Introduction

In order to analyze the impact of hazards to a community, and to then assess risk and vulnerability of a community to such hazards, it is first necessary to identify the hazards which have a likelihood of affecting the community. This Section of the Plan includes material descriptions of the hazards reasonably expected to impact jurisdictions within the Commonwealth Regional Council Planning District (PD-14), written from a general and national perspective, while Section 5 of the Plan will go into detail about historical occurrences of these hazards within the Planning District, and Section 6 will provide an assessment of their overall risk to the Planning District.

Information on the hazards contained in the previous Plan has been updated to better reflect the available data as well as the principal element that comprises the threat. For instance, tropical storms comprise wind and rain, but are not unique threats in and of themselves, unlike tornadoes. Additionally, with this update of the Plan, four (4) additional individual hazards have been added, as follows: Invasive Species, Radon, Pandemic/Infectious Agent, and Climate Change. With respect to Climate Change, as discussed in that specific subsection, the focus is less on this as an individual hazard, but rather conditions that will effect most every other hazard within the Plan.

The following hazards have the greatest likelihood of impacting the communities within the Planning District, given historical, as well as more recent, experiences:

- **Floods**
- **Hurricanes and Tropical Storms**
- **Thunderstorms (Lightning and Strong Wind)**
- **Tornadoes**
- **Wildfire**
- **Drought**
- **Extreme Heat**
- **Winter Weather and Ice Storms (and Nor'easters)**
- **Hail**
- **Erosion**
- **Dam/Levee Failure**
- **Earthquakes, Sinkholes and Landslides**
- **Technological Hazards:**
    - **Hazardous material/chemical spills**
    - **Biological (Bio)-hazards**
    - **Accidents at fertilizer/other chemical facilities**
    - **Accidents at power plants/substations**
    - **Pipeline explosions**
- **Invasive Species**
- **Radon**
- **Pandemic/Infectious Agent**
- **Climate Change**

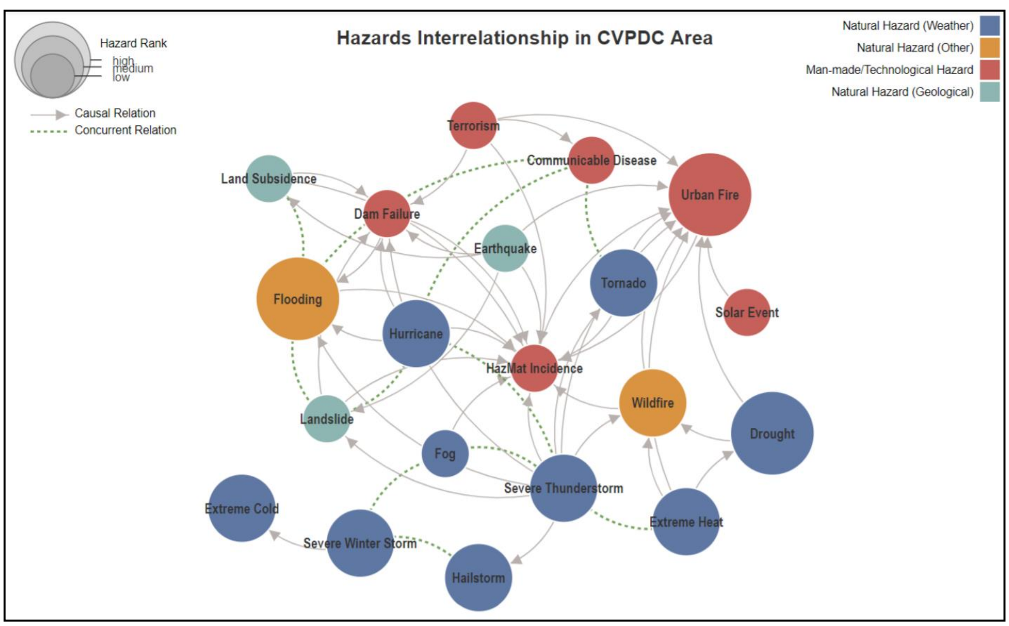
Interrelation of Hazards and Cascading Effects

In identifying hazards, as well as assessing risk and vulnerability, and then developing mitigation strategies, it is important to acknowledge both the interrelatedness of hazards, as well as the potential for associated cascading effects. The previous Plan addressed this, noting that "some 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 – or, more specific to this region, high winds, heavy rain and flooding)." While the intent of this Section is principally to discuss the nature of individual hazards, considering the direct causal relationship amongst hazards – or the correlation between hazards – is important to determining and assessing risk and vulnerability, and planning for mitigation, as well as response activities.

The following **Figure 4.1** is from the *Central Virginia PDC Hazard Mitigation Plan 2020 Update* and depicts "relationships between hazards and their impacts on people, built environment, and infrastructure," with "natural and man-made hazards…represented by nodes that are connected by edges. The edges represent two types of primary relations between hazards: causal and concurrent. A causal relation is one where one hazard is a prerequisite for a correlated hazard. A concurrent relation means hazards that are probable to occur at the same time due to common root causes."

While the interrelatedness of hazards affecting this Planning District are not analyzed to the degree to which the Central Virginia PDC explored such considerations, their conclusions are applicable to the Planning District's consideration of hazard impacts; in short, that "preparing for and responding to hazard events could be improved by integrating information on hazard interactions and cascading effects." Diagrams such as the one below can be beneficial to the communication of risks to local officials and residents, and may have additional applicability in community zoning and land use decision-making.

Figure 4.1 Interrelationship of Hazards for CVPDC Area



Climate Change

Climate change is the gradual change from temperature and weather norms which humans and ecosystems have become acclimatized to. Climate change is the result of more total energy (primarily from the sun's radiation) being stored in the atmosphere, seas, and other energy sinks due to the accumulation of greenhouse gases, loss of surface albedo,[1] and other interlinked planetary systems. The result is higher average annual temperatures, sea level rise, changes to the frequency and intensity of storms, and related downstream effects such as longer droughts, increased risk of heat stroke and other health problems, and the migration of cold-intolerant species northward. In short, the effects of climate change can serve to exacerbate the risks and predictability presented by identified hazards.

For the purpose of the update to this Plan, the focus on climate change is not as an individual hazard, but as conditions that will have some level of effect on every hazard in the Plan, whether directly or through correlation with other effects. As the various hazards of this Plan are reviewed, consideration should be given to the potential effects of climate change. Additionally, underserved and marginalized communities are particularly vulnerable to the effects of climate change and can be disproportionately harmed by disasters.[2]

Because climate change adds to the total energy of the atmosphere and may increase heat, shift precipitation patterns, cause seasonal temperature swings, and potentially increase the frequency or intensity of storms, it has the potential to change or worsen most naturally occurring hazards save for erosion and earthquakes. For further discussion, see the future occurrence portion for each hazard in Section 5.

[1] "Albedo is an expression of the ability of surfaces to reflect sunlight (heat from the sun). Light-coloured surfaces return a large part of the sunrays back to the atmosphere (high albedo). Dark surfaces absorb the rays from the sun (low albedo). Ice- and snow-covered areas have high albedo, and an ice-covered Arctic reflects solar radiation which otherwise would be absorbed by the oceans and cause the Earth's surface to heat up…Low albedo (dark surfaces) leads to higher uptake of energy and, hence, warming. Moreover, when more ice and snow melt, there will be more dark surfaces." Source: Norwegian Polar Institute

[2] FEMA Resources for Climate Resilience https://www.fema.gov/sites/default/files/documents/fema_resources-climate-resilience.pdf

Floods

Flooding is the most frequent and costly natural hazard in the United States. According to the National Weather Service, floods have caused more than 10,000 deaths since 1900. It is such a common occurrence that, in many years, 75% or more of all presidential disaster declarations result – at least, in part – from flooding.

Floods are generally the result of excessive precipitation. In the Planning District, as a non-coastal region, the main types of flooding experienced are riverine and stormwater flooding. These in turn can be classified under two main categories:

1. General floods, precipitation over a given river basin for a long period of time; and
2. Flash floods, the product of heavy localized precipitation in a short time period over a given location.

Riverine flooding swallows River Road and threatens the Main Street bridge in downtown Farmville, VA after a large rainstorm on November 12, 2020. (*Image courtesy of Virginia Preparedness*)

The severity of a flooding event is determined by a combination of stream and river basin topography and physiography; precipitation and weather patterns; recent soil moisture conditions; and the degree of vegetative clearing.

General floods are usually long-term events that may last for several days. The primary types of general flooding impacting the Planning District include riverine and urban drainage or stormwater flooding. Riverine flooding is when streams and rivers exceed the capacity of their natural or constructed channels to accommodate water flow and water overflows the banks, spilling into adjacent low-lying, dry land,[3] while urban flooding occurs where man-made development has obstructed the natural flow of water and decreased the ability of natural groundcover to absorb and retain surface water runoff. Flash flooding events usually occur either from a dam or levee failure, within minutes or after 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 and/or where infrastructure conditions, specifically stormwater infrastructure, are not designed to accommodate sudden increases in stormwater or is poorly maintained. 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, destroy buildings, and obliterate bridges and roads, resulting also in landslides, erosion, and sinkholes.

The periodic flooding of lands adjacent to rivers, streams, and shorelines (land known as the floodplain) is a natural and inevitable 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.

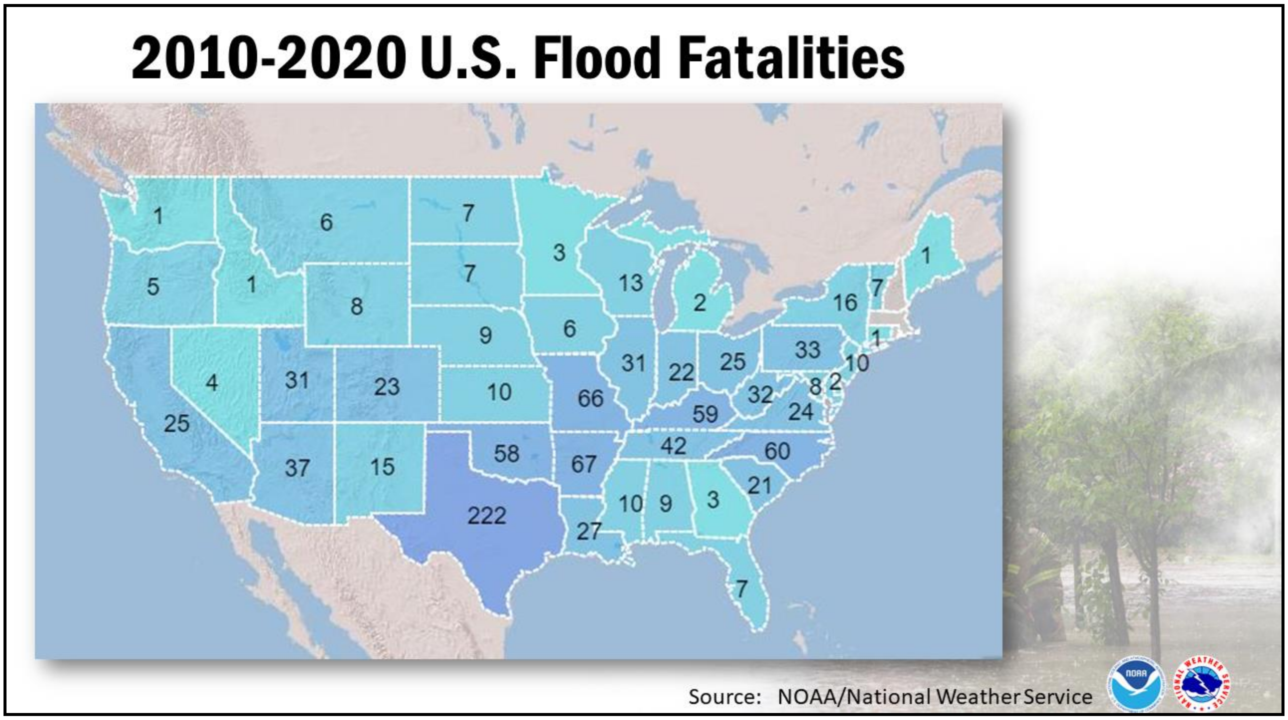
Floodplains are designated by the average annual statistical likelihood of a flood covering that area within a 100-year timespan. For example, the 10-year floodplain has a 10% annual chance of being covered, while the 100-year floodplain has a 1% annual chance of being flooded. Flood frequencies are determined by plotting a graph of the size of all known floods for an area and determining how often floods of a particular size occur.

Flood property damages range wildly from year to year across the US, mostly due to the influence of unusual storm seasons. Since 1960, according to the National Weather Service (NWS), damages have ranged from a low of $89M in 1962 to $61B in 2017 (adjusted to 2020 dollars), caused by hurricanes Harvey, Irma, and Maria hitting highly populated, urbanized areas. It should be noted that these NWS estimates do not include all damages from Hurricane Katrina in 2005 (an estimated $170B) and Hurricane Sandy in 2012 ($70B) which occurred from storm surges and not primarily freshwater flooding or precipitation.

As noted, flooding also results in the loss of life. **Figure 4.2** provides preliminary U.S. flood fatalities from 2010-2020 based upon media sources and Storm Data / NWS input. Only direct flood fatalities are included and may not include cases where the fatality occurred from other circumstances.

[3] FEMA National Risk Index Technical Manual
https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

Figure 4.2 NWS Preliminary US Flood Fatality Statistics



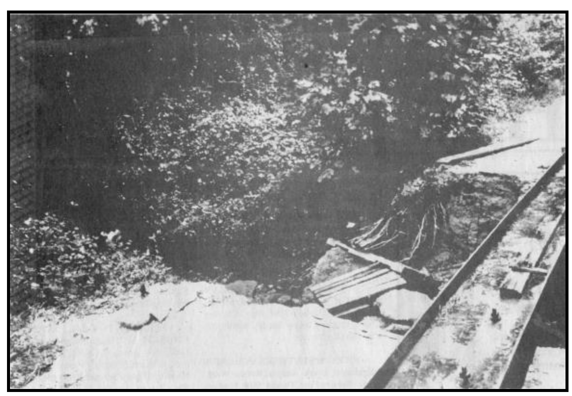
Hurricanes and Tropical Storms

Hurricanes, tropical storms, and typhoons, also classified as cyclones, are any closed circulation of wind 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. A hurricane, specifically, is a tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph); the hurricane data also include tropical storms for which wind speeds range from 39 to 74 mph.[4]

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 from the spinning of the earth, and the absence of 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, and Gulf of Mexico during the official Atlantic hurricane season, which encompasses the months of June through November. According to the National Hurricane Center, the average Atlantic hurricane season has 14 named storms, 7 hurricanes, and 3 major hurricanes (Category 3, 4, or 5 on the Saffir-Simpson Hurricane Wind Scale; Source: https://www.nhc.noaa.gov/climo/).

Tree damage in Farmville from Hurricane Isabel in September 2003. (Photo courtesy of *The Farmville Herald*)

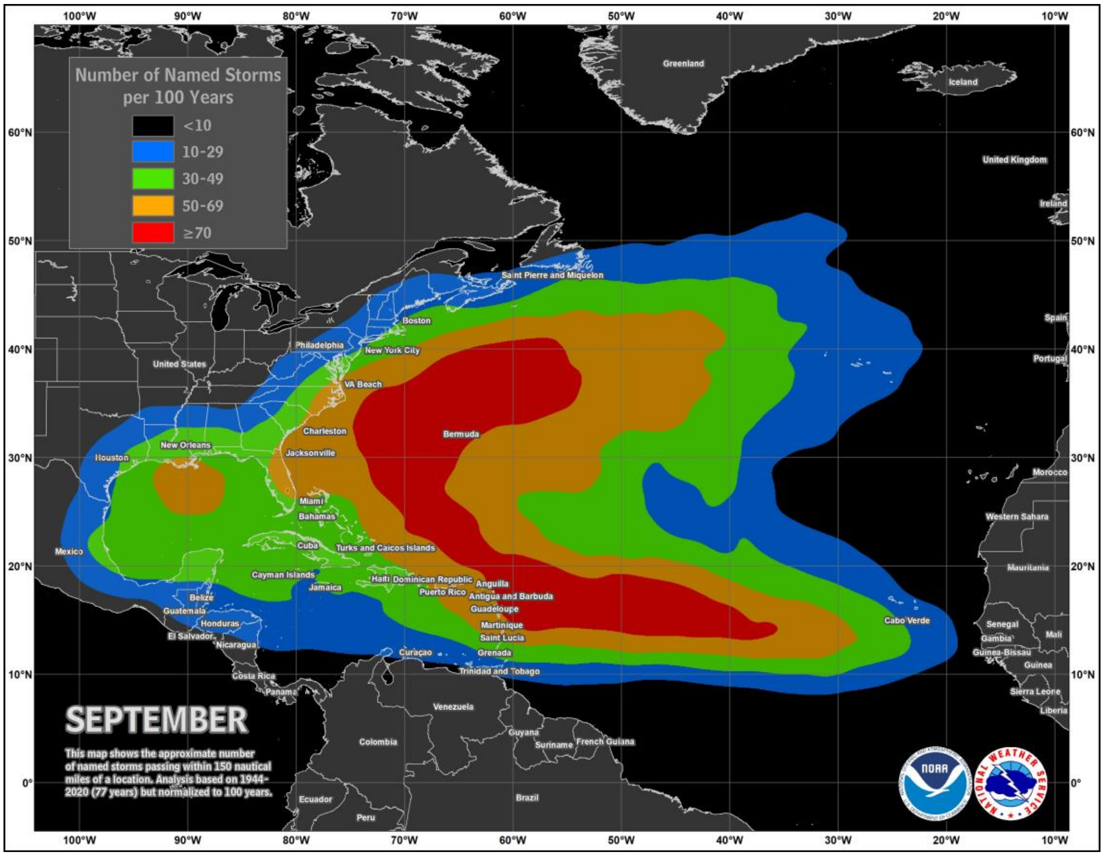


A section of Route 642 in Nottoway County, just south of Crewe, was washed out by heavy rains from Tropical Storm Gaston in August 2004. The steel beam in the photo was placed across the washed-out section of road so vehicles could pass until the road was repaired. (Photo courtesy of *The Crewe-Burkeville Journal*)

[4] FEMA National Risk Index Technical Manual https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

Figure 4.3 shows where tropical cyclones (named storms and hurricanes) tend to occur during the month of September, the peak of the Atlantic hurricane season. The data are shown as the number of named storms or hurricanes whose centers pass within 150 nautical miles of a point on the map during a 100-year period. The analysis is based on data from the 77-year period from 1944 to 2020 (starting at the beginning of the aircraft reconnaissance era) but normalized to 100 years.

Figure 4.3 Number of Named Storms per 100 Years for September



Source: National Oceanic and Atmospheric Administration/National Hurricane Center ***https://www.nhc.noaa.gov/climo/***

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 (and 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 classified as a hurricane. Hurricane intensity is classified by the Saffir-Simpson Scale, which rates hurricane intensity on a scale of 1 to 5, with 5 being the most intense (see **Table 4.1**). It should be noted that the Saffir-Simpson Scale has been updated, and no longer includes surge values or minimum surface pressures.

The Saffir-Simpson Scale categorizes hurricane intensity linearly based upon maximum sustained winds, barometric pressure, and storm surge potential, 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 percent of total tropical cyclone landfalls, they account for over 70 percent of the damage in the United States. **Table 4.1** also describes the damage that could be expected for each category of hurricane.

Table 4.1 Saffir-Simpson Scale, Hurricane Damage Classification

Category	Maximum Sustained Wind Speed (MPH)	Damage Level	Damage Description
1	74 – 95	MINIMAL – MODERATE	Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96 – 110	EXTENSIVE	Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	111 – 129	DEVASTATING	Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4	130 – 156	CATASTROPHIC	Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5	157 and higher	CATASTROPHIC	A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Source: National Hurricane Center

Damage during hurricanes may also result from spawned tornadoes and inland flooding associated with heavy rainfall, interrelated hazards that usually accompany 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. Parts of southeastern Virginia suffered significant flooding as a result of the storm. Rainfall amounts were as high as 20 inches in certain locales and 67 counties sustained damages. A total of 57 deaths were attributed to Floyd, all but one of those occurring in the United States (which included 35 in North Carolina and three in Virginia).

Thunderstorms (Lightning and Strong Winds)

According to the National Weather Service, more than 100,000 thunderstorms occur each year, though only about 10 percent of these storms are classified as "severe." Although thunderstorms generally affect a small area when they occur, they are very dangerous because of their ability to generate tornadoes, hailstorms, strong winds (classified as exceeding 58 mph), flash flooding, and damaging lightning. While thunderstorms can occur in all regions of the United States, they are most common in the central and southern states because atmospheric conditions in those regions are most ideal for generating these powerful storms.

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

Multiple cloud-to-ground and cloud-to-cloud lightning strikes observed during a nighttime thunderstorm. (*Photo courtesy of David Mark*)

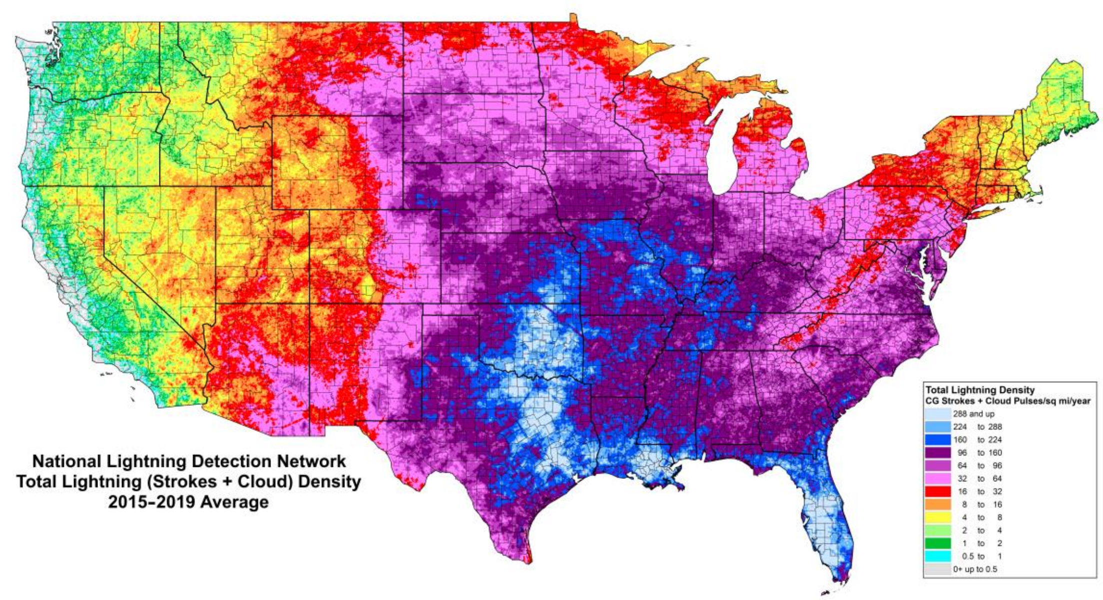
Lightning is a visible electrical discharge or spark of electricity in the atmosphere between clouds, the air, and/or the ground often produced by a thunderstorm. A bolt of lightning can reach temperatures approaching 50,000 degrees Fahrenheit. Lightning rapidly heats the sky as it flashes but the surrounding air cools following the bolt. This rapid heating and cooling of the surrounding air causes thunder. According to the

National Weather Service, from 1989 to 2018, lightning strikes have caused an average of 43 fatalities annually.[5]

The National Weather Service collected data for thunder days, number and duration of thunder events, and lightning strike density for the 30-year period from 1948 to 1977. A series of maps was generated showing the annual average thunder event duration, the annual average number of thunder events, and the mean annual density of lightning strikes.

Figure 4.4 illustrates the average total density of all lightning events in the United States between 2015-2019.

Figure 4.4 Annual Average Number of Thunder Events



Source: National Hurricane Center

[5] Source: https://www.weather.gov/safety/lightning-odds

Tornadoes

A tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground and is visible only if it forms a condensation funnel made up of water droplets, dust, and debris.[6] Tornadoes are most often generated by thunderstorm activity (but sometimes result from hurricanes and other 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 National Weather Service, 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 projectiles.

At least one confirmed tornado struck Lunenburg County on April 16, 2010. Areas north of Victoria were hit, with several houses and some other buildings receiving damage. Pictured above is tornado damage in and around the Victoria Golf Club. (Photo courtesy *Kenbridge-Victoria Dispatch*)

Each year, an average of over 1,100 tornadoes are reported nationwide, resulting in an average of more than 70 deaths and 1,500 injuries per year over the last 30 years (NOAA, 2015). 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 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.

The destruction caused by tornadoes ranges from light to inconceivable depending on the intensity, size, and duration of the storm. Typically, tornadoes cause the greatest damages to structures of light construction, such as residential homes (particularly mobile homes), and tend to remain localized in impact. The Enhanced F Scale for Tornado Damage (**Table 4.2**) was developed in 2007, replacing the Fujita Scale, with the new scale more accurately matching wind speeds to the severity of damage caused by a tornado.

[6] FEMA National Risk Index Technical Manual
https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

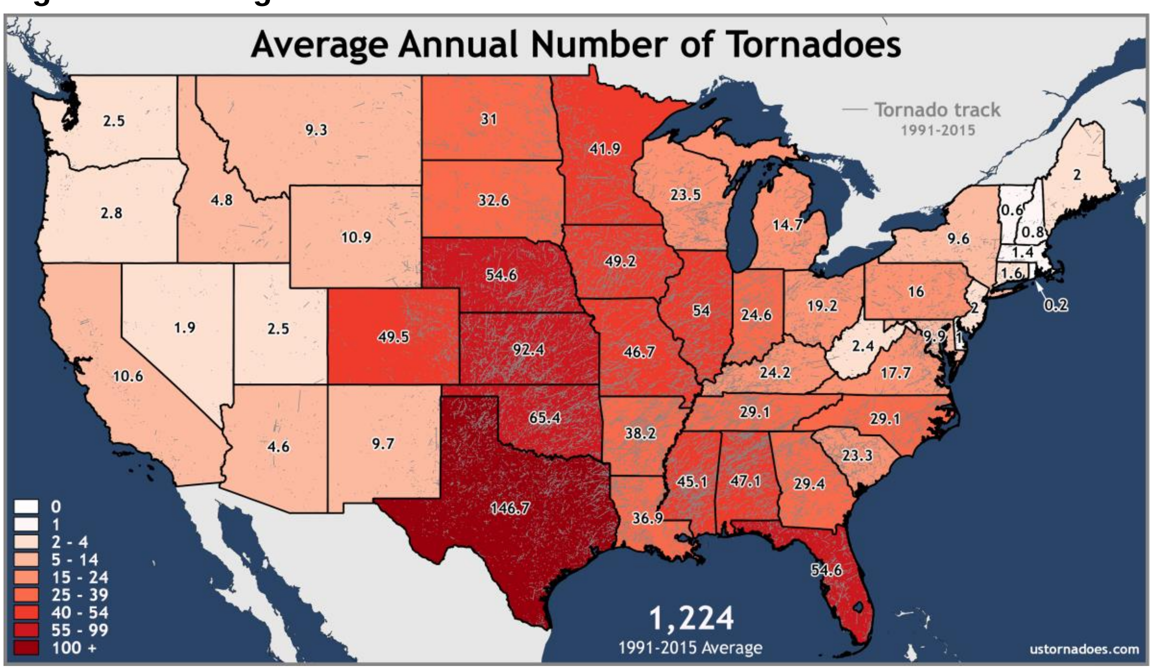
Table 4.2 Enhanced F Scale for Tornado Damage

Fujita Scale			Derived EF Scale		Operational EF Scale	
F-Number	Fastest 1/4-mile (mph)	3-second Gust (mph)	EF Number	3-second Gust (mph)**	EF Number	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

NOTE: The Enhanced F-scale is still a set of wind estimates (not measurements) based on damage. Its uses three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage to the 28 Enhanced F Scale Damage Indicators (see Source link below). These estimates vary with height and exposure. The 3 second gust is not the same wind as in standard surface observations. Standard measurements are taken by weather stations in open exposures, using a directly measured "one minute mile" speed. Source: NOAA (http://www.spc.noaa.gov/faq/tornado/ef-scale.html)

According to the NOAA Storm Prediction Center (SPC), the highest concentration of tornadoes in the United States occur in Oklahoma, Texas, Kansas (an area known as "Tornado Alley"). Although the Great Plains region of the Central United States does favor the development of the largest and most dangerous tornadoes, Florida experiences the greatest number of tornadoes per square mile of all U.S. states (SPC, 2002). **Figure 4.5** shows the average annual number of tornadoes for the United States, by state, based upon data from 1991 to 2015.

Figure 4.5 Average Annual Number of Tornadoes



***Source:* www.ustornadoes.com/**

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.

Wildfire

A wildfire is an unplanned fire burning in natural or wildland areas, such as forest, shrub lands, grasslands, or prairies.[7] Wildfires do not include prescription burning, or "controlled burning," the process, undertaken by land management agencies, 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. Over 80 percent 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.

Large brush fire on Shelton Store Road, Buckingham County on June 27, 2021. (*Photo by Toga Volunteer Fire Department Facebook*)

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 hazards (i.e., 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.

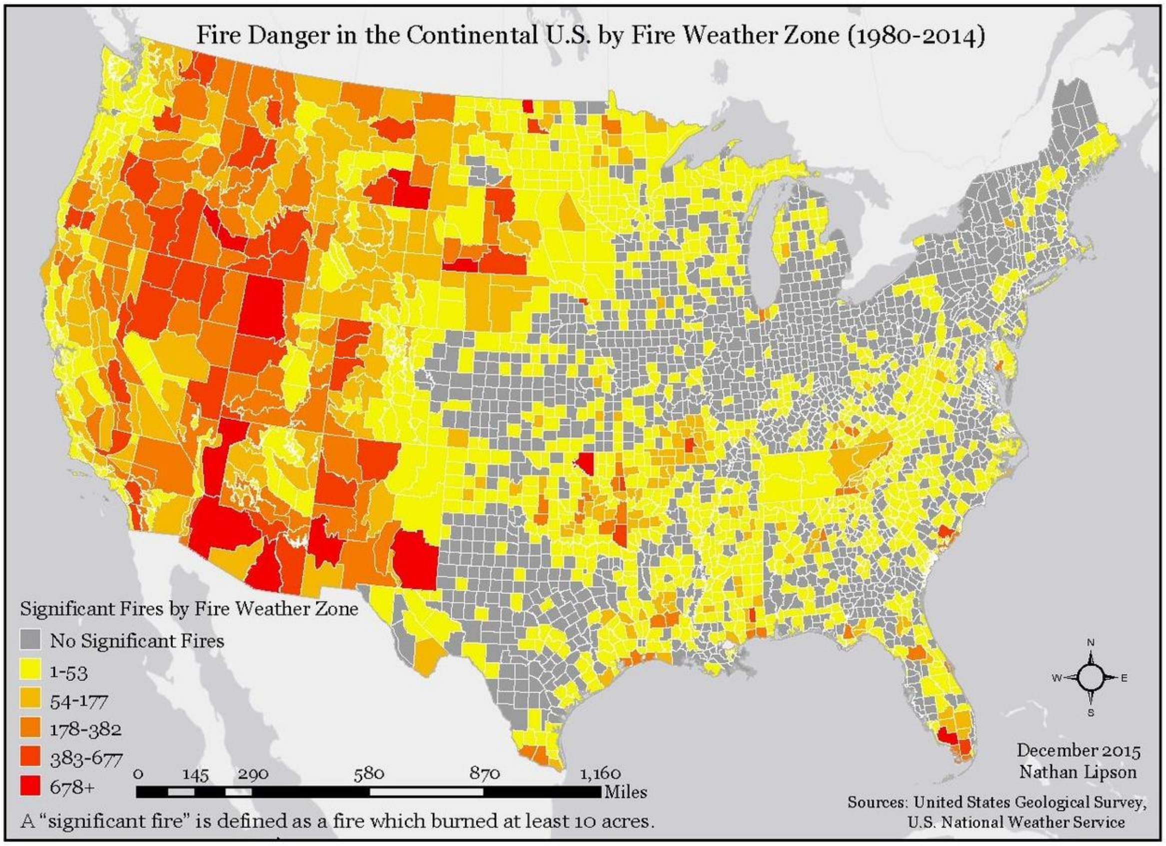
Many individual homes and cabins, subdivisions, resorts, recreational areas, organizational camps, businesses, and industries are located within high fire hazard areas. The increasing demand for outdoor recreation places more people in wildlands

[7] FEMA National Risk Index Technical Manual https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

during holidays, weekends, and vacation periods. Unfortunately, wildland residents and visitors are rarely educated or prepared for the inferno that can sweep through the brush and timber and destroy property in minutes.

Figure 4.6 shows burden to wildfires by "fire weather zone," as defined by the National Weather Service, for the United States, from 1980-2014. Only "significant fires" are depicted, those burning 10 acres or more.

Figure 4.6 Wildfire Activity per County 1994-2014



Source: Nathan Lipson https://en.wikipedia.org/wiki/File:WildfiresUS.pdf

Drought

A drought is a deficiency of precipitation over an extended period of time resulting in a water shortage.[8] High temperatures, high winds, and low humidity can worsen drought conditions, and can make areas more susceptible to wildfire. Human demands and actions can also hasten drought-related impacts. It is a slow-onset hazard that can last weeks or years.

Droughts are frequently classified as one of following four types:

- Meteorological,
- Agricultural,
- Hydrological, and
- 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.

A USGS stream flow gauging station at the Ogeechee River near Eden, Georgia in July 2000 illustrates the drought conditions that can severely affect water supplies, agriculture, stream water quality, recreation, navigation, and forest resources. (*Photo courtesy of the United States Geological Survey*)

Figure 4.7 is the Drought Monitor summary map for the United States for the week of February 21, 2023. **Figure 4.8** shows the weekly change in drought conditions in Virginia. Drought Monitor summary maps identify general drought areas and label droughts by intensity, with D1 being the least intense and D4 being the most intense.[9]

[8] FEMA National Risk Index Technical Manual https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

[9] Source: https://droughtmonitor.unl.edu. The U.S. Drought Monitor is produced through a partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.

Figure 4.7 U.S. Drought Monitor – Nationwide

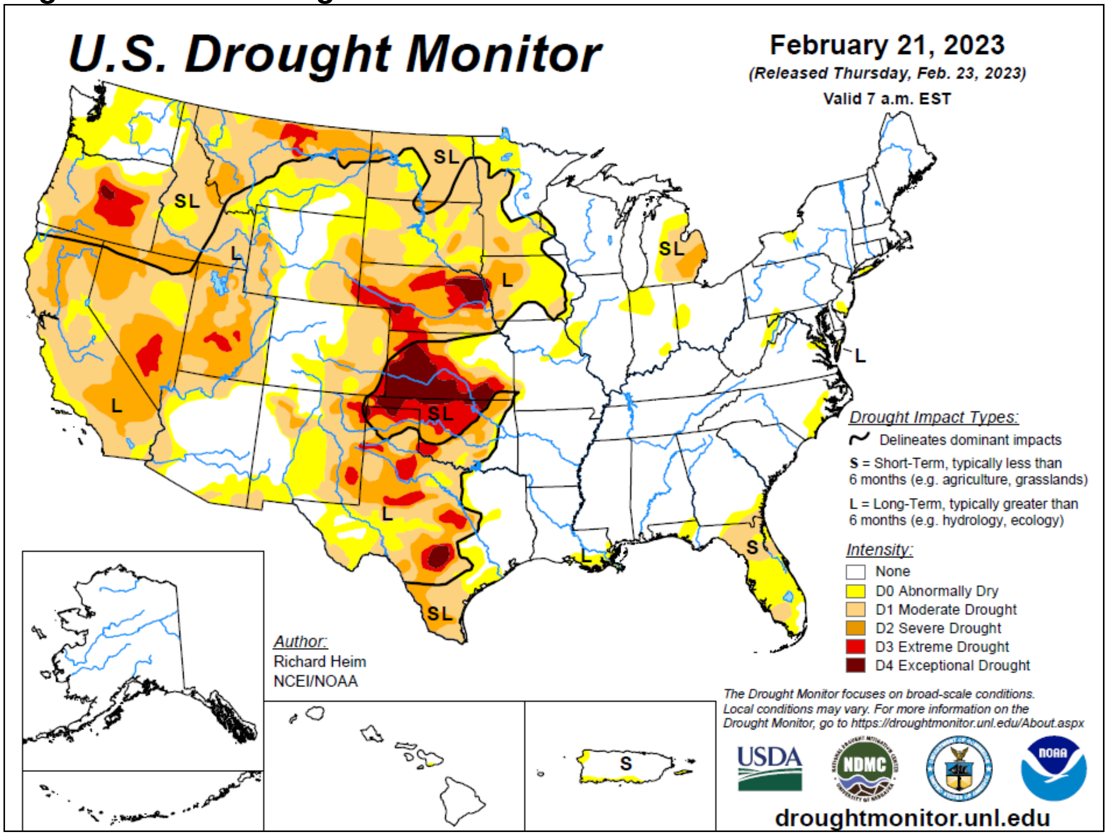
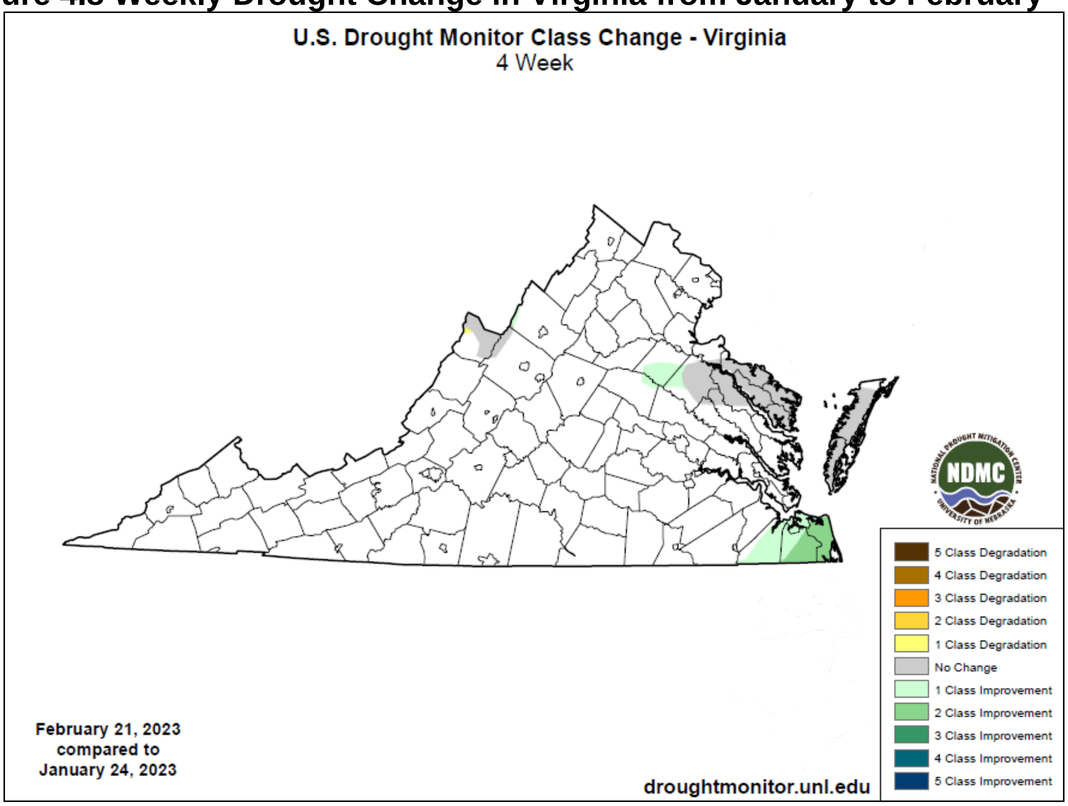


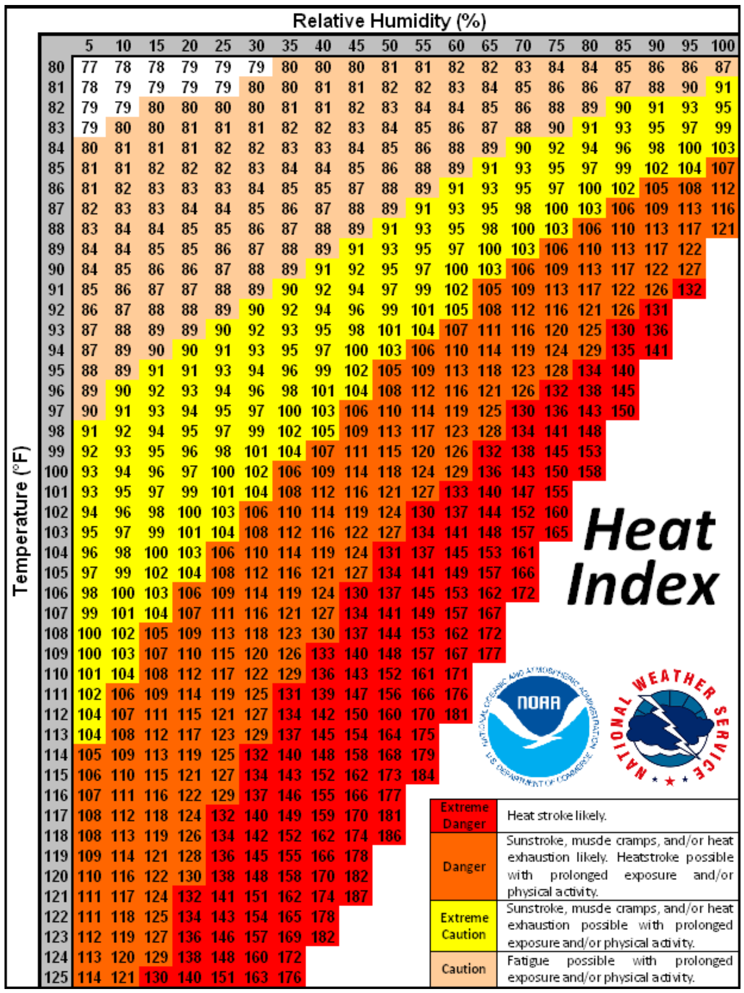
Figure 4.8 Weekly Drought Change in Virginia from January to February



Extreme Heat

While drought mostly impacts land and water resources, extreme heat can pose a significant risk to humans. Extreme heat can be defined as temperatures that hover 10 degrees or more above the average high temperature for the region, last for prolonged periods of time, and are often accompanied by high humidity. FEMA's National Risk Index includes the related term *heat wave*, defined as a period of abnormally and uncomfortably hot and unusually humid weather typically lasting two or more days with temperatures outside the historical averages for a given area; the temperatures classified as a heat wave are dependent on the location and defined by the local NWS weather forecast office.[10]

Figure 4.9 National Weather Service Heat Index



Temperature (°F) \ Relative Humidity (%)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
80	77	78	78	79	79	79	80	80	80	81	81	82	82	83	84	84	85	86	86	87
81	78	79	79	79	79	80	80	81	81	82	82	83	84	85	86	86	87	88	90	91
82	79	79	80	80	80	80	81	81	82	83	84	84	85	86	88	89	90	91	93	95
83	79	80	80	81	81	81	82	82	83	84	85	86	87	88	90	91	93	95	97	99
84	80	81	81	81	82	82	83	83	84	85	86	88	89	90	92	94	96	98	100	103
85	81	81	82	82	82	83	84	84	85	86	88	89	91	93	95	97	99	102	104	107
86	81	82	83	83	83	84	85	85	87	88	89	91	93	95	97	100	102	105	108	112
87	82	83	83	84	84	85	86	87	88	89	91	93	95	98	100	103	106	109	113	116
88	83	84	84	85	85	86	87	88	89	91	93	95	98	100	103	106	110	113	117	121
89	84	84	85	85	86	87	88	89	91	93	95	97	100	103	106	110	113	117	122	
90	84	85	86	86	87	88	89	91	92	95	97	100	103	106	109	113	117	122	127	
91	85	86	87	87	88	89	90	92	94	97	99	102	105	109	113	117	122	126	132	
92	86	87	88	88	89	90	92	94	96	99	101	105	108	112	116	121	126	131		
93	87	88	89	89	90	92	93	95	98	101	104	107	111	116	120	125	130	136		
94	87	89	90	90	91	93	95	97	100	103	106	110	114	119	124	129	135	141		
95	88	89	91	91	93	94	96	99	102	105	109	113	118	123	128	134	140			
96	89	90	92	93	94	96	98	101	104	108	112	116	121	126	132	138	145			
97	90	91	93	94	95	97	100	103	106	110	114	119	125	130	136	143	150			
98	91	92	94	95	97	99	102	105	109	113	117	123	128	134	141	148				
99	92	93	95	96	98	101	104	107	111	115	120	126	132	138	145	153				
100	93	94	96	97	100	102	106	109	114	118	124	129	136	143	150	158				
101	93	95	97	99	101	104	108	112	116	121	127	133	140	147	155					
102	94	96	98	100	103	106	110	114	119	124	130	137	144	152	160					
103	95	97	99	101	104	108	112	116	122	127	134	141	148	157	165					
104	96	98	100	103	106	110	114	119	124	131	137	145	153	161						
105	97	99	102	104	108	112	116	121	127	134	141	149	157	166						
106	98	100	103	106	109	114	119	124	130	137	145	153	162	172						
107	99	101	104	107	111	116	121	127	134	141	149	157	167							
108	100	102	105	109	113	118	123	130	137	144	153	162	172							
109	100	103	107	110	115	120	126	133	140	148	157	167	177							
110	101	104	108	112	117	122	129	136	143	152	161	171								
111	102	106	109	114	119	125	131	139	147	156	166	176								
112	104	107	111	115	121	127	134	142	150	160	170	181								
113	104	108	112	117	123	129	137	145	154	164	175									
114	105	109	113	119	125	132	140	148	158	168	179									
115	106	110	115	121	127	134	143	152	162	173	184									
116	107	111	116	122	129	137	146	155	166	177										
117	108	112	118	124	132	140	149	159	170	181										
118	108	113	119	126	134	142	152	162	174	186										
119	109	114	121	128	136	145	155	166	178											
120	110	116	122	130	138	148	158	170	182											
121	111	117	124	132	141	151	162	174	187											
122	111	118	125	134	143	154	165	178												
123	112	119	127	136	146	157	169	182												
124	113	120	129	138	148	160	172													
125	114	121	130	140	151	163	176													

Extreme Danger	Heat stroke likely.
Danger	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.
Extreme Caution	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	Fatigue possible with prolonged exposure and/or physical activity.

Source: National Weather Service
https://www.wrh.noaa.gov/psr/general/safety/heat/heatindex.png

Under normal conditions, the human body's internal thermostat produces perspiration that evaporates and cools the body. However, in extreme heat and high humidity, evaporation is slowed and the body must work much harder to maintain a normal temperature. Elderly persons, young children, persons with respiratory difficulties, and those who are sick or overweight are more likely to become victims of extreme heat. Because men sweat more than women, they are more susceptible to heat-related illness because they become more quickly dehydrated. Studies have shown that a significant rise in heat-related illness occurs when excessive heat persists for more than two days. Spending at least two hours per day in air conditioning can significantly reduce the number of heat-related illnesses.

Figure 4.9 is the Heat Index developed by the National Weather Service. According to the National Weather Service, the Heat Index is one tool to assess the potential for heat stress due to extreme temperatures; "the Heat Index is a measure of how hot it really feels

[10] FEMA National Risk Index Technical Manual https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

when relative humidity is factored in with the actual air temperature. As an example, if the air temperature is 96°F and the relative humidity is 65%, the heat index--how hot it feels--is 121°F. The red area without numbers indicates extreme danger. The National Weather Service will initiate alert procedures when the Heat Index is expected to exceed 105°-110°F (depending on local climate) for at least 2 consecutive days."[11]

Extreme heat in urban areas can create health concerns when stagnant atmospheric conditions trap pollutants, thus adding unhealthy air to excessively hot temperatures. In addition, the "urban heat island effect" can produce significantly higher nighttime temperatures because asphalt and concrete (which store heat longer) gradually release heat at night.

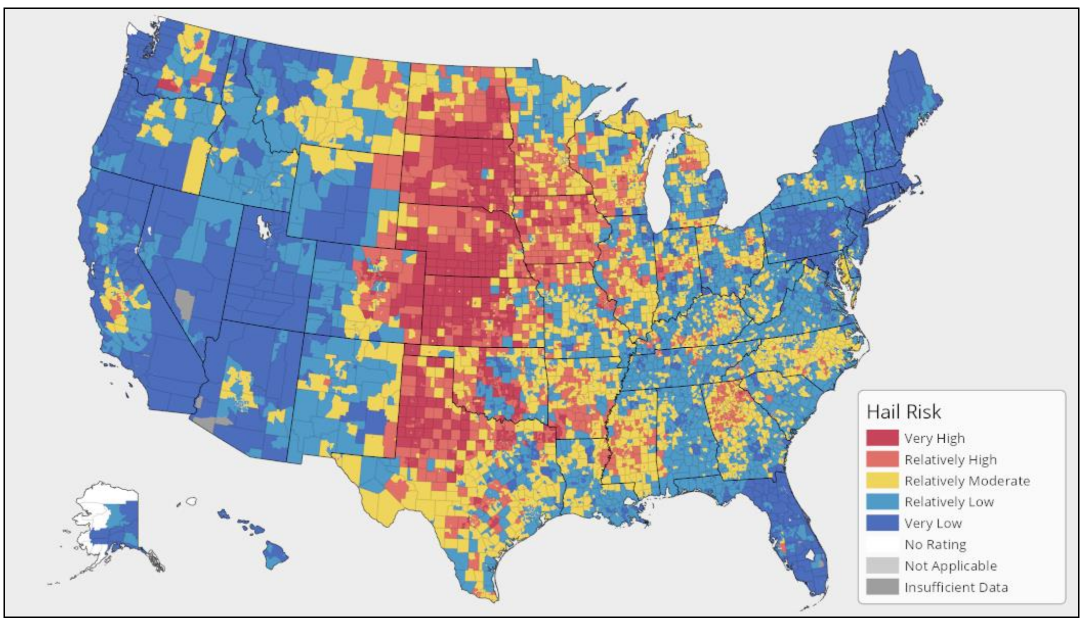
[11] National Weather Service https://www.weather.gov/ama/heatindex

Hail

Hail is a form of precipitation that occurs during thunderstorms when raindrops, in extremely cold areas of the atmosphere, freeze into balls of ice before falling towards the earth's surface.[12] 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 4.10** shows the annual frequency of hailstorms in the United States.

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

Figure 4.10 Hail Risk Index Score Map



Source: Federal Emergency Management Agency, National Risk Index

[12] FEMA National Risk Index Technical Manual
https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

Winter Weather and Ice Storms

Winter weather consists of winter storm events in which the main types of precipitation are snow, sleet, or freezing rain.[13] 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 may be large enough to affect several states, while others may affect only a single community. Many winter storms are accompanied by low temperatures and heavy and/or blowing snow, which can severely impair visibility.

Sleet – Pellets of ice composed of frozen or mostly frozen raindrops or refrozen partially melted snowflakes. Sleet pellets usually bounce when hitting a surface and do not stick to objects; however, sleet can accumulate like snow and cause a hazard to motorists. Heavy sleet is a relatively rare event defined as an accumulation of ice pellets covering the ground to a depth of ½-inch or more.

Freezing rain – Rain that falls as a liquid onto a surface with a temperature below freezing (32 degrees farenheit), forming a glaze of ice on a layer of ice on roads, walkways, trees and power lines. Even small accumulations of ice can cause a significant hazard, especially on power lines and trees.

Ice storm – Freezing rain situation with significant ice accumulations of 0.25 inches or greater.[14] Communications and power can be disrupted for days, and even small accumulations of ice may cause extreme hazards to motorists and pedestrians.

Snow – Precipitation in the form of ice crystals, mainly of intricately branched, hexagonal form and often agglomerated into snowflakes, formed directly from the freezing (deposition) of the water vapor in the air.

These trees in a residential neighborhood in Blackstone succumbed to the heavy layer of ice that resulted from the February 2021 ice storm that swept through the region. The storm brought down trees, power lines and telephone lines throughout the region, leaving some people without electricity for days. (*Photo courtesy WWBT, NBC 12, Richmond*)

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

[13; 14] FEMA National Risk Index Technical Manual
https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

In 2004, staff from the National Weather Service developed the Northeast Snowfall Impact Scale (NESIS). It characterizes and ranks high-impact snowstorms (have had large areas of snowfall accumulations that total 10 inches or more), using snowfall and population information from the eastern two-thirds of the United States. NESIS has five categories: Extreme, Crippling, Major, Significant, and Notable. The index differs from other meteorological indices in that it uses population information in addition to meteorological measurements, thereby giving an indication of a storm's societal impacts. This scale was developed because of the impact Northeast snowstorms can have on the rest of the country in terms of transportation and economic impact.

NESIS scores are a function of the area affected by the snowstorm, the amount of snow, and the number of people living in the path of the storm. **Table 4.3** shows NESIS categories. The aerial distribution of snowfall and population information are combined in an equation that calculates a NESIS score which varies from around one for smaller storms to over ten for extreme storms. The raw score is then converted into one of the five NESIS categories. The largest NESIS values result from storms producing heavy snowfall over large areas that include major metropolitan centers.

Table 4.3 NESIS Classifications

Category	NESIS Value	Description
1	1 – 2.499	Notable
2	2.5 – 3.99	Significant
3	4 – 5.99	Major
4	6 – 9.99	Crippling
5	10.0 +	Extreme

Source: NOAA, NCDC

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 types of soil erosion: wind erosion and water erosion. Wind erosion can cause significant soil loss. Winds blowing across sparsely vegetated or disturbed land can pick up soil particles and carry them through the air, thus displacing them. Water erosion can occur over land or in streams and channels. Water erosion that takes place over land may result from raindrops, shallow sheets of water flowing off the land, or shallow surface flow, which is concentrated in low spots. Stream channel erosion may occur as the volume and velocity of water flow increases enough to cause movement of the streambed and bank soils. Major storms such as hurricanes may cause significant erosion by combining high winds with heavy surf and storm surge to significantly impact the shoreline.

An area's potential for erosion is determined by four factors: soil characteristics, vegetative cover, topography climate or rainfall, and topography. Soils composed of a large percentage of silt and fine sand are most susceptible to erosion. As the content of these soils increases in the level of clay and organic material, the potential for erosion decreases. Well-drained and well-graded gravels and gravel-sand mixtures are the least likely to erode. Coarse gravel soils are highly permeable and have a good capacity for absorption, which can prevent or delay the amount of surface runoff. Vegetative cover can be very helpful in controlling erosion by shielding the soil surface from falling rain, absorbing water from the soil, and slowing the velocity of runoff. Runoff is also affected by the topography of the area including size, shape and slope. The greater the slope length and gradient, the more potential an area has for erosion. Climate can 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 of the year.

During the past 25 to 30 years, the importance of erosion control has gained the increased attention of the public. Implementation of erosion control measures consistent with sound agricultural and construction operations is 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.

Dam/Levee Failure

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.

There are more than 80,000 dams in the United States today, according to data from the Army Corps of Engineers National Inventory of Dams. A large majority of those (approximately 60-70%) are privately owned, with the remainder owned by state and local authorities, public utilities, federal agencies, and other entities.

Dam – Structure built across a stream or river to hold water back. Dams are typically man made and can be used to store water, control flooding, and generate electricity.

Levee – Natural or artificial wall that blocks water from going where we don't want it to go, usually made of earthen materials. Natural levees are typically created by water pushing sediment to the side of a water body. Artificial levees are usually built by piling soil, sand, or rocks on a cleared, level surface.

The benefits of dams are numerous: they provide water for drinking, navigation, and agricultural irrigation. Dams also provide hydroelectric power, create lakes for fishing and recreation, and save lives by preventing or reducing floods.

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.

Dam and spillway at Bear Creek Lake State Park, Cumberland County. (*Photo: Virginia DCR*)

Dam failure can result from natural events, human-induced events, or a combination of the two. Failures due to natural events such as hurricanes, earthquakes or landslides are significant because there is generally little or no advance warning. The most common cause of dam failure is prolonged rainfall that produces flooding.

Earthquakes

An earthquake is a shaking of the earth's surface by energy waves emitted by slowly moving tectonic plates overcoming friction with one another underneath the earth's surface.[15] Earthquakes result from crustal strain, volcanism, the collapse of caverns, or landslides (though not likely). 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.

Many structures in Louisa County, including the house pictured above in Cuckoo (near the Town of Mineral), were damaged by the 5.8 magnitude earthquake that struck near Mineral on August 23, 2011. Other buildings damaged in Louisa County include the High School (pictured below) and a number of businesses in Mineral and the surrounding areas. (Photos courtesy *Richmond Times-Dispatch*)

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 the ability to resist shear and flows much like quick sand. In the case of liquefaction, anything relying on the substrata for support can shift, tilt, rupture, or collapse.

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 seven major tectonic plates (there are also many minor 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.

[15] FEMA National Risk Index Technical Manual
https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

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. It should be noted that some earthquakes occur in areas that are far from tectonic plate boundaries.

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 4.4**). Each unit increase in magnitude on the Richter Scale corresponds to a ten-fold increase in wave amplitude, or a 32-fold increase in energy.

Table 4.4 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.

Source: North Carolina Division of Emergency Management

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 Modified Mercalli Intensity Scale of earthquake intensity and its correspondence to the Richter Scale is given in **Table 4.5**.

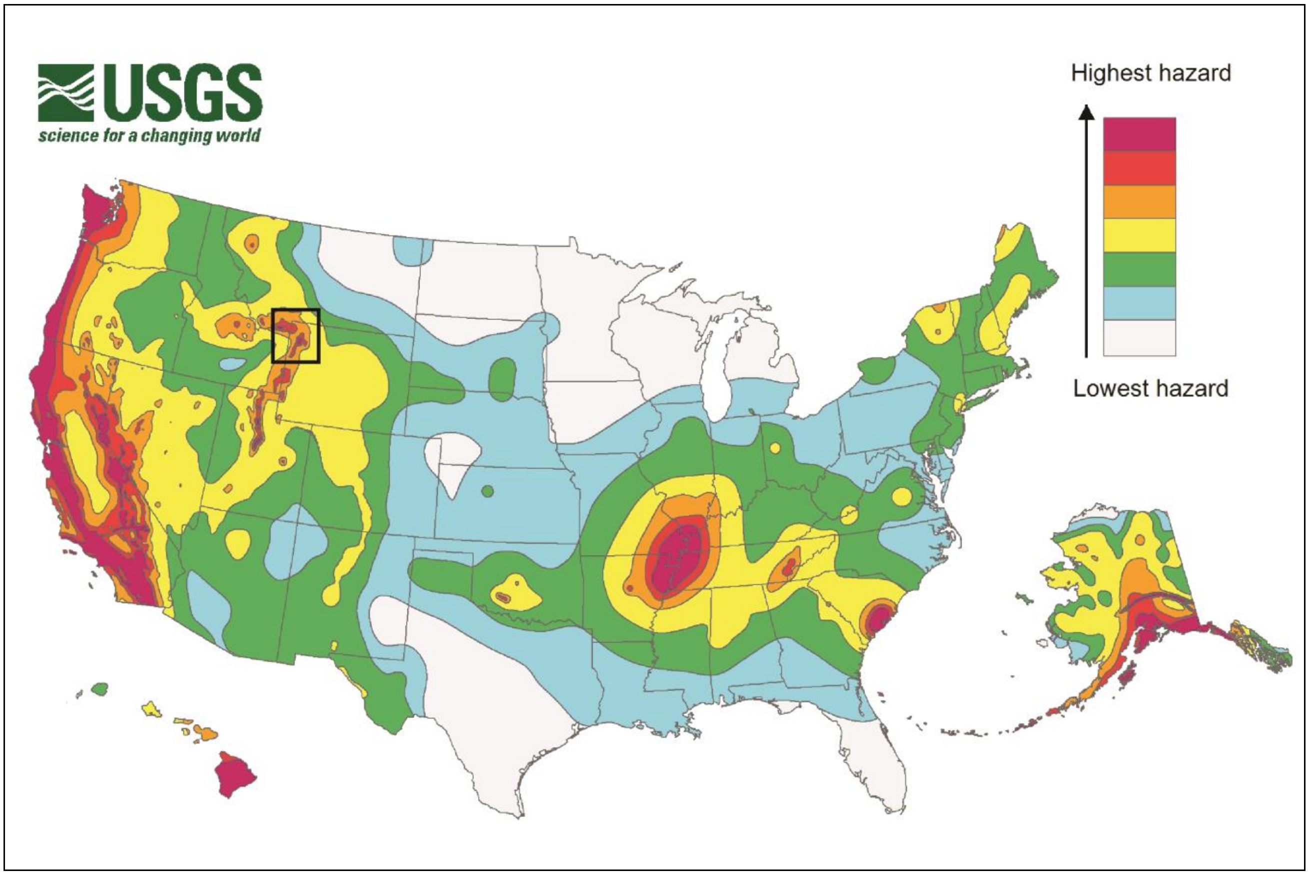
Table 4.5 Modified Mercalli Intensity Scale for Earthquakes

Scale	Intensity	Description of Effects	Richter Magnitude
I	Instrumental	Detected mainly on seismographs, felt by very few people	1.0 – 2.0
II	Feeble	Some people feel it, especially on upper floors	2.0 – 3.0
III	Slight	Felt by people resting, especially on upper floors; May not be recognized as an earthquake	3.0 – 4.0
IV	Moderate	Felt by many people indoors, a few outdoors; may feel like a large truck rumbling by	4.0
V	Slightly Strong	Felt by almost everyone, some people awakened; small objects moved, trees and poles may shake.	4.0 – 5.0
VI	Strong	Felt by everyone; difficult to stand, some heavy furniture moved, some plaster falls; chimneys may be slightly damaged.	5.0 – 6.0
VII	Very Strong	Slight to moderate damage in well built, ordinary structures, considerable damage to poorly built structures; some walls may fall.	6.0
VIII	Destructive	Little damage in specially built structures, considerable damage to ordinary buildings, severe damage to poorly built structures; some walls collapse.	6.0 – 7.0
IX	Ruinous	Considerable damage to specially built structures, buildings shifted off foundations; ground cracked noticeably; wholesale destruction, landslides.	7.0
X	Disastrous	Most masonry and frame structures and their foundations destroyed; ground badly cracked; landslides, wholesale destruction.	7.0 – 8.0
XI	Very Disastrous	Total damage; few, if any, structures standing; bridges destroyed, wide cracks in ground, waves seen on ground.	8.0
XII	Catastrophic	Total damage; waves seen on ground; objects thrown up into air.	8.0 or greater

Source: Michigan Tech

Figure 4.11 shows peak ground accelerations having a 2 percent probability of being exceeded in 50 years, for a firm rock site. (black box outlines Yellowstone region.) The map is based on the most recent USGS models for the conterminous U.S. (2018), Hawaii (1998), and Alaska (2007). The models are based on seismicity and fault-slip rates, and take into account the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown, because site geology may amplify ground motions.

Figure 4.11 Earthquake Hazard Map - Peal Ground Accelerations



Source: U.S.G.S. https://www.usgs.gov/media/images/earthquake-hazard-map-showing-peak-ground-accelerations

Sinkholes

Sinkholes are a natural and common geologic feature in areas with underlying limestone and other rock types that are soluble in natural water. Most limestone is porous, allowing the acidic water of rain to percolate through their strata, dissolving some limestone and carrying it away in solution. Over time, this persistent erosional process can create extensive underground voids and drainage systems in much of the carbonate rocks. Collapse of overlying sediments into the underground cavities produces sinkholes.

The three general types of sinkholes are: subsidence, solution, and collapse. Collapse sinkholes are most common in areas where the overburden (the sediments and water contained in the unsaturated zone, surficial aquifer system, and the confining layer above an aquifer) is thick, but the confining layer is breached or absent. Collapse sinkholes can form with little warning and leave behind a deep, steep sided hole. Subsidence sinkholes form gradually where the overburden is thin and only a veneer of sediments is overlying the limestone. Solution sinkholes form where no overburden is present and the limestone is exposed at land surface.

Sinkholes occur in many shapes, from steep-walled holes to bowl or cone shaped depressions. Sinkholes are dramatic because the land generally stays intact for a while until the underground spaces get too big. If there is not enough support for the land above the spaces, then a sudden collapse of the land surface can occur. Under natural conditions, sinkholes form slowly and expand gradually. However, human activities such as dredging, constructing reservoirs, diverting surface water, and pumping groundwater can accelerate the rate of sinkhole expansions, resulting in the abrupt formation of collapse sinkholes.

Although a sinkhole can form without warning, specific signs can signal potential development:

- Slumping or falling fenceposts, trees, or foundations;
- Sudden formation of small ponds;
- Wilting vegetation;
- Discolored well water; and/or
- Structural cracks in walls, floors.

Collapses, such as the sudden formation of sinkholes, may destroy buildings, roads, and utilities. (*Photo: Bettmann*)

Sinkhole formation is aggravated and accelerated by urbanization. Development increases water usage, alters drainage pathways, overloads the ground surface, and redistributes soil. According to the Federal Emergency Management Agency (FEMA), the number of human-induced sinkholes has doubled since 1930. Insurance claims for damages as a result of sinkholes increased 1,200 percent from 1987 to 1991, costing nearly $100 million.

Landslides

A landslide is the movement of a mass of rock, debris, or earth down a slope.[16] 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 surface of rupture, which separates the slide material from the more stable underlying material. Mudflows, sometimes referred to as mudslides, mudflows, 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.

Aerial view of the June 1995 landslide near Graves Mill in Madison County, Virginia. This landslide was caused by heavy rains, which resulted in flooding throughout Central Virginia (*photo from The debris flows of Madison County, Virginia: 34th Annual Virginia Geological Field Conference Guidebook*).

Landslides are typically associated with periods of heavy rainfall or rapid snow melt and tend to worsen the effects of flooding that often accompanies these 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.

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, Washington. Areas near the

[16] FEMA National Risk Index Technical Manual https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

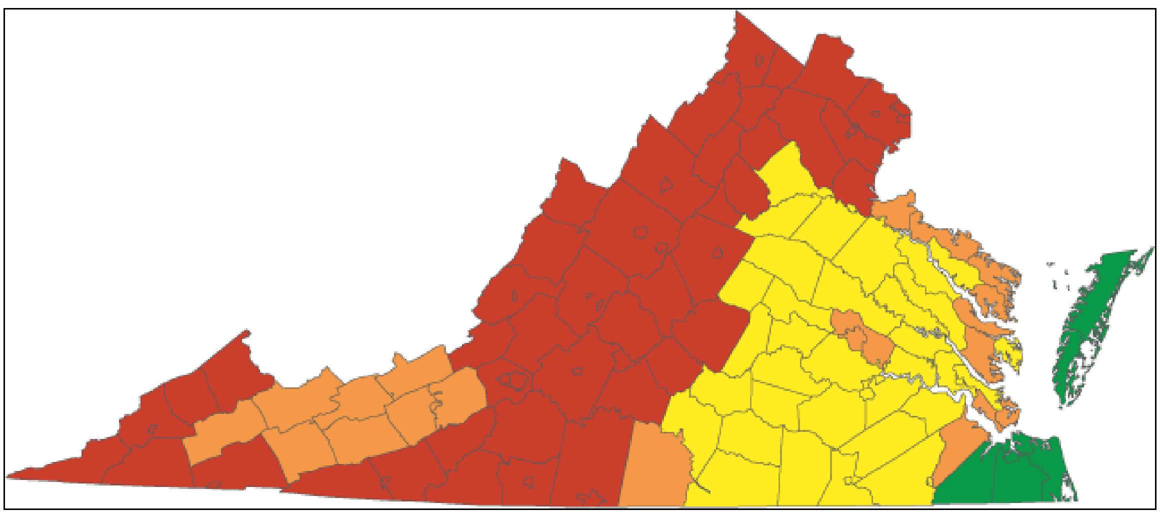
bases of many volcanoes in the Cascade Mountain Range of California, Oregon and Washington are at risk from the same types of flows during future volcanic eruptions.

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.

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 4.25 delineates susceptibility of counties in Virginia to landslides, adapted from the *USGS Landslide Overview Map of the Conterminous United States*. As can be seen, at least half of the Commonwealth falls into zones of high potential.

Figure 4.12 Landslide Susceptibility Overview Map of Virginia



Red = high potential; orange = moderate potential; yellow = moderate to low potential; green = low potential.

Source: Virginia Energy; https://energy.virginia.gov/geology/Landslides.shtml

Technological Hazards

Technological hazards are those hazards which originate from technological or industrial accidents, infrastructure failures, or certain human activities. These hazards cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation, and often come with little to no warning.

Hazardous materials (hazmat) spills

Hazmat substances, because of their chemical nature, can pose a danger to life, health or property if released. Hazmat spills can happen during production, storage, transportation, use or disposal of these substances. Virginia's hazardous materials officers typically receive 2,000 notifications of hazmat incidents a year, according to the Virginia Department of Emergency Management. Of these, spills or releases of flammable liquids are the most common. Most of these incidents occur in "fixed facilities" such as industrial plants, highways and waterways. Homes, businesses and schools located near the site of a hazmat spill or release are not likely to be affected unless the substance is airborne and poses a threat to areas outside the accident site. In that case, local emergency officials would evacuate areas that could potentially be affected. The length of the evacuation would depend on the type of substance, and could range from hours to days. In some cases, special equipment might be used to decontaminate people, objects or buildings affected.

Accidents at fertilizer/chemical facilities

Fertilizer and chemical plants and storage facilities are prone to accidents that can have a significant impact on the facility as well as the surrounding community. Accidents at these facilities can be caused by inadequate process hazards analysis, use of inappropriate or poorly-designed equipment, inadequate indications of process condition, and other factors. For significant accidents tracked by the U.S. Environmental Protection Agency and Occupational Safety and Health Administration, issues of note include installation of emissions or pollution control equipment (occurred prior to a number of accidents, which highlight the need for stronger systems for management of change) and similar accidents, near-misses, or low-level failures occurring just before a major accident (indicating the need for more attention to lessons-learned implementation and more thorough company investigation of near-misses and low-level failures). Such accidents can cause serious injury or death, as well as property damage to the facility. In some cases, residents in nearby communities need to be evacuated due to the release of toxins into the air.

Biological (Bio)-hazards

Bio-hazards can pose a threat to people, animals, and the environment when biological agents are accidentally or intentionally released into the air or water. Samples of bio-hazards include medical waste, samples of a microorganism, virus or toxin (from a biological source), or substances that are harmful to animals. Biohazard severity ranges from Level 1 (not considered dangerous, precautions required are minimal) to Level 4 (can cause severe to fatal disease in humans, and for which vaccines or other treatments are not available).

Accidents at power plants

Reactors in nuclear power plants use a process called fission, or atom splitting, to produce energy. Nuclear reactors control the fission process by slowing it down, cooling it off, and controlling the number of splitting atoms in the reactor. Nuclear reactors cannot explode like a nuclear bomb, since they use different materials and structures, and nuclear power plants are designed to prevent the release of radioactive materials and include multiple protective barriers placed around reactors, making the accidental release of radiological materials extremely unlikely. However, accidents do sometimes occur at nuclear power plants that result in the release of radioactive materials into the atmosphere or nearby water sources. Other types of power plants (coal fired, gas fired) and electric substations can sometimes experience accidents or malfunctions that can cause injury or death to plant workers and disrupt the flow of electricity for homes and businesses in the area.

Pipeline explosions/Accidents at above-ground storage facilities

While pipelines are considered the safest way to move gas, petroleum, and other hazardous materials, they can sometimes malfunction and even explode. If corrosion controls fail to properly function, and/or corrosion is not repaired in a timely manner, then the pipeline could explode. An explosion can cause serious injury, even death, and significant damage to property.

Storage tanks for gas, oil, and other chemicals can sometimes experience "catastrophic failure" and explode. This can occur when flammable vapors are ignited, causing a break in either the shell-to-bottom or side seam of the tank. Sometimes, workers performing maintenance or other operations can introduce an ignition source. This type of accident can cause injury or death to workers, and release harmful chemicals into the atmosphere. Such accidents can happen anywhere, but are more of a concern in cases where the tanks were built before 1950 or tanks are poorly maintained, rarely inspected, or repaired without attention to the tank's design.

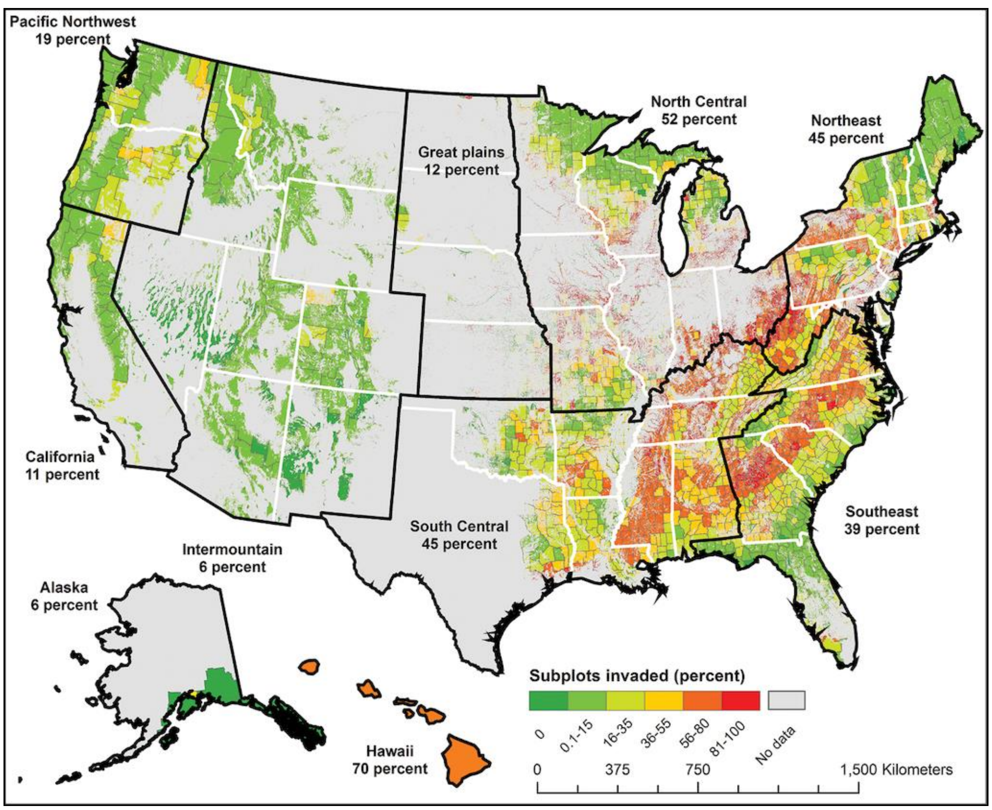
Invasive Species

According to the Virginia Department of Conservation and Recreation (DCR), invasive species are "species intentionally or accidentally introduced by human activity into a region in which they did not evolve and cause harm to natural resources, economic activity or humans." Invasive plants and animals proliferate and displace native plant species, reduce wildlife habitat and alter natural processes. Economists have estimated that all invasive species - plants, animals, and diseases - cause $120 billion in losses each year.[17] These costs include degradation of agricultural pastures, clogging of important waterways, the spread of diseases to plants and animals, and increased effort to maintaining open power line rights-of-way, among others.

Capacity for invasiveness is usually marked by rapid growth and maturity, highly successful reproduction, and difficulty in extermination. Because they do not have the same biological stressors as native plants and animals, or fill an ecosystem niche that lets them outcompete natives, invasives have the potential to grow without check and damage native biospheres.

For plants alone, U.S. Forest Service research has shown that at least one invasive species is present in 39 percent of forested plots sampled nationwide. **Figure 4.26** shows the extent of invasive plants in their nationwide survey.

Figure 4.13 Invasive Plants in US Forests



[17] Source: Pimental et al. 2005, "Update on the environmental and economic costs associated with alien-invasive species in the United States", https://doi.org/10.1016/j.ecolecon.2004.10.002

Common established invasives include species such as Kudzu, English Ivy, Tree of Heaven, Asian Carp, Wild Hogs, and Stink Bugs. Invasives on the horizon include such pests as Giant Hogweed and Spotted Lanternfly. Different state agencies monitor and have plans to control for certain species being introduced to Virginia. DCR maintains a list of the plants of most concern, shown in **Table 4.5 below.**

None of the invasive species identified in the Commonwealth of Virginia Hazard Mitigation Plan have been found within Planning District 14.

Table 4.5 List of Plants Invasive to Virginia

Scientific Name	Common Name	VA Invasiveness Rank
Ailanthus altissima	Tree-of-heaven	High
*Aldrovanda vesiculosa**	Waterwheel	High
Alliaria petiolata	Garlic Mustard	High
Alternanthera philoxeroides	Alligator-weed	High
Ampelopsis brevipedunculata	Porcelain-berry	High
Carex kobomugi	Japanese Sand Sedge	High
Celastrus orbiculatus	Oriental Bittersweet	High
Centaurea stoebe ssp. micranthos	Spotted Knapweed	High
Cirsium arvense	Canada Thistle	High
Dioscorea polystachya	Cinnamon Vine	High
*Eichhornia crassipes**	Water Hyacinth	High
Elaeagnus umbellata	Autumn Olive	High
Euonymus alatus	Winged Euonymus	High
Ficaria verna	Lesser Celandine	High
Hydrilla verticillata	Hydrilla	High
*Imperata cylindrica**	Cogon Grass	High
Iris pseudacorus	Yellow Flag	High
Lespedeza cuneata	Sericea Lespedeza	High
Ligustrum sinense	Chinese Privet	High
Lonicera japonica	Japanese Honeysuckle	High
Lonicera maackii	Amur Honeysuckle	High
Lonicera morrowii	Morrow's Honeysuckle	High
*Ludwigia grandiflora ssp. hexapetala**	Large flower primrose willow	High
Lythrum salicaria	Purple Loosestrife	High
Microstegium vimineum	Japanese Stiltgrass	High
Murdannia keisak	Marsh dewflower	High

Myriophyllum aquaticum	Parrot Feather	High
Myriophyllum spicatum	Eurasian Water-milfoil	High
*Oplismenus hirtellus ssp. undulatifolius**	Wavyleaf Grass	High
Persicaria perfoliata	Mile-a-minute	High
Phragmites australis ssp. australis	Common Reed	High
Pueraria montana var. lobata	Kudzu	High
Reynoutria japonica	Japanese knotweed	High
Rosa multiflora	Multiflora Rose	High
Rubus phoenicolasius	Wineberry	High
Sorghum halepense	Johnson Grass	High
Urtica dioica	European Stinging Nettle	High
*Vitex rotundifolia**	Beach Vitex	High

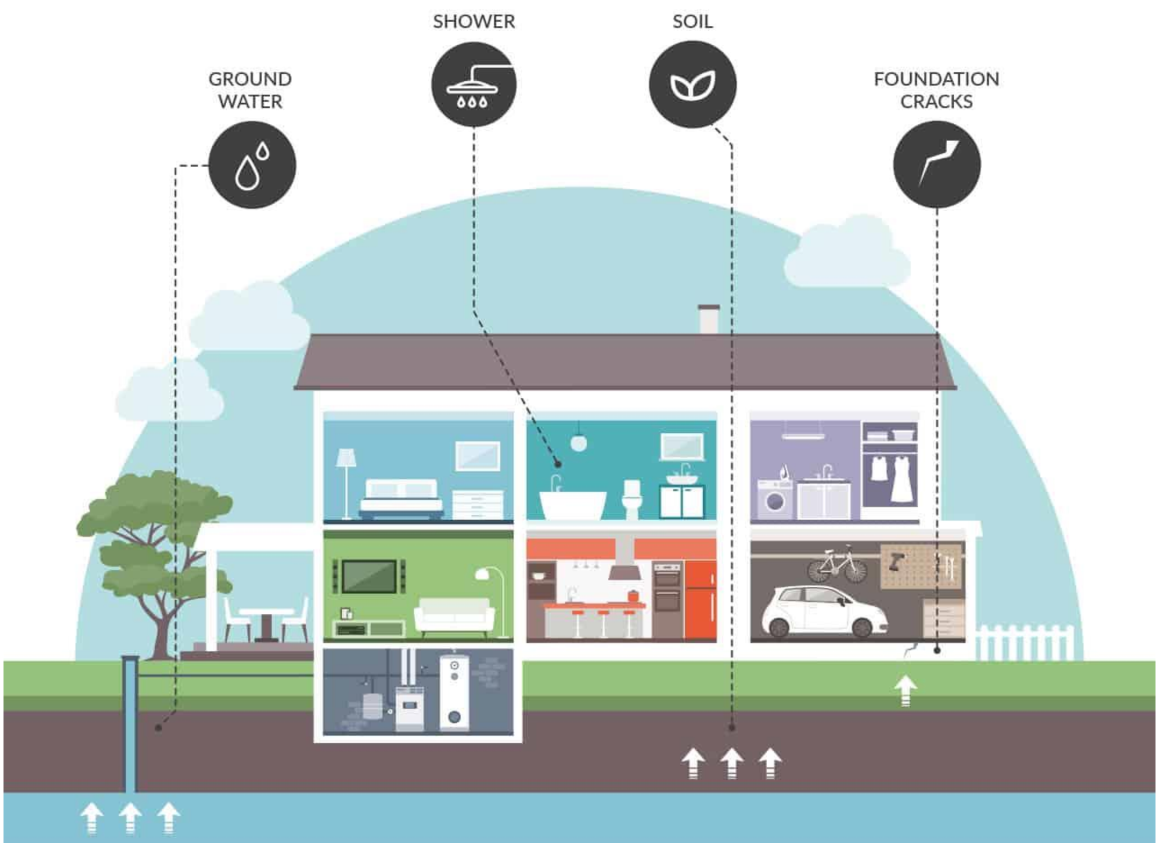
Radon

Radon is a naturally occurring radioactive gas that is produced from the natural radioactive decay of uranium. It may be found in igneous rock and soil, although in some cases in water as well. It is also considered a cancer-causing radioactive gas. Radon cannot be seen, smelled, nor tasted, yet it could still be a potential issue in homes. Radon is measured in picocuries per liter (pCi/L).

Radon is considered to be second as the leading cause of lung cancer. The U.S. Environmental Protection Agency (EPA) and the Surgeon General's Office have estimated that as many as 20,000 lung cancer deaths are caused each year by radon exposure. The costs of radon-induced lung cancer in the United States are currently over $2 billion annually in both direct and indirect healthcare costs.

Radioactivity caused by airborne radon has been considered to be an important component in the natural background of natural radioactivity exposure of humans. Radon can seep into your home from exposed dirt such as a crawl space, plumbing cutouts, and old cellars. It can also pass through openings in your foundation, such as unsealed sumps, joints, cracks, and open top block walls. The highest levels of radon are typically found in rooms in direct contact with the ground, such as basements.

Figure 4.14



Source: VDH

Table 4.6 illustrates the radon test results for counties within the region from the 1980s through 2013. The data is derived from AIR Chek, a vendor for short-term radon testing.

Table 4.6 Radon Test Results for the Commonwealth Regional Council Region

County	Total Tests	AVG pCi/L	MAX pCi/L	EPA Risk	0-3.9 pCi/L	4-10 pCi/L	10-20 pCi/L	20-50 pCi/L	50-100 pCi/L
Amelia	26	3.6	37.9	HIGH	19	6	0	1	0
Buckingham	57	4.7	18.9	HIGH	36	8	13	0	0
Charlotte	40	3.8	58.4	MODERATE	29	10	0	0	1
Cumberland	20	3.4	10.2	HIGH	14	5	1	0	0
Lunenburg	14	1.0	2.6	MODERATE	14	0	0	0	0
Nottoway	20	7.6	65.5	HIGH	16	2	0	0	2
Prince Edward	85	3.1	26.9	MODERATE	64	19	1	1	0

Radon levels can vary tremendously - even among houses in the same neighborhood. Consequently, the only way to know if a particular home has a problem is to test for it. At this time, the Virginia Department of Health (VDH) does not maintain a comprehensive database of radon test results These results come from various sources and VDH does not currently have the regulatory authority or the resources to collect and map this data.

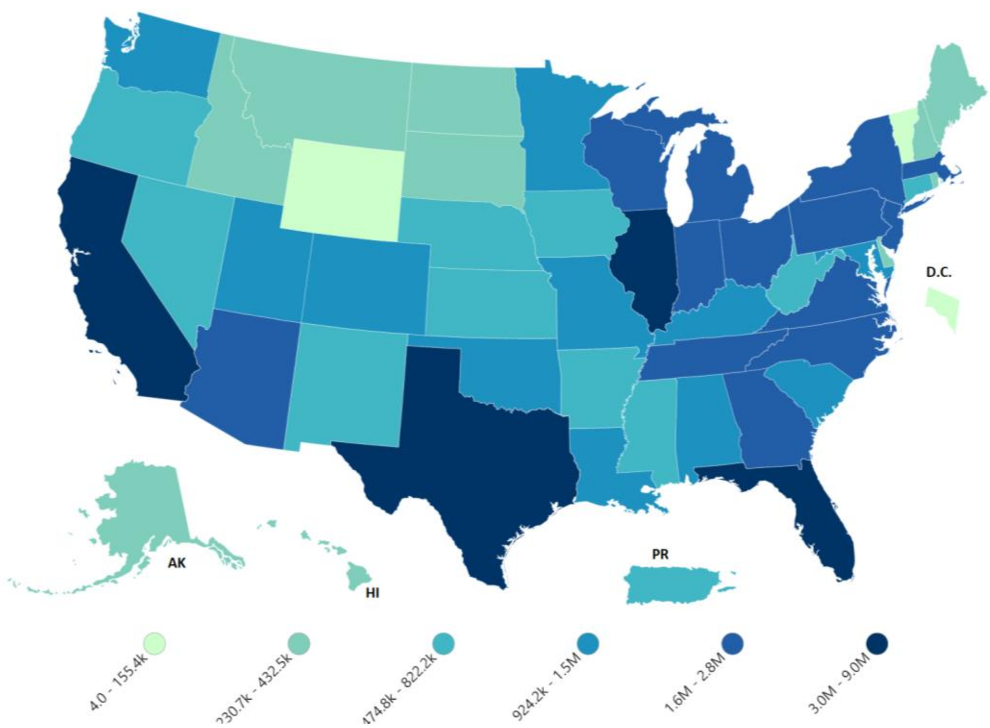
Pandemic/Infectious Agent

A pandemic, as opposed to an epidemic, is a bacterial or viral disease outbreak that has spread rapidly across the world. The COVID-19 pandemic has brought to the forefront a challenging and multi-faceted hazard which few if any localities were prepared to handle. The CDC has guidelines on how to approach influenza outbreaks, but otherwise there is sparse information for how to respond to any individual infectious agent. The response to the novel coronavirus in Virginia was largely driven by federal recommendations, but implemented locally through Virginia Department of Health (VDH) district offices, which led to different responses across the Commonwealth.

Because pandemics of this nature evolve as new information emerges, the recommendations for this Plan will likely be more general in nature. However, having examples of local planning and of emergency responses to specific pandemic-related threats provides for a solid baseline that is germane to the character of the region.

Other serious past flu pandemics include the 1918 H1N1 Spanish Flu outbreak, the 1957-1958 H2N2 influenza pandemic, the 1968 H3N2 flu pandemic, and the 2009 swine flu pandemic. Each occurrence killed millions of people, and often led to upheavals in the social order.

Figure 4.15 Total Covid-19 Cases in the US Since January 21, 2020 by State



Source: Centers for Disease Control https://covid.cdc.gov/covid-data-tracker/#cases_totalcases