Chapter 4. Hazard Identification and Risk Assessment (HIRA)

4.1 Introduction

The New River Valley is susceptible to a wide range of natural hazards. This chapter discusses each of the natural hazards possible in the region, including history, risk assessment and vulnerability, and past or existing mitigation. The hazard risk assessment and vulnerability looks specifically at two criteria: locations where the hazard is most likely to have negative impacts and the probability and severity of the hazard should it occur. When information is available, the specific impacts of a hazard is discussed, sometimes based on the usual impact in the region. These sections haven been completely revised since the 2005 plan to include additional, more helpful information.

4.1.1 Hazard Identification

Although hazards are classified in various ways, this plan places hazards into one of six categories: drought, geologic, flooding, severe weather, wildfire, and human-caused. Both geologic and severe weather hazards cover more than one specific event or situation. Geologic hazards include landslides, earthquakes, rockfall and karst. Severe weather hazards include freezing temperatures, non-rotational winds, snowfall, ice storms and tornados. Each hazard section includes mapping to identify areas with potential impacts.

4.1.2 Risk Assessment

Risk assessment seeks to define the probability of events and the likely consequences of events. The risk assessment and vulnerability presented herein is a result of an extensive analysis of historic event data, scholarly research and field work. The risk assessment and vulnerability portion of this plan was conducted by Radford University's Geography Department. For more information regarding this data and information please contact Dr. Bernd Kuennecke at bkuennec@radford.edu.

The box below defines some common terms used throughout this HIRA section, as well as the remainder of the plan.

Definitions

- Hazard: an event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss.
- Mitigation: sustained action taken to reduce or eliminate the long-term risk to human life and property from natural hazards and their effects; the emphasis on long-term risk distinguishes mitigation from actions geared primarily to emergency preparedness and short-term recovery.
- Natural hazard: hurricanes, tornados, storms, floods, high or wind-driven waters, earthquakes, snowstorms, wildfires, droughts, landslides, and mudslides.
- Hazard identification: the process of defining and describing a hazard, including its physical characteristics, magnitude and severity, probability and frequency, causative factors, and locations or areas affected.
- Risk: The potential losses associated with a hazard, defined in terms of expected probability and frequency, exposure, and consequences.
- Vulnerability: The level of exposure of human life and property to damage from natural hazards.

Source: *Planning for Post-Disaster Recovery and Reconstruction*, FEMA and APA, 1998.

4.1.3 Mitigation

Many times mitigation seeks to prevent the impacts of hazards on life and property. The primary goal of mitigation is to learn to live within the natural environment. This plan reviews past mitigation efforts in the New River Valley and identifies both strategies and specific projects that could further mitigate these impacts.

Mitigation options fall generally into six categories: prevention, property protection, natural resource protection, emergency services, structural projects and public information. Prevention projects are those activities that keep hazard areas from getting worse through effective regulatory planning efforts, such as comprehensive planning, building code update and enforcement, burying utility lines and water source planning. Property protection activities are usually undertaken on individual properties or parcels with coordination of the property owner, such as elevation, relocation and acquisition of frequently flooded or damaged structures, eliminating fuel sources surrounding the property, installing rain catchment systems and purchasing additional insurance. Natural resource protection activities seek to preserve or restore natural areas or natural functions of floodplain and watershed areas. They are often implemented by parks, recreation, or conservation agencies or organizations. Emergency services measures are taken during a hazard event to minimize its impact. These measures can include response planning, regional coordination and collaboration and critical facilities protection. Structural projects include activities associated with building new or additional infrastructure or features to minimize impacts from a hazard. The final category of public information is possibly the most important, empowering residents to take action to protect themselves and their property in the event of a hazard event. This category can include additional information available to the public, such as maps, brochures, and workshops, as well as property specific information included in parcel records.

4.2 Overview of Assessments

Each hazard assessment follows a similar format: introduction, history, risk assessment and vulnerability, past or existing mitigation, and mitigation goals, objectives and strategies. Some hazards include a brief discussion of special hazards areas that may be more prone to experiencing a certain hazard or more likely to be severely impacted by a specific hazard event.

Each identified hazard was prioritized by the steering committee using a standardized worksheet (see Appendix 1). Each hazard was evaluated on a 1-5 scale for frequency and a 1-4 scale for both intensity and area affected. Relative risk was then calculated using these ratings. Table 4-1 below illustrates how the hazards ranked in their relative risk to the region. A more detailed discussion of this risk assessment is included with each hazard section.

Table 4-1. New River Valley Regional Assessment of Relative Risk of Natural Hazards

High	Medium	Low
Freezing Temperatures Flooding High Winds (Non-rotational)	Drought Snowfall Human-caused Ice Storms	Landslides Wildfires Earthquake Rockfall Karst Tornado

4.3 Drought

4.3.1 History

According to the database from the National Climatic Data Center, there have been seven notable drought events since 1990, including several months in 1998, 1999, 2007 and 2008 that drought events were reported.

In the past decade, the New River Valley has experienced two significant droughts that have affected agriculture and water supply in the region. The first of these two recent droughts began in 2000 and continued through the early fall of 2002. Figure 4-1 below depicts the extent of the drought in September 2002, when portions of the region were under extreme and exceptional droughts with impacts predicted for agriculture, water supply and increased fire dangers. The accumulated rainfall deficit was at least 20 inches before precipitation resumed in the fall. The effects of this drought were more dramatic because precipitation deficits occurred in the summer, when vegetation used the moisture before it could recharge the groundwater.

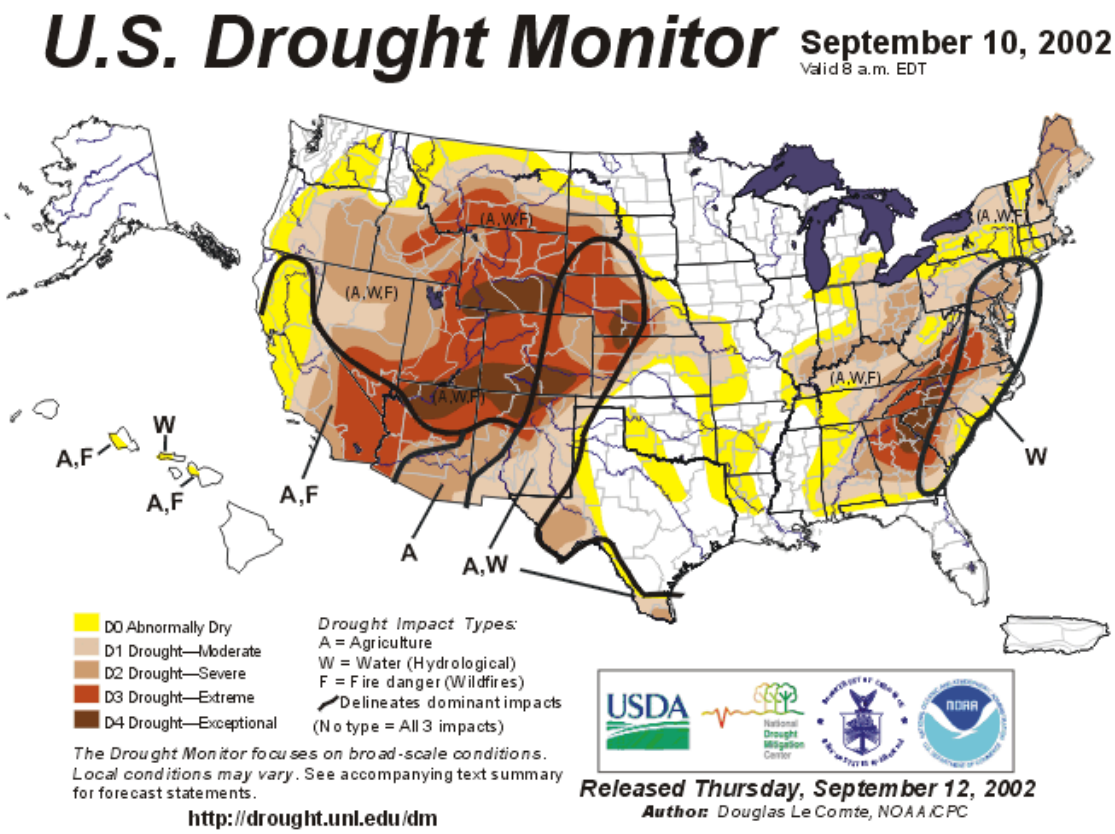


Figure 4-1. Impact Extent during 2000-2002 Drought

The second notable drought in recent years began in early 2007 and ended in early 2009. Figure 4-2 below shows the drought at its most severe for the region. At the time of this map, most of the region is in either severe or extreme drought with impacts predicted for both agriculture and water supplies.

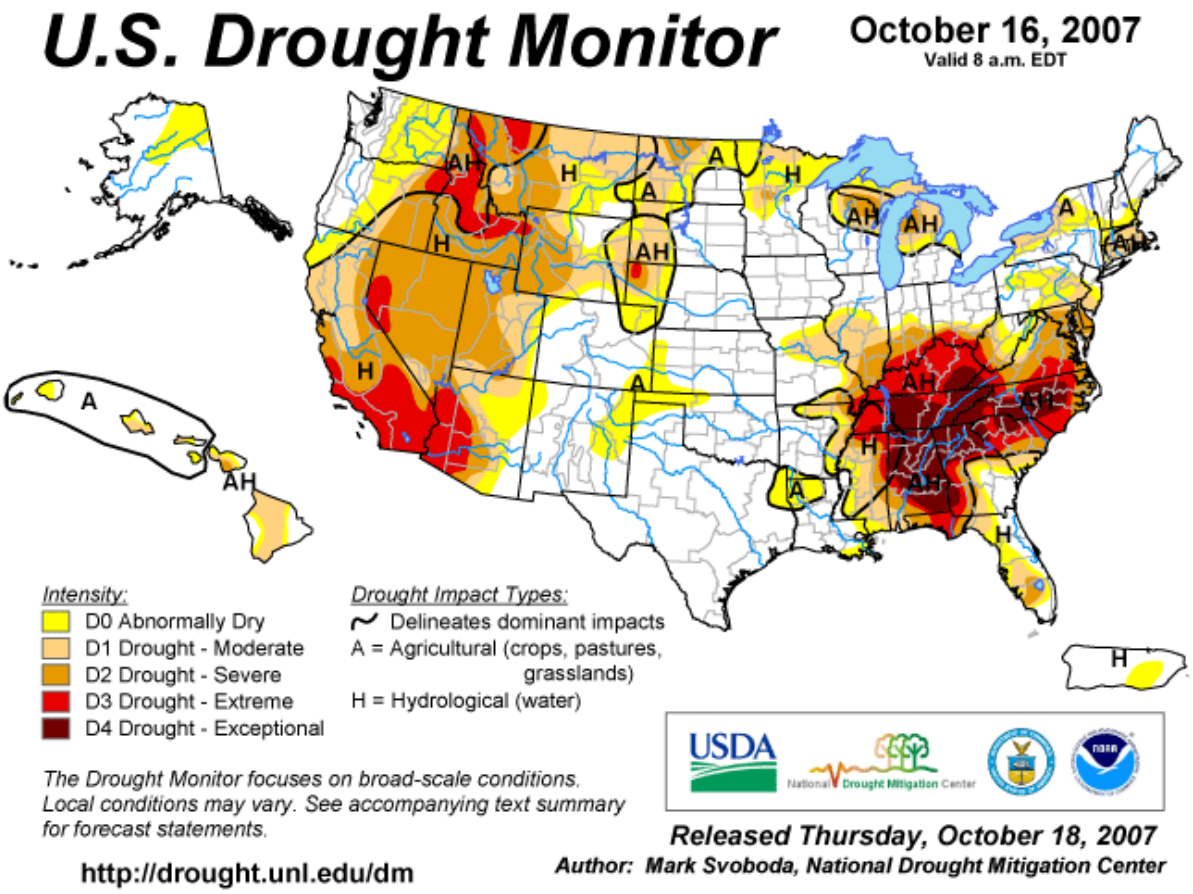


Figure 4-2. Impact Extent during 2007-2009 Drought

Figure 4-3 (below) tracks the regional Drought Monitor levels from January 2000 until May 2009. The two previously discussed droughts are easily observed in this time series data. Table 4-2 provides information on the basis of each drought status indicated in the time series.

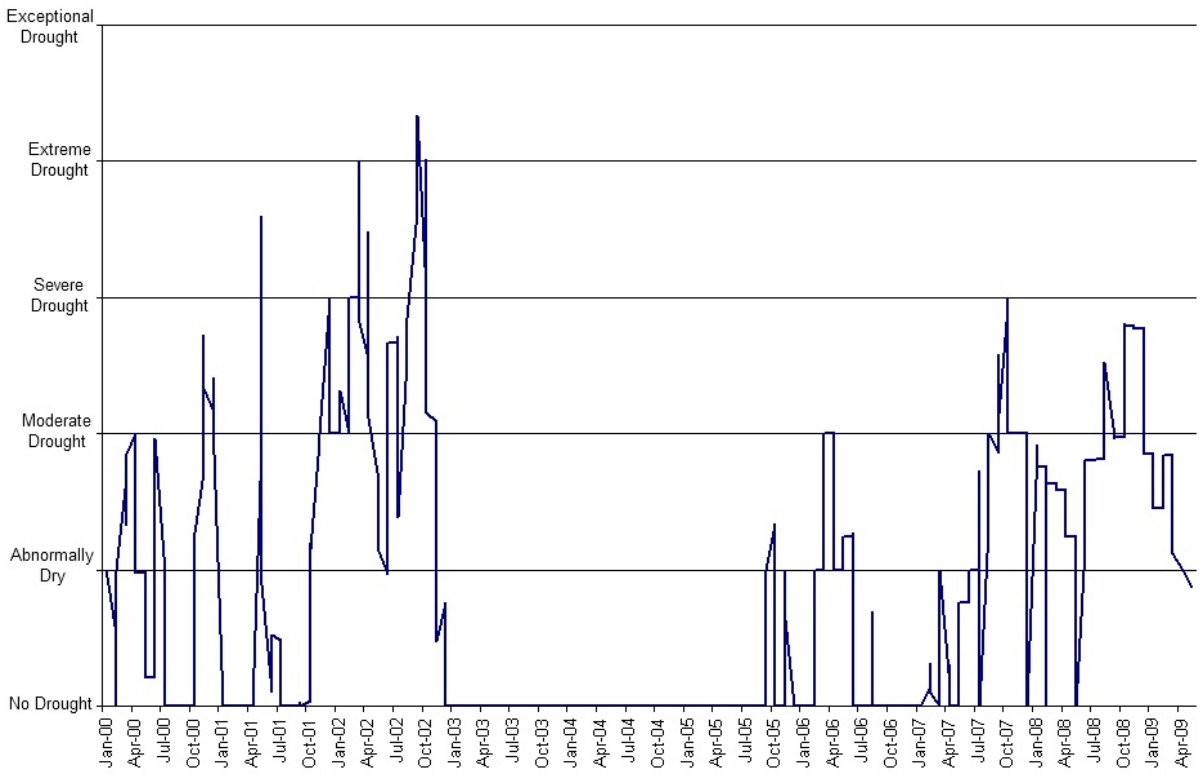


Figure 4-3. Drought Monitor Data: January 2000 – May 2009

Table 4-2. Drought Monitor Status Descriptions

Description	Possible Impacts
Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures; fire risk above average. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered.
Moderate Drought	Some damage to crops, pastures; fire risk high; streams, reservoirs, or wells low, some water shortages developing or imminent, voluntary water use restrictions requested.
Severe Drought	Crop or pasture losses likely; fire risk very high; water shortages common; water restrictions imposed.
Extreme Drought	Major crop/pasture losses; extreme fire danger; widespread water shortages or restrictions.
Exceptional Drought	Exceptional and widespread crop/pasture losses; exceptional fire risk; shortages of water in reservoirs, streams, and wells, creating water emergencies.

The Drought Monitor is a joint effort between the US Department of Agriculture (USDA) and National Oceanic and Atmospheric Administration (NOAA) to measure and predict impacts of drought nation-wide. The monitor synthesizes multiple indices and impacts to represent a consensus of federal and academic scientists. The Drought Monitor is released on a weekly basis; archived data is available dating to 2000. This data was downloaded as GIS shapefiles in

mid-2009. For weeks when a portion of the region was classified as being in a stage of drought, a weighted average was calculated based on the proportion of the region in each drought stage. This weighted regional average is depicted in the time series above.

While not in a declared drought stage, the NRV has been experiencing very dry conditions during the summer of 2010. Many counties in eastern Virginia are in a declared drought and have applied for assistance from the USDA. During this dry period, Montgomery and Pulaski Counties have also applied for assistance from the USDA for their farmers. Floyd County has not been nearly as hard hit, with corn crops only being somewhat below average.

4.3.2 Risk Assessment and Vulnerability

No place in the world is immune to drought. Rainfall fluctuates year to year, and to experience a year of "below average" precipitation is not uncommon. Recently, a study of drought was published by researchers from Columbia University. Specifically, these scientists were looking for causes of drought in the southeastern United States. Based on climate data, there is a very weak relationship between La Niña events and dry winters in the southeast. Dry summers appear to be caused by more local atmospheric variability that is very difficult to predict. Additionally, these researchers looked at historical precipitation records (i.e., tree-ring records) and found several multi-year droughts, including a 21-year drought in the mid-1700s. The historic drought record indicates that while there have been several notable droughts in recent years, overall the 20th century has been unusually moist.

While considering the relative risk of all hazards possible in the New River Valley, the steering committee considered frequency of the event and severity, as well as the area affected by the hazard. using these considerations, drought was ranked as a moderate risk in the region. the steering committee noted that relative to other hazards, drought occurs occasionally, on average every three to five years, though more severe droughts have been known to last through several consecutive years. In many cases, precipitation deficits occurring during the summer months leading to a drought status are remedied by winter precipitation.

While recent droughts may not be of the magnitude of some historical droughts, it is clear that precipitation shortfalls in the region can pose a serious threat to water supplies, agriculture, and increase wildfire dangers. Wildfire will be discussed in a separate section.

4.3.3 Water Supplies

About 67% of NRV residents receive their water from a public water system; therefore, about 57,000 people are dependent on private springs and wells (see Table 4-3). Based on discussions with local PSA directors, it is assumed that most residents within town limits are on public water supplies and the exceptions to that assumption likely are less than 10 residences in a given town. The well permit data gathered from VDH paints another picture, as seen in Table 4-4 indicating the number of well permits obtained from 2004 to 2009 that are within town boundaries. The public water systems across the NRV are not generally interconnected, leaving systems vulnerable to inadequate supplies. For example, the Giles County Public Service Authority system, which supplies five towns and much of the unincorporated area, has only one primary source (wells).

Table 4-3. Populations with Public and Private Water Sources

Locality	Population (counties w/o Towns)	Public Water	Private Water (Well or Spring)	% On Private Water
Floyd*	13,874	982	12,892	93%
Giles	9,867	2,121	7,746	79%
Glen Lyn	163	163	0	0%
Narrows	2,148	2,148	0	0%
Pearisburg	2,764	2,764	0	0%
Pembroke	1,163	1,163	0	0%
Rich Creek	681	681	0	0%
Montgomery	27,109	5,302	21,808	80%
Blacksburg	41,796	41,796	0	0%
Christiansburg	19,477	19,477	0	0%
Pulaski	23,366	8,901	14,465	62%
Dublin	2,190	2,190	0	0%
Pulaski	8,983	8,983	0	0%
Radford City	16,125	16,125	0	0%
New River Valley	169,976	113,065	56,911	33%

* Floyd Co. population includes the town because PSA is joined.

Table 4-4. Well Permits within Town Boundaries

Town	Number of well permits
Blacksburg	35
Christiansburg	27
Dublin	1
Floyd	8
Glen Lyn	0
Narrows	2
Pearisburg	5
Pembroke	4
Pulaski	17
Rich Creek	1

According to Virginia Department of Health well permits dated between 2004 and 2009, 771 wells were drilled in the NRV. Of those, over 98% were new wells. As Figure 4-4 illustrates, there is a sharp spike in the number of permits filed for wells in 2007 and 2008. The numbers appear to fall in 2009, but data was only available through June 2009 at the time of collection.

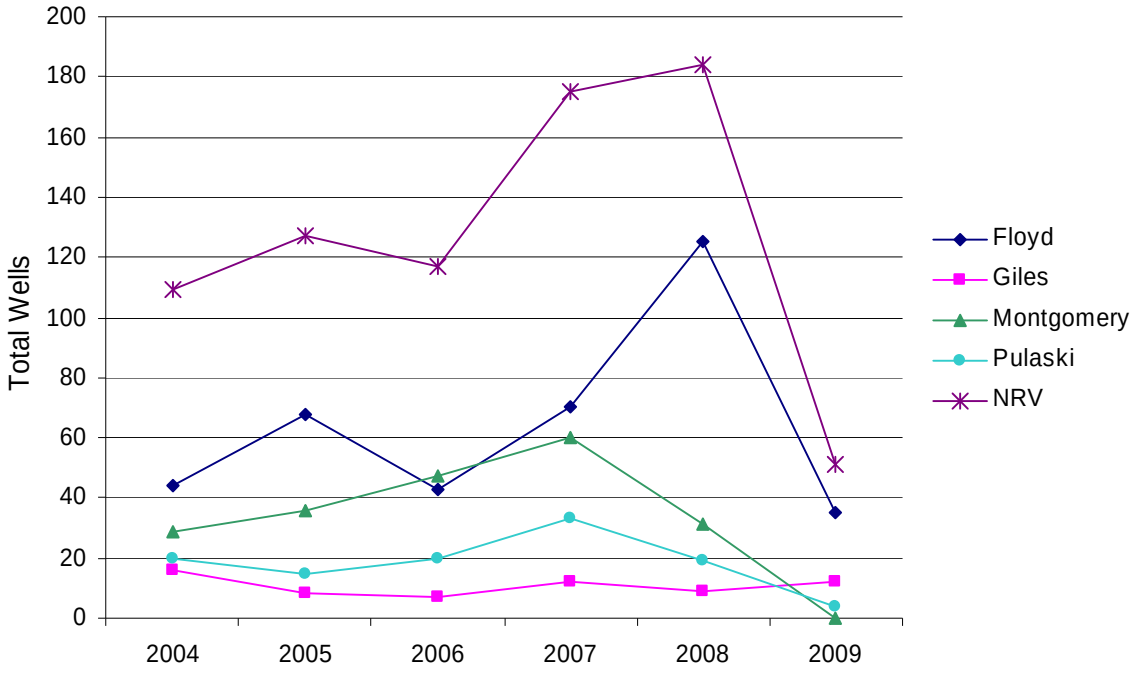
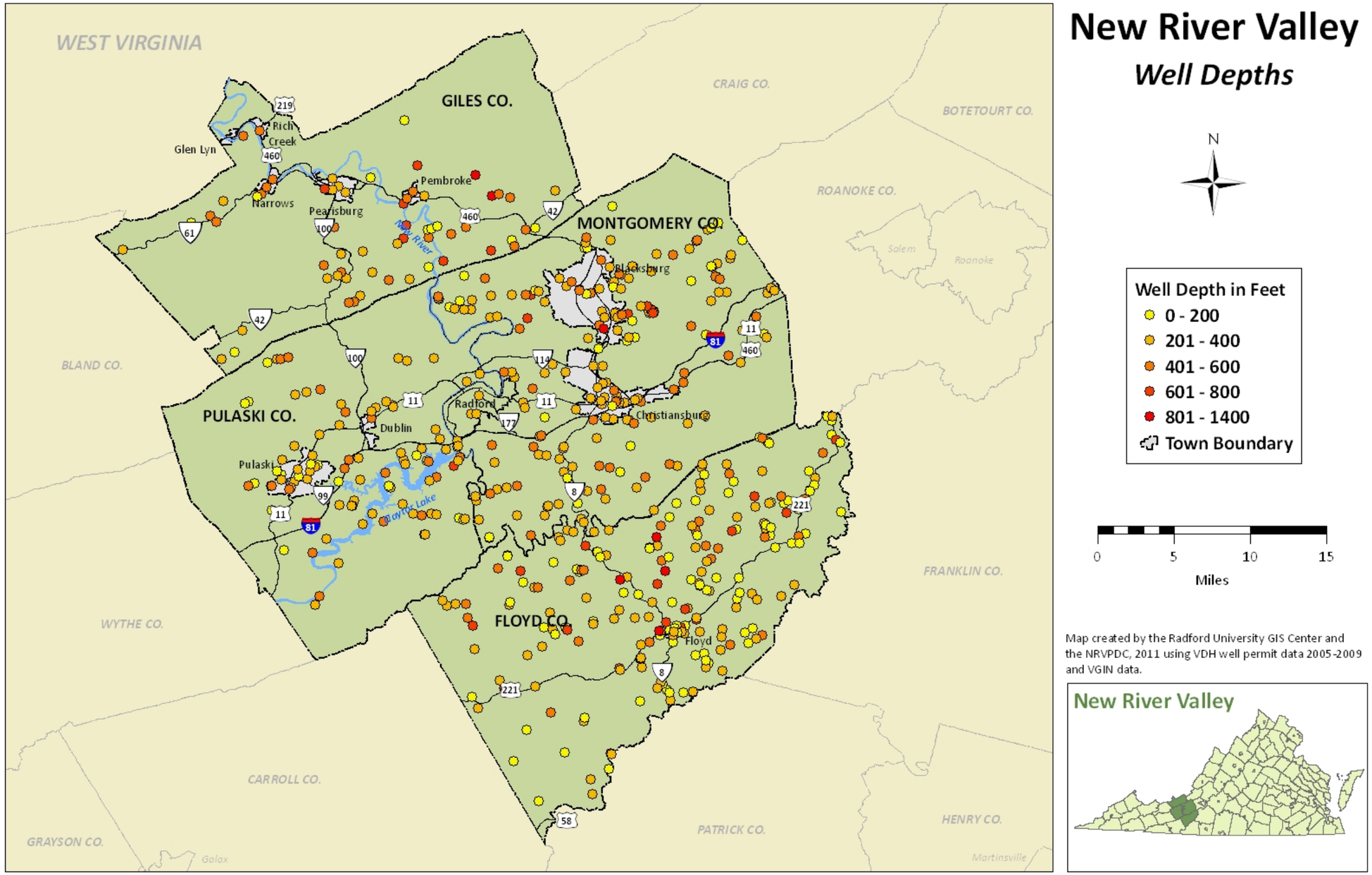


Figure 4-4. Well Permits in the NRV

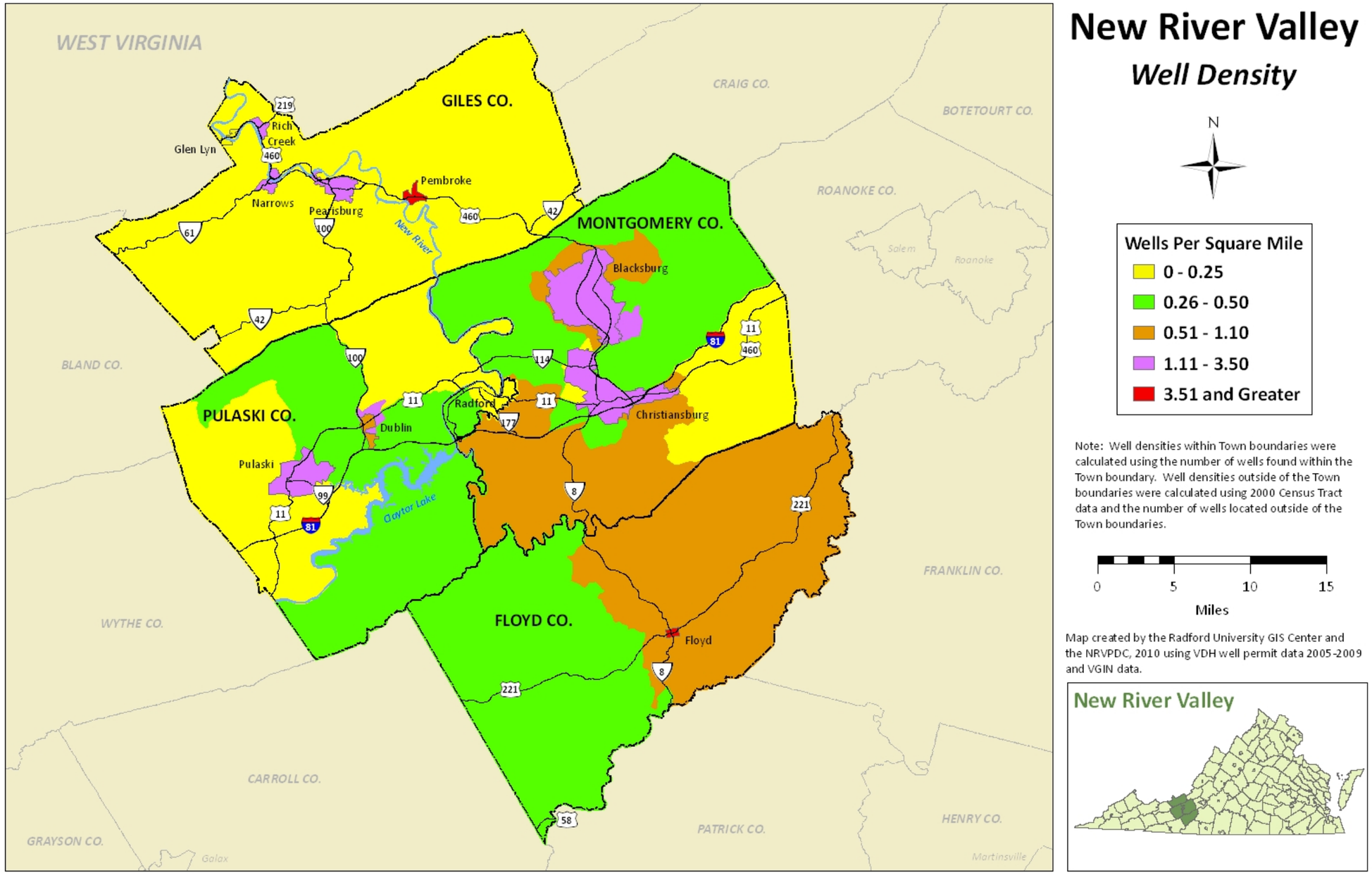
Map 1 below illustrates the distribution of wells throughout the planning district from 2004 to 2009 and the depths of the wells as reported on well permits to VDH.

Map 2 below illustrates the densities of wells per square mile throughout the region. The densities were calculated two ways. First, the density of wells within town boundaries was calculated based on the square miles in town. Second, the density of wells in census tracts throughout the counties was calculated. In areas where census tracts overlapped town boundaries, wells within town and the overlapping area were subtracted from the census data.

Map 1. NRV Well Depths



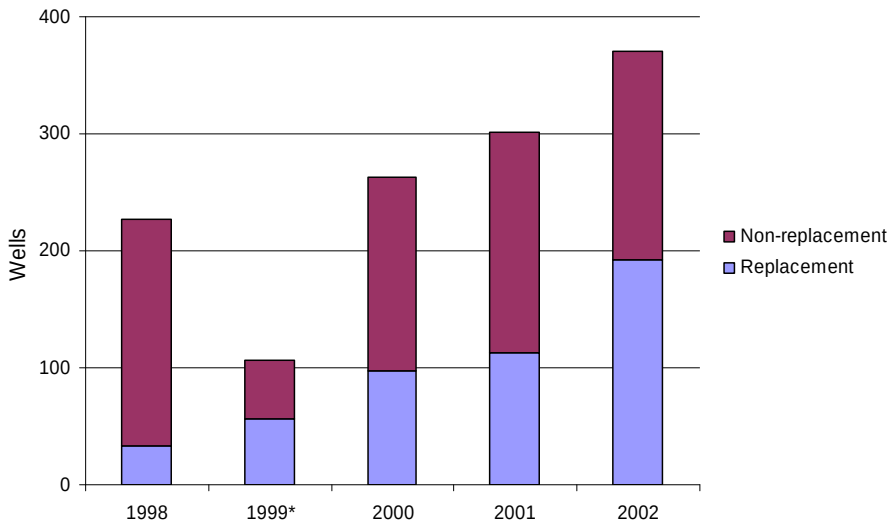
Map 2. NRV Well Density



4.3.4 Special Hazard Area

About 63% of the replacement wells in the NRV from August 1999 to November 2002 were in Floyd County, which is the only NRV jurisdiction in the Blue Ridge physiographic region. Throughout the period more than 43% of well permits in Floyd County were for replacement wells. By the worst part of the drought in 2002, this percentage increased to more than half (* 1999 does not have a full year of data available

Figure 4-5).



* 1999 does not have a full year of data available

Figure 4-5. Wells in Floyd County, 1998-2002

Floyd County had the most total number of well permits filed between 2004 and 2009, exceeded by Montgomery County by only four applications in 2006. During the same time period, Floyd County had the most applications for wells identified as replacement wells for the entire planning district. Based on the proportion of Floyd County's population dependent on private wells for their drinking water, this county's residents require additional consideration in times of drought when their wells might be most susceptible.

4.3.5 Agricultural Losses

Beyond threats to water supplies, the agricultural losses due to drought can be significant in the region. According to the NCDC database, the drought events recorded since 1990 have caused approximately $17 million in agricultural damages. As Table 4-5 demonstrates, agricultural losses for the drought of 2000-2002 were $10 million. Fortunately, the USDA classified all four counties in the NRV as federal drought disaster areas following the 2000-2002 drought. A Secretarial Designation (by the Secretary of Agriculture) requires several very specific conditions be met, specifically that the damages and losses must be due to a natural disaster; and a minimum 30-percent production loss of at least one crop in the county must have occurred. Following this designation, several programs from the Farm Service Agency are initiated including the Disaster Debt Set-Aside Program and a low-interest emergency loan program for

producers. Floyd County is again the most vulnerable to drought of the NRV localities, based on the estimates of loss from the USDA shown in Table 4-5.

Table 4-5. Agricultural Losses 2000-2002 Drought

County	# Farm Facilities (developed springs, wells)	Value of Farm Facilities Lost	$ Livestock, Loss of Weight Gain	Total $ Loss
Floyd	560	$300,000	$3,700,000	$4,000,000
Giles	100	$100,000	$1,000,000	$1,100,000
Montgomery	370	$200,000	$2,500,000	$2,700,000
Pulaski	200	$200,000	$2,000,000	$2,200,000
Total	1230	$800,000	$9,200,000	$10,000,000

4.3.6 Other Economic Losses

Beyond the risks posed to water supply and agriculture, the region's tourism industry can be vulnerable to drought conditions. The New River draws tourists from around the area, as well as from outside the region to participate in various water-based activities. Additionally, Mountain Lake (the set for the movie *Dirty Dancing*) attracts tourists during the summer season. Mountain Lake is located on a fault line and periodically empties, especially during drought conditions. In both 2002 and 2008, the lake was virtually empty (Figure 4-6). During the 2008 season, the owners of Mountain Lake placed an emphasis on recreational activities around the resort area that were not water-centered. Despite these efforts, the low lake levels had a significant effect on revenue.

To address the nearly-dry pond at Mountain Lake in 2002, the private owners attempted to pump water back into the lake. They found this to be ineffective, however. Fortunately, heavy rains in 2003 and 2009 re-charged the lake.

Figure 4-6. Mountain Lake, 2002

During the drought of 2000-2002, Chateau Morrisette, a winery and fine dining establishment in Floyd County, suffered the loss of its principal spring.

4.3.7 Past or Existing Mitigation

The existing public water systems themselves, especially those with multiple sources, are one measure of mitigation, adding versatility and reliability to local public water supplies. Four years of water study has explored the possibility of a regional water authority, transmitting water from treatment facilities to users in a large portion of the valley. The City of Radford's water treatment facility and other current sources produce enough water to provide public water to not only the residents of the city, but also to parts of Pulaski, Montgomery, and Floyd Counties. These water systems are either totally unconnected or under-connected. By interconnecting systems, these localities can reliably provide their customers with access to public water, with abundant backup sources of drinking water.

Other mitigation efforts include conservation and rainwater catchment systems. Conservation efforts were largely voluntary until the State Emergency Declaration in September 2002. Rainwater catchment systems have traditionally been personal efforts to provide additional water supply during "normal" years (Figure 4-7). During extended periods without rain, many of the systems can serve as cisterns, with water being delivered by truck from other sources.

(Photo Courtesy of Rainwater Harvesting, Inc.)

Figure 4-7. Rain barrel

New sophistication in rainwater systems is also resulting in larger-scale projects. The Carillion New River Valley Medical Center in Montgomery County constructed a rainwater catchment system to simultaneously reduce stormwater run-off and supply re-use needs. This clay-lined pool collects all stormwater run-off from the medical center and some from the adjacent surgical center to supply recycled water for cooling the building. Since the system became operational in 2007, the Medical Center has recycled over two million gallons of water. These large systems are based on the same principals as the traditional "rain barrels."

4.3.8 Mitigation Opportunities

A complete listing of NRV hazard mitigation goals, objectives, and strategies can be found in Chapter 5: Mitigation Strategy. Below are the goals, objectives, and strategies identified by the drought working group to specifically lessen the impacts of drought in the region.

1. **Minimize economic losses and health risks during droughts.**
    a. *Develop a set of planning tools that mitigate the impacts of drought.*
        i. Improve data and inventory of water users to better assess the vulnerability of water supplies to drought.
        ii. Identify back-up water sources or increase storage capacity for public water systems.
        iii. Develop a system of notification of precipitation predictions that will assist agricultural producers in short-term decision making.
        iv. Pursue MOUs between localities and companies to haul in water as an alternative source of water during drought conditions.
        v. Encourage water providers in the region to take advantage of programs designed to prevent leaks and water losses in their systems.
        vi. Continue efforts to promote interconnections of municipal water systems for use should an emergency situation arise.
    b. *Encourage research and development of prediction capabilities that will assist in decision-making during drought conditions.*
        i. Support the improvement of drought forecasting and predictions available from government sources (i.e., NOAA, NWS).
        ii. Support efforts to develop and improve simulation modeling that provides information regarding all potential impacts and outcomes for decision-makers.
    c. *Promote educational efforts to assist residents in dealing with the impacts of drought.*
        i. Provide information to residents of existing conservation measures and the sliding scale of prescriptive measures to assist in mitigating the impacts of drought.
        ii. Promote educational efforts developed for private well owners about proper care and maintenance of their well, as well as the potential impacts associated with drought.

4.4 Geologic Hazards: Landslides, Rockfall, Karst, and Earthquakes

Geologic hazards, including landslides, rockfall, karst, and earthquakes occur frequently within the New River Valley. In 1897, the region experienced a magnitude 5.8 earthquake centered in Giles County. In this section, each type of geologic hazard will be discussed individually, their history, risk assessment and vulnerability, past mitigation, and mitigation opportunities. At the end of the section goals and objectives specific to geologic hazards will be presented.

4.4.1 Landslides

Two types of sudden and often catastrophic landslide events are common in mountainous areas in Virginia: 1) storm-generated mudslides and debris flows; and 2) highway landslides, rockfalls, and rockslides. Both can have serious potential economic impact and public safety consequences.

1) **Storm-generated debris flows** occur when hurricanes or other storms of high precipitation intensity saturate mountainsides in areas of unstable soil and rock. Once movement is initiated at higher elevations, mud, rock, and other debris rushes down first order mountain streams growing in size and destructive energy. Debris flows are known to have occurred in the New River Valley, as evidenced by ancient debris flow deposits found in many of its tributary drainage systems.

2) **Highway landslides, rockfalls, and rockslides** can be a hazard anywhere that terrain has been modified for the construction of transportation corridors including roads, railroads, and canals. Terrain modifications include cuts which create unnaturally steep slopes in both soil and rock that are subject to weathering and the pull of gravity. Older cuts are especially prone to instability because construction methods have changed through the years and landslide mechanics were not as well understood in the past as they are today and older cuts have had more time for rock and soil materials to weather and weaken.

4.4.1.1 History

Western Virginia was the site of one of the most devastating landslides in US history. Nelson County and its vicinity had 150 deaths and $133 million in damage from Hurricane Camille remnants in 1969. The catastrophic debris flows occurred following 20+ inches of rain.

While no devastating landslides have occurred in the NRV, significant landslides have occurred. The 1897 earthquake triggered significant rockslides in Giles County, though little information is available on damage. Major flooding in 1940 resulted in landslides that temporarily closed rail lines and roads. The most significant slide on recent record was in the Draper community of Pulaski County in June 1994, when six inches of rain in three hours produced landslides that knocked at least one home from its foundation and blocked five miles of roads. Narrows in Giles County has periodic landslides that affect Route 460. In February 2003, winter storms and flooding caused landslides in the NRV like the one shown in Figure 4-8.

Figure 4-8. Minor landslide in Elliston, February 2003

In March 2010, a rockfall event in Pulaski County on Route 11 between Dublin and Fairlawn closed the road for approximately two hours (Figure 4-9). The rockfall occurred in the afternoon with no apparent cause, such as precipitation or immediate disturbance to the area. As discussed below in the risk assessment and vulnerability section, this particular road cut had been rated as an "A" site indicating a high potential for a rockfall event that could impact traffic flow and/or result in property damage and/or injury.

Figure 4-9. Rockfall in Pulaski County, March 2010

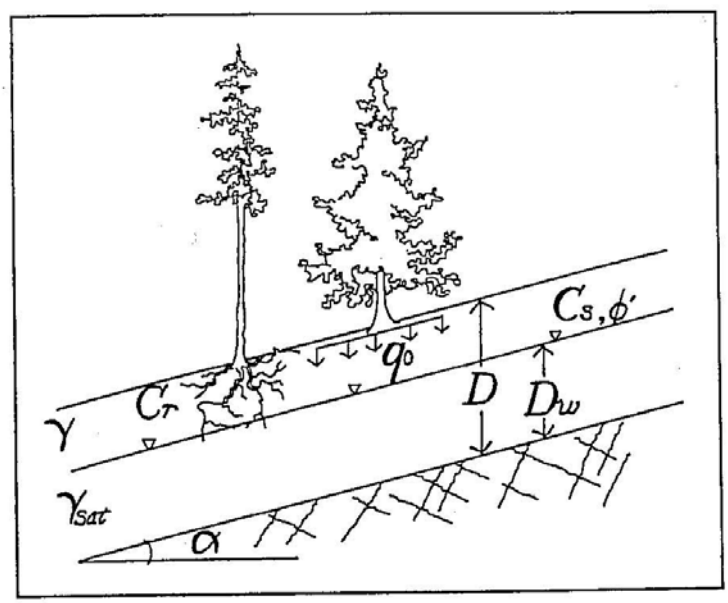
4.4.1.2 Risk Assessment and Vulnerability

two sets of risk assessment mapping were developed for this updated hazard mitigation plan. These maps are 1) storm-generated debris flow safety factor maps, and 2) highway landslide, rockfall, and rockslide hazard potential inventory. The methods for both maps are discussed below.

Storm-generated debris flow safety factor map (Map 3) was created using digital elevation models (DEMs) overlain by USDA soils maps. The DEMs were manipulated using GIS mapping techniques to generate slope maps from which slope inclination and slope direction can be determined within 10 meter cells across the landscape. The USDA soils maps and accompanying reports provide information about the physical characteristics and thicknesses of the soil layers within each of the slope map cells.

The Level I Stability Analysis (LISA) safety factor equation (Figure 4-10) is applied to each cell and assigned a color based on the relative stability of the soil within the cell when saturated by a major storm event. The exact magnitude of the storm is not required since the safety values for

individual cells are evaluated relative to safety values of the surrounding cells. Those most likely to be unstable for a moderate storm will be the same as those most likely to be unstable for a major storm and vice-versa.



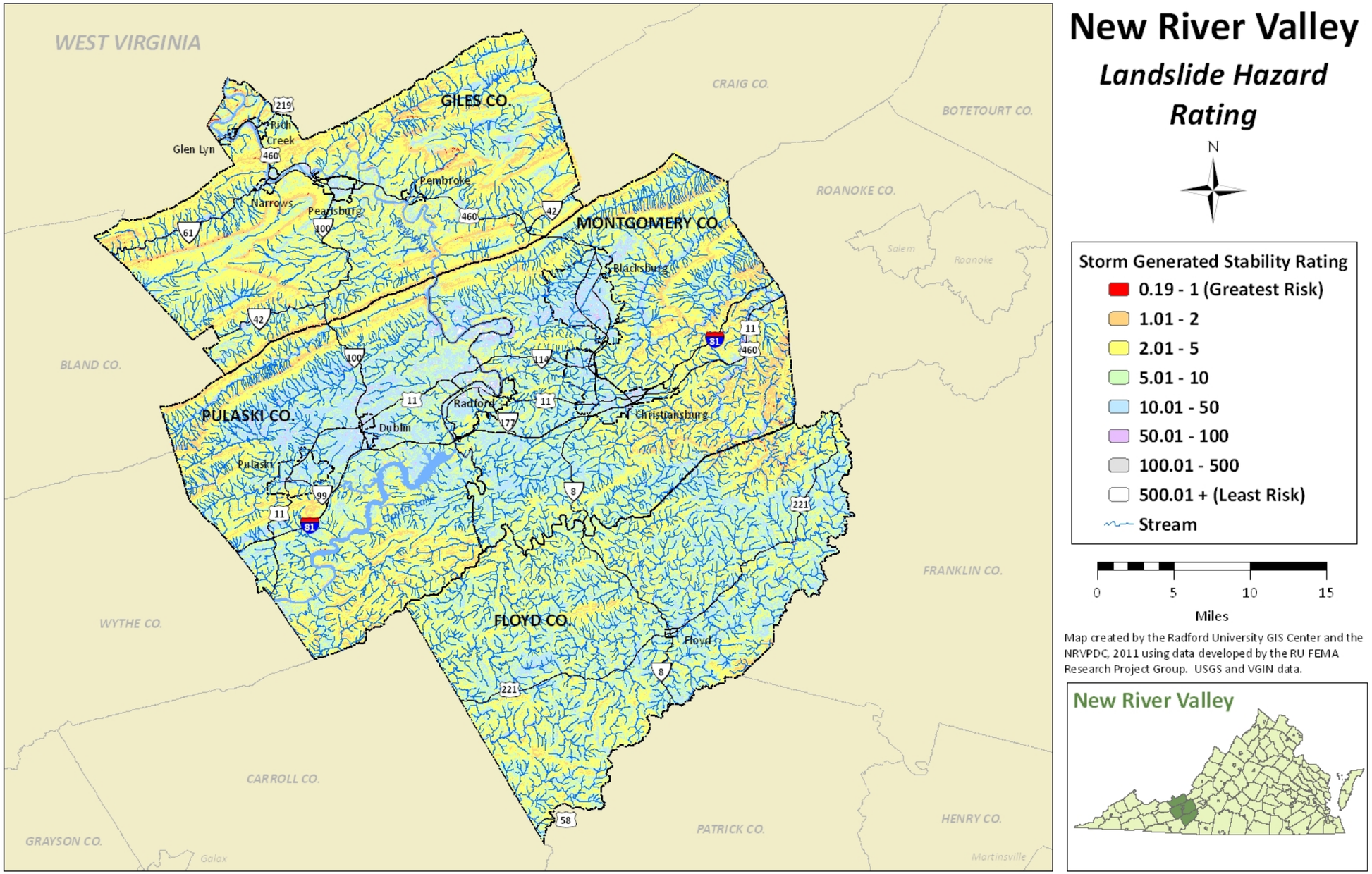
$$FS = \frac{C_r + C_s' + \cos^2\alpha[q_0 + \gamma(D - D_w) + (\gamma_{sat} - \gamma_w)D_w]\tan\phi'}{\sin\alpha\cos\alpha[q_0 + \gamma(D - D_w) + \gamma_{sat}D_w]}$$

where FS = factor of safety
α = slope of the ground surface, degrees
D = total soil thickness, ft
D_w = saturated soil thickness, ft
C_r = tree root strength expressed as cohesion, psf
q_0 = tree surcharge, psf
C_s' = soil cohesion, psf
ϕ' = effective internal angle of friction, degrees
γ_d = dry soil unit weight, pcf
γ = moist soil unit weight, pcf
γ_{sat} = saturated soil unit weight, pcf
γ_w = water unit weight, pcf

Figure 4-10. Level I Stability Analysis (LISA) model

The red end of the storm-generated stability rating spectrum (reds and oranges) indicates probable landslide initiation points during storms. Communities and infrastructure down slope from initiation points following the first order tributary drainage systems will be at greatest risk. The blue end of the spectrum and neutral colors indicate areas least likely to initiate landslides according to the LISA stability calculations.

Map 3. Landslide Hazard Rating



Highway landslide, rockfall, and rockslide hazard potential is shown on the following maps (4 through 9) by colored "pins" marking the starting points of measured road cuts. Red pins indicate the most hazardous A-rated slopes, blue pins indicate the least hazardous C-rated slopes, and green pins indicate slopes of moderate hazard according to the FHWA rating guidelines.

All A and B-rated slopes have associated field data collection forms available for reference (Figure 4-11). These field sheets provide information about each road cut and the basis for its preliminary rating. Each field sheet has spaces available for detailed rating parameters and scoring should it be necessary to return to the site at some time in the future to perform a detailed numerical evaluation for remediation or ranking purposes.

RHRS FIELD DATA SHEET

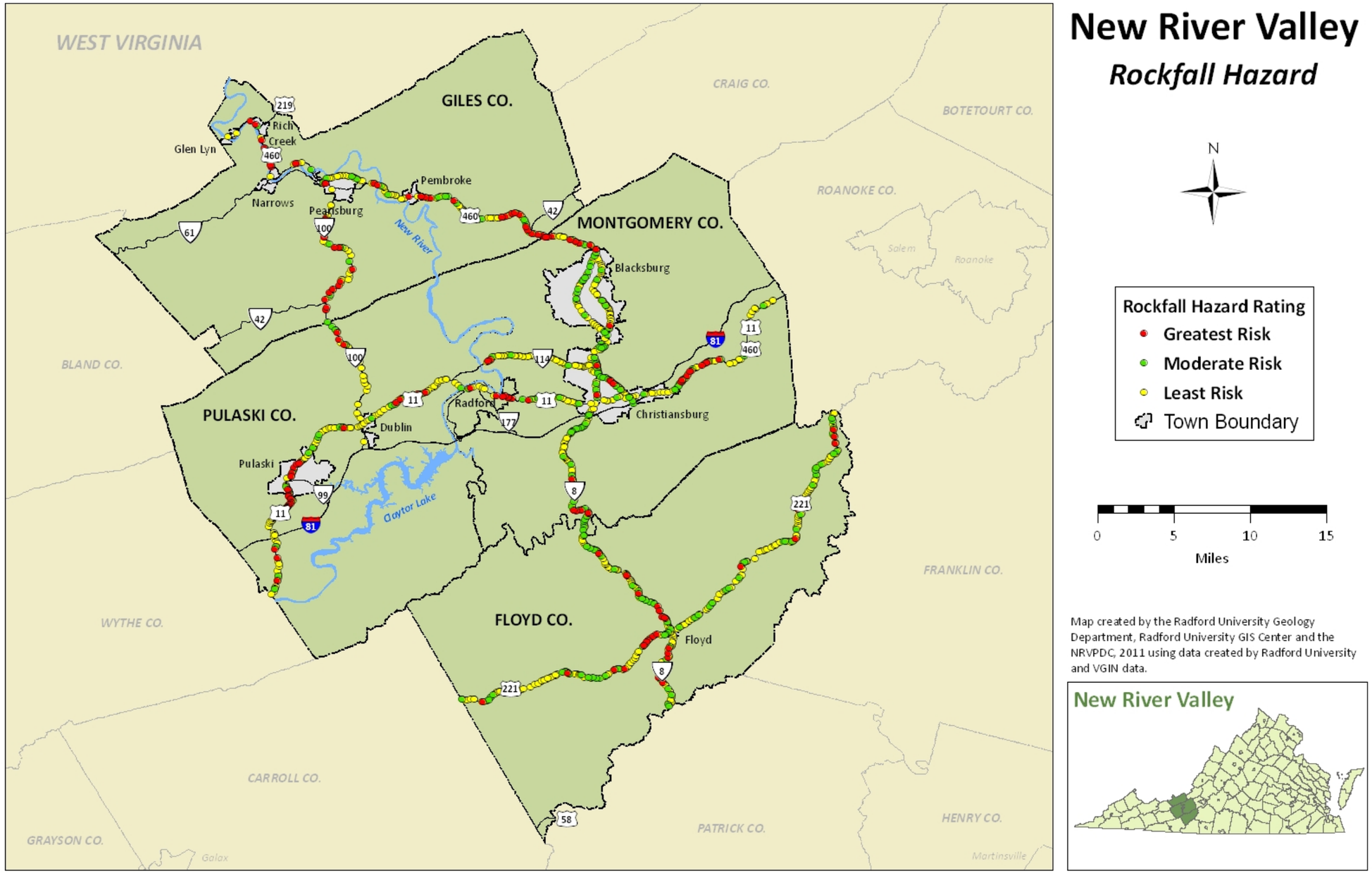
HIGHWAY: 99E REGION: 1

HIGHWAY # 1E	Beginning M.P. 12.62	[L] / R	Ending M.P. 12.94
COUNTY # 3	DATE 91 08 07	NEW	Rated By Siel
CLASS [A] B	ADT 18,300	UPDATE	Speed Limit 30

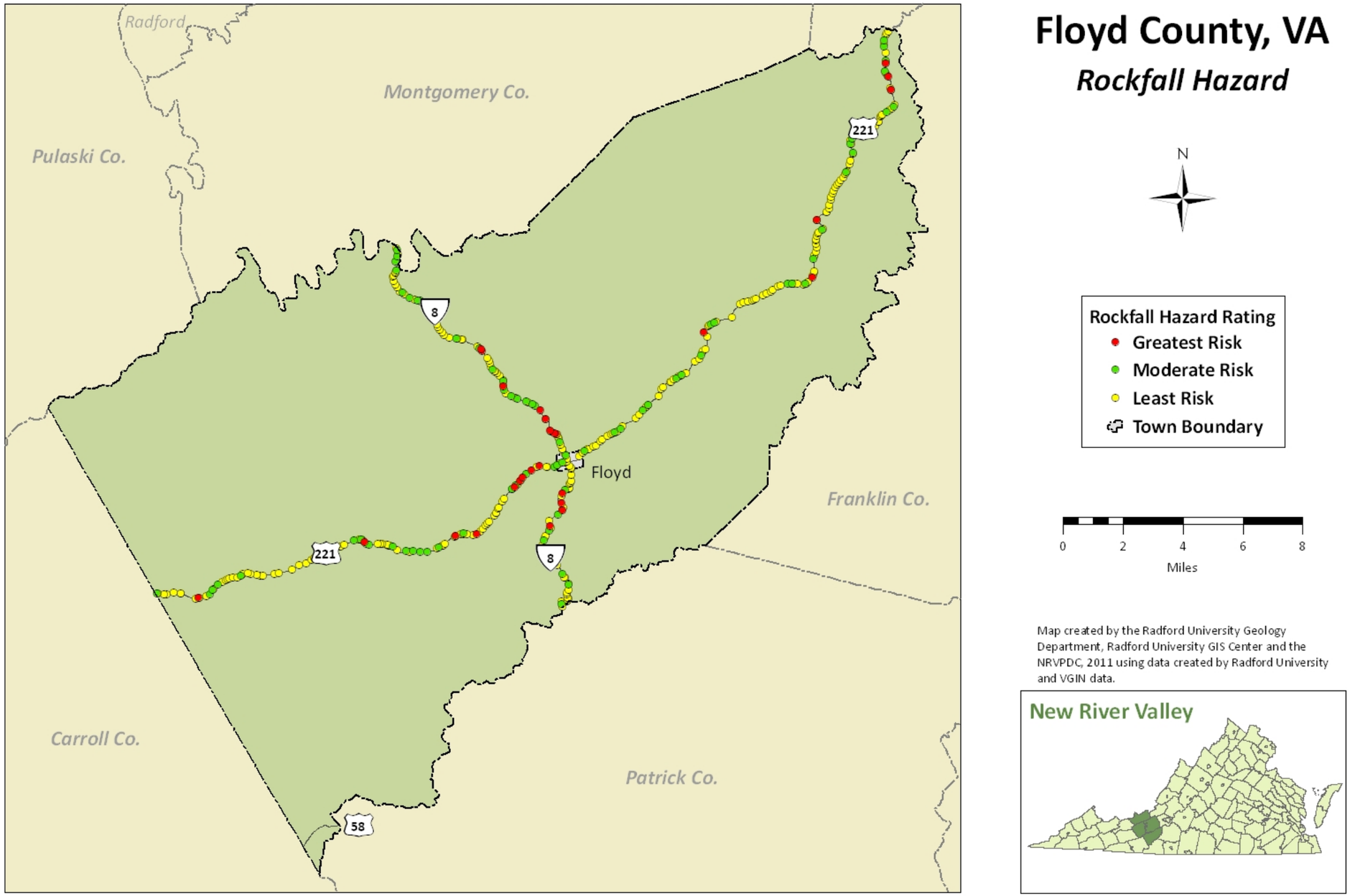
CATEGORY	REMARKS	CATEGORY SCORE	
Slope Height 116 ft °/ °/	Access to top of slope. Height measured with tape.	SLOPE HEIGHT	100
Ditch Effectiveness G M L [N]	None	DITCH EFFECT	100
Average Vehicle Risk 813 %		AVR	100
Sight Distance 450 ft Percent Decision Site Distance 100 %		SIGHT DISTANCE	3
Roadway Width 48 ft		ROADWAY WIDTH	2
GEOLOGIC CHARACTER		GEOLOGIC CHARACTER	
CASE 1		CASE 1	
Structural Condition D [C]/F R [A]	Toppling	STRUCT COND	81
Rock Friction R I [U] P C - S		ROCK FRICTION	9
CASE 2		CASE 2	
Differential Erosion Features F O N M		DIF ER FEATURES	
Difference in Erosion Rates S M L E		DIF ER RATES	
Block Size/Volume 3 ft ft/yd^3	Up to 8 yd^3	BLOCK SIZE	27
Climate Precipitation L M [H] Freezing Period N [S] L Water on Slope N I [C]		CLIMATE	50
Rockfall History F O M [C]		ROCKFALL HISTORY	75
COMMENTS: History of accidents. Road patrols required year round.		TOTAL SCORE	547

Figure 4-11. Sample field data collection sheet for rating highway rockfall hazards

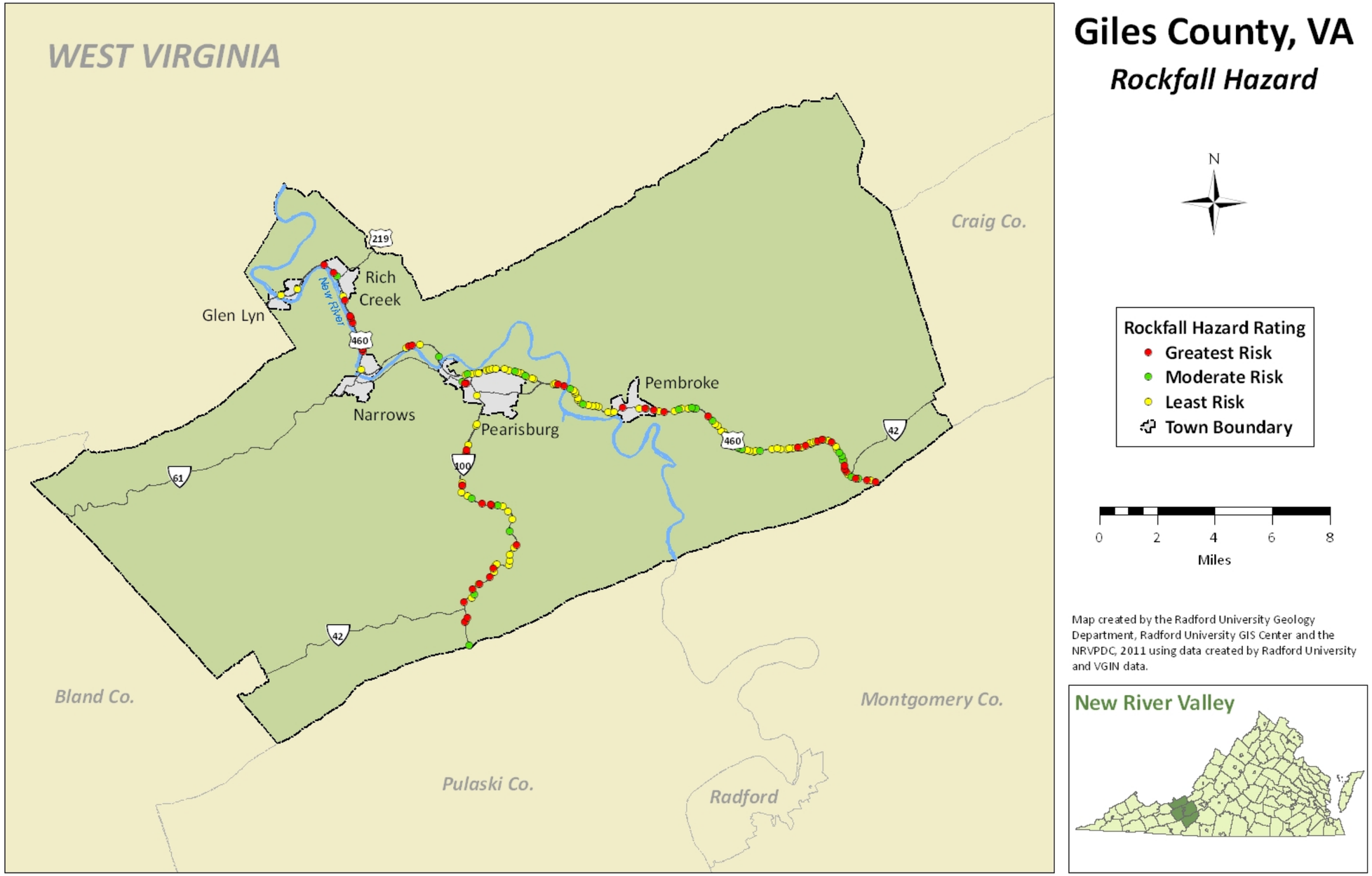
Map 4. NRV Rockfall Hazard



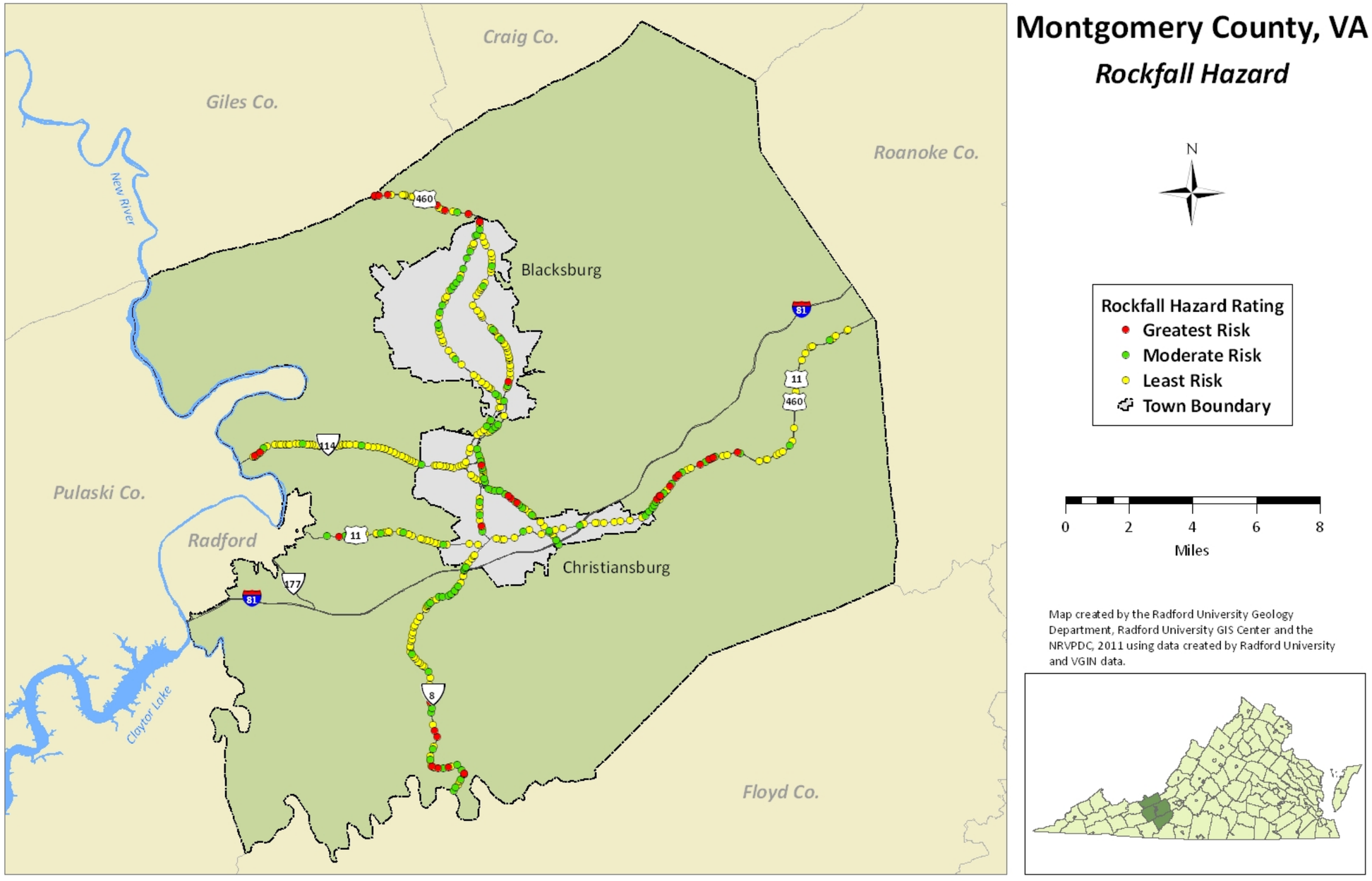
Map 5. Floyd County Rockfall Hazard



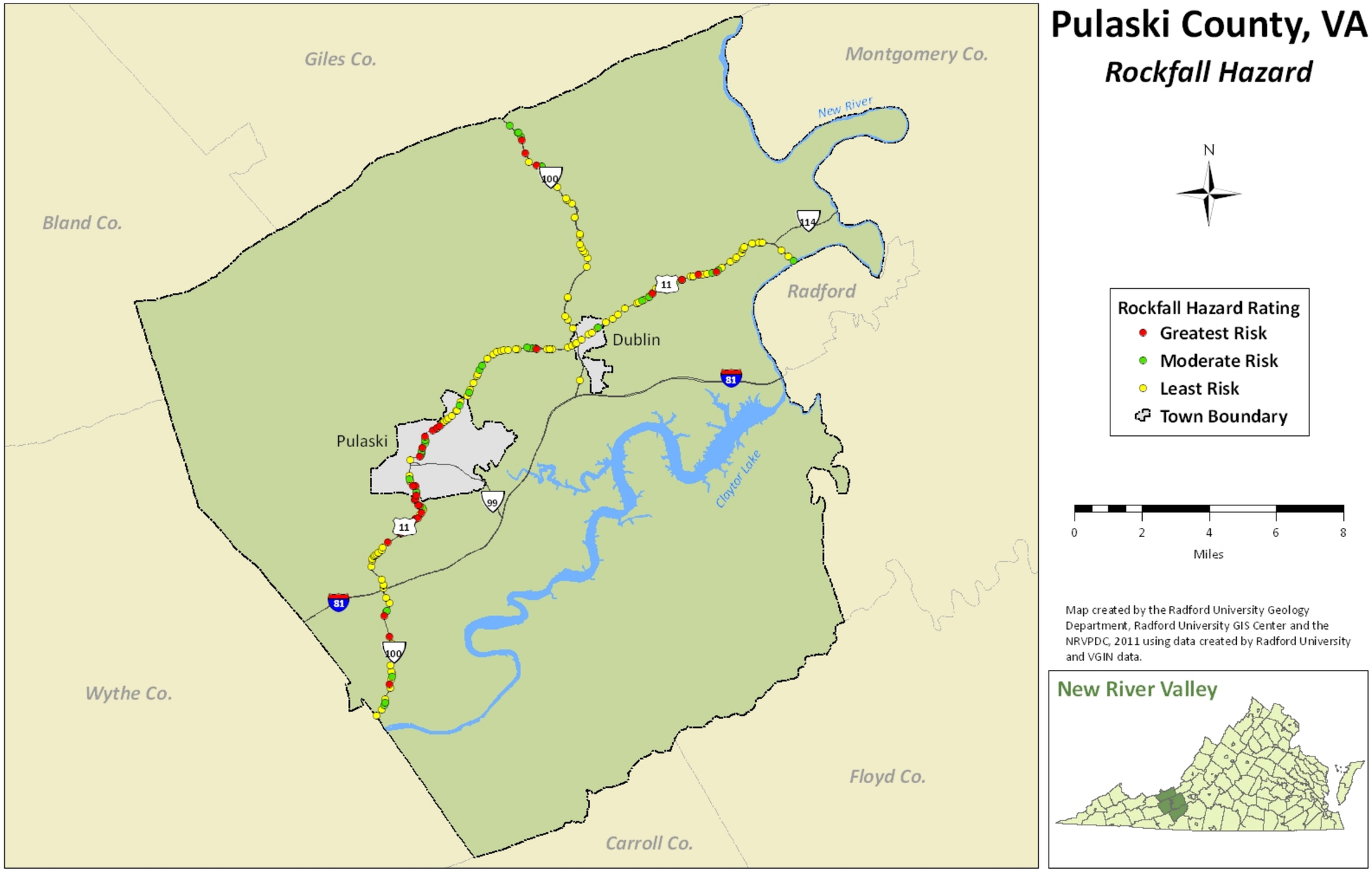
Map 6. Giles County Rockfall Hazard



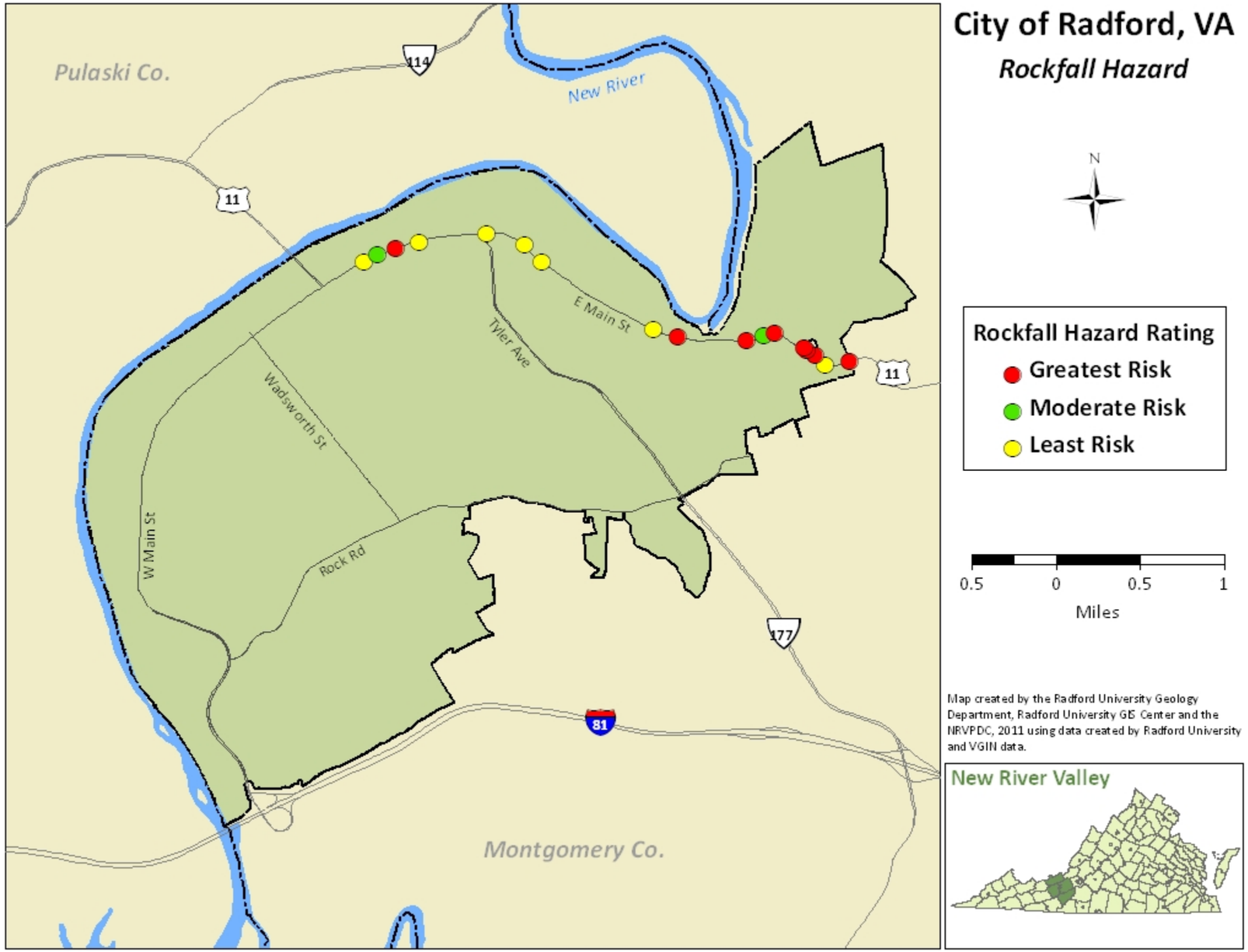
Map 7. Montgomery County Rockfall Hazard



Map 8. Pulaski County Rockfall Hazard



Map 9. City of Radford Rockfall Hazard



While considering the relative risk of all hazards possible in the New River Valley, the Steering Committee considered frequency of the event and severity, as well as the area affected by the hazard. Using these considerations, Landslide was ranked as a low risk in the region. The Steering Committee noted that relative to other hazards, landslides occur occasionally, on average every three to five years. Relatively speaking though, landslides are relatively isolated and their intensity is moderate in comparison to other hazards.

4.4.1.3 Past or Existing Mitigation

Most zoning and subdivision ordinances in the NRV have only weak language stating that "size, location, shape, slope and condition of land shall be suitable" for development. Generally, no specific parameters are set. So, development on steep or unstable slopes is largely unrestricted in the NRV. The one exception is the Town of Blacksburg which requires that "primary conservation areas" such as floodplains, wetlands, and steep slopes "shall be dedicated as open space" (where slopes are 25% or greater.) Also, the Virginia Department of Transportation (VDOT) does utilize safety fences to help protect against minor rockfalls into traffic along primary roads (Figure 4-12).

Figure 4-12. Safety fence along I-81 near Christiansburg Mountain

4.4.2 Karst

The term "karst topography" is derived from the surface topography of a limestone region in Slovakia where these landscapes were first studied. Limestone is a very common type of rock in the upper crustal sections of the earth. All of the numerous types of limestone are highly susceptible to chemical weathering mostly brought about by the presence of acids, foremost of which is carbonic acid (carbonation). Karst is typified by landscapes of pitted bumpy surface topography, poor surface drainage, and the common presence of underground solution channels in the form of cavern systems which, in turn, often form labyrinths of far-reaching underground networks.

Karst can only develop under the following conditions:

a) The geologic formations must consist of limestone containing at least 80% calcium carbonate for solution processes for this development to occur effectively;

b) The limestone formations must be jointed (fractures by warping, lifting, lateral tectonic pressure) to allow for passages along which water can travel through the otherwise impermeable limestone;

c) There must be aeration between the surface of the rock formation and the water table; and

d) A variety of different additional acids may be derived from the vegetation cover, enhancing the solution processes.

One of the dominant signs of karst is the presence of sinkholes. These are typified by circular or semi-circular surface depressions with depths from 7 to 330 feet and diameters ranging from 33 to 3300 feet. When the bottom of a sinkhole collapses into an underlying cave system, these sinkholes can become quite large. Figure 4-13 and Figure 4-14 below illustrate two different types of sinkholes possible in karst areas.

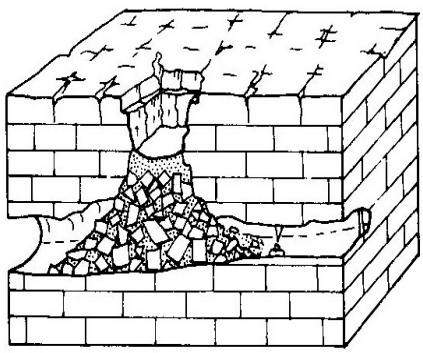


Figure 4-13. Cover Collapse Sinkhole

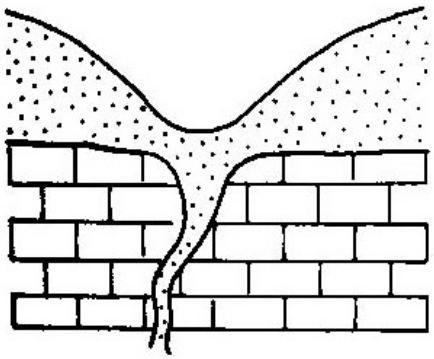


Figure 4-14. Subsidence Sinkhole

Surface water in karst areas typically flows into sinkholes and through the bottom into underlying cavern systems. This water often travels for significant distances in these underground drainage channels, to re-emerge from caves that surface streams have cut into, or it becomes part of the local water table, flowing through the limestone formations along fractures.

4.4.2.1 History

Much of the NRV rests on karst topography, and therefore the landscape is dotted with sinkholes (Figure 4-15). While there are no records of major structural damage caused by sinkholes in the NRV, such incidents have occurred in other karst regions. Major highway collapses are a recurring event for example. On the contrary, sinkholes opened up in Pearisburg during the 2002 flooding which provided sufficient temporary drainage to avoid significant flood damage to structures. Sinkholes are always challenging, however, as there is potential for direct groundwater contamination.

Figure 4-15. Sinkhole in Castle Rock Recreation Area, Giles County

4.4.2.2 Risk Assessment and Vulnerability

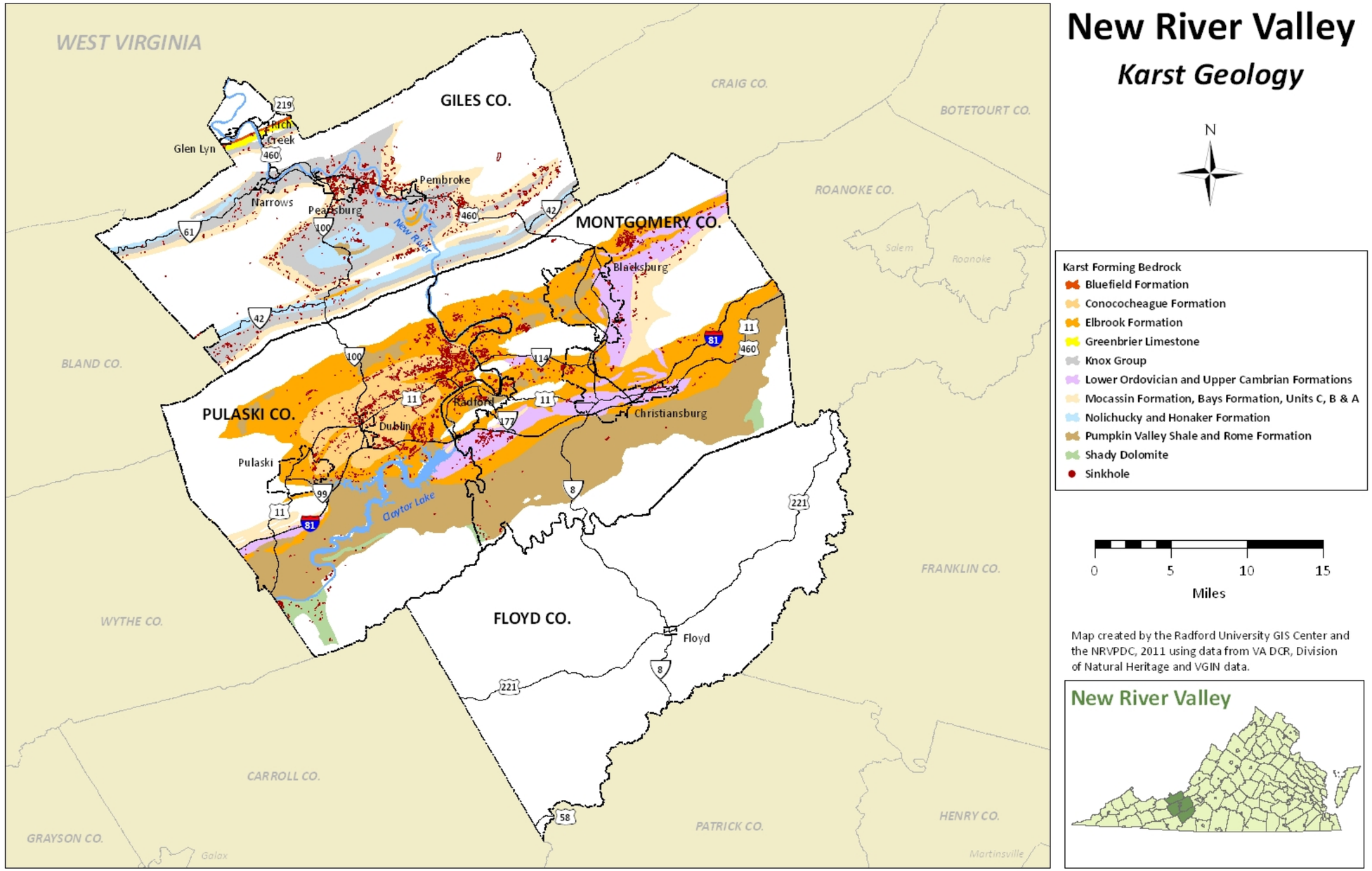
The distribution of karst-forming bedrock throughout the NRVPDC area is shown on Map 10. Of note is the fact that Floyd County has no karst-forming bedrock formations. The county is underlain by igneous rocks do not lend themselves to karst and the formation of sinkholes.

Pulaski and Montgomery Counties have karst-forming bedrock beneath more than 60% of their respective land areas. The percentage for Giles County is slightly less: nearly 50%. The City of Radford is completely underlain by karst-forming bedrock. Sinkholes, cave entrances, and the occasional subsidence of surface areas due to collapse of underlying cavern systems are common throughout all areas where these karst-forming formations (mostly limestone formations) are encountered.

The principal event associated with karst is subsidence, or sinkholes, which may open up under structures such as a home. The risk of new sinkholes developing is highest during times of flooding or drought. In terms of structural damage, a new sinkhole would likely impact only one property.

Sinkholes also literally open up a direct avenue for potential groundwater contamination, which can occur naturally through run-off or when people dump waste or dead animals into them. Surface contaminations typically percolate into the sub-surface cavern systems. Here they commonly travel for significant distances (several dozen miles at times) with the sub-surface water-flow, and the contaminated water then re-emerges to the surface along stream-cut valleys or simply becomes part of the contamination of the water table. Such movement of subsurface-water-borne contaminants is not easily traceable (or visible), and the impact can be truly regional. The risk for the population is associated with the unconscious use of such contaminated water pumped from private wells. While all wells in all areas are as risk of contamination, it is the presence of wells in the karst regions that are of particular concern, due to the significant distance which sub-surface water travels here. While fecal coliform has been found in 25-30% of wells in some areas, expensive dye tracing is necessary to trace paths from sinkholes, so no cases of direct contamination have been discovered.

Map 10. NRV Karst Geology



While considering the relative risk of all hazards possible in the New River Valley, the Steering Committee considered frequency of the event and severity, as well as the area affected by the hazard. Using these considerations, karst was ranked as a low risk in the region. The Steering Committee noted that relative to other hazards, land subsidence related to karst occurs seldom, with negligible and isolated effects.

4.4.2.3 Past or Existing Mitigation

Most land use ordinances in the NRV, including zoning and subdivision ordinances, have only weak language regarding karst, such as "land deemed to be topographically unsuitable shall not be platted for residential use."

Most karst mitigation efforts to date have been made by the Virginia Department of Conservation and Recreation (DCR), which has an office in the NRV, or the Senior Environmental Corp, or the Cave Conservancy. DCR has sponsored local workshops for planners and local officials.

Also, VDOT requires the locality and developer to make additional stormwater management provisions in areas with karst topography prior to the acceptance of subdivision streets.

4.4.3 Earthquake

As the name implies, an earthquake is the trembling at the Earth's surface or below, resulting from the release of energy or strain on the Earth's tectonic plates. The shaking and movement can cause serious damage to buildings and structures. There are four hazards associated with earthquakes (from *Planning for Post-Disaster Recovery*):

- Ground motion: waves of vibration
- Seismic activity: energy transferred, measured by magnitude (total energy) and intensity (subjective description at a particular place)
- Surface faulting: visible, lasting ground changes
- Ground failure: weak or unstable soils can liquefy and move

The most familiar terminology associated with earthquakes are magnitude and intensity. Table 4-6 below provides explanation of the Modified Mercalli Intensity Scale (MMI) and relates it to likely magnitude and damages at the epicenter. The value on MMI Scale recorded for the same event can vary based on the distance from the epicenter.

Table 4-6. Richter/Modified Mercalli Scales for Earthquakes

Richter Scale Magnitude	Typical Modified Mercalli Intensity	Type	Damage Description
1.0 – 3.0	I	Instrumental	– Not felt by many people unless in favorable conditions.

Richter Scale Magnitude	Typical Modified Mercalli Intensity	Type	Damage Description
3.0 – 3.9	II – III	Weak – Slight	– Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing. – Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
4.0 – 4.9	IV – V	Moderate – Rather Strong	– Felt indoors by many people, outdoors by few people during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. Dishes and windows rattle alarmingly. – Felt outside by most, may not be felt by some outside in non-favorable conditions. Dishes and windows may break and large bells will ring. Vibrations like large train passing close to house.
5.0 – 5.9	VI – VII	Strong – Very Strong	– Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight. – Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.

Richter Scale Magnitude	Typical Modified Mercalli Intensity	Type	Damage Description
6.0 – 6.9	VII – IX	Very Strong – Destructive – Violent	– Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars. – Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved. – General panic; damage considerable in specially designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

Richter Scale Magnitude	Typical Modified Mercalli Intensity	Type	Damage Description
7.0 +	VIII or higher	Destructive – Violent – Intense – Extreme – Cataclysmic	– Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved. – General panic; damage considerable in specially designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. – Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent. – Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly. – Total destruction - Everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. In some cases, even the route of rivers is changed.

4.4.3.1 History

In the New River Valley, earthquakes are common, although typically of such a minor scale that the movements are not felt by residents, but rather recorded by instruments at Virginia Tech's Seismic Observatory. There are three types of faults present in the NRV: 1) surface faults (most have strong vertical movements), 2) reverse faults (with horizontal movements and can involve sections of the crust rolling over either partially or completely), and 3) ground failure (involving primarily unconsolidated rock debris and soil).

On May 31, 1897 an earthquake estimated at 5.8 on the Richter scale occurred in the NRV. The epicenter was in Pearisburg, but it was felt as far north as Cleveland, Ohio and as far south as Atlanta, Georgia. In the Giles County area, chimneys fell, brick homes were damaged, streams changed course, and rockslides and landslides covered railroad tracks. This is the largest recorded earthquake in the state of Virginia, though smaller earthquakes frequently occur throughout the state.

4.4.3.2 Risk Assessment and Vulnerability

Map 11 below illustrates the estimated damages in 2000 dollars if the earthquake of 1897 were to occur presently. The following table shows the estimated damages based on the state's HAZUS modeling of earthquakes in their 2010 state plan.

Table 4-7. HAZUS Total Annualized Loss (2010 State Plan, Table 3.13-10)

Locality	Annualized Loss Amount
Montgomery County	$474,519
Pulaski County	$236,341
City of Radford	$102,522
Giles County	$100,542
Floyd County	$55,855

According to Martin Chapman, PhD, a seismologist at Virginia Tech, a 6 to 6.5 magnitude earthquake is estimated to be a 1-in-2,500-year event in the New River Valley. Specifically, he suggests that the region within 30 kilometers of the epicenter of the 1897 earthquake is most likely to see the next significant event.

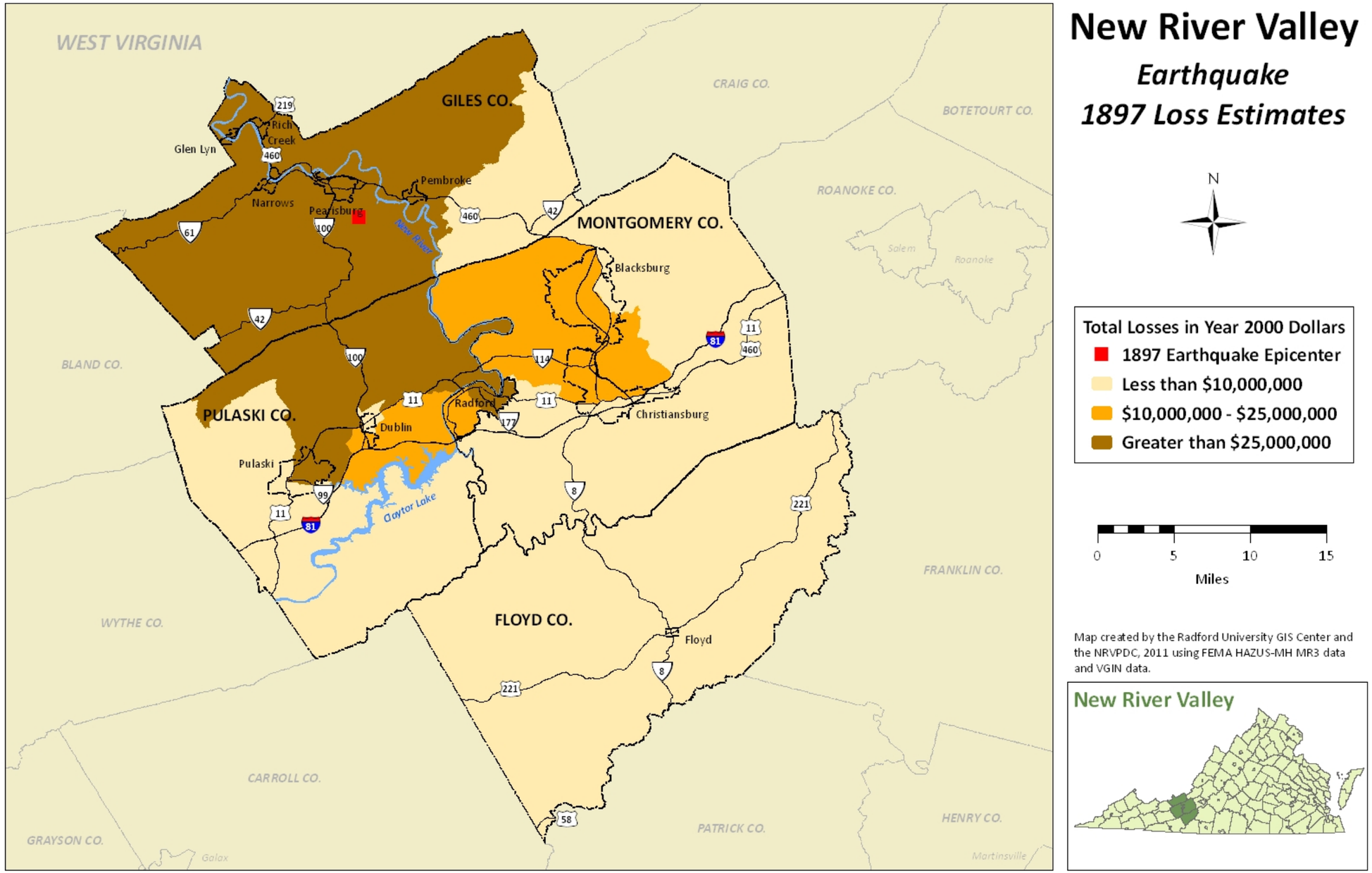
The probability of an earthquake with a significant force striking the NRVPDC is highly unlikely in the near future. However, one has to keep in mind that earthquakes are unpredictable, both in occurrence as well as in magnitude. The results of modeling using FEMA's HAZUS-MH MR3 and USGS data is indicated on Map 12. The model assumption is an earthquake with a magnitude of 5 striking the area and the resultant loss as annualized costs.

Also according to Dr. Chapman, old brick and block construction results in the most death and injuries during this level of earthquake. Specifically, he mentioned that firehouse doors and hospital equipment not restrained may be rendered inoperable. There are four hospitals in this high hazard area, and there are approximately 15 firehouses. A major earthquake could damage medical and rescue equipment, as well as major bridges—causing millions of dollars in damage.

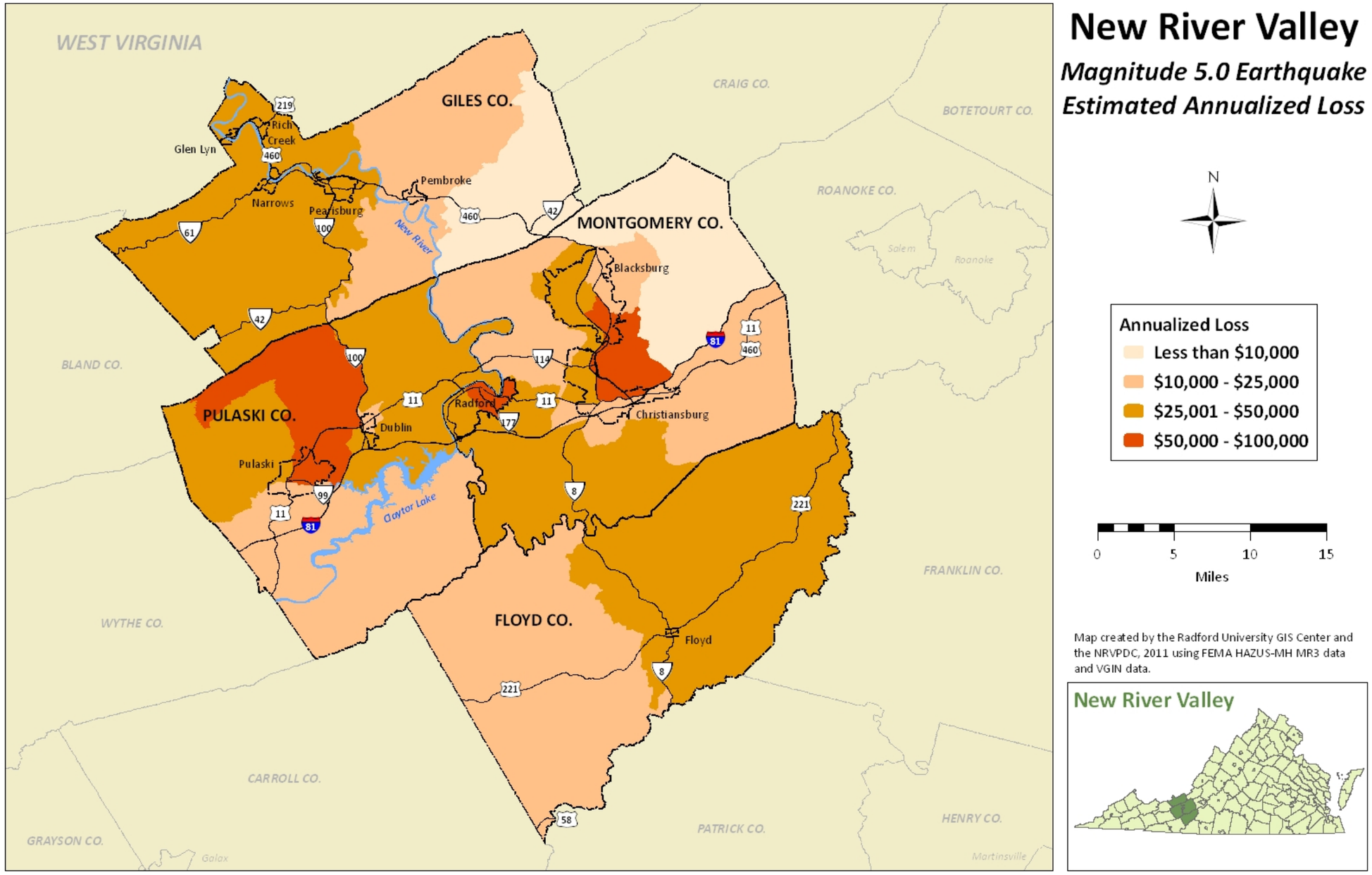
There is also one major underground natural gas transmission line (through Pulaski and Montgomery Counties) and a major hydroelectric dam (Claytor Dam in Pulaski County) that could be affected by a major quake. Given the very low probability of this type event, however, no additional assessment was deemed necessary at this time.

While considering the relative risk of all hazards possible in the New River Valley, the Steering Committee considered frequency of the event and severity, as well as the area affected by the hazard. Using these considerations, earthquake was ranked as a low risk in the region. Though a significant earthquake event could be catastrophic for the region, it is unlikely to occur frequently.

Map 11. NRV 1897 Earthquake Loss Estimates



Map 12. NRV Magnitude 5.0 Earthquake Estimate Annualized Loss



4.4.3.3 Past or Existing Mitigation

The only earthquake mitigation currently in effect is the statewide building code. The building standards in earthquake hazard areas will be further increased with the new International Building Code.

4.4.3.3.1 Mitigation Opportunities

A complete listing of NRV hazard mitigation goals, objectives, and strategies can be found in Chapter 5: Mitigation Strategy. Below are the goals, objectives, and strategies identified by the geologic working groups to specifically lessen the impacts of geologic hazards in the region.

1. **Minimize structural damage due to landslides.**
    a. *Develop strategies to protect existing structures from the impacts of landslides and debris flows.*
        i. Identify areas where potential debris flow could be diverted to avoid existing structures.
        ii. Re-vegetate areas in danger of becoming slides.
    b. *Develop educational materials and notification systems to better inform residents of landslide hazards.*
        i. Create a database or reporting system for landslides.
        ii. Notify permit applicants of site vulnerability to landslide and debris flow.
        iii. Develop appropriate signage that warns of the danger of landslide and rockfall, especially during heavy rain periods.
        iv. Install warning devices on extremely vulnerable sites that have remote notification for emergency and response personnel.
    c. *Encourage planning practices that mitigate the impacts of landslides and rockfall on new and existing developments.*
        i. Ensure that the most accurate data is available while making planning decisions (i.e., zoning, subdivisions).
        ii. Restrict future development in landslide prone areas.
        iii. Continue to improve data available for future planning and mitigation.
        iv. Incorporate additional language into ordinances to mitigate impacts from landslides.
        v. Continue to monitor A-rated rockfall cuts for future slope movement.
        vi. Encourage projects that expand catchment areas (i.e., ditches and shoulders) in potential rockfall areas of roads.
        vii. Encourage slope protection, reinforcement and reconstruction projects to prevent future rockfall events.
        viii. Engage in pre-demolition activities that control rockfall events.
    d. *Engage in activities to plan for and avoid future landslide and rockfall impacts.*
        i. Gather existing route information for detours that may be necessary in the event of a rockfall event.
2. **Minimize risks to developments and structures in areas prone to earthquakes and new sinkholes.**
    a. *Encourage activities to protect structures from future events.*
        i. Ensure that seismic requirements are included in building codes.
        ii. Reinforce critical facilities to withstand seismic events.

b. *Develop educational programs to increase residents' awareness of likelihood of geologic events.*
    i. Develop training/education activities for all government staff on appropriate response for geologic events.
    ii. Maintain awareness of regional seismic activity.
    iii. Develop informational materials about potential for sinkholes in vulnerable areas.
c. *Engage in planning activities to minimize impacts of earthquakes and sinkholes.*
    i. Identify and mark known sinkholes.
    ii. Conduct aerial surveys of hazardous conditions resulting from sinkholes.
    iii. Survey local surveyors, well diggers, septic installers, soil scientists and other local experts to identify new sinkhole locations.
    iv. Ensure that identified sinkholes are marked on plats, easements, and building permits.
    v. Conduct water quality assessments to determine impacts of sinkholes on water sources.
    vi. Encourage further dye tracing to track water as it moves between the surface and below ground.
    vii. Ensure that groundwater sources are protected from contamination by requiring septic drainfields to be a minimum distance from a known sinkhole.
    viii. Ensure structures are not placed near known sinkholes.