4.5 Hurricane

4.5.1 Hazard Profile

A hurricane is a classification of a tropical cyclone in which the maximum sustained surface wind is 74 miles per hour (mph) or more. The term hurricane is used for Northern Hemisphere tropical cyclones east of the International Dateline to the Greenwich Meridian. The term typhoon is used for Pacific tropical cyclones north of the Equator west of the International Dateline.

A tropical cyclone is the general term for a low-pressure system that originates over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects). [34]

Depending on strength, they are classified as hurricanes (> 74 mph wind), tropical storms (39-73 mph), or tropical depressions (< 38 mph). Tropical cyclones involve both atmospheric and hydrologic characteristics, such as severe winds, storm surge flooding, high waves, coastal erosion, extreme rainfall, thunderstorms, lightning, and, potentially, tornadoes. Storm surge flooding can push inland and increase riverine flooding associated with heavy inland rains. High winds associated with hurricanes cause widespread debris due to damaged and downed trees, damaged buildings, and power outages.

4.5.1.1 Geographical Location and Extent

The hurricanes that affect Virginia typically form in the Atlantic or Gulf of Mexico during the months of June through November. Virginia has been struck by 48 hurricanes from 1900 to 2018 according to the National Hurricane Center. Most hurricanes affect eastern Virginia due to its proximity to the coast; however, it is not uncommon for hurricanes and tropical storms to track through the state and impact inland jurisdictions. According to NOAA's storm events database, the CVPDC area has not experienced a direct hurricane landfall since 1950. The CVPDC area's location makes it susceptible to the remnants of hurricanes bringing heavy rains and winds throughout the region.

4.5.1.2 Magnitude / Severity / Frequency

As a hurricane develops, barometric pressure (measured in millibars or inches) at the center falls and winds increase. When maximum sustained winds reach or exceed 39 miles per hour, the system is designated a tropical storm. When sustained winds reach or exceed 74 mph, the storm is classified as a hurricane. Hurricane intensity is categorized 1-5 by the Saffir-Simpson Hurricane Damage Scale (Table 4-109). The Saffir-Simpson Scale categorizes hurricane intensity based upon maximum sustained wind speeds and barometric pressure which are combined to estimate potential damage. Categories 3, 4, and 5 are classified as "major" hurricanes, and while hurricanes within this range comprise only 20% of total tropical cyclone landfalls, they cause 70% of the damage in the United States. Table 4-110 describes expected damage per hurricane category.

[34] National Hurricane Center. Glossary of NHC Terms. https://www.nhc.noaa.gov/aboutgloss.shtml

Table 4-109 Saffir-Simpson Hurricane Damage Scale (Source: National Weather Service)

Category	Maximum Sustained Wind Speed (MPH)	Minimum Surface Pressure (Millibars)	Summary
1	74-95	Greater than 980	Very dangerous winds will produce some damage
2	96-110	979-965	Extremely dangerous winds will cause extensive damage
3	111-130	964-945	Devastating damage will occur
4	131-155	944-920	Catastrophic damage will occur
5	155+	Less than 920	Catastrophic damage will occur

Table 4-110 Hurricane Damage Classification (Source: National Hurricane Center)

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

4.5.1.3 Previous Occurrences

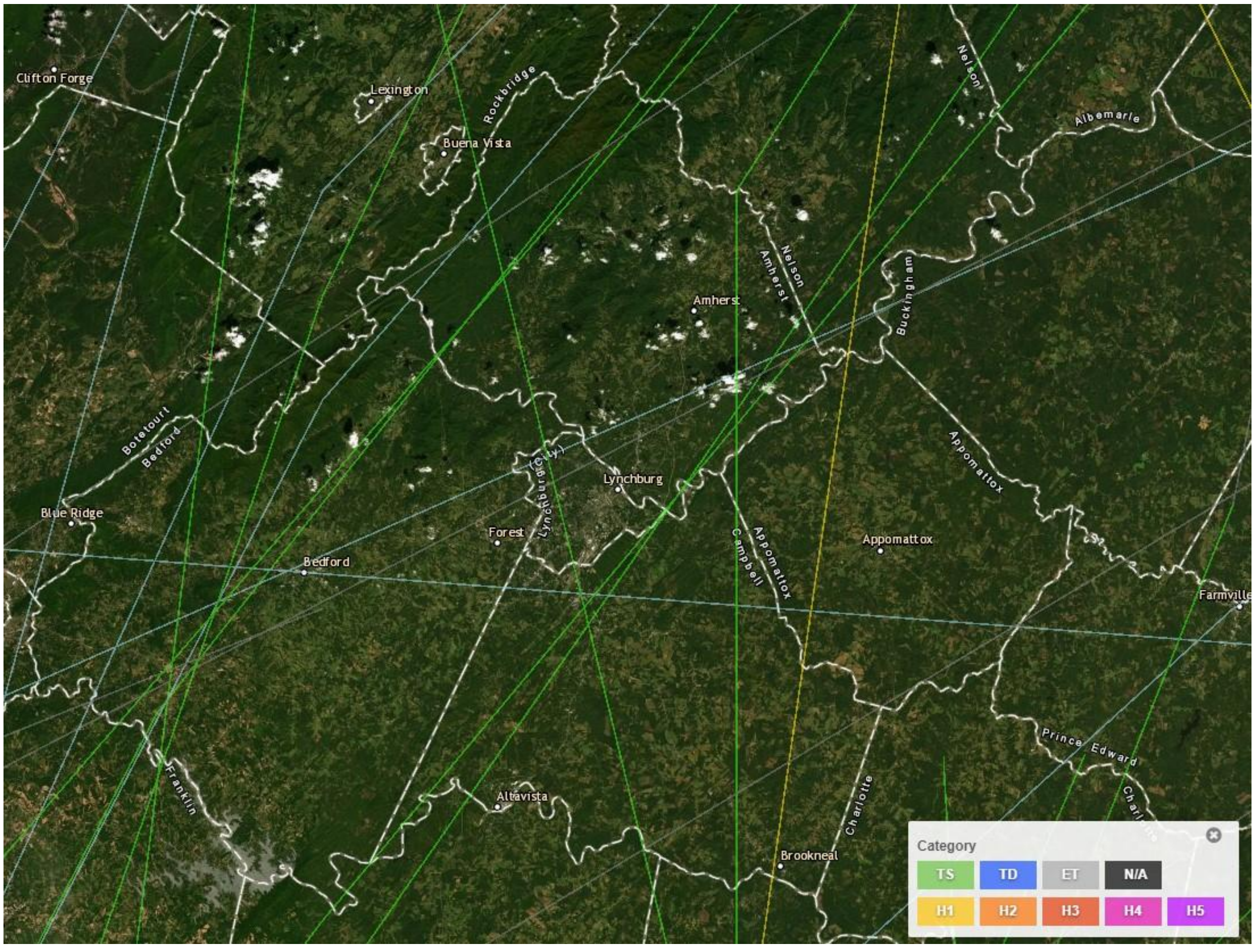
The National Oceanic and Atmospheric Administration has tracked the path of all tropical cyclones (including hurricanes) from 1851 to 2018. The tropical cyclone track map in Figure 4-90 shows the historical occurrences of tropical cyclones that have passed through the CVPDC area. There has only been one categorized hurricane that passed through and it occurred in 1896 when hurricanes were unnamed. In total, 7 tropical storms and 3 tropical depressions were tracked through the CVPDC area. It should be noted that the paths shown in the map indicate the location of the centerline of the storms. Impacts from tropical cyclones and hurricanes span many miles in all directions of the designated track.

Recent hurricanes affecting the region include:

Hurricane Camille (1969) Camille made landfall in the gulf coast as a category 5 and weakened to a tropical depression before reaching Virginia. Areas within Amherst, Bedford, and Campbell Counties, as well as the City of Lynchburg, were impacted by the storm.

Hurricane Fran (1996) Fran was downgraded to a tropical storm before reaching the area, but still had widespread effects. Rainfall amounts between 8 and 20 inches fell over the mountains and Shenandoah Valley, leading to record-level flooding in many locations within this region.

Hurricane Isabel (2003) Isabel's track passed east of the CVPDC area at hurricane strength, which was enough to cause wind and flood damage locally.



Legend: H1 - H5 represent category 1 through 5 hurricanes, TS - Tropical Storm, TD - Tropical Depression, ET - the system is classified as extratropical

Figure 4-90 CVPDC Area Tropical Cyclone Tracks from 1851-2018 (Source: National Hurricane Center)

4.5.1.4 Relationship to Other Hazards

Figure 4-91 shows the interrelationship (causation, concurrence, *etc.*) between this hazard and other hazards discussed in this plan update.

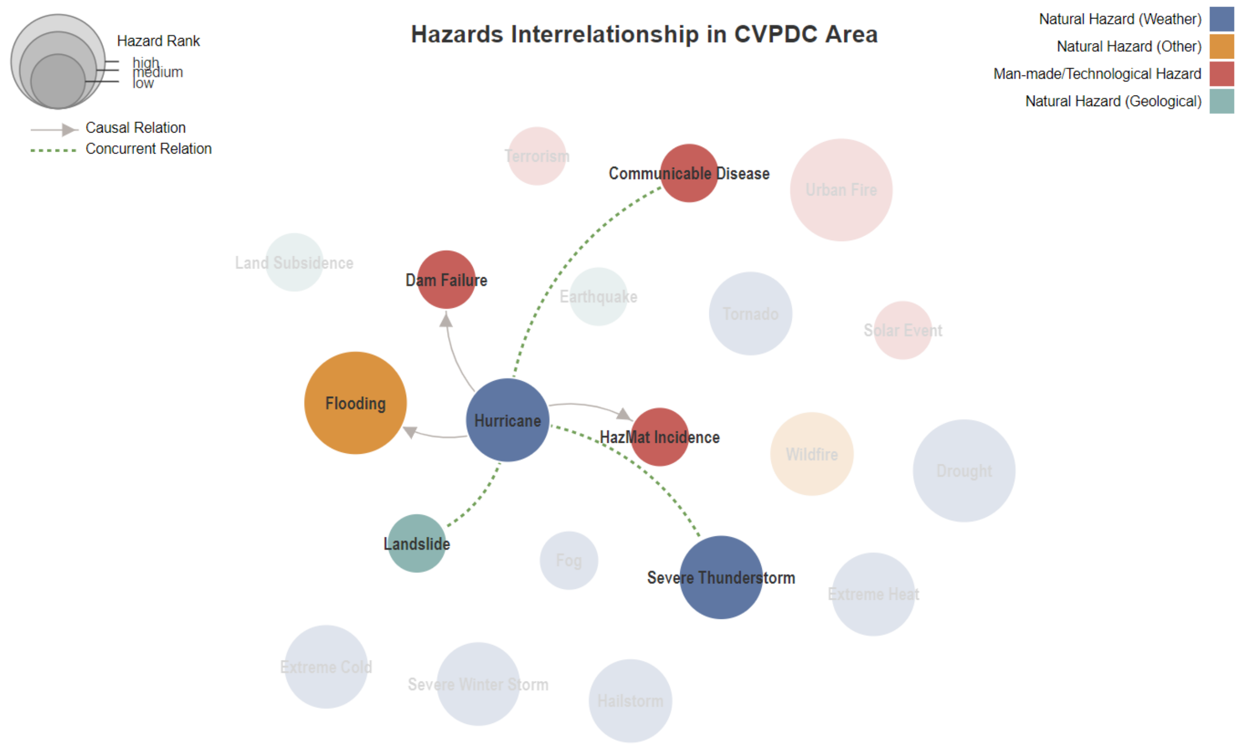


Figure 4-91 Hazards interrelationship

4.5.2 Impact and Vulnerability

Hurricanes are one of the most devastating natural disasters in the United States. Although the CVPDC area rarely experienced a direct landfalling hurricane in the past, it is still susceptible to the remnants of an event. Secondary hazards from a hurricane event could include heavy rains, flooding, high winds, and tornadoes. A foot or more of rain may fall in less than a day, causing flash floods and mudslides. The rain eventually drains into the large rivers, which may still be flooding for days after the storm has passed. The storm's driving winds can topple trees, utility poles, and damage buildings. Communication and electricity can be lost for days and roads made impassable due to fallen trees and debris.

Vulnerability and impact are generally measured in terms of population and property damage from hurricane winds. Potential injuries and damages to the property vary based on the hurricane category and various other factors.

4.5.3 Risk Assessment and Jurisdictional Analysis

Hazus (Version 4.2) software was used to complete the hurricane wind analysis for vulnerability and loss estimates. The model uses state of the art wind field models and calibrated and validated hurricane data. Wind speed has been calculated as a function of central pressure, translation speed, and surface roughness. This assessment is based on a Level 1 analysis with default parameters and no local data adjustments. In this analysis, the hurricane model ran at the census tract level. The results are captured in the vulnerability analysis and loss estimation.

4.5.3.1 Ground Surface Roughness

In Hazus software, a critical component in the modeling of hurricane wind effects, damage, and loss to buildings and facilities is the assessment of the ground roughness. As the ground surface becomes rougher, the wind speeds near the ground decrease, although the upper level wind speed remains the same. The wind loads experienced by structures located in a typical suburban, treed, or urban environment (*i.e.,* high surface roughness area) are much lower than those experienced by buildings located in relatively unobstructed regions such as waterfront and open field locations (*i.e.,* low surface roughness area). The surface roughness is measured by roughness length, which is defined as the height at which the mean wind speed theoretically becomes zero due to substrate roughness. The smaller the roughness length, the smoother the ground surface is. In this plan update, critical facilities built on low surface roughness areas (roughness length < 0.3 meter) are considered as at higher risk in a hurricane event, and are identified as in Table 4-111. Most of these facilities are located in Bedford County, while the rest are in Campbell County. Figure 4-92, Figure 4-93, Figure 4-94, Figure 4-95, Figure 4-96, and Figure 4-97 are a series of ground surface roughness maps at census block level for the PDC and each jurisdiction. Bedford County has more low surface roughness areas than other jurisdictions in the region.

Table 4-111 Critical facilities in low ground surface roughness areas (roughness length < 0.3m) in CVPDC Area

Locality	Facility Name	Facility Type	Location	Coordinates
Bedford County	Spring Valley Farm Campground	Campground	2077 Meadors Spur Rd, Moneta	37.2234, -79.6669
Bedford County	Wheelabrator Landfill (Winoa Usa, Inc.)	HazMat Facility	3 Abrasive Ave	37.3462, -79.5526
Bedford County	Bedford Memorial Hospital	Public Health	1613 Oakwood St	37.3513, -79.5172
Bedford County	Liberty High	Schools	100 Liberty Minutemen Dr	37.3717, -79.4980
Bedford	Pump Station #8	Sewer Pump Station		37.3537, -79.5212
Bedford County	Montvale Pump Station	Sewer Pump Station		37.3788, -79.7098
Bedford County	Electrical Substation	Electrical Substation		37.3746, -79.5021
Campbell County	Gladys Volunteer Fire Department	Fire Stations	8569 Brookneal Highway	37.1600, -79.0717
Campbell County	Otter River Water Tank	Water Storage Facility	9625 Leesville Rd	37.2109, -79.2992
Campbell County	Otter River Water Treatment Plant	Wastewater Treatment Plant	9605 Leesville Rd	37.2113, -79.2988
Campbell County	Campbell Co Util And Serv Auth/Sewer Pump Station	Sewer Pump Station	Leesville Rd, Evington	37.2075, -79.2997

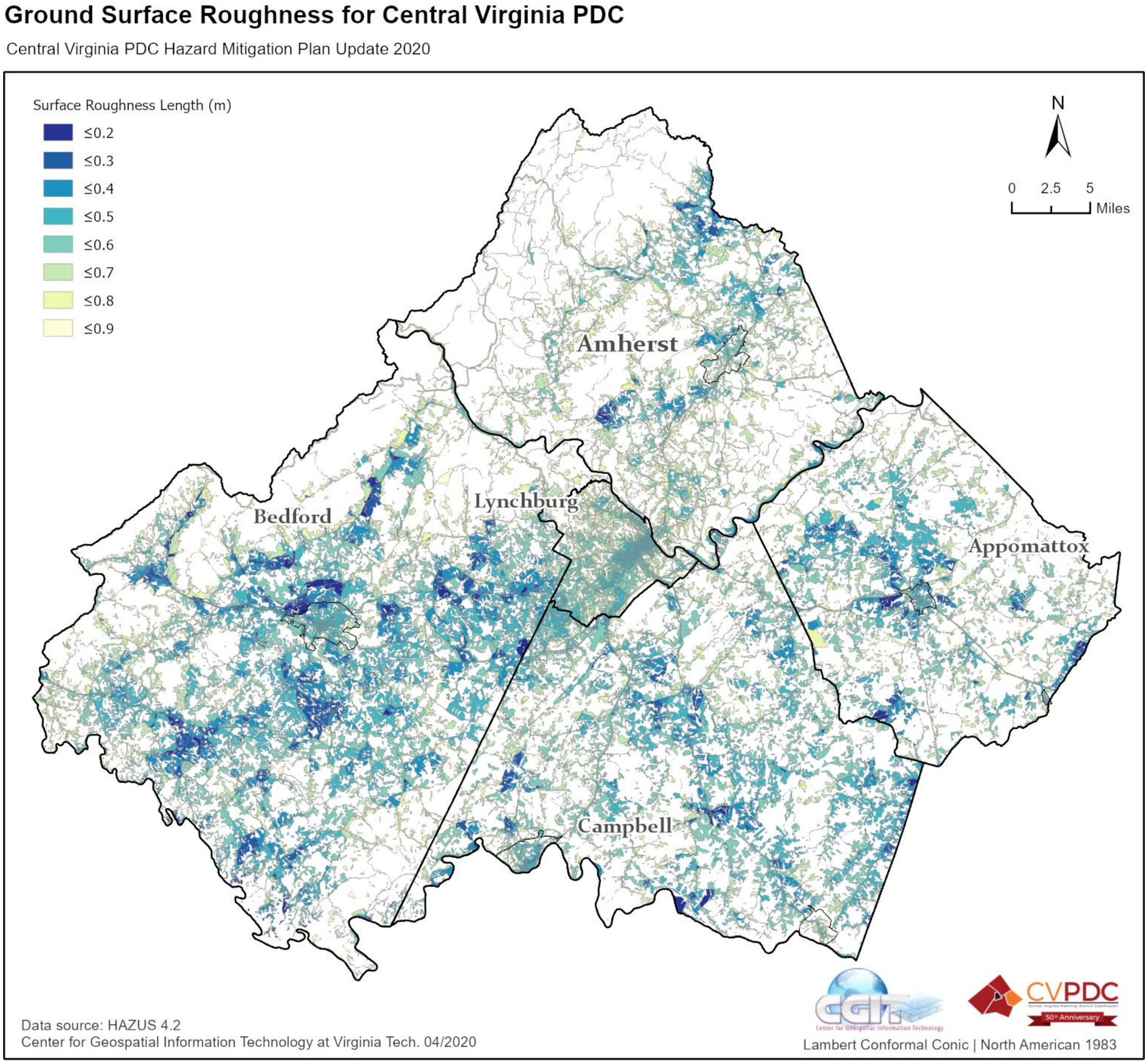


Figure 4-92 Ground surface roughness map for CVPDC Area

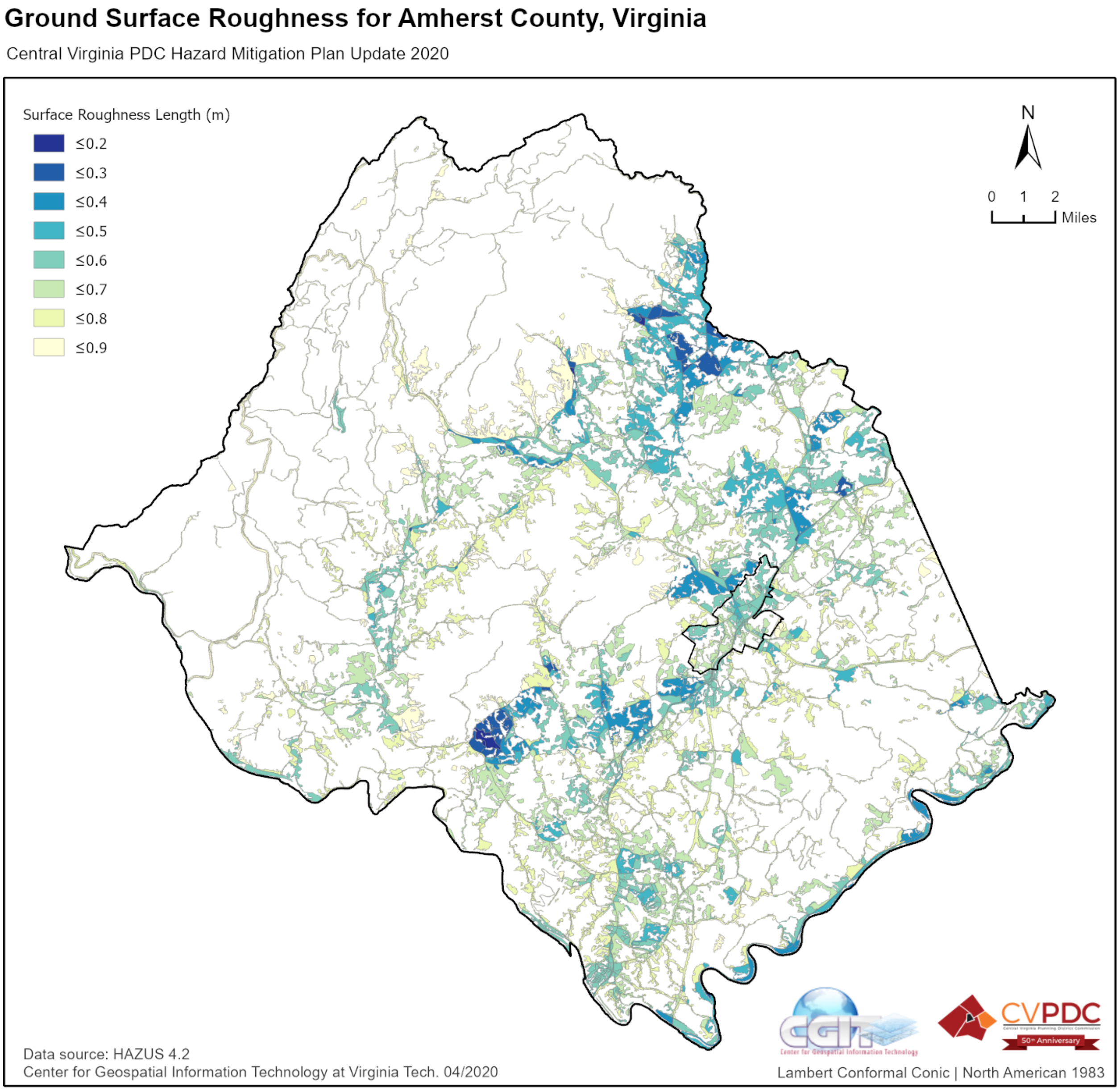


Figure 4-93 Ground surface roughness map for Amherst County in CVPDC Area

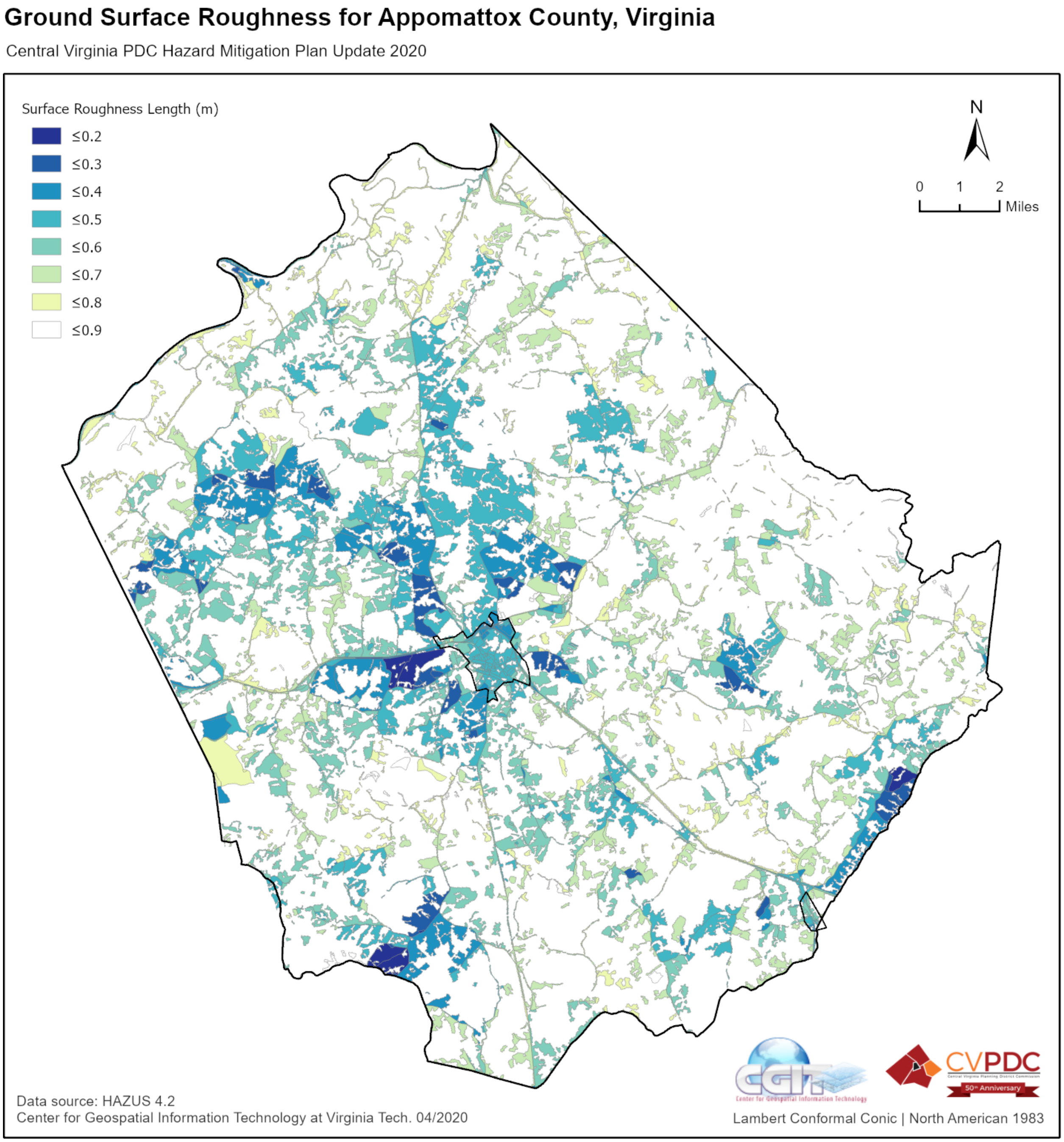


Figure 4-94 Ground surface roughness map for Appomattox County in CVPDC Area

Ground Surface Roughness for Bedford County, Virginia

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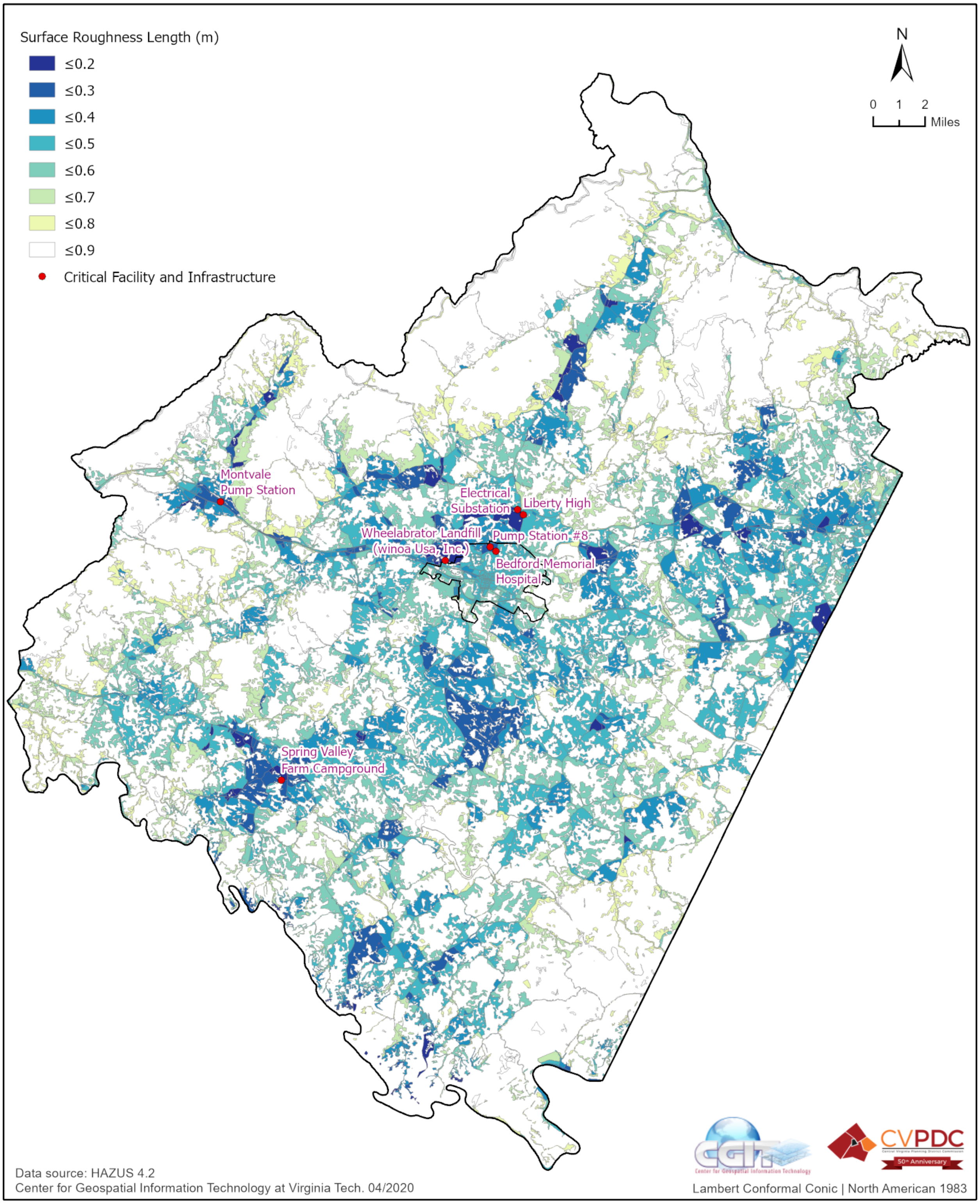

Figure 4-95 Ground surface roughness map for Bedford County in CVPDC Area

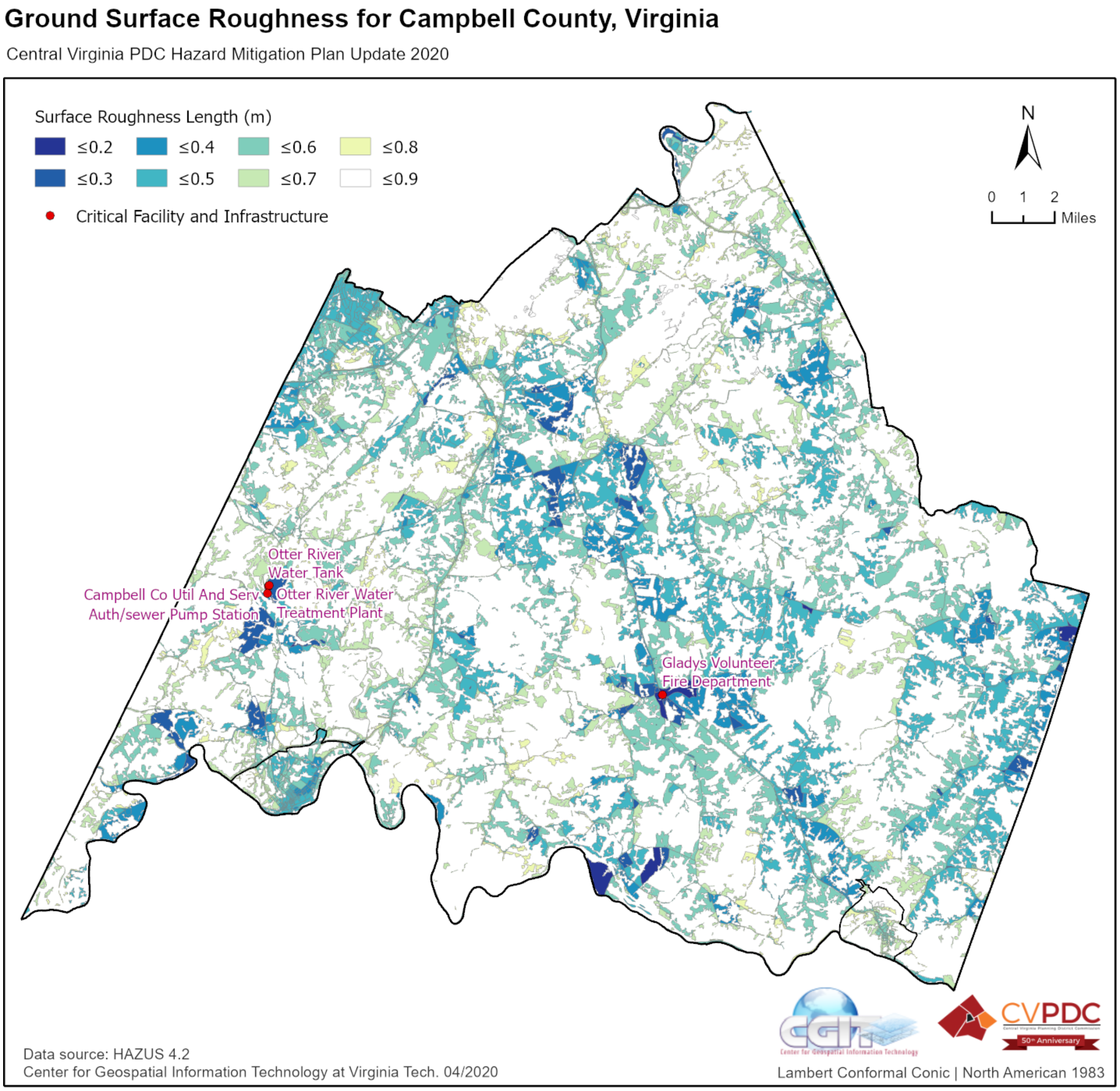

Figure 4-96 Ground surface roughness map for Campbell County in CVPDC Area

Ground Surface Roughness for City of Lynchburg, Virginia

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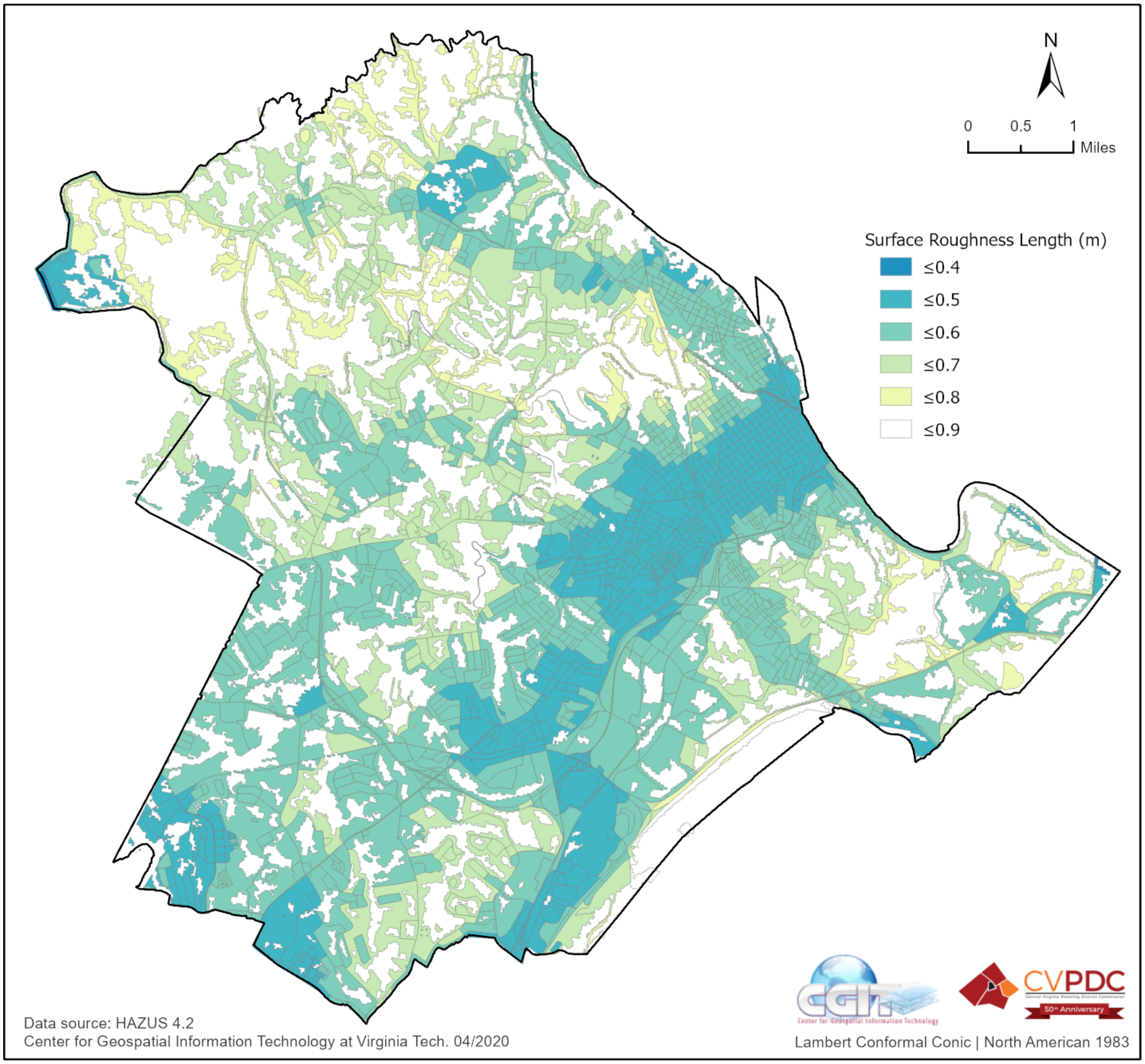

Figure 4-97 Ground surface roughness map for City of Lynchburg in CVPDC Area

4.5.3.2 Loss Analysis (Probabilistic Hurricane Scenario)

Hazus uses historical hurricane tracks and computer modeling to identify the probabilistic tracks of a range of hurricane events. When a hurricane impacts these areas, these maps can be used to determine what areas will be more impacted than others (in the U.S. Census tract level).

Probability is the percent chance that a hurricane of a specific magnitude will occur in any given year (Table 4-112). Probabilistic scenarios were used to run the hazard identification and risk analysis. The scenario considers the associated impacts of many thousands of potential storms that have tracks and intensities reflecting the full spectrum of Atlantic and Central Pacific hurricanes (Hazus User Manual). The probabilistic windspeeds shown in Table 4-112 are provided by the ASCE in their 7-98 publication.

Table 4-112 Hurricane Return Period and its Chance of Occurrence

Return Period (Years)	10	20	50	100	200	500	1000
Chance of Occurrence in any given year (%)	10	5	2	1	0.5	0.2	0.1
ASCE windspeed values (mph)	25-32	37-43	53-58	62-66	69-74	77-82	84-88

Loss estimation for the hurricane module is based on specific input data including square footage of buildings for specified types or population, and information on the local economy that is used in estimating losses. The loss categories used to calculate annualized losses in the CVPDC area is shown in Table 4-113.

Table 4-113 Hazus direct economic loss categories and descriptions

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

4.5.3.2.1 Capital Stock Loss and Income Losses

The model predicts no building damage for 10-year and 20-year return periods. For a 1000-year return period, Hazus estimates 4,215 structures would experience some type of damage (Table 4-114).

Table 4-114 Number of Buildings Damaged from a Hurricane

Return Period (years)	Minor	Moderate	Severe	Destruction	Total
10 or 20	0	0	0	0	0
50	43	0	0	0	43
100	97	1	0	0	98
200	371	10	0	0	381
500	1,376	65	1	0	1,442

Return Period (years)	Minor	Moderate	Severe	Destruction	Total
1000	3,959	285	4	3	4,215

4.5.3.2.1 Direct Economic Losses for Buildings: Annualized Losses by Jurisdiction

Annualized loss is defined as the expected value of loss in any one year, and is developed by aggregating the losses and exceedance probabilities for the 10-, 20-, 50-, 100-, 200-, 500-, and 100- year return periods. Hazus estimates direct and indirect economic losses due to winds that include: damage to buildings and contents, economic loss, and social interruptions. The following tables (Table 4-115 and Table 4-116) show the direct economic losses for the individual localities.

Table 4-115 Estimate of Potential Building Damage - Wind Only

Locality	Capital Stock Losses ($K)				Income Losses ($K)				Total Loss ($K)
	Cost of Building Damage	Cost of Contents Damage	Inventory Loss	Total	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	
Amherst	55	10	0	65	2	0	0	1	67
Appomattox	46	17	0	63	1	0	0	0	65
Bedford	174	33	0	207	7	0	0	2	217
Town of Bedford	12	1	0	13	1	0	0	0	15
Campbell	123	22	0	145	5	0	0	2	152
Lynchburg	175	59	0	234	6	1	1	3	244

Note: The hurricane wind damage for the Towns of Amherst, Appomattox, Altavista, and Brookneal are found in their respective county's totals.

The annualized loss, or long-term average losses in a given year, is $727,000 dollars for total building structures. More than 80% of the annualized capital loss results from damage to the buildings, while no loss is derived from inventory loss.

The annualized damages were developed from the results of the hurricane model. The impacts of these various events are combined to create a total annualized loss. Figure 4-98 illustrates the annualized damages from hurricane winds. It should be noted that these are climatologically trend tracks, and therefore the specified track, realistically, can vary significantly from what is shown.

Table 4-116 Direct Economic Losses for Buildings in 1000-year Event

Locality	Capital Stock Losses ($K)				Income Losses ($K)				Total Loss ($K)
	Cost of Building Damage	Cost of Contents Damage	Inventory Loss	Loss Ratio %	Relocation Loss	Capital Related Loss	Wage Losses	Rental Income Loss	
Amherst	$14,597	$2,394	$13	.43	$551	$0	$0	$224	$17,778
Appomattox	$6,233	$1,957	$1	.39	$192	$0	$0	$63	$8,446
Bedford	$21,744	$3,078	$6	.26	$641	$0	$0	$218	$25,687
Town of Bedford	$1,026	$5	$0	.11	$6	$0	$0	$3	$1,039
Campbell	$25,034	$2,778	$25	.42	$969	$17	$7	$352	$29,181

Lynchburg	$44,053	$12,887	$52	.45	$1,430	$66	$25	$831	$59,345

Note: The hurricane wind damage for the Towns of Amherst, Appomattox, Altavista, and Brookneal are found in their respective county's totals.

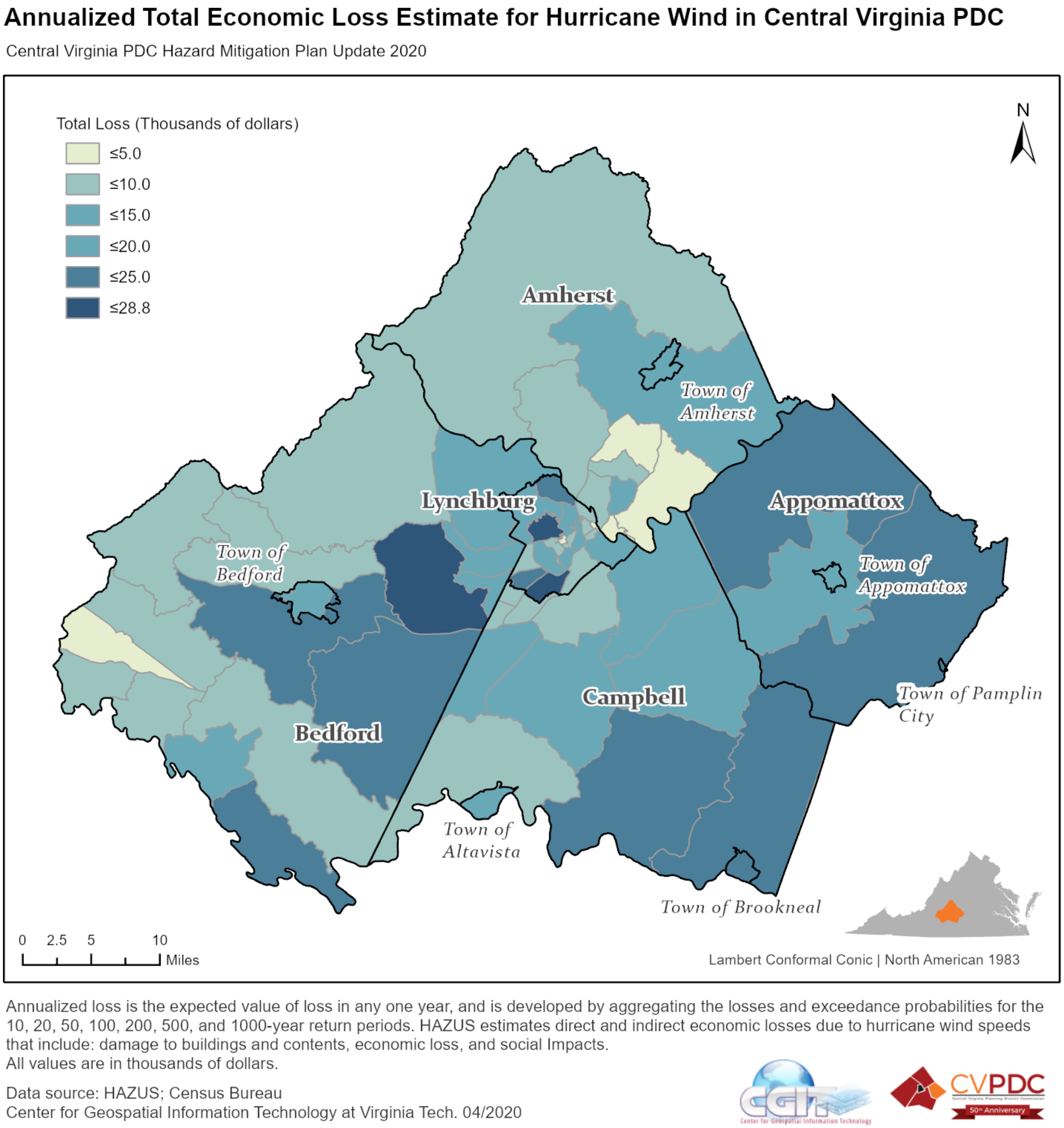

Figure 4-98 Annualized Total Hurricane Loss Estimate in CVPDC Area

4.5.4 Probability of Future of Occurrences

It was agreed that there is no specific area in the CVPDC area that is more likely to experience a hurricane event. Thus, the entire region shares the same probability of a future hurricane event. According to the IPCC warming scenarios, it is likely that hurricane intensity will increase with stronger winds and heavier precipitation throughout the 21st century. The Geophysical Fluid Dynamics Laboratory (GFDL) from NOAA has developed and uses atmospheric and climate models for improving the understanding and prediction of hurricane behavior. They predict that while there may be less frequent, low-category storm events (Tropical Storms, Category 1 Hurricanes), there will be more high-category storm events (Category 4 and 5 Hurricanes) in the future. This means that there may be fewer hurricanes overall in any given year, but when hurricanes do form, it is more likely that they will become large storms that can create massive damage.

4.5.5 References

- Federal Emergency Management Agency. *Hazus Hurricane Model User Guidance (Hazus 4.2)*. Washington, D.C., 2018.
- Geophysical Fluid Dynamics Laboratory (GFDL), National Oceanic & Atmospheric Administration. Global Warming and Hurricanes: An Overview of Current Research Results. August, 15, 2019. https://www.gfdl.noaa.gov/global-warming-and-hurricanes/ (Accessed September 25, 2019)
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