlington County	0	0	0	0	0
Fairfax County	0	0	0	0	0
Town of Herndon	0	0	0	0	0
Town of Vienna	0	0	0	0	0
Town of Clifton	0	0	0	0	0
Loudoun County	0	0	0	0	0
Town of Leesburg	0	0	0	0	0
Town of Lovettsville	0	0	0	0	0
Town of Purcellville	0	0	0	0	0
Town of Middleburg	0	0	0	0	0
Town of Round Hill	0	0	0	0	0
Prince William County	0	0	1	0	0
Town of Dumfries	0	0	0	0	0
Town of Haymarket	0	0	0	0	0
Town of Occoquan	0	0	0	0	0
Town of Quantico	0	0	0	0	0
City of Alexandria	0	0	0	0	0
City of Fairfax	0	0	0	0	0
City of Falls Church	0	0	0	0	0
City of Manassas	0	0	0	0	0
City of Manassas Park	0	0	0	0	0

Table 4.29. HAZUS^{MH} Estimate: Shelter Requirements.		
Jurisdiction	**# of Displaced People**	**# of People Needing Short-Term Sheltering**
Arlington County	0	0
Fairfax County	3,065	2,016
Town of Herndon	0	0
Town of Vienna	0	0
Town of Clifton	0	0
Loudoun County	3,641	2,961
Town of Leesburg	0	0
Town of Lovettsville	0	0
Town of Purcellville	0	0
Town of Middleburg	0	0
Town of Round Hill	0	0
Prince William County	4,601	3,329
Town of Dumfries	0	0
Town of Haymarket	0	0
Town of Occoquan	0	0
Town of Quantico	0	0
City of Alexandria	685	627
City of Fairfax	0	0
City of Falls Church	0	0
City of Manassas	0	2
City of Manassas Park	0	0

Information for the HAZUS^{MH} identified critical facilities in the flood zones is available in Appendix D, as is information regarding the potential flood risk for locally-identified critical assets for each jurisdiction.

The most vulnerable properties to flooding in the Northern Virginia region are located in SFHAs identified by FEMA through the completion of detailed Flood Insurance Studies. The DFIRMs depicting the SFHAs in Appendix D illustrate the location of these areas for each jurisdiction based upon the most up-to-date digital floodplain data as provided by the FEMA Map Service

Center. Digital data was available for all of the localities within the Northern Virginia planning region.

4. Overall Loss Estimates and Ranking

The loss estimates and ranking results for the flood hazard in the Northern Virginia region is principally based on the results of the detailed GIS and HAZUS^{MH} analysis, NCDC storm events, and the Commonwealth of Virginia's 2013 HIRA.

There have been a number of past flooding events throughout the region, ranging widely in terms of location, magnitude, and impact. The most frequent flooding events are quite localized in nature, resulting from heavy rains in a short period of time over urbanized areas that are not able to appropriately handle storm water runoff. These events typically do not threaten lives or property and will not result in emergency or disaster declarations, thus historical data is difficult to obtain. Table 4.21 (earlier in this section) summarizes the number of flood events since 1950 which have caused a notable impact on the Northern Virginia region as recorded by the NCDC. This includes 553 flood events that have caused approximately $16.6 million in property and crop damages.

The Commonwealth of Virginia's 2013 hazard mitigation plan ranking was based on the NCDC database. This update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. The geographic extent score for each jurisdiction is based on the percent of the jurisdiction that falls within the SFHA, as defined by FEMA.

For the 2016 plan update, the qualitative assessment was organized by participating jurisdiction. Jurisdictions with a determined probability of 'Highly Likely' were determined to have 'High' vulnerability to the flood hazard. Those with 'Likely' probabilities were determined to have 'Moderate' vulnerability. Those with 'Unlikely' probability were determined to have 'Low' vulnerability.

Arlington County

Table 4.30. 2016 Qualitative Assessment for Flood.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.31. 2016 Qualitative Assessment for Erosion.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Fairfax County

Table 4.32. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.33. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Clifton

Table 4.34. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Minor	Negligible	6 to 12 hours	Less than one week

Table 4.35. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Herndon

Table 4.36. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.37. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Vienna

Table 4.38. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.39. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Loudoun County

Table 4.40. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.41. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Leesburg

Table 4.42. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.43. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Lovettsville

Table 4.44. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Moderate	Moderate	6 to 12 hours	Less than one week

Table 4.45. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Minor	Negligible	More than 24 hours	More than one week

Town of Middleburg

Table 4.46. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.47. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Purcellville

Table 4.48. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.49. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Round Hill

Table 4.50. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Moderate	Moderate	6 to 12 hours	Less than one week

Table 4.51. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Minor	Negligible	More than 24 hours	More than one week

Prince William County

Table 4.52. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.53. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Dumfries

Table 4.54. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.55. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Haymarket

Table 4.56. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.57. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

Town of Occoquan

Table 4.58. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Minor	Moderate	6 to 12 hours	Less than one week

Table 4.59. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Minor	Negligible	More than 24 hours	More than one week

Town of Quantico

Table 4.60. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.61. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

City of Alexandria

Table 4.62. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.63. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

City of Fairfax

Table 4.64. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.65. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

City of Falls Church

Table 4.66. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.67. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

City of Manassas

Table 4.68. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.69. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

City of Manassas Park

Table 4.70. 2016 Qualitative Assessment for Flood.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Critical	Moderate	6 to 12 hours	Less than one week

Table 4.71. 2016 Qualitative Assessment for Erosion.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

VII. Winter Storm

NOTE: As part of the 2016 plan update, the Winter Storm hazard was reexamined and new analyses performed. This new analyses included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining the number of hazard events and losses by jurisdiction using NCDC and other data sources (where available); 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4 Section IV Ranking and Analysis Methodologies. Extreme Cold was separated from the winter storm section for the 2016 plan update, and included in the Extreme Temperatures section. Each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

A winter storm can range from a moderate snow over a period of a few hours to blizzard conditions with blinding wind-driven snow that lasts for several days. Some winter storms impact multi-State regions. Winter storms may be accompanied by low temperatures, ice, and heavy and/or blowing snow, which can severely impair visibility.

Winter storms may include snow, sleet, freezing rain, or a mix of these wintry forms of precipitation. Sleet – raindrops that freeze into ice pellets before reaching the ground – usually bounce when hitting a surface and do not stick to objects; however, sleet can accumulate like snow and cause a hazard to motorists. Freezing rain is rain that falls onto a surface with a temperature below freezing, forming a glaze of ice. Even small accumulations of ice can cause a significant hazard, especially on power lines and trees. An ice storm occurs when freezing rain falls and freezes immediately upon impact. Communications and power can be disrupted for days, and even small accumulations of ice may cause extreme hazards to motorists and pedestrians.

A freeze is weather marked by low temperatures, especially when below the freezing point (zero degrees Celsius or 32 degrees Fahrenheit). House fires and carbon monoxide poisoning are possible as people use supplemental heating devices (wood, kerosene, etc.) and fuel burning lanterns or candles for emergency lighting.

2. Geographic Location/Extent

The Northern Virginia region is located in a part of the country that experiences hazardous winter weather conditions, including severe winter storms that bring heavy accumulations of snow, sleet, and freezing rain. On average, the region receives approximately 15 to 21 inches of snow annually. The region's biggest winter storms are typically associated with Nor'easters. During these events, winds around the storm's center can become intense, building waves that erode the Potomac shoreline and sometimes pile water inland causing extensive coastal flooding and severe erosion. These systems may also produce blinding snowfall that can accumulate to a foot or more or mixed precipitation that may leave a coating of ice. Other types of winter weather systems are more of a nuisance and generally do not cause major damage. Weather systems such as the "Alberta Clipper" (a fast moving storm from the Alberta, Canada region), or a cold front sweeping through from the west, generally do not bring more than a few inches of snow in a narrow 50 to 60 mile-wide band. Figures 4.24 and 4.25 (later in this chapter) show the average number of days in Virginia with at least 3 and 6 inches of snowfall, as calculated by VDEM.

3. Magnitude or Severity

The Northeast Snowfall Impact Scale (NESIS) developed by Paul Kocin and Louis Uccellini attempts to rank Northeast snowstorms based on the impacts these systems have on society. The scale is broken into five categories ranging from Category 1 which is considered a "Notable" event, to a Category 5 which is considered "Extreme." The amount of snowfall for a particular storm and the population impacted are the factors used in assigning NESIS values. This scale is

mentioned here as background information for the reader and is infrequently referenced by the media or the NWS in describing significant snowfall events.

4. Previous Occurrences

Since 1996, there have been 461 winter storm event reports recorded by the NCDC for the Northern Virginia region, causing more than $1 million in crop and property damage. (Most storm damages are attributable to traffic accidents and roof or other structural collapses. It is important to note that the considerable costs associated with lost wages and business opportunities, lowered productivity, and snow and ice removal are not factored into NCDC loss estimates, and are therefore not accounted for here.) Table 4.72 illustrates the distribution of these events. Note that the NCDC records winter storm events at a geographic county level, and because of this, all towns and cities within the same geographic area are included in the storm and damage estimates for that area. This is because of the typically widespread spatial nature of winter storm events. Therefore, the table below illustrates the data in the same manner, by geographic area, with specific jurisdictions included noted.

Table 4.72. Winter Storm Events in the Northern Virginia Region, 1996–2015, based on NCDC data.

Jurisdiction	# of Winter Storm Events	Property Damage	Crop Damage	Total
Arlington County, the City of Alexandria, & the City of Falls Church	97	$460,000	$0	$460,000
Fairfax County, the City of Fairfax, & the Towns of Clifton, Herndon, and Vienna	123	$335,000	$0	$335,000
Loudoun County & the Towns of Leesburg, Lovettsville, Middleburg, Purcellville, and Round Hill	131	$135,000	$100,000	$235,000
Prince William County, the City of Manassas, the City of Manassas Park, & the Towns of Dumfries, Haymarket, Occoquan, and Quantico	110	$55,000	$0	$55,000
Total	**461**	**$985,000**	**$100,000**	**$1,085,000**

Planning Area Occurrences

The winter of 2014 was particularly harsh in the planning area. In January, four separate storms moved through the area, each dumping ice or snow in the area. The January 21st event was

particularly harsh, with the majority of the planning area receiving in excess of five inches of snow. The City of Manassas reported receiving 6-10 inches of snow, and partially activating their EOC for the event. February 12-13 saw the next round of snow, with more than two inches falling on the 12th and another six inches or more falling the next day. March 3rd saw yet another round of significant snowfall throughout the area, with more than five inches recorded throughout the area; some area, such as the City of Manassas, reported accumulations of 6-10 inches.

Arlington County, Fairfax County, Loudoun County, Prince William County, the City of Alexandria, the City of Fairfax, the City of Falls Church, the City of Manassas, and the City of Manassas Park were all included in DR 1905, which occurred February 5-11, 2010. This event was declared as a result of severe winter storms and snowstorms. Record-breaking snowfall fell over Northern Virginia and much of the Mid-Atlantic. A storm system moving through the Midwest phased with another system moving across the South, growing more powerful off the Carolina coast. The system then tracked northeast and then east along the Mid-Atlantic coast before heading out to sea. Snow began during the afternoon hours of February 5 and continued into the early evening of February 6. As much as 32.4 inches fell over the two-day period at the NWS Forecast Office in Sterling, Virginia near Dulles International Airport, with 17.8 inches at Ronald Reagan Washington National Airport. Whether by air, rail, or roadway, travel became nearly impossible, as winds gusting over 35 mph whipped snow into drifts of up to four feet deep. This storm was the second paralyzing snowstorm of the season for what would turn out to be (according to NWS data) northern Virginia's snowiest winter on record. The storm was nicknamed 'Snowpocalypse' and 'Snowmageddon' by local media and others. The snow forced the shutdown of the Federal government for four and a half consecutive days.

A dry, powdery snow accompanied by wind gusts of 40 to 50 mph caused white-out conditions across a considerable portion of northern Virginia, particularly on the morning of February 10. Snow drifts up to four feet high leftover from the storm of February 5-6 and up to a foot of additional accumulation from this storm brought travel in the area to a standstill once again. Conditions were so fierce that at 7am, the Virginia Department of Transportation ceased snowplow operations citing visibility of less than 100 feet at times. Total accumulations from this storm were greatest over the eastern and northern sections of the region where 10 to 14 inches was common near the borders with the District of Columbia and Maryland. Lighter amounts of generally 5 to 9 inches fell over the rest of the region.

Arlington County, Fairfax County, Prince William County, the City of Alexandria, the City of Fairfax, the City of Falls Church, the City of Manassas, and the City of Manassas Park were also included in DR 1874, which occurred December 18-20, 2009. A storm system that formed over the Gulf of Mexico gathered strength as it tracked to a position off the Carolina coast and then along the Eastern Seaboard. Snow began over northern Virginia during the evening of Friday, December 18, and continued into much of the following day. The storm caused travel to ground to a halt as roads, railways, and runways became snow covered and in some cases impassable. The initial heavy, wet nature of the snow combined with winds that gusted to over 35 mph at times left thousands in the Mid-Atlantic without power. Ronald Reagan Washington National Airport recorded 15 inches of snow on December 19, for a two-day storm total of 16.4 inches.

Slightly higher amounts fell just to the west and south with Dulles International Airport receiving 19.3 inches.

B. Risk Assessment

1. Probability of Future Occurrences

The probability of future winter weather events is usually determined based on an examination of the historical frequency of occurrence of such events. The NCDC Storm Events database contains winter weather events and damages dating back to 1996, but it does not systematically document the magnitude or intensity of each event. The NCDC database also records these events at a geographic county level, with individual accounts from municipalities or unincorporated areas of the county included in the reports. Long-term weather station observation data provides more detailed information on event magnitude (as measured by snowfall depth, precipitation types, and temperature), but does not provide any information regarding historical impacts.

Rather than relying solely on existing climatology information, independent analyses of weather station data were performed for the Commonwealth of Virginia Emergency Operations Plan to estimate the probability of specific winter weather occurrences.

Using daily weather station data involves decisions about which weather stations to include in the analysis and how to handle any gaps in the data record. In deciding which weather stations to use, the location, period of record, and data variables reported are the key considerations. Virginia stations with substantially complete data from 1960 through 2000 were chosen for the Virginia Hazard Mitigation Plan analysis. Small interruptions or gaps exist in these stations' data records, which may indicate periods when the station was not operational. Entire years with no data were removed from consideration when conducting the analyses in this report, but smaller data gaps were ignored. As a result, the statistics generated from this data may slightly underestimate the frequency or intensity of winter weather phenomena. Future plan updates might consider more involved techniques, which could potentially improve this area of the analysis.

As part of the analysis for the State plan, weather station data was downloaded from the NCDC archives. A selection of cooperative weather stations operating between 1960 and 2000 was loaded into a Microsoft Access database in order to determine the annual frequency of occurrence of certain conditions. The daily station data variables relevant to this investigation include 24-hour snowfall depth, minimum temperature, and daily weather type codes.

The NCDC archives, and specifically the Daily Surface Data records (DS3200 / 3210 / 3205 / 3206), provide data in comma-delimited text files, which must be transformed in order to create a database table as a single daily record. This transformation was accomplished using a macro written with Visual Basic for Applications in Access. This macro converts the data from its original format, with all days of a month in one record, to a format containing only one day per record. With the daily data thus transformed, a second macro calculated and reported the annual frequency of occurrence for user-specified conditions. In this instance, the probability that a given year would contain at least three days with three inches of snowfall was examined.

Figures 4.24 and 4.25 are a selection of results from CGIT analysis of the daily snowfall and temperature weather station data from the Virginia Hazard Mitigation Plan. These figures illustrate a general trend towards more frequent and more intense winter weather at higher elevations and at higher latitudes. In these figures, the station-specific statistics have been used as the basis for a seamless statewide estimate based on multiple linear regressions between the weather statistics (dependent variable) and elevation and latitude (independent variables). The analysis shows that the average number of days with at least three inches of snowfall varies from approximately two to almost seven days in western portions of Loudoun County, to two to three days throughout the remainder of Northern Virginia. The average number of days with at least six inches of snowfall was between one and 1.5 over western sections of Loudoun County and generally one day or fewer in the remainder of Northern Virginia. This data was validated for this plan update, and found to be accurate.

Based on this analysis and the historical record, winter storms will remain a highly likely occurrence for the entire Northern Virginia region. If history continues to hold true, western sections of Loudoun County can expect a slightly higher likelihood of experiencing accumulating snowfall relative to the remainder of Northern Virginia.

Long range climate modeling suggests that as the planet warms, a trend of more winter precipitation taking the form of liquid precipitation, rather than snowfall would result.[9] Future hazard mitigation plan updates might consider factoring the latest climate science as part of a quantitative method for determining the probability of future occurrence of wintry weather.

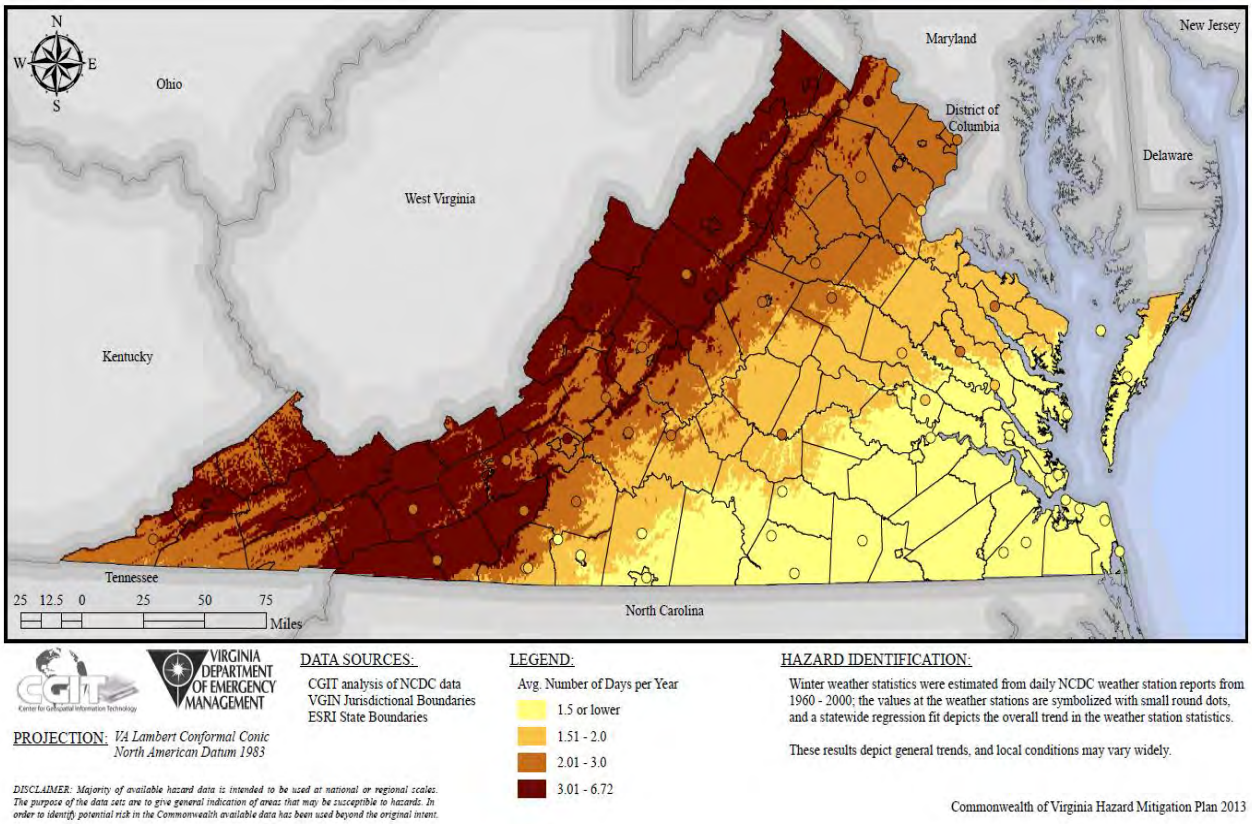

Figure 4.24. Average Number of Days with At Least Three Inches of Snow.

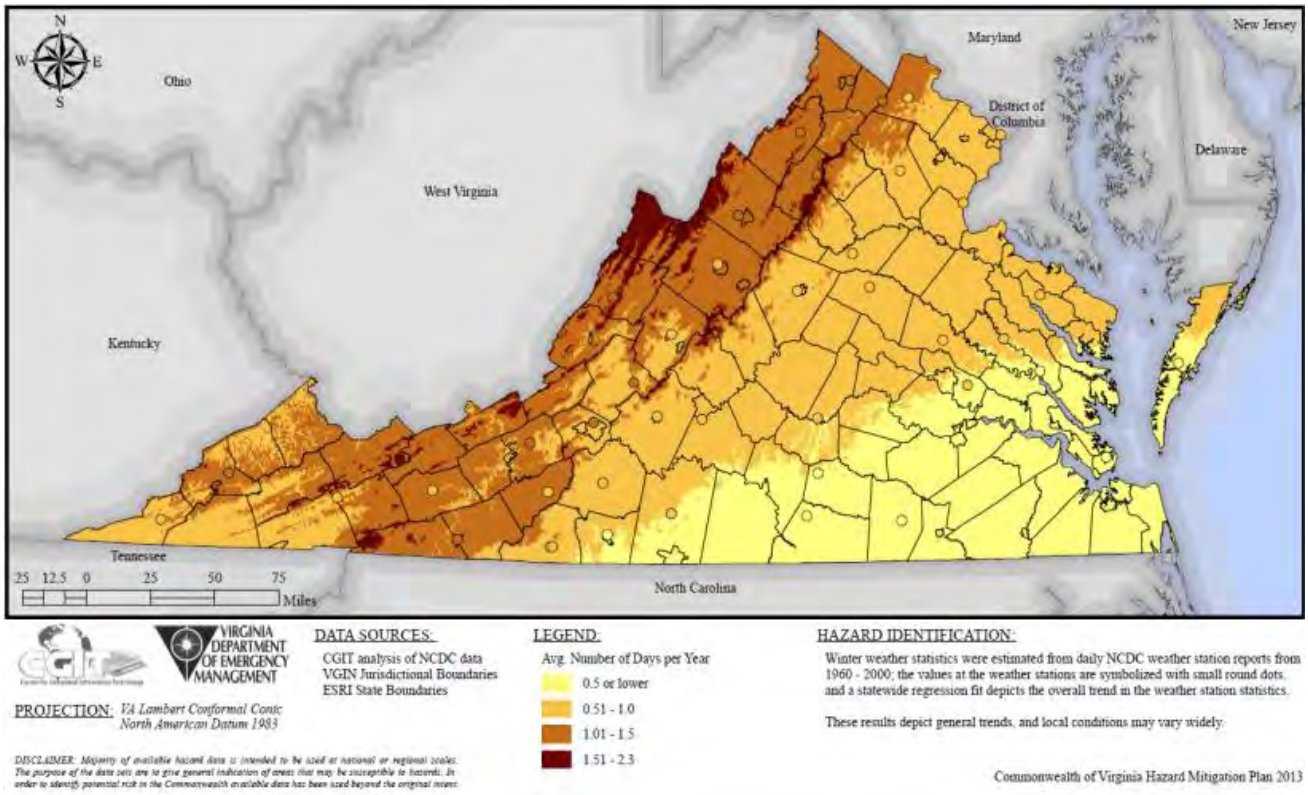

Figure 4.25. Average Numbers of Days with At Least Six Inches of Snow.

2. Impact & Vulnerability

Winter storm vulnerability can be thought of in terms of individual, property, and societal elements. For example, the exposure of individuals to extreme cold, falling on ice-covered walkways, and automobile accidents is heightened during winter weather events. Property damage due to winter storms includes damage done by and to trees, water pipe breakage, structural failure due to snow loads, and injury to livestock and other animals. The disruption of utilities and transportation systems, as well as lost business and decreased productivity are vulnerabilities of society as a whole. The vulnerability to these damages varies in large part due to specific factors; for example, proactive measures such as regular tree maintenance and utility system winterization can minimize property vulnerability. Localities accustomed to winter weather events are typically more prepared to deal with them and therefore less vulnerable than localities that rarely experience winter weather.

The impacts of winter storms are primarily quantified in terms of the financial cost associated with preparing for, response during, and recovering from them. The primary source of data providing some measurement of winter storm impacts is the NCDC Storm Events database. The database includes winter event data back to 1993, but is not necessarily complete or consistent from event to event. Although a more comprehensive, labor-intensive analysis consisting of using weather station data, NCDC damages, and other data sources could possibly produce an intensity-damage relationship between winter weather occurrences and resultant damages, this type of analysis was not performed for the update of this or the State Plan. The branches of government most often affected by winter storms include the Virginia Department of Transportation and local public works and transportation departments. Roadway treatment operations often begin in advance of a winter storm, and continue for as long as necessary.

3. Risk

Risk, as defined as probability multiplied by impact, cannot be fully estimated for winter storms due to the lack of intensity-damage models for this hazard. Instead, estimates of the financial impacts of winter storms can be developed based on NCDC winter weather event data that runs from January 1996 to December 2015. Examination of NCDC data shows that there were at least 461 winter weather events in the database, producing an estimated annualized loss of $57,105, based on total estimated losses of more than $1 million for the 19 year period of record.

The winter weather frequency data from the Commonwealth shows a strong trend toward more winter weather occurring in areas at higher latitudes and at higher elevations. The mountainous western portion of the State and the northern portions of the State, including Northern Virginia, experience winter weather more often and with greater severity than other portions of Virginia. While the magnitude of damages from winter storms are perhaps not typically as great as experienced in association with extreme flooding or a severe earthquake, winter storms occur much more frequently and usually over broader areas. In addition, storm events with relatively low intensity can nevertheless cause significant impacts, especially in areas unaccustomed to such events.

Losses associated with winter storms are typically related to snow removal and business interruption, although power failure is also a significant secondary hazard commonly associated with winter storms, and particularly ice events. In addition to the impacts on transportation,

power transmission, and communications, severe winter storms in the Northern Virginia region have at times cause severe property damage due to roof collapses. According to FEMA, most injuries and fatalities related to winter storms are caused by vehicle accidents and hypothermia. The entire Northern Virginia region is generally equally susceptible to winter storms, and has experienced similar numbers of events and levels of damage. Due to higher residential and commercial densities, Arlington and Fairfax counties may be more severely impacted by winter storms in terms of interruption to services (transportation, communication, etc.), but are not considered significantly more vulnerable.

Critical Facility Risk

Quantitative assessment of critical facilities for winter storm risk was not feasible for this update. Even so, it is apparent that transportation structures are at greater risk from winter storms. In addition, building construction type – particularly roof span and construction method, are factors that determine the ability of a building to perform under severe stress weights from snow. Finally, not all critical facilities have redundant power sources and may not even be wired to accept a generator for auxiliary heat. Future plan updates should consider including a more comprehensive examination of critical facility vulnerability to winter storms.

Existing Buildings and Infrastructure Risk

Risk to existing buildings and infrastructure is largely determined by building construction type – particularly roof span and construction method. Both are factors that determine the ability of a building to perform under severe stress weights from snow.

Overall Loss Estimates and Ranking

The Commonwealth of Virginia's 2013 HIRA ranking was based largely on the NCDC storm events database. The 2016 update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. In determining a score and ranking for winter storm, the geographic extent score for each jurisdiction is based on the analysis of the average annual number of days receiving at least three inches of snow (Figure 4.24, calculated as an area weighted average for each jurisdiction.) The methodology for the scoring and ranking of hazards is described in detail in the Risk Assessment and Methodology section. Based on this methodology, all of Northern Virginia is considered at 'High' risk for winter storms and winter weather.

For the 2016 plan update the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. Therefore, to avoid repetition, Table 4.73 provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results.

Table 4.73. 2016 Qualitative Assessment for Winter Storm.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

VI. High Wind/Severe Storms
(Including thunderstorms and hurricanes)

NOTE: As part of the 2016 plan update, the High Wind/Severe Storm hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profiles; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Wind is the motion of air past a given point caused by a difference in pressure from one place to another. Wind poses a threat to Northern Virginia in many forms, including wind produced by severe thunderstorms and tropical weather systems. The effects can include blowing debris, interruptions in elevated power and communications utilities, and intensified effects of winter weather. Harm to people and animals as well as damage to property and infrastructure may result.

Severe Thunderstorms

According to the NWS, more than 100,000 thunderstorms occur each year in the United States, though only about 10% of these storms are classified as *severe*. A thunderstorm with wind gusts in excess of 58 miles per hour (50 knots) and/or hail with a diameter of 3/4" or more is classified as a severe thunderstorm. Although thunderstorms generally affect a small area, they are dangerous because of their ability to generate tornadoes, hail, strong winds, flash flooding, and lightning. While thunderstorms can occur in all regions of the United States, they are most common in the central and southern states because atmospheric conditions in those areas are ideal for generating and feeding these powerful storms.

Multiple cloud-to-ground and cloud-to-cloud lightning strikes observed during a nighttime thunderstorm. (Photo courtesy of NOAA Photo Library, NOAA Central Library; OAR/ERL/ National Severe Storms Laboratory)

Thunderstorms are caused when air masses of varying temperatures and moisture content meet. Rapidly rising warm moist air serves as the driving force for thunderstorms. These storms can occur singularly, in lines, or in clusters. They can move through an area very quickly or linger for several hours.

Lightning is a discharge of electrical energy resulting from the buildup of positive and negative charges within a thunderstorm, creating a bolt when the buildup of charges becomes strong enough. This flash of light usually occurs within the clouds or between the clouds and the ground. A bolt of lightning can reach temperatures approaching

50,000 degrees Fahrenheit. Lightning rapidly heats the sky as it flashes, but the surrounding air cools following the bolt. This rapid heating and cooling of the surrounding air causes thunder. On average, 89 people are killed each year by lightning strikes in the United States.

Some storms produce a particular type of high wind called a derecho. Derechos are widespread, long-lived, straight-line wind storms associated with severe thunderstorms. They can cause hurricane-force winds, tornadoes, heavy rains, and flooding. Derechos travel quickly, with sustained winds that often exceed hurricane-force. They typically occur in the summer months, though they can occur any time of year and ant any time of the day or night.

2. Geographic Location/Extent

Although most frequent in the Southeast and parts of the Midwest, thunderstorms are a relatively common occurrence across Northern Virginia and have been known to occur in all calendar months. The NWS collected data for thunderstorm days, number and duration of thunder events, and lightning strike density for the 30-year period from 1948 to 1977. The analysis of this data determined that on average, 50 to 60 thunderstorm events occur annually in Northern Virginia. No one portion of Northern Virginia is deemed to be more likely to experience thunderstorms than another portion of the region.

Figure 4.26 illustrates thunderstorm hazard severity based on the annual average number of thunder events from 1948 to 1977.

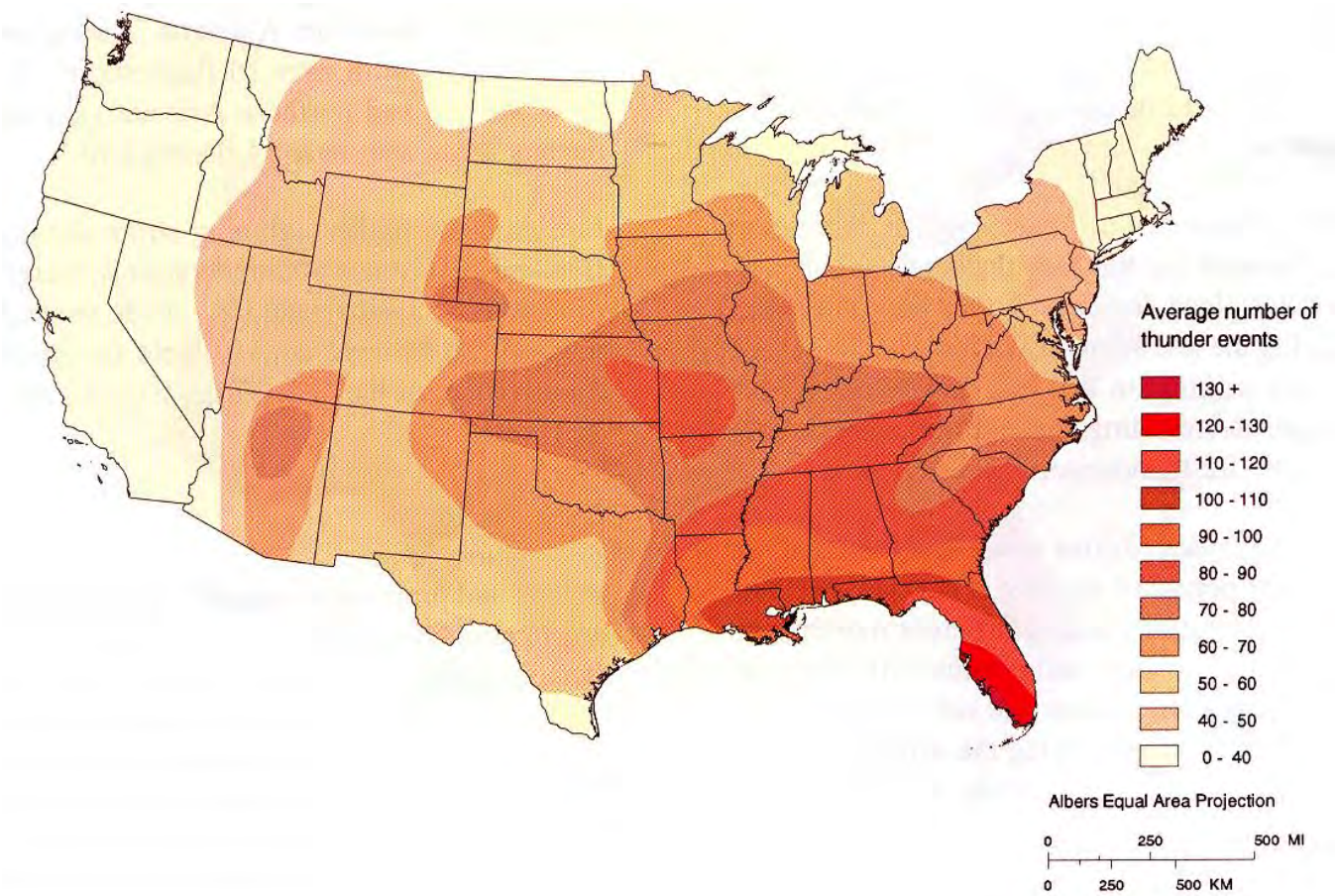

Figure 4.26. Annual Average Number of Thunder Events.
Source: Federal Emergency Management Agency

3. Magnitude or Severity

Straight-line winds, which in extreme cases have the potential to cause wind gusts that exceed 100 miles per hour, are responsible for most thunderstorm wind damage. One type of straight-line wind, the downburst, can cause damage equivalent to a strong tornado and can be extremely dangerous to aviation. Figure 4.27 shows how the frequency and strength of extreme windstorms vary across the United States. The map was produced by FEMA and is based on 40 years of tornado history and over 100 years of hurricane history. Zone IV, the darkest area on the map, has experienced both the greatest number of tornadoes and the strongest tornadoes. As shown by the map key, wind speeds in Zone IV can be as high as 250 MPH. As depicted in this figure, the planning area falls within Zone II, a hurricane-susceptible region where winds can be as high as 160 MPH.

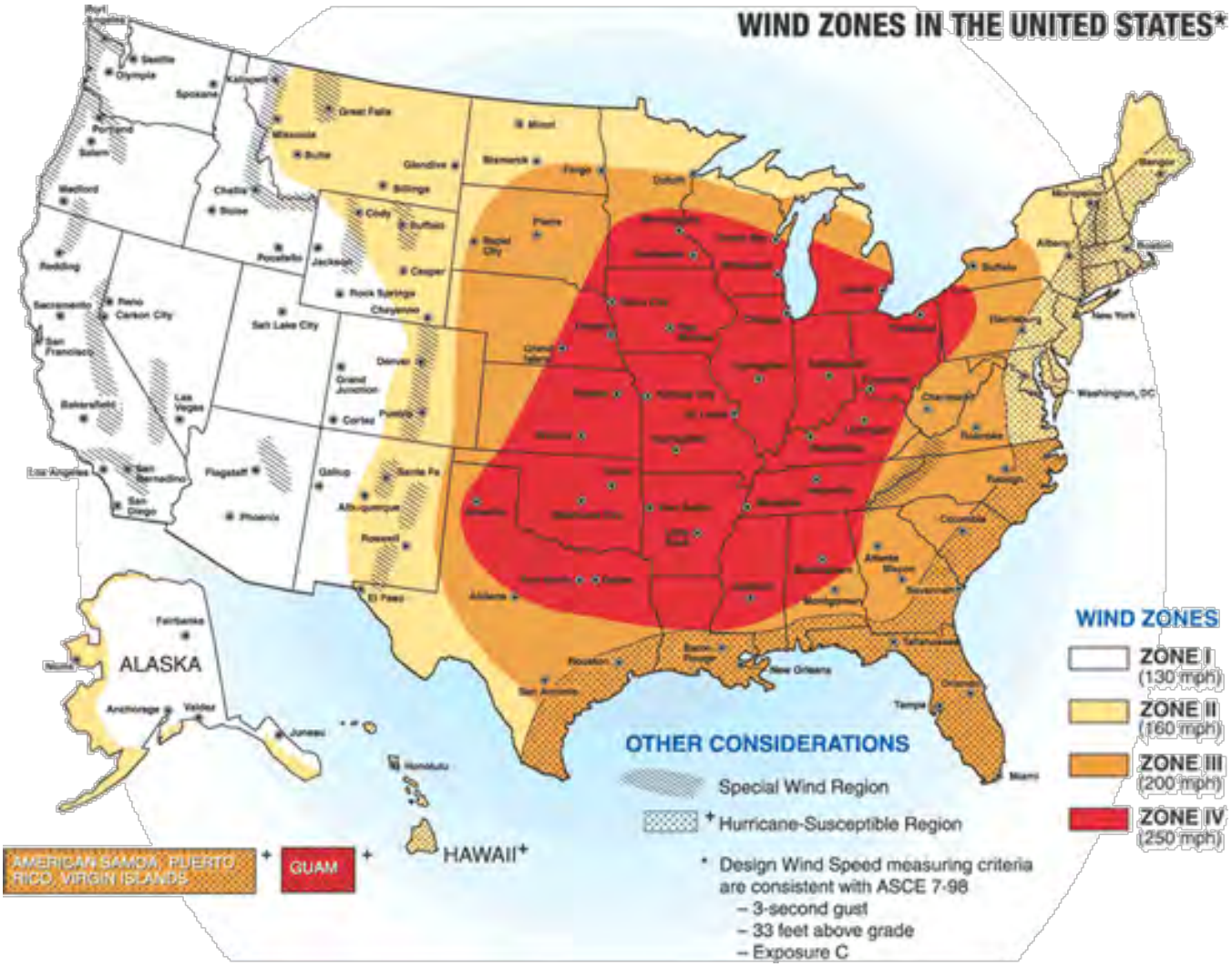

Figure 4.27. Wind Zones in the United States.
Source: Federal Emergency Management Agency

Hailstorms are another potential damaging outgrowth of severe thunderstorms. Early in the developmental stages of a hailstorm, ice crystals form within a low-pressure front due to the rapid rising of warm air into the upper atmosphere and the subsequent cooling of the air mass. Frozen droplets gradually accumulate on the ice crystals until, having developed sufficient weight, they fall as precipitation — as balls or irregularly shaped masses of ice greater than 0.75 in. (1.91 cm) in diameter. The size of hailstones is a direct function of the size and severity of the storm. High velocity updraft winds are required to keep hail in suspension in thunderclouds. The strength of the updraft is a function of the intensity of heating at the Earth's surface. Higher temperature gradients relative to elevation above the surface result in increased suspension time and hailstone size. Figure 4.28 shows the annual frequency of hailstorms in the United States.

Large hail collects on streets and grass during a severe thunderstorm. Larger stones appear to be nearly two to three inches in diameter. (NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory)

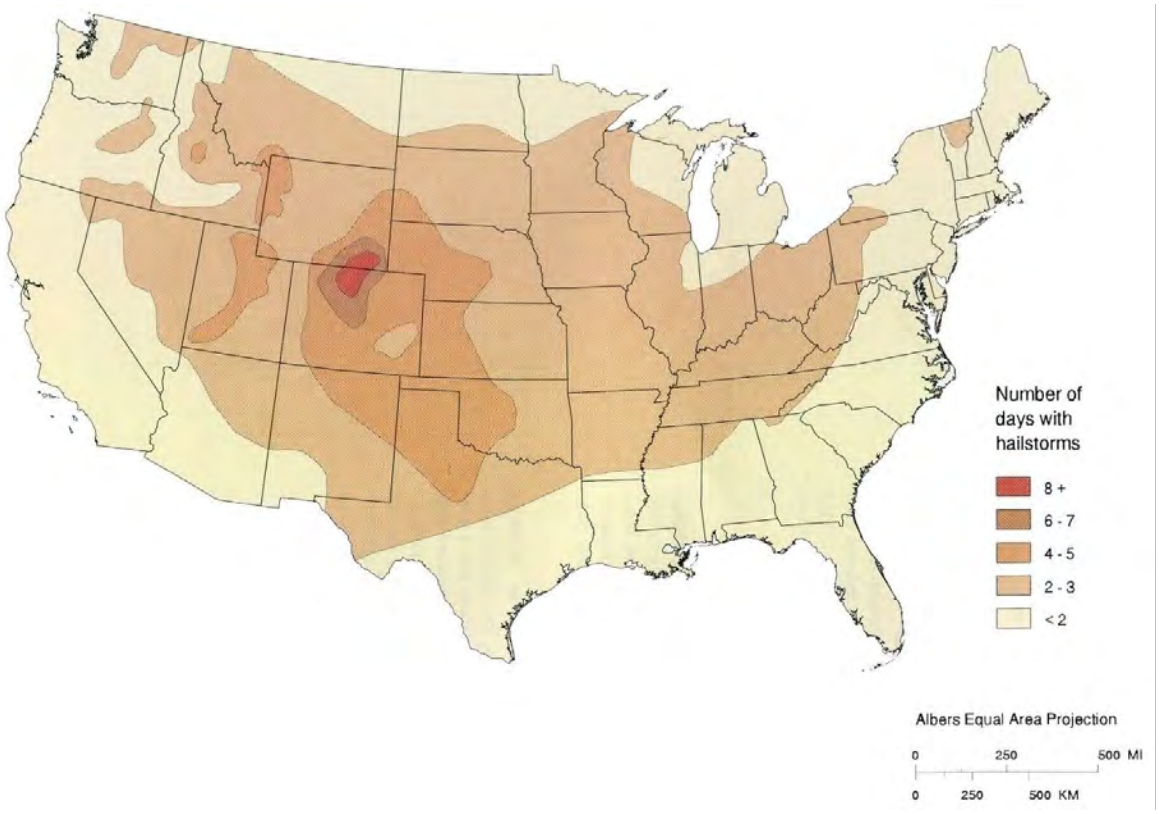

Figure 4.28. Annual Frequency of Hailstorms in the United States
Source: Federal Emergency Management Agency

Though more frequent in the Mississippi River Valley, derechos occur often enough in the eastern United States for the National Weather Service to map their typical frequency of occurrence. Figure 4.29 illustrates the typical distribution of occurrences, as determined by the NWS. Based on this data, the planning area could expect to experience at least one derecho every 2-4 years, on average.

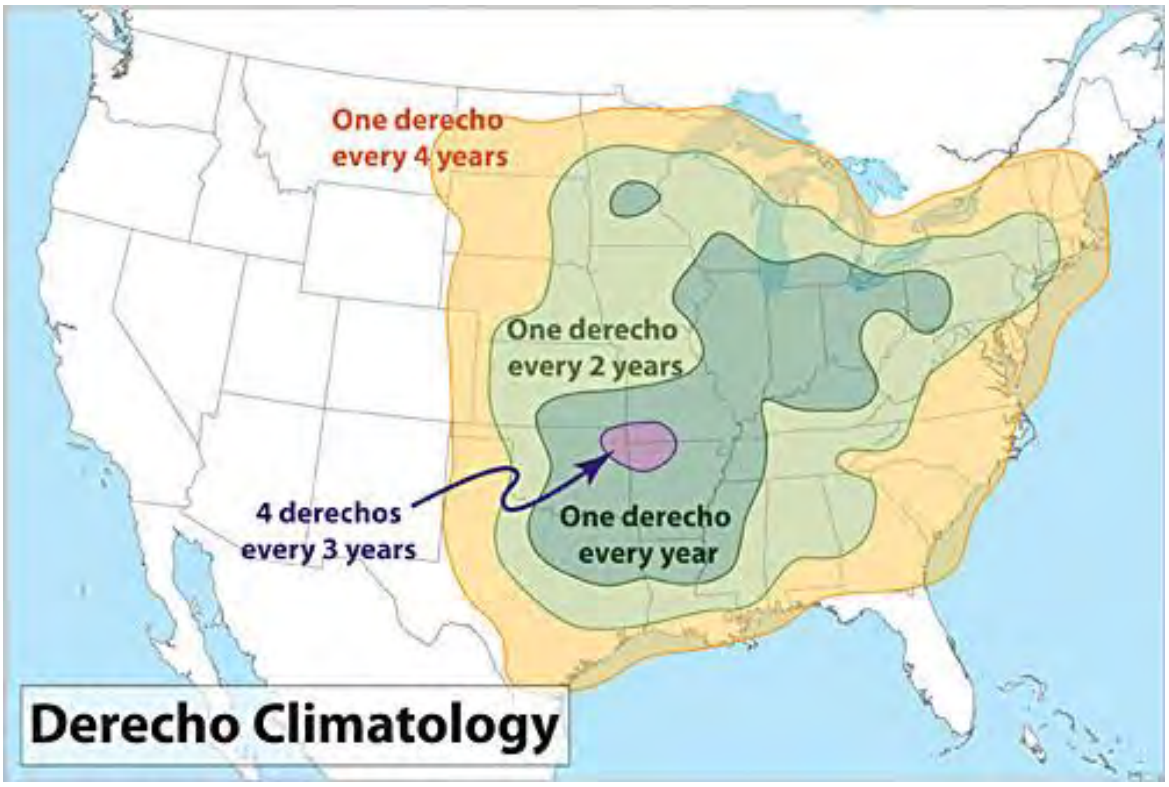

Figure 4.29. Derecho Climatology in the United States.
Source: The National Weather Service Forecast Office, Cleveland, Ohio.

In addition to high winds and hail associated with these events, severe storms can also bring dangerous lightning that can cause fires, property damage, and death or serious injury to humans.

4. Previous Occurrences

There have been a number of past severe storm and high wind events throughout the region, ranging widely in terms of location, magnitude, and impact; these events are captured and reported by the NCDC. Where possible, NCDC tracks reports separately by impacted jurisdiction; it is not always possible, however, to estimate damages below a county or city level. In most cases, therefore, damages that were reported for counties and cities include damages that occurred within towns. Therefore, Table 4.74 illustrates the number of events reported by participating jurisdiction, and the number of injuries reported, but assumes that all reported damage estimates are captures at the county and city level. To avoid duplication, no damages are reported in the table following for towns. This table summarizes the number of severe storm and high wind events (by participating jurisdiction) since 1950 which have caused a notable impact on the Northern Virginia region as recorded by the NCDC. This includes 1,344 events that have caused approximately $101.6 million in property and crop damages and have resulted in

approximately 87 injuries. In addition, at least four fatalities were recorded by NDCD – two each in Fairfax and Loudoun Counties.

Note: In the case of Fairfax County and the City of Fairfax, the number of events reported, the number of fatalities and injuries, and the approximate dollar amount of damages reported were identical, leading to the conclusion that the reports for each jurisdiction are duplicates. Therefore, for the purposes of this calculation, the jurisdictions were combined into a single line item, to avoid over-estimation of occurrences and damages.

Table 4.74. Severe Storm & High Wind Events in the Northern Virginia Region, 1950–2015 based on NCDC data.

Jurisdiction	# of Severe Storm & High Wind Events	Property Damage	Crop Damage	Total
Arlington County	144	$10,318,000	$5,750	$10,323,750
Fairfax County & the City of Fairfax	63	$20,468,000	$40,000	$20,508,000
Loudoun County	434	$2,943,000	$289,600	$3,232,600
Prince William County	191	$17,365,000	$81,750	$17,446,750
City of Alexandria	90	$9,720,000	$0	$9,720,000
City of Fairfax	--	--	--	--
City of Falls Church	54	$9,730,000	$0	$9,730,000
City of Manassas	52	$15,556,000	$79,000	$15,635,000
City of Manassas Park	31	$14,955,000	$77,000	$15,032,000
Town of Clifton	1	--	--	--
Town of Dumfries	27	--	--	--
Town of Haymarket	26	--	--	--
Town of Herndon	12	--	--	--
Town of Leesburg	70	--	--	--
Town of Lovettsville	33	--	--	--
Town of Middleburg	29	--	--	--
Town of Occoquan	1	--	--	--
Town of Purcellville	38	--	--	--
Town of Quantico	17	--	--	--
Town of Round Hill	21	--	--	--
Town of Vienna	10	--	--	--
Total	**1344**	**$101,055,000**	**$573,100**	**$101,628,100**

Arlington County
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012.

Fairfax County - including the Town of Clifton, the Town of Herndon, and the Town of Vienna
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012.

Loudoun County - including the Town of Leesburg, the Town of Lovettsville, the Town of Middleburg, the Town of Purcellville, and the Town of Round Hill
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012.

On July 25, 2010, severe thunderstorms raked the area during the late afternoon producing damaging winds in excess of 60 mph that brought down trees and power lines. Torrential rainfall caused flash flooding of low-lying and poorly drained areas. A large tree struck and killed a child in Claude Moore Park near Sterling Park in Loudoun County. Numerous trees were also downed in Leesburg. A roof collapsed on a parking garage near Reston where wind gusts were estimated at 75 mph.

Prince William County - including the Town of Dumfries, the Town of Haymarket, the Town of Occoquan, and the Town of Quantico
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012. In Prince William County, the derecho caused power outages and wind damages to the Public Safety Communications Center, resulting in the temporary loss of 911 service to the area.

City of Alexandria
On August 5, 2010, thunderstorm outflow winds of between 70 and 90 mph tore through parts of Northern Virginia knocking down hundreds of trees and power lines and causing extensive damage to homes, businesses, and vehicles. The mid-afternoon storms hit Arlington and Alexandria particularly hard and resulted in the closure of major roadways including the George Washington Parkway near Slaters Lane, and the loss of power to thousands of residents for several days. Damage from the storms also halted Metrorail service at Alexandria's King Street station for a time.

City of Fairfax
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012.

City of Falls Church
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012.

City of Manassas
The City of Manassas reported derecho winds of 60-80 MPH on June 29, 2012, with periodic gusts in excess of 50 MPH lasting for another 15-20 minutes. Because of these winds, the 911 call center was inoperable for approximately 36 hours, causing emergency services to rely on ham radio operators throughout the City.

City of Manassas Park
In late June and early July of 2012, the planning area experienced a number of severe storms and straight-line winds, including a derecho – a phenomena that previously had not been recorded in the planning area. These storms resulted in DR-4072, issued on July 27, 2012. As a result of this derecho, the city experienced power outages.

B. Risk Assessment

1. Probability of Future Occurrences

Since severe storms are difficult to predict, it is extremely difficult to determine probability of future occurrence with any degree of accuracy. It can, however, with considerable confidence, based on historical record, be projected that Northern Virginia will continue to experience severe thunderstorms with great frequency – several times a year, in most cases. Based on analysis of previous events in the NCDC database, it appears that those events causing injury, death or damage have occurred on a seemingly random basis with no particular portion of Northern Virginia more likely to experience them than any other.

Climate change is projected to increase the frequency and intensity of extreme weather events, including severe thunderstorms. Using global climate models and a high-resolution regional climate model, one study that investigated the link between severe thunderstorms and global warming found a net increase in the number of days with environmental conditions that foster the development of severe thunderstorms. This was true for much of the United States, including northern Virginia.[10]

2. Impact & Vulnerability

The Northern Virginia region faces uniform susceptibility to the effects of severe thunderstorms, including high winds, lightning, and hail.

Similar to hurricane and tropical storm force-winds, the most at-risk buildings to thunderstorm winds are assumed to include manufactured homes and older residential structures (see discussion under *Hurricanes and Tropical Storms*). Another great concern for the Northern Virginia region with regard to high winds is damage to electric power lines which regularly cause power outages for residents and businesses across the area, and have disrupted the

availability of emergency services, including 911. During past events, storm winds have downed trees across power lines, snapped utility poles and even blown down transformers resulting in widespread outages. Downed power lines create a dangerous threat to public safety; while difficult to quantify, long-term power outages can result in significant hardship for residents and major economic impacts for local businesses.

Lightning presents a significant threat to human safety and has historically caused injuries and death in the Northern Virginia region. Lightning has also been known to cause structural fires that can destroy property and present further life/safety issues. According to the Virginia State Climatology Office, most lightning related deaths and injuries in Virginia have been males between the ages of 20 and 40 years old who were caught outdoors on golf courses, ball fields, near open water or under trees.

Hail, while not a major threat to human safety, can be extremely destructive to crops and personal property (particularly vehicles, as well as roofs, siding, and windows of buildings). Most hail damage recorded for the Northern Virginia region has been in Fairfax and Loudoun counties, though all areas are considered to be equally at risk.

3. Risk

Risk, as defined as probability multiplied by impact, cannot be fully estimated for damaging thunderstorm wind, hail, and lightning events due to the lack of intensity-damage models for these hazards. Instead, financial impacts of damaging thunderstorm events can be developed based on NCDC Storm Events data. Using this data, property and crop damage related to severe storm and high wind events totaled more than $101 million.

Critical Facility Risk

Quantitative assessment of critical facilities for thunderstorm wind risk was not feasible for this update. Even so, the type and age of construction plays a role in vulnerability of facilities to thunderstorm winds. In general, concrete, brick, and steel-framed structures tend to fare better in thunderstorm wind events than older, wood-framed structures. Finally, it is important to note that not all critical facilities have redundant power sources and may not even be wired to accept a generator. Future plan updates should consider including a more comprehensive examination of critical facility vulnerability to thunderstorm winds.

Existing Buildings and Infrastructure Risk

Risk to existing buildings and infrastructure is largely determined by building construction type. As explained in Critical Facility Risk, concrete, brick, and steel-framed structures tend to fare better in thunderstorm wind events than older, wood-framed structures.

Overall Loss Estimates and Ranking

Based on data obtained from the NCDC Storm Event database (presented earlier in Table 4.74), severe storm and high wind events have produced a total of approximately $101.6 million in property and crop damages for the region. Table 4.75 (following) provides a breakdown of these damages in both real estimates and an annualized format, by participating jurisdiction.

Table 4.75. Loss Estimates Due to Severe Storms and High Winds.		
Jurisdiction(s)	Annualized Property and Crop Damage	Total Property and Crop Damage
Arlington County	$158,827	$10,323,750
Fairfax County & the City of Fairfax (including Town of Clifton, Town of Herndon, and Town of Vienna)	$315,508	$20,508,000
Loudoun County (including Town of Leesburg, Town of Lovettsville, Town of Middleburg, Town of Purcellville, and Town of Round Hill)	$49,732	$3,232,600
Prince William County (including Town of Dumfries, Town of Haymarket, Town of Occoquan, and Town of Quantico)	$268,412	$17,446,750
City of Alexandria	$149,538	$9,720,000
City of Fairfax	--	--
City of Falls Church	$149,692	$9,730,000
City of Manassas	240,538	$15,635,000
City of Manassas Park	$231,261	$15,032,000
Total	**$1,563,509**	**$101,628,100**

For the 2016 plan update the qualitative assessment was organized by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard, and a vulnerability of 'High'. Therefore, to avoid repetition, Table 4.76 provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results.

Table 4.76. 2016 Qualitative Assessment for High Wind & Severe Storms.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week

C. Hurricanes and Tropical Storms

Hurricanes and tropical storms, as well as nor'easters and typhoons, are classified as cyclones and defined as a closed circulation developing around a low-pressure center in which the winds rotate counter-clockwise in the Northern Hemisphere (or clockwise in the Southern Hemisphere) and whose diameter averages 10 to 30 miles across. A tropical cyclone refers to any such circulation that develops over tropical waters. Tropical cyclones act as a safety-valve, limiting the continued build-up of heat and energy in tropical regions by maintaining the atmospheric heat and moisture balance between the tropics and the pole-ward latitudes. The primary damaging forces associated with these storms are high-level sustained winds, heavy precipitation, and tornadoes. Coastal areas are also vulnerable to the additional forces of storm surge, wind-driven waves, and tidal flooding which can be more destructive than cyclone wind.

The key energy source for a tropical cyclone is the release of latent heat from the condensation of warm water. Their formation requires a low-pressure disturbance, warm sea surface temperature, rotational force created by the earth's rotation, and the absence of significant wind shear in the lowest 50,000 feet of the atmosphere. The majority of hurricanes and tropical storms form in the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico during the official Atlantic hurricane season, which encompasses the months of June through November. The peak of the Atlantic hurricane season is in early to mid-September.

1. Geographic Location/Extent

Although the Northern Virginia region rarely experiences the wrath of a direct land falling hurricane, it is located in an area quite susceptible to the remnants of such storms. This includes the perils of hurricane and tropical storm force winds, heavy rains, and significant storm surge and tidal flooding. These events can be extremely dangerous and costly across a large geographic area, as was learned during Hurricane Isabel in 2003 when the region suffered approximately $32 million in damages (nearly $2 billion statewide). In 2011, the remnants of Tropical Storm Lee impacted Fairfax and Prince William Counties, and the City of Alexandria. The storm dropped between five and seven inches of rain over the Northern Virginia area. In Fairfax County, VDOT estimated the storm caused approximately $10 million in damages to roads and bridges throughout the county. In late October 2012, Hurricane Sandy blanketed the region with heavy rain and high winds, resulting in downed trees, debris issues, and transportation interruptions.

Figure 4.30 shows the probability of a named tropical storm or hurricane affecting any single area during a June to November Atlantic hurricane season. The figure was created by the NOAA's Hurricane Research Division using data from 1944 to 1999 and counting hits when a storm or hurricane was within approximately 100 miles (165 km) of each location.

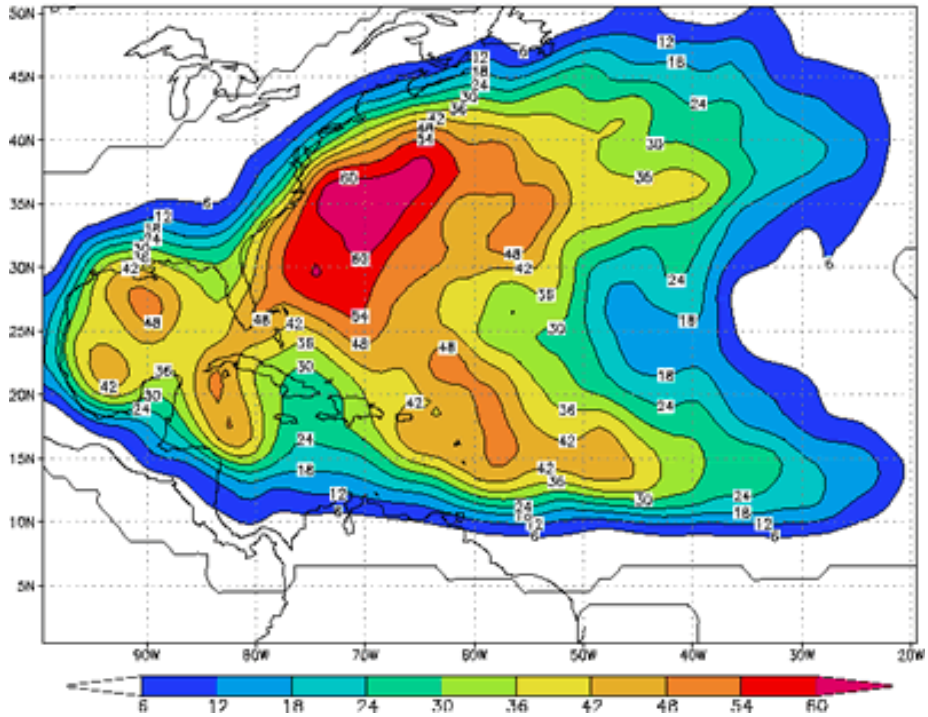

Figure 4.30. Empirical Probability of a Named Storm.
Source: National Oceanic and Atmospheric Administration, Hurricane Research Division

2. Magnitude or Severity

As an incipient hurricane develops, barometric pressure (measured in millibars or inches) at its center falls and winds increase. If the atmospheric and oceanic conditions are favorable, it can intensify into a tropical depression. When maximum sustained winds reach or exceed 39 miles per hour, the system is designated a tropical storm, given a name, and is closely monitored by the National Hurricane Center in Miami, Florida. When sustained winds reach or exceed 74 miles per hour the storm is deemed a hurricane. Hurricane intensity is further classified by the Saffir-Simpson Scale currently in use by NOAA's National Hurricane Center (see Table 4.77), which rates hurricane intensity on a scale of 1 to 5, with 5 being the most intense.

Table 4.77. Saffir-Simpson Scale.

Category	Maximum Sustained Wind Speed (MPH)	Minimum Surface Pressure (Millibars)
1	74—95	Greater than 980
2	96—110	979—965
3	111—130	964—945
4	131—155	944—920
5	155+	Less than 920

The Saffir-Simpson Scale categorizes hurricane intensity based upon maximum sustained winds and barometric pressure which are combined to estimate potential damage. Categories 3, 4, and 5 are classified as "major" hurricanes, and while hurricanes within this range comprise only 20%

of total tropical cyclone landfalls, they cause 70% of the damage in the United States. Table 4.78 describes expected damage per hurricane category.

Table 4.78. Hurricane Damage Classification.

Category	Damage Level	Description
1	Minimal	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal flooding and minor pier damage.
2	Moderate	Some roofing material, door, and window damage. Considerable damage to vegetation, mobile homes, etc. Flooding damages piers and small craft in unprotected moorings may break their moorings.
3	Extensive	Some structural damage to small residences and utility buildings, with a minor amount of curtain wall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.
4	Extreme	More extensive curtain wall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland.
5	Catastrophic	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required.

Source: National Hurricane Center

A storm surge is a large dome of water often 50 to 100 miles wide and rising anywhere from four to five feet in a Category 1 hurricane, up to 20 feet or more in a Category 5 storm. The storm surge arrives ahead of the storm's eye making landfall and the more intense the hurricane is, the sooner the surge arrives. Water rise can be very rapid, posing a serious threat to those who have not yet evacuated flood prone areas. A storm surge is a wave that has outrun its generating source and become a long period swell. The surge is highest in the right-front quadrant of the direction in which the hurricane is moving. As the storm approaches shore, the greatest storm surge will be to the north of the hurricane eye. Such a surge and associated breaking waves can be devastating to coastal regions, causing severe beach erosion and property damage along the immediate coast.

Storm surge heights, and associated waves, are dependent upon the shape of the continental shelf (narrow or wide) and the depth of the ocean bottom (bathymetry). A narrow shelf, or one that drops steeply from the shoreline and subsequently produces deep water close to the shoreline, tends to produce a lower surge but higher and more powerful storm waves. Damage during hurricanes may also result from spawned tornadoes and inland flooding associated with heavy rainfall that usually accompanies these storms. Hurricane Floyd, as an example, was at one time a Category 4 hurricane racing towards the North Carolina coast. As far inland as Raleigh, the State capital located more than 100 miles from the coast, communities were preparing for

extremely damaging winds exceeding 100 miles per hour. However, Floyd made landfall as a Category 2 hurricane and will be remembered for causing the worst inland flooding disaster in North Carolina's history. In Virginia, Floyd dropped 10-20 inches of rain over southeast Virginia, causing the closure of more than 300 roads from flooding and downed trees. A total of 64 jurisdictions were affected by the more $255 million in storm damages.

Similar to hurricanes, nor'easters are ocean storms capable of causing substantial damage to coastal areas in the eastern United States due to their associated strong winds and heavy surf. Nor'easters are named for the winds that blow in from the northeast. These storms track up the East Coast along the Gulf Stream, a band of warm water that lies off the Atlantic coast. They are caused by the interaction of the jet stream with horizontal temperature gradients and generally occur during the fall and winter months when moisture and cold air are plentiful.

Nor'easters are known for dumping heavy amounts of rain and snow, producing hurricane-force winds, and creating high surfs that cause severe beach erosion and coastal flooding. There are two main components to a nor'easter: (1) a Gulf Stream low-pressure system (counter-clockwise winds) generated off the southeastern coast, gathering warm air and moisture from the Atlantic, and pulled up the East Coast generating strong northeasterly winds along the western forward quadrant of the storm; and (2) an Arctic high-pressure system (clockwise winds) which meets the low-pressure system with cold, arctic air blowing down from Canada. When the two systems collide, the moisture and cold air produce a mix of precipitation and have the potential for creating dangerously high winds and heavy seas. As the low-pressure system deepens, the intensity of the winds and waves will increase and cause serious damage to coastal areas as the storm moves northeast. Table 4.79 shows an intensity scale proposed for nor'easters that is based on levels of coastal degradation.

Table 4.79. Dolan-Davis Nor'easter Intensity Scale.

Storm Class	Beach Erosion	Dune Erosion	Over wash	Property Damage
1 (Weak)	Minor changes	None	No	No
2 (Moderate)	Modest; mostly to lower beach	Minor	No	Modest
3 (Significant)	Erosion extends across beach	Can be significant	No	Loss of many structures at local level
4 (Severe)	Severe beach erosion and recession	Severe dune erosion or destruction	On low beaches	Loss of structures at community-scale
5 (Extreme)	Extreme beach erosion	Dunes destroyed over extensive areas	Massive in sheets and channels	Extensive at regional-scale; millions of dollars

Source: North Carolina Division of Emergency Management

3. Previous Occurrences

Most hurricanes and tropical storms that have affected Virginia have originated in the Atlantic Ocean. Since 1851, there have been a total of 32 storms to come within 75 miles of the Northern Virginia region. Other notable storms, including hurricanes Floyd (1999), Fran (1996), and Agnes (1972) are discussed herein, but were beyond the 75 mile radius used for this analysis. A chosen distance of 75 miles was used for this analysis in order to focus on those storms that came

through areas closest to the Northern Virginia region. However, the effects of large hurricanes and tropical storms may be felt up to 200 miles away from the center of circulation. Six of these storms were classified as hurricanes (including Isabel in 2003 and Irene in 2011), and 25 as tropical storms as they impacted the region. These events are listed in Table 4.80 with a graphical depiction of historical hurricane tracks between 1851 and 2012 shown in Figure 4.31.

Table 4.80. Historical Hurricane and Tropical Storms in the Northern Virginia Region, 1851–2015.

Year	Month	Name	Wind Speed (MPH)	Intensity
1872	October	Not named	45	Tropical Storm
1874	September	Not named	60	Tropical Storm
1876	September	Not named	80	Category 1
1878	October	"Gale of '78"	105	Category 2
1882	September	Not named	45	Tropical Storm
1883	September	Not named	45	Tropical Storm
1888	September	Not named	50	Tropical Storm
1888	September	Not named	40	Tropical Storm
1893	August	Not named	70	Tropical Storm
1893	October	Not named	90	Category 1
1893	October	Not named	50	Tropical Storm
1896	September	Not named	80	Category 1
1899	October	Not named	65	Tropical Storm
1904	September	Not named	65	Tropical Storm
1928	September	Not named	45	Tropical Storm
1933	August	Not named	60	Tropical Storm
1943	October	Not named	40	Tropical Storm
1944	August	Not named	50	Tropical Storm
1945	September	Not named	40	Tropical Storm
1949	August	Not named	45	Tropical Storm
1952	September	Able	45	Tropical Storm
1954	October	Hazel	78	Tropical Storm
1955	August	Connie	60	Tropical Storm
1955	August	Diane	65	Tropical Storm
1979	September	David	45	Tropical Storm
1983	September	Dean	45	Tropical Storm
1992	September	Danielle	45	Tropical Storm
1996	July	Bertha	70	Tropical Storm
2003	September	Isabel	75	Category 1
2008	September	Hanna	40	Tropical Storm
2011	September	Irene	120	Category 1
2011	September	Lee (remnants)	60	Tropical Storm

Of these, eight storm tracks made direct paths through the region. This includes the "Gale of '78," a category 2 hurricane which is further described under Previous Occurrences. An additional 25 storm tracks for tropical depressions and extratropical systems came within 75 miles of the region.

Although some good narrative information has been gathered on the impacts of these events (see Previous Occurrences), data on estimated property damages could only be accessed through the NCDC since the mid-1990s. Table 4.81 summarizes estimated damage figures caused by hurricane and tropical storm events since 1993 as recorded by the NCDC, and includes all damages recorded for all participating jurisdictions. These events have amounted to more than $45 million in property damages, most of which is attributable to effects of storm surge and tidal flooding resulting from the storms. More detailed information on historical hurricane and tropical storm events can be obtained through the NCDC Storm Event database, referenced earlier in this section.

Table 4.81. Historical Hurricane and Tropical Storm Damages in the Northern Virginia Region, 1993–2015, Based on NCDC Data.

Estimated Property Damage	
Total	**$45,204,000**

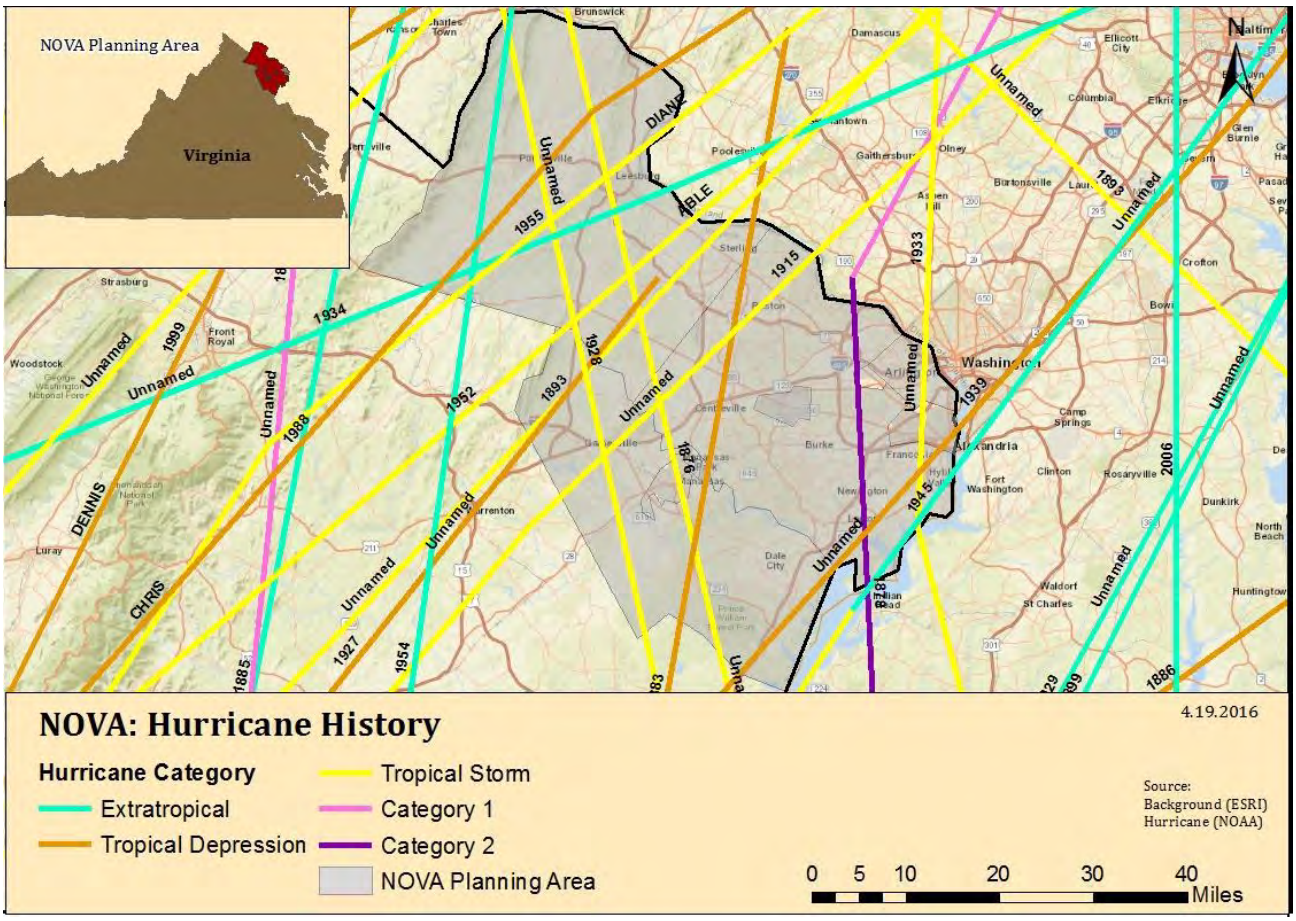

Figure 4.31. Historic Hurricane Tracks, 1851-2012

Significant Historical Events

Planning Area

On October 29, 2012, Hurricane Sandy passed by Northern Virginia on her way up the Atlantic Coast, before she turned northwest and made landfall northeast of Maryland. On her way, she brought high winds and heavy rains to the Northern Virginia regions, resulting in tropical storm force winds throughout the area, downed trees and power lines, river flooding, and some isolated flash flooding. Some structures were damaged throughout the area, mostly due to falling trees, which displaced some residents.

On September 4, 2011, Tropical Storm Lee made landfall in southern Louisiana. Several days later, the remnants of Lee arrived in Northern Virginia. Record rainfall, coming on the heels of Hurricane Irene a few days before, resulted in flooding of most of the creeks and waterways throughout Northern Virginia, leading to an estimated four fatalities, all from drowning. In Manassas Park, one home was displaced in a dry creek bed on the west side of the city.

On August 27-28, 2011, Hurricane Irene impacted the entire Northern Virginia area. Widespread power outages impacted utility production and distribution throughout the area, resulting in several utility service providers being offline and tens of thousands of residents and businesses without electrical service. Trees were also downed throughout the area, and some minor flooding was reported, including basement flooding.

On September 6-7, 2008, Tropical Storm Hanna made landfall between North and South Carolina on September 6, 2008, with maximum sustained winds of near 70 mph. The storm tracked north and then northeast through eastern Virginia, traveling just to the east of Northern Virginia through the Chesapeake Bay, before moving into the Northeast and New England. Slowly weakening, maximum sustained winds were between 40 and 50 mph at the time of the center's closest proximity to Northern Virginia. Peak winds across Northern Virginia gusted to between 35 and 45 mph and the storm produced rainfall amount of three to eight inches across the area. Weak or decaying trees were downed and flooding of low-lying areas was reported.

On September 18-19, 2003, Hurricane Isabel made landfall on the North Carolina coast. Its huge wind field was already piling water up into the southern Chesapeake Bay. By the time Isabel moved into central Virginia, it had weakened and was downgraded to a tropical storm. Isabel's eye tracked well west of the bay, but the storm's 40 to 60 mph sustained winds pushed a bulge of water northward up the bay and its tributaries producing a record storm surge. The Virginia western shore counties of the Chesapeake Bay and the tidal tributaries of the Potomac, Rappahannock, and other smaller rivers, experienced a storm surge which reached five to nine feet above normal tides.

Arlington County had two homes destroyed and 46 with major damage, while another 146 residences had minor damage. Costs of flooding and damage from falling trees were estimated at $2.5 million. In Fairfax County, 160 homes and 60 condominiums were flooded in the Belleview area south of Alexandria. Over 2,000 units had minor to moderate damage from storm surge flooding. In addition, many trees fell causing additional property damage across the county. In Prince William County, seven homes were destroyed and 24 homes and three businesses had

major damage. Scattered trees and wires were down causing roads to be closed. The storm surge washed away 20 feet of embankment along the Potomac which caused one of the CSX tracks to collapse along the Cherry Hill Peninsula. Damages at Quantico Marine Base were significant. Quantico's weather station recorded a two minute sustained wind of 54 miles per hour with a peak gust of 78 miles per hour between 11 pm and Midnight on the 18th. Damages to the base included buildings, houses, and vehicles hit by fallen trees and flooding destroyed their marina. Total damages were reported to be $9.5 million.

In Alexandria, the water level in Old Town reached 9.5 feet above sea level. Numerous businesses were flooded and the marinas were hard hit. Winds also knocked trees down around the city. Damages totaled $2 million. Storm surge water flooded the employee parking lot of Ronald Reagan Washington National Airport. In the City of Fairfax, 15 homes had major damage from trees. Fairfax County damages came to $18 million.

On September 16, 1999, Hurricane Floyd made landfall just east of Cape Fear, North Carolina, in the early morning hours of the 16th and moved north-northeast across extreme southeast Virginia to near Ocean City, Maryland, by evening on the 16th. Rain bands on the outer edge of the hurricane began to affect Northern Virginia shortly after 8:00 AM on the 15th and continued to cross the area through afternoon on the 16th. Winds and rain combined to topple 130 trees in Arlington County and the City of Alexandria. One tree damaged a home and 4,500 power outages were reported. In Fairfax County, a 61 year old woman was killed when a tree fell onto her car and crushed it on Fair Lakes Drive. In Loudoun County, a handful of trees were downed and a road was blocked near Mt. Weather. Siding was also torn from a few homes. In Prince William County, 17 trees came down on roads and power lines, and two homes were slightly damaged by fallen trees. One business was destroyed by fallen trees and another in Falls Church was damaged. A 70-foot oak tree fell onto a home and tore a hole in the 2nd floor, shattering windows and tearing off rain gutters. The tree also damaged a detached garage and a swing set. A few trees were downed in the Manassas area.

On September 6, 1996, the rapid runoff produced by the heavy rains from Hurricane Fran caused substantial, damaging, and in some cases record river flooding across much of the Northern Virginia watershed from late on the 6th until early on the 10th. Flash flooding on the 6th rapidly became river flooding late on the 6th along the headwaters of the Potomac, Shenandoah, and Rappahannock River basins, and continued throughout the basins over the weekend and into early the following week. Crests at gauging points in these basins were similar to those in January 1996 across the Lower Main Stem of the Potomac. Levels were one to five feet higher across the Upper Main Stem Potomac and Rappahannock Rivers. The Shenandoah Basin had levels similar to the October 1942 flood with three points reaching record levels (Lynnwood, Cootes Store, and Strasburg). There were numerous road closures, rescues, evacuations, washed out and damaged bridges, and culverts; the flood also produced major agricultural damage. Debris covered pasture and farmland, and filled small creeks and streams to levels higher than surrounding roads, which redirected the natural stream flow. River sand and mud covered streets and multiple levels of homes and businesses. There were several electric and phone outages. Three deaths occurred in the northern half of Virginia due to flash flooding.

Washington National Airport in southern Arlington County had damage with the river crest late Sunday into Monday morning. Flooding tore out security fence and flooded boat houses where rescue equipment is kept, while mud and debris had to be removed from the grounds.

In June 1972, Hurricane Agnes, in its tropical storm stage, caused torrential rains over Virginia and the Mid-Atlantic States. All rivers in Virginia were affected. Ten inches of rain fell over Northern Virginia resulting in widespread flash flooding and major flooding on the Potomac River.

On October 22-23, 1878, Hurricane Gale's eye made landfall at Cape Fear, NC and moved north across Richmond and Washington, DC, and seemed to lose little strength. The storm was thought to resemble that of Hurricane Hazel in 1954. Winds downed trees and fences and unroofed homes, and very high tides occurred on the coast. Fields of corn were submerged in the ensuing flood around Washington, DC. Rock Creek became a raging river, but produced little damage. Many young shade trees in the area were leveled. Telegraph lines fell between Baltimore and New York. Flooding from the Potomac inundated many basements and county roads crossing the Stickfoot Branch of the Anacostia River were washed out.

Arlington County
From 1950 through 2015, NCDC recorded four tropical storm events as impacting Arlington County, resulting in more than $4.6 million in property damages and 26 injuries.

Fairfax County
From 1950 through 2015, NCDC reports describe six occurrences of tropical storms impacting Fairfax County. These tropical storms caused more than $18 million in property and crop damages, one fatality, and one injury.

Loudoun County
NCDC recorded two tropical storms that impacted NCDC from 1950 through 2015. These events resulted in approximately $5,000 in damages.

Prince William County
NCDC recorded impacts to Prince William County from three tropical storms between 1950 and 2015, resulting in more than $14.5 million in property damages and approximately $50,000 in crop damages. No injuries or fatalities were attributed to these events.

City of Alexandria
From 1950 through 2015, NDCD recorded four occurrences of tropical storms impacting the City of Alexandria. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the City of Alexandria.

City of Fairfax
NDCD reports verify that the City of Fairfax experienced six tropical storms from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the City of Fairfax.

City of Falls Church
For the City of Falls Church, NCDC reports verify that four tropical storms impacted the City between 1950 and 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the City of Falls Church.

City of Manassas
NCDC reports indicate that three tropical storms impacted the City of Manassas from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the City of Manassas.

City of Manassas Park
NCDC reports indicate that three tropical storms impacted the City of Manassas Park from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the City of Manassas Park.

Town of Clifton
NCDC reports indicate that no tropical storms impacted the Town of Clifton from 1950 through 2015.

Town of Dumfries
NCDC reports indicate that two tropical storms impacted the Town of Dumfries from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Dumfries.

Town of Haymarket
NCDC reports indicate that one tropical storm impacted the Town of Haymarket from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Haymarket.

Town of Herndon
NCDC reports indicate that two tropical storms impacted the Town of Herndon from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Herndon.

Town of Leesburg
NCDC reports indicate that one tropical storm impacted the Town of Leesburg from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Leesburg.

Town of Lovettsville
NCDC reports indicate that no tropical storms impacted the Town of Lovettsville from 1950 through 2015.

Town of Middleburg
NCDC reports indicate that no tropical storms impacted the Town of Middleburg from 1950 through 2015.

Town of Occoquan
NCDC reports indicate that no tropical storms impacted the Town of Occoquan from 1950 through 2015.

Town of Purcellville
NCDC reports indicate that no tropical storms impacted the Town of Purcellville from 1950 through 2015.

Town of Quantico
NCDC reports indicate that one tropical storm impacted the Town of Quantico from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Quantico.

Town of Round Hill
NCDC reports indicate that no tropical storms impacted the Town of Round Hill from 1950 through 2015.

Town of Vienna
NCDC reports indicate that one tropical storm impacted the Town of Vienna from 1950 through 2015. Damage reports for these occurrences are captured in the reports for larger geographic areas, cannot be reliably separated to account for specific damages to the Town of Vienna.

D. Risk Assessment

1. Probability of Future Occurrences

Although not likely to experience a direct hit from a Category 4 or Category 5 hurricane, the Northern Virginia region remains susceptible to the effects from such storms making landfall along the Atlantic coast of the United States. According to HAZUS^{MH}, the Northern Virginia region can expect to see hurricane force winds (with peak gust wind speeds of up to 89 miles per hour) at least once every 50 years. The effects of tropical storms will be more frequent, particularly from those storms making landfall further south and proceeding up the Atlantic seaboard.

2. Impact & Vulnerability

Based on a range of long-term global climate models under IPCC warming scenarios, it is likely that hurricanes will become more intense, with stronger winds and heavier precipitation

throughout the 21st century. Using an ensemble-mean of 18 climate models, IPCC A1B emissions scenario[11], and operational hurricane forecast models, one study[12] showed a decrease in the total number of tropical storms and hurricanes, but an increase in the number of intense hurricanes, particularly Category 4 or 5 hurricanes.

Historical evidence shows that the Northern Virginia region is vulnerable to damaging hurricane and tropical storms. For purposes of this assessment, vulnerability is quantified for hurricane and tropical storm-force winds. For the most part, the Northern Virginia region faces a uniform susceptibility to hurricanes and tropical storm winds. Though historical data and computer models indicate that Fairfax County may on average face higher wind speeds than other areas, the difference in peak gusts is not deemed significant (less than 20 miles per hour). However, based on the higher amount of residential and commercial exposure, Fairfax and Arlington counties are considered to be slightly more vulnerable to these winds.

3. Risk

The hurricane wind analysis for the HIRA was completed using HAZUS^{MH}. The model uses state of the art wind field models, calibrated and validated hurricane data. Wind speed has been calculated as a function of central pressure, translation speed, and surface roughness. This assessment is based on a Level 1 analysis. A Level 1 analysis involves using the HAZUS^{MH} provided data with no local data adjustments. This is an acceptable level of information for mitigation planning; future versions of this plan can be enhanced with Level 2 and 3 analyses. Dollar values shown in this report should only be used to represent cost of large aggregations of building types. Highly detailed, building specific, loss estimations have not been completed for this analysis as they require additional local data inputs, which could not be accomplished for this update. Note that storm surge and waves have not been implemented in the present version of the Hurricane Model[13].

Additional information generated by HAZUS^{MH} for the planning area can be found in Appendix D, including additional imagery of wind fields for the area, presented by participating jurisdiction.

Loss estimation for this HAZUS^{MH} module is based on specific input data. The first type of data includes square footage of buildings for specified types or population. The second type of data includes information on the local economy that is used in estimating losses. Table 4.82 displays the economic loss categories used to calculate annualized losses by HAZUS^{MH}.

Table 4.82. HAZUS^{MH} direct economic loss categories and descriptions.

Category Name	Description of Data Input into Model	HAZUS^{MH} Output
Building	Cost per sq ft to repair damage by structural type and occupancy for each level of damage	Cost of building repair or replacement of damaged and destroyed buildings
Contents	Replacement value by occupancy	Cost of damage to building contents
Inventory	Annual gross sales in $ per sq ft	Loss of building inventory as contents related to business activities

Table 4.82. HAZUS^{MH} direct economic loss categories and descriptions.		
Category Name	**Description of Data Input into Model**	**HAZUS^{MH} Output**
Relocation	Rental costs per month per sq ft by occupancy	Relocation expenses (for businesses and institutions)
Income	Income in $ per sq ft per month by occupancy	Capital-related incomes losses as a measure of the loss of productivity, services, or sales
Rental	Rental costs per month per sq ft by occupancy	Loss of rental income to building owners
Wage	Wages in $ per sq ft per month by occupancy	Employee wage loss as described in income loss

For the hurricane wind scenario models, the built-in default inventory of assets - known as the Comprehensive Data Management System (CDMS) - was utilized. No adjustments were made to the inventory to account for any locally-reporting critical assets. Therefore, discrepancies may appear related to critical assets between self-reported data, such as historic occurrences, and HAZUS-generated data, such as the data in this section. See Appendix D for a description of the methodology used for the hurricane wind scenarios, and the grouping of counties, cities, and towns in each model.

Annualized loss is defined as the expected value of loss in any one year, and is developed by aggregating the losses and exceedance probabilities for the 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods. HAZUS^{MH} estimates direct and indirect economic losses due to hurricane wind speeds that include:

- Damage to buildings and contents
- Economic loss (business interruptions)
- Social Impacts

The figures contained in Appendix D illustrate the 3-second peak wind gust speeds for the 100- and 1000-year return periods. Wind speeds are based on estimated 3-second gusts in open terrain at 10 meters above ground at the centroid of each census track. Buildings that must be designed for a 100-year mean recurrence interval wind event include[14]:

- Buildings where more than 300 people congregate in one area
- Buildings that will be used for hurricane or other emergency shelter
- Buildings housing a day care center with capacity greater than 150 occupants
- Buildings designed for emergency preparedness, communication, or emergency operation center or response
- Buildings housing critical national defense functions
- Buildings containing sufficient quantities of hazardous materials

For Northern Virginia, HAZUS^{MH} wind gust data for the 1000-year and 100-year return period events indicate that the southeastern portions of Northern Virginia are generally more likely to experience the highest wind gusts in both scenarios. This corresponds to the strongest winds associated with hurricanes typically occurring in the storm's right front quadrant (relative to the direction of the storm's movement). For a 1000-year event, southeastern sections of both Fairfax and Prince William counties can expect to see gusts topping 90 mph. Although slightly lower wind gusts are expected in this scenario in western Loudoun County and far western Prince William County, gusts may still exceed 80 mph in both locations. For a 100-year event, wind

gusts of slightly greater than 70 mph may impinge on portions of Fairfax and Arlington counties, with gusts of between 50 and 70 mph expected elsewhere in Northern Virginia.

Critical Facility Risk

HAZUS^{MH} estimates very minor expected damage to critical facilities for the different return periods.

- The expected loss of use for the 100-year event is less than one day for the planning area as a whole. EOCs and hospitals for all the modeled return periods result in 100% functionality.
- For the 1000-year event, hospitals in the areas of Arlington and Fairfax counties may experience a least moderate damage, resulting in at least 50% functionality. Hospitals in the Loudoun and Prince William counties areas may expect to retain full functionality even in a 1000-year hurricane.
- Fire stations, police stations, and schools throughout the planning area may expect to retain the vast majority of their functionality even during a 1000-year hurricane event, and would have less than a day of loss of function.

The HAZUS^{MH} model also estimates the number of households that are expected to be displaced from their homes due to the hurricane and the number of displaced people that will require accommodations in temporary public shelters. Based on the probabilistic analysis, one household in Alexandria and two in Arlington County would be displaced and seek shelter from a 1000-year event, though no people would be expected to require short-term sheltering. In Fairfax County and the City of Fairfax, 46 households would be displaced, with five persons requiring short-term sheltering from a 1000-year event. For Loudoun County and its associated townships, even a 1000-year event would not displace any households or persons, and no one would require short-term sheltering; the same is the case for Prince William County, its associated towns, the City of Manassas, and the City of Manassas Park.

Existing Buildings and Infrastructure Risk

The most at-risk buildings to high wind events are assumed to include manufactured homes, along with residential structures that were built many years ago (due to probable deterioration and less stringent building code enforcement during original construction).

Table 4.83 summarizes the HAZUS^{MH} information for the Northern Virginia region. Residential buildings make up the majority of damages due to hurricane winds. The more frequent return periods result in fewer damages that fall within the moderate to destruction classifications. The 500- and 100-year return periods result in severe damage and destruction to buildings in the Northern Virginia region.

Table 4.83. HAZUS^{MH} Estimate: Number of buildings damaged.										
Return Period	Minor		Moderate		Severe		Destruction		Total	
	Residential	Total	Residential	Total	Residential	Total	Residential	Total	Residential	Total
10	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
50	92	134	0	0	0	0	0	0	92	134
100	426	564	8	11	0	0	0	0	434	575
200	517	2,050	81	84	0	0	0	0	598	2,134
500	10,277	10,906	705	736	1	2	0	0	10,983	11,644
1000	22,999	24,228	2,111	2,212	4	11	8	8	25,122	26,459

In the case of a 100-year hurricane event, HAZUS^{MH} estimates the building loss for Northern Virginia to be approximately $77.9 million. Should the region experience a 1000-year hurricane event, the model estimates the building loss for the region would be approximately $1.2 billion. Tables 4.84, 4.85, and 4.86 provide summaries of losses by jurisdiction.

Note that details for some of the participating jurisdictions were included with other jurisdictions by the model, and could not be reliably separated out in this Level 1 assessment.

Table 4.84. HAZUS^{MH} Estimate: Total Annualized Building Loss by Jurisdiction .								
Jurisdiction	**Building Loss**	**Content Loss**	**Inventory Loss**	**Relocation Loss**	**Income Loss**	**Rental Loss**	**Wage Loss**	**Total Loss**
Arlington County	$613,000	$77,000	$0	$26,000	$2,000	$17,000	$3,000	**$738,000**
Fairfax County and the City of Fairfax	$2,632,000	$388,000	$1,000	$78,000	$5,000	$33,000	$6,000	**$3,143,000**
Town of Herndon	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Vienna	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Clifton	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Loudoun County	$684,000	$104,000	$0	$24,000	$1,000	$8,000	$1,000	**$822,000**
Town of Leesburg	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Lovettsville	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Purcellville	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Middleburg	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Round Hill	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Prince William County	$779,000	$140,000	$0	$0	$0	$0	$0	**$919,000**
Town of Dumfries	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Haymarket	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Town of Occoquan	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*

Table 4.84. HAZUS^{MH} Estimate: Total Annualized Building Loss by Jurisdiction .								
Jurisdiction	**Building Loss**	**Content Loss**	**Inventory Loss**	**Relocation Loss**	**Income Loss**	**Rental Loss**	**Wage Loss**	**Total Loss**
Town of Quantico	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
City of Alexandria	$451,000	$65,000	$0,000	$20,000	$2,000	$12,000	$3,000	**$553,000**
City of Falls Church	$42,000	$7,000	$0	$2,000	$0	$1,000	$0	**$51**,000
City of Manassas	$0	$0	$0	$0	$0	$0	$0	**$0**
City of Manassas Park	$0	$0	$0	$0	$0	$0	$0	**$0**
Total	**$5,201**,000	**$781**,000	**$1**,000	**$150**,000	**$10**,000	**$71**,000	**$137**,000	**$5,398**,000

Table 4.85. HAZUS^{MH} Estimate: 100-Year Hurricane Building Loss by Jurisdiction.								
Jurisdiction	**Building Loss**	**Content Loss**	**Inventory Loss**	**Relocation Loss**	**Income Loss**	**Rental Loss**	**Wage Loss**	**Total Loss**
Arlington County	$6,358,000	$505,000	$0	$12,000	$0	$0	$0	**$6,874**,000
Fairfax County and the City of Fairfax	$34,415,000	$4,434,000	$0	$9	$0	$0	$0	**$38,857**,000
Town of Herndon	Included	Included	Included	Included	Included	Included	Included	Included
Town of Vienna	Included	Included	Included	Included	Included	Included	Included	Included
Town of Clifton	Included	Included	Included	Included	Included	Included	Included	Included
Loudoun County	$7,662,000	$1,044,000	$0	$0	$0	$0	$0	**$8,707**,000
Town of Leesburg	Included	Included	Included	Included	Included	Included	Included	Included
Town of Lovettsville	Included	Included	Included	Included	Included	Included	Included	Included
Town of Purcellville	Included	Included	Included	Included	Included	Included	Included	Included
Town of Middleburg	Included	Included	Included	Included	Included	Included	Included	Included
Town of Round Hill	Included	Included	Included	Included	Included	Included	Included	Included
Prince William County	$14,481,000	$1,333,000	$0	$6,000	$0	$0	$0	**$15,821**,000
Town of Dumfries	Included	Included	Included	Included	Included	Included	Included	Included
Town of Haymarket	Included	Included	Included	Included	Included	Included	Included	Included
Town of Occoquan	Included	Included	Included	Included	Included	Included	Included	Included
Town of Quantico	Included	Included	Included	Included	Included	Included	Included	Included
City of Alexandria	$5,409,000	$590,000	$0	$8,000	$0	$0	$0	**$6,107**,000
City of Falls Church	$465,000	$258,000	$0	$0	$0	$0	$0	**$523**,000
City of Manassas	$723,000	$57,000	$0	$0	$0	$0	$0	**$781**,000
City of Manassas Park	$243,000	$1,000	$0	$0	$0	$0	$0	**$244**,000
Total	**$69,756**,000	**$8,222**,000	**$0**	**$35**,000	**$0**	**$0**	**$0**	**$42,914**,000

Table 4.86 HAZUS^{MH} Estimate: 1000-Year Hurricane Building Loss by Jurisdiction								
Jurisdiction	**Building Loss**	**Content Loss**	**Inventory Loss**	**Relocation Loss**	**Income Loss**	**Rental Loss**	**Wage Loss**	**Total Loss**
Arlington County	$129,966,000	$11,858,000	$15,000	$5,533,000	$216,000	$3,955,000	$78,000	**$151,620**,000
Fairfax County and the City of Fairfax	$529,472,000	$64,624,000	$69,000	$15,476,000	$729,000	$7,663,000	$264,000	**$618,298**,000
Town of Herndon	Included	Included	Included	Included	Included	Included	Included	Included
Town of Vienna	Included	Included	Included	Included	Included	Included	Included	Included
Town of Clifton	Included	Included	Included	Included	Included	Included	Included	Included
Loudoun County	$134,753,000	$14,012,000	$18,000	$4,632,000	$0	$1,687,000	$0	**$155,102**,000
Town of Leesburg	Included	Included	Included	Included	Included	Included	Included	Included
Town of Lovettsville	Included	Included	Included	Included	Included	Included	Included	Included
Town of Purcellville	Included	Included	Included	Included	Included	Included	Included	Included
Town of Middleburg	Included	Included	Included	Included	Included	Included	Included	Included
Town of Round Hill	Included	Included	Included	Included	Included	Included	Included	Included
Prince William County	$184,839,000	$18,273,000	$26,000	$5,690,000	$74,000	$44,000	$2,196,000	**$211,142**,000
Town of Dumfries	Included	Included	Included	Included	Included	Included	Included	Included
Town of Haymarket	Included	Included	Included	Included	Included	Included	Included	Included
Town of Occoquan	Included	Included	Included	Included	Included	Included	Included	Included
Town of Quantico	Included	Included	Included	Included	Included	Included	Included	Included
City of Alexandria	$100,724,000	$11,129,000	$18,000	$4,096,000	$429,000	$2,886,000	$155,000	**$119,437**,000
City of Falls Church	$7,482,000	$927,000	$1,000	$254,000	$0	$127,000	$0	**$8,790**,000
City of Manassas	$14,600,000	$1,181,000	$3,000	$553,000	$0	$234,000	$0	**$16,571**,000
City of Manassas Park	$5,346,000	$180,000	$26,000	$5,690,000	$74,000	$2,196,000	$44,000	**$5,817**,000
Total	**$1,107,479**,000	**$122,184**,000	**$196**,000	**$41,924**,000	**$1,522**,000	**$18,792**,000	**$2,737**,000	**$1,286,777**,000

Overall Loss Estimates and Ranking

Based on the HAZUS^{MH} models, the annualized losses due to hurricanes in Northern Virginia total approximately $6.5 million. The models used the HAZUS^{MH} probabilistic hurricane scenario to compute loss which takes into the expected value of loss in any one year, and is developed by aggregating the losses and exceedance probabilities for the 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods.

On an annual basis, NCDC records estimate property and crop losses in Northern Virginia due to severe storm and high wind events, including tropical storms and hurricanes, totals an estimated $1.5 million. Actual losses for the period of record (1950-2015) total more than $101.6 million.

The details of these estimates, by participating jurisdiction, were presented earlier in this section, in Table 4.75.
The Commonwealth of Virginia's 2013 Hazard Mitigation Plan ranking was based largely on the NCDC database. The update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. In determining a score and ranking for high wind, the geographic extent score for each jurisdiction is based on the average maximum wind speed throughout the entire jurisdiction as determined through GIS analysis of HAZUS^{MH} generated data. The high wind hazard ranking factors damaging wind events that include severe thunderstorms, hurricanes, and non-thunderstorm related wind events.

Based on this analysis and available data, the high wind/severe storm hazard is ranked as being 'High' for all jurisdictions in Northern Virginia.

Although a separate ranking was not made for hurricanes, historical damage due to hurricane wind is included in the 2016 ranking assessment for severe storms/high wind below. The high wind/severe storm hazard incorporates both thunderstorm wind and hurricane/tropical storm winds along with non-thunderstorm related wind damage.

Refer to the Risk Assessment Methodology section of the HIRA for a full description of the methodology and the limitations of the data used for ranking the hazards. NCDC data, although somewhat limited, provides a comprehensive historical record of natural hazard events and damages.

For the 2016 plan update, the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. Therefore, to avoid repetition, Table 4.87 provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results.

Table 4.87. 2016 Qualitative Assessment for Hurricane & Tropical Storm-Force Winds.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Critical	Moderate	12 to 24 hours	Less than one week

IX. Tornadoes

NOTE: As part of the 2016 plan update, the Tornado hazard was reexamined and new analyses performed. These new analyses included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4 Section IV Ranking and Analysis Methodologies.

Each section of the plan was also reformatted for improved clarity and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud extending to the ground. Tornadoes are most often generated by thunderstorm activity (but sometimes result from hurricanes and other tropical storms) when cool, dry air intersects and overrides a layer of warm, moist air forcing the warm air to rise rapidly. The damage caused by a tornado is a result of the high wind velocity and wind-blown debris, also accompanied by lightning or large hail. According to the NWS, tornado wind speeds normally range from 40 to more than 300 miles per hour. The most violent tornadoes have rotating winds of 250 miles per hour or more and are capable of causing extreme destruction and turning normally harmless objects into deadly missiles.

According to NOAA, each year an average of over 800 tornadoes is reported nationwide, resulting in 80 deaths and 1,500 injuries, on average. They are more likely to occur during the spring and early summer months of March through June and can occur at any time of day, but are more likely to form in the late afternoon and early evening. Most tornadoes are a few dozen yards wide and only touchdown briefly, but even small, short-lived tornadoes can inflict tremendous damage. Highly destructive tornadoes may carve out a path over a mile wide and several miles long.

Waterspouts are weak tornadoes that form over warm water and are most common along the Gulf Coast and southeastern states. Waterspouts occasionally move inland, becoming tornadoes that cause damage and injury. However, most waterspouts dissipate over the open water causing threats only to marine and boating interests. Typically a waterspout is weak and short-lived, and because they are so common, most go unreported unless they cause damage.

The destruction caused by tornadoes ranges from light to devastating depending on the intensity, size, and duration of the storm. Typically, tornadoes cause the greatest damage to structures of light construction such as residential homes (particularly mobile homes), and tend to remain localized in impact. The Fujita-Pearson Scale for Tornadoes (F Scale) was developed in 1971 to rate tornado intensity based on associated damages. An Enhanced Fujita Scale (EF Scale) was developed and implemented operationally in 2007 and is shown in Table 4.88, along with a comparison of the original F Scale.

Table 4.88. Enhanced Fujita Scale for Tornadoes Vs. Fujita Scale.				
Fujita Scale			**Enhanced Fujita Scale**	
F Number	**Fastest 1/4-mile (mph)**	**3 Second Gust (mph)**	**EF Number**	**3 Second Gust (mph)**
0	40-72	45-78	0	65-85
1	73-112	79-117	1	86-110
2	113-157	118-161	2	111-135
3	158-207	162-209	3	136-165
4	208-260	210-261	4	166-200
5	261-318	262-317	5	Over 200

2. Geographic Location/Extent

According to the NOAA Storm Prediction Center (SPC), the highest concentration of tornadoes in the United States has been in Oklahoma, Texas, Kansas and Florida respectively. Although the Great Plains region of the central United States does favor the development of the largest and most dangerous tornadoes (earning the designation of 'tornado alley'), Florida experiences the greatest number of tornadoes per square mile of all states (SPC, 2002). Although the region is located outside of "tornado alley" and does not experience as many tornadoes as Florida, there are many examples of tornadoes tracking through Northern Virginia. Figure 4.32 shows tornado activity in the United States based on the number of recorded tornadoes per 1,000 square miles.

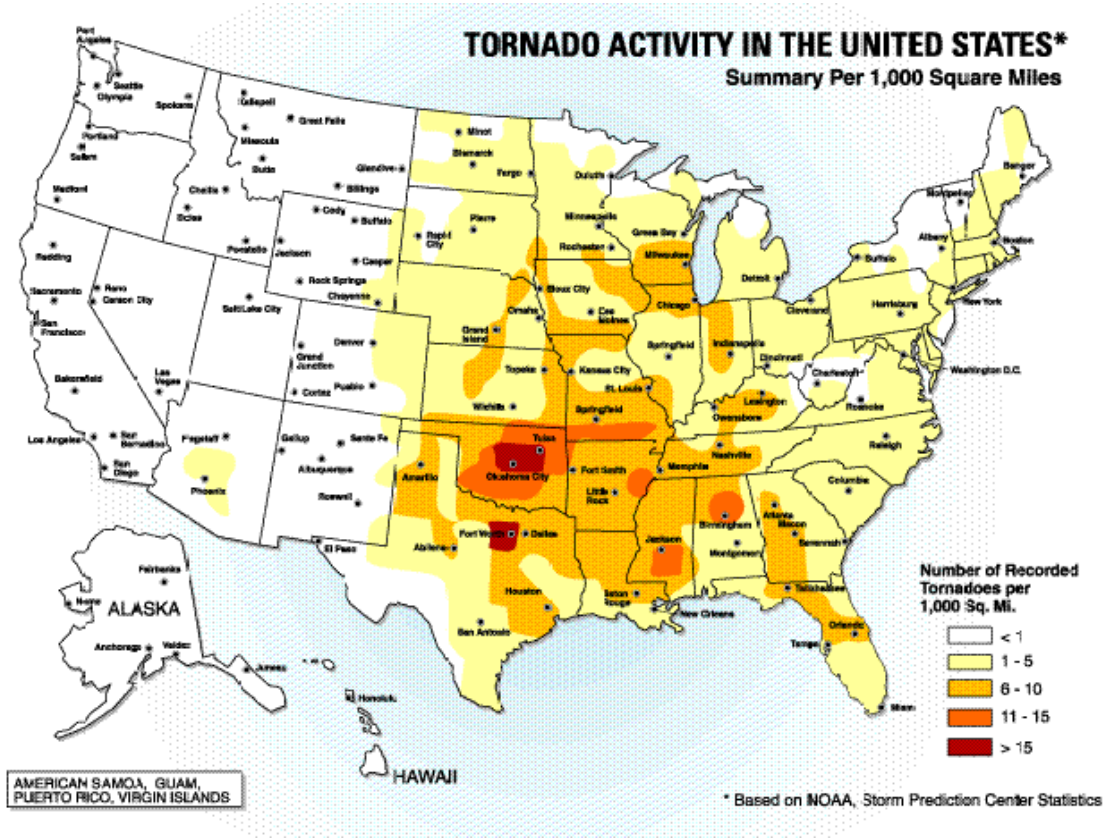

Figure 4.32. Tornado Activity in the United States
Source: American Society of Civil Engineers

The tornadoes associated with tropical cyclones are most frequent in September and October when the incidence of tropical storm systems is greatest. This type of tornado usually occurs around the perimeter of the storm, and most often in the northeast quadrant and ahead of the storm path or the storm center as it comes ashore. These tornadoes commonly occur as part of large outbreaks and generally move in an easterly direction.

3. Magnitude or Severity

When compared with other states, Virginia ranks 29th in the nation in number of tornado events, 25th in tornado deaths, 26th in tornado injuries, and 28th in damages. These rankings are based upon data collected for all states and territories for tornado events between 1950 and 1994 by NOAA's SPC. Most tornadoes that occur in Virginia are less intense (F0 through F2 on the Fujita-Pearson Scale) than those that occur elsewhere in the country, but occasionally they are of significant magnitude causing major damage and destruction.

From 1950 through the year 2001, 376 tornadoes were documented in Virginia (an average of seven tornadoes per year). Nationally, statistics have suggested that prior to 1990, only a third of all tornadoes were actually recorded. Many occurred in unpopulated areas or caused little property damage and therefore are not reported to the NWS, while others may have been recorded separately as high wind events instead of tornadoes. Thus, the actual average number of tornadoes that Virginia experiences in a given year is likely higher than historical NOAA records indicate. Tornado fatality records began in 1916.

According to NCDC records, the Northern Virginia region experienced approximately 70 funnel cloud and tornado events from 1950 through 2015. Figure 4.33 graphically depicts the touchdown points and tracks of the tornadoes, as well as the Fujita scale rating for each of those events. As can be seen in the figure, most of these events were recorded as either F0 or F1 events although there have also been some stronger F2 and F3 events.

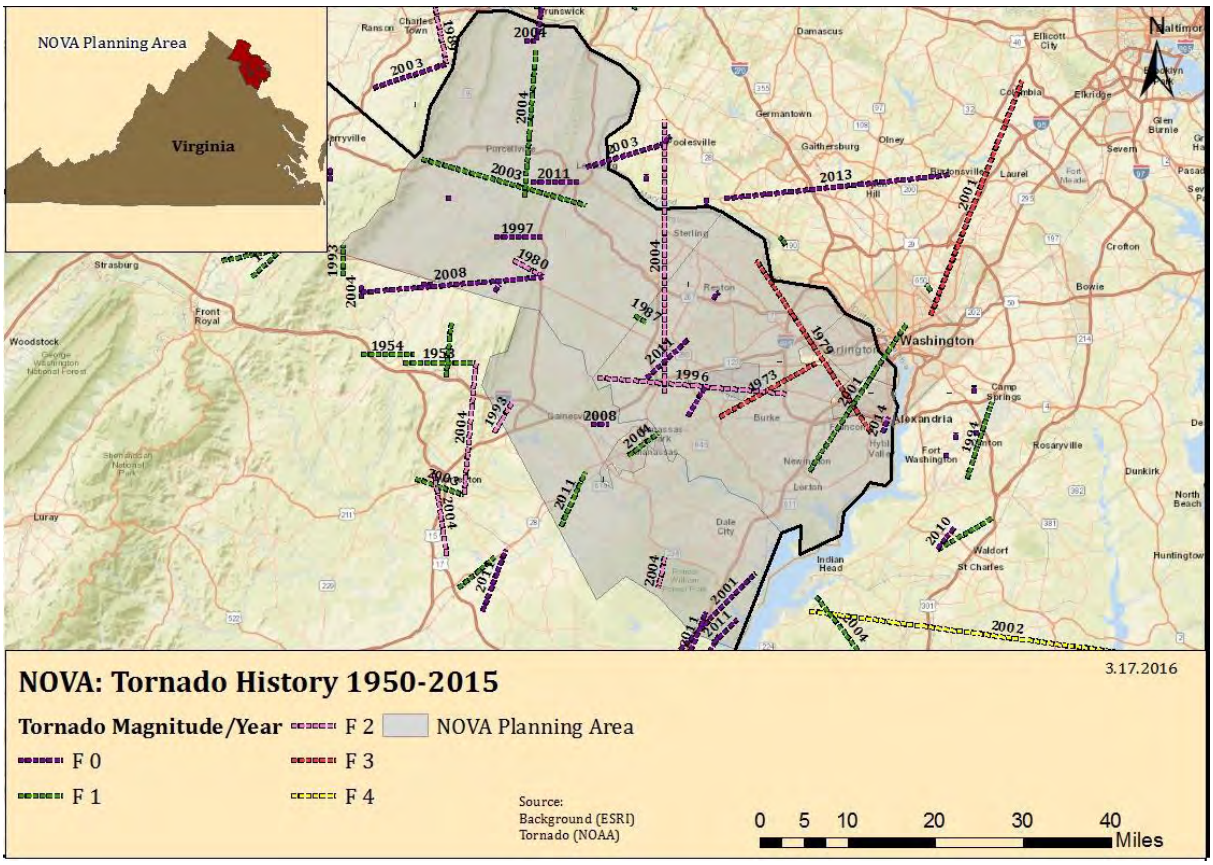

Figure 4.33. Historic Tornado Tracks, 1950 to 2015.

In total, these tornado events are reported to have caused approximately four fatalities, 12 injuries and approximately $13.6 million in property and crop damages as summarized by jurisdiction in Table 4.89. More detailed information on each of these historical tornado events can be obtained through the NCDC Storm Event database.

Table 4.89. NCDC Tornado Events in the Northern Virginia Region, 1950–2015, Based on NCDC Data.					
Tornado Events in Northern Virginia					
Years of Record: 1950 - 2015	**Annualized Property and Crop Damage**	**Total Property and Crop Damage**	**Injuries**	**Fatalities**	**Number of Events**
Arlington County	$16,923	$1,100,000	0	2	2
Fairfax County	0	0	0	0	0
Loudoun County	$78,200	$5,083,000	2	0	25
Prince William County	$60,185	$3,912,000	0	1	17
City of Alexandria	0	0	0	0	0
City of Fairfax**	0	0	0	0	0
City of Falls Church	$38,462	$2,500,000	0	0	1
City of Manassas*	$0	$0	0	0	2
City of Manassas Park*	$0	$0	0	0	1
Town of Clifton	$0	$0	0	0	0
Town of Dumfries	$0	$0	0	0	2
Town of Haymarket	$0	$0	0	0	0
Town of Herndon	$0	$0	0	0	0
Town of Leesburg	$6,215	$404,000	0	0	5
Town of Lovettsville	$9,054	$588,500	0	0	6
Town of Middleburg	$123	$8,000	0	0	3
Town of Occoquan	$0	$0	0	0	0
Town of Purcellville	$0	$0	0	0	0
Town of Quantico	$385	$25,000	10	1	3
Town of Round Hill	$0	$0	0	0	1
Town of Vienna	$0	$0	0	0	0
Total	$209,662	$13,628,000	12	4	70

*NCDC database does not contain damage data for the September 17, 2004 tornado events that impacted Manassas and Manassas Park

**NCDC has no record of any tornado events having impacted the City of Fairfax since 1950; this conflicts with other sources indicating that tornadoes did impact the City, causing damage on September 5, 1979 as a result of Hurricane David.

4. Previous Occurrences

Supplemental to the previous occurrences recorded by NCDC (shown in Table 4.89), the following events are notable within the planning area.

On June 20, 2015, an EF-0 tornado produced a 2.1 mile path of damage that was approximately 100 yards wide. The bulk of the damage occurred at the Broad Run golf training center in Prince William County, where about a half-dozen softwood trees between 12 and 18 inches in diameter were snapped approximately 4 feet above the ground. The damage at the baseball fields at the intersection of Route 28 and Godwin Road included a scoreboard secured by 4x4s being snapped, along with baseball dugout roofs lifted and blown away. The damage was sporadic along the 2.1 mile path.

On October 15, 2014, severe thunderstorms produced a confirmed EF-0 tornado near Belle Haven in Eastern Fairfax County. The tornado created a path of vegetative damage for approximately 1.5 miles. The tornado continued north across the Belle Haven Country Club where more large tree limbs were snapped. The tornado then briefly moved into the City of Alexandria, likely lifting across Interstate 495 at the intersection of George Washington Parkway, where large tree branches were also downed. Several large tree branches were snapped in the immediate adjacent neighborhood to the north before the radar couplet signature weakened after 12:26 pm. Estimated maximum winds were 55-65 mph.

On May 16, 2014, a tornado touched down near Sunny Bank in Loudoun County. A large tree was uprooted, and other trees and large branches were found uprooted and collapsed in different directions, along with branches snapped or twisted at various points along Light Horse Court.

On April 27, 2011, an EF-1 tornado snapped numerous trees along Carriage Ford Road, Aden Road and Garman Drive in Prince William County. Siding and shingles were removed from several homes in the area. Horse run-ins and sheds were also damaged. Garage doors were blown in on a detached garage. A fence was also damaged along with some signs and small trees in the parking lot of a shopping center. A few trees were snapped along Linton Hall Road before the tornado lifted.

On October 13, 2011, thunderstorms developed that contained strong aloft winds. Thunderstorms developed behind the front produced damaging wind gusts. Rapidly changing winds in both direction and speed caused some of the stronger thunderstorms to produce tornadoes near the warm front. Trees were sporadically uprooted and snapped for about a three mile path, starting near Clifton to just west of Fairfax City.

On July 23, 2008, a weak tornado touched down in Prince William County in an industrial park near Wellington at 6:43PM. The tornado produced siding and roof damage to homes and toppled trees. The twister damaged the roof of a retail home center in Sudley Towne Plaza before lifting after crossing Sudley Road near Route 234.

On June 4, 2008, strong upper level thunderstorms developed over the area, resulting in several severe thunderstorms. An EF-1 tornado crossed into south central Loudoun County, producing a damage path near the town of Aldie.

On July 4, 2007, a funnel cloud was spotted near Pickett Road in Fairfax by Department of Public Works and Environmental Services. Severe weather in the area caused the need for sheltering those attending Fourth of July celebrations. No reports of damage or injuries were received as a result of this particular funnel cloud, but a man was killed when a tree fell onto his car in Annandale during storms earlier in the afternoon.

On September 17, 2004, a tornadic thunderstorm entered western Fairfax County from Prince William County. The storm had a path of approximately seven miles. Beginning on Old Centerville Road, the storm produced scattered tree damage and minor roof damage in the Loudoun Town area. A line of damage was carved from Lee Highway northward into the Centerville and Chantilly areas. The tornado destroyed one estate and damaged approximately 50 other structures, and was responsible for downed trees and powerlines. The parent thunderstorm produced another tornado on the east side of the City of Manassas causing structural and tree damage before continuing on into Manassas Park where several dwellings were damaged in the Yorkshire subdivision. At its strongest, this tornado produced F2 damage estimated at approximately $1 million.

On September 24, 2001, five tornadoes touched down in Northern Virginia during the afternoon and early evening of the 24th. A tornado, which remained on the ground for 15 miles, passed through densely populated areas of Eastern Fairfax County, the western portion of the City of Alexandria, and Arlington County causing minor injuries and significant damage to trees, residences, and businesses. Its strength varied between F0 and F1 as it crossed the Interstates three times during rush hour traffic. Cars were hit with flying debris and some windows were blown out. Hundreds of homes and numerous parked vehicles were also damaged. Most of the damage was minor to the exterior and roofs of homes. A few homes suffered more significant damage, mainly in the Shirlington area of Arlington County. Total damages were estimated at $1 million. Only two people are known to have been injured. Before the tornado moved into Washington, DC, it passed right by the Pentagon City Mall and the Pentagon itself. Numerous recovery workers at the Pentagon in the aftermath of the 9-11 attack had to take cover from the tornado in underground tunnels. One of the tornadoes touched down in Prince William County where it downed some trees in Prince William Forest Park area. The tornado moved north into the Lake Montclair community where it took down a few trees, broke branches, and bent siding up on homes. The weak tornado lifted shortly after.

On May 25, 1997, a small, brief tornado, packing winds up to 70 miles per hour, knocked down between 75 and 100 trees and limbs, some of which fell onto residences, vehicles, and other property in South Arlington. Scattered structural damage included aluminum siding, gutters, shingles, and plastic fascia.

On June 24, 1996, a tornado, associated with the mesocyclone of a heavy-precipitation super cell, touched down in extreme southeastern Loudoun County near the Bull Run, then proceeded east-southeast for 20 miles knocking down over 1,000 trees and causing substantial property damage, especially in western Fairfax County, before lifting along the Capital Beltway at the Braddock Road interchange less than two miles west of Annandale. The most significant damage occurred along Tree Line Drive, where 11 of 17 homes incurred moderate to major

damage. The combined effort of several agencies produced property damage estimates along the track (not including flora) totaling $2.9 million. Included in that total are 323 homes which sustained minor damage. An estimated 80,000 homes lost power along the track of the tornado in Fairfax County, with some homes not receiving power until several days after the event.

On April 16, 1993, a tornado touched down approximately a 0.5 mile southwest of Saint Louis in the southern part of Loudoun County, and moved east northeast for about 1.7 miles. The storm knocked down and damaged hundreds of trees. Roofs of two barns were blown off, windows were blown out, and fences were ripped up.

On September 5, 1979, Hurricane David spawned six tornadoes across Virginia. A strong F3 tornado struck Fairfax County tracking 18 miles, killing one and injuring six people. It struck the same school hit by a tornado on April 1, 1973, this time causing $150,000 damage. Numerous cars were demolished, 90 homes were damaged, and trees and debris blocked roads. Damages in Fairfax County reached $2.5 million dollars.

On April 1, 1973, a strong F3 tornado struck a populated area of Northern Virginia. It touched down in Prince William County and traveled 15 miles northeast through Fairfax and into Falls Church. Extensive damage occurred along a six-mile stretch in Fairfax. A high school, two shopping centers, an apartment complex, and 226 homes were damaged. Thirty-seven people were injured. It could have been much worse, but it was Sunday and "Blue Laws" were still in effect--the normally busy shopping center which had extensive damage was closed and school was not in session. Damage totaled an estimated $14 million.

On May 2, 1929, on a day known as "Virginia's Deadliest Tornado Outbreak," the town of Hamilton in Loudoun County (six miles northwest of Leesburg) experienced one of the five tornadoes that caused widespread destruction across the state. The tornado path was reportedly 200 yards across and two miles long. It destroyed a house, barn, and some smaller buildings at one farm. It caused several injuries but no deaths. Other nearby farms were damaged, as well as a brick church.

On November 17, 1927, a tornado touched down in a rural part of Fairfax County and moved northeast across the western part of Alexandria, across the Potomac River and Washington, DC, and into Maryland. Over 100 people were injured in Alexandria and over 200 homes were unroofed and torn apart.

B. Risk Assessment

1. Probability of Future Occurrences

The probability of future occurrences of tornadoes was examined through analysis of the NCDC historical data and in consideration of data developed for the 2013 Commonwealth of Virginia Hazard Mitigation Plan. For the Commonwealth's plan, an extensive frequency analysis was performed on the historical tornado record (including touchdown points and tornado tracks) using GIS techniques. Results of this analysis (see Figure 4.34) pinpoint areas that have experienced slightly higher frequency of tornadoes based on past occurrences. It should be noted that what is determined to be 'High' in the figure is relative to tornado frequency in the entire

Commonwealth of Virginia. This 'High' designation is still low in comparison with frequencies experienced in 'tornado alley' and throughout the southern States. An examination of the NCDC data shows that Loudoun County has experienced 25 tornado events since 1950, more than any other jurisdiction in Northern Virginia. Prince William County is not too far behind having recorded 17 such events during that same period of time.

Based on this analysis, it is likely that the Northern Virginia region will continue to experience weak to moderately intense tornadoes. It is unlikely that very strong tornadoes (F4 or F5) will strike the area, though it does remain a possibility. Climate change is projected to increase the frequency and intensity of extreme weather events[15], including severe thunderstorms. At this time, it remains uncertain if this might also translate into an increased frequency of tornadoes.

2. Impact & Vulnerability

Tornadoes are high-impact, low-probability hazards. A tornado's impact is dependent on its intensity and the vulnerability of development in its path. Qualification of tornado impact has not been performed for this analysis. Future plan updates might investigate the feasibility of methods for doing so. Tornado vulnerability is based on building construction and standards, the availability of shelters or safe rooms, and advanced warning capabilities. Even well-constructed buildings are vulnerable to the effects of a stronger (generally EF2 or higher) tornado.

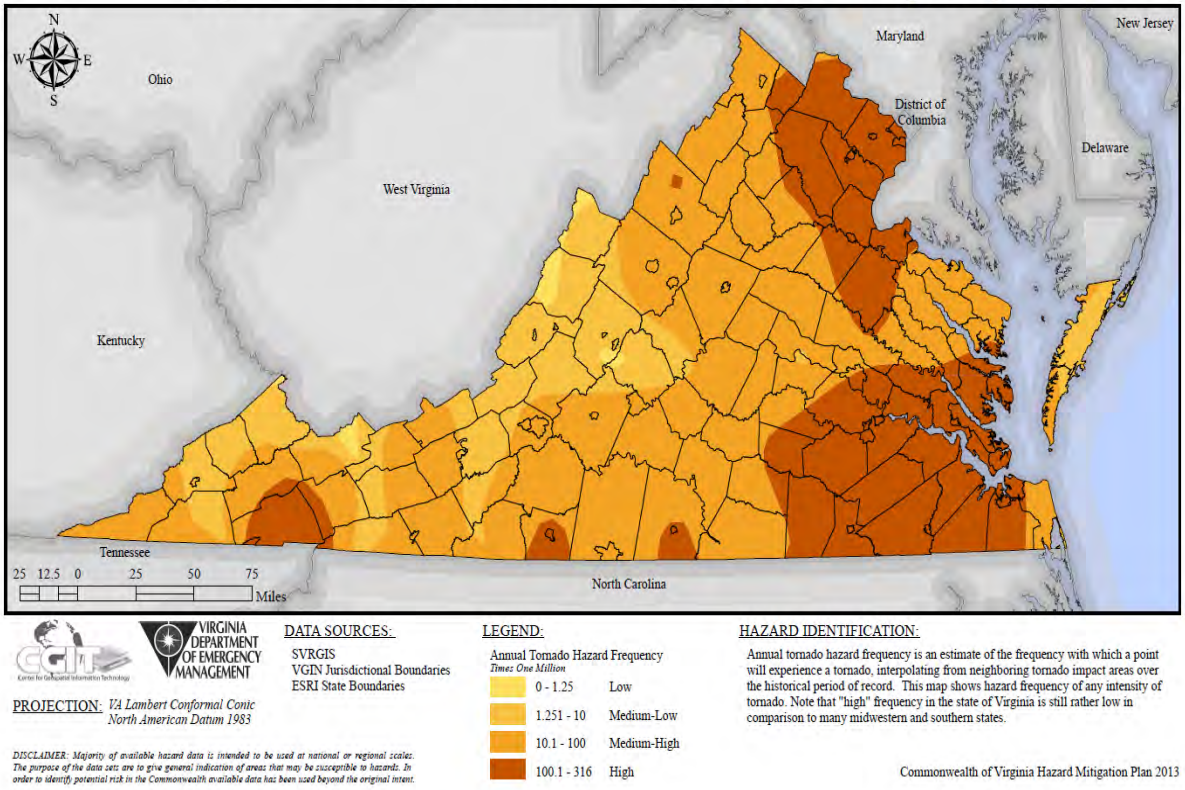

Figure 4.34 Tornado Hazard Frequency. *Source: Commonwealth of Virginia Hazard Mitigation Plan.*

3. Risk

Risk, defined as probability multiplied by impact, cannot be fully estimated for tornadoes due to the lack of intensity-damage models for this hazard. Instead, estimates of the financial impacts of tornadoes can be developed based on historical data contained within the NCDC storm event data. Examination of NCDC data shows that there were 70 tornado events in Northern Virginia between 1950 and December 2015 that caused approximately $13.6 million in property and crop damages. Loudoun County has recorded more damage than other Northern Virginia jurisdictions due to tornadoes. NCDC data shows that the county experienced more than $5 million in property and crop damages since 1950.

Critical Facility Risk

Quantitative assessment of critical facilities for tornado risk was completed for this update using a scenario developed for each participating jurisdiction. The track of a historic tornado in the jurisdiction or an adjacent area was relocated to insect with the participating jurisdiction. Locally-identified critical assets were mapped in relation to the tornado track. Images were created for each scenario; those images can be found in Appendix D.

Table 4.90 provides details of the critical assets that were determined to be damaged in each scenario. For the purposes of this assessment, no assumption was made as to the level of damage that the asset would sustain; therefore, the values displayed represent the entire value of the asset and its contents.

The type and age of construction plays a role in vulnerability of facilities to tornadoes. In general, concrete, brick, and steel-framed structures tend to fare better in tornadoes than older, wood-framed structures or manufactured homes. Finally, not all critical facilities have redundant power sources and may not even be wired to accept a generator. Future plan updates should consider closer examination of critical facilities risk by looking at construction type of critical facilities in jurisdictions considered to be at higher risk of tornadoes.

Table 4.90. Scenario Assessment for Tornadoes by Jurisdiction.

Jurisdiction	Number of Assets Damaged	Value of Assets	Value of Contents	Total
Arlington County	83	$488,255,187	$27,000,723	$515,255,910
Fairfax County	61	$511,768,862	$78,281,693	$590,050,555
Loudoun County	22	$245,335,780	$245,335,780	$490,671,560
Prince William County	0	$0	$0	$0
City of Alexandria	6	$55,873,350	$50,000,000	$105,873,350
City of Fairfax	0	$0	$0	$0
City of Falls Church	3	$18,662,700	$0	$18,662,700
City of Manassas	7	$10,191,160	$796,050	$10,987,210

Table 4.90. Scenario Assessment for Tornadoes by Jurisdiction.				
Jurisdiction	**Number of Assets Damaged**	**Value of Assets**	**Value of Contents**	**Total**
City of Manassas Park	6	$40,408,100	$0	$40,408,100
Town of Dumfries	0	$0	$0	$0
Town of Haymarket	6	$3,187,813	$205,877	$3,393,690
Town of Herndon	8	$18,762,385	$2,514,029	$21,276,414
Town of Leesburg	14	$26,397,517	$1,517,642	$27,915,159
Town of Lovettsville	$0	$0	$0	$0
Town of Middleburg	4	$297,620	$297,620	$595,240
Town of Purcellville	2	$28,030	$28,030	$56,060
Town of Quantico	0	$0	$0	$0
Town of Round Hill	0	$0	$0	$0
Town of Vienna	6	$13,250,000	$700,000	$13,950,000

Existing Buildings and Infrastructure Risk

Risk to existing buildings and infrastructure is largely determined by building construction type including construction method, materials and roof span. As mentioned previously, concrete, brick, and steel-framed structures tend to fare better in tornadoes than older, wood-framed structures

Overall Loss Estimates and Ranking

As detailed in Table 4.89 (earlier in this section), the annualized losses due to tornadoes in Northern Virginia totals approximately $209,662. Based on historical occurrences, tornado events in the Northern Virginia region are more common in Loudoun County, with Prince William County coming in a close second. However, it is expected that susceptibility for tornado occurrences is relatively uniform across the region. Historical data indicates that Loudoun County is by far the most vulnerable of the four counties in terms of property damages, fatalities, and injuries.

Similar to hurricane and tropical storm force-winds, the most at-risk buildings to tornadoes are assumed to include manufactured homes and older residential structures (see discussion under *Hurricanes and Tropical Storms*). Even small F1 tornadoes can cause severe damage to these buildings. For more intense tornadoes (F2 and higher), all buildings are considered at-risk with the exception of those specifically built to withstand wind speeds of more than 120-150 miles per hour (such as designated shelters, EOCs, etc.).

The Commonwealth of Virginia's 2013 Hazard Mitigation Plan ranking was based largely on the NCDC database. The update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. In determining a score and ranking for tornadoes, the geographic extent score for each jurisdiction is based on a frequency analysis of historical tornado events completed for the 2013 Commonwealth plan.

Based on this analysis and the available data, the tornado hazard is ranked as being 'High' for all jurisdictions in Northern Virginia (See Figure 4.34). Refer to the Risk Assessment Methodology section of the HIRA for a full description of the methodology and the limitations of the data used for ranking the hazards. NCDC data, although somewhat limited, provides a comprehensive historical record of natural hazard events and damages.

For the 2016 plan update, the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. Therefore, to avoid repetition, Table 4.91 provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same result.

Table 4.91. 2016 Qualitative Assessment for Tornadoes.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Critical	Moderate	0 to 12 hours	Less than one week

X. Drought

NOTE: As part of the 2016 plan update, the Drought hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Though Drought and Extreme Heat are often interrelated hazards, they can and do occur independent of each other. Though the 2010 plan update consolidated their analysis into one section, the 2016 plan update separated them into different hazards. In addition, each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Drought is generally defined as a persistent and abnormal moisture deficiency having adverse impacts on vegetation, people, or animals. High temperatures, high winds, and low humidity can worsen drought conditions and make areas more susceptible to wildfire. Human demands and

actions can also hasten drought-related impacts. Droughts are frequently classified as one of following four types:

- Meteorological;
- Agricultural;
- Hydrological; or
- Socio-economic.

Meteorological droughts are typically defined by the level of "dryness" when compared to an average, or normal, amount of precipitation over a given period of time. Agricultural droughts relate common characteristics of drought to their specific agricultural-related impacts. Emphasis tends to be placed on factors such as soil/water deficits, water needs based on differing stages of crop development, and water reservoir levels. Hydrological drought is directly related to the effect of precipitation shortfalls on surface and groundwater supplies. Human factors, particularly changes in land use, can alter the hydrologic characteristics of a basin. Socio-economic drought is the result of water shortages that limit the ability to supply water-dependent products in the marketplace.

Figure 4.35 shows the Palmer Drought Severity Index (PDSI) summary map for the United States from 1895 to 1995. The PDSI is a meteorological index that is based on temperature, precipitation, and Available Water Content of the soil data. The PDSI drought classifications are based on observed drought conditions and range from -0.5 (incipient dry spell) to -4.0 (extreme drought). As can be seen, the Eastern United States has historically not seen as many significant long-term droughts as the Central and Western regions of the country.

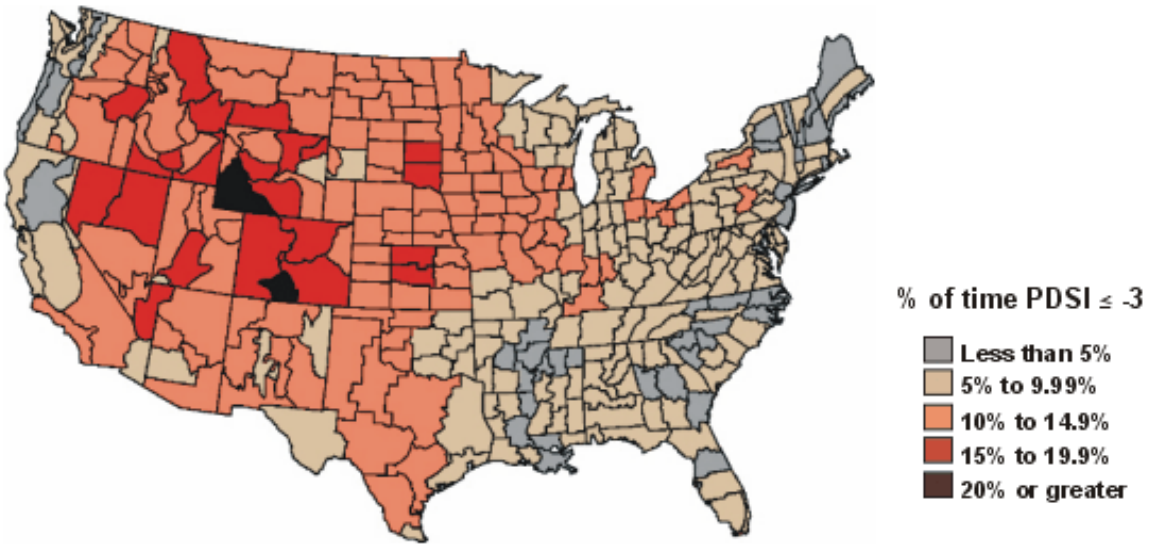

Figure 4.35. Palmer Drought Severity Index, 1895-1995 Percent of Time in Severe and Extreme Drought. *Source: National Drought Mitigation Center*

2. Geographic Location/Extent

The Northern Virginia region is susceptible to drought conditions, although these are typically not nearly as severe as in other regions of the country. According to historical PDSI records for the years 1895 to 1995, the Northern Virginia region was in severe to extreme drought conditions

for only 5 to 10 percent of the time (See Figure 4.35), as compared with areas in the western portion of the United States that experienced severe to extreme drought conditions for more than 20% of the time.

According to the U.S. Department of Commerce, Bureau of Economic Analysis, less than one percent of the Northern Virginia region's civilian workforce is involved in the farm or agriculture sector. Those that are tend to be most involved in hay production, which is grown primarily to feed livestock populations, and viticulture. Other vulnerable crops include corn, alfalfa, and soybeans. According to the USDA's Census of Agriculture, Loudoun County leads the Northern Virginia region with more than 1,400 active farms on 142,452 acres of farmland, with the average farm size being approximately 100 acres.

3. Magnitude or Severity

There are 95 records of drought events contained within the NCDC database. (See Table 4.92) Many of these instances are considered overlapping (counted twice or possibly more), as adjacent jurisdictions experiencing the same drought were considered separate instances. Data regarding the impact or occurrence of drought on the towns is contained within the estimates for the counties. Also, unlike the very distinct beginning and end to other hazards (e.g., tornado), the period of a drought occurrence is not clear because multiple instances may be recorded for the same long-term drought. More detailed information on historical drought events can be obtained through the NCDC Storm Event Database.

Table 4.92. Annualized Property and Crop Loss Due to Drought, Based on NCDC Data.

Number of Events	**151**
Years of Record: 1950-2015	**Annualized Property and Crop Damage**
Arlington County	$22,315
Fairfax County	$22,315
Loudoun County	$317,304
Prince William County	$28,160
City of Alexandria	$22,315
City of Fairfax	$0
City of Falls Church	$22,315
City of Manassas	$28,160
City of Manassas Park	$0
Town of Clifton	Included in Loudoun County estimate
Town of Dumfries	Included in Prince William County estimate
Town of Herndon	Included in Fairfax County estimate
Town of Haymarket	Included in Prince William County estimate
Town of Leesburg	Included in Loudoun County estimate

Table 4.92. Annualized Property and Crop Loss Due to Drought, Based on NCDC Data.	
Town of Lovettsville	Included in Loudoun County estimate
Town of Middleburg	Included in Loudoun County estimate
Town of Occoquan	Included in Prince William County estimate
Town of Purcellville	Included in Loudoun County estimate
Town of Quantico	Included in Prince William County estimate
Town of Round Hill	Included in Loudoun County estimate
Town of Vienna	Included in Loudoun County estimate
Total	**$462,886**

Lack of rainfall during drought conditions will affect water levels along the Potomac River, the main water source for the Northern Virginia region. Many of the major reservoirs serving the Northern Virginia region, including the Occoquan (Fairfax County) and the Beaverdam (Loudoun County), have experienced dangerously low levels in the past due to ongoing drought periods. During these periods, many locations are forced to begin water restrictions, which could lead to potential economic impacts for the region. The most vulnerable residents during these dry periods are those who live in the more rural areas located away from the larger cities and populated suburbs of the region (many of whom draw their water supply from wells).

4. Previous Occurrences

Because of the widespread geographic nature of the hazard, droughts typically impact large geographic areas, such as the entire Northern Virginia region. To avoid repetition, descriptions of the occurrences of drought in Northern Virginia have been consolidated to cover the entire planning area.

Planning Area

On October 1, 2007 – October 30, 2007, rainfall deficits of nearly 10 inches were common across northern Virginia at the beginning of the month. All counties and independent cities in the Commonwealth, with the exception of Arlington County and the independent cities of Alexandria and Falls Church, were declared primary disaster areas by the State. Many jurisdictions instituted water restrictions (both voluntary and mandatory) during this particularly dry stretch. Much of Northern Virginia was categorized as experiencing Extreme Drought by the National Drought Monitor during the later portions of the month. Several storm systems brought much-needed rainfall as the month ended, alleviating drought conditions.

In August 1998-August 1999, the PDSI indicated Northern Virginia was in an extreme drought. July was the 10th month in the previous 12 that precipitation was below normal. During this

period, precipitation was a staggering 10 to 16 inches below average, the second driest 12 months on record.

The lack of rainfall affected water levels along the Potomac River, the main water source for the region. Many upstream tributaries also reported extremely low water levels. For the first time, water was released from the Randolph and Little Seneca reservoirs near the Potomac headwaters to help maintain a safe water level for wildlife and human consumption. By July 31st, the Randolph Reservoir was 13.8 percent below capacity and the Little Seneca Reservoir was down four inches.

Across Northern Virginia, several crops such as corn and soybeans never reached maturity, trees prematurely shed leaves and fruit in orchards, pasture land became nearly non-existent, and watering holes and irrigation sources dried up.

These instances of drought came to an end in September 1999 as the remnants of two hurricanes brought significant rainfall to the region. Following these storms, most areas recorded a major increase in water supplies and upgraded their condition from an extreme drought to a mild drought.

July 1997 was a very dry month that included one seven-day heat wave, and exacerbated drought-like conditions across much of the fertile farmland of Northern Virginia. The weather in July resulted in the failure of several crops, including corn, hay, alfalfa, and soybeans. Counties in the Northern Virginia region reported damage via local farms, though no formal declarations of Federal emergency were received from them.

B. Risk Assessment

1. Probability of Future Occurrences

The future incidence of drought is highly unpredictable and may be localized, which makes it difficult to assess the probability of drought. No sources of information on long-term historic frequency of drought or future probability were identified for inclusion in this plan. This may be a result of many different definitions resulting in spotty reporting. Based on past events, it certainly remains possible over the long-term that the Northern Virginia region will experience recurring drought conditions, the severity of which cannot be quantified.

2. Impact & Vulnerability

Short-term droughts can impact agricultural productivity, while longer term droughts are more likely to impact not only agriculture, but also water supply. Jurisdictions that have invested in water supply and distribution infrastructure are generally less vulnerable to drought. Short and long-term drought may lead to an increase in the incidence of wildfires which might in turn lead to increased potential for landslides or mudflows once rain does fall.

There is no standardized methodology for estimating vulnerability to the drought hazard. As opposed to posing a direct threat to life and property, drought impact is primarily measured by its potential and actual economic effect on the agricultural sector as well as municipal and industrial

water supplies. This economic effect can also be expected to affect related sectors, such as wholesale and retail trade.

3. Risk

The risk associated with drought in Northern Virginia has not been formally quantified, due to the difficulty in assessing the rate of incidence, and the lack of complete data on drought impacts. There is low risk of human injury/death due to drought in Northern Virginia, and low risk of property damage. Crop damages due to drought are uncertain, as agricultural productivity often varies with growing conditions from year to year. However, the NCDC Storm Events database does report crop losses due to drought of approximately $463,000 annually (see Table 4.92). Future updates to this plan should consider methods for quantifying annual drought losses in sectors outside of agriculture. This might include defining losses related to maintaining water supply, hydropower, tourism, and recreation and would require data sources outside of NCDC storm events data – including detailed local reports of both occurrences and associated damages.

Critical Facility Risk

Risk associated with drought has not been quantified in terms of geographic extent for this revision; as a result, critical facility risk has not been calculated. The majority of drought related damages do not impact buildings or infrastructure.

As discussed previously, the entire Northern Virginia region is vulnerable to drought and historically suffers drought conditions between five and 10 percent of the time. Since 1950, the region has been severely impacted by numerous instances of a long-term drought with damages totaling approximately $25 million (most of which was attributed to agricultural losses in Loudoun and Prince William counties). Prior to this period of record, very little historical data exists on past drought events.

The Commonwealth of Virginia's 2013 HIRA ranking was based largely on the NCDC database. The update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. No geographic extent data was available for drought probability. Based on this analysis and the available data, the drought hazard is considered to be 'Moderate' for Loudoun County, Prince William County, and the Towns of Leesburg, Lovettsville, Purcellville, Middleburg, Round Hill, Dumfries, Haymarket, Occoquan, and Quantico, and 'Low' for all other jurisdictions.

For the 2016 plan update the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. Therefore, to avoid repetition, Tables 4.93 and 4.94 provides the results of the qualitative assessment for all participating jurisdictions.

Arlington County, Fairfax County, the City of Arlington, the City of Fairfax, the City of Falls Church, the Town of Clifton, the Town of Herndon, and the Town of Vienna

Table 4.93. 2016 Qualitative Assessment for Drought.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Low	Moderate	3 to 6 months	More than one month

Loudoun County, Prince William County, the City of Manassas, the City of Manassas Park, the Town of Dumfries, the Town of Haymarket, the Town of Leesburg, the Town of Lovettsville, the Town of Middleburg, the Town of Occoquan, the Town of Purcellville, the Town of Quantico, and the Town of Round Hill

Table 4.94. 2016 Qualitative Assessment for Drought.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Likely	Moderate	Moderate	3 to 6 months	More than one month

XI. Earthquake

NOTE: As part of the 2016 plan update, the Earthquake hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the Plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

An earthquake is the motion or trembling of the ground produced by sudden displacement of rock in the Earth's crust. Earthquakes result from crustal strain, volcanism, landslides, or the collapse of caverns. Earthquakes can affect hundreds of thousands of square miles; cause damage to property measured in the tens of billions of dollars; result in loss of life and injury to hundreds of thousands of persons; and disrupt the social and economic functioning of the affected area.

Most earthquakes are caused by the release of stresses accumulated as a result of the rupture of rocks along opposing fault planes in the Earth’s outer crust. These fault planes are typically found along borders of the Earth's 10 tectonic plates. These plate borders generally follow the outlines of the continents, with the North American plate following the continental border with the Pacific Ocean in the west, but following the mid-Atlantic trench in the east. As earthquakes

occurring in the mid-Atlantic trench usually pose little danger to humans, the greatest earthquake threat in North America is along the Pacific Coast.

The areas of greatest tectonic instability occur at the perimeters of the slowly moving plates, as these locations are subjected to the greatest strains from plates traveling in opposite directions and at different speeds. Deformation along plate boundaries causes strain in the rock and the consequent buildup of stored energy. When the built-up stress exceeds the rocks' strength, a rupture occurs. The rock on both sides of the fracture is snapped, releasing the stored energy and producing seismic waves, generating an earthquake.

2. Geographic Location/Extent

Figures 4.36 and 4.37 show the probability that ground motion will reach a certain level during an earthquake. The data show peak horizontal ground acceleration (the fastest measured change in speed, for a particle at ground level that is moving horizontally due to an earthquake) with a 10 percent and 2 percent probability of exceedance in 50 years, respectively. The maps were compiled by the USGS Geologic Hazards Team, which conducts global investigations of earthquake, geomagnetic, and landslide hazards.

Figure 4.38 from the Commonwealth of Virginia's Hazard Mitigation Plan shows the epicenter locations of historical earthquakes and the two main zones in Virginia that are more susceptible to earthquakes. These zones, as mapped by the USGS, are believed to be sources of most Magnitude 6 or greater earthquakes during the past 1.6 million years around Virginia.

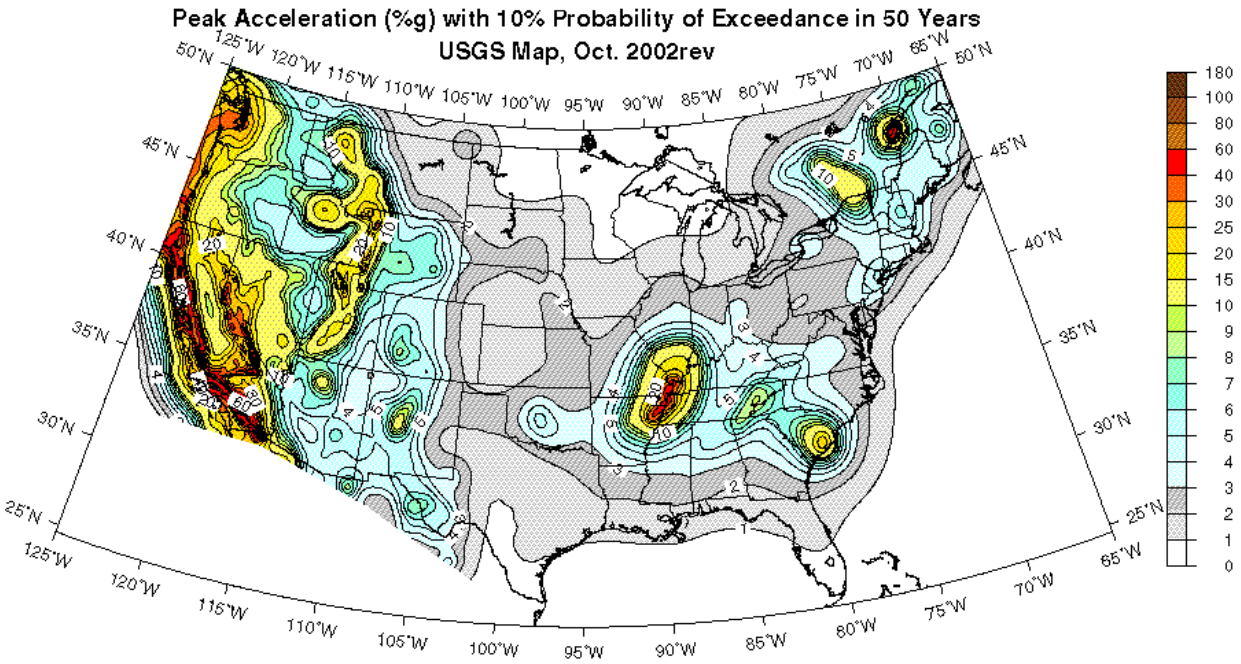

Figure 4.36. Peak Acceleration with 10 Percent Probability of Exceedance in 50 Years.
Source: USGS

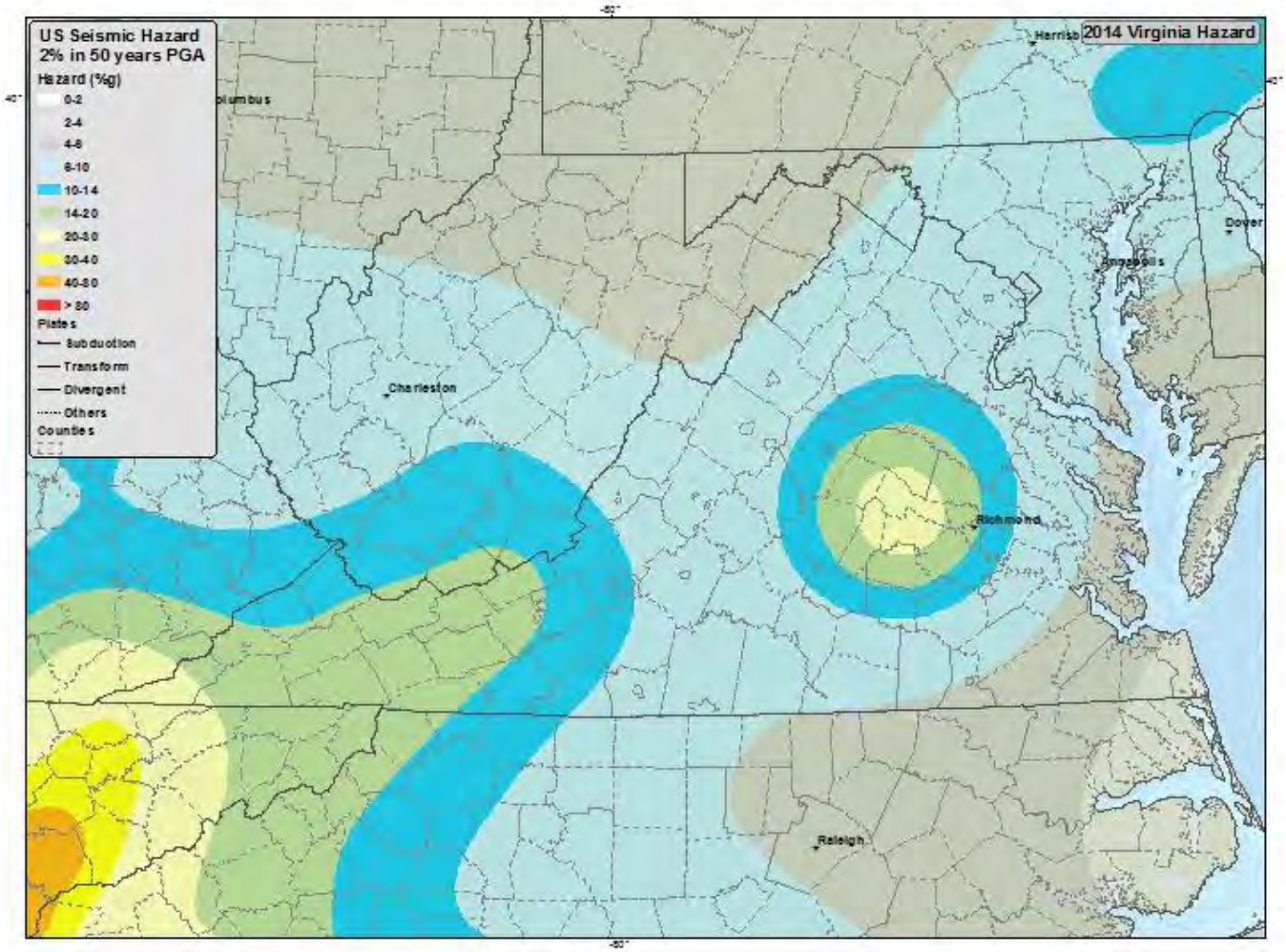

Figure 4.37. Peak Acceleration with 2 Percent Probability of Exceedance in 50 Years.
Source: USGS

3. Magnitude or Severity

Ground shaking can lead to the collapse of buildings and bridges and disrupt gas lines, electricity, and phone service. Death, injuries, and extensive property damage are possible vulnerabilities from this hazard. Some secondary hazards caused by earthquakes may include fire, hazardous material release, landslides, flash flooding, avalanches, tsunamis, and dam failure.

Most property damage and earthquake-related deaths are caused by the failure and collapse of structures due to ground shaking. The level of damage depends upon the amplitude and duration of the shaking, which are directly related to the earthquake size, distance from the fault, site, and regional geology. Other damaging earthquake effects include landslides, the down-slope movement of soil and rock (mountain regions and along hillsides), and liquefaction, in which ground soil loses shear strength and the ability to support foundation loads. In the case of liquefaction, anything relying on the substrata for support can shift, tilt, rupture, or collapse.

Earthquakes are measured in terms of their magnitude and intensity. Magnitude is measured using the Richter Scale, an open-ended logarithmic scale that describes the energy release of an earthquake through a measure of shock wave amplitude (see Table 4.95). Each unit increase in magnitude on the Richter Scale corresponds to a 10-fold increase in wave amplitude, or a 32-fold increase in energy. Intensity is most commonly measured using the Modified Mercalli Intensity (MMI) Scale based on direct and indirect measurements of seismic effects. The scale levels are typically described using roman numerals, with a I corresponding to imperceptible (instrumental) events, IV corresponding to moderate (felt by people awake), to XII for catastrophic (total destruction). A detailed description of the MMI Scale of earthquake intensity and its correspondence to the Richter Scale is given in Table 4.96.

Table 4.95, The Richter Magnitude Scale.

Richter Magnitudes	Earthquake Effects
Less than 3.5	Generally not felt, but recorded.
3.5-5.4	Often felt, but rarely causes damage.
Under 6.0	At most slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions.
6.1-6.9	Can be destructive in areas up to about 100 kilometers across where people live.
7.0-7.9	Major earthquake. Can cause serious damage over larger areas.
8 or greater	Great earthquake. Can cause serious damage in areas several hundred kilometers across.

Table 4.96. Modified Mercalli Intensity Scale for Earthquakes.

Scale	Intensity	Description of Effects	Corresponding Richter Scale Magnitude
I	Instrumental	Detected only on seismographs	
II	Feeble	Some people feel it	<4.2
III	Slight	Felt by people resting; like a truck rumbling by	
IV	Moderate	Felt by people walking	
V	Slightly Strong	Sleepers awake; church bells ring	<4.8
VI	Strong	Trees sway; suspended objects swing, objects fall off shelves	<5.4
VII	Very Strong	Mild Alarm; walls crack; plaster falls	<6.1
VIII	Destructive	Moving cars uncontrollable; masonry fractures, poorly constructed buildings damaged	

Table 4.96. Modified Mercalli Intensity Scale for Earthquakes.			
Scale	**Intensity**	**Description of Effects**	**Corresponding Richter Scale Magnitude**
IX	Ruinous	Some houses collapse; ground cracks; pipes break open	<6.9
X	Disastrous	Ground cracks profusely; many buildings destroyed; liquefaction and landslides widespread	<7.3
XI	Very Disastrous	Most buildings and bridges collapse; roads, railways, pipes and cables destroyed; general triggering of other hazards	<8.1
XII	Catastrophic	Total destruction; trees fall; ground rises and falls in waves	>8.1

4. Previous Occurrences

The first recorded earthquake in Virginia occurred in 1774. Since then, more than 300 earthquakes have occurred in the State, with 18 having a magnitude of 4.5 or higher on the Richter Scale. The largest of these events occurred in Giles County in 1897 with a magnitude of 5.8. Most earthquake events have resulted in very little property damage, if any, and there are no historical records of any earthquake-related damages in the Northern Virginia region. Historical event information for earthquakes in Virginia occurrences is based on information made available through the USGS Earthquake Hazards Program. There have been no Federally Declared Disasters or NCDC recorded events in the Northern Virginia region for earthquakes.

According to the USGS, there have been 62 significant earthquake events to occur within 300 miles of the Northern Virginia region (including those centered outside of Virginia). The epicenter locations of these events are shown in Figure 4.38[16] along with the year in which they occurred for the larger events. There are no reported casualties or significant property damages for the Northern Virginia region as a result of these events. Below is a summary of significant events that impacted the Northern Virginia region. It is assumed that these events were experienced across the planning region, though it is possible that there were no specific reports of damages in specific geographic areas.

On August 23, 2011, a magnitude 5.8 earthquake struck the Piedmont region of Virginia. Its epicenter was in Louisa County, and was one of the highest magnitude earthquakes to occur east of the Rocky Mountains. The earthquake was felt in approximately a dozen states and well into Canada. No fatalities from the event were recorded, though some injuries were reported; however, damage was widespread and estimated at hundreds of millions of dollars, much of which was uninsured. The earthquake caused the automatic shutdown of the North Anna Nuclear Power Station in Mineral, Virginia, located approximately 11 miles west-southwest of the station. In Arlington County, a pipe ruptured in the Pentagon, resulting in flooding of at least two corridors. Damage was also reported at a theater in Arlington County and several structures in the City of Arlington; the City of Manassas reported slight damage to City Hall and the Fire and Rescue Headquarters for the City. In Prince William County, the earthquake was blamed for damage to a dam and slight damage to several county facilities. A Federal Disaster Declaration

was issued for the event in Virginia, though no part of the Northern Virginia planning area was included in the declaration.

On July 16, 2010, a magnitude 3.4 occurred near Gaithersburg, Maryland. The earthquake was felt in the Potomac-Shenandoah Region of Virginia. An hour after the quake, more than 5,500 people reported feeling it across Maryland, Washington, DC, West Virginia, Virginia, and Delaware[17]. No injuries or property damages were reported. The earthquake occurred in a part of the Eastern Seaboard that is less seismically active than central Virginia, New England, and the area surrounding New York City. Since 1980, 14 earthquakes have been felt within 80 km (about 50 miles) of the July 16th earthquake. All were smaller than this event. Other earthquakes have been reported in that area as far back as at least 1758[18].

On May 6, 2008, a minor earthquake (2.0 magnitude) occurred near Annandale, Virginia. Felt reports were primarily received from people in Fairfax County, the District of Columbia, and Montgomery County, Maryland.

On December 9, 2003, an earthquake was widely felt in the Washington-Baltimore area and occurred west of Richmond, Virginia, in the Central Virginia Seismic Zone. It had a magnitude of 4.3[19].

On April 9, 1918, the Shenandoah Valley region was strongly shaken by an earthquake. It was called the "most severe earthquake ever experienced" at Luray. Although little damage resulted, people in many places over the northern valley region were greatly alarmed and rushed from their houses. Broken windows were reported in Washington, DC. The tremor was noticed by President Wilson and his family at the White House; the President's secretary called a newspaper office to learn the cause of the terrifying noise. The felt area extended over 155,000 square kilometers, including parts of Maryland, Pennsylvania, and West Virginia.

On May 3, 1897, the largest historical earthquake to originate in Virginia occurred. The epicenter was in Giles County, where on May 3rd, an earlier tremor at Pulaski, Radford, and Roanoke had caused damage. Loud rumblings were heard in the epicentral region at various times between May 3rd and 31st. The shock on the latter date was felt from Georgia to Pennsylvania and from the Atlantic Coast westward to Indiana and Kentucky, an area covering about 725,000 square kilometers. It was especially strong at Pearisburg, where the walls of old brick houses were cracked and bricks were thrown from chimney tops. Springs were muddied and a few earth fissures appeared. Chimneys were shaken down in Bedford City, Houston, Pulaski, Radford, and Roanoke. Chimneys were also broken at Raleigh, North Carolina; Bristol and Knoxville, Tennessee; and Bluefield, West Virginia. Minor tremors continued in the epicentral region from time to time until June 6; other disturbances felt on June 28, September 3, and October 21 were probably aftershocks.

On August 31, 1861, the earthquake epicenter was probably in extreme southwestern Virginia or western North Carolina. At Wilkesboro, North Carolina, bricks were shaken from chimneys. The lack of Virginia reports may perhaps be ascribed to the fact that the Civil War was under way and there was rather heavy fighting in Virginia at the time. This shock affected about 775,000 square kilometers and was felt along the Atlantic coast from Washington, DC, to

Charleston, South Carolina, and westward to Cincinnati, Louisville, and Gallatin, Tennessee, and southwestward to Columbus, Georgia.

On April 29, 1852, another moderately strong, widely felt shock occurred. At Buckingham and Wytheville, chimneys were damaged. The felt area extended to Washington, DC, Baltimore, and Philadelphia, and also included many points in North Carolina - approximately 420,000 square kilometers.

On August 27, 1833, the earthquake covered a broad felt area from Norfolk to Lexington and from Baltimore, Maryland, to Raleigh, North Carolina - about 135,000 square kilometers. Two miners were killed in the panic the shock caused at Brown's Coal Pits, near Dover Mills, about 30 kilometers from Richmond. At Charlottesville, Fredericksburg, Lynchburg, and Norfolk, windows rattled violently, loose objects shook, and walls of buildings were visibly agitated.

On March 9, 1828, an earthquake, apparently centered in southwestern Virginia, was reported felt over an area of about 565,000 square kilometers, from Pennsylvania to South Carolina and the Atlantic Coastal Plain to Ohio. Very few accounts of the shock were available from places in Virginia; it was reported that doors and windows rattled. President John Quincy Adams felt this tremor in Washington, DC, and provided a graphic account in his diary. He compared the sensation to the heaving of a ship at sea.

On February 21, 1774, a strong earthquake was felt over much of Virginia and southward into North Carolina. Many houses were moved considerably off their foundations at Petersburg and Blandford. The shock was described as "severe" at Richmond and "small" at Fredericksburg. However, it "terrified the inhabitants greatly." The total felt area covered about 150,000 square kilometers.

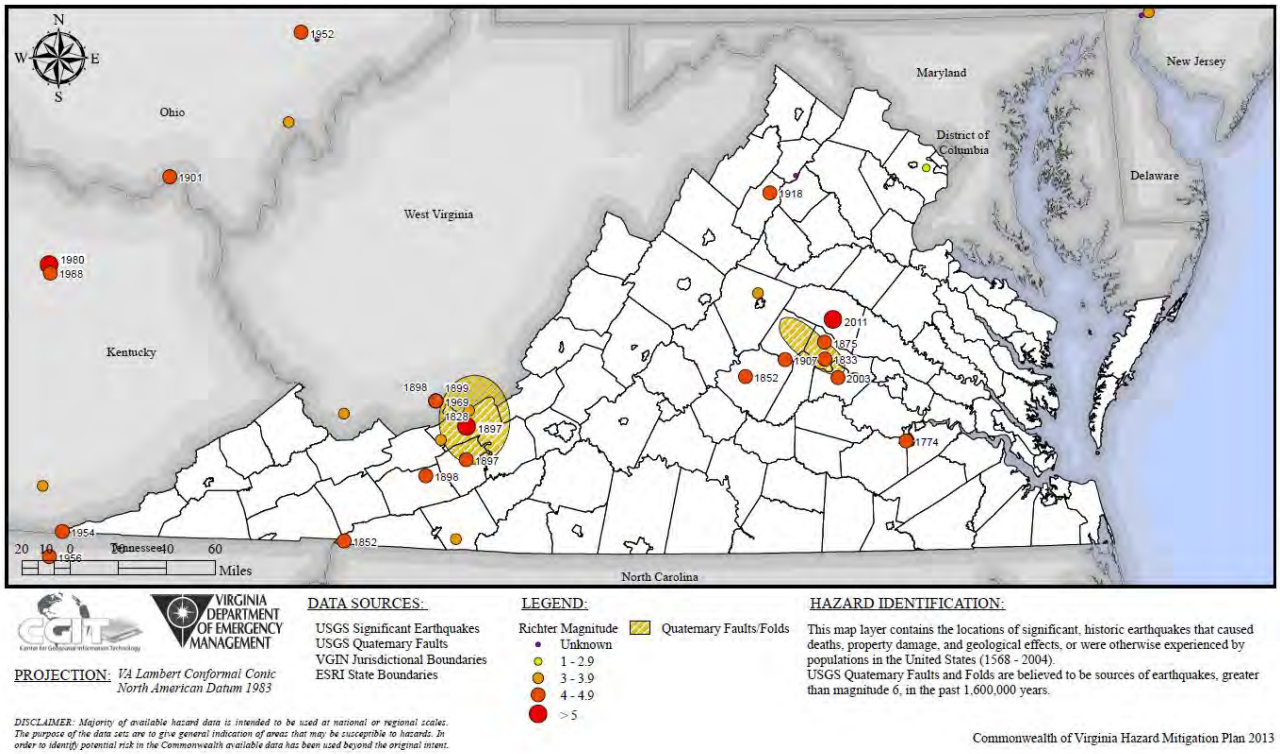

Figure 4.38. Significant Earthquakes 1568 – 2011.

B. Risk Assessment

Similar to other states on the eastern seaboard, the State of Virginia is designated as a moderate risk state for earthquake occurrence by the USGS. Earthquake events can and occasionally do occur in the State, though of much less intensity than those that occur along the west coast. The greatest seismic risk in Virginia is in the Eastern Tennessee Seismic Zone, located in the southwestern portions of the State and far from the Northern Virginia region.

1. Probability of Future Events (Chance of Occurrence)

Earthquakes are low probability, high-consequence events. Although earthquakes may occur only once in the lifetime of an asset, they can have devastating impacts. A moderate earthquake can cause serious damage to unreinforced buildings, building contents, and non-structural systems, and can cause serious disruption in building operations. Moderate and even very large earthquakes are inevitable, although very infrequent, in areas of normally low seismic activity. Consequently, in these regions buildings are seldom designed to deal with an earthquake threat; therefore, they are extremely vulnerable.

Probabilistic ground motion maps are typically used to assess the magnitude and frequency of seismic events. These maps measure the probability of exceeding a certain ground motion, expressed as percent peak ground acceleration (%PGA), over a specified period of years. The severity of earthquakes is site specific, and is influenced by proximity to the earthquake epicenter and soil type, among other factors. Figure 4.39[20] shows the PGA zones for the 2500-year Return Period derived from HAZUS^{MH} data developed by VDEM for the Commonwealth

Hazard Mitigation Plan. The 2500-year Return period, or 0.04%-annual-chance of occurrence, is much more varied than the 100-year Return period and similar to the two USGS earthquake zones discussed in the earthquake Previous Occurrence section. Southwest and Central Virginia have an increased likelihood of experiencing a significant earthquake. The PGA zones for the 2500-year Return Period were used as the geographic extent parameter for ranking earthquakes. See the Risk Assessment and Methodology and Risk section for more details.

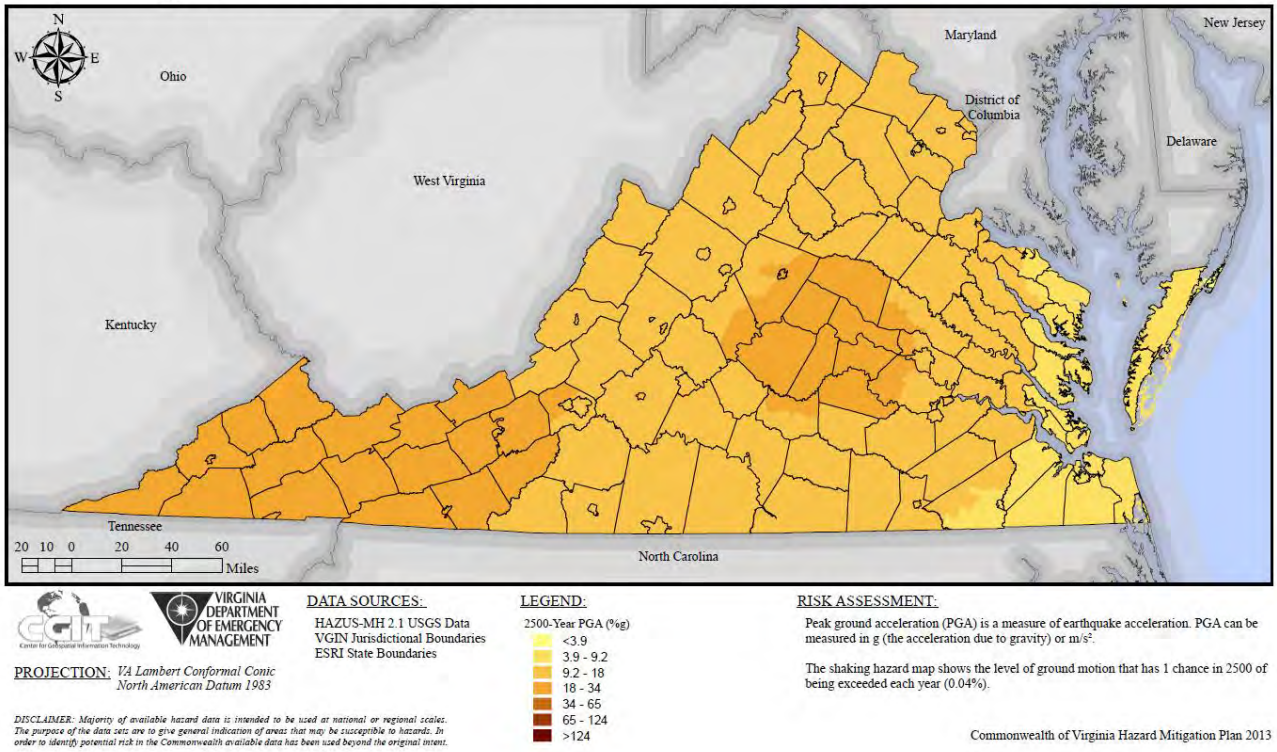

Figure 4.39. 2500-year Return Period Peak Ground Acceleration.

The recurrence interval for significant earthquake events in the Northern Virginia region is very low; however, the potential impact of a major seismic event along the Eastern Tennessee or Central Virginia seismic zone could be moderately destructive. Based on correspondence with Dr. Martin Chapman[21], director of the Virginia Tech Seismological Observatory, the majority of continued earthquake activity takes place in Goochland County, Virginia, and therefore would be a reasonable earthquake scenario for Northern Virginia. This scenario has been modeled using HAZUS^{MH}; results are summarized below in the Risk section.

2. Impact & Vulnerability

Impacts from earthquakes can be severe and cause significant damage. Table 4.97 provides the corresponding intensity equivalents in terms of MMI, as well as perceived shaking and potential damage expected for given values. These values were used as thresholds to group State and critical facilities into different vulnerability/risk zones based on potential damage.

Table 4.97. Modified Mercalli Intensity (MMI) and PGA.			
MMI	**PGA (%g)**	**Perceived Shaking**	**Potential Damage**
I	<0.17	Not Felt	None
II	0.17 - 1.4	Weak	None
III	0.17 - 1.4	Weak	None
IV	1.4 -3.9	Light	None
V	3.9 -9.2	Moderate	Very Light
VI	9.2 -18	Strong	Light
VII	18 -34	Very Strong	Moderate
VIII	34 - 65	Severe	Moderate to Heavy
IX	65 - 124	Violent	Heavy
X	> 124	Extreme	Very Heavy
XI	> 124	Extreme	Very Heavy
XII	> 124	Extreme	Very Heavy

The Northern Virginia planning region vulnerability and impact has been calculated in terms of total direct economic loss, as defined by HAZUS^{MH}. This includes damage to structural, non-structural, building, contents, inventory loss, relocation, income loss, rental loss, and wage loss. Additional information can be found in the Jurisdiction Risk portion of this section.

3. Risk

Moderate and even very large earthquakes are inevitable, although very infrequent, in areas of normally low seismic activity. Earthquake HAZUS^{MH} analysis was completed for the 2016 plan update, to continue the methodology used in previous plans. Below are highlights of the results.

HAZUS-MH Analysis

Due to the region's relatively low seismic risk, buildings and infrastructure throughout the region are not designed to withstand major ground shaking events. This means that if such events do occur, while unlikely, the losses would likely be substantial. HAZUS^{MH} was used to update damage and loss estimates for the probabilistic ground motions associated with each of eight return periods (100, 250, 750, 1000, 2000, and 2500 years). The building damage estimates were then used as the basis for computing direct economic losses. These include building repair costs, contents and business inventory losses, costs of relocation, capital-related, wage, and rental losses. Annualized loss was computed, in HAZUS^{MH}, by multiplying losses from the eight potential ground motions by the respective annual frequencies of occurrence, and summing the values.

Specific result reports and GIS-generated by HAZUS can be found in Appendix D.

HAZUS^{MH} can be used to evaluate a variety of hazards and associated risk to support hazard mitigation. This revision utilized a Level 1 analysis for the earthquake module. Level 1 analysis involves using the provided hazard and inventory data with no additional local data collection. This is an acceptable level of information for mitigation planning; a future version of this plan could be enhanced with Level 2 or 3 analyses. The estimates of social and economic impacts contained in this report were produced using HAZUS^{MH} loss estimation methodology software, which is based on current scientific and engineering knowledge. There are uncertainties inherent

in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific earthquake. These results can be improved by using enhanced inventory, geotechnical, and observed ground motion data.

For this plan update, the probabilistic scenario in HAZUS^{MH} was run on a region-wide basis, with the assessment focusing on the 2500-year return event. Based on this analysis, the Northern Virginia region can expect over $1.49 million in annualized damages to transportation, utility, and building stock throughout the region. The scenario modeled a 6.5 magnitude earthquake, centered near the same location as the actual 2011 Louisa County earthquake, with a depth of 10 meters, which was the same scenario used in the 2010 update. This scenario was maintained for continuity of the assessment. As discussed above, this would be a reasonable and likely scenario for the region. The results of this magnitude earthquake would result in over $3.74 billion dollars in damages to building stock, utility infrastructure, and transportation infrastructure. Table 4.98 summarizes the results of the region-wide analysis for the probabilistic scenario. (*Note: Town information is included the county totals.*) Building stock data includes damages to buildings, contents, inventory, and business interruption costs. Utility infrastructure includes damages to facilities and pipelines. Transportation infrastructure accounts for segments, bridges, tunnels, and facilities.

Table 4.98. HAZUS^{MH} Estimate: Damages from probabilistic scenario 2500-year return interval.

Jurisdiction	Building Stock	Transportation Infrastructure	Utility Infrastructure	Total
Arlington County	$343,903,000	$4,726,000	$3,172,000	$347,551,000
Fairfax County	$1,794,989,000	$12,702,000	$20,528,000	$1,828,219,000
Loudoun County	$430,261,000	$1,985,000	$8,280,000	$440,526,000
Prince William County	$679,957,000	$4,027,000	$15,648,000	$699,632,000
City of Alexandria	$274,089,000	$3,011,000	$4,038,000	$281,238,000
City of Fairfax	$63,431,000	$28,000	$286,000	$63,745,000
City of Falls Church	$274,089,000	$0	$154,000	$274,243,000
City of Manassas	$74,521,000	$854,000	$5,412,000	$80,787,000
City of Manassas Park	$20,296,000	$131,000	$165,000	$20,592,000
Total	$3,708,422,000	$27,464,000	$57,684,000	$3,793,570,000

Critical Facility Risk

HAZUS^{MH} estimates the region has 2,857 hospital beds available for use. Based on the scenario, on the day of the earthquake the region would have 71% of hospital beds available (functionality) for use by patients already in the hospital and those injured by the earthquake. All essential facilities would have functionality of greater than 50% on the day of the earthquake. After one week, 87% of the beds would be back in service; by 30 days after the event, 97% would be back in service.

Sheltering Needs

The model estimates 2,437 households to be displaced from the scenario. Of these, 1,283 people (out of a total population of 2,230,623) will seek temporary shelter.

Debris Generation

HAZUS^{MH} estimates the region would have to deal with a total of 1.21 million tons of debris from the scenario event. Of that amount, 69% would be made up of brick and wood debris, with the remainder being reinforced concrete and steel. If this amount of debris is converted to an estimated number of truckloads (assuming 25 tons per truckload), the scenario requires 48,520 truckloads to remove the debris generated by this scenario earthquake.

Existing Buildings and Infrastructure Risk

As discussed in the community profiles previously, there is an estimated 663,000 buildings in the region with an aggregate total building replacement value (excluding contents) of $320,418 million dollars. The majority of the buildings in the region are associated with residential housing. Wood frame construction makes up 73.6% of the building inventory.

Based on the HAZUS^{MH} scenario, there would be about 22,807 buildings with at least moderate damage. Approximately 554 buildings would be damaged beyond repair. Table 4.99 summarizes the expected damage and number of buildings damaged, by occupancy.

Table 4.99. HAZUS^{MH} Estimate: Expected Building Damage by Occupancy.

Occupancy Type	None		Slight		Moderate	
	Count	%	Count	%	Count	%
Agriculture	1,311	0.20	219	0.34	99	0.44
Commercial	26,688	4.67	4,502	6.97	2,524	11.06
Education	1,458	0.26	237	0.37	134	0.59
Government	918	0.16	154	0.24	93	0.41
Industrial	6,281	1.10	1,072	1.66	663	2.91
Other Residential	21,475	3.76	2,924	4.53	1,482	6.50
Religious	2,920	0.51	395	0.61	203	0.89
Single Family	510,548	89.32	55,062	85.28	17,609	77.21
Sub-totals:	**571,600**	**--**	**64,566**	**--**	**22,807**	**--**
	Extensive		**Complete**		**Totals**	
	Count	**%**	**Count**	**%**	**Count**	**--**
Agriculture	19	0.45	2	0.29	1,650	--
Commercial	464	11.16	51	9.19	34,229	--
Education	22	0.52	3	0.53	1,854	--
Government	15	0.36	2	0.33	1,182	--
Industrial	116	2.80	12	2.25	8,144	--
Other Residential	201	4.82	18	3.29	26,100	--

Table 4.99. HAZUS^{MH} Estimate: Expected Building Damage by Occupancy.						
Religious	41	0.99	5	0.93	3,564	--
Single Family	3,281	78.90	461	83.20	586,961	--
Sub-totals:	**4,158**	**--**	**554**	**--**	**--**	**--**

Overall Loss Estimates and Ranking

No earthquake events were recorded in the NCDC database for the Northern Virginia region; as a result, no NCDC annualized loss estimates were calculated.

The hazard ranking for earthquake is based on events reported in the NCDC Storm Events database and a generalized geographic extent. The geographic extent ranking category used the PGA values for the 2500 Return Period. This return period represents a 0.04%-annual-chance of occurrence in any given year. The Northern Virginia planning region was ranked as 'Moderate' for earthquakes. Figure 4.39 shows the seven parameters that were used to derive the overall risk ranking. As discussed in the risk assessment methodology section, parameters that did not have recorded events in the NCDC database were given the lowest default score (1).

For the 2016 plan update the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. Therefore, to avoid repetition, Table 4.100 provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results.

Table 4.100. 2016 Qualitative Assessment for Earthquakes.					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Possible	Critical	Moderate	Less than 6 hours	Less than one week

XII. Landslides

NOTE: As part of the 2016 plan update, the Landslides hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Landslides are the downward movement of large volumes of surface materials under gravitational influences.[22] Types of movement include: rotational, translational, block, falls, topples, avalanche, earth flow, creep, and lateral spreading.[23] Landslide materials in motion generally consist of fractured or weathered rock, loose or unconsolidated soils, and vegetative debris Landslides may be triggered by both natural and human-caused changes in the environment, including heavy rain, rapid snow melt, steepening of slopes due to construction or erosion, earthquakes, volcanic eruptions, and changes in groundwater levels.

There are several types of landslides: rock falls, rock topple, slides, and flows. Rock falls are rapid movements of bedrock, which result in bouncing or rolling. A topple is a section or block of rock that rotates or tilts before falling to the slope below. Slides are movements of soil or rock along a distinct failure surface. Mudflows, sometimes referred to as mudslides, lahars, or debris avalanches, are fast-moving rivers of rock, earth, and other debris saturated with water. They develop when water rapidly accumulates in the ground, such as heavy rainfall or rapid snowmelt, changing the soil into a flowing river of mud or 'slurry.' Slurry can flow rapidly down slopes or through channels, and can strike with little or no warning at avalanche speeds. Slurry can travel several miles from its source, growing in size as it picks up trees, cars, and other materials along the way. As the flows reach flatter ground, the mudflow spreads over a broad area where it can accumulate in thick deposits.

Among the most destructive types of debris flows are those that accompany volcanic eruptions. A spectacular example in the United States was a massive debris flow resulting from the 1980 eruptions of Mount St. Helens, in the State of Washington. Areas near the bases of many volcanoes in the Cascade Mountain Range of California, Oregon, and Washington are at risk from the same types of flows during future volcanic eruptions.

2. Geographic Location/Extent

In the United States, it is estimated that landslides cause up to $2 billion in damages and from 25 to 50 deaths annually. Globally, landslides cause billions of dollars in damage and thousands of deaths and injuries each year. Figure 4.40 delineates areas where large numbers of landslides have occurred and areas that are susceptible to landslides in the conterminous United States. This map layer is provided in the USGS Professional Paper 1183, "Landslide Overview Map of the Conterminous United States."

While mountainous areas in Virginia are the most susceptible to landslide events, landslide and subsidence hazards do exist elsewhere in the State, including the Northern Virginia region – though these events are quite rare and limited in terms of their impact on people and property. Minor landslide events are possible in localized, steep-sloped areas of the Northern Virginia region during extremely wet conditions. These areas are primarily located in western Loudoun County, as well as some areas of moderate risk in extreme eastern areas of Fairfax and Prince William counties. Figure 4.41 provides a general indication of where landslide events are most likely to occur in Virginia based on landslide incidence and susceptibility data provided by the USGS and mapped by VDEM.

Areas that are generally prone to landslide hazards include: previous landslide areas; the bases of steep slopes; the bases of drainage channels; and developed hillsides where leach-field septic systems are used. Areas that are typically considered safe from landslides include: areas that have not moved in the past; relatively flat-lying areas away from sudden changes in slope; and areas at the top or along ridges, set back from the tops of slopes.

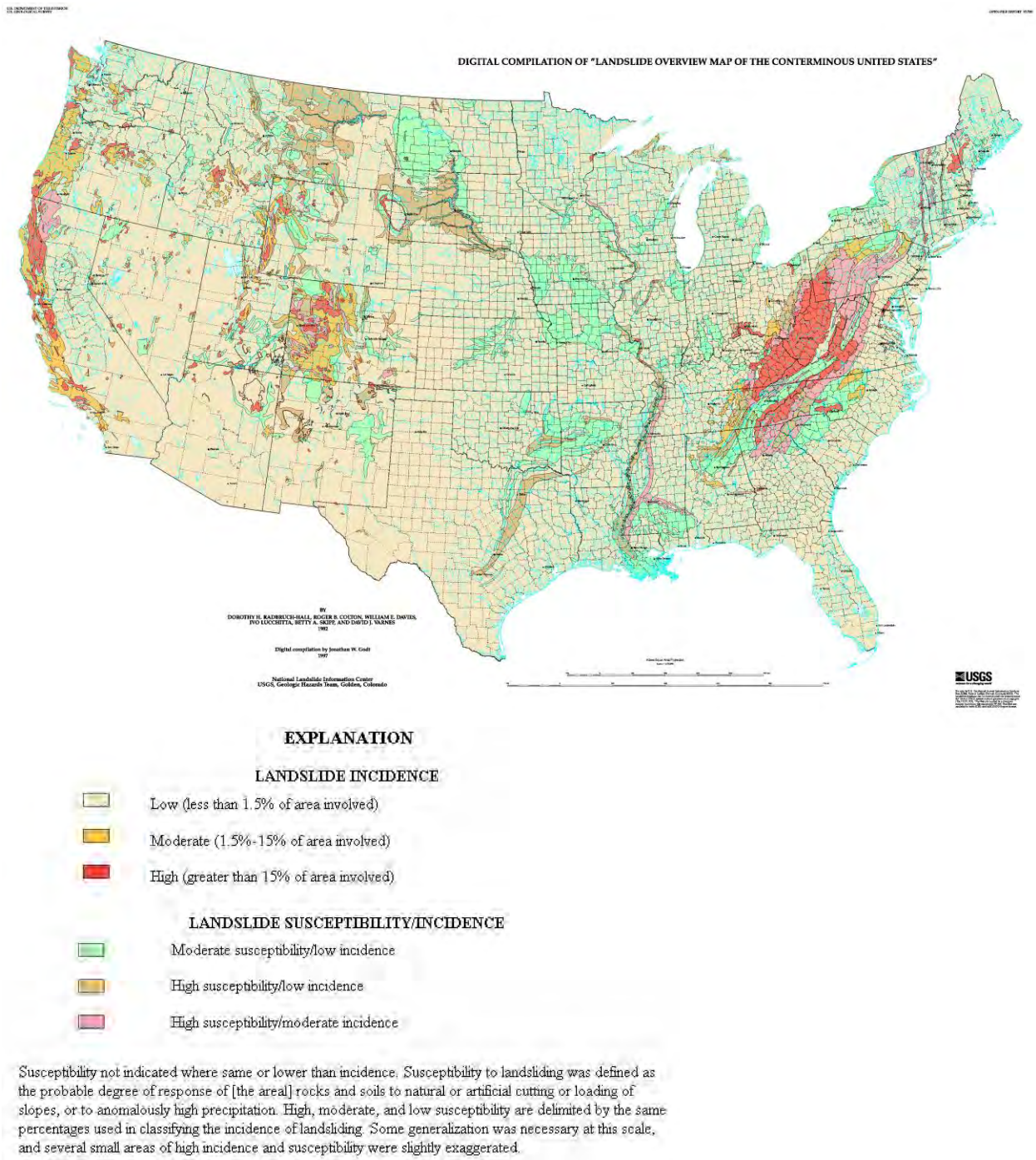

Figure 4.40. Landslide Overview Map of the Conterminous United States.

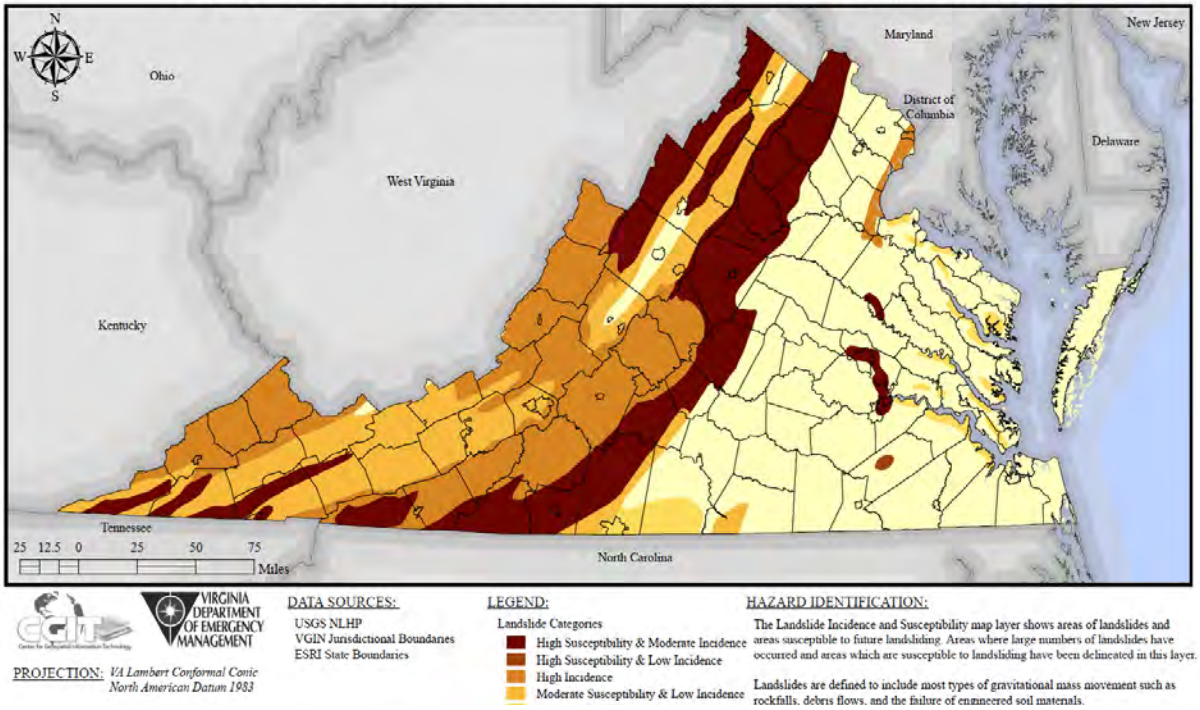

Figure 4.41. Landslide Incidence and Susceptibility.

3. Magnitude or Severity

Landslides are frequently associated with periods of heavy rainfall or rapid snow melt. Such landslides tend to worsen the effects of flooding that often accompanies these weather events. In areas burned by forest and brush fires, a lower threshold of precipitation may initiate landslides. Some landslides move slowly and cause damage gradually, whereas others move so rapidly that they can destroy property and take lives suddenly and unexpectedly.

4. Previous Occurrences

There are no historical records of major landslide events in the Northern Virginia region, as they are relatively uncommon events. No recent incidents were reported for the 2016 update to this plan. Minor landslide events are possible and have been known to occur in localized, steep-sloped areas of the region during extremely wet conditions. Though there are no documented occurrences, landslides are more likely to occur in western portions of Loudoun County than other areas of the region. Small landslides and minor subsidence issues are possible in eastern areas of Fairfax County, possibly due to the presence of marine clay, though no major damages have ever been recorded.

In June 2003, a minor landslide occurred in the Lansdowne area of Loudoun County, breaching a retaining wall, disrupting underground utility lines, and threatening 10 homes. According to local officials this was a very isolated incident brought on by heavy spring rains and should not indicate that the area is prone to recurring landslides.

B. Risk Assessment

The landslide data set shows areas in the United States where large numbers of landslides have occurred and areas that are susceptible to landslides. This data set is a digital representation of USGS Open-File Report 97-289, which is a PDF version of the 1997 USGS Digital representation of Landslide Overview Map (scale 1:4,000,000). The report classifies the major physical subdivision of the United States and assesses the vulnerability based on subdivision characteristics. Figure 4.42 highlights the areas of increased incidence and susceptibility. The purpose of this dataset is to provide a general indication of areas that may be susceptible to sliding. It is not suitable for site selection or local planning initiatives.

As is evident from the following figure, the majority of the planning area falls within a low risk of incidence area, with small portions falling within a high risk of incidence area and the remainder within an area defined as high susceptibility/moderate incidence.

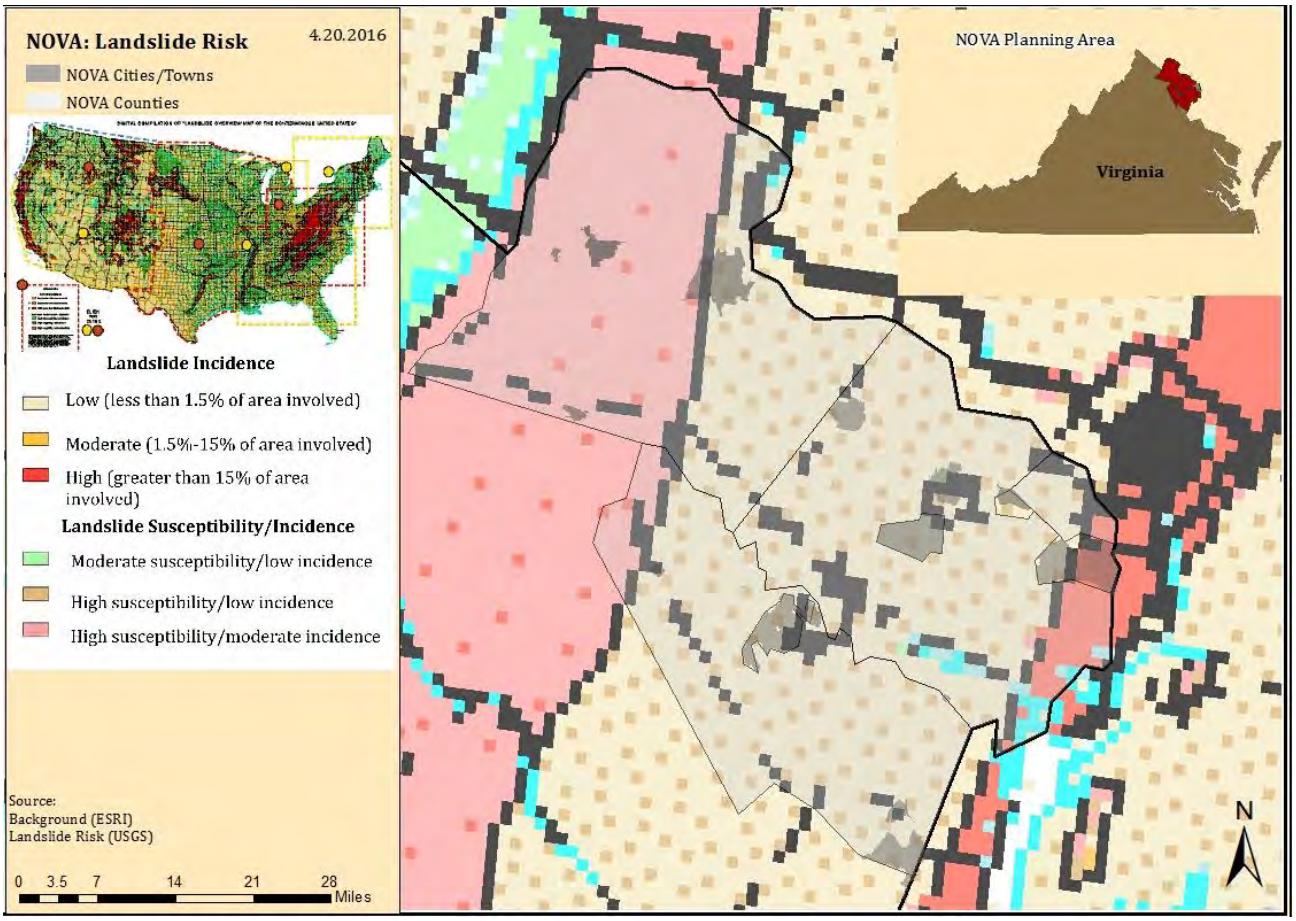

Figure 4.42. Planning Area Landslide Risk.

1. Probability of Future Occurrences

Landslide probability is highly site-specific, and cannot be accurately characterized on a statewide basis, except in the most general sense. Relative risk ranking is intended only for general comparison to the other hazards that impact the region. The magnitude of landslides is dependent on the amount of liquid and landmass in motion and the amount of development in the area. Often a landslide will be more severe in areas with higher slopes and poorly drained soils. Some areas that are generally prone to landslides include old landslide sites, the base of slopes, the base of minor drainage hollows, the base or top of old fill slope, the base or top of a steep cut slope, and developed hillsides where leach field septic systems are used.

2. Impact & Vulnerability

Landslides can cause serious damage to highways, buildings, homes, and other structures that support a wide range of economies and activities. Landslides commonly coincide with other natural disasters. Expansion of urban development contributes to greater risk of damage by landslides.

3. Risk

While some slope stability problems have been associated with marine clay in Fairfax County (marine clay becomes loose as moisture content increases, and is subject to slope creep if the natural slope is steepened during site development) the county has identified areas of marine clay and has established regulations requiring special engineering investigations and design procedures in the areas.

With future growth, various non-structural methods, such as zoning and grading ordinances, as well as structural methods, should be analyzed in terms of cost-effective alternatives. Zoning and grading ordinances to avoid building in areas of potential hazard or to regulate construction to minimize the potential for landslides is one non-structural method to reduce the likely consequences of debris flows. Loudoun County has adopted zoning ordinances preventing the development of building sites with steep slopes along the Blue Ridge (defined in the ordinance as exceeding a 15% grade, equivalent to an eight degree slope), which substantially reduces the hazards of landslides and debris flows within that area.

Critical Facility Risk

Due to the lack of specific data regarding landslides and specific building information in the planning area, the potential risk to critical facilities and existing buildings and infrastructure was not estimated for this plan update.

Existing Buildings and Infrastructure Risk

For the purposes of this risk assessment, potentially at-risk buildings for landslides were not considered due to the fact that the landslide incidence data is highly generalized, owing to the small scale and the scarcity of precise landslide information for much of the country, and is unsuitable for local planning or actual site selection. This precaution should be noted and is applicable to the analysis completed for critical facilities in the landslide zones.

Overall Loss Estimates and Ranking

Due to the lack of any historical landslide damage data and well established occurrence probabilities, damages caused by landslides and associated dollar losses could not be estimated for the 2016 update or any previous version of this plan.

The Commonwealth of Virginia's 2013 Hazard Mitigation Plan ranking was based on the NCDC database. The update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards. While this ranking methodology makes sense for the majority of the hazards in this plan, the data is limited/non-existent for landslides.

Inputs for landslide were very limited as a result of having no landslide events available in the NCDC database. To be able to include landslide in the ranking, some general assumptions were made; geographic extent was the primary basis for establishing risk and was calculated as what percent of the jurisdiction is in the high risk zone, as defined by USGS. In lieu of probability for future occurrence, areas with high landslide risk were assumed to be at greater risk. Since there are no recorded landslide events, the lowest ranking score (1) was assigned to the jurisdictions for events, damages, deaths, and injuries to be able to compare landslide to the other hazards.

For the 2016 plan update the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard. It is possible that Loudoun County may have a slightly higher level of risk to the hazard, but this cannot be determined from the available data and a single occurrence. For practical and planning purposes, the region is assumed to have a uniform qualitative risk of 'Low'. Therefore, to avoid repetition, Table 4.101 below provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results

Table 4.101. 2016 Qualitative Assessment for Landslide.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Unlikely	Critical	Moderate	Less than 6 hours	Less than one week

XIII. Wildfire

NOTE: As part of the 2016 plan update, the Wildfire hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

A wildfire is any fire occurring in a wildland area (i.e., grassland, forest, brush land) except for fire under prescription. Prescription burning, or 'controlled burn,' undertaken by land management agencies is the process of igniting fires under selected conditions, in accordance with strict parameters. Wildfires are part of the natural management of the Earth's ecosystems, but may also be caused by natural or human factors. More than 80% of forest fires are started by negligent human behavior such as smoking in wooded areas or improperly extinguishing campfires. The second most common cause for wildfire is lightning.

There are three classes of wildland fires: surface fire, ground fire, and crown fire. A surface fire is the most common of these three classes and burns along the floor of a forest, moving slowly and killing or damaging trees. A ground fire (muck fire) is usually started by lightning or human carelessness and burns on or below the forest floor. Crown fires spread rapidly by wind and move quickly by jumping along the tops of trees. Wildland fires are usually signaled by dense smoke that fills the area for miles around.

State and local governments can impose fire safety regulations on home sites and developments to help curb wildfire. Land treatment measures such as fire access roads, water storage, helipads, safety zones, buffers, firebreaks, fuel breaks, and fuel management can be designed as part of an overall fire defense system to aid in fire control. Fuel management, prescribed burning, and cooperative land management planning can also be encouraged to reduce fire hazards.

Fire probability depends on local weather conditions; outdoor activities such as camping, debris burning, and construction; and the degree of public cooperation with fire prevention measures. Drought conditions and other natural disasters (tornadoes, hurricanes, etc.) may increase the probability of wildfires by producing fuel in both urban and rural settings. Forest damage from hurricanes and tornadoes may block interior access roads and fire breaks, pull down overhead power lines, or damage pavement and underground utilities.

Many individual homes and cabins, subdivisions, resorts, recreational areas, organizational camps, businesses, and industries are located within high fire hazard areas. The increasing demand for outdoor recreation places more people in wildlands during holidays, weekends, and vacation periods. Unfortunately, wildland residents and visitors are rarely educated or prepared for the inferno that can sweep through brush and timber and destroy property in minutes.

2. Geographic Location/Extent

Wildfires commonly begin unnoticed and spread quickly through vegetative fuels. As discussed in the ranking methodology section, the VDOF risk assessment represents the geographic extent or locations throughout the Commonwealth that have a higher risk for wildfire. The geographic extent score for a given jurisdiction is based on the percent of the jurisdiction that falls within the "high" risk area as defined by VDOF. Fairfax and Prince William Counties have the highest percent of their land area within the high risk classifications as compared to the other jurisdictions in the planning region. Figure 4.43 reflects the VDOF risk assessment and includes the geographic extent parameter used in the hazard ranking. Several areas in Northern Virginia

are conducive to wildfires: the Conway-Robinson State Forest and Prince William Forests Park in Prince William County among them.

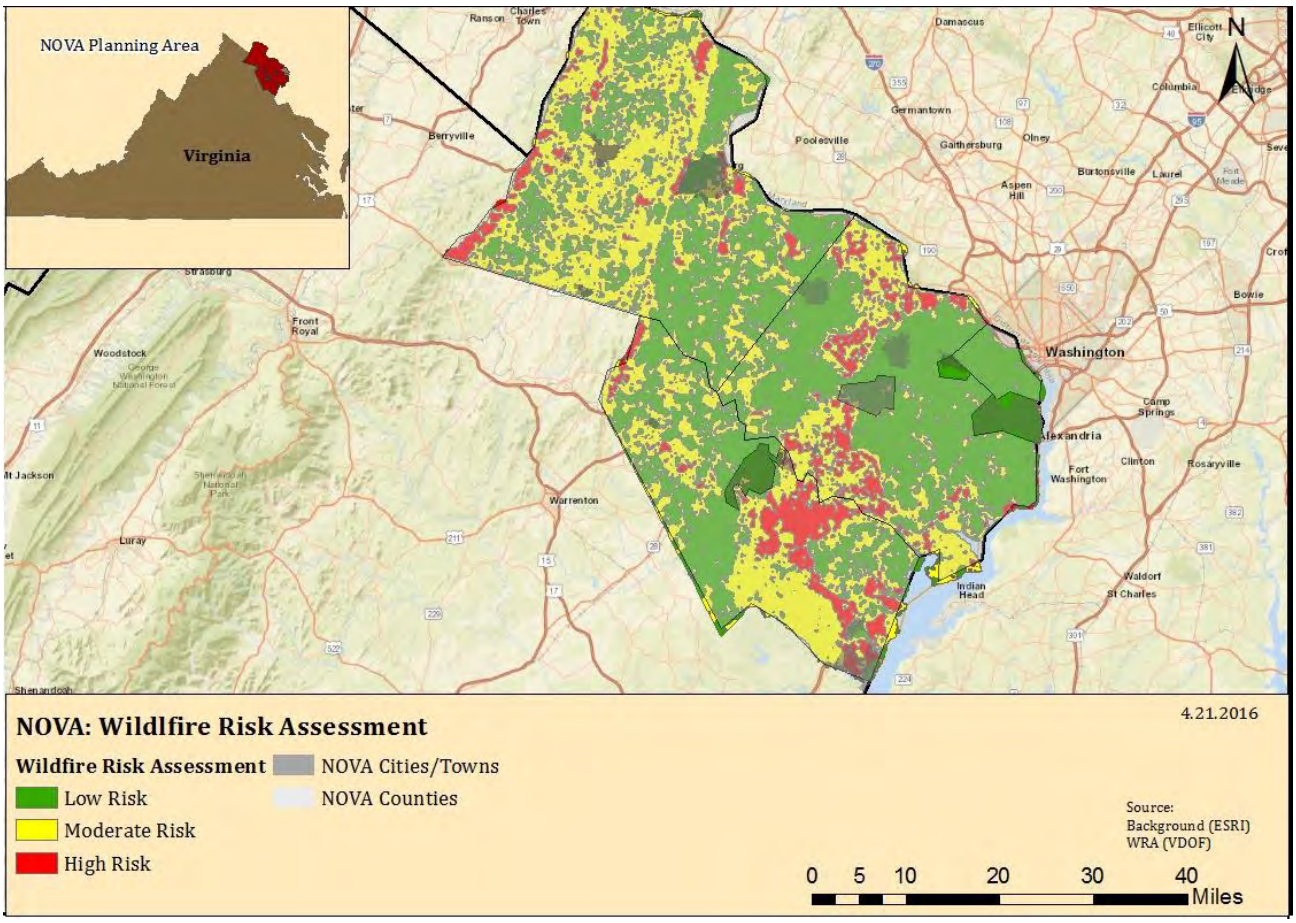

Figure 4.43. VDOF Wildfire Risk Assessment of Northern Virginia.

3. Magnitude or Severity

The Northern Virginia region is not considered as at-risk to wildfire as other areas of the State, but wildfire occurrence is certainly a hazard that does occur. According to VDOF records, there were 141 wildfire events in the Northern Virginia region between 1995 and 2013 (the latest year for which data was available). These fires burned a total of 966 acres, but fortunately caused no deaths or injuries. These fires were typically small in size, burning an average of approximately 16 acres before being suppressed. Of the 141 recorded historical incidents during this period, 16 six fires burned an area greater than 10 acres (all in Loudoun or Prince William County). This is a significant increase in the last few years, as ten of these fires occurred between 2009 and 2013. Table 4.102 lists the number of these fire events, acres burned, and estimated damages by jurisdiction for the Northern Virginia region (where available).

4. Previous Occurrences

While the Commonwealth of Virginia rarely experiences the large, extensive wildfires typically seen in the western regions of the United States, wildfire risk remains a genuine concern. According to the VDOF, as of 2011 (the most recent year for which acreage calculations were

available), about 1,411 wildfires consume an average of 10,181 acres in the State each year. During 2011, Virginia lost more than 22,000 acres to wildfires.

Local records of wildfire occurrences do exist, though the detail recorded in them varies significantly from jurisdiction to jurisdiction. This makes determining if an incident was, in fact, a wildfire and the consequences of that incident difficult to do for comparison purposes. The majority of wildfires that do occur are contained before they grow large, and are handled by local fire resources, which means that the majority of data regarding previous occurrences is stored, in some form, at the local level.

Given the amount of wildland/urban interface acreage within the planning area, it is unsurprising that there are numerous instances where local responders are called upon to deal with wildfires – sometimes multiple times in a single day. For example, on February 19, 2011, Fairfax County responded to a 20-acre wildfire, a 2-acre wildfire, a 5-acre wildfire, and numerous other incidents – all on the same day.

Virginia's wildfire season normally occurs in the spring (March and April) and then again in the fall (October and November). During these times, the relative humidity is usually lower, winds tend to be higher, and the fuels are cured to the point where they readily ignite. Also during these times hardwood leaves are on the ground providing more fuel and allowing sunlight to directly reach the forest floor, warming and drying the surface fuels.

Fire activity fluctuates during each month and also varies from year to year based on precipitation amounts. During years of adequate rain and snow, wildfire occurrence is typically low. Lack of moisture during other years means extended periods of warm, dry, windy days and therefore increased fire activity. The damage caused by Hurricane Isabel in 2003 increased the threat of wildfires in Virginia, and creating a major threat to lives and homes in the eastern half of Virginia for several years to come. The dead and downed timber caused by the storm has had time to cure and could produce wildfires that will be larger and much harder and dangerous to suppress.

Records indicate that most of Virginia's wildfires are caused by people. According to VDOF, the majority of wildfire incidents in the State from 1995 to 2011 (the most recent year for which data was available) occurred because of debris burning – a human-caused activity. Virginia is growing more rapidly than many other States, and its population has more than doubled in the last 50 years. Further, people are moving into residential developments located within forested areas, and there is an increased use of the forests for recreational uses. All of these trends increase the risk of wildfires and require continued fire prevention and protection activities.

There have been 141 wildfire burning 966 acres during 1995 through 2013 (the most recent year for which data was available) totaling at least $180,895 in damages. Table 4.102 shows the total number of fires, acres burned, jurisdictions that had recorded wildfire events by VDOF. Loudoun and Prince William County wildfires make up the majority of damages in Northern Virginia during the period of record (1995-2013).

Table 4.102. Wildfire events in the Northern Virginia Region, 1995-2013, based on VDOF Data.		
Jurisdiction	**Number of Fires**	**Total Acres**
Fairfax County	2	3
Loudoun County	100	379
Town of Leesburg	2	2
Prince William County	36	615
Town of Dumfries	1	6
Total	**120**	**368**

The available data illustrates that majority of the wildfire occurrences in the Northern Virginia region were caused by debris burning and other human activities. Table 4.103 shows the leading causes of wildfires in the region based on VDOF records for the 141 historical wildfires occurring between 1995 and 2013 (the most recent year for which data was available).

Table 4.103. Leading Causes of Wildfires in the Northern Virginia Region, 1995-2013		
Cause	**# of Fires**	**% of Wildfires**
Debris Burning	42	30%
Children	24	17%
Miscellaneous	31	22%
Incendiary	15	10%
Smoking	12	8%
Equipment Use	9	6%
Campfire	2	1%
Lightning	1	1%
Railroad	1	1%
Power Lines	2	1%
Prescribed Burn	1	1%
Firearms/Ammunition	1	1%

Source: VDOF

Based on the number of historical occurrences, wildfires are fairly prevalent events in the Northern Virginia region. These events, however, are usually contained to very small areas and have caused minimal damages to property due to strong fire response and suppression capabilities.

B. Risk Assessment

1. Probability of Future Events

Future wildfire incidents are difficult to predict, as the factors influencing wildfire generation vary greatly with changing weather conditions and human activities. There is currently no quantitative estimate of future wildfire probability for specific regions of the State.

While the VDOF Wildfire Risk Assessment does indicate the relative propensity for wildfires across the State, this assessment does not assign probabilities of occurrence or return intervals as is common with some of the other hazards. Based on available data from VDOF, during the years 1995 – 2011 (the most recent year for which data was available), Virginia experiences an average of 1,141 wildfires per year, affecting an average of 10,181 acres annually.

2. Impact & Vulnerability

Vulnerability to wildfire is influenced by a variety of factors, such as land cover, weather, and the effectiveness of land management techniques. Highly urbanized areas may be less vulnerable to wildfire, but suburban neighborhoods located at the urban/wildland interface are vulnerable to wildfire. The primary impacts of most wildfires are timber loss and environmental damage, although the threat to nearby buildings is always present. Secondary impacts may also include landslides and mudslides caused by the loss of groundcover which stabilizes the soil.

3. Risk

In 2002 and 2003, VDOF used GIS to develop a statewide spatial *Wildfire Risk Assessment* model that aims to: (1) identify areas where conditions are more conducive and favorable to wildfire occurrence and wildfire advancement; (2) identify areas that require closer scrutiny at larger scales; and (3) examine the spatial relationships between areas of relatively high risk and other geographic features of concern, such as woodland home communities, fire stations, and fire hydrants. This model incorporates data from several other State and Federal agencies including land cover, demographics, transportation corridors, and topography to illustrate the level of wildfire risk for all areas across the State of Virginia. The results of this model were merged and the wildfire risks were classified and scored as: 1 (low), 2 (moderate), and 3 (high). This data is presented in Table 4.104.

Prince William County has over 15% of its acreage in the high risk category, with the Town of Round Hill having almost one-third of its acreage at high risk. Fairfax County has approximately 12% of its acreage in the high risk category, with over 16% of the Town of Clifton's area in high risk. The Northern Virginia region is mostly low (48.97%) and medium (41%) risk, with a tenth of the region in the high risk category.

Table 4.104. Wildfire Risk by Jurisdiction

Jurisdiction	Low (acres)	Low % Area	Medium (acres)	Medium % Area	High (acres)	High % Area	Total Acres
Arlington County	16,064	**96.30%**	435	**2.61%**	183	**1.10%**	**16,682**
Fairfax County	143,682	**57.22%**	77,244	**30.76%**	30,174	**12.02%**	**251,100**
Town of Herndon	2,734	***99.93%***	1	***0.04%***	0	***0.00%***	**2,736**
Town of Vienna	2,795	***99.25%***	21	***0.75%***	0	***0.00%***	**2,816**
Town of Clifton	43	***26.06%***	95	***57.58%***	27	***16.36%***	**165**
Loudoun County	136,046	**42.16%**	166,511	**51.60%**	20,114	**6.23%**	**322,672**
Town of Leesburg	4,670	***58.46%***	2,635	***32.98%***	684	***8.56%***	**7,989**

Table 4.104. Wildfire Risk by Jurisdiction							
Jurisdiction	**Low (acres)**	**Low % Area**	**Medium (acres)**	**Medium % Area**	**High (acres)**	**High % Area**	**Total Acres**
Town of Purcellville	278	***13.69%***	1,738	***85.62%***	14	***0.69%***	**2,030**
Town of Middleburg	219	***33.08%***	389	***58.76%***	55	***8.31%***	**662**
Town of Round Hill	0	***0.00%***	165	***69.62%***	71	***29.96%***	**237**
Prince William County	87,118	**39.77%**	98,129	**44.79%**	33,828	**15.44%**	**219,076**
Town of Dumfries	745	***73.40%***	255	***25.12%***	14	***1.38%***	**1,015**
Town of Haymarket	240	***78.43%***	66	***21.57%***	0	***0.00%***	**306**
Town of Occoquan	83	***74.77%***	27	***24.32%***	0	***0.00%***	**111**
Town of Quantico	44	***93.62%***	3	***6.38%***	0	***0.00%***	**47**
City of Alexandria	9,644	**98.83%**	114	**1.17%**	0	**0.00%**	**9,758**
City of Fairfax	3,801	**94.65%**	215	**5.35%**	0	**0.00%**	**4,016**
City of Falls Church	1,275	**100.00%**	0	**0.00%**	0	**0.00%**	**1,275**
City of Manassas	6,130	**95.50%**	287	**4.47%**	2	**0.03%**	**6,419**
City of Manassas Park	741	**65.29%**	265	**23.35%**	129	**11.37%**	**1,135**
TOTAL	**416,352**	**48.97%**	**348,595**	**41.00%**	**85,295**	**10.03%**	**850,247**

Critical Facility Risk

The US Forest Service offers a product called the Wildfire Hazard Potential (WHP) map. This product is a raster geospatial product that can help to inform evaluations of wildfire risk across large landscapes. On its own, the WHP is not an explicit map of wildfire threat or risk, but when paired with data depicting highly valued local resources and assets – such as critical facilities – it can provide approximate relative wildfire risk to those resources and assets.

The locally-provided critical and historical facilities data was intersected with the US Forest Service's wildfire hazard potential to determine which facilities were at an increased risk for wildfire, or being in the urban/wildland interface. Figure 4.44 illustrates the current estimates for wildland fire potential throughout the Northern Virginia region. Figure 4.45 illustrates the location of locally-identified critical facilities within the fire potential estimates. As can be seen in these images, the majority of the region falls within areas currently classified as having very low or low potential for wildfire, with other significant amounts of areas classified as non-burnable.

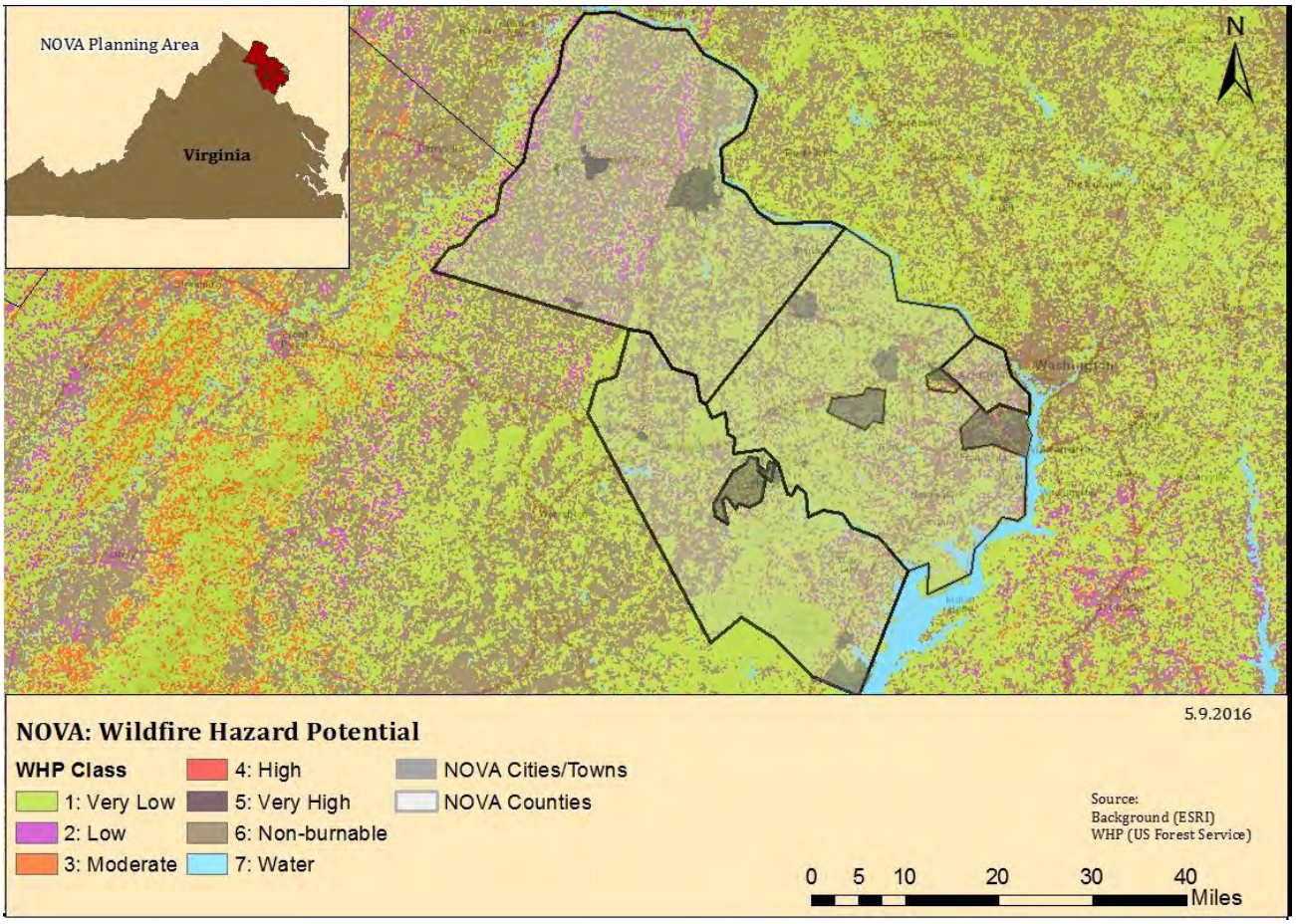

Figure 4.44. Wildfire Hazard Potential for Northern Virginia, based on USFS data.

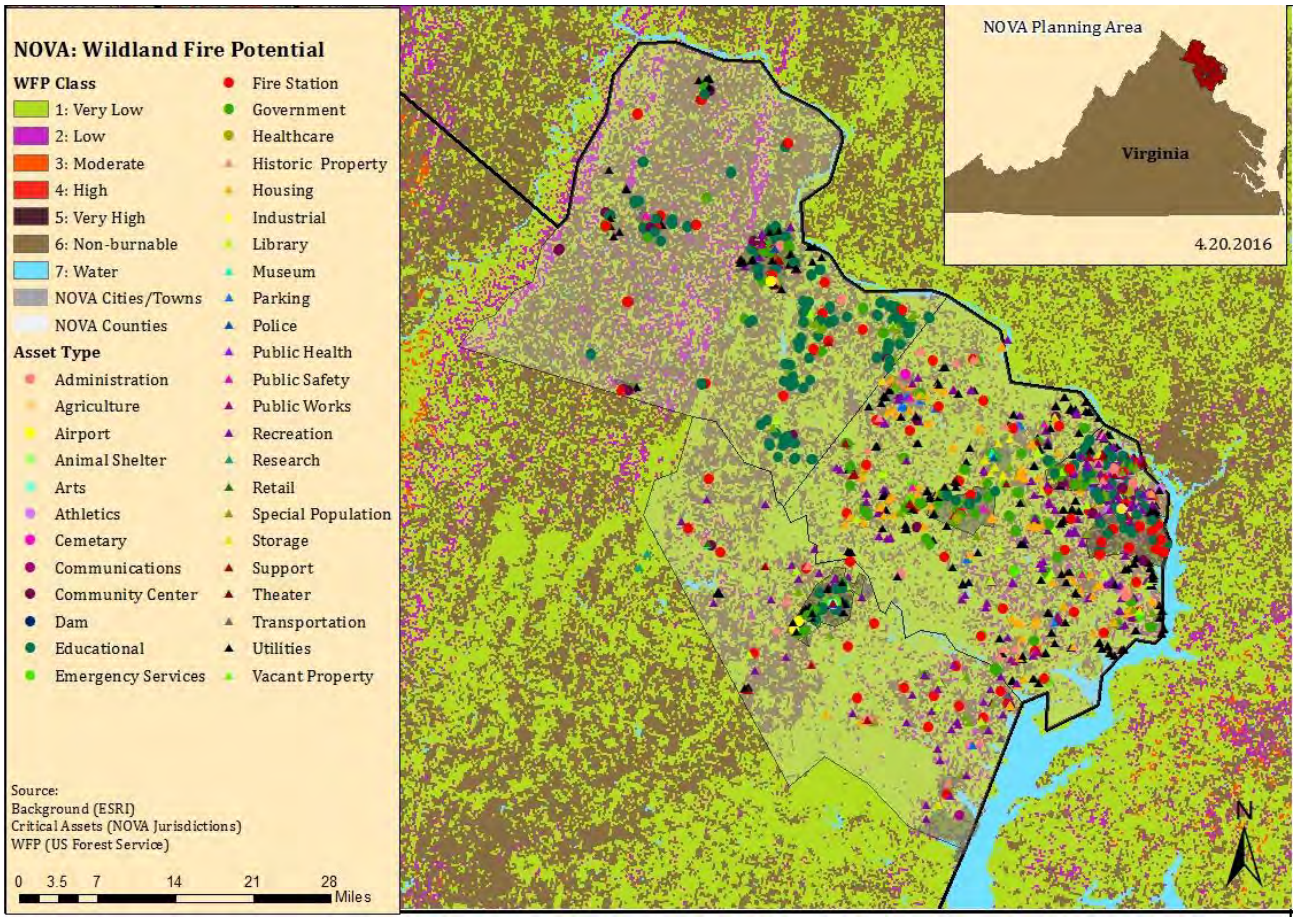

Figure 4.45. Wildfire Hazard Potential for Northern Virginia – With Critical Facilities.

Table 4.105 shows the number of critical facilities, by locality, and the corresponding wildfire potential for their location. The names and information for the local critical facilities in the wildfire risk zones are available in the Critical Facility-Risk Appendix D. Figures for each participating jurisdiction can also be found in Appendix D. The lack of wildfire probabilities and detailed infrastructure data led to the inability to calculate potential losses due to wildfire.

Table 4.105. Wildfire Hazard Class Exposure for Locally-Provided Critical and Historic Assets

Jurisdiction	WHP Class	Asset Value	Contents Value	Total Value of Exposure
Arlington County	Non-burnable or Water	$976,001,803	$96,448,098	$1,072,449,901
	Very Low	$600,313,587	$107,401,659	$707,715,246
	Low	$47,190,500	$3,209,400	$50,399,900
	Undefined	$81,600	$2,000	$83,600
	Subtotal	*$1,623,587,490*	*$207,061,157*	*$1,830,648,647*
Fairfax County	Non-burnable or Water	$1,281,440,265	$157,830,545	$1,439,270,810
	Very Low	$583,864,501	$53,541,788	$637,406,289
	Low	$32,697,355	$4,364,984	$37,062,339
	Undefined	$161,505,240	$15,975,815	$177,481,055

Table 4.105. Wildfire Hazard Class Exposure for Locally-Provided Critical and Historic Assets				
Jurisdiction	**WHP Class**	**Asset Value**	**Contents Value**	**Total Value of Exposure**
	Subtotal	*$2,059,507,361*	*$231,713,132*	*$2,291,220,493*
Loudoun County	Non-burnable or Water	$1,087,409,540	$1,087,409,540	$2,174,819,080
	Very Low	$1,093,424,340	$1,093,424,340	$2,186,848,680
	Low	$1,141,390	$1,141,390	$2,282,780
	Subtotal	*$2,181,975,270*	*$2,181,975,270*	*$4,363,950,540*
Prince William County	Non-burnable or Water	$463,216,250	$78,327,055	$541,543,305
	Very Low	$107,653,000	$6,417,385	$114,070,385
	Subtotal	*$570,869,250*	*$84,744,440*	*$655,613,690*
City of Alexandria	Non-burnable or Water	$13,455,000	$5,000,000	$18,455,000
	Very Low	$257,461,735	$59,000,000	$316,461,723
	Low	$25,434,825	$0	$25,434,825
	Subtotal	*$296,351,560*	*$64,000,000*	*$360,351,560*
City of Fairfax	Non-burnable or Water	$194,474,176	$0	$194,474,176
	Subtotal	*$194,474,176*	*$0*	*$194,474,176*
City of Falls Church	Non-burnable or Water	$71,530,100	$0	$71,530,100
	Very Low	$1,860,200	$0	$1,860,200
	Subtotal	*$73,390,300*	*$0*	*$73,390,300*
City of Manassas	Non-burnable or Water	$181,079,188	$49,562,538	$230,641,726
	Very Low	$175,569,875	$24,132,350	$199,702,225
	Subtotal	*$356,649,063*	*$73,694,888*	*$430,343,951*
City of Manassas Park	Non-burnable or Water	*$38,897,500*	*$0*	*$38,897,500*
	Very Low	*$61,770,900*	*$0*	*$61,770,900*
	Subtotal	*$100,668,400*	*$0*	*$100,668,400*
Town of Clifton	Non-burnable or Water	$0	$0	$0
	Very Low	$0	$0	$0
	Subtotal	*$0*	*$0*	*$0*
Town of Haymarket	Non-burnable or Water	$3,671,280	$203,863	$3,875,143
	Very Low	$324,353	$2,014	$326,367
	Subtotal	*$3,995,633*	*$205,877*	*$4,201,510*
Town of Herndon	Non-burnable or Water	$30,010,198	$2,780,084	$32,790,282
	Very Low	$17,103,282	$2,459,867	$19,563,149
	Subtotal	*$47,113,480*	*$5,239,951*	*$52,353,431*
Town of Leesburg	Non-burnable or Water	$91,153,261	$28,138,520	$119,291,781
	Very Low	$53,707,958	$17,131,332	$70,839,290
	Low	$1,783,300	$1,997,900	$3,781,200

Table 4.105. Wildfire Hazard Class Exposure for Locally-Provided Critical and Historic Assets				
Jurisdiction	**WHP Class**	**Asset Value**	**Contents Value**	**Total Value of Exposure**
	Subtotal	*$146,644,519*	*$47,267,752*	*$193,912,271*
Town of Lovettsville	Very Low	$164,950	$164,950	329,900
	Subtotal	*$164,950*	*$164,950*	*329,900*
Town of Middleburg	Non-burnable or Water	$675,400	$675,400	$1,350,800
	Very Low	$191,700	$191,700	$383,400
	Low	$6,220	$6,220	$12,440
	Subtotal	*$873m320*	*$873,320*	*$1,746,646*
Town of Occoquan	Non-burnable or Water	$1,645,900	$0	$1,645,900
	Very Low	$320,300	$30,000	$350,300
	Subtotal	*$1,966,200*	*$30,000*	*$1,006,200*
Town of Purcellville	Non-burnable or Water	$2,015,900	$2,015,900	$4,031,800
	Very Low	$3,246,770	$3,246,770	$6,493,540
	Subtotal	*$5,262,670*	*$5,262,670*	*$10,525,340*
Town of Round Hill	Non-burnable or Water	$386,370	$386,370	$772,740
	Subtotal	*$386,370*	*$386,370*	*$772,740*
Town of Vienna	Non-burnable or Water	$25,875,000	$1,945,000	$27,820,000
	Very Low	$6,925,000	$750,000	$7,675,000
	Subtotal	*$32,800,000*	*$2,695,000*	*$34,495,000*
Total Exposure	**Non-burnable or Water**	**$4,280,937,131**	**$1,510,722,913**	**$5,973,660,044**
	Very Low	**$2,963,902,451**	**$1,368,280,525**	**$4,332,182,006**
	Low	**$108,253,590**	**$184,537,720**	**$1,480,253,006**
	Undefined	**$161,586,840**	**$2,398,931,432**	**$5,516,919,344**

Existing Buildings and Infrastructure Risk

As demonstrated above and in the critical facility analysis, most of the wildfire risk in the Northern Virginia region is located in areas of Loudoun and Prince William counties. Historically, wildfires have been larger and caused more damages in these counties mainly due to not only increased vegetative fuel loads, but also because the areas are sparsely settled and have less rapid fire response capabilities. The most at-risk properties within these areas are considered to be those structures located along the wildland-urban interface, defined by the National Wildfire Coordinating Group[24] as "the line, area or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels." Structures with combustible roofs and less than 30 feet of cleared defensible space are particularly at risk.

Overall Loss Estimates and Ranking

Between 1995 and 2013 (the most recent year for which data was available), the VDOF recorded 141 wildfire events in the Northern Virginia. Table 4.106 shows the specific annualized number of fires by jurisdiction. This is based on the total VDOF reported damages divided by the number of years of record.

Table 4.106. Annual Number of Wildfires Annualized, based on VDOF data, 1993 – 2013.

Jurisdiction	Annualized Number of Fires
Fairfax County	0.11
Loudoun County	5.55
Town of Leesburg	0.11
Prince William County	2.0
Town of Dumfries	0.05

No wildfire events were recorded in the NCDC database for the Northern Virginia region; as a result, no NCDC annualized loss estimate was calculated**.** The Commonwealth of Virginia's 2013 Hazard Mitigation Plan ranking was based on the VDOF data. The update to the Northern Virginia plan used this same framework to establish a common system for evaluating and ranking hazards.

For the 2016 plan update the qualitative assessment was organized by jurisdiction. Based on the data available, Prince William and Loudoun Counties and their associated participating towns were determined to have different risks than all other participating jurisdictions, that of 'Moderate', while all other participating jurisdictions were determined to be 'Low'. To avoid repetition, all other participating jurisdictions are represented below in a single table, and Loudoun and Prince William Counties (and their associated participating towns) are represented in standalone tables.

Loudoun County and the Town of Leesburg, the Town of Lovettsville, the Town of Purcellville, the Town of Middleburg, and the Town of Round Hill; Prince William County and the Town of Dumfries, the Town of Haymarket, the Town of Occoquan, and the Town of Quantico

Table 4.107. 2016 Qualitative Assessment for Wildfire

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Likely	Critical	Moderate	Less than 6 hours	Less than one week

Arlington County and the Town of Clifton, the Town of Herndon, and the Town of Vienna; Fairfax County, the City of Alexandria; the City of Fairfax; the City of Falls Church; the City of Manassas; and the City of Manassas Park.

Table 4.108. 2016 Qualitative Assessment for Wildfire

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Unlikely	Critical	Small	Less than 6 hours	Less than one week

XIV. Sinkholes / Karst / Land Subsidence

NOTE: As part of the 2016 plan update, the Sinkholes/Karst/Land Subsidence hazards were reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Sinkholes are a frequent occurrence in areas underlain by calcareous carbonate formations, especially limestone and dolomite. Groundwater flow through cracks, fissures, joints, and other discontinuities in the rock mass dissolves the carbonate minerals creating small voids. Over time continued water seepage and dissolution of minerals enlarges the void to form caves and caverns in the rock. As the void increases in size, so does the load supported by the void roof. If the strength of the roof layer becomes less than the weight of the material above it the roof fails and the overburden materials collapse into the void. If the collapse manifests itself at the surface, the resulting depression is referred to as a sinkhole. Other calcareous carbonate materials include partially-cemented to well-cemented shell formations found in coastal areas of the southeastern United States.

The process of sinkhole formation depends on a complex set of variables including geologic structure, geochemistry, hydrologic conditions, and development activity. If the roof above the void is sound rock and the water level falls below the roof level, future growth of the void may not reduce the roof thickness and collapse may not occur. However, if the roof rock is fractured or otherwise cracked, shallow groundwater from above can flow into the void bringing with it eroded overburden soil. The erosion of overburdened soil into the rock void creates a similar soil void that can migrate to the surface, resulting in a collapse of the soil roof even though the underlying rock has not collapsed.

Changes in hydrologic conditions, natural or man-made, can increase the occurrence of sinkholes. An increase in the volume and/or velocity of flow through the rock provides more fresh water to dissolve soluble minerals and more energy to erode solid particles, increasing existing voids or creating new ones. Water supply and open pit mining are common reasons for pumping large volumes of water through soluble calcareous formations.

Sink holes vary in size, ranging from a few feet to a mile or more in diameter. Sink holes can reach several hundred feet below the surface. Areas of abundant sinkholes are referred to as karst topography. Karst areas have few surface streams as drainage is primarily through underground solution channels.

Sinkholes can also occur due to the impacts of constructed facilities in most geologic environments, including those not underlain by calcareous carbonate rocks. Undetected leaks in underground utility lines can result in subsurface erosion of soil from around the pipe. Left undetected, the erosion creates a void that expands upward until the soil roof cannot support the overburden load and the roof collapses.

2. Geographic Location/Extent

Sinkholes are prevalent in the Great Valley region of central Virginia, including karst terrains in the Shenandoah Valley where voids are formed by the natural dissolution of soluble rock such as limestone and dolomite.

According to the Virginia Department of Mines, Minerals and Energy, sinkholes are very rare in the Northern Virginia region and do not pose a significant risk. However, a band of metamorphosed limestone, dolostone, and marble located in eastern Loudoun County and the Town of Leesburg has a history of sinkhole activity. Figure 4.46 shows the karst regions and areas of historical subsidence in the Commonwealth, based on the USGS Engineering Aspects of Karst. The karst regions in Northern Virginia are considered short karst type, which include fissured, tube, and caves generally less than 1,000 feet long; and 50 feet or less in vertical extent.

Loudoun County has a region of karst geology located in an area roughly one mile on either side of State Route 15 from just south of Leesburg, north to the Potomac River bridge. The region is bounded sharply to the west by the Bull Run Fault, which runs at the base of Catoctin Mountain through Loudoun County. Figure 4.47 shows the limestone district for Loudoun County. The Limestone Overlay District (LOD) is primarily comprised of the following geologic formations:

- Cf-Frederick Limestone;
- Ct-Tomstown Dolomite;
- JTRc-Catharpin Creek Formation;
- JTRcg-Catharpin Creek Formation Goose Creek Member;
- TRbl-Balls Bluff Siltstone Leesburg Member; and
- TRbs-Balls Bluff Siltsone Fluvial and Deltaic Sandstone Member.

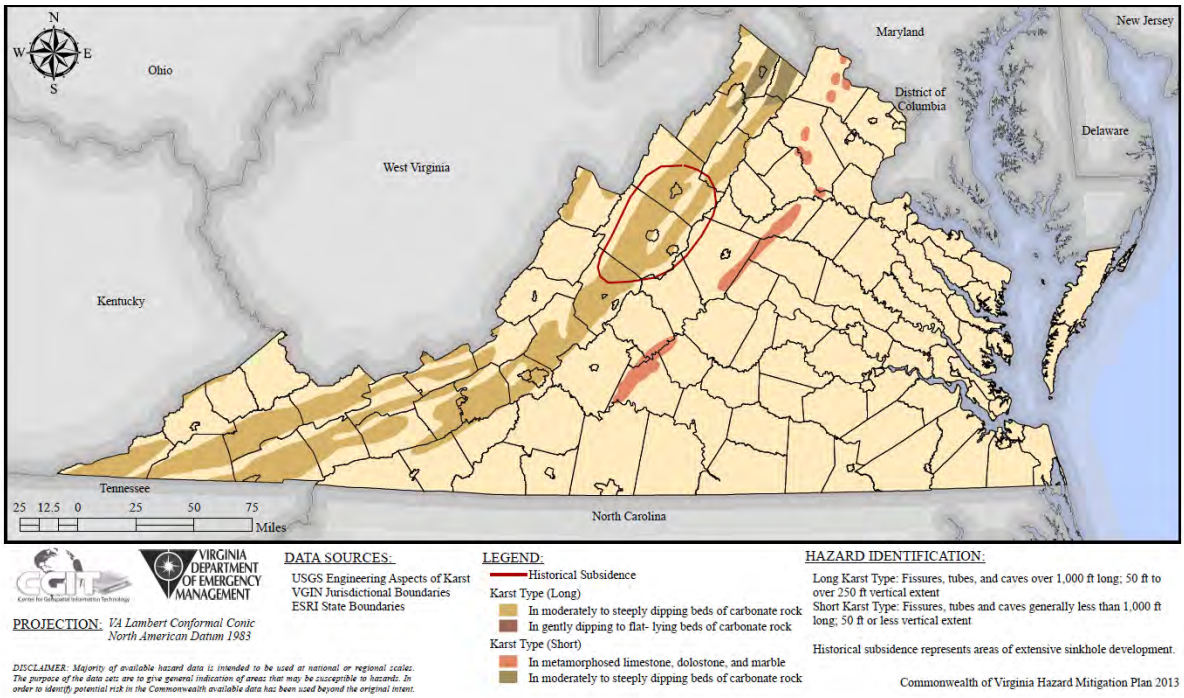

Figure 4.46. Karst Regions and Historical Subsidence in Virginia.
Source: Commonwealth of Virginia Hazard Mitigation Plan

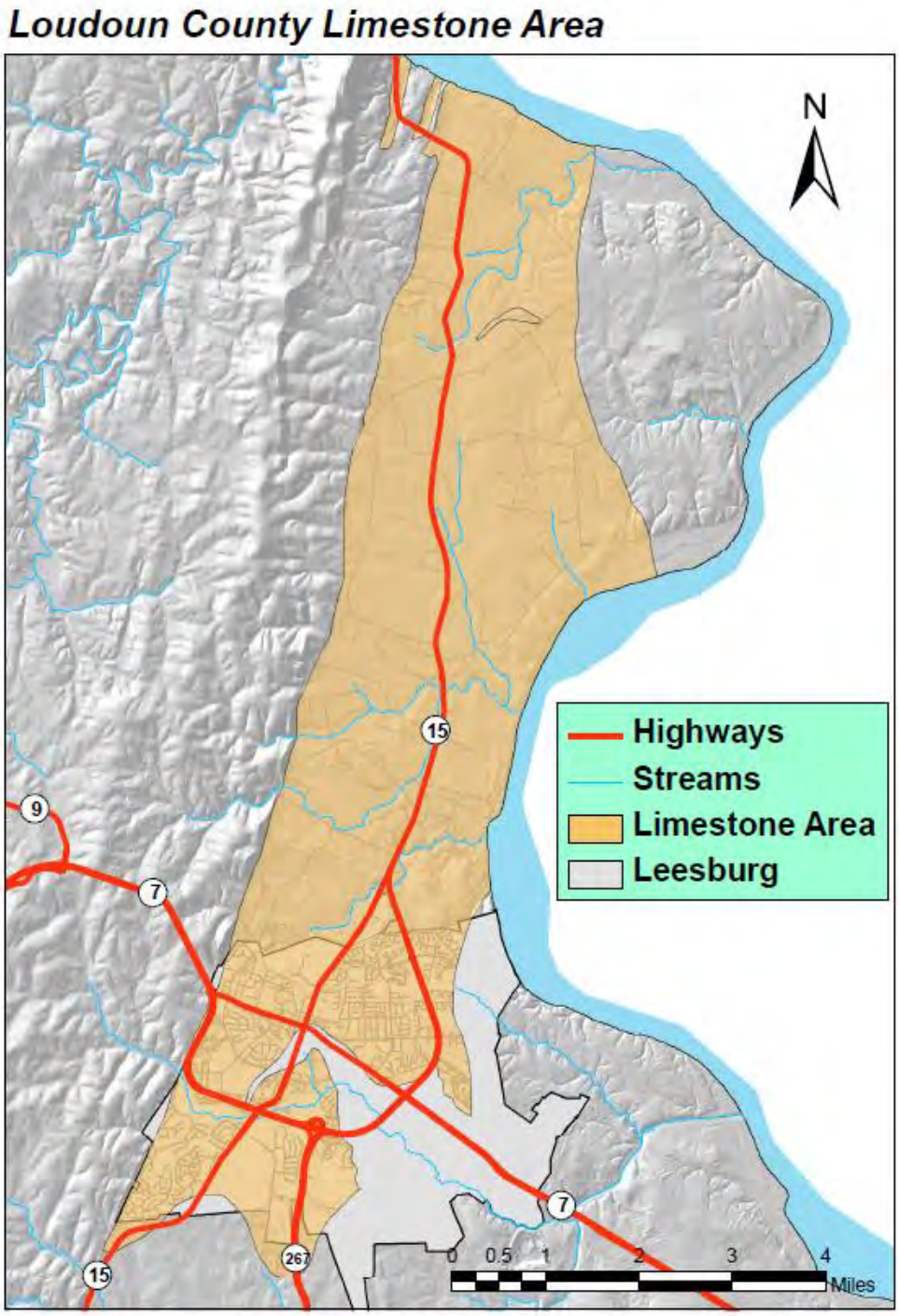

Figure 4.47. Loudoun County limestone district.
Source: Loudoun County

3. Magnitude or Severity

Although sinkholes frequently occur without notice, there are warnings of potential sinkhole development including:

- Slumping or leaning fence posts, utility poles, trees, etc.;
- Discolored vegetation;
- Tension crack visible in the ground surface;
- Discolored well water;
- New cracks in building walls and/or; and
- Newly sagging floors or pavements.

Sinkhole formation is aggravated and accelerated by urbanization. Development increases water usage, alters drainage pathways, overloads the ground surface, and redistributes soil. According to FEMA, the number of human-induced sinkholes has doubled since 1930, costing nearly $100 million. The increasing frequency of sinkholes could be affected by reporting biases. A paper published by the USGS, Tampa, Florida shows a significant increase in sinkhole development that corresponds to a period of drought. Changes in ground water levels increase the overburden stress on the void roof increasing the potential for roof collapse. Thus using that period as indicating a larger trend may not be appropriate, especially given the context of the initial data. Additionally, Florida data suggests that the jump in sinkhole development in the 1987 to 1991 period was caused, at least in part, by natural events. Further, the reason for the jump in insurance payouts is likely the result of naturally caused sinkholes occurring under more expensively developed real estate[25].

4. Previous Occurrences

Water leaking from culverts or other drainage structures can create a void beneath the drainage structure by compaction or internal scour of the soil. This reduction in support can result in displacement of the leaking structure and an increase in leakage or breakage. The void may increase in size to the extent that the soil has insufficient strength to support itself with subsequent failure, leading to the formation of a steep sided, collapsed sinkhole.

Sinkholes remain a possible occurrence in localized areas of the Northern Virginia region. To date, there have been no Federal Declared Disasters or NCDC recorded events for karst related events.

In April 2015, a sinkhole opened in the Exeter Community of Loudoun County. The hole, which measured approximately 30 by 40 feet, formed in the parking lot of a townhouse community, and caused some damages, including the sinking of the roadway and disruption of water service to approximately 65 structures in the area. Reports indicate this was the second sinkhole in this same area in the previous two decades.

Other known events, although not comprehensive, include:

- Heavy rain caused the collapse of a major thoroughfare in Loudoun County in June 2014. The collapse occurred on Dry Mill Road and exposed a 48-inch water main, and resulted in a five-mile detour for motorists.

- A sinkhole 20 feet deep and 25 feet wide closed down Dale Boulevard west of Mapledale Avenue, about four miles from Interstate 95 in Prince William County (2008).
- August 11, 2001, heavy rainfall washed out a culvert and created a sinkhole in Arlington County, though no damages were reported.

B. Risk Assessment

The Engineering Aspects of Karst data set shows areas of karst in the United States. This data set is a digital representation of USGS Open-File Report 2004-1352, which is a PDF version of the 1984 USGS Engineering Aspects of Karst map (scale 1:7,500,000). These maps depict areas containing distinctive surficial and subterranean features, developed by solution of carbonate and other rocks and characterized by closed depressions, sinking streams, and cavern openings. Loudoun County and the Town of Leesburg are the only areas in the planning region that have been included in the USGS Engineering Aspects of Karst.

David Hubbard, geologist with the Virginia Department of Mines, Minerals, and Energy developed 1:24,000 scale sinkhole boundary maps during 1980 and 1988 for the State. Sinkhole distribution is shown in three main regions along the Valley and Ridge province. A total of 48,807 sinkholes have been mapped over 254 standard (7.5 minute) topographic maps for an average of 192.1 sinkholes per map. The southern third of the project area represented more than half of the mapped location. There appears to be an increase in the relative degree of karstification from north to south across the State of Virginia[26]. These maps are not currently available in digital format. Additional analysis may be able to be completed in future versions of this plan as digital data becomes available.

In May 2010, Loudoun County re-adopted and re-enacted the LOD. In February 2010 the Board of Supervisors adopted amendments to the Zoning Ordinance Zoning Map, Facilities and Standards Manual, the land Subdivision & Development Ordinance, and other county ordinances to create the LOD. The amendments will implement the County's adopted Comprehensive Plan provisions concerning limestone areas by creating and mapping a new LOD and amending Section 6-407(A) of the Zoning Ordinance to add a LOD to the list of environmental overlay districts for which the Zoning Administrator is authorized to make cartographic interpretations, and amending Article 8, Definitions, of the Zoning Ordinance to add and/or revise definitions for uses and terminology used in the proposed amendments.

1. Probability of Future Occurrences

The exact time that land subsidence will occur cannot be predicted; it can occur suddenly without warning or over an extended period of several years. However, some factors that can cause a decrease in strength are wet conditions, vibrations, and increased surface loading. Land subsidence that occurs as a result of a drawdown of the groundwater table is likely to take place over a number of years. Procedures for predicting the occurrence of land subsidence have not yet been developed.

To be able to include karst in the risk assessment some general assumptions were made. Geographical Extent, using USGS Karst Topography maps, was the primary basis for establishing risk and was calculated as a percent of the jurisdictional area. In lieu of probability of future occurrence, areas with more karst were assumed to be at greater risk.

2. Impact & Vulnerability

The potential impacts of land subsidence depend on the type of subsidence that occurs (regional or localized, gradual or sudden) and the location that the subsidence occurs. The impacts of subsidence occurring in nonurban areas are likely to be less damaging than subsidence that occurs in heavily populated locations. The amount of structural damage depends on the type of construction, the structure location and orientation with respect to the subsidence location, and the characteristics of the subsidence event (sag or pit).

Potential impacts from land subsidence could include damage to residential, commercial, and industrial structures; damage to underground and above-ground utilities; damage to transportation infrastructure, including roads, bridges, and railroad tracks; as well as damage or loss of crops. The extent and value of the potential damage cannot be assessed because the nature of the damage is site- and event-specific.

3. Risk

As discussed previously, sinkholes are relatively uncommon events in the Northern Virginia region. The existing soil types are not conducive to creating natural sinkholes, and those that do occur are related to soil piping or the dissolution of sparse carbonate rock and typically cause very little damage. There are no known sources of sinkhole probability data for the region and no record of historical incidences causing property damages.

As previously mentioned, Loudoun County has adopted a LOD in their zoning ordinance that seeks to preserve and protect the unique geologic characteristics and the quality of the groundwater in its limestone area. The ordinance is intended to regulate land use and development in areas underlain by limestone and in areas with Karst features and Karst terrain in such a manner as to[27]:

- Protect the health, safety and welfare of the public;
- Protect groundwater and surface water resources from contamination; and
- Reduce potential for property damage resulting from subsidence or other earth movement.

Critical Facility Risk

The vulnerability of each identified critical facility was assessed using GIS analysis by comparing their physical location with the extent of known hazard areas that can be spatially defined through GIS technology. Of those critical facilities identified in the region, some were indeed determined to be in known hazard areas upon further GIS analysis and thereby determined to be 'potentially at-risk.'

Loudoun County maintains a karst feature database (the mapped karst features in the County are the developer's responsibility to provide necessary information to determine if all the requirements or ordinances and provisions have been met). For applications within the LOD, all documentation and studies are outlined in Section 4-1900 of the zoning ordinance. This organization allows Loudoun County to significantly reduce risk of sinkhole development to facilities, property, and people.

Using the Limestone Layer available through Loudoun County's website, mapped critical assets in Loudoun County were viewed via the County's GIS portal. Of the mapped critical assets, which include schools, fire stations, police stations, other public safety assets, and emergency medical assets, at least one fire station was found to be located within the known limestone area of Loudoun County. Figure 4.48 provides this graphic; the area identified as limestone is indicated in pink on the image.

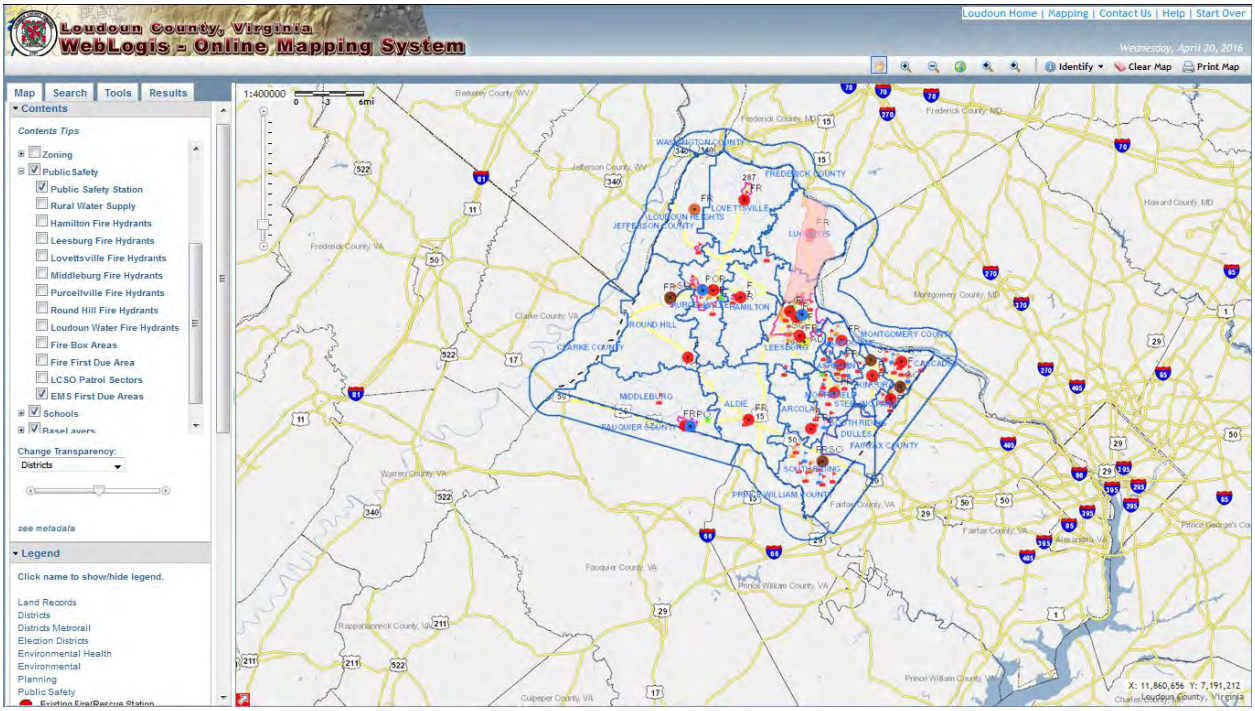

Figure 4.48. Loudoun County Limestone and Critical Assets Map.

Existing Buildings and Infrastructure Risk

Loss estimates could not be calculated for land subsidence events due to a lack of detailed and accurate information regarding structures and assets located in the previously determined hazard areas. In addition, due to the extremely localized and site specific nature of typical subsidence events, any inventory of potential at risk structures may grossly over-estimate potential losses.

Overall Loss Estimates and Ranking

As stated above, loss estimates could not be calculated for land subsidence events due to a lack of historical data causing property damages and probability of future occurrences.

There are currently no karst related records in NCDC; as a result, the lowest ranking score (1) was assigned to the annualized data for events, damages, and deaths and injuries to be able to compare karst to the other hazards, as described in Risk Assessment Methodology section. Refer to the Risk Assessment Methodology section of the HIRA for a full description of the methodology and the limitations of the data used for ranking the hazards.

For the 2016 plan update the qualitative assessment was organized by jurisdiction. The hazard ranking for land subsidence is based on events reported and a generalized geographic extent. As

previously discussed, Loudoun County and the Town of Leesburg has a slightly elevated risk due to the short karst features in the region, resulting in a vulnerability ranking of 'Moderate', compared to 'Low' for all other participating jurisdictions in the planning area. Loudoun County has ordinances in place to help mitigate their risk to this hazard.

Loudoun County and the Town of Leesburg

Table 4.109. 2016 Qualitative Assessment for Sinkholes					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Moderate	Moderate	Low	6 to 12 hours	Less than one week

All Other Jurisdictions

Table 4.110. 2016 Qualitative Assessment for Sinkholes					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Low	Moderate	Low	6 to 12 hours	Less than one week

XV. Dam Failure

NOTE: As part of the 2016 plan update, the Dam Failure hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining the number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) updating the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4, Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Worldwide interest in dam and levee safety has risen significantly in recent years. Aging infrastructure, new hydrologic information, and population growth in floodplain areas downstream from dams and near levees have resulted in an increased emphasis on safety, operation, and maintenance. The distinction between dams and levees is their purpose: dams are constructed to impound water behind them and levees are constructed to keep water out of the land behind them.

There are about 87,000 dams in the United States today, the majority of which are privately owned. Public owners include State and local authorities, and Federal agencies. The benefits of dams are numerous: they provide water for drinking, improved waterway navigation,

hydroelectric power, flood control, and agricultural irrigation. Dams also provide enhanced recreation opportunities.

2. Geographic Location/Extent

The National Inventory of Dams (NID) was developed by the U.S. Army Corps of Engineers (USACE) in cooperation with FEMA's National Dam Safety Program. The full inventory contains over 87,000 dams, and is used to track information on the country's water control infrastructure.

According to the NID, there are 11 major dams located in the Northern Virginia region and 133 non-major dams. Major dams are defined as dams being 50 feet or more in height, or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more. The state regulatory agency for dams is the Virginia Department of Conservation and Recreation (DCR) through the Dam Safety and Floodplain Management Program. In addition to the 11 major dams discussed here, the DCR tracks and regulates a number of other smaller dams (e.g., farm pond impoundments, etc.) that present less severe hazard threats. The DCR maintains additional data on State-regulated dams in the Northern Virginia region, as well as information on the potential impact of failure. There are no major levees located in the Northern Virginia region.

Both the NID and the DCR use the same classification terminology to categorize the hazard potential of dams – high, significant, or low. This classification can change over time, as it is tied to how the failure of the dam may lead to loss of life and property downstream in the event of failure. Hazard potential is unrelated to the structural integrity of the dam; rather, it is directly related to the potential adverse downstream impacts should the dam fail. The classifications are described by the DCR as follows:

High – Dams that upon failure would cause probably loss of life or serious economic damage.
Significant – Dams that upon failure might cause loss of life or appreciable economic damage.
Low – Dams that upon failure would lead to no expected loss of life or significant economic damage. Special criteria: This classification includes dams that upon failure would cause damage only to the property of the dam owner.

Of the 11 major dams located in the region, six are classified as high hazards where failure of the dam may cause loss of human life. Another four major dams are classified as significant hazards, where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns. Only one of the 11 major dams is classified as a low hazard. It is important to remember that these hazard classifications are not related to the physical condition or structural integrity of the dam (nor the probability of its failure), but strictly to the potential for adverse downstream effects if the dam were to fail.

Table 4.111 lists some of the descriptive information made available for each of the 11 major dams in the Northern Virginia region.

Table 4.111. Major Dams in the Northern Virginia Region, Based on the National Inventory of Dams.

Dam Name	Hazard Class	Drainage Area (Sq. Mi.)	Primary Purpose	Owner
Upper Occoquan Dam	High	595	Water Supply	Fairfax County Water Authority
T. Nelson Elliott Dam	High	60	Water Supply	City of Manassas
Barcroft Dam	High	14.5	Recreation	Lake Barcroft Watershed Improvement District
Lake Montclair Dam	High	11.3	Recreation	Montclair Property Owners Association
Pohick Creek Dam #1	High	6.2	Flood Control	Fairfax County Board of Supervisors
Lake Thoreau Dam	High	<1	Flood Control	Reston Association
Sleeter Lake Dam	Significant	10	Irrigation	Round Hill Investors, LLC
Beaverdam Creek Dam*	Significant	5.5	Water Supply	City of Fairfax
Kingstowne Lake Dam	Significant	<1	Recreation	Kingstowne Community Association
Possum Point Ash Dam #D	Significant	< 1	Debris Control	Dominion
Horsepen Dam	Low	22.8	Water Supply	Metro-Washington Airport Authority

** This dam is now owned by Loudoun County, rather than the City of Fairfax, as reported in the NID.*

3. Magnitude or Severity

Though dams have many benefits, they also can pose a risk to communities if not designed, operated, and maintained properly. In the event of a dam failure, the energy of the water stored behind even a small dam is capable of causing loss of life and great property damage if development exists downstream of the dam. Downstream properties may be quickly submerged in floodwaters and residents may become trapped by this rapidly rising water. The failure of dams has the potential to place large numbers of people and great amounts of property in harm's way.

4. Previous Occurrences

While dam failures are not common occurrences, there have been some notable recent events throughout Virginia. Most failures occur due to lack of maintenance of the dam in combination with major rainfall, such as hurricanes and thunderstorms. In 1995, torrential rains burst the Timberlake Dam in Campbell County, killing two people downstream in the flooding. Following Hurricane Floyd in 1999, 13 dam failures were reported across the eastern portion of the State causing significant damages.

The Barcroft dam in Fairfax County failed during heavy rains associated with Hurricane Agnes (June 1972). Although it caused no loss of life, the dam failure resulted in damage to the Holmes Run area, most notably the destruction of an overpass at Van Dorn Street and Holmes Run ($300,000 plus an additional $200,000 to clear away 29 acres of trees and debris from the stream). The dam, which had originally been built in 1913, also suffered major damage and had to be rebuilt in order to restore Lake Barcroft, a recreational area for community residents.

No additional occurrences were reported for the 2016 plan update.

B. Risk Assessment

1. Probability of Future Occurrences

Predicting the probability of flooding due to dam failure requires a detailed, site-specific engineering analysis for each dam in question. Failure may result from hydrologic and hydraulic design limitations, or from geotechnical or operational factors.

Dam failure remains an unlikely occurrence for all major and non-regulated dams in the Northern Virginia region. The DCR is tasked with monitoring the routine inspection and maintenance of those dams that present the greatest risk or are in need of structural repair.

2. Impact & Vulnerability

Failure of dams may result in catastrophic localized damages. Vulnerability to dam failure is dependent on dam operations planning and the nature of downstream development. Depending on the elevation and storage volume of the impoundment, the impact of flooding due to dam failure may include loss of human life, economic losses such as property damage and infrastructure disruption, and environmental impacts such as destruction of habitat. Evaluation of vulnerability and impact is highly dependent on site-specific conditions.

3. Risk

Dam failure is considered unlikely in the Northern Virginia region due to existing safety measures and rigorous inspection reporting programs. The DCR requires specific operation and maintenance procedures, as well as routine inspections and regularly updated emergency action plans for each of the major and State-regulated dams in the Northern Virginia region. Therefore, future damages caused by dam failure and associated dollar losses are expected to be negligible – though the danger remains real and will continue to receive critical attention through the DCR's Dam Safety and Floodplain Management Program.

Due to the lack of specific data on dam failure probability or inundation zones, the potential risk to critical facilities and existing buildings and infrastructure was not estimated for this revision of the Plan. Virginia's new Impounding Structure Regulations require dam break inundation zone mapping and additional information is available from the DCR Dam Safety Program.

There are 11 dams in the region classified as major. Ten of those are classified as significant or high hazard class. Four are located in Fairfax County, three are located in Loudoun County, three are located in Prince William County, and the remaining one is located in both Prince William

and Fairfax Counties. Again, these hazard classifications are not related to the physical condition or structural integrity of the dam (nor the probability of its failure), but strictly to the potential for adverse downstream effects from failure or mis-operation of the dam or facilities. There are no dam failure inundation maps available for the Northern Virginia region that can be included in this plan.

Only three of the major dams classified as high hazard have a drainage area of more than 20 square miles (the Upper Occoquan dam in Fairfax County, the T. Nelson Elliot dam in Prince William County, and the Horsepen Dam in Loudoun County), making the possibility of a catastrophic dam failure event elsewhere highly unlikely in the region. The Northern Virginia region is likely more prone to intentional water releases by dam operators immediately prior to or during major rainfall events, though in such cases the releases are coordinated with local emergency management officials to minimize potential risks to people and property.

Overall Loss Estimates and Ranking

Dam failure was not ranked with the hazards as a result of limited data available for analysis. As discussed regarding critical facilities, loss estimates were not developed due to the lack of specific data on dam failure probability or inundation zones. Fairfax County has the highest percentage of dams in the high and significant downstream hazard potentials in relation to the rest of the planning region.

For the 2016 plan update the qualitative assessment was organized by jurisdiction.

Fairfax County, Loudoun County, Prince William County, Town of Purcellville, and Town of Round Hill

Table 4.113. 2016 Qualitative Assessment for Dam Failure.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Possible	Critical	Moderate	Less than 6 hours	Less than one week

All Other Jurisdictions

Table 4.112. 2016 Qualitative Assessment for Dam Failure.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Unlikely	Critical	Moderate	Less than 6 hours	Less than one week

XVI. Extreme Temperatures

NOTE: As part of the 2016 plan update, the extreme temperatures hazard was examined and analyzed separately. This new analysis included, but was not limited to: 1) creating the hazard profile; 2) consolidating the previous occurrences; 3) determining the number of hazard events and losses by jurisdiction using NCDC and other data sources where available; 4) completing the assessment of risk by jurisdiction based on new data; and 5) ranking of the hazard by jurisdiction using the methodology described in detail in Chapter 4 Section IV Ranking and Analysis Methodologies. Each section of the plan was also reformatted for improved clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

Extreme heat is defined as summertime weather that is substantially hotter and/or more humid than average for a location at that time of year. Extreme heat conditions can increase the incidence of mortality and morbidity in affected populations. People can suffer heat-related illnesses when the body is unable to compensate for the extreme heat and properly cool itself. Very high body temperatures can cause damage to the brain and other vital organs.

What is considered an excessively cold temperature varies according to the normal climate for that region. Whenever temperatures drop decidedly below normal and wind speed increases, heat leaves the human body more rapidly, increasing the possibility of negative effects of these extreme temperatures.

The greatest danger from extreme cold is to people, as prolonged exposure can cause frostbite or hypothermia, and can become life threatening. Body temperatures that are too low affect the brain, making it difficult for the victim to think clearly or move well. This makes hypothermia particularly dangerous for those suffering from it, as they may not understand what is happening to them or what to do about it.

2. Geographic Location/Extent

Extreme temperature is not a hazard with a defined geographic boundary. All areas of the Northern Virginia area are subject to experience the hazard.

The National Weather Service (NWS) issues a range of watches and warnings associated with extreme heat, as illustrated below:

- Excessive Heat Outlook: when the potential exists for an excessive heat event in the next 3 to 7 days. An outlook is used to indicate that a heat event may develop. It is intended to provide information to those who need considerable lead time to prepare for the event, such as public utilities, emergency management and public health officials.
- Excessive Heat Watch: when conditions are favorable for an excessive heat event in the next 12 to 48 hours. A watch is used when the risk of a heat wave has increased, but its occurrence and timing is still uncertain. It is intended to provide enough lead time so

those who need to set their plans in motion can do so, such as established individual city excessive heat event mitigation plans.

- Excessive Heat Warning/Advisory: when an excessive heat event is expected in the next 36 hours. These products are issued when an excessive heat event is occurring, is imminent, or has a very high probability of occurrence. The warning is used for conditions posing a threat to life or property. An advisory is for less serious conditions that cause significant discomfort or inconvenience and, if caution is not taken, could lead to a threat to life and/or property.

The NWS also developed the Heat Index (HI). The HI is sometimes referred to as the "apparent temperature". The HI, given in degrees F, is a measure of how hot it really feels when relative humidity (RH) is added to the actual air temperature. To find the HI, NWS uses the Heat Index Chart, found following in Figure 4.49. As an example, if the air temperature is 96 degrees Fahrenheit (found on the top of the table) and the RH is 65% (found on the left of the table), the HI - or how hot it really feels - is 121 degrees Fahrenheit. This is at the intersection of the 96 degrees column and the 65% row.

Since HI values were devised for shady, light wind conditions, exposure to full sunshine can increase HI values by up to 15 degrees Fahrenheit. Also, strong winds, particularly with very hot, dry air, can be extremely hazardous. Note the shaded zone above 105 degrees Fahrenheit on the Heat Index Chart. This corresponds to a level of HI that may cause increasingly severe heat disorders with continued exposure and/or physical activity.

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	118	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	126	130					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Streuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Figure 4.49. NOAA's National Weather Service Heat Index.

When extreme heat occurs or is forecast to occur, the NWS issues heat advisories based on heat indices; these advisories are issued through the media and the Emergency Alert System. The NWS provides assistance to state and local health officials in preparing civil emergency messages for severe heat waves, in addition to preparing special weather statements that define who is most at risk, safety rules, and the expected severity of the situation. The NWS also aids state and local authorities with issuing warnings and survival tips.

Extreme cold has a wide range of extent and severity markers and characteristics. The National Weather Service issues Extreme Cold Warnings when the temperature feels like it is -30 degrees Fahrenheit or colder across a wide area for a period of at least several hours. When possible, these advisories are issued a day or two in advance of the onset of the conditions.

Perhaps the most common extent/severity marker for extreme cold is the Wind Chill scale. Figure 4.50 depicts the National Weather Service's methodology for determining wind chill, using wind speed and actual temperature. While wind chill is not necessarily related to extreme cold as a single cause, the advisory system that the NWS currently uses relies on wind chill to relay warning and advisory information to the public. Extreme cold severity is a function of wind chill and other factors, such as precipitation amount (rain, sleet, ice, and/or snow).

NWS Windchill Chart

Wind (mph) \ Temperature (°F)	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

Figure 4.50 NWS Windchill Chart.

3. Magnitude or Severity

Health risks from extreme heat include sunburn, dehydration, heat cramps, heat exhaustion, and heat stroke. Heat disorders generally result from a reduction or collapse of the body's ability to cool itself by circulatory changes and sweating, or a chemical (salt) imbalance caused by too

much sweating. When the body cannot cool itself, or when it cannot compensate for fluids and salt lost through perspiration, the temperature of the body's inner core begins to rise, and heat-related illness may develop. All other factors being equal, the severity of heat disorders tends to increase with age. Heat cramps in a 17-year-old may be heat exhaustion in someone who is 40, and heat stroke in a person over 60. Table 4.133 provides the potential health hazards associated with heat, by category.

Table 4.133. Health Hazards Associated with Heat.

Category	Heat Index	Health Hazards
Extreme Danger	130 degrees Fahrenheit and Higher	Heat stroke/ sunstroke is likely with continued exposure.
Danger	105 degrees Fahrenheit to 129 degrees Fahrenheit	Sunstroke, muscle cramps, and/or heat exhaustion with prolonged exposure and/or physical activity.
Extreme Caution	90 degrees Fahrenheit to 105 degrees Fahrenheit	Sunstroke, muscle cramps, and/or heat exhaustion with prolonged exposure and/or physical activity.
Caution	80 degrees Fahrenheit to 90 degrees Fahrenheit	Fatigue possible with prolonged exposure and/or physical activity.

In addition to the effects that extreme heat can have on people, there are also potential effects to assets from extreme heat. Northern Virginia is home to a significant human population. Increases in the exterior temperature mean that the utilities and processes by which interior spaces are controlled and conditioned must work harder to regulate those interior temperatures. This places an additional strain on existing utility systems, which can fail under the increased workload. Failure of cooling mechanisms places research, patients, and people at risk from prolonged exposure to extreme heat.

Extreme cold can also have significant impacts on people. Hypothermia is most likely at very cold temperatures, but can occur at higher temperatures (above 40 degrees Fahrenheit) if the person exposed is also wet from rain, sweat, or submersion. Warning signs of hypothermia include shivering, exhaustion, confusion, fumbling hands, memory loss, slurred speech, or drowsiness. In infants, symptoms include bright red and cold skin and very low energy. A person with hypothermia should receive medical attention as soon as possible, as delays in medical treatment may result in death.

In addition to the threat posed to humans, extreme cold weather poses a significant threat to utility production, which in turn threatens facilities and operations that rely on utilities, specifically climate stabilization. As temperatures drop and stay low, increased demand for heating places a strain on the electrical grid, which can lead to temporary outages. These outages can impact operations throughout the campus, which can result in interruptions and delays in services. Broken pipes may cause flooding in buildings, causing property damage and loss of utility service.

4. Previous Occurrences

In 1996, the NCDC began keeping records of occurrences of extreme temperatures. Because of the widespread spatial nature of the hazard, the most reliable records are found at the county-level. The independent cities of Northern Virginia have their own reports, of course, but they are largely identical to those provided for the geographically adjacent counties, with the exception of the City of Falls Church. The towns in Northern Virginia are included in the reports for the counties. To account for this method of reporting, and to limit overestimation of occurrences and damages where possible, the records for the four counties and for the City of Falls Church are included in this assessment. All other records are excluded as duplications.

From 1996 to 2015, there have been at least 275 extreme temperature event reports recorded by the NCDC for the Northern Virginia region. Approximately $75,000 in crop damages in Prince William County were recorded for these events, though other damages have undoubtedly occurred as an indirect result of the hazard. In addition, there were three fatalities and 102 injuries recorded.

The following occurrences, taken from NCDC records, impacted large portions of the planning area:

July 18, 2013 (Extreme Heat)
High pressure was located over much of the eastern United States and light southerly flow persisted all week. This led to above normal temperatures throughout the region and dew points in the mid-70s. Heat indices were approximately 105 to 107 degrees Fahrenheit at Quantico, 105 degrees Fahrenheit at Dulles International Airport, and 105 to 107 degrees Fahrenheit at Reagan National Airport.

July 21-22, 2011 (Extreme Heat)
Upper level high pressure caused excessive heat conditions throughout the planning area. Surface pressure over the Atlantic caused moist air to move into the region from the south. The combination of heat and humidity caused heat indices in excess of 100 degrees Fahrenheit in some locations, and up to 110-112 degrees Fahrenheit in other parts of the region. Heat indices of up to 116 degrees Fahrenheit at Dulles International Airport and 118 degrees Fahrenheit at Quantico were recorded during this period.

June 8, 2008 (Extreme Heat)
A strong ridge of high pressure over the eastern United States set the stage for a period of hot weather and high humidity in Northern Virginia. One person died due to heat-related complications in Alexandria as temperatures on this day reached into the mid to upper 90s combining with dew points in the lower 70s to produce heat indices that approached 105 degrees Fahrenheit.

December 7, 2002 (Extreme Cold)
Record-breaking cold settled into northern Virginia on this day as low temperatures reached 1 degree above zero at Dulles International Airport. Temperatures fell to -1 degrees Fahrenheit in Lincoln in Loudoun County and -4 degrees Fahrenheit at the NWS Forecast Office in Sterling.

January 27, 2000 (Extreme Cold)
High pressure was located directly over the Mid-Atlantic region between the 27th and 29th. The combination of clear skies, calm winds, and a snowpack led to extremely cold temperatures that fell to below zero degrees Fahrenheit. On the 27th, a 59-year-old woman was found dead in the parking lot of a shopping center in Fairfax, an apparent victim of hypothermia.

July 4–7, 1999 (Extreme Heat)
High pressure sat off the Mid-Atlantic coast, drawing extremely warm and humid air into Northern Virginia. Temperatures on the 4th through the 7th were oppressively hot, and extremely humid conditions added to the misery. Temperatures soared into the upper 90s to lower 100s during the period, and dew points were in the lower to middle 70s, creating heat indices between 100 and 115 degrees Fahrenheit. Overnight lows only dipped into the 70s and heat index values ranged from the upper 70s to upper 80s. The heat index only dropped to 90 degrees Fahrenheit at National Airport in the Washington, DC, suburbs on the morning of the 6th. Record highs were broken at Washington National Airport on the 5th and 6th. The record high at Dulles International Airport was broken on the 4th and tied on the 5th.

August 16–17, 1997 (Extreme Heat)
West winds circulating around a "Bermuda High" pressure system allowed temperatures to soar over the weekend of the 16th and 17th. Maximum temperatures surpassed the century mark across most of Northern Virginia (except in the higher elevations) both days. Heat index values ranged from 105 to 110 degrees Fahrenheit each day, but aside from a few heat exhaustion cases, it appeared that at-risk residents remained in air conditioned locations. No heat-related deaths were reported by Virginia medical authorities. A record high was achieved at Dulles International Airport on the 16th with a new maximum of 100 degrees Fahrenheit. That temperature was matched on the 17th, before strong to severe thunderstorms moved through.

April 10, 1997 (Extreme Cold)
A record cold arctic air mass overspread the Northern Virginia piedmont and the Shenandoah Valley overnight on the 9th and 10th, dropping temperatures into the upper teens to lower 20s across the entire area. These temperatures arrived on the heels of an above normal winter season, especially pronounced in late March, when peach and apple blossoms reached critical bloom stage up to 2 weeks ahead of schedule. This accelerated growth led to high kill percentages across the region, with estimates showing at least a 70 to 90 percent kill of the peach crop, and similar kills among the Red Delicious apple crop.

July 1995 (Extreme Heat)
A 38-hour period of extremely hot and humid weather in mid-July took its toll on humans and animals. The heat was caused by strengthening of a Bermuda High, extending from the surface to the upper levels of the atmosphere. The most life-threatening period of the heat wave occurred during the afternoon of the 15th, when temperatures ranged from 98 to 103 degrees Fahrenheit, with heat indices between 115 and 129 degrees Fahrenheit. On this day, an all-time record for power usage was established in Northern Virginia, with 13,512 megawatts recorded (mostly from air conditioning usage). Five thousand customers were without power in the same general area. In Alexandria, a National Park Service bicycle patrol ranger collapsed near Daingerfield Island, then later died from complications resulting from hyperthermia.

There were several additional instances of heat exhaustion during the remainder of the month, concentrated during the middle two weeks. Alexandria hospitals reported about 80 persons requiring treatment between the 14th and 23rd. The heat wave returned twice in late July, from the 21st through the 25th and again from the 29th through the 31st. However, temperatures were not as oppressive, ranging from 90 to 97 degrees Fahrenheit. Daytime heat indices ranged from 105 to 115 degrees Fahrenheit, but fell below 90 each night. No deaths or injuries were directly attributed to either episode.

B. Risk Assessment

1. Probability of Future Occurrences

The future incidence of extreme temperatures is highly unpredictable and may be localized, which makes it difficult to assess the probability of a future occurrence. Some form of extreme temperature typically impacts the Northern Virginia region annually. As a result, while the future probability of some type of extreme temperature may be estimated as High, the exact severity or manifestation of the hazard cannot be quantified at this time.

2. Impact & Vulnerability

While this hazard occurs with some regularity, it is not one with a significant history of causing damages or losses to property in the Northern Virginia region. The risk of exposure and negative health impacts to people, animal, and agriculture are the greatest risk, with the risk to the loss of utility service (particularly electrical) also a consideration. Humans and animals can be injured or die from exposure to both extreme cold and extreme heat; agriculture can be damaged or destroyed by extremes in temperature, rending crops unusable. Utility systems may fail under strains of demand, resulting in increases in exposure of humans and animals to extreme temperatures, as facilities cannot provide regulated temperatures and climate.

3. Risk

Estimates of the financial impacts or losses from extreme temperatures can be developed based on NCDC data that runs from January 1996 to December 2015. Examination of NCDC data shows that there were approximately 275 extreme temperature events in the database.

Risk to People

NCDC reports describe three fatalities and 102 injuries for the 19 year period of record. This equates to annualized rates of .15 fatalities per year and 5.3 injuries per year for the period of record. It is people that are at the greatest risk from extreme temperatures, and people that must be protected from this hazard.

Critical Facility and Infrastructure Risk

Quantitative assessment of critical facilities for the extreme temperature risk was not feasible for this update. Even so, it is apparent that the infrastructure that supports critical facilities are at risk from extreme temperatures, as demands on generation and distribution networks may overtax the system and result in failure. Finally, not all critical facilities have redundant power sources and may not even be wired to accept a generator for auxiliary heat or cooling. Future plan updates should consider including a more comprehensive examination of critical facility vulnerability to

extreme temperatures, including those that have emergency heating or cooling equipment and those that may be wired to receive portable equipment.

Overall Loss Estimates and Ranking

In keeping with other assessments updated or validated for this plan, the assessment for extreme temperatures is based on NCDC data.

For the 2016 plan update the qualitative assessment was performed by jurisdiction. Given the widespread nature of the hazard, however, all counties, cities, and towns were determined to have the same qualitative risk to the hazard, that of 'High'. Therefore, to avoid repetition, Table 4.134 below provides the results of the qualitative assessment for all participating jurisdictions, as all jurisdictions were found to have the same results.

Table 4.134. 2016 Qualitative Assessment for Extreme Temperatures.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Minor	Large	More than 24 hours	Less than one week

Endnotes

[1] NCDC's Storm Event database is available at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms.
[2] National Water Service Instruction 10-1605. Operations and Services Performance: Storm Data Preparation Guide. August 17, 2007. Available at: http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf
[3] Commonwealth of Virginia Emergency Operations Plan Annex 3 (Volume II)
[4] IPCC. (2007). Climate Change 2007: The Physical Science Basis. Intergovernmental Panel on Climate Change.

[5] Pfeffer, W., Harper, J., & O'Neil, S. (2008). Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science , 321*, 1340-1343.
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[7] National Flood Insurance Program
[8] HAZUS-MH Flood User Manual
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[10] Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing; Robert J. Trapp*†, Noah S. Diffenbaugh*, Harold E. Brooks‡, Michael E. Baldwin*, Eric D. Robinson*, and Jeremy S. Pal; PNAS December 11, 2007, vol. 104, no. 50.
[11] IPCC Special Report on Emissions Scenarios, 2000
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[16] Significant Earthquakes figure is from the 2013 Commonwealth of Virginia's Hazard Mitigation Plan. Earthquake Section 3.13, Figure 3.13-1.
[17] The Daily News Spot July 16, 2010 interview with Amy Vaughan, geophysicist USGS National Earthquake Information Center.

[18]Recent Earthquakes from NEIC Earthquake Bulletin: Magnitude 3.4-Potomac-Shenandoan Region. USGS July 16, 2010. http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2010yua6.php
[19]Recent Earthquakes from NEIC Earthquake Bulletin: Magnitude 3.4-Potomac-Shenandoan Region. USGS July 16, 2010. http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2010yua6.php
[20] 2500-year Return Period Peak Ground Acceleration (PGA) figure is from the 2013 Commonwealth of Virginia's Hazard Mitigation Plan. Earthquake Section 3.13, Figure 3.13-3.
[21] Telephone and Email correspondence with Dr. Martin Chapman. June 3, 2010.
[22] Smith, K., *Environmental Hazards, Assessing Risk and Reducing Disaster,* Third Edition, Rutledge Press, New York 1991
[23] USGS Fact Sheet 2004-3072
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