



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. In Falls Church, more than three inches of rain fell in two to three hours. Red Cross Chapter Headquarters was damaged when water flooded a portion of the building. In Prince William County, side roads were flooded by heavy downpours in Manassas. Four homes and two cars were damaged by flood waters.

January 19–22, 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. Four people were rescued by the National Park Service and Fairfax County Fire Department at Great Falls when they wandered onto the rocks to view the raging Potomac and became stranded. 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.

November 4-7 1985

The “Election Day Flood” caused 22 deaths and nearly \$800 million in damages across Virginia. The Potomac River in Alexandria crested at 11.8 feet, 4.8 feet above flood stage (7 feet).

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 on the Potomac and James rivers. 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.

October 11–18, 1942

Although there is very little data on specific flood impacts, the Northern Virginia region suffered a significant flood event in 1942 following a period of torrential rains that resulted in six to 10 inches of water falling across the region. Damage was probably restricted to Old Town Alexandria. To make matters worse, up to 15 inches fell in areas to the west and upriver. Flood losses on the swollen Potomac River were estimated at \$4.5 million, which at the time was deemed the worst river flood to hit the State of Virginia. During this time, the Potomac River at Washington, DC, reached 17.6 feet (flood stage is seven feet), and areas of



Floodwaters reach to the steps of the Jefferson Memorial, October 17, 1942. (Photo courtesy of NOAA)



Alexandria and Arlington were reportedly seriously flooded.

April 1937

Just one year after the record flood of March 1936, another major flood struck Virginia. Heavy rains caused widespread flooding over all but southwest Virginia. Flooding on the Potomac was not as bad as the previous year, yet the river rose to 14.3 feet at Wisconsin Avenue in Georgetown and portions of Alexandria and Arlington again flooded. Total damages to roads and bridges in Virginia came to nearly a half a million dollars. Agricultural losses came to over a million dollars in Northern Virginia alone.

March 17–18, 1936

During the period of March 9–22, successive storms crossed the eastern region of the U.S. with floods occurring from Virginia to Maine. In Virginia, the Potomac, Shenandoah, Rappahannock, James, and York Rivers flooded. The winter of 1935–1936 was marked by long-continued periods of low temperatures and heavy snowfalls. In December, it was estimated that areas in the northern Blue Ridge Mountains exceeded 40 inches of snow. Some snow melted during a mild January, but more fell in late January to mid-February. March began with warm temperatures and a thaw. The first rainstorm came in the second week with up to three inches falling. The rains melted the snow, adding an equivalent of one to two inches of rainfall. This caused the rivers to rise and set the stage for the next rain event. The primary flood-producing rains came March 17 and 18, when a storm drawing moisture from the Gulf of Mexico, tracked across Virginia. It dumped an additional six inches of rain on top of the already saturated soil. The Potomac River in Washington, DC, rose nine feet above flood stage flooding portions of Arlington and Alexandria including the old airport.

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 4.21 shows the dates each of the jurisdictions were identified with Flood Hazard Boundary Maps (FHBM), 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 4.21. Communities participating in the NFIP.

Community Name	Init FHBM Identified	Init FIRM Identified	Current Effective Map Date	Reg-Emer Date	DFIRM/Q3
Arlington County		10/1/1969	5/3/1982	12/31/1976	DFIRM
Fairfax County	5/5/1970	3/5/1990	3/5/1990	1/7/1972	DFIRM
<i>Town of Herndon</i>	6/14/1974	8/1/1979	8/1/1979	8/1/1979	
<i>Town of Vienna</i>	8/2/1974	2/3/1982	2/3/1982	2/3/1982	
<i>Town of Clifton</i>	3/28/1975	5/2/1977		5/2/1977	
Loudoun County	4/25/1975	1/5/1978	7/5/2001	1/5/1978	DFIRM
<i>Town of Leesburg</i>	8/3/1974	9/30/1982	7/5/2001	9/30/1982	
<i>Town of Purcellville</i>	7/11 1975	11/15, 1989	7/5/2001	11/15/1989	
<i>Town of Middleburg</i>	-	7/5/2001	7/5/2001	7/31/2001	
<i>Town of Round Hill</i>	5/13/1977	7/5/2001	7/5/2001	1/10/2006	
Prince William County	1/10/1976	12/1/1981	1/5/1995	12/1/1981	DFIRM
<i>Town of Dumfries</i>	6/18/1976	5/15/1980	1/5/1995	5/15/1980	
<i>Town of Haymarket</i>	8/9/1974	1/17/1990	1/5/1995	1/31/1990	
<i>Town of Occoquan</i>	7/19/1974	9/1/1978	1/5/1995	9/1/1978	
<i>Town of Quantico</i>	11/1/1974	8/15/1978	1/5/1995	8/15/1978	
City of Alexandria	8/22/1969	8/22/1969	5/15/1991	5/8/1970	Q3
City of Fairfax	5/5/1970	12/23/1971	6/2/2006	12/17/1971	DFIRM
City of Falls Church	9/6/1974	2/3/1982	7/16/2004	2/3/1982	DFIRM
City of Manassas	5/31/1974	1/3/1979	1/5/1995	1/3/1979	DFIRM
City of Manassas Park	3/11/1977	9/29/1978	1/5/1995	9/29/1978	DFIRM

as of 7/6/2010 <http://www.fema.gov/cis/VA.html>

As of July 6, 2010, there was a total of 10,398 flood insurance policies in-force in the Northern Virginia region, accounting for 9.5% of the total policies in the Commonwealth. These policies amounted to more than \$2.35 billion in total insurance coverage. Approximately 1,253 claims have been filed, accounting for \$17 million in payments. Fairfax County and its towns make up more than 43% of the total claims payments. Table 4.22 shows the NFIP policy statistics for each of the participating jurisdictions of the Northern Virginia region.



Table 4.22. NFIP policy and claim statistics

County	Community Name	Policy Statistics (as of 3/31/2010)		Claim Statistics 1/1/1978 – 3/31/2010	
		Policies In-Force	Insurance In-Force	Total Claims	Total Payment
Arlington County	Arlington County	790	\$144,938,600	91	\$285,832
	<i>TOTAL</i>	<i>790</i>	<i>\$144,938,600</i>	<i>91</i>	<i>\$285,832</i>
Fairfax County	Fairfax County	5,324	\$1,211,797,500	501	\$7,218,144
	Town of Herndon	52	\$16,055,300	6	\$8,407
	Town of Vienna	87	\$24,256,400	12	\$277,745
	Town of Clifton	3	\$1,200,000	1	\$29,923
	<i>TOTAL</i>	<i>5,466</i>	<i>\$1,253,309,200</i>	<i>520</i>	<i>\$7,534,219</i>
Loudoun County	Loudoun County	517	\$143,350,200	87	\$1,076,933
	Town of Leesburg	84	\$20,683,900	6	\$140,160
	Town of Purcellville	11	\$2,623,000	-	-
	Town of Middleburg	-	-	-	-
	Town of Round Hill	2	\$70,000	-	-
<i>TOTAL</i>	<i>614</i>	<i>\$166,727,100</i>	<i>93</i>	<i>\$1,217,092</i>	
Prince William County	Prince William County	1,091	\$273,055,600	237	\$3,615,233
	Town of Dumfries	16	\$3,965,100	6	\$34,841
	Town of Haymarket	2	\$700,000	-	-
	Town of Occoquan	38	\$12,124,600	15	\$56,912
	Town of Quantico	2	\$600,000	-	-
<i>TOTAL</i>	<i>1,149</i>	<i>\$290,445,300</i>	<i>258</i>	<i>\$3,706,986</i>	
City of Alexandria	City of Alexandria	1,590	\$371,645,100	221	\$3,677,306
	<i>TOTAL</i>	<i>1,590</i>	<i>\$371,645,100</i>	<i>221</i>	<i>\$3,677,306</i>
City of Fairfax	City of Fairfax	558	\$63,887,000	27	\$388,720
	<i>TOTAL</i>	<i>558</i>	<i>\$63,887,000</i>	<i>27</i>	<i>\$388,720</i>
City of Falls Church	City of Falls Church	141	\$39,887,300	18	\$111,260
	<i>TOTAL</i>	<i>141</i>	<i>\$39,887,300</i>	<i>18</i>	<i>\$111,260</i>
City of Manassas	City of Manassas	66	\$16,254,800	20	\$164,618
	<i>TOTAL</i>	<i>66</i>	<i>\$16,254,800</i>	<i>20</i>	<i>\$164,618</i>
City of Manassas Park	City of Manassas Park	24	\$5,579,400	5	\$66,527
	<i>TOTAL</i>	<i>24</i>	<i>\$5,579,400</i>	<i>5</i>	<i>\$66,527</i>
NoVA TOTAL		10,398	\$2,352,673,800	1,253	\$17,152,560
VIRGINIA TOTAL		109,712	\$25,557,799,200	38,038	\$548,242,841

Source: <http://bsa.nfipstat.com/> 7/6/2010

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.

FEMA Repetitive Flood Claims Program

Requirement §201.6(c)(2)(ii): [The risk assessment] must also address National Flood Insurance Program (NFIP) insured structures that have been repetitively damaged floods.]

The Repetitive Flood Claims (RFC) grant program was authorized by the Bunning-Bereuter-Blumenauer Flood Insurance Reform Act of 2004 (P.L. 108–264), which amended the National Flood Insurance Act of 1968 (42 U.S.C. 4001, et al). Currently up to \$10 million is available annually for FEMA to provide RFC funds to help States and communities reduce flood damages to insured properties that have had one or more claims to the NFIP.¹⁰

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 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 63 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.¹¹ Over \$5.2 million has been paid in total repetitive losses (for 177 losses) for the Northern Virginia planning region. Table 4.23 shows the total number of properties, total number of losses experienced, and losses paid for all of the communities within the planning region, according to the VDEM.

Prince William County accounts for almost 40% of the total repetitive loss payments, followed by the City of Alexandria (25%). Prince William and Loudoun counties both have one severe repetitive loss property.



Table 4.23 Repetitive Loss Properties, April 2011.

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		2	4	\$101,395	\$16,529	\$117,924
Fairfax County	6		6	14	\$368,416	\$52,384	\$420,800
<i>Town of Herndon</i>							
<i>Town of Vienna*</i>	1		1	2	\$4,819	\$0	\$4,819
<i>Town of Clifton</i>							
Loudoun County	11	1	12	38	\$691,276	\$122,730	\$814,006
<i>Town of Leesburg</i>							
<i>Town of Purcellville</i>							
<i>Town of Middleburg</i>							
<i>Town of Round Hill</i>							
Prince William County	8	2	10	42	\$1,303,075	\$788,669	\$2,091,744
<i>Town of Dumfries</i>							
<i>Town of Haymarket</i>							
<i>Town of Occoquan</i>							
<i>Town of Quantico</i>							
City of Alexandria	15	7	22	52	\$1,205,361	\$107,825	\$1,313,186
City of Fairfax	1	1	2	4	\$66,944	\$20,364	\$87,308
City of Falls Church	2		2	4	\$76,169	\$18,987	\$95,156
City of Manassas	6	1	7	20	\$272,585	\$61,507	\$334,092
City of Manassas Park							
TOTAL	51	12	63	178	\$4,085,222	\$1,188,995	\$5,274,217

*Town information included in the county totals



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 nationwide¹². The main recurrence intervals used on the FIRMs are shown in the table below (Table 4.24).

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 2010 revision using the probabilistic and 100-year scenarios. The below section summarizes the module and highlights the results and differences of the HAZUS^{MH} runs. The HAZUS^{MH} runs are summarized in Appendix D5.

HAZUS^{MH} MR4 is a regional multi-hazard loss estimation model that was developed by FEMA and the National Institute of Building Sciences. The 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 recovery¹³.

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. Probabilistic events are modeled by looking at the damage caused by an event that is likely to occur over a given period of time, known as a return period or recurrence interval. 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} MR4 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 a Level 1 analysis with user-provided depth grids that were generated from the FEMA DFIRM and Q3 data.



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 4.25 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 4.25: 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 probabilistic HAZUS^{MH} flood analysis predicts that the Northern Virginia region can expect, annually, \$99,049,000 in damages due to flood events. Property or “capital stock” losses make up about \$98,899,000 of the damages (99.8%). This includes the values for building, content, and inventory. Business interruption accounts for 0.2% of the annualized losses and includes income, rental, wage, and relocation costs.

Table 4.26 illustrates the expected annualized losses broken down by county and city. Fairfax County has the highest annualized loss, \$47,214,000 accounting for 48% of the total annualized losses for Northern Virginia. 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 results provided in Tables 4.27 and 4.28 are the total losses for the pre- and post-FIRM census blocks.



The stream threshold used to delineate stream reaches included a 10 mi² 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 mi² 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.



Table 4.26. HAZUS^{MH} Flood Module Annualized Building Loss

Jurisdiction	Building Loss	Content Loss	Inventory Loss	Relocation Loss	Income Loss	Rental Loss	Wage Loss	Total Loss
Arlington County	\$1,935,000	\$1,620,000	\$20,000	\$3,000	\$0	\$0	\$15,000	\$3,593,000
Fairfax County	\$27,603,000	\$19,456,000	\$85,000	\$46,000	\$0	\$5,000	\$19,000	\$47,214,000
<i>Town of Herndon</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Vienna</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Clifton</i>	\$27,000	\$47,000	\$2,000	\$0	\$0	\$0	\$0	\$76,000
Loudoun County	\$10,332,000	\$7,935,000	\$105,000	\$7,000	\$1,000	\$1,000	\$11,000	\$18,392,000
<i>Town of Leesburg</i>	\$474,000	\$339,000	\$0	\$0	\$0	\$0	\$0	\$813,000
<i>Town of Purcellville</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Middleburg</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Round Hill</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Prince William County	\$8,715,000	\$6,546,000	\$98,000	\$1,000	\$0	\$0	\$8,000	\$15,368,000
<i>Town of Dumfries</i>	\$396,000	\$449,000	\$7,000	\$0	\$0	\$0	\$2,000	\$854,000
<i>Town of Haymarket</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Occoquan</i>	\$409,000	\$372,000	\$7,000	\$0	\$0	\$0	\$1,000	\$789,000
<i>Town of Quantico</i>	\$16,000	\$17,000	\$0	\$0	\$0	\$0	\$0	\$33,000
City of Alexandria	\$6,460,000	\$5,306,000	\$54,000	\$10,000	\$1,000	\$12,000	\$7,000	\$11,850,000
<i>City of Fairfax</i>								
<i>City of Falls Church</i>								
City of Manassas	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
City of Manassas Park	\$36,000	\$31,000	\$0	\$0	\$0	\$0	\$0	\$67,000
Total	\$56,403,000	\$42,118,000	\$378,000	\$67,000	\$2,000	\$18,000	\$63,000	\$99,049,000



Table 4.27. Annualized Building Loss Pre-FIRM

Jurisdiction	Building Loss	Content Loss	Misc.	Total Loss
Arlington County	\$1,291,000	\$1,024,000	\$19,000	\$2,334,000
City of Alexandria	\$3,906,000	\$3,265,000	\$59,000	\$7,230,000
City of Manassas	\$0	\$0	\$0	\$0
City of Manassas Park	\$1,000	\$1,000	\$0	\$2,000
Prince William County	\$4,232,000	\$3,245,000	\$58,000	\$7,535,000
Town of Dumfries	\$210,000	\$239,000	\$5,000	\$454,000
Town of Occoquan	\$220,000	\$211,000	\$3,000	\$434,000
Town of Quantico	\$16,000	\$17,000	\$0	\$33,000

Table 4.28. Annualized Building Loss Post-FIRM

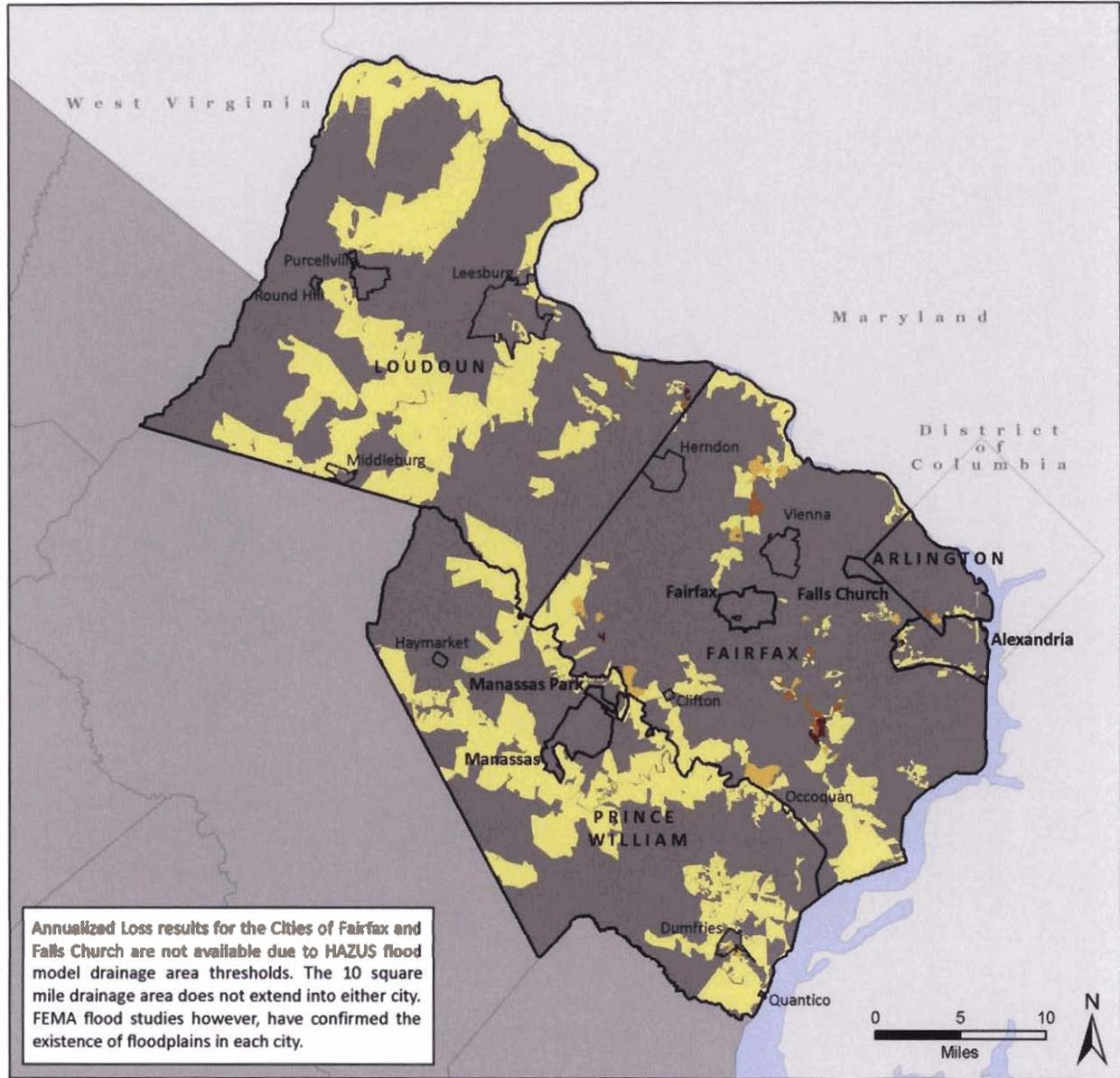
Jurisdiction	Building Loss	Content Loss	Misc.	Total Loss
Arlington County	\$644,000	\$596,000	\$19,000	\$1,259,000
City of Alexandria	\$2,554,000	\$2,041,000	\$25,000	\$4,620,000
City of Manassas	\$0	\$0	\$0	\$0
City of Manassas Park	\$35,000	\$30,000	\$0	\$65,000
Prince William County	\$4,483,000	\$3,301,000	\$49,000	\$7,833,000
Town of Dumfries	\$186,000	\$210,000	\$4,000	\$400,000
Town of Occoquan	\$189,000	\$161,000	\$5,000	\$355,000
Town of Quantico	\$0	\$0	\$0	\$0

Figures 4.13 through 4.17 show the total annualized loss for the Northern Virginia planning region and individual counties. DFIRM and Q3 maps may be found in Appendix D4. As seen on the figures, there are several areas within cities that have limited loss estimates calculated. This may be a result of several conditions, one of which is the default 10 square miles of drainage area may be too large of a threshold to define streams with HAZUS^{MH} and results in no stream networks being created for those areas. Future versions of this plan and mitigation actions may want to investigate using a smaller drainage threshold for analysis; for example, a one square mile drainage would be comparable to the FEMA DFIRM maps.

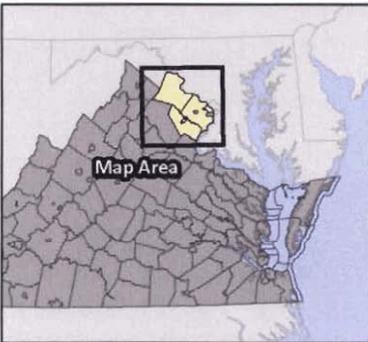
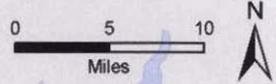
A DFIRM-based 1%-annual-chance-flood or 100-year analysis was completed in order to assess risk for the Cities of Fairfax and Falls Church, as well as to provide information on impacts of the 100-year floodplain on critical facilities. The results of this analysis are shown in Table 4.29. Fairfax County accounts for over 60% of the losses from the 100-year scenario; \$1.7 million in damages could be expected for the county. Prince William County could expect damages near a half million from to the 100-year scenario.



HAZUS Flood Model Total Annualized Loss



Annualized Loss results for the Cities of Fairfax and Falls Church are not available due to HAZUS flood model drainage area thresholds. The 10 square mile drainage area does not extend into either city. FEMA flood studies however, have confirmed the existence of floodplains in each city.



Total Direct Economic Building Loss Annualized, All Occupancies

Total per Census Block

	<= \$500,000
	\$500,001 - \$1,000,000
	\$1,000,001 - \$2,000,000
	\$2,000,001 - \$4,023,000

Notes
Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

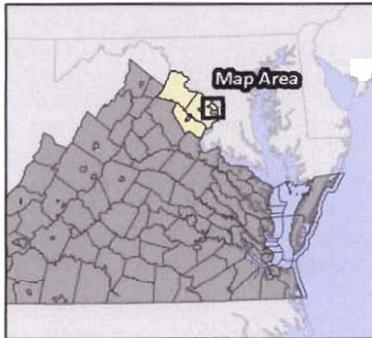
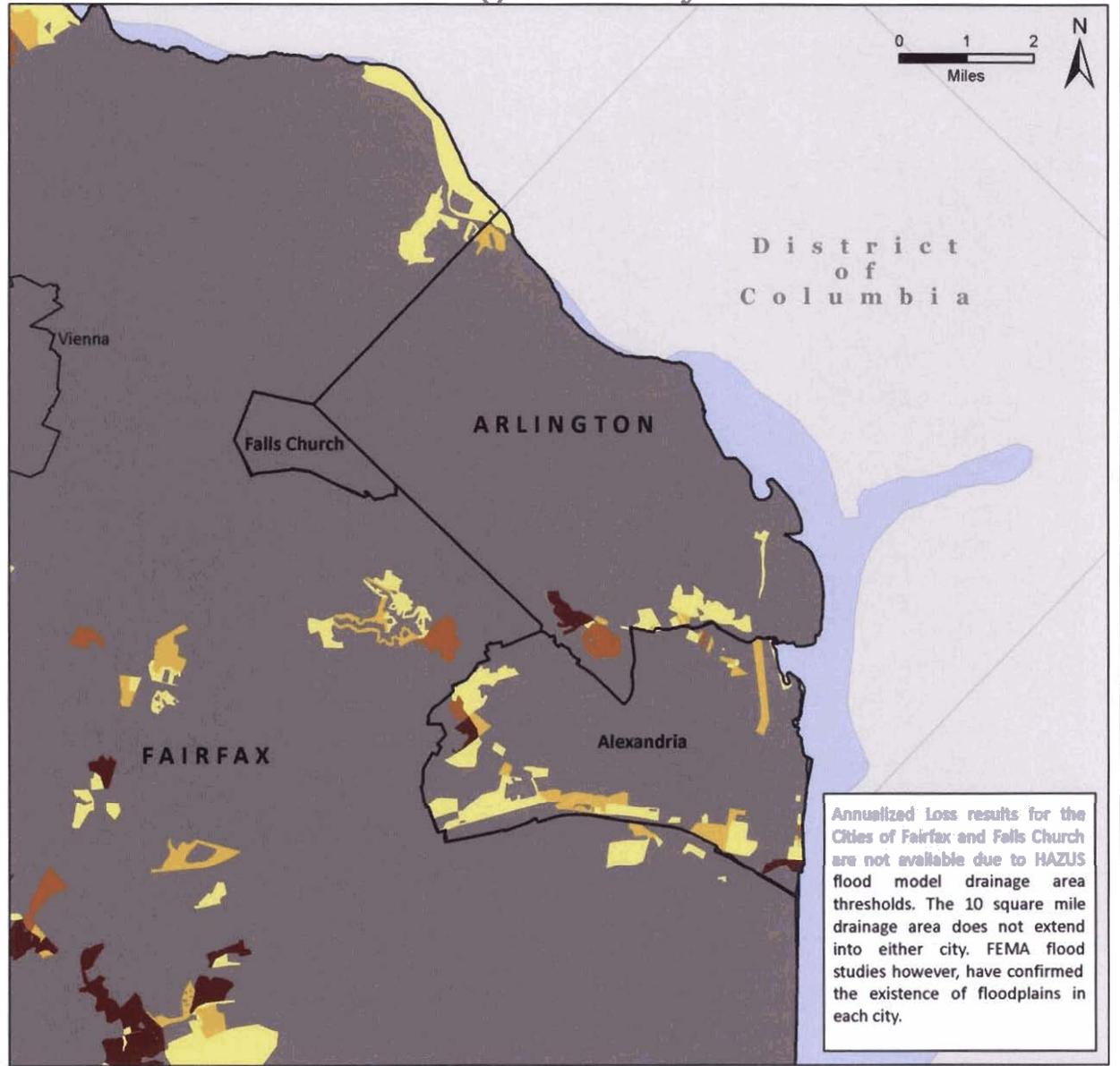
Data Sources
Loss Estimates (HAZUS-MH MR4)
PDC Boundaries (VGIT)
City Boundaries (US Census)
State Boundaries (National Atlas)



Figure 4.13. Total Annualized Loss based on HAZUS^{MH} MR4 Flood Module.



HAZUS Flood Model Arlington County Total Annualized Loss



Total Direct Economic Building Loss Annualized, All Occupancies

Total per Census Block

- <= \$100,000
- \$100,001 - \$500,000
- \$500,001 - \$1,000,000
- \$1,000,001 - 4,023,000

Notes
 Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

Data Sources

- Loss Estimates (HAZUS-MH MR4)
- PDC Boundaries (VGIT)
- City Boundaries (US Census)
- State Boundaries (National Atlas)

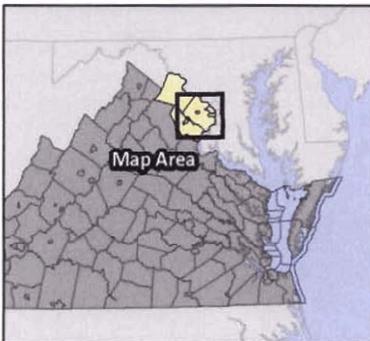
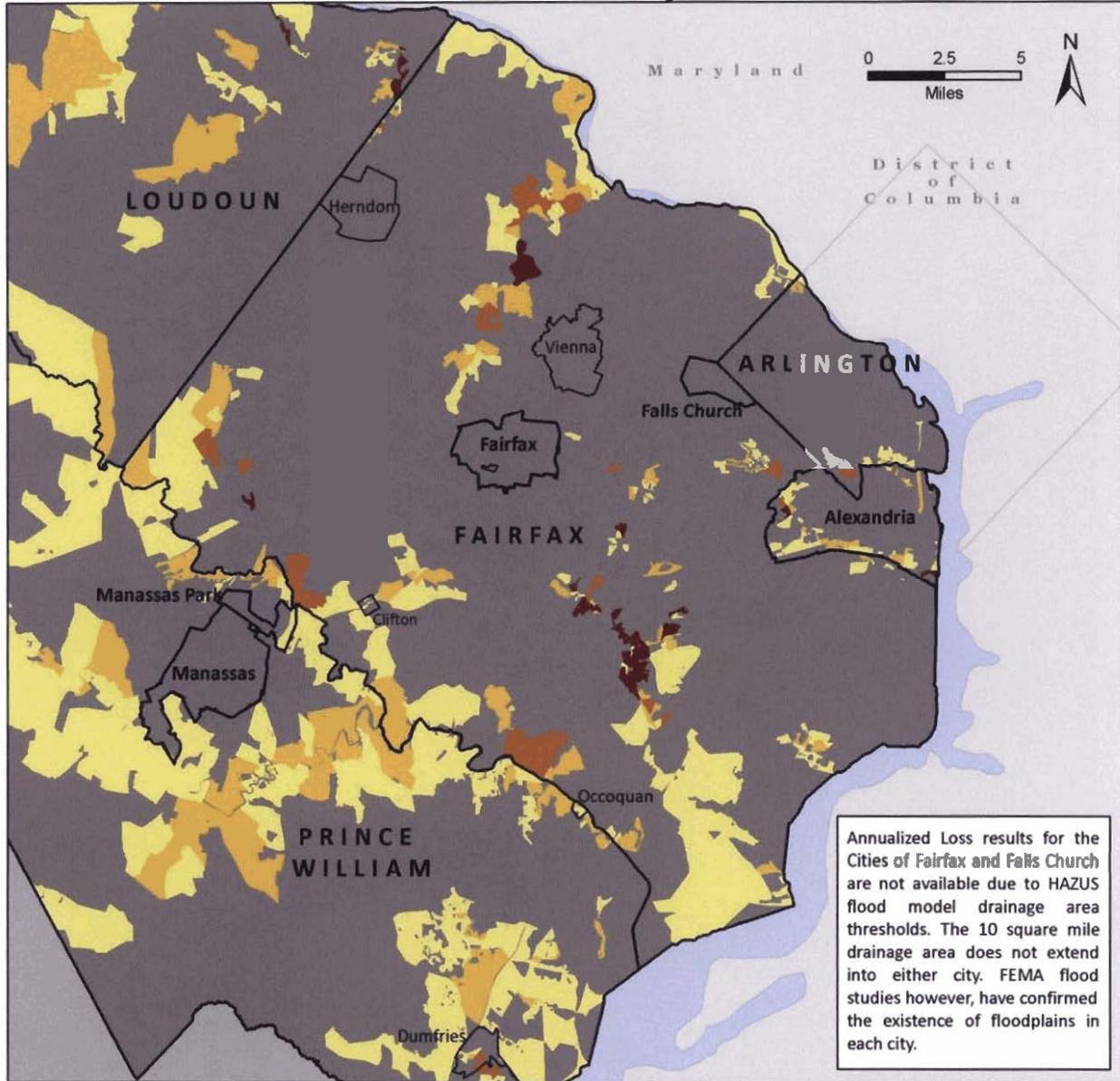


Dewberry

Figure 4.14. Arlington County Total Annualized Loss based on HAZUS^{MH} Flood Module.



HAZUS Flood Model Fairfax County Total Annualized Loss



Total Direct Economic Building Loss Annualized, All Occupancies

Total per Census Block

Yellow	<= \$100,000
Orange	\$100,001 - \$500,000
Brown	\$500,001 - \$1,000,000
Dark Brown	\$1,000,001 - 4,023,000

Notes
 Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

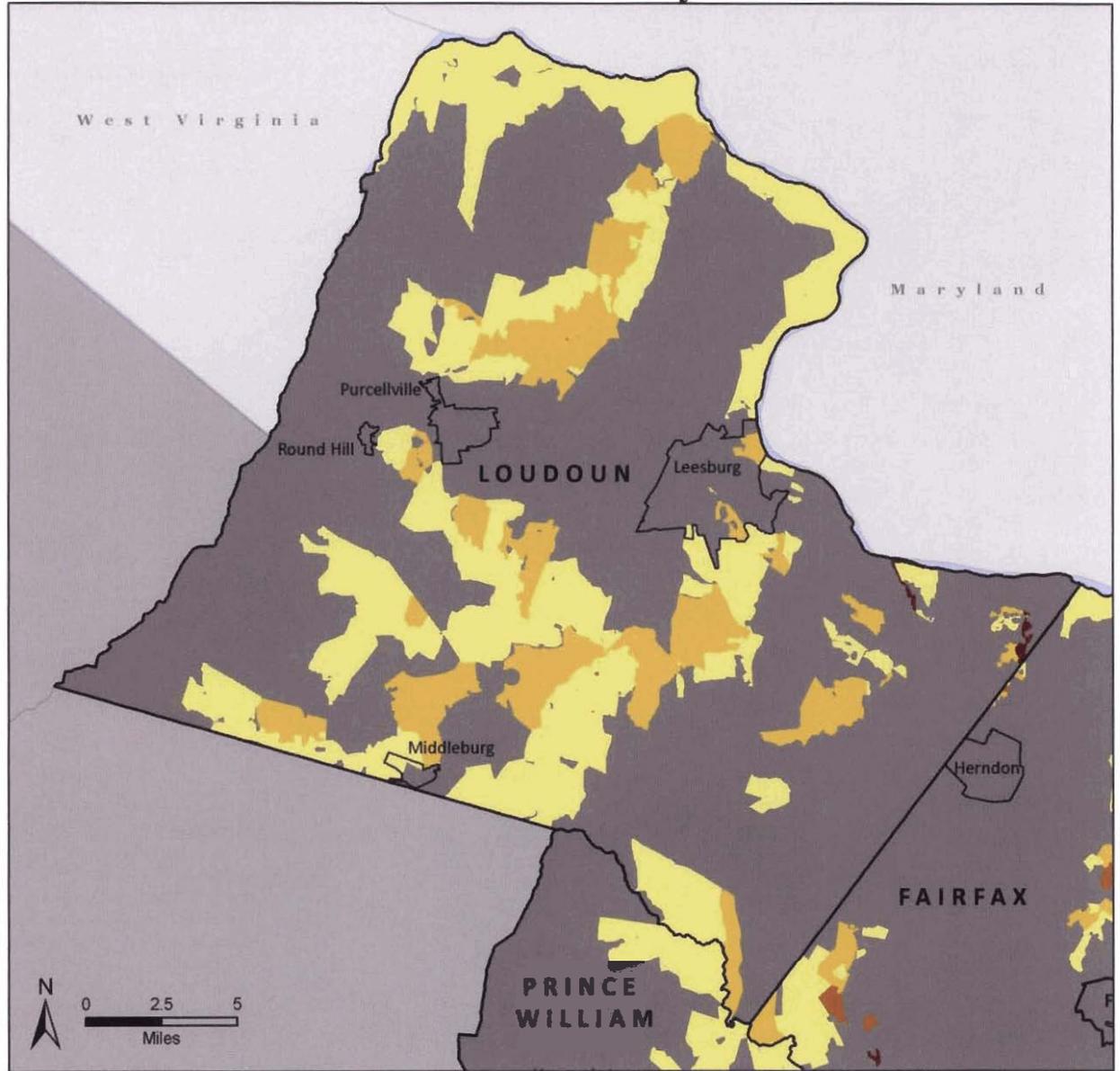
Data Sources
 Loss Estimates (HAZUS-MH MR4)
 PDC Boundaries (VGIT)
 City Boundaries (US Census)
 State Boundaries (National Atlas)



Figure 4.15. Fairfax County Total Annualized Loss based on HAZUS^{MH} Flood Module.



HAZUS Flood Model Loudoun County Total Annualized Loss



Total Direct Economic Building Loss Annualized, All Occupancies

Total per Census Block

<= \$100,000
\$100,001 - \$500,000
\$500,001 - \$1,000,000
\$1,000,001 - \$4,023,000

Notes
Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

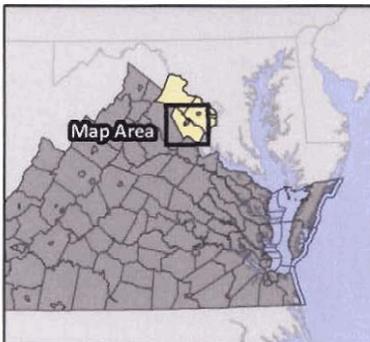
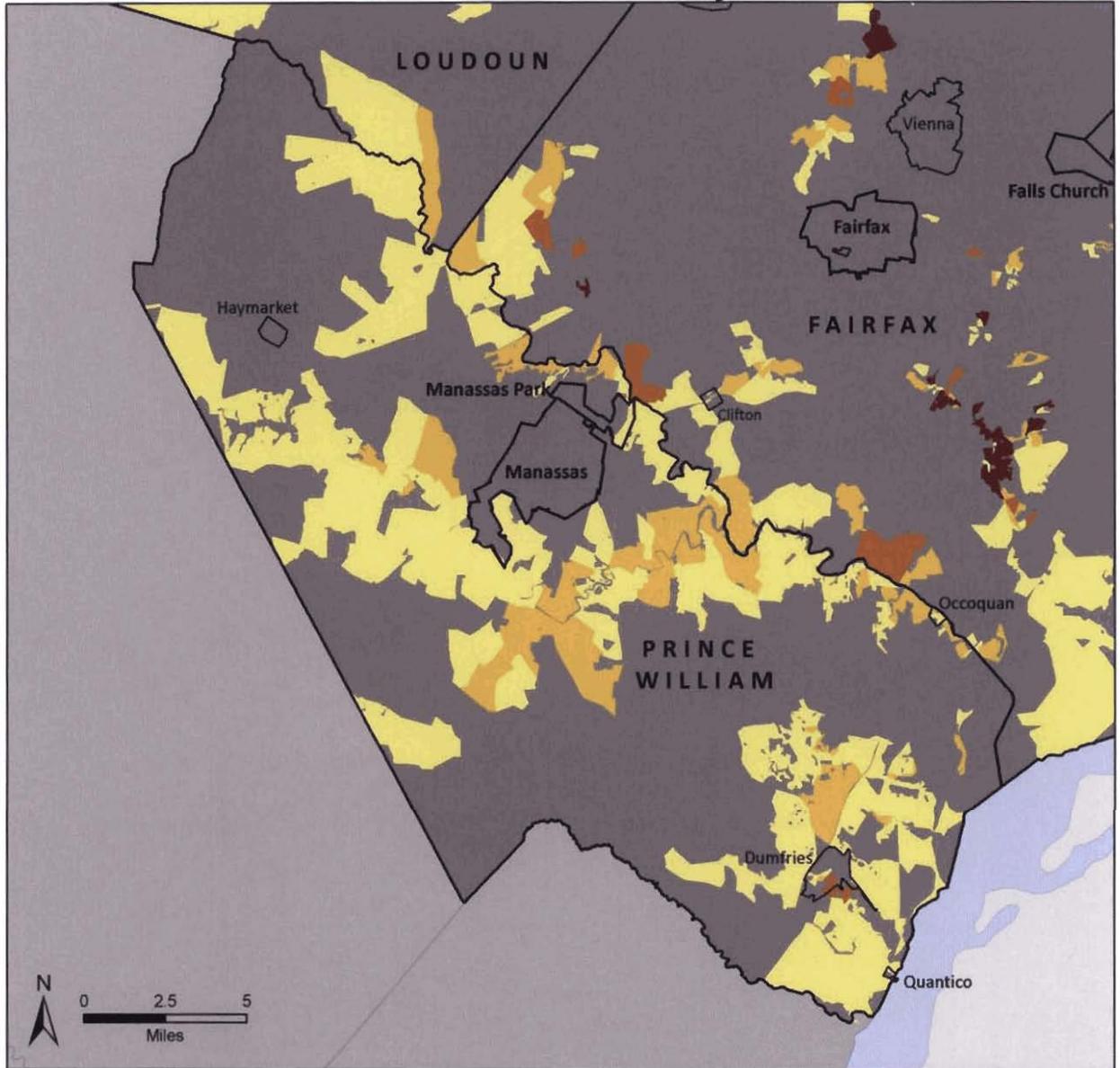
Data Sources
Loss Estimates (HAZUS-MH MR4)
PDC Boundaries (VGIT)
City Boundaries (US Census)
State Boundaries (National Atlas)



Figure 4.16. Loudoun County Total Annualized Loss based on HAZUS^{MH} MR4 Flood Module.



HAZUS Flood Model Prince William County Total Annualized Loss



Total Direct Economic Building Loss Annualized, All Occupancies

Total per Census Block

-  <= \$100,000
-  \$100,001 - \$500,000
-  \$500,001 - \$1,000,000
-  \$1,000,001 - \$4,023,000

Notes
Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

Data Sources
Loss Estimates (HAZUS-MH MRM)
PDC Boundaries (VGIT)
City Boundaries (US Census)
State Boundaries (National Atlas)



Dewberry

Figure 4.17. Prince William County Total Annualized Loss based on HAZUS^{MH} Flood Module.



Table 4.29 100-year HAZUS DFIRM Simulation Building Loss

Jurisdiction	Building Loss	Content Loss	Inventory Loss	Relocation Loss	Income Loss	Rental Loss	Wage Loss	Direct Loss	Total
Arlington County	\$26,664	\$26,244	\$302	\$48	\$70	\$21	\$565	\$323	\$54,237
Fairfax County	\$934,184	\$805,776	\$14,417	\$2,050	\$1,790	\$745	\$5,907	\$7,569	\$1,772,438
<i>Town of Herndon</i>	<i>\$17,531</i>	<i>\$27,888</i>	<i>\$899</i>	<i>\$46</i>	<i>\$126</i>	<i>\$32</i>	<i>\$966</i>	<i>\$558</i>	<i>\$48,046</i>
<i>Town of Vienna</i>	<i>\$9,199</i>	<i>\$28,171</i>	<i>\$73</i>	<i>\$52</i>	<i>\$131</i>	<i>\$18</i>	<i>\$100</i>	<i>\$381</i>	<i>\$38,125</i>
<i>Town of Clifton</i>	<i>\$673</i>	<i>\$1,085</i>	<i>\$20</i>	<i>\$0</i>	<i>\$8</i>	<i>\$0</i>	<i>\$12</i>	<i>\$17</i>	<i>\$1,815</i>
Loudoun County	\$215,815	\$190,307	\$3,184	\$408	\$437	\$151	\$2,546	\$2,037	\$414,885
<i>Town of Leesburg</i>	<i>\$25,500</i>	<i>\$33,242</i>	<i>\$800</i>	<i>\$66</i>	<i>\$118</i>	<i>\$26</i>	<i>\$468</i>	<i>\$535</i>	<i>\$60,755</i>
<i>Town of Purcellville</i>	<i>\$3,857</i>	<i>\$5,868</i>	<i>\$309</i>	<i>\$5</i>	<i>\$20</i>	<i>\$1</i>	<i>\$93</i>	<i>\$167</i>	<i>\$10,320</i>
<i>Town of Middleburg</i>	<i>\$122</i>	<i>\$119</i>	<i>\$2</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$1</i>	<i>\$0</i>	<i>\$244</i>
<i>Town of Round Hill</i>	<i>\$135</i>	<i>\$173</i>	<i>\$4</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$5</i>	<i>\$4</i>	<i>\$321</i>
Prince William County	\$271,914	\$237,750	\$4,691	\$594	\$464	\$191	\$1,667	\$2,212	\$519,483
<i>Town of Dumfries</i>	<i>\$6,305</i>	<i>\$7,864</i>	<i>\$293</i>	<i>\$24</i>	<i>\$17</i>	<i>\$9</i>	<i>\$105</i>	<i>\$96</i>	<i>\$14,713</i>
<i>Town of Haymarket</i>	<i>\$2</i>	<i>\$1</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>	<i>\$3</i>
<i>Town of Occoquan</i>	<i>\$4,003</i>	<i>\$9,388</i>	<i>\$319</i>	<i>\$19</i>	<i>\$64</i>	<i>\$15</i>	<i>\$107</i>	<i>\$144</i>	<i>\$14,059</i>
<i>Town of Quantico</i>	<i>\$228</i>	<i>\$197</i>	<i>\$1</i>	<i>\$0</i>	<i>\$1</i>	<i>\$0</i>	<i>\$1</i>	<i>\$2</i>	<i>\$430</i>
City of Alexandria	\$137,548	\$183,526	\$2,695	\$377	\$915	\$275	\$2,818	\$2,637	\$330,791
City of Fairfax	\$32,086	\$50,831	\$1,310	\$102	\$298	\$57	\$482	\$771	\$85,937
City of Falls Church	\$2,954	\$4,575	\$103	\$14	\$33	\$5	\$61	\$144	\$7,889
City of Manassas	\$10,668	\$14,533	\$749	\$25	\$49	\$11	\$113	\$150	\$26,298
City of Manassas Park	\$2,739	\$2,298	\$40	\$8	\$1	\$0	\$11	\$35	\$5,132
Total	\$1,516,132	\$1,374,073	\$25,314	\$3,312	\$3,246	\$1,209	\$12,543	\$14,045	\$2,949,874



Critical Facility Risk

The vulnerability of each identified critical facility 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. For the Northern Virginia region, this includes flood (100-year flood zones), landslides (areas of high or moderate incidence/susceptibility), and wildfire (areas of high or moderate risk). For purposes of this vulnerability assessment, the other defined hazard areas are not deemed unique enough to make definitive vulnerability assessments for potentially at-risk buildings or facilities that differentiate them from other areas of the region (for example, the insignificant spatial differences in peak ground acceleration for the earthquake hazard).

Of those critical facilities identified in the region, many were indeed determined to be in known hazard areas upon further GIS analysis and thereby determined to be “potentially at-risk.” Tables 4.30 – 4.32 summarize the number of potentially at-risk buildings or 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 4.30. Number of Local Critical Facilities Potentially At-Risk to Flood (2010 plan analysis)

Jurisdiction	EOC	Schools	Police	Fire Station	Fire Dept.	Hospital	Nursing Homes
Arlington County	0	0	0	0	0	0	0
Fairfax County	-	0	0	0	-	0	-
Town of Herndon	-	0	0	0	-	0	-
Town of Vienna	-	0	0	0	-	0	-
Town of Clifton	-	0	0	0	-	0	-
Loudoun County	-	0	-	-	-	0	-
Town of Leesburg	-	0	-	-	-	0	-
Town of Purcellville	-	0	-	-	-	0	-
Town of Middleburg	-	0	-	-	-	0	-
Town of Round Hill	-	0	-	-	-	0	-
Prince William County	-	-	-	-	-	-	-
Town of Dumfries	-	-	-	-	-	-	-
Town of Haymarket	-	-	-	-	-	-	-
Town of Occoquan	-	-	-	-	-	-	-
Town of Quantico	-	-	-	-	-	-	-
City of Alexandria	-	2	0	0	0	0	0
City of Fairfax	-	0	0	-	-	0	-
City of Falls Church	-	0	-	-	-	-	-
City of Manassas	-	-	-	-	-	-	-
City of Manassas Park	-	-	-	-	-	-	-



Table 4.31. Number of HAZUS^{MH} Critical Facilities Potentially At-Risk to Flood (2010 plan analysis)

Jurisdiction	EOC	Schools	Police	Fire Station	Fire Dept.	Hospital	Nursing Homes
Arlington County	0	0	0	0	0	0	0
Fairfax County	0	2	0	0	0	0	0
Town of Herndon	0	0	0	0	0	0	0
Town of Vienna	0	0	0	0	0	0	0
Town of Clifton	0	0	0	0	0	0	0
Loudoun County	0	1	0	1	0	0	0
Town of Leesburg	0	0	0	0	0	0	0
Town of Purcellville	0	0	0	0	0	0	0
Town of Middleburg	0	0	0	0	0	0	0
Town of Round Hill	0	0	0	0	0	0	0
Prince William County	0	1	0	0	0	0	0
Town of Dumfries	0	0	1	0	0	0	0
Town of Haymarket	0	0	0	0	0	0	0
Town of Occoquan	0	0	0	0	0	0	0
Town of Quantico	0	0	0	0	0	0	0
City of Alexandria	0	2	0	0	0	0	0
City of Fairfax	0	0	0	0	0	0	0
City of Falls Church	0	0	0	0	0	0	0
City of Manassas	0	2	0	0	0	0	0
City of Manassas Park	0	0	0	0	0	0	0

Table 4.32. HAZUS Critical Facilities At-Risk to Flood (2010 Plan Analysis)

Jurisdiction	Total
City of Alexandria	2
Samuel W. Tucker Elementary	1
St. Mary's Elementary School	1
City of Manassas	2
George Carr Round Elementary	1
La Petite Academy	1
Fairfax County	2
Browne Academy	1
Lees Corner (School)	1
Loudoun County	2
Aldie Volunteer Fire Department Inc.	1
Hutchison Farms Elementary	1



Jurisdiction	Total
Prince William County	1
Stonewall Jackson High School	1
Town of Dumfries	1
Dumfries Police Dept	1
Total	10

During the 2006 plan, no schools were determined to be at risk for flooding, based on available data. For the 2010 update, HAZUS^{MH} analysis revealed that eight schools, one fire and one police station could expect moderate damage from a 100-year flood scenario. These facilities are included in Table 4.32.

Information for the HAZUS^{MH} local critical facilities in the flood zones are available in the Critical Facility-Risk Appendix D2.

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 D4 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 (<http://www.msc.fema.gov>). Digital data was available for all of the localities within the Northern Virginia planning region.

During the 2006 plan creation, the digital flood data was overlaid with local parcel data and used to perform a GIS-based risk assessment for critical facilities (summarized previously in this section) and for determining the exposure (number and value) of potentially at-risk structures. In order to further assess the Northern Virginia region's flood hazard vulnerability, a detailed GIS-based hazard assessment was completed for those jurisdictions that had submitted the necessary GIS data layers. This included digital flood data, tax parcel records (including year-built and assessed building value data) and building footprint data. With 100% of the requested data, it is possible to estimate total building exposure in the 100-year floodplain. Table 4.33 summarizes the results of the assessment by jurisdiction to the maximum extent possible based upon data availability. As can be seen in the table, exposure data is limited for certain jurisdictions. Total building exposure can only be calculated for the City of Alexandria (\$459 million) and the City of Fairfax (\$123 million).



Table 4.33. 100-year Floodplain Exposure in the Northern Virginia Region (Zones A and AE) from 2010 plan analysis

Jurisdiction	Parcels	Parcels in SFHA	Assessed Bldg Value in SFHA	Developed Parcels in SFHA	Vacant Parcels in SFHA	Buildings	Buildings In SFHA
Arlington County	38,174	643	-	-	-	42,866	267
Fairfax County	344,917	13,380	-	-	-	231,412	2,264
Town of Clifton	142	25	-	-	-	143	7
Town of Herndon	6,998	279	-	-	-	4,175	43
Town of Vienna	5,964	323	-	-	-	6,224	135
Loudoun County		-		-		82,519	1,072
Town of Leesburg		-				9,754	266
Town of Middleburg		-		-		574	3
Town of Purcellville		-				3,148	26
Town of Round Hill		-		-		464	10
Prince William County	138,989	6,852			-	141,579	2,314
Town of Dumfries	1,671	163	-	-	-	1,739	145
Town of Haymarket	540	17	-	-	-	554	3
Town of Occoquan	459	127	-	-	-	274	90
Town of Quantico	366	19	-	-	-	228	1
City of Alexandria	24,786	2,304	\$2,212,767,492	2,019	285	41,158	1,916
City of Fairfax	7,375	630	-	-	-	7,986	233
City of Falls Church	4,311	288	-	-	-	4,602	278
City of Manassas	15,714	556	\$316,910,200	393	163	8,024	122
City of Manassas Park	-	-	-	-	-	4,152	77

To supplement what was completed in 2006, HAZUS^{MH} flood scenarios were completed for the 100-year and probabilistic scenario. The HAZUS^{MH} analysis and loss estimation is further described in the following sections.



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, the Commonwealth of Virginia’s 2010 HIRA, and the 2006 analysis completed for this plan.

Since 1993, the Northern Virginia region has been severely impacted by numerous instances of flooding. Based on the NCDC data for 439 flood events, there has been over \$25,708,755 in property and \$2,386,304 in crop total damages from 1993 through August 2009. To be able to determine annualized loss for the region, the total damages from NCDC were divided by the length of available record. Table 4.34 summarizes the total damages and annualized damages for each county and city in the planning region. At this time, town specific information is not recorded in the NCDC database. The county that the town resides in should be used as a reference point for estimated damages. Table 4.35 summarizes the annualized loss values from the Virginia State plan, which utilizes a general risk based on percent of census tracts located in the SFHA. Prior to this period of record, very little historical damage data exists for past flood events.

Table 4.34. NCDC flood damages and annualized loss estimates.

Jurisdiction	Damages (1993 - 2009)			Annualized		
	Property	Crop	Property + Crop	Property	Crop	Property + Crop
Arlington County	\$4,405,124	\$341,254	\$4,746,378	\$259,125	\$20,074	\$279,199
Fairfax County	\$13,254,002	\$378,349	\$13,632,352	\$779,647	\$22,256	\$801,903
Loudoun County	\$3,449,790	\$229,495	\$3,679,285	\$202,929	\$13,500	\$216,429
Prince William County	\$2,225,367	\$410,387	\$2,635,753	\$130,904	\$24,140	\$155,044
City of Alexandria	\$628,307	\$341,254	\$969,561	\$36,959	\$20,074	\$57,033
City of Fairfax	\$0	\$0	\$0	\$0	\$0	\$0
City of Falls Church	\$576,049	\$341,254	\$917,302	\$33,885	\$20,074	\$53,959
City of Manassas	\$1,170,116	\$344,312	\$1,514,428	\$68,830	\$20,254	\$89,084
City of Manassas Park	\$0	\$0	\$0	\$0	\$0	\$0
Total	\$25,708,755	\$2,386,304	\$28,095,058	\$1,512,280	\$140,371	\$1,652,650



Table 4.35 Commonwealth of Virginia's 2010 HMP flood rank and annualized losses

Jurisdiction (rank in Virginia HMP)	Annualized Loss
Fairfax County (2)	\$7,505,247
Prince William County (6)	\$3,069,348
Loudoun County (8)	\$2,157,842
Alexandria, City of (10)	\$1,997,414
Fairfax, City of	\$420,031
Arlington County	\$308,235
Manassas, City of	\$212,413
Falls Church, City of	\$112,540
Manassas Park, City of	\$41,588
TOTAL	\$15,824,658

During the 2006 plan creation, annualized losses for flooding were estimated at \$3,912,000 for the region. For the 2010 plan update, seven additional years of record were utilized to develop updated annualized loss estimates of \$1,652,650 for NCDC data. The HAZUS^{MH} annualized loss for the region is over \$99 million. Based on the 100-year flood HAZUS^{MH} scenario, the region could expect \$2,949,874 in damages (impact to assets) from the 100-year flood. Table 4.36 compared the different loss estimates and methodologies used to derive them.

Table 4.36 Comparison of annual loss estimates and methodologies:

Plan	Loss Estimate	Methodology
2006 NoVA HMP	\$3,912,000	Based on recorded historical events and applied loss estimation methodology.
HAZUS ^{MH} Annualized Loss	\$99,049,000	HAZUS ^{MH} riverine analysis
NCDC (1993 – 2009) Annualized Loss	\$1,652,650	Total reported property damages divided by total number of years of record
2010 VA HMP Annualized Loss	\$15,824,658	Based on FIA Depth-Damage assumptions, DFIRMS, and census data for building exposure

The Commonwealth of Virginia's 2010 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. The geographic extent score for each jurisdiction is based on the percent of the jurisdiction that falls within the SFHA, as defined by FEMA. Figure 4.18 shows the seven parameters that were used to calculate the overall risk of flooding for the Northern Virginia region.



Initially the entire region, except for the City of Fairfax, was ranked high, where the city received a medium-high ranking for flooding. This was found to be attributed to several of the ranking parameter scores (i.e., population vulnerability, damages, and geographic extent). However, based upon committee feedback, the City of Fairfax ranking parameters have been changed in the final plan to mirror that of Fairfax County. This is reflected in Figure 4.55 and the overall ranking map (Figure 4.61) at the end of the Risk Assessment. NCDC values contained within the tables have not been adjusted and reflect what was available in the database.

According to the 2006 qualitative assessment performed using the PRI tool, the flood hazard scored a PRI value of 3.3 (from a scale of 0 to 4, with 4 being the highest risk level). Table 4.37 summarizes the risk levels assigned to each PRI category. The updated ranking aligns appropriately with the 2006 rankings for both the qualitative and quantitative measures.

Table 4.37 2006 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

According to the 2006 qualitative assessment performed using the PRI tool, the erosion hazard scored a PRI value of 1.9 (from a scale of 0 to 4, with 4 being the highest risk level). Table 4.38 summarizes the risk levels assigned to each PRI category.

Table 4.38 2006 Qualitative Assessment for Erosion					
	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Likely	Minor	Negligible	More than 24 hours	More than one week

The 2006 PRI assessment still is valid and supports the updated ranking and loss estimates.

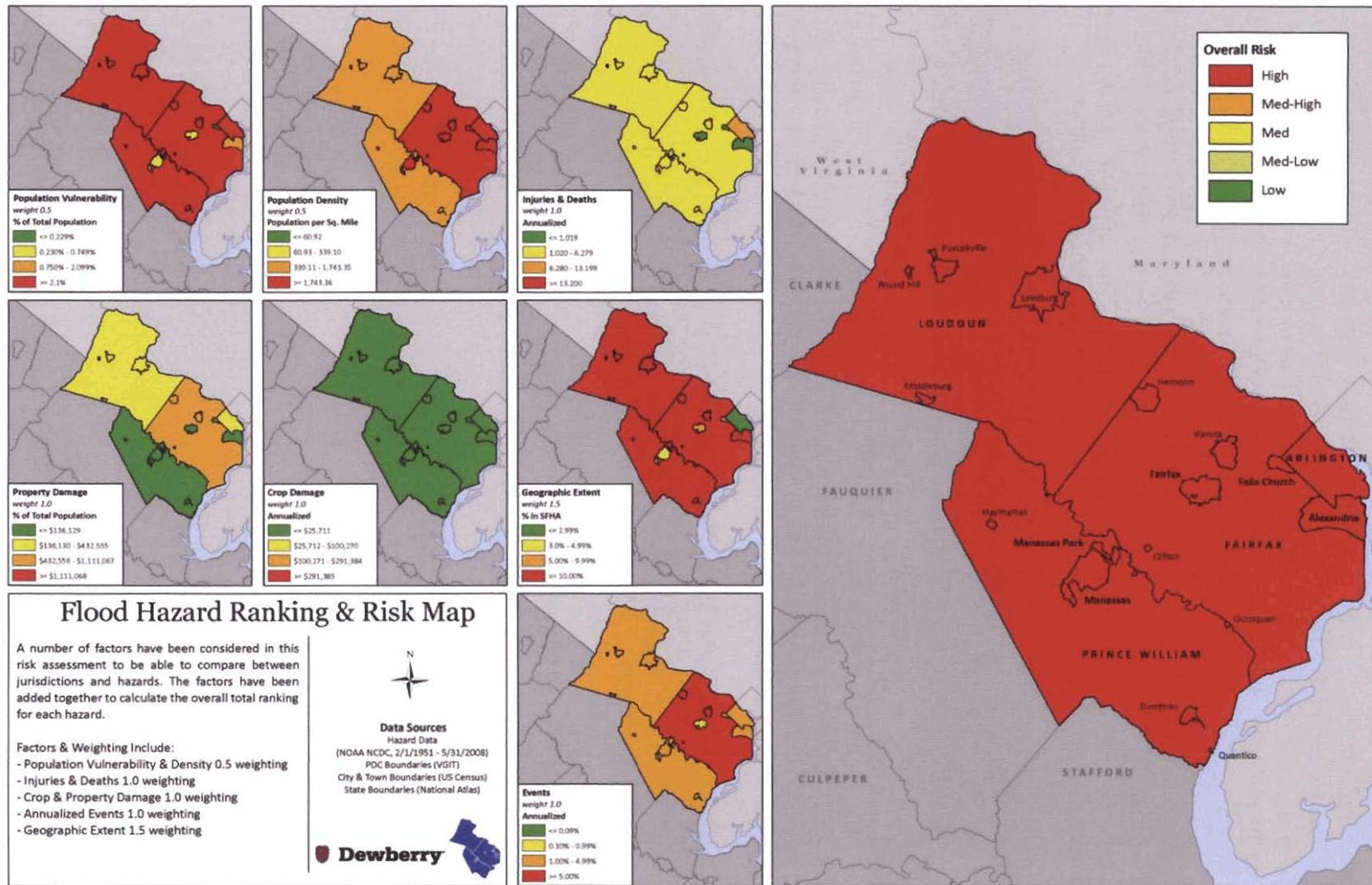


Figure 4.18. Flood Hazard Ranking



VI. Winter Storm (with extreme cold)

NOTE: As part of the 2010 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 annualized 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. In an attempt to make for a more cohesive analysis of winter related natural hazards, Extreme Cold was incorporated into the Winter Storm section for the 2010 plan update. 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.



February, 2010 winter storm impacts NOVA

A freeze is weather marked by low temperatures, especially when below the freezing point (zero degrees Celsius or 32 degrees Fahrenheit). Extreme cold can lead to hypothermia and frostbite, which are both serious medical conditions. House fires and carbon monoxide poisoning are also 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 4.19 and 4.20 show the average number of days in Virginia with at least 3 and 6 inches of snowfall.

3. Magnitude or Severity

Since 1993, there have been 857 winter storm event reports recorded by the NCDC for the Northern Virginia region, causing an estimated \$394,974 in annualized 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 annualized losses due to winter storm events.

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

December 18-19, 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.



December 19, 2009; Heavy snow falling over northern Virginia almost as fast as it can be removed by Department of Transportation crews.

February 5-6, 2010

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. Preliminary indications are that 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 preliminary 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.

February 9-10, 2010

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.



Source: February 6, 2010; Pentagon City, Arlington, Virginia, North American Blizzard of February 2010.
Mariordo Mario Roberto Duran Ortiz.

Other significant winter weather events:

February 14-18, 2003

A major winter storm dumped 20 to 36 inches of snow in northern Virginia over the four-day period, with a 24-hour snowfall record of 16.7 inches set at Ronald Reagan Washington National Airport.

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° F in Lincoln in Loudoun County and -4° F 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.

January 24-25, 2000

A nor'easter spread heavy snow into Virginia during the night of the 24th and through the 25th. Several inches of snow were on the ground at daybreak, with winds gusting at 25 to 45 mph creating blizzard-like conditions in some areas. The region was at a standstill. Airports and transit systems were shut down and schools were closed. Federal, State, and county government offices were closed or quickly closed once the full impact of the storm was realized. Some Federal employees in Northern Virginia who began their commutes before the government shutdown were left battling the storm in their attempts to return home.

March 9, 1999

Heavy snow fell across the region. Schools were closed and some parents stayed home with their children, but many others found themselves at work and on the roads in rapidly deteriorating conditions. In the heaviest band, snow was falling at a rate of two inches per hour, making it hard for road crews to keep up. Cars were stuck in snow and abandoned and soon



littered the roadways making plowing even more difficult and travel for others even more hazardous. Ronald Reagan Washington National Airport and Dulles International Airport were closed for most of the day. Loudoun County alone reported 53 vehicle accidents and 18 injuries. For those schools that did not close, 24 school buses got stuck on rural routes. At least 200 abandoned, damaged, or stuck vehicles had to be towed off Interstates 95 and 66. Fairfax County reported 500 disabled vehicles and 30 injuries in just six hours.

April 10, 1997 (Extreme Cold)

A record cold arctic air mass overspread the Northern Virginia piedmont and the Shenandoah Valley over night 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.

January 6-13, 1996

On the morning of January 6th, much of Virginia and the Washington, DC, area was buried under two feet of snow. Many rural and some residential areas did not see a snow plow for five days. The Federal government remained shut down for four days. Many local governments and businesses were also closed. Schools announced their closure for the entire week and some were closed longer. A second storm struck on Friday, January 12th dumping another two to six inches. Snowfall totals across the region ranged from 19 inches in Prince William County to 35 inches in Loudoun County.

February 2-3 and February 16, 1996

A continuing series of Alberta clippers followed by strong nor'easters struck the region. The storm on February 2nd and 3rd dropped 6 to 10 inches of snow. On the 16th, a nor'easter moved up the coast dumping an additional six to 12 inches of snow.

March 13-14, 1993

The "Superstorm of March '93" was also known as "The Storm of the Century" for the eastern United States, due to its large area of impact, reaching all the way from Florida and Alabama through New England. The storm was blamed for some 200 deaths and cost approximately 2 billion dollars to repair damages and remove snow. In a large swath from Alabama to New England, it dropped over a foot of snow. As the storm's center crossed Virginia, weather stations recorded their lowest pressure ever. It brought heavy snow and blizzard conditions over portions of the region, and some roofs collapsed under the weight of the snow.

February 18-19, 1979

"The Presidents Day Storm" was considered the worst storm in 57 years to strike Northern Virginia. Snow depths from the storm accumulated up to 20 inches. At times, snow was falling two to three inches per hour and temperatures were in the single digits to teens. Huge tractors and other farm machinery had been driven to the Mall in Washington, DC, to protest for higher agricultural pricing. When the storm hit, the farmers used their equipment to help locals dig out



of nearly two feet of snow. Four deaths were attributed to heart attacks from stress due to overexertion during and after the storm, and 18 injuries occurred from falls on ice.

February 15-16 and March 20-21, 1958:

Over 14 inches of snow fell in Northern Virginia in mid-February. Transportation was paralyzed, and two deaths were attributed to the storm. Another nor'easter struck on March 21st, dropping 10 to 15 inches across the region.

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 1993, but it does not systematically document the magnitude or intensity of each event. 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.¹⁴ 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

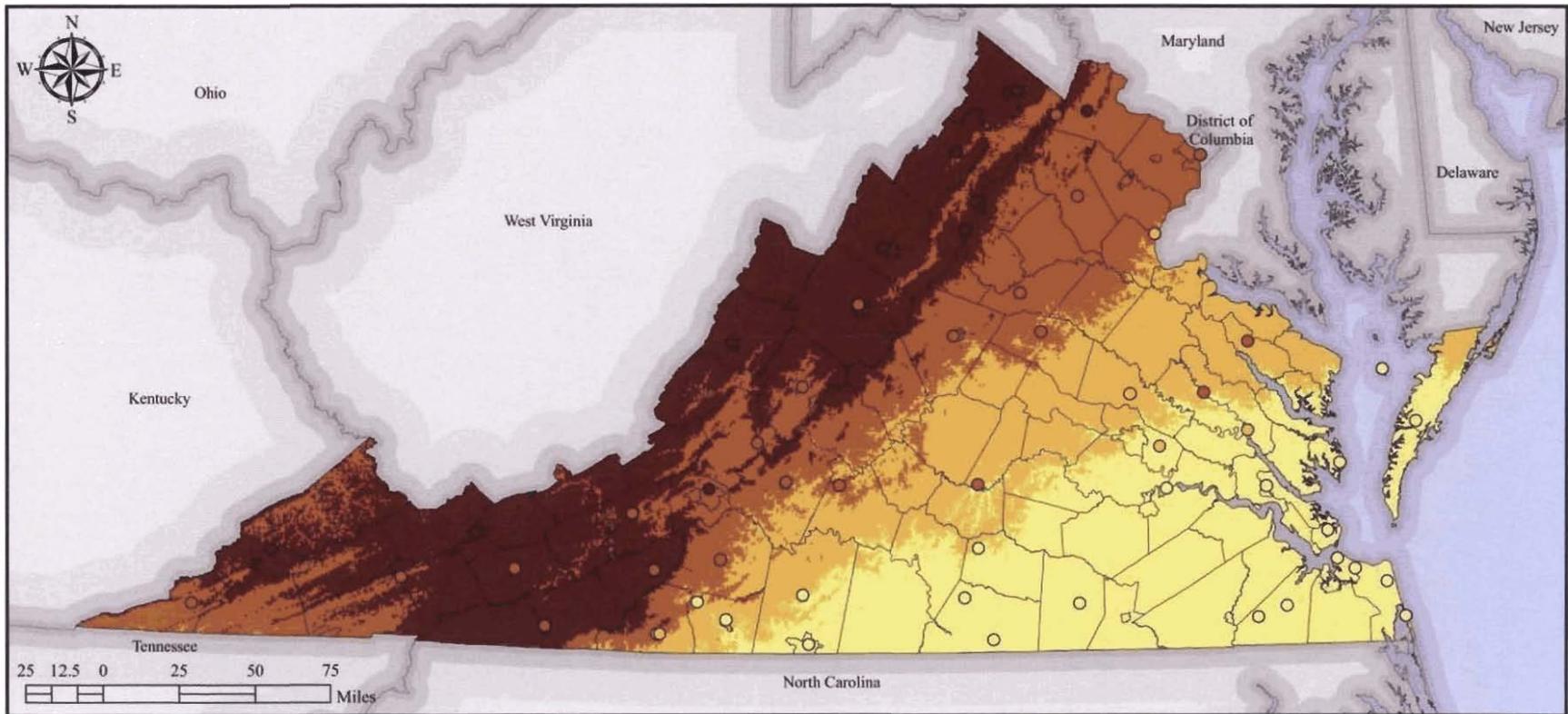


frequency of occurrence for user-specified conditions. In this instance, the probability that a given year would contain at least three days with three inches of snowfall was examined.

Figures 4.18 and 4.19 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 three to 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.

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.¹⁵ 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.



DATA SOURCES:
 CGIT analysis of NCDC data
 VGIN Jurisdictional Boundaries
 ESRI State Boundaries

LEGEND:
 Avg. Number of Days per Year

Light Yellow	1.5 or lower
Yellow	1.51 - 2.0
Orange	2.01 - 3.0
Dark Orange	3.01 - 6.72

HAZARD IDENTIFICATION:

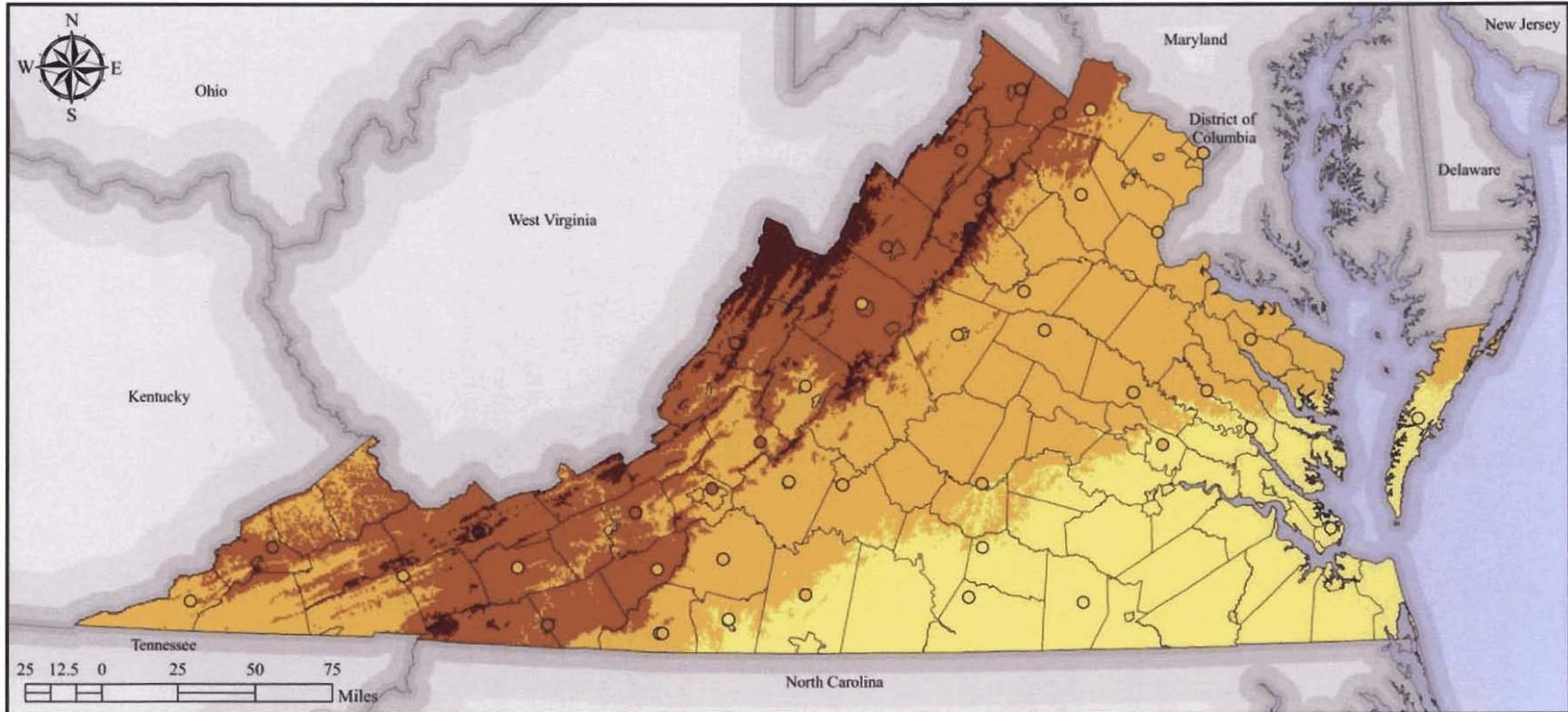
Winter weather statistics were estimated from daily NCDC weather station reports from 1960 - 2000; the values at the weather stations are symbolized with small round dots, and a statewide regression fit depicts the overall trend in the weather station statistics.

These results depict general trends, and local conditions may vary widely.

PROJECTION: VA Lambert Conformal Conic
 North American Datum 1983

DISCLAIMER: Majority of available hazard data is intended to be used at national or regional scales. The purpose of the data sets are to give general indication of areas that may be susceptible to hazards. In order to identify potential risk in the Commonwealth available data has been used beyond the original intent.

Figure 4.19. Average Numbers of Days with At Least Three Inches of Snow



DATA SOURCES:

CGIT analysis of NCDC data
VGIN Jurisdictional Boundaries
ESRI State Boundaries

LEGEND:

Avg. Number of Days per Year

Lightest Yellow	0.5 or lower
Yellow	0.51 - 1.0
Orange	1.01 - 1.5
Dark Orange	1.51 - 2.3

HAZARD IDENTIFICATION:

Winter weather statistics were estimated from daily NCDC weather station reports from 1960 - 2000; the values at the weather stations are symbolized with small round dots, and a statewide regression fit depicts the overall trend in the weather station statistics.

These results depict general trends, and local conditions may vary widely.

PROJECTION: VA Lambert Conformal Conic
North American Datum 1983

DISCLAIMER: Majority of available hazard data is intended to be used at national or regional scales. The purpose of the data sets are to give general indication of areas that may be susceptible to hazards. In order to identify potential risk in the Commonwealth available data has been used beyond the original intent.

Figure 4.20. 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 1993 to November 2009. Examination of NCDC data shows that there were 857 winter weather events in the database, producing an estimated annual loss of \$394,977 (See Table 4.39). The data indicates that Fairfax County reported the highest annualized property and crop losses due to winter storms at \$60,537.

**Table 4.39 Annualized Property and Crop Loss Due to Winter Storms**

Winter Storms	
Number of Total Events	857
Years of Record 1993 - 2009	Annualized Property and Crop Damage
Arlington County	\$60,484
Fairfax County	\$60,537
Loudoun County	\$31,982
Prince William County	\$60,502
City of Alexandria	\$60,484
City of Fairfax	\$0
City of Falls Church	\$60,484
City of Manassas	\$60,502
City of Manassas Park	\$0
Total	\$394,977

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 aren't 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

During the 2006 plan creation, annualized loss for winter storms was estimated at \$109,000 for the region. For the 2010 plan update, seven additional years of NCDC storm events data were utilized to develop updated annualized loss estimates of \$394,977.

The Commonwealth of Virginia’s 2010 HIRA ranking was based largely on the NCDC storm events 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 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 4.18), 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 (see Figure 4.21). It should also be noted that the overall rankings for Winter Weather have been altered to reflect MAC feedback for the Cities of Fairfax and Manassas Park. Based solely on the ranking parameter data, these two cities received slightly lower scores as compared to the rest of the region. According to the qualitative assessment performed for the 2006 Plan raking using the PRI tool, the winter storm hazard scored a PRI value of 3.0 (from a scale of 0 to 4, with 4 being the highest risk level). Table 4.40 summarizes the risk levels assigned to each PRI category.

Table 4.40. 2006 Qualitative Assessment for Winter Storms					
	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Limited	Large	More than 24 hours	Less than one week

The 2006 PRI assessment still is valid and supports the updated ranking and loss estimates.

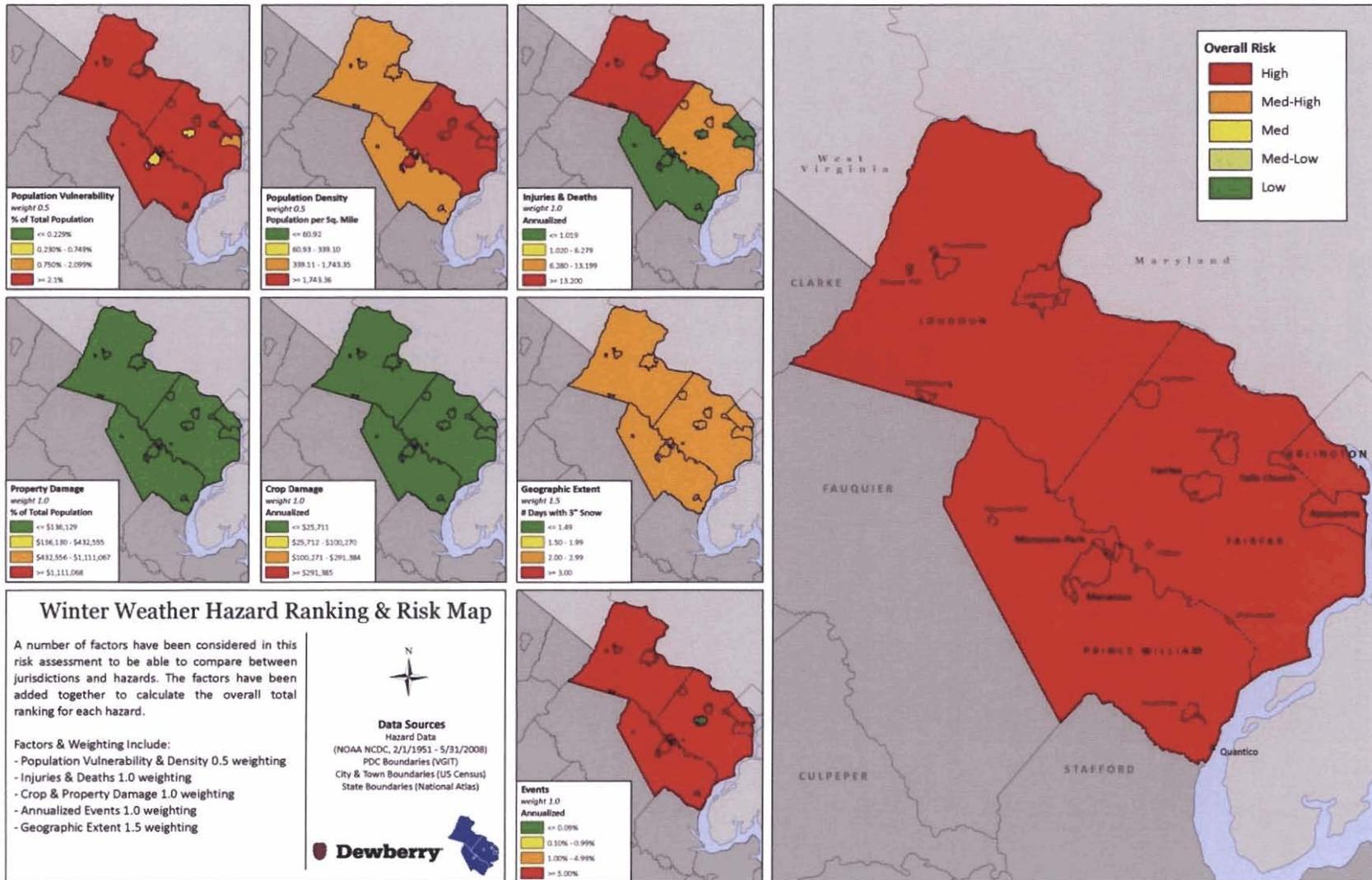


Figure 4.21. Winter Hazard Ranking and Risk



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

NOTE: As part of the 2010 plan update, the High Wind / Severe Storm hazards were 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 annualized 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 that 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.

B. Severe Thunderstorms

According to the NWS, more than 100,000 thunderstorms occur each year in the U.S., 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 very 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 regions are most ideal for generating these powerful storms.

Thunderstorms are caused when air masses of varying temperatures and moisture content meet. Rapidly rising warm moist air serves as the “engine” 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.



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)

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.

1. 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 4.22 illustrates thunderstorm hazard severity based on the annual average number of thunder events from 1948 to 1977.

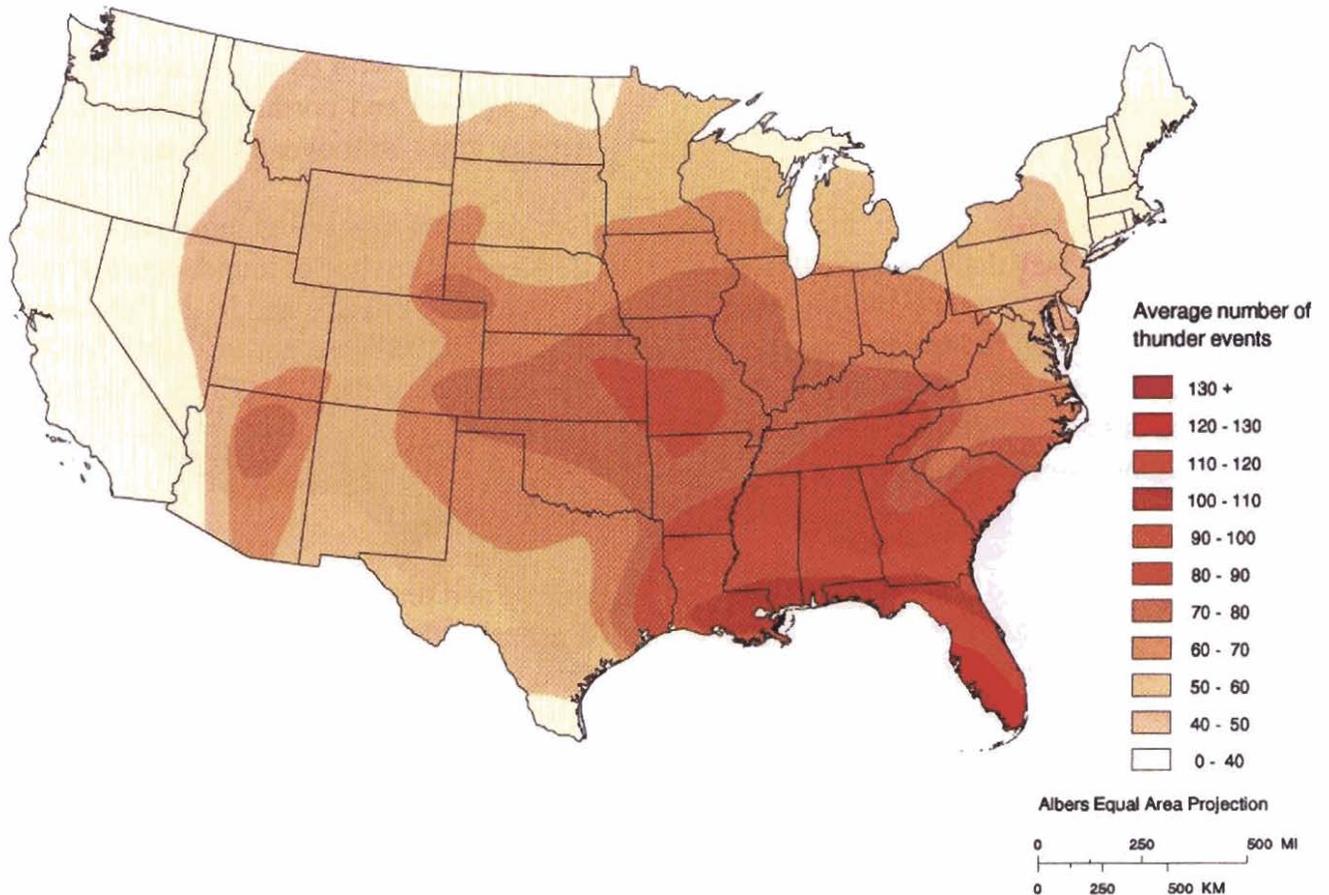


Figure 4.22. Annual Average Number of Thunder Events
Source: Federal Emergency Management Agency

2. 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 4.23 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.

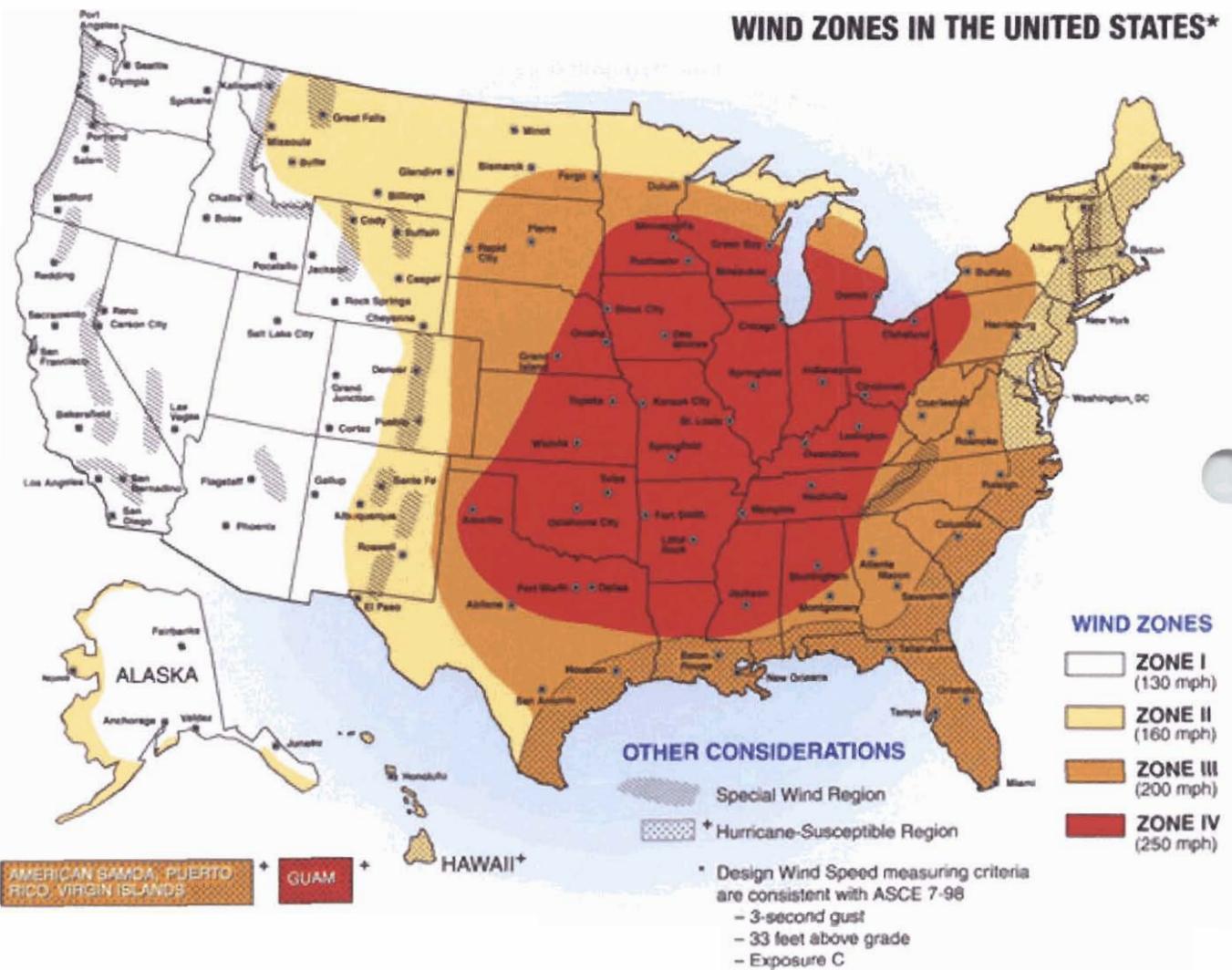


Figure 4.23. Wind Zones in the United States
Source: Federal Emergency Management Agency



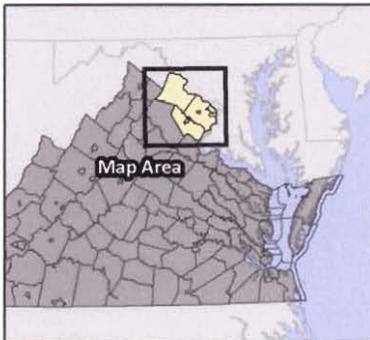
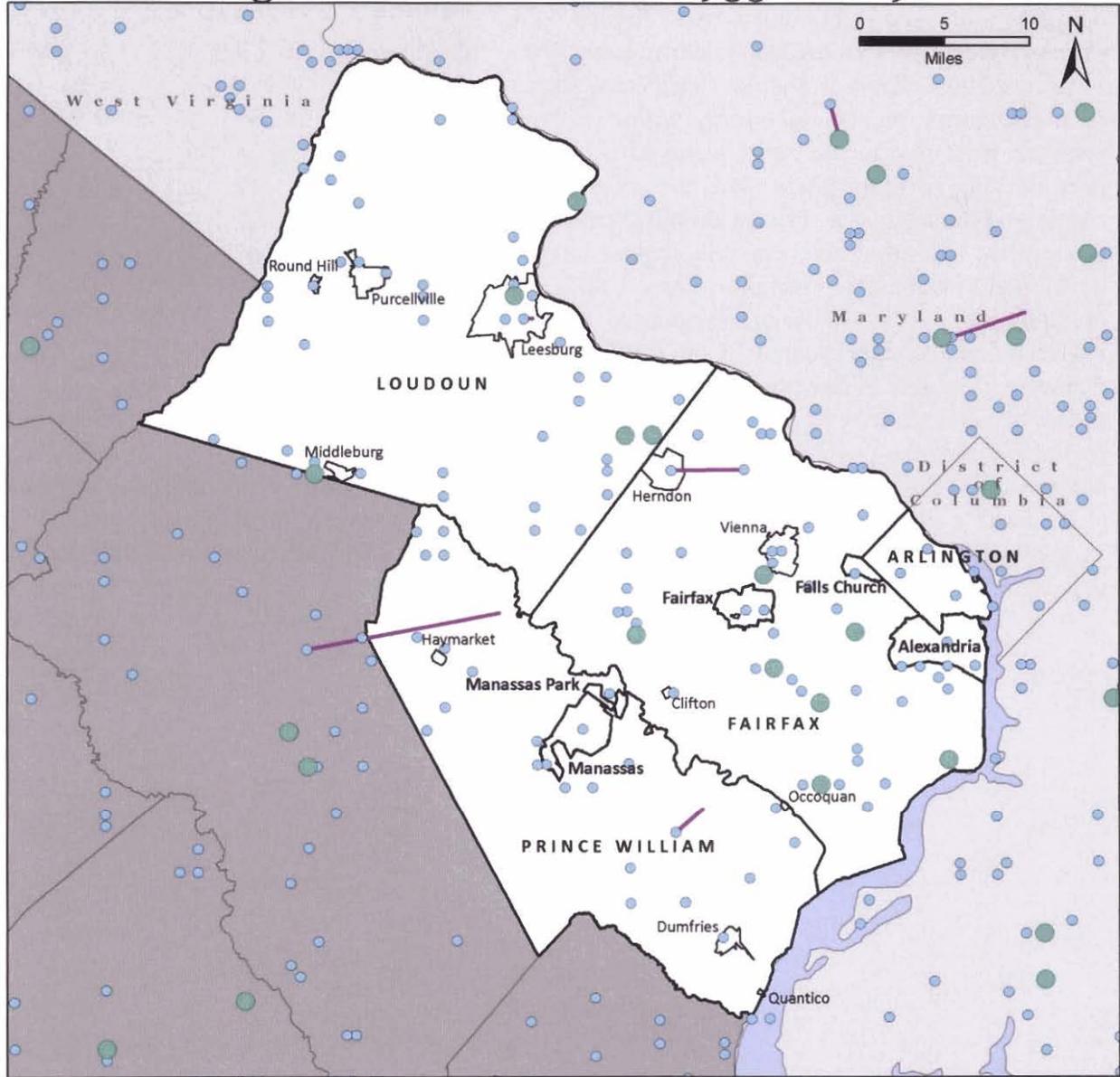
Hailstorms are another potential damaging outgrowth of severe thunderstorms. Figure 4.24 shows significant hail events occurring between 1955 and 2009. Early in the developmental stages of a hailstorm, ice crystals form within a low-pressure front due to the rapid rising of warm air into the upper atmosphere 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 4.25 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)



Significant Hail Events 1955 - 2009



Hail Events

- Hail 2 inches & Greater
- Hail Events
- Hail Swaths

Data Sources

- Hail Events (NOAA-SVRGIS)
- PDC Boundaries (VGIT)
- City & Town Boundaries (US Census)
- State Boundaries (National Atlas)



Dewberry

Figure 4.24. Significant Hail Events 1955 – 2009 *Source: NOAA-SVRGIS*

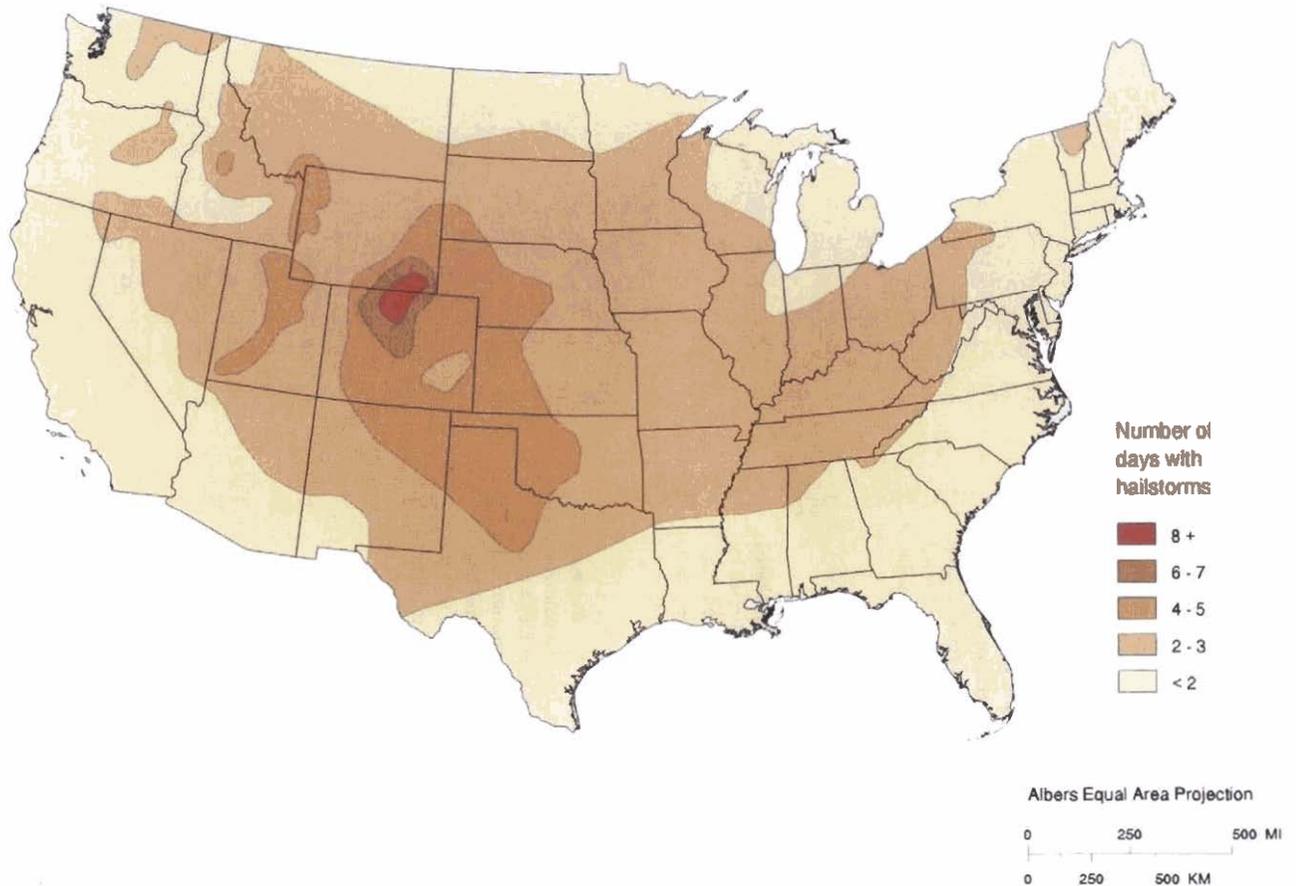


Figure 4.25. Annual Frequency of Hailstorms in the United States

Source: Federal Emergency Management Agency

In addition to high winds and hail associated with these events, thunderstorms can also bring dangerous lightning that can cause fires, property damage, and death or serious injury to humans. According to NWS statistics, an average of 58 deaths per year occur in the U.S. due to lightning (based on 1979-2008 data).

3. Previous Occurrences

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.

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.

June 4, 2008

A powerful line of storms raced across the region producing damaging winds over a wide swath of Northern Virginia. Winds gusted to 59 mph at Dulles International Airport, 64 mph at Fort Belvoir Davison Army Airfield, and 61 mph at Stone Hill Middle School in Brambleton. Extensive tree and power line damage resulted throughout the area, including downed trees across the George Washington Parkway. Washington Metro rail service was stopped for a time between the East and West Falls Church stations because of downed wires.

May 25, 2004

Severe storms impacted Northern Virginia with large hail, damaging winds, and at least one tornado. A tornado touched down briefly as hail to the size of golf balls pounded parts of Loudoun County near Lovettsville. The hail lasted long enough to cover the ground. Large hail was also reported with storms in the cities of Fairfax, Alexandria, and Falls Church.

August 3, 2002

Numerous thunderstorms with high winds, large hail, frequent lightning, and heavy downpours moved through the region during the afternoon and evening hours. In Fairfax, a spotter reported a wind gust in excess of 50 miles per hour. In Prince William County, nearly \$2 million in damage was reported in the Manassas area (a wind gust of 67 miles per hour was recorded at the Manassas Airport). The high winds downed numerous trees in Manassas and Manassas Park. In addition, dime to quarter sized hail fell in Manassas and Manassas Park for over 20 minutes, resulting in extensive roof, siding, and vehicle damage. Very heavy downpours also caused minor flooding on streets. An observer in Manassas Park reported a total of 5¼ inches of rainfall in only 90 minutes.

August 7, 2000

Scattered thunderstorms developed across northeast Virginia during the hot and humid afternoon and evening hours, causing nearly hundreds of trees to be downed onto homes, roads, cars, and power lines across the region. These thunderstorms produced winds in excess of 55 miles per hour, large hail, frequent lightning, and heavy rainfall. Over 70,000 customers lost power across Northern Virginia as a direct result of the storms.

April 23, 1999

A line of thunderstorms developed in West Virginia during the early afternoon and moved rapidly southeast across Northern Virginia. These storms produced high winds and very large hail across the region, causing significant damage to cars and structures. Loudoun County bore the brunt of the storm, where up to baseball-sized hail broke store windows and damaged several vehicles in Middleburg. Prince William County suffered damage from hail between 1 and 1¾ inches in diameter, resulting in damage to cars, roofs, and siding. Much of Fairfax County also received significant damage, with hail up to 2¾ inches in diameter. Reportedly hundreds of cars were dented, several windows and skylights were broken, trees and bushes were stripped of their leaves, siding and shutters were damaged, and roof shingles were chipped.



September 6, 1996

Gusty winds in excess of 40 miles per hour, combined with soft soil from previous rainfall, caused scattered tree damage across much of the region. In Fairfax County, a motorist died when his car slammed into a fallen tree. Tree damage was also noted in Arlington and Prince William County. Virginia Power estimated 38,300 customers were without power in Northern Virginia mainly due to the high winds; however, there were likely more than 50,000 customers without power after accounting for rural electric cooperatives.

October 21, 1995

A cold front which produced flash flooding during the late evening of the October 20 induced thunderstorms east of the mountains. One lightning strike hit a fast food restaurant in Fairfax County, setting it ablaze and destroying it. Damage was estimated to be at least \$300,000.

April 12, 1994

Lightning started several house fires in Fairfax County. One house fire caused \$400,000 in damage, while another one caused \$200,000 damage.

July 20, 1975

Sixteen people were struck and injured by a lightning strike while picnicking in Annandale (Fairfax County).

C. Risk Assessment

1. Probability of Future Occurrences

Since thunderstorms 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. 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 U.S., including northern Virginia.¹⁶

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 thunderstorm winds is damage to electric power lines which regularly cause power outages for residents and businesses across the area. During past events, thunderstorm 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 adjusted for inflation related to thunderstorm wind, hail, and lightning events totaled nearly \$64.9 million or \$309,649 on an annualized basis.

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

During the 2006 plan creation, annualized loss for thunderstorms was estimated at \$1,100,000 for the region. For the 2010 plan update, thunderstorm wind, hail, and lightning events have produced a total of approximately \$64.9 million in property and crop damage in Northern Virginia since 1951. (See Table 4.41) The highest loss estimates for any jurisdiction in Northern



Virginia for these hazards have occurred in Fairfax County where the NCDC records indicate a total of \$38.8 million or approximately \$168,888 annually in property and crop damages.

**Table 4.41 Loss Estimates Due to Thunderstorm Wind, Hail and Lightning
Thunderstorms (Wind, Hail, Lightning Events)**

Jurisdiction	Annualized Property and Crop Damage	Total Property and Crop Damage
Arlington County	\$19,018	\$1,145,583
Fairfax County	\$168,888	\$38,804,365
Loudoun County	\$41,143	\$12,571,937
Prince William County	\$50,857	\$5,450,969
City of Alexandria	\$6,615	\$638,792
City of Fairfax	\$1,699	\$2,668,507
City of Falls Church	\$8,563	\$466,437
City of Manassas	\$12,865	\$3,190,193
City of Manassas Park	\$0*	\$0*
Total	\$309,649	\$64,936,782

The NCDC database does not include any damages for the City of Manassas Park for thunderstorm wind, hail, or lightning events. Even so, it is likely that some damaging events in the city went unreported and the loss figures here underrepresent this reality.

Although a separate ranking was not made for severe thunderstorms, historical damage due to thunderstorm wind gusts is included in the 2010 ranking assessment for high wind below. The high wind hazard incorporates both thunderstorm and hurricane/tropical storm winds along with non-thunderstorm related damaging wind events. According to the 2006 qualitative assessment performed using the PRI tool; the severe thunderstorm hazard scored a PRI value of 2.7 (from a scale of 0 to 4, with 4 being the highest risk level). Table 4.42 summarizes the risk levels assigned to each PRI category.

Table 4.42 2006 Qualitative Assessment for Severe Thunderstorms

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Highly Likely	Limited	Small	Less than 6 hours	Less than 6 hours

The 2006 PRI assessment still is valid and supports the updated ranking and loss estimates.

D. 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 and the average number of storms that reach hurricane intensity per year in this basin is about six.

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).

Figure 4.25 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.

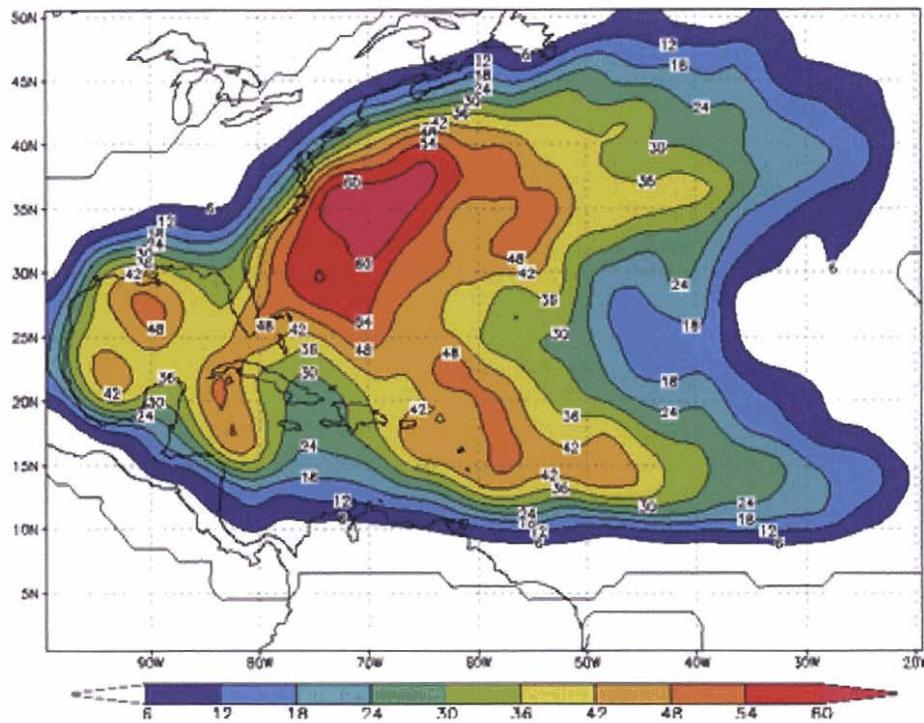


Figure 4.25 Empirical Probability of a Named Storm
 Source: National Oceanic and Atmospheric Administration, Hurricane Research Division

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 (see Table 4.43), which rates hurricane intensity on a scale of 1 to 5, with 5 being the most intense.

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

Source: National Hurricane Center



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 4.44 describes expected damage per hurricane category.

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. Figure 4.26 shows the modeled storm surge zones for the Commonwealth of Virginia. As shown, portions of Prince



William, Fairfax, and Arlington counties, as well as the City of Alexandria are located within the category 1 storm surge zones. 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. Rainfall amounts were as high as 20 inches in certain locales and 67 counties sustained 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 U.S. 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 4.45 shows an intensity scale proposed for nor’easters that is based on levels of coastal degradation.

Table 4.45 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

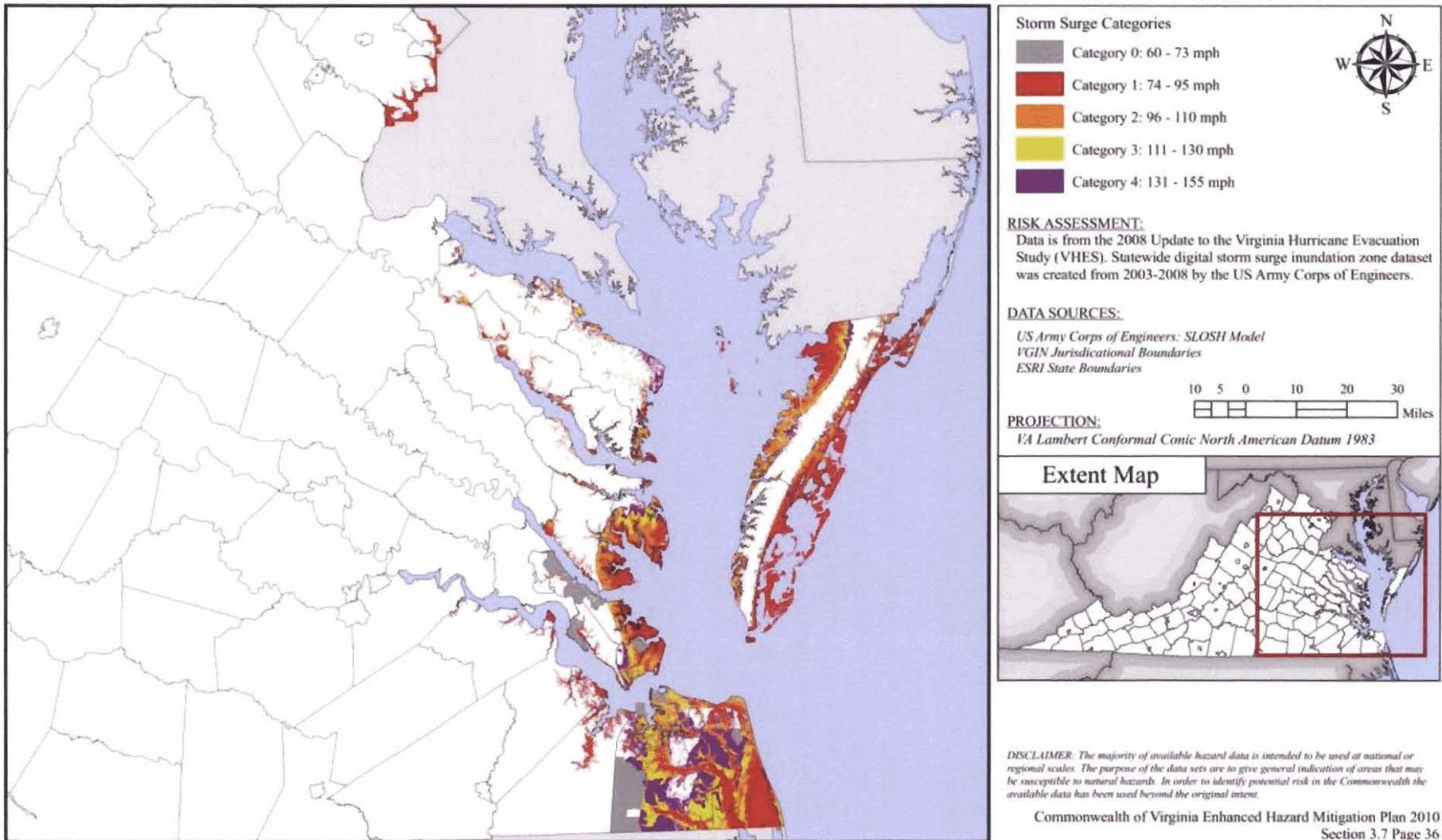


Figure 4.26. Storm Surge Categories for Virginia. Source: Commonwealth of Virginia 2010 Hazard Mitigation Plan



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 30 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. Five of these storms were classified as hurricanes (including Isabel in 2003), and 25 as tropical storms as they impacted the region. These events are listed in Table 4.46 with a graphical depiction of historical hurricane tracks between 1851 and 2009 shown in Figure 4.27.

Table 4.46 Historical Hurricane and Tropical Storms in the Northern Virginia Region, 1851–2010

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



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 4.47 summarizes estimated damage figures caused by hurricane and tropical storm events since 1993 as recorded by the NCDC. 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 as referenced on page three of this section.

Table 4.47. Historical Hurricane and Tropical Storm Damages in the Northern Virginia Region, 1993–2010	
Estimated Property Damage	
Total	\$45,048,000

Source: NOAA, National Climatic Data Center

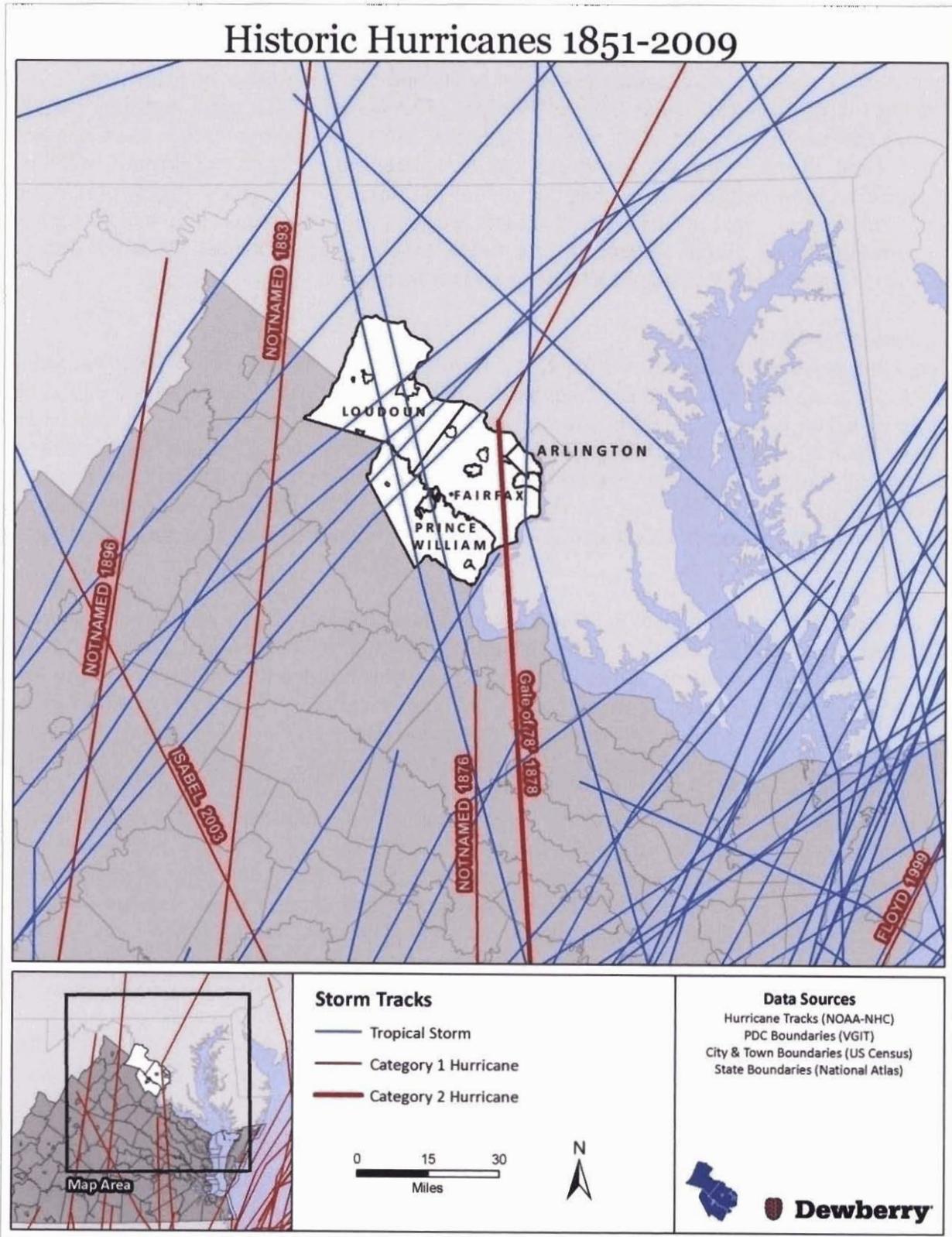


Figure 4.27. Historic Hurricane Tracks, 1851-2009



Significant Historical Events

September 6-7, 2008 (Hanna)

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.

September 18-19, 2003 (Isabel)

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.

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. Arlington 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 the City of Fairfax, 15 homes had major damage from trees. Fairfax County damages came to \$18 million. 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.

September 16, 1999 (Floyd)

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. Trainbands 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. Gusty winds of 30 to 50 miles per hour blew north and east of a line from



Spotsylvania County to Frederick County between 11:00AM and midnight on the 16th. Hundreds of trees were downed from the combination of very heavy rain and strong winds. A total of two to five inches of rain fell in this area and 16,000 power outages were reported.

In Prince William County, 17 trees came down on roads and power lines, and two homes were slightly damaged by fallen trees. In the Montclair area, 1,000 residents lost power. Some secondary roads were also flooded. A few trees were downed in the Manassas area. In Fairfax County, a 61 year old woman was killed when a tree fell onto her car and crushed it on Fair Lakes Drive. 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. The Mason Neck area saw several large trees downed, including a 100-foot poplar that put a hole through a bedroom of a two story home. Mt. Vernon and Vienna also reported several downed trees, including one which damaged a car. The County had to hire 16 tree trimming contractors to clear downed trees that blocked roadways. Flooding caused problems at seven major intersections and on 20 secondary roads. Winds and rain combined to topple 130 trees in Arlington County and Alexandria. One tree damaged a home and 4,500 power outages were reported. 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.

September 5, 1999 (Dennis)

The remnants of Hurricane Dennis moved across the northern half of Virginia from midday on the 4th through midday on the 6th. Its legacy included very heavy rain and wind gusts in excess of 45 miles per hour. The heaviest period of rain in the region occurred between 3:00AM and 8:00AM on the 5th. The City of Alexandria along the tidal Potomac River reported minor problems with flooding. The storm surge from Hurricane Dennis along with persistent southeast winds made tide levels two to three feet above normal on the 5th and 6th. At high tide, portions of the city near the waterfront were invaded by water which subsided again with each low tide. The 100 block of King and Union Streets was flooded for a time on Sunday. River levels reached as high at 6.5 feet at the Wisconsin Avenue gauge during the early morning and late afternoon both days.

September 6, 1996 (Fran)

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.

The Old Town section of Alexandria also saw extensive tidal flooding from the Potomac River. Water was five feet deep in the lower portion of the city and many shops were flooded, some losing merchandise. Heavy rains and wind driven water exacerbated the tidal flooding problem. The wind driven storm surge reached over five feet above normal and came at about the same time as high tide, which was 4:11PM at the Wisconsin Avenue gage in Washington, DC. Because of Alexandria's orientation to the wind, water levels were likely a little higher. Washington National Airport in southern Arlington County also 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.

September 5, 1979 (David)

Hurricane David spawned eight tornadoes across Virginia. Two cities and five counties were hit from Norfolk in the southeast to Leesburg in the north. Because the tornadoes were associated with the spiral bands of a hurricane, they moved from the southeast to the northwest. In total there was one death and 19 injuries caused by the storm. Fairfax County had \$2.5 million in damages.

June 1972 (Agnes)

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. Lake Barcroft Dam in Fairfax County failed, but resulted in no loss of life.

August 31, 1952 (Able)

The first hurricane of the season made landfall between Charleston and Savannah and moved north across Virginia and Washington, DC, in a weakened form. Rainfall was around two to three inches. It produced winds of 30 to 40 miles per hour with peak gusts to 60 miles per hour. Its greatest impact on Virginia was a small tornado (F2) that struck Franconia in Fairfax County. It traveled two miles and was around 100 yards wide. Property damage in the area was \$500,000 caused by flooding, the tornado, and falling trees and branches that disrupted power and telephone facilities.

October 22-23, 1878 (Gale of '78)

The hurricane'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.



E. 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 should 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 (sustained wind speeds of at least 39 miles per hour and torrential rains) 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 scenario¹⁷, and operational hurricane forecast models, one study¹⁸ 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 (sustained winds of greater 39 miles per hour). 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 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 has been completed for a level 1 analysis only. A level 1 analysis involves using the provided data with no local data inputs. 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. Note that storm surge and waves have not been implemented in the present version of the Hurricane Model¹⁹.

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 4.48 displays the economic loss categories used to calculate annualized losses by HAZUS^{MH}.



Table 4.48. 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
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 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 following figures 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 tract. Buildings that must be designed for a 100-year mean recurrence interval wind event include²⁰:

- 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 (See Figures 4.28 and 4.29) 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.

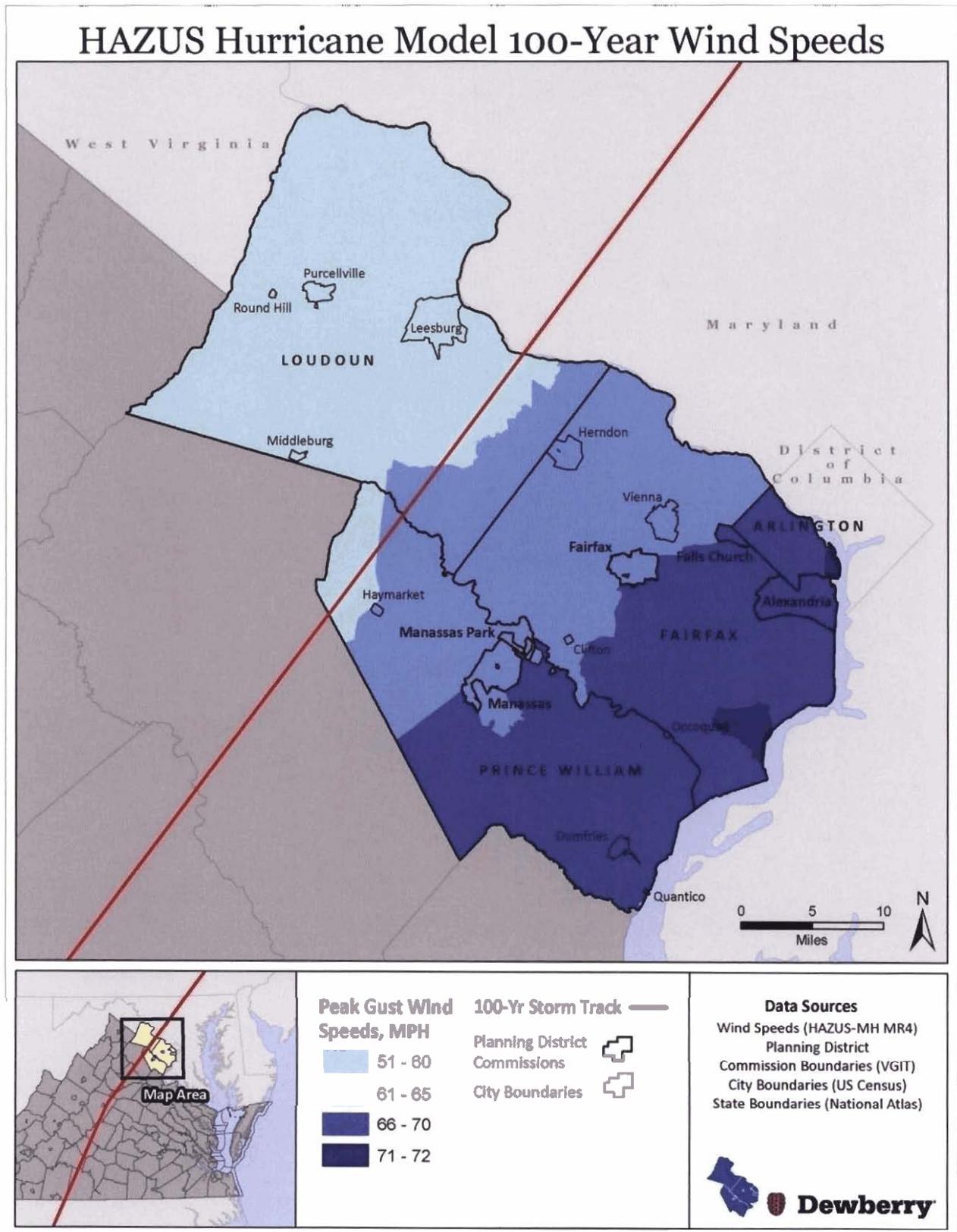


Figure 4.28. HAZUS^{MH} Peak Wind Gusts for 100-Year Event

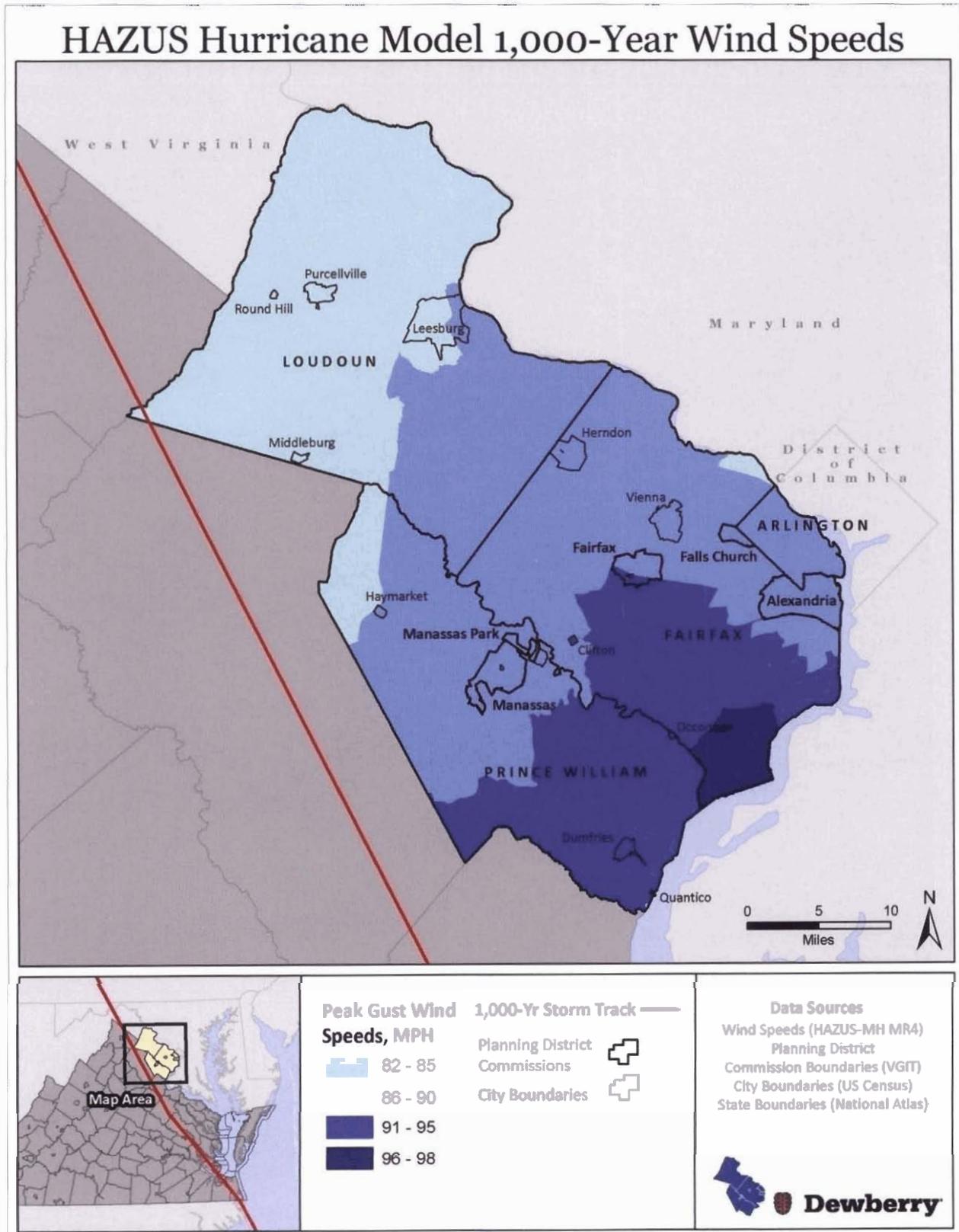


Figure 4.29. HAZUS^{MH} Peak Wind Gusts for 1,000-Year Event



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. EOCs and hospitals for all the modeled return periods result in 100% functionality.

- Fire stations, for the 1000-year event will result in 95.59% functionality; Fairfax County and City will maintain 95.24% functionality of 42 fire stations, and Prince William County will maintain 88.89% of nine fire stations.
Police stations, for the 500 and 1000-year event, will result in 97.50% functionality; Prince William County will maintain 88.89% functionality of nine police stations.
- Schools, for the 500-year event will result in 99.69% functionality; Fairfax County and City will maintain 99.70% functionality of 337 schools and Prince William County will maintain 99.70% of 115 schools. The 1000-year event will result in 93.87% functionality; Fairfax County and City will maintain 96.14% functionality of 337 schools and Prince William County will maintain 77.39% of 115 schools

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 Arlington County would be displaced and seek shelter from a 200-year event, 40 households (10 in the City of Alexandria and 23 in Arlington County) would be displaced and seek shelter from a 500-year event and 182 households (31 in the City of Alexandria, 39 in Arlington County, 31 in Fairfax County and City, three in the City of Manassas and 28 in Prince William County) would be displaced and seek shelter from a 1000-year event.

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 4.49 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 4.49. HAZUS^{MH} Number of buildings damaged

Return Period	Minor		Moderate		Severe		Destruction		Total	
	Residential	Total	Residential	Total	Residential	Total	Residential	Total	Residential	Total
10	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-
50	188	247	3	3	-	-	-	-	191	250
100	723	884	24	25	-	-	-	-	747	909
200	3,529	3,869	294	304	1	1	-	-	3,824	4,174
500	14,551	15,421	1,343	1,404	2	6	-	1	15,896	16,832
1000	36,986	38,862	3,828	4,040	13	34	37	37	40,864	42,973

HAZUS^{MH} estimates annualized hurricane/tropical storm wind loss in Northern Virginia at approximately \$4.8 million. In terms of annualized loss by jurisdiction, Fairfax County tops the list at approximately \$2.5 million. See Table 4.50 for a complete breakdown of total annualized building loss by jurisdiction.

In the case of a 100-year hurricane event, HAZUS^{MH} estimates the building loss for Northern Virginia to be approximately \$53.3 million. Should the region experience a 1000-year hurricane event, the model estimates the building loss for the region would be approximately \$807 million. Tables 4.51 and 4.52 provide a detailed summary of losses by jurisdiction. Figures 4.30 through 4.32 depict the total direct economic building loss on an annualized basis, as well as for the 1000-year and 100-year hurricane events by census tract.



Table 4.50. 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	\$543,847	\$77,574	\$573	\$40,176	\$5,554	\$24,946	\$7,342	\$700,012
Fairfax County	\$2,086,176	\$212,519	\$1,641	\$119,367	\$11,790	\$50,745	\$13,512	\$2,495,750
<i>Town of Herndon</i>	<i>\$36,459</i>	<i>\$4,273</i>	<i>\$63</i>	<i>\$2,429</i>	<i>\$456</i>	<i>\$1,099</i>	<i>\$559</i>	<i>\$45,338</i>
<i>Town of Vienna</i>	<i>\$36,154</i>	<i>\$3,979</i>	<i>\$43</i>	<i>\$2,263</i>	<i>\$403</i>	<i>\$791</i>	<i>\$460</i>	<i>\$44,093</i>
<i>Town of Clifton</i>	<i>\$504</i>	<i>\$36</i>	<i>\$0</i>	<i>\$22</i>	<i>\$3</i>	<i>\$7</i>	<i>\$12</i>	<i>\$584</i>
Loudoun County	\$242,275	\$20,143	\$435	\$12,197	\$1,113	\$4,444	\$1,341	\$281,948
<i>Town of Leesburg</i>	<i>\$23,601</i>	<i>\$1,807</i>	<i>\$20</i>	<i>\$1,312</i>	<i>\$160</i>	<i>\$612</i>	<i>\$233</i>	<i>\$27,745</i>
<i>Town of Purcellville</i>	<i>\$730</i>	<i>\$41</i>	<i>\$1</i>	<i>\$29</i>	<i>\$3</i>	<i>\$10</i>	<i>\$4</i>	<i>\$818</i>
<i>Town of Middleburg</i>	<i>\$89</i>	<i>\$5</i>	<i>\$0</i>	<i>\$4</i>	<i>\$1</i>	<i>\$2</i>	<i>\$1</i>	<i>\$101</i>
<i>Town of Round Hill</i>	<i>\$44</i>	<i>\$2</i>	<i>\$0</i>	<i>\$2</i>	<i>\$0</i>	<i>\$1</i>	<i>\$0</i>	<i>\$48</i>
Prince William County	\$423,454	\$34,613	\$427	\$24,402	\$1,736	\$9,219	\$2,155	\$496,004
<i>Town of Dumfries</i>	<i>\$4,441</i>	<i>\$451</i>	<i>\$4</i>	<i>\$392</i>	<i>\$23</i>	<i>\$191</i>	<i>\$41</i>	<i>\$5,542</i>
<i>Town of Haymarket</i>	<i>\$123</i>	<i>\$9</i>	<i>\$0</i>	<i>\$6</i>	<i>\$1</i>	<i>\$2</i>	<i>\$1</i>	<i>\$143</i>
<i>Town of Occoquan</i>	<i>\$898</i>	<i>\$84</i>	<i>\$1</i>	<i>\$57</i>	<i>\$6</i>	<i>\$29</i>	<i>\$6</i>	<i>\$1,080</i>
<i>Town of Quantico</i>	<i>\$2,050</i>	<i>\$370</i>	<i>\$4</i>	<i>\$211</i>	<i>\$38</i>	<i>\$151</i>	<i>\$40</i>	<i>\$2,864</i>
City of Alexandria	\$387,234	\$57,628	\$427	\$30,477	\$4,701	\$17,598	\$6,277	\$504,342
City of Fairfax	\$45,380	\$5,279	\$98	\$3,158	\$731	\$1,460	\$770	\$56,876
City of Falls Church	\$29,561	\$3,820	\$36	\$2,127	\$401	\$1,034	\$488	\$37,468
City of Manassas	\$62,939	\$6,288	\$115	\$3,899	\$396	\$1,534	\$667	\$75,838
City of Manassas Park	\$16,418	\$1,395	\$30	\$903	\$47	\$275	\$78	\$19,145
Total	\$3,942,333	\$430,314	\$3,918	\$243,431	\$27,563	\$114,149	\$33,987	\$4,795,691



Table 4.51. 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	\$6,139,634	\$21,530	\$0	\$20,923	\$0	\$0	\$0	\$6,182,087
Fairfax County	\$29,852,097	\$15,370	\$0	\$25,286	\$0	\$4,885	\$0	\$29,897,638
<i>Town of Herndon</i>	\$432,523	\$158	\$0	\$207	\$0	\$0	\$0	\$432,887
<i>Town of Vienna</i>	\$484,137	\$32	\$0	\$55	\$0	\$0	\$0	\$484,224
<i>Town of Clifton</i>	\$8,426	\$0	\$0	\$0	\$0	\$0	\$0	\$8,426
Loudoun County	\$1,421,694	\$0	\$0	\$160	\$0	\$0	\$0	\$1,421,854
<i>Town of Leesburg</i>	\$55,072	\$0	\$0	\$12	\$0	\$0	\$0	\$55,085
<i>Town of Purcellville</i>	\$0	\$0	\$0	\$1	\$0	\$0	\$0	\$1
<i>Town of Middleburg</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
<i>Town of Round Hill</i>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Prince William County	\$8,133,575	\$5,512	\$0	\$5,855	\$0	\$1,625	\$0	\$8,146,567
<i>Town of Dumfries</i>	\$84,031	\$689	\$0	\$426	\$0	\$500	\$0	\$85,646
<i>Town of Haymarket</i>	\$1,098	\$0	\$0	\$0	\$0	\$0	\$0	\$1,098
<i>Town of Occoquan</i>	\$14,920	\$25	\$0	\$35	\$0	\$0	\$0	\$14,979
<i>Town of Quantico</i>	\$24,459	\$543	\$0	\$485	\$0	\$664	\$0	\$26,151
City of Alexandria	\$4,277,879	\$5,300	\$0	\$16,162	\$0	\$0	\$0	\$4,299,341
City of Fairfax	\$629,736	\$163	\$0	\$358	\$0	\$0	\$0	\$630,257
City of Falls Church	\$373,618	\$242	\$0	\$553	\$0	\$0	\$0	\$374,413
City of Manassas	\$923,987	\$763	\$0	\$448	\$0	\$0	\$0	\$925,197
City of Manassas Park	\$278,494	\$24	\$0	\$5	\$0	\$0	\$0	\$278,522
Total	\$53,135,380	\$50,351	\$0	\$70,971	\$0	\$7,674	\$0	\$53,264,373



Table 4.52 1,000-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	\$70,939,305	\$3,488,124	\$24,301	\$3,864,307	\$373,793	\$3,032,942	\$133,748	\$81,856,519
Fairfax County	\$392,911,283	\$13,659,771	\$160,982	\$15,870,006	\$1,613,721	\$8,109,935	\$976,681	\$433,302,379
<i>Town of Herndon</i>	\$7,008,016	\$274,363	\$6,329	\$325,809	\$81,258	\$197,720	\$29,447	\$7,922,942
<i>Town of Vienna</i>	\$6,378,136	\$181,891	\$3,991	\$231,024	\$43,781	\$90,759	\$15,862	\$6,945,443
<i>Town of Clifton</i>	\$112,748	\$1,622	\$30	\$2,972	\$0	\$759	\$0	\$118,130
Loudoun County	\$47,359,196	\$794,608	\$39,229	\$1,824,149	\$31,326	\$692,955	\$14,699	\$50,756,162
<i>Town of Leesburg</i>	\$4,697,446	\$84,571	\$935	\$203,548	\$0	\$98,611	\$0	\$5,085,111
<i>Town of Purcellville</i>	\$146,228	\$751	\$106	\$6,221	\$0	\$2,136	\$0	\$155,442
<i>Town of Middleburg</i>	\$17,454	\$104	\$7	\$816	\$0	\$300	\$0	\$18,680
<i>Town of Round Hill</i>	\$8,983	\$14	\$0	\$393	\$0	\$127	\$0	\$9,517
Prince William County	\$106,333,123	\$4,542,895	\$86,422	\$5,158,653	\$652,490	\$2,326,676	\$608,142	\$119,708,401
<i>Town of Dumfries</i>	\$1,123,665	\$83,270	\$973	\$90,495	\$12,703	\$55,469	\$23,484	\$1,390,060
<i>Town of Haymarket</i>	\$25,741	\$229	\$22	\$1,041	\$0	\$414	\$0	\$27,447
<i>Town of Occoquan</i>	\$232,421	\$13,512	\$116	\$12,782	\$1,510	\$8,478	\$939	\$269,757
<i>Town of Quantico</i>	\$655,775	\$116,300	\$1,055	\$76,365	\$16,720	\$56,669	\$19,686	\$942,570
City of Alexandria	\$54,730,304	\$3,314,401	\$22,582	\$3,304,733	\$445,687	\$2,606,544	\$159,724	\$64,583,975
City of Fairfax	\$9,345,815	\$441,010	\$11,567	\$424,397	\$101,297	\$235,033	\$36,543	\$10,595,662
City of Falls Church	\$4,563,583	\$190,593	\$1,823	\$231,968	\$46,545	\$146,683	\$16,555	\$5,197,752
City of Manassas	\$12,956,384	\$491,309	\$14,293	\$519,766	\$83,255	\$265,632	\$30,505	\$14,361,145
City of Manassas Park	\$3,389,750	\$69,796	\$3,611	\$113,451	\$2,474	\$32,682	\$891	\$3,612,655
Total	\$722,935,356	\$27,749,134	\$378,374	\$32,262,896	\$3,506,560	\$17,960,524	\$2,066,906	\$806,859,749

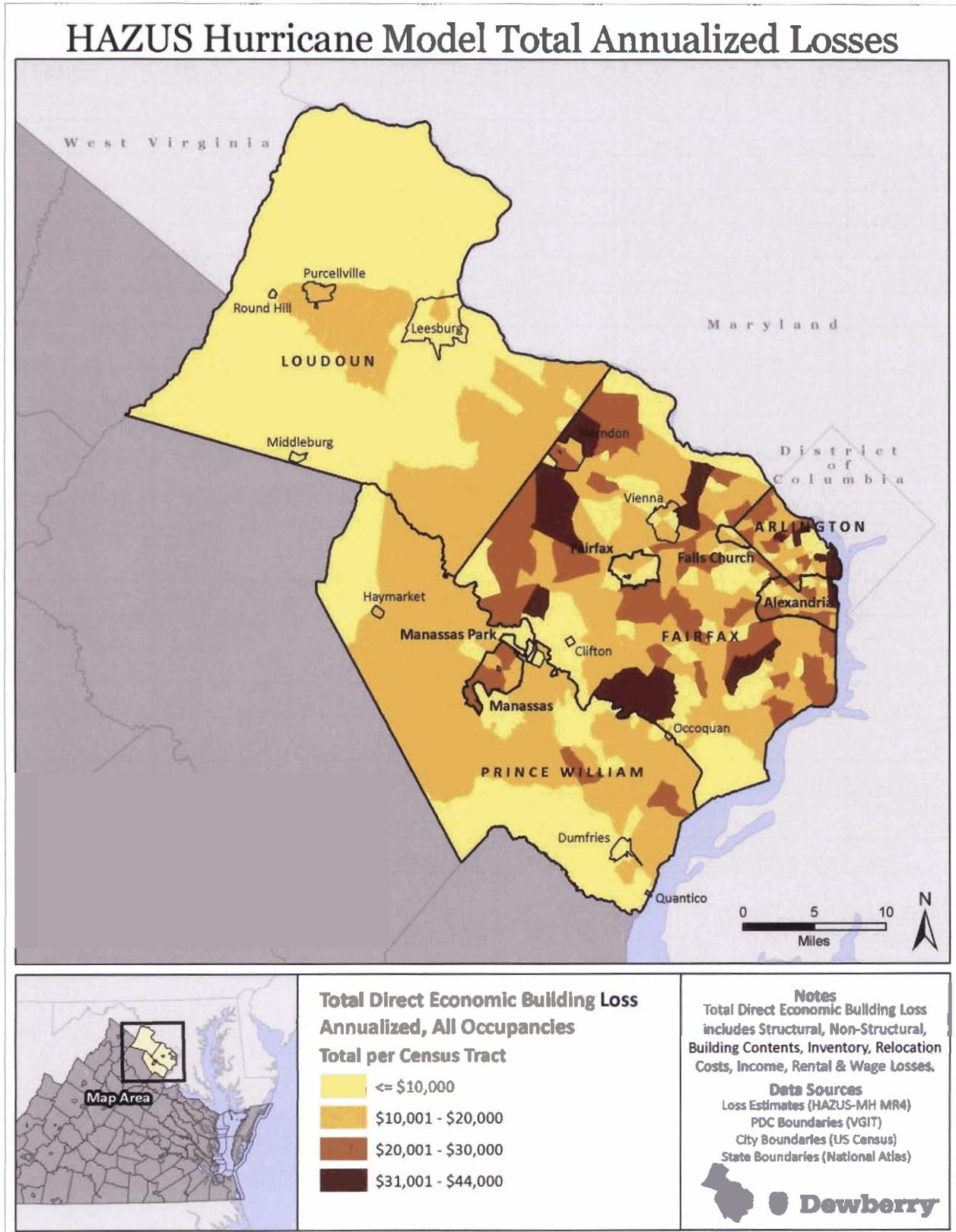
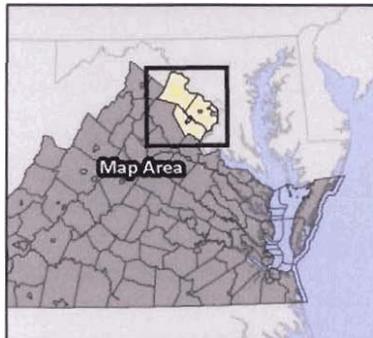
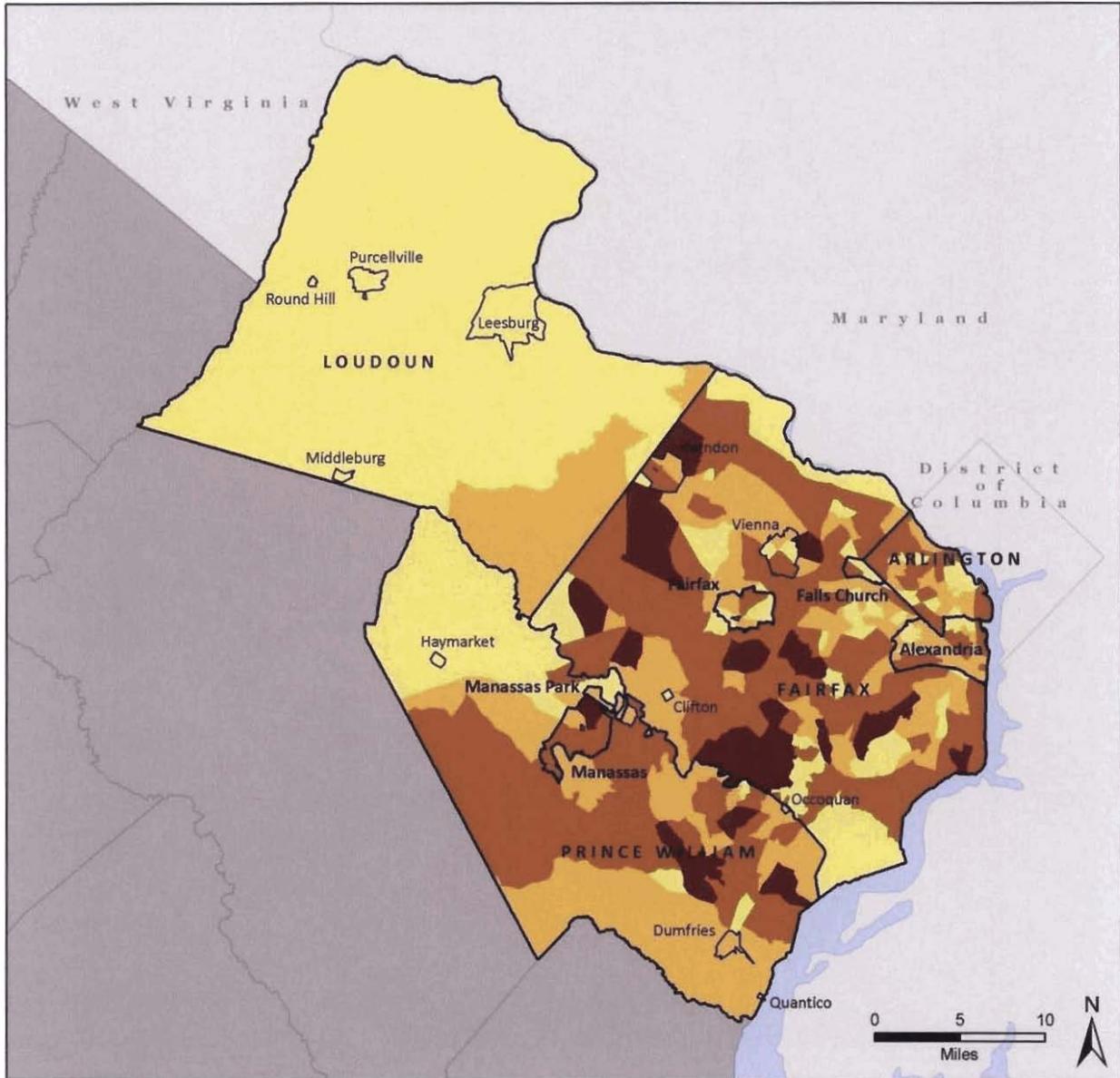


Figure 4.30. Total Annualized Total Direct Economic Building Losses



HAZUS Hurricane Model Total Losses 100-Year Event



**Total Direct Economic Building Loss
100-Yr Event, All Occupancies
Total per Census Tract**

- <= \$100,000
- \$100,001 - \$175,000
- \$175,001 - \$300,000
- \$300,001 - \$630,000

Notes
Total Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

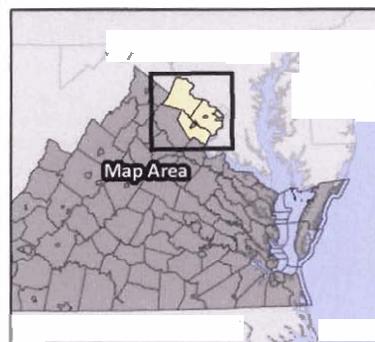
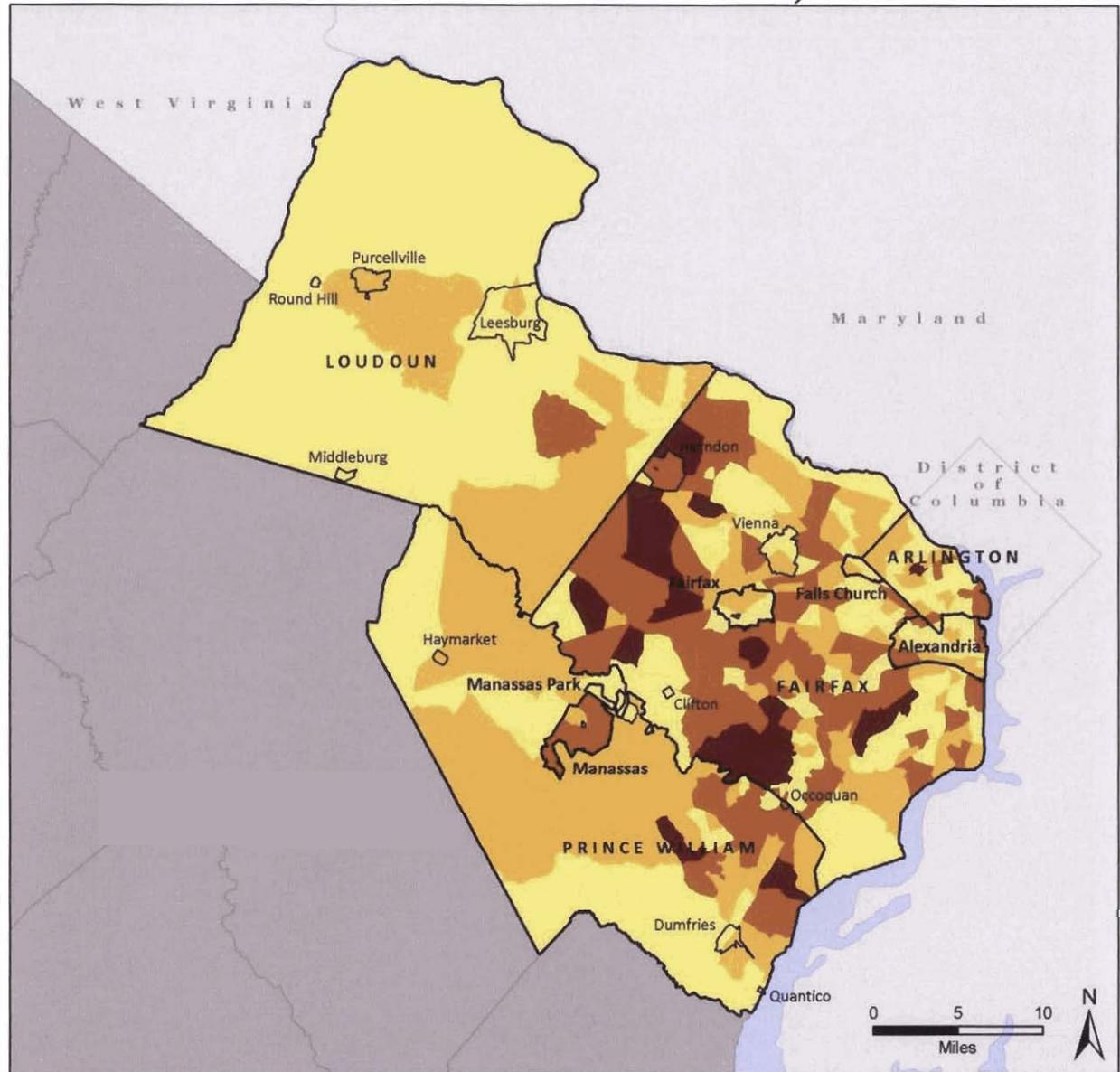
Data Sources
Loss Estimates (HAZUS-MH MR4)
PDC Boundaries (VGIT)
City Boundaries (US Census)
State Boundaries (National Atlas)



Figure 4.31. 100-Year Hurricane Model Total Direct Economic Building Loss



HAZUS Hurricane Model Total Losses 1,000-Year Event



**Total Direct Economic Building Loss
1,000-Yr Event, All Occupancies
Total per Census Tract**

- <= \$2 million
- \$2.1 million - \$3 million
- \$3.1 million - \$5 million
- \$5.1 million - \$7.9 million

Notes
Total Direct Economic Building Loss includes Structural, Non-Structural, Building Contents, Inventory, Relocation Costs, Income, Rental & Wage Losses.

Data Sources
Loss Estimates (HAZUS-MH MR4)
PDC Boundaries (VGIT)
City Boundaries (US Census)
State Boundaries (National Atlas)



Figure 4.32. 1,000-Year Hurricane Model Total Direct Economic Building Loss



Overall Loss Estimates and Ranking

During the 2006 plan creation, annualized loss for hurricanes was estimated at \$33,723,000 for the region. For the 2010 plan update as determined by HAZUS^{MH}, the annualized losses due to hurricanes in Northern Virginia totals approximately \$4.8 million. The differences in these values is a result of the methodology used to total annualized loss; in 2006 HAZUS^{MH} was completed for the 50-, 100-, and 500-year events and the annualized loss is based on those events. The 2010 update uses 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, property and crop losses in Northern Virginia due to high wind events average approximately \$2.9 million (NCDC storm events data). Based on analysis of the historical data and on the high end of the scale, Prince William County experiences approximately \$795,511 in property and crop damage annually, while the City of Manassas is not far behind with an estimated \$694,402 per year in losses due to high wind (Table 4.53).

Table 4.53. Property and Crop Annualized Loss Due to High Wind	
High Wind	
	856
<i>Years of Record: 1955 - 2009</i>	Annualized Property and Crop Damage
Arlington County	\$226,057
Fairfax County	\$612,562
Loudoun County	\$176,618
Prince William County	\$795,511
City of Alexandria	\$193,936
City of Fairfax	\$4,482
City of Falls Church	\$198,830
City of Manassas	\$694,402
City of Manassas Park	\$573
Total	\$2,902,973

The Commonwealth of Virginia’s 2010 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} 3-second Peak Wind Gusts. 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 hazard is ranked as being “High” for all jurisdictions in Northern Virginia. Figure 4.32 shows each of the ranking criteria used to come



up with the overall ranking. It should also be noted that the overall rankings for high wind has been altered to reflect steering committee feedback for the Cities of Fairfax and Manassas Park. Based solely on the ranking parameter data, these two cities received slightly lower scores as compared to the rest of the region.

Although a separate ranking was not made for hurricanes, historical damage due to hurricane wind is included in the 2010 ranking assessment for high wind below. The high wind 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.

According to the 2006 qualitative assessment performed using the PRI tool, the hazard of hurricane and tropical storm-force winds scored a PRI value of 2.6 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.54 summarizes the risk levels assigned to each PRI category.

Table 4.54. 2006 Qualitative Assessment for Hurricane and Tropical Storm-Force Winds

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Possible	Critical	Large	More than 24 hours	Less than 24 hours

The 2006 PRI assessment is valid and supports the updated ranking and loss estimates.

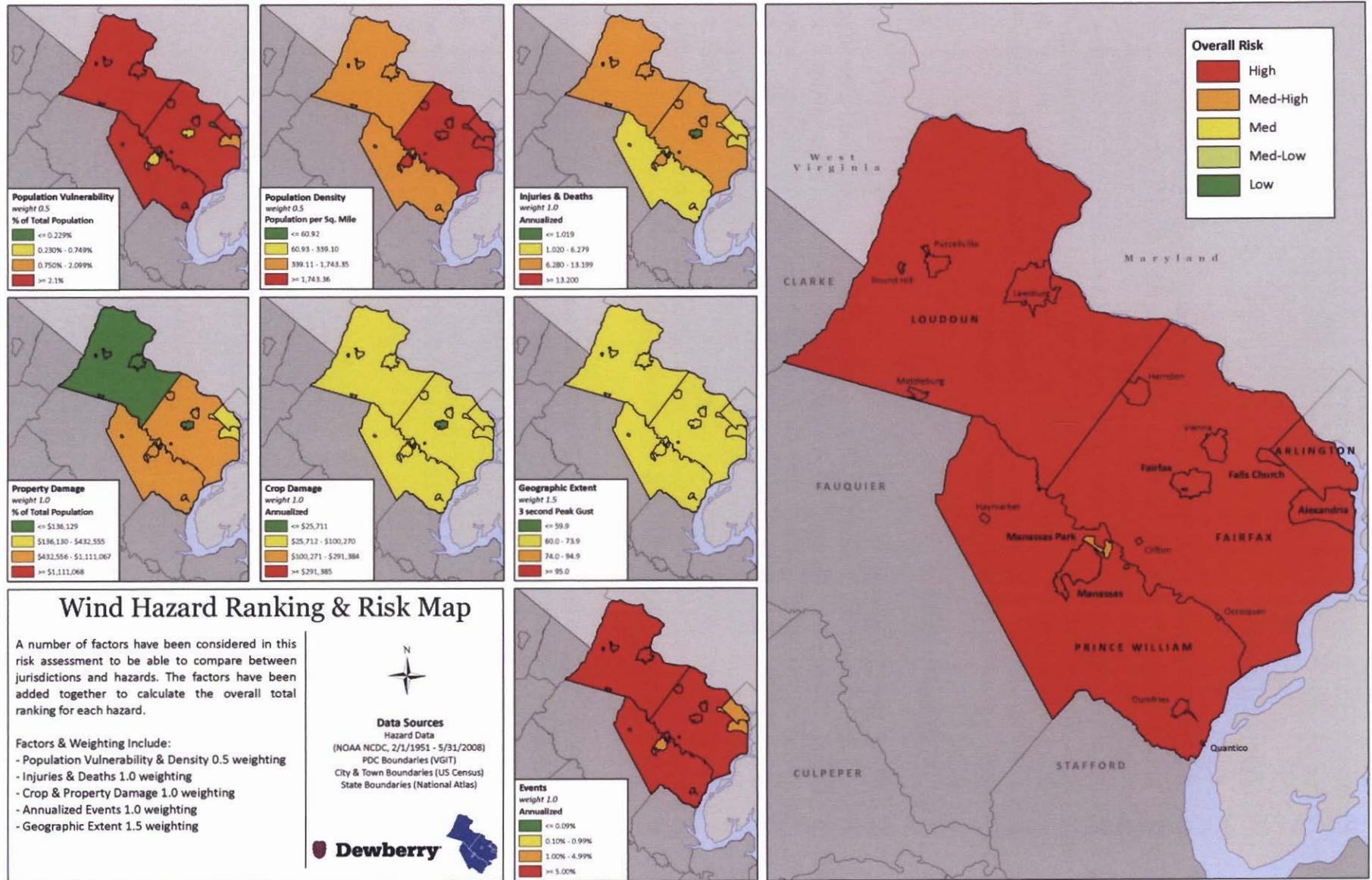


Figure 4.33. High Wind ranking and risk.



VIII. Tornadoes

NOTE: As part of the 2010 plan update, the Tornado 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 annualized 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 an average of 80 deaths and 1,500 injuries. 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 likely to form in the late afternoon and early evening. Most tornadoes are a few dozen yards wide and only touch down 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 was developed in 1971 to rate tornado intensity based on associated damages, and is shown in Table 4.55. An Enhanced Fujita Scale (EF Scale) was developed and implemented operationally in 2007 and is shown in Table 4.56. The EF Scale was developed to better align tornado wind speeds with associated damages.



Table 4.55 Fujita-Pearson Scale for Tornadoes

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40-72 MPH	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages to sign boards.
F1	Moderate tornado	73-112 MPH	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 MPH	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 MPH	Roof and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted.
F4	Devastating tornado	207-260 MPH	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 MPH	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-enforced concrete structures badly damaged.
F6	Inconceivable tornado	319-379 MPH	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies.

Source: *The Tornado Project*, 2002.



Table 4.56 Enhanced Fujita Scale for Tornadoes Vs. Previously used 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 U.S. States (SPC, 2002). Although the region is located outside of “tornado alley” and does not experience as many twisters as Florida, there are many examples of tornadoes tracking through Northern Virginia. Figure 4.34 shows tornado activity in the United States based on the number of recorded tornadoes per 1,000 square miles.

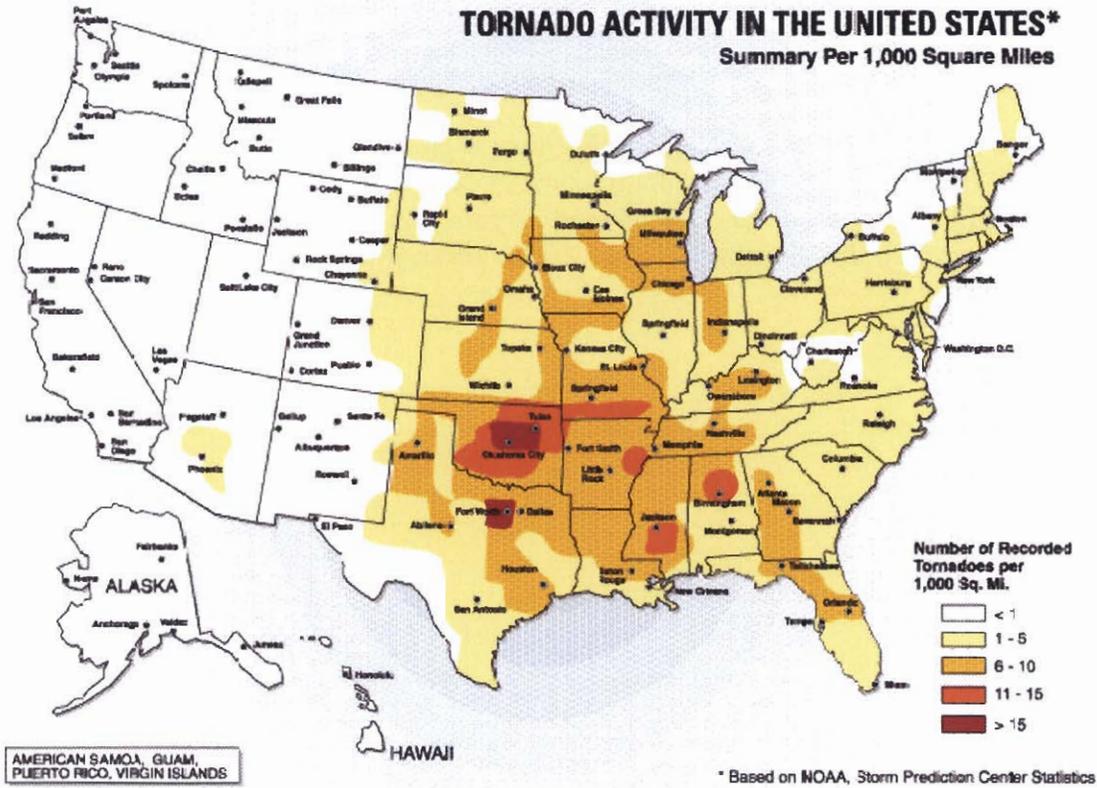


Figure 4.34. Tornado Activity in the United States
Source: American Society of Civil Engineers

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 to the right 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, and since then only 65 people have been known to have died from tornadoes in Virginia. A third of these deaths occurred during a tornado outbreak on May 2, 1929, Virginia's worst tornado outbreak.

According to NCDC records, the Northern Virginia region experienced 53 tornado events from 1950 through October 2009. Figure 4.35 graphically depicts the touchdown points and tracks, 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.

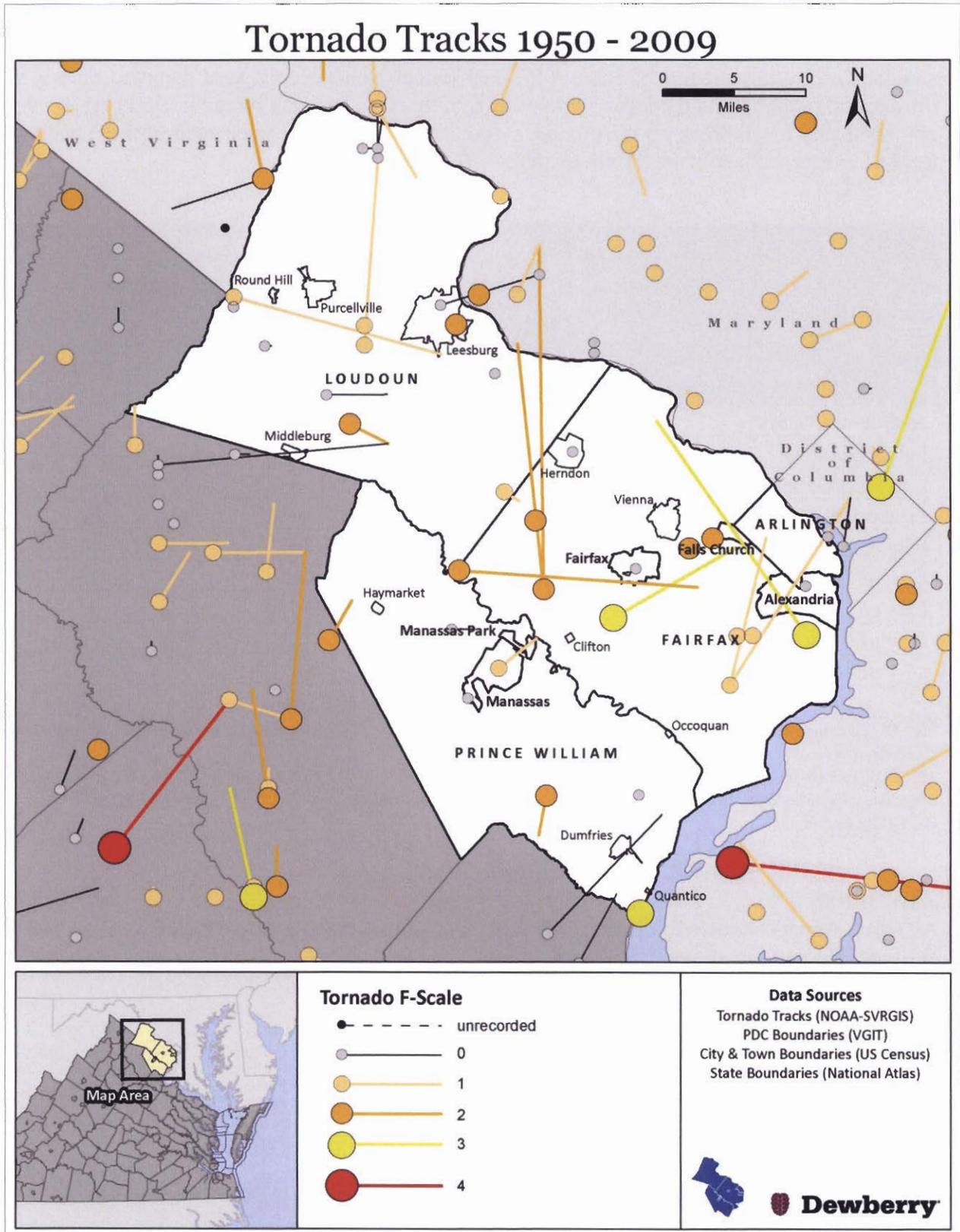


Figure 4.35. Historic Tornado Tracks 1950 to 2009



In total, these tornado events are reported to have caused two deaths, 59 injuries and approximately \$154 million (accounting for inflation) in property and crop damages as summarized by jurisdiction in Table 4.57. Ten funnel cloud events were recorded during this time period, although no damages are associated with these systems since the cloud system does not physically touch down on the ground. More detailed information on each of these historical tornado events can be obtained through the NCDC Storm Event.

Table 4.57 NCDC Tornado Events in the Northern Virginia Region, 1955–2009

Tornado Events in Northern Virginia					
<i>Years of Record: 1951 - 2009</i>	Annualized Property and Crop Damage	Total Property and Crop Damage	Injuries	Deaths	Number of Events
Arlington County	\$22,033	\$1,299,947	2		2
Fairfax County	\$2,265,041	\$133,637,444	45	1	13
Loudoun County	\$119,785	\$7,067,323	2		23
Prince William County	\$117,080	\$6,907,746	10	1	11
City of Alexandria	\$149	\$8,781	0		1
City of Fairfax	\$0**	\$0**			0**
City of Falls Church	\$88,210	\$5,204,367	0		1
City of Manassas	\$0*	\$0*	0		1
City of Manassas Park	\$0*	\$0*	0		1
Total	\$2,612,298	\$154,125,609	59	2	53

*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 conflict with other sources indicating that tornadoes did impact the City doing damage on September 5, 1979 as a result of Hurricane David.

4. Previous Occurrences

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.

A funnel cloud in the vicinity of Fairfax on July 4, 2007.

July 4, 2007

Although not recorded in NWS storm reports or the NCDC database, a funnel cloud was spotted (see image above) 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.

September 17, 2004

Several tornadoes touched down across Northern Virginia leading to scattered damage on the afternoon of September 17th. The tornadoes were associated with the remnants of what had been Hurricane Ivan that made landfall in Alabama the day before. A tornado moved into western portions of Loudoun County at approximately 4:20PM producing intermittent damage from Hamilton to Lovettsville. A short while later, another tornado associated with a severe thunderstorm touched down in Prince William County near Dale City. This twister uprooted trees. 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. Another tornado touched down at Dulles International Airport about 5:14PM and moved north, damaging seven buildings at the Beaumede Corporate Park. A tractor trailer was overturned and two cars were blown into the side of a building.

September 24, 2001

Five tornadoes touched down in Northern Virginia during the afternoon and early evening of the 24th. One of these 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. A second 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.



Photo of the September 24, 2001 tornado as it entered Washington DC. The Washington Monument can be seen to the left of the U.S. Flag pole. (Photo courtesy of Michael Shore)

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.

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.

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.

October 13, 1983

An F2 tornado touched down in Fairfax and moved seven miles into Falls Church and McLean, heavily damaging many homes and overturning cars and trucks.

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. An F2 tornado struck the Sugarland Run Subdivision of Sterling in Loudoun County, injuring two people and damaging 80 homes. Four homes were unroofed or seriously damaged. Damages were estimated at \$250,000.

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.



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.

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

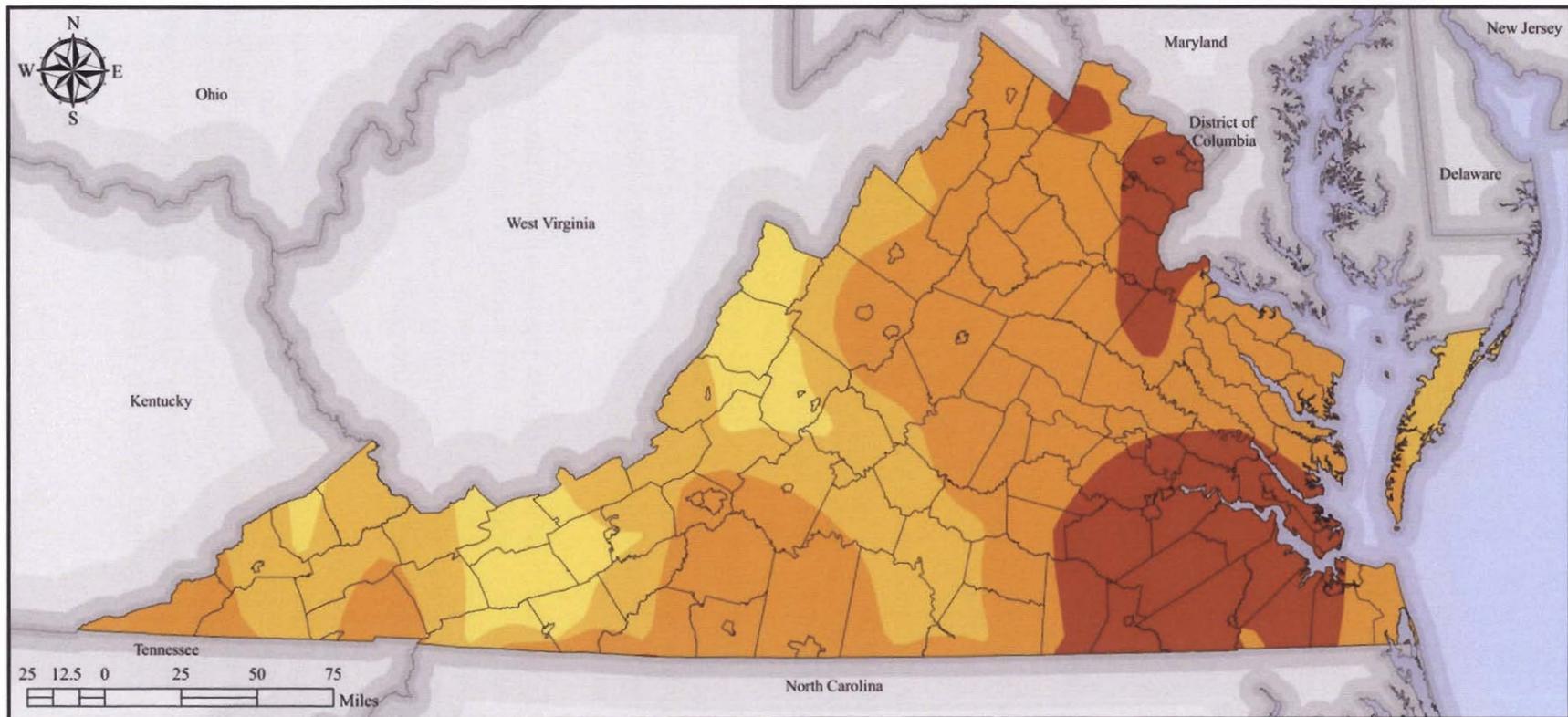
1. Probability of Future Occurrences

The probability of future occurrences of tornadoes was examined through analysis of the NCDC historical data and by inclusion of data developed for the 2010 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 4.36) 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 23 tornado events since 1950, more than any other jurisdiction in Northern Virginia. Fairfax County is not too far behind having recorded 13 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 events²¹, 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.



DATA SOURCES:
 SVRGIS / SeverePlot
 VGIN Jurisdictional Boundaries
 ESRI State Boundaries

LEGEND:
 Annual Tornado Hazard Frequency
Times One Million

	0 - 1.25	Low
	1.251 - 10	Medium-Low
	10.1 - 100	Medium-High
	100.1 - 316	High

HAZARD IDENTIFICATION:
 Annual tornado hazard frequency is an estimate of the frequency with which a point will experience a tornado, interpolating from neighboring tornado impact areas over the period of record. This map shows hazard frequency of any intensity of tornado. Note that "high" frequency in the state of Virginia is still rather low in comparison to many midwestern and southern states.

PROJECTION: VA Lambert Conformal Conic
 North American Datum 1983

DISCLAIMER: Majority of available hazard data is intended to be used at national or regional scales. The purpose of the data sets are to give general indication of areas that may be susceptible to hazards. In order to identify potential risk in the Commonwealth available data has been used beyond the original intent.

Commonwealth of Virginia Enhanced Hazard Mitigation Plan 2010
 Section 3.8b Page 7

Figure 4.36. 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 53 tornado events in Northern Virginia between 1950 and October 2009 that caused approximately \$154 million (inflated dollars) in property and crop damage, or approximately \$2.6 million annually. Fairfax County has recorded more damage than other Northern Virginia jurisdictions due to tornadoes. NCDC data shows that the county suffered approximately \$136 million (inflated dollars) in property and crop damage, or approximately \$2.3 million annually from tornado events since 1950.

Critical Facility Risk

Quantitative assessment of critical facilities for tornado risk was not feasible for this update. Even so, 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.

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 above, concrete, brick, and steel-framed structures tend to fare better in tornadoes than older, wood-framed structures

Overall Loss Estimates and Ranking

During the 2006 plan creation, annualized loss for hurricanes was estimated at \$731,000 for the region. For the 2010 plan update, the annualized losses due to tornadoes in Northern Virginia totals approximately \$2,612,298. Differences in these estimates can be attributed to several factors described in the Risk Assessment and Methodology section; the main difference being the fact that the 2010 estimate takes into account inflation of the NCDC events.

Based on historical occurrences, tornado events in the Northern Virginia region are more common in Loudoun County (almost half of the events recorded for the region took place in Loudoun County). However, it is expected that susceptibility for tornado occurrences is relatively uniform across the region. Historical data indicates that Fairfax County is by far the most vulnerable of the four counties in terms of property damages, fatalities, and injuries. This is likely due to the more populated and developed nature of Fairfax County and its incorporated cities and towns.

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 2010 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 2010 Commonwealth plan.

Based on this analysis and the available data, the tornado hazard is ranked as being “High” for all jurisdictions in Northern Virginia with the exception of the City of Falls Church and the City of Manassas Park, in which the tornado hazard is ranked as being “Medium-High” (See Figure 4.37). 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.

According to the 2006 qualitative assessment performed using the PRI tool, the tornado hazard scored a PRI value of 2.7 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.58 summarizes the risk levels assigned to each PRI category.

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Likely	Critical	Small	Less than 6 hours	Less than 6 hours

The 2006 PRI assessment still is valid and supports the updated ranking and loss estimates.

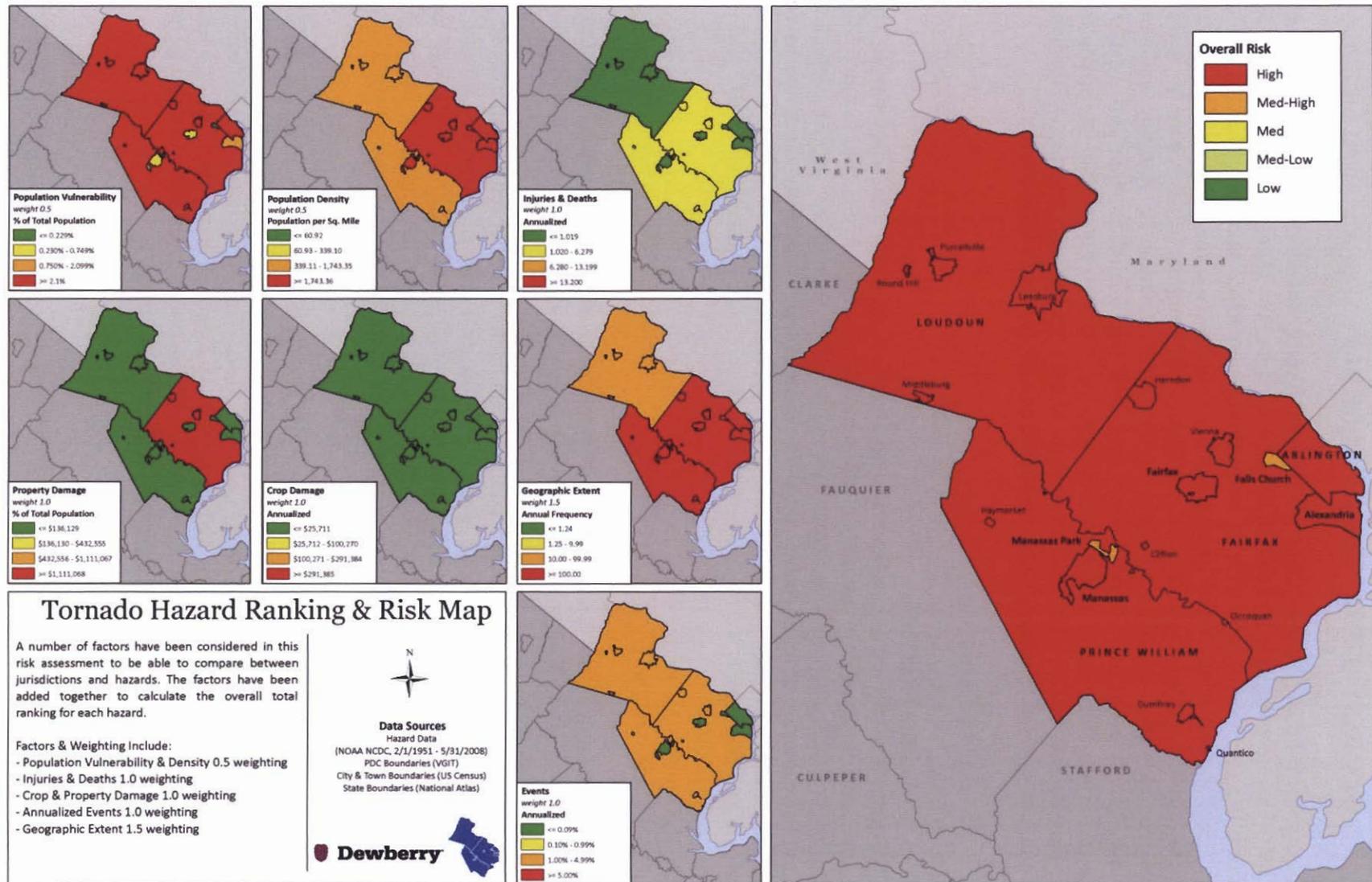


Figure 4.37. Tornado Hazard Ranking



IX. Drought (and extreme heat)

NOTE: As part of the 2010 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 annualized 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. Drought and Extreme Heat are often interrelated hazards and usually most common during the summer months. For these reasons, the 2010 plan update consolidates their analysis into one section. 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 4.38 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.

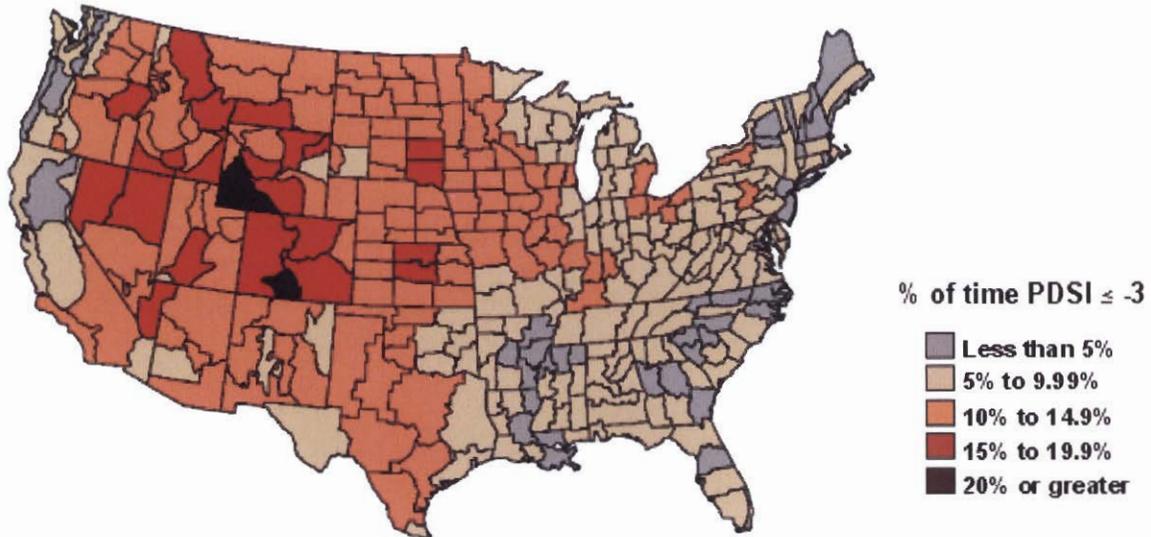


Figure 4.38. Palmer Drought Severity Index, 1895-1995 Percent of Time in Severe and Extreme Drought. *Source: National Drought Mitigation Center*

Extreme Heat

There have not been any Presidential Disaster or Federal Emergency declarations, nor is there a history of any State Disasters or other major incidents, for extreme heat in Northern Virginia. While Northern Virginia generally has a temperate climate, periods of extreme heat can and have occurred. According to NCDC data, in July of 1995, three people were hospitalized for heat related injuries. Similarly, in the summer of 1999, three people were treated for severe heat disorders. The NWS can issue heat-related products to inform citizens of forecasted extreme heat conditions. These products are based on projected or observed heat index values and include:

- Excessive Heat Outlook: When there is a potential for an excessive heat event within three to seven days;
- Excessive Heat Watch: When conditions are favorable for an excessive heat event within 12 to 48 hours but some uncertainty exists in regards to occurrence and timing; and
- Excessive Heat Warning / Advisory: When an excessive heat event is expected within 36 hours. These products are usually issued when confidence is high that the event will occur. A warning implies that conditions could pose a threat to life or property, while an advisory is issued for less serious conditions that may cause discomfort or inconvenience, but could still lead to threat to life and property if caution is not taken.

In Northern Virginia, extreme heat constitutes a low risk to the general populace. Even so, the elderly, small children, the chronically ill, and pets are considered to be more vulnerable to excessive heat than the general population.

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 4.38), 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 Virginia Farm Bureau, Loudoun County leads the Northern Virginia region with more than 1,000 active farms on 184,000 acres of farmland and close to 400 residents that describe farming as their principal occupation.

3. Magnitude or Severity

There are 151 records of drought events contained within the NCDC database. (See Table 4.59) Many of these instances are considered overlapping (counted twice or possibly more), as adjacent counties experiencing the same drought were considered separate instances. 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 4.59 Annualized Property and Crop Loss Due to Drought	
Number of Events	151
<i>Years of Record: 1993-2009</i>	Annualized Property and Crop Damage
Arlington County	\$90,655
Fairfax County	\$90,655
Loudoun County	\$351,549
Prince William County	\$114,402
City of Alexandria	\$90,655
City of Fairfax	\$0
City of Falls Church	\$90,655
City of Manassas	\$114,402
City of Manassas Park	\$0
Total	\$942,971

Source: NOAA, National Climatic Data Center

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 – most recently in 1999. 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

June 8, 2008 (Extreme Heat)

A strong ridge of high pressure over the eastern U.S. 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 dewpoints in the lower 70s to produce heat indices that approached 105 degrees.

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.

August 1998 – August 1999

By the last week of July 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. The Occoquan Reservoir, the main water source for Southern Fairfax County, was 21 percent below capacity by the end of the month. The Beaverdam Reservoir in Loudoun County was at 50 percent capacity, still recovering from being drained to fill Goose Creek Reservoir. This reservoir fell to 2.5 feet below the dam by the end of the month, a level officials called dangerously low. With such low water levels, most locations were forced to begin voluntary water restrictions and some locations such as Loudoun County began mandatory restrictions. Many residents located outside the Washington, DC, suburbs and larger cities became dependent on water deliveries after wells dried up.

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. Hay production in Prince William County was cut by 65 percent. During this period, Loudoun County estimated there had been \$20,000,000 in agricultural losses and was declared a Federal drought disaster area.

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 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. 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 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 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. That temperature was matched on the 17th, before strong to severe thunderstorms moved through.

July 1997

This 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.

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, with heat indices between 115 and 129. 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. Daytime heat indices ranged from 105 to 115, 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 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.

Based on historical climatic data, it is also clear that the Northern Virginia region will likely continue to experience occasional periods of extreme heat. Long-term climate forecast models suggest that a warming planet will lead to changes in precipitation distribution and more frequent and severe drought in some parts of the country. The IPCC Fourth Assessment Report indicates that it is very likely that hot extremes and heat waves will become more frequent as the Earth warms.

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. In terms of extreme heat, the elderly, small children, the chronically ill, and pets are most vulnerable.

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. Although extreme heat does present a risk to the health of humans, the risk is generally considered low in Northern Virginia. 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 \$942,971 annually (see Table 4.59). 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.



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.

During the 2006 plan creation, annualized loss for drought was estimated at \$2,207,000 for the region. For the 2010 plan update, several additional years of NCDC data were utilized to develop updated annualized loss estimates of \$942,971. Differences in these values can be attributed to the data sources used, years of record, and methodology for developing annualized loss estimates. It should be noted that this estimate may be somewhat inflated due to the lack of historical drought data prior to 1993 to counterbalance the region’s recent costly drought events. 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 estimating annualized loss.

As discussed above, the entire Northern Virginia region is vulnerable to drought and historically suffers drought conditions between five and 10 percent of the time. Since 1993, 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.

According to the qualitative assessment performed using the PRI tool, the drought hazard scored a PRI value of 2.3 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.60 summarizes the risk levels assigned to each PRI category.

Table 4.60. 2006 Qualitative Assessment for Drought

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Possible	Limited	Moderate	More than 24 hours	More than one week

According to the qualitative assessment performed using the PRI tool, the extreme temperatures hazard scored a PRI value of 2.4 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.61 summarizes the risk levels assigned to each PRI category.

Table 4.61. 2006 Qualitative Assessment for Extreme Temperatures

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

The 2006 PRI assessments are still valid and support the updated ranking and loss estimates.

The Commonwealth of Virginia’s 2010 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, each locality was considered low throughout the planning region.

Based on this analysis and the available data, the drought hazard is considered to be “High” for Loudoun County, Prince William County, and the Towns of Leesburg, Purcellville, Middleburg, Round Hill, Dumfries, Haymarket, Occoquan, and Quantico. Figure 4.39 shows the ranking criteria and overall risk for the planning region. Based on committee feedback, the City of Fairfax ranking parameters have been changed to mirror Fairfax County. This is reflected in Figure 4.55 and the overall ranking map (Figure 4.61) at the end of the Risk Assessment. NCDC values contained within the tables have not been adjusted and reflect the information available in the database.

Extreme heat was not ranked and no loss estimates were calculated.

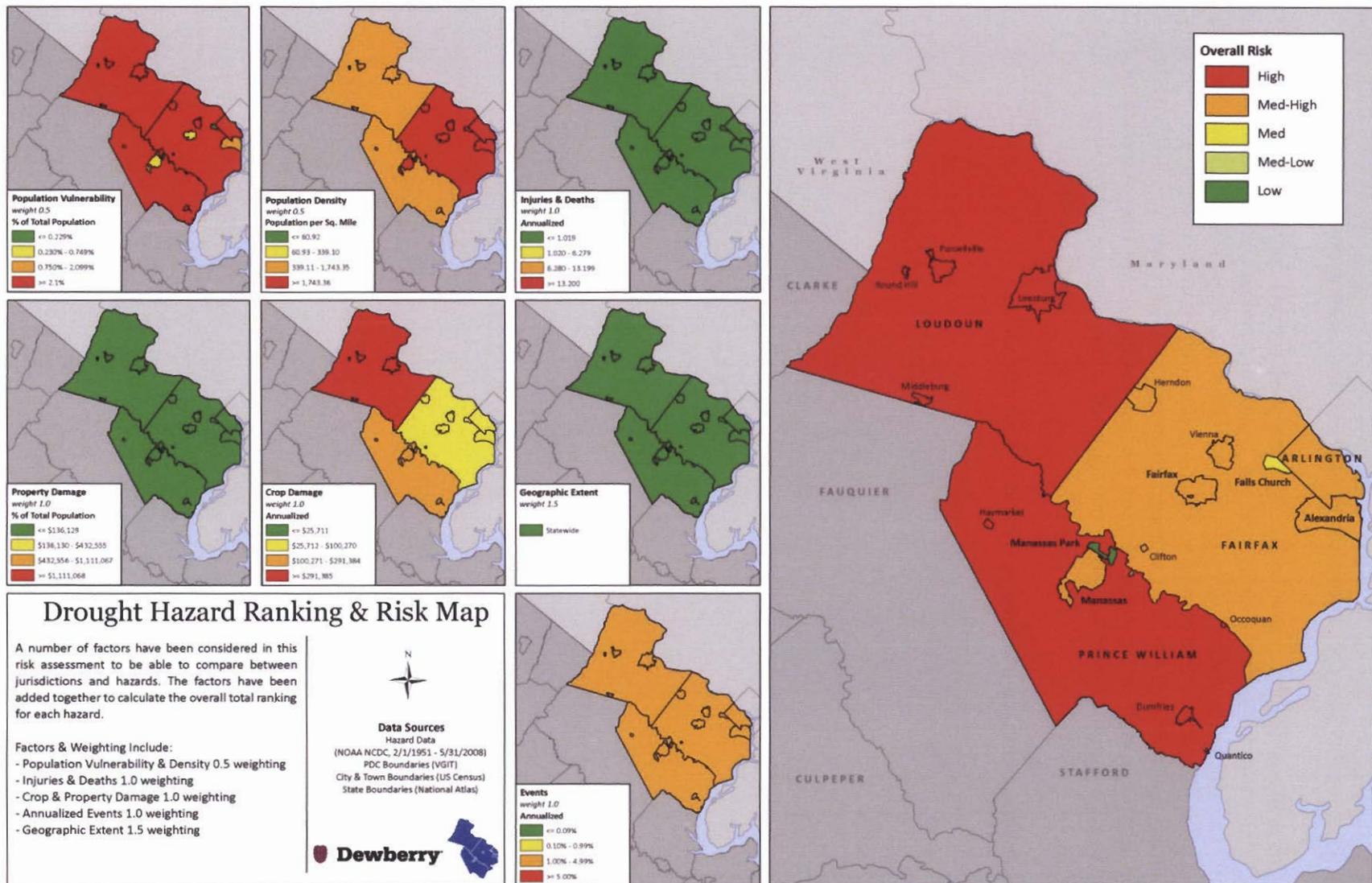


Figure 4.39. Drought hazard ranking and risk.



X. Earthquake

NOTE: As part of the 2010 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 annualized 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

Figure 4.40 shows 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 probability of exceedance in 50 years. The map was compiled by the USGS Geologic Hazards Team, which conducts global investigations of earthquake, geomagnetic, and landslide hazards.

Figure 4.41 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.

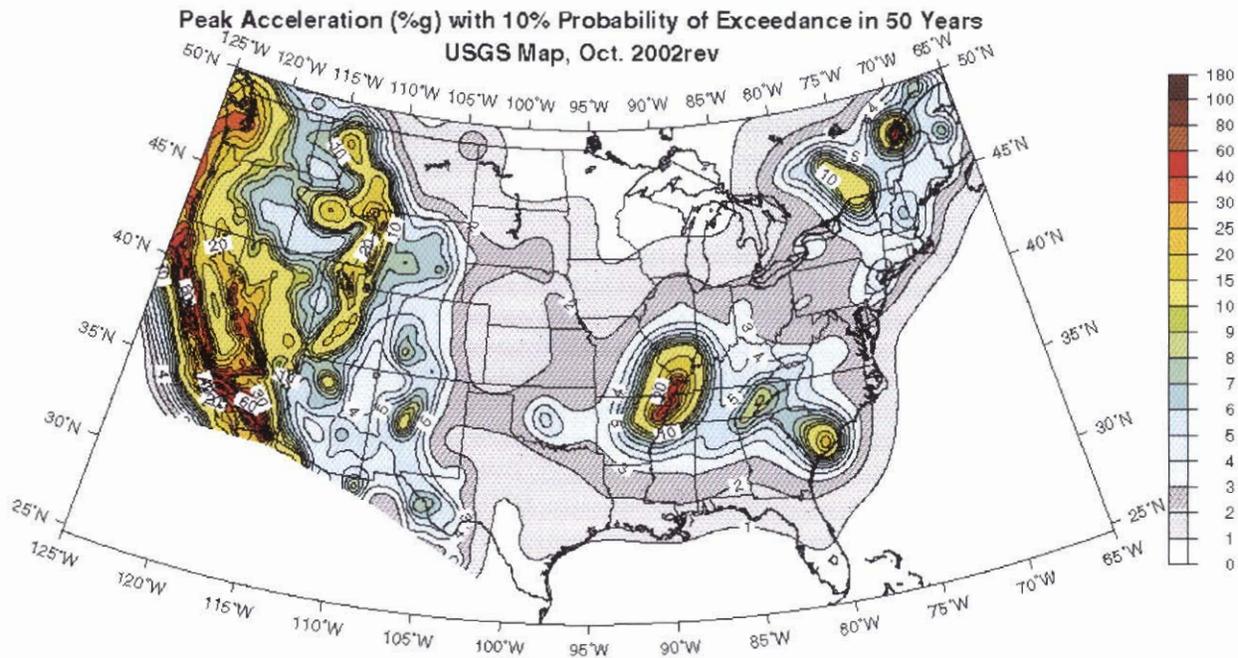


Figure 4.40. Peak Acceleration with 10 Percent Probability of Exceedance in 50 Years
Source: USGS

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 4.62). 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 4.63.

Table 4.62. Richter 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 4.63. 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	
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. The last notable seismic event to occur in the area was on July 16, 2010, near Gaithersburg, Maryland. 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 Commonwealth of Virginia.

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 4.41²² 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:

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 Delaware²³. 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 1758²⁴.

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.

December 9, 2003

The most recent earthquake to have been widely felt in the Washington area occurred west of Richmond, Virginia, on December 9, 2003, in the Central Virginia Seismic Zone. It had a magnitude of 4.3 and was felt throughout the Washington-Baltimore area²⁵.

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.

May 31, 1897

This is the largest historical earthquake to originate in Virginia. 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.

August 31, 1861

The 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.

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.

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.

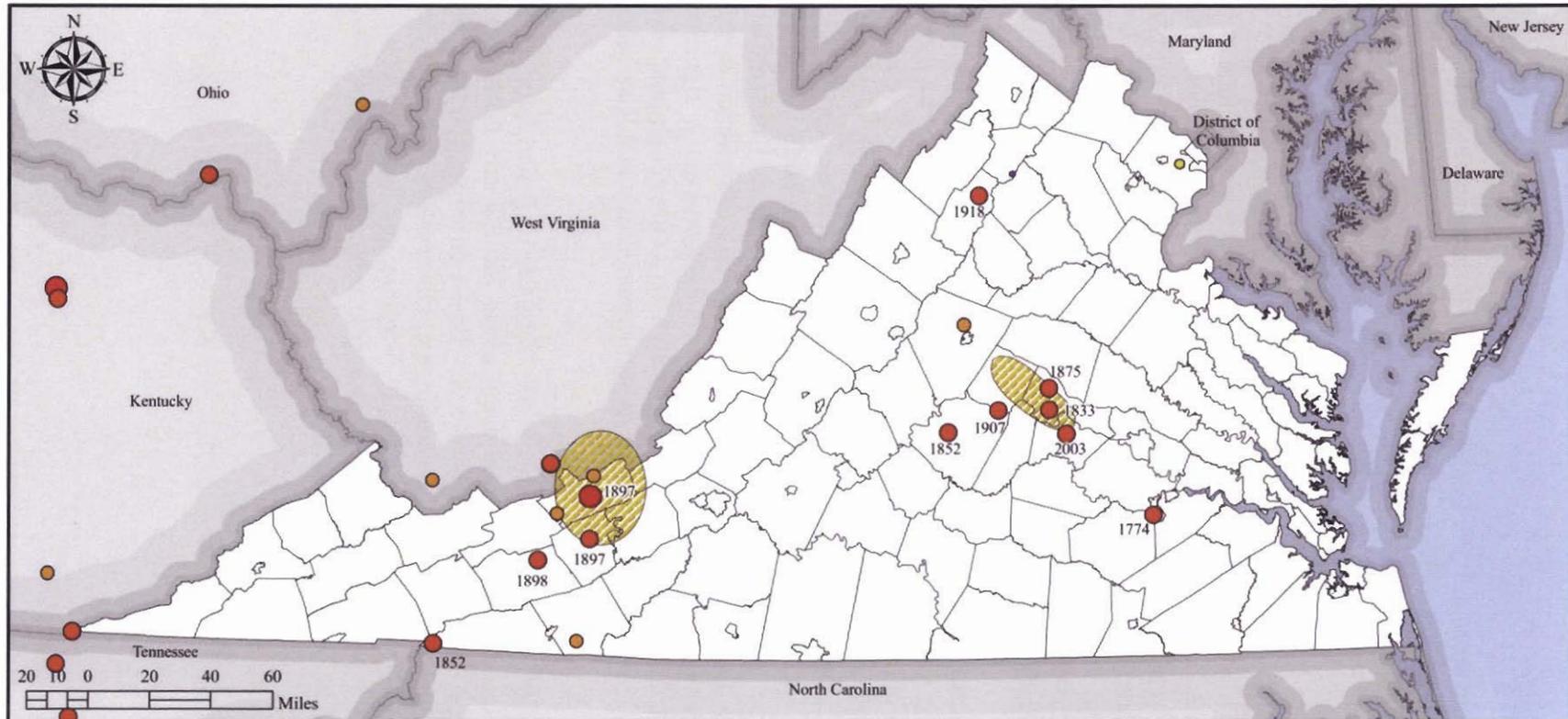
March 9, 1828

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.



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.



DATA SOURCES:

- USGS Significant Earthquakes
- USGS Quaternary Faults
- VGIN Jurisdictional Boundaries
- ESRI State Boundaries

LEGEND:

- Richter Magnitude**
- Unknown
 - 1 - 2.9
 - 3 - 3.9
 - 4 - 4.9
 - > 5

- Quaternary Faults/Folds

HAZARD IDENTIFICATION:

This map layer contains the locations of significant, historic earthquakes that caused deaths, property damage, and geological effects, or were otherwise experienced by populations in the United States (1568 - 2004). USGS Quaternary Faults and Folds are believed to be sources of earthquakes, greater than magnitude 6, in the past 1,600,000 years.

*The 2008 Annandale event has been added to this map for comparison to Table 3.13-2.

Commonwealth of Virginia Enhanced Hazard Mitigation Plan 2010
Section 3.13 Page 7

Figure 4.41. Significant Earthquakes 1568 – 2004, with 2008 Annandale event.



B. Risk Assessment

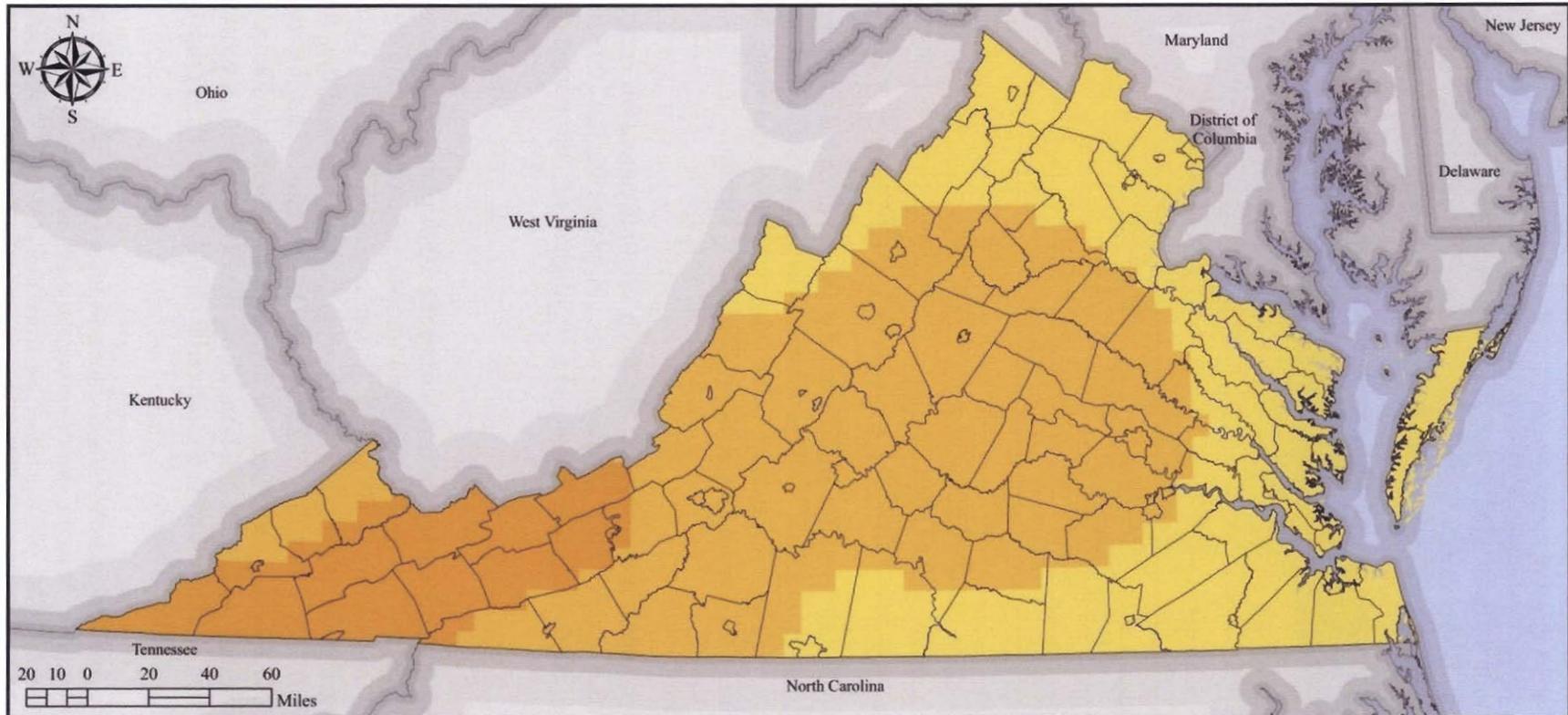
Similar to other States on the eastern seaboard, the State of Virginia is designated as a moderate risk State for earthquake occurrence by the USGS. Earthquake events can and occasionally do occur in the State, though of much less intensity than those that occur along the west coast. The greatest seismic 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 4.43²⁶ shows the PGA zones for the 2500-year Return Periods derived from the HAZUS^{MH} data. 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.

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 Chapman²⁷, 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.



 **VIRGINIA DEPARTMENT OF EMERGENCY MANAGEMENT**
PROJECTION: VA Lambert Conformal Conic
North American Datum 1983

DATA SOURCES:
HAZUS-MH MR3 USGS Data
VGIN Jurisdictional Boundaries
ESRI State Boundaries

LEGEND:
2500-Year PGA (%g)

<3.9
3.9 - 9.2
9.2 - 18
18 - 34
34 - 65
65 - 124
>124

RISK ASSESSMENT:
Peak ground acceleration (PGA) is a measure of earthquake acceleration. PGA can be measured in g (the acceleration due to gravity) or m/s².
The shaking hazard map shows the level of ground motion that has 1 chance in 2500 of being exceeded each year (0.04%).

Commonwealth of Virginia Enhanced Hazard Mitigation Plan 2010
Section 3.13 Page 11

Figure 4.43. 2500-year Return Period Peak Ground Acceleration.



2. Impact & Vulnerability

Impacts from earthquakes can be severe and cause significant damage. Table 4.64 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.

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 2006 plan creation and updated during the 2010 revision. Below are highlights of the results and differences of the HAZUS^{MH} runs.

2006 HAZUS Analysis

Countywide loss estimates for earthquake were developed during the 2006 plan creation based on probabilistic scenarios using HAZUS^{MH} (Level 1 analysis) and the general building stock data. In determining annualized loss estimates, HAZUS^{MH} employs a probabilistic hazard approach that accounts for the contribution of earthquakes of varying magnitudes and locations over return periods of 100, 250, 500, 750, 1,000, 1,500, 2,000, and 2,500 years. This approach results in predictive damage modeling that takes into account events that are highly unlikely, yet certainly within the realm of possibility. A Level 1 analysis using HAZUS^{MH} yields a baseline estimate built upon national inventory databases and is considered by FEMA to be an appropriate method for assessing risk for DMA 2000 purposes.

Table 4.65 shows estimated losses (building damages and contents losses) for 500, 1,000 and 2,500-year return periods by planning area. Based upon the potential earthquake losses for these scenarios, an annualized loss estimate of \$341,000 was derived from the HAZUS^{MH} assessment