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

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

I. Introduction

The 2006 planning area for this study included the unincorporated areas of Arlington, Fairfax, Loudoun, and Prince William counties; the Cities of Alexandria, Fairfax, Falls Church, Manassas, and Manassas Park; and the Towns of Herndon, Vienna, Leesburg, Purcellville, and Dumfries. The 2010 update to the plan was expanded to include several additional jurisdictions. This update includes:

Counties

Arlington County
Fairfax County
Loudoun County
Prince William County

Cities

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

Towns

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

Although some anecdotal information may be included regarding the villages and towns located within these counties, these areas are not fully included in this study due to the lack of data available. For the purpose of simplicity, the study area will be referred to as the Northern Virginia planning area throughout the remainder of this chapter.

The MAC is made up of public representatives, private citizens, businesses, and organizations and was brought together to provide input at key stages of the hazard identification and vulnerability assessment process. Efforts to involve county, city, and town departments and community organizations that might have a role in the implementation of mitigation actions or policies included invitations to attend meetings and serve on the MAC, e-mails of minutes and updates, and opportunities for input and comment on all draft deliverables. Additional information on how this chapter was developed in coordination with the MAC is available in the Planning Process Chapter.

The purpose of this section of the plan is to:

1) Identify the natural hazards that could affect the Northern Virginia planning area;

2) Assess the extent to which the area is vulnerable to the effects of these hazards; and
3) Prioritize the potential risks to the community.

The first step, identifying hazards, will assess and rank all the potential natural hazards in terms of probability of occurrence and potential impacts. It will also identify those hazards with the highest likelihood of significantly impacting the community. This section will be completed based on a detailed review of the planning area hazard history. The 2010 update evaluated and reviewed the 2006 ranking and it was decided by the steering committee to expand the ranking and better align it with the Commonwealth of Virginia's methodologies.

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

The 2010 update to this plan included the review, revision, and reformatting of the 2006 HIRA. The foundation of the 2006 hazard identification remained valid with the additional communities added to the analysis.

II. Data Availability and Limitations

This study includes data collected from a variety of resources including local, State, and national datasets. Whenever possible, data has been incorporated into a GIS to aid in analysis and to develop area-wide maps for depicting historical hazard events, hazard areas, and vulnerable infrastructure. Critical facility data has been collected from the FEMA loss estimating module, Hazards U.S. ($HAZUS^{MH}$), and has been supplemented, to the extent possible, by local data. The local data provided is summarized below in the Building Inventory & Local Critical Facility Data section.

In accordance with FEMA mitigation planning guidance, the results of this study are based on the best available data. In most cases, detailed data regarding the structural characteristics of facilities does not exist in a usable format. Recognizing this deficiency in detailed local data, the strategy developed as part of the full mitigation plan will address these needs by recommending specific measures to increase the level of detail of data to prepare usable and effective hazard assessments. By enhancing the building inventory, a greater level of vulnerability analysis, and consequently risk assessment, will be possible. The Northern Virginia Regional Planning Commission (NVRC) and individual jurisdictions should actively pursue funding for this strategy.

Local Critical Facility and Building Data

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

Table 4.1. Local Building Inventory per Jurisdiction

Jurisdiction	Number of Buildings
Arlington County	42,866
Fairfax County	231,412
Town of Clifton	143
Town of Herndon	4,175
Town of Vienna	6,224
Loudoun County	82,519
Town of Leesburg	9,754
Town of Purcellville	3,148
Town of Middleburg	574
Town of Round Hill	464
Prince William County	141,579
Town of Dumfries	1,739
Town of Haymarket	554
Town of Occoquan	274
Town of Quantico	228
City of Alexandria	41,158
City of Fairfax	7,986
City of Falls Church	4,602
City of Manassas	8,024
City of Manassas Park	4,152

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

- Emergency Operations Centers (EOCs);
- Hospitals and medical care facilities;
- Police stations;

- Fire stations;
- Schools (particularly those designated as shelters);
- Hazardous material facilities;
- Potable water facilities;
- Wastewater facilities;
- Energy facilities (electric, oil, and natural gas); and
- Communication facilities.

In preparing the inventory of critical facilities for the Northern Virginia region, each participating jurisdiction was asked to submit best available GIS data layers for their primary critical facilities to be used in combination with HAZUS^{MH} inventory data. This resulted in the identification of hundreds of critical facilities for the Northern Virginia region. It is understood that this listing is incomplete due to data limitations associated with both the local GIS and HAZUS^{MH} inventories, but that further enhancements to the data will be made over time and incorporated during future plan updates. When analysis for critical facilities was performed, both the local and HAZUS^{MH} summary results are presented in the hazard specific sections. Additional information about the data sources behind the HAZUS^{MH} stock inventory may be found by following this link: http://www.fema.gov/plan/prevent/hazus/hz_database.shtm**.**

During the 2010 update, each of the localities was provided a data matrix to assist them in compiling local data. The Data Matrix found in Appendix D1 contains the populated data matrices for localities that provided data during the data collection phase of this update. Table 4.2 summarizes the main critical facility types provided. Figures 4.1 through 4.4 show the provided critical facility locations within each of the jurisdictions.

Prince William County and the Cities of Manassas and Manassas Park did not provide critical facility data in GIS format for the plan update. In each of the hazard sections, the analysis for critical facilities was performed with both local data and HAZUS^{MH} data to ensure each locality is represented in the hazard risk assessments.

Arlington County provided several different types of critical facilities that are represented in Table 4.2. The remaining jurisdictions in the planning region provided the basic critical facility categories of EOCs, Schools, Police Stations, Fire Stations, Hospitals, and Nursing Homes. For consistent analysis across the region, these six critical facility categories were used for the hazard specific analysis.

The names and information for the HAZUS^{MH} and local critical facilities in the hazard risk zones are available in Appendix D2 Critical Facility-Risk.

Table 4.2 Local GIS critical facility data provided.

Jurisdiction	EOCs	Schools	Police	Fire Station	Fire Dept.	Hospital	Nursing Homes	Pharmacy	Dialysis Center	Critical Federal &State Facilities	Generator Buildings	Critical Water Station	Water Station	Water Pollution Control Plant	Fuel Distribution Center	Community Center	Jail	Equipment Shop	TOTAL
Arlington County	5	34	1	10	2	2	15	25	2	5	34	1	5	1	1	1	1	1	**146**
Fairfax County	-	257	26	36	-	19	-	-	-	-	-	-	-	-	-	-	-	-	**338**
Town of Herndon	-	7	1	1	-		-	-	-	-	-	-	-	-	-	-	-	-	**9**
Town of Vienna	-	8	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	**11**
Town of Clifton	-	-	-	1	-		-	-	-	-	-	-	-	-	-	-	-	-	**1**
Loudoun County	-	62	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	**63**
Town of Leesburg	-	17	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	**18**
Town of Purcellville	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**4**
Town of Middleburg	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**1**
Town of Round Hill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Prince William County	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Town of Dumfries	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Town of Haymarket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Town of Occoquan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Town of Quantico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
City of Alexandria	**	28	1	9		1	7												**46**
City of Fairfax*	-	3	5	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	**9**
City of Falls Church**	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**1**
City of Manassas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
City of Manassas Park	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Total	**5**	**421**	**36**	**58**	**2**	**26**	**22**	**25**	**2**	**5**	**34**	**1**	**5**	**1**	**1**	**1**	**1**	**1**	**647**

** Data summarized from Fairfax County Data*

*** No permanent EOC facility*

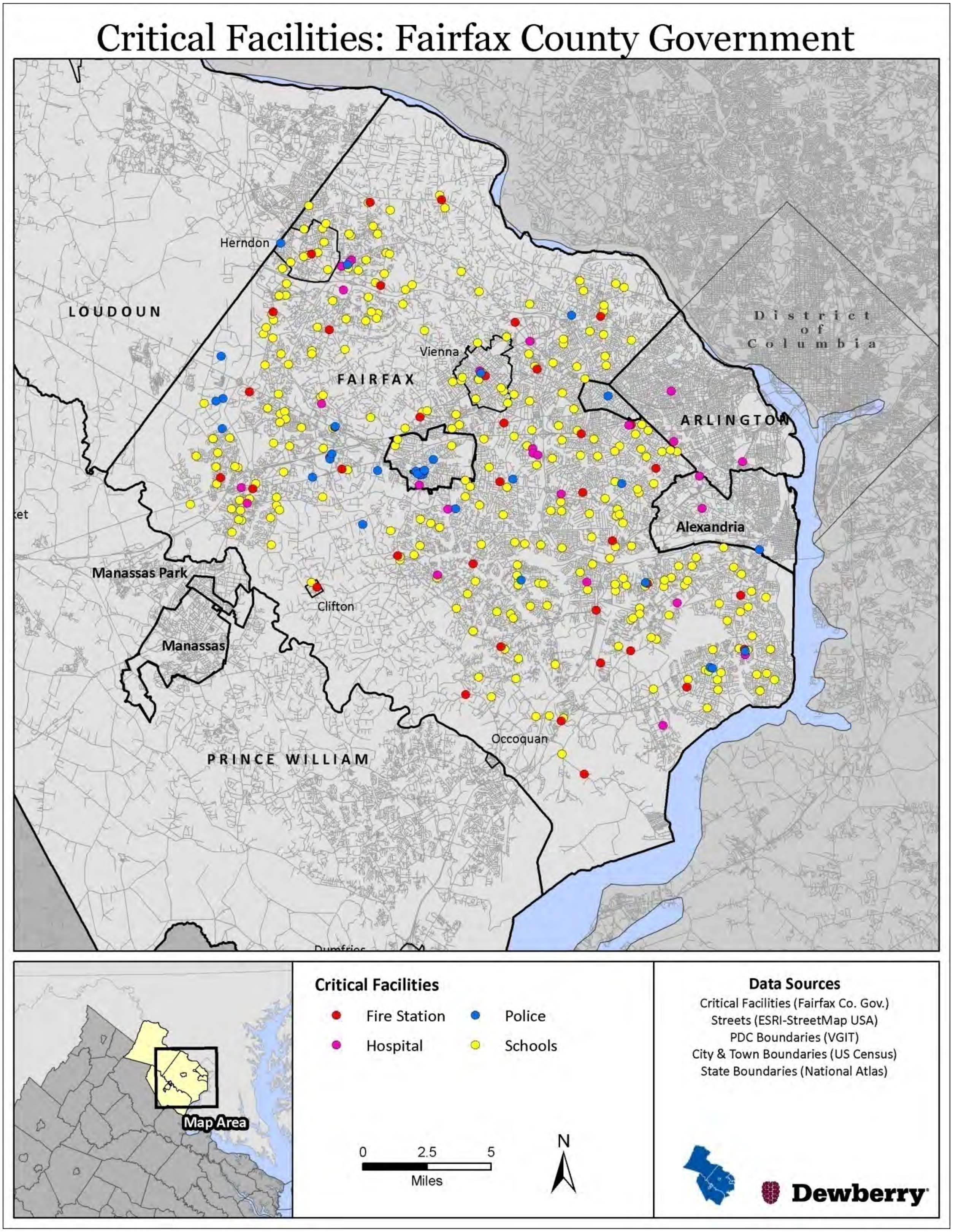

Figure 4.1. Fairfax County local critical facility data.

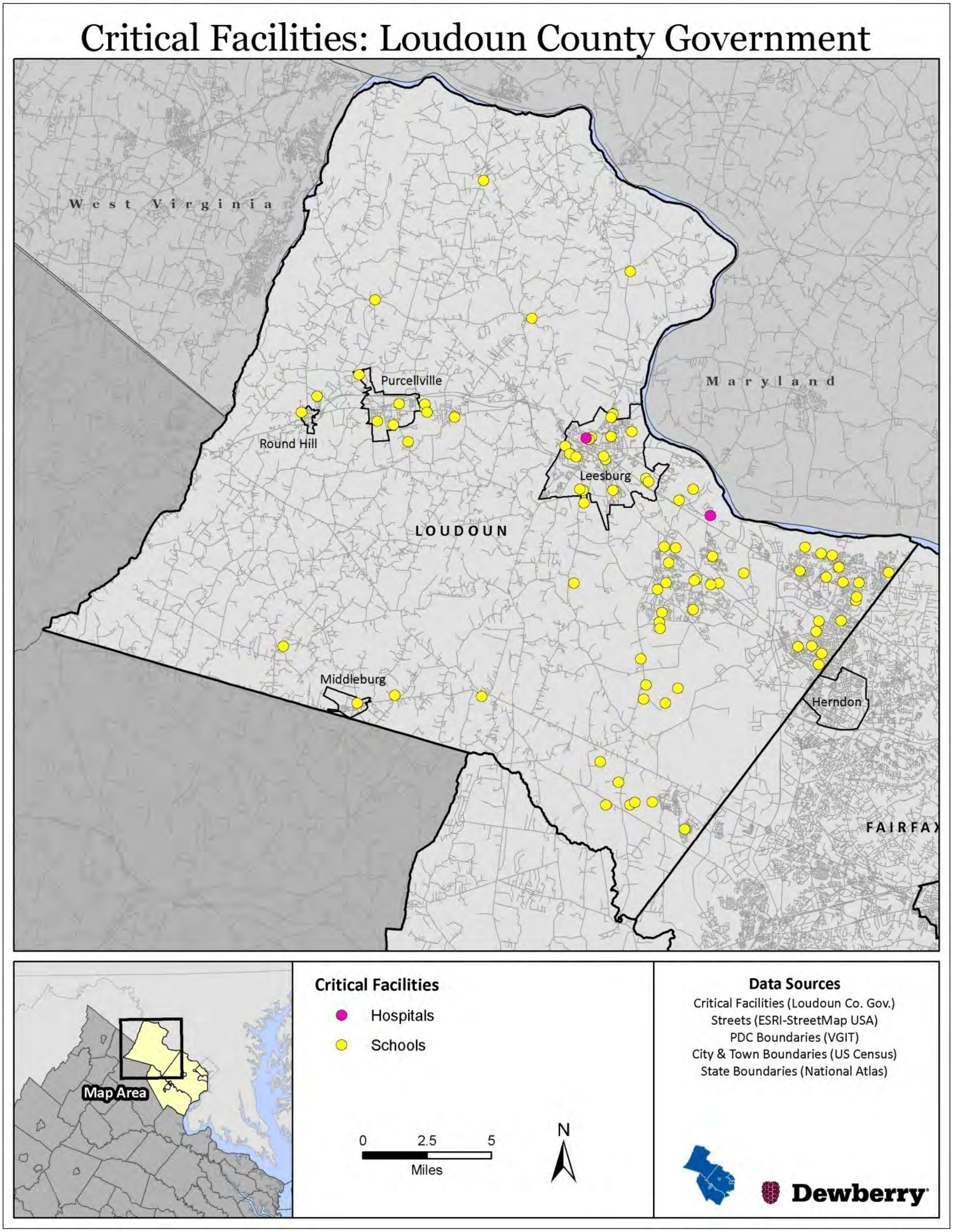

Figure 4.2. Loudoun County local critical facility data.

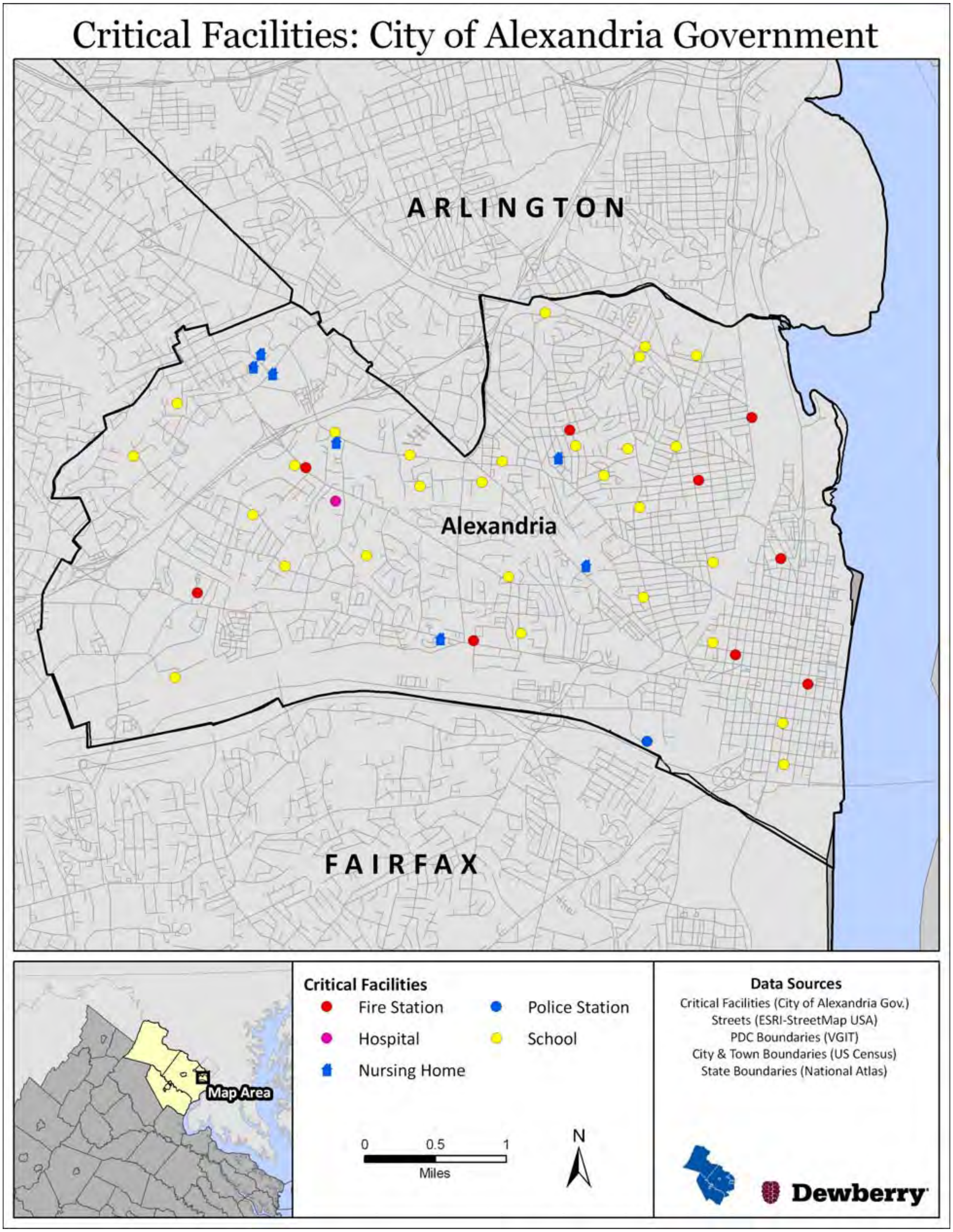

Figure 4.3. City of Alexandria local critical facility data.

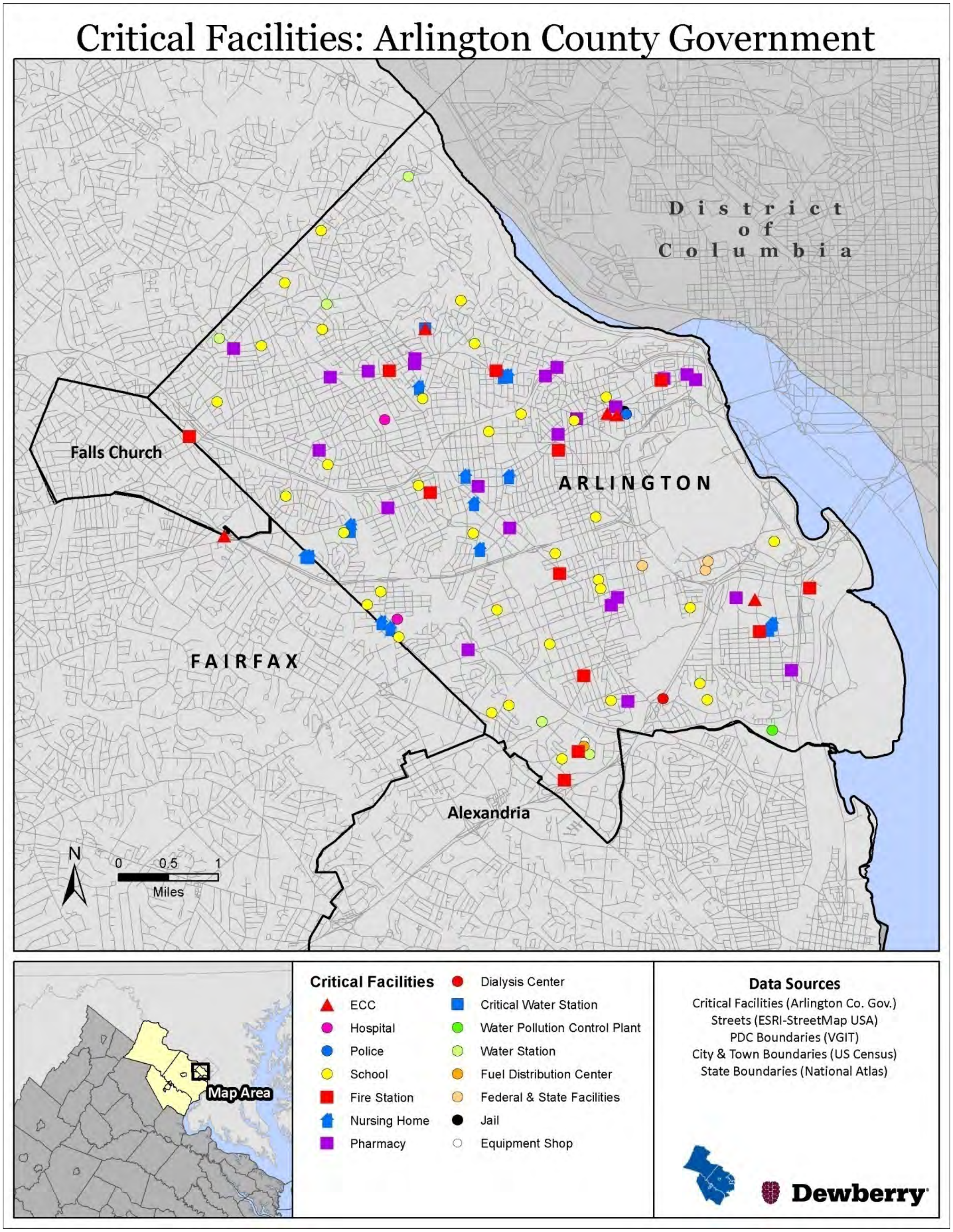

Figure 4.4. Arlington County local critical facility data.

HAZUS^{MH} MR4

HAZUS^{MH} essential facilities data was used to supplement the hazard specific analysis. This data provides a uniform look at essential facilities in the region. There are 762 facilities, including medical care facilities, police stations, EOCs, fire stations, and schools. Facilities within towns have been manually edited from the county totals based on the point location of the data.

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

Fairfax County has the largest number of essential facilities, 355, with over 85% of those facilities labeled as grade schools. Table 4.3 below shows the number of facilities in each of the HAZUS^{MH} essential facility classes. Figures 4.5 through 4.8 show the distribution of HAZUS^{MH} essential facilities within the regions. With many national datasets, accuracy and completeness leave much to be desired. Mitigation actions address the need for better regional spatial data for analysis.

The names and information for the HAZUS^{MH} and local critical facilities in the hazard risk zones are available in Appendix D2.

Table 4.3: HAZUS-MH MR4 Essential Facilities for Northern Virginia planning area.

Jurisdiction	EOC	Fire Station	Hospitals	Police Stations	Schools (grade)	Total
Arlington County	-	3	3	1	43	**50**
Fairfax County	-	35	8	9	303	**355**
Town of Herndon	-	1	-	1	8	**10**
Town of Vienna	-	1	-	1	11	**13**
Town of Clifton	-	1	-	-	-	**1**
Loudoun County	1	8	3	-	61	**73**
Town of Leesburg	-	2	-	5	17	**24**
Town of Purcellville	-	-	-	1	3	**4**
Town of Middleburg	-	-	-	1	2	**3**
Town of Round Hill	-	1	0	-		**1**
Prince William County	-	9	1	5	114	**129**
Town of Dumfries	-	-	-	1	2	**3**
Town of Haymarket	-	-	-	1	-	**1**
Town of Occoquan	-	-	-	1	-	**1**
Town of Quantico	-	-	-	1	-	**1**
City of Alexandria*	-	1	1	2	31	**35**
City of Fairfax	-	4	-	4	14	**22**
City of Falls Church	-	-	-	1	5	**6**

Table 4.3: HAZUS-MH MR4 Essential Facilities for Northern Virginia planning area.						
Jurisdiction	**EOC**	**Fire Station**	**Hospitals**	**Police Stations**	**Schools (grade)**	**Total**
City of Manassas	-	1	1	5	19	**26**
City of Manassas Park	-	1	-	-	3	**4**
Total	**1**	**68**	**17**	**40**	**636**	**762**

*The HAZUS MH stock inventory for the City of Alexandria differs from reality. There are actually nine fire stations and one police station in the City of Alexandria.

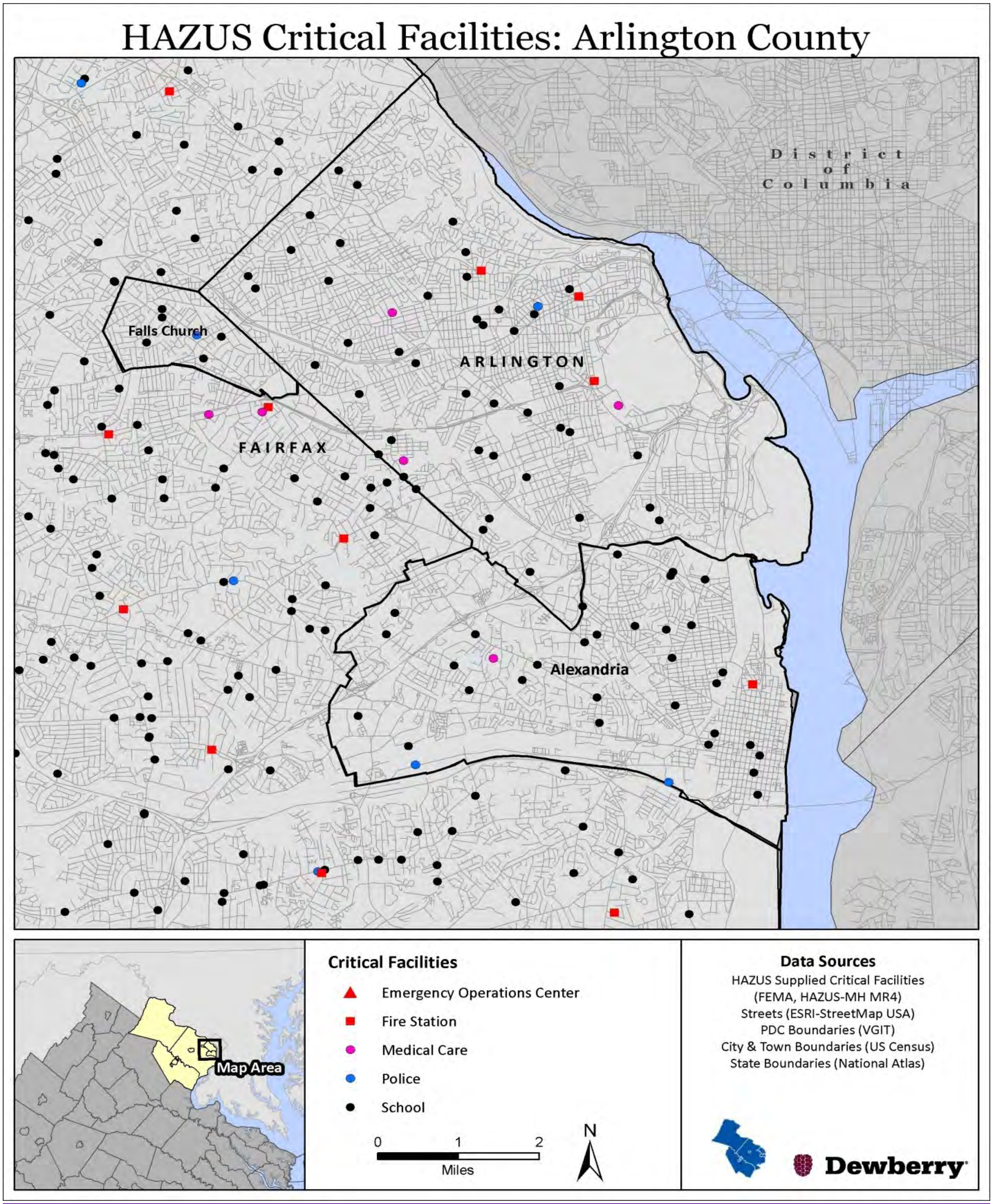

Figure 4.5. Arlington County HAZUS^{MH} critical facility data.

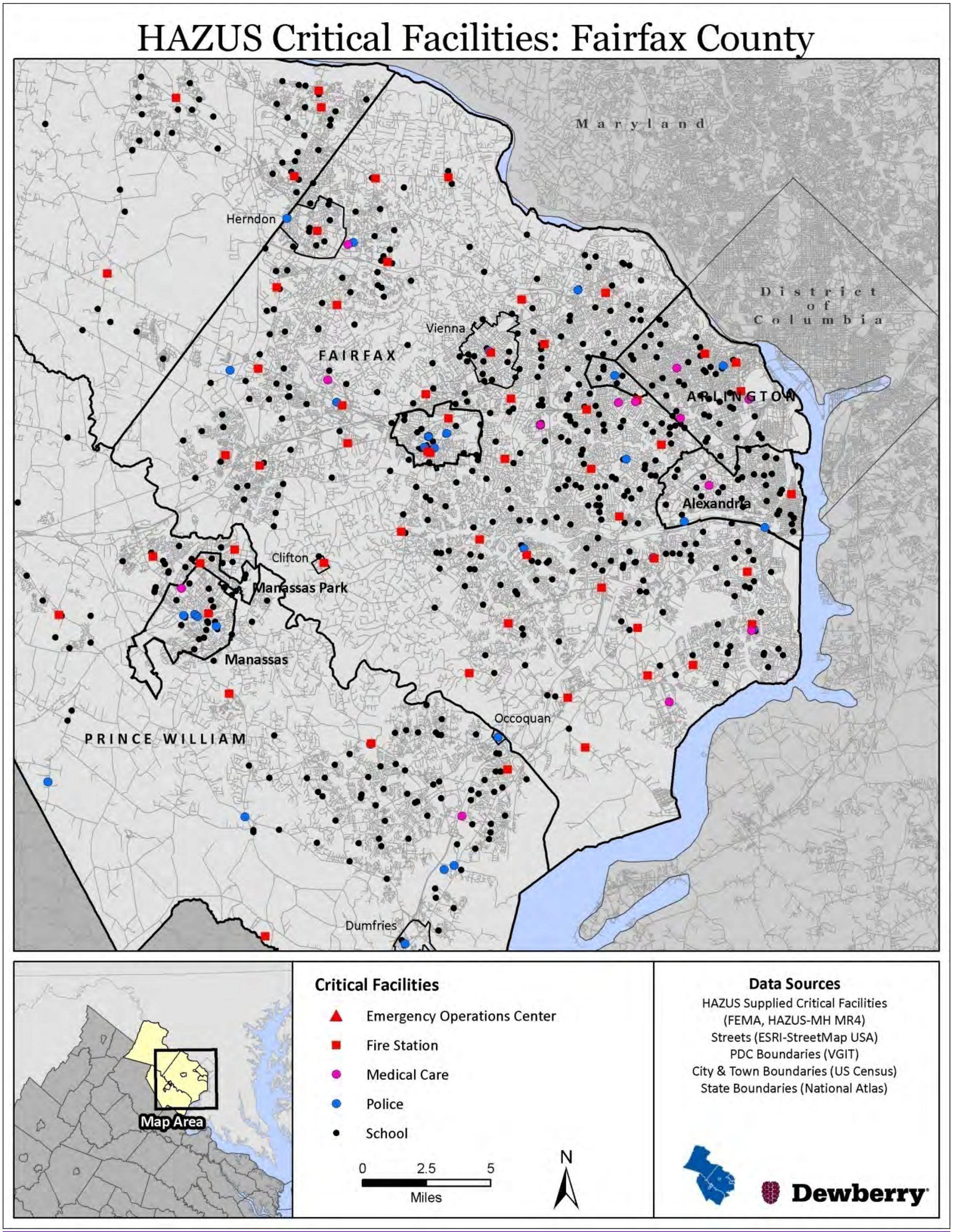

Figure 4.6. Fairfax County HAZUS^{MH} critical facility data.

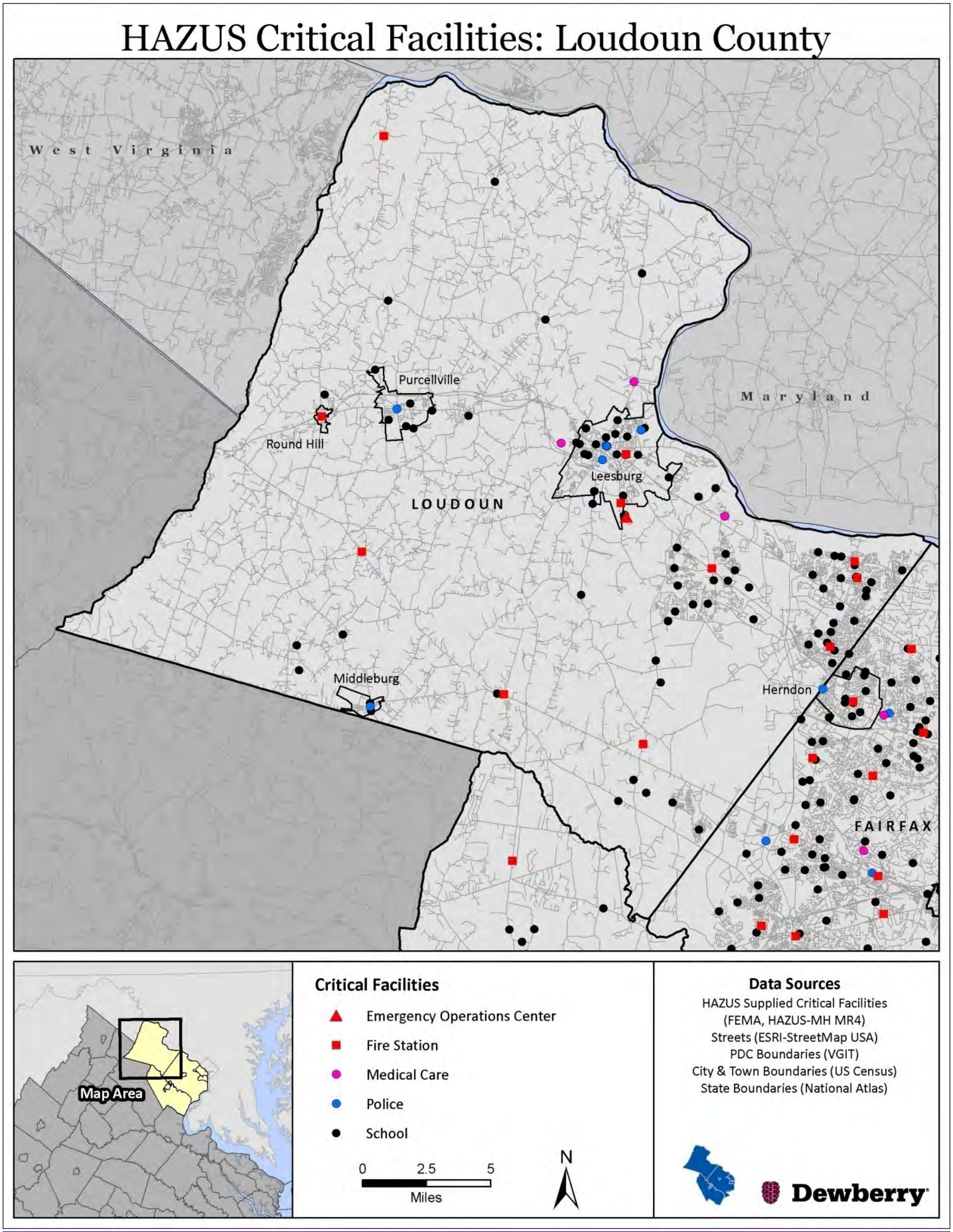

Figure 4.7. Loudoun County HAZUS[MH] critical facility data.

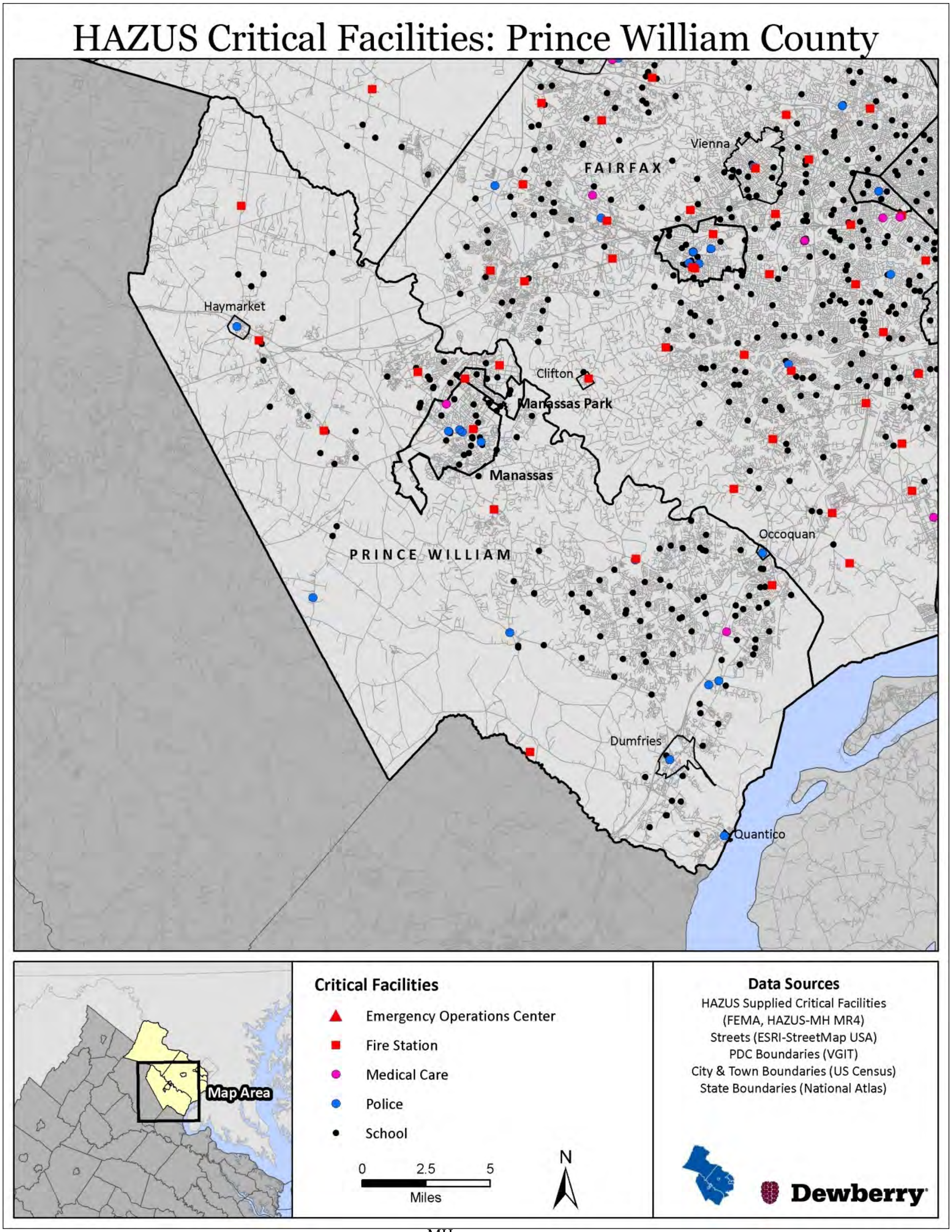

Figure 4.8. Prince William County HAZUS^{MH} critical facility data.

Data

The HAZUS^{MH} building stock for Northern Virginia contains 564,247 structures with an estimated exposure value of approximately $159 million (2002 dollars). HAZUS^{MH} estimates 92% of the region's general occupancy is categorized as residential, which represents 77% of the building value for the region. Fairfax County represents 56% of the region's total building value summarized in Table 4.4.

Table 4.4 Total Building Value per Jurisdiction

Jurisdiction	Residential	Non-Residential	Total	% Total
Arlington County	$12,867,851	$4,075,592	$16,943,443	10.7%
Fairfax County	$69,782,043	$18,936,097	$88,718,140	55.8%
Loudoun County	$12,240,971	$4,016,883	$16,257,854	10.2%
Prince William County	$16,183,895	$3,853,944	$20,037,839	12.6%
City of Alexandria	$8,360,736	$3,759,489	$12,120,225	7.6%
City of Falls Church	$772,821	$396,977	$1,169,798	0.7%
City of Manassas	$2,090,589	$899,122	$2,989,711	1.9%
City of Manassas Park	$589,358	$170,266	$759,624	0.5%
Total	**$122,888,264**	**$36,108,370**	**$158,996,634**	-

Table 4.5 shows the estimated total exposure values by jurisdiction. Residential housing represents 77% of the building value in the region, followed by commercial properties representing 17%. The remaining occupancy types account for the remaining 6% of the region.

Table 4.5 Building stock exposure for general occupancy type by jurisdiction.

Jurisdiction	Residential	Commercial	Industrial	Agriculture	Religion	Government	Education	Total
Arlington County	$12,867,851	$2,997,089	$228,293	$16,366	$412,483	$243,309	$178,052	**$16,943,443**
Fairfax County	$69,782,043	$14,551,381	$1,714,269	$179,020	$1,309,470	$289,035	$792,922	**$88,618,140**
Loudoun County	$12,240,971	$2,837,905	$575,890	$99,322	$256,349	$88,186	$159,231	**$16,257,854**
Prince William County	$16,183,895	$2,749,642	$485,743	$105,462	$252,167	$75,096	$175,834	**$20,027,839**
City of Alexandria	$8,360,736	$2,447,302	$199,685	$12,880	$379,692	$83,617	$636,313	**$12,120,225**
City of Falls Church	$772,821	$309,040	$25,472	$4,580	$38,994	$7,529	$11,362	**$1,169,798**
City of Manassas	$2,090,589	$629,525	$161,690	$7,612	$42,905	$25,566	$31,824	**$2,989,711**
City of Manassas Park	$589,358	$103,628	$42,782	$4,805	$4,209	$3,500	$11,342	**$759,624**
Total	**$122,888,264**	**$26,625,512**	**$3,433,824**	**$430,047**	**$2,696,269**	**$815,838**	**$1,996,880**	**$158,886,634**

Building stock exposure is also classified by building type. General Building Types have been developed as a means to classify different building construction types. This provides an ability to differentiate between buildings with substantially different damage and loss characteristics. Model building types represent the average characteristics of buildings in a class. The damage and loss prediction models are developed for model building types and the estimated performance is based upon the "average characteristics" of the total population of buildings within each class. Five general classifications have been established, including wood, masonry, concrete, steel, and manufactured homes (MH). A brief description of the building types is available in Table 4.6. The HAZUS^{MH} inventory serves as the default when a user does not have better data available.

Table 4.6: HAZUS-MH General Building Type Classes.

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

Wood construction represents the majority (60%) of building types in the region, followed by masonry, which represents 27% of building stock exposure. The remaining percentage is distributed among other building types. Table 4.7 below provides building stock exposure for the five main building types. *The differences in the building stock tables are a result of aggregation by HAZUS^{MH} and rounding.* HAZUS^{MH} only provides building stock for the counties and cities in Northern Virginia. Towns participating in this plan are represented in their respective county totals.

Table 4.7: Building stock exposure for general building type by jurisdiction.

Jurisdiction	Wood	Masonry	Concrete	Steel	MH	Total
City of Alexandria	$6,412,296	$3,477,780	$605,578	$1,620,688	$3,877	**$12,120,219**
Arlington County	$9,632,111	$4,755,713	$733,158	$1,819,227	$3,238	**$16,943,447**
Fairfax County	$54,518,093	$23,632,992	$2,350,441	$8,137,070	$79,531	**$88,718,127**
City of Falls Church	$638,496	$321,708	$42,290	$167,207	$98	**$1,169,799**
Loudoun County	$9,792,019	$4,268,333	$443,420	$1,745,598	$8,475	**$16,257,845**
City of Manassas	$1,647,936	$791,647	$123,189	$419,862	$7,082	**$2,989,716**
City of Manassas Park	$469,785	$193,413	$15,994	$80,215	$217	**$759,624**
Prince William County	$12,484,085	$5,242,591	$505,278	$1,742,746	$63,120	**$20,037,820**
Total	**$95,594,821**	**$42,684,177**	**$4,819,348**	**$15,732,613**	**$165,638**	**$158,996,597**

III. Hazard Identification

***Requirement** §201.6(c)(2)(i): [The risk assessment shall include a] description of the type … of all natural hazards that can affect the jurisdiction.]*

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

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

Depending on the severity, location, and timing of the specific events, each of these hazards could have devastating effects on homes, businesses, agricultural lands, infrastructure, and ultimately citizens. In order to gain a full understanding of the history of these hazards in the planning area, detailed data related to the hazard history was compiled and available in each of the hazard sections. Appendix D3 contains the National Climactic Data Center (NCDC) storm events database used in the 2010 analysis.

For the 2006 plan, information was collected from meetings with local community officials, existing reports and studies, State and national data sets, and local newspaper clippings, among others sources. The 2010 plan updated the 2006 information based on the National Weather Service's (NWS) NCDC storm events, and local, State and national datasets.

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

To a large extent, historical records are used to identify the level of risk within the Northern Virginia region with the assumption that the data sources cited are reliable and accurate. Unless otherwise cited, all data on historical weather-related events is based on information made available through the Storm Event Database by the NWS NCDC[4]. From a regional planning perspective, it is important to use a consistent source for hazard-related data such as the NCDC.

That being said, descriptions of historical hazard events and numerical damage data are based on the collection of information reported by local offices of the NWS and should only be considered approximate figures for general analysis and planning purposes.

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

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

Federally Declared Disasters

Presidential disaster declarations are issued for county (including towns) or independent city jurisdictions when an event has been determined to be beyond the capabilities of State and local governments to respond. There have been a total of 52 declared disasters in Virginia, and 14 of those disasters have been declared in at least one community in the Northern Virginia planning area since 1965. The City of Alexandria has been declared in 11 of these events, and Arlington and Fairfax Counties have been declared in 9 of the disasters. Prior to January 1, 1965, presidential disaster declarations did not have county or independent city designations. The region has also experienced a significant number of additional emergencies and disasters that were not severe enough to require Federal disaster relief through a presidential declaration. Table 4.8 summarizes the disasters and the localities that were included in the declaration.

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

Table 4.8: Major disaster declarations for Northern Virginia planning area (1965-April 2010)

Date of Declaration	Disaster	Declared Jurisdiction								
		Arlington County	Fairfax County	Loudoun County	Prince William County	Alexandria, City of	Fairfax, City of	Falls Church, City of	Manassas, City of	Manassas Park, City of
4/27/2010	Severe Winter Storms and Snowstorms	✓	✓	✓	✓	✓	✓	✓	✓	✓
2/16/2010	Severe Winter Storm and Snowstorm	✓	✓		✓	✓	✓	✓	✓	✓
7/13/2006	Severe Storms, Tornadoes, and Flooding	✓	✓			✓				
9/18/2003	Hurricane Isabel	✓	✓	✓	✓	✓	✓	✓	✓	✓
3/27/2003	Severe Winter Storm	✓	✓	✓	✓	✓	✓	✓	✓	✓
9/21/2001	Terrorism	✓								
2/28/2000	Severe Winter Storm	✓	✓	✓	✓	✓	✓		✓	
10/12/1999	Hurricane Floyd		✓				✓			
10/23/1996	Hurricane Fran				✓					
2/2/1996	Blizzard of 1996	✓	✓	✓	✓	✓	✓	✓	✓	✓
11/10/1985	Severe Storms & Flooding					✓				
10/10/1972	Severe Storms & Flooding					✓				
10/7/1972	Severe Storms & Flooding					✓				
6/29/1972	Tropical Storm Agnes	✓	✓	✓	✓	✓	✓	✓		

Source: Federal Emergency Management Agency (FEMA)

NCDC Storm Events Database

NCDC Storm Data is published by the National Oceanic and Atmospheric Administration (NOAA), part of the U.S. Department of Commerce. The storm events database contains information on storms and weather phenomena that have caused loss of life, injuries, significant property damage, and/or disruption to commerce. Efforts are made to collect the best available information, but because of time and resource constraints, information may be unverified by the NWS. The NWS does not guarantee the accuracy or validity of the information. Although the historical records in the database often vary widely in their level of detail, the NWS does have a set of guidelines used in the preparation of event descriptions.[5]

It should be noted that NCDC is well known for having limited records of geological hazards (i.e., earthquake, landslide, and karst). In the absence of better data it was decided to proceed with the records available in NCDC for these events, in all cases. NCDC records for these events are severe under-representations of what has happened in Northern Virginia's past. To date, no comprehensive digital databases exist for these hazards[6].

Event records from February 1, 1951, through August 31, 2009, have been used for the HIRA analysis. There have been 3,161 events recorded in the NCDC storm events database for the Northern Virginia planning area spanning 1950 through 2009; 795 of those events have not been included in the analysis. High wind and winter storm events make up over 72% of the records and almost 25% of the recorded property damages, followed by flood events (19% of the events and 11% of the property damages). Tornado events account for only 3% of the events but over 64% of the recorded property damages. Table 4.9 shows the number of NCDC events for each county and city by hazard type. Table 4.10 summarizes, by jurisdiction, the total injuries, deaths, and damages. NCDC data is only provided for the counties and cities in the Northern Virginia planning area. Town information is included in the county totals. Table 4.11 summarizes, by hazard, the years of record, number of events, and damages incurred.

Figure 4.9 summarizes the number of reported events in the NCDC storm events database by year. As shown, reporting of events has significantly improved in the past 20 years. More than 80% of the recorded events are from 1990 to 2009.

Table 4.9: Number of Events in the NCDC database.						
Jurisdiction	**Drought**	**Flood**	**High Wind**	**Tornado**	**Winter Storm**	**Total**
Arlington County	20	50	94	2	113	**279**
Fairfax County	20	101	209	19	126	**475**
Loudoun County	31	75	244	24	144	**518**
Prince William County	20	75	128	13	128	**364**
City of Alexandria	20	47	60	1	111	**239**
City of Fairfax		5	20			**25**
City of Falls Church	20	38	46	1	111	**216**
City of Manassas	20	46	54	2	124	**246**
City of Manassas Park		2	1	1		**4**
Total	**151**	**439**	**856**	**63**	**857**	**2,366**

Table 4.10: Jurisdictional totals of NCDC database.					
Jurisdiction	**Injuries**	**Fatalities**	**Total Events**	**Total Crop Damage**	**Total Property Damage**
Arlington County	5	1	279	$2,860,525	$10,502,359
Fairfax County	59	2	475	$2,620,475	$160,083,383
Loudoun County	11	0	518	$7,317,346	$13,658,281
Prince William County	18	2	364	$3,080,631	$26,141,962
City of Alexandria	0	0	239	$2,860,525	$4,759,845
City of Fairfax	0	1	25	$0	$94,131
City of Falls Church	0	1	216	$2,860,525	$10,005,946
City of Manassas	0	0	246	$3,014,556	$16,055,674
City of Manassas Park	5	0	4	$0	$12,041
Total	**98**	**7**	**2,366**	**$24,614,583**	**$241,313,623**

Table 4.11: Jurisdictional totals of NCDC database.						
Hazard Type	**Timeframe**	**Years of Record**	**Number of Events**	**Total**		
				Property Damage	***Crop Damage***	***Property + Crop Damages***
Drought	1993-2009	17	151	$0	$16,030,513	$16,030,513
Flood	1993-2009	17	439	$25,708,755	$2,386,304	$28,095,058
High Wind	1955-2009	21	856	$54,960,271	$6,002,154	$60,962,425
Tornado	1951-2009	59	63	$154,079,301	$46,308	$154,125,609
Wildfire	1995-2009	15	0	$0	$0	$0
Winter Storm	1993-2009	17	857	$6,565,296	$149,305	$6,714,601
Landslide	1993-2009	17	0	$0	$0	$0
		Total	**2,366**	**$241,313,623**	**$24,614,583**	**$265,928,206**

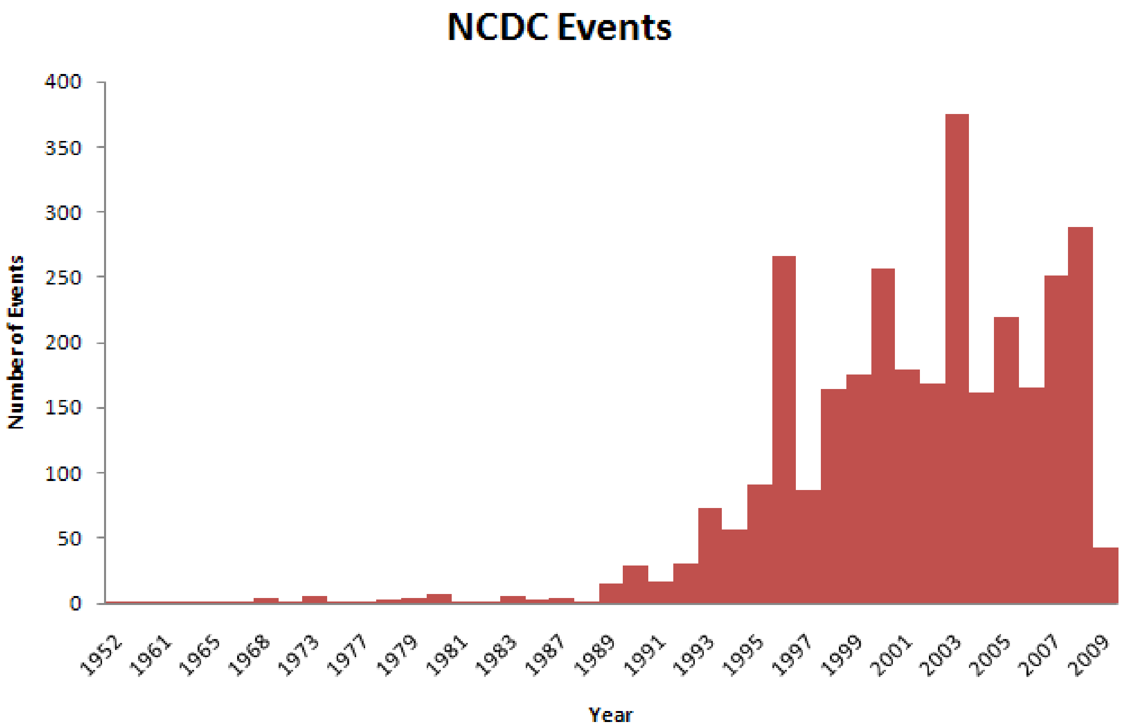

Figure 4.9: Number of reported NCDC events (1950 – 2009).

To use the NCDC data in the same fashion as it was used in the *Commonwealth of Virginia Hazard Mitigation Plan* Risk Assessment, the data had to be processed. The following excerpt on processing the NCDC data has been taken from Virginia's hazard mitigation plan. The data used in the Virginia plan was provided by VDEM for the Northern Virginia plan update. The storm events used for the Virginia plan span February 1, 1951, through May 31, 2008. Storm events from June 1, 2008, through August 21, 2009, were provided by the NWS and processed, according to the procedure outlined below, for the update.

NCDC Normalizing Data

Information for specific hazard events is sometimes reported by the NWS and found in the NCDC database only at a zonal level. This is particularly true for events that impact a wide area, such as winter storm and drought events. Each zone may contain one or many political jurisdictions. These zonal events may include information regarding deaths, injuries, and damages caused by the event, but may not break these down by individual jurisdiction. To accurately count the number of events occurring in a single county or city, the zonal data records were expanded into a set of individual city/county records, based on NCDC zone definitions. For example, if there were three political jurisdictions in a given zone, a record in the database for a winter storm covering that zone would be replaced with three records for that storm, corresponding to each of the political jurisdictions. During this process, the damages, fatalities, and injuries associated with a storm event in a certain zone were divided evenly among the political jurisdictions in that zone.

Injuries and fatalities, once normalized, were combined into a single number. While there is no good method to equate injuries with fatalities, FEMA's cost-benefit analysis documentation has suggested that the cost of a fatality is 176 times the cost of an injury. Therefore, fatalities have been multiplied by a factor of 176 and added to the injuries for each jurisdiction. Table 4.8 above shows the normalized total of injuries and deaths by hazard type.

General time statistics were generated to determine how the different hazards were represented in the NCDC data. This consisted of developing percentile (tabular and graphical) and histograms of events versus date for each hazard type. For all events except high wind, the percentile graph was relatively linear. This suggests that reporting has remained roughly equal over the entire period of record, and all records should be counted. However, the high wind period of record showed very few events between 1955 and 1989, and a linear trend after that. Therefore, since a longer period of record is only necessary when the data has been reported consistently, high wind was only evaluated using the period of record from 1989 to 2009 for the annualized data analysis.

Once the zonal records were replaced with individual jurisdictional records, the NCDC database was used to calculate a variety of summary statistics on a jurisdictional basis. For example, the total number of each type of storm event, and the total damages associated with a storm event, were summarized on a statewide and jurisdictional basis. Statistics were generated for the dates of events in each HIRA category, percentile (tabular and graphical), and a histogram of events versus date. For all events except high wind, the percentile graph was relatively linear. This suggests that reporting has remained roughly equal over the entire period of record, and all records should be counted. However, the high wind period of record showed very few events between 1955 and 1989, and a linear trend after that. Therefore, since a longer period of record is only useful when the data has been reported consistently, high wind was only evaluated using the period from 1989 to 2008 for the annualized data analysis.

NCDC Inflation Computation

The damages entered into the NCDC Storm Events database portray how much damage was incurred in the year of the event. Due to inflation and the changing value of money, the values of damages incurred have been adjusted so that they reflect their worth in 2007. This process was done by obtaining information from the Bureau of Labor Statistics, which provides a yearly index of Consumer Prices. Each value was multiplied by the index of its year of occurrence and subsequently divided by the index value in 2007, the target year. The year 2007 was chosen because it was the most recent full year available in the index values list at the time of this writing, but the values could have been adjusted to any other year without changing the relative ranking of each hazard.

NCDC Annualizing Data

After the data was normalized, inflation accounted, and summary statistics calculated, the data was annualized in order to be able to compare the results on a common system (i.e., ranking the hazards). In general, this was completed by taking the parameter of interest and dividing by the length of record for each hazard. The annualized value should only be utilized as an estimate of what can be expected in a given year. Deaths/injuries, property and crop damage, and events were all annualized in this fashion, on a per-jurisdiction basis. The NCDC formatted data that was used in the analysis is available through VDEM. High wind events before 1989 have not been included as they would skew the record due to the reasons described under the normalizing data section.

NCDC Data Compilation

The NCDC Storm Events database uses very detailed event categories. The reported storm events were summarized in simplified classifications to correspond to the major hazard types considered in this plan. Table 4.12 shows how the NCDC categories were grouped into the HIRA hazard categories. The ranking methodologies, explained later in this section, summarize how the NCDC data was used in ranking the hazards.

Table 4.12: NCDC categories to align with hazards addressed in the HIRA.

HIRA Category	NCDC Event Categories	Number of NCDC Events for each Category in NOVA
Drought	DROUGHT	144
	DROUGHT/EXCESSIVE HEAT	7
Flood	COASTAL FLOOD	3
	COASTAL FLOODING	
	FLASH FLOOD	132
	FLASH FLOODING	1
	FLOOD	288
	FLOOD/FLASH FLOOD	6
	STORM SURGE	4
	STORM SURGE/TIDE	2
	TIDAL FLOODING	2
	URBAN/SMALL STRM FLDG	1
High Wind	GUSTY WIND	1
	GUSTY WIND/HVY RAIN	5
	GUSTY WINDS	12
	HIGH WIND	114
	HIGH WINDS	27
	STRONG WIND	82
	THUNDERSTORM WIND	133
	THUNDERSTORM WINDS	43
	TROPICAL STORM	21
	TSTM WIND	416
	WET MICROBURST	2

Table 4.12: NCDC categories to align with hazards addressed in the HIRA.		
HIRA Category	**NCDC Event Categories**	**Number of NCDC Events for each Category in NOVA**
Tornado	FUNNEL CLOUD	10
	TORNADO	53
Winter Storm	BLIZZARD	1
	HEAVY SNOW	115
	ICE	1
	ICE STORM	63
	SNOW	26
	SLEET/SNOW	1
	WINTER STORM	340
	WINTER WEATHER	195
	WINTER WEATHER/MIX	115
N/A	AGRICULTURAL FREEZE	3
	BLACK ICE	11
	DENSE FOG	133
	DUST DEVIL	1
	FREEZE	1
	FREEZING FOG	12
	FROST/FREEZE	67
	HAIL	300
	HEAT	11
	HEAVY RAIN	107
	RIP CURRENT	7
	UNSEASONABLY COLD	6
	UNSEASONABLY WARM	7
	UNUSUALLY WARM	1
	EXTREME COLD	16
	EXTREME COLD/WIND CHILL	17
	EXCESSIVE HEAT	25
	LIGHTNING	70

IV. Ranking and Analysis Methodologies

HAZUS^{MH} Methodology

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

HAZUS^{MH} uses a statistical approach and mathematical modeling of risk to predict a hazard's frequency of occurrence and estimated impacts based on recorded or historic damage information. The HAZUS^{MH} risk assessment methodology includes distinct hazard and inventory parameters. For example, wind speed and building type were modeled using the HAZUS^{MH} software to determine the impact (damages and losses) on structures. Figure 4.10 shows a conceptual model of HAZUS^{MH} methodology. More information on HAZUS^{MH} loss estimation methodology is available through FEMA at www.fema.gov/hazus.

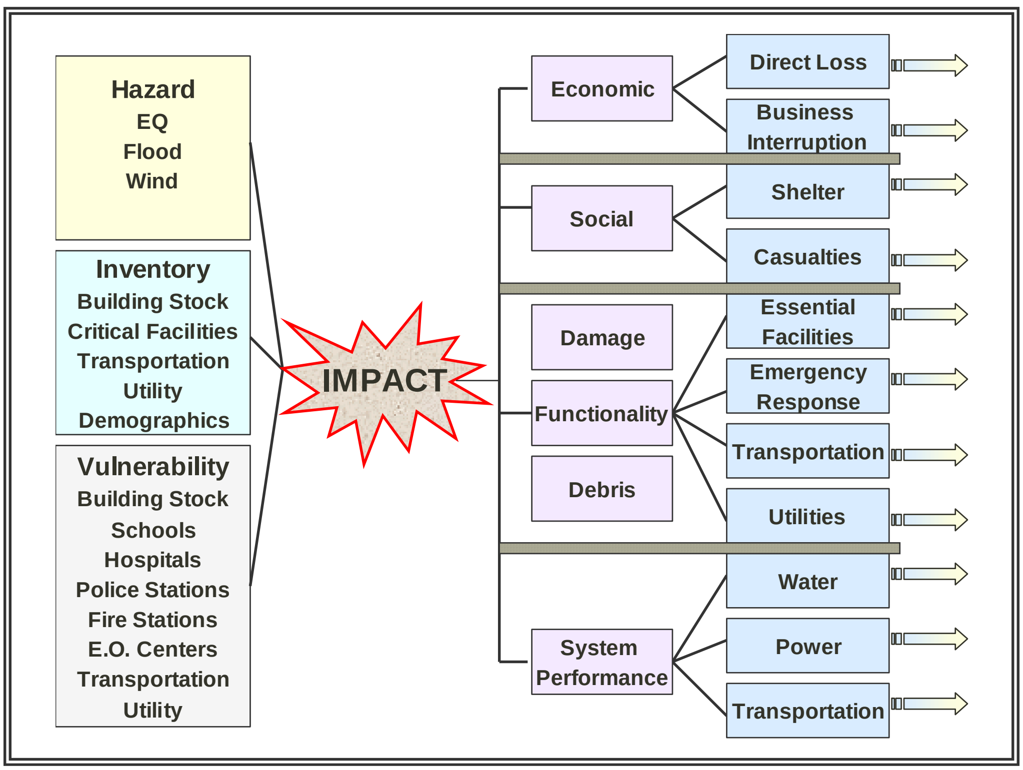

Figure 4.10 Conceptual Model of HAZUS^{MH} Methodology

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

Supplemental Annualized Loss Estimate Methodology

The first step in conducting supplemental annualized loss calculations and risk assessment included the collection of relevant GIS data from local, State and national sources. This began with the collection of local data from each participating jurisdiction through NVRC (considered most accurate), then continued up to best available data at the national inventory level (considered least accurate). The data determined to be "best available" was then used for purposes of this assessment. Data matrices were compiled based on the data provided by each of the localities; these may be found in Appendix D1.

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

- For the flood, drought, severe thunderstorm, tornado, wildfire and winter storm hazards, best available data on historical hazard occurrences (limited to NOAA NCDC and Virginia Department of Forestry [VDOF] records) was used to produce an annualized loss estimate of potential damages. Using this data, annualized loss estimates were generated by totaling the amount of property damage over the period of time for which records were available, and calculating the average annual loss. The 2010 update includes inflated property and crop damages whereas the 2006 plan did not take this into account.
- For the hazards of extreme temperatures, erosion, sinkholes, landslides, and dam failure, meaningful historical data (meaning data which would have included past property damages and other essential indicators) was virtually non-existent, and therefore annualized potential losses for these hazards could not be calculated.

Critical Facility and Building Risk

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

For the flood hazard, GIS was used to further assess risk utilizing the FEMA Digital Flood Insurance Risk Maps (DFIRMs) in combination with locally-available GIS data layers. Primary data layers used include local building footprints and tax parcel data. For the 2006 plan, total floodplain exposure was determined for each jurisdiction by calculating the assessed building value for all pre-Flood Insurance Rate Map (FIRM) structures located in identified flood hazard areas. Exposure values do not include any estimated values for building contents. The methodology used for determining potential flood loss estimates assumes that pre-FIRM structures would not have been constructed to minimum National Flood Insurance Program (NFIP) standards, and therefore are more likely to be vulnerable to the flood hazard than post-FIRM structures. Pre-FIRM structures were identified by comparing the date of construction for each structure to the NFIP entry date for that jurisdiction. For the 2010 plan, exposure values were not readily available and as a result only the count of building parcels in the Special Flood Hazard Area (SFHA) are summarized in the flood section.

2006 Ranking Methodology

To drive the risk assessment effort for the Northern Virginia region, two distinct methodologies were applied. The first includes a ***quantitative*** analysis that relies upon best available data and technology, while the second methodology includes a ***qualitative*** analysis that relies more on local knowledge and rational decision making. Upon completion, the methodologies are combined to create a "hybrid" approach for assessing hazard vulnerability for the Northern Virginia region that allows for some degree of quality control and assurance. The quantitative assessment focuses on estimated hazard loss estimates and specifically at-risk community assets, while the qualitative assessment is comprised of a scoring system built around values assigned by the MAC as to the likelihood of occurrence, spatial extent, and potential impact of each hazard studied.

The quantitative methodology consists of utilizing HAZUS^{MH}, a GIS-based loss estimation software available from the FEMA, as well as a detailed GIS-based approach independent of the HAZUS^{MH} software. These two GIS-based studies together help form a quantitative risk assessment.

The qualitative assessment relies less on technology, but more on historical and anecdotal data, community input, and professional judgment regarding expected hazard impacts. The qualitative assessment completed for the Northern Virginia region is based on the Priority Risk Index (PRI), a tool used by PBS&J to measure the degree of risk for identified hazards in local communities. The PRI is also used to assist community officials in ranking and prioritizing those hazards which pose the most significant threat to their area based on a variety of important factors.

While the quantitative assessment focuses on using best available data, computer models, and GIS technology, the PRI system relies more on historical data, local knowledge, and the general consensus of the MAC. The PRI is used for hazards with no available GIS data or relevant information to perform quantitative analysis, and also provides an important opportunity to compare, crosscheck, or validate the results of those that do have available data.

The PRI results in numerical values that allow identified hazards to be ranked against one another (the higher the PRI value, the greater the hazard risk). PRI values are obtained by assigning varying degrees of risk to five categories for each hazard (probability, impact, spatial extent, warning time, and duration). Each degree of risk has been assigned a value (1-4) and an agreed upon weighting factor, as summarized in Table 4.13. The PRI weighting scheme may also be adjusted by the MAC based upon any unique concerns for the region.

To calculate the PRI value for a given hazard, the assigned risk value for each category is multiplied by the weighting factor. The sum of all five categories equals the final PRI value, as demonstrated in the example equation below:

PRI Value =
(Probability x .30) + (Impact x .30) + (Spatial Extent x .20) + (Warning Time x .10) + (Duration x .10)

According to the weighting scheme applied for the Northern Virginia region, the highest possible PRI Value is 4.0. Prior to being finalized, PRI values for each hazard were reviewed and accepted by the MAC.

Table 4.13 : Summary of Priority Risk Index (PRI)

PRI Category	Degree of Risk			Assigned Weighting Factor
	Level	Criteria	Index Value	
Probability	Unlikely	Less than 1% annual probability	1	30%
	Possible	Between 1 and 10% annual probability	2	
	Likely	Between 10 and 100% annual probability	3	
	Highly Likely	100% annual probability	4	
Impact	Minor	Very few injuries, if any. Only minor property damage and minimal disruption on quality of life. Temporary shutdown of critical facilities.	1	30%
	Limited	Minor injuries only. More than 10% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for more than one day.	2	
	Critical	Multiple deaths/injuries possible. More than 25% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for more than one week.	3	
	Catastrophic	High number of deaths/injuries possible. More than 50% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for 30 days or more.	4	
Spatial Extent	Negligible	Less than 1% of area affected	1	20%
	Small	Between 1 and 10% of area affected	2	
	Moderate	Between 10 and 50% of area affected	3	
	Large	Between 50 and 100% of area affected	4	
Warning Time	More than 24 hours	Self explanatory	1	10%
	12 to 24 hours		2	
	6 to 12 hours		3	
	Less than 6 hours		4	
Duration	Less than 6 hours	Self explanatory	1	10%
	Less than 24 hours		2	
	Less than one week		3	
	More than one week		4	

Using both the qualitative and quantitative analyses to evaluate the hazards that impact the region provides members of the MAC with a dual-faceted review of the hazards. This allows officials to not only recognize the potentially most costly hazards, but also to plan and prepare for hazards that although not causing much monetary damage could put a strain on the local resources needed to recover after their impact on the region.

For the 2010 update, the 2006 PRI assessment was determined to be valid and supports the updated ranking and loss estimates.

2010 Ranking Methodology

During the January 2010 HIRA kick-off meeting, committee members liked the new NCDC ranking methods developed for the Commonwealth of Virginia's Emergency Operations Plan HIRA. It was agreed that this approach would be used in the update to the Northern Virginia plan update. Methods used in 2006 were kept in the update for archival and comparative purposes.

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

All conclusions of the HIRA completed for the Northern Virginia region are presented at the end of each of the hazard specific sections. Overall hazard rankings, in cases such as wind and winter storm, were altered based on review and feedback from the steering committee.

Ranking Methodology

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

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

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

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

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

Population Vulnerability and Density

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

Population vulnerability was calculated as a percent of the total population of Virginia present in each jurisdiction. The 2007 U.S. Census population projections for each jurisdiction were divided by the total population for the State and a value between one and four was assigned based on a geometric breaks pattern. By ranking jurisdictions this way, those cities and counties with significantly larger populations have effectively been given extra weight. Table 4.14 below describes the breaks and assigned scores for population vulnerability.

Table 4.14: Population Vulnerability as the percentage of people that will be affected by the occurrence of the hazard.

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

Population density was based on the population per square mile for each jurisdiction. The 2007 population projections for each jurisdiction were divided by the total area for the jurisdiction; a value between one and four was assigned based on geometric intervals. By ranking jurisdictions this way, those cities and counties with densely populated areas have effectively been given extra weight. Table 4.15 below describes the breaks and assigned scores for population density.

Table 4.15: Population Density as the number of people per square mile that will be affected by the occurrence of the hazard.	
Population Density	
Rank	***Definition***
1	<= 60.92 people/sq mi
2	60.93 – 339.10 people/sq mi
3	339.11 - 1,743.35 people/sq mi
4	>= 1,743.36 people/sq mi

Geographic Extent

Probable geographic extent (GE) would ideally be measured consistently for each hazard; however, the available data sources vary widely in their depiction of hazard geography. As a result, one uniform ranking system could not be accomplished at this time. In this version of the plan each hazard has been assigned individual category break points based on the available hazard data. In the overall scoring system, geographic extent was given a 1.5 weighting relative to the other parameters, as geographic extent was deemed to be critically important, and more reliable than some of the other parameters. GE data sources, ranking criteria, and category breaks are summarized in Table 4.16 below.

Table 4.16: Geographic Extent as the percentage of a jurisdiction impacted by the hazard.			
Geographic Extent			
Hazard	***Description***	***Category Breaks***	
		Rank	*Definition*
Flood	Percent of a jurisdiction that falls within FEMA Special Flood Hazard Area (SFHA).	*1*	*<=2.99%*
		2	*3.00-4.99%*
		3	*5.00 -9.99%*
	Data: FEMA Floodplains (DFIRMs)	*4*	*>=10.00%*
High Wind	Average maximum wind speed throughout the entire jurisdiction.	*1*	*<= 59.9*
		2	*60.0 - 73.9*
	Data: HAZUS^{MH} 3-second Peak Gust Wind Speeds	*3*	*74.0 - 94.9*
		4	*>= 95.0*
Wildfire	Percent of jurisdiction that falls within a “high” risk.	*1*	*<= 9.9%*
		2	*10.0% - 19.9%*
		3	*20.0% - 49.9%*
	Data: VDOF Wildfire Risk Assessment	*4*	*>= 50.0%*
Karst	Percent of jurisdiction where the risk is “high” for karst related events.	*1*	*<= 24.9%*
		2	*25.0% - 49.9%*
		3	*50.0% - 74.9%*
	Data: USGS Engineering Aspects of Karst	*4*	*>= 75.0%*

Table 4.16: Geographic Extent as the percentage of a jurisdiction impacted by the hazard.			
Geographic Extent			
Hazard	***Description***	***Category Breaks***	
		Rank	*Definition*
Landslide	Percent of jurisdiction where a high landslide risk exists.	*1*	*<= 24.9%*
		2	*25.0% - 49.9%*
	Data: USGS Landslide Incidence & Susceptibility	*3*	*50.0% - 74.9%*
		4	*>= 75.0%*
Earthquake	Average 2,500-year return period max percent of gravitational acceleration (PGA). Data: HAZUS^{MH} 2,500-year PGA	*1*	*<= 0.069*
		2	*0.070 - 0.159*
		3	*0.160 - 0.299*
		4	*>= 0.300*
Winter Storm	Average annual number of days receiving at least 3 inches of snow, calculated as an area-weighted average for each jurisdiction. Data: NWS snowfall statistics	*1*	*<= 1.49*
		2	*1.50 - 1.99*
		3	*2.00 - 2.99*
		4	*>= 3.0*
Tornado	Annual tornado hazard frequency (times 1 million), calculated as an area-weighted average for each jurisdiction. Data: NCDC tornado frequency statistics	*1*	*<= 1.24*
		2	*1.25 - 9.99*
		3	*10.00 - 99.9*
		4	*>= 100.00*

Annualizing the Data for Analysis

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

Deaths/injuries, property and crop damage, and events were all annualized in this fashion. A summary of the parameters and the period of record used for each hazard can be found above further describes the NCDC data.

Annualized Deaths and Injuries

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

In order to consolidate the data, fatalities were given a weight of 176 times that of an injury, and then added together. This follows the standard practice used for FEMA cost benefit analysis[7]. The combined injury/death values were annualized over the period of record for each event category and scored, using natural breaks (Table 4.17). A summary of deaths/injuries and the period of record used for each hazard can be found in the description of the NCDC data.

Table 4.17: Annualized Deaths and Injuries as the number of deaths or injuries that a hazard event would likely cause in a given year.

Annualized Deaths and Injuries	
Rank	*Definition*
1	<= 1.019 deaths and/or injuries per year
2	1.020 – 6.279 deaths and/or injuries per year
3	6.280 – 13.199 deaths and/or injuries per year
4	>= 13.200 deaths and/or injuries per year

Annualized Crop and Property Damage

Crop damage and property damage were also analyzed separately in order to give each jurisdiction a score of one (1) to four (4). This data was obtained from the NCDC storm events database and annualized according to the period of record for each event category (Table 4.18).

Table 4.18: Annualized Crop and Property Damage as the estimated damages that a hazard event will likely cause in a given year.

Annualized Crop and Property Damage		
Rank	*Definition: Crop Damage*	*Definition: Property Damage*
1	*<= $25,711 per year*	*<= $ 136,129 per year*
2	*$25,712 – $100,270 per year*	*$136,130 - $432,555 per year*
3	*$100,271 - $291,384 per year*	*$432,556 - $1,111,067 per year*
4	*>= $291,385 per year*	*>= $1,111,068 per year*

Annualized Events

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

It should be noted that there were no significant events reported for land subsidence (karst), earthquake, and landslide in NCDC; as a result, the events for these hazards all received a rank of one (1). Table 4.19 describes the annual frequency breaks for events.

Table 4.19: Annualized Events as the number of times that a hazard event would likely happen in a given year.

Annualized Events	
Rank	***Definition***
1	<= 0.09 events per year
2	0.10 – 0.99 events per year
3	1.00 – 4.99 events per year
4	>= 5.00 events per year

Overall Hazard Ranking

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

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

This revision does not include a map of the overall hazards ranking, as was done in the 2006 version of this plan, to avoid overarching conclusions about the ranking and what communities are at risk. Knowing which communities are high for multiple hazards is important for determining mitigation actions, but one overall map, taken out of context, would lead to inaccurate statements about risk in the Commonwealth. The plan's committee members fully supported, and even suggested, that this revision not include this graphic.

Comparison of Methodologies

Differences in 2006 and 2010 annualized loss estimates can be attributed to several factors:

- Time frame of storm events database and/or data sources;
- Inflation of storm events database (taken into account in 2010); and
- Methodologies used for analysis (i.e., HAZUS^{MH})

Results of the updated ranking align nicely with the quantitative and qualitative methodologies used in the 2006 plan. See the Overall Risk Assessment Results section for hazard specific comparisons.

Additional Risk Assessments Completed for the Northern Virginia Region

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

March 2007 NCR HIRA *National Capital Region Hazard Identification and Risk Assessment: A Uniquely Regional Perspective:* This plan discusses natural and human-caused hazards and provides risk summaries for each of the hazards. Hazards that were determined to impact/disrupt regional continuity were used to create scenarios to further analyze the hazard and determine estimated damages/impact and estimated casualties. Additional hazards were reviewed, risks profiled, and determined not to disrupt regional continuity. The scenarios in this report represent worst-case scenarios and should be used in conjunction with the information presented in this HIRA.

Hazards that Disrupt Regional Continuity:

- Communicable Disease (Pandemic Flu)
- Severe Storms (Hail. Nor'easters, Rain, Thunderstorms)
- Extreme Temperatures
- High Winds
- Tropical Cyclones (Tropical Storms and Hurricanes)
- Winter Storm/Blizzard
- Drought
- Flooding (Flash, Riverine)
- Accidental Release of Communicable Diseases
- Nuclear Detonation
- Aerosol Anthrax Attack
- Chemical Attack (Chlorine Tank Explosion)
- Radiological Dispersal Device (RDD) Attack
- Armed Attack (Beltway Sniper)
- Aircraft as Weapon (9-11 Attacks)
- Cyber Attack or Malfunction
- Toxic Industrial Chemical Spill (Chemical Spill into Water)

Hazards that do not disrupt Regional Continuity:

- Landslide
- Land Subsidence
- Coastal Erosion
- Earthquake
- Tsunami
- Wildfire
- Plague
- Foreign Animal Disease
- Food and Water Contamination (intentional release)
- IED/Conventional Bomb
- Blistering Agents
- Nerve Agents
- Nuclear Reactor Incident, Research and Test Reactors, and Improvised Nuclear Device
- Nuclear Bomb
- Urban Fire
- Hostage Taking/ Assassination
- Civil Disobedience
- Maritime Attacks
- Radio Frequency/EMP
- Workplace Violence

November 2008 NCR SHIELD

National Capital Region Strategic Hazard Identification and Evaluation for Leadership Decisions (NCR SHIELD) *Assessment of Risk to the National Capital Region from Terrorist Attacks and Natural Hazards: Risk Management Strategic Recommendations.* This assessment is also scenario-based. For terrorism, Department of Homeland Security standards for terrorist attack were discussed. For Natural hazards, the FEMA categorization for the different hazard types was used. Analysis was limited to those scenarios that can cause loss of life over 100 people or property loss of over $25 million. Some hazards were not included due to comparatively lower consequences. The scales used for natural and terrorist events are not comparable.

- Highest risk scenarios are:
  - For Terrorism— Improvised Explosive Device and Vehicle-borne Improvised Explosive Device
  - For Natural Hazards—Extreme Heat and Flooding
- Highest consequence scenarios are, for wide-area attacks on the NCR:
  - For Terrorism—Nuclear Attacks, Contagious and Non-Contagious Human Disease (Biological Attacks)
  - For Natural Hazards—Pandemic Disease
- Highest risk sectors are:
  - For Terrorism—Banking & Finance, Commercial, Government Facilities, Transportation
  - For Natural Hazards—Commercial, Electric, Healthcare & Public Health, Transportation

September 2005 CIP MCR RBFRS

Critical Infrastructure Protection in the National Capital Region *Risk-Based Foundations for Resilience and Sustainability c*reated by University Consortium for Infrastructure Protection managed by the Critical Infrastructure Protection Program School of Law George Mason University. In 2002, the National Capital Region's Eight Commitments to Action identified critical infrastructure protection as a high priority of the region's homeland security strategy. Teams of experts in each of the eight critical infrastructures review literature and investigated vulnerability with key managers of the facilities. Each sector has listed key findings and listed recommendations, some of which include:

- Healthcare and public health sector is the least advanced due to its extensive redundancy and geographical dispersion.
- Banking and finance and telecommunications have a very high level of risk management due to close working relationships with government agencies that stress reliability and risk management.

V. Flood

NOTE: As part of the 2010 plan update, the Flood hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining 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 the HIRA Introduction section. Erosion in Northern Virginia is often the result of flooding and has been incorporated into the Flood section for this update. In addition, each section of the plan was also reformatted to improve clarity, and new maps and imagery, when available and appropriate, were inserted.

A. Hazard Profile

1. Description

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

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

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

Hurricane Isabel September 2003
Bellevue section of Fairfax County
(Photo from Fairfax County)

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

The average global sea level has been rising at the rate of about 3.1 mm per year (data from 1993 to 2003)[8]. This same trend is apparent in the historical gage records for Washington, DC, (Station 8594900) along the tidally-influenced Potomac River where rates have averaged about 3.2 mm/year.

Sea Level Rise

Sea level rise is expected to continue and possibly accelerate as the planet warms. Based on output from multiple computer models, a low sea level rise scenario is one with a sea level rise of 7 to 15 inches by 2100. A high scenario would include a sea level rise of 10 to 23 inches by 2100. Neither scenario includes the possibility of ice sheet melting contributing to sea level rise. Some scientists suggest that should the Greenland and West Antarctic ice sheets collapse; sea level rise will be on the order of several feet higher than the high scenario shown here.[9]

Using the high Intergovernmental Panel on Climate Change (IPCC) emissions growth scenario and overlaying corresponding projected sea levels expected with that scenario, it is anticipated that significant portions of the eastern sections of Old Town Alexandria, including the eastern portions of King Street will be at risk of inundation (Figure 4.11). A study being conducted by NVRC as part of Sustainable Shorelines & Community Management indicates that approximately 49 buildings may be inundated under a high sea-level rise scenario.

Also at risk of inundation under projected rises in sea-level is Ronald Reagan Washington National Airport. Situated along the banks of the Potomac, the airport opened in 1941. The site had originally been mostly underwater and was built up by sand and gravel fill. Approximately 200 acres of the airport are within the 100-year floodplain which is 11.4 feet above mean sea level. Under the high emissions scenario, permanent inundation of portions of taxiways and access roadways is possible (See Figure 4.12).

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

In addition to producing high resolution sea level rise and storm surge inundation mapping for Northern Virginia, the NVRC study, completed in late 2010, will also quantify specific elements vulnerable for both the built and natural environments and develop strategies to protect, adapt or retreat communities located in areas at risk.

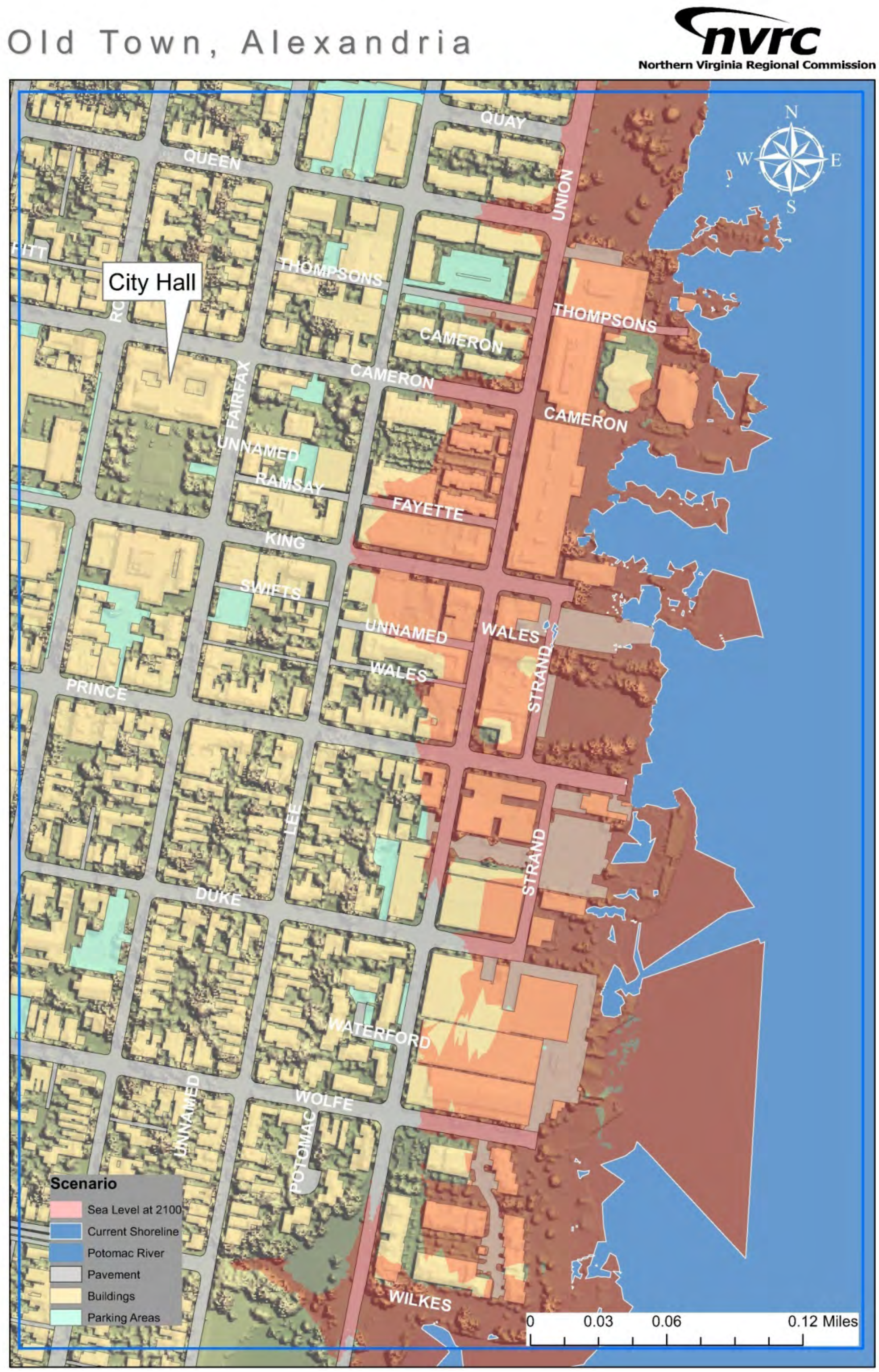

Figure 4.11. Projected “high scenario” sea-level rise for Old Town, Alexandria Year 2100.
Source: NVRC, 2010

Figure 4.12. Projected "high-scenario" sea-level rise for Ronald Reagan Washington National Airport Year 2100.
Source: NVRC, 2010

Erosion

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

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

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

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

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

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

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

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

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

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

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

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

2. Geographic Location / Extent

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

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

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

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

Figure 4.12 shows the potential flood hazard areas throughout the Northern Virginia region based on the FEMA DFIRM and Q3 data. Jurisdiction specific flood maps that show the FEMA floodplain in relation to dominant geographic features in the region can be found in Appendix D4.

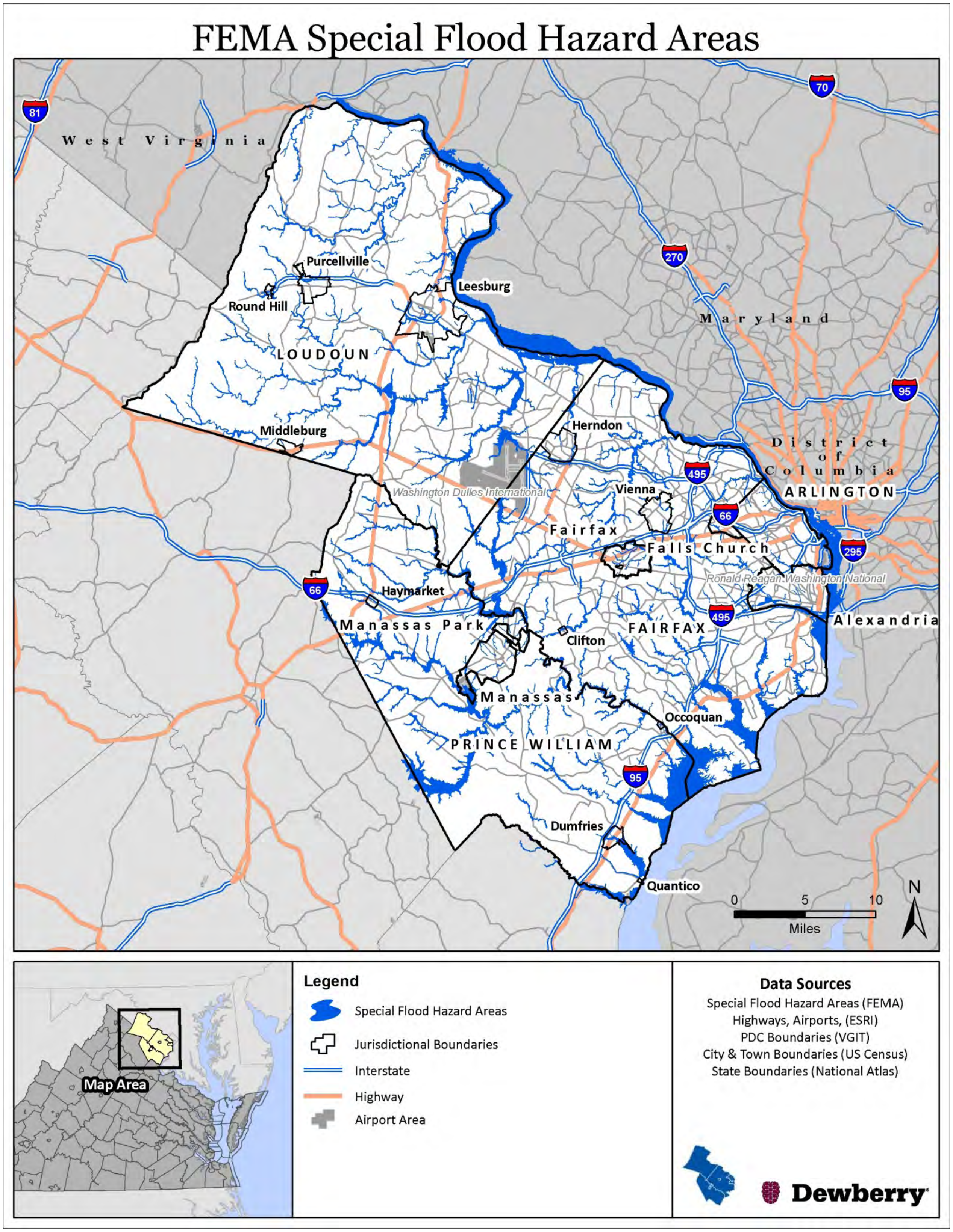

Figure 4.12 FEMA Digital Flood Insurance Rate Maps (DFIRM) and Q3 data.

There have been a number of past flooding events throughout the region, ranging widely in terms of location, magnitude, and impact. The most frequent flooding events are quite localized in nature, resulting from heavy rains in a short period of time over urbanized areas that are not able to appropriately handle storm water runoff. These events typically do not threaten lives or property and will not result in emergency or disaster declarations, thus historical data is difficult to obtain. Table 4.20 summarizes the number of flood events (by county) since 1993 which have caused a notable impact on the Northern Virginia region as recorded by the NCDC. This includes 439 flood events that have caused approximately $28 million in property and crop damages, as well as one death and one injury in Arlington County.

Table 4.20 Flood Events in the Northern Virginia Region, 1993–2009 based on NCDC storm events data

Jurisdiction	# of Flood Events	Property Damage	Crop Damage	Property + Crop Damage
Arlington County	50	$4,405,124	$341,254	$4,746,378
Fairfax County	101	$13,254,002	$378,349	$13,632,352
Loudoun County	75	$3,449,790	$229,495	$3,679,285
Prince William County	75	$2,225,367	$410,387	$2,635,753
City of Alexandria	47	$628,307	$341,254	$969,561
City of Fairfax	5	$0	$0	$0
City of Falls Church	38	$576,049	$341,254	$917,302
City of Manassas	46	$1,170,116	$344,312	$1,514,428
City of Manassas Park	2	$0	$0	$0
Total	**439**	**$25,708,755**	**$2,386,304**	**$28,095,058**

3. Magnitude or Severity

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

The severity of a flood on a community can be magnified to the degree floodwaters affect special needs populations and critical facilities. Special needs populations are those that may require special assistance during a flood event, may not be able to protect themselves prior to an event, or may not be able to understand potential risks. These can include non-English populations, elderly populations, or those in a lower socioeconomic group. (Further discussed in the Populations at Risk section above)

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

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

4. Previous Occurrences

June 23-27, 2006

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

September 23, 2003

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

Street flooding during the flood of August 11, 2001. Flooding occurred along a narrow band from Warrenton, Virginia through Fairfax County, and extended into northern Washington, DC. Up to seven inches of rain fell in some areas. (Photo courtesy of WJLA)

August 11, 2001

Showers and thunderstorms with very heavy rainfall and frequent lightning moved across Northern Virginia during the afternoon of the 11th. In Loudoun County, high water stranded motorists in Sterling and the bridge at Lawson Road in Leesburg was impassible after a stream overflowed its banks. Water covered roads in the City of Fairfax. In McLean, four houses were flooded and two cars were submerged by flood waters. Also in McLean, a car and a dumpster were washed downstream after Pimmit Run overflowed. In Arlington County, heavy rainfall washed out a culvert and created a sinkhole. Trees were downed along streams when the waterways overflowed their banks. Flooded roads and downed power lines were reported in North Arlington where a total of 5½ inches of rain was recorded. 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.

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.

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).

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 (FHBMs), when the first FIRM became effective, the date of the current FIRMs used for insurance purposes, and the date the community entered into the NFIP.

Table 4.21. 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
Town of Herndon	6/14/1974	8/1/1979	*8/1/1979*	8/1/1979	
Town of Vienna	8/2/1974	2/3/1982	*2/3/1982*	2/3/1982	
Town of Clifton	3/28/1975	5/2/1977		5/2/1977	
Loudoun County	4/25/1975	1/5/1978	7/5/2001	1/5/1978	DFIRM
Town of Leesburg	8/3/1974	9/30/1982	7/5/2001	9/30/1982	
Town of Purcellville	7/11/1975	11/15/1989	7/5/2001	11/15/1989	
Town of Middleburg	-	7/5/2001	7/5/2001	7/31/2001	
Town of Round Hill	5/13/1977	7/5/2001	7/5/2001	1/10/2006	
Prince William County	1/10/1976	12/1/1981	1/5/1995	12/1/1981	DFIRM
Town of Dumfries	6/18/1976	5/15/1980	1/5/1995	5/15/1980	
Town of Haymarket	8/9/1974	1/17/1990	1/5/1995	1/31/1990	
Town of Occoquan	7/19/1974	9/1/1978	1/5/1995	9/1/1978	
Town of Quantico	11/1/1974	8/15/1978	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
	TOTAL	*790*	*$144,938,600*	*91*	*$285,832*
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*
	TOTAL	*5,466*	*$1,253,309,200*	*520*	*$7,534,219*
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*	-	-
	TOTAL	*614*	*$166,727,100*	*93*	*$1,217,092*
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	-	-
	TOTAL	*1,149*	*$290,445,300*	*258*	*$3,706,986*
City of Alexandria	City of Alexandria	1,590	$371,645,100	221	$3,677,306
	TOTAL	1,590	$371,645,100	221	$3,677,306
City of Fairfax	City of Fairfax	558	$63,887,000	27	$388,720
	TOTAL	558	$63,887,000	27	$388,720
City of Falls Church	City of Falls Church	141	$39,887,300	18	$111,260
	TOTAL	141	$39,887,300	18	$111,260
City of Manassas	City of Manassas	66	$16,254,800	20	$164,618
	TOTAL	66	$16,254,800	20	$164,618
City of Manassas Park	City of Manassas Park	24	$5,579,400	5	$66,527
	TOTAL	24	$5,579,400	5	$66,527
	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
Town of Herndon							
*Town of Vienna**	*1*		*1*	*2*	*$4,819*	*$0*	*$4,819*
Town of Clifton							
Loudoun County	11	1	12	38	$691,276	$122,730	$814,006
Town of Leesburg							
Town of Purcellville							
Town of Middleburg							
Town of Round Hill							
Prince William County	8	2	10	42	$1,303,075	$788,669	**$2,091,744**
Town of Dumfries							
Town of Haymarket							
Town of Occoquan							
Town of Quantico							
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 nationwide[12]. The main recurrence intervals used on the FIRMs are shown in the table below (Table 4.24).

Table 4.24 Annual probability based on flood recurrence intervals.

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

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

2. Impact & Vulnerability

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

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

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

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

3. Risk

Riverine HAZUS^{MH} analysis was completed for the 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 recovery[13].

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 mi^2 threshold. The stream threshold influenced a lack of stream delineation within two communities: the City of Fairfax and City of Falls Church. This does not mean streams or floodplains do not exist in these communities, however it does mean that the automated, GIS-based method used to define a sub-watershed and the number of grid cells flowing through the community was less than the 10 mi^2 threshold. In order to try and compensate for the lack of data for these two communities, coupled with the need to quantify other flood-related loss estimates, additional flood model work was performed using the 100-year scenario.

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**
Town of Herndon	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
Town of Vienna	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
Town of Clifton	*$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
Town of Leesburg	*$474,000*	*$339,000*	*$0*	*$0*	*$0*	*$0*	*$0*	*$813,000*
Town of Purcellville	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
Town of Middleburg	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
Town of Round Hill	*$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
Town of Dumfries	*$396,000*	*$449,000*	*$7,000*	*$0*	*$0*	*$0*	*$2,000*	*$854,000*
Town of Haymarket	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
Town of Occoquan	*$409,000*	*$372,000*	*$7,000*	*$0*	*$0*	*$0*	*$1,000*	*$789,000*
Town of Quantico	*$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
City of Fairfax								
City of Falls Church								
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.

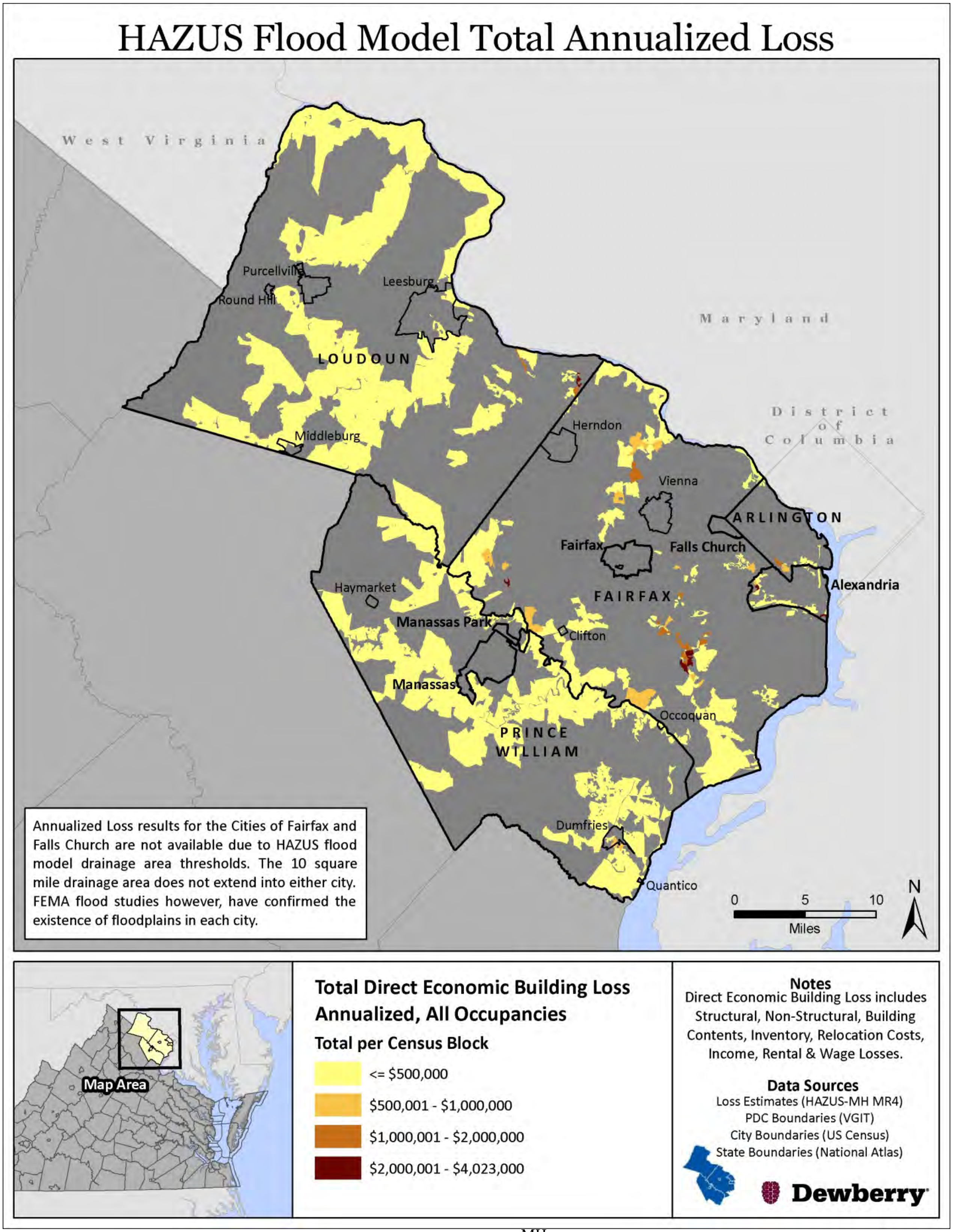

Figure 4.13. Total Annualized Loss based on HAZUS^{MH} MR4 Flood Module.

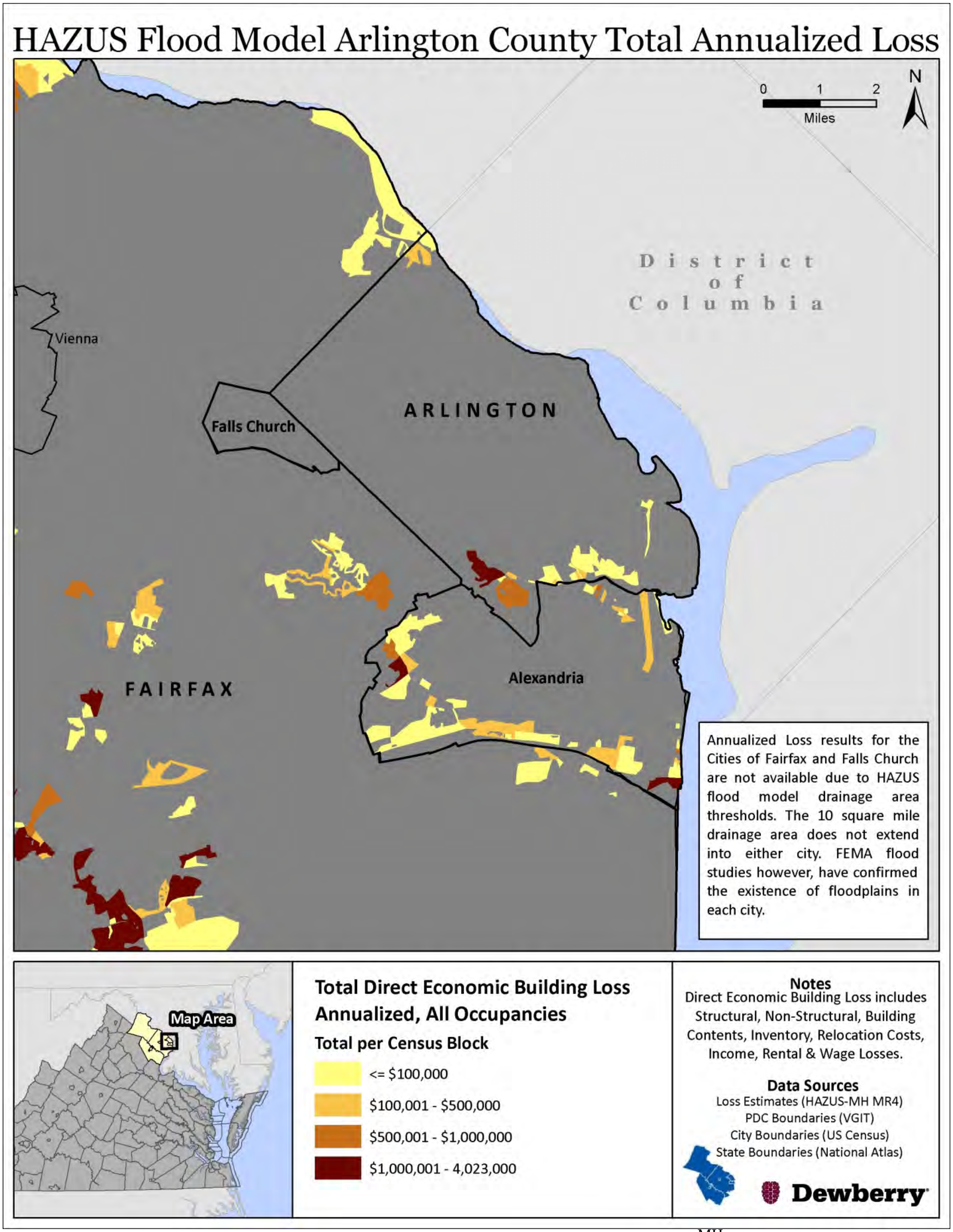

Figure 4.14. Arlington County Total Annualized Loss based on HAZUS[MH] Flood Module.

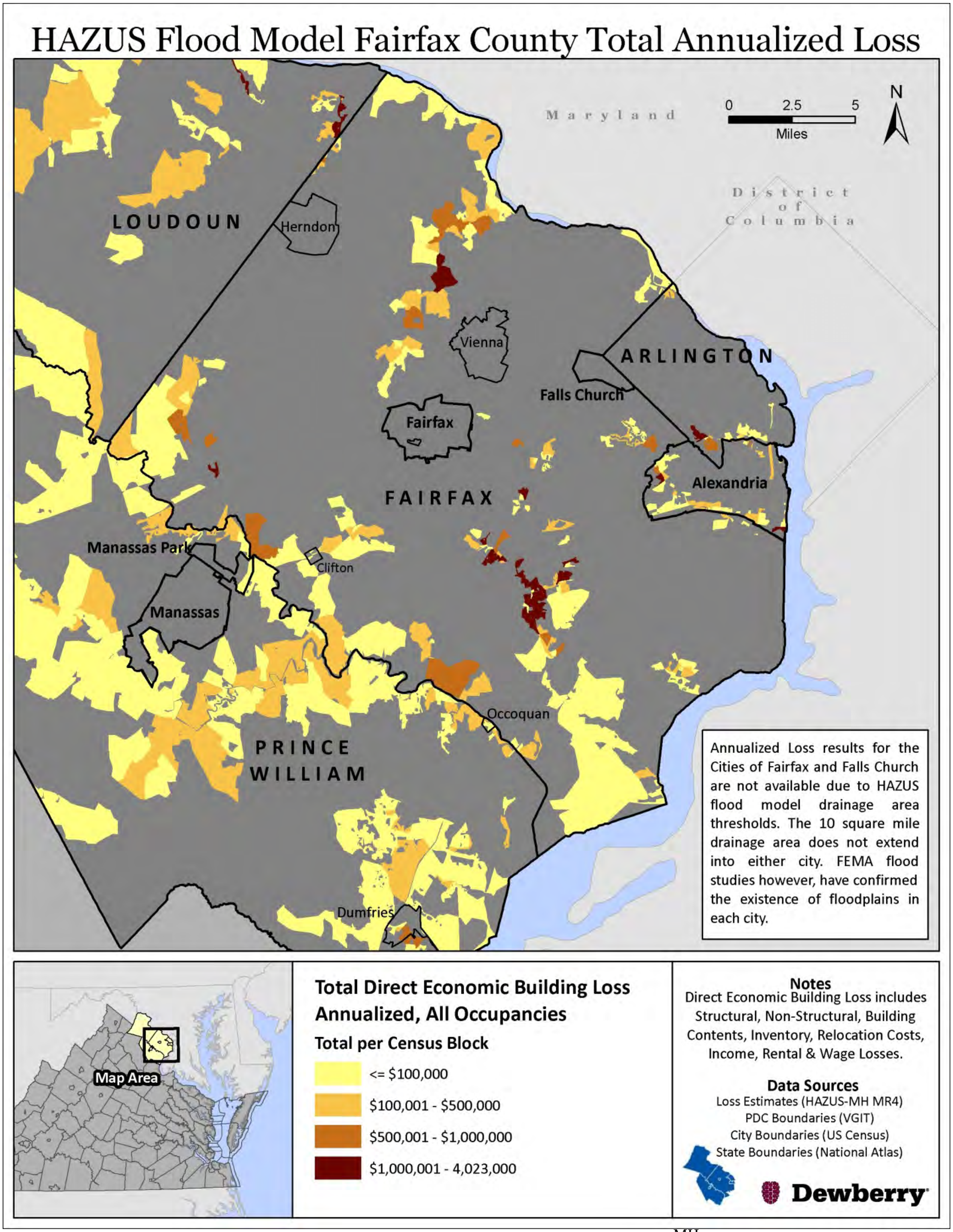

Figure 4.15. Fairfax County Total Annualized Loss based on HAZUS^{MH} Flood Module.

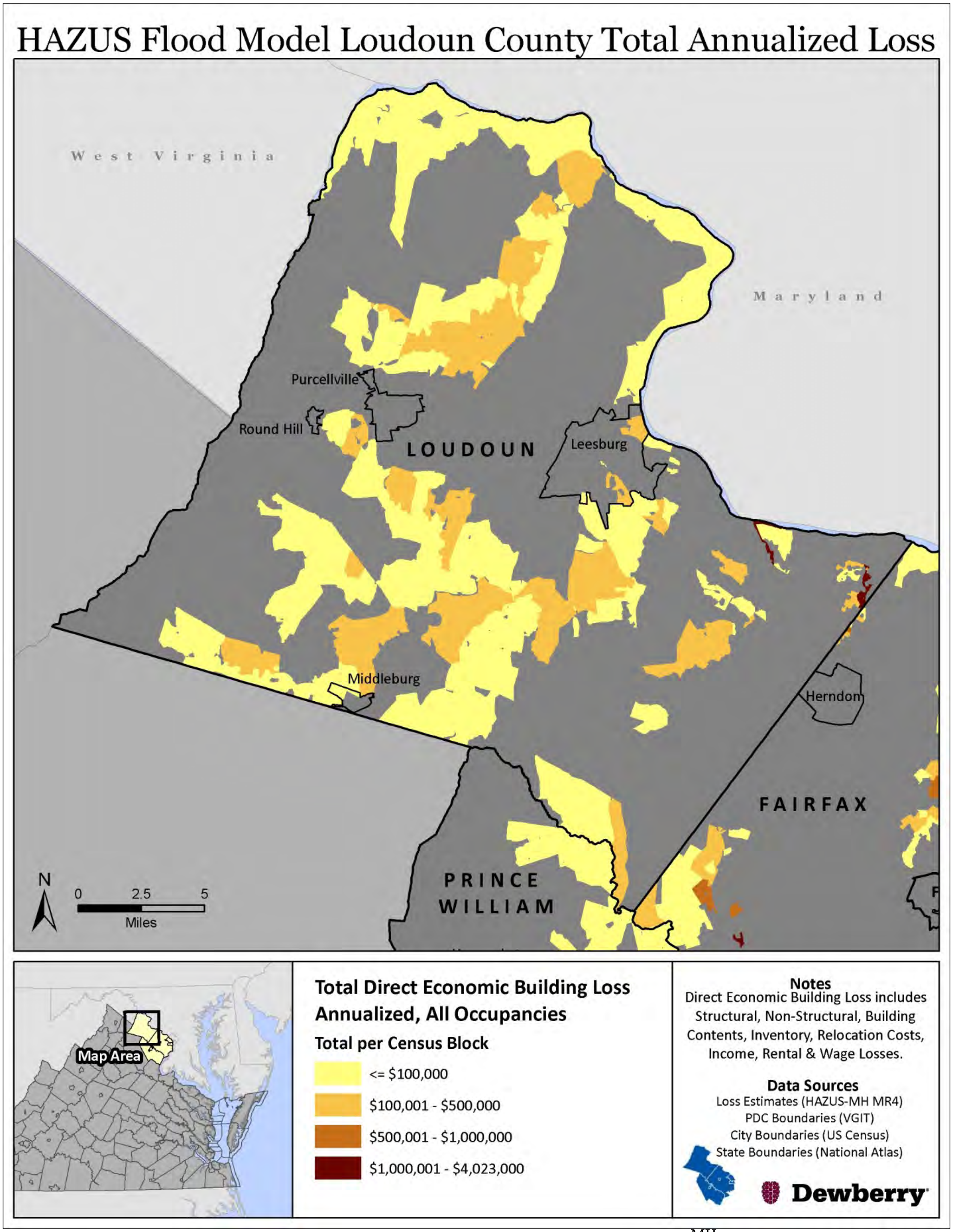

Figure 4.16. Loudoun County Total Annualized Loss based on HAZUS^{MH} MR4 Flood Module.

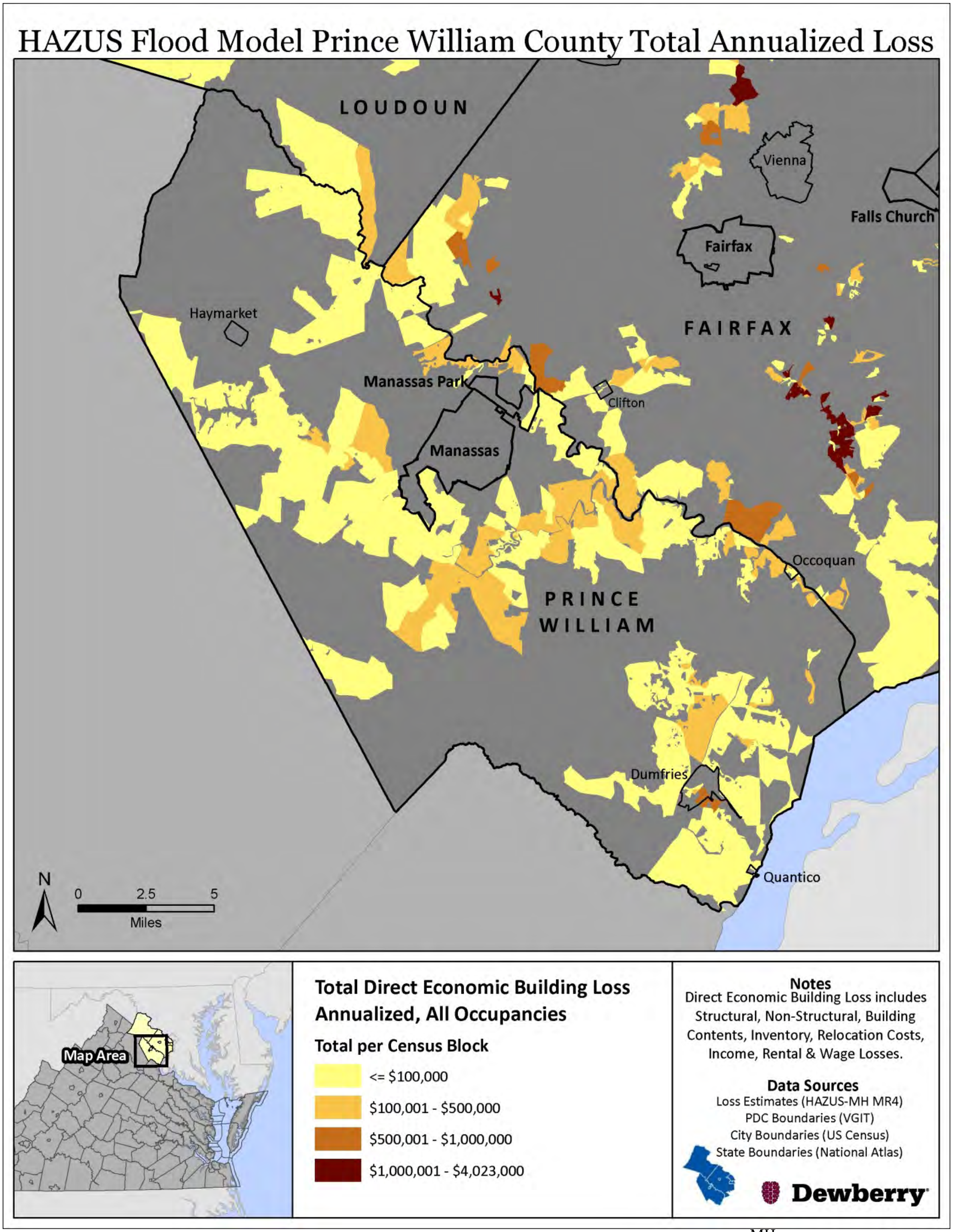

Figure 4.17. Prince William County Total Annualized Loss based on HAZUS^{MH} Flood Module.

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 Loss**
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**
Town of Herndon	*$17,531*	*$27,888*	*$899*	*$46*	*$126*	*$32*	*$966*	*$558*	*$48,046*
Town of Vienna	*$9,199*	*$28,171*	*$73*	*$52*	*$131*	*$18*	*$100*	*$381*	*$38,125*
Town of Clifton	*$673*	*$1,085*	*$20*	*$0*	*$8*	*$0*	*$12*	*$17*	*$1,815*
Loudoun County	$215,815	$190,307	$3,184	$408	$437	$151	$2,546	$2,037	$414,885
Town of Leesburg	*$25,500*	*$33,242*	*$800*	*$66*	*$118*	*$26*	*$468*	*$535*	*$60,755*
Town of Purcellville	*$3,857*	*$5,868*	*$309*	*$5*	*$20*	*$1*	*$93*	*$167*	*$10,320*
Town of Middleburg	*$122*	*$119*	*$2*	*$0*	*$0*	*$0*	*$1*	*$0*	*$244*
Town of Round Hill	*$135*	*$173*	*$4*	*$0*	*$0*	*$0*	*$5*	*$4*	*$321*
Prince William County	$271,914	$237,750	$4,691	$594	$464	$191	$1,667	$2,212	$519,483
Town of Dumfries	*$6,305*	*$7,864*	*$293*	*$24*	*$17*	*$9*	*$105*	*$96*	*$14,713*
Town of Haymarket	*$2*	*$1*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$3*
Town of Occoquan	*$4,003*	*$9,388*	*$319*	*$19*	*$64*	*$15*	*$107*	*$144*	*$14,059*
Town of Quantico	*$228*	*$197*	*$1*	*$0*	*$1*	*$0*	*$1*	*$2*	*$430*
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

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

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

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

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.

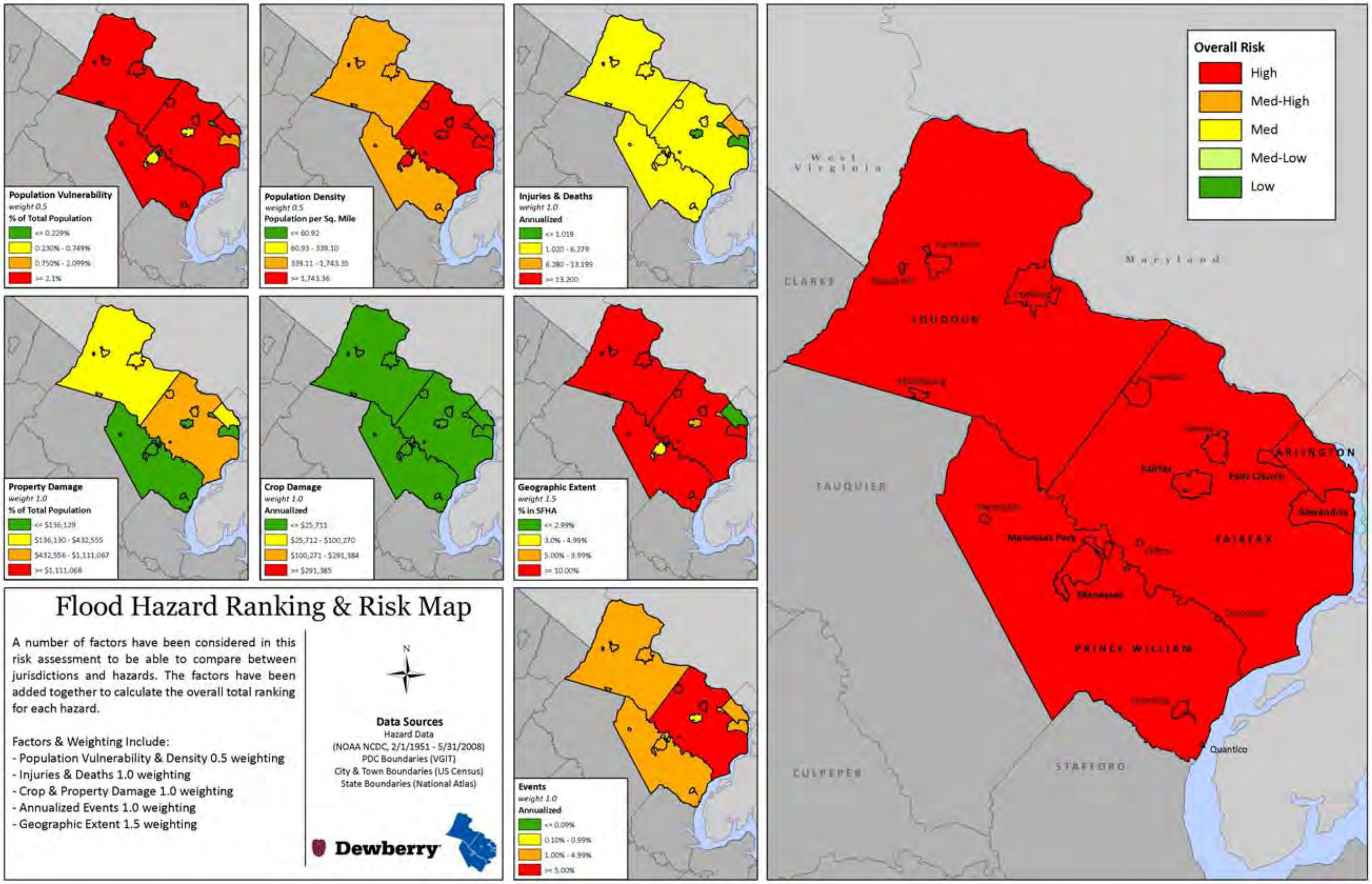

Figure 4.18. Flood Hazard Ranking

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.

February, 2010 winter storm impacts NOVA

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

A freeze is weather marked by low temperatures, especially when below the freezing point (zero degrees Celsius or 32 degrees Fahrenheit). 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.

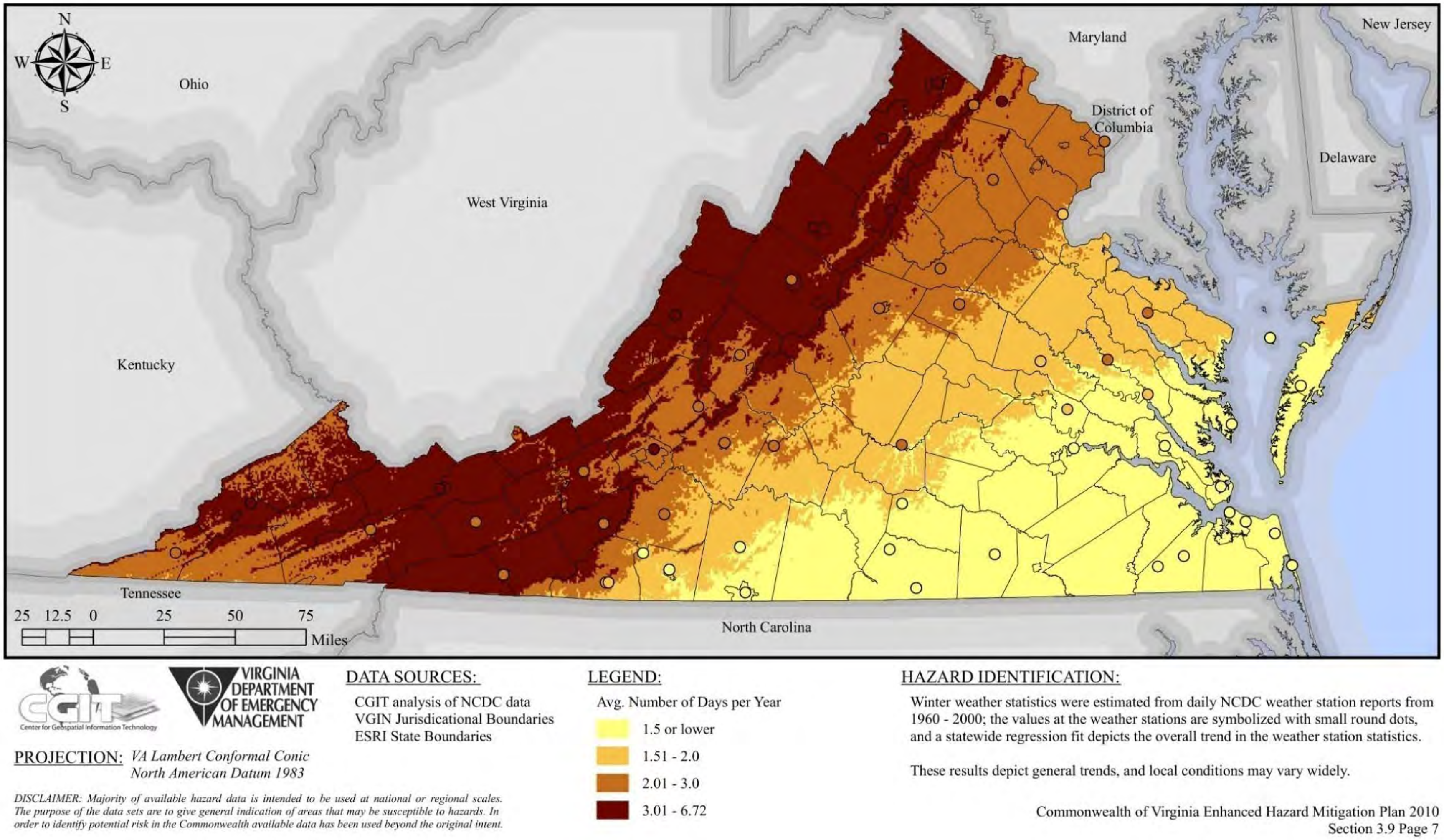

Figure 4.19. Average Numbers of Days with At Least Three Inches of Snow

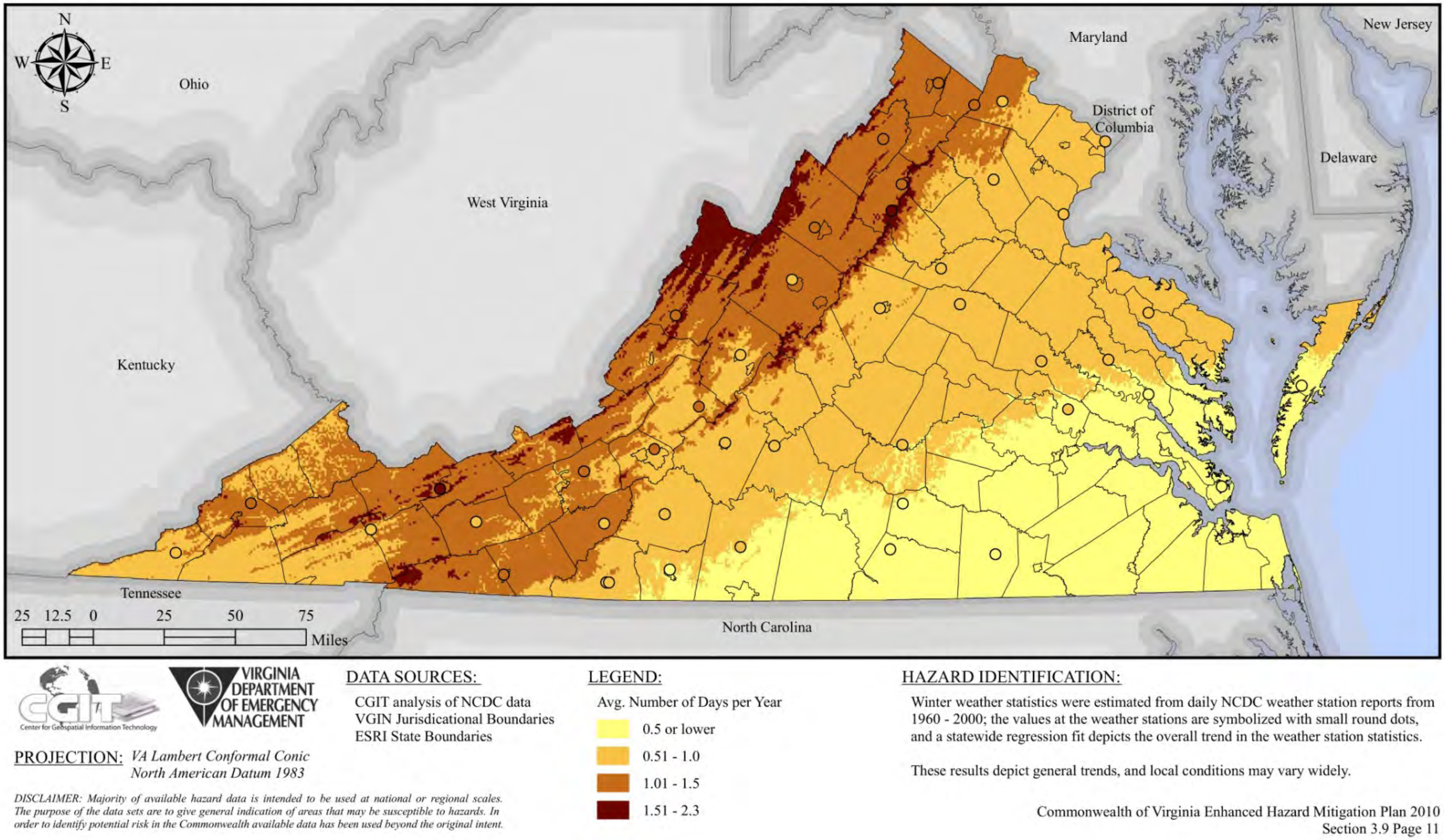

Figure 4.20. Average Numbers of Days with At Least Six Inches of Snow

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.

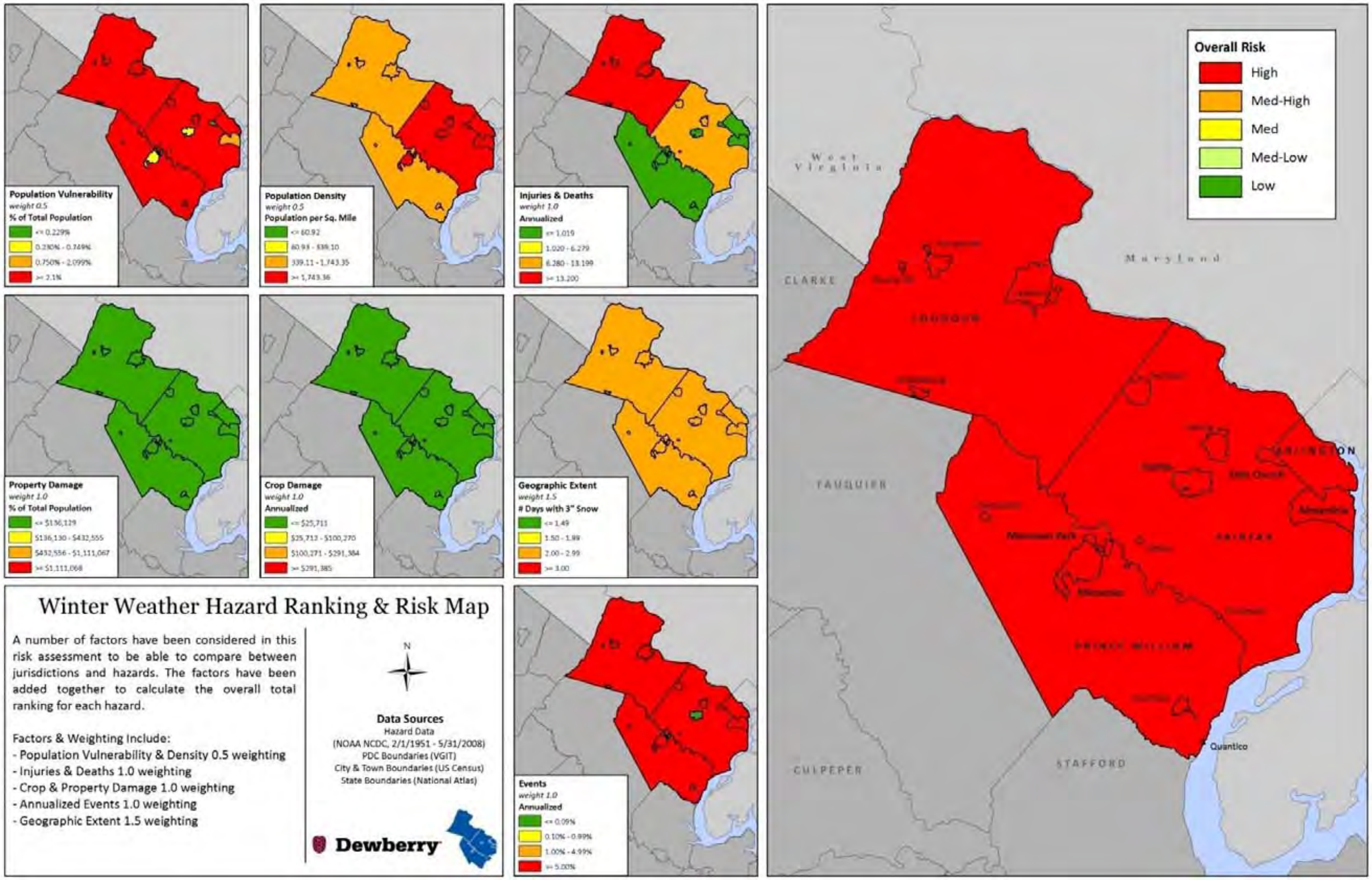

Figure 4.21. Winter Hazard Ranking and Risk

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.

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

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

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.

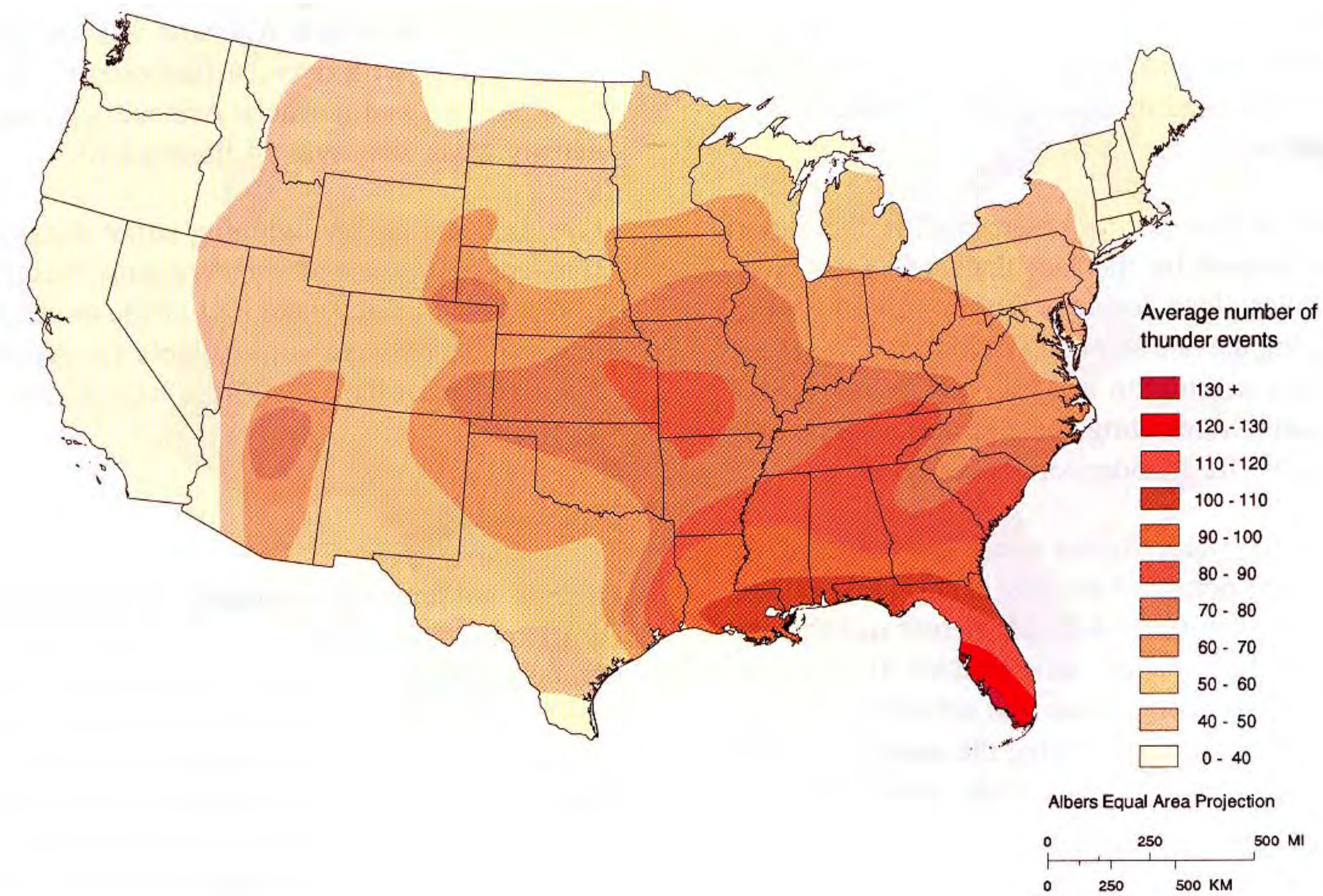

Figure 4.22. Annual Average Number of Thunder Events
Source: Federal Emergency Management Agency

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.

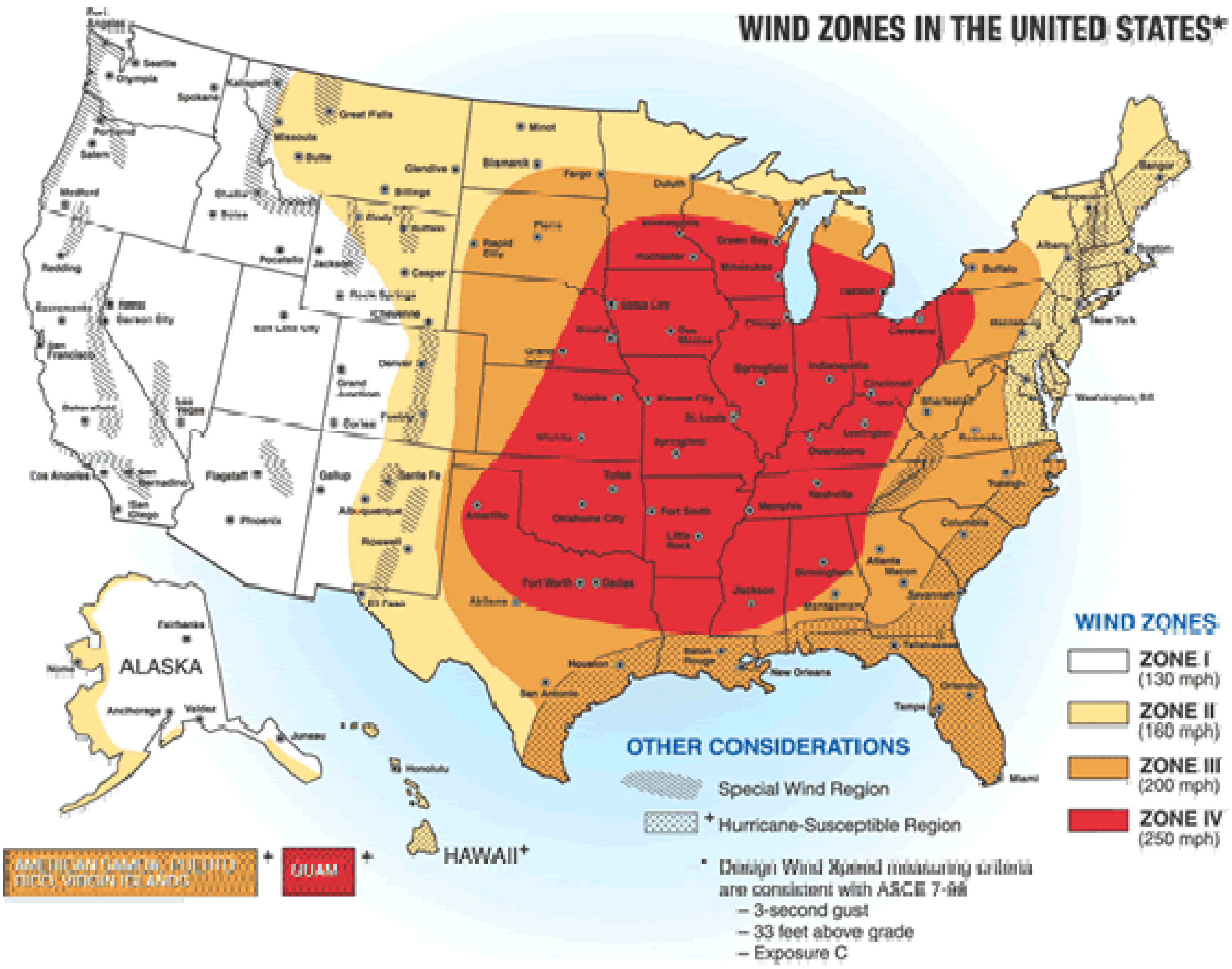

Figure 4.23. Wind Zones in the United States
Source: Federal Emergency Management Agency

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)

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.

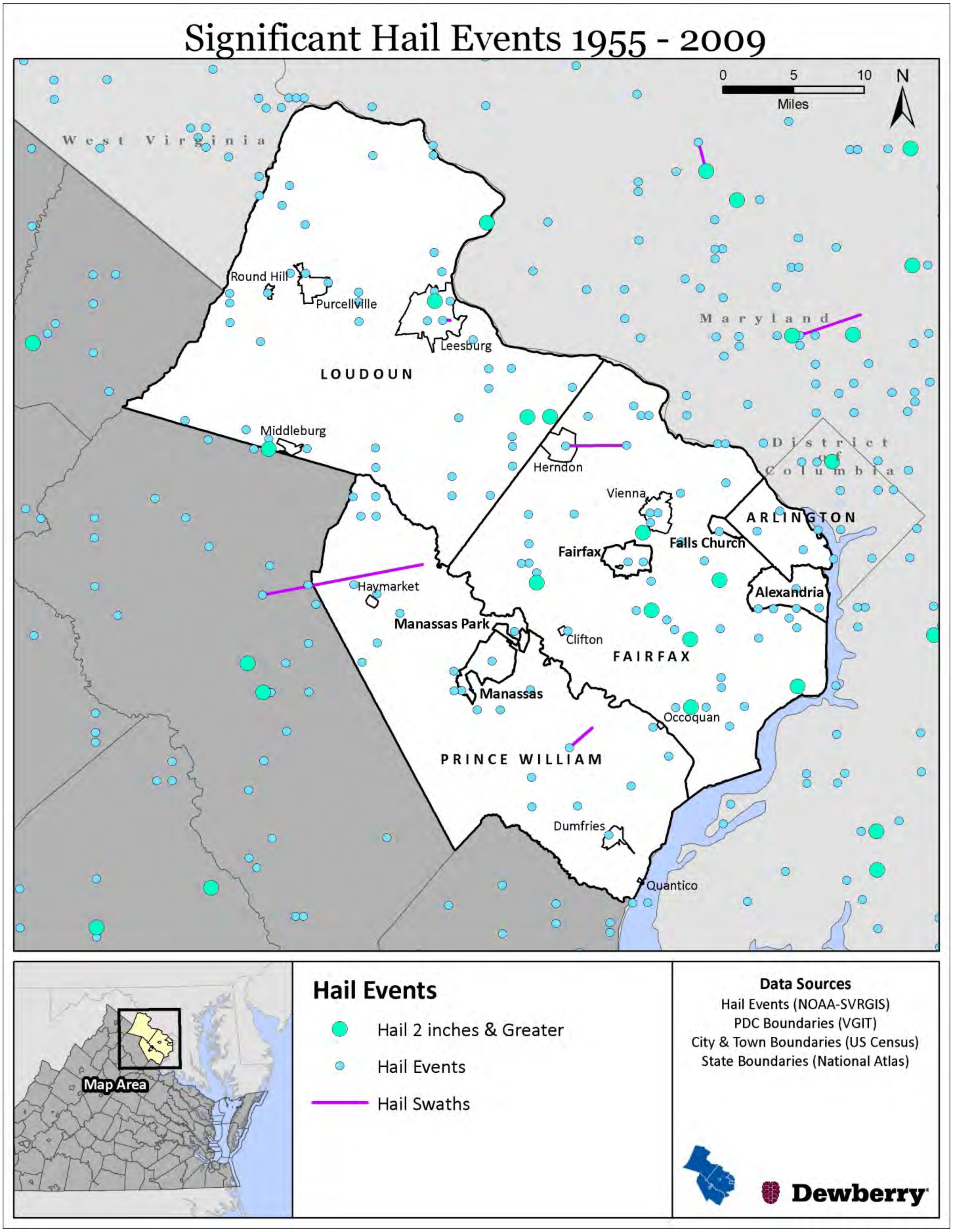

Figure 4.24. Significant Hail Events 1955 – 2009 *Source: NOAA-SVRGIS*

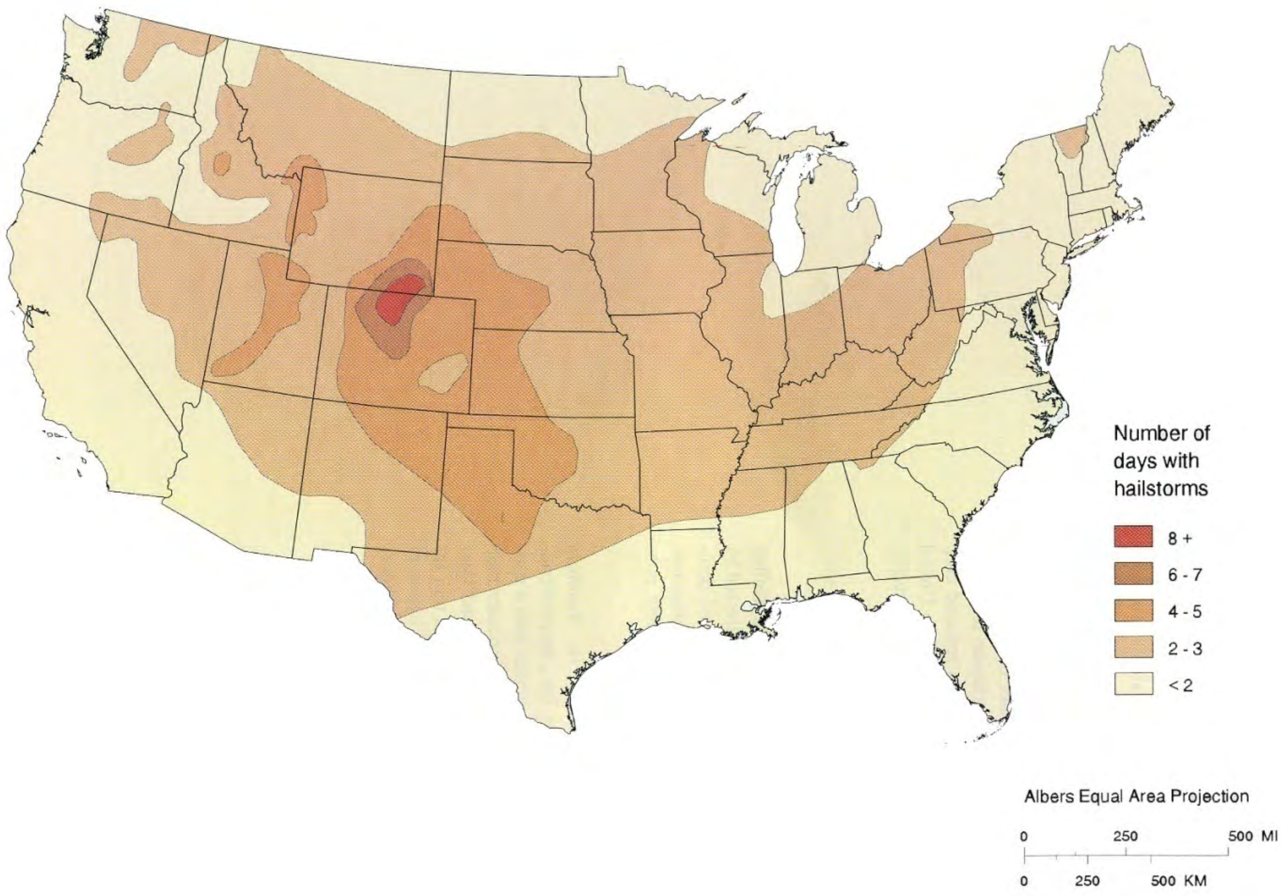

Figure 4.25. Annual Frequency of Hailstorms in the United States
Source: Federal Emergency Management Agency

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 swatch 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.

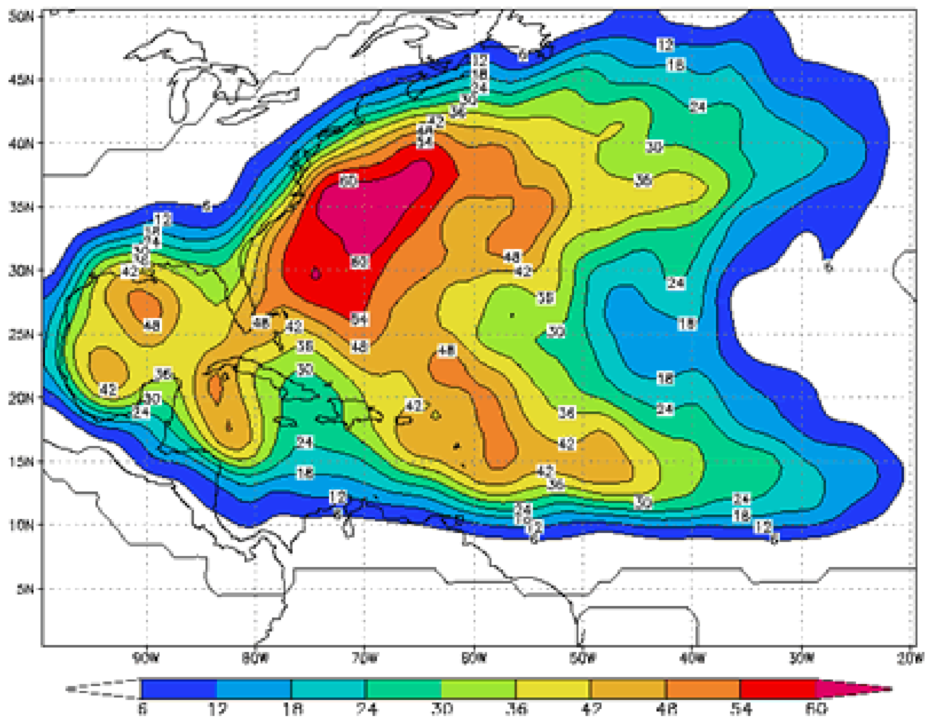

Figure 4.25 Empirical Probability of a Named Storm
Source: National Oceanic and Atmospheric Administration, Hurricane Research Division

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.

Table 4.43 Saffir-Simpson Scale

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

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.

Table 4.44 Hurricane Damage Classification		
Category	**Damage Level**	**Description**
1	MINIMAL	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal flooding and minor pier damage.
2	MODERATE	Some roofing material, door, and window damage. Considerable damage to vegetation, mobile homes, etc. Flooding damages piers and small craft in unprotected moorings may break their moorings.
3	EXTENSIVE	Some structural damage to small residences and utility buildings, with a minor amount of curtain wall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.
4	EXTREME	More extensive curtain wall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland.
5	CATASTROPHIC	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required.

Source: National Hurricane Center

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

Storm surge heights, and associated waves, are dependent upon the shape of the continental shelf (narrow or wide) and the depth of the ocean bottom (bathymetry). A narrow shelf, or one that drops steeply from the shoreline and subsequently produces deep water close to the shoreline, tends to produce a lower surge but higher and more powerful storm waves. 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

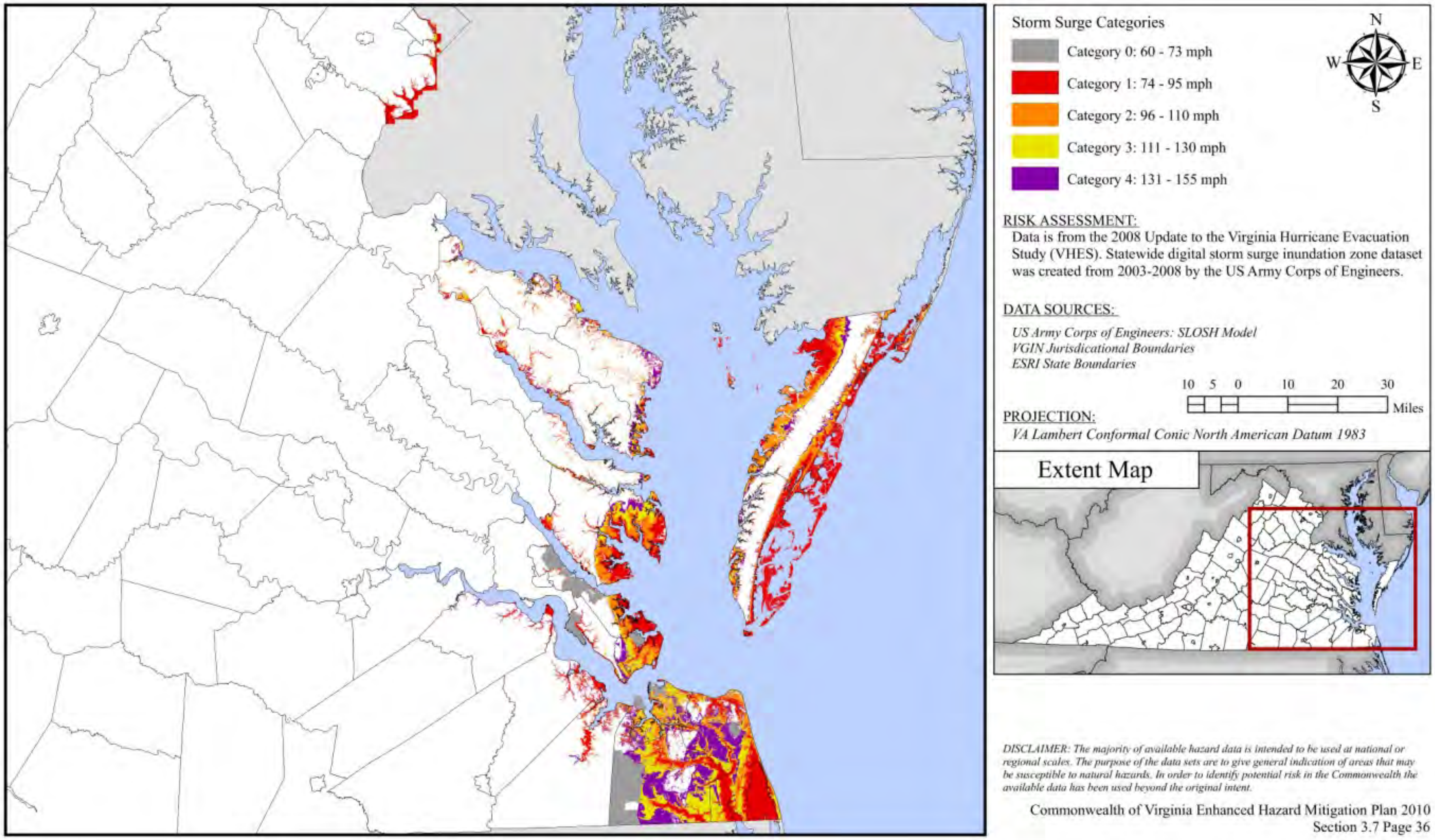

Figure 4.26. Storm Surge Categories for Virginia. *Source: Commonwealth of Virginia 2010 Hazard Mitigation Plan*

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

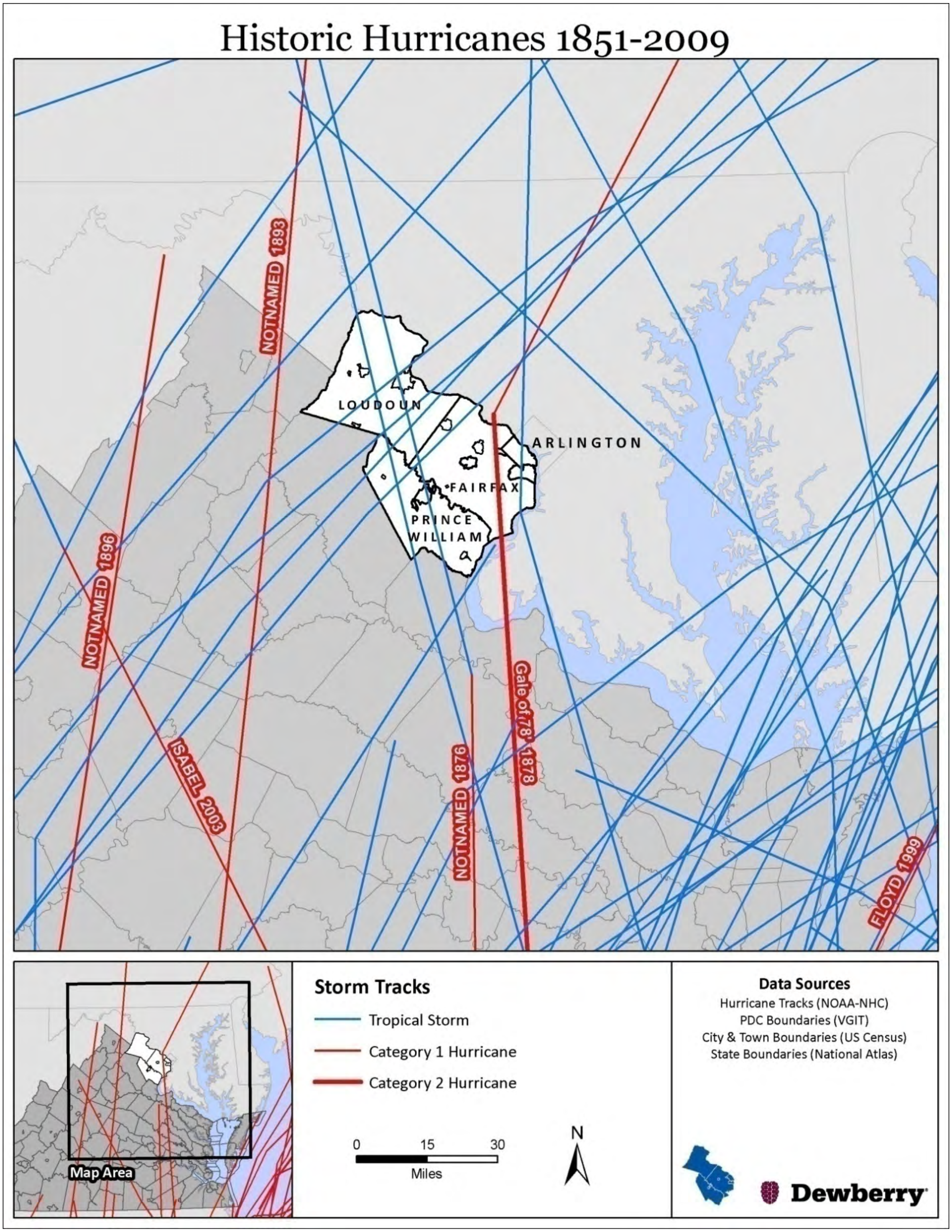

Figure 4.27. Historic Hurricane Tracks, 1851-2009

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 scenario[17], and operational hurricane forecast models, one study[18] 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 Model[19].

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 track. Buildings that must be designed for a 100-year mean recurrence interval wind event include[20]:

- 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.

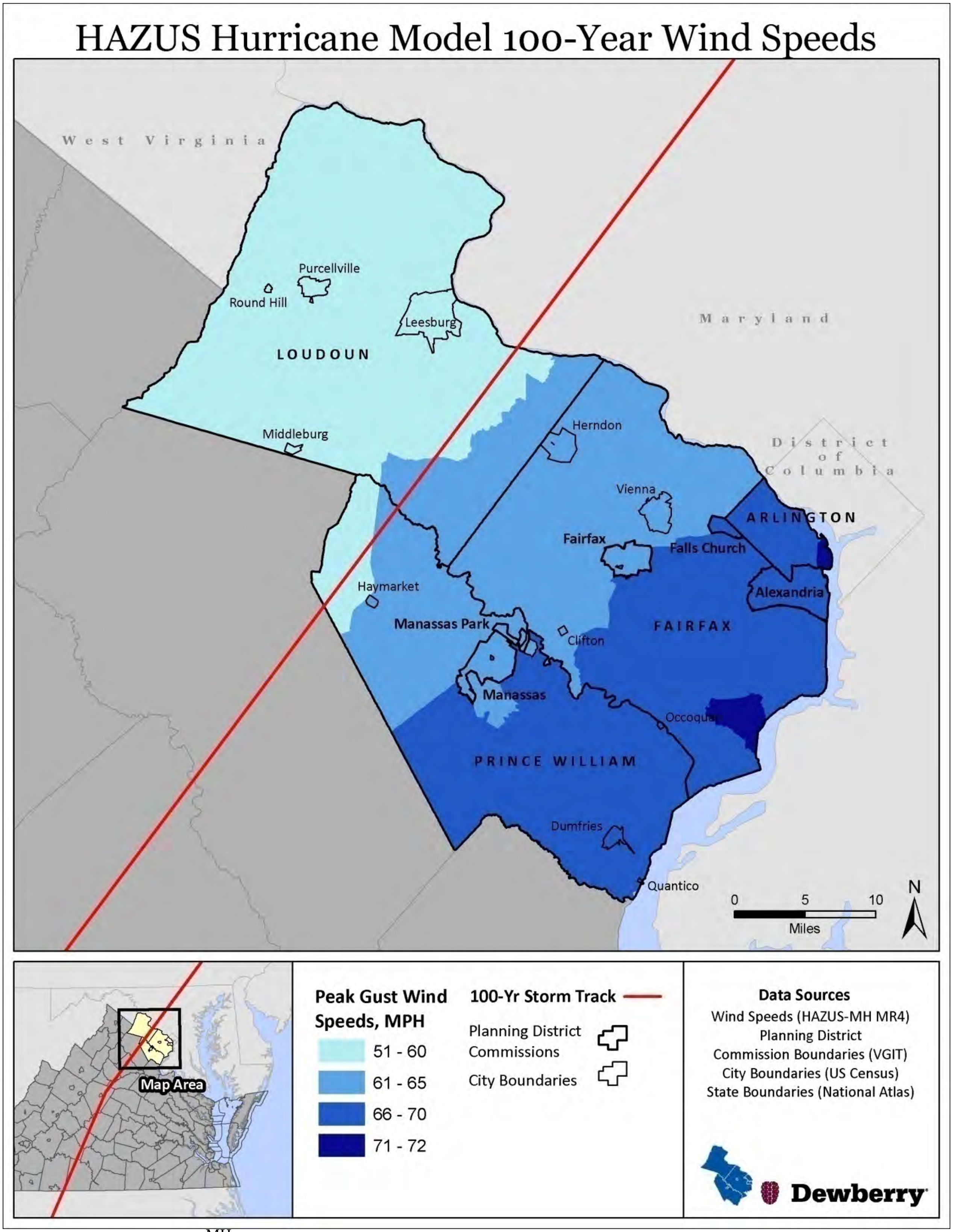

Figure 4.28. HAZUS^{MH} Peak Wind Gusts for 100-Year Event

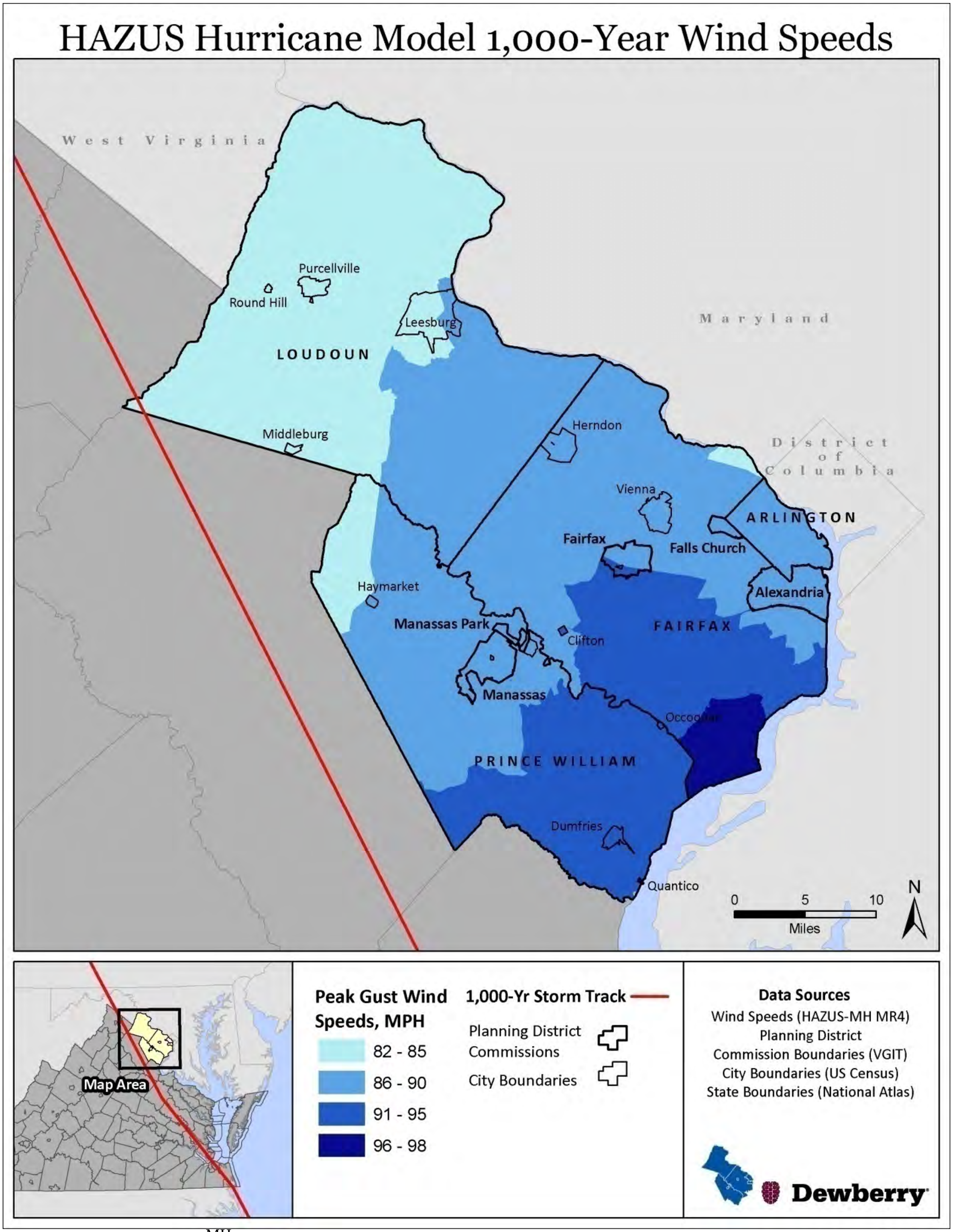

Figure 4.29. HAZUS[MH] Peak Wind Gusts for 1,000-Year Event

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**
Town of Herndon	*$36,459*	*$4,273*	*$63*	*$2,429*	*$456*	*$1,099*	*$559*	***$45,338***
Town of Vienna	*$36,154*	*$3,979*	*$43*	*$2,263*	*$403*	*$791*	*$460*	***$44,093***
Town of Clifton	*$504*	*$36*	*$0*	*$22*	*$3*	*$7*	*$12*	***$584***
Loudoun County	$242,275	$20,143	$435	$12,197	$1,113	$4,444	$1,341	**$281,948**
Town of Leesburg	*$23,601*	*$1,807*	*$20*	*$1,312*	*$160*	*$612*	*$233*	***$27,745***
Town of Purcellville	*$730*	*$41*	*$1*	*$29*	*$3*	*$10*	*$4*	***$818***
Town of Middleburg	*$89*	*$5*	*$0*	*$4*	*$1*	*$2*	*$1*	***$101***
Town of Round Hill	*$44*	*$2*	*$0*	*$2*	*$0*	*$1*	*$0*	***$48***
Prince William County	$423,454	$34,613	$427	$24,402	$1,736	$9,219	$2,155	**$496,004**
Town of Dumfries	*$4,441*	*$451*	*$4*	*$392*	*$23*	*$191*	*$41*	***$5,542***
Town of Haymarket	*$123*	*$9*	*$0*	*$6*	*$1*	*$2*	*$1*	***$143***
Town of Occoquan	*$898*	*$84*	*$1*	*$57*	*$6*	*$29*	*$6*	***$1,080***
Town of Quantico	*$2,050*	*$370*	*$4*	*$211*	*$38*	*$151*	*$40*	***$2,864***
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**
Town of Herndon	$432,523	$158	$0	$207	$0	$0	$0	**$432,887**
Town of Vienna	$484,137	$32	$0	$55	$0	$0	$0	**$484,224**
Town of Clifton	$8,426	$0	$0	$0	$0	$0	$0	**$8,426**
Loudoun County	$1,421,694	$0	$0	$160	$0	$0	$0	**$1,421,854**
Town of Leesburg	$55,072	$0	$0	$12	$0	$0	$0	**$55,085**
Town of Purcellville	$0	$0	$0	$1	$0	$0	$0	**$1**
Town of Middleburg	$0	$0	$0	$0	$0	$0	$0	**$0**
Town of Round Hill	$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**
Town of Dumfries	$84,031	$689	$0	$426	$0	$500	$0	**$85,646**
Town of Haymarket	$1,098	$0	$0	$0	$0	$0	$0	**$1,098**
Town of Occoquan	$14,920	$25	$0	$35	$0	$0	$0	**$14,979**
Town of Quantico	$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**
Town of Herndon	$7,008,016	$274,363	$6,329	$325,809	$81,258	$197,720	$29,447	**$7,922,942**
Town of Vienna	$6,378,136	$181,891	$3,991	$231,024	$43,781	$90,759	$15,862	**$6,945,443**
Town of Clifton	$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**
Town of Leesburg	$4,697,446	$84,571	$935	$203,548	$0	$98,611	$0	**$5,085,111**
Town of Purcellville	$146,228	$751	$106	$6,221	$0	$2,136	$0	**$155,442**
Town of Middleburg	$17,454	$104	$7	$816	$0	$300	$0	**$18,680**
Town of Round Hill	$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**
Town of Dumfries	$1,123,665	$83,270	$973	$90,495	$12,703	$55,469	$23,484	**$1,390,060**
Town of Haymarket	$25,741	$229	$22	$1,041	$0	$414	$0	**$27,447**
Town of Occoquan	$232,421	$13,512	$116	$12,782	$1,510	$8,478	$939	**$269,757**
Town of Quantico	$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**

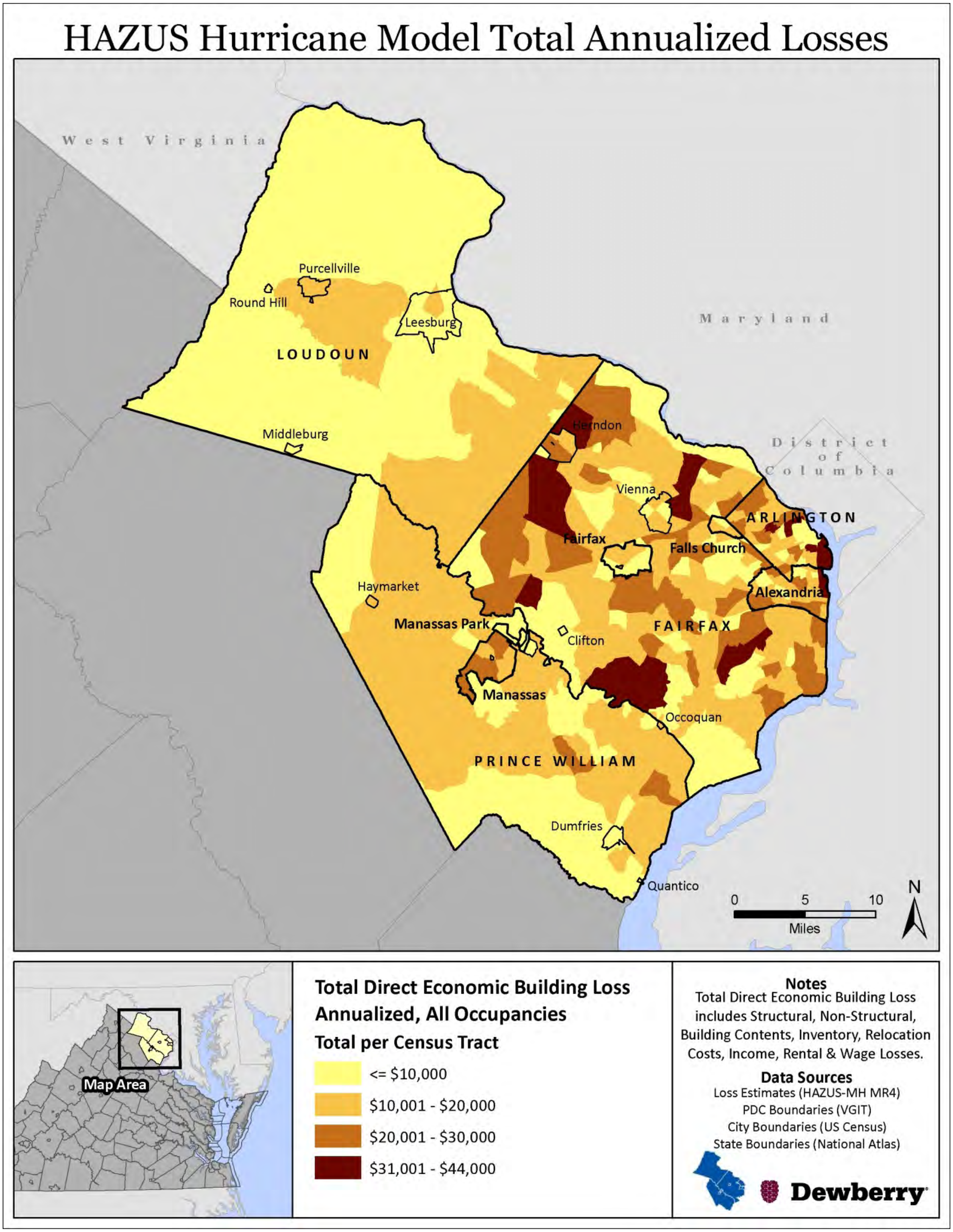

Figure 4.30. Total Annualized Total Direct Economic Building Losses

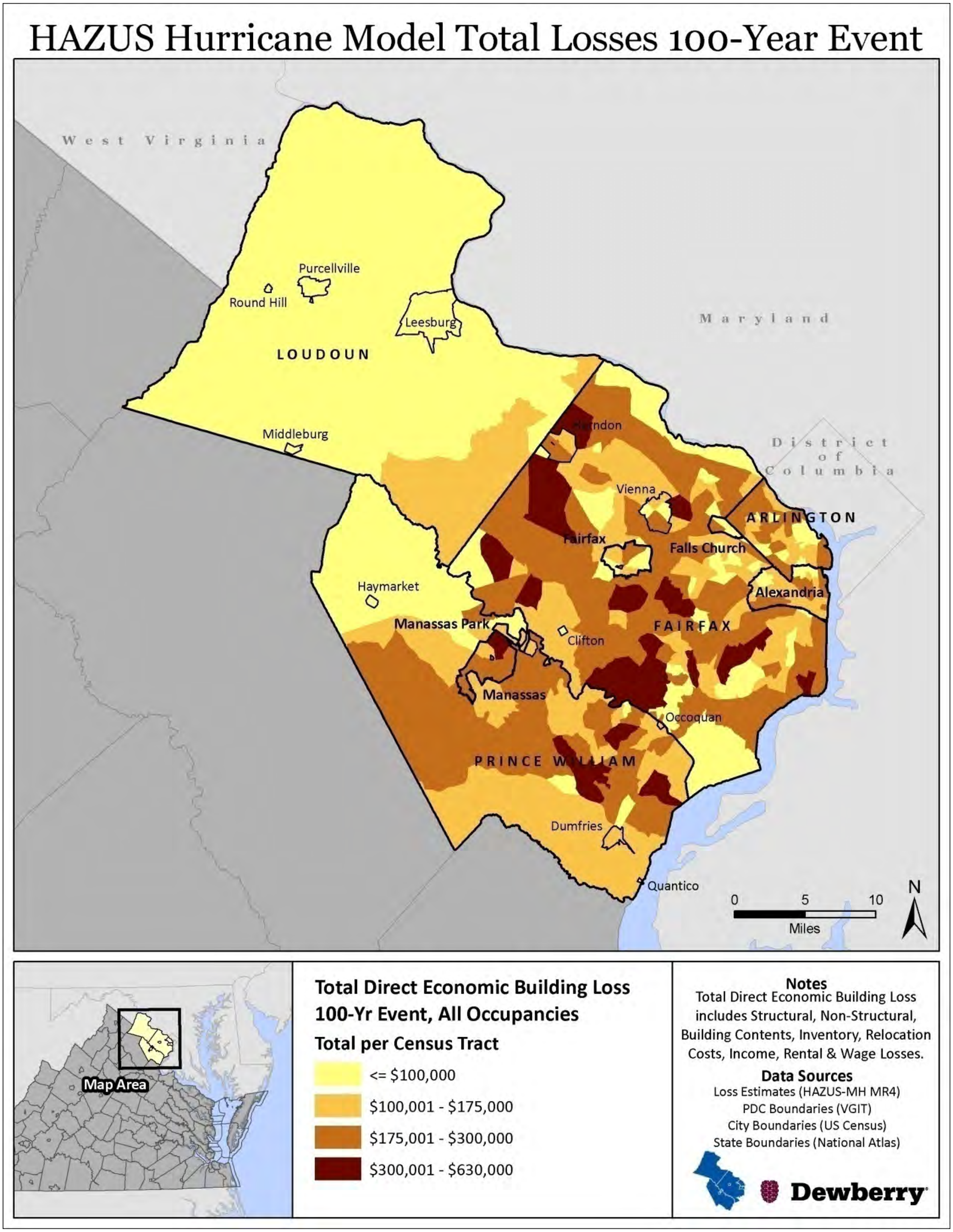

Figure 4.31. 100-Year Hurricane Model Total Direct Economic Building Loss

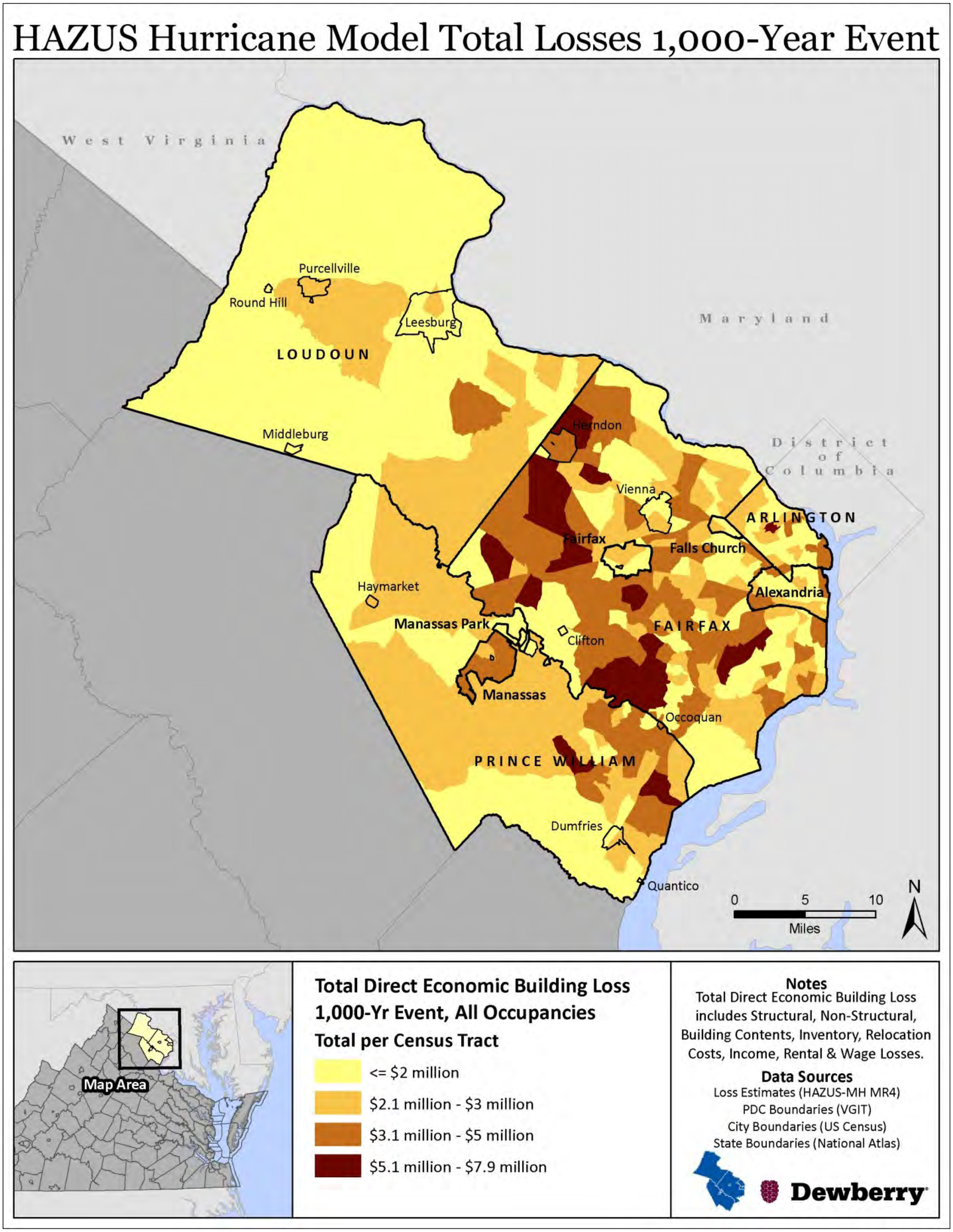

Figure 4.32. 1,000-Year Hurricane Model Total Direct Economic Building Loss

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	
Number of Events	856
Years of Record: 1955 - 2009	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.

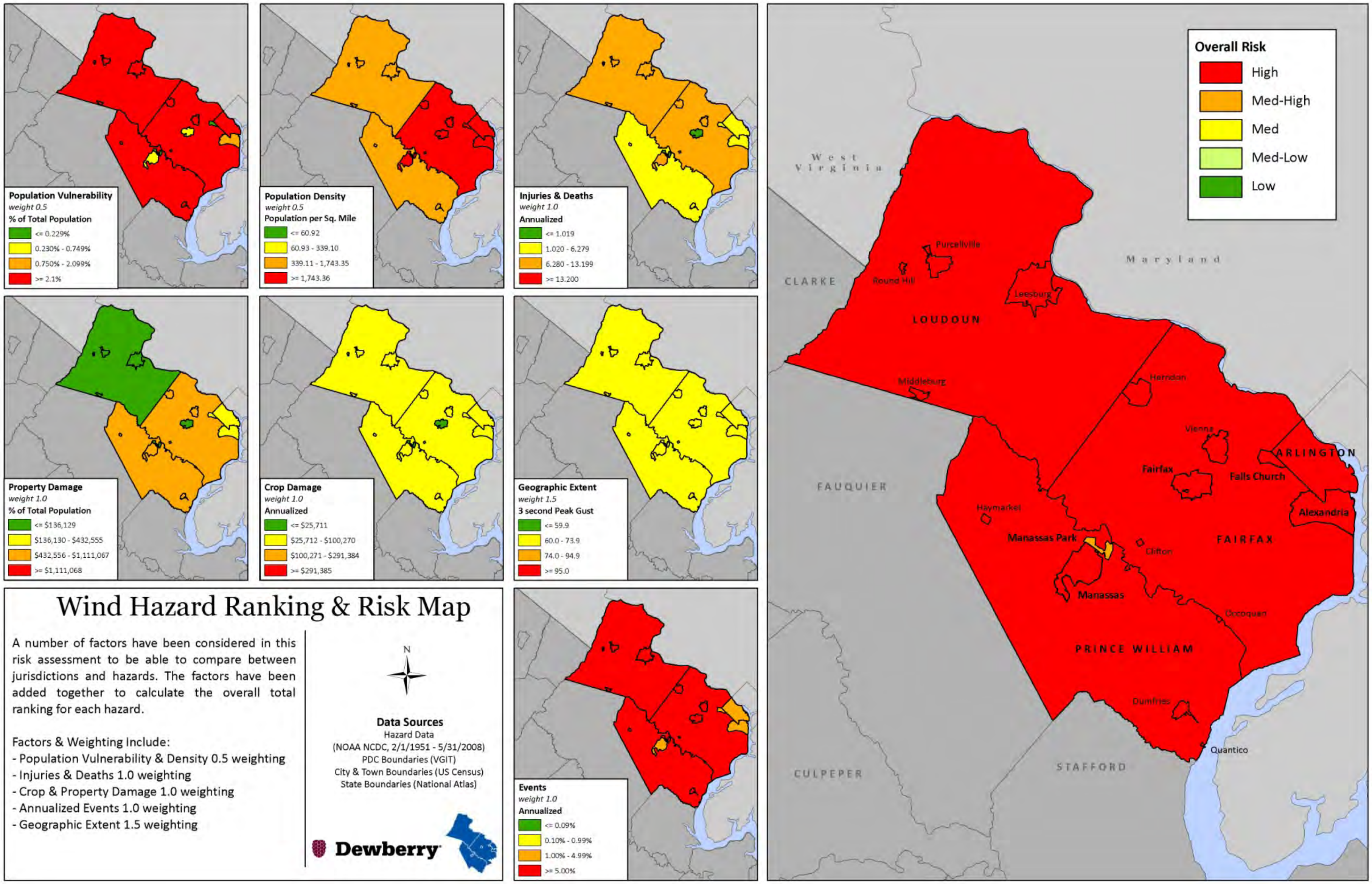

Figure 4.33. High Wind ranking and risk.

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.

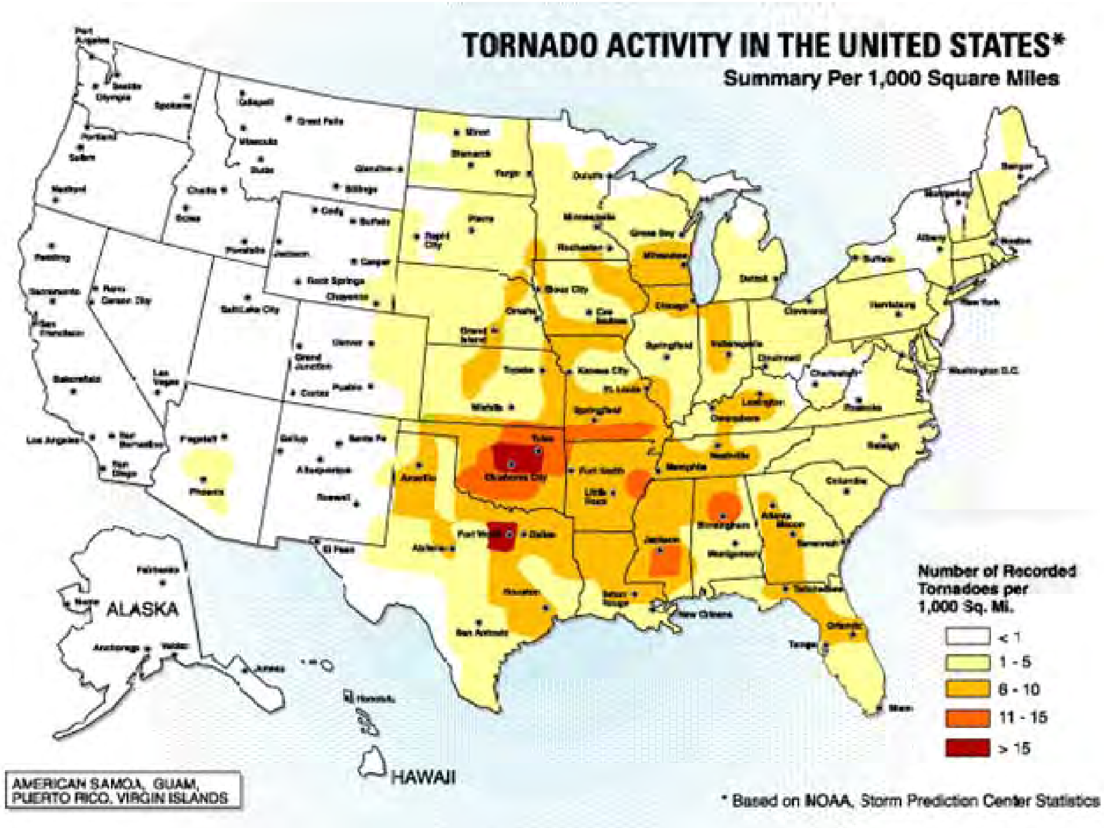

Figure 4.34. Tornado Activity in the United States
Source: American Society of Civil Engineers

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.

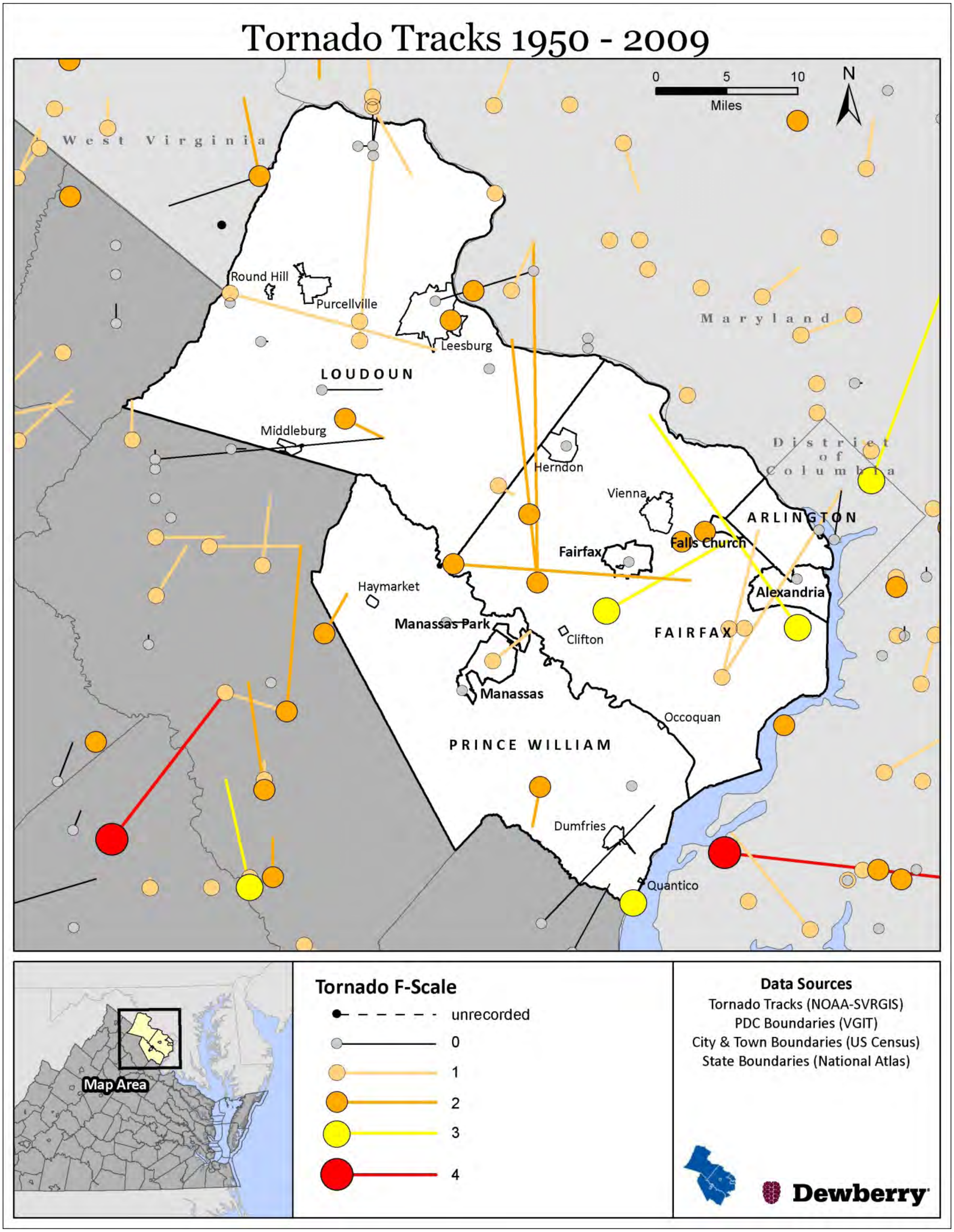

Figure 4.35. Historic Tornado Tracks 1950 to 2009

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					
Years of Record: 1951 - 2009	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.

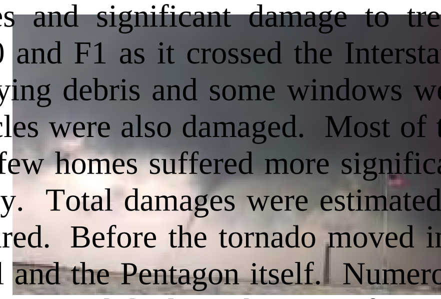

Photo of the September 24, 2001 tornado as it entered Washington DC. The Washington Monument can be seen to the left of the U.S. Flag pole. (Photo courtesy of Michael Shore)

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 80,000homes 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 tate. 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 events[21], including severe thunderstorms. At this time, it remains uncertain if this might also translate into an increased frequency of tornadoes.

2. Impact & Vulnerability

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

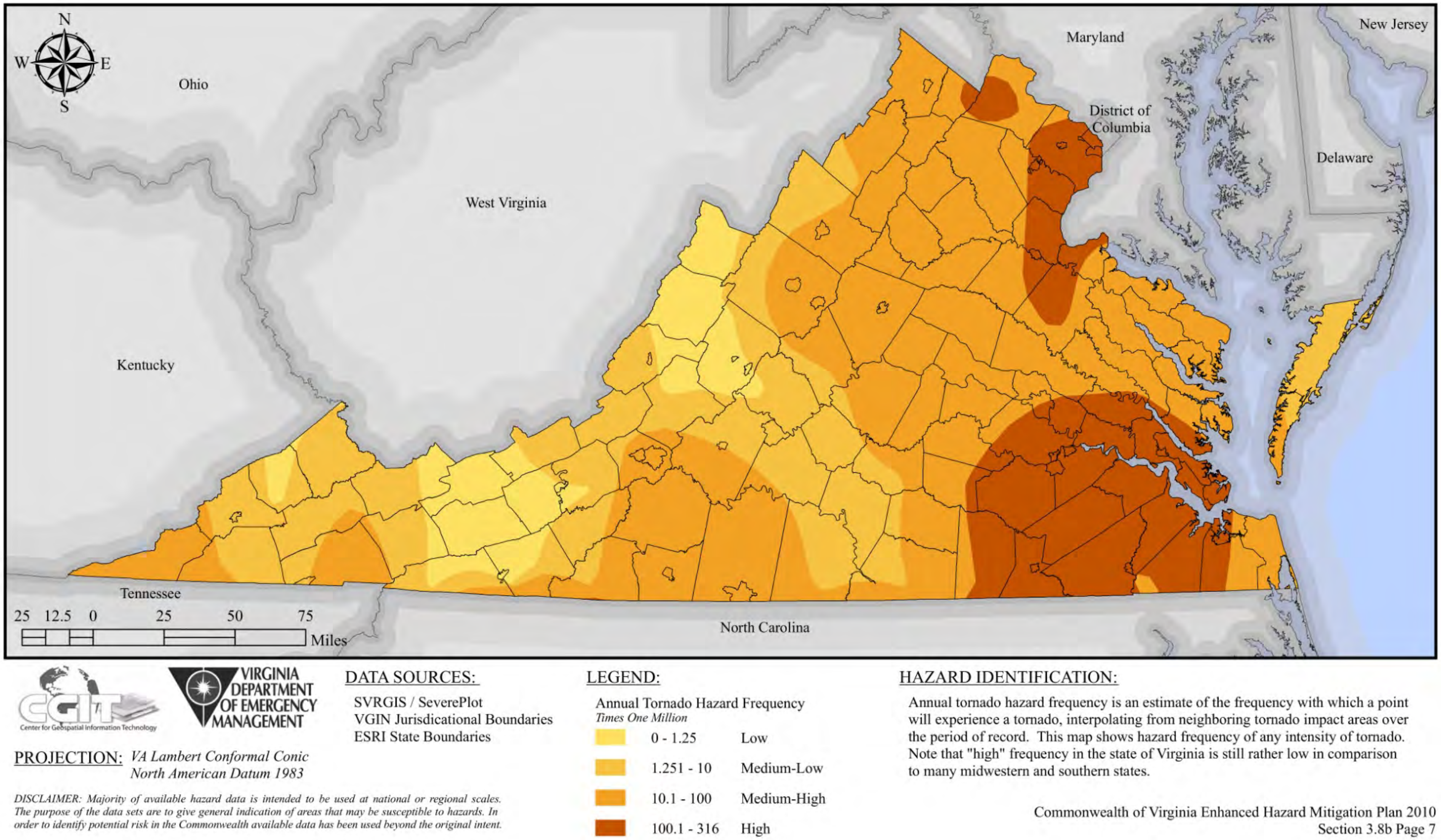

Figure 4.36. Tornado Hazard Frequency. *Source: Commonwealth of Virginia Hazard Mitigation Plan.*

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.

Table 4.58 2006 Qualitative Assessment for Tornadoes

	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.

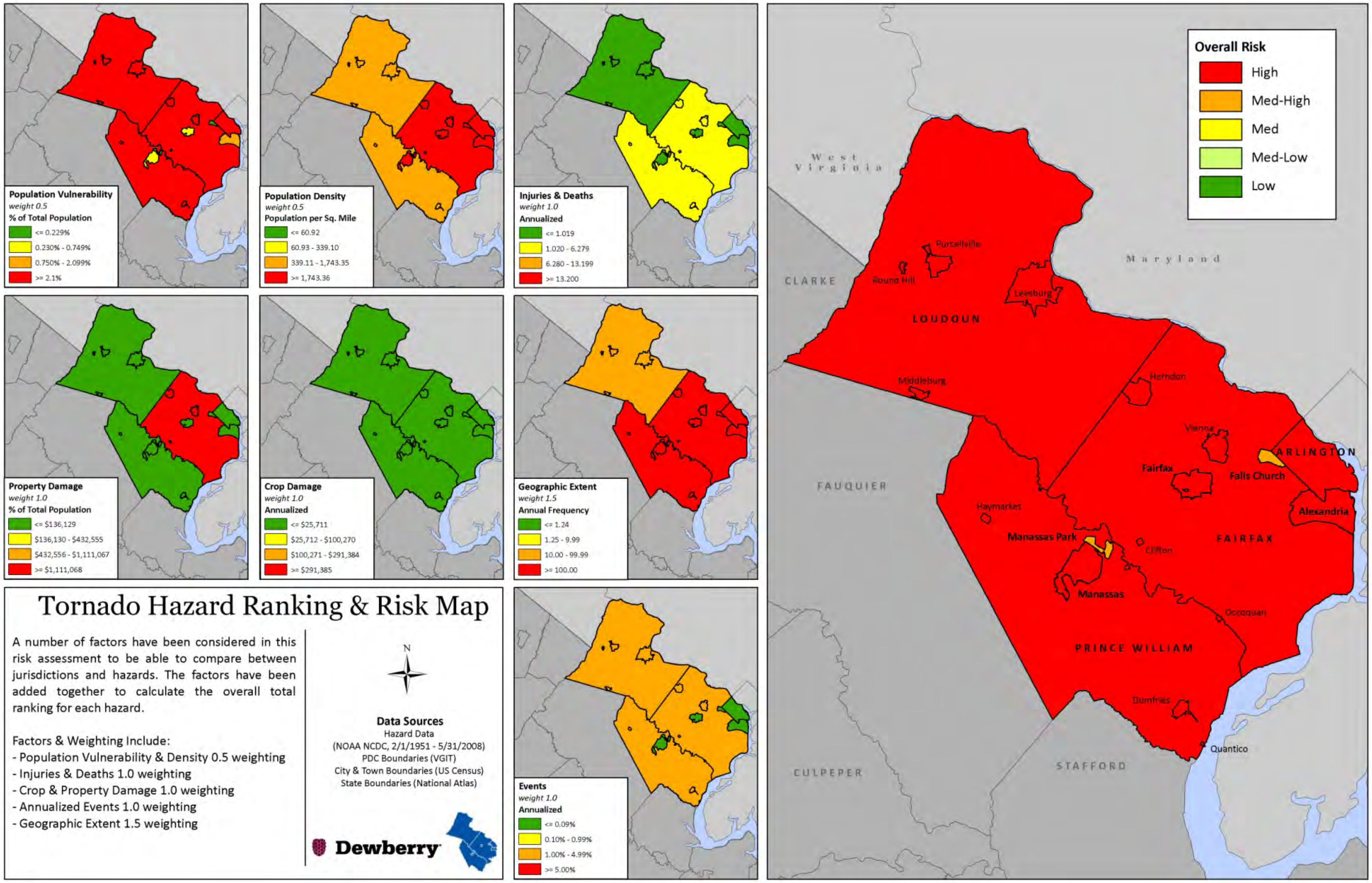

Figure 4.37. Tornado Hazard Ranking

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.

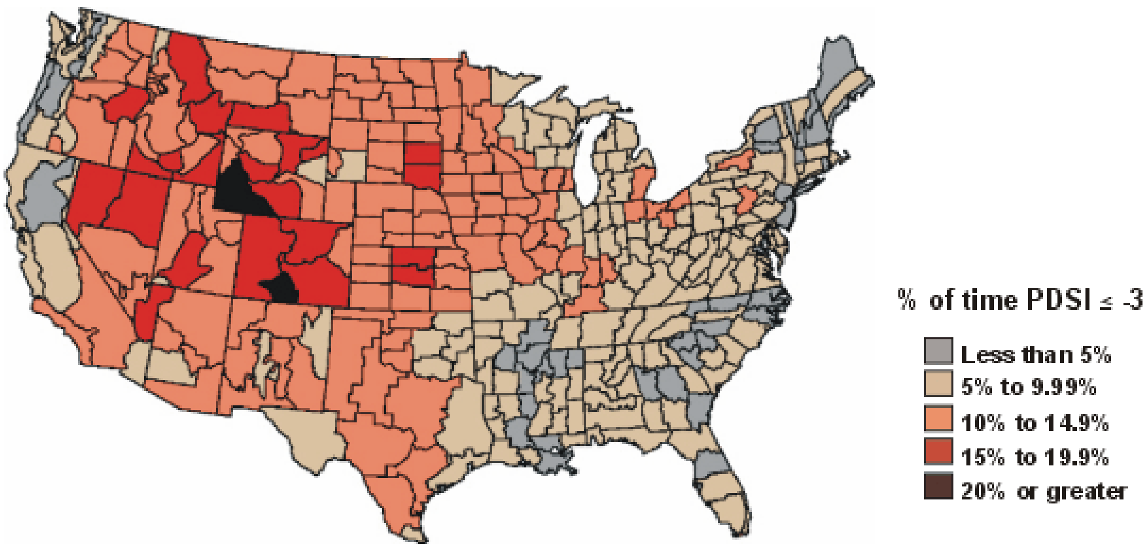

Figure 4.38. Palmer Drought Severity Index, 1895-1995 Percent of Time in Severe and Extreme Drought. *Source: National Drought Mitigation Center*

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**
Years of Record: 1993-2009	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 previous12 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.

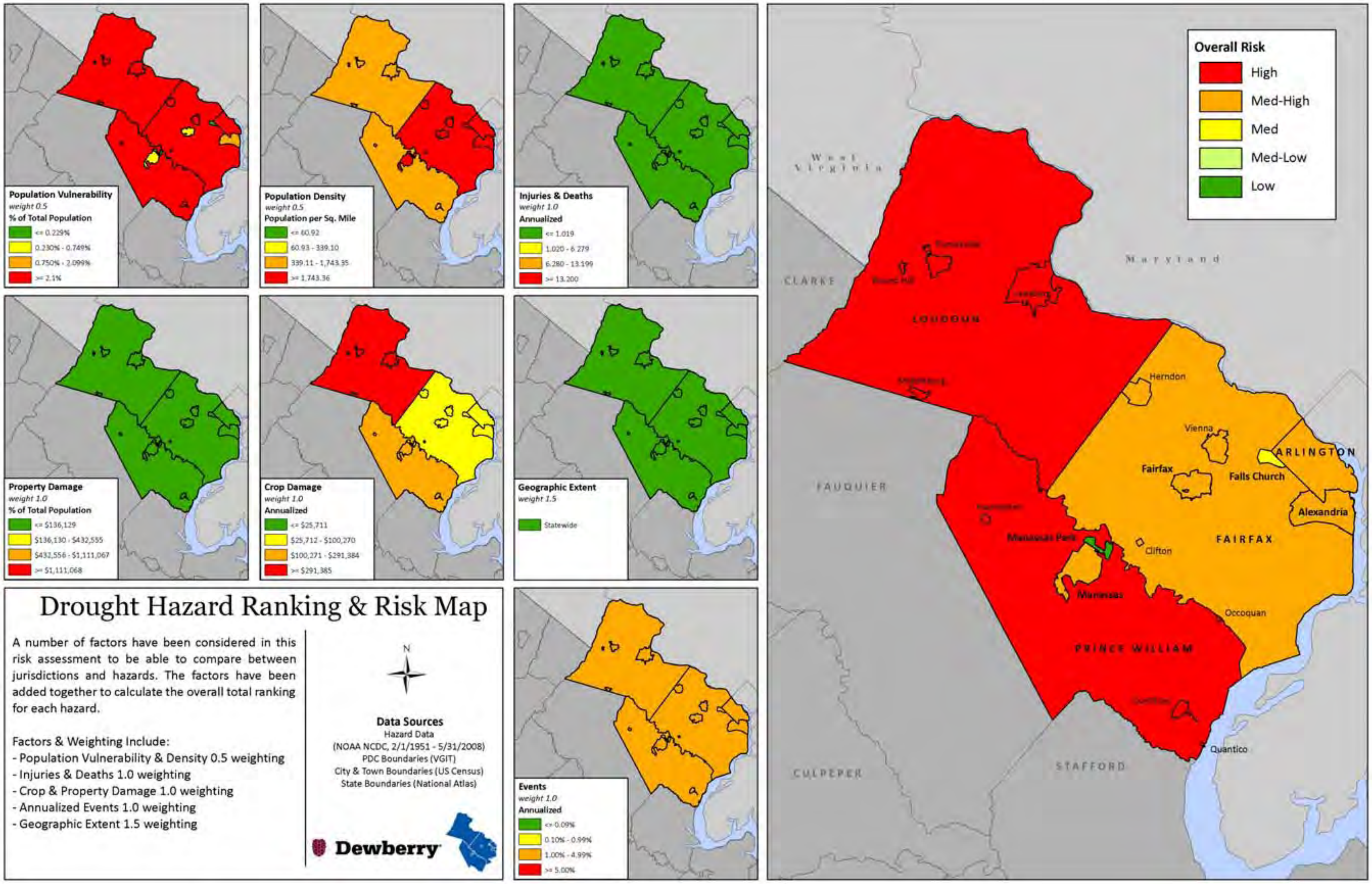

Figure 4.39. Drought hazard ranking and risk.

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.

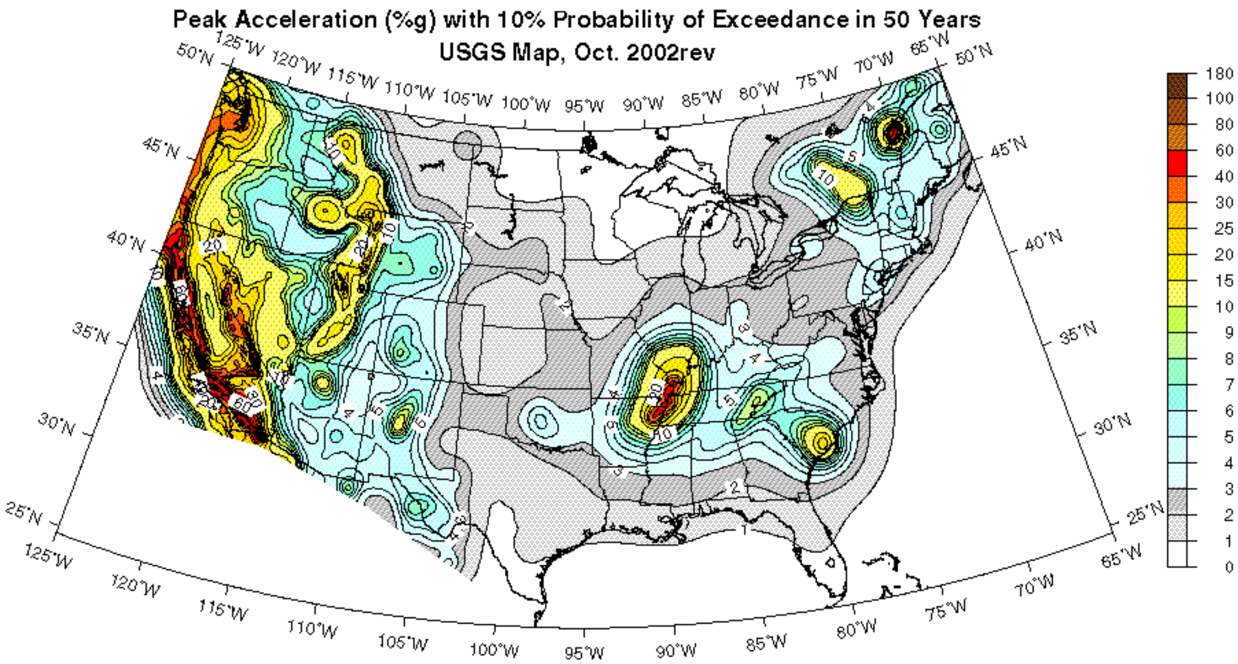

Figure 4.40. Peak Acceleration with 10 Percent Probability of Exceedance in 50 Years
Source: USGS

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 4.41[22] 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 Delaware[23]. No injuries or property damages were reported. The earthquake occurred in a part of the Eastern Seaboard that is less seismically active than central Virginia, New England, and the area surrounding New York City. Since 1980, 14 earthquakes have been felt within 80 km (about 50 miles) of the July 16th earthquake. All were smaller than this event. Other earthquakes have been reported in that area as far back as at least 1758[24].

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 area[25].

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.

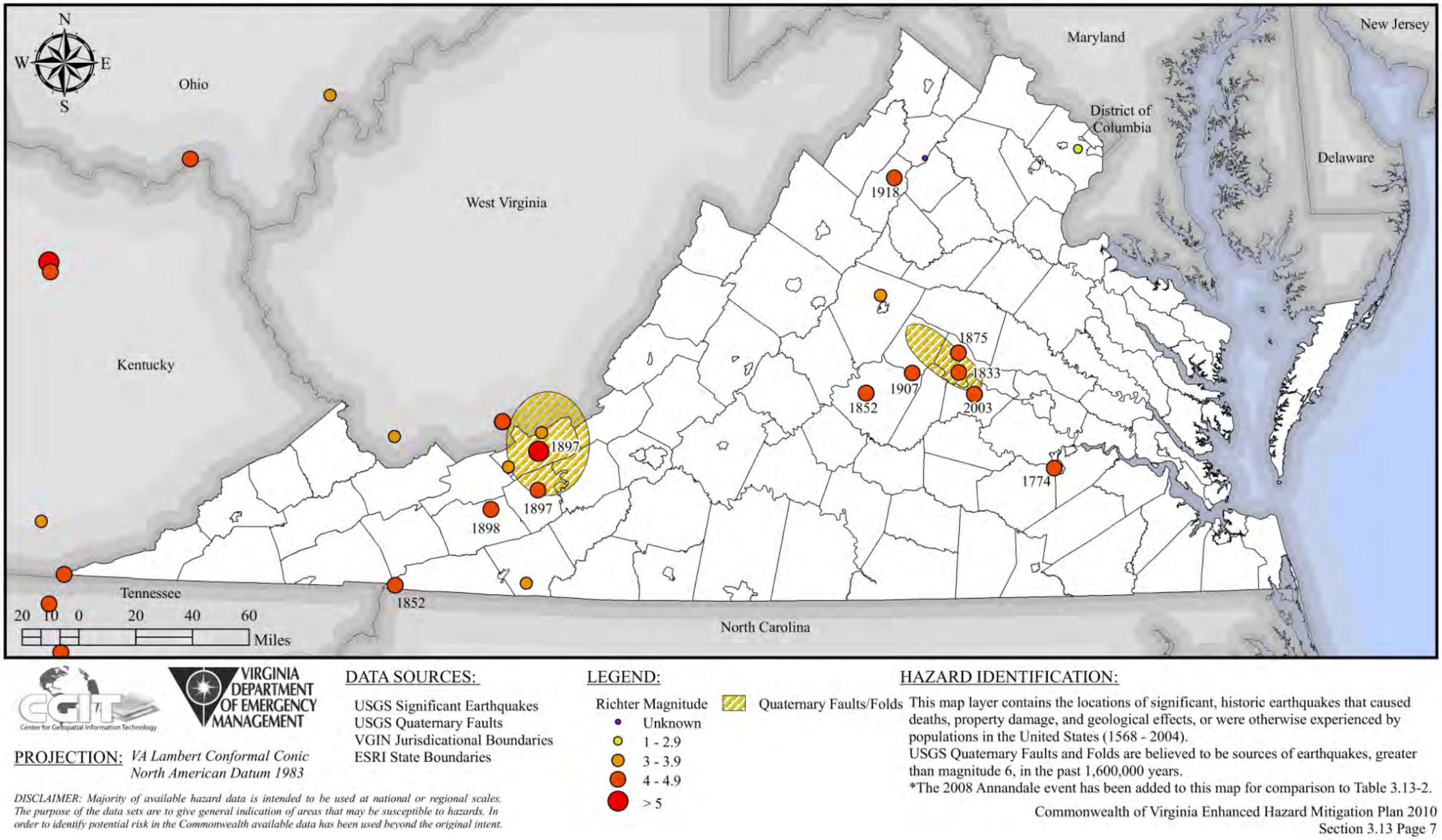

Figure 4.41. Significant Earthquakes 1568 – 2004, with 2008 Annandale event.

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 4.43[26] 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 Chapman[27], 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.

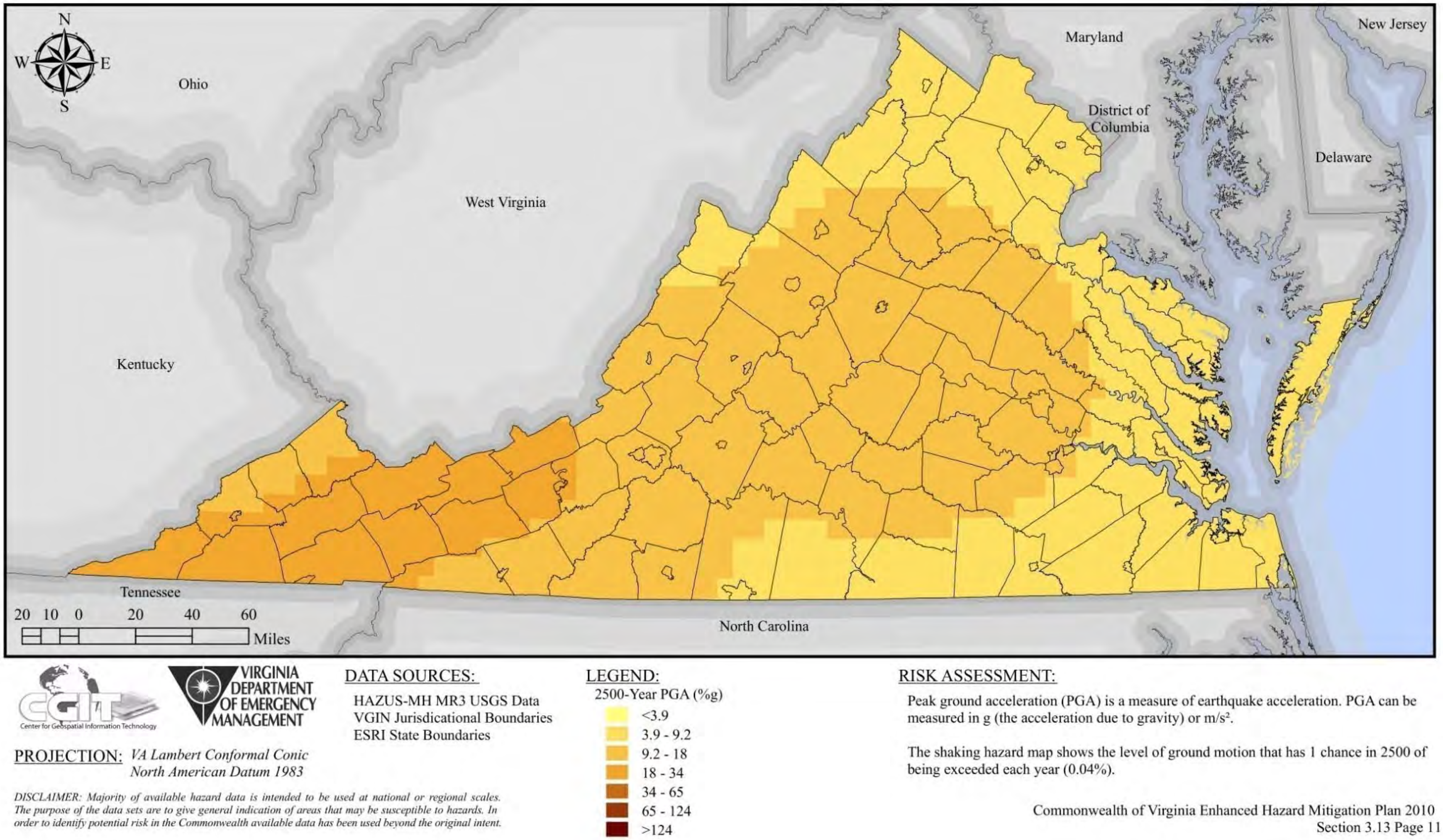

Figure 4.43. 2500-year Return Period Peak Ground Acceleration.

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.

Table 4.64. Modified Mercalli Intensity (MMI) and PGA			
MMI	**PGA (%g)**	**Perceived Shaking**	**Potential Damage**
I	<0.17	Not Felt	None
II	0.17 - 1.4	Weak	None
III	0.17 - 1.4	Weak	None
IV	1.4 -3.9	Light	None
V	3.9 -9.2	Moderate	Very Light
VI	9.2 -18	Strong	Light
VII	18 -34	Very Strong	Moderate
VIII	34 - 65	Severe	Moderate to Heavy
IX	65 - 124	Violent	Heavy
X	> 124	Extreme	Very Heavy
XI	> 124	Extreme	Very Heavy
XII	> 124	Extreme	Very Heavy

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

3. Risk

Moderate and even very large earthquakes are inevitable, although very infrequent, in areas of normally low seismic activity. Earthquake HAZUS^{MH} analysis was completed for the 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 for the entire Northern Virginia region. Loss estimates do not take into account the potential for collateral hazards such as liquefaction, fire or landslide.

Table 4.65. 2006 Estimates of Potential Losses for Earthquakes				
Planning Area	**500-Year Event**	**1,000-Year Event**	**2,500-Year Event**	**Annualized Losses**
Region I. Arlington County	$12,171,000	$37,673,000	$139,293,000	$32,000
Region II. Fairfax County City of Alexandria City of Fairfax City of Falls Church Town of Herndon Town of Vienna	$73,295,000	$236,459,000	$849,044,000	$218,000
Region III. Loudoun County Town of Leesburg Town of Purcellville	$12,349,000	$39,305,000	$141,866,000	$33,000
Region IV. Prince William County City of Manassas City of Manassas Park Town of Dumfries	$20,085,000	$64,809,000	$228,090,000	$58,000
Total	**$117,900,000**	**$378,246,000**	**$1,358,293,000**	**$341,000**

2010 HAZUS-MH MR4 Analysis

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

HAZUS^{MH} can be used to evaluate a variety of hazards and associated risk to support hazard mitigation. This revision utilized only Level 1 analysis for the earthquake module. Level 1 analysis involves using the provided hazard and inventory data with no additional local data collection. This is an acceptable level of information for mitigation planning; a future version of this plan can be enhanced with Level 2 and 3 analyses. The estimates of social and economic impacts contained in this report were produced using HAZUS^{MH} loss estimation methodology software, which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific earthquake. These results can be improved by using enhanced inventory, geotechnical, and observed ground motion data.

During the 2010 update of the hazard mitigation plan, it was decided to run the probabilistic annualized loss scenario in HAZUS^{MH} on a countywide basis. Based on analysis, the region can expect over $2.4 million in annualized damages. Fairfax County accounts for 49.6% of the total, or 52.2% of the total including damages of the towns within the county. Prince William County accounts for 12.7% of the total, or 12.8% including the damages occurring within the county. Figure 4.44 illustrates the total annualized loss per census tract for the region. The Goochland County Scenario modeled a 6.5 magnitude earthquake with a depth of 10 meters. As discussed above, this would be a reasonable and likely scenario for the region. The results of this magnitude earthquake would result in over $616.4 million dollars in damages. Close to 50% of the damages would be located in Fairfax County, followed by Prince William County (19.4%). Figures 4.45 and 4.46 show the distribution of total direct economic loss for residential building occupancies and total building loss. Table 4.66 summarizes the results of the countywide analysis for the probabilistic and Goochland County scenarios. Town information has been extracted from the county totals based on the census blocks located within the towns.

Table 4.66. HAZUS^{MH} Annualized and Goochland County, VA scenario.		
Jurisdiction	**Annualized Loss**	**Goochland County Scenario**
Arlington County	$256,214	$50,596,616
Fairfax County	$1,194,034	$305,516,774
Town of Herndon	*$32,972*	*$6,502,171*
Town of Vienna	*$29,422*	*$6,231,392*
Town of Clifton	*$475*	*$157,123*
Loudoun County	$222,490	$40,023,317
Town of Leesburg	*$29,955*	*$4,527,822*
Town of Purcellville	*$911*	*$149,581*
Town of Middleburg	*$129*	*$27,861*
Town of Round Hill	*$53*	*$7,490*
Prince William County	$304,948	$119,524,967
Town of Dumfries	*$2,492*	*$1,143,557*
Town of Haymarket	*$165*	*$50,753*
Town of Occoquan	*$635*	*$233,037*
Town of Quantico	*$1,032*	*$468,964*
City of Alexandria	$198,495	$42,904,170
City of Fairfax	$49,175	$11,398,801
City of Falls Church	$20,589	$4,217,152
City of Manassas	$53,304	$18,694,282
City of Manassas Park	$11,457	$4,096,617
Total	**$2,408,945**	**$616,472,447**

Comparison of the 2006 and 2010 HAZUS^{MH} results reveal a difference in over $2 million for the annualized loss estimates. Several factors may have led to this gap; the 2006 analysis, completed on a four region basis, may have only taken the 500-, 1000- and 2500-year events into consideration for the annualized estimate and not the eight return-periods used in the 2010 HAZUS^{MH} analysis.

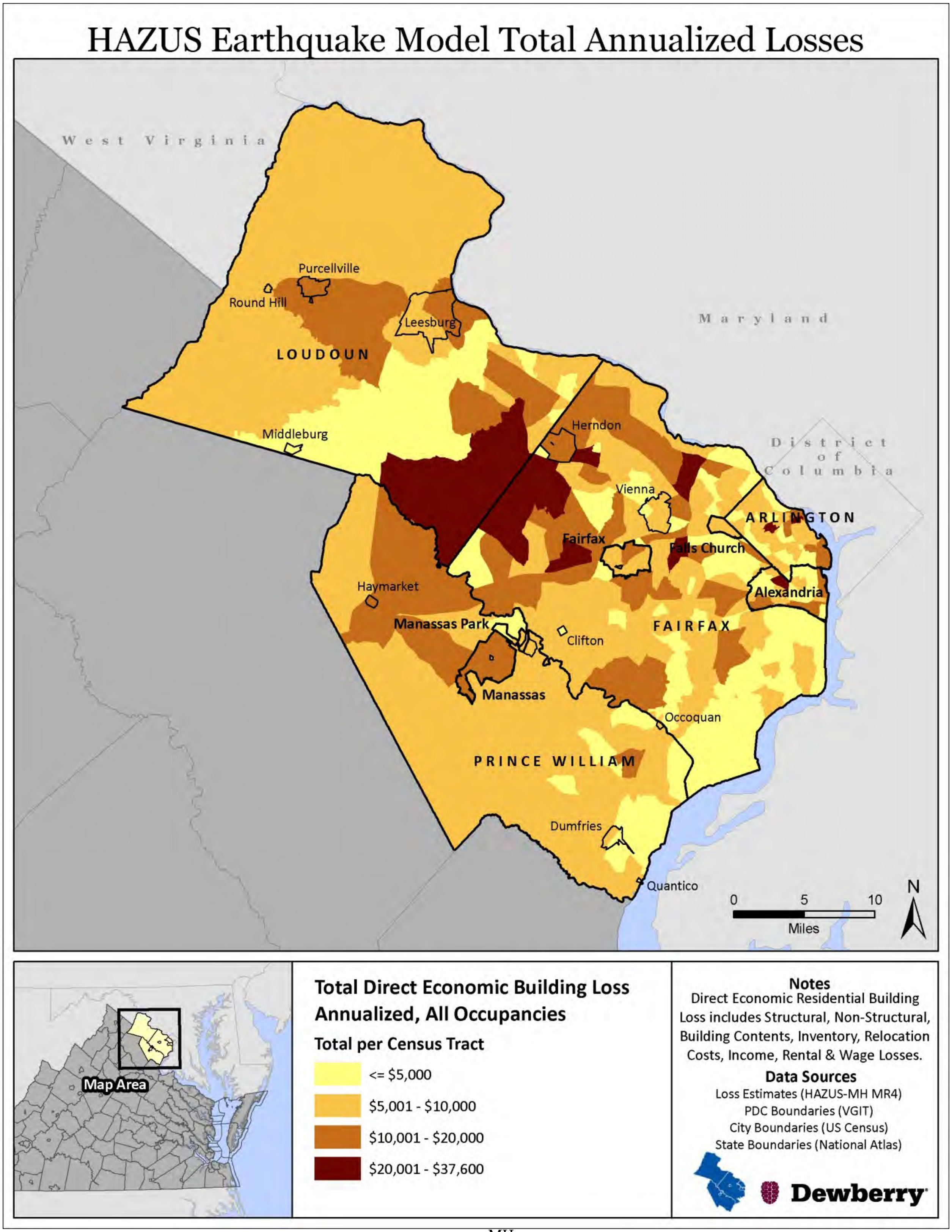

Figure 4.44. Total Annualized Loss from HAZUS[MH]

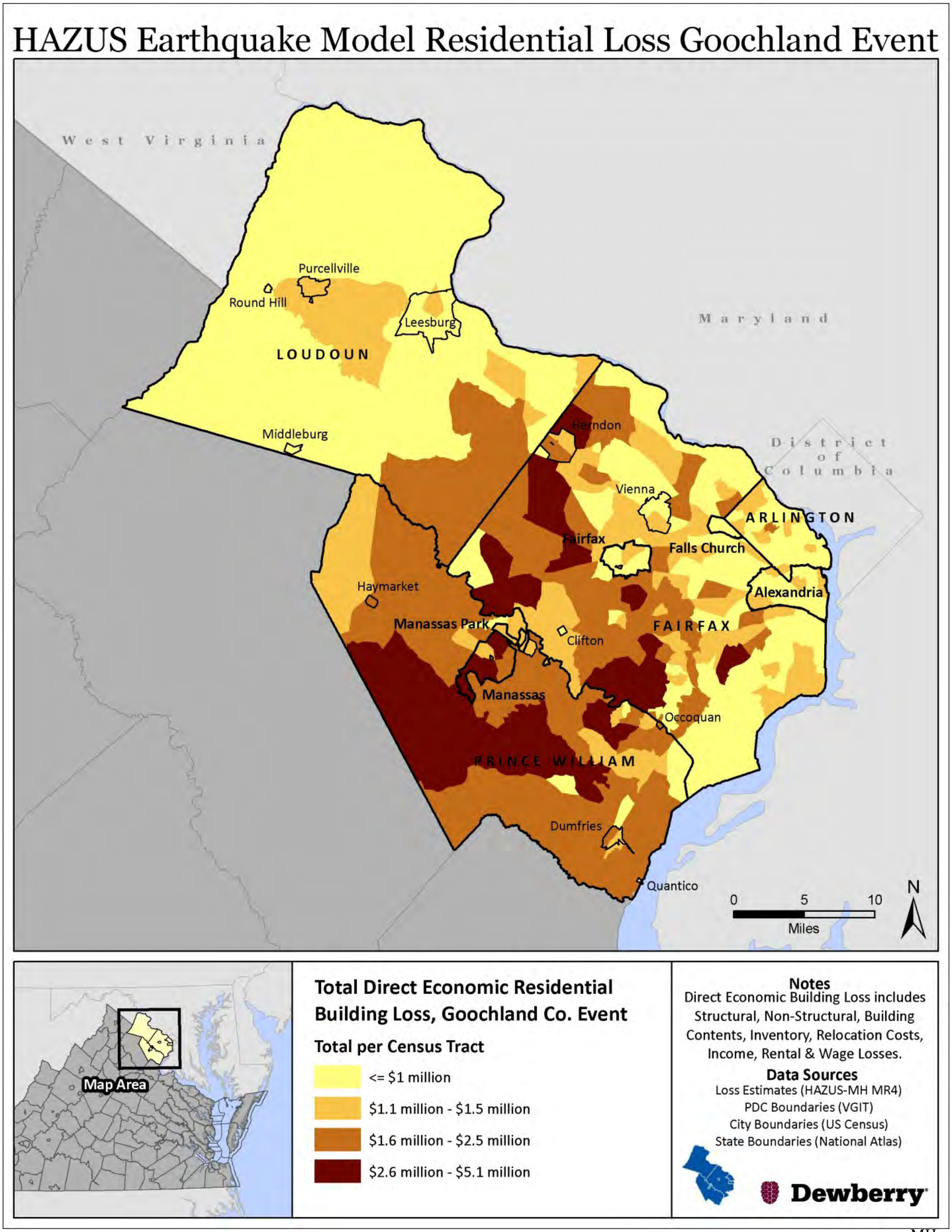

Figure 4.45. Total Residential Loss for Goochland County, VA epicenter event from HAZUS[MH]

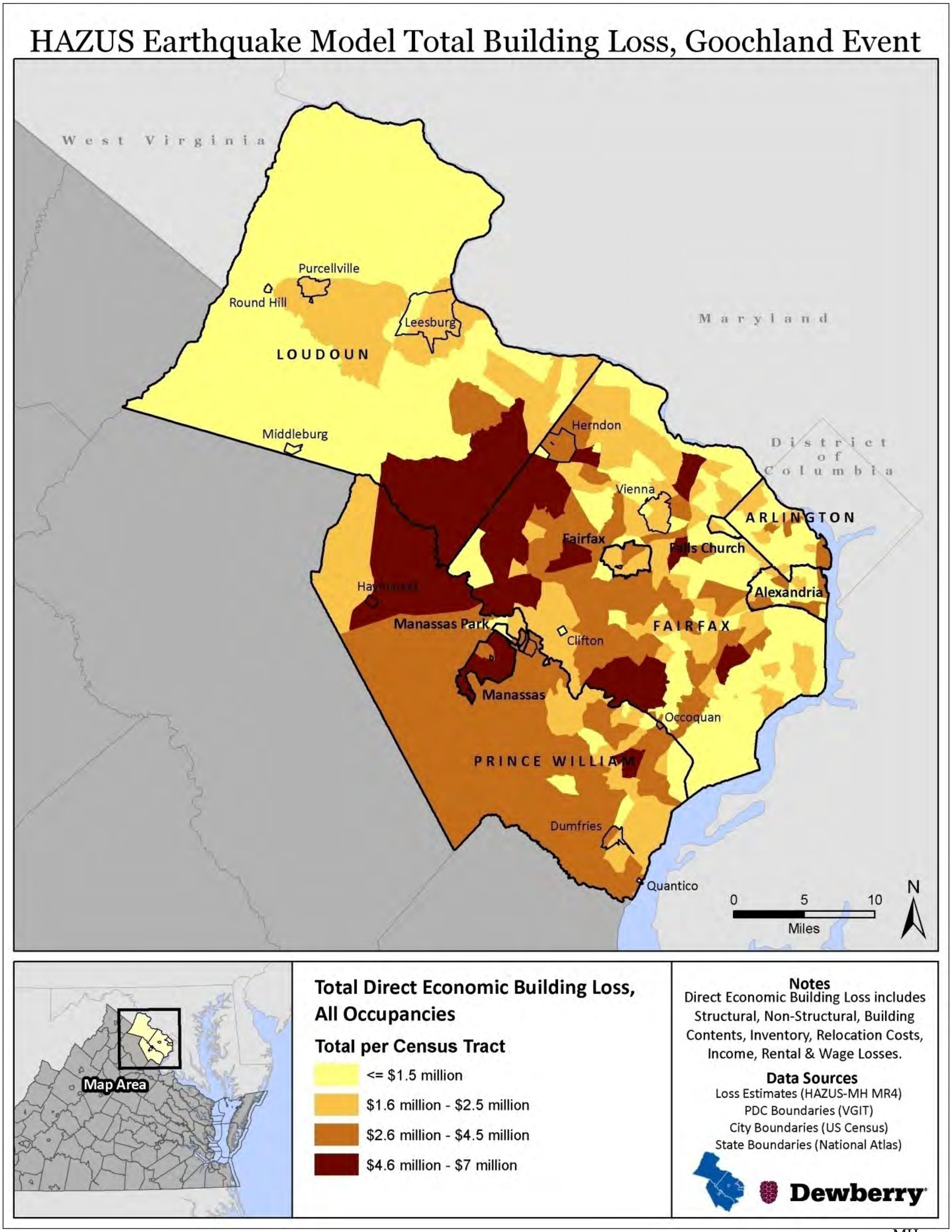

Figure 4.46. Total Building Loss for Goochland County, VA, epicenter event from HAZUS^{MH}

Critical Facility Risk
Based on the Goochland County HAZUS^{MH} scenario, on the day of the earthquake the region would have 85% of hospital beds available (functionality) for use by patients already in the hospital and those injured by the earthquake. All essential facilities would have functionality of greater than 50% on the day of the earthquake. After one week, 94% of the beds would be back in service. The model also estimates 457 households to be displaced from the Goochland County scenario. Of these, 250 people (out of a total population of 1,815,197) will seek temporary shelter.

The Goochland County HAZUS^{MH} scenario estimates six police stations, and one fire station would have less than 80% functionality on day one of the event, after day three, functionality would be above 90%. These include:

- Prince William County Criminal (Police)
- McLean Police Department
- Prince William County Criminal
- Prince William Criminal Division
- Quantico Police Department
- Fire Protection/Prevention Branch

The majority of schools would have less than 90% functionality on days one through three following an earthquake; functionality greatly improves after day seven.

Existing Buildings and Infrastructure Risk
As discussed in the community profiles above, there is an estimated 564,000 buildings in the region with a total building replacement value (excluding contents) of $158,996 million dollars. The majority of the buildings in the region are associated with residential housing. Wood frame construction makes up 69% of the building inventory.

One-third of the estimated losses with the probabilistic scenario (annualized loss) are related to business interruption in the region. The largest loss is sustained by residential occupancies which make up over 55% of the total loss estimates. The 2010 HAZUS^{MH} analysis above provides additional information for each of the jurisdictions.

Based on the Goochland County HAZUS^{MH} scenario, there would be about 8,292 buildings with at least moderate damage. Approximately 111 buildings would be damaged beyond repair. Table 4.67 summarizes the expected damage and number of buildings damaged, by occupancy.

Table 4.67. Expected Building Damage by Occupancy.										
Occupancy Type	None		Slight		Moderate		Extensive		Complete	
	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	1,611	0.30	96	0.41	31	0.43	4	0.41	0	0.22
Commercial	28,621	5.37	1,758	7.56	673	9.47	96	8.89	7	6.4
Education	1,536	0.29	87	0.38	33	0.46	4	0.39	0	0.34
Government	942	0.18	53	0.23	20	0.28	2	0.22	0	0.16
Industrial	7,304	1.37	437	1.88	174	2.45	23	2.1	2	1.37
Other Residential	37,982	7.13	1,843	7.93	665	9.36	74	6.84	6	5.4
Religion	2,680	0.50	148	0.64	60	0.84	10	0.89	1	0.8
Single Family	452,034	84.86	18,824	80.98	5,448	76.71	864	80.26	95	85.3
Total	**532,710**		**23,246**		**7,104**		**1,077**		**111**	

Overall Loss Estimates and Ranking

During the 2006 plan creation, annualized loss for earthquake was estimated at $341,000 for the region. For the 2010 plan update, HAZUS^{MH} was utilized to come up with the probabilistic annualized loss estimates of $2,408,947.

For the 2010 update, the Northern Virginia planning region could expect over $2 million in annualized damages due to earthquakes. Fairfax County had the highest annualized loss for the entire Commonwealth based on the updated analysis and the Virginia State plan analysis (Table 4.68). Approximately 19% of Virginia's earthquake loss is from the Northern Virginia region of the State. The slight differences in annualized damages from the State plan and plan update can be attributed to several factors: different versions of HAZUS software, updated building stock information, and level of analysis completed.

Table 4.68. Annualized loss estimate comparison of updated HAZUS^{MH} results and the 2010 Virginia hazard mitigation plan loss estimates.		
Jurisdiction	2010 Commonwealth of VA Plan	HAZUS^{MH} Derived Annualized Loss
Arlington County	$356,165	$256,214
Fairfax County	$1,734,714	$1,256,903
Loudoun County	$345,482	$253,538
Prince William County	$415,002	$309,272
City of Alexandria	$270,594	$198,495
City of Fairfax	$71,004	$49,175
City of Falls Church	$28,303	$20,589
City of Manassas	$71,952	$53,304
City of Manassas Park	$11,181	$11,457
Total	**$3,304,397**	**$2,408,947**

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

The hazard ranking for earthquake is based on events reported in the NCDC Storm Events database and a generalized geographic extent. The geographic extent ranking category used the PGA values for the 2500 Return Period. This return period represents a 0.04%-annual-chance of occurrence in any given year. The Northern Virginia planning region was ranked as "Medium" for earthquakes. The majority of the jurisdictions ranked Medium and the Cities of Falls Church and Manassas Park ranked as Medium-Low. Figure 4.47 shows the seven parameters that were used to derive the overall risk ranking. As discussed in the risk assessment methodology section, parameters that did not have recorded events in the NCDC database were given the lowest default score (1).

During the 2006 plan, annualized loss for the region was quantified as $341,000 based on HAZUS^{MH} results. According to the qualitative assessment performed in 2006 using the PRI tool, the earthquake hazards scored a PRI value of 1.9 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.69 summarizes the risk levels assigned to each PRI category.

Table 4.69. 2006 Qualitative Assessment for Earthquakes

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Unlikely	Minor	Large	Less than 6 hours	Less than 6 hours

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

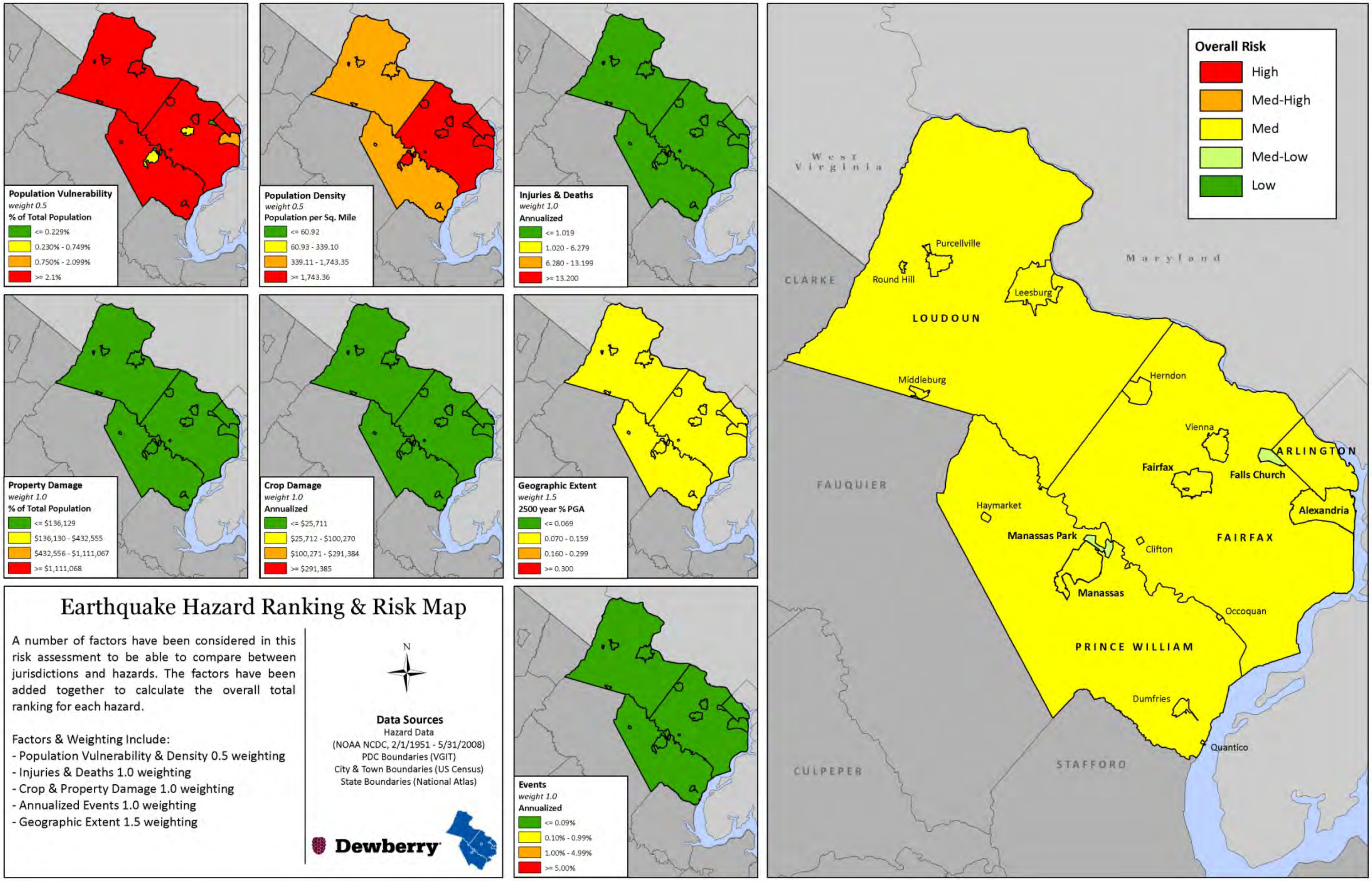

Figure 4.47. Earthquake Ranking and Risk.

XI. Landslides

NOTE: As part of the 2010 plan update, the Landslides hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining 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

Landslides are the downward movement of large volumes of surface materials under gravitational influences[28]. Types of movement include: rotational, translational, block, falls, topples, avalanche, earth flow, creep, and lateral spreading.[29] Landslide materials in motion generally consist of fractured or weathered rock, loose or unconsolidated soils, and vegetative debris. Landslides may be triggered by both natural and human-caused changes in the environment, including heavy rain, rapid snow melt, steepening of slopes due to construction or erosion, earthquakes, volcanic eruptions, and changes in groundwater levels.

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

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

2. Geographic Location / Extent

In the United States, it is estimated that landslides cause up to $2 billion in damages and from 25 to 50 deaths annually. Globally, landslides cause billions of dollars in damage and thousands of deaths and injuries each year. Figure 4.47 delineates areas where large numbers of landslides have occurred and areas that are susceptible to landslides in the conterminous United States.

This map layer is provided in the USGS Professional Paper 1183, "Landslide Overview Map of the Conterminous United States."

While mountainous areas in Virginia are the most susceptible to landslide events, landslide and subsidence hazards do exist elsewhere in the State, including the Northern Virginia region – though these events are quite rare and limited in terms of their impact on people and property. Minor landslide events are possible in localized, steep-sloped areas of the Northern Virginia region during extremely wet conditions. These areas are primarily located in western Loudoun County, as well as some areas of moderate risk in extreme eastern areas of Fairfax and Prince William counties. Figure 4.48 provides a general indication of where landslide events are most likely to occur in Virginia based on landslide incidence and susceptibility data provided by the USGS.

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

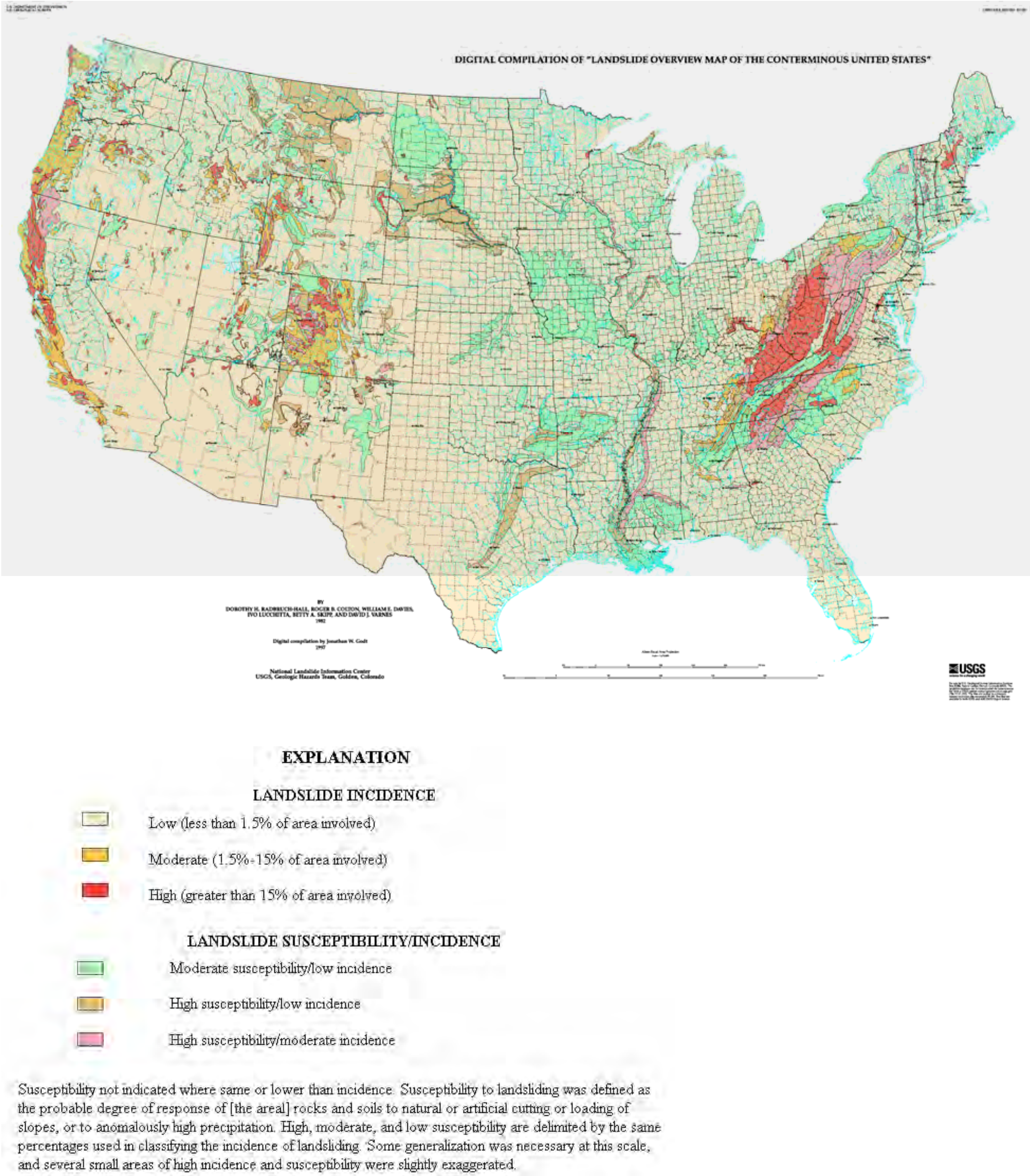

Figure 4.47. Landslide Overview Map of the Conterminous United States
Source: USGS

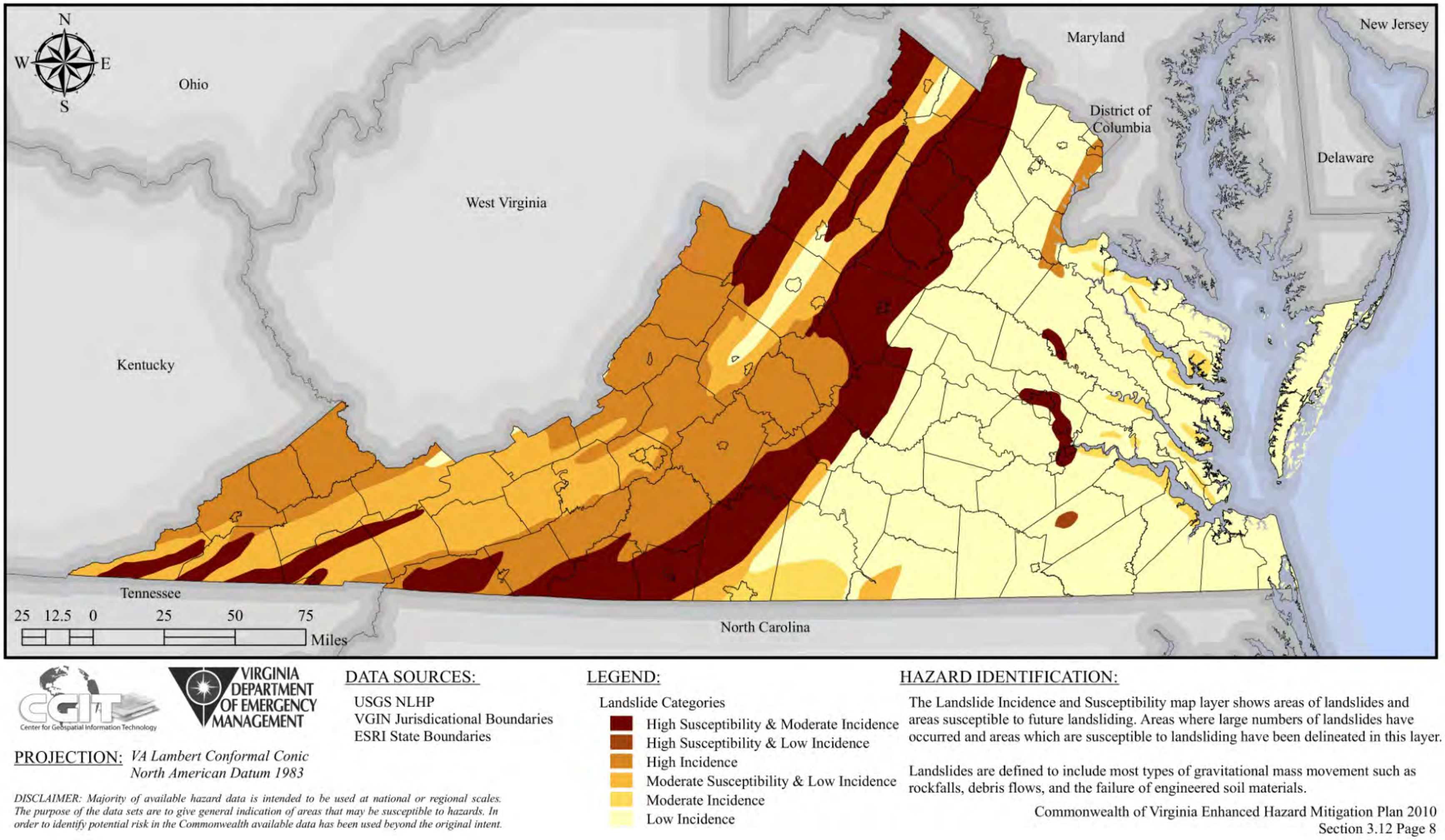

Figure 4.48. Landslide Incidence and Susceptibility.
Source: Commonwealth of Virginia Hazard Mitigation Plan

3. Magnitude or Severity

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

4. Previous Occurrences

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

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

B. Risk Assessment

The landslide data set shows areas in the United States where large numbers of landslides have occurred and areas that are susceptible to landslides. This data set is a digital representation of USGS Open-File Report 97-289, which is a PDF version of the 1997 USGS Digital representation of Landslide Overview Map (scale 1:4,000,000). The report classifies the major physical subdivision of the United States and assesses the vulnerability based on subdivision characteristics. Figures 4.49 highlights the areas of increased incidence and susceptibility. The purpose of this dataset is to provide a general indication of areas that may be susceptible to landsliding. It is not suitable for site selection or local planning initiatives.

1. Probability of Future Occurrences

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

2. Impact & Vulnerability

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

3. Risk

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

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

Critical Facility Risk

The vulnerability of each identified critical facility was assessed using GIS analysis by comparing their physical location with the extent of known hazard areas that can be spatially defined through GIS technology. Of those critical facilities identified in the region, many were indeed determined to be in known hazard areas upon further GIS analysis and thereby determined to be “potentially at-risk.” Tables 4.70 and 4.71 summarize the number of potentially at-risk buildings or facilities in the region to landslide by jurisdiction and facility type. These determinations are based solely on best available data for critical facility locations and delineable hazard areas, and the actual level of risk for each facility may only be determined by further on-site assessments.

The majority of critical facilities (both HAZUS^{MH} and locally supplied) are located in the low incidence and susceptibility landslide risk. Approximately 14% of the HAZUS^{MH} and 22% of the locally supplied facilities are located in the high incidence moderate susceptibility zone. Loudoun County has 13 locally supplied critical facilities (16 HAZUS^{MH}) located in the high susceptibility moderate incidence risk. Figures 4.50 and 4.51 show the location of critical facilities in relation to the different landslide susceptibility and incidence zones.

The names and information for the HAZUS^{MH} and local critical facilities in the landslide risk zones are available in the Critical Facility-Risk Appendix D2.

It should be noted that the landslide incidence data is highly generalized, owing to the small scale and the scarcity of precise landslide information for much of the country, and is unsuitable for local planning or actual site selection.

Table 4.70. Number of Local Critical Facilities Potentially At-Risk to Landslide			
Jurisdiction	**High Incidence**	**High Susceptibility Moderate Incidence**	**Low**
Arlington County	30	-	79
Fairfax County	58	-	280
Town of Clifton	-	-	1
Town of Herndon	-	-	9
Town of Vienna	-	-	11
Loudoun County	-	13	50
Town of Leesburg	-	2	16
Town of Middleburg	-	1	-
Town of Purcellville	-	4	-
City of Alexandria	*	-	46*
City of Fairfax	-	-	9
City of Falls Church	-	-	1
TOTAL	**132**	**20**	**458**

* Critical facilities have been removed from the "High Incidence" category to "Low" risk based on committee feedback from the City of Alexandria.

Table 4.71. Number of HAZUS[MH] Critical Facilities Potentially At-Risk to Landslide			
Jurisdiction, Facility	**High Incidence**	**High Susceptibility Moderate Incidence**	**Low**
Arlington County	7	-	43
Fairfax County	57	-	298
Town of Clifton	-	-	1
Town of Herndon	-	-	10
Town of Vienna	-	-	13
Loudoun County	-	16	57
Town of Leesburg	-	2	22
Town of Middleburg	-	3	-
Town of Purcellville	-	4	-
Town of Round Hill	-	1	-
Prince William County	12	-	117
Town of Dumfries	-	-	3
Town of Haymarket	-	-	1
Town of Occoquan	-	-	1
Town of Quantico	1	-	-
City of Alexandria	*	-	36*
City of Fairfax	-	-	22

Table 4.71. Number of HAZUS^{MH} Critical Facilities Potentially At-Risk to Landslide			
Jurisdiction, Facility	**High Incidence**	**High Susceptibility Moderate Incidence**	**Low**
City of Falls Church	-	-	6
City of Manassas	-	-	26
City of Manassas Park	-	-	4
TOTAL	**110**	**26**	**626**

* Critical facilities have been removed from the "High Incidence" category to "Low" risk based on committee feedback from the City of Alexandria.

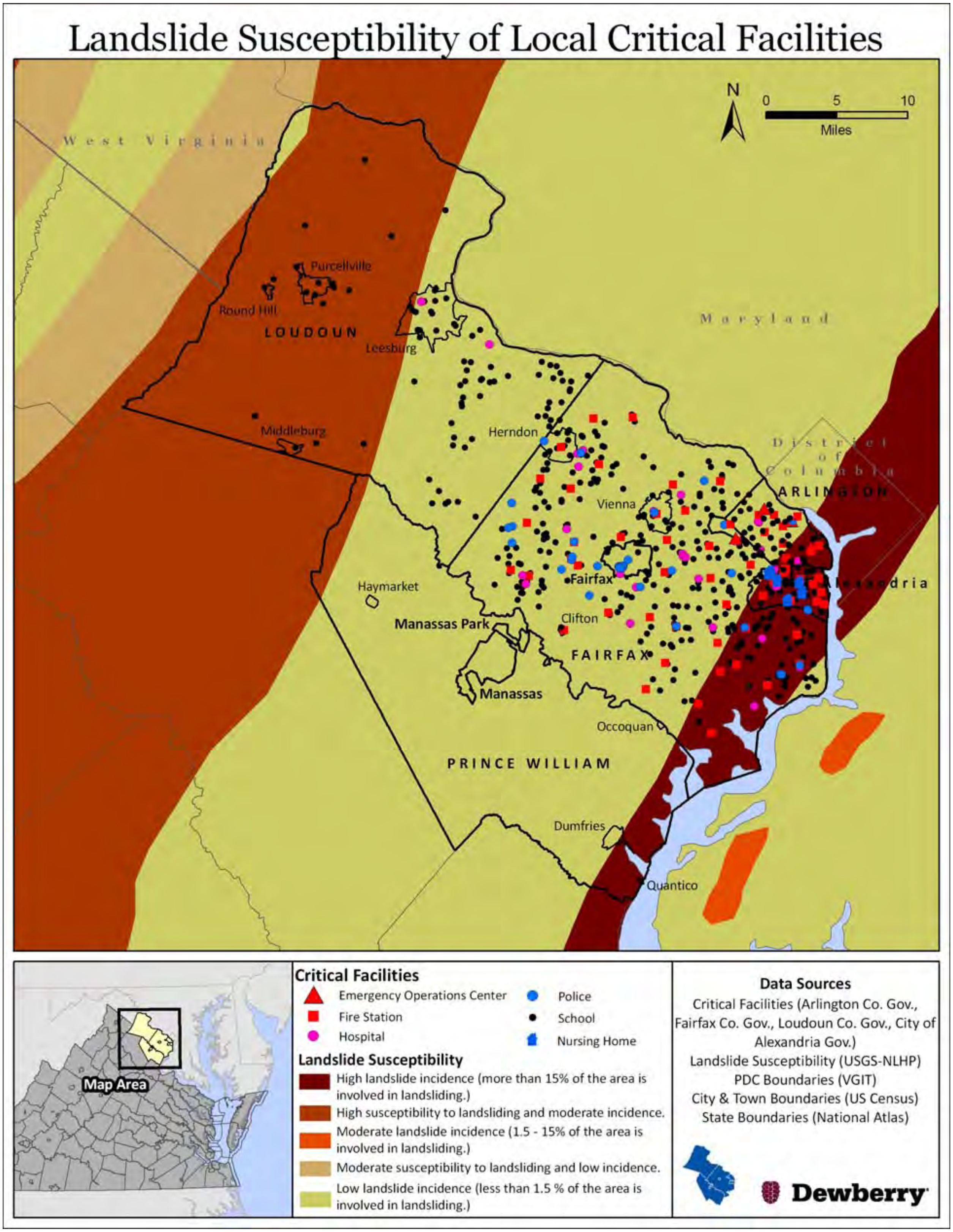

Figure 4.50. Landslide Susceptibility of Local Critical Facilities

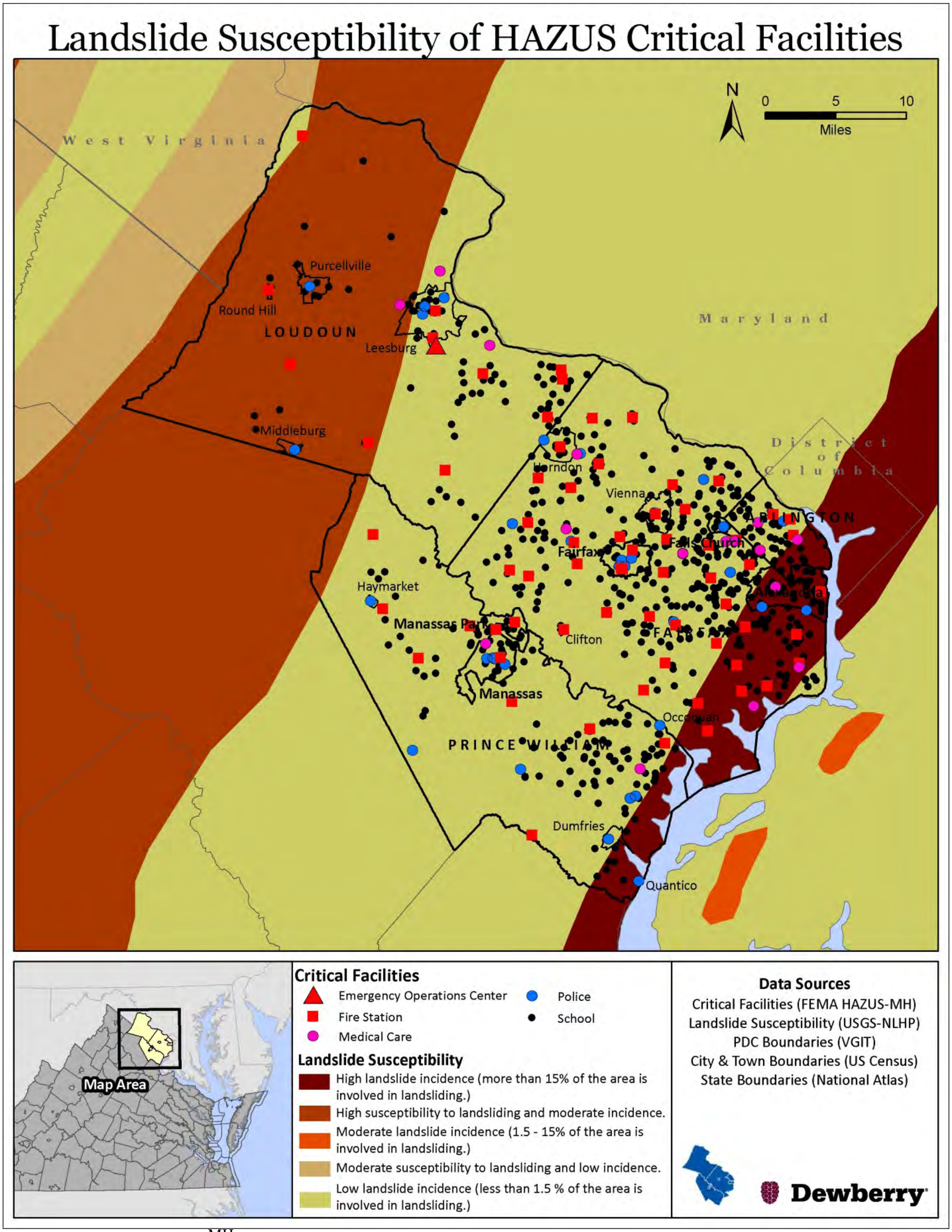

Figure 4.51. HAZUS^{MH} critical facility locations in relation to landslide susceptibility.

Existing Buildings and Infrastructure Risk

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

Overall Loss Estimates and Ranking

Due to the lack of any historical landslide damage data and well established occurrence probabilities, damages caused by landslides and associated dollar losses could not be estimated for the 2006 plan creation or 2010 update.

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. While this ranking methodology makes sense for the majority of the hazards in this plan, the data is limited/non-existent for landslides.

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

Figure 4.52 summarizes each of the parameters used in the ranking and the overall relative ranking for landslides. The City of Alexandria and Loudoun County, in relation to the other jurisdictions in the planning region, have a higher risk for landslides. This can be attributed to population density and vulnerability and the geographic extent of USGS landslide mapping. The overall ranking for the City of Alexandria was modified to low based on feedback from city officials.

According to the 2006 qualitative assessment performed using the PRI tool, the landslide hazard scored a PRI value of 1.6 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.75 summarizes the risk levels assigned to each PRI category.

Table 4.72. 2006 Qualitative Assessment for Landslide

	Probability	Impact	Spatial Extent	Warning Time	Duration
Risk Level	Possible	Minor	Small	12 to 24 hours	Less than 6 hours

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

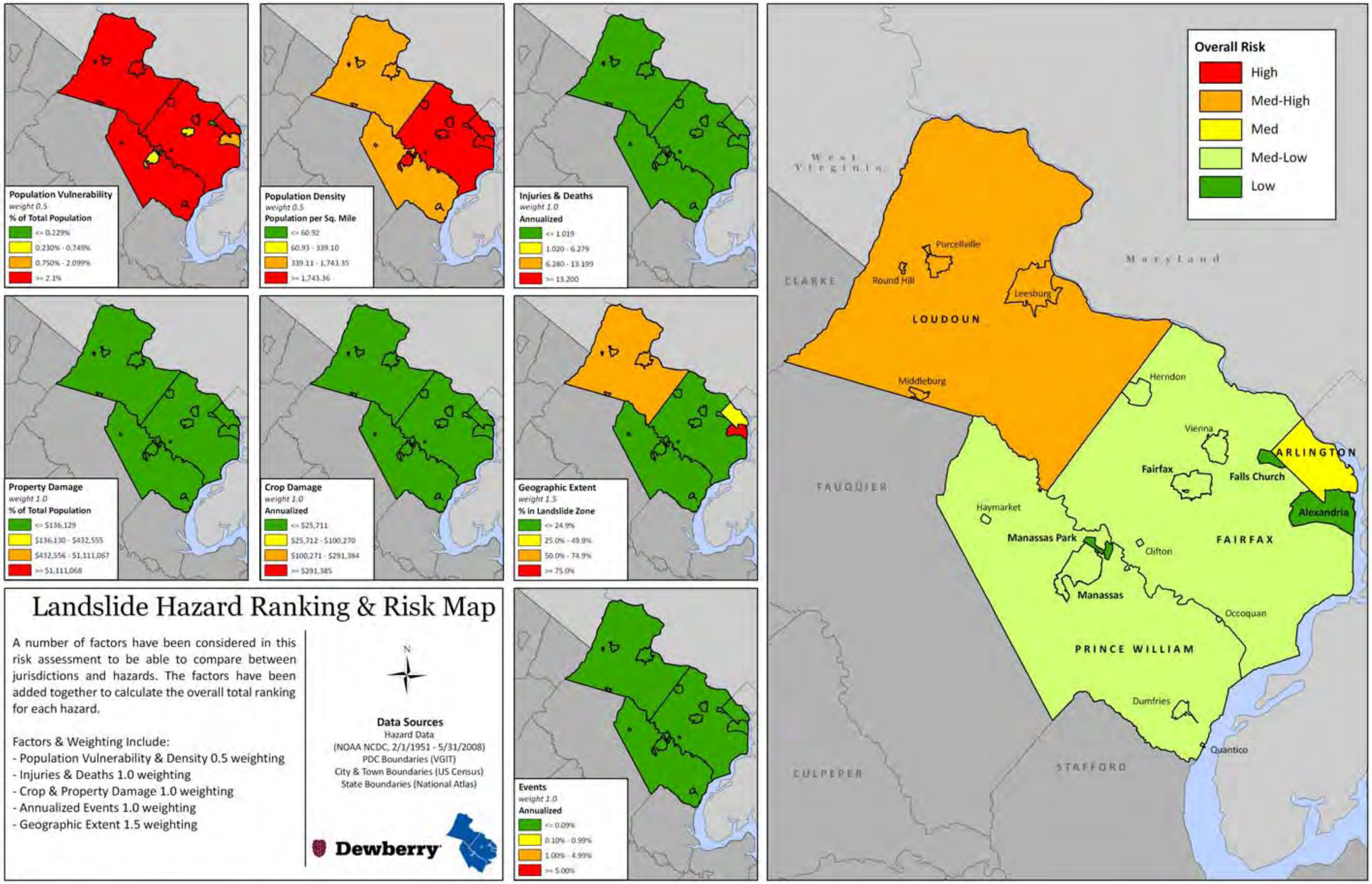

Figure 4.52. Landslide hazard ranking and risk.

XII. Wildfire

NOTE: As part of the 2010 plan update, the Wildfire hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining 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

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

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

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

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

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

2. Geographic Location / Extent

Wildfires commonly begin unnoticed and spread quickly through vegetative fuels. As discussed in the ranking methodology section, the VDOF risk assessment represents the geographic extent or locations throughout the Commonwealth that have a higher risk for wildfire. The geographic extent score for a given jurisdiction is based on the percent of the jurisdiction that falls within the "high" risk area as defined by VDOF. Fairfax and Loudoun Counties have the highest percent of their land area within the high risk classifications as compared to the other jurisdictions in the planning region. Table 4.73 and Figure 4.53 reflect the VDOF risk assessment and Figure 4.57 includes the geographic extent parameter used in the hazard ranking. Several areas in Northern Virginia are conducive to wildfires: the Conway-Robinson State Forest and Prince William Forests Park in Prince William County among them.

3. Magnitude or Severity

The Northern Virginia region is not considered as at-risk to wildfire as other areas of the State, but wildfire occurrence is certainly prevalent – particularly in Loudoun and Prince William counties. According to VDOF records, there were 120 wildfire events in the Northern Virginia region between 1995 and 2008. These fires burned a total of 368 acres and caused an estimated $180,895 in property damages, but fortunately caused no deaths or injuries. These fires were typically small in size, burning an average of approximately four acres before being suppressed (an estimated $7.5 million in damages were prevented by fire control efforts during this period). Of the 120 recorded historical incidents during this period, only six fires burned an area greater than 10 acres (all in Loudoun County). Table 4.74 lists the number of these fire events, acres burned, and estimated damages by jurisdiction for the Northern Virginia region.

4. Previous Occurrences

While the Commonwealth of Virginia rarely experiences the large, extensive wildfires typically seen in the western regions of the United States, wildfire risk remains a genuine concern. According to the VDOF, about 1,600 wildfires consume a total of 8,000 to 10,000 acres of forest and grassland in the State each year. During the fall drought of 2001, Virginia lost more than 13,000 acres to wildfires.

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

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

Records indicate that most of Virginia's wildfires are caused by people. Virginia is growing more rapidly than many other States, and its population has doubled in the last 45 years. Further, people are moving into residential developments located within forested areas, and there is an increased use of the forests for recreational uses. All of these trends increase the risk of wildfires and require continued fire prevention and protection activities.

There have been 120 wildfire burning 368 acres during 1995 through 2008 totaling $180,895 in damages. Table 4.73 shows the total number of fires, acres burned, total damages, and total saved for jurisdictions that had recorded wildfire events by VDOF. Loudoun County wildfires make up the majority of damages in Northern Virginia during the period of record (1995-2008).

Table 4.73. Wildfire events in the Northern Virginia Region, 1995-2008

Jurisdiction	Number of Fires	Total Acres	Total Damages	Total Saved
Fairfax County	2	3	$0	$0
Loudoun County	90	287	$165,355	$17,778,450
Town of Leesburg	2	2	$200	0
Prince William County	25	70	$15,340	$3,374,600
Town of Dumfries	1	6	$0	$0
Total	**120**	**368**	**$180,895**	**$21,153,050**

Source: VDOF

The majority of the wildfire occurrences in the Northern Virginia region were caused by debris burning and other human activities. Table 4.74 shows the leading causes of wildfires in the region based on VDOF records for the 120 historical wildfires occurring between 1995 and 2008.

Table 4.74. Leading Causes of Wildfires in the Northern Virginia Region, 1995-2008

Cause	# of Fires	% of Wildfires
Debris Burning	35	29%
Children	24	20%
Miscellaneous	23	19%
Incendiary	14	12%
Smoking	12	10%
Equipment Use	8	7%
Campfire	2	2%
Lightning	1	1%
Railroad	1	1%

Source: VDOF

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

B. Risk Assessment

1. Probability of Future Events

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

While the VDOF Wildfire Risk Assessment does indicate the relative propensity for wildfires across the State, this assessment does not assign probabilities of occurrence or return intervals as is common with some of the other hazards. Based on available data from VDOF, during the years 1995 – 2008, Virginia experiences an average of 1,188 wildfires per year, affecting an average of 8,844 acres annually.

2. Impact & Vulnerability

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

3. Risk

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

Prince William County has over 15% of its acreage in the high risk category, with the Town of Round Hill having almost one-third of its acreage at high risk. Fairfax County has approximately 12% of its acreage in the high risk category, with over 16% of the Town of Clifton's area in high risk. The Northern Virginia region is mostly low (48.97%) and medium (41%) risk, with a tenth of the region in the high risk category. More information on VDOF's GIS-based Wildfire Risk Assessment is available at www.dof.virginia.gov.

Table 4.75. Wildfire Risk by Jurisdiction							
Jurisdiction	**Low (acres)**	**Low % Area**	**Medium (acres)**	**Medium % Area**	**High (acres)**	**High % Area**	**Total Acres**
Arlington County	16,064	**96.30%**	435	**2.61%**	183	**1.10%**	**16,682**
Fairfax County	143,682	**57.22%**	77,244	**30.76%**	30,174	**12.02%**	**251,100**
Town of Herndon	2,734	***99.93%***	1	***0.04%***	0	***0.00%***	**2,736**
Town of Vienna	2,795	***99.25%***	21	***0.75%***	0	***0.00%***	**2,816**
Town of Clifton	43	***26.06%***	95	***57.58%***	27	***16.36%***	**165**
Loudoun County	136,046	**42.16%**	166,511	**51.60%**	20,114	**6.23%**	**322,672**
Town of Leesburg	4,670	***58.46%***	2,635	***32.98%***	684	***8.56%***	**7,989**
Town of Purcellville	278	***13.69%***	1,738	***85.62%***	14	***0.69%***	**2,030**
Town of Middleburg	219	***33.08%***	389	***58.76%***	55	***8.31%***	**662**
Town of Round Hill		***0.00%***	165	***69.62%***	71	***29.96%***	**237**
Prince William County	87,118	**39.77%**	98,129	**44.79%**	33,828	**15.44%**	**219,076**
Town of Dumfries	745	***73.40%***	255	***25.12%***	14	***1.38%***	**1,015**
Town of Haymarket	240	***78.43%***	66	***21.57%***	0	***0.00%***	**306**
Town of Occoquan	83	***74.77%***	27	***24.32%***	0	***0.00%***	**111**
Town of Quantico	44	***93.62%***	3	***6.38%***	0	***0.00%***	**47**
City of Alexandria	9,644	**98.83%**	114	**1.17%**	0	**0.00%**	**9,758**
City of Fairfax	3,801	**94.65%**	215	**5.35%**	0	**0.00%**	**4,016**
City of Falls Church	1,275	**100.00%**	0	**0.00%**	0	**0.00%**	**1,275**
City of Manassas	6,130	**95.50%**	287	**4.47%**	2	**0.03%**	**6,419**
City of Manassas Park	741	**65.29%**	265	**23.35%**	129	**11.37%**	**1,135**
TOTAL	**416,352**	**48.97%**	**348,595**	**41.00%**	**85,295**	**10.03%**	**850,247**

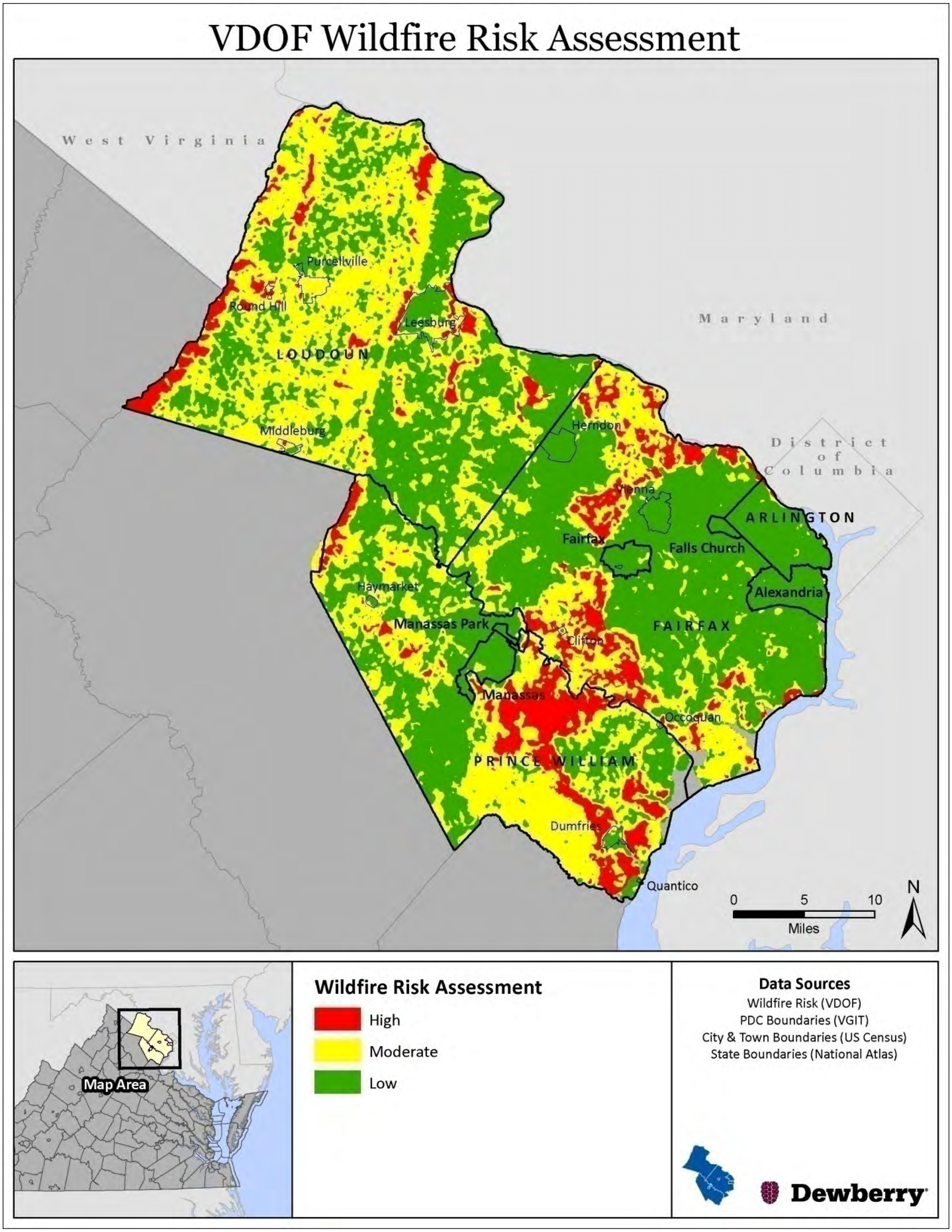

Figure 4.53. VDOF Wildfire Risk Assessment of Northern Virginia

Critical Facility Risk

The HAZUS^{MH} critical facilities data was intersected with the VDOF wildfire risk assessment to determine which facilities were at an increased risk for wildfire, or being in the urban/wildland interface. Table 4.76 shows the number of critical facilities, by locality, for the moderate and high VDOF risk zones. The results of this analysis indicate 22 critical facilities are located in high wildfire risk zones and 89 in moderate risk zones. Prince William County has the highest number of critical facilities in moderate (34) and high (15) risk zones. Schools represent the majority of critical facilities in the high wildfire risk zone. Only localities with critical facilities located in the moderate and high risk zones have been included in Table 4.76.

Risk for the locally supplied critical facilities data was calculated in the same fashion as described above for the HAZUS^{MH} facilities. Table 4.77 shows the number of critical facilities, by locality, for the moderate and high VDOF risk zones. Fairfax and Loudoun Counties were the only localities with critical facilities in moderate and high risk zones. Similar to the HAZUS^{MH} analysis, schools represent the majority of critical facilities in the high wildfire risk zone.

The names and information for the HAZUS^{MH} and local critical facilities in the wildfire risk zones are available in the Critical Facility-Risk Appendix D2.

The lack of wildfire probabilities and detailed infrastructure data led to the inability to calculate potential losses due to wildfire.

Table 4.76. Number of Local Government Critical Facilities Potentially At-Risk to Wildfire

Jurisdiction	**Wildfire Risk**		
Facility Type	*Moderate*	*High*	**Total**
Fairfax County	**25**	**2**	**27**
Fire Station	*3*	*0*	*3*
Hospital	*1*	*0*	*1*
Police	*2*	*0*	*2*
Schools	*19*	*2*	*21*
Loudoun County	**29**	**2**	**31**
Hospitals	*1*	*0*	*1*
Schools	*28*	*2*	*30*
Total	**54**	**4**	**58**

Table 4.77. Number of HAZUS[MH] Critical Facilities Potentially At-Risk to Wildfire

Jurisdiction / Facility Type	Wildfire Risk: Moderate	Wildfire Risk: High	Total
Fairfax County	**19**	**5**	**24**
Fire Station	2	1	3
School	17	4	21
Town of Clifton	**1**	**0**	**1**
Fire Station	1	0	1
Loudoun County	**24**	**2**	**26**
Fire Station	3	0	3
Medical Care	2	0	2
School	19	2	21
Town of Leesburg	**5**	**0**	**5**
Fire Station	1	0	1
School	4	0	4
Town of Purcellville	**4**	**0**	**4**
Police Station	1	0	1
School	3	0	3
Town of Round Hill	**1**	**0**	**1**
Fire Station	1	0	1
Prince William County	**34**	**15**	**49**
Fire Station	4	1	5
Medical Care	1	0	1
Police Station	2	1	3
School	27	13	40
City of Fairfax	**1**	**0**	**1**
School	1	0	1
Total	**89**	**22**	**111**

Existing Buildings and Infrastructure Risk

According to VDOF statistics collected in 2003, Virginia has more than 4,000 woodland home communities. These areas are defined by VDOF as "clusters of homes located along forested areas at the wildland-urban interface that could possibly be damaged during a nearby wildfire incident." In the Northern Virginia region, there are 91 woodland home communities, all of which are located in Loudoun (21) and Prince William (70) counties. Table 4.78 lists the number of woodland home communities by planning area for the Northern Virginia region that are located in areas identified as being either high or moderate risk for wildfires. Figure 5.54 shows the location of these woodland home communities in relation to the identified wildfire hazard areas. More information on these communities is readily available through the VDOF.

Table 4.78. At-Risk Woodland Communities in the Northern Virginia Region

County	Low Risk	Moderate Risk	High Risk
Prince William County	7	27	36
Loudoun County	1	13	7
Total	**8**	**40**	**43**

Source: VDOF

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

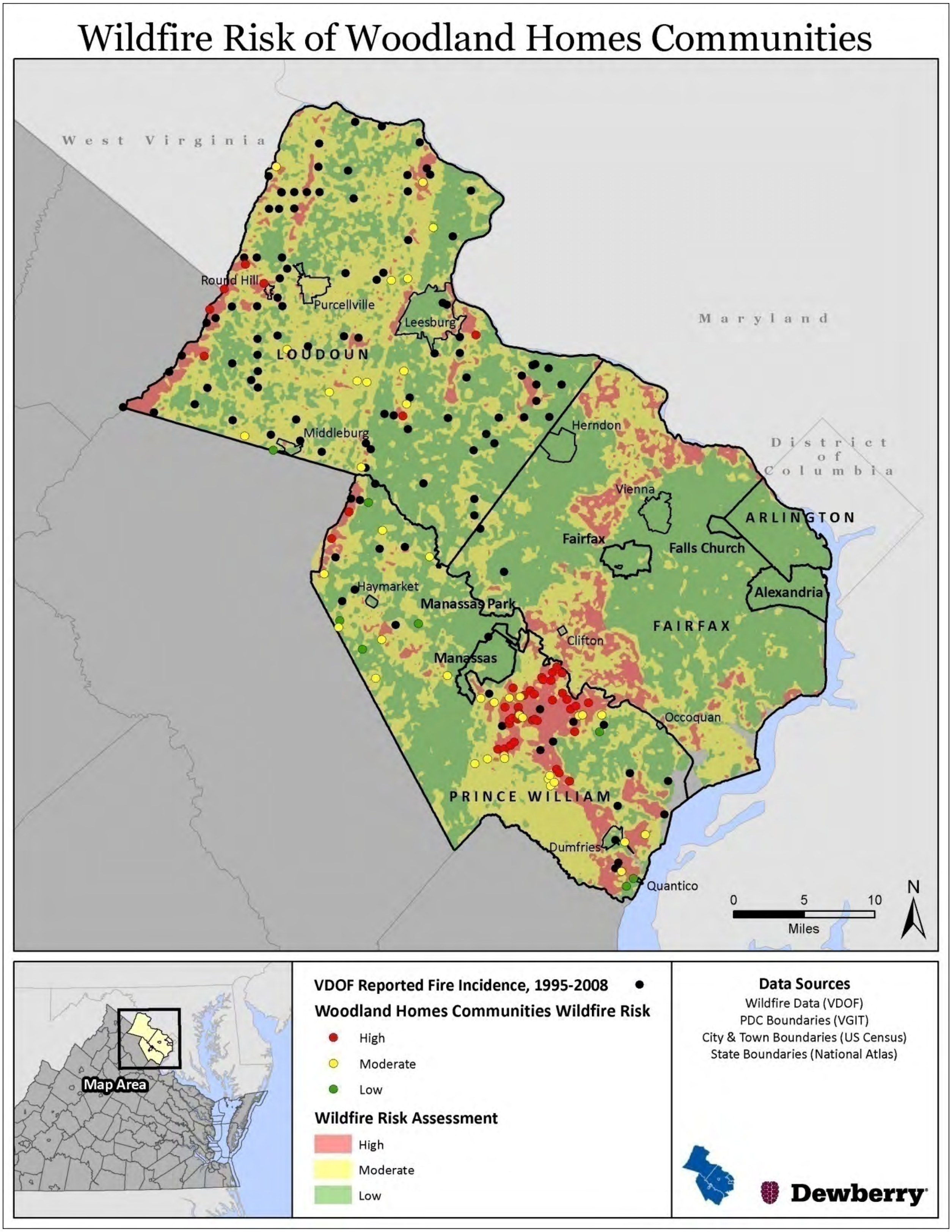

Figure 4.53. Wildfire Risk to Woodland Homes Communities

Wildfire Risk to Historic Buildings

Historic site data provided by Fairfax County and Arlington County was used to identify historical buildings and lands that are vulnerable to wildfire, shown in Figure 4.54. In Fairfax County, six historic sites are at moderate risk of wildfire. These sites include George Washington's House at Mt. Vernon, George Washington's Gristmill, Sully Plantation, Matildaville Ruins, Woodland Plantation, and The Old Schoolhouse at Great Falls Grange Park. In Arlington County, only one of 30 historic sites is vulnerable, The Glenmore House at 3440 North Roberts Lane.

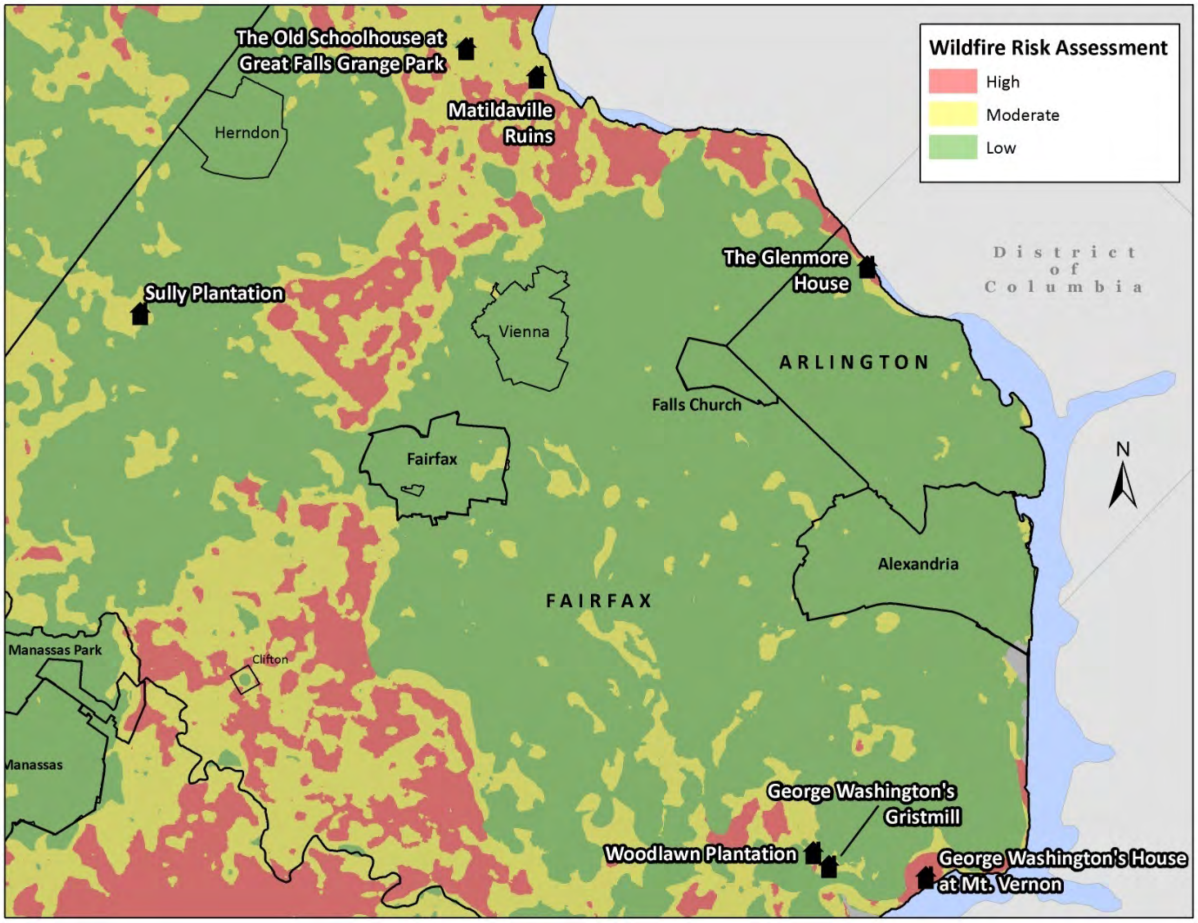

Figure 4.54. Wildfire Vulnerability of Historic Sites

Overall Loss Estimates and Ranking

During the 2006 plan creation, annualized loss for wildfire was estimated at $25,000 for the region. For the 2010 plan update, seven additional years of VDOF record were utilized to develop updated annualized loss estimates of $13,915.

Between 1995 and 2008, the VDOF recorded 120 wildfire events in the Northern Virginia region totaling approximately $180,895 in damages. Table 4.79 shows the specific annualized loss by jurisdiction. This is based on the total VDOF reported damages divided by the number of years of record. The regional annualized loss estimate for the wildfire hazard in the Northern Virginia region is $13,915. The annualized loss has decreased since the 2006 plan; this can be attributed to the longer length of record with 34 additional wildfires with a total of $5,895 in damages being added to the dataset.

Table 4.79. Wildfire Annualized Loss Estimate based on VDOF data, 1993 – 2008.

Jurisdiction	Annualized Loss
Fairfax County	$0
Loudoun County	$12,720
Town of Leesburg	$15
Prince William County	$1,180
Town of Dumfries	$0
Total	**$13,915**

No wildfire events were recorded in the NCDC database for the Northern Virginia region; as a result, no NCDC annualized loss estimate was calculated**.** The Commonwealth of Virginia's 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. While this ranking methodology makes sense for the majority of the hazards in this plan, the data is limited and/or non-existent for wildfires. The geographic extent score for each jurisdiction is based on the percent of the jurisdiction that falls within the "high" risk zone, as defined by VDOF. Since there are no recorded wildfire events, the lowest ranking score (1) was assigned to the jurisdictions for events, damages, and deaths and injuries to compare wildfire to the other hazards.

Figure 4.55 shows the relative wildfire rankings for each jurisdiction. The majority of the region is located in Medium and Medium-Low risk zones. As shown, the population parameters and VDOF risk assessment drive the overall results of this ranking. Fairfax and Prince William counties have a Medium ranking, while Loudoun County, as a result of the other parameters, has an overall ranking of Medium-Low. Based on committee feedback, the City of Fairfax ranking parameters have been changed to mirror Fairfax County. This is only reflected in Figure 4.55 and on 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 qualitative assessment performed in 2006 by the steering committee using the PRI tool, the wildfire hazard scored a PRI value of **2.6** (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.80 summarizes the risk levels assigned to each PRI category.

Table 4.80. 2006 Qualitative Assessment for Wildfire

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

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

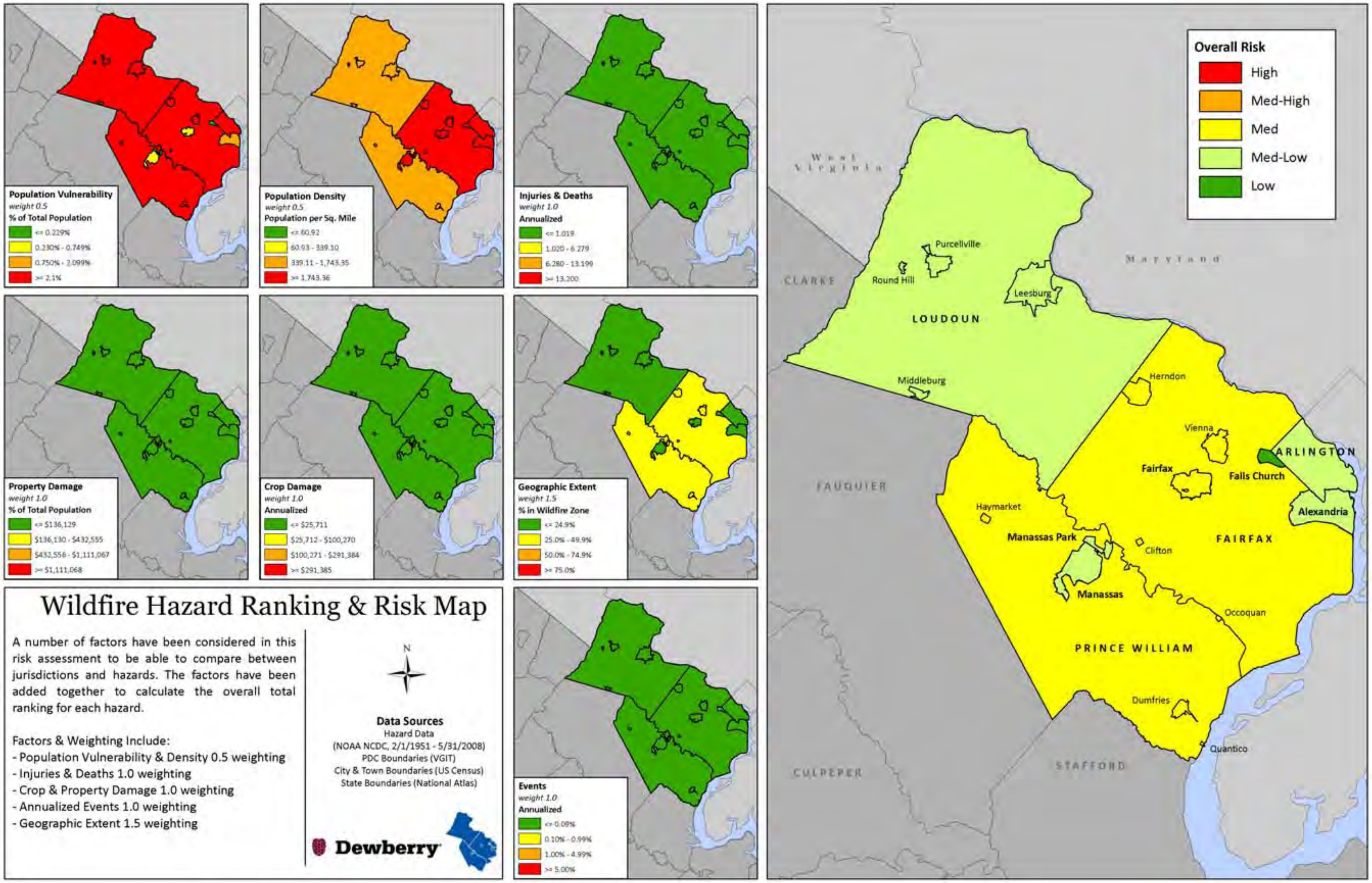

Figure 4.55. Wildfire ranking and overall risk.

C. Building Fires

In addition to those caused by wildfires, building fires may also be the result of arson or accidents. Accidental building fires are relatively unpredictable and could be caused by a variety of sources.

Potential ignition sources include:

- Heat from fuel-fired, fuel-powered object (e.g., heat, spark, ember, or flame from equipment);
- Heat from electrical equipment arcing, overloaded (e.g., short circuit arc, fluorescent light ballast);
- Heat from smoking material (e.g., cigarette);
- Heat from open flame (e.g., lighter, candle);
- Heat from a hot object (e.g., electric lamp, spark from friction);
- Heat from natural source (e.g., lightning);
- Heat spreading from another hostile fire (exposure) (e.g., radiated heat, direct flame); and
- Other[31].

Vulnerability of buildings to fire is in part related to existing fire protection, construction type (interior, exterior, roofing) and the building's contents. High-occupancy areas (high-rise buildings, dormitories, etc.) and areas containing flammable or incendiary materials (laboratories, chemical storage facilities, libraries, etc.) are of special concern and mitigation activities should be tailored accordingly.

On Sunday, December 31, 2006 a car smashed into a gas meter at an apartment complex in the Tysons Corner area resulting in a fire and explosion. Several apartments were damaged and residents were displaced. (Photo from Fairfax County, VA)

Buildings are also vulnerable to fires that result from criminal activity such as acts of vandalism, illicit substance use, malicious or intentional acts, and rioting.

Building fires also are inter-related to other hazards, as is mitigation of these hazards. For example, if fire suppression hydrants are unusable due to a severe winter cold snap (freeze) or if a blizzard makes them inaccessible due to snow plowing blocking access, building fire suppression is compromised.

XIII. Sinkholes / Karst / Land Subsidence

NOTE: As part of the 2010 plan update, the Sinkholes/Karst/Land Subsidence hazards were reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining 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

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

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

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

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

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

2. Geographic Location/Extent

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

According to the Virginia Department of Mines, Minerals and Energy, sinkholes are very rare in the Northern Virginia region and do not pose a significant risk. However, a band of metamorphosed limestone, dolostone, and marble located in eastern Loudoun County and the Town of Leesburg has a history of sinkhole activity. Figure 4.56 shows the karst regions and areas of historical subsidence in the Commonwealth, based on the USGS Engineering Aspects of Karst. The karst regions in Northern Virginia are considered short karst type, which include fissured, tube, and caves generally less than 1,000 feet long; and 50 feet or less in vertical extent.

Loudoun County has a region of karst geology located in an area roughly one mile on either side of State Route 15 from just south of Leesburg, north to the Potomac River bridge. The region is bounded sharply to the west by the Bull Run Fault, which runs at the base of Catoctin Mountain through Loudoun County. Figure 4.57 shows the limestone district for Loudoun County. The Limestone Overlay District (LOD) is primarily comprised of the following geologic formations:

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

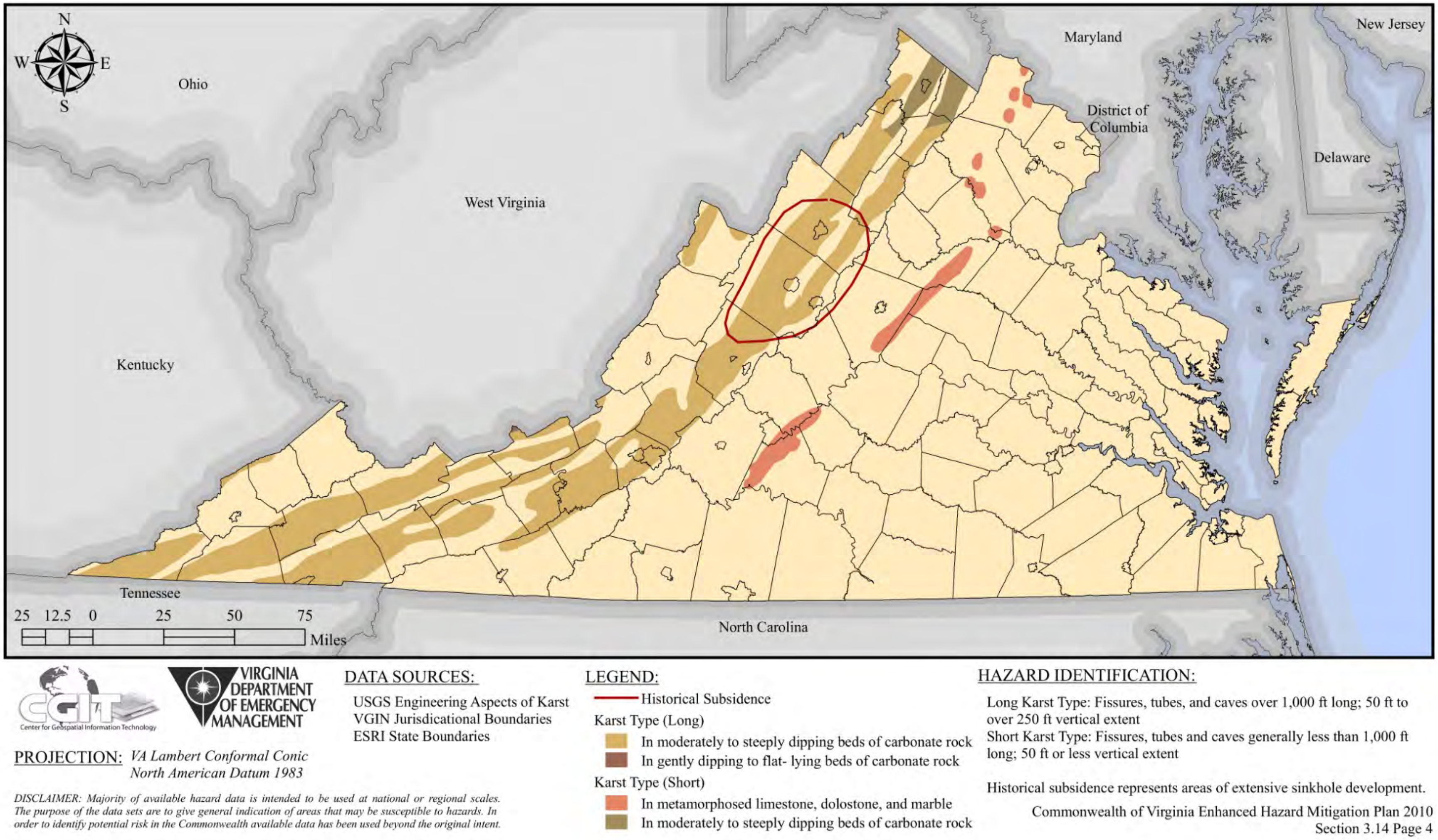

Figure 4.56. Karst Regions and Historical Subsidence in Virginia. *Source: Commonwealth of Virginia Emergency Operations Plan*

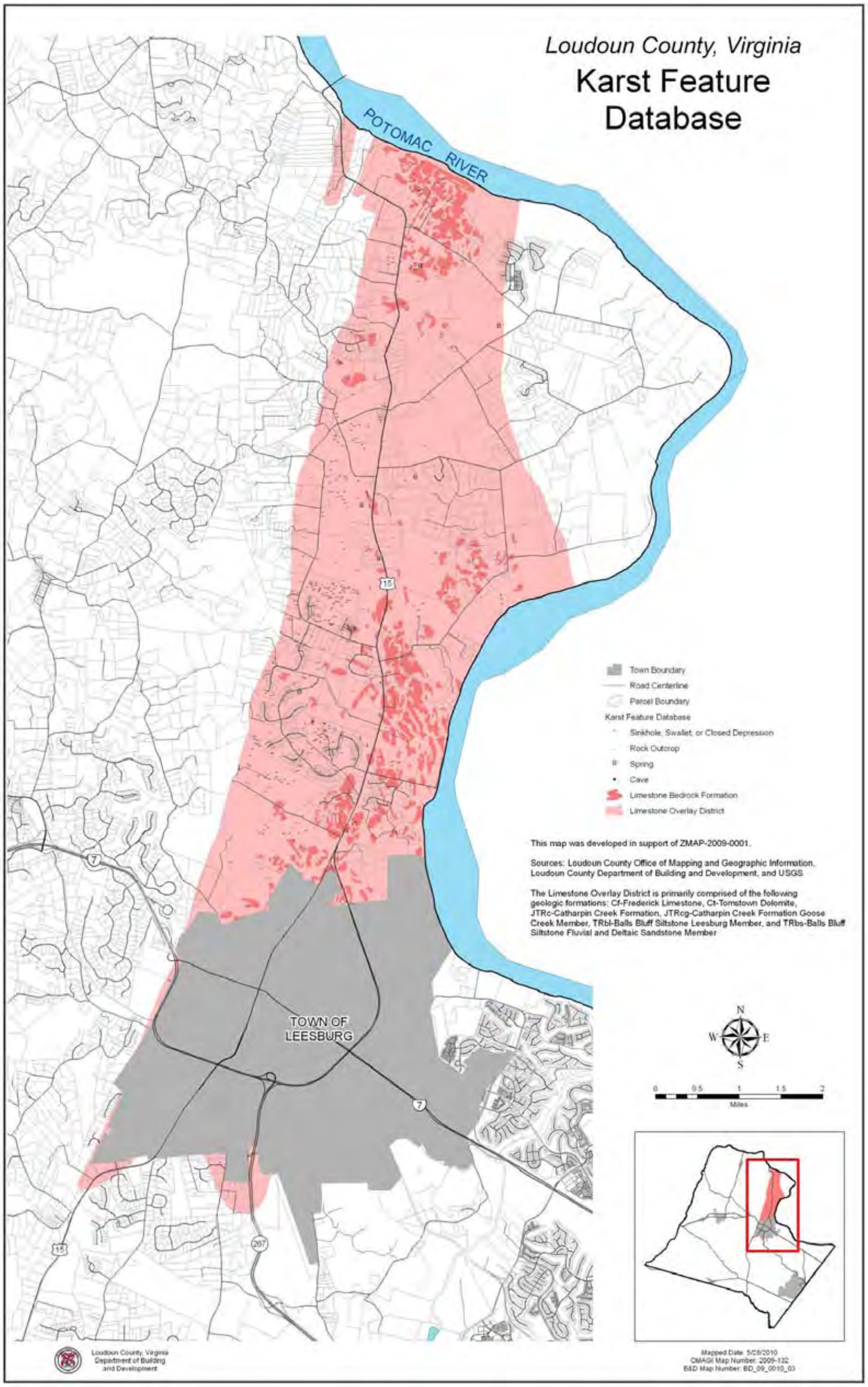

Figure 4.57. Loudoun County limestone district. Source: Loudoun County website http://www.loudoun.gov

3. Magnitude or Severity

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

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

Sinkhole formation is aggravated and accelerated by urbanization. Development increases water usage, alters drainage pathways, overloads the ground surface, and redistributes soil. According to FEMA, the number of human-induced sinkholes has doubled since 1930, costing nearly $100 million. The increasing frequency of sinkholes could be affected by reporting biases. A paper published by the USGS, Tampa, Florida shows a significant increase in sinkhole development that corresponds to a period of drought. Changes in ground water levels increase the overburden stress on the void roof increasing the potential for roof collapse. Thus using that period as indicating a larger trend may not be appropriate, especially given the context of the initial data. Additionally, Florida data suggests that the jump in sinkhole development in the 1987 to 1991 period was caused, at least in part, by natural events. Further, the reason for the jump in insurance payouts is likely the result of naturally caused sinkholes occurring under more expensively developed real estate[32].

4. Previous Occurrences

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

Sinkholes remain a possible occurrence in localized areas of the Northern Virginia region. To date, there have been no Federal Declared Disasters or NCDC recorded events for karst related events. Land subsidence is very site-specific. Currently there is no comprehensive long-term record of past events in Virginia.

Known events, although not comprehensive, include:

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

B. Risk Assessment

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

David Hubbard, geologist with the Virginia Department of Mines, Minerals, and Energy developed 1:24,000 scale sinkhole boundary maps during 1980 and 1988 for the State. Sinkhole distribution is shown in three main regions along the Valley and Ridge province. A total of 48,807 sinkholes have been mapped over 254 standard (7.5 minute) topographic maps for an average of 192.1 sinkholes per map. The southern third of the project area represented more than half of the mapped location. There appears to be an increase in the relative degree of karstification from north to south across the State of Virginia[33]. These maps are not currently available in digital format. Additional analysis may be able to be completed in future versions of this plan as digital data becomes available.

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

1. Probability of Future Occurrences

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

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

2. Impact & Vulnerability

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

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

3. Risk

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

As mentioned above, Loudoun County has adopted a LOD in their zoning ordinance that seeks to preserve and protect the unique geologic characteristics and the quality of the groundwater in its limestone area. The ordinance is intended to regulate land use and development in areas underlain by limestone and in areas with Karst features and Karst terrain in such a manner as to[34]:

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

Critical Facility Risk

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

There are approximately 22 HAZUS^{MH} critical facilities and 14 local critical facilities (some of which are most likely duplicates) located in or near mapped karst regions all located within Loudoun County (Table 4.81). Critical facilities provided by Loudoun County are shown in Table 4.82. Schools make up the majority of the critical facilities located within the hazard zones. Figure 4.58 shows the location of the mapped karst regions and the HAZUS^{MH} critical facilities.

The names and information for the HAZUS^{MH} and local critical facilities located in the karst regions are available in Critical Facility Risk, Appendix D2.

Table 4.81. HAZUS^{MH} critical facilities located in USGS karst zones.					
Jurisdiction	Fire Station	Medical Care Facilities	Police Station	School	Total
Loudoun County	1	2	0	4	**7**
Town of Leesburg	0	0	3	12	**15**
Total	**1**	**2**	**3**	**16**	**22**

Table 4.82. Local critical facilities located in USGS karst zones.					
Jurisdiction	Fire Station	Medical Care Facilities	Police Station	School	Total
Loudoun County	0	1	0	5	**0**
Town of Leesburg	0	1	0	9	**0**
Total	**0**	**2**	**0**	**14**	**0**

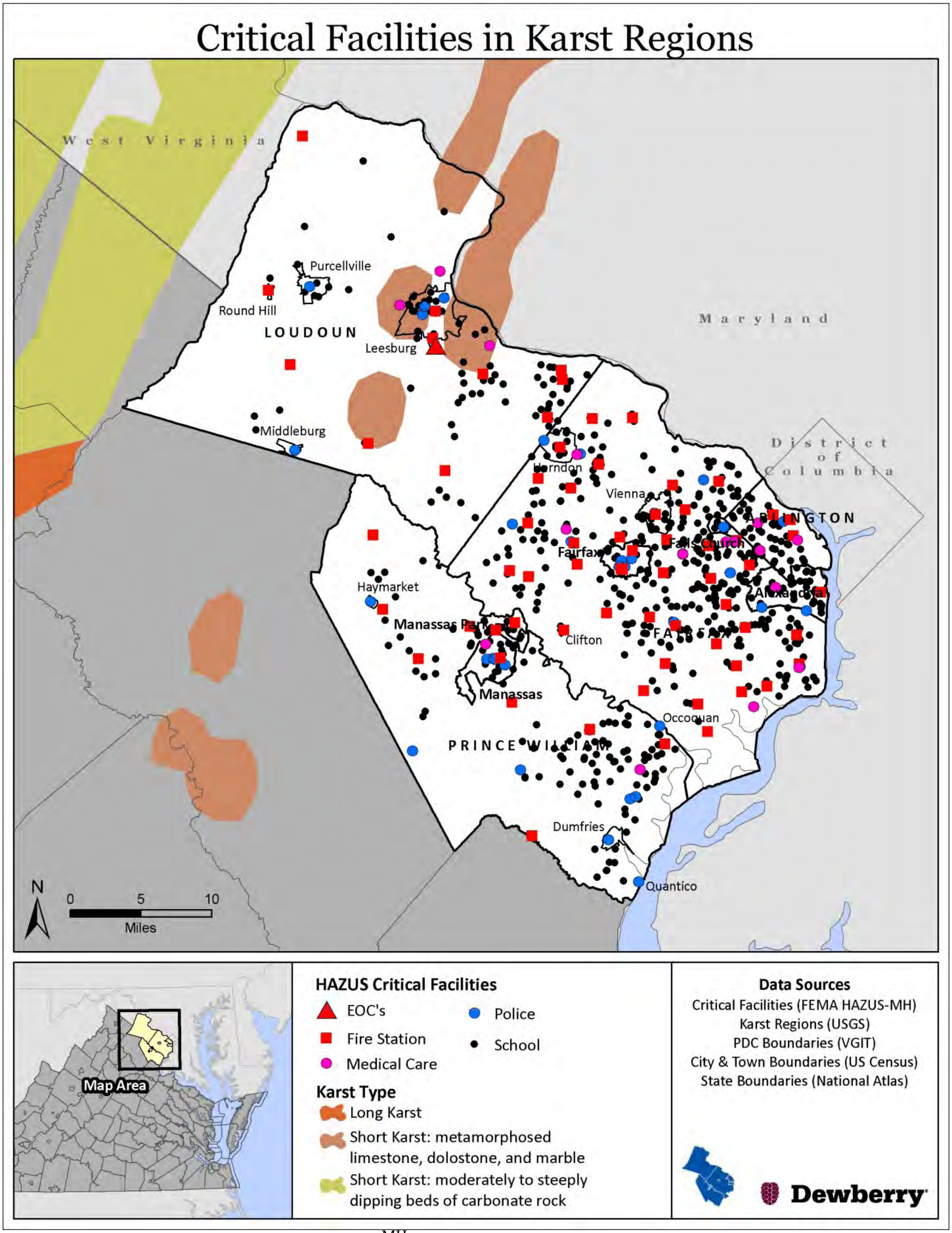

Figure 4.58. Karst regions and HAZUS^{MH} critical facilities.

Existing Buildings and Infrastructure Risk

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

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

Overall Loss Estimates and Ranking

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

The hazard ranking for land subsidence is based on events reported in the NCDC Storm Events database and a generalized geographic extent. These parameters in the karst risk assessment are illustrated in Figure 4.59, along with the overall hazard ranking. The entire planning region for the 2010 hazard ranking was considered to be at a Medium-Low risk due to land subsidence (karst). As discussed above, Loudoun County and the Town of Leesburg has a slightly elevated risk due to the short karst features in the region. Loudoun County has ordinances in place to help mitigate their risk to this hazard.

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

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

According to the 2006 qualitative assessment performed using the PRI tool, the sinkhole hazard scored a PRI value of 1.5 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.83 summarizes the risk levels assigned to each PRI category.

Table 4.83. 2006 Qualitative Assessment for Sinkholes					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Possible	Minor	Negligible	6 to 12 hours	Less than 6 hours

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

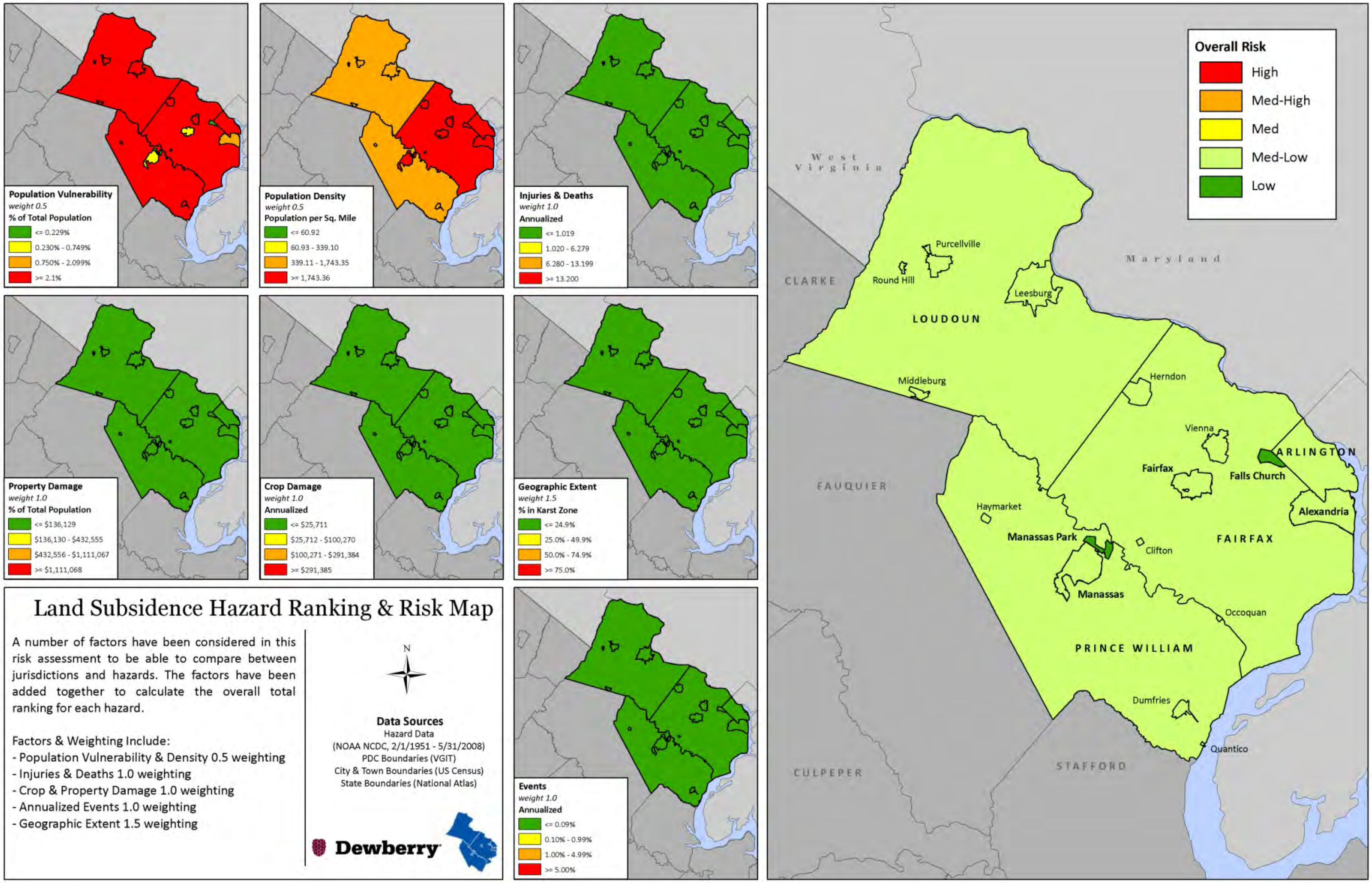

Figure 4.59. Land Subsidence (karst) hazard ranking and risk.

XIV. Dam Failure

NOTE: As part of the 2010 plan update, the Dam Failure hazard was reexamined and a new analysis performed. This new analysis included, but was not limited to: 1) refreshing the hazard profile; 2) updating the previous occurrences; 3) determining the 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

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

There are about 80,000 dams in the United States today, the majority of which are privately owned. Public owners include State and local authorities, and Federal agencies. The benefits of dams are numerous: they provide water for drinking, improved waterway navigation, hydroelectric power, flood control, and agricultural irrigation. Dams also provide enhanced recreation opportunities.

2. Geographic Location / Extent

The National Inventory of Dams (NID) was developed by the U.S. Army Corps of Engineers (USACE) in cooperation with FEMA's National Dam Safety Program. The full inventory contains over 75,000 dams, of which 7,700 are classified as major, and is used to track information on the country's water control infrastructure.

According to the NID, there are 12 major dams located in the Northern Virginia region and 73 non-major dams. Major dams are defined as dams being 50 feet or more in height, or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more. The state regulatory agency for dams is the Virginia Department of Conservation and Recreation (DCR) through the Dam Safety and Floodplain Management Program. In addition to the 12 major dams discussed here, the DCR tracks and regulates a number of other smaller dams (e.g., farm pond impoundments, etc.) that present less severe hazard threats. The DCR maintains additional data on State-regulated dams in the Northern Virginia region, as well as information on the potential impact of failure. There are no major levees located in the Northern Virginia region.

Of the 12 major dams located in the region, six are classified as “high” hazards where failure or mis-operation of the dam may cause loss of human life. Another five major dams are classified as "significant" hazards, where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns. Only one of the 12 major dams is classified as a "low" hazard. It is important to note that these hazard classifications are not related to the physical condition or structural integrity of the dam (nor the probability of its failure), but strictly to the potential for adverse downstream effects if the dam were to fail.

Table 4.84 lists some of the descriptive information made available for each of the 12 major dams in the Northern Virginia region, while each of their general locations are illustrated in Figure 4.60.

Table 4.84. Major Dams in the Northern Virginia Region. ***Source Army Corp of Engineers.***

Dam Name	Hazard Class	Drainage Area (Sq. Mi.)	Primary Purpose	Owner
Upper Occoquan	High	595	Hydroelectric	Fairfax County Water Authority
T. Nelson Elliott	High	74	Hydroelectric	City of Manassas
Barcroft	High	15	Recreation	Lake Barcroft Watershed Improv. Dist.
Lake Montclair	High	11	Recreation	Montclair Property Owners Association
Pohick Creek #1	High	6	Flood Control	Fairfax County Board of Supervisors
Lake Thoreau	High	1	Recreation	Reston Home Owners Association
Sleeter Lake	Significant	10	Irrigation	Round Hill Associates
Beaverdam Creek	Significant	6	Water Supply	City of Fairfax
Kingstowne Lake	Significant	1	Recreation	Kingstowne Limited Partnership
Possum Point Ash	Significant	< 1	Debris Control	Virginia Power
Breckinridge	Significant	< 1	Water Supply	U.S. Department of Defense (USMC)
Horsepen	Low	23	Other	Metro-Washington Airport Authority

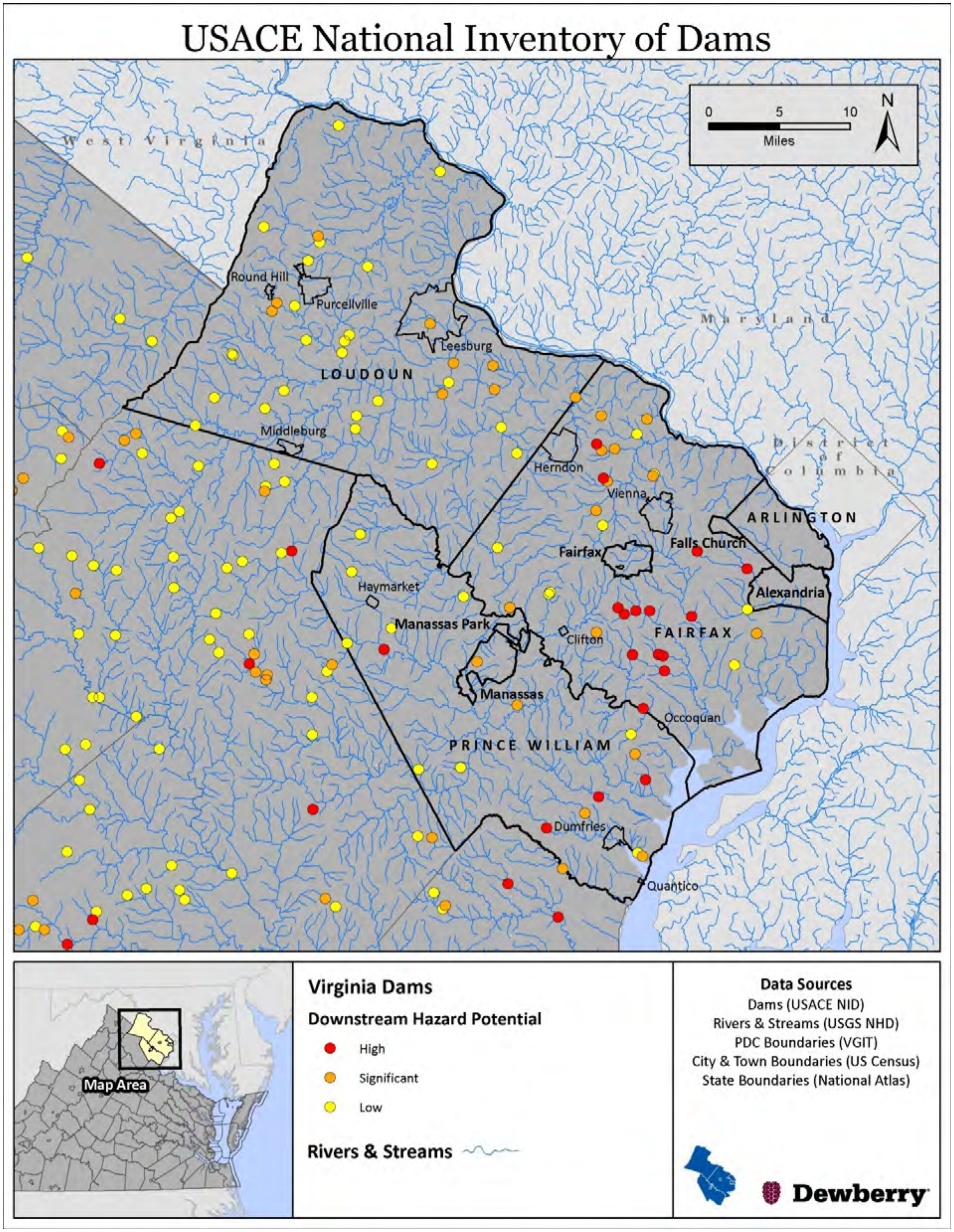

Figure 4.60. Dam downstream hazard potential. *Source: USACE*

3. Magnitude or Severity

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

4. Previous Occurrences

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

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

B. Risk Assessment

1. Probability of Future Occurrences

Predicting the probability of flooding due to dam failure requires a detailed, site-specific engineering analysis for each dam in question. Failure may result from hydrologic and hydraulic design limitations, or from geotechnical or operational factors.[35]

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

2. Impact & Vulnerability

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

3. Risk

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

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

There are 19 dams in the region classified as "high" hazard; all located in Fairfax and Prince William counties. These dams are summarized in Table 4.85. Again, these hazard classifications are not related to the physical condition or structural integrity of the dam (nor the probability of its failure), but strictly to the potential for adverse downstream effects from failure or mis-operation of the dam or facilities. While there are no dam failure inundation maps available for the Northern Virginia region, the distribution of dams throughout the region is shown in Figure 4.60.

Only two of the major dams classified as high hazard have a drainage area of more than 20 square miles (the Upper Occoquan dam in Fairfax County and the T. Nelson Elliot dam in Prince William County), making the possibility of a catastrophic dam failure event elsewhere highly unlikely in the region. The Northern Virginia region is likely more prone to intentional water releases by dam operators immediately prior to or during major rainfall events, though in such cases the releases are coordinated with local emergency management officials to minimize potential risks to people and property.

Table 4.85: NID Downstream Hazard Potential for Dams

Jurisdiction	Low	Significant	High	Total
Arlington County	0	0	0	**0**
Fairfax County	8	10	15	**33**
Town of Herndon	0	0	0	**0**
Town of Vienna	0	0	0	**0**
Town of Clifton	0	0	0	**0**
Loudoun County	24	8	0	**32**
Town of Leesburg	0	1	0	**1**
Town of Purcellville	0	0	0	**0**
Town of Middleburg	0	0	0	**0**
Town of Round Hill	0	0	0	**0**

Table 4.85: NID Downstream Hazard Potential for Dams				
Jurisdiction	**Low**	**Significant**	**High**	**Total**
Prince William County	9	5	4	**18**
Town of Dumfries	0	0	0	**0**
Town of Haymarket	0	0	0	**0**
Town of Occoquan	0	0	0	**0**
Town of Quantico	0	0	0	**0**
City of Alexandria	0	0	0	**0**
City of Fairfax	0	0	0	**0**
City of Falls Church	0	0	0	**0**
City of Manassas	0	1	0	**1**
City of Manassas Park	0	0	0	**0**
Total	**41**	**25**	**19**	**85**

Overall Loss Estimates and Ranking

Dam failure was not ranked with the hazards as a result of limited data available for analysis. As discussed regarding critical facilities, loss estimates were not developed due to the lack of specific data on dam failure probability or inundation zones. Fairfax County has the highest percentage of dams in the high and significant downstream hazard potentials in relation to the rest of the planning region.

According to the 2006 qualitative assessment performed using the PRI tool; the dam failure hazard scored a PRI value of 2.3 (on a scale of 0 to 4, with 4 being the highest risk level). Table 4.86 summarizes the risk levels assigned to each PRI category.

Table 4.86. 2006 Qualitative Assessment for Dam Failure					
	Probability	**Impact**	**Spatial Extent**	**Warning Time**	**Duration**
Risk Level	Unlikely	Critical	Small	Less than 6 hours	Less than one week

Future updates to this Plan will attempt to address dam failure vulnerability in greater detail, if warranted. This may include a detailed analysis of properties directly downstream of the high hazard dams in order to better determine the amount of people and value of properties located in potential inundation zones and thereby vulnerable to dam failure.

XV. Overall Hazard Results

The preceding sub-sections discuss the probability, impacts, vulnerability, and risks for each of the natural hazards that have been determined to have a significant impact on the Northern Virginia planning region. The final section of the HIRA provides an overall assessment, summary, and comparison of the overall hazard ranking and estimated losses. Risk to critical facilities has been discussed, to the extent possible, in each of the hazard sub-sections. These sections highlight the results of the analysis completed during the 2006 plan creation and 2010 plan update. Refer to the tables in these sections to determine what facilities or facility types are at greater risk for each hazard. This information is ideal for determining structural mitigation strategies. The names and information for the HAZUS^{MH} and local critical facilities in the wildfire risk zones are available in the Critical Facility Risk, Appendix D2.

Hazard Ranking

For the 2006 plan creation, the qualitative and quantitative assessments, combined with final determinations from the MAC, were fit into three categories for a final summary of hazard risk for the Northern Virginia region based on High, Moderate, or Low designations. During the 2010 plan update, the NCDC ranking, 2006 qualitative assessments, and feedback from the MAC helped to reposition the ranking into five categories of High, Medium-High, Medium, Medium-Low, and Low. The reclassification of the hazards allows for a clearer distinction of the hazards that pose the greatest risk in the Northern Virginia region. Table 4.87 summarizes the jurisdiction specific and overall region ranking.

The ranking methodology used in the 2010 update to the HIRA was originally developed for the VDEM by CGIT at Virginia Tech for the Commonwealth of Virginia Hazard Mitigation Plan 2010 Update. During the Northern Virginia HIRA kick-off meeting it the MAC agreed to use the scoring and ranking framework that was developed by the State, with modifications as deemed necessary.

To determine the overall hazard risk, the total hazard ranking values for each of the hazards were separately averaged to determine what hazards should be considered the most significant in the region. Through this analysis, it was determined that Flood, High Wind, Tornado, and Winter Weather pose the highest risk for communities in the Northern Virginia planning region. Figure 4.61 illustrates the jurisdictional rankings for these significant hazards.

It should be noted that although some hazards are classified as posing Low risk, their occurrence at varying or unprecedented magnitudes is still possible and should continue to be re-evaluated during future updates of this Plan. Hazards that were considered low risk or negligible were included as textual descriptions in the major hazard sections. This includes erosion, sea-level rise, lightning, hail, extreme heat, and extreme cold.

It should also be noted that the overall rankings for Flooding, Drought, Wind, Wildfire, and Winter Weather have been slightly altered to reflect the MAC's 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. For the hazards mentioned above, the City of Fairfax was updated to mirror Fairfax County.

It should also be noted that the overall rankings for Landslide was changed for the City of Alexandria from high to low based on the city's feedback.

Limitations of the data, specifically NCDC storm events data, are discussed in detail in the Risk Assessment and Methodology section of the HIRA.

Table 4.87. Overall Hazard Ranking by Jurisdiction

Jurisdiction	Flood	Wind	Tornado	Winter Weather	Drought	Earthquake	Landslide	Wildfire	Karst
Arlington County	High	High	High	High	Med-High	Med	Med	Med-Low	Med-Low
Fairfax County	High	High	High	High	Med-High	Med	Med-Low	Med	Med-Low
Town of Herndon									
Town of Vienna									
Town of Clifton									
Loudoun County	High	High	High	High	High	Med	Med-High	Med-Low	Med-Low
Town of Leesburg									
Town of Purcellville									
Town of Middleburg									
Town of Round Hill									
Prince William County	High	High	High	High	High	Med	Med-Low	Med	Med-Low
Town of Dumfries									
Town of Haymarket									
Town of Occoquan									
Town of Quantico									
City of Alexandria	High	High	High	High	Med-High	Med	Low	Med-Low	Med-Low
City of Fairfax	High	High	High	High	Med-High	Med	Med-Low	Med	Med-Low
City of Falls Church	High	High	Med-High	High	Med	Med-Low	Low	Low	Low
City of Manassas	High	High	High	High	Med-High	Med	Med-Low	Med-Low	Med-Low
City of Manassas Park	High	High	Med-High	High	Low	Med-Low	Low	Med-Low	Low
Overall Risk	**High**	**High**	**High**	**High**	**Med-High**	**Medium**	**Medium**	**Med-Low**	**Med-Low**

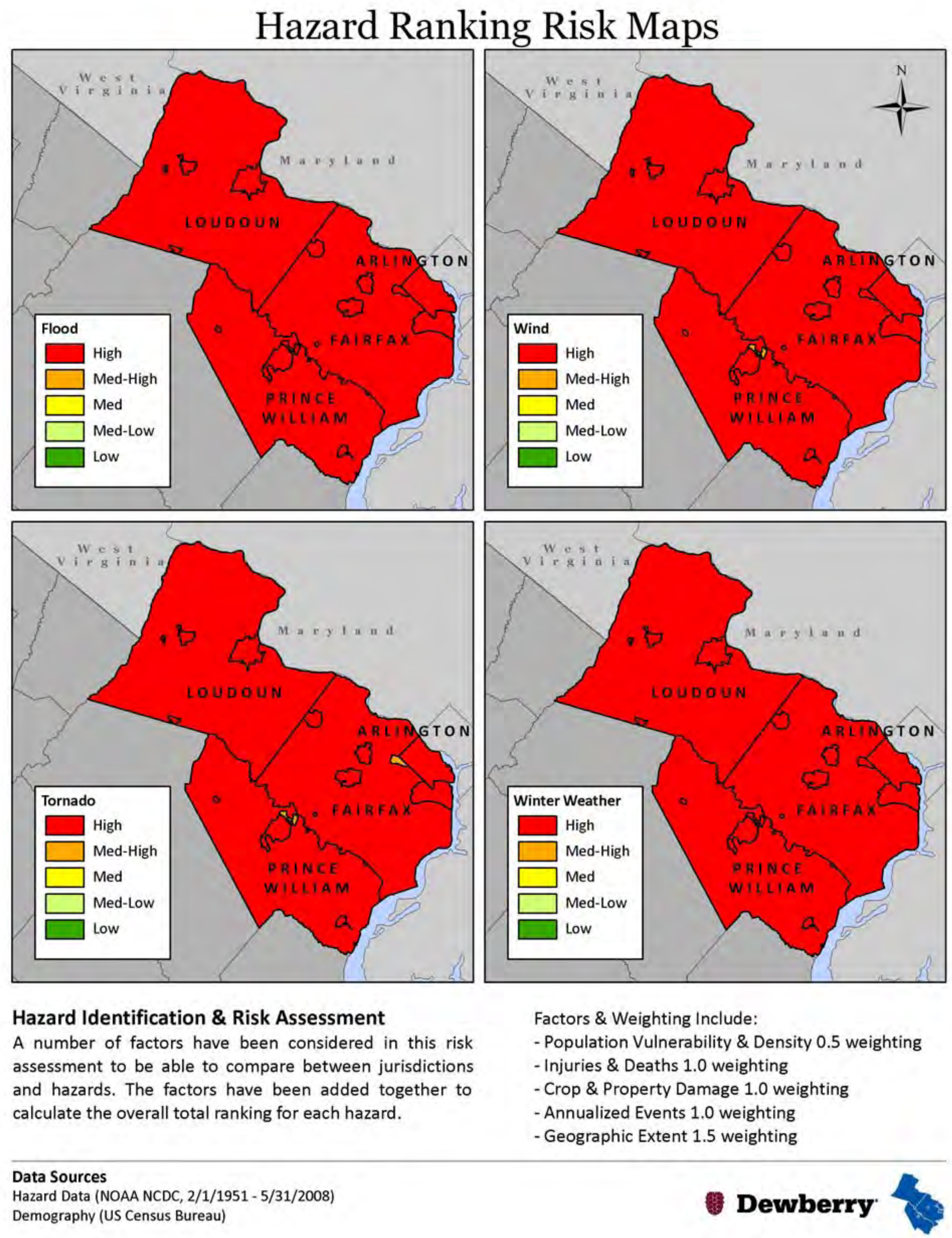

Figure 4.61. Overall Hazard Ranking for High Ranking Hazards

As mentioned above, during the 2006 plan creation, the MAC reviewed the results of quantitative and qualitative assessments shown in Table 4.88. This table summarizes the degree of risk assigned to each category for all identified hazards in the Northern Virginia region based on the application of the PRI tool (discussed in the Risk Assessment and Methodology section). Assigned risk levels were based on historical and anecdotal data, as well as input from the MAC. The results were then used in calculating PRI values and making conclusions for the qualitative assessment.

Table 4.88 Summary of Qualitative Assessment (2006)

Hazard	Category / Degree of Risk				
	Probability	Impact	Spatial Extent	Warning Time	Duration
Flood	Highly Likely	Critical	Moderate	6 to 12 hours	Less than one week
Severe Thunderstorms	Highly Likely	Limited	Small	Less than 6 hours	Less than 6 hours
Hurricanes and Tropical Storms	Possible	Critical	Large	More than 24 hours	Less than 24 hours
Tornadoes	Likely	Critical	Small	Less than 6 hours	Less than 6 hours
Winter Storms	Highly Likely	Limited	Large	More than 24 hours	Less than one week
Drought	Possible	Limited	Moderate	More than 24 hours	More than one week
Earthquakes	Unlikely	Minor	Large	Less than 6 hours	Less than 6 hours
Landslides	Possible	Minor	Small	12 to 24 hours	Less than 6 hours
Wildfire	Highly Likely	Minor	Small	Less than 6 hours	Less than one week
Sinkholes	Possible	Minor	Negligible	6 to 12 hours	Less than 6 hours
Erosion	Likely	Minor	Negligible	More than 24 hours	More than one week
Extreme Temperatures	Likely	Minor	Large	More than 24 hours	Less than one week
Dam Failure	Unlikely	Critical	Small	Less than 6 hours	Less than one week

Loss Estimation

The Northern Virginia planning region can expect over $8.5 million in annualized damages due to natural hazards impacting the region. These totals have been based on the available records from the NCDC storm events database, adjusted for inflation. Fairfax County makes up 45% of the overall total estimated losses, followed by Prince William County (14.6%). Table 4.89 below includes the total of all the hazards available in the NCDC storm events database.

Table 4.89. Total NCDC storm events data and annualized loss estimates.

Jurisdiction	Total Events	Total Crop Damage	Total Property Damage	Annualized Crop Damage	Annualized Property Damage	Total Annualized Loss
Arlington County	279	$2,860,525	$10,502,359	$157,315	$521,113	**$678,428**
Fairfax County	475	$2,620,475	$160,083,383	$146,300	$3,684,398	**$3,830,698**
Loudoun County	518	$7,317,346	$13,658,281	$418,180	$478,184	**$896,364**
Prince William County	364	$3,080,631	$26,141,962	$173,094	$1,069,445	**$1,242,539**
City of Alexandria	239	$2,860,525	$4,759,845	$157,315	$244,942	**$402,257**
City of Fairfax	25	$0	$94,131	$0	$4,482	**$4,482**
City of Falls Church	216	$2,860,525	$10,005,946	$157,315	$334,823	**$492,138**
City of Manassas	246	$3,014,556	$16,055,674	$169,207	$789,182	**$958,390**
City of Manassas Park	4	$0	$12,041	$0	$573	**$573**
Total	**2,366**	**$24,614,583**	**$241,313,623**	**$1,378,727**	**$7,127,143**	**$8,505,869**

Supplemental annualized loss estimates for flooding, hurricane winds, and earthquake have also been derived from the other sources as described in each of the individual hazard sections. NCDC did not include any historical information about damages due to land subsidence (karst/sinkholes), landslides, or wildfires, and as a result, these are not included in the loss estimates. Dam failure was not included as part of the hazard ranking (see the Dam Failure section for more details).

Based on the information from the NCDC storm events database, the Northern Virginia region can expect approximately $8,505,869 in annualized damages due to all the hazards that impact the region. As discussed, this data has limitations due to the amount of historical data available, and reporting of events. By substituting the supplemental annualized loss values for flood, hurricane wind, earthquake, and wildfire, the region could expect $110,217,797 in annualized damages due to all the hazards that impact the region.

Table 4.90 compares the 2006 and 2010 annualized loss estimates for each of the hazards. Differences in the values can be attributed to a wide range of factors, including significantly different methodologies for calculating losses that are further discussed in the individual hazard sections. The estimates provided for the 2010 update account for inflation.

High wind and winter weather each make up about one-third of the NCDC loss estimates for the region. Even so, these estimates are believed to be an underrepresentation of the actual losses experienced due to both hazards as losses from events that go unreported or that are difficult to quantify are not likely to appear in the NCDC database. Additionally, the HAZUS^{MH} loss estimates for flooding appear high in comparison to the other hazards. It should be kept in mind that the HAZUS^{MH} results take into account many additional factors that are not represented in the NCDC values, which only account for property and crop damages. The factors considered in the flood module are further explained in the flood section of this report.

Tornados have resulted in 59 injuries and two deaths in the region, followed by high wind events that resulted in 25 injuries and two deaths. Lightning, not included in the ranking, is responsible for 13 injuries and two deaths. There has been one injury and one death related to flooding in Arlington County as recorded in the NCDC storm events database. It is known that winter weather can cause significant injuries and related deaths (i.e., heart attack while shoveling; accidents due to icy roadways and sidewalks, etc.). At this time, no injury and death totals are available in the database.

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

Table 4.90. Hazard Ranking and Loss Estimate Comparison.

Ranking	Hazard Classification 2010	Hazard Classification 2006	PRI Value	2006 Annualized Loss	2010 Annualized Loss from NCDC	Annualized Loss from Other Sources	Data Source
High	Flood*	Flood	3.3	$3,912,000	$1,652,650	$99,049,000	FEMA HAZUS^{MH}
		Erosion	1.9	Negligible			
High	High Wind	Severe Thunderstorms	2.7	$1,110,000	$2,902,973	$4,795,691	FEMA HAZUS^{MH}
		Hurricanes and Tropical Storms	2.6	$33,723,000			
High	Tornadoes	Tornadoes	2.7	$731,000	$2,612,298		
High	Winter Storms**	Winter Storms	3	$109,000	$394,977		
		Extreme Temps	2.4	Negligible			
Med-High	Drought***	Drought	2.3	$2,207,000	$942,971		
		Extreme Temps	2.4	Negligible			
Medium	Earthquakes	Earthquakes	1.9	$341,000	None Recorded	$2,408,945	FEMA HAZUS^{MH}
Medium	Landslides	Landslides	1.6	Negligible	None Recorded		
Medium	Wildfire	Wildfire	2.6	$25,000	None Recorded	$13,915	VDOF 1993-2008 wildfire statistics
Med-Low	Sinkholes	Sinkholes	1.5	Negligible	None Recorded		
Med-Low	Dam Failure	Dam Failure	2.3	Negligible	None Recorded		
				$42,158,000	**$8,505,869**	**$106,267,551**	
					$110,217,797		

**Erosion included but not ranked or annualized*

*** Extreme cold included but not ranked or annualized*

****Extreme heat included but not ranked or annualized*

Unique Risks for Local Jurisdictions

During the 2006 plan creation, officials from each of the participating local jurisdictions were asked to provide information on any unique hazard risks that were omitted or not satisfactorily addressed during the drafting stage of the Plan and through a survey instrument distributed at the Mitigation Strategies Meeting.

In response to that request, officials from three jurisdictions responded with specific concerns. These responses are summarized in Table 4.91. No other local jurisdiction identified unique hazards of concern beyond those already covered under this Plan.

Table 4.91. Unique Risks and Hazard Concerns

Jurisdiction	Unique Risk / Hazard Concern
City of Fairfax	A large petroleum tank farm facility located in the city, and potentially vulnerable to manmade and natural hazards including lightning, high winds, and flooding.
City of Manassas	The airport (and particularly areas around Broad Run) is prone to frequent flooding. A nearby mobile home park (approximately 200 units) is identified as presenting a unique risk, in addition to approximately 10 commercial buildings and the air traffic control tower.
Prince William County	Pipeline rupture and train derailment identified as unique risks.

Limitations of Data

It should be noted that the data sources used in the hazard ranking and loss estimation are varied in their degree of completeness, accuracy, and precision as the ability to accurately prioritize some of the hazards would be improved by better information (e.g., landslide, karst, etc.). Further discussion on the data limitations and how the data was adapted for analysis is available in the Risk Assessment and Methodology section.