Commonwealth of Virginia Emergency Operations Plan
Standard Hazard Mitigation Support Annex 3
(Volume II)

CHAPTER 3

Hazard Identification and Risk Assessment (HIRA)

Section 3.8b:
Tornado Wind

2010

SECTION 3.8b

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Section 3.8b: Tornado

City of Suffolk Tornado
April 28, 2008
Source: Civik Air Patrol and VDEM

Description

Tornadoes are rotating columns of air extending from a thunderstorm cloud to the ground; while most tornadoes measure less than 200 feet wide and have wind speeds less than 100 mph, severe tornadoes sometimes occur with much broader swath widths and wind speeds approaching 200 mph, or even higher. Tornadoes with winds in excess of 75 mph begin to cause significant structural damage to most buildings, but tornadoes with lower wind speeds can also cause secondary damage, for example, by causing a tree to fall into a house. In the United States, tornadoes have been classified on the Fujita Scale, assigning numeric scores from zero to five (or higher) based on the severity of observed damages. The traditional Fujita scale, introduced in 1971, was used to rate the intensity of tornadoes thereafter, and was also applied to previously documented tornadoes (Table 3.8b-1). Starting in February of 2007, an "enhanced" Fujita scale was implemented, with somewhat lower wind speeds at the higher F-numbers, and more thoroughly-refined structural damage indicator definitions. Table 3.8b-2 shows the differences between the old and new tornado intensity scales.

In Virginia, tornadoes primarily occur from April through September, although tornadoes have been observed in every month. Low-intensity tornadoes occur most frequently; tornadoes rated F2 or higher are very rare in Virginia, although F2, F3, and a few F4 storms have been observed. In comparison to other states, Virginia ranks 28th in terms of the number of tornado touchdowns reported between 1950 and 2006; Midwestern and Southern states ranked significantly higher.[1]

Table 3.8b- 1: Original Fujita Scale (F Scale) classifications[2]

F #	Est. Wind (mph)	Typical Damage
F0	< 73	Light: chimneys damaged, shallow-rooted trees pushed over
F1	73-112	Moderate: mobile homes pushed off foundations, cars blown
F2	113-157	Considerable: mobile homes demolished, trees uprooted, roofs torn off frame houses

[1] Determined from CGIT analysis of SVRGIS tornado database, discussed in the Probability section
[2] Adapted from http://www.spc.noaa.gov/faq/tornado/f-scale.html

F #	Est. Wind (mph)	Typical Damage
F3	158-206	Severe: roof and walls torn down, trains overturned, cars thrown
F4	207-260	Devastating: well-constructed walls leveled, large objects thrown
F5	261-318	Incredible: homes lifted and carried, cars thrown 300 ft, trees de-barked

Table 3.8b- 2: Operational EF scale classifications in relation to original F Scale[3]

Fujita Scale			Derived EF Scale		Operational EF Scale	
F #	Fastest ¼ mile (mph)	3 Second Gust (mph)	EF #	3 Second Gust (mph)	EF #	3 Second Gust (mph)
0	40-72	45-78	0	65-85	0	65-85
1	73-112	79-117	1	86-109	1	86-110
2	113-157	118-161	2	110-137	2	111-135
3	158-207	162-209	3	138-167	3	136-165
4	208-260	210-261	4	168-199	4	166-200
5	261-318	262-317	5	200-234	5	Over 200

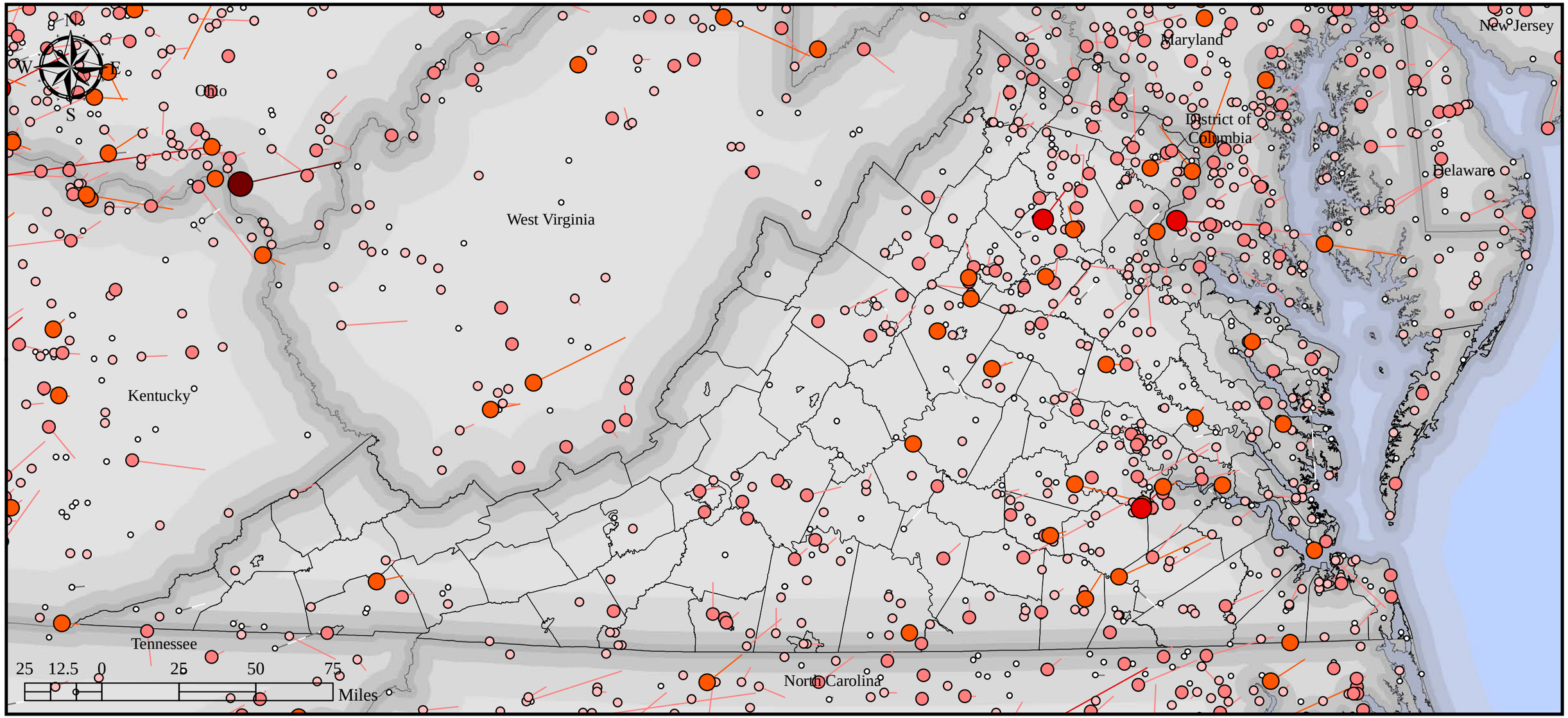
Historic Occurrence

Numerous low-intensity tornadoes are reported almost every year in Virginia. Figure 3.8b-1 shows the historic tornado touchdowns and tracks. Of the more intense tornadoes which have occurred, a few recent incidents stand out from the rest:[4]

- On June 13, 1951, an F3 tornado went through the heart of Richmond creating a four mile path and over one million in damages. Reports suggest that it was a multi-vortex tornado with four visible vortices.
- On August 6, 1993, four tornadoes were reported across southeast Virginia, ranging in intensity from F2 to F4. The F4 tornado impacted commercial and residential areas in Petersburg, Colonial Heights, and Hopewell, killing 4 people, injuring 246, and causing about $50 million in damages.
- On September 4, 1999, an F2 tornado caused about $7.7 million in damages in Hampton, as well as many injuries.
- On the afternoon of September 17, 2004, thunderstorms produced twelve tornadoes across the state, causing over $65 million in damages, with $54 million of the damages occurring at a factory in Fieldale.
- On April 28, 2008, an F3 tornado traveled from north of Suffolk to the Norfolk Naval Air Station, causing a total of $30 million in commercial and residential damage, with at least a dozen homes completely destroyed.
- On May 8, 2008, an EF2 tornado caused $10 million damage in Berea (North of Fredericksburg); 160 homes damaged, with 25 rendered uninhabitable.

[3] http://www.spc.noaa.gov/faq/tornado/ef-scale.html, http://www.spc.noaa.gov/faq/tornado/ef-ttu.pdf
[4] Source: National Climatic Data Center (NCDC) Storm Events Database

Figure 3.8b-1: Historic Tornado Touchdowns and Tracks: 1950 - 2006



DATA SOURCES:

SVRGIS
VGIN Jurisdicational Boundaries
ESRI State Boundaries

LEGEND:

Tornado F-Scale

- 0
- 1
- 2
- 3
- 4
- 5

HAZARD IDENTIFICATION:

Historic tornado touchdowns and tracks are symbolized for visual effect and are not drawn to scale. Actual tornado swath widths vary considerably, although more intense tornadoes are generally wider.

PROJECTION: *VA Lambert Conformal Conic*
North American Datum 1983

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

Risk Assessment

Probability

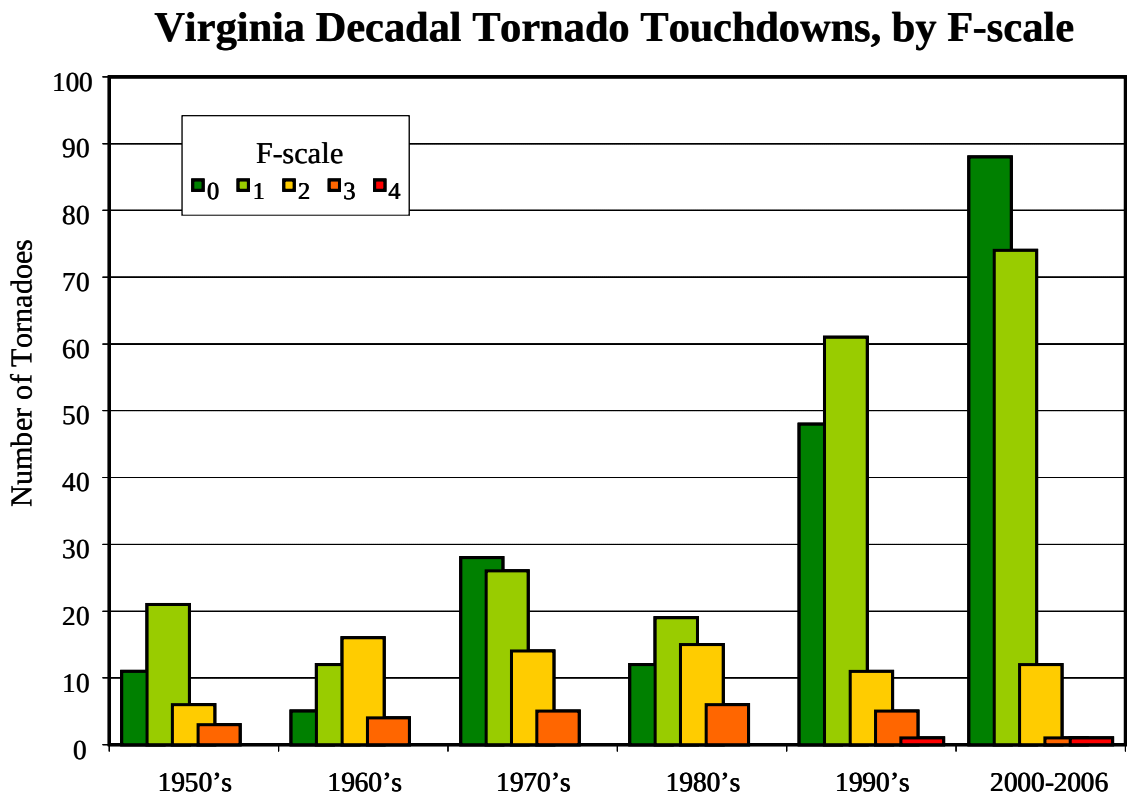
Tornado formation is a complex process for which it is difficult to develop a physically-based model. The simplest way to estimate the probability of future tornadoes is to analyze historical tornado incidence data and generate descriptive statistics, such as the frequency of occurrence. Records of historical tornadoes are maintained by the National Climatic Data Center (NCDC) and by the National Weather Service's Storm Prediction Center. Tornado incidence is rare, especially in Virginia, and the available historic data is insufficient to estimate tornado probability conclusively. Therefore, while the data can be used to show the geographic variation in tornado frequency, such data should not be taken as an exact determination of tornado probability.

John Hart, at the National Weather Service Storm Prediction Center in Norman Oklahoma, has developed a graphical program, SeverePlot[5], to display a database of tornado occurrence that was derived from the NCDC Storm Events Database. This database dates from 1950 to 2006, and also contains data on hail and high wind. Bryan Smith, as an intern with the National Weather Service in Indianapolis, has converted the SeverePlot program data into shapefiles which are ready to use in GIS software; these files are collectively referred to as SVRGIS.[6] Other researchers have developed tornado databases extending further back into history, or which contain additional attributes. However the SVRGIS dataset, based on SeverePlot data, was sufficient for the purpose of this analysis.

In reviewing the historic tornado database, a few important points must be noted. First, although tornadoes are reported back to the year 1950, there are vastly higher numbers of low-intensity (F0 and F1) tornadoes reported in recent decades (refer to Figure 3.8b-2). The general consensus among climatologists is not that there are more low-intensity tornadoes occurring in recent years; rather, that with increased population and advanced technology such as weather radar, more of these low-intensity tornadoes are observed and documented than were historically. Second, while tornadoes are reported throughout the state, there are more tornadoes reported in areas of higher population. This may be due in part to the fact that many population centers are located in areas where tornadoes are likely to occur, but the correlation is probably also indicative of human bias in reporting. Conversely, the mountainous counties in the western part of the state have lower populations and in some cases, no reported historical tornadoes, but tornado occurrence is still theoretically possible, albeit less probable.

[5] The current version of this software is available online at: http://www.spc.noaa.gov/software/svrplot2/
[6] The current collection of SVRGIS data is available online at: http://www.crh.noaa.gov/ind/?n=svrgis

Figure 3.8b- 2: Historic tornado counts in Virginia



Data source: SVRGIS dataset

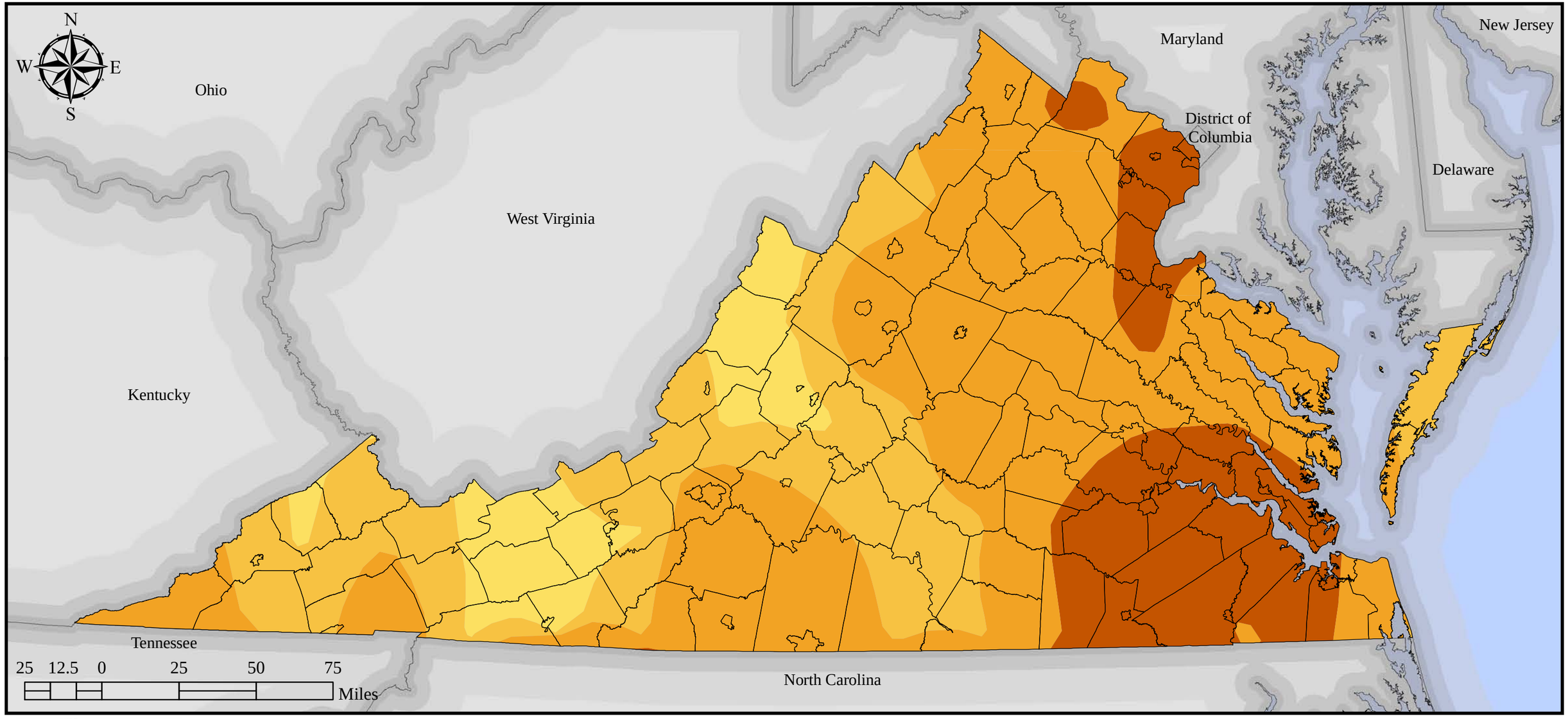
The frequency analysis conducted on the SVRGIS tornado data is described in the Tornado Hazard Frequency Analysis Appendix (section 3.8c). In brief, this analysis consisted of tabulating the area impacted by tornadoes for individual cells in a grid overlaid on the state of Virginia. The tornado hazard frequency is calculated as the total area impacted by each tornado in the grid divided by the area of the grid cell and the number of years in the period of record. Virginia annual tornado hazard frequencies were calculated in each analysis grid cell, for tornado intensities F0, F1, F2, and F3+. The annual hazard frequency of each tornado intensity class was calculated separately; these results are added together to depict the overall tornado hazard frequency as shown in Figure 3.8b-3. In calculating the F0 and F1 intensity hazard frequencies, the 1985 – 2006 subset of the SVRGIS dataset was used, as this period was estimated to be more representative of the true frequency of these low-intensity tornadoes. In calculating the F2 and F3+ intensity hazard frequencies, the entire period of record (1950 – 2006) was used, as the reported frequency of occurrence has not changed noticeably over time. Figure 3.8b-4 shows the Significant Tornado Hazard Frequencies (for F2 and larger tornadoes).

In calculating these annual hazard frequencies, a multiplier of one million was added to make the results easier to read. When interpreting these results, for example, a value of 1 actually means that the annual tornado hazard frequency at a point is 1 divided by 1 million, or 0.000001 –essentially, assuming that past trends prove true,

that there would be a 1 in 1 million chance that a given point would experience a tornado in a given year.

The results of the tornado frequency analysis show a much higher incidence of tornadoes in the eastern parts of the state, and a much lower incidence of tornadoes in the mountainous western parts of the state. Despite concerns about biases in the historical data, the results of the probability analysis provide a reasonable depiction of the relative tornado risk in different regions of the state. Finally, while the overall statewide probability of tornadoes is low relative to many other states, the probability of tornadoes in Virginia should not be overlooked, especially in the eastern parts of the state.

Figure 3.8b-3: Tornado Hazard Frequency



DATA SOURCES:

SVRGIS / SeverePlot
VGIN Jurisdicational Boundaries
ESRI State Boundaries

PROJECTION: *VA Lambert Conformal Conic*
North American Datum 1983

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LEGEND:

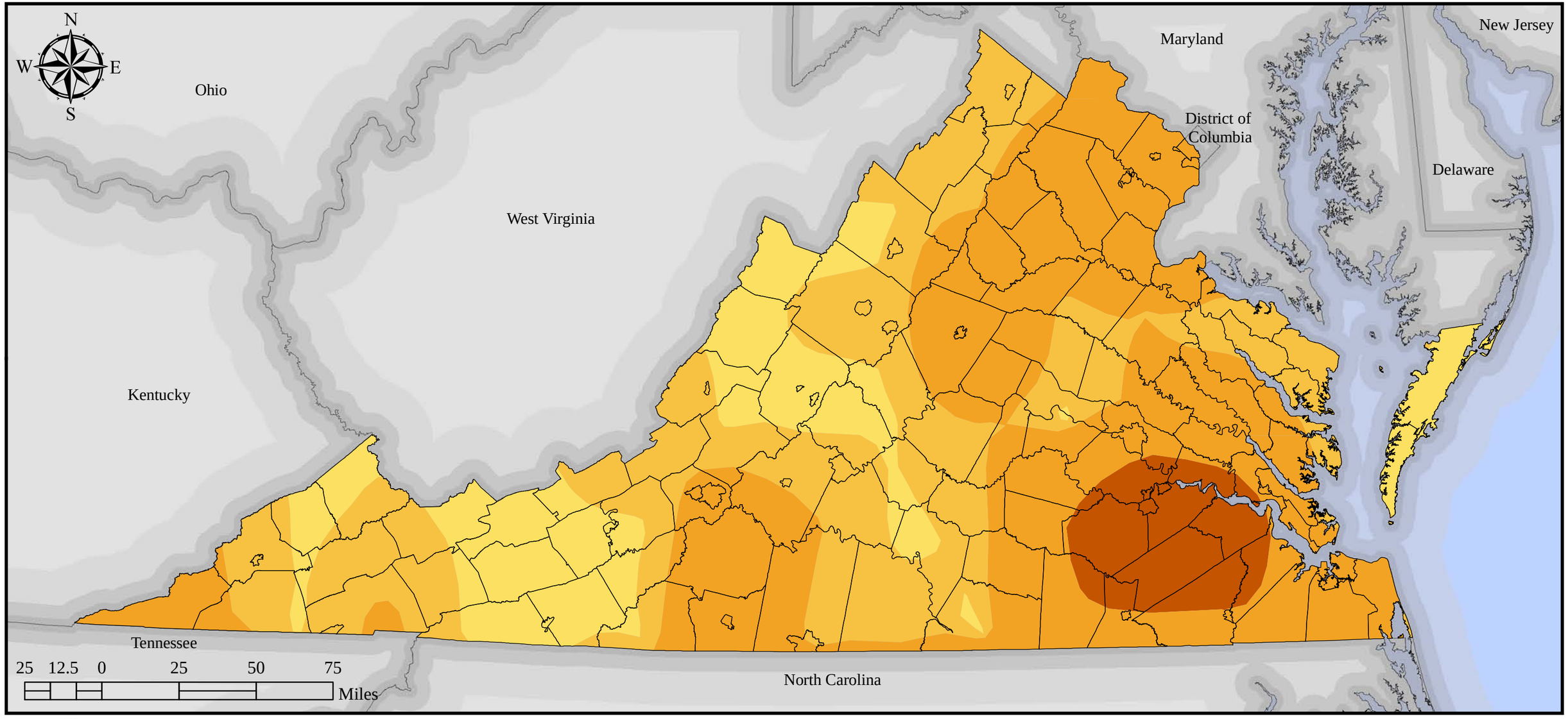
Annual Tornado Hazard Frequency
Times One Million

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

HAZARD IDENTIFICATION:

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

Figure 3.8b-4: Significant Tornado Hazard Frequency (F2+)



Center for Geospatial Information Technology

VIRGINIA DEPARTMENT OF EMERGENCY MANAGEMENT

DATA SOURCES:

SVRGIS / SeverePlot
VGIN Jurisdicational Boundaries
ESRI State Boundaries

PROJECTION: *VA Lambert Conformal Conic*
North American Datum 1983

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LEGEND:

Annual Tornado Hazard Frequency
Times One Million

0 - 1.25	Low
1.251 - 10	Medium-Low
10.1 - 100	Medium-High
100.1 - 252	High

HAZARD IDENTIFICATION:

Annual tornado hazard frequency is an estimate of the frequency with which a point will experience a tornado, interpolating from neighboring tornado impact areas over the period of record. This map shows hazard frequency of "significant" tornadoes, defined as F2 or greater. Note that "high" frequency in the state of Virginia is still rather low in comparison to many midwestern and southern states.

Impact and Vulnerability

Tornado vulnerability is based on building construction materials and standards, availability of safe rooms, and advanced warning system capabilities. Low-intensity tornadoes may not completely destroy a well-constructed building, although even the most well-constructed buildings are vulnerable to the effects of a more intense (F2 or higher) tornado. In cases involving intense tornadoes, the best defense against injury or death is a properly engineered safe room or tornado shelter.

Tornadoes are high-impact, low-probability hazards. The net impact of a tornado depends on the storm intensity and the vulnerability of development in its path. An intensity-damage relationship for tornadoes would need to consider a variety of variables, and such a relationship has not been established for Virginia. Theoretically, an intensity-damage relationship could be estimated based on an analysis of reported damages, but such an analysis was beyond the scope of this planning process. In FEMA's Benefit-Cost Analysis Toolkit (Version 3.0, July 2006), the calculations to determine whether tornado shelter construction is justified are based on injuries and deaths prevented, not total economic loss. This approach was based on relationships between injuries/deaths, tornado F-scale, and basic building construction type. The next version of the FEMA Benefit-Cost Analysis Toolkit may or may not be based on similar calculations.

Risk

A formal calculation of annualized tornado risk, as a function of probability and impact, has not been performed for this analysis. Tornado probability has been quantified in terms of historical hazard frequency, and despite concerns regarding population bias in the original reporting, the results of the tornado hazard frequency analysis provide a reasonable estimation of the relative tornado hazard probability across the state. However, tornado impact has not been quantified in the form of an intensity-damage relationship that could be used for tornado damage prediction.

Rough estimates of annualized losses due to tornadoes can be generated based on the NCDC Storm Events database, which documents the damage costs associated with many tornadoes. In the 58 years from 1951 through 2008, NCDC reports a statewide total of $704 million dollars in tornado property damages, or an annual average of about $12 million per year (all dollars expressed in inflation-adjusted 2007 dollars).

Tornado hazard zones were developed from the annual tornado hazard frequency results. This scoring system, as shown in Table 3.8b-3, is used to identify facilities "at risk", and to identify the jurisdictions exposed to the greatest tornado hazards.

Table 3.8b- 3: Tornado hazard frequency scores.

Tornado Hazard Zone	Annual Tornado Hazard Frequency (times 1 million)
Low	<1.25
Medium-Low	1.25-10
Medium-High	10-100
High	100-316

State Facility Risk

State facility risk was determined by intersecting the VAPS facilities with the Annual Tornado Hazard Frequency layer. Risk for building polygons was determined by taking the area weighted average for the building and assigning a risk category based on the results. Intensity-damage information due to tornadoes has not been quantified at this time; as a result annualized loss estimates have not been calculated for state facilities.

As shown in Table 3.8b-4, when these categories are applied to the Virginia state-owned/operated facilities database (VAPS), a large number of facilities are identified as being in the medium-high or high tornado hazard zones. Since the more urbanized eastern portions of the state are also the areas of higher tornado hazard, these results are not surprising.

Table 3.8b- 4: State facilities in tornado hazard zones.

Tornado Hazard Zone	Number of State Facilities	Total Building Value
Low	441	$440,827,319
Medium-Low	1,391	$2,386,837,087
Medium-High	4,209	$6,859,450,861
High	2,910	$6,173,686,180
Total	**8,951**	**$15,860,801,447**

The results of this analysis indicate 2,901 buildings are at high risk for tornados. A total of 116 different state agencies are situated within a high risk zone. The top five agencies by building value have been listed in table 3.8b-5. The agencies listed represent 19% of the buildings and 55% of total building value that is within a high risk zone.

Table 3.8b- 5: The top five agencies in a high risk zone.

Agency	Number of Buildings in High Hazard	Building Value in High Hazard
The College of William & Mary	197	$1,045,940,682
George Mason University	140	$687,949,328
Old Dominion University	130	$653,394,489
Virginia Commonwealth University	70	$596,397,753
Department of General Services	28	$436,022,905
Total	**565**	**$3,419,705,157**

Critical Facility Risk

Critical facilities were intersected with the Annual Tornado Hazard Frequency layer to determine the corresponding risk zone. The results of this analysis are in table 3.8b-6. A large number of schools are identified as being in the Medium-High or High tornado hazard zones, followed by law enforcement and fire station buildings. Approximately 29% of critical facilities are located in high tornado hazard zones. Intensity-damage information due to tornadoes has not been quantified at this time; as a result annualized loss estimates have not been calculated for critical facilities.

Table 3.8b- 6: Critical facilities in tornado hazard zones.

Tornado Zones	Law Enforcement	Fire Station	Hospital	Nursing Home	School	EOC	Total
Low	38	27	8	19	306	15	**413**
Medium-Low	87	79	20	44	837	26	**1,093**
Medium-High	235	203	58	138	2,054	63	**2,751**
High	182	128	44	78	1,278	43	**1,753**
Total	**542**	**437**	**130**	**279**	**4,475**	**147**	**6,010**

Jurisdictional Risk

The jurisdictional tornado hazard rank is based on NCDC Storm Events database parameters, as well as the tornado hazard frequency analysis. The "geographic extent" score for a given jurisdiction is higher in areas with a higher tornado hazard frequency. These scores were assigned by calculating the area-weighted average tornado hazard frequency in each jurisdiction, and then applying the scoring system in Table 3.8b-3. Figure 3.8b-5 shows maximum geographic extent, as well as the other parameters, for tornado events on a countywide basis.

The overall tornado hazard rankings for jurisdictions in the Commonwealth were based on the geographic extent scores, population, and measures of historical impact from NCDC including injuries/deaths, property damage, crop damage, and the reported number of events. The overall Tornado hazard rank for the Commonwealth, shown in Figure 3.8b-5, shows that the jurisdictions facing the greatest tornado risk are mostly in the eastern and northern parts of the state,

although a few jurisdictions in southern and southwest Virginia also receive an elevated risk rating.

The jurisdictions with a "high" tornado risk include:

- Albemarle County
- City of Alexandria
- City of Arlington
- Augusta County
- City of Chesapeake
- Chesterfield County
- Colonial Heights
- Dinwiddie County
- Fairfax County
- City of Fairfax
- Fauquier County
- Fluvanna County
- Frederick County
- City of Fredericksburg
- City of Hampton
- Hanover County
- Henrico County
- Henry County
- City of Hopewell
- Isle of Wight County
- James City County
- King George County
- Loudoun County
- City of Manassas
- City of Newport News
- City of Norfolk
- City of Portsmouth
- Prince George County
- Prince William County
- City of Richmond
- Stafford County
- Suffolk County
- Surry County
- Sussex County
- City of Virginia Beach
- York County

Tornadoes occur almost every year in Virginia, and their incidence is significantly higher in the south-eastern and northern parts of the state. Although some jurisdictions may have few (or no) reported tornadoes in the historical record, tornadoes can still possibly occur in these jurisdictions.

Local Plan Risk Assessment

Local plans were reviewed for spatial data sources used, historical occurrences, hazard probabilities, vulnerability, loss estimations, and land use and development trends. When available, this information supplements the text and figures of each of the sections in this revision.

Twenty-four plans provided a general description of tornados, statistics and impacts. Several of the plans included tornado in the "wind" hazard for their region. A lot of ambiguity exists in how jurisdictions define specific hazards. This variability can drastically impact how the local plans are compared to each other; section 3.6 further addresses this issue.

Six plans calculated annualized loss for tornado using the NCDC storm events database. The NCDC database was also used in the ranking for this revision. Table 3.11-7 compares the local and statewide loss values. Since both the local and

statewide revision used NCDC one would assume that the values should be identical. The difference in the loss estimates can be attributed to several factors including the time period of the events. The statewide analysis uses events from 1951 through 2008, since the local plans were approved in 2004 through 2006 one could assume that the state plan has anywhere from two to four years more years of events used in the analysis. NCDC used many different storm event categories in their database. The categories used in this analysis are fully described in section 3.3 and in Table 3.3-4; the categories used by the local plans were not provided.

Table 3.8b- 7: Comparison of local plan and statewide annualized loss.

PDC/Jurisdiction	Annualized Tornado Loss	
	Local Plan	2009 State Plan
Northern Virginia RC	$731,000	$2,656,217
Southside Hampton Roads	$309,725	$1,469,245
Rappahannock-Rapidan RC	$186,328	$488,206
Commonwealth RC (Virginia's Heartland)	$105,157	$239,888
Southampton County	$6,127	$24,193
City of Franklin	$9,091	$0

Comparison with Local Ranking

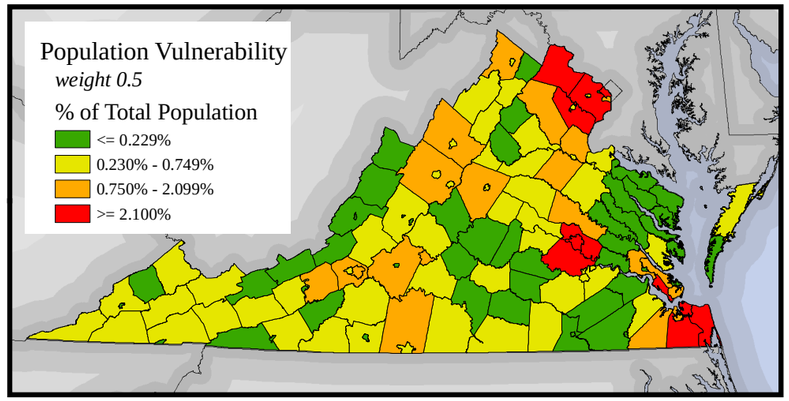
Northern Virginia RC (Arlington County, Fairfax County, Loudoun County, Prince William County, City of Alexandria, Fairfax City, Falls Church City, Manassas City, Manassas Park City) and Middle Peninsula PDC (Essex County, King and Queen County, King William County, Middlesex County, Gloucester County, Mathews County) ranked tornado as a high hazard, and the City of Chesapeake ranked tornado as medium-high hazard in its local plan.

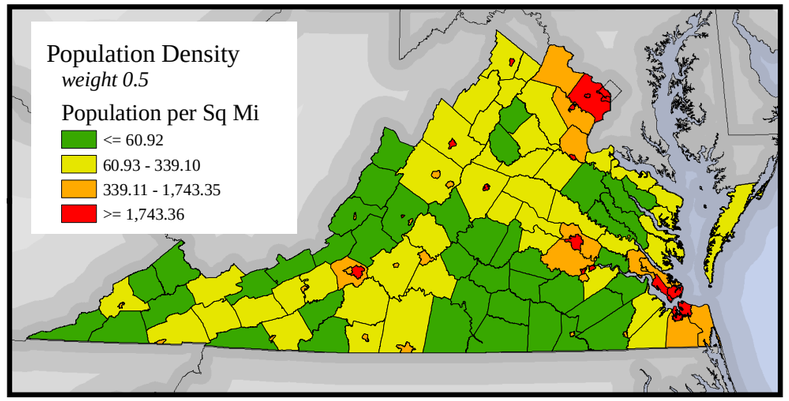
Overall, two PDC/local plans ranked tornado as high, one as medium-high, ten as medium, and eleven as a low hazard. The average of the local plans for tornado was medium-low. The 2010 statewide analysis has ranked tornado medium. Section 3.6 (Table 3.6-2) includes the complete ranking of all the local plans.

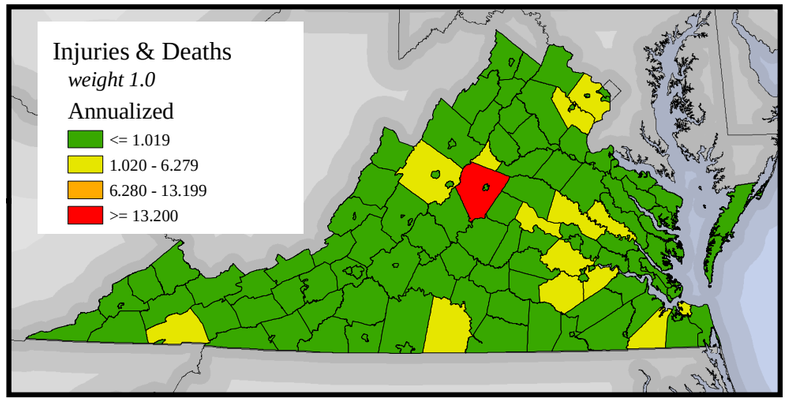
Changes in Development

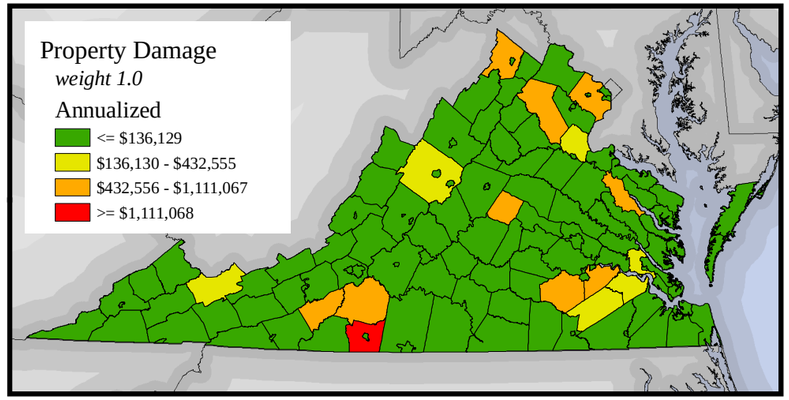
The majority of local plans did not specifically address changes in development for each hazard or the effects of changes in development on loss estimates. In most cases overall development patterns were discussed in general. Seventeen of the twenty-seven local plans cite their comprehensive plans for current and future land use changes (section 3.2). No local plan addressed how or if tornado hazards are considered for changes in development.

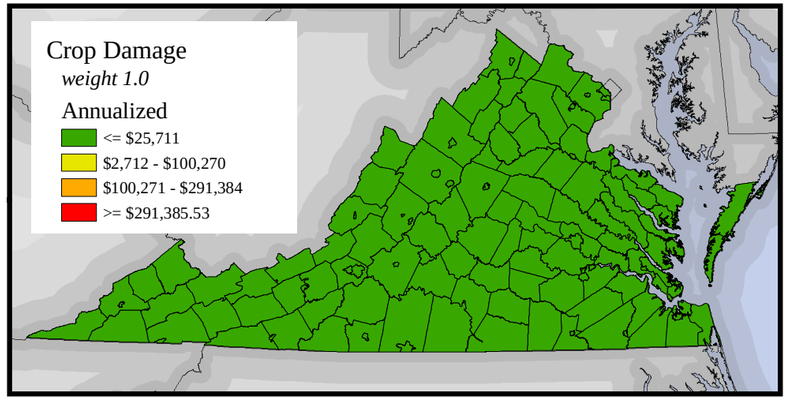
Figure 3.8b-5: Tornado Hazard Ranking Parameters and Risk Map

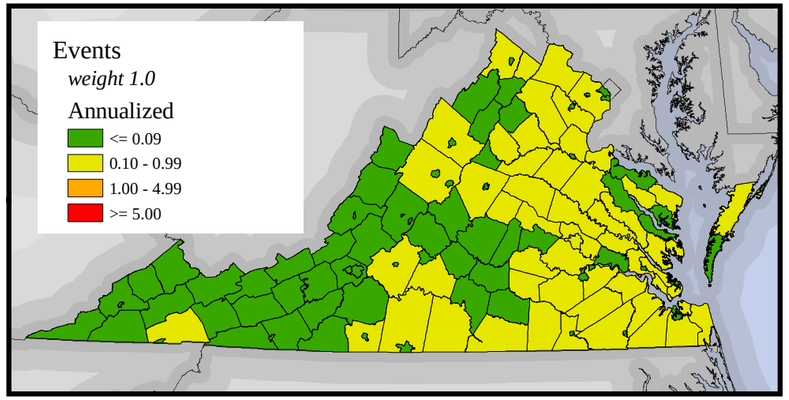


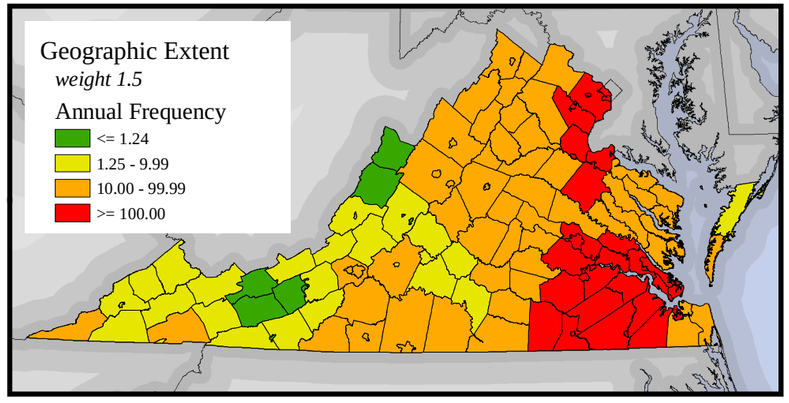


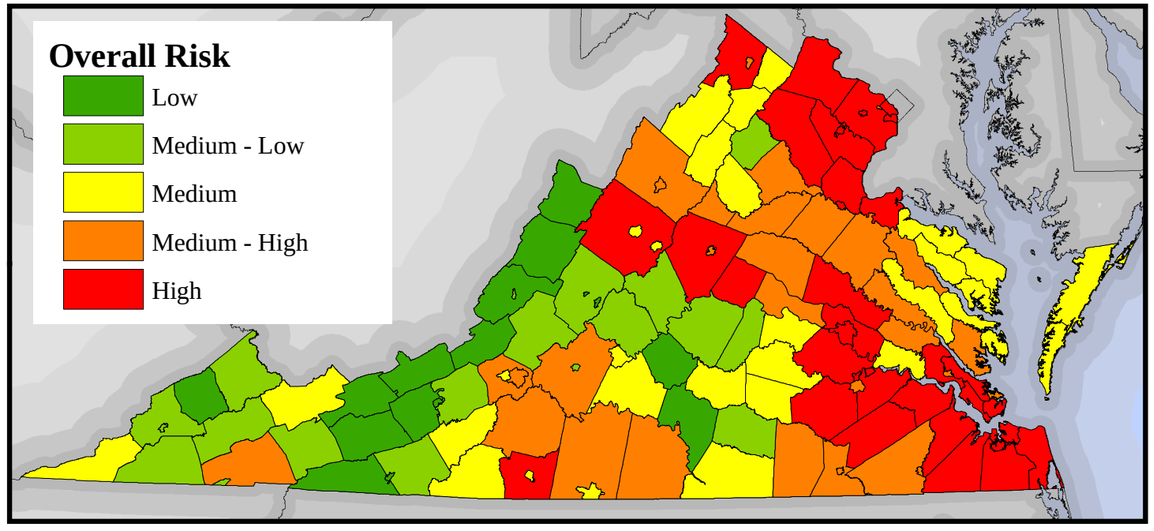












HAZARD RANKING:

A number of factors have been considered in this risk assessment to be able to compare between jurisdictions and hazards. The factors have been added together to come up with the overall total ranking for each hazard.
Some factors were weighted based on imput from the HIRA sub-committee.

Section 3.5 explains each of the factors in detail.

Factors & Weighting Include:

- Population Vulnerability & Density 0.5 weighting
- Injuries & Deaths 1.0 weighting
- Crop & Property Damage 1.0 weighting
- Annualized Events 1.0 weighting
- Geographic Extent 1.5 weighting

DATA SOURCES:

CGIT Ranking Methodology
VGIN Jurisdicational Boundaries
ESRI State Boundaries

PROJECTION: *VA Lambert Conformal Conic*
North American Datum 1983

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Table 3.8b-8: EMAP Analysis

Subject	Detrimental Impacts
Health and Safety of Public	Localized impacts are expected to be severe for the event area, and moderate for the outlying areas.
Health and Safety of Response Personnel	Localized impacts could be serious as local responders are working within the impacted area, if they live within the impacted area then they may be displaced for an extended period of time.
Continuity of Operations	Damage to facilities/personnel in the area of the event may require temporary relocation of some operations.
Property, Facilities, and Infrastructure	Depending on the magnitude of the event, localized impact to facilities, residential properties, and infrastructure in the area of the event could be severe.
Delivery of Services	Localized disruption of roads, facilities, communications and/or utilities caused by the event may postpone the delivery of some services.
The Environment	Localized impacts expected to be severe for the impacted areas, soil stability impacted, area likely to be vulnerable to landslides. With a high potential for debris, HAZMAT may be an issue.
Economic and Financial Condition	Local economic and financial conditions may be impacted for a long period of time depending on duration and geographical area of the event, as well as the size and capabilities of the local jurisdiction.
Public Confidence in the Jurisdiction's Governance	Ability to respond and recover may be questioned and challenged if planning, response, and recovery time is not sufficient

*****_Table was modeled from the Missouri State Hazard Mitigation Plan_