Final Report:

RP-291 – Evaluation of Deer-Vehicle Collision Rates in West Virginia and a Review of Available Mitigation Techniques

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16. Abstract

This project reviewed police crash reports involving deer and carcass data reported by the West Virginia Department of Transportation from 2008-2012. The police crash reports were deemed the most reliable in terms of location reliability and consistency across the state. This data was used for identifying hotspots across the state based on 2-mile segment lengths. Segments identified as being "high" ranged from 13-22 reported deer-vehicle collisions (DVC) over the 5-year period, which is assumed to be lower than the actual number due to underreporting. Modeling completed as part of the project suggested that the DVC frequency was positively related to landscape diversity and urban/urbanized areas and negatively related to presence of roadside slopes exceeding 60 degrees (uphill or downhill). The report provides a summary of DVC mitigation measures and funding mechanisms, including specific mitigation recommendations for West Virginia. The report evaluates various transportation metrics for normalizing state-by-state DVC estimates generated by State Farm insurance for national ranking purposes, including the rural and urban components of the metrics.

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EXECUTIVE SUMMARY

Background

Wildlife-vehicle collisions (WVCs) affect human safety, property (through damage) and wildlife. The total number of large mammal–vehicle collisions has been estimated at 1-2 million in the United States annually. These collisions are estimated to cause 211 human fatalities, 29,000 human injuries, and over $1B in property damage annually. More recent estimates that include costs associated with human injuries and human fatalities estimate the yearly costs associated with WVCs between $6B-12B. A single deer-vehicle collision (DVC) can cost as much as $6,717, when taking into account vehicle repair, medical care, towing and law enforcement services, monetary value of deer, and carcass removal and disposal.

Over the last few years, West Virginia has been consistently identified as the state with the highest rate of DVCs within the United States. The likelihood of a licensed driver in West Virginia hitting a deer in 2012-13 was calculated by State Farm Insurance to be 1 in 41, whereas the probability is only 1 in 174 for the United States. This likelihood is interpreted as one out of every 41 licensed drivers in West Virginia are estimated to have hit a deer during that timeframe.

In January 2011, an agency review of the West Virginia Division of Natural Resources (WVDNR), as part of the Departmental Review of the Department of Commerce, was conducted by the Performance Evaluation and Research Division of the West Virginia Legislative Auditor's office. No major wrongdoing with the WVDNR was identified by the audit, however, the legislative auditor recommended that the WVDNR increase efforts to reduce the potential for DVCs in the state. As a partial response to the aforementioned auditor recommendation, WVDNR initiated this evaluation and review of DVCs in cooperation with the West Virginia Department of Transportation (WVDOT). This project was jointly funded by State Farm Insurance, WVDNR, Federal Aid in Wildlife Restoration (W-48-R), and WVDOT. Other states have conducted similar studies to evaluate DVCs and investigate mitigation strategies for high frequency locations, including Alabama, Illinois, Iowa, Pennsylvania, Kansas, Washington, and Wisconsin.

Research Objectives

The overall goals of this project are to evaluate DVC rates in West Virginia to identify hotspots and review available mitigation techniques. The primary objectives that were defined at the outset of the project to achieve these goals are as follows:

1. Determine the site characteristics and other variables, inclusive of all roadway types (e.g. local routes, arterials, Interstates, etc.) that national and regional studies have shown to contribute to DVCs.

2. Identify and evaluate available DVC mitigation technologies and techniques.

3. Evaluate and summarize the current practices used in West Virginia for addressing DVC issues.

4. Identify DVC mitigation policies and practices, or parts thereof, from other state transportation and wildlife management agencies that would be applicable to West Virginia.

5. Summarize and rate the available mitigation technologies, countermeasures, policies, practices etc. that would apply to West Virginia and that should be considered for implementation and further study.

6. Evaluate national reports on DVC ranking methods and the statistics used for validity.

7. Evaluate and summarize the DVC data that has been collected in West Virginia and the collection methods used.

8. Conduct a Geographic Information System (GIS) analysis of DVCs in West Virginia to identify and rank hotspots, if the available data is adequate.

9. Model probable DVC locations across West Virginia to identify roadway, landscape, environmental, and traffic characteristics that contribute to DVC, if available data is adequate.

10. Identify possible funding sources at the local, state, and federal level for DVC mitigation implementation.

Results

The recommended mitigation measures for West Virginia, based on what measures have been shown to be effective in previous research or show promise for effectiveness based on inconclusive data, include night-time speed reduction, animal detection systems with signage, overhead roadway lighting, removal of vegetation from right-of-ways, population reduction through direct killing of deer by professionals or public archery hunts (in specific locations with high deer concentration), and wildlife fencing with safe crossing opportunities (e.g., wildlife underpasses and overpasses, fence gaps with jump-outs, or fence gaps with animal detection systems). As long as relatively long road sections are mitigated with wildlife fencing (≥3 mi), DVCs can be expected to be reduced by at least 30-80%.

Other than the standard deer crossing signs installed along roadways throughout the state by WVDOT and efforts by the WVDNR to control deer population, the only other documented DVC mitigation strategy used in West Virginia has been wildlife fencing installed on portions of US 33 from I-79 to Elkins, WV. From 2008-2012, there were a total of 24 DVCs reported along the entire 41.7 mile segment. Of those,

only 3 crashes occurred along the 19.1 miles with wildlife fencing (crash rate of 0.8 DVCs per hundred million vehicle miles) and the other 21 occurred along the 22.6 miles that had no fencing or standard right-of-way fencing only (crash rate of 4.8 DVCs per hundred million vehicle miles).

Interviews with transportation and wildlife management agencies in states bordering West Virginia did not identify any new mitigation measures or techniques that weren't previously documented in other research studies. In general, the role of natural resource management agencies related to DVC mitigation is to control deer population size through public hunting. The implementation of roadside DVC mitigation measures depends on the transportation agencies. In general there seems to be no high level coordination between transportation agencies and natural resource management agencies. The current and planned efforts in West Virginia seem to be consistent with the adjoining states.

Police crash reports indicating a deer was the cause served as the basis for the hotspot analysis. Verification of the 6,833 DVC police reports from 2008-2012, resulted in 90% having usable location information (route and milepost) for the modeling and hotspot analysis. The majority of the crashes were reported in October and November, crashes were evenly distributed across each weekday, and most crashes occurred at night. The majority of drivers involved in a DVC had a West Virginia driver's license. However, the percentage of out-of-state drivers involved in a DVC was 6% higher than the percentage of out-of-state drivers involved in all crash types in West Virginia (22% compared to 16%). There were a total of 12 fatalities that resulted from a DVC (5 on US routes, 4 on WV routes, and 3 on County routes), which is less than 1% of all fatal crashes (of all crash types) in West Virginia during that 5-year period.

The West Virginia roadway network was divided into 2-mile segments for hotspot analysis with the DVCs from police crash reports assigned. High frequency segments are defined as segments that experienced 13 or more crashes over the 5 year period, MEDIUM frequency is defined as segments that experienced 3-12 crashes, and LOW frequency is defined as segments that experienced 1-2 crashes. There are a total of 3,128 Interstate, US Route, and WV Route segments statewide, which result in 0.6% of them being high, 16.9% medium, and 31.2% low. Therefore, 51.3% of the Interstate, US Route, and WV Route segments in the state did not have a documented DVC. The high DVC threshold of 13 per two-mile segment over five years (1.3 per mile per year) is slightly less than the "High" threshold applied in an Iowa study (1.75 per mile per year). The general locations of the High segments are the eastern panhandle, the Summersville area in the central part of the state, the Parkersburg area in the western part

of the state, and the Kanawha River Valley near Winfield in the western part of the state. The highest observed count was 22 on US-19 in Nicholas County.

Regression analysis was performed on Interstate and US routes to identify roadway, landscape, environmental, and traffic characteristics that might be correlated to location with high DVCs. There were are a total of 1,150 segments on Interstate and US Routes and 698 segments with at least one observed crash (61%). In this study, four types of models – negative binomial, zero-inflated negative binomial, two-step hurdle, and generalized additive negative binomial (GANB) – were developed to understand the factors affecting DVCs. Based on the Akaike information criterion (AIC) values, all four models performed very similarly, but the GANB yielded the best results, accounting for spatial relationships among the segments. The variables in the GANB model and the signs of their coefficients were reasonable. As the AADT and landscape diversity increased, the expectation of a DVC increased. The presence of steep slopes on the side of the road reduced the expectation that a deer would be hit on a segment. Compared to rural areas, urban areas (defined as small towns and suburban areas around large cities) have higher expectation of crashes, while urbanized areas (defined as large city centers) have a lower expectation of crashes.

There are a number of possible DVC mitigation funding sources available at the federal and state levels. However, each funding source has different funding amounts and project requirements, so some effort is necessary to locate the appropriate funding for the appropriate project. Currently, the most appropriate and available funding source are the Highway Safety Improvement Program funds, which are intended to improve the safety along roadway segments and/or intersections that have exhibited a crash history that can be mitigated. However, projects that qualify for this funding are prioritized by their benefit-cost ratios, where the benefits are derived from expected reduction in crashes. Therefore, these funds are primarily allocated to locations that experience a high number of crashes that result in fatalities and injuries. Based on this analysis, the DVC hotspots would not rise to the top of that list due to the limited number of severe crashes that occur. Other states are creating partnerships among public transportation agencies, natural resource management agencies and wildlife-related private entities to help fund mitigation projects. If it is desirable to accomplish a robust program of future DVC mitigation projects across West Virginia, it will be incumbent on WVDOT and WVDNR to seek a wider source of funding than that provided by traditional transportation programs.

TABLE OF CONTENTS

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. __INTRODUCTION__

1.1. __Background__

Wildlife-vehicle collisions (WVCs) affect human safety, property (damage) and wildlife. The total number of large mammal–vehicle collisions has been estimated at 1-2 million in the United States annually (*1, 2, 3*). These collisions are estimated to cause 211 human fatalities, 29,000 human injuries, and over $1B in property damage annually (*1*). More recent estimates that include costs associated with human injuries and human fatalities estimate the yearly costs associated with WVCs between $6B-12B (*2*). In most cases, the animals die immediately or shortly after the collision (*4*). In some cases, it is not just the individual animals that suffer. Road mortality may also affect some species on the population level (e.g., *5, 6*), and some species may even be faced with a serious reduction in population survival probability as a result of road mortality, habitat fragmentation, and other negative effects associated with roads and traffic (*7, 8*). In addition, some species also represent a monetary value that is lost once an individual animal dies (*9, 10*).

Over the last few years, West Virginia has been consistently identified as the state with the highest rate of deer-vehicle collisions (DVCs) within the United States (*3, 11*). The likelihood of a licensed driver in West Virginia hitting a deer in 2012-13 was calculated by State Farm Insurance to be 1 in 41, whereas the probability is only 1 in 174 for the United States. This likelihood is interpreted as one out of every 41 licensed drivers in West Virginia are estimated to have hit a deer during that timeframe. Montana, Iowa, South Dakota, and Pennsylvania complete the top five states with the highest probability for DVCs. Four out of the five states neighboring West Virginia (Pennsylvania, Virginia, Kentucky, and Maryland) have also been identified by State Farm Insurance as states with a "high risk" for DVCs, while Ohio is classified as having a "medium risk".

In January 2011, an agency review of the West Virginia Division of Natural Resources (WVDNR), as part of the Departmental Review of the Department of Commerce, was conducted by the Performance Evaluation and Research Division of the West Virginia Legislative Auditor's office (*12*). No major wrongdoing with the WVDNR was identified by the audit, however, the legislative auditor recommended that the WVDNR increase efforts to reduce the potential for DVCs in the state. As a partial response to the aforementioned auditor recommendation, WVDNR initiated this evaluation and review of DVCs in cooperation with the West Virginia Department of Transportation (WVDOT). This project was jointly funded by State Farm Insurance, WVDNR, Federal Aid in Wildlife Restoration (W-48-R), and WVDOT.

1.2. Problem Definition

Nationally, crash databases report only 300,000 WVCs per year with deer-vehicle collisions (DVCs) accounting for nearly 90% of those collisions (*13*). However, these collisions are considered to be significantly under-reported due to the exclusion of accidents with less than $1,000 in property damage, unreported DVCs from drivers, and insufficient crash report details (e.g., lack of a field to indicate collision involved a deer). From 1990 to 2004, WVCs showed an increase of 50% (*13*) with DVCs following a similar trend. A single DVC can cost as much as $6,717, when taking into account vehicle repair, medical care, towing and law enforcement services, monetary value of deer, and carcass removal and disposal (*13*). Due to the increase in DVCs and their cost, many states have conducted studies to evaluate DVCs and investigate mitigation strategies for high frequency locations. Among those states are Alabama, Illinois, Iowa, Pennsylvania, Kansas, Washington, and Wisconsin.

When WVC data are used to identify and prioritize locations along highways that may require wildlife mitigation measures, then the concern is primarily with human safety and reducing collisions with large mammals, specifically the most common ungulates in North America such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and moose (*Alces alces*). The two primary sources of WVC data used for this purpose are police crash reports and carcass removal data.

While there is much emphasis on mitigating for WVCs in North America, crashes, dead animals, and associated costs and risks to humans are not the only reason mitigation for wildlife along highways may be considered. Five different categories of effects of roads and traffic on wildlife that may trigger action are listed below and illustrated in Figure 1-1.

1) <u>Habitat loss</u>. The roadway and its associated elements (e.g., paved surface, shoulders, mowed clear zone) result in a direct loss of habitat.
2) <u>Direct wildlife mortality</u>. Loss of life that results from vehicle collisions with animals.
3) <u>Barrier to wildlife movements</u>. Wildlife movement is altered due to the roadway. Animals do not cross the road as often as they would have crossed natural terrain and only a portion of the crossing attempts are successful.
4) <u>Decrease in habitat quality in a zone adjacent to the road</u>. Wildlife is affected by noise and light disturbance, air and water pollution, and increased access to the areas adjacent to the highways for humans.

5) <u>Right-of-way habitat and corridor</u>. Depending on the surrounding landscape, the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refuge for native species (surrounding landscape heavily impacted by humans).

If mitigation is required for (1) habitat loss, (3) barrier effects, (4) decrease in habitat quality in a zone adjacent to the road, or (5) the ecological functioning of right-of-ways, data other than WVC data are needed. Examples of such data include the quantity and quality of the habitat impacted, animal movement data, data on noise or chemical pollutants, and the presence and spread of non-native invasive species.

For the current project, the problem was identified by the WVDNR and WVDOT as the relatively high number of collisions with large mammals, particularly with white-tailed deer and the associated risks for human safety.
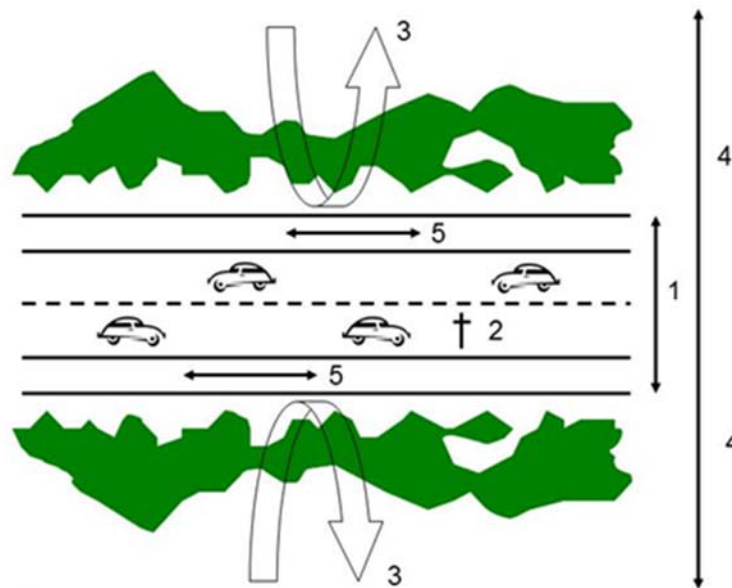
Figure 1-1 Effects of Roads and Traffic on Wildlife

1.3. Project Objectives

The overall goals of this project are to evaluate DVC rates in West Virginia to identify hotspots and review available mitigation techniques. The primary objectives that were defined at the outset of the project to achieve these goals are as follows:

1. Determine the site characteristics and other variables, inclusive of all roadway types (e.g. local routes, arterials, Interstates, etc.) that national and regional studies have shown to contribute to DVCs.
2. Identify and evaluate available DVC mitigation technologies and techniques.
3. Evaluate and summarize the current practices used in West Virginia for addressing DVC issues.
4. Identify DVC mitigation policies and practices, or parts thereof, from other state transportation and wildlife management agencies that would be applicable to West Virginia.
5. Summarize and rate the available mitigation technologies, countermeasures, policies, practices etc. that would apply to West Virginia and that should be considered for implementation and further study.
6. Evaluate national reports on DVC ranking methods and the statistics used for validity.
7. Evaluate and summarize the DVC data that has been collected in West Virginia and the collection methods used.
8. Conduct a Geographic Information System (GIS) analysis of DVCs in West Virginia to identify and rank hotspots, if the available data is adequate.
9. Model probable DVC locations across West Virginia to identify roadway, landscape, environmental, and traffic characteristics that contribute to DVC, if available data is adequate.
10. Identify possible funding sources at the local, state, and federal level for DVC mitigation implementation.

1.4. Project Approach

While mitigation is a common remedy for WVCs, avoidance is better and should generally be considered first (*14*). For example, WVCs or the negative effects of roads and traffic on wildlife may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from known habitat areas (Figure 1-2a). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 1-2b) and may include measures aimed at reducing WVCs and reducing the barrier effect (e.g., providing safe wildlife crossing locations) (*15*, *16*). However, mitigation may not always be possible or the mitigation may not be sufficient. Then a third approach may be considered, by compensation (Figure 1-2c). Compensation may include increasing the size of existing habitat patches, creating new habitat patches or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network populations. Finally, in some situations it is possible to implement a combination of avoidance, mitigation, and compensation (Figure 1-2d).

For the current project the approach is primarily to suggest measures aimed at mitigating (reducing) the relatively high number of collisions with white-tailed deer and the associated risks for human safety. However, some of the suggestions in this report can be classified as avoidance or compensation.

Note that the potential implementation of mitigation measures aimed at reducing DVCs should not increase the barrier effect of roads and traffic for wildlife, particularly not for species which may already be threatened or endangered. Therefore measures that keep wildlife from entering the road (e.g. wildlife fencing) are typically implemented in combination with safe crossing opportunities for wildlife whenever feasible (e.g. wildlife underpasses or overpasses), rather than wildlife fencing only.

Similar studies completed by other states evaluated DVCs based on time, environmental factors, and roadway factors. DVCs were found to be more frequent in spring or early summer and during the fall (breeding season) (*13*, *17*). When analyzed by the weekday, the DVC occurrences on Mondays were more than double that of other weekdays. The number of DVCs decreased as the week progressed. Throughout the day, DVCs were more frequent in the early morning (5 a.m.-7 a.m.) and evening (6 p.m.-10 p.m.) (*13*). Environmental factors found to be correlated to DVCs were landscape diversity, infrastructure, and deer population. Roadways surrounded by abundant edge (i.e., boundary between two habitats) and riparian habitats (i.e., interface between land and river or stream) are prone to DVCs, while areas heavily populated with buildings have fewer collisions (*13*). DVCs are also positively correlated with the deer population size. Roadway factors that affect the number of DVCs are the type of roadway, roadway curvature, speed limit, annual average daily traffic (AADT), and vehicle miles traveled (VMT). More DVCs were found on principal arterial roadways, particularly those with two lanes, lower traffic volumes, higher VMT, and travel speeds greater than 60 mph (*13*, *17*). Compared to other types of vehicle crashes, DVCs also occur more often on straight, dry roads.

In order to evaluate these relationships for DVCs in West Virginia, the researchers evaluated police crash reports, carcass removal data, and other available sources. Sources of roadway, traffic, landscape, and environmental data were analyzed in GIS with the DVC data to determine possible relationships. This data was also processed to identify the locations with the highest frequency of DVCs that might be considered for mitigation in the future.
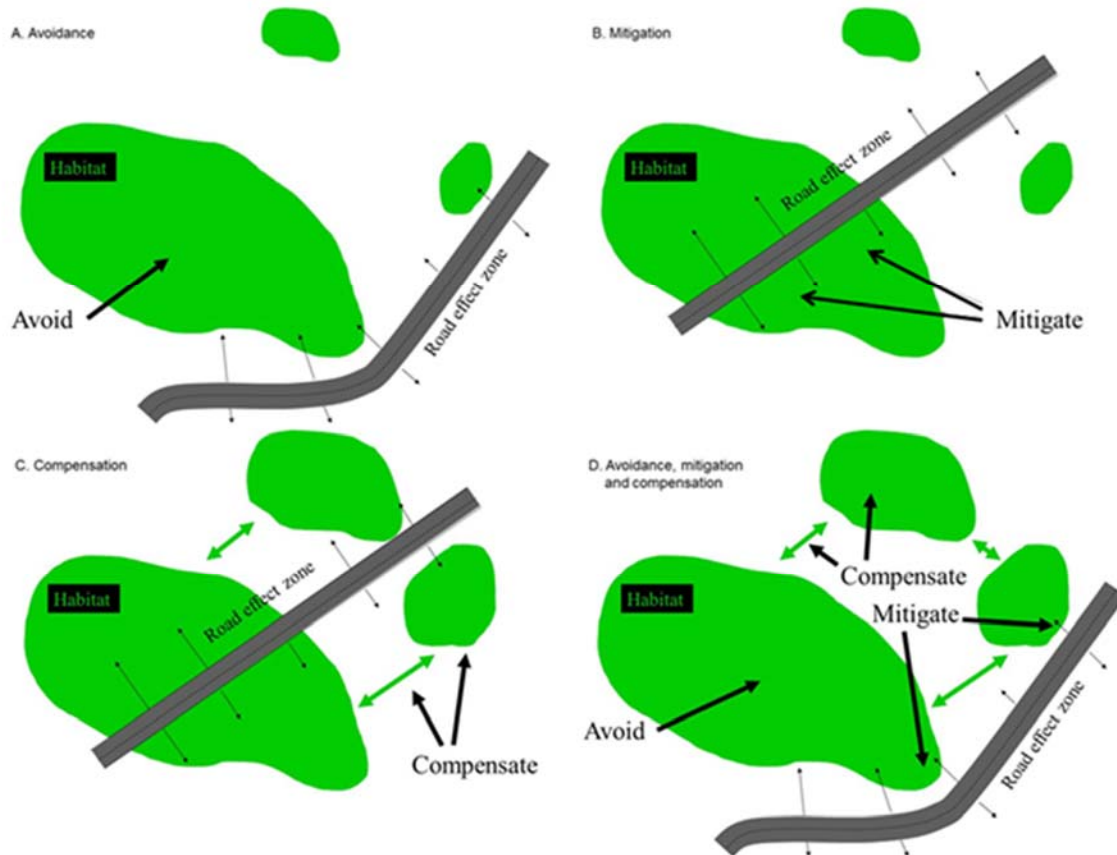
Figure 1-2 Illustration of Avoidance, Mitigation, and Compensation for DVC

1.5. <u>Report Organization</u>

The remaining chapters in this report are summarized below.

- Chapter 2 contains the <u>Literature Review</u> that was completed for study, which includes DVC study methodologies, DVC characteristics, DVC mitigation types, DVC used in West Virginia, interview results with surrounding states, and mitigation recommendations for West Virginia. This chapter addresses objectives 1-5.

- Chapter 3 discusses <u>National Deer-Vehicle Collision Statistics</u>, specifically the State Farm Insurance DVC estimates, and evaluates other metrics that can be used to normalize the data. This chapter addresses objective 6.

- Chapter 4 provides a review and evaluation of <u>West Virginia Deer-Vehicle Collision Data</u> sources and the procedure used to verify the location of DVC police reports, which are used in the hotspot analysis and modeling exercises. This chapter addresses objective 7.

- Chapter 5 summarizes the analysis of police crash reports to identify <u>West Virginia Deer-Vehicle Crash Report Characteristics</u>. These characteristics include temporal trends, crash severities, road

conditions, in-state vs. out-of-state drivers, and frequencies on Interstate and US routes. This chapter does not specifically address a study objective, but the information in this chapter is very useful to be able to compare DVC characteristics in West Virginia to other states.

- Chapter 6 explains the methodology used in the <u>West Virginia Deer-Vehicle Collision Hotspot Identification</u> and the results of that analysis. Hotspots were identified based on both DVC raw counts as well as crash rates, which account for the segment length and traffic volumes. This chapter addresses objective 8.

- Chapter 7 presents the results of the <u>West Virginia Deer-Vehicle Collision Modeling</u> effort completed for this study, including the relationships between DVC presence and frequency with roadway and adjacent land use characteristics. This chapter addresses objective 9.

- Chapter 8 discusses <u>Wildlife-Vehicle Collision Mitigation Funding Sources</u> that are available at a Federal, State, and Local level from both public and private organizations. This chapter addresses objective 10.

- Chapter 9 contains a <u>Summary</u> of the report's findings and recommendations. This chapter also provides mitigation suggestions for three of the segments identified as hotspots in Chapter 6.

2. LITERATURE REVIEW

2.1. Overview

This section addresses the following objectives in this study.

1. Determine the site characteristics and other variables, inclusive of all roadway types (e.g. local routes, arterials, Interstates, etc.) that national and regional studies have shown to contribute to DVCs. [Section 2.5]
2. Identify and evaluate available DVC mitigation technologies and techniques. [Sections 2.7 and 2.8]
3. Evaluate and summarize the current practices used in West Virginia for addressing DVCs issues. [Section 2.9]
4. Identify DVC mitigation policies and practices, or parts thereof, from other state transportation and wildlife management agencies that would be applicable to West Virginia. [Section 2.10]
5. Summarize and rate the available mitigation technologies, countermeasures, policies, practices etc. that would apply to West Virginia and that should be considered for implementation and further study. [Section 2.11]

Throughout this Chapter, both wildlife-vehicle collisions (WVC) and deer-vehicle collisions (DVC) are referenced in the discussion. As stated previously, the majority of WVC are actually DVC. However, some of the cited publications from studies that included other large mammals do not discuss findings for deer specifically. Therefore, discussion of those publications include reference to WVCs to prevent mis-interpretation.

2.2. Deer Species

There are essentially two deer species in the United States, white-tailed deer and mule deer, and each has their subspecies. It is challenging to make generalizations about the characteristics of each species and subspecies, as it might relate to DVC risk and mitigation, because of the variations within a given species across different regions and across different species within the same region. Further complicating the issue is that mammals in the "deer family" in North America (e.g. elk, moose, caribou), do not have the word "deer" in their common name. Similar to the fact that many research studies have not segregated deer from other mammals when examining WVCs, it is also rare for a study to further segregate the species of deer when examining DVCs.

While migration (i.e., regular seasonal movements) is mostly associated with mule deer, there have been migratory white-tailed deer populations in some regions. Different species in different regions also exhibit varying levels of dispersal (i.e., a one-time long-range movement without returning). While dispersal is relatively rare, it is very important to the long term survival of many species.

Considering these factors, the researchers have attempted to provide background information and recommendations that are applicable to the white-tailed deer, which is the primary focus in West Virginia. However, there are instances that the discussion includes other species or subspecies, which are unavoidable due to the reference that is being cited.

2.3. <u>Hotspot Identification and Prioritization</u>

2.3.1. <u>Wildlife-Vehicle Collision Data Types</u>

In the United States, wildlife mitigation measures along highways are often primarily based on WVC data and a desire to improve safety for humans. In general, wildlife mitigation measures are only installed at road sections that have a relatively high number or concentration of WVCs (i.e., the "hotspots"). In the United States, there are several types of WVC data that can be considered when identifying hotspots.

- <u>Crash data</u>. These data are typically collected by law enforcement personnel. For a crash to be entered into the database there is often a threshold (e.g. minimum estimated vehicle repair cost of least $1,000) and/or human injuries and human fatalities (*8*).
- <u>Carcass data</u>. These data are typically collected by road maintenance crews when they remove carcasses of large mammals that are found on the road or that are easily visible from the road in the right-of-way and that are an immediate safety hazard or a distraction to drivers (*8*).
- <u>Insurance industry data</u>. This type of data is often collected by the individual insurance companies and their individual databases may primarily show where their customers are, rather than where most DVCs occur.
- <u>Wildlife conservation data</u>. In some states, natural resource management agencies remove carcasses of large mammals that have been hit along the road, in addition to the efforts of road maintenance crews of state transportation agencies. Sometimes the agency will test the dead animals for the presence of certain diseases (e.g. Chronic Wasting Disease). The sampling effort may be highest in areas where the presence or spread of a disease is considered to be a concern.
- <u>Research and citizen science data</u>. Carcasses of road killed animals are sometimes also collected by personnel from natural resource management agencies, researchers, or the general public (*18*).

Crash and carcass data are typically collected as part of a statewide effort along all roadways. Insurance industry data and data from natural resource management agencies are less likely to have consistent search and reporting effort across a state as they may depend primarily on where clients are (e.g., insurance industry data), or where there is a specific interest to collect data on wildlife and potential wildlife diseases (e.g., natural resource management agency). Furthermore, the insurance industry may not provide the specific location of the crash, which is necessary to identify hotspots.

2.3.2. Data Quality and Quantity Considerations

WVC data are typically used to answer questions that relate to temporal trends (i.e., changes in numbers over time) and spatial distribution (i.e., the location of WVC hotspots). To be able to answer these types of questions, it is important that the WVC data have been collected with consistent search and reporting effort over time for trend analyses and over the geographical area of interest for hotspot analyses.

Crash data collected by law enforcement agencies and carcass removal data collected by road maintenance crews are more likely to have the required search and reporting effort over multiple years and large geographical areas than wildlife conservation data (often targeted at specific species in specific areas), research data (often relatively short time periods), or citizen science data (potentially inconsistent search and reporting effort, often limited geographical area). However, depending on the number of law enforcement officers in an area, potential emergencies that prevent officers from visiting a crash site and filing a report, and differences in search and data recording practices between road maintenance crews, crash and carcass data may also suffer from data quality problems. Nonetheless, crash and carcass data are often the highest quality data available, and they are often used to answer questions about potential trends in WVC numbers and the spatial distribution of WVC hotspots.

Note that crash data typically represent only a fraction (14-50%) of the carcass data, even if both data sets relate to large mammals only (*19, 20, 21, 22*). However, carcass data are far from complete as well; animals that are not easily visible from the road in the right-of-way may not be removed and do not get recorded. Wounded animals that make it beyond the right-of-way fence before they die are also usually not recorded at all.

If only relatively recent crash and carcass data are used to identify WVC hotspots, it indicates where WVCs have occurred recently. However, a spatial pattern that is based on one or only a few years may not be very robust and may misidentify true collision hotspots. On the other hand, if several decades'

worth of data is used, the hotspot analyses may identify road sections where collisions were concentrated in the past rather than where they occur now. This not only relates to the changes to the road or in the right-of-way, but also to changes in the surrounding landscape. Though there is no general rule on this matter, around 10 years' worth of data appears to be a good balance between being able to identify current or recent hotspots and having a robust dataset to minimize the likelihood of misidentifying hotspots. This is not a minimum threshold for completing an analysis and many studies have been completed with fewer years of data if 10 years are not available.

While consistent search and reporting effort is essential for analyzing temporal and spatial trends, it is not assumed that every WVC (or DVC in this particular case) ends up in the crash database or the carcass removal database. Consistent search and reporting effort can relate to only a fraction of the actual number of collisions. What matters is that a crash or carcass has similar likelihood of being recorded in different years (for temporal analyses to investigate if the DVCs may have increased or decreased over the years) and similar likelihood of being recorded on different road sections (for spatial analyses to investigate if there are concentrations of DVCs on certain road sections).

2.3.3. Hotspot Identification and Prioritization

There are several methods that can be used to identify hotspots. Most of the hotspot analyses require the data to be analyzed in a Geographical Information System and they include Kernel Density analyses (*23*). Below are a few examples:

- Hotspot identification based on a disproportional number of WVCs compared to the road length on which these collisions are located (relative to the road length within the total study area). A road section is considered a hotspot as long as the percentage of the WVCs in a particular road section (relative to the total number of WVCs in the study area) is greater than the percentage road length (relative to the total road length in the study area) on which these collisions have occurred (based on *24*, see *22*). It is possible that this analysis does not identify any hotspots should the WVCs be spaced relatively far apart in the study area.

- Hotspot identification based on the highest percentile(s) of road sections that have WVCs (see *22*). This analysis "always" identifies hotspots within a study area as long as there are WVCs within the study area, and the hotspots identified are the "worst" hotspots within the study area.

- Hotspot identification based on non-random point clusters. This analysis is based on comparing the actual distance between a collision point and its nearest neighbor to the hypothetical distance

between that collision point and its nearest neighbor should the points have a random distribution (e.g., *25*).

Note that the hotspot identification process results in hotspots that are based on human safety data only (e.g., crash reports or carcass data). Once WVC hotspots have been identified they are often prioritized based on one or more types of parameters. These parameters may be based on human safety, nature conservation, and economic parameters (see e.g. *22*).

The calculations of the first two examples of hotspot analysis listed above are facilitated by assigning the locations of individual crashes to roadway segments of defined length and computing the total number of crashes per segment length. In some studies, the segment lengths are uniform and fixed, ranging from 0.5 miles to 5 miles, regardless of the roadway and roadside characteristics. This method can be the least cumbersome for hotspot analysis because minimal time is spent determining where to start and stop segments. Some studies have defined homogenous segments of roadway with varying length. For example, a department of transportation may define roadway segments that have common lane configuration, shoulder width, and roadside treatments. Segmenting the data in this way can result in more reliable modeling, but this data should be normalized to account for the wide range of lengths before conducting hotspot analyses.

The state of Washington centered their roadway segments at whole mile markers and evenly split DVC counts at half-mile markers to adjacent segments (*17*). High DVC counts have been defined differently by each state. Washington defined high thresholds for different regions of the state, which ranged from 15 to 33 carcasses (not police crash reports) over a five-year period on segments ranging from 2-13 miles in length (*17*). Illinois defined the high threshold at 15 DVCs (police crash reports) over a five-year period based on segment lengths of two miles (*26*). Iowa defined high DVC segments as those with more than 14 DVCs (police crash reports) over an eight-year period with segment lengths of one mile (*27*).

2.3.4.   Use of DVC Hotspot Characteristics

There are typically two reasons for describing DVC hotspots based on their association with road, traffic or landscape characteristics. These relationships can be derived through a correlation analysis or modeling effort.

- Predicting crashes on other roadways. DVC hotspots may need to be predicted for road sections for which no data are available. Should DVC data be available for all road sections of interest,

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then it is better to use the actual collision data rather than use a subset of the data and try to predict where the hotspots may be along the other road sections for which the data have been ignored. An exception is when the purpose of such an exercise is to validate the predictive model, but this would still suggest that there is a group of other roads for which no DVC data are available and for which hotspots need to be identified based on predictions from a model.

- Selecting mitigation. Hotspot characteristics may provide clues for mitigating DVCs. If DVC hotspots are associated with certain road, traffic or landscape characteristics, then this may provide clues for potential mitigation measures. However, changes to road, traffic, or landscape characteristics may not always be possible based on other considerations, such as general engineering standards, land ownership, etc.

2.4. Modeling Deer-Vehicle Collisions

2.4.1. Landscape, Habitat, and Roadway Characteristic Data Inputs

Previous studies to correlate DVC frequency with other landscape, habitat, and roadway characteristics use a variety of data inputs. Typically, all available data is initially incorporated into a model, then variables are tested for their significance during the modeling process. A study completed in the state of Washington mapped the high DVC areas in GIS along with the following landscape, habitat, and roadway characteristics (*17*).

- National Land Cover Data (NLCD)
- Hydrology (locations of water by type)
- Digital Elevation Model (DEM)
- Deer concentration and range
- State and federal highway layout with reference mile markers
- Posted speed limits
- Average annual daily traffic (AADT)
- Road functional classification

The first three sets of data were obtained from the Washington Department of Fish and Wildlife (WDFW) Wildlife Program and the fourth data set was from the WDFW Priority Habitat Species (PHS). The rest of the data was obtained from the Washington State Department of Transportation (WSDOT). Each characteristic was a unique layer within GIS.

Landscape, habitat, roadway, and deer population are all characteristics that have been used in DVC models for other states. Landscape and habitat characteristics that have been used by multiple models include adjacent land use, presence of cropland, distance to woodland, presence of fencing, roadside slope, topography, presence and distance to water, and woodland size and density.

These characteristics are often evaluated by their total acreage, percentage of total buffer acreage, density, and/or patch size (*28*). Sources used by other states to collect this information include: the Department of Natural Resources (DNR), Census of Agriculture, and U.S. Department of Agriculture (*29*). The land cover, elevation, and ortho-imagery layers could also be utilized to calculate the landscape and habitat characteristics if the data aren't directly available.

Roadway characteristics that appeared in more than one model include speed limit, AADT, number of bridges, and number of traffic lanes (*28*). This data is typically obtained from the state transportation agency. When utilized, the deer population characteristics are usually based on population density or hunting data, such as the bag limit and number of hunting licenses (*30*, *28*). If available, this data is typically provided by the state natural resource management agency.

2.4.2. Assigning Data to Roadway Segments

Once the data layers are constructed in GIS, those attributes must be assigned to the roadway segments that have been defined. Since many of the data types pertain to the area surrounding the road segment (e.g., roadside slope, land use), and not the road segment itself (e.g., number of lanes, speed limit), a methodology must be applied for assigning those attributes. The most common method is to build a buffer area of defined width around the road segment and count the pixels in that area. For the Washington study, three buffer layers were created in GIS to define the landscape and habitat characteristics: a circular buffer centered at the segment midpoint with a 0.5-mile radius and two linear buffers that ran parallel to the roadway with 30- and 60-meter widths from the shoulders. After some analysis, it was determined the three buffers were highly correlated; therefore, only the buffer with the highest impact on the response variable (i.e., DVC frequency) was used, which was the circular buffer. The total non-road acreage and the difference between the largest non-road acreage and the remaining acreage within the buffer area were measured for each landscape characteristic.

2.4.3.   Statistical Modeling

The objective of crash modeling is to evaluate all data types and identify those variables that help explain the presence of a crash and/or the frequency of a crash. In most cases, the modeling is conducted on segmented data where the number of crashes on the segment is the variable being predicted by the model. Variables are added and removed from the model with different combinations being evaluated until the optimal model is obtained, as defined by the minimum amount of error in the model's predictions compared to the actual data. Frequently when modeling crash data, the optimal model is not necessarily a good model. A good model is one that adequately captures the variations in crash frequency from segment to segment and is able to reliably predict the crash frequency when compared to the observed frequency. The variables and corresponding coefficients should lend themselves to logical interpretation in a good model. Since there are so many factors that can affect DVC occurrence and frequency on roadways and are difficult to capture in a variable, most studies have identified optimal models and based findings on those, even though they are not necessarily good. If a model is poor, it should not be used for predicting crashes or decision making purposes.

The primary statistical models used in crash analysis are forms of regression analysis, where the response variable y (i.e., deer vehicle collisions) is predicted from multiple variables x (e.g., speed limit, AADT, etc.) with coefficients estimated for the model. The sign and coefficient of the variables define whether changes in that variable will increase or decrease the occurrence or frequency of a DVC. Linear, Poisson, zero-inflated Poisson (ZIP), negative binomial, zero-inflated negative binomial (ZINB), and logistic regression have been evaluated for use in DVC models (*17, 27, 28, 31, 32*). Linear and Poisson regression were found to be inadequate for modeling DVC characteristics (*17, 28*). The most frequently used regression models are negative binomial and logistic.

Pennsylvania used stepwise logistic regression to calibrate their DVC prediction model (*31*). The final logistic regression model consisted of the following characteristic variables: [C]ommerical buildings, [D]istance to woodlands, [F]encing, [N]on-wooded, [R]esidences, in-line [V]isbility, and [S]hortest visibility. The final model with coefficients was:

$$\ln[p/(1-p)]=-4.775+(-63.857)C+(-0.032)D+(-9.694)F+(7.133)N+(-4.946)R+(0.004)V+(-0.013)S$$

In this model, p represents the probability of the segment being defined as a high DVC location. A coefficient with a negative sign indicates that the characteristic decreases the probability of a DVC and a

positive sign increases the probability. For example, the presence of commercial buildings, longer distance to woodlands, increased amount of fencing, and increased visibility all reduced the probability of a DVC. Based on the results of previous DVC analysis, DVCs were found by multiple models to be positively correlated to deer population characteristics, woodland acreage, the number of bridges, and the number of traffic lanes and negatively correlated to the distance to woodlands and adjacent cropland acreage. Some of the states had different correlation outcomes for the same characteristics. These relationships will be discussed later in this literature review.

2.5. Deer-Vehicle Collision Characteristics

2.5.1. General Trends

The number of vehicle crashes of all types in the United States has remained relatively stable at about 6 million per year between 1990 and 2004 (*15*). However, over the same time period, collisions with animals (both wild and domesticated) increased by about 50% (*15*), and the total number of collisions with large mammals were estimated at 1-2 million per year (*2*). There are regional differences with regard to the species (*15*). However, WVCs in mid-west and north-east are predominantly (>80%) with white-tailed deer, but moose may be involved with about 30% of the WVCs in Maine (*15*). Thus not only the absolute number of collisions with large mammals has been increasing but large mammal-vehicle collisions also form an increasing percentage of the total number of crashes that take place within the United States. This may justify increased attention for large mammal-vehicle collisions and mitigation measures aimed at reducing these WVCs.

2.5.2. Temporal Distribution

While DVCs occur year-round in the United States, studies have documented that there is a marked peak in the fall (October-November) and a smaller peak in spring (March-April) or early summer (May-June) (*4, 15, 33, 34, 35*). The peak in the fall seems to be associated with the rut when the deer, especially the males, are more active and pay less attention to threats including roads and traffic. DVCs also occur at all times of the day. However, studies have shown that there is a distinct peak in the morning (5-7 am) and evening (6-10 pm) (*15, 36*).

2.5.3. General Spatial Distribution

DVCs are relatively numerous and widespread in the United States. Studies that focused on the spatial distribution of DVCs have generally found that the locations are not random though; DVCs have a higher concentration in some areas than in other areas (*34, 35, 37*). Because DVCs are also widespread this means that there is often insufficient funding to implement mitigation measures aimed at reducing DVCs along all road sections where mitigation measures may be required, needed, or justified. Nonetheless, widespread should not be confused with random; white-tailed deer vehicle collisions occur in relatively high numbers in some areas and relatively low numbers in other areas.

2.5.4. Road and Traffic Characteristics

Table 2-1 lists roadway characteristics that have been analyzed in other studies and their correlation with DVCs. A positive/negative sign indicate that a correlation was identified and blank indicates that no correlation was identified. It is estimated that over 89% of WVCs (mostly DVCs) occur on two-lane roads whereas only 52% of all crashes (all types) occur on two-lane roads (*15*). Two-lane roads in rural or suburban areas seem to be particularly prone to the occurrence of DVCs (*15, 34, 38*). DVCs are associated with relatively low road density (calculated within a 0.5-mile buffer on each side of the road being evaluated) (*35*). This is logical as higher road densities may not leave enough available habitat for deer to live in. Some have found a possible concentration of DVCs near intersections with other roads (*39*). However, it is possible that this phenomenon could be caused by the data reporting since intersections are convenient points of reference if a crash occurs along a segment where mile markers are not easily identified.

While it seems intuitive that higher traffic volumes result in higher numbers of DVCs, several authors have suggested the relationship between traffic volume and DVCs may be quite complex (*40, 41, 42*). As traffic volume increases, WVCs (including DVCs) may increase initially, but when traffic volume reaches high levels, fewer animals attempt to cross the road, resulting in fewer DVCs. This means that at higher traffic volumes, DVCs may decrease while the barrier effect of the road and traffic may increase (*15, 40*). Compared to all crashes (all types), WVCs occur disproportionally on low volume roads (<10,000 vehicles per day, especially <5,000 vehicles per day), considering the high quantity of low volume roadway mileage (*15*).

DVCs are disproportionally associated with moderate to high speed limits (45 mph and above) (*4, 15, 35, 38*). Though evidence is scarce, the probability of DVCs declines notably with speed limits below 45 mph

(*15*, *43*). While two-lane roads that have been upgraded with wider lanes, wider shoulders, and increased sight distance have improved overall safety, they tend to have an increase in WVCs (*44*). An increase in design speed of the highways was identified as the most likely explanation for the increase in WVCs (including DVCs) (*44*). Interestingly, the vast majority (91.7%) of all WVCs (including DVCs) occur on straight road sections with longer sightlines than road sections with curves and shorter sight lines (*15, 31*). This could be attributed to the relative frequency of these road types.

While there is a shortage of data, concrete median barriers (e.g., Jersey barriers) may be a contributing factor to WVCs (including DVCs) (*45*). While these barriers may reduce the likelihood that animals will try to cross the road (i.e. they may increase the barrier effect of roads and traffic), they may also cause the animals to spend more time on the road as they are trying to cross the barriers (*45*).

Table 2-1 Roadway Characteristics Used in DVC Models

State	Characteristics	Correlation	Source
Alabama	Vehicle density	+	(*32*)
	Vehicle miles traveled (VMT)		
Illinois	Right-of-way		(*26*)
	Road curvature		
Iowa	AADT		(*27*)
	Distance to nearest city		
	Distance to nearest town		
	Number of bridges	+	
	Number of traffic lanes	+	
Kansas	AADT	+	(*29*)
	Deer warning sign	+	
	Number of traffic lanes	+	
	Number of bridges/culverts	+	
	Speed limit	+	
Pennsylvania	In-line visibility	+	(*31*)
	Shortest visibility	-	
	Speed limit	-	
Washington	AADT		(*17*)
	Road classification		
	Road curvature		
	Speed limit		
Wisconsin	AADT		(*28*)
	VMT	+	

2.5.5. Landscape and Deer Population Size Characteristics

White-tailed deer occur in a wide variety of habitat types. Nonetheless, previous studies have associated DVC locations with certain landscape elements and with deer population density parameters. Some of these are summarized in Table 2-2 and Table 2-3.

The location of DVCs is, in general, positively associated with edge habitat (transition cover-open habitat), proximity to forest, high landscape diversity, water, and to some degree also with development (houses), but only if sufficient green is mixed in with the houses and no physical barriers are present. Proximity of houses may also provide deer with shelter from human hunters and other predators. Larger areas of forest (natural habitat) tend to be associated with fewer DVCs than mixed landscapes with abundant edge habitat. The effect of grasslands and croplands can be complex and partially depends on the proximity of cover (forest). Linear features (ridges, gullies) can lead deer to roads, but DVCs can also occur elsewhere in relatively high numbers. Not surprisingly, deer population size parameters are generally associated with higher numbers of DVCs.

Table 2-2 Landscape Parameters and Correlation with DVC Locations

	Parameter	Correlation	Region	Source(s)
Cover	Forest	+	Pennsylvania	(*33*)
	Forest	+	Edmonton, Alberta, Canada	(*35*)
	Forest	+	Illinois	(*46*)
	Forest	+	Minneapolis, Minnesota	(*47*)
	Proximity to forest	+	Illinois	(*46*)
	Proximity to forest	+	Edmonton, Alberta, Canada	(*35*)
	Proximity to forest	+	Pennsylvania	(*31*)
	Shrubs	+	Seeley-Swan, Montana	(*48*)
	Shrubs	+	Minneapolis, Minnesota	(*47*)
	Forest	-	Vigo County, Indiana	(*37*)
Open	Non-forested	+	Edmonton, Alberta, Canada	(*35*)
	Agricultural fields	+	Pennsylvania	(*33*)
	Vegetation productivity	+	Edmonton, Alberta, Canada	(*35*)
	Planted/cultivated	+	Vigo County, Indiana	(*37*)
	Forage habitat	+	Illinois	(*46*)
	Non-wooded habitat	+	Pennsylvania	(*31*)
	Pasture	+	Alabama	(*30*)
	Cropland	-	Illinois	(*46*)
	Cropland	-	Alabama	(*30*)
	Grassland	-	East central South Dakota	(*49*)
Edge Habitat	Edge habitat	+	Edmonton, Alberta, Canada	(*35*)
	Edge habitat	+	Pennsylvania	(*33*)
	Edge habitat	+	Illinois	(*46*)
	Forest edge	+	Seeley-Swan, Montana	(*48*)
	Shelterbelts	+	East central South Dakota	(*49*)
	Tree lines	+	Seeley-Swan, Montana	(*48*)
Landscape	Landscape diversity	+	Illinois	(*46*)
	Landscape diversity	+	Seeley-Swan, Montana	(*48*)
	Landscape diversity	+	Minneapolis, Minnesota	(*47*)
	Landscape heterogeneity	+	Seeley-Swan, Montana	(*48*)
	Landscape patchiness	+	Kent County, Michigan	(*50*)
	Gullies	+	Illinois	(*46*)
	Road cuts	+	Pennsylvania	(*51*)
Water	Proximity to water	+	Edmonton, Alberta, Canada	(*35*)
	Riparian corridor	+	Illinois	(*46*)
	Riparian habitat	+	Seeley-Swan, Montana	(*48*)
	Water bodies	+	Illinois	(*46*)
	Water courses	+	Kent County, Michigan	(*50*)
	Wetlands and water	-	Vigo County, Indiana	(*37*)
Development	Development	+	Vigo County, Indiana	(*37*)
	Residences	+	Illinois	(*46*)
	Buildings	+	Seeley-Swan, Montana	(*48*)
	Buildings	-	Pennsylvania	(*31*)
	Buildings	-	Minneapolis, Minnesota	(*47*)
	Urban	+	Alabama	(*30*)

Table 2-3 Deer Population Parameters and Correlation with DVC Locations

	Parameter	Correlation	Region	Source(s)
Deer Population*	More than 31 deer/km^2	+	Alabama	(*30*)
	< Hunting license sales	+	Alabama	(*30*)
	Deer grazing in R/W	+	Pennsylvania	(*51*)
	> Buck harvest	+	Wisconsin	(*52*)
	> Deer population size	+	Southeastern Michigan	(*36*)
	> Deer population size	+	Pennsylvania	(*33*)
	Deer harvest levels	+/-	Clark County, Virginia	(*53*)
	Deer density	+/-	Clark County, Virginia	(*53*)

* < indicates a decrease in the parameter and > indicates an increase

2.6. Deer Behavior Adjacent to Roadways

White-tailed deer appear to be near and on roads for two main reasons: intent to cross to a habitat on the other side of the road and because of the foraging opportunities the vegetation in the right-of-way may provide. Table 2-4 lists findings from studies related to these activities based on deer observations rather than crash data. Vegetation in the right-of-way may be especially attractive in areas further away from other foraging opportunities (i.e. agricultural crops or grassland). While large scale forests may have fewer DVCs overall, the food availability in the right-of-way (grasses and herbs) may be a strong attractant. In these situations the right-of-way through a forested area may function as edge habitat.

Table 2-4 Deer Behavior On and Near Highways

	Behavior	Region	Source(s)
Foraging	Deer forage in R/W, predominantly between 5pm-7am	Illinois	(*54*)
	70% of deer in R/W were grazing	Pennsylvania	(*51*)
	32-68% of deer in R/W feed on the grass in R/W	Illinois	(*54*)
	Deer are more likely to graze in R/W in forested areas than in agricultural areas where they feed on crops	Central Pennsylvania	(*55*)
	35% of large mammals (mostly deer) observed at a fence end were foraging in the R/W	Western Montana	(*56*)
Crossing	36-70% of the observed deer in R/W crossed or attempted to cross the highway	Illinois, U.S.A	(*54*)
	Deer generally walk to the highway and stop at the edge of the pavement before moving across cautiously	Illinois, U.S.A	(*54*)
	It is common for deer to look at approaching vehicle	Illinois, U.S.A	(*54*)
	36% of large mammals (mostly deer) that appeared at a fence end crossed the highway	Western Montana	(*56*)

2.7. <u>Mitigation Measures Intended to Modify Human Behavior</u>

DVC mitigation falls in two general groups – measures intended to modify human behavior and measures intended to modify deer behavior. While there are numerous types of mitigation that have been recommended over time, only the most common and potentially useful ones are addressed here. A more exhaustive list of types are provided in Appendix A (*13*). This section discusses the measures intended to modify human behavior, which include posted speed limit reductions, signage, animal detection systems, vehicle-based warning systems, roadway lighting, and removal of vegetation from right-of-way.

2.7.1. <u>Vehicle Speed Reduction</u>

Vehicle speed reduction seems to be a relatively simple way to reduce the number and severity of DVCs. However, vehicle speed would have to be reduced to 45 mph or less in order to obtain a substantial reduction. These relatively low speeds may not be acceptable to drivers and policy makers. In addition, it is dangerous to reduce the posted speed limit far below the design speed of a road. The geometric design of a road (e.g. lane width, shoulder width, clear zone width, sight distance, curvature) is based on its assumed design speed. The operating speed of vehicles is the speed drivers actually drive their vehicles. Some drivers will have a speed consistent with the posted speed limit while others will drive closer to the design speed of a road. This means that there will be a mix of slow and fast vehicles on the road (speed dispersion) which is associated with an increase in overall crashes (e.g. because of dangerous passing behavior).

For these reasons, the posted speed limit cannot be reduced far below the design speed. Some experiments have seen limited success of a reduction in the posted speed limit at night though. In Montana, a night time speed limit reduction from 70 mph to 55 mph may have reduced collisions by about 30% (*57*).

Alternatively, traffic calming measures can be implemented to reduce vehicle travel speeds (e.g. speed bumps, bulb-outs). However, these types of measures are typically implemented on low volume roads, often in an urban setting rather than along higher volume highways through rural areas. A relatively recent initiative is to implement wider striping on the pavement to reduce vehicle speeds (*58*). While the actual road width remains the same, the perspective of the driver is that of a narrower lane that requires lower vehicle speed to keep the vehicle from driving on the lines.

2.7.2. Roadside Signage and Animal Detection Systems

Wildlife warning signs aim to warn drivers and urge them to be more attentive to wildlife that may be on or near the road and reduce their speed. The primary goal of wildlife warning signs is to improve human safety by reducing the rate and severity of WVCs. The types of signage discussed here have been utilized to address crashes with all types of large mammals, and their effectiveness for white-tailed deer may not be the same.

Standard Signage

Standard "deer crossing" signs, like the one in Figure 2-1a are normally installed at road sections that have a relatively high number of DVCs. Most standard wildlife warning signs are not very specific in time or place. The distance to which the warning applies may be many miles. Only 5-10% of the drivers that were stopped 0.1 mile after passing a warning sign were able to recall it (*59*) and a dummy of a moose along a roadway with this signage either was not noticed or barely noticed by drivers (*60*). Another factor that contributes to the abundance of wildlife warning signs along roads is that once a sign has been installed it is rarely removed, even if the problem no longer exists.

Enhanced Signage

Enhanced wildlife-warning signs tend to be larger than standard signs and have flashing lights or bright flags attached to them. They may also include eye-catching or perhaps even disturbing illustrations and images of certain species that the warning relates to, WVC statistics or other customized text. An example of an enhanced warning sign is shown in Figure 2-1b. These characteristics aim to capture the attention of motorists and educate them about the safety and nature conservation impact of WVCs. Enhanced warning signs are generally more frequently observed and recalled by drivers than standard warning signs (*61*). They are normally installed at road sections that have a relatively high number of WVCs or in areas where species of conservation concern occurs.

Seasonal (Temporal) Signage

Seasonal (temporal) wildlife warning signs warn drivers of wildlife presence during specific times of the year or day. These signs tend to be species-specific and may only be visible to drivers during the most potentially hazardous time of year or day. Signs may fold in half to be concealed, removed in the off-season, or be dynamic message signs with programmable text or symbols that can be turned on and off. Examples are shown in Figure 2-1c and d. Note that these sign types are also commonly used with animal detection systems.

Seasonal warning signs may be placed where roads intersect migration corridors (e.g. mule deer migration routes in the western US) or where species are attracted to the highway during specific times of year (e.g. bighorn sheep licking road salt in specific areas in the Rocky Mountains). Seasonal warning signs can also apply to smaller animals such as amphibians that leave their winter hibernacula to move to breeding habitat in large numbers during a short period in spring. If the warning relates to certain hours of the day, the signs may be permanent, but their message may be enhanced during the time of day with peak wildlife activity (e.g. flashing lights around dusk and dawn).

Animal Detection Systems

Animal detection systems use electronic sensors to detect large animals (i.e. deer size and larger) that approach the road and then activate signs to warn drivers. These signs are very specific in time and place. Dynamic message signs can be utilized within these systems or the activation of flashing lights on enhanced signs. Examples of animal detection system components are shown in Figure 2-2. Figure 2-3 lists six possible scenarios and applications of animal detection systems that are described below (reproduced from *48*).

a. System installed over a relatively long road section without wildlife fencing.
b. System installed in a gap with *extensive* wildlife fences on either side, including illustration of potential wildlife movements into the fenced right-of-way, which exists in all scenarios.
c. System installed in a gap with *limited* wildlife fences on either side intended to funnel the animals towards the road section with the system.
d. System installed at the end of extensive wildlife fencing.
e. System installed at the end of extensive wildlife fencing intended to funnel the animals through an underpass/overpass.
f. System installed at a low volume frontage road adjacent to a high volume highway with a wildlife underpass/overpass and wildlife fencing.

Signage Effectiveness

Wildlife warning signs are typically considered effective if they result in a reduction in the number of WVCs. Other parameters may also be used to measure effectiveness, such as a reduction in vehicle speed or other driver responses such as touching the brakes or being more alert. While drivers may reduce vehicle speed in response to standard and enhanced signs (*50*, *62*, *63*, *64*), the majority of studies of the effectiveness of these sign types in reducing WVCs concluded that they were not effective (e.g. *50*, *62*, *65*, *66*, *67*). However, some have found standard warning signs to be effective (34% reduction in

collisions) immediately after installation (*68*) or at a gap in a fence with a crosswalk painted on the road surface (37-43%) (*69*). Regardless, implementing standard wildlife warning signs may still be required or desirable to limit liability concerns for transportation or wildlife management agencies. While standard and enhanced signs have some driver educational value, one could also argue that drivers may wrongfully think that these sign types reduce collisions, and consequently might not support implementing more effective mitigation measures that may be more expensive, but more effective.

Seasonal (temporal) warning signs can reduce collisions, although effectiveness varies substantially (9-50%) (*64*, *70*). The effectiveness of animal detection systems is also variable, but they appear to reduce WVCs more than seasonal signs: 33-97% reduction in collisions with large mammals (*71*, *72*, *73*, *74*, *75*, *76, 77*). Since the risk of severe crashes increases exponentially with increasing vehicle speed (*78*), it is useful to also evaluate the potential effect of activated warning signs associated with animal detection systems on vehicle speed. Drivers tend to reduce their speed somewhat (<5 mph) (*72, 79, 80, 81*) or more substantially (≥5-15 mph) in response to activated signs of animal detection systems (*75, 77, 79, 82, 83*). The greatest reductions in vehicle speed seem to occur when the signs are associated with advisory or mandatory speed limit reductions or if road conditions and visibility for drivers are poor (*79, 80*).

In conclusion, standard warning signs and enhanced warning signs do not appear to be effective in reducing WVCs. Seasonal (temporal) warning signs can somewhat reduce WVCs for selected species that display seasonal migration in selected road sections. White-tailed deer are generally not considered to be migratory, but this varies by region. If properly designed, installed, and maintained, animal detection systems can be substantially effective in reducing WVCs. However, they should still be regarded as experimental rather than a mitigation measure that is predictable with regard to the percentage reduction in large mammal-vehicle collisions (*84*).

(a) Standard

(b) Enhanced

(c) Seasonal Activation

(d) Seasonal Activation

Figure 2-1 Wildlife Warning Signs

(a) Triggered Enhanced Sign	(b) Triggered LED Sign
(c) Solar Powered Pole-Mounted Sensor	(d) Ground Mounted Sensor

Figure 2-2 Animal Detection System Components
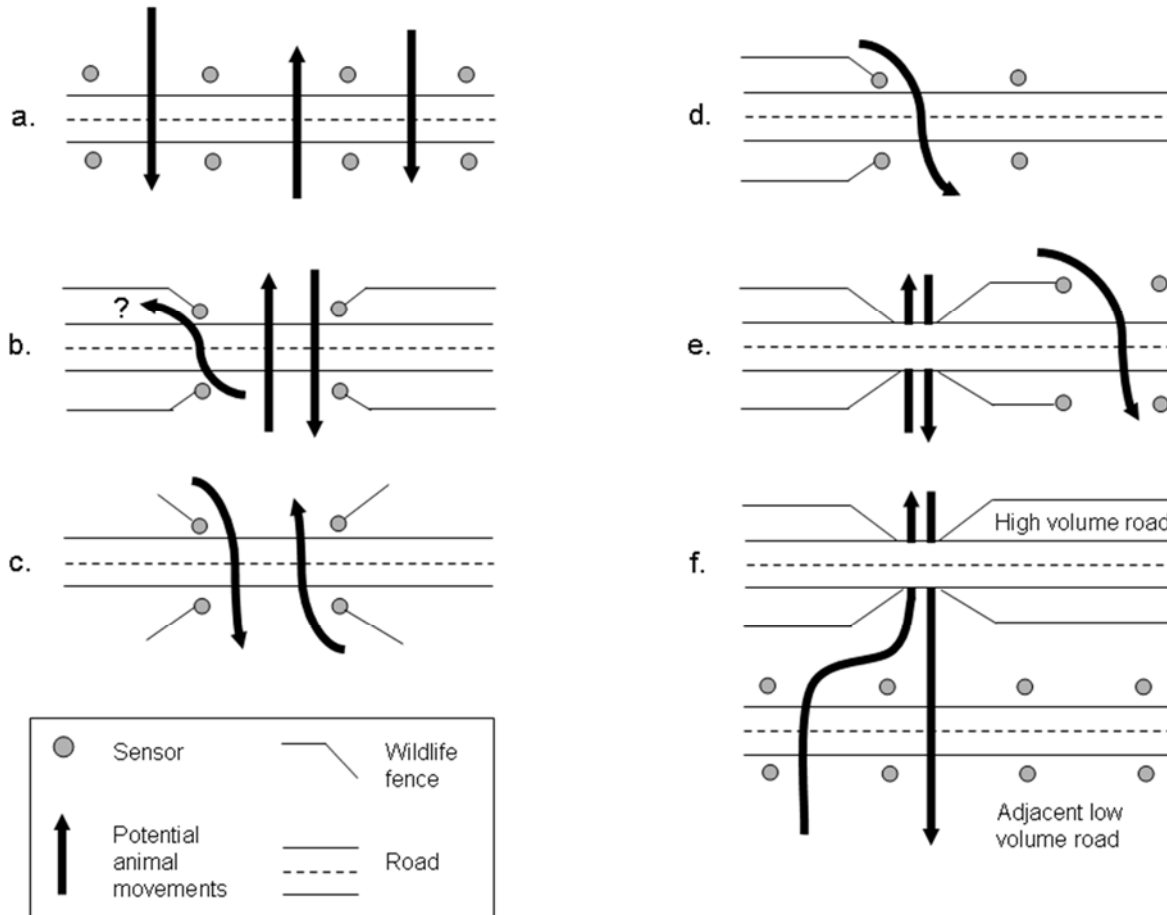
Figure 2-3 Schematic Representation of Animal Detection System Applications

2.7.3. Vehicle-Based Warning Systems

In-vehicle based sensors and warning systems are being developed and may eventually be capable of detecting large animals at a long distance to allow for sufficient response time of the driver or the vehicle (*85*). Roadside animal detection systems only protect the selected short road sections where they are installed. With vehicle-based systems, any driver can benefit, regardless of the vehicle they drive or the road they are on. Vehicle based detection systems could eventually work nearly everywhere, but it may take many decades before the vast majority of vehicles are actually equipped with on-board detection systems.

2.7.4. Roadway Lighting

Roadway lighting increases the visibility for drivers and may help reduce the likelihood of large mammal-vehicle collisions (*86, 87, 88*). Data on effectiveness are scarce and variable. One study revealed DVCs

did not reduce with lighting, but drivers did substantially reduce vehicle speed after seeing a deer (*89*). However, a lighted highway section in Alaska had moose-vehicle collisions decline by 65% (*90*). Note that roadway lighting may increase the barrier effect of roads and traffic for certain species and that the reduction in collisions may be, at least partially, also because fewer animals attempt to approach and cross a lighted highway rather than drivers responding earlier to animals on or near the road. If roadway lighting is implemented, use configurations that minimize light pollution off to the sides of the road (beyond the right-of-way) and the sky. From a wildlife ecology standpoint, it is good practice to only increase the barrier effect of roads and traffic if appropriate safe crossing opportunities are also provided, in this case with no or minimal light pollution.

2.7.5.   Shrub and Tree Removal in Right-of-Way

Brushing of the right-of-way vegetation has been implemented along various highways, especially in areas with a history of moose-vehicle collisions. Brushing removes shrubs and trees that grow close to the road in the right-of-way, thereby increasing available sight distance for drivers. Thus drivers may also be able to see large mammals including deer earlier and may be able to avoid a collision. Clearing vegetation from roadsides resulted in a 20% reduction in moose-vehicle collisions in Sweden (*86*). In a study examining the effect of scent marking, intercept feeding and forest clearing, analyses demonstrated that forest clearing resulted in a 49% reduction in collisions (*91*). While it is recognized that the results may not translate to a highway setting, the clearing of vegetation across a 70-100 feet wide zone on each side of a Norwegian railway reduced moose-train collisions by 56% (*92*). Regrowth of shrubs and trees can be attractive forage for large mammals. The time of year influences when regrowth will occur and what the quality of the forage is. Regardless, cutting or brushing needs to occur regularly to keep the vegetation short and remove attractive regrowth. Note that brushing or cutting of shrubs and trees alongside roads can increase the barrier of roads and traffic for certain species. Species that depend on cover would be particularly affected.

2.8. Mitigation Measures Intended to Modify Deer Behavior

DVC mitigation falls in two general groups – measures intended to modify human behavior and measures intended to modify deer behavior. While there are numerous types of mitigation that have been recommended over time, only the most common and potentially useful ones are addressed here. A more exhaustive list of types are provided in Appendix A (*13*). This section discusses the measures intended to modify deer behavior, which include mirrors and reflectors, acoustic devices on cars, deer population reduction methods, and barriers along highways.

2.8.1. Wildlife Mirrors or Reflectors in Right-of-Way

The mechanism through which deer mirrors and reflectors are supposedly reducing DVCs is as follows. A car's headlights reflect in the mirrors or reflectors located on short poles in the right-of-way (see Figure 2-4). The light is then reflected into the right-of-way. This light is observed by the wildlife (including deer), and is intended to cause the animal to move away from the highway and right-of-way, thereby reducing the likelihood of a collision. Most studies into the effectiveness of these mirrors and reflectors in reducing collisions with large mammals suggest that they are ineffective or inconclusive (*50, 54, 93, 94, 95, 96, 97*). Some studies found a reduction in collisions though (*98, 99*). Research into the behavioral response of white-tailed deer to the car headlights reflected by reflectors suggests that if there is an initial effect, deer may eventually habituate (*100*). Others have found no evidence of deer displaying less dangerous behavior when cars passed by correctly installed and maintained reflectors, regardless of the color of the reflectors (*101*). The latter suggests that potential effects of incorrect placement or maintenance of mirrors or reflectors is inconsequential; there is no evidence for the underlying mechanism of how deer mirrors or reflectors are supposed to work.

Figure 2-4 Wildlife Reflector Installed in Right-of-Way

2.8.2. Acoustic Devices on Cars or in Right-of-Way

Whistling or other alarming sounds from vehicles or devices installed in the right-of-way depend on a mechanism similar to that for mirrors or reflectors (see previous section). Deer are able to hear the sound of typical deer whistles (*102, 103*). However, there is no evidence deer display behavior that is less likely to result in a collision when exposed to various sounds (*104, 105, 106*).

2.8.3. Changes to Food and Cover Availability

The grass-herb vegetation in the right-of-way can be an attractant to deer, especially in forested areas. Frequent mowing or cutting can reduce the quantity of the available forage, but regrowth may still be attractive because of the higher quality. However, it is best to plant or seed slow growing native species that have relatively low nutritional value to deer. At the same time, shrubs and trees cannot grow adjacent to the pavement in order to maintain the roadside clear zone. Avoid seeding clover in right-of-ways.

Changes to the vegetation beyond the right-of-way are typically not possible because of the land use and land ownership. However, proximity and abundance of forest edges are associated with higher numbers in DVCs. This means that removing forest edges and having forest edges end further away from the road may help reduce DVCs. Since the home range of white-tailed deer may be 60-775 acres (*107, 108, 109, 110*), the diameter of their home range may be 0.35-1.25 miles. This means that a forest edge would have to be set back a significant distance from the highway if it is to substantially reduce the probability that deer will be on or near the road. Besides land ownership and land use issues, this practice will also substantially increase the footprint of the transportation corridor and it is likely to also increase the barrier effect of roads and traffic, especially for species that depend on cover.

2.8.4. Deer Population Size Reduction

In addition to public hunting, deer population size can be reduced through direct killing ("culling"), relocation, and reducing the animal's fertility. These measures are sometimes applied in an urban or suburban setting where other measures to reduce human-wildlife conflicts have failed or are not considered feasible. None of these measures are intended to affect deer population over large areas. The reasons for reducing the deer population size are often broader than collisions alone. Other concerns related to threats to human safety as a result of the deer losing their fear of humans, damage to gardens and parks, and disease. In more natural areas or suburban areas that border relatively natural areas, damages to the ecosystem, for example as a result of overpopulation or concentration in small areas, can also be one of the reasons to consider reducing deer population size. Reducing the deer population size should result, at least in theory, in fewer individual deer and reduced conflict with humans, potentially including reduced DVCs.

Relocation and anti-fertility treatment of deer seem humane alternatives to direct killing. However, relocation may not be effective because deer may return unless they are transported very far away, and it

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puts substantial stress on the animals relocated as well as the species and ecosystem that is present in the release areas. Anti-fertility treatment is very labor intensive, and just like direct killing or relocation has to be repeated regularly (*111*). As population density is reduced, increased effort is needed to keep the deer density at the lower level (*111, 112*). Capture and relocation costs per deer have been documented to vary between $400-3,200 per individual while anti-fertility treatment may cost about $1,000 per deer (*113*).

Wildlife culling in urban or sub-urban areas can be considered a risk for human safety, especially if firearms are used, and it is sometimes met with strong public opposition, possibly causing delay or abandonment of the effort. A public relations campaign should be considered before a culling effort begins, especially in urban and suburban areas. Shotgun or archery hunting can address some of the human safety concerns, and archery appears to be preferred by most home owners over the use of firearms *(114, 115, 116)*. Furthermore, archery bypasses firearms-discharge laws (*114, 115, 116*). Using bait in an urban setting is about twice as effective as not using bait, even on small properties (*116*). However, the use of bait may increase the transmission of disease for the wildlife feeding on the bait through greater direct and indirect contact (e.g. saliva on salt blocks) (*117*). Sharpshooting has been documented to cost between $200-350 per deer, but costs may be lower if the hunt is conducted by the public (*113*).

Culling efforts are more likely to result in a substantial reduction in deer population size if the herd size is relatively small to begin with, and if it is a closed population that does not allow influx of animals from nearby places. In addition it is important to focus the killing on does (females) rather than mature bucks (males), and potential refugia (i.e. non-huntable areas) in the area subject to the deer population culling area should be minimized (*114*, *118*). A rigorous selection process for the hunters in the case of public hunting is considered important because of the human safety risks and the potential for other conflicts (*119*). Deer population reduction efforts may need to be repeated every year or once every few years because of high deer reproduction rates and potential influx of new deer.

Sharp shooting by professionals over bait was deemed to be the most effective and adaptable culling method in an urban setting, as opposed to controlled hunts in large parks and refuges or opportunistic sharp shooting by professionals (*120*). If the public is to participate in the culling, consider modifying hunting regulations to stimulate hunters to target younger animals and does rather than bucks. But if the number of hunters and harvest numbers decline, a shift from recreational hunting to professional culling may need to be considered.

Actual data on the effectiveness of population reduction programs on WVCs are few. A field test showed that a deer population reduction program in Minnesota reduced winter deer densities by 46% and DVCs by 30% (*120*). While reductions in population size of 50% or more may be hard to achieve and the potential reduction in DVCs may be capped at 50% or less (*120*), some culling efforts reduced deer population density by 92% (*121*). Because of the highly variable relationship between population size, population size reduction, and DVCs, this measure should be considered experimental.

2.8.5.   Physical Barriers for Deer Along Highways

Barriers for wildlife along highways typically consist of fencing, similar to those shown in Figure 2-5. However, in some cases rows of large boulders have been used as an alternative barrier for large mammals (see review in *15*, *122*). Wildlife fencing for large mammals, including white-tailed deer, is primarily aimed at reducing collisions by keeping these species from entering the road or road corridor, including the right-of-way.

Wildlife fencing, typically in association with safe crossing opportunities for wildlife, can reduce WVCs substantially (≥80%) ((*123*): 79%; (*124*): 90%; (*125*): 4%–97%; (*126*): 80%; (*127*): 87%). However, when wildlife fencing is installed over relatively short road segments (e.g. up to a few miles), wildlife fencing may be less effective in reducing WVCs for two reasons:

1) If only relatively short sections of road are fenced at the actual collision hotspot, animals that approach the road section at the former hotspots may simply walk to the fence end, and either cross at grade or wander into the fenced road corridor. This would relocate WVCs to another roadway segment, rather than substantially reducing them.

2) Fence end effects may alter the effectiveness of the fenced road section more with shorter fenced road lengths as the fence ends could take up a greater portion of the mitigated road length.

Fences for deer should at least extend 0.3-0.6 miles beyond where the actual collision hotspot was identified. This would locate the fence end beyond the likely diameter of the home range of white-tailed deer that approach the road at the former hotspot. Thus a fenced road section should at a minimum include the length of the former hotspot and buffer zones of 0.3-0.6 miles road length from each end of the hotspot. Fence end effects may still reduce the overall effectiveness of the fence if only a few miles of road are fenced. However, depending on the terrain (e.g. topography or other natural barriers) it may be appropriate to have short road sections with fencing that do not extend beyond the actual hotspot.

It is critical though that the fence is designed correctly for the target species. Typically fences for deer consist of woven wire mesh fencing. The fences are 8 feet tall with wooden or metal posts. In some cases, electrical fences are used with fiberglass poles. Examples are shown in Figure 2-5. Details on fence material and dimensions have been reported by Clevenger & Huijser (*16*).

Important considerations with regard to wildlife fencing are safe crossing opportunities for wildlife, access points for people, escape opportunities from the fenced road corridor for wildlife, and fence end treatments. These components are discussed in the following sections.

| (a) Mesh Fence with Metal and Wood Posts | (b) Electric Fence with Fiberglass Posts |
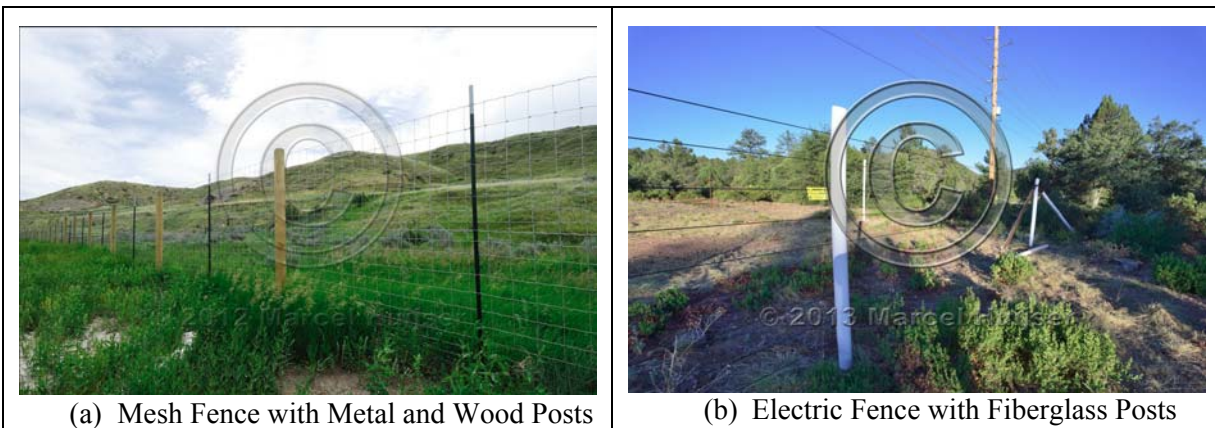
Figure 2-5 Wildlife Fencing

Wildlife Safe Crossing Opportunities
Through its very nature, wildlife fencing alone increases the barrier effect of roads and traffic. Therefore, it is considered good practice to always combine wildlife fencing with safe crossing opportunities for wildlife. These crossing opportunities typically consist of wildlife underpasses and overpasses. However, in some cases, at grade crossing opportunities are provided at a gap in the fence, with or without an animal detection system. Providing safe crossing opportunities not only helps address the barrier effect of roads and traffic, they can also help reduce intrusions of large mammals into the road corridor as the animals no longer need to breach or climb the fence in order to get to the other side of the road.

Six different types of safe crossing opportunities and their approximate dimensions are listed in Table 2-5. Examples of these are shown in Figure 2-6. Note that there are other types of crossing structures (e.g. for amphibians), but these are not included in this report because this report primarily focuses on large mammals such as white-tailed deer and most amphibians and reptiles are also able to pass through a standard the wildlife fence. While Table 2-5 classifies crossing structures based on their dimensions, there is no generally agreed upon definition of different types of crossing structures. One may also choose to

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modify the dimensions of an underpass based on the species of interest and the physical environment at the location of the underpass.

Table 2-5. Dimensions of Safe Crossing Opportunities

Safe Crossing Opportunity	Dimensions (as seen by the animal)	
	Width	Height
Wildlife Overpass	160 feet	n/a
Open Span Bridge	40 feet	≥ 15 feet
Large Mammal Underpass	20-30 feet	14-16 feet
Medium Mammal Underpass	3-10 feet	1.5-8 feet
Small-Medium Mammal Underpass	1-2 feet in diameter	
Animal Detection Systems	n/a	

(a) Wildlife Overpass in Montana   (b) Wildlife Underpass in Montana
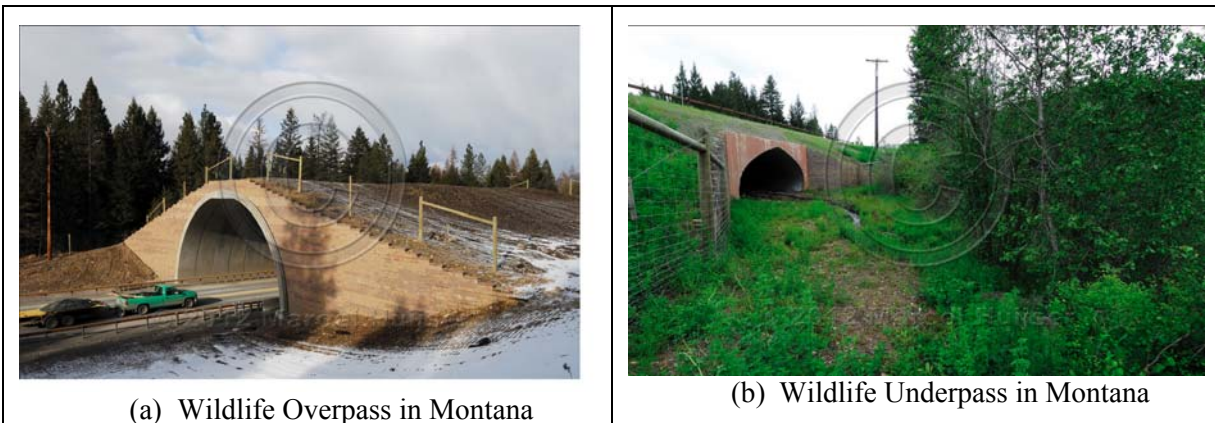
Figure 2-6 Wildlife Safe Crossing Examples

Table 2-6 provides an overview of the suitability of the six different types of safe crossing opportunities for the medium and large mammal species that may occur in West Virginia (red fox size and larger) (*16*; Huijser et al., preliminary data; Clevenger, unpublished data). When evaluating the suitability, the authors assumed no human use of the crossing opportunities. The suitability of the different types of safe crossing opportunities is not only influenced by the size of the species, but also by species-specific behavior.

Most animal detection systems only detect large mammals and are therefore, by definition, not suitable for medium and small species. Because the suitability of the different safe crossing opportunities depends on the species, and large landscape connectors (e.g. tunneling or elevated road sections) are rare, providing a variety of different types of safe crossing opportunities generally provides habitat connectivity for more species than implementing only one type of crossing structure, even if that structure is relatively large. For some species there is little or no information on what type and dimension of crossing structure is considered suitable. However, for some species the researchers made an educated guess.

Note that some have found a gap in a fence with a crosswalk painted on the road surface effective in reducing collisions with mule deer by 37-43% (*69*). The reduction is a result in both the deer behavior being modified with the fence and possibly by the driver slowing down for the crosswalk and possibly being more alert to something in the roadway.

Table 2-6 Suitability of Different Types of Safe Crossings for Large Mammal Species

	Bobcat	Mountain Lion	Gray Fox	Red Fox	Coyote	Deer	Elk	Wolf	Black Bear
Wildlife Overpass	●	●	●	●	●	●	●	●	●
Open Span Bridge	●	●	●	●	●	●	●	●	●
Large Mammal Underpass	●	●	●	●	●	●	◉	◉	●
Medium Mammal Underpass	●	⊗	●	●	●	⊗	⊗	⊗	⊗
Small-Medium Mammal Underpass	●	⊗	●	●	●	⊗	⊗	⊗	⊗
Animal Detection Systems	⊗	◉	⊗	⊗	⊗	●	●	◉	●

● Recommended/Optimum Solution
◉ Possible solution if adapted to species' specific needs
⊗ Not Recommended

The spacing of safe crossing opportunities along a roadway for wildlife can be calculated in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow).
- Allowing a wide variety of species to change their spatial distribution drastically, for example in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements.

- Allowing individuals, regardless of the species, that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is permeable for wildlife, at least to a certain degree, and at least for the individuals that live close to the road.

A further complication of selecting and spacing safe crossing opportunities is that animals that disperse (i.e., one-time long-range movement with no return), animals that display seasonal migration, or animals that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing animals may grow up far away from the areas where one is used to seeing them; they may not move through habitat that we may expect them to be in; they typically travel long distances much further and quicker compared to resident animals; they may also stay away from roads, traffic, and other types of human disturbance that they are unfamiliar with. Safe crossing opportunities may not be encountered by dispersing animals as they are new in the area and are not familiar with their location, and when confronted with a road or associated wildlife fence they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing animals do encounter a safe crossing opportunity, they may be more hesitant to use them compared to resident animals that not only know about their location, but that also have had time to learn that it is safe to use them.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. For this report, the researchers chose a simpler approach. White-tailed deer may have an average home range of about 60-775 acres (diameter of circular home range = 0.35-1.25 miles). The distance between safe crossing opportunities for white-tailed deer was set to be equal to the average diameter of the home range, say about 0.80 miles. This allows individual deer that have the center of their home range somewhere on the road to have access to at least one safe crossing opportunity (see individual x in Figure 2-7). However, individuals that may have had their home range on both sides of the road may or may not have access to a safe crossing opportunity (see individuals y and z in Figure 2-7). This approach assumed homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat and habitat quality may vary greatly, causing variations in density of individuals and irregular shaped home ranges. The researchers would like to emphasize that this approach does not necessarily result in viable populations for white-tailed deer (let alone other species), and that not every individual that approaches the road and associated wildlife fence, will encounter and use a safe crossing opportunity. Nonetheless, it provides some guidance for how frequently

a crossing structure suitable for white-tailed deer may be desirable if fenced road sections should still have substantial permeability for individual deer that approach the fenced road section.

The approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the researchers do think that this approach would at least be consistent, practical, based on the available ecological data, and likely to result in considerable permeability of the road corridor and associated wildlife fencing for white-tailed deer.

Another way to decide on "appropriate distance" between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.2 miles (range for the average spacing of structures in these individual areas is 0.5-1.8 miles). However, the 1.2 mile spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area.
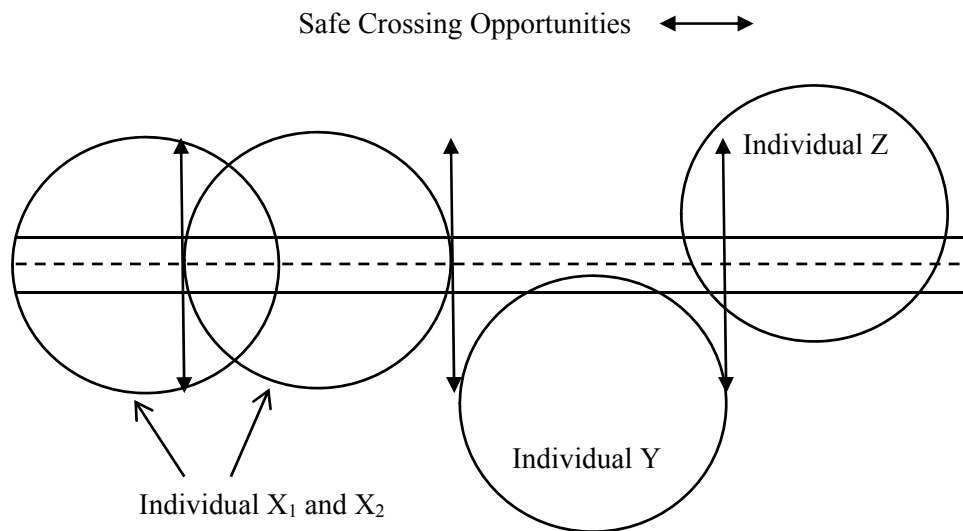
Figure 2-7 Representation of Home Ranges for 4 Individuals with Safe Crossing Opportunities

Access Points for People
A fence can keep wildlife off the fenced road corridor. However, people may still need to access the main highway or the areas adjacent to the highway. This requires access points for people that are suitable for

non-motorized and motorized traffic. There is no access facility that is optimal for all user groups. Therefore, if multiple user groups need to have access at a certain location, multiple access facilities may be provided adjacent to each other.

The suitability of different types of access facilities for three non-motorized user groups is summarized in Table 2-7.   While there are many forms of non-motorized use, Table 2-7 only includes access points for pedestrians, bicyclists and equestrian use. Figure 2-8a and b illustrate two types of swing gates. The suitability of different types of access facilities for motorized vehicles is summarized in Table 2-8. Figure 2-8c and d illustrate wildlife grates and cattle guards on access roads.

Each access point is a potential weak point in the fence where wildlife may be better able to access the fenced road corridor. In addition, access points along major highways are also a general traffic safety concern. For these reasons it is considered good practice to minimize the number of access points. Swing gates, when closed are typically a substantial barrier for large mammals, similar to the fence. Wildlife guards and electric mats can also be a substantial barrier to large mammals, though they are not necessarily an absolute barrier (*128*). Note that black bears will readily walk across wildlife guards, unless they are electrified.

Table 2-7 Suitability of Access Facilities In and Out of Fenced Road Corridors for Humans

Access Facility Type	Pedestrians	Bicyclists	Equestrian
Walk-thru gate	●	⊗	⊗
Swing gate at grade	●	◉	◉
Swing gate with steps	●	⊗	⊗
Swing gates with lock chamber	●	◉	◉
Carousel	●	◉	●
Wildlife guard (bars)	⊗	◉	⊗
Wildlife guard (grate)	●	●	⊗
Wildlife guard (electrified)	⊗	◉	⊗
Electric mat	◉	◉	⊗

● Suitable
◉ Somewhat suitable
⊗ Not suitable

Table 2-8 Suitability of Access Facilities In and Out of Fenced Road Corridors for Vehicles

Access Facility Type	Vehicle does not have to stop	Vehicle does not have to slow down	People remain in vehicle	Comfortable to drive over
Swing gate (manual open/close)	⊗	⊗	⊗	●
Swing gate (automatic)	O	⊗	●	●
Wildlife guard (bars)	●	⊗	●	⊗
Wildlife guard (grate)	●	●	●	●
Wildlife guard (electrified)	●	O	●	●
Electric mat	●	●	●	●

● Suitable

O Somewhat suitable

⊗ Not suitable

(a) Swing Gate at Grade

(b) Swing Gate with Steps

(c) Wildlife Grate on Main Road

(d) Wildlife Grate at Access Road

(e) Wildlife Guard on Access Road

(f) Electric Mat on Main Road

Figure 2-8 Fencing Access Points for Humans and Vehicles

Escape Opportunities for Wildlife

Some animals will end up in the fenced road corridor. This is a very dangerous situation, both for humans driving on the road and the animals concerned. Therefore, wildlife fences are typically accompanied with measures that allow animals to escape from the fenced road corridor. These measures may function best if they are set back from the road with some cover (i.e., vegetation or topography) to block visual disturbance originating from the road (i.e. vehicles). In some cases, short sections of wildlife fencing are placed perpendicular to the escape opportunities to encourage animals to investigate and use the escape

measures. Escape opportunities have also been offset in the wildlife fence so that an animal that moved alongside the fence (at least from one direction) would end up "bumping into" the escape opportunity (*129*). If the fence is moved away from the road after about 40 feet, a second escape opportunity for animals traveling from the opposite direction may be installed (*129*).

There are no established standards for the spacing of escape opportunities. It has been recommended though that the number of escape opportunities for large ungulates should be four per mile of road length (two on each side of the road) (*130*). Others have recommended a spacing of 0.25 mile between escape opportunities for large mammals, eight per mile.

One-way gates for large mammals typically consist of spring loaded steel tines, as shown in Figure 2-9a (*129*). The gates are installed in a wildlife fence and allow large mammals that are caught in the fenced right-of-way to push themselves through the spring loaded steel tines that are pointing towards the safe side of the fence (i.e. away from the road). The direction of the tines, their range of motion, and the springs minimize the probability that large animals can travel from the safe side of the fence into the fenced road corridor. Between 33-49% of the mule deer that were in the fenced road corridor and that approached one-way gates used the gates to leave the fenced road corridor (*131*). However, in other cases use was much lower at 16% (*132*). While one-way gates are designed to only allow animals to pass from the fenced road corridor to the safe side of the fence, animals do sometimes succeed in using the gate to access the fenced right-of-way. Depending on the design of the gates, a study showed that 3.8% to 6.0% of all passages were in the wrong direction (*129*). Some large species, including elk and moose, can bend the tines out of shape and can transform a one-way gate into a two-way opening (*129*). To reduce death or injuries to animals trying to get into the fenced road corridor (e.g. *15*) the tines of some one-way gates have curved ends or plastic disks or balls to prevent spiking the animals. However, animals' hoofs and legs may get caught in the open curved ends. Therefore only solid disks or balls at the ends of the tines are now recommended.

Wildlife jump-outs or escape ramps are hills that are positioned in the fenced road corridor and allow animals to walk up the slope and through an opening in the fence. Examples are shown in Figure 2-9b, c, and d. They are now often used as an alternative to one-way gates. The height of the jump-outs should be low enough for the target species to readily jump down to the safe side of the fence. At the same time the jump-outs should be high enough to discourage animals that are on the safe side of the fence to jump up into the fenced road corridor. This implies that finding an optimum height for the target species is important. However, there is very little information available on the appropriate height of jump-outs. The

backing for the wildlife jump-outs has been made out of wooden planks, concrete walls or stacked interlocking concrete stones. In some cases metal sheeting has been attached to the backing to reduce the likelihood of bears climbing up the wall into the fenced road corridor (*122*). Wildlife jump-outs that were about 5 feet high appear to be used much more readily (about 7.9-11.0 times more) by mule deer than one-way gates (*131*). Wildlife jump-outs that were between 5.6-7.9 feet high were used by about 25-60% of the mule deer that appeared on top of the jump-outs, but none or almost none of the white-tailed deer that were present on top of the jump-outs jumped down to safety (*133*). Recommended wildlife jump-out height for mule deer, white-tailed deer and elk is 5.5-6.0 feet (*130*). Others have set the height at 6.5 feet in combination with a horizontal plank that stuck out from the edge (*134*). However, these jump-outs did not function well for mule deer and it was suggested to either remove the horizontal plank or reduce the height of the jump-outs (*134*).

A jump-out can be made to appear higher for animals that may be interested in jumping up into the fenced road corridor and lower for animals that may be interested in jumping down to the safe side of the wildlife fence. The area in front of the backing, on the safe side of the fence, may be dug out in an area up to 5-6 feet from the backing (*130*). The soil may be deposited on the "landing pad" which may start 5-6 feet from the backing. Similarly the top of the jump-out can be made to appear higher by adding soil on top of the jump-out starting about 8 feet away from the edge of the top of the jump-out (*130*). Alternatively, a metal bar or wooden plank may be attached about 18 inches close to the edge of the jump-out (*135*). This still allows animals that are on top to step over the bar or plank before jumping down, while animals wanting to jump up would also have to clear the bar or plank.

(a) One-Way Gate with Curved Tines

(b) Jump Out Escape Ramp

(c) Jump-out (Upper View)

(d) Jump-out (Lower View)
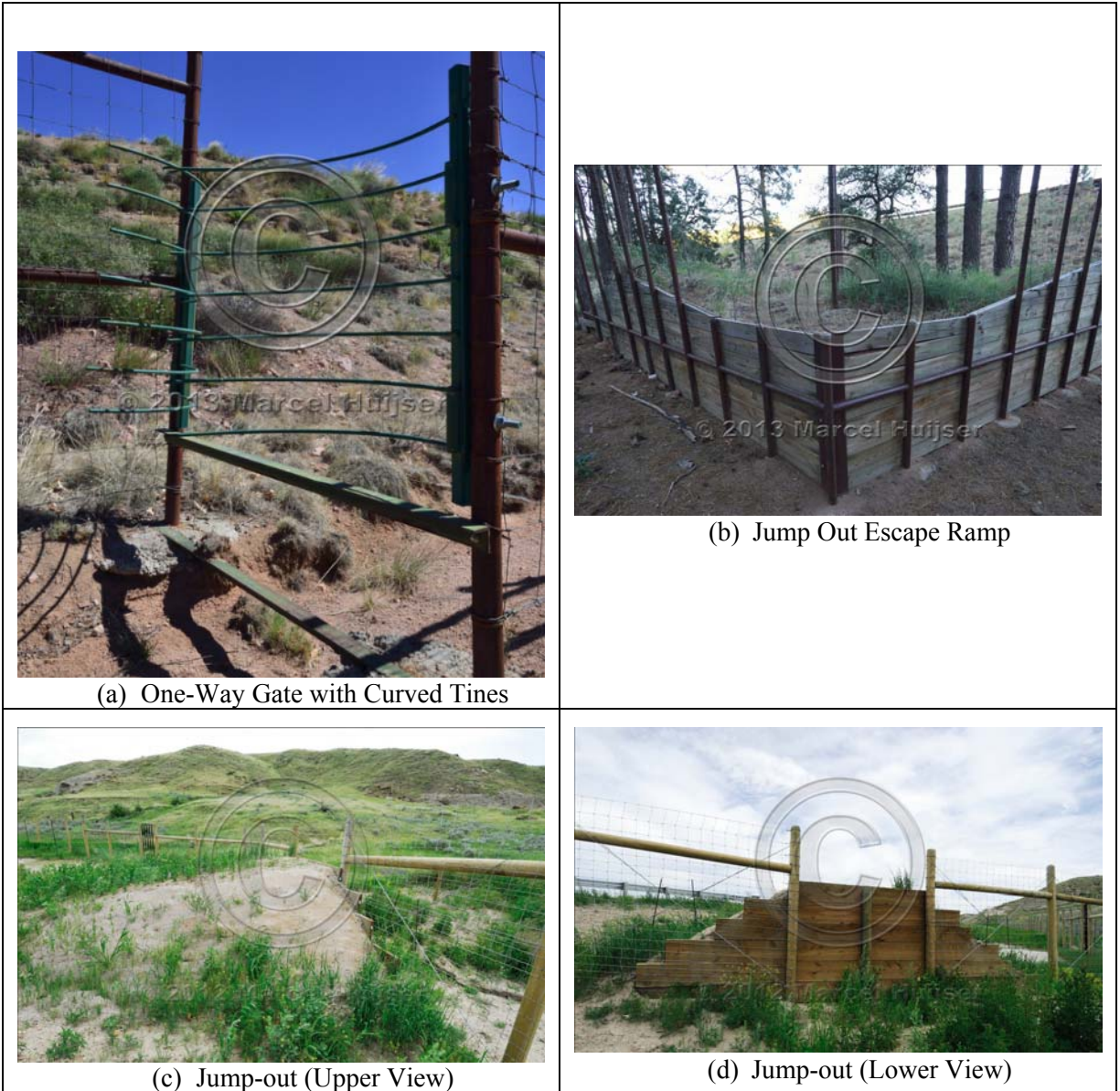
Figure 2-9 Wildlife Escape Mechanisms Used with Fencing

Fence End Treatments

In many cases, a wildlife fence is angled away from the road at a fence end. In some cases the fence angles only slightly away from the road (e.g. 45°) whereas it is 90° (perpendicular) to the road in other cases (*136*). There are also examples where the wildlife fence first angles away from the road at 90° and then bends back another 90° essentially paralleling the main fence for some distance (*136*). The main purpose of having a wildlife fence angle away from the road is to discourage animals from crossing the road at grade at the fence end; it helps avoid a "fence end run" effect.

In some cases, the fence angles towards the road surface at a fence end. The main purpose of having a wildlife fence angle towards the road surface at a fence end is to discourage animals from wandering off into the fenced right-of-way. It does not help avoid a fence end run effect though. Bringing a fence close to the road surface typically results in having the fence and the end post in the "clear zone". The clear zone should be free of obstacles so that drivers whose vehicle has left the paved road surface may still recover and regain control of the vehicle without crashing into large objects. This means that measures must be taken to prevent cars from crashing into the fence or fence end. Guardrail or Jersey barriers can deflect vehicles that have left the roadway at fence ends where the fence end has been brought close to the road surface.

Boulder fields may be used at fence ends between the paved road surface and fence ends, and in the median of a divided highway (*15, 16*). It is an alternative to bringing a fence end close to the paved road surface as boulder fields are believed to discourage wildlife from walking into the fenced road corridor. The suggested size of a boulder field is 165-325 feet measured in road length from the edge of the fence into the fenced right-of-way (*16*). The width of the boulder field (perpendicular to the road) should be equivalent to the distance between the edge of the pavement to the fence. An example is shown in Figure 2-10a.

Modified cattle guards or wildlife guards can be embedded in the road surface at fence ends, as shown in Figure 2-10b. They typically consist of a pit with metal bars or bridge grate material on top. They may extend into the clear zone until they connect with a fence end. They may also be used in combination with fence ends that are close to the road surface or boulder fields. The main purpose of these modified cattle guards or wildlife guards is to discourage wildlife from using the road surface to enter the fenced road corridor. If modified cattle guards or wildlife guards are used at a fence end, the road in which it is embedded typically has a relatively high traffic volume and relatively high traffic speed. This means that a standard cattle guard with large round or flat metal bars may not be suitable or safe (*137*). Modified bridge grate material may be much more suitable and safe for relatively high traffic volumes and high traffic speed (e.g., *138*). Wildlife guards that use modified bridge grate material are also safer for pedestrians and cyclists than standard cattle guards (*137*).

Electric mats at fence ends are embedded in the roadway and discourage animals from entering the fenced road corridor, as shown in Figure 2-10c (*75, 134*). Whenever an animal steps on the electric mat, the animal receives an electric shock. Pedestrians wearing shoes and cyclists will not be shocked when they cross the mat. However, dogs, horses and people without shoes will be exposed to an electric shock (*16*).

Cattle or wildlife guards may also be electrified. Depending on the design, traditional steel wildlife or cattle guards (double wide) can be a substantial barrier to large mammals, sometimes a more substantial barrier than wildlife guards (*139*), but they tend to be a poor barrier to bears (*128*). Electric mats or electrified cattle guards or wildlife guards seem to be a much greater barrier to bears. Fence configuration at electric mats or electrified cattle guards should be similar to that for cattle or wildlife guards.

(a) Boulder Field

(b) Wildlife Grate on Main Road

(c) Electric Mat on Main Road
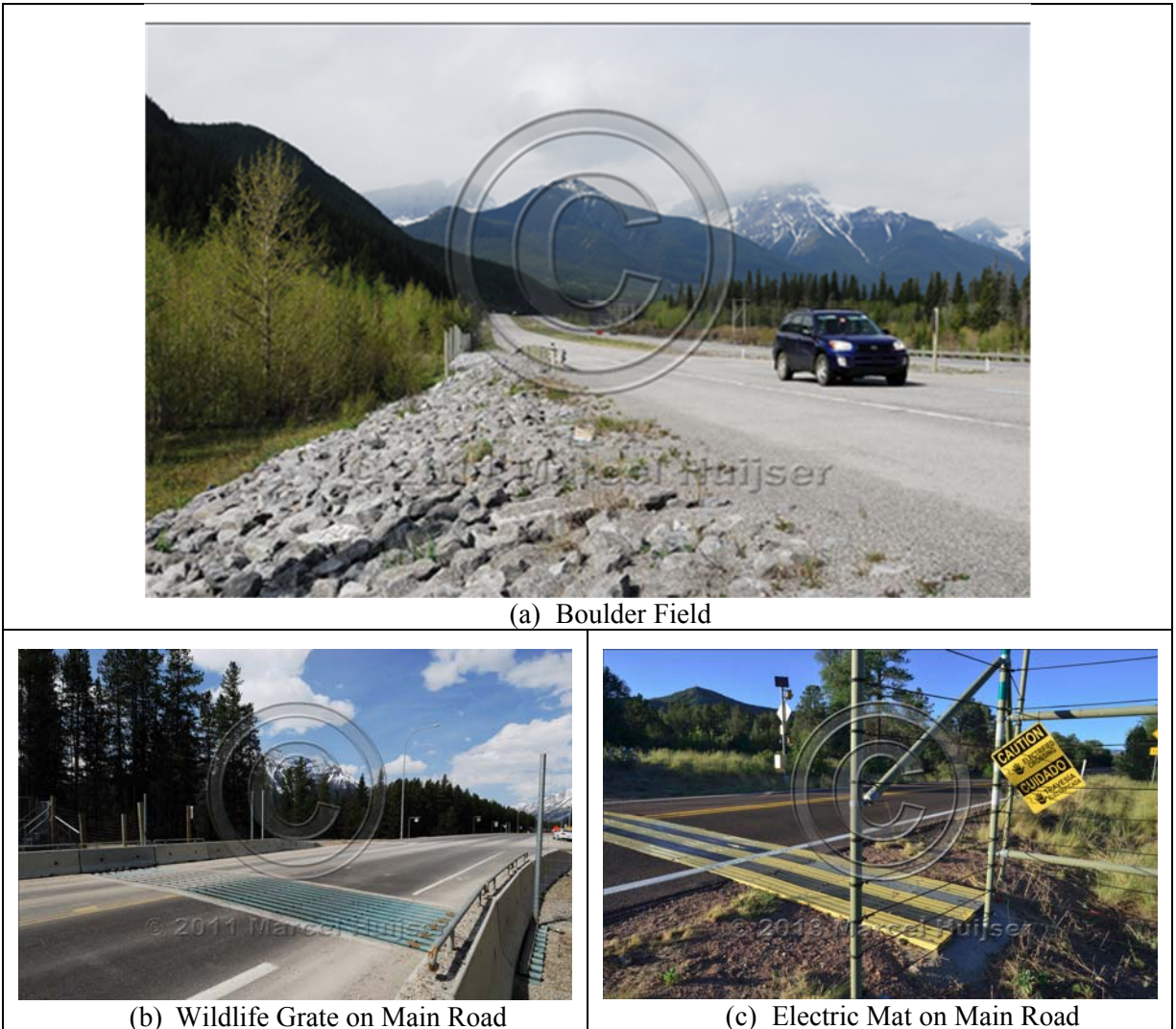
Figure 2-10 Fence End Treatments

2.9. Mitigation Efforts in West Virginia

2.9.1. Standard Deer Crossing Signs

The WVDOT has installed standard deer crossing signs across the state (see Figure 2-1a). Based on documentation provided by WVDOT, there are approximately 144 signs on paved roads, however the actual number is likely higher. The WVDOT policy for the placement of these deer crossing signs (Appendix B) states that one of these conditions be satisfied:

- At least seven deer killed per mile for any one year, or
- At least five deer killed per mile per year for any two year or more period.

2.9.2. Seeding and Planting in Right-of-Way

It has been reported that the WVDOT has experimented with various types of seeding and planting in the right-of-way to affect deer behavior, in consultation with the WVDNR, but the specifics of this testing and whether a formal evaluation was conducted is unknown. At the time of this report, the WVDOT has initiated a research project evaluating various types of seed mixtures and one of the objectives pertains to mixtures and plantings that do not attract deer.

2.9.3. Roadside Reflectors

It has been reported that roadside reflectors have been implemented in West Virginia, but the specifics of the installations and any associated effectiveness testing could not be identified for inclusion in this report.

2.9.4. Wildlife Fencing

When US 33 from I-79 to Elkins, WV was upgraded to a four-lane divided highway in 1991 (from Lorentz to Buckhannon) and 1994 (from Buckhannon to Elkins), fencing that is taller than the normal right-of-way fence height of 3-4 feet was installed along sections of the roadway in an effort to prevent deer from crossing the roadway. This recommendation was a result of a 3-year study initiated on I-79 by the WVDNR in 1974 (*140*). Figure 2-11 illustrates two sections of the fence, which utilized both wood post and metal post with mesh wire. The majority of the fence utilized wood posts. The approximate height of this wildlife fencing ranged from 6-8 feet.

The general location of the wildlife fencing is illustrated on a map in Figure 2-12. The wildlife fencing begins approximately 8.2 miles east of the I-79 interchange (location #1 in Figure 2-12) and continues on both sides of the road for approximately 4.7 miles (location #2). Standard height right-of-way fencing is installed for the next 1.6 miles on both sides of the roadway, likely due to the presence of the interchange with US 119 in Buckhannon. The wildlife fencing was then installed for the next 14.4 miles on both sides of the roadway (location #3 to location #4). The four-lane section of US 33 continues another 12.8 miles toward Elkins with standard right-of-way fencing. There is a break in the wildlife fencing at each access road to US 33 and there were no end treatments utilized at these locations to prevent deer from entering the roadway. There also appear to be no safe crossings for deer installed along this roadway.

The distance from the roadway to the fencing varies significantly and appears to be dictated by the adjacent topography. It is likely that the fencing location was dictated by the right-of-way location rather than effectiveness for preventing deer crossings.

DVC data from police reports were analyzed for this entire segment of US 33 for the period covering 2008-2012. Crash data before installation of the fencing was not available to conduct a before and after study of the effectiveness. A summary of the segment-based analysis is provided in Table 2-9. There were a total of 24 DVCs reported along the entire 41.7 mile segment. Of those, only 3 crashes occurred along the 19.1 miles of wildlife fencing and the other 21 occurred along the 22.6 miles that had no fencing or standard right-of-way fencing. Crash rates for roadway segments are computed using Equation 1 shown below. Average Annual Daily Traffic (AADT) for 2009 and 2012 were obtained from the WVDOT for this roadway segment. The resulting crash rate calculations using Equation 1 indicate that the crash rates on segments without wildlife fencing (rate = 4.8) were six times higher than those segments with wildlife fencing (rate = 0.8).

Equation 1

$$Crash\ Rate = Crashes\ per\ hundred\ million\ vehicle\ miles\ traveled\ (RHMVM)$$

$$\boldsymbol{Crash\ Rate} = \frac{Total\ \#\ of\ Crashes * 10^8}{\#\ of\ Years * Segment\ AADT * Segment\ Length * 365\ ^{days}/_{year}}$$

| (a) Mesh Fencing with Wooden Posts | (b) Mesh Fencing with Metal Posts |
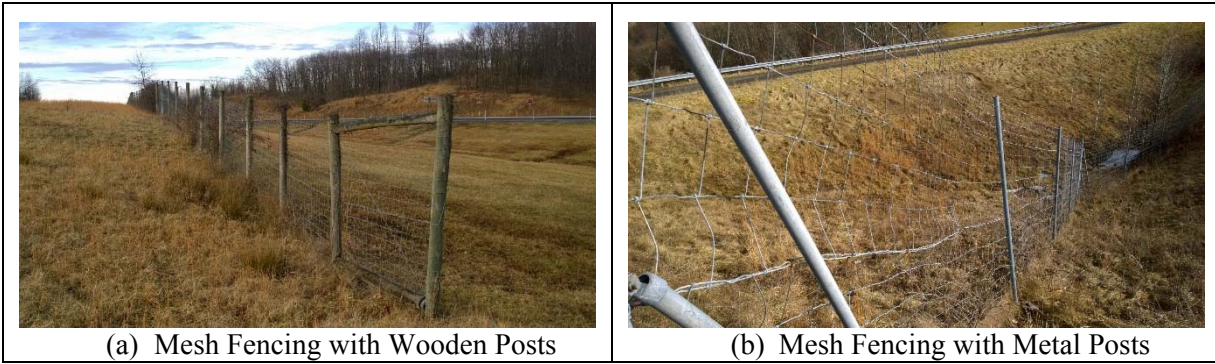
Figure 2-11 Wildlife Fencing Used on US 33 in West Virginia
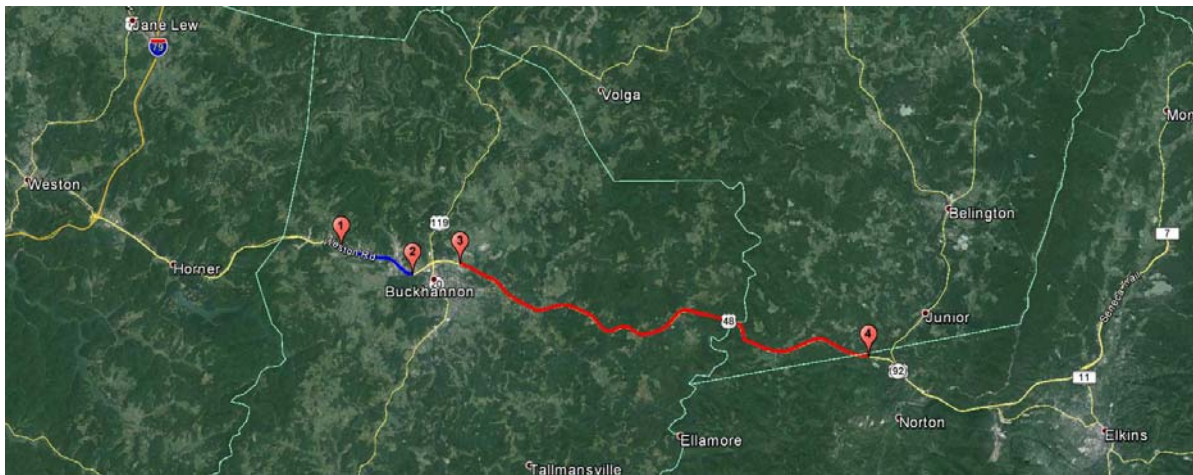
Figure 2-12 Fencing Location on US 33 in West Virginia

Table 2-9 Summary of DVCs on US 33 in West Virginia (2008-2012)

Segment	Fencing	Length	# of DVC Reported	AADT (veh/day)	Crash Rate (per HMVM)
I-79 to #1	None	8.2 miles	15	14,000 (2009)	7.2
#1 to #2	Wildlife ~	4.7 miles	2	14,000 (2009)	1.7
#2 to #3	Standard R/W height	1.6 miles	2	12,507 (2009, 2012)	5.5
#3 to #4	Wildlife ~	14.4 miles	1	9,731 (2012)	0.4
#4 to Elkins	None	12.8 miles	4	8,245 (2012)	2.1
Totals	With Wildlife Fencing No Wildlife Fencing	19.1 miles 22.6 miles	3 24		0.8 4.8

2.10.   Mitigation Efforts in Surrounding States

2.10.1. Interview Overview

Phone interviews were conducted with representatives from the transportation agencies and natural resource management agencies in the five states bordering West Virginia – Pennsylvania, Maryland, Virginia, Kentucky, and Ohio. The purpose of these phone interviews was to document any policies and practices of the agencies with regard to addressing DVCs in their state. It was anticipated that the results may help formulate new policies and practices for DVCs in West Virginia. The questions utilized to steer the discussion during the phone interview are listed below.

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?
2. If yes,
   a. What are they?
   b. How is their implementation location identified?
   c. Does implementation take place on a project-by-project basis or are the practices incorporated into all highway projects?
   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?
   e. How are these efforts funded and who provided funding?
   f. Has the effectiveness of the mitigation efforts been quantified or deemed successful/unsuccessful?
3. If no,
   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?
   b. Is the lack of implementation due to funding? Or are deer-vehicle collisions perceived as minor problem?
4. Does your agency have a structural working relationship with either the transportation agency or natural resource management agency in your state with regard to deer-vehicle collisions?

2.10.2. Interview Results – Transportation Agencies

Below is a general discussion of the findings from the interviews with the surrounding states' transportation agencies. The responses from each agency for each question are provided in Appendix C.

- Data Usage. DOTs typically use crash data, including DVCs, to identify and prioritize road sections that may require mitigation measures to increase human safety. Maryland and Kentucky also stated carcass removal data are included in the analyses. The identification and prioritization of road sections that require mitigation is often conducted by individual districts of the transportation agency.

- Mitigation Measures Used. Mitigation measures implemented include standard deer warning signs, deer fencing in combination with wildlife underpasses, retrofitting of existing culverts or bridges, making culverts and bridges that need to be built for other purposes wider so that they are better suitable for wildlife, animal detection systems, public safety messages (especially during the deer rut), mowing of right-of-way vegetation, seeding of non-attractive plant species, clearing of shrubs and trees to increase visibility of deer to drivers, scent treatment of vegetation in right-of-way as a deterrent to deer, and deer size population reduction programs (typically initiated by the natural resource management agency or local government or landowners). While not part of the survey, specific mitigation measures (fencing, dynamic message signs) have been discussed and/or implemented for elk in certain areas.

- Mitigation Locations. While there may be differences between individual districts, crash data analyses for all types of crashes are conducted on a regular basis as part of the Highway Safety Improvement Program (HSIP), and this process can be considered standard. However, DVCs are analyzed along with other crash types.

- Mitigation Funding/Programming. If certain crash or carcass thresholds are met or exceeded, deer warning signs may be installed, regardless of road (re)construction. This is typically funded through operation and maintenance funds. Retrofitting of existing culverts and bridges, including wildlife fencing may also take place without major road (re)construction. However, new structures, both for wildlife only and multifunctional structures are typically only constructed if there is major highway (re)construction, and these measures are therefore typically tied to a specific project. Structures are typically funded out of federal highway (re)construction funds.

- Mitigation Effectiveness. The effectiveness of mitigation measures in terms of reducing DVCs is typically not investigated. In most cases it appears monitoring or investigating of the measures are not included in the work scope. In other cases the data quality of the crash and carcass data (including spatial accuracy) is in doubt. In some cases, wildlife use of multifunctional culverts and bridges is monitored.

- Problem Perception. In general, DVCs are seen as a problem that requires mitigation, however the problem seems to be a lower priority for the agencies than other crash safety priorities. Some states are considering making modifications to the data analyses for identification and

prioritization of road sections that may require mitigation so that DVCs are not filtered out as much. A different approach to funding is required, as maintenance funds are clearly insufficient to implement mitigation measures that are most effective and robust in reducing DVCs (e.g. wildlife fencing in combination with underpasses and overpasses, animal detection systems).

- Coordination. Most transportation agencies do not coordinate with natural resource management agencies about DVCs and potential mitigation measures aimed at reducing these collisions. However, some transportation agencies do consult with natural resource management personnel, especially during the design phase, but is on a project-by-project basis. When wildlife fencing is proposed some natural resource management agencies stress that this should only be implemented if safe wildlife crossing opportunities are an integral part of the mitigation measures. There seems to be no process for general coordination between a transportation agency and a natural resource management agency on a regular basis.

2.10.3. Interview Results – Natural Resources Management Agencies

Below is a general discussion of the findings from the interviews with the surrounding states' natural resource management agencies. The responses from each agency for each question are provided in Appendix D.

- Data Usage. Natural resource management agencies use harvest (kill) data as an indicator of deer population size. The relative population size index is typically calculated by county or district, and if the deer population size seems higher than desired, the number of hunting tags, specifically doe tags, is increased. Some natural resource management agencies also include agricultural damage, opinions from farmers, and DVC and carcass data in their analyses that precedes setting the hunting quota. Pennsylvania even uses a more general survey about human-wildlife conflicts, and Virginia manages the deer towards what is considered the "social carrying capacity". In Ohio, deer crash report data are now considered less reliable indicators of deer population size since a crash report is no longer required by insurance agencies.

- Mitigation Measures Used. Natural resource management agencies can help reduce DVCs in certain areas through increasing the hunting quota and thus reducing deer population size. Natural resource management agencies are typically not directly involved with roadside mitigation measures. Natural resource management agencies mostly rely on public hunting. In some cases managed hunts (more oversight of public hunters) and sharpshooting (by professionals) are also used. Virginia issues kill permits to farmers and law enforcement personnel. Some states have a public message campaign during the deer rut alerting drivers of the higher risk for DVCs.

- Mitigation Funding. Funding for general deer management is provided through the fees for hunting tags and the Pittman-Robertson Act. Sharpshooting, though relatively rare, is typically paid for by other entities (county, city, home owner association).

- Mitigation Effectiveness. While it may take several years, increased hunting pressure on deer is generally believed to result in reduced deer population size and reduced DVCs (as well as other human-deer conflicts). Better data are available from smaller areas (e.g. a state park). Deer population size reduction is problematic in areas where there is little access for hunters (e.g., inside city limits). This results in refuge for the deer.

- Problem Perception. Access for hunters (the public) and dropping hunter numbers are a major concern for some states as they mostly rely on public hunting to stabilize or reduce deer population size.

- Coordination. Coordination with transportation agencies is typically on a project basis only.

2.10.4. Discussion of Interview Results

Crash data only represent a fraction of the total number of accidents that occur, and they are likely biased towards the most severe crashes that include substantial vehicle damage, human injuries, and human fatalities. This is especially true for DVCs. Thus most DVCs do not end up in the crash database. Carcass removal data capture more of the DVCs that occur, but if the animal is removed (legally or illegally), if the injured animal leaves the road and right-of-way, or if the incident does not result in a crash report, no data on the accident are recorded. This is despite the fact that vehicle repair costs are likely still involved. Thus, analyses that only include crash data probably include the crashes with the highest risk for human injuries and fatalities, but they disproportionally ignore crash types that mostly only result in vehicle repair costs. Analyses based on crash data are primarily based on human safety, and only secondary on costs or cost-benefit analyses for mitigation measures. Analyses that (also) include carcass removal data probably allow for better estimates of costs and more realistic cost-benefit analyses.

Not all of the mitigation measures implemented are likely to substantially reduce DVCs. Most notably, standard or enhanced wildlife warning signs, public safety messages, and scent treatment of vegetation in right-of-way as a deterrent to deer, are all unlikely to reduce DVCs. On the other hand there is evidence that deer fencing in combination with wildlife underpasses, retrofitting of existing culverts or bridges, making culverts and bridges that need to be built for other purposes wider so that they are better suitable for wildlife can help to substantially reduce DVCs. Mowing of right-of-way vegetation, seeding of non-attractive plant species, and clearing of shrubs and trees to increase visibility of deer to drivers can reduce

DVCs, but the reduction may not be substantial and somewhat unpredictable. For example, frequent mowing can also lead to increased regrowth which may be especially attractive to deer. Animal detection system projects have a relatively high risk of failure because of technological challenges as well as management problems. Deer size population reduction programs can also be effective, but they are more likely to be effective if the deer population is relatively small and isolated. Access for hunters and a high level of hunting effort are essential. Most likely deer population size reduction programs have to be repeated every few years.

The quality of the crash and carcass data can be improved by entering data in the field (e.g. pocket PC, app on cell phone), especially if those devices are equipped with a GPS.

Funding for mitigation measures that are most effective and robust in reducing DVCs (e.g. wildlife fencing in combination with underpasses and overpasses, animal detection systems) cannot come from the current operation and maintenance budgets. Currently, most of the effective mitigation relies on federal funding.

Natural resource management agencies typically only increase hunting pressure in areas where deer population is considered too high. Hunting by the public is by far the main measure. Sharpshooting by professionals occurs occasionally, though the initiative and funding tends to come from others.

Deer population size reduction can result in fewer DVCs, though it may be most effective in distinct and relatively small areas.

The activity of natural resource management agencies has no particular funding problems, but their effectiveness is threatened by the lack of access for hunters in certain areas (private land), and by a decline in hunters.

2.10.5. <u>Interview Conclusion</u>

Based on the interviews conducted, it appears that the efforts that have been undertaken in West Virginia related to DVC are consistent with the surrounding states that are also dealing specifically with white-tailed deer. No new mitigation measures were identified through the interviews with states surrounding West Virginia that have not already been discussed in the literature review. It appears that the role of natural resource management agencies is to control deer population size through public hunting. The

implementation of roadside mitigation measures depends on transportation agencies. While general crash data analyses are standard to identify and prioritize road sections that may require mitigation, DVCs do not rank as a high priority because relatively few of these collisions result in human injuries and fatalities. DVCs would be better represented in the analyses if they also included vehicle repair costs, or more fundamentally, also included deer carcass removal data to account for under-reporting. This would then lead to more recognition of the DVC problem and the associated allocation of funding. However, it would involve a shift from primarily human injuries and fatalities to a more general monetary analysis. Some agencies are considering modifying their analysis process to allow for more emphasis on DVCs.

The funding of effective mitigation measures currently comes from federal sources, and implementation of these mitigation measures is typically restricted to (re)construction projects. Funding of roadside based mitigation measures is currently regarded as insufficient.

In general there seems to be no high level coordination between transportation agencies and natural resource management agencies. Better coordination may lead to more population size reduction efforts through hunting in areas with high DVC numbers. It may also lead to a shift to more effective mitigation measures as wildlife managers may be better informed about wildlife behavior and management tools than most engineers.

2.11.   Mitigation Recommendations for West Virginia

While dozens of mitigation measures and combinations of mitigation measures have been described elsewhere (e.g. *15, 28, 122*), the previous sections listed the measures that are implemented most often or that the researchers consider most effective. In this section, the researchers recommend the measures that are most effective in reducing collisions, most robust in terms of low maintenance effort and predictable outcome with regard to DVC reduction, and those that there is not much information for but appear promising.

The recommended mitigation measures for consideration in West Virginia are summarized in Table 2-10 (for modifying driver behavior) and Table 2-11 (for modifying deer behavior). Note that many of the mitigation measures are not considered robust in terms of a predictable reduction in DVCs based on previous studies. In addition, only a few measures provide safe crossing opportunities for wildlife. The annualized costs in Table 2-10 and Table 2-11 are based on estimates of the installation costs, maintenance costs, and removal costs at the end of the assumed life span. Each mitigation has a different

assumed life span, but the analysis period for all mitigation was set to 75 years, which resulted in many mitigation types being replaced. For example, wildlife fencing only uses an assumed installation cost of $154,460/mile (fence installed on both sides of the road), maintenance of $805/mile, and removal cost of $16,010/mile. The life span of the fencing was assumed to be 25 years, which results in an annualized cost of $10,145/mile/year.

The researchers consider wildlife fencing in combination with wildlife underpasses and overpasses the most robust mitigation measure. As long as relatively long road sections are mitigated ($\geq$3 mi), DVCs can be expected to be reduced by at least 80%. Animal detection systems also have the potential to reduce DVCs substantially, but many projects suffer from technical and management problems. In addition, the effectiveness of animal detection systems in reducing DVC is less predictable than the effectiveness of wildlife fencing in combination with wildlife underpasses and overpasses.

Wildlife fencing in combination with wildlife underpasses and wildlife overpasses and animal detection systems are also relatively costly. These types of measures may only be implemented at a select few road sections. Therefore, it appears justified to experiment with less robust and more experimental measures that can be implemented over much greater road lengths because their costs are likely relatively low. However, reduction of night time speed limit to 45-55 mph and wider striping (appearance of narrower travel lanes) may or may not actually be effective in reducing DVCs, and if they are, they may not be as effective as the wildlife fencing in combination with wildlife underpasses, overpasses, or animal detection systems. Similarly, roadway lighting may or may not be effective in reducing DVCs. Costs for roadway lighting are likely higher than reduced night time speed limits or wider lines, and there are likely negative side effects of roadway lighting (increase barrier effect of the transportation corridor for wildlife).

Planting or seeding native species in the right-of-way that have relatively low productivity and low nutritional value is a good practice. However, the reality is often that other species, including highly productive species with high nutritional value colonize the right-of-way on their own. This may negate any effect of this measure on DVC reduction.

Direct killing of deer may be considered in specific areas if other measures are not an option and the population is small and isolated. Implementation is most often in a suburban setting with the killing done by professional sharpshooters or public archery controlled hunts. If implemented, direct killing of deer needs to be accompanied with substantial outreach to the public.

Although studies have shown that seasonal signage can be somewhat effective at reducing WVCs (including DVCs), these installations were used at locations that experience migratory movement of certain species. White-tailed deer in West Virginia are not considered migratory and therefore the specificity in time and location of their crossings are not conducive to this type of mitigation. Therefore, seasonal signage is not recommended by the researchers as a mitigation measure that is likely to be effective in West Virginia.

All mitigation measures cost money, but if mitigation measures are effective in reducing collisions with large mammals, or reducing the severity of a collision, then they can pay for themselves (*2*). An average DVC was estimated to cost about $6,717, including vehicle repair costs and the costs associated with the occasional human injury and fatality (*2*). Of course, it is most advantageous if a mitigation measure is highly effective in reducing DVCs and it is also inexpensive. Huijser et al. 2009 conducted extensive analyses that showed how much money different types and combinations of mitigation measures had to earn through reducing collisions with large mammals in order to pay for themselves. While lower dollar amounts appear advantageous, the ultimate cost-effectiveness also needs to take the effectiveness of the measure into account in reducing large mammal-vehicle collisions. The researchers refer to Huijser et al. (*2*) for details of the cost-benefit analyses.

Table 2-10 Recommended Mitigation for WV Intended to Modify Driver Behavior (*2*)

Mitigation Measure	Estimated DVC Reduction	Robustness	Safe Wildlife Crossing Opportunity	Annualized Cost[a] ($/mi/yr)	Source(s)
Night time speed limit reduction (≤45-55 mph)	30%?	Uncertain. More data needed.	No	Unknown, but costs are very low for signs. Enforcement is likely most expensive component.	(*57*)
Wider striping, narrower lanes	?	Uncertain. More data needed.	No	Unknown, but incremental costs are likely relatively low when installed during routine re-striping.	(*58*)
Animal detection systems (most appropriate for roads with ≤10,000 vehicles per day)	33-97%	No. Many deployments fail because of technical or management problems. Nonetheless, systems that are installed successfully can detect large mammals reliably and can reduce deer-vehicle collisions.	Somewhat (drivers have been warned).	~$60,000	(*2, 71, 72, 73, 74, 75, 76, 77*)
Roadway lighting (be careful with negative side effects on wildlife)	65%?	No, more data are needed.	Somewhat (drivers can better see the animals)	Installation and operating costs for the lights are likely moderately expensive	(*90*)

[a] Includes installation cost, annual maintenance, and disposal cost converted to an annual cost over an assumed life cycle using a 3% discount rate.

Table 2-11 Recommended Mitigation for WV Intended to Modify Deer Behavior

Mitigation Measure	Estimated DVC Reduction	Robustness	Safe Wildlife Crossing Opportunity	Annualized Cost[a] ($/mi/yr)	Source(s)
Plant or seed native species in R/W that have low productivity and low nutritional quality	?	Uncertain. More data needed.	No	Costs are likely relatively low (seeding).	
Direct killing of deer by professionals or public hunts (if other measures are not an option and the population is small and isolated; only in very specific situation and needs to have outreach)	30-50%?	Uncertain. More data needed.	No	~$5,000 (if done by professionals)	(2, 120)
Wildlife fencing	79-97%	Yes, if implemented over relatively long distances (e.g. ≥3 mi)	No	~$10,145[b]	(2, 123, 124, 125, 126, 127)
Wildlife fencing in combination with jump-outs, gap in fence and traffic calming and standard or enhanced warning signs.	37-43%	Uncertain. More data needed.	Somewhat (drivers are warning at a specific location and vehicle speed may be lower at the crossing)	~$16,280	(2, 69)
Wildlife fencing in combination with jump-outs, underpasses, and/or overpasses	79-97%	Yes, if implemented over relatively long distances (e.g. ≥3 mi)	Yes	~$29,000-$39,000	(2, 123, 124, 125, 126, 127)
Wildlife fencing in combination with jump-outs, at grade crossing opportunity (gap in fence) with animal detection system.	33-97%	No. Many deployments fail because of technical or 59gmt. problems.	Somewhat (drivers have been warned).	~$45,300	(2, 71, 72, 73, 74, 75, 76, 77)

[a] Includes installation cost, annual maintenance, and disposal cost converted to an annual cost over an assumed life cycle using a 3% discount rate.

[b] Based on installation cost of $154,460/mile, maintenance cost of $805/mile, removal cost of $16,010/mile and a 25-year life span.

3. NATIONAL DEER-VEHICLE COLLISION STATISTICS

3.1. Overview

This section of the report addresses the following objective of the study.

6. Evaluate national reports on DVC ranking methods and the statistics used for validity.

In addition to the national comparison, it was also desirable to compare DVCs to states near West Virginia since white-tailed deer are more prominent in the Appalachian region compared to other parts of the United States. The regional analysis also allows for more detailed data to be obtained for comparison that might not be available at a national level.

The national and regional comparisons are based on a 3-year summary of available data. However, due to inconsistencies in agencies' data reporting, not all comparisons cover the same period. The variability and availability of this data was the controlling factor for what years could be analyzed. Several types of data were investigated for use in normalizing the count data to adjust for differences in state-to-state characteristics that could influence the DVC counts.

3.2. Computation of Deer-Vehicle Collision Rates on a State-by-State Basis

Statewide DVC rate calculations on a national or regional level have been based on an estimate of the total number of deer vehicle collisions divided by a measure that is intended to "normalize" the data and hopefully account for factors that might cause there to be a true variation from state-to-state. Currently, the only national level comparisons are conducted by State Farm Insurance and the Insurance Institute for Highway Safety. Both studies currently use the number of licensed drivers in a state as the measure for normalization. State Farm Insurance previously used the number of registered vehicles in the state for normalization but changed starting with the 2010 report.

It is important to note that it is not feasible to calculate a valid and reliable rate for state level comparison or ranking purposes because there are numerous factors that affect the frequency of DVCs (see discussion in Section 2 of this report) and data on all of those microscopic factors is not available across multiple states to facilitate a macroscopic comparison. An example of a factor that would seem important is deer population or deer density. Most states do not estimate deer populations or densities and the states that do produce them use a variety of methods and inputs, including deer harvest numbers, sampling observations, and DVC counts (*141*).

3.2.1. Data used for Estimating Statewide Deer-Vehicle Collisions (Numerator)

The primary source of national DVC data that was utilized was the annual estimates produced by State Farm Insurance. At the time of this study, only data from 2008-09, 2010-11, 2011-12, and 2012-13 were available. The data was obtained from an annual report were they perform their own DVC risk analysis. Their analysis consisted of normalizing estimated DVC data by registered vehicles for 2008-09 and by licensed drivers for subsequent years. Some drawbacks to using insurance claims for DVC estimates are their restriction to only vehicles with comprehensive insurance and the presence of false claims. State Farm estimates DVC based on their insurance claims with an adjustment to account for their market share in each state relative to other insurance carriers. Their estimates are also based on the state in which the insured individual resides, not in the state where the crash was reported. Therefore, an Ohio resident that hits a deer in West Virginia will be accounted for in Ohio's estimate.

3.2.2. Data used for Normalization (Denominator)

For this analysis, data sources were sought that are available on a national and regional level and might provide a logical normalized calculation. Since there were no sources of deer population or density data available on a national level, the data were all related to the transportation system, land area, population, and drivers. As noted previously, the annual State Farm Insurance report currently utilizes the number of licensed drivers in the state. The following national and regional sources of data were obtained and utilized in this analysis:

- National Level
  - Land area (square miles) obtained from US Census Bureau
  - Vehicle Miles Traveled (VMT) obtained from Federal Highway Administration
  - Roadway miles (by centerline and by lane) obtained from Federal Highway Administration
  - Number of licensed drivers obtained from Federal Highway Administration
  - Number of registered vehicles obtained from Federal Highway Administration
- Regional Level
  - Number of total crashes reported
  - Estimates of the number of deer harvested

Additionally, the national level data were subdivided into rural and urban estimates. Statistics that are based on overall population, drivers, and vehicles can be significantly skewed for states with large urban

areas, where much of the population may not leave the city and wouldn't be a direct indicator of driver exposure to DVCs. For example, the population in the state of West Virginia was just above 1,850,000 in 2012, with the largest city being Charleston with 51,400 people. By comparison, Ohio had a total population of 11,570,000 in 2012 with the largest city being Columbus with almost 810,000 people. If the large urban areas are removed from the statistics, the researchers believe that a more valid comparison could be derived. The United States Census Bureau defines both urban and rural areas on a national level. Urban areas are defined as areas that encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters (e.g., prison, nursing homes, and juvenile institutions). Rural areas encompass all population, housing, and territory not included within an urban area.

Data regarding the total number of crashes in each state could not be located at the national level. However, it was located on a regional level from individual states. This data was used to give insight into how the DVC estimates (from State Farm) compared to the total number of reported crashes. Each state has different crash reporting criteria, so this may not be an ideal data source, but provides an interesting comparison.

Deer harvest data was used as a surrogate for deer population estimates because population estimates were difficult to consistently find. However, upon further investigation of how harvest data was collected, it was determined that the information could not be used to accurately compare states because the methods for collecting harvest data varied between states too much. According the Southeastern Deer Study Group, different methods of data collection include check stations, mail surveys, jawbone collection, computer models, telephone surveys, and telechecks (*141*). Each state included in this study group uses a different combination of these methods to collect harvest data, making the data inconsistent. It was unfortunate that deer harvests or populations were not consistent enough for analysis because DVCs are obviously greatly affected by the number of deer present in a state.

3.3. <u>State Comparisons on a National Level</u>

The main purpose of the national review was to compare West Virginia to the rest of the continental United States regarding DVC rates. To ensure an effective comparison, the DVC estimates were normalized by multiple data inputs such as land area, VMT, roadway mileage, licensed drivers, and registered vehicles. Additionally, since DVCs primarily occur in rural areas, it was considered that normalizing DVC data using rural components may be a more accurate method. Therefore, most data inputs used for normalization were further divided into rural and urban components for this detailed

analysis. Using a variety of inputs to normalize the DVC data allowed for alternative comparisons of West Virginia to other states.

3.3.1. Total Estimated Deer-Vehicle Collisions

The first row in Table 3-1 shows how West Virginia ranked nationally regarding total DVC count. DVC estimates remained relatively constant in the United States over the 2008-2013 period analyzed. A 1.5% decrease occurred from 2008-09 to 2010-11, followed by a 7.7% increase from 2010-11 to 2011-12, and a 1.2% decrease from 2011-12 to 2012-13. This averages out to a 1.7% increase over the period of 2008 to 2013. Most states experienced minimal change over this period. However, West Virginia saw a larger fluctuation. From 2008-09 to 2010-11, DVC estimates decreased 23% and then increased 9% from 2010-11 to 2011-12 and decreased again 4% from 2011-12 to 2012-13, resulting in an average decrease of 6% over the 2008 to 2013 period. Therefore, a national increase or decrease is not necessarily representative of each state's trends.

Figure 3-1 illustrates the DVC estimates for each state in the 2012-13 period. The same maps for the other years are located in Appendix E. In terms of total DVC estimates, Pennsylvania ranked first every year, followed by Michigan in second. West Virginia ranked 11th, 17th, 16th, and 17th in 2008-09, 2010-11, 2011-12, and 2012-13, respectively.
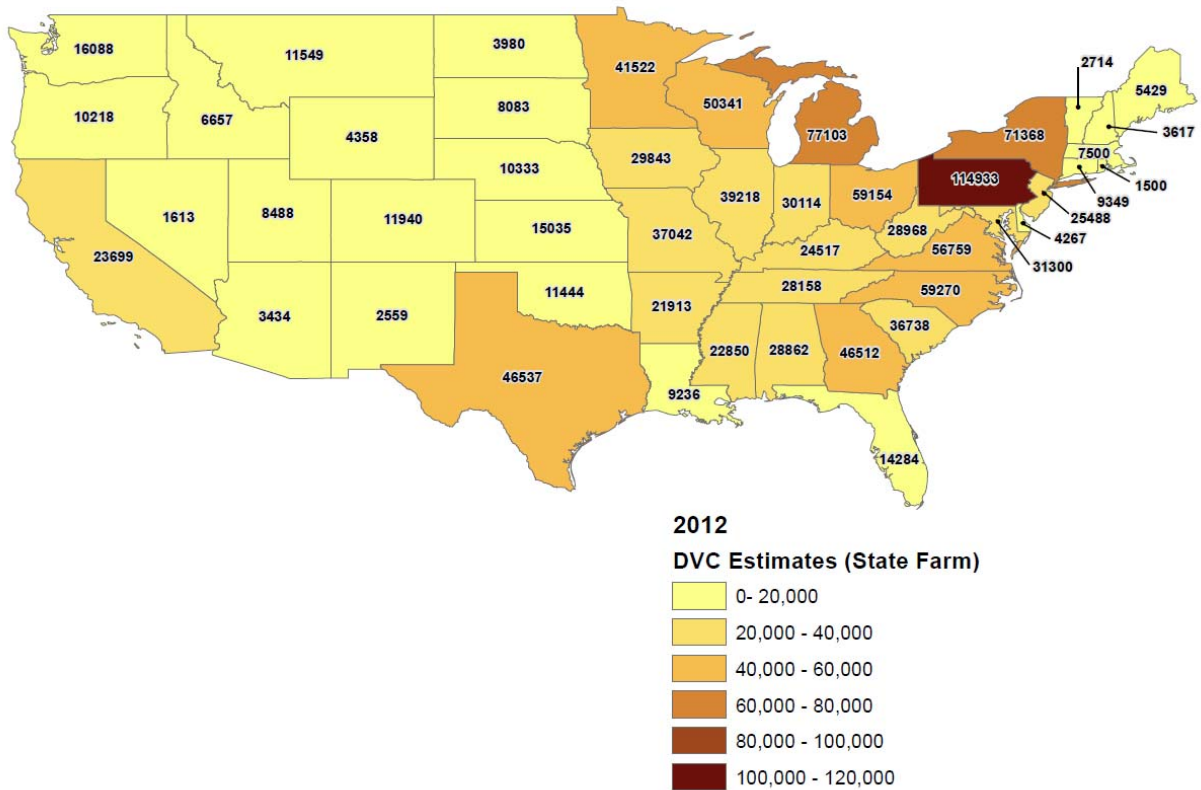
Figure 3-1 State Farm DVC Estimate by State (2012-13)

3.3.2. Normalized Deer-Vehicle Collisions

Table 3-1 contains a summary of West Virginia's national rank based on each normalization type. Figure 3-2 through Figure 3-8 contain the national maps for each normalization for 2012-13. The same maps for 2008-09, 2010-11, and 2011-12 are provided in Appendix E along with the maps illustrating the values of the variables used for normalization.

Analysis of the normalized DVC rates supported that West Virginia drivers are at a high risk of colliding with deer compared to other states. When comparing the state totals (i.e., both rural and urban), West Virginia was consistently ranked very high with an average ranking of 1.8. West Virginia ranked 1st every year when using total licensed drivers, VMT, and registered vehicles. However, based on the rural portion of the normalization measures, West Virginia had an average ranking of 7.2.

Since vehicle miles traveled is a true measure of driver exposure, this would be the most logical measure to use. However, this measure is the least precise among the normalizing measures because these are

estimates derived by the FHWA from AADT and other data and may not accurately account for roadways where data collection is sparse.

Table 3-1 Summary of West Virginia DVC Rankings by Normalization Measure

		2008-09	2010-11	2011-12	2012-13	
Number of DVC Claims	Total	11th	17th	16th	17th	(Figure 3-1)
Per Registered Vehicle	Total	1st	1st	1st	1st	(Figure 3-2)
Per Square Mile Area	Total	11th	12th	11th	11th	
	Rural	11th	12th	12th	12th	
Per Licensed Driver	Total	1st	1st	1st	1st	(Figure 3-3)
	Rural	6th	7th	7th	6th	(Figure 3-4)
Per Roadway Mileage	Total	2nd	4th	6th	4th	(Figure 3-5)
	Rural	10th	11th	11th	11th	(Figure 3-6)
Per Vehicle Miles Traveled	Total	1st	1st	1st	1st	(Figure 3-7)
	Rural	3rd	6th	4th	3rd	(Figure 3-8)
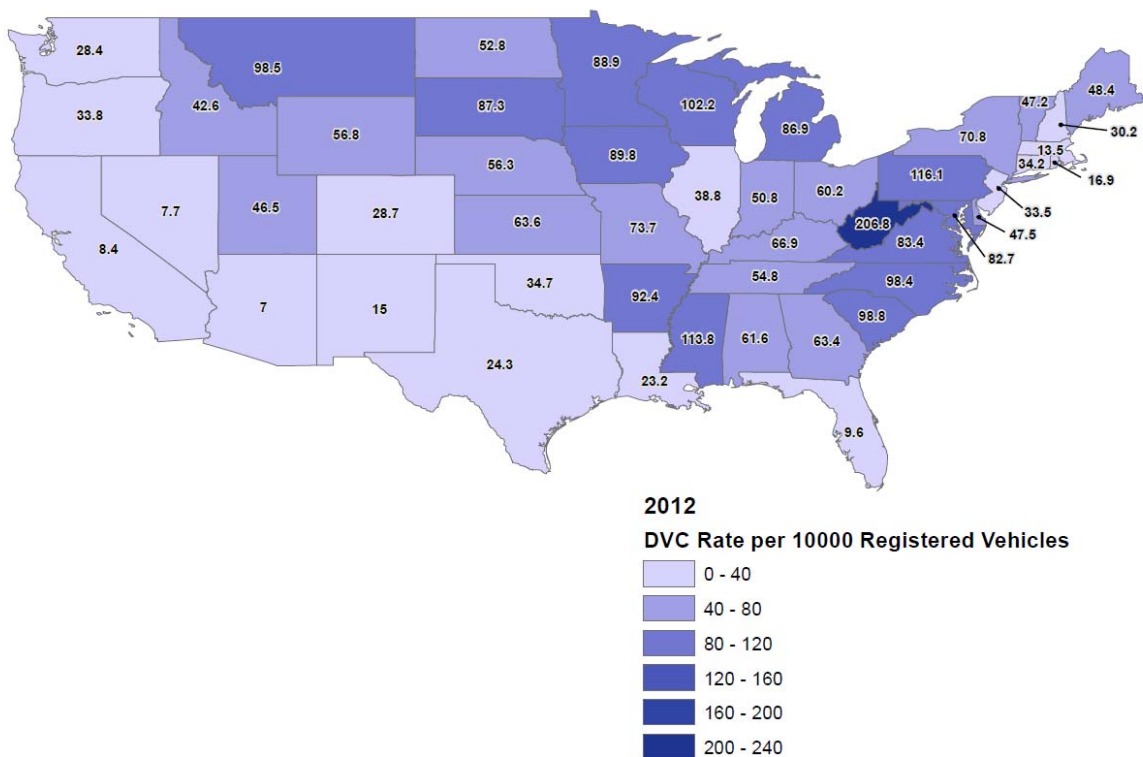
Figure 3-2 State Farm DVC Estimate per 10,000 Registered Vehicles (2012-13)
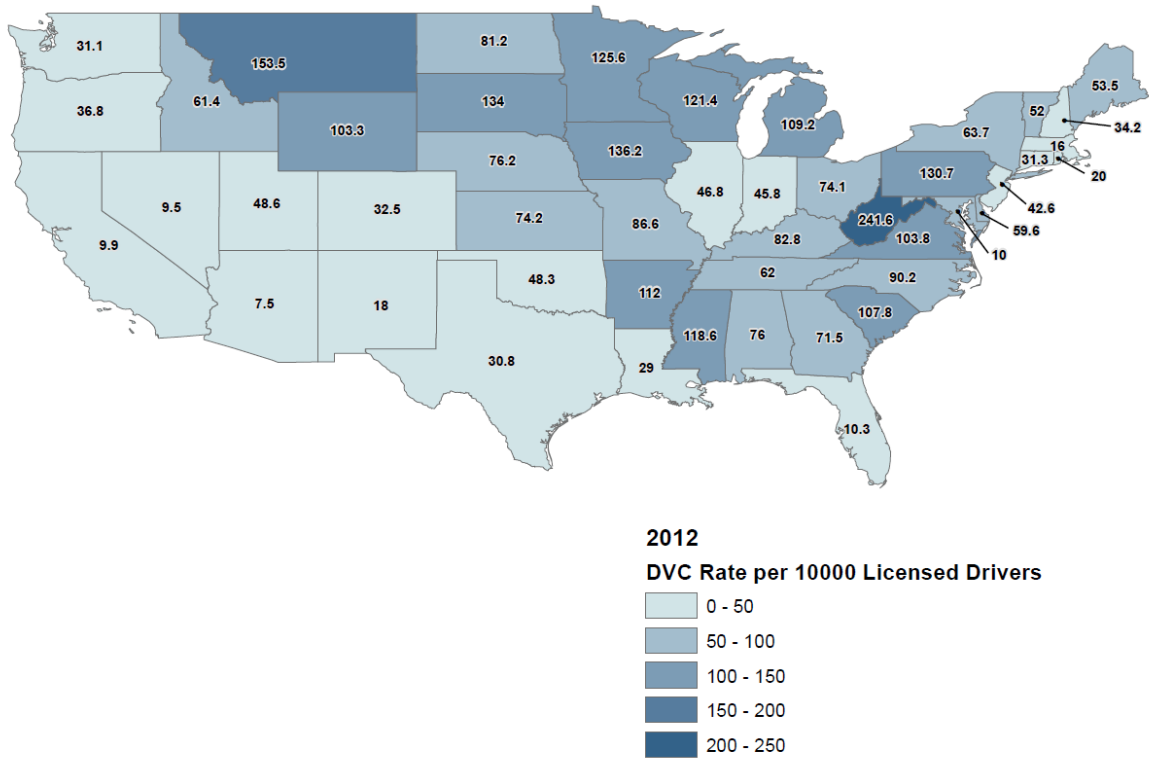
Figure 3-3 State Farm DVC Estimate per 10,000 Licensed Drivers (2012-13)
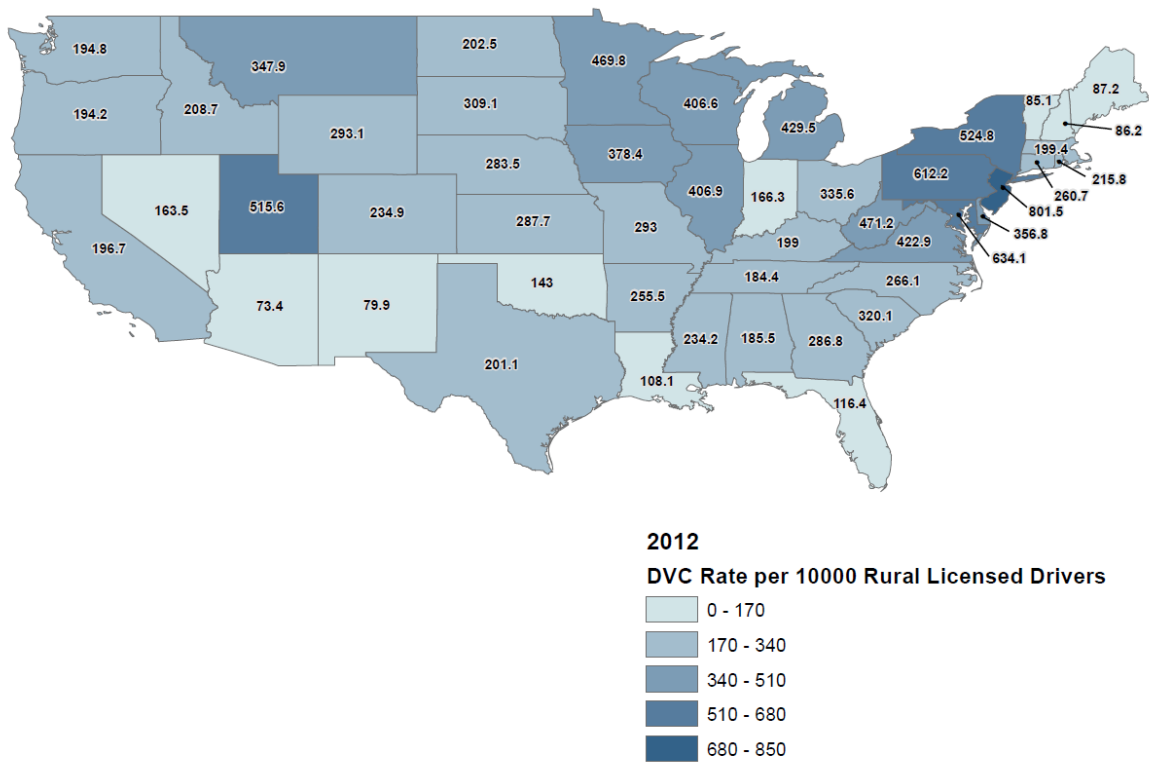
Figure 3-4 State Farm DVC Estimate per 10,000 Rural Licensed Drivers (2012-13)
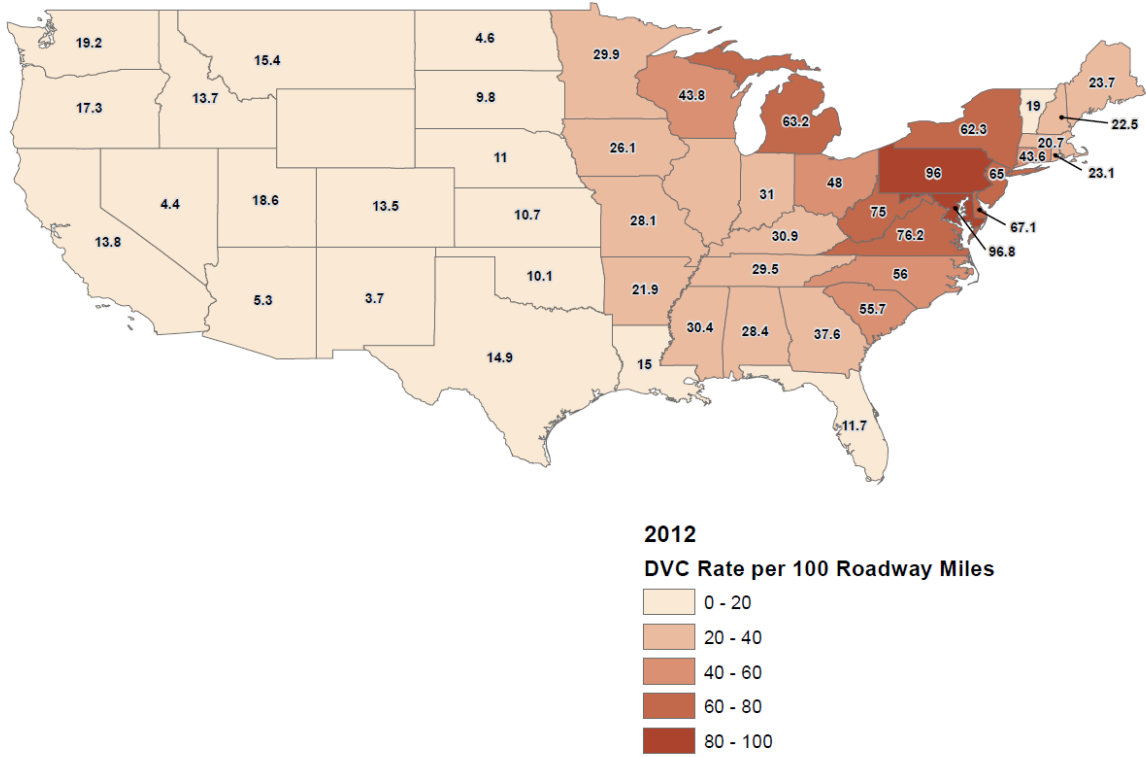
Figure 3-5 State Farm DVC Estimate per 100 Roadway Miles (2012-13)
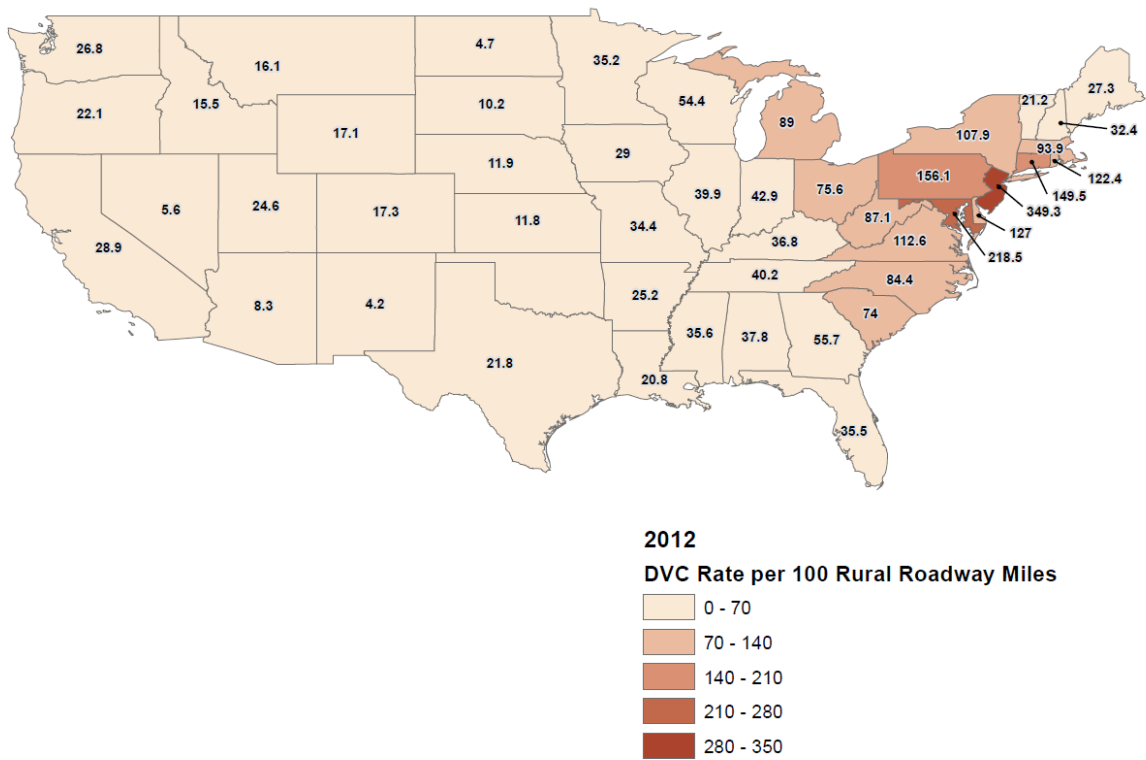
Figure 3-6 State Farm DVC Estimate per 100 Rural Roadway Miles (2012-13)
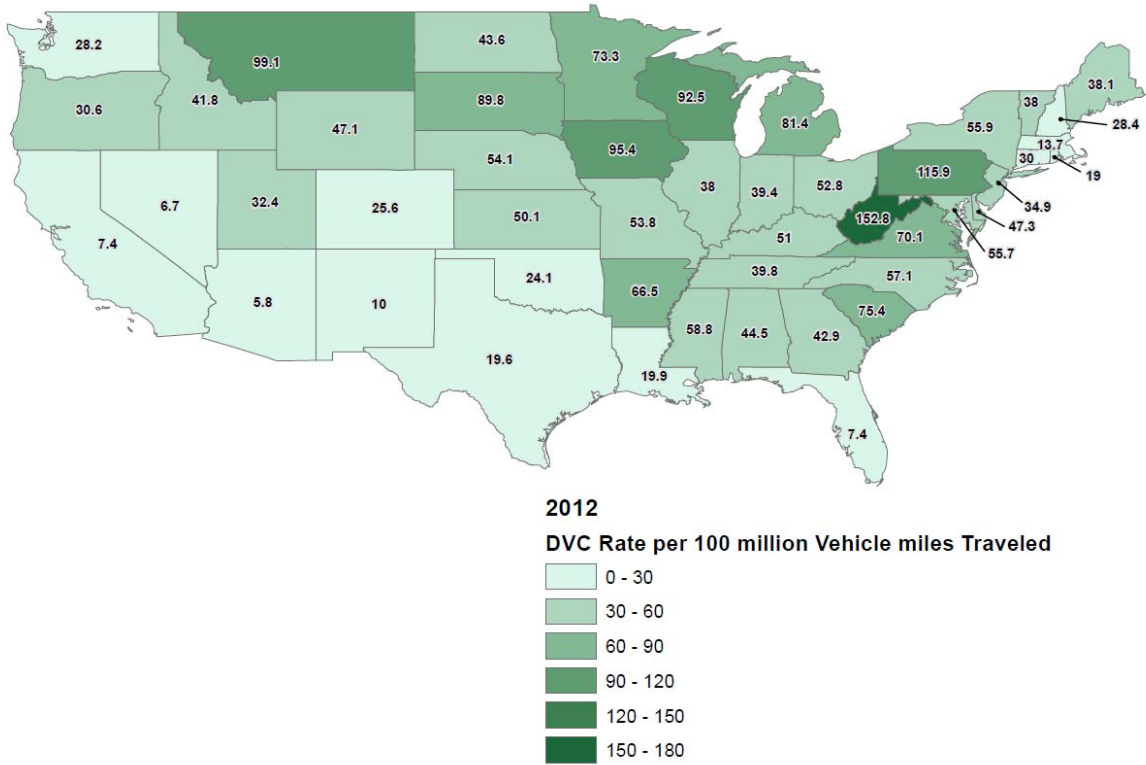
Figure 3-7 State Farm DVC Estimate per 100M Vehicle-Miles Traveled (2012-13)
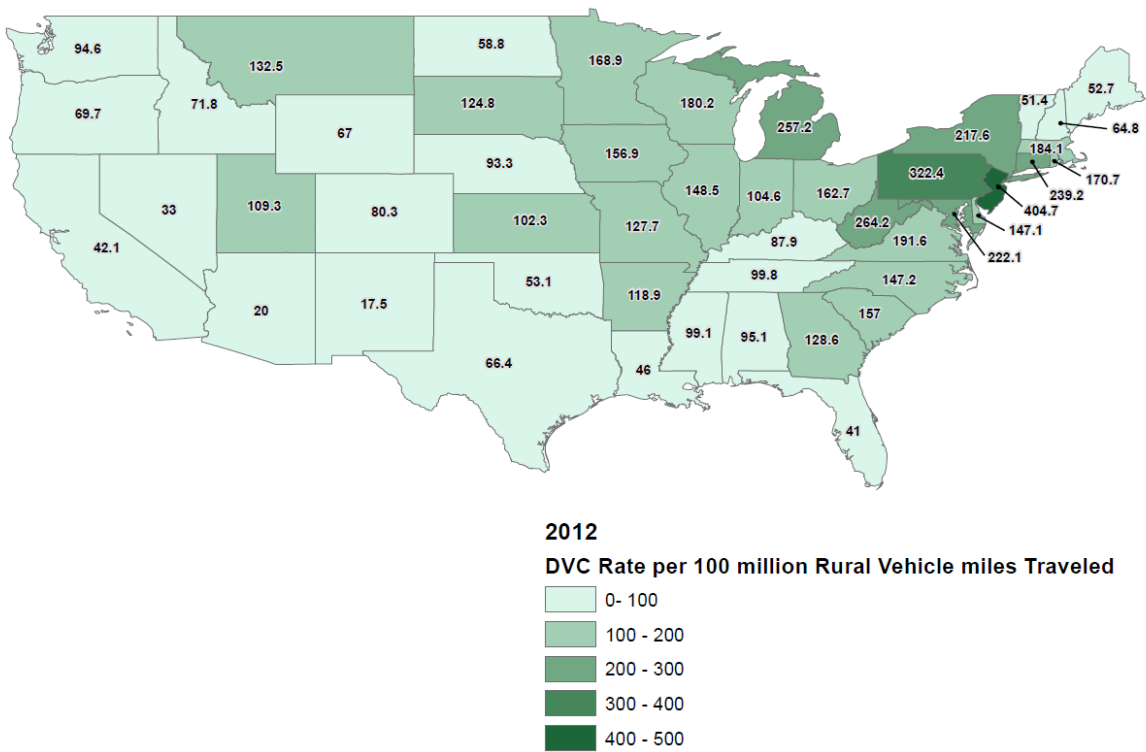
Figure 3-8 State Farm DVC Estimate per 100M Rural Vehicle Miles Traveled (2012-13)

3.4. State Comparisons on a Regional Level

Similar to the national review, the regional review's intent was to compare West Virginia to its surrounding states, only with more detailed data. The regional review was proposed because some categories of data deemed desirable for comparison would have been very difficult and time consuming to obtain for the entire United States, or non-existent. This data includes deer harvest and total reported crashes. However, upon further investigation it was determined that total crashes were the only credible data of the two. As explained previously, deer harvest data collection varies too greatly among states to be a consistent method of comparison. Nonetheless, the results are still presented here.

Figure 3-9 illustrates the State Farm DVC estimates to the estimated number of deer harvested statewide. As mentioned before, this is not a valid comparison because the reliability of the deer harvest numbers is very low due to inconsistent data collection methods, in addition to differences in the number of hunters in each state. Nonetheless, the comparison shows that Maryland and Pennsylvania have the highest ratios at 30-35 DVC per harvested deer. West Virginia ranges from 22-26 DVC per harvested deer. If one were to assume that harvested deer is directly related to deer population, a possible interpretation (flawed in this study) of this data is that Maryland and Pennsylvania have higher DVC rates when normalizing for deer population.

Figure 3-10 illustrates the ratio of State Farm DVC estimates to the total number of police reported crashes. It is important to note that this is not a true percentage (although it is computed as such in the figure) because many DVCs likely get filed with insurance without a police report being completed. The ratio of DVC estimates to total crashes in Pennsylvania was nearly 9:10 in all three years of analysis. West Virginia ranged from 6.5 to 8.5:10. The other four surrounding states were less than 1:2.
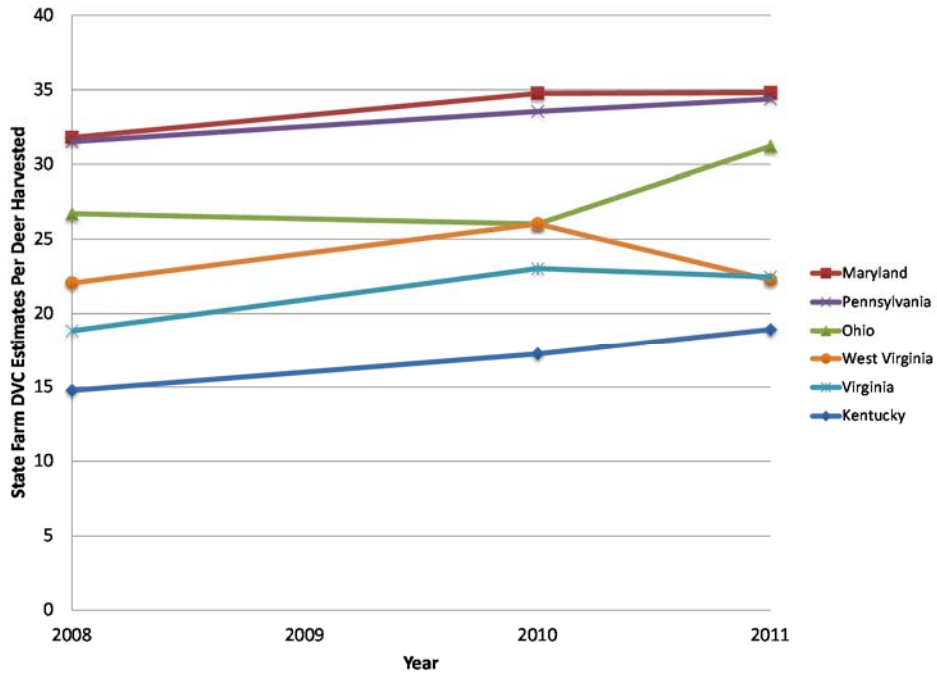
Figure 3-9 Ratio of State Farm DVC Estimate by Number of Harvested Deer
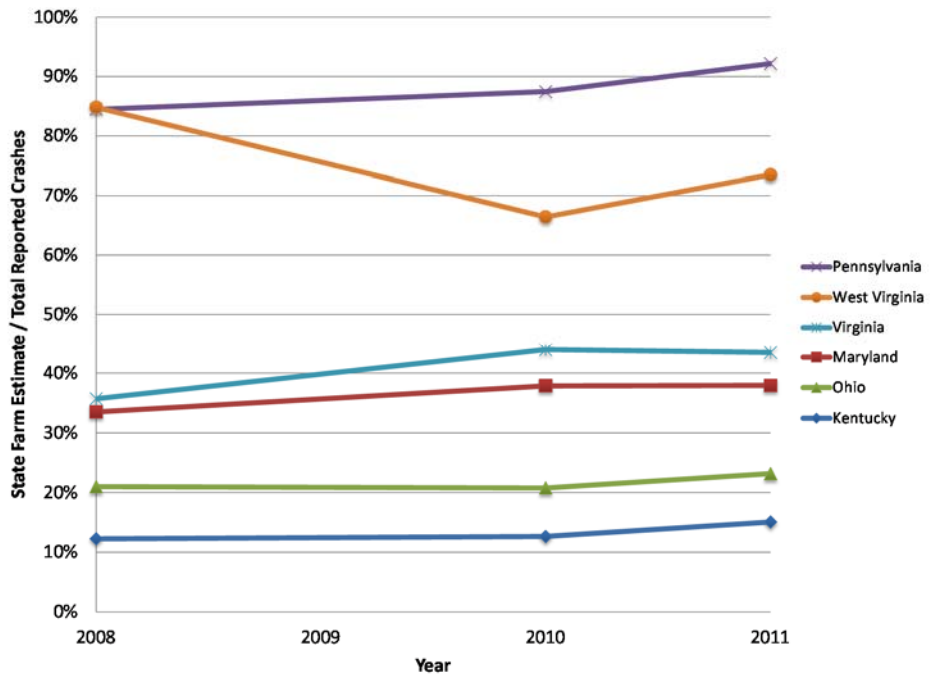
Figure 3-10 Ratio of State Farm DVC Estimates Divided to Total Reported Crashes

3.5. <u>Summary</u>

Motorists in West Virginia are certainly at a higher risk of being involved in DVCs than most states. West Virginia's ranking based on each normalization metric discussed is summarized in Table 3-1. West Virginia is not in the top 10 of the total number of DVC estimates. However, West Virginia ranks first in all normalized comparisons that were drawn from the national data, except roadway mileage, before removing the urban portion of the normalizing data. When removing the large urban areas from all states, West Virginia's ranking drops, but is still in the top 5-11. The truth likely lies somewhere in the middle of these various scenarios since one could argue that completely removing urban statistics is biased because those individuals living in a city also drive out of city limits. Furthermore, the number of DVCs are likely influenced by many of the normalization factors, not just one. An effort was made within this study to conduct a more detailed analysis of the normalization factors and their ability to predict the number of crashes, but no reliable model could be developed.

Unfortunately, there is not a valid and reliable measure for performing state-by-state comparisons, although vehicle miles traveled is the most logical. The rankings and estimates should be used for informational purposes only and not for decision-making purposes in absence of other data for implementing DVC mitigation.

4. WEST VIRGINIA DEER-VEHICLE COLLISION DATA

4.1. Overview of DVC Data Sources

This section of the report addresses the following objective of the study.

7. Evaluate and summarize the DVC data that has been collected in West Virginia and the collection methods used.

The sources of West Virginia DVC data that were identified for possible use in this study are listed in Table 4-1 along with the type of data and the DVC location reporting resolution. These data and their collection methods are discussed in the following sections. In order to identify hotspots and perform correlation analysis, it was necessary to utilize data that included the approximate location of the crash along the roadway. Therefore, the carcass counts from maintenance forms, police crash reports, and chronic wasting disease data were the only options. The other data sources are only summarized by state or county.

The total statewide counts for all six data sources were computed for the period 2008 to 2011 and are shown in Figure 4-1. This provides some insight into the variation of the quantities from each form of data. It is interesting to note that the State Farm Insurance estimates each year are higher than the insurance estimates derived by the WV Insurance Commission. The reported number of carcasses picked up by WVDOT is the next highest quantity and is relatively close to the WV Insurance Commission estimates. The difference between the two carcass data will be discussed in a later section. The police crash reports and chronic wasting disease samples are much lower counts than the other estimates. In general, the trends observed in the insurance estimates and the carcass counts are similar, with a decline from 2008 to 2010, then a slight increase from 2010 to 2011.

Table 4-1 Sources of DVC Data and Location Information

Type of Data	Crash Location Resolution	Source
Estimate from Insurance Claims	State Total	State Farm Insurance
Estimate from Insurance Claims	County Totals	WV Insurance Commission
Carcass Counts Reported Verbally	County Totals	WVDOT
Carcass Counts from Maintenance Forms	County, Route, Milepost for each carcass	WVDOT
Deer Vehicle Police Crash Reports	County, Route, Milepost, GPS for each crash	Police Agencies (reported through WVDOT)
Chronic Wasting Disease Sampling	GPS Coordinate for each sample	WVDNR
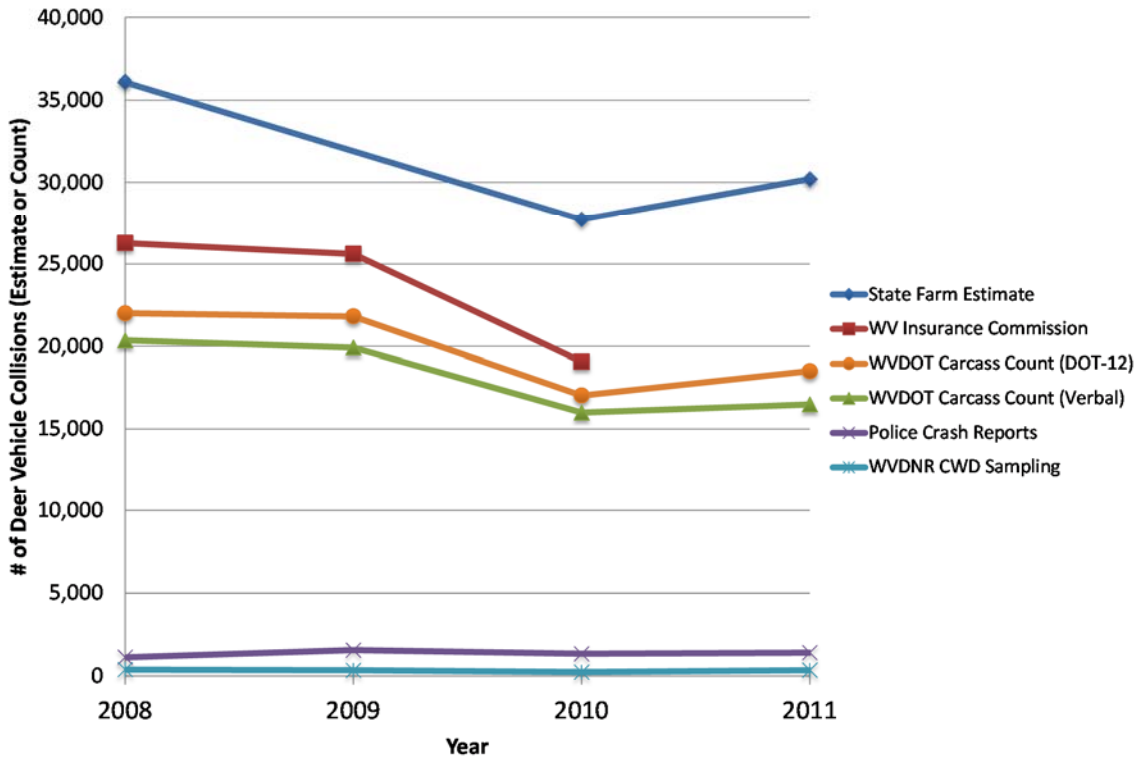
Figure 4-1 Comparison of West Virginia DVC Data Sources

4.2. WV Insurance Commission Data

The WV Insurance Commission estimates DVC in West Virginia using insurance data obtained from insurers via an annual request for data. Participation by insurers is voluntary. The data that is received is weighted by market share for each insurer for that same year. This data is aggregated by county, so it is only useful for monitoring trends across counties and over time, not for identifying hotspots.

4.3. WVDNR Chronic Wasting Disease Data

The WVDNR annually collects deer heads from carcasses laying on the side of the road that have been hit by a car. The heads are then transported to another location to be tested for chronic wasting disease and disposal. When a head is collected, the GPS coordinates of the location are collected because it is important to know where diseased animals are located within the state. Therefore, the accuracy of the location in this data is likely the most reliable of all data sources. However, there could be a lack of bias in the frequency of sampling at specific locations since the WVDNR wants to monitor the disease on a statewide basis. Therefore, they will likely not collect multiple samples along a segment that experiences a high frequency of DVC. Due to the lack of frequency bias, this data is likely not suitable for hotspot analysis at the road segment level. Figure 4-2 illustrates the total number of samples by county from 2008-2012.
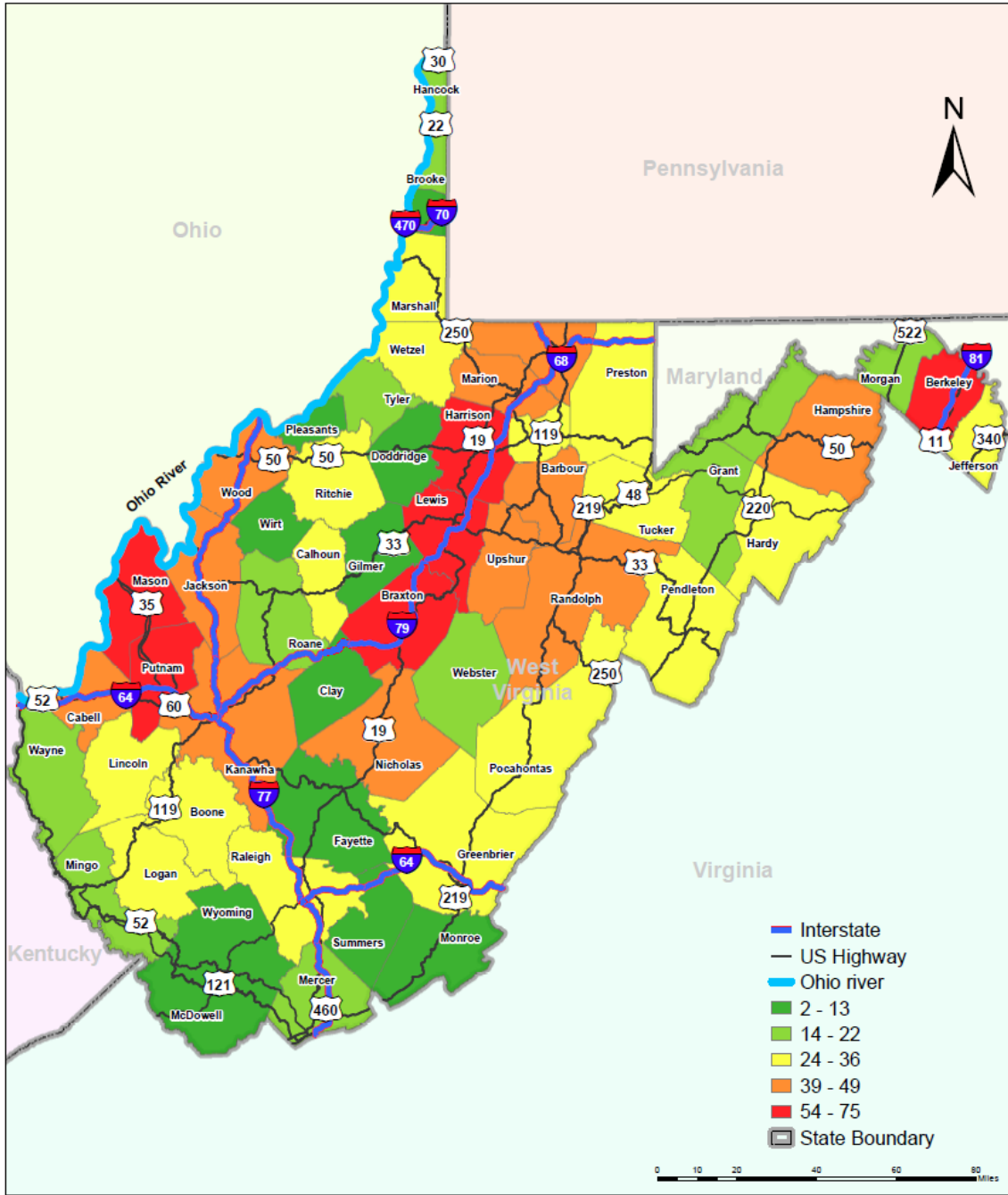
Figure 4-2 WVDNR Chronic Wasting Disease Samples by County (2008-2012)

4.4. WVDOT Carcass Data

4.4.1. DOT-12 Forms

The WVDOT Daily Work Report – Form DOT-12 is used by WVDOT maintenance crews to track their daily activities and those forms are uploaded to a central database for accounting purposes. County and district budgets are generated and tracked using various historical activity trends. An example of a DOT-12 form is shown in Appendix G. Crews are supposed to use activity code #310 for the removal of a non-deer carcass and code #315 for the removal of a deer carcass. The WVDOT provided DOT-12 form data from their central database for the period covering 2007-2011 that was flagged with activity code 315.

In addition to the activity code, the crews are able to denote on the form the location where the carcass was picked up. The location in this case would be route and milepost, not GPS coordinates since crews do not currently have this capability. At the outset of this project, it was anticipated that the carcass data reported by the DOT-12 forms would be the main data used in the hotspot and modeling analysis because it was the data source with the highest quantity that included location information. However, after the data was reviewed, it is was clear that not all crews were recording the location information consistently, if at all. Figure 4-3 and Table 4-2 contain a summary of the percentage of records by county that contained the route on which the carcass was picked up. Most of the counties are fairly high and consistent from year-to-year. However, route alone is not enough to identify hotspots. Figure 4-4 and Table 4-3 contain a summary of the percentage of records by county that contained the route and the milepost. Unfortunately, very few counties had a consistently high rate of recording milepost information with the data. It is unclear whether the location information isn't being entered by the maintenance crews in the field or if this information isn't being coded into the database when the forms are entered.

Another challenge with using the DOT-12 data was interpreting the record types. The record types in the data were (1) Invoices, (2) Payroll, (3) Equipment, and (4) Inventory. It was unclear how maintenance crews were documenting the carcass pickups – by payroll, equipment, or both. Figure 4-5 contains a comparison of the quantity of personnel records versus equipment records (ignoring the units entered for each) for each county and year. There appears to be a relationship of two personnel records for every equipment record. This would seem logical since two individuals typically ride in a truck for maintenance activities. However, this contradicts anecdotal information provided by WVDOT that the personnel record type is only filled out for the crew supervisor and not each crew member. Since many deer carcasses are picked up by maintenance crews when they are on their way to complete another activity, it seemed more likely that a deer carcass being picked up would be reported more accurately by

personnel rather than equipment. Based on anecdotal information provided by multiple county offices, there does not seem to be a consistent method for recording this activity on the DOT-12 forms.

In addition to the record type, the corresponding units could be entered. The manner in which the units field was estimated as it related to each record type was also unclear. If it were an equipment record type, the units could refer to the number of hours or miles associated with the activity. If it were a personnel record type, the units should refer to the number of hours that personnel worked on the activity. Figure 4-6 illustrates the frequency of values in the units field for both the personnel and equipment record types. Some values were negative, but the majority were between 1.0 and 3.0.

The interpretation of the unit data could not be reconciled, so it was decided to count the number of personnel records and use it as a basis for comparison to the other data sources.
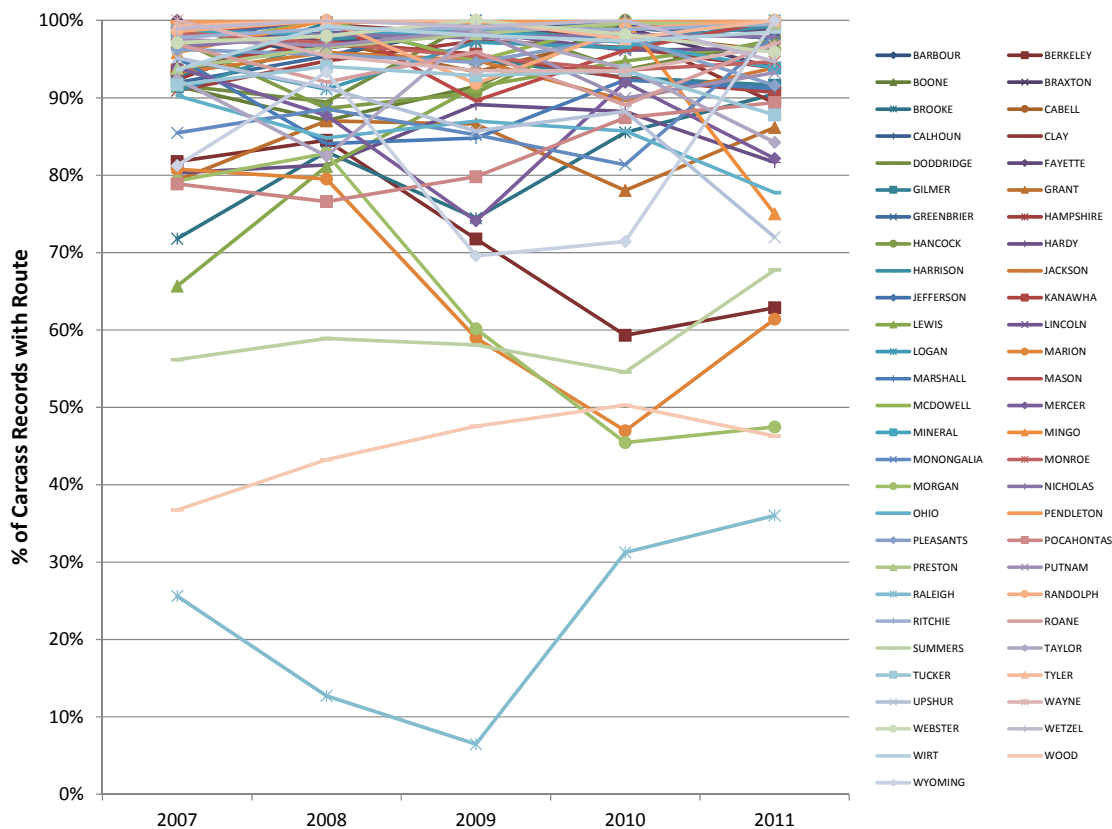
Figure 4-3. % of DOT-12 Records with Route Information by County

Table 4-2 % of DOT-12 Deer Pickup Records with Route by County

% of Records	County	% of Records	County
100%	Pendleton	95%	Hampshire
99%	Jefferson	94%	Doddridge
99%	Tyler	94%	Gilmer
99%	Calhoun	94%	Roane
99%	Ritchie	94%	Mingo
99%	Fayette	94%	Kanawha
99%	Wetzel	94%	Boone
98%	McDowell	94%	Jackson
98%	Barbour	92%	Tucker
98%	Randolph	90%	Taylor
98%	Webster	90%	Marshall
98%	Nicholas	88%	Monongalia
98%	Preston	86%	Upshur
97%	Wirt	86%	Lewis
97%	Braxton	86%	Mercer
97%	Mineral	85%	Ohio
97%	Lincoln	84%	Hardy
97%	Cabell	83%	Grant
97%	Greenbrier	83%	Wyoming
97%	Mason	82%	Pocahontas
97%	Harrison	81%	Brooke
96%	Logan	72%	Berkeley
96%	Wayne	66%	Marion
96%	Monroe	63%	Morgan
96%	Clay	59%	Summers
95%	Hancock	45%	Wood
95%	Putnam	22%	Raleigh
95%	Pleasants		
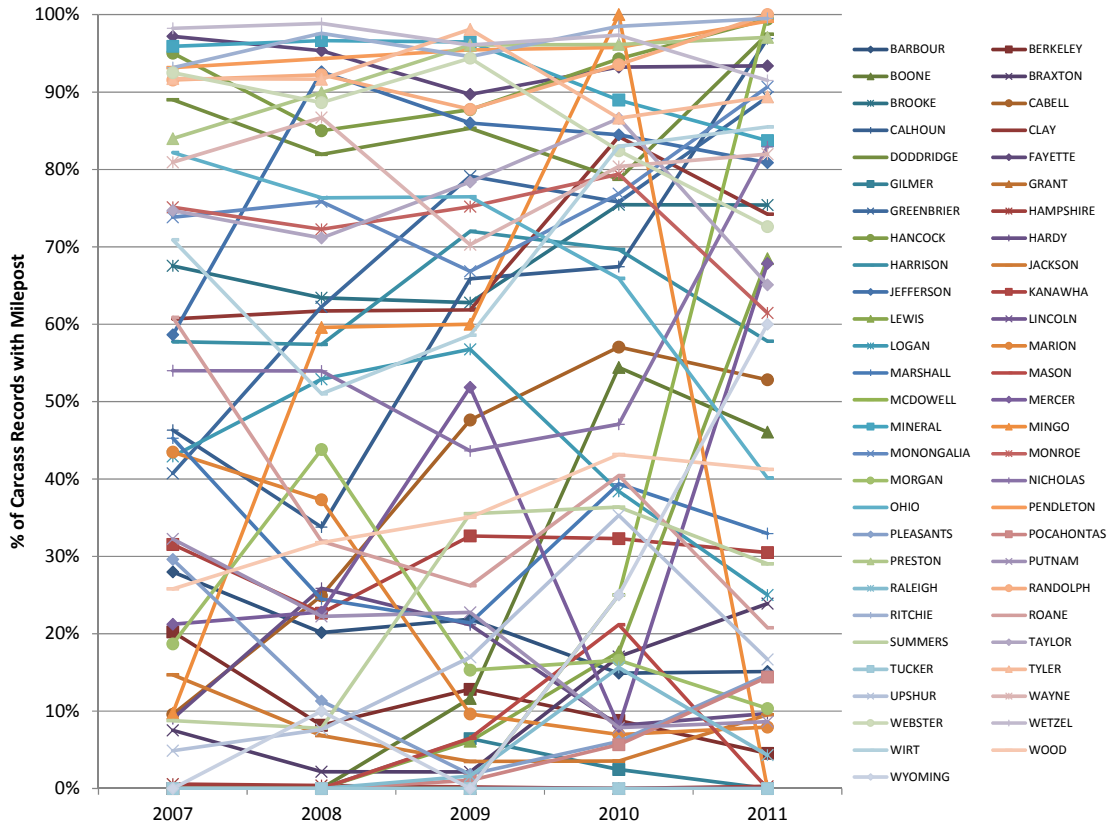
Figure 4-4 % of DOT-12 Records with Route and Milepost Information by County

The chart legend includes the following counties:

BARBOUR, BERKELEY, BOONE, BRAXTON, BROOKE, CABELL, CALHOUN, CLAY, DODDRIDGE, FAYETTE, GILMER, GRANT, GREENBRIER, HAMPSHIRE, HANCOCK, HARDY, HARRISON, JACKSON, JEFFERSON, KANAWHA, LEWIS, LINCOLN, LOGAN, MARION, MARSHALL, MASON, MCDOWELL, MERCER, MINERAL, MINGO, MONONGALIA, MONROE, MORGAN, NICHOLAS, OHIO, PENDLETON, PLEASANTS, POCAHONTAS, PRESTON, PUTNAM, RALEIGH, RANDOLPH, RITCHIE, ROANE, SUMMERS, TAYLOR, TUCKER, TYLER, UPSHUR, WAYNE, WEBSTER, WETZEL, WIRT, WOOD, WYOMING

Table 4-3 % of DOT-12 Deer Pickup Records with Route & Milepost by County

% of Records	County	% of Records	County
97%	Ritchie	35%	Wood
96%	Wetzel	34%	Mercer
96%	Pendleton	33%	Marshall
94%	Fayette	30%	Kanawha
93%	Randolph	25%	McDowell
93%	Preston	23%	Summers
92%	Mineral	22%	Boone
92%	Hancock	21%	Marion
92%	Tyler	21%	Morgan
86%	Doddridge	20%	Barbour
86%	Webster	19%	Wyoming
81%	Jefferson	19%	Putnam
80%	Wayne	18%	Lewis
77%	Monongalia	16%	Upshur
75%	Taylor	15%	Hardy
73%	Monroe	13%	Pleasants
70%	Wirt	11%	Berkeley
69%	Greenbrier	11%	Braxton
69%	Brooke	8%	Jackson
69%	Clay	6%	Mason
68%	Ohio	4%	Raleigh
63%	Harrison	4%	Pocahontas
62%	Calhoun	2%	Gilmer
56%	Nicholas	0%	Hampshire
46%	Mingo	0%	Grant
43%	Logan	0%	Lincoln
38%	Cabell	0%	Tucker
36%	Roane		

Figure 4-5 DOT-12 Personnel vs. Equipment Record Types by Year and County
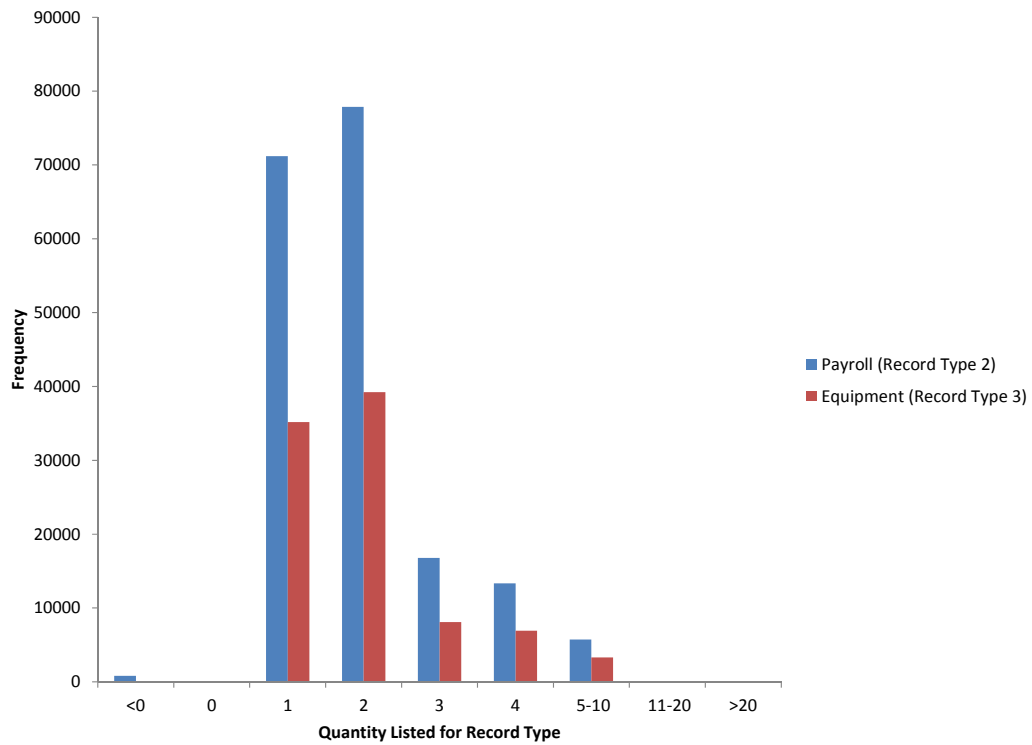
Figure 4-6 Frequency of Quantity Values by Record Type for DOT-12 Data

4.4.2. Verbal Reports

WVDOT county offices are also required to directly report monthly carcass counts to the Traffic Management Center. These reports are either emailed or called in, where they are tracked in a single spreadsheet. These monthly summaries by county were also provided by WVDOT for this study. These are referred to as "verbal" carcass counts. An initial review of the verbal carcass counts and the carcass counts based on the DOT-12 forms revealed that these two data sources did not match (see Figure 4-1). Therefore, a more detailed comparison was performed. Figure 4-7 shows a comparison of the verbal reported carcass count with the DOT-12 carcass count based on the number of equipment records by county and year. There does not appear to be a consistent pattern. Figure 4-8 shows a comparison of the verbal reported carcass count with the DOT-12 carcass count based on the number of personnel records by county and year. Again, there does not appear to be a consistent pattern. A few WVDOT county offices were contacted to inquire about how the counts reported verbally were generated. One county generated their counts directly from the DOT-12 forms when they were being coded into the central database. In another county, the maintenance crews were asked to record the number of carcasses picked up on a central calendar each day, then at the end of the month, the total was computed and submitted. This method likely resulted in discrepancies between the two because crews would sometimes forget to record their daily totals on the calendar.
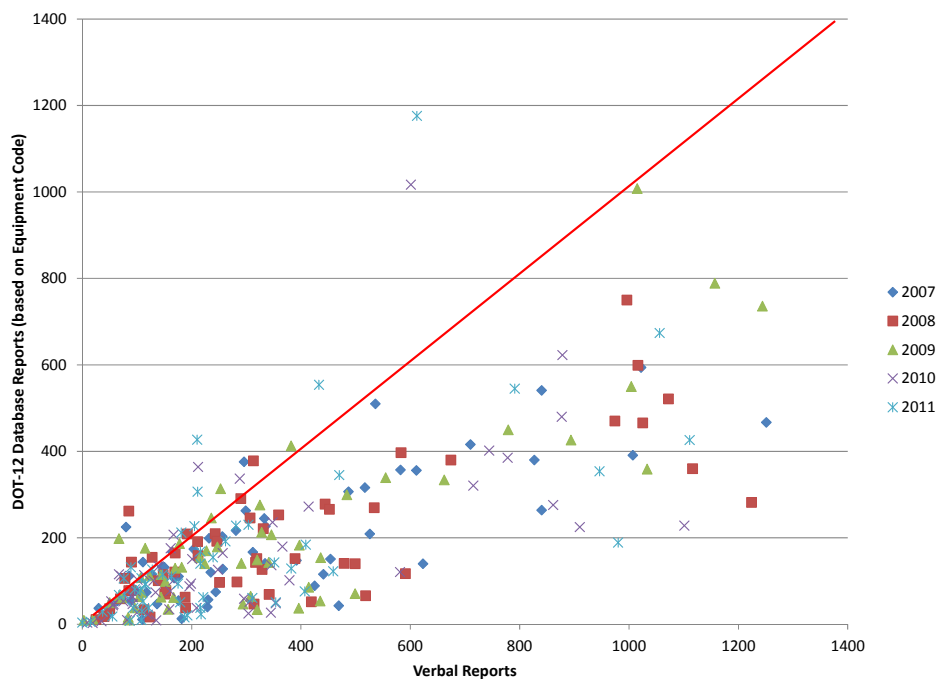
Figure 4-7 Verbal Carcass Reports vs. DOT-12 Equipment Records by County and Year
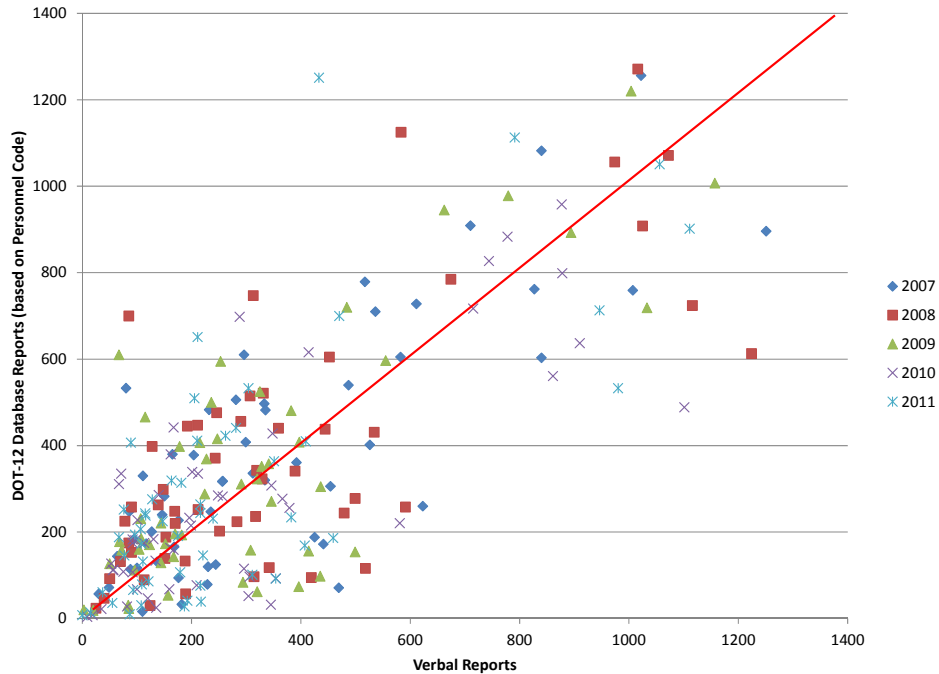
Figure 4-8 Verbal Carcass Reports vs. DOT-12 Personnel Records by County and Year

4.5. Police Crash Report Data

In West Virginia, the majority of the law enforcement agencies complete crash reports electronically on laptops in their vehicles. Those reports are uploaded to a central database that is maintained by the WVDOT. Starting in 2007, the crash report contained a field where the officer could indicate whether the crash involved an animal and the type of animal could be listed. The current crash report format is provided in Appendix F. Since the animal type is a free-form field, analysis of the database revealed that there were multiple terms used by officers to identify deer, including buck, doe, fawn, two deer, and others. Therefore, the identification of these records was a manual process. For this project, the reports covering the period 2008-2012 that indicated the crash was caused by or involved an animal were obtained from WVDOT. Then, these records were analyzed to identify those involving deer.

As discussed previously, a major disadvantage of using police crash reports for this type of study is that they are significantly underreported due to the minimum property damage threshold that must be exceeded. In West Virginia, the minimum threshold is $1,000 (*142*). A significant advantage of police crash reports are that they include multiple forms of location data, but is reliant on the officer completing them. The location can be reported by GPS coordinates, route and milepost, and a written description including the nearest intersecting road if milepost information is not known (which is common on state, county, and local routes). Table 4-4 provides a summary of crashes that were analyzed for each year,

including the total crash reports, number involving an animal, the number involving a deer, and the location information for those involving a deer. On average, 4.0% of the total reported crashes statewide involved an animal and 3.6% specifically involved a deer. Other animals that were listed on reports included turkeys, bears, dogs, livestock, and squirrels. On average, 89% of the deer crashes contained both route and milepost information, 29% contained GPS information, and 28% contained both type of location information. This location information is important because it allows crashes to be mapped and analyzed for hotspots.

Table 4-4 WV Police Crash Report Data Summary

	2008	2009	2010	2011	2012	Total
Total Crashes	27,856	41,969	42,180	40,967	39,075	192,047
Total Animal Crashes	1,386	1,763	1,539	1,513	1,432	7,633
Total "Deer" Crashes	1,140	1,575	1,351	1,421	1,346	6,833
Deer w/ Route & Milepost	1,053	1,455	1,251	1,259	1,073	6,091
% of Deer Crashes	92%	92%	93%	89%	80%	89%
Deer w/ GPS	419	498	394	367	306	1,984
% of Deer Crashes	37%	32%	29%	26%	23%	29%
Deer w/ Route & Milepost & GPS	413	492	391	361	303	1,960

4.6. Selection of Data for Analysis

After evaluating the three data sources that contained location data, it was decided that the police crash report data would be utilized for the hotspot analysis and modeling for the reasons listed below. These findings are similar to other states based on the discussion in the literature review.

- The WVDOT carcass data based on the DOT-12 forms did not contain enough records with route and milepost that would facilitate completion of the desired analysis. The quality of the data collection from county-to-county was not consistent and therefore introduced a bias that could not be accounted for. While those counties where quality data appeared to be collected could be used for the basis of the modeling effort and then extrapolated to the other counties, it would result in the identification of hotspots on a statewide basis from modeled data estimates, which can be unreliable if good models are not obtained.

- While the police crash reports are significantly underreported, it is assumed that the underreporting bias will be consistent across the state. The data will also be biased toward roads where collisions with deer result in more damage to the vehicle and the objects hit. This typically occurs on higher speed roads, such as Interstates and divided highways. Since the hotspot analysis in this study is focused on Interstate, US Routes, and WV Routes, this isn't a significant concern.

- Police crash reports are a constant and readily available data source. If DVC hotspot analysis is computed in future years, this data will already be collected and no new data collection effort would be needed.
- Crash analysis procedures that are already utilized by WVDOT are based on police crash reports. These analyses are conducted statewide for all crash types to identify locations that experience a high rate of crashes. The WVDOT could easily incorporate the analysis of DVCs into that routine activity. Since the quantity of other non-deer related crashes types are likely representative in terms of quantity, it may not be advisable to directly compare DVC rates with other crash rates when prioritizing projects due to the known underreporting of DVCs. However, if the project prioritization is based on crash severity, which accounts for injuries and fatalities to occupants, the comparison would likely be valid since a DVC that results in an injury or fatality is highly likely to be reported.

If it were desirable to approximate the total number of DVCs on a segment from the number of reported DVCs, the number of crash reports could be divided by 3-8% based on the statewide relationships shown in Figure 4-9. This figure is the assumed percentage of DVC claims and carcasses that generate a crash report. This was calculated directly from the data in Figure 4-1. However, it is unlikely that the underreporting rate is uniform across the state and across road segments, therefore caution should be exercised when using this to approximate total number of DVC from crash reports for a segment.
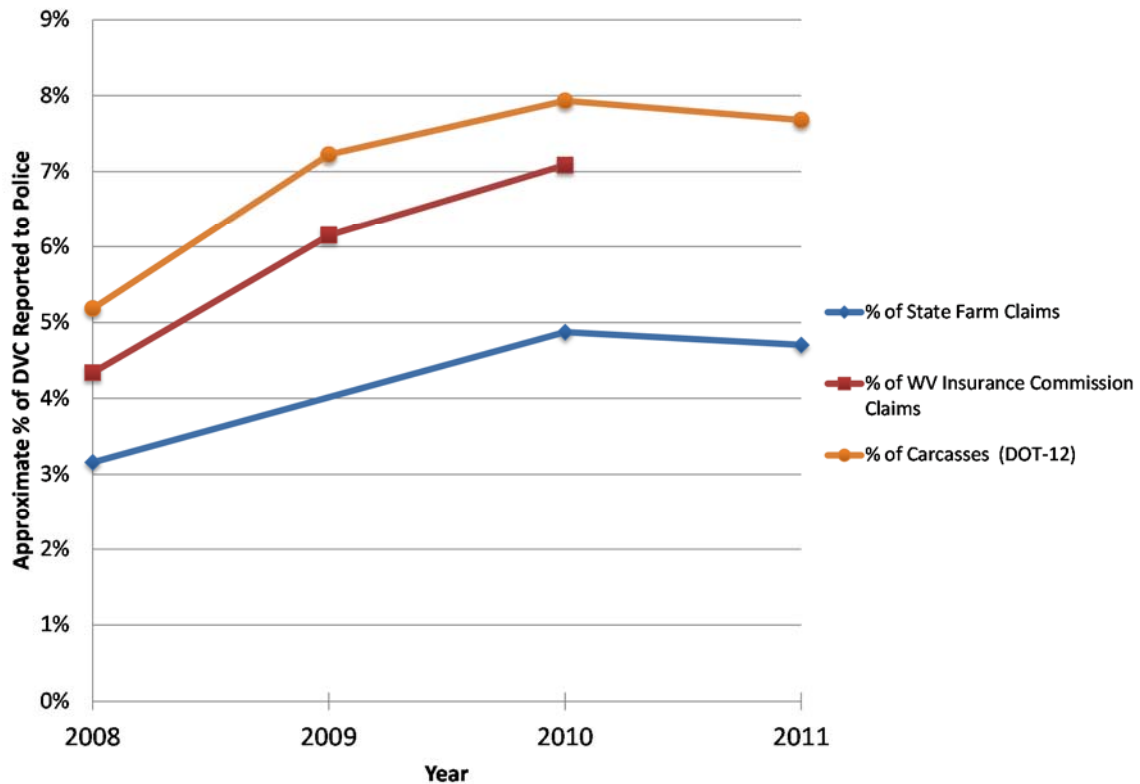
Figure 4-9 Approximated % of DVC by Source that Produce a Crash Report

4.7. Verification of Police Report Crash Location Data

Prior to conducting any hotspot identification or modeling with the police crash report data, the location information in each report was verified. As shown in Table 4-4, a high percentage of records had route and milepost information, and a lower percentage contained GPS coordinates. The researchers' prior experiences with the locations reported on police crash records prompted a review of the locations of all records. The analysis was conducted using GIS software and plotting the route and milepost and/or the GPS coordinates and comparing this information to the auxiliary location data contained in the crash report.

4.7.1. Comparison of GPS Coordinates and Route/Milepost

The records that contained both GPS coordinates and route/milepost information were plotted to evaluate the distances between the two locations. Figure 4-10 contains a histogram of the distances in miles. The majority of the records (53%) were within 1.0 mile of the location. It isn't surprising to have this much variation since most police officers are likely to round to the nearest whole mile when recording milepost information. However, 47% were greater than 1.0 mile, with the largest discrepancy being 100 miles. Some of the more extreme values are likely due to an error when recording GPS coordinates. However, this amount of discrepancy needed to be addressed prior to using the data for hotspot analysis and modeling.
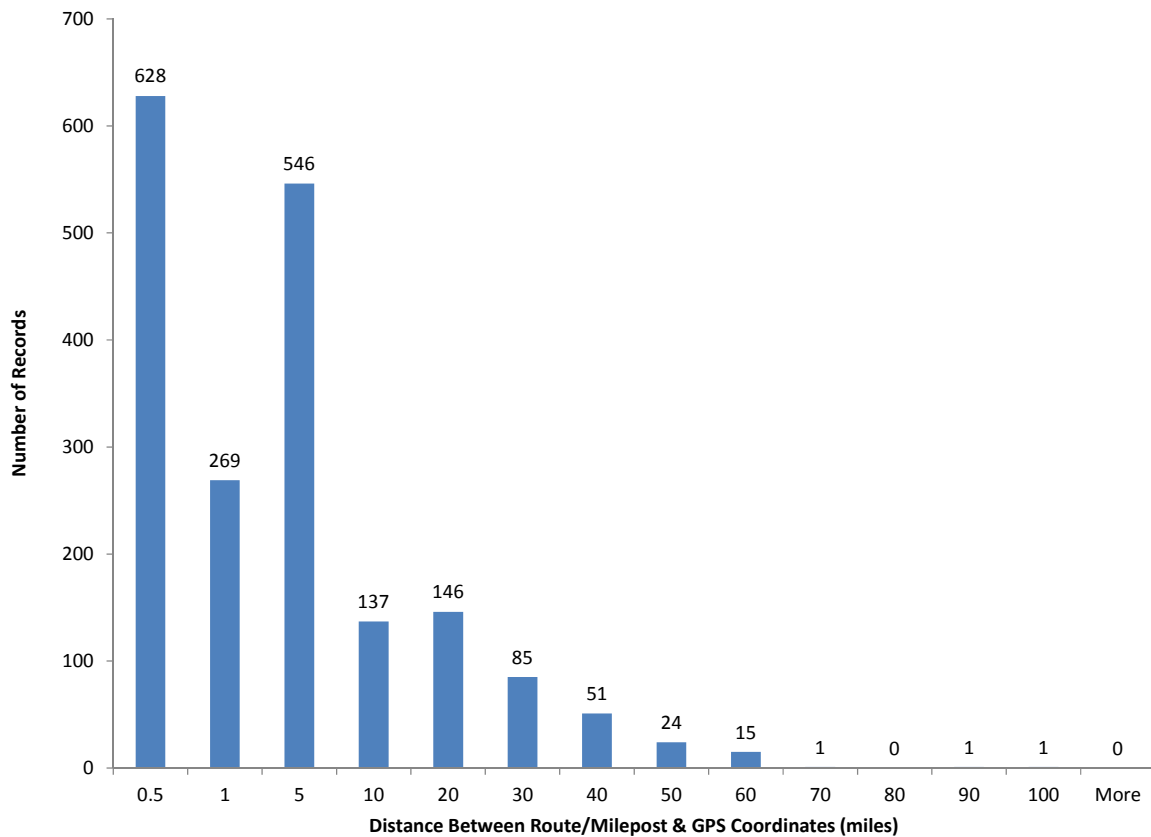
Figure 4-10 Frequency of Distance between Locations in DVC Reports (2008-12)

4.7.2. Route and Milepost Accuracy

Figure 4-11 depicts a summary of the number of records that had accurate route and milepost information, inaccurate information, and unusable/unverifiable information. The Accurate column (82%) shows the number of records where the original route and milepost were deemed to be accurate representations of where the collision occurred. The Inaccurate column (3%) shows the number of records where the GPS coordinates were deemed to be a more accurate representation of where the collision occurred. The Unverifiable column (4%) represents the records that contained a location, but it could not be determined that the location was accurate based on the information given. The No Data column (11%) shows all records that had no available location data. The Data Error column (<1%) shows all records that had a partial description of the route and milepost, but there was an error that prevented the data from being plotted.
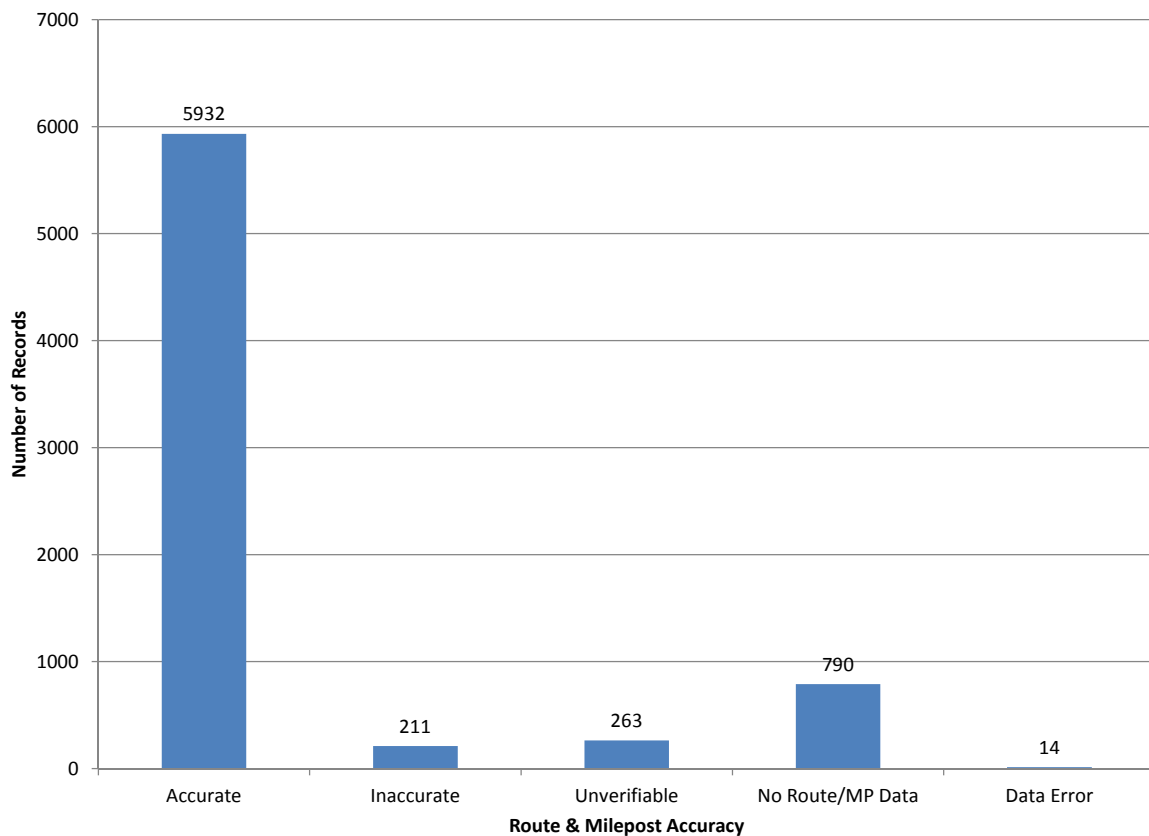
Figure 4-11 Accuracy of Route and Milepost in DVC Police Reports (2008-12)

4.7.3. GPS Accuracy

Figure 4-12 depicts a summary of the number of records that had accurate GPS coordinates, inaccurate coordinates, unverifiable coordinates, and no coordinates. The Accurate column (11%) shows the number of records where the GPS coordinates were deemed to be accurate representations of where the collision occurred. The Inaccurate column (14%) shows the number of records where the GPS coordinates were deemed to be inaccurate representations of where the collision occurred compared to the Route/Milepost. The Unverifiable column (3%) represents all points that represented a location, but it could not be determined that the location was accurate. The No Data column (74%) is all crashes that had no GPS data.
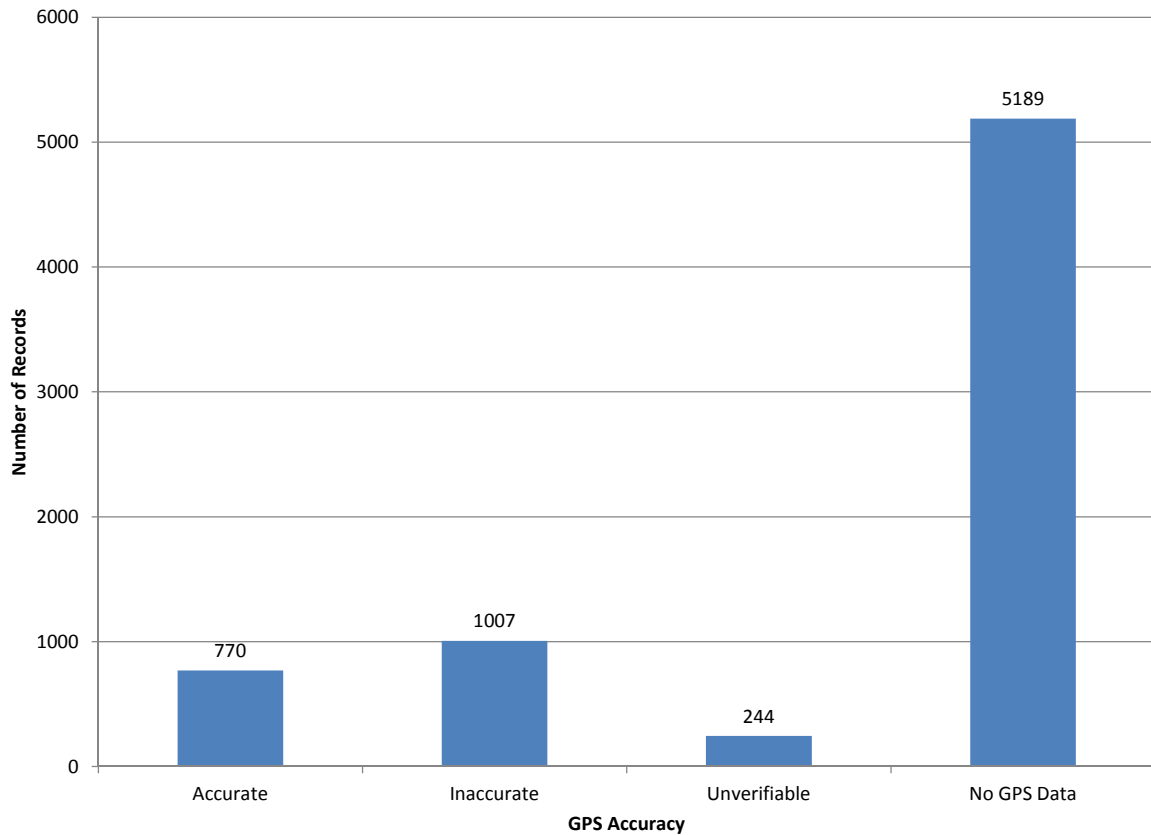
Figure 4-12 Accuracy of GPS Coordinates in DVC Police Reports (2008-12)

4.7.4. Location Reconciliation

Figure 4-13 contains a summary of how the location information in each record was reconciled. The original route and milepost was used in approximately 80% of the records. The original GPS coordinates were used in 5% of the records. Completely new locations were defined for less than 1% of the records. Approximately 14% of the records were either unverifiable, contained a data error, or contained no location information. This resulted in 6,150 crash records with a usable location for hotspot analysis and modeling.
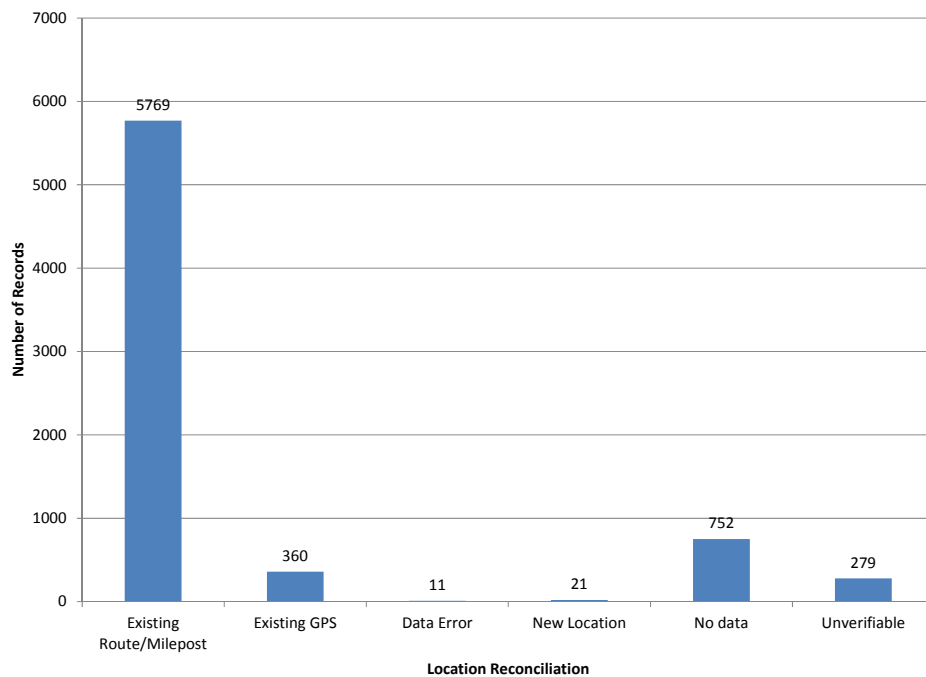
Figure 4-13 Reconciliation of Locations in DVC Crash Reports

4.8. Comparison of Primary Data Sets

An extensive analysis of the police crash report data, WVDOT carcass data, and WVDNR chronic wasting disease data was conducted to determine if there was any correlation between the three datasets. Since the chronic wasting disease data is a random sample, it was not expected that much correlation would exist with the other two datasets. However, it seems feasible that the carcass data and crash report data might be correlated, if consistent percentage of crashes get reported. However, the inconsistency in carcass reporting by WVDOT is a known hurdle.

4.8.1. Fitting Regression Lines to Data Comparisons

Since milepost information was not available in the carcass data for all counties to facilitate segment-level comparisons, the analysis was conducted at the county level for each Interstate, US Route, WV Route, and County Route. For all route segments in the county, the total number of records for each dataset was plotted in pairs and a regression line was fit to the county/route level data. An example of the plot of the carcass and crash report data in Nicholas County is shown in Figure 4-14 (regression coefficient = 3.6 and $R^2 = 0.90$). Similar plots for the other counties are provided in Appendix H. In these plots, red circles represent Interstates, green circles represent US Routes, and black circles represent WV and County Routes. The regression coefficients and R^2 values were calculated and summarized in order to draw conclusions about the relationships. A regression coefficient (or slope) near 1 would indicate the two datasets have a one-to-one relationship. However, just because the coefficient is not close to one, doesn't mean that there isn't a correlation. If consistent values of 0.1 occurred when comparing the crash reports to the carcass counts, this would indicate that roughly 10% of the crashes that resulted in a carcass being picked up generated a crash report. The R^2 value indicates how well the data is correlated, with the maximum being 1.0. In order for a correlation to be verified, consistent slopes and high R^2 values would be necessary.
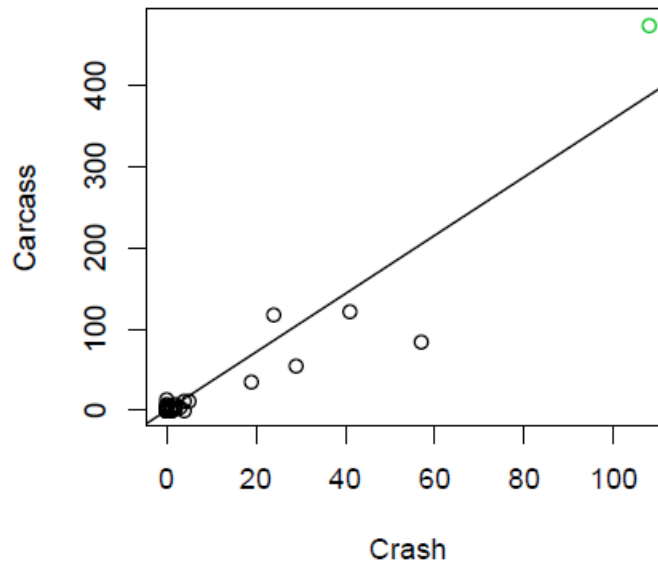
Figure 4-14 Regression Analysis of Carcass and Crash Report Data for Nicholas County

4.8.2. Regression Modeling Output Histograms

Figure 4-15 illustrates the frequency of the R^2 values for each county (all routes combined) when comparing all three datasets in pairs. More than half of the counties' R^2 value is above 0.5 for all 3 comparisons. Figure 4-16 illustrates the frequency of the regression coefficients (slopes) for each county when comparing all 3 datasets. Based on (a), the majority of the counties have carcass counts that are 0-20 times the number of crash reports. Based on (b), the majority of the counties have carcass counts that are 0-50 times the number of CWD data points. Based on (c), the majority of the counties have crash reports that are 0-2 times the number of CWD data points.
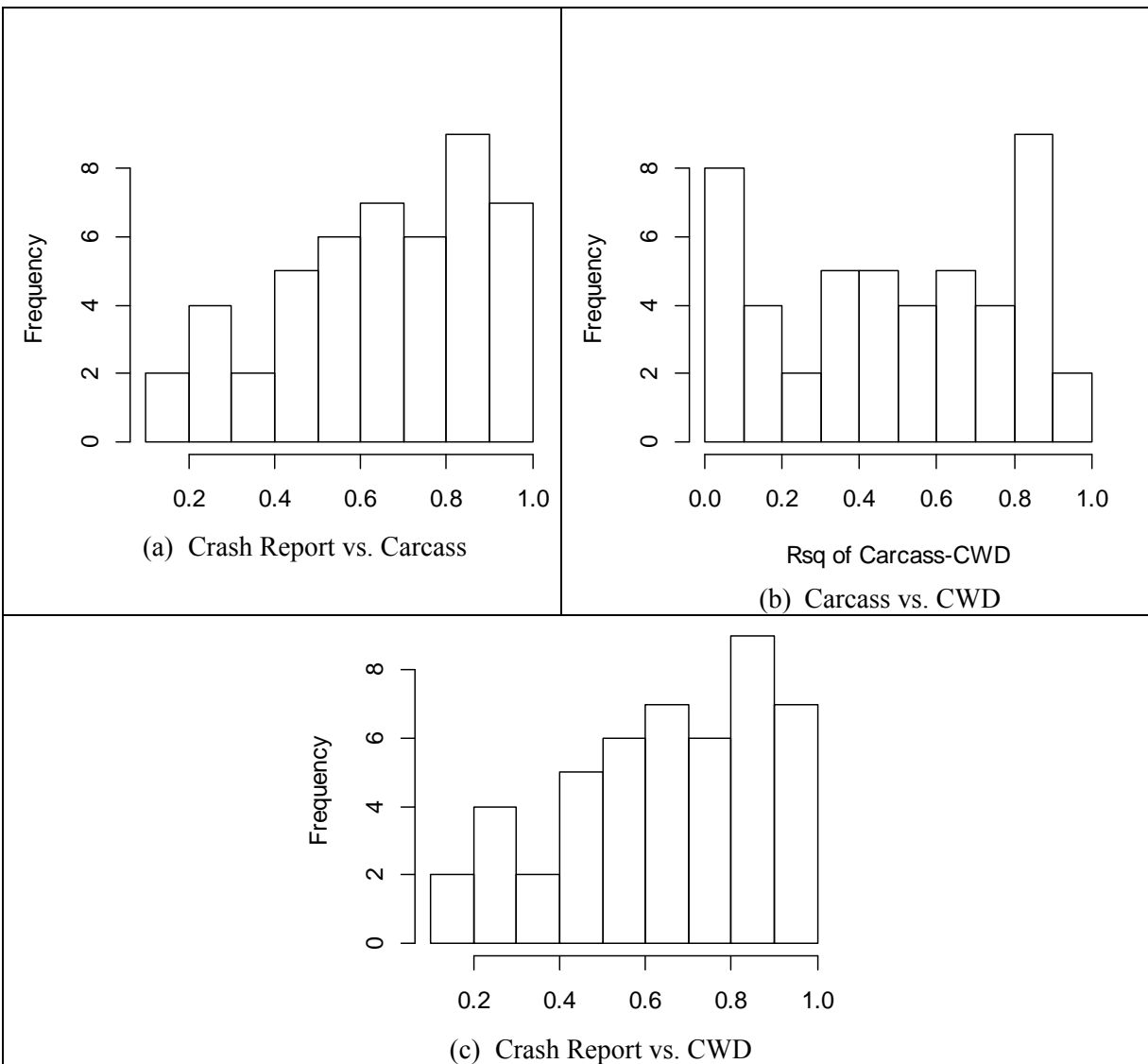
Figure 4-15 Histogram of R^2 Values for Data Set Relationships by County

(a) Carcass vs. Crash Report

(b) Carcass vs. CWD

(c) Crash Report vs. CWD
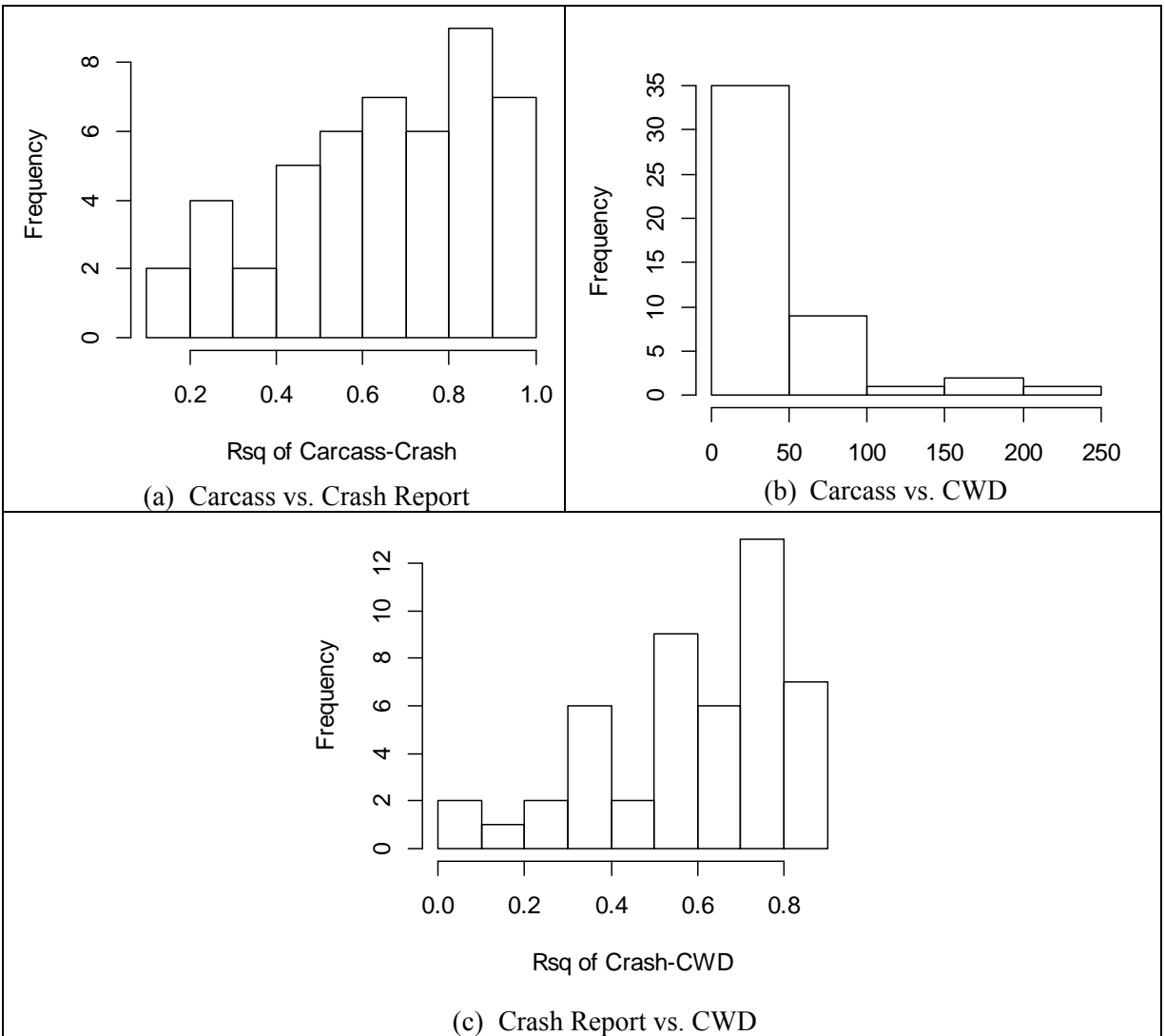
Figure 4-16 Histogram of Regression Coefficients for Data Set Relationships by County

4.8.3. Cross-Tabulation Analysis

The distributions of regression coefficients and R^2 values are interesting, but the regression coefficient values for the counties that also have high R^2 values is of particular interest. Therefore, a cross-tabulation was conducted and those results are provided in Table 4-5, Table 4-6, and Table 4-7 for each paired dataset comparison. The bottom row of each table lists the range of slopes for those counties with an R^2 greater than 0.75. Table 4-8 lists these specific counties and their corresponding values for the carcass count and crash report regression analysis. Since there is such a wide range of regression coefficients for the counties that illustrate a high R^2 value, it is concluded that there is minimal correlation between the datasets. This is most likely due to inconsistencies in the carcass data collection.

Table 4-5 Cross-Tabulation for Crash Report vs. Carcass Relationship

		Slope				
		(0, 26.5)	(26.5, 52.5)	(52.5, 78.6)	(78.6, 105)	(105, 131)
R^2	(0.00, 0.25)	3	1	0	0	0
	(0.25, 0.50)	9	0	0	0	0
	(0.50, 0.75)	11	5	0	1	0
	(0.75, 1.0)	12	1	3	0	2

Table 4-6 Cross-Tabulation for Carcass vs. CWD Relationship

		Slope				
		(0, 41.9)	(41.9, 84.0)	(84.0, 126)	(126, 168)	(168, 210)
R^2	(0.00, 0.25)	13	0	0	0	0
	(0.25, 0.50)	6	3	1	1	0
	(0.50, 0.75)	7	3	0	0	0
	(0.75, 1.0)	7	3	2	0	2

Table 4-7 Cross-Tabulation for Crash Report vs. CWD

		Slope				
		(0.0, 2.5)	(2.5, 5.1)	(5.1, 7.6)	(7.6, 10.1)	(10.1, 12.7)
R^2	(0.00, 0.25)	3	1	0	0	0
	(0.25, 0.50)	7	0	0	2	0
	(0.50, 0.75)	14	5	1	0	0
	(0.75, 1.0)	7	4	3	0	1

Table 4-8 Slope and R^2 Values of Counties where $R^2 > 0.75$ based on Crash Report vs. Carcass

County	Slope	R^2
HAMPSHIRE	0.6	0.80
NICHOLAS	3.6	0.90
MASON	3.8	0.88
FAYETTE	4.8	0.77
BRAXTON	7.0	0.93
PLEASANTS	8.3	0.97
TAYLOR	10.3	0.87
CLAY	11.3	0.89
JEFFERSON	11.8	0.83
GREENBRIER	14.7	0.92
WAYNE	15.2	0.81
HARRISON	21.6	0.91
WIRT	51.9	0.88
TYLER	60.6	0.88
MONROE	67.5	0.91
HANCOCK	74.2	0.81
WEBSTER	129.0	0.91
CALHOUN	131.0	0.96

4.9. Summary and Recommendations

The police crash report data was determined to be the most consistent and reliable source of DVC with specific locations across West Virginia. While the quantity of carcasses reported by WVDOT is approximately 13 times higher than the crash reports, that data is collected too inconsistently by maintenance crews across the state. It is known that crashes involving deer are underreported to police, but the rate of underreporting is expected to be consistent across the state. Therefore, it can be used to identify relative hotspots, but the true number of DVC will not be known for that location.

Analysis of the crash report data and carcass data indicated that there was minimal correlation in terms of frequency by route within each county across the state. This does not indicate that a correlation between the presence of carcasses and the location of police reported crashes does not exist. This is most likely attributed to the deficiencies (e.g., no location) and inconsistencies in the carcass data collection among the various districts and maintenance crews.

To facilitate future DVC analysis using crash data, it would be beneficial to specifically add a check box on the crash report form for the officer to indicate that a deer was involved. A free-form text box was previously added where the officer could indicate the type of animal after checking that an animal was a

contributing factor. However, querying the free-form field for all variations of deer descriptions will always yield inaccuracies.

If the WVDOT wants to collect more detailed data for evaluating DVCs, they should provide training and clear guidelines for maintenance crews to record carcass data locations more accurately and reliably. Communicating the value of this data to the crews collecting it and illustrating how it could be used would also help increase the quality of their data collection efforts. Some states use handheld data collection devices in order to facilitate the data collection process and to assign GPS coordinates where the carcass is picked up. An example of a mobile device is the roadkill observation collection system (ROCS), shown in Figure 4-17 (*143*). This type of database data collection system can easily be imported into a GIS platform for further analysis and guarantees the accuracy of the location information if used correctly.

The locations reported in the police crash reports could also be improved. Officers have the option to record route and milepost or GPS coordinates. Approximately 14% of the crash records had no location information or incomplete location information, which resulted in their exclusion from the analysis. This problem could be resolved through additional training and awareness among law enforcement agencies.

Figure 4-17 Roadkill Observation Collection System (ROCS)

5. WEST VIRGINIA DEER-VEHICLE CRASH REPORT CHARACTERISTICS

5.1. Overview

The police crash reports contain information that can be analyzed to better characterize the DVCs in a way that isn't possible with any other data source. This includes analysis by time-of-day, day-of-week (which can't be done with carcass data since the deer could be laying there for days before being removed), crash severity, object hit by vehicle, roadway conditions, and driver home state. The following sections investigate these characteristics in West Virginia from 2008-12.

5.2. DVC Temporal Distribution

Figure 5-1 depicts the frequency of crashes by year and month. October and November were consistently the highest months, with another peak occurring during the summer. These findings are consistent with other studies discussed in the literature review.

Figure 5-2 depicts the frequency of crashes by hour of the day and by reported light conditions. Analyzing by time of day alone is not as useful since light conditions during dusk and dawn vary throughout the year. While a number of crashes were reported during daylight hours, the majority of crashes occurring during darkness with no roadway lighting present.

Figure 5-3 depicts the frequency by day of week and year. Over the 5-year period, the distribution was fairly even. However, the equal distribution is not maintained from year-to-year. In 2009, the majority of crashes were reported on Sunday. In 2011, Tuesday appeared to experience the highest percentage of crashes. There is no reason to believe that these relationships are anything but random. Traffic volumes are usually higher during mid-week and lower on weekends and DVC trends typically follow this same trend in other studies. However, it is not evident based on the data analyzed in West Virginia.
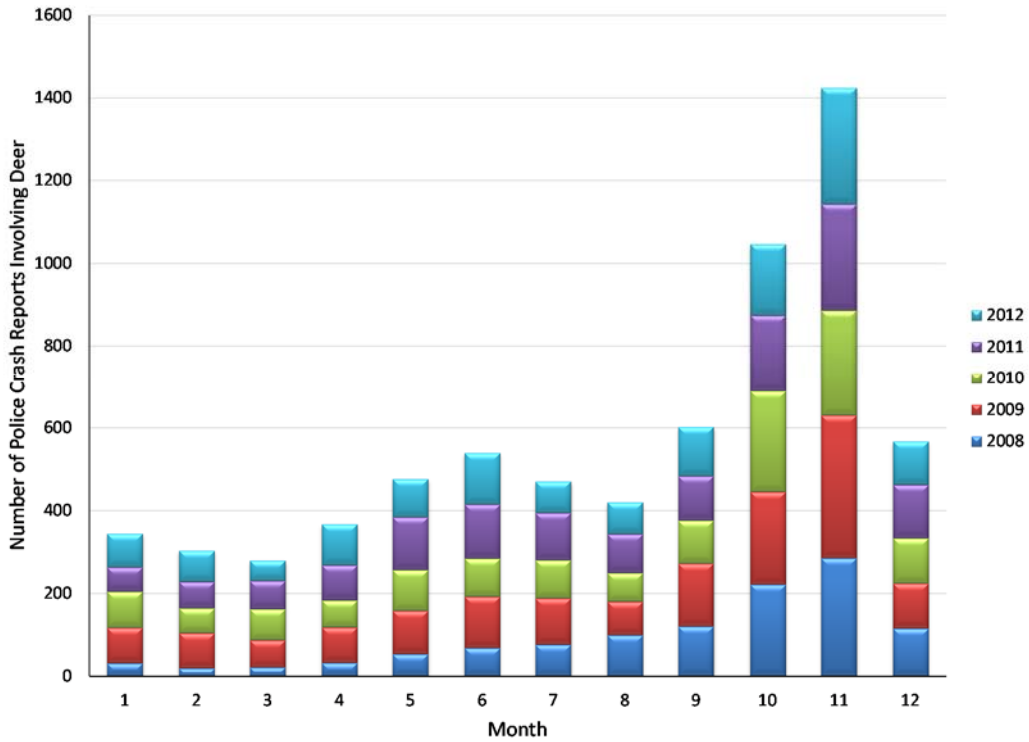
Figure 5-1 Deer-Vehicle Crash Reports by Year and Month
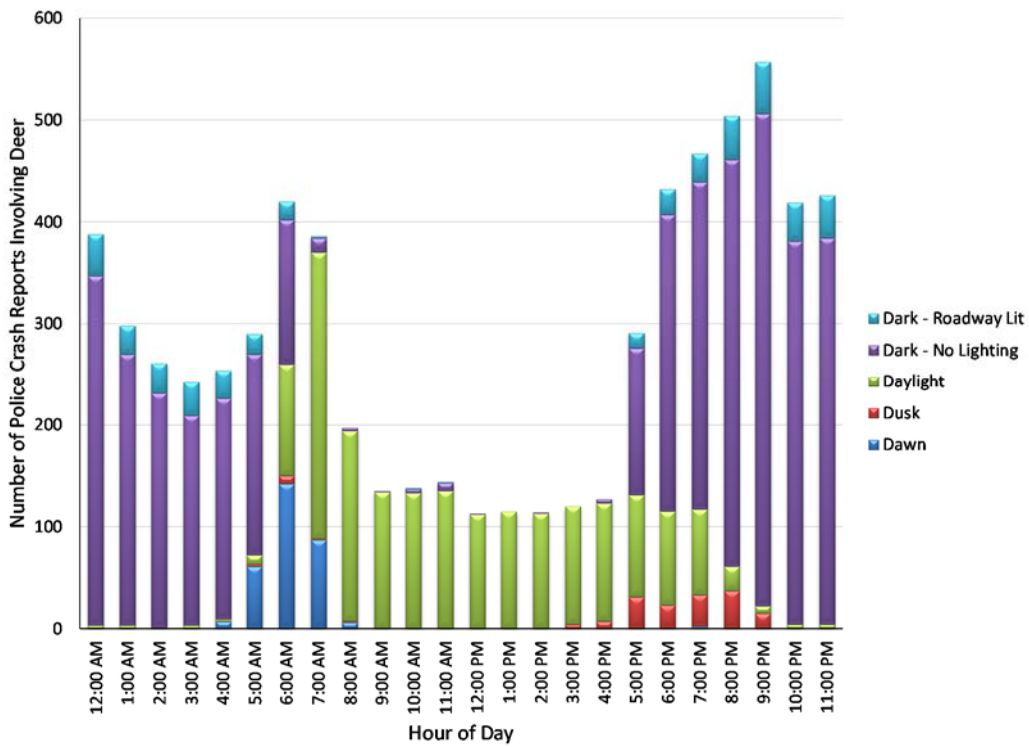
Figure 5-2 Deer-Vehicle Crash Reports by Hour of Day and Light Conditions (2008-12)
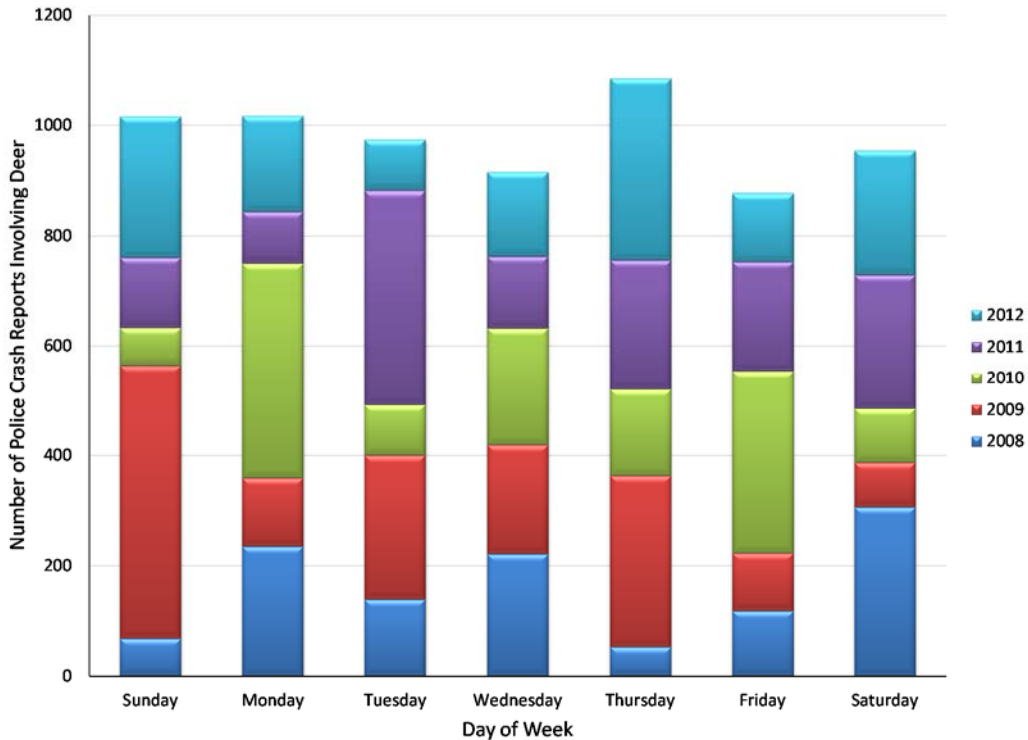
Figure 5-3 Deer-Vehicle Crash Reports by Year and Day of Week (2008-12)

5.3. DVC by Severity and First Object Hit

Figure 5-4 illustrates the number of DVCs by severity and by the object hit, where the object hit is another vehicle, a barrier or other roadside object, or the deer itself. Since multiple objects could be hit in a crash, this analysis is based on the initial object reported to be hit. Another vehicle was hit in approximately 3% of the crashes. Of those crashes, 35% of them resulted in an injury or fatality of one or more people. In 29% of the crashes, the vehicle either ran off the road or struck a roadside object. Of those crashes, approximately 38% of them resulted in an injury or fatality of one or more people. In 68% of the crashes, the deer was the first object struck. When the deer was struck, only 10% of the crashes resulted in someone getting injured or killed.

Figure 5-5 shows the overall percentage of objects first hit for each injury type. When the driver hits the deer first instead of swerving to miss the deer and running off the road or into another vehicle, the probability of injury is greatly decreased. However, half of the observed fatalities occurred when the deer was first struck.

	No Injuries	One Injury	Two or more Injuries	Fatality
Struck Another Vehicle	128	45	22	1
Struck Barrier or Run Off Road	1252	601	153	5
Struck Deer	4172	374	79	6
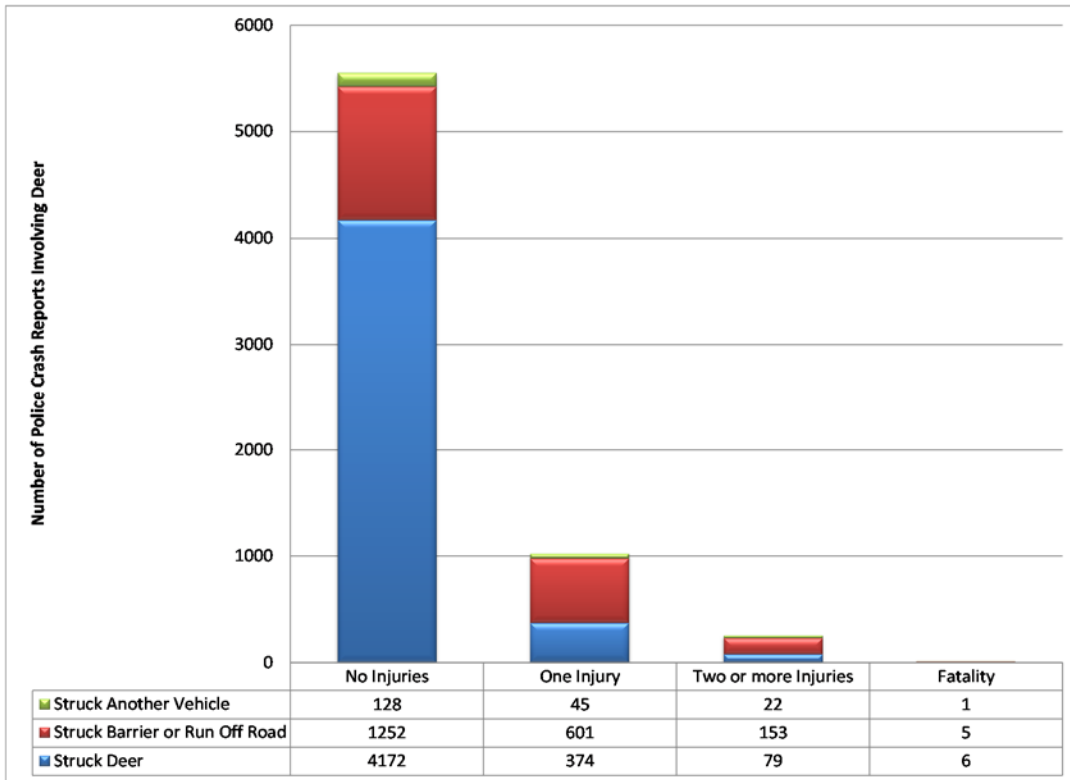
Figure 5-4 Deer-Vehicle Crash Reports by Severity and Object Hit (2008-12)
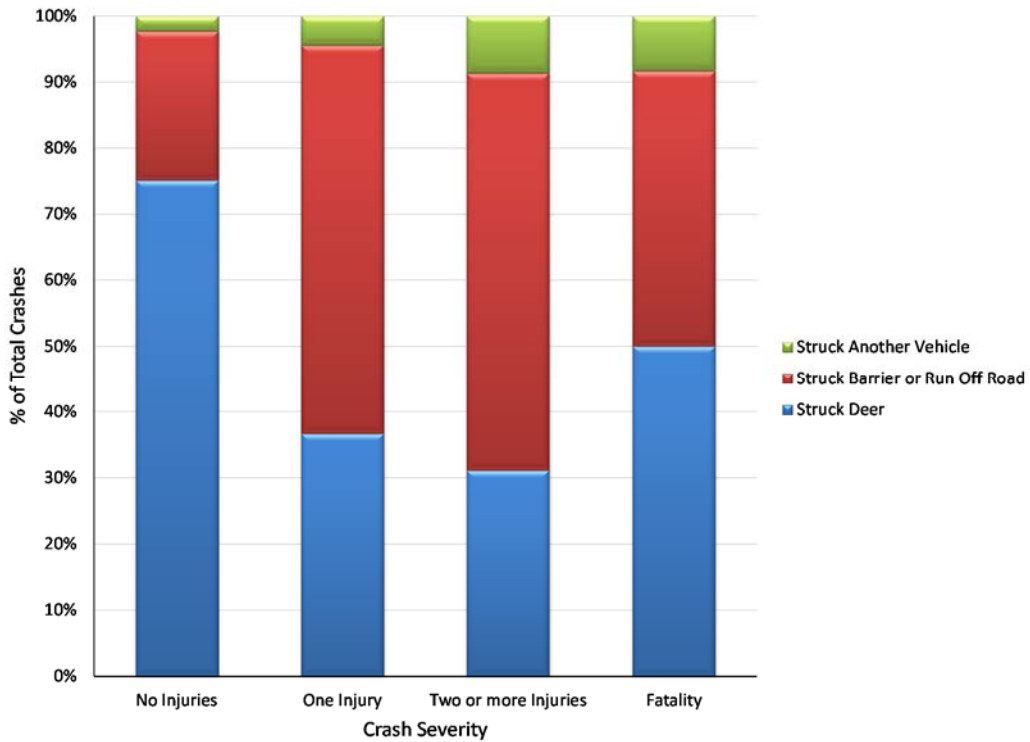
Figure 5-5 % of Deer-Vehicle Crash Reports by Severity and Object Hit (2008-12)

West Virginia Deer-Vehicle Crash Report Characteristics   101

5.4. DVC by Severity and Road Conditions

Figure 5-6 illustrates the reported roadway conditions for each crash and the severity. The majority of crashes occurred when the conditions were dry. Wet roadways and presence of snow and ice, which would increase the vehicle stopping distance did not seem to be a significant factor in crashes. If roads are snowy and icy, drivers are more likely to be traveling at a slower speed and be more alert, so they would be able to respond faster to compensate for the increased stopping distance.

	Dry	Wet	Snow/Slush	Ice/Frost
Fatality	10	2		
Two or more Injuries	208	41	5	
One Injury	811	195	8	6
No Injuries	4485	968	65	34
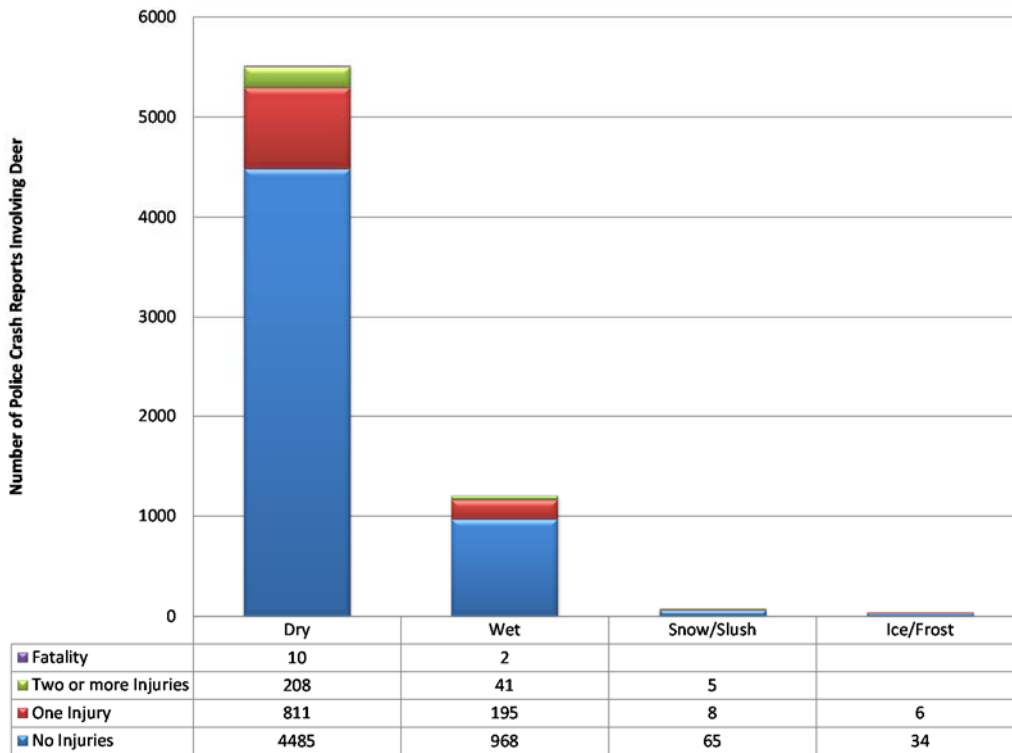
Figure 5-6 Deer-Vehicle Crash Reports by Severity and Roadway Conditions (2008-12)

5.5. DVC by Driver's License Issuing State

It is frequently questioned whether drivers who hit deer are predominantly out-of-state drivers who may not be as aware of the risk of hitting deer. The state in which the driver was licensed is used in this analysis. This isn't an ideal measure because individuals can move to or from West Virginia and not update their driver's license for months. Also, drivers who live in bordering states may work in West Virginia and be a regular driver as well. Figure 5-7 depicts the distribution of the issuing state for the DVCs from 2008-2012. The majority of drivers hitting deer are licensed in West Virginia (78%). The next highest percentages are drivers from the bordering states of Ohio (6%), Virginia (3%), Pennsylvania (2%), Maryland (2%), North Carolina (1%), and Kentucky (1%). The remaining states comprise the other

7%. There are certainly more WV drivers on the roads in WV, so their exposure and opportunity to hit a deer is much higher than other drivers.

Unfortunately, there isn't data available for the number of miles driven by in-state and out-of-state drivers. However, the in-state and out-of-state percentages for DVCs can be compared to the overall crashes to see if DVCs are over-represented. Figure 5-8 shows the percentage of drivers by state for all crash types from 2008-2012. Overall 84% of all crashes involved a driver licensed in WV, as compared to 78% for the DVC. Based on these numbers alone, it can be stated that a higher percentage of DVCs (22%) involve an out-of-state driver compared to all crash types (16%).
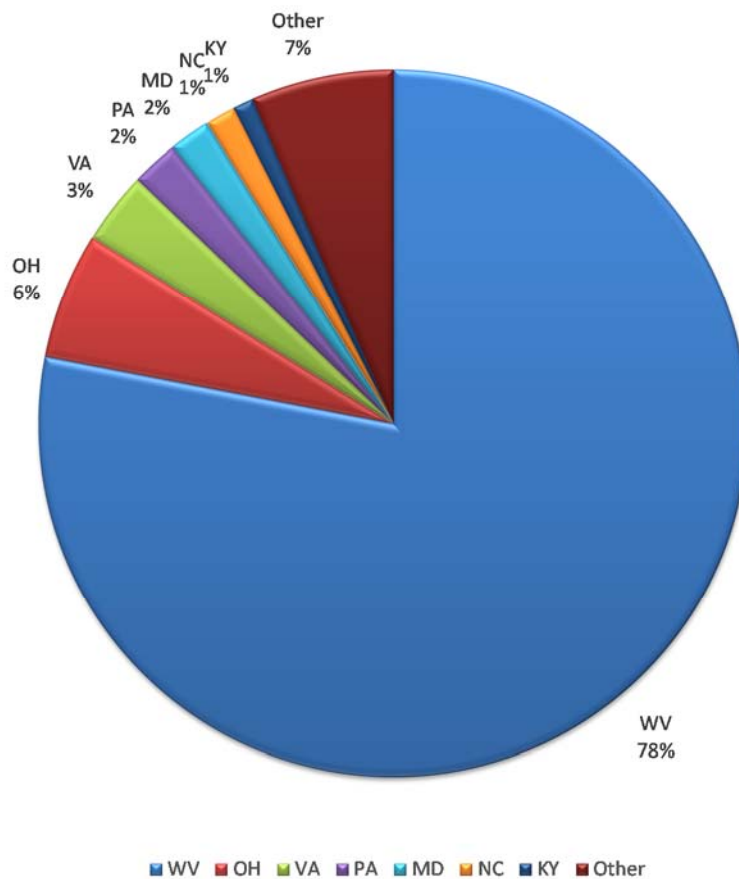
Figure 5-7 Deer-Vehicle Crash Reports by Driver's License Issuing State (2008-12)

■ WV ■ OH ■ VA ■ PA ■ MD ■ NC ■ KY ■ Other
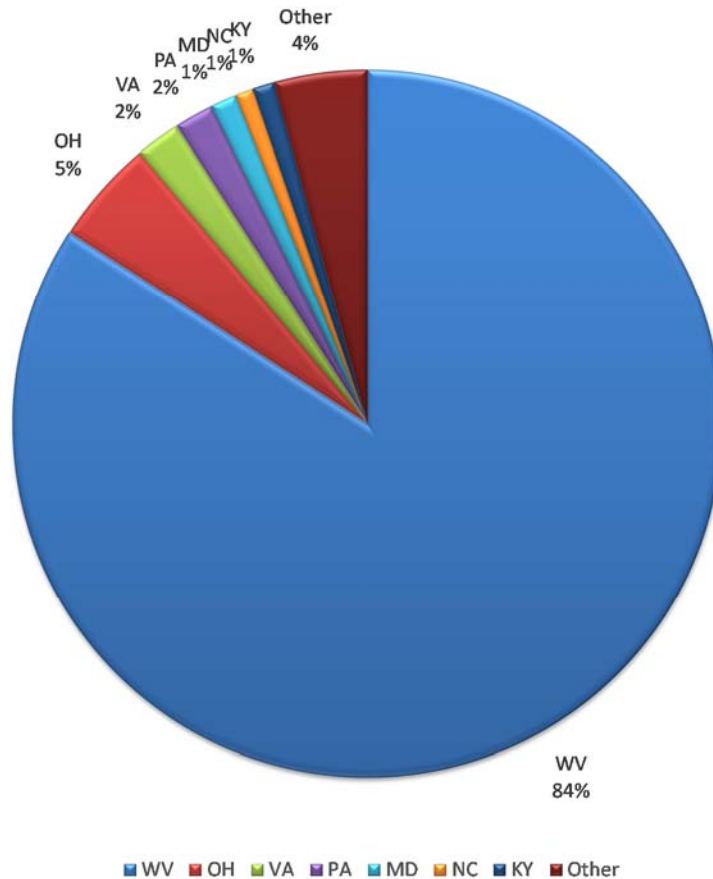
Figure 5-8 Total Crash Reports by Driver's License Issuing State (2008-12)

5.6. DVC by Severity and Road Classification

Figure 5-9 depicts the crash severity by roadway type. It is assumed that severity increases as speeds increase. The most DVCs were reported on WV and County Routes. Those routes also experienced a higher number of injuries. This is most likely explained by the fact that most WV and county routes are 2-lane roadways. If a driver swerves to miss a deer, the probability of leaving the roadway is significantly higher because there are narrower shoulders and less recovery area compared to Interstates and US Routes. The probability of hitting another vehicle on an Interstate or US route with multiple lanes and a divided median is much lower.
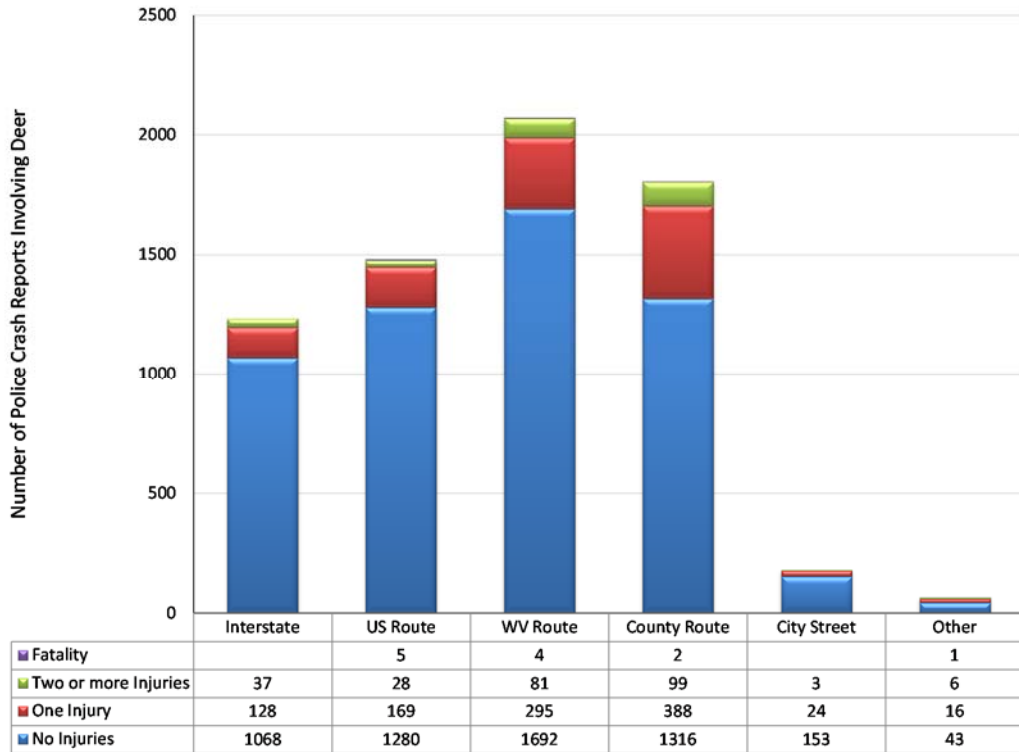
Figure 5-9 Deer-Vehicle Crash Reports Severity and Roadway Classification (2008-12)

5.7. DVC by Severity and Interstate Route Number

Figure 5-10 illustrates the number of DVCs reported on each Interstate route and by severity level. Figure 5-11 provides the percentage of crashes for each Interstate route. Note that Interstate distances vary significantly, and there is no adjustment applied here to take that into account. I-64 and I-77 both had 29% of the crashes, followed by I-79 with 26%. All three of these appeared to have similar proportions of crashes with injuries. There were no fatalities from DVCs on Interstates.

	I-64	I-68	I-70	I-77	I-79	I-81	I-470
■ Two or more Injuries	7	4		14	10	1	1
■ One Injury	41	5	3	41	35	3	
■ No Injuries	310	65	42	303	282	52	14
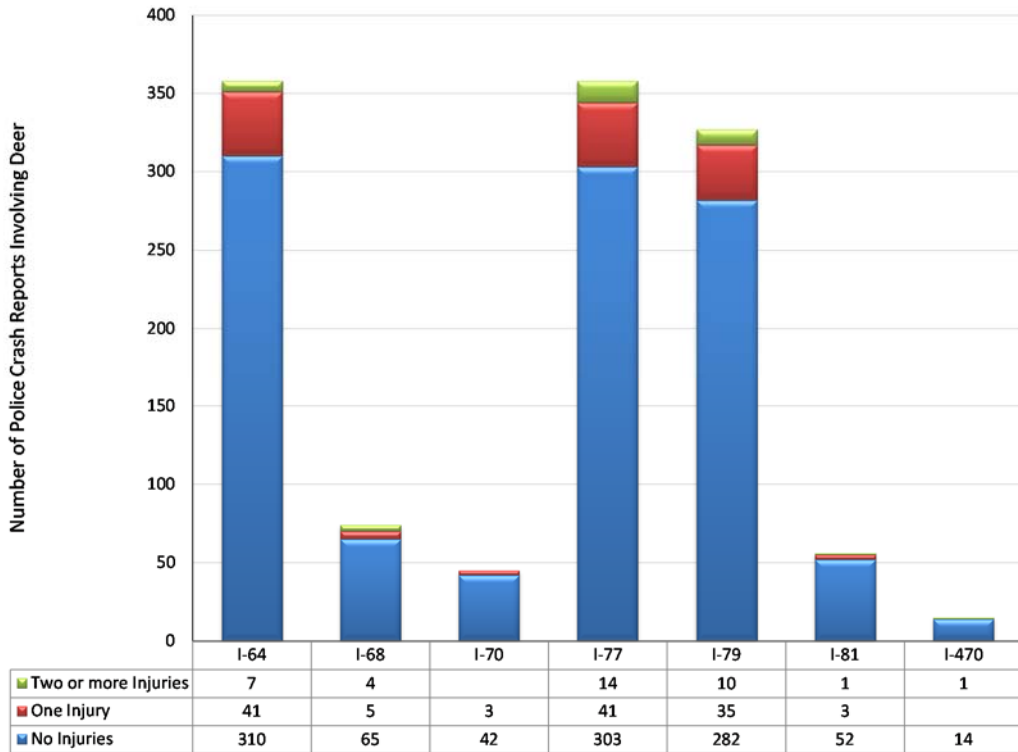
Figure 5-10 Deer-Vehicle Crash Reports by Severity and Interstate Route (2008-12)
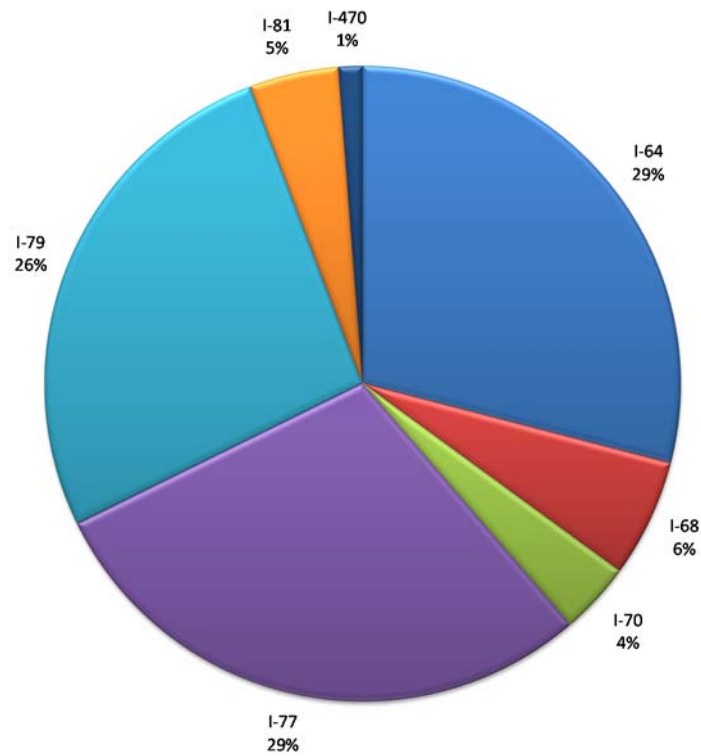
Figure 5-11 % of Deer-Vehicle Crash Reports by Interstate Route (2008-12)

5.8. DVC by Severity and US Route Number

Figure 5-12 illustrates the number of DVCs reported on each US route and by severity level. Figure 5-13 provides the percentage of crashes for each US route. Similar to Interstates, the US route distances vary significantly, and there is no adjustment applied here to take that into account. US 19 had the highest percentage of crashes (22%), followed by US 50 (13%), US 119 (12%), and US 60 (11%). The only US routes that appear to have a disproportionate amount of crashes with injuries are US 33 and US 219. One fatality occurred on US 19, US 35, US 119, US 219, and US 460 due to a DVC.

	011	019	022	030	033	035	040	050	052	060	119	219	220	250	340	460	522
■ Fatality		1				1					1	1				1	
■ Two or more Injuries		3	2		4	1		3	2	3	2	2		1	1	3	1
■ One Injury		25	3		23	1	1	33	7	18	13	23	4	7	7	2	2
■ No Injuries	14	300	11	1	78	82	25	155	23	148	162	54	17	45	51	60	54
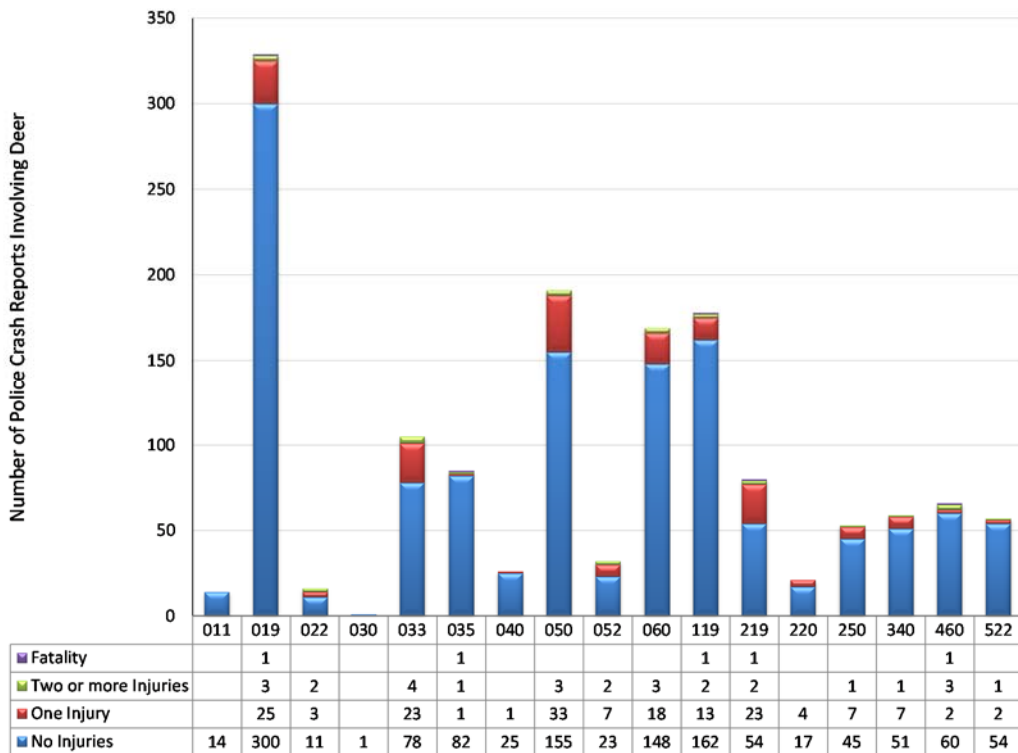
Figure 5-12 Deer-Vehicle Crash Reports by Severity and US Route (2008-12)
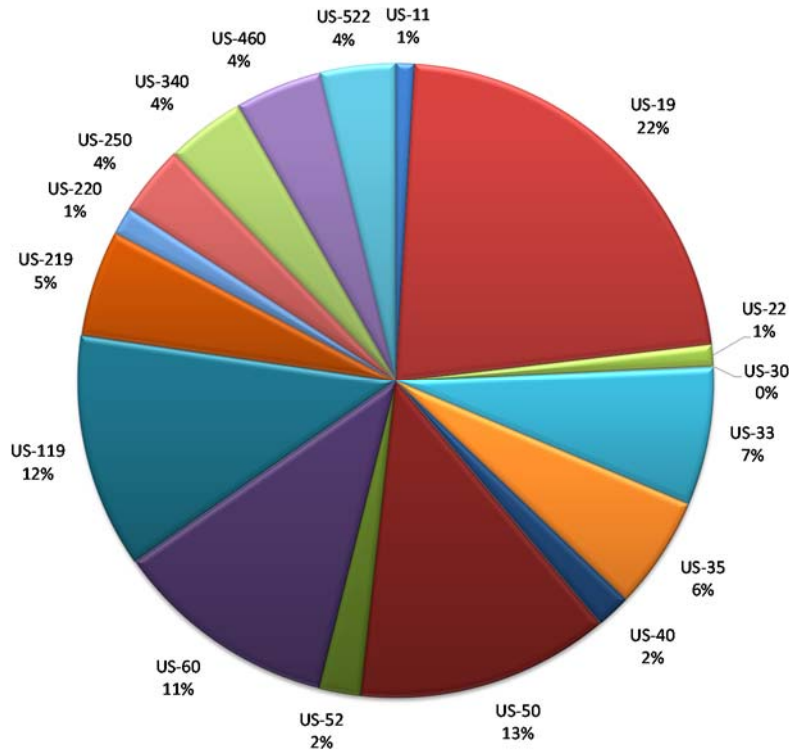
Figure 5-13 % of Deer-Vehicle Crash Reports by US Route (2008-12)

5.9. Summary

This section contained an analysis of the police crash reports that indicated a deer was involved. The data was analyzed to provide insight regarding the frequency by month, by day of the week, hour of the day, light conditions, severity, type of object first hit, road conditions, driver's license state, and route. The majority of crashes were reported during October and November each year. Crashes were evenly distributed across each weekday during the 5-year period analyzed. The majority of crashes occurred at night, although there were a considerable number of daytime crashes. Most crashes occurred with dry pavement conditions. The majority of drivers hitting deer are licensed drivers in West Virginia. However, the percentage of out-of-state drivers involved in DVCs was 6% higher than the percentage of out-of-state drivers in all crash types in West Virginia (22% compared to 16%). There were a total of 12 fatalities during the 5-year period that occurred as a result of a deer. Six occurred when the deer was hit first and the other six occurred when the driver presumably swerved to miss the deer and hit another vehicle or ran off the road and struck another object or overturned. Five fatalities occurred on US Routes, four on WV Routes, and three on County Routes.

Because funding for safety-related roadway projects is allocated based primarily on crash severity, it is important to put the quantity and severity of crashes involving a deer into perspective. While DVCs are

perceived as a problem in West Virginia, there are other types of preventable crashes occurring that have much higher injury and fatality rates. Table 5-1 shows the breakdown of DVC severity compared to other types of crashes in West Virginia. Less than 1% of all fatal crashes involve a deer and approximately 2% of all non-fatal crashes with an injury involve a deer. The crash types with the highest percentage of the overall fatalities are drivers hitting other vehicles due to various causes (31%), vehicle rollovers (16%), vehicles running off the road and hitting trees and embankments (13% and 7%), and vehicles hitting pedestrians (7%).

When implementing mitigation to reduce crashes using safety funding, projects are ranked based on their benefit-cost ratios where the costs are the actual construction and maintenance cost and the benefits are derived through a reduction in crashes. The cost basis that is used for these calculations are dependent on the severity level of the crash. The Highway Safety Manual provides comprehensive crash costs by severity (*144*). The WVDOT applies an adjustment to account for inflation and the rates below correspond to the rates for 2013.

- Fatality = $5,289,928
- Injuries = $59,248 to $285,022 depending on injury type
- Property Damage Only = $9,765

Therefore, mitigating crashes that involve a high rate of fatalities and injuries will always take priority over crash types that are predominantly property damage only, which tends to often be the case with DVCs. Approximately 542 property damage only crashes would have the equivalent cost of a single fatality from a benefit-cost calculation standpoint.

Table 5-1 Comparison of DVC and Non-DVC Crashes by First Harmful Event (2008-12)

First Harmful Event	Property Damage Only		Injury		Fatality	
	DVC	Non-DVC	DVC	Non-DVC	DVC	Non-DVC
Animal	4,402	2,871	463	307	6	2
Bridge Overhead Structure		115	0	22		
Bridge Pier or Support		68	2	59		3
Bridge Rail	7	522	1	262		9
Cable Median Barrier	18	1,102	1	185		3
Cargo/Equipment Loss or Shift	1	266	0	41		
Concrete Traffic Barrier	11	1,437	4	655		4
Culvert	25	442	16	388		7
Curb		423	0	136		7
Ditch	195	4,294	98	2,291		36
Embankment	248	5,056	143	3,609	1	108
Fell/Jumped from Motor Vehicle		32	3	128		16
Fence	59	2,072	20	510		16
Fire/Explosion	2	33	0	5		5
Guardrail End	25	616	15	341		14
Guardrail Face	149	4,629	54	1,926	1	68
Immersion		27	0	19		4
Impact Attenuator/Crash Cushion		86	0	31		
Jackknife	1	154	2	41		
Mailbox	18	562	7	181		1
Other Moving Vehicle	114	80,303	64	30,873	1	468
Other Fixed Object	44	3,036	22	1,056		34
Other Non-Collision	80	3,904	46	1,576		52
Other Non-Fixed Object	9	1,189	5	277		9
Other Post, Pole, or Support	14	864	7	272		6
Other Traffic Barrier	5	98	1	27		5
Overturn/Rollover	143	3,393	160	4,202	3	242
Parked Motor Vehicle	19	12,492	5	1,196		13
Pedalcycle		84	0	369		4
Pedestrian		170	0	1,573		100
Railway Vehicle		34	0	22		1
Thrown or Falling Object	1	184	0	39		3
Traffic Sign Support	16	850	4	203		4
Traffic Signal Support		63	0	22		1
Tree (Standing)	172	2,922	134	2,710		201
Utility Pole/Light Support	91	3,400	52	2,075		57
Work Zone/Maint Equipment		103	0	25		2
Total	5,869	137,896	1,329	57,654	12	1,505

6. <u>WEST VIRGINIA DEER-VEHICLE COLLISION HOTSPOT IDENTIFICATION</u>

6.1. <u>Methodology</u>

This section of the report addresses the following objective of the study.

8. Conduct a Geographic Information System (GIS) analysis of DVCs in West Virginia to identify and rank hotspots, if the available data is adequate.

The WVDOT Linear Reference System (LRS) of routes and mileposts was obtained and used as the basis for this GIS analysis. In order to identify hotspots and conduct a correlation analysis, the roadway network was broken up into segments of a desirable length. GIS software was used to quantify and assign the various roadway and environmental attributes to each roadway segment for the calculation of crash rates and modeling to identify correlations. Due to the milepost numbering system utilized in the WVDOT LRS on WV and County Routes, static segments had to be used for the hotspot analysis. Ideally, a sliding window analysis could be conducted, where a fixed window length (e.g., 1.0 mile) is used to evaluate each interval (e.g., 0.0 to 1.0, 0.1 to 1.1, 0.2 to 1.2, etc.). Currently, milepost numbers for WV and County routes reset to zero at county lines and there was no feasible way to overcome this hurdle to implement the sliding window. WVDOT is in the process of updating the LRS system to have continuous milepost numbering, which will facilitate this type of analysis in the future.

Initially, the roadway was divided into 0.5-mile segments. This distance was chosen in order to best pinpoint the locations of the hotspots. However, after the hotspot maps that resulted from this exercise were evaluated, it was clear that many crash locations being reported by the police were concentrated around the whole-mile and half-mile markers on Interstates and US Routes, as well as major intersections or interchanges. Therefore, the roadway network was divided into 2.0-mile segments and this formed the basis of the analysis in the remainder of the project. Knowing that crashes were likely to be assigned to the half-mile and whole-mile markers, a conscious decision was made for the first segment (starting at 0.0) to be 2.25 miles in length and each subsequent segment to be 2.0 miles. Therefore, the most frequent locations would be less likely to occur on a segment boundary and more likely to be in the interior of the segment. Figure 6-1 illustrates the distribution of segment lengths in the analysis for Interstates, US Routes, and WV Routes. The roadway segments that are less than a half mile were most likely WV Routes that had a short total segment length. The roadway segments that are greater than 2.5 miles are most likely the end of a route where the additional length less than 2.0 miles was appended to the adjacent full 2.0-mile segment.
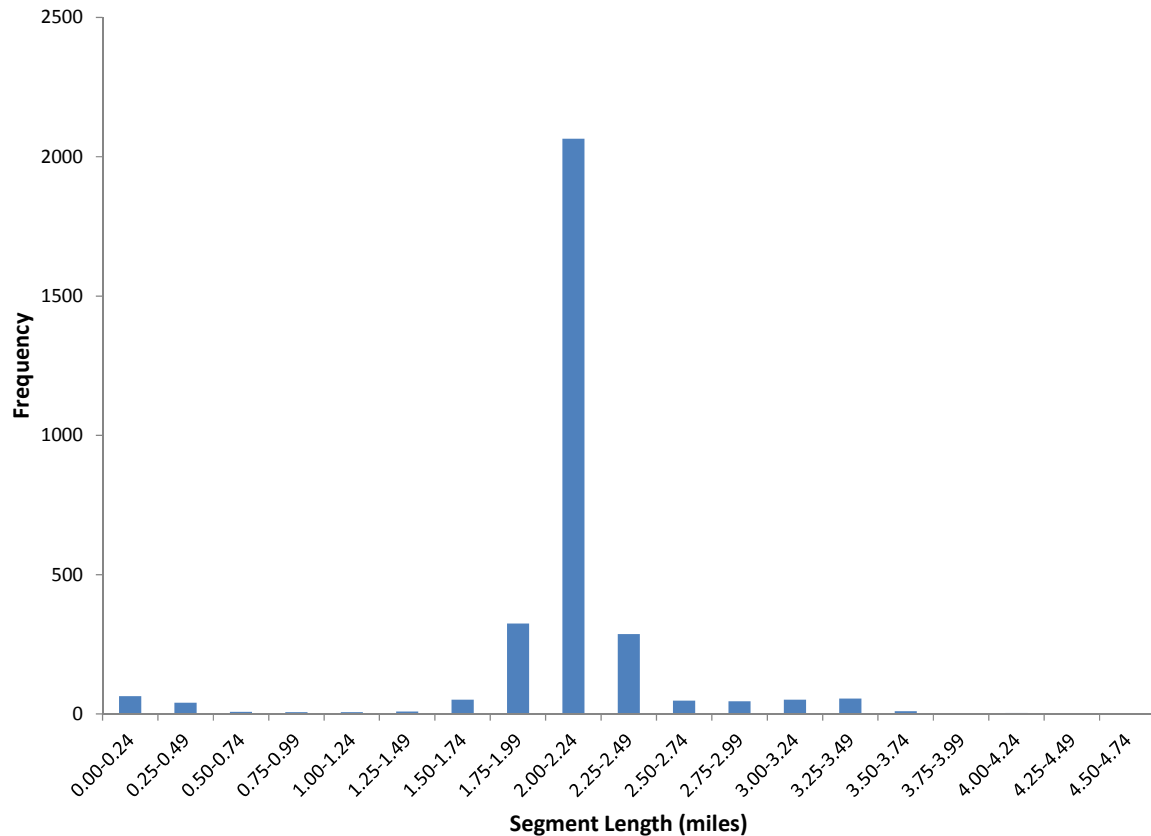
Figure 6-1 Distribution of Statewide Segment Lengths on Interstates, US and WV Routes

6.2. Deer-Vehicle Collision Hotspots

After the frequencies were assigned to the segments, the histogram in Figure 6-2 was generated for the Interstate, US Routes, and WV Routes.   Based on this distribution, HIGH frequency segments are defined as segments that experienced 13 or more crashes over the 5 year period, MEDIUM frequency is defined as segments that experienced 3-12 crashes, and LOW frequency is defined as segments that experienced 1-2 crashes. There are a total of 3,128 Interstate, US Route, and WV Route segments statewide, which results in 0.6% of them being high, 16.9% medium, and 31.2% low. Therefore, 51.3% of the Interstate, US Route, and WV Route segments in the state did not have a documented crash. The high DVC threshold of 13 per two-mile segment over five years (1.3 per mile per year) is slightly less than the "High" threshold applied in an Iowa study (1.75 per mile per year).

The map in Figure 6-3 depicts the locations of the hotspots statewide based on the count per segment. Based on this map, the general locations of the High segments are the eastern panhandle, the Summersville area in the central part of the state, the Parkersburg area in the western part of the state, and the Kanawha River Valley near Winfield in the western part of the state.

While these counts of DVC per 2-mile segment may not seem very high for a 5-year period, the actual number of DVCs is likely much higher due to underreporting. Based on the 3-8% approximation of the police crash underreporting from Section 4.6, the High frequency threshold of 13 reported crashes could be representative of 162-433 crashes over a 5-year period.
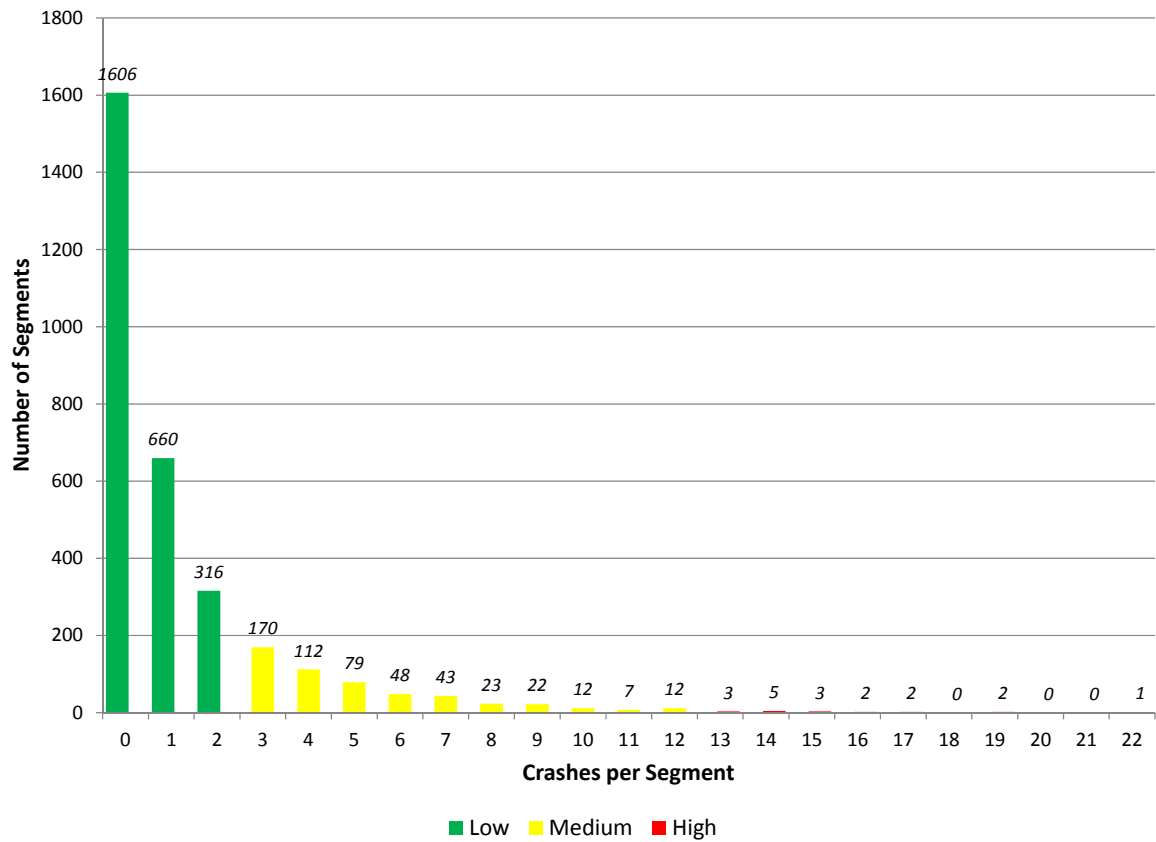
Figure 6-2 Frequency of DVCs per Segment (2008-2012)
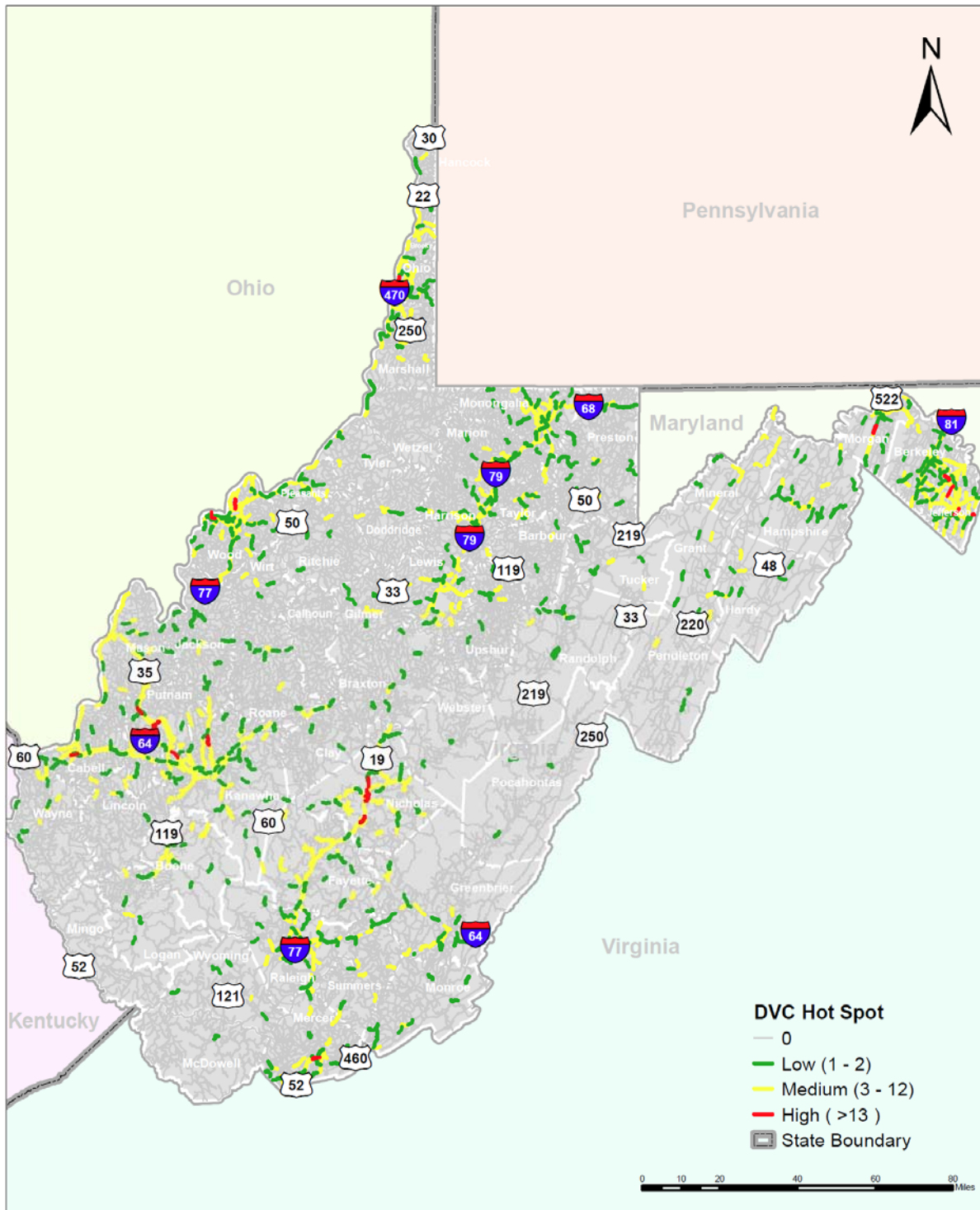
Figure 6-3 Location of Hotspot Segments based on Raw Count for All Roads (2008-2012)

6.3. Top Locations Based on Raw Count

The Interstate, US Route, and WV Route high frequency segments that are identified as the hotspots based on the police crash reported DVC raw counts are summarized in Table 6-1 with the corresponding county, route, milepost range, AADT, and crash rate (calculated using Equation 1 in Section 2.9.4). The crash rates are used to sub-rank the segments within each group that has the same DVC count. Figure 6-4 to Figure 6-21 depict the locations of these segments for easier interpretation. The locations of each crash are shown along with the severity and year the crash was reported. Table 6-2 contains a list of the medium frequency segments (8-12 count only) with four or more lanes only.

Table 6-1 Location Details of High Frequency Segments based on DVC Count

Rank	DVC Count	County	Route	Milepost Range	AADT	Crash Rate**	Map
1	22	Nicholas	US 19	10.3-12.3	17,613	34.0	Figure 6-4
2*	19	Mason	WV 62	4.3-6.3	2,041	254.9	Figure 6-5
3	19	Kanawha	I 64	45.4-47.7	62,787	7.3	Figure 6-6
4	17	Wood	US 50	0.0-2.3	13,354	31.0	Figure 6-7
5	17	Jefferson	US 340	6.2-8.2	19,786	23.5	Figure 6-8
6*	16	Nicholas	WV 41	15.0-17.0	6,600	66.3	Figure 6-9
7	16	Cabell	US 60	10.3-12.3	22,781	19.2	Figure 6-10
8*	15	Morgan	US 522	8.2-10.2	9,355	44.0	Figure 6-11
9	15	Nicholas	US 19	14.3-16.4	13,745	29.7	Figure 6-12
10	15	Kanawha	I 77	109.7-111.7	21,438	19.1	Figure 6-13
11*	14	Jefferson	WV 9	0.0-1.66	4,972	92.9	Figure 6-14
12	14	Nicholas	US 19	4.3-6.3	12,803	29.8	Figure 6-15
13*	14	Putnam	WV 34	18.5-21.4	10,897	23.7	Figure 6-16
14	14	Mercer	US 460	12.7-14.8	16,564	23.0	Figure 6-17
15	14	Putnam	I 64	36.0-38.0	36,500	10.5	Figure 6-18
16*	13	Putnam	US 35	16.5-18.5	6,663	52.8	Figure 6-19
17*	13	Ohio	WV 2	4.6-6.6	14,433	24.7	Figure 6-20
18	13	Mercer	US 460	0.0-2.3	15,600	19.7	Figure 6-21

* Denotes 2-lane roadway
**Crash Rate = (Total # of Crashes * 10^8) ÷ (# of years * Segment AADT * Segment Length * 365)

Table 6-2 Location Details of Medium Frequency Segments based on DVC <u>Count</u> (4+ lanes)

Rank	DVC Count	County	Route	Milepost Range	AADT	Crash Rate*
1	12	Ohio	US 40	4.4-6.5	7,177	45.5
2	12	Putnam	US 35	10.4-12.4	11,786	27.5
3	12	Fayette	US 19	16.4-18.4	12,200	26.7
4	12	Jefferson	US 340	4.2-6.2	17,653	18.6
5	12	Putnam	US 35	4.3-6.3	19,496	16.7
6	12	Ohio	I 70	2.3-4.3	30,550	10.5
7	12	Putnam	I 64	38.0-40.0	41,590	7.9
8	12	Brooke	US 22	2.5-5.9	26,123	7.3
9	11	Fayette	US 19	6.3-8.3	24,358	12.3
10	11	Cabell	I 64	28.2-30.2	32,500	9.2
11	10	Lewis	US 33	22.3-24.3	13,750	19.9
12	10	Boone	US 119	10.3-12.3	13,898	19.6
13	10	Boone	US 119	12.3-14.3	17,988	15.2
14	10	Marshall	US 250	36.4-39.2	17,699	11.0
15	10	Putnam	I 64	31.8-34.0	36,500	6.7
16	9	Harrison	US 50	2.2-4.2	9,819	25.2
17	9	Nicholas	US 19	8.3-10.3	14,800	16.6
18	9	Putnam	US 35	8.4-10.4	14,754	16.5
19	9	Lewis	I 79	93.9-95.9	17,455	14.0
20	9	Wood	I 77	169.3-171.3	18,984	13.0
21	9	Kanawha	I 77	111.7-113.7	20,500	12.0
22	9	Fayette	US 19	12.4-14.4	21,800	11.2
23	9	Raleigh	US 19	20.4-22.4	22,069	11.1
24	9	Monongalia	I 68	6.3-8.3	32,627	7.5
25	9	Putnam	I 64	34.0-36.0	36,500	6.7
26	9	Ohio	I 470	0.0-2.3	33,189	6.5
27	9	Cabell	I 64	18.2-20.2	40,658	6.0
28	8	Wood	US 50	14.3-16.3	10,800	20.3
29	8	Fayette	US 19	22.4-24.5	11,800	18.4
30	8	Nicholas	US 19	6.3-8.3	12,870	16.9
31	8	Putnam	US 35	6.3-8.4	19,496	11.1
32	8	Lewis	I 79	99.9-102.0	23,000	9.4
33	8	Cabell	I 64	24.2-26.2	33,500	6.5
34	8	Harrison	I 79	124.7-126.7	41,873	5.2
35	8	Cabell	I 64	16.2-18.2	42,500	5.1
36	8	Ohio	I 70	0.0-2.3	39,811	4.8

* Crash Rate = (Total # of Crashes * 10^8) ÷ (# of years * Segment AADT * Segment Length * 365)
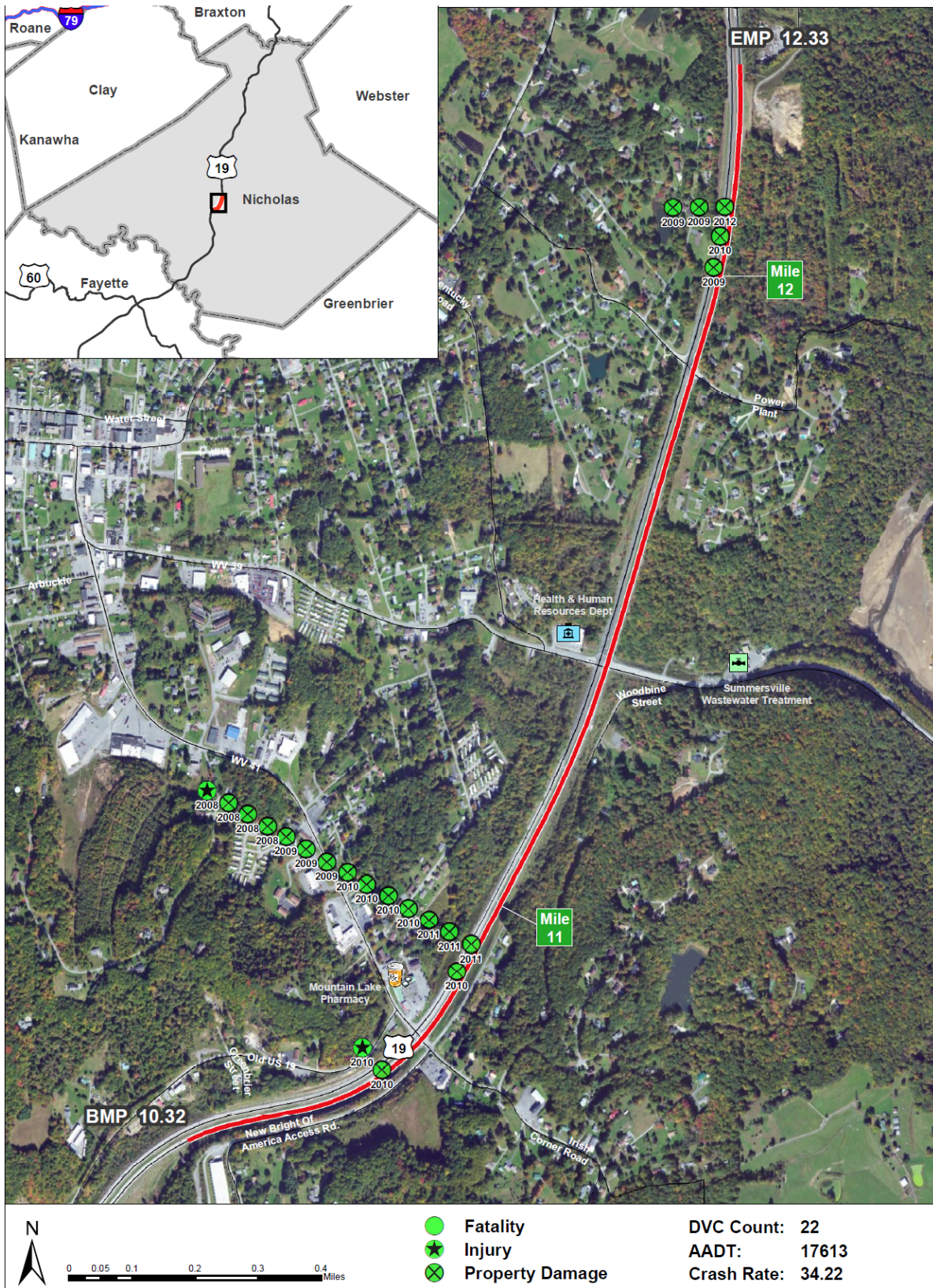
Figure 6-4 Location Map for US-19 in Nicholas County, Milepost 10.3-12.3 (Rank 1)
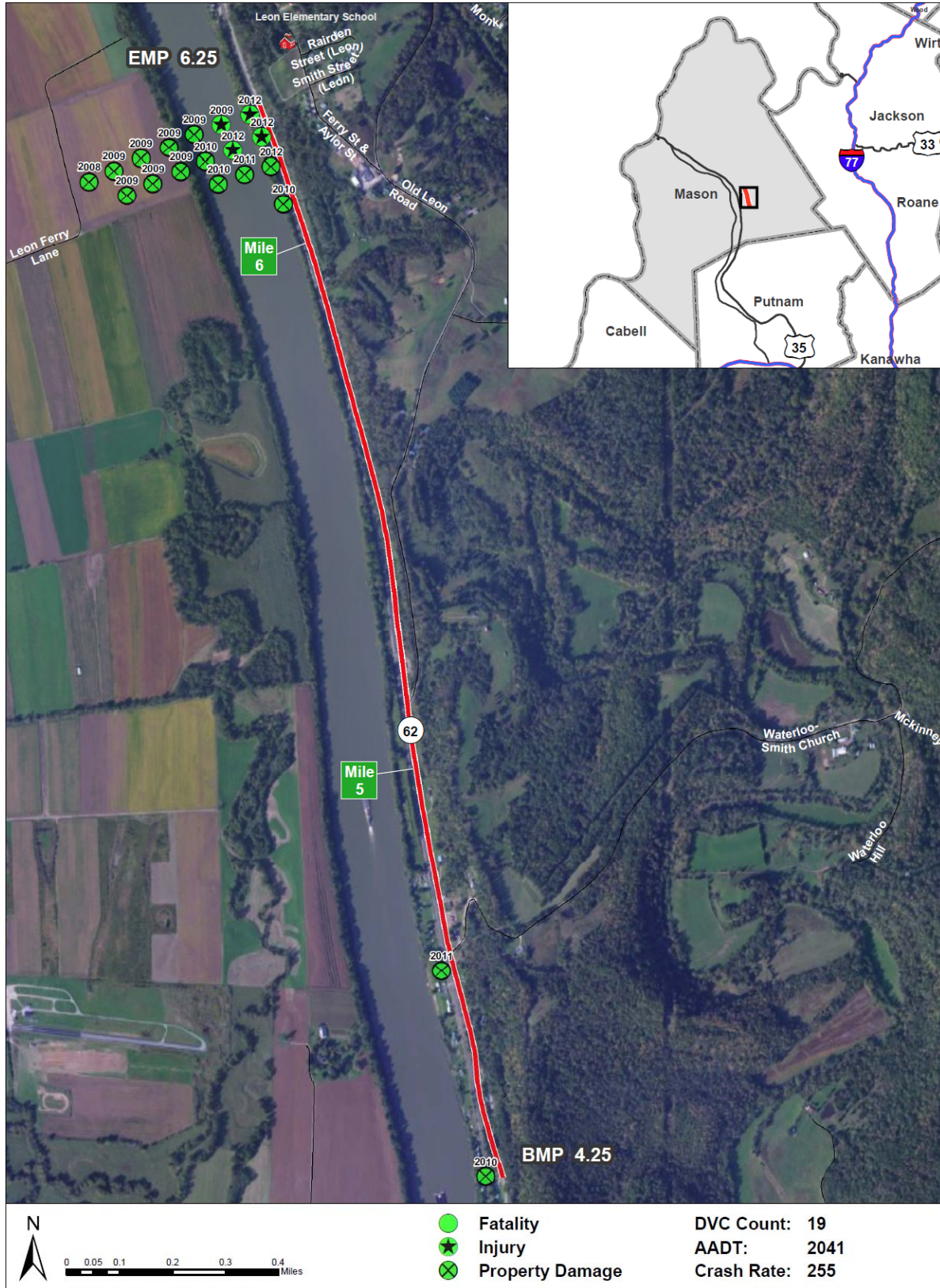
Figure 6-5 Location Map for WV-62 in Mason County, Milepost 4.3-6.3 (Rank 2)
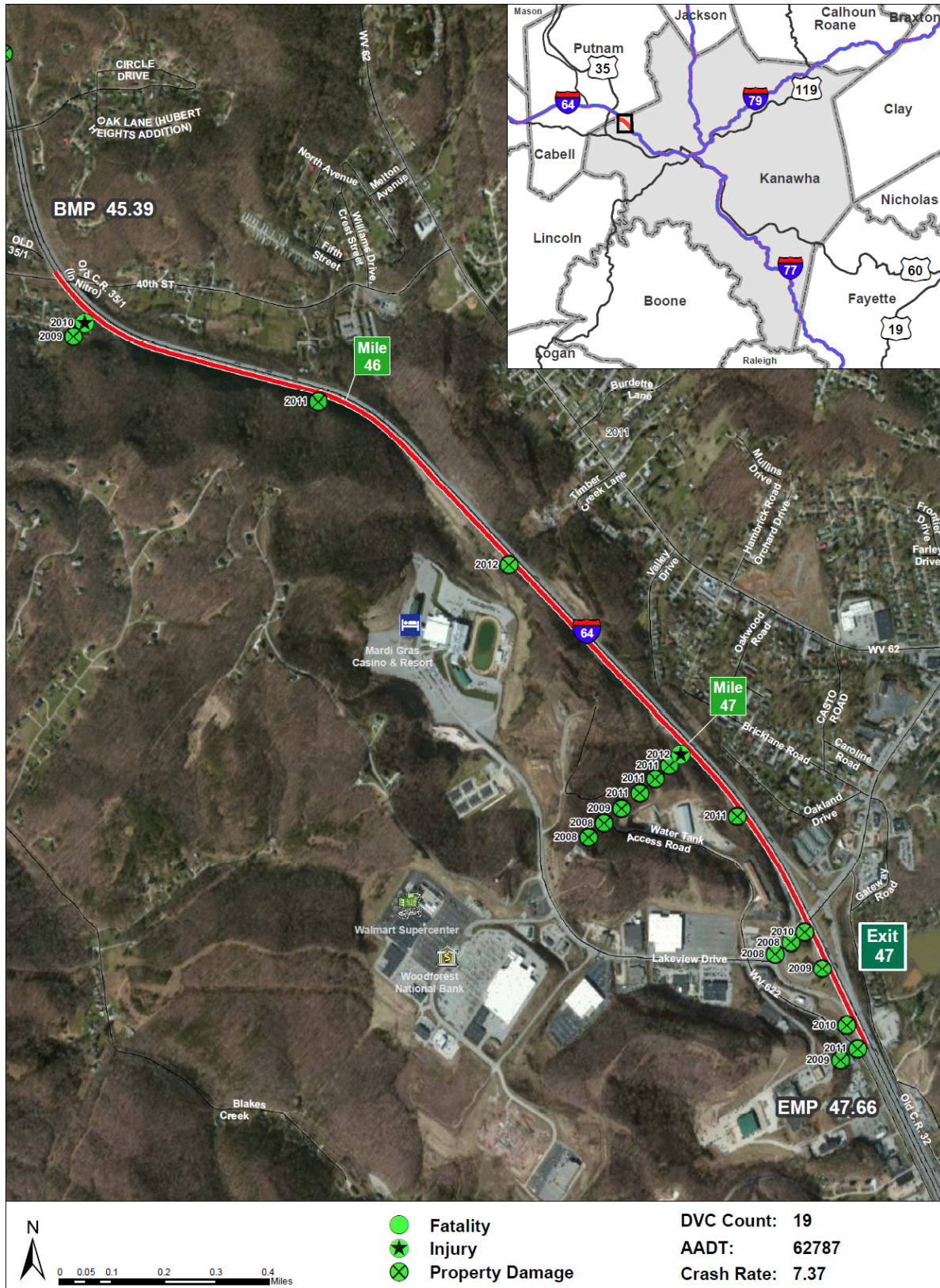
Figure 6-6 Location Map for I-64 in Kanawha County, Milepost 45.4-47.7 (Rank 3)
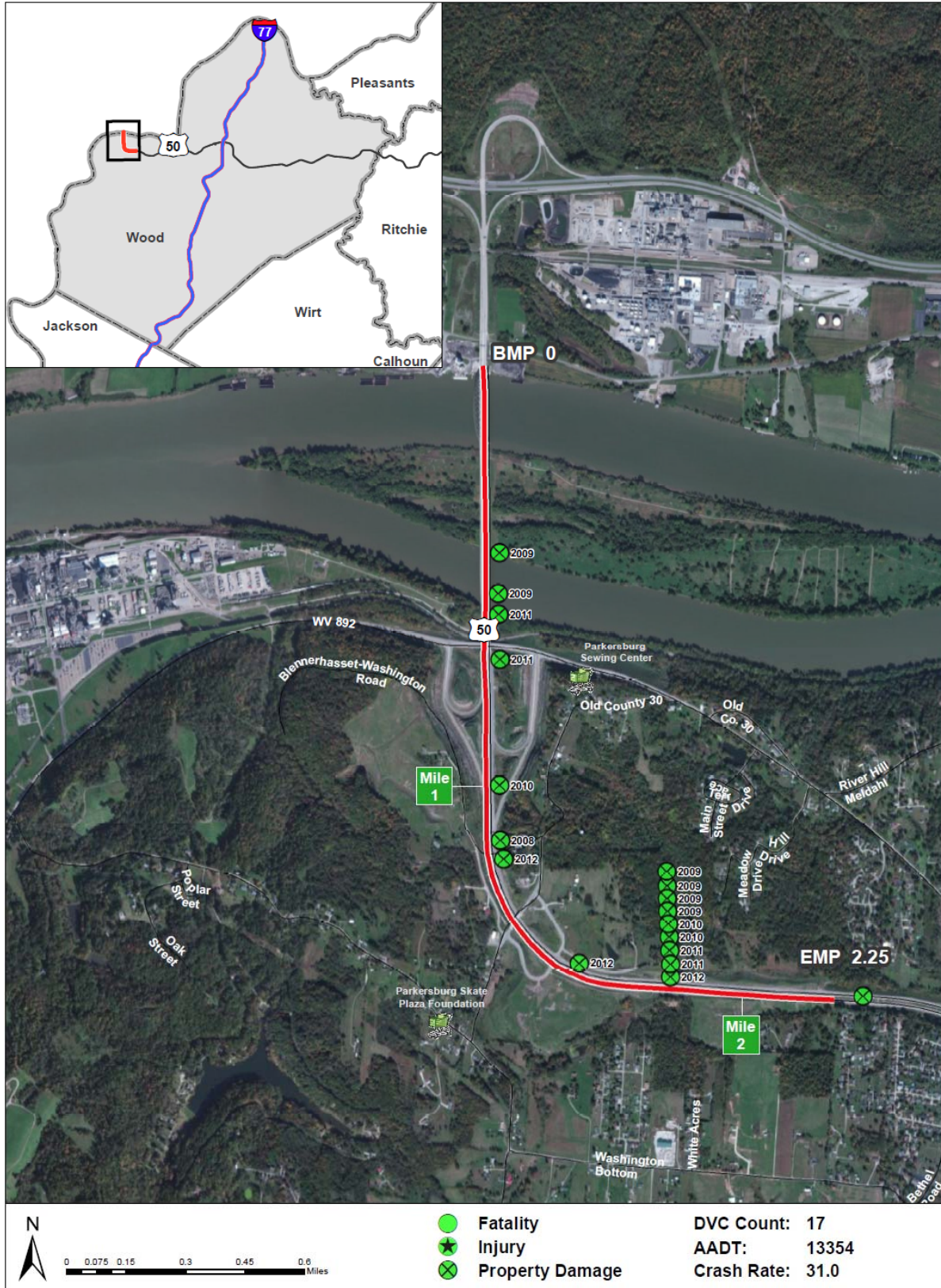
Figure 6-7 Location Map for US-50 in Wood County, Milepost 0.0-2.3 (Rank 4)
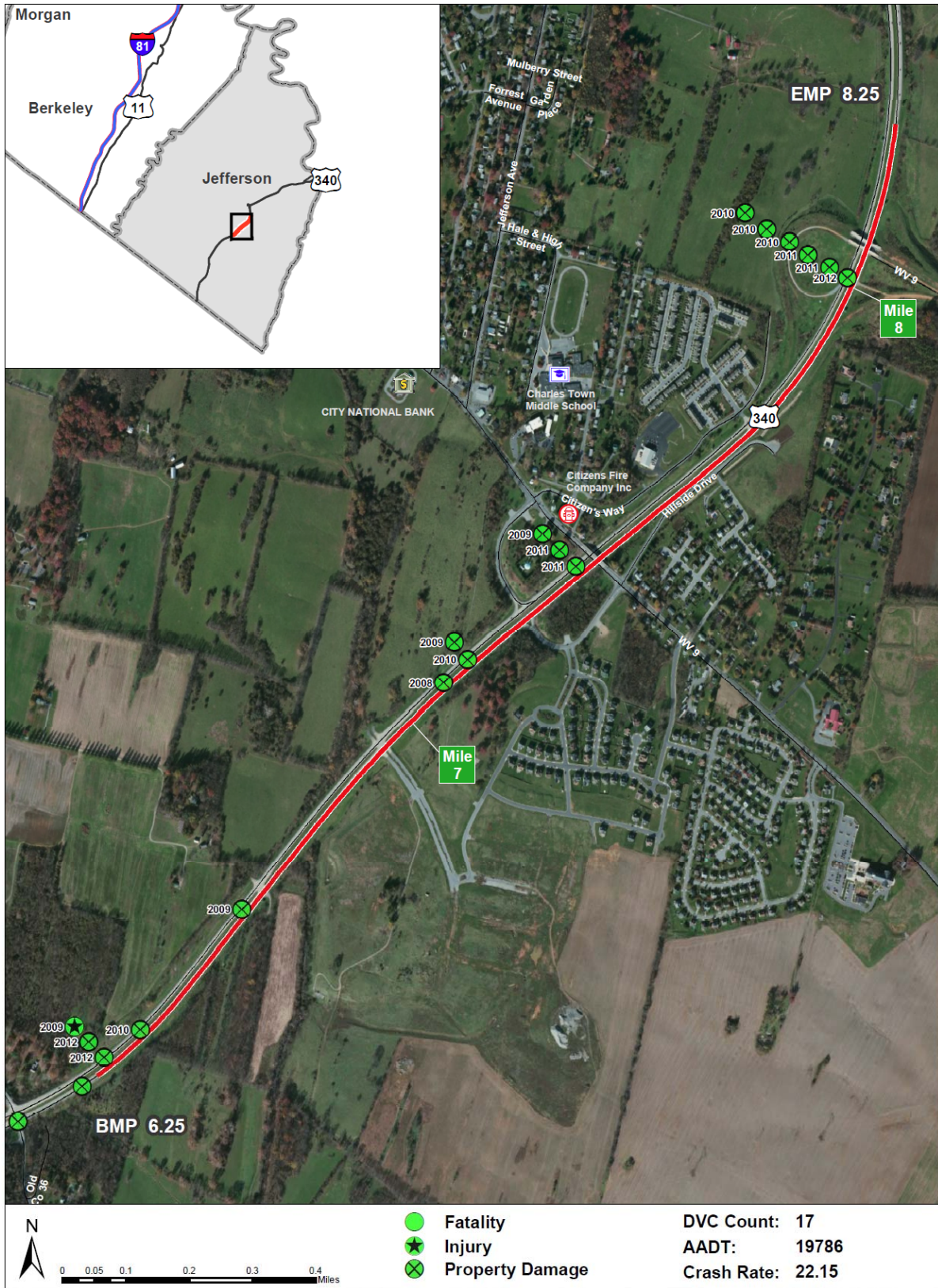
Figure 6-8 Location Map for US-340 in Jefferson County, Milepost 6.2-8.2 (Rank 5)
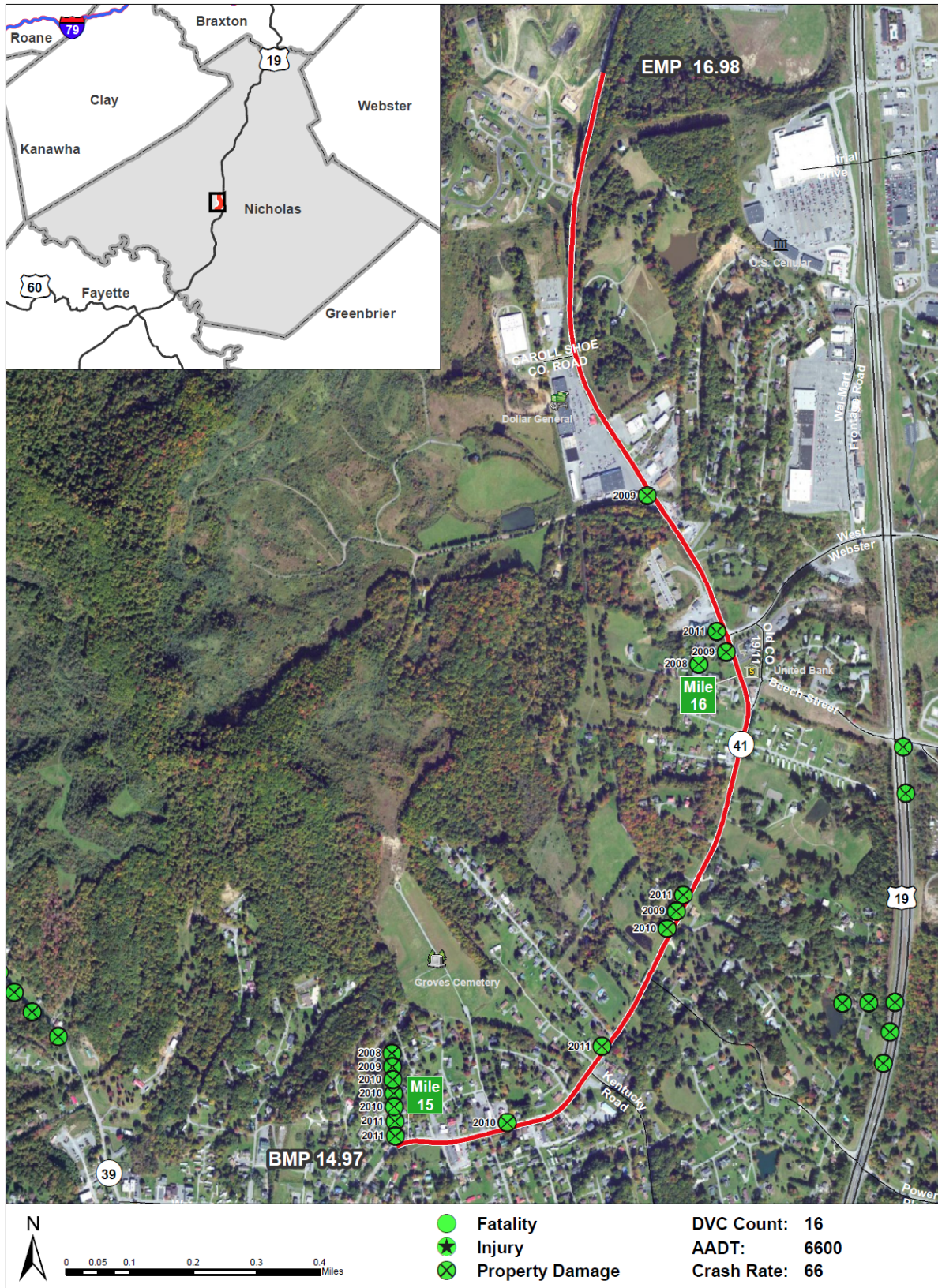
Figure 6-9 Location Map for WV-41 in Nicholas County, Milepost 15.0-17.0 (Rank 6)
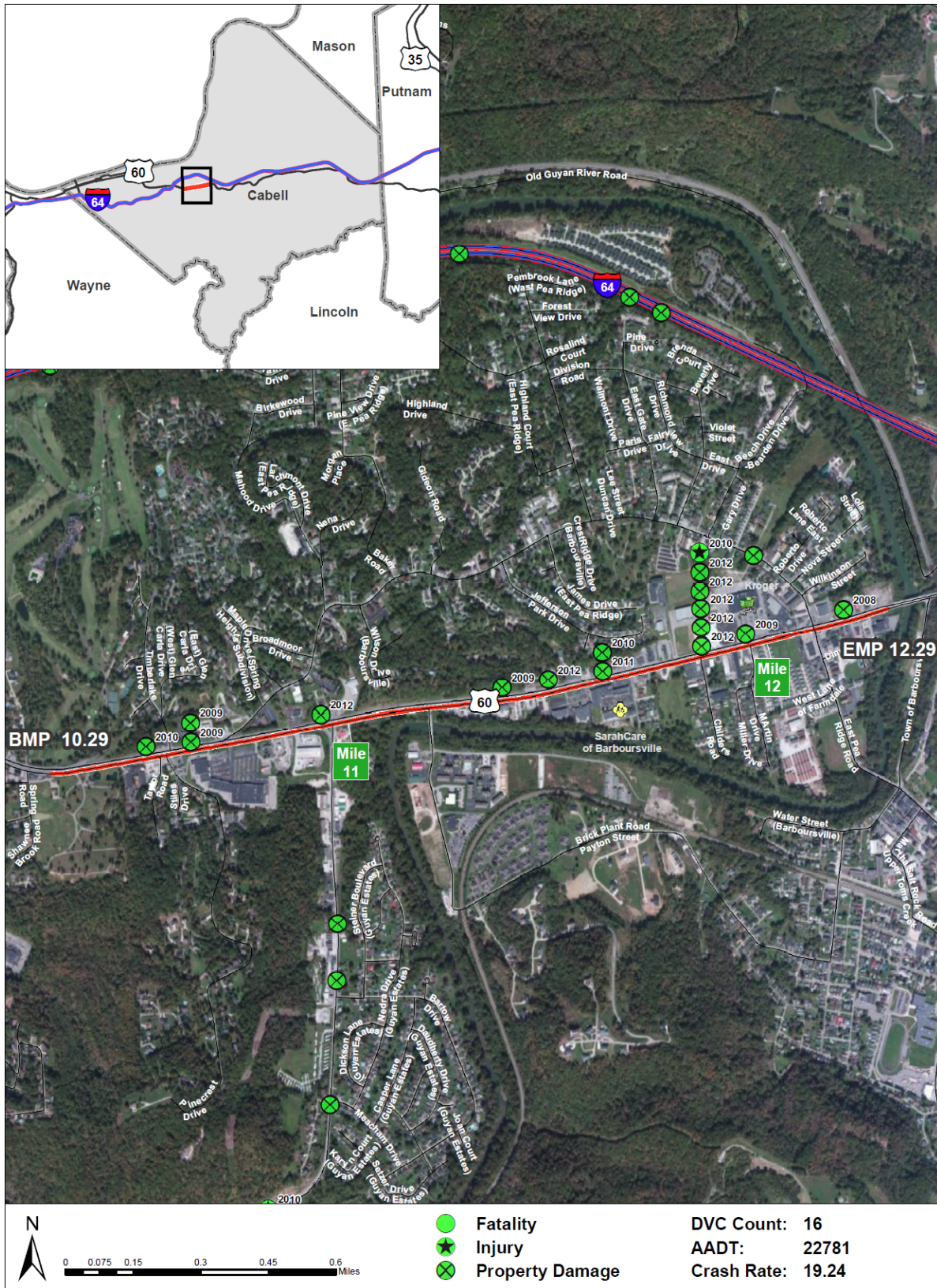
Figure 6-10 Location Map for US-60 in Cabell County, Milepost 10.3-12.3 (Rank 7)
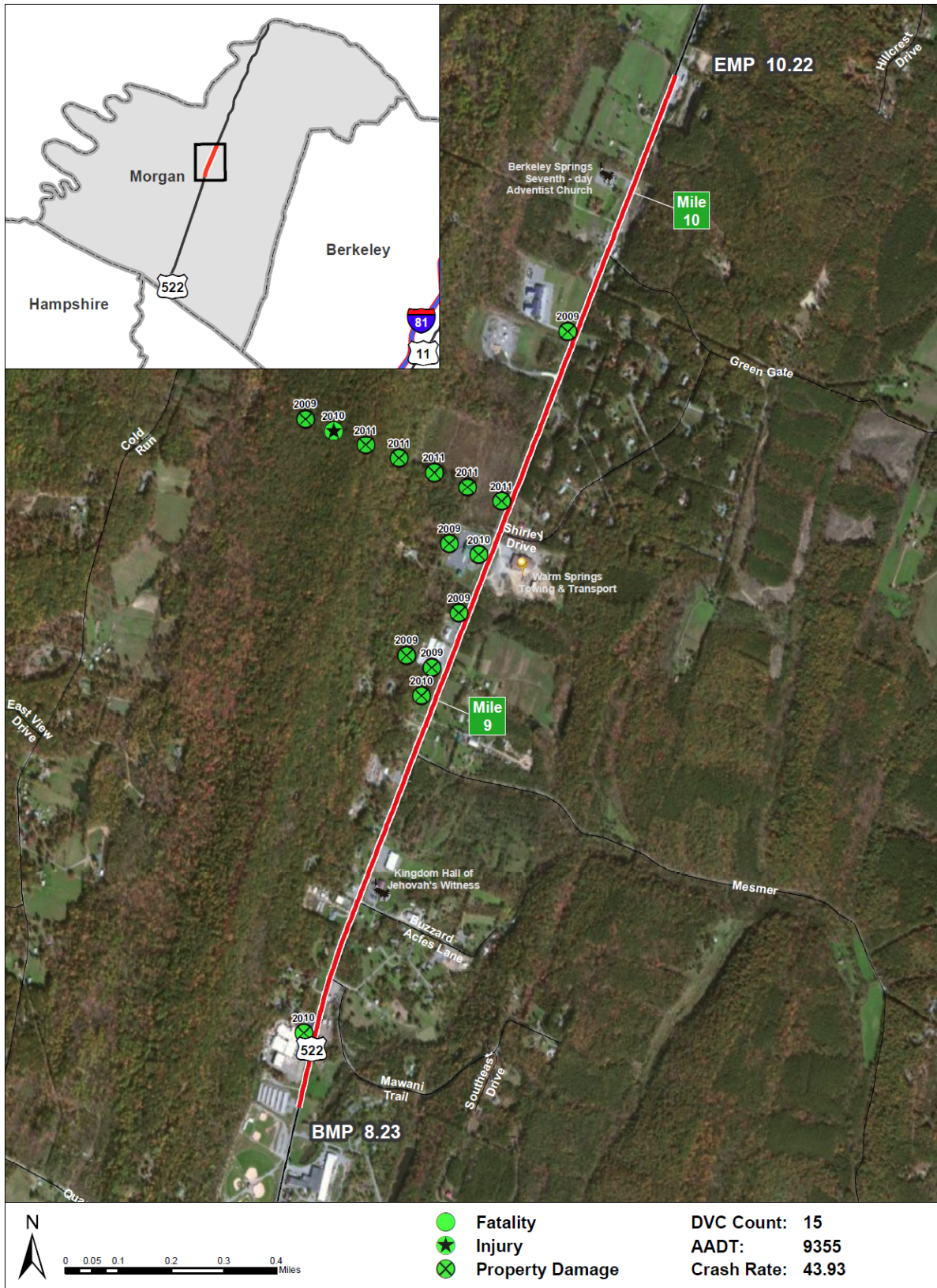
Figure 6-11 Location Map for US-522 in Morgan County, Milepost 8.2-10.2 (Rank 8)
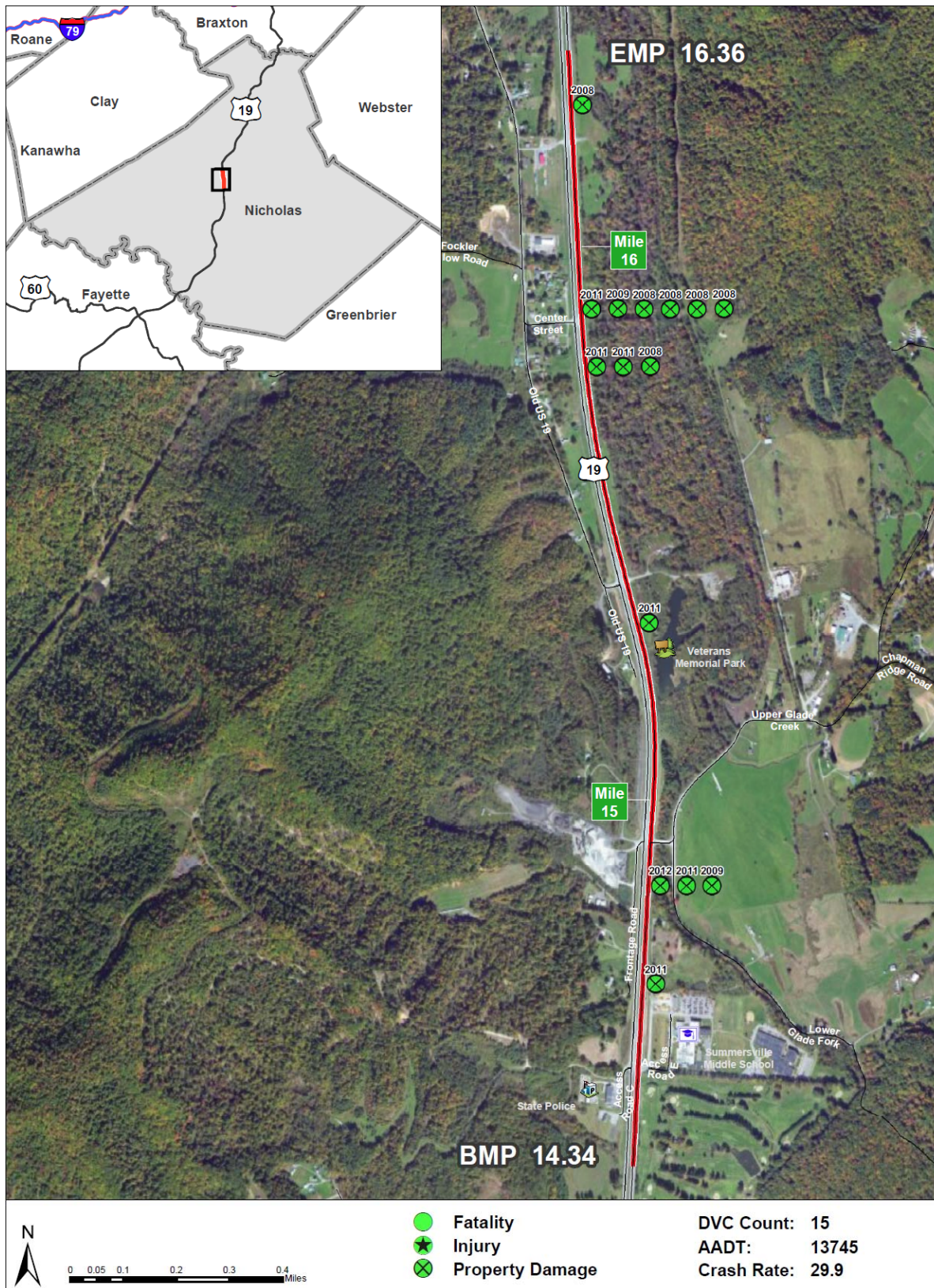
Figure 6-12 Location Map for US-19 in Nicholas County, Milepost 14.3-16.4 (Rank 9)
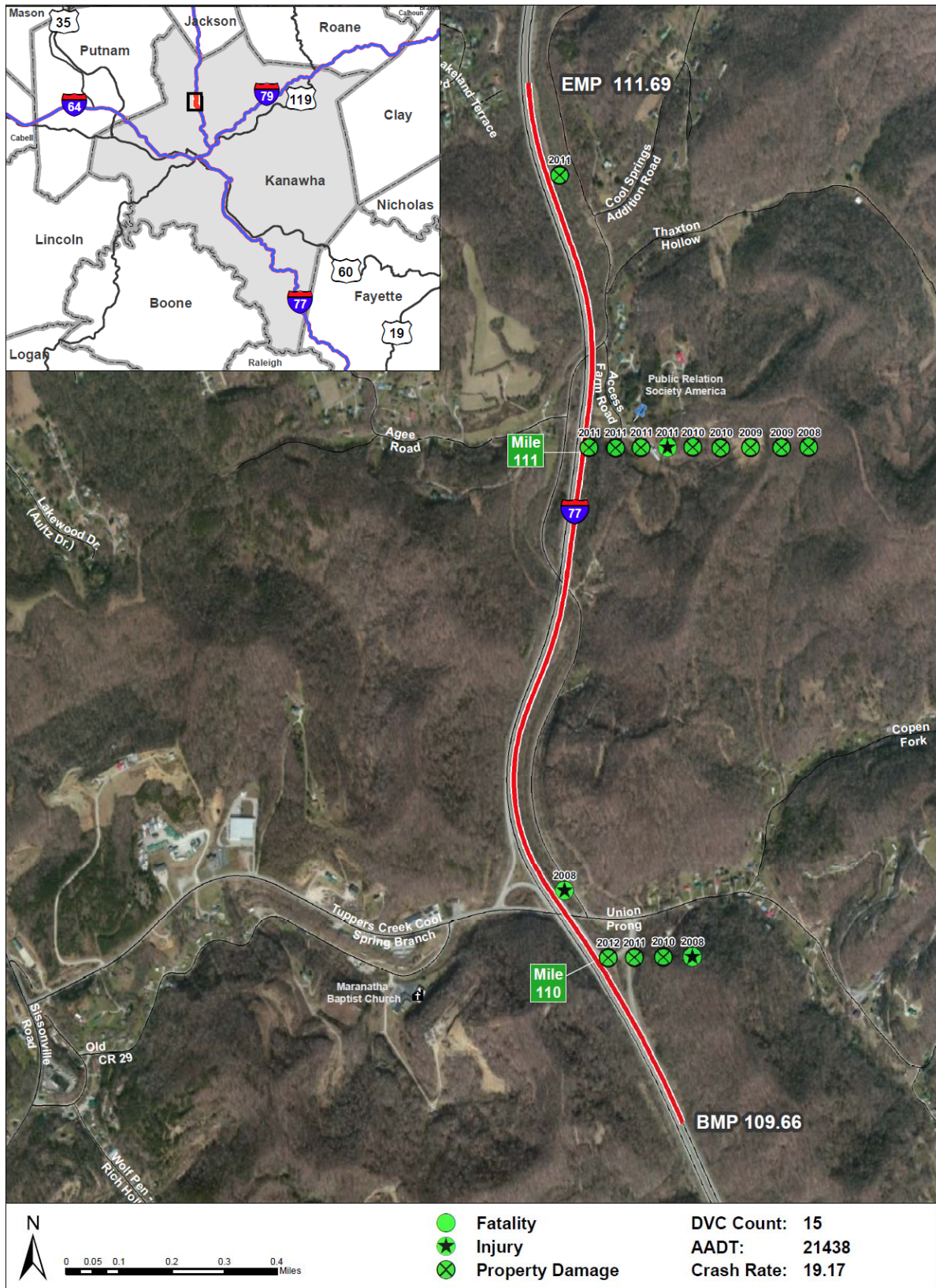
Figure 6-13 Location Map for I-77 in Kanawha County, Milepost 109.7-111.7 (Rank 10)
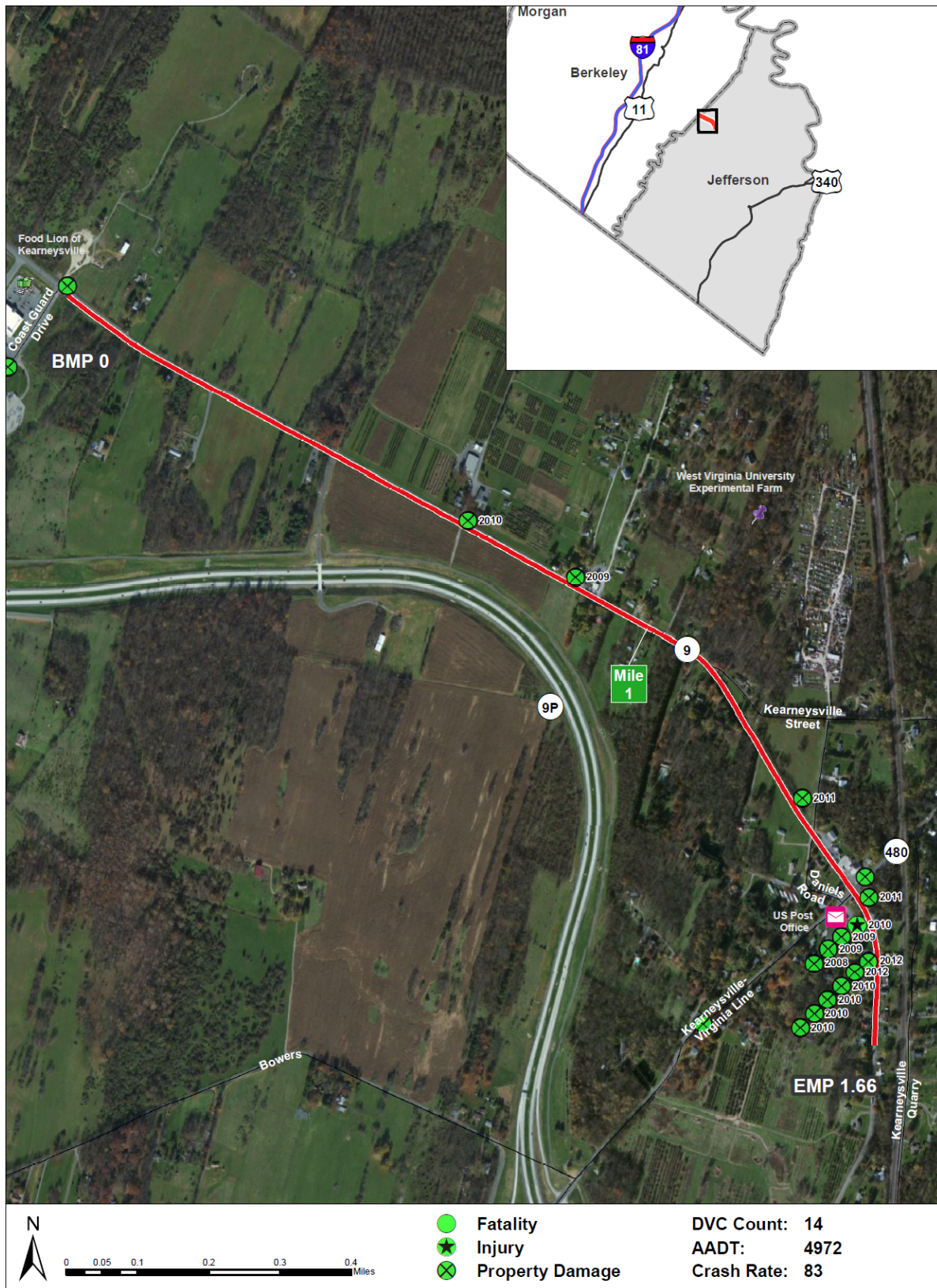
Figure 6-14 Location Map for WV-9 in Jefferson County, Milepost 0.0-1.7 (Rank 11)
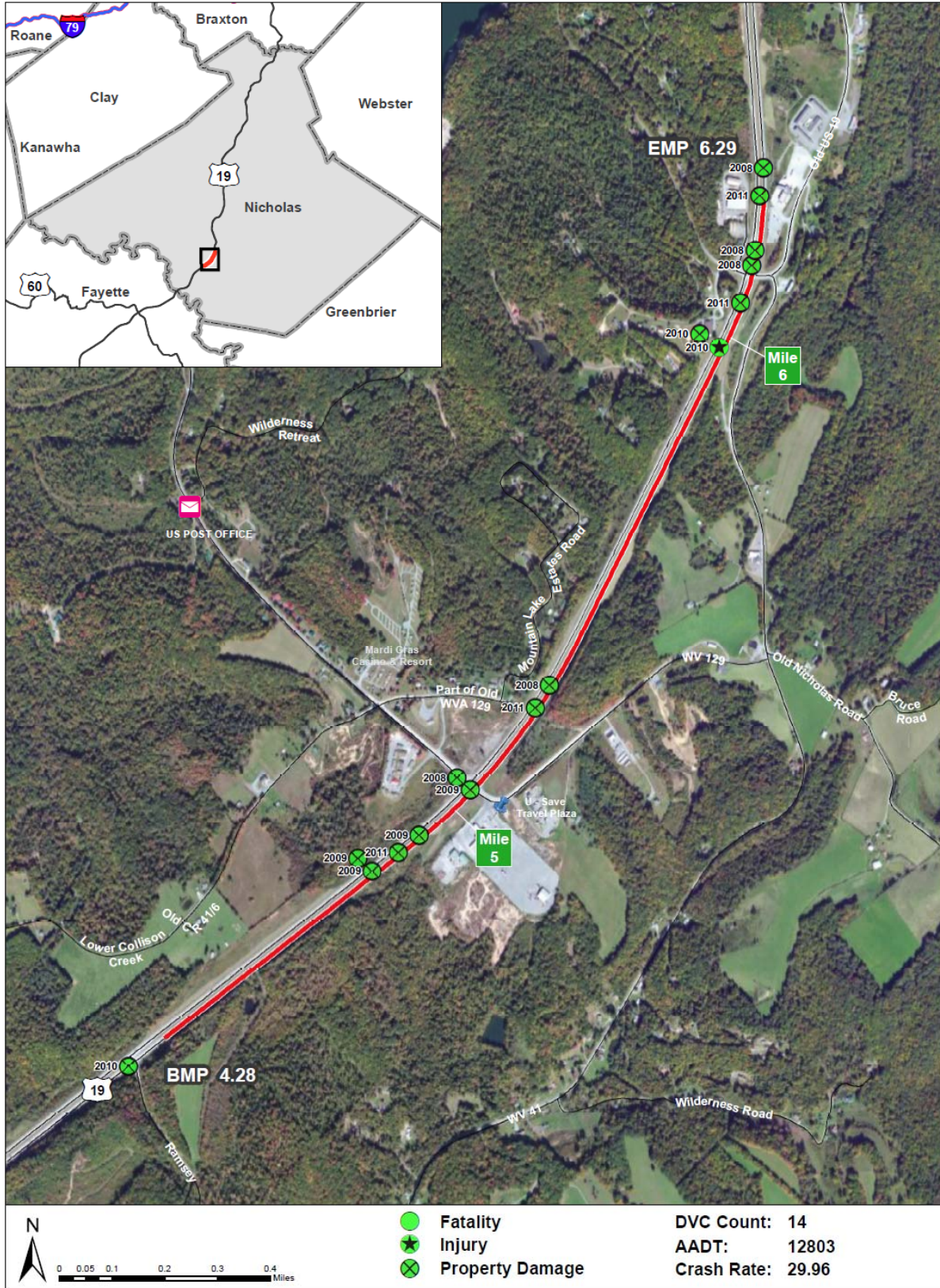
Figure 6-15 Location Map for US-19 in Nicholas County, Milepost 4.3-6.3 (Rank 12)
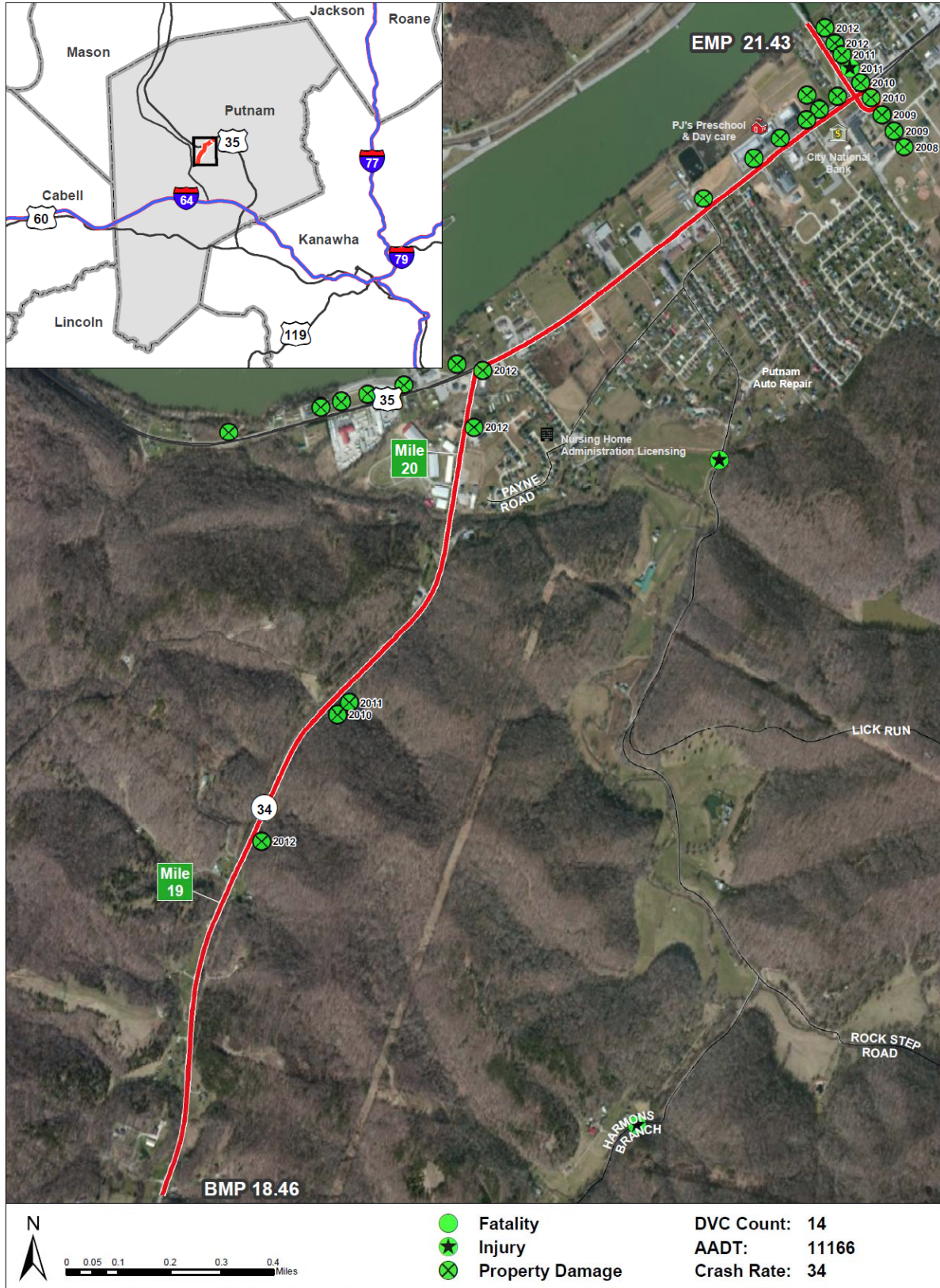
Figure 6-16 Location Map for WV-34 in Putnam County, Milepost 18.5-21.4 (Rank 13)
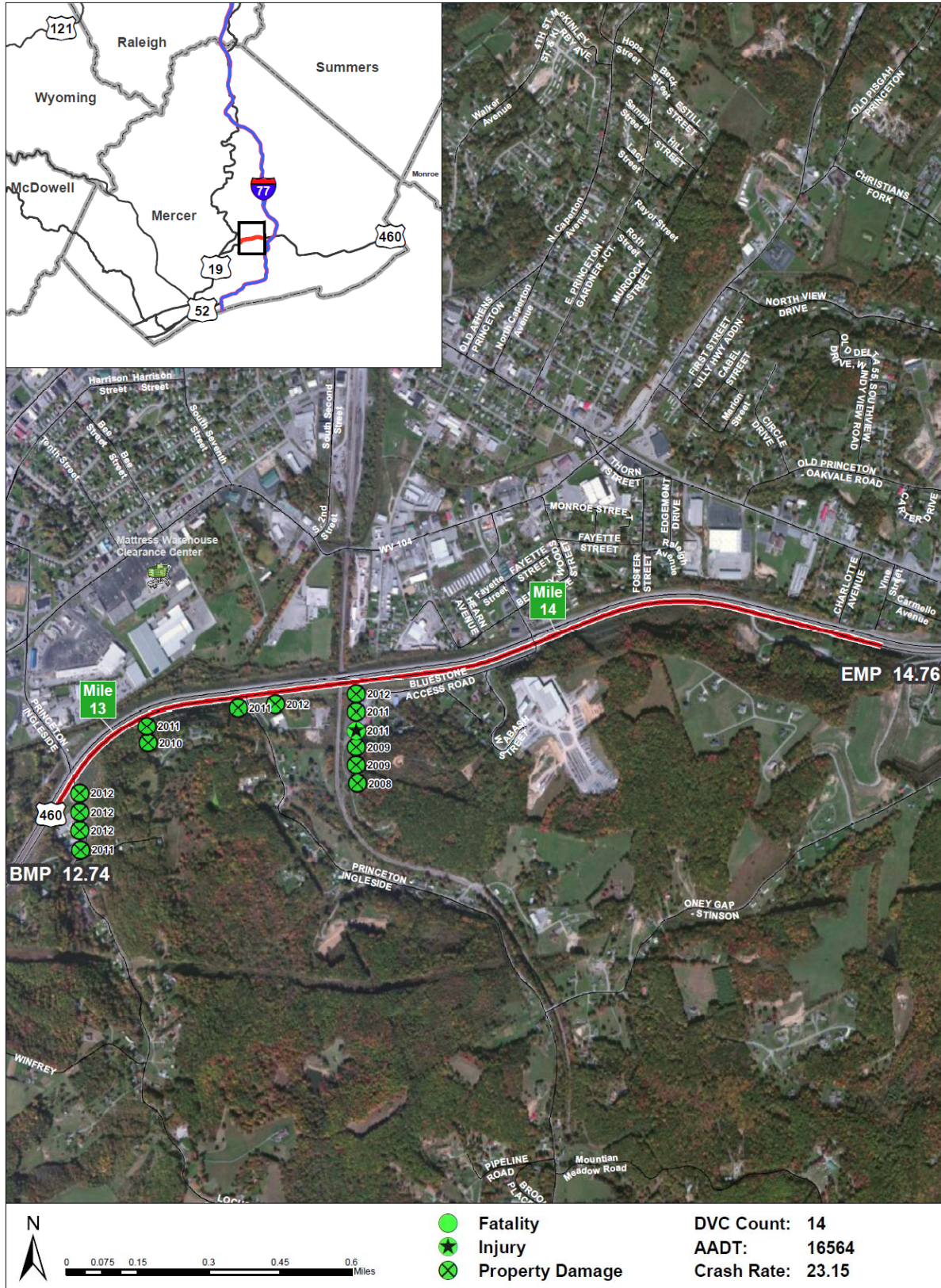
Figure 6-17 Location Map for US-460 in Mercer County, Milepost 12.7-14.8 (Rank 14)
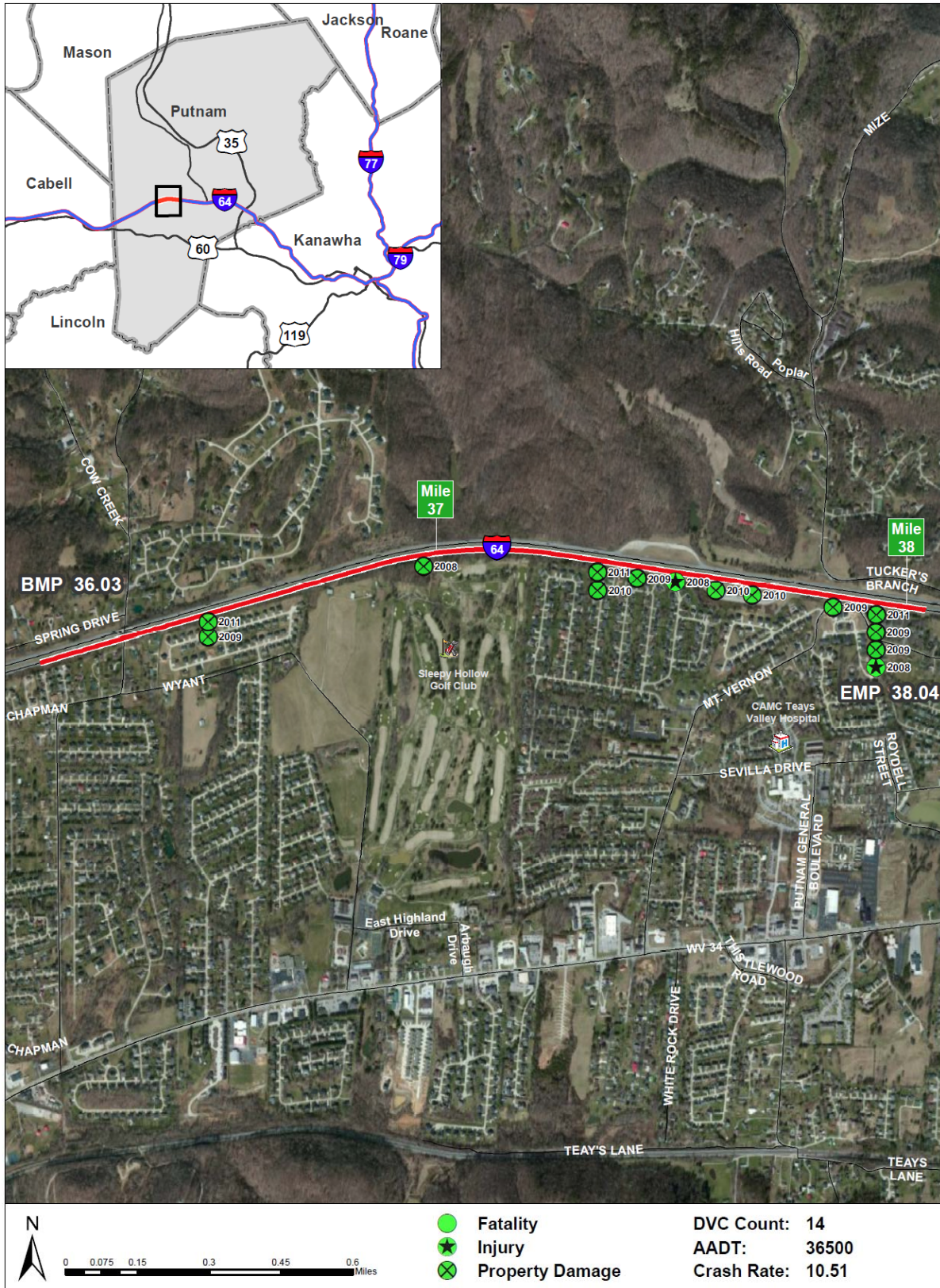
Figure 6-18 Location Map for I-64 in Putnam County, Milepost 36.0-38.0 (Rank 15)
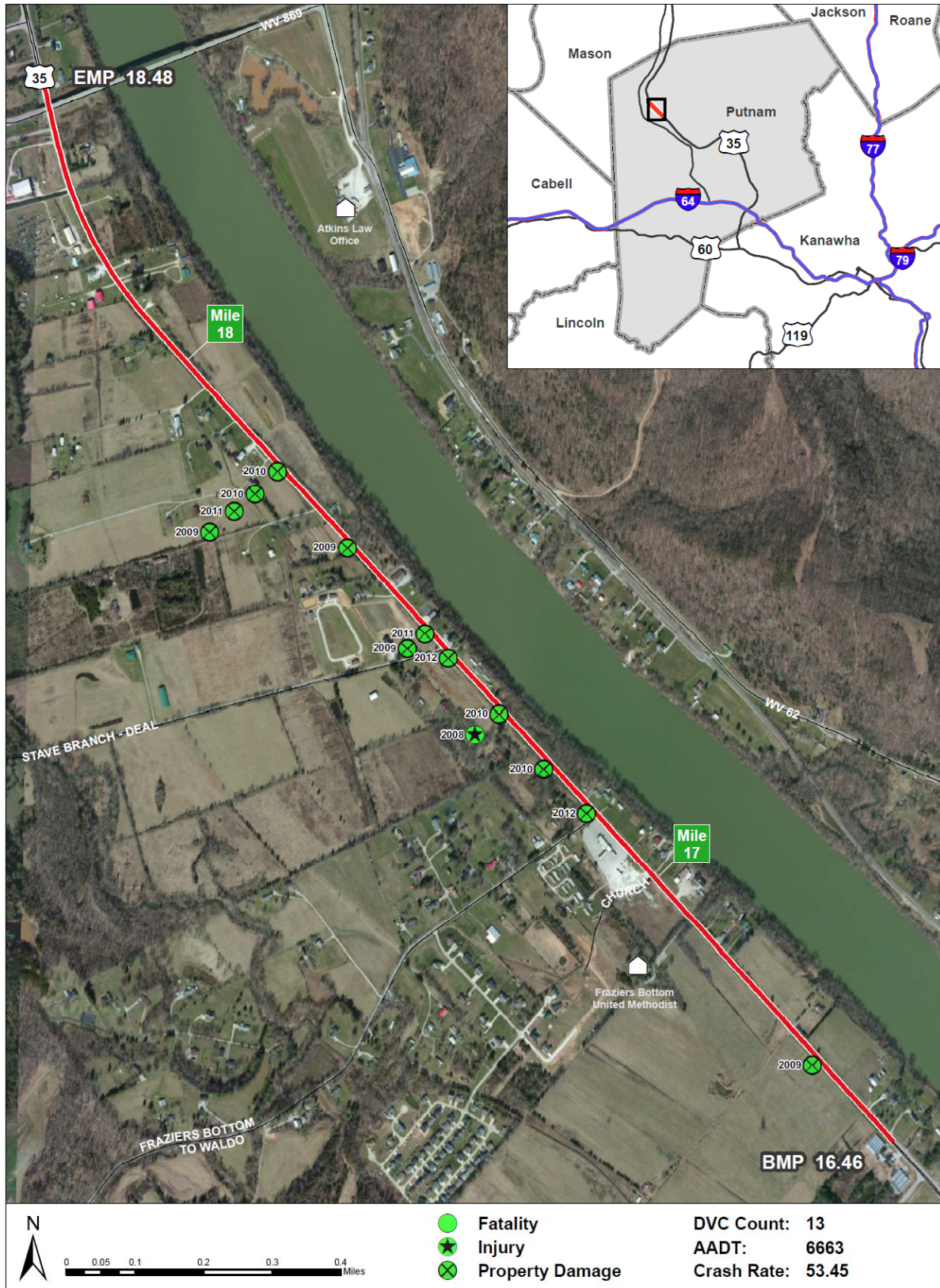
Figure 6-19 Location Map for US-35 in Putnam County, Milepost 16.5-18.5 (Rank 16)
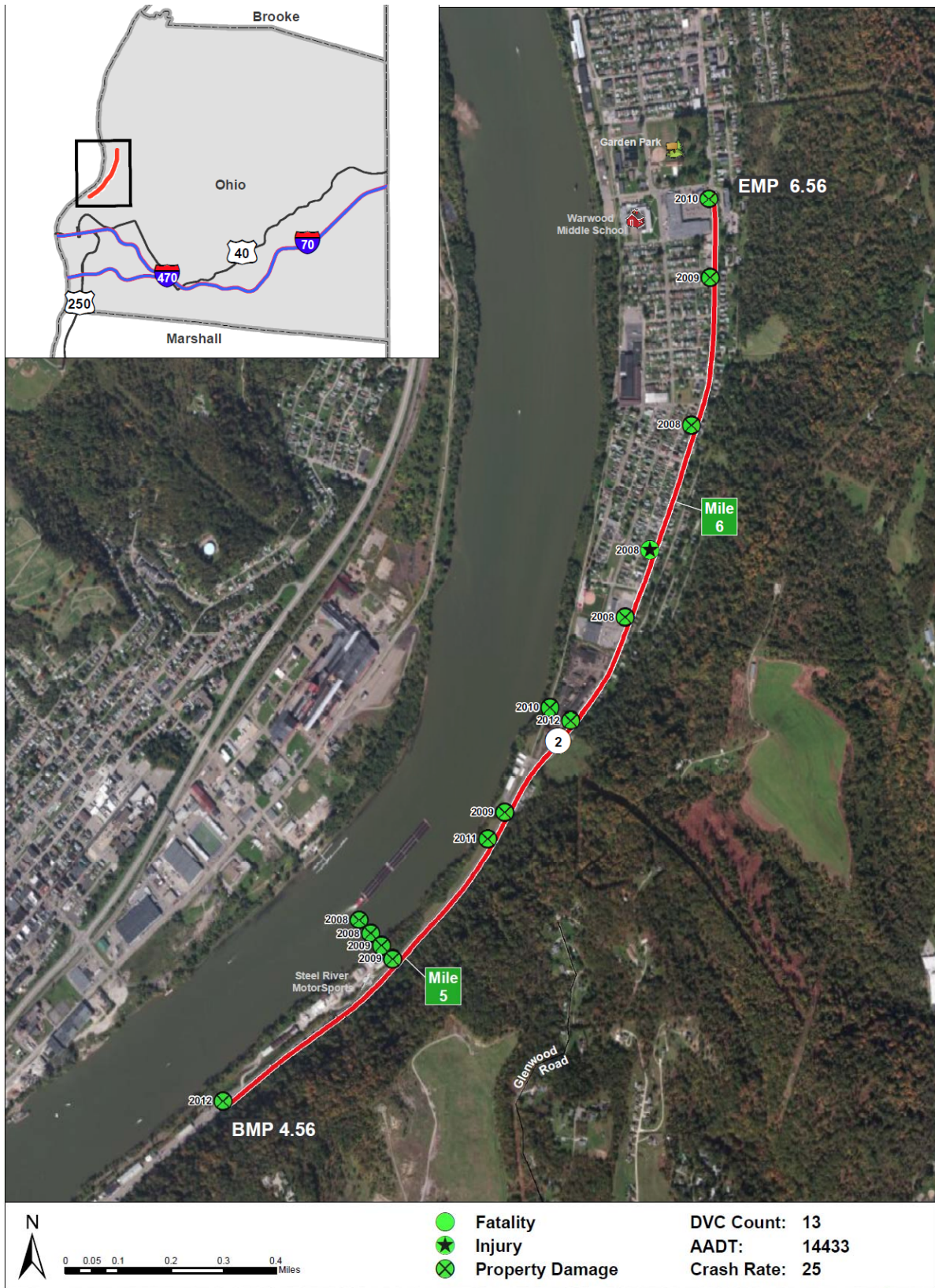
Figure 6-20 Location Map for WV-2 in Ohio County, Milepost 4.6-6.6 (Rank 17)
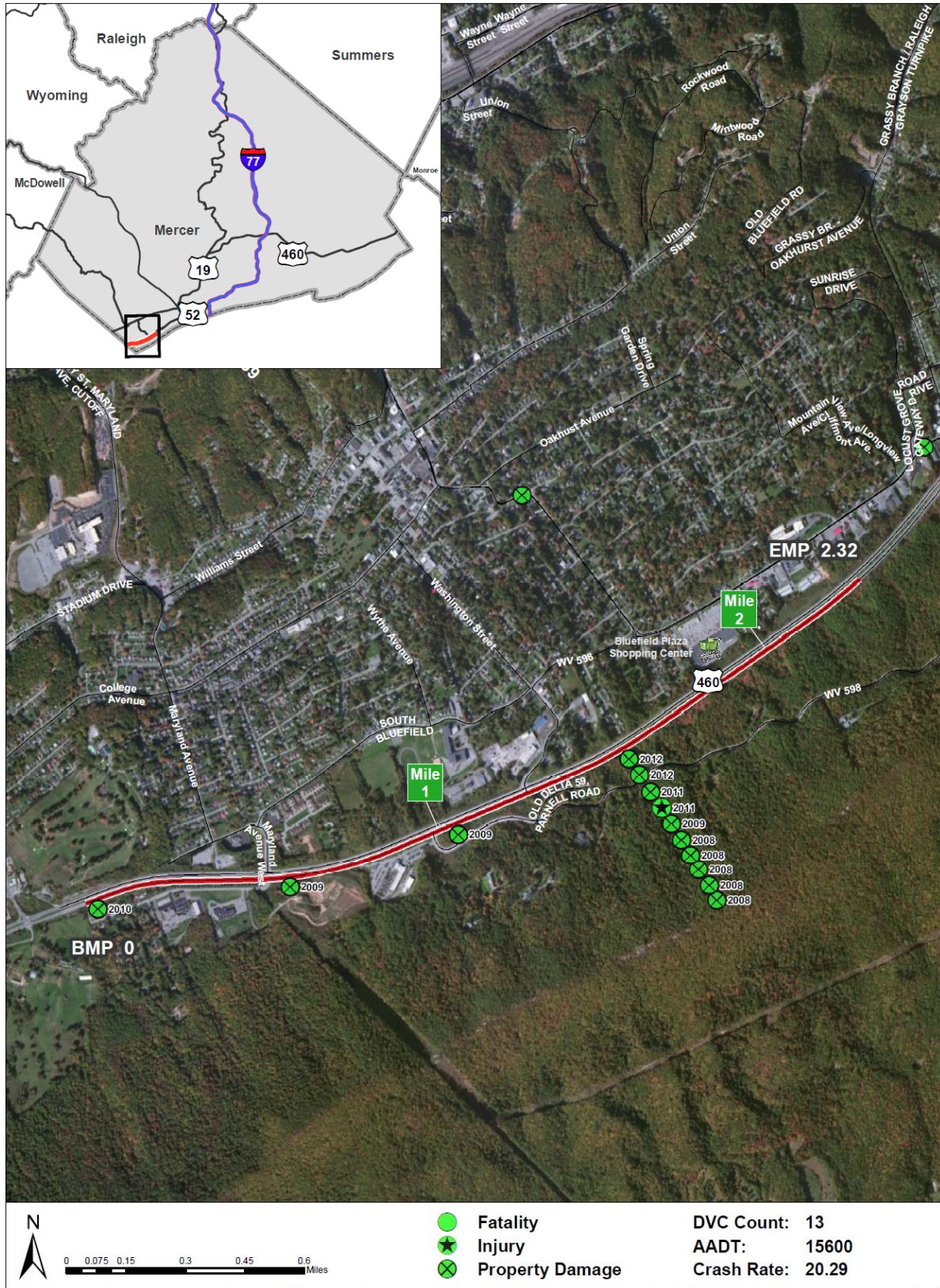
Figure 6-21 Location Map for US-460 in Mercer County, Milepost 0.0-2.3 (Rank 18)

6.4. Top Locations Based on Crash Rate

In addition to ranking segments by the total number of reported crashes, they were also ranked by the crash rate, which normalizes the data based on AADT and segment length. Table 6-3 contains the list of the top 35 Interstate, US Route, and WV Route segments ranked by crash rate. The distribution of crash rates across all segments that had at least one reported DVC is shown in Figure 6-22. There appear to be 3-10 segments that are visibly higher than the rest of the segments, with crash rates above 130. Due to the lack of clear breakpoints in the data, thresholds for delineating high, medium, and low are not specifically defined here, other than for the purpose of producing the map in Figure 6-23. The majority of the top 35 sites are WV Routes, where the AADT values are much lower than the Interstates and US Routes. There are no Interstate segments on this list. Only two of the segments that were identified as hotspots in the previous section based on raw count are on this list: WV-62 in Mason County (ranked #2 by count and #3 by rate) and WV-9 in Jefferson County (ranked #11 by count and #20 by rate).

Crash rates are the most common metric used to prioritize projects for safety funding. However, the validity of crash rate calculations is heavily dependent on the AADT information utilized. The AADT data used in these calculations was provided by WVDOT and will be discussed in more detail in a following section. The AADT data is collected by WVDOT every year on the Interstates and a 3-year cycle on other routes. The method of data collection typically results in a few observations along an entire route, which is then used to estimate the values for the segments in between. The data collection intensity decreases with the road classification and proximity to urbanized areas. Therefore, WV Routes in rural areas and most County Routes may have AADT values that are less reliable than other locations because it is based on estimates rather than observed data. There were also missing AADT values, which further complicates calculations. The lack of reliable data for the County Routes resulted in their exclusion from the analysis.

Table 6-3 Location Details of Segments with Highest DVC Rates

Rank	Crash Rate*	County	Route	Milepost Range	AADT	DVC Count
1	327.1	Summers	WV 20	29.4-31.4	250	3
2	268.6	Fayette	WV 39	5.46-5.52	3,400	1
3	254.9	Mason	WV 62	4.3-6.3	2,041	19
4	177.9	Nicholas	WV 129	4.3-6.3	1,232	8
5	163.1	Summers	WV 122	0.0-1.7	200	1
6	147.1	Nicholas	WV 41	6.3-8.3	928	5
7	139.2	Summers	WV 20	0.0-2.2	1,400	8
8	137.1	Fayette	WV 41	12.4-14.4	986	5
9	134.6	Wood	WV 31	3.5-5.8	718	4
10	131.7	Summers	WV 12	2.2-4.2	1,041	5
11	116.2	Raleigh	WV 307	2.3-4.3	700	3
12	116.2	Mason	WV 62	14.3-16.3	1,649	7
13	114.6	Lewis	US 19	16.3-18.4	1,188	5
14	112.1	Marshall	US 250	10.3-12.3	1,218	5
15	108.6	Monroe	WV 3	1.2-3.2	250	1
16	108.5	Wood	WV 68	2.3-4.3	2,257	9
17	107.9	Nicholas	WV 41	0.0-2.3	450	2
18	102.5	Raleigh	WV 307	4.3-6.3	1,058	4
19	94.1	Nicholas	WV 129	2.3-4.3	1,159	4
20	92.9	Jefferson	WV 9	0.0-1.7	4,972	14
21	90.8	Lewis	US 19	8.3-10.3	1,200	4
22	88.8	Ritchie	WV 31	8.3-10.3	613	2
23	86.3	Tucker	WV 38	4.3-6.3	633	2
24	85.2	Roane	WV 36	4.3-6.3	640	2
25	83.0	Mason	WV 62	12.3-14.3	1,649	5
26	81.9	Wood	WV 68	14.3-16.4	1,328	4
27	81.0	Wirt	WV 14	6.3-8.4	668	2
28	78.7	Nicholas	WV 39	36.0-38.0	4,100	12
29	77.8	Mercer	US 19	24.4-26.4	350	1
30	76.0	Nicholas	WV 39	13.7-15.8	2,136	6
31	75.7	Doddridge	WV 18	2.3-4.3	359	1
32	71.8	Mercer	US 19	20.4-22.4	758	2
33	71.5	Mason	WV 62	2.3-4.3	2,679	7
34	71.5	Berkeley	WV 45	12.2-14.1	1,929	5
35	69.8	Ritchie	WV 47	7.8-9.8	782	2

* Crash Rate = (Total # of Crashes * 10^8) ÷ (# of years * Segment AADT * Segment Length * 365)
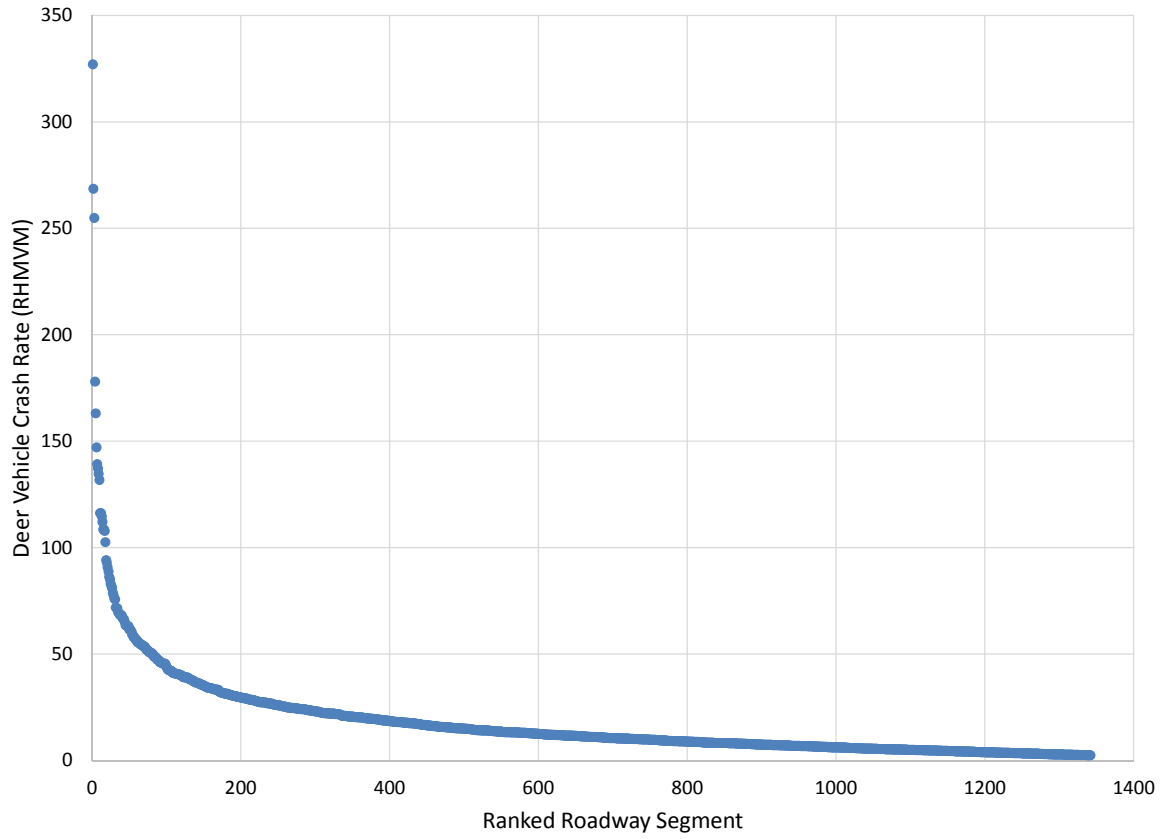
Figure 6-22 Distribution of DVC Crash Rates (RHMVM) across 2-mile Segments
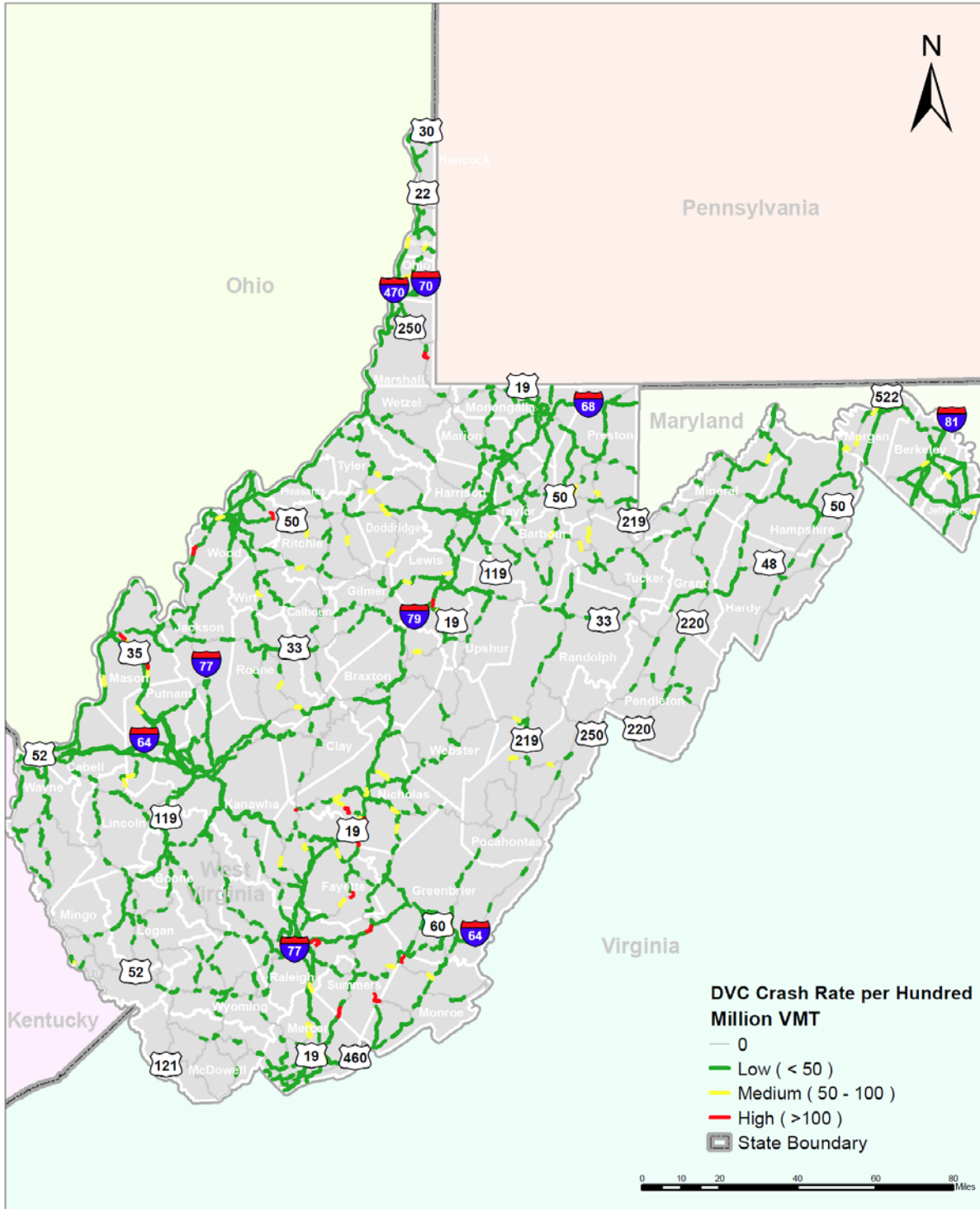
Figure 6-23 Location of Hotspot Segments based on Crash Rate for All Roads (2008-2012)

6.5. Summary and Recommendations

The roadway segmentation utilized in this study was 2.0 miles after an initial analysis of 0.5-mile segments. The decision to shift to a larger segment length was based on the observation of the crash locations in the 0.5-mile hotspot maps. Police officers tend to locate crashes at the nearest half or whole mile marker on Interstate and US Routes or a major intersection or interchange. This can be seen in Figure 6-13 for I-77 where the majority of crashes are located at the whole mile markers. Likewise in Figure 6-16, many crashes appear to be located at the bridge ramp on WV-34.

The hotspots were identified based on both the raw count of police reports on each segment, as well as the corresponding crash rate utilizing the segment length and AADT. Thresholds for High, Medium, and Low frequency were identified based on the distribution of raw counts for the segments. There were 18 segments in the High category, which corresponded to a count of 13 and above. The highest observed count was 22 on US-19 in Nicholas County. The highest observed crash rate was 327 crashes per hundred million vehicle miles, which occurred on WV-20 in Summers County. Only two locations made both lists and those were WV-62 in Mason County (Figure 6-5) and WV-9 in Jefferson County (Figure 6-14).

Due to some concerns with the validity of the AADT data for some roadway segments, the raw count hotspots were considered to be the official list for which maps were generated, although the ranked list by crash rate is certainly a useful tool. If a decision is made to implement mitigation, both the count and crash rate should be considered. It is anticipated that the site selections for mitigation will involve field visits to identify the specific locations that crossings are likely occurring since the reported locations are suspected to be imprecise. Selecting a segment that has a high crash rate, but a low crash count may make it more difficult to identify the potential locations to investigate along the road segment.

The use of static segments for the hotspot analysis is not necessarily the preferred method, but it was the only option based on the current WVDOT LRS. A recommendation for WVDOT is to complete the continuous LRS mapping in order to facilitate the application of more dynamic hotspot analysis techniques. It is also recommended that the AADT data be further evaluated to ensure that data is being collected and estimated for as many roadway segments as possible. The WVDOT may also consider tagging their AADT data to indicate the reliability of each estimate. For example, segments that are based on direct observation would be more reliable than segments that were estimated either from

adjacent segments or from historical data. There are methods to communicate this information to the end user so that they can make informed decisions on how to use the data.

7. WEST VIRGINIA DEER-VEHICLE COLLISION MODELING

7.1. Overview

This section of the report addresses the following objective of the study.

9. Model probable DVC locations across West Virginia to identify roadway, landscape, environmental, and traffic characteristics that contribute to DVC, if available data is adequate.

In addition to identifying the hotspots, an objective of the study was to examine the relationship of DVC presence and frequency with possible contributing factors. Since statewide DVC data was used, there wasn't a need to develop a model for prediction. Instead, the goal of the model was to identify roadway, landscape, environmental, and traffic characteristics that might be correlated to location with high DVCs. West Virginia data sets that could be converted to GIS layers were sought for this analysis. A summary of the data utilized in this study is listed in Table 7-1 and further discussed in the subsequent sections.

While it was desirable to examine this relationship for all types of roadways in West Virginia, the analysis was limited to the Interstates and US routes due to the availability and reliability of data for some of the data sets provided by the WVDOT. The attributes were assigned to each 2-mile roadway segment defined in the previous section. Most of the data provided by the WVDOT are linear features that can be assigned directly to the segment. There were instances where multiple levels for an attribute occurred along a single 2.0-mile segment (e.g., change in number of lanes or change in speed limit). In this instance, the majority attribute was assigned. Many of the data were in the form of a raster image that was not directly attributed to the roadway itself. In order to assign its attributes to a segment, a buffer zone parallel to the roadway was applied and calculations were performed for the entire area. Note that buffer zone sizes given this section are the total width with half of the buffer on each side of the roadway. The details on the ArcGIS processes used to process the various data types are provided in Appendix I.

The various regression models discussed in the literature review were applied to these data sources to identify any significant relationships between variables.

Table 7-1 Summary of Data Used for Modeling

Data	Format	Analysis	Source
National Land Cover Data	Raster Image	400 meter buffer	USGS
Landscape Diversity Index	Raster Image	400 meter buffer	From NLCD
AADT	Linear feature of road	Direct Assignment	WVDOT RIL
Speed Limit	Linear feature of road	Direct Assignment	WVDOT RIL
Lane Width	Linear feature of road	Direct Assignment	WVDOT RIL
Median Type	Linear feature of road	Direct Assignment	WVDOT RIL
Median Width	Linear feature of road	Direct Assignment	WVDOT RIL
Functional Classification	Linear feature of road	Direct Assignment	WVDOT RIL
Rural/Urban Designation	Linear feature of road	Direct Assignment	WVDOT RIL
Shoulder Type	Linear feature of road	Direct Assignment	WVDOT RIL
Left and Right Shoulder Width	Linear feature of road	Direct Assignment	WVDOT RIL
Pavement Type	Linear feature of road	Direct Assignment	WVDOT RIL
Number of Lanes	Linear feature of road	Direct Assignment	WVDOT RIL
Distance to Water	Raster and lines	Euclidean Distance	WVDEP, USGS
Roadway Curvature	Linear feature of road	Sinuosity Index	WVDOT LRS
Roadside Slope	Raster	60 meter buffer	USGS

7.2. Data Sources

7.2.1. National Land Cover Data

The US Geological Survey (USGS) collects and maintains data that shows both natural and manmade land cover of the United States. These data are collected from orbiting Landsat satellites and produced for access through the National Land Cover Database (NLCD) for three epochs: 1992, 2001, and 2006. NLCD 1992 and 2006 encompass the conterminous United States, whereas NLCD 2001 encompasses all 50 States and Puerto Rico. NLCD 1992 is a 21-class land cover classification scheme that includes urban, agricultural, rangeland, forest, surface waters, wetlands, barren lands, tundra, and perennial ice/snow classes. The spatial resolution of the data is 30 meters. NLCD 2001 is a 16-class land cover classification scheme (with an additional four classes in Alaska only) also at a spatial resolution of 30 meters, but improves on NLCD 1992 by offering three different products: land cover, percent developed impervious surface, and percent tree canopy density. NLCD 2006 quantifies land cover change for the conterminous U.S. between the years 2001 to 2006. Generation of NLCD 2006 helped identify and correct issues in the NLCD 2001 land cover and percent developed impervious surface products only, and no changes were made to the NLCD 2001 percent tree canopy product.

There are fifteen land cover types in West Virginia. The NLCD code and description of each type are listed in Table 7-2. Based on preliminary analysis, it was determined that some of the similar land cover types could be combined in order to improve the reliability of the analysis because a few groups had very

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few observations. Based on input from the WVDNR, it was decided that the following nine unique groups could be created from the perspective of impacts on deer presence and attraction.

- Open Water (11)
- Developed Open Space (21), Low Intensity (22), Medium Intensity (23)
- Developed High Intensity (24)
- Barren Land (31)
- Deciduous Forest (41) and Mixed Forest (43)
- Evergreen Forest (42)
- Shrub/Scrub (52), Woody Wetlands (90), and Emergent Herbaceous Wetlands (95)
- Grassland/Herbaceous (71) and Pasture/Hay (81)
- Cultivated Crops (82)

The 2.0-mile segments were processed to identify the percentage of each land use within a 400-meter buffer zone (200-meter on each side of the road). The modeling effort treated each land use type as a continuous variable ranging from 0-100% corresponding to the percentage of the total buffer area with that land use type. Therefore, the significance of each land use type could be evaluated.

Table 7-2 National Land Cover Types and Descriptions

NLCD Code	Short Description	Long Description
11	Open Water	areas of open water, generally with less than 25% cover of vegetation or soil.
21	Developed, Open Space	areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	Developed, High Intensity	highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
31	Barren Land (Rock/Sand/Clay)	areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41	Deciduous Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
52	Shrub/Scrub	areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
71	Grassland/ Herbaceous	areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
81	Pasture/Hay	areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	Cultivated Crops	areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
90	Woody Wetlands	areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	Emergent Herbaceous Wetlands	areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

7.2.2. Landscape Diversity Index

The processed National Land Cover Data (nine combined groups) was also used to calculate the Shannon landscape diversity index (*48*). This index is intended to quantify how many land use types are within the area. The logic behind this variable is that deer are more attracted to areas with multiple land uses because those areas tend to have food sources (e.g., gardens in suburban areas, borders between forested areas and cropfields, etc.). The index is calculated as the proportion of each land use's area relative to the total area within the 400-meter buffer, and then multiplied by the natural logarithm of this proportion. The resulting product is summed for all of the land uses and multiplied by -1.

After an initial investigation of this data, a second method of combining the land usage was developed based on statistical analysis of the data, which reduced the number of groups from nine to six. The major differences from the previous combinations are that Woody Wetland and Herbaceous Wetlands are grouped with Open Water instead of Shrub/Scrub; Deciduous and Mixed Forest are combined with Evergreen Forest, Shrub/Scrub, Grassland, and Pasture. Figure 7-1 illustrates the landscape diversity values assigned to the 2-mile Interstate and US Route segments. This new grouping yielded a better relationship with DVC than the initial grouping and was therefore used in the modeling effort.

- Open Water (11), Woody Wetlands (90), and Emergent Herbaceous Wetlands (95)
- Developed Open Space (21), Low Intensity (22), Medium Intensity (23)
- Developed High Intensity (24)
- Barren Land (31)
- Deciduous Forest (41), Evergreen Forest (42), Mixed Forest (43), Shrub/Scrub (52), Grassland/Herbaceous (71) and Pasture/Hay (81)
- Cultivated Crops (82)

Figure 7-1 Landscape Diversity Values (6 Combined Land Uses) by Segment

7.2.3.   WVDOT Roadway Inventory Log (RIL)

The WVDOT maintains a roadway inventory log (RIL) that contains a number of roadway characteristics assigned by roadway segment. This information is maintained for planning and reporting purposes. The segments defined in the RIL do not correspond to the 2.0-mile segments utilized in the study, therefore each dataset was converted to a GIS layer and then a process was utilized to assign the corresponding attributes along each 2.0-mile segment. The following sections discuss the RIL data that was utilized as well as the distribution of characteristics across the roadway network.

AADT

The Average Annual Daily Traffic (AADT) values in the RIL are based on both observed short-term traffic counts and normalizing calculations that account for historical data. Data is collected annually for Interstates and every three years for other roadways. Table 7-3 provides a breakdown of the AADT values by range and by sign system (i.e., Interstate, US Routes, WV Routes, etc.). Figure 7-2 illustrates the same information in a more detailed color-coded map. The map group number referenced in Table 7-3 corresponds to the ordered fields in the legend on the map. Of particular concern for this study were the portions of the roadway network that contained null values because null AADT values prohibit the calculation of crash rates. The null values are shown in blue on the map. There are a number of shorter segments in between other segments as well as entire routes that are missing data. The entire routes are most likely new roadways that have opened in recent years but haven't been added to the data collection or data processing schedule. Approximately 0.1% of the Interstate was null, 8.3% of the US Routes, and 1.2% of the County Routes. Another hurdle in the crash rate ranking was the effect of AADTs less than 100. Approximately 56% of the County Routes had an AADT in this range, which would result in their crash rates being extremely high even with only one reported DVC. The missing values on the Interstates and some of the US Routes were estimated in order for those segments to be included in the modeling effort.

In the modeling effort, AADT was treated as a continuous variable. The expectation is that the DVC count would increase as AADT increases, resulting in a positive relationship. It should be noted that a log transformation was performed on the AADT to obtain a distribution of values are more normally distributed, which is desirable for regression models.

Table 7-3 AADT Range by Sign System from Roadway Inventory Log

Map Group	AADT	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	1.1	322.9	-	341.8	0.1%	8.3%	-	1.2%
2	0	-	-	-	-	-	-	-	-
3	1 - 100	-	1.6	1.3	16148.6	-	0.0%	0.0%	56.1%
4	101 - 500	-	43.1	313.9	8080.3	-	1.1%	8.5%	28.1%
5	501 - 1000	-	268.6	468.0	2255.7	-	6.9%	12.7%	7.8%
6	1001 - 10000	69.4	2315.1	2659.2	1891.0	6.3%	59.8%	72.3%	6.6%
7	10001 - Up	1025.5	920.2	289.4	43.8	93.6%	23.8%	7.9%	0.2%
Total LRS Mileage		1096.0	3871.5	3731.8	28761.2				

Figure 7-2 AADT Values by Segment from Roadway Inventory Log

Speed Limit

The speed limit data corresponds to the speed at which the segment is signed in the field. Table 7-4 illustrates the breakdown by speed limit range and by sign system. Figure 7-3 illustrates the same information on a map. There was a very high percentage of the Interstates (83.7%) that did not have a speed limit assigned. These values were manually entered for both the Interstate and US Routes based on publicly available information and imagery in order for this variable to be included in the modeling effort.

For the modeling effort, this variable was treated as a two-level categorical variable with low being 0-50 mph and high being speeds above 50 mph. As previously discussed, DVC frequency tends to be lower when speeds are lower, presumably because the driver has more time to react and avoid a collision. Therefore, it would be expected that roadways with higher speed limits would have a higher rate of DVC.

Table 7-4 Speed Limit Range by Sign System from Roadway Inventory Log

Map Group	Speed Limit	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	917.4	322.4	176.7	19732.7	83.7%	8.3%	4.8%	68.0%
2	0	-	61.3	36.1	1774.1		1.6%	1.0%	6.1%
3	0 - 35	-	329.1	392.7	5393.1		8.5%	10.7%	18.6%
4	35 - 45	3.2	558.3	778.3	1578.5	0.3%	14.4%	21.1%	5.4%
5	45 - 55	17.8	2139.1	2287.0	282.8	1.6%	55.2%	62.1%	1.0%
6	55 - 65	-	461.3	6.8	-		11.9%	0.2%	
7	70	157.5	-	-	-	14.4%			
Total LRS Mileage		1096.0	3874.2	3682.8	29036.1				
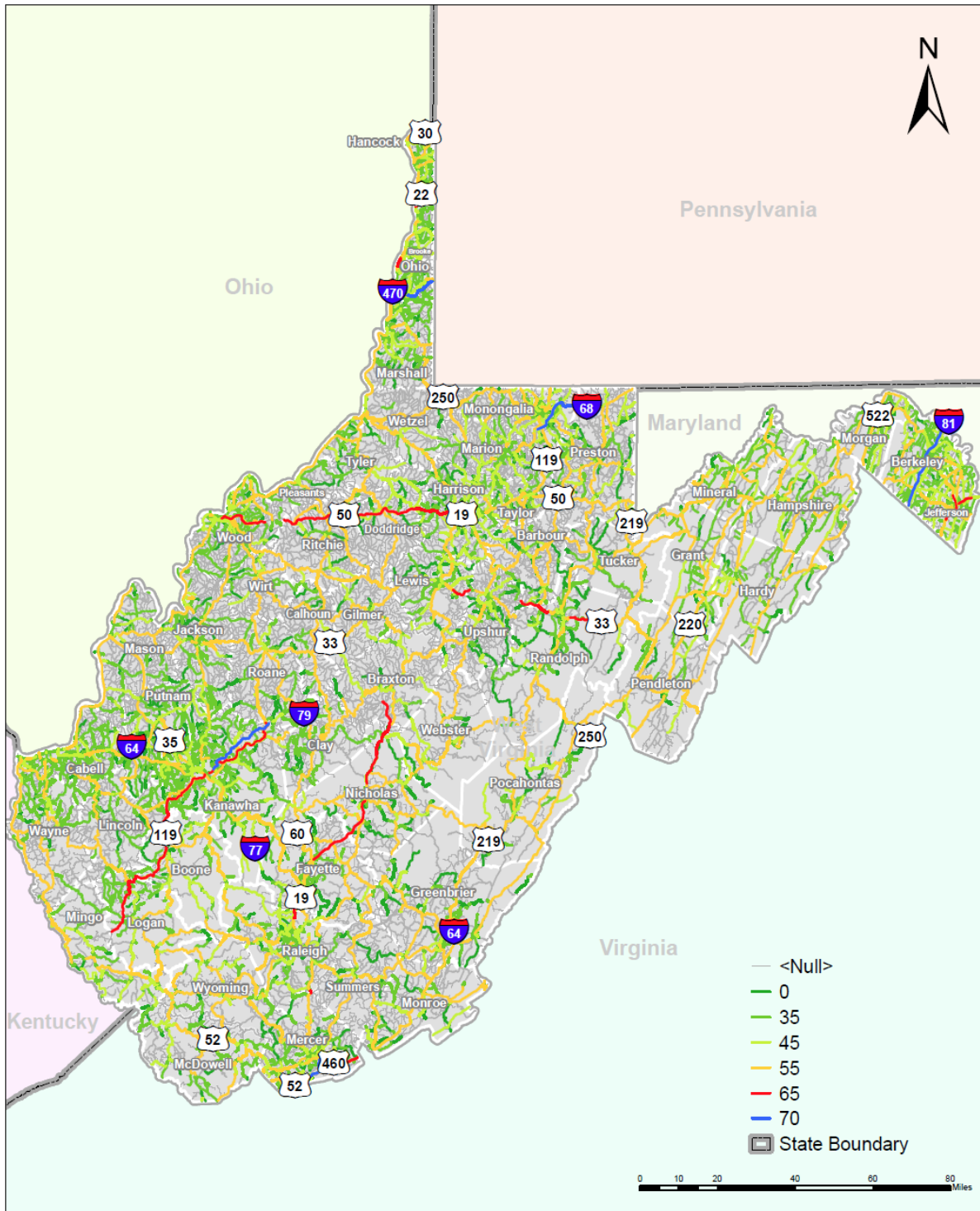
Figure 7-3 Speed Limit by Segment from Roadway Inventory Log

Lane Width

A summary of the lane width information in the RIL is provided in Table 7-5 and mapped in Figure 7-4. This data set contained a high percentage of null values for the US Routes that were not feasible to manually generate because lane width information isn't easily obtained from publicly available sources. Therefore, this variable was not incorporated into the model. The literature review discussed that reducing the lane widths on a roadway could possibly reduce the DVC rate because drivers may be inclined to drive slower on narrower lanes. Therefore, the modification of driver behavior would be the end result. If this dataset were completed, that type of relationship could be explored.

Table 7-5 Lane Width Range by Sign System from Roadway Inventory Log

Map Group	Lane Width	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	\<Null\>	17.9	2669.1	-	28207.3	1.6%	43.0%	-	49.8%
2	7 - 9	-	195.0	136.6	338.2	-	3.1%	3.7%	0.6%
3	10 - 11	-	409.8	357.5	126.7	-	6.6%	9.6%	0.2%
4	12 - 13	1074.6	576.7	188.6	87.8	96.6%	9.3%	5.1%	0.2%
5	14 - 40	3.4	20.9	5.5	1.2	0.3%	0.3%	0.1%	0.0%
Total LRS Mileage		1112.8	6213.5	3731.8	56626.7				
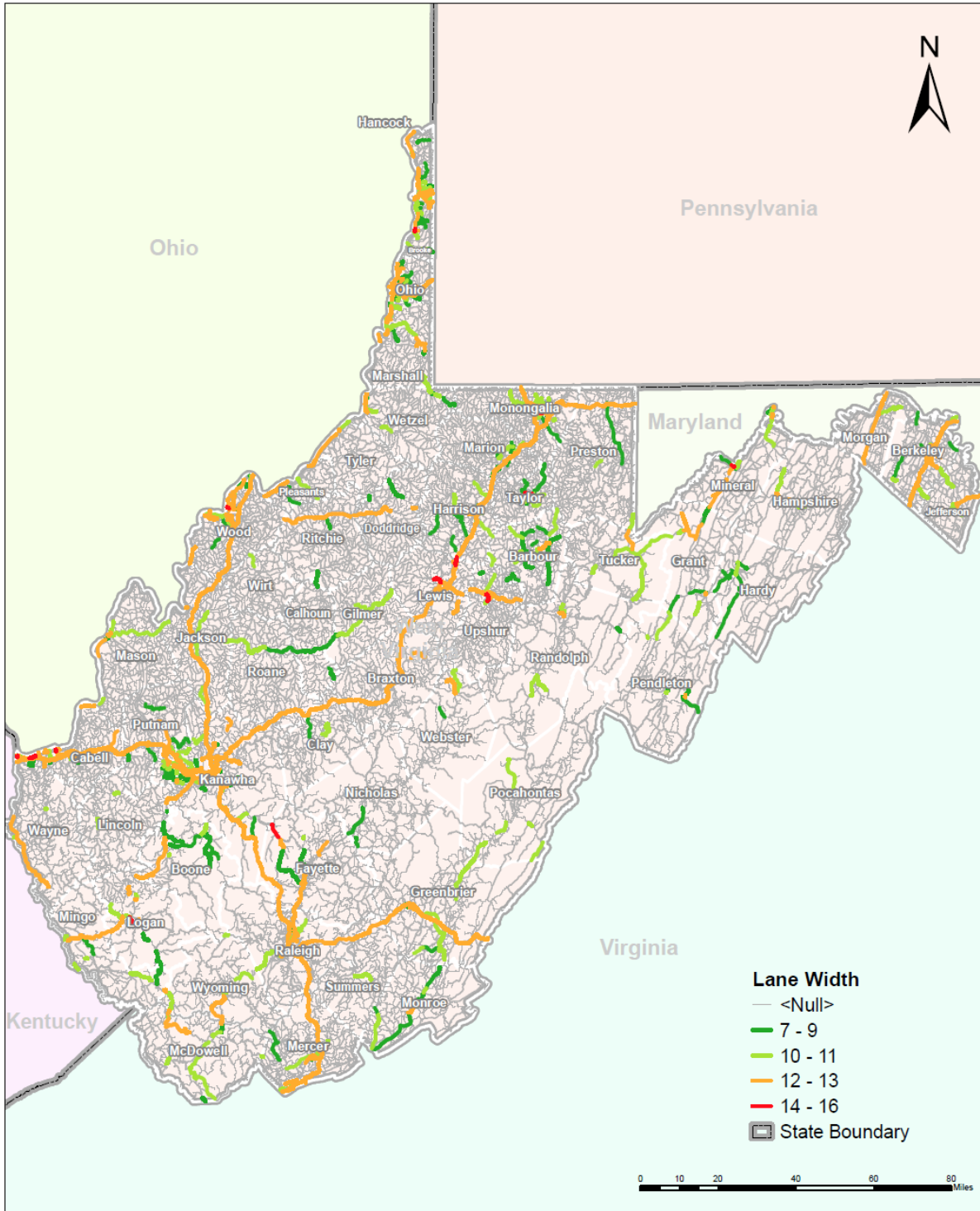
Figure 7-4 Lane Width Values by Segment from Roadway Inventory Log

Median Type

The median type by sign system in the RIL is shown in Table 7-6 and mapped in Figure 7-5. This dataset contains a specific value to be entered for "none" if there is no median, which is common on a 2-lane roadway. Therefore, there shouldn't be any null values in the dataset. However, there are 9.6% on the Interstate and 45.3% on US Routes. Due to the amount of data on the Interstate and US Routes that would need to be manually entered and the method required to view the publicly available data, this data was not adjusted. However, this variable was still utilized in the model and the segments with null values were removed from the analysis.

For modeling purposes, this attribute was treated as a two-level categorical variable to indicate whether a physical barrier existed that might be a physical or visual deterrent to deer crossing. Therefore, "null", "none", "unprotected", and "curbed" medians were grouped together and "positive barrier" and "rigid barrier" were grouped together. Initially, it was assumed that the rigid barrier would represent concrete Jersey barriers and positive barriers would represent cable median barriers (which wouldn't likely be a deterrent to deer). However, investigation of the quantity and location of the rigid barrier revealed that the rigid barrier on the Interstate had been classified as positive barrier. Therefore, the concrete barriers and cable median barriers could not be separated. This variable was still considered in the modeling process.

Table 7-6 Median Type by Sign System from Roadway Inventory Log

Map Group	Median Type	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	\<Null\>	115.7	2929.6	3178.4	28330.0	9.6%	45.3%	46.0%	49.9%
2	None	-	679.6	528.3	429.3		10.5%	7.6%	0.8%
3	Unprotected	798.0	206.6	6.4	-	65.9%	3.2%	0.1%	
4	Curbed	-	29.1	17.9	1.9		0.4%	0.3%	0.0%
5	Positive Barr.	182.2	25.4	0.8	-	15.1%	0.4%	0.0%	
6	Rigid Barr.	-	1.2	-	-		0.0%		
Total LRS Mileage		1210.6	6474.0	6910.1	56749.4				
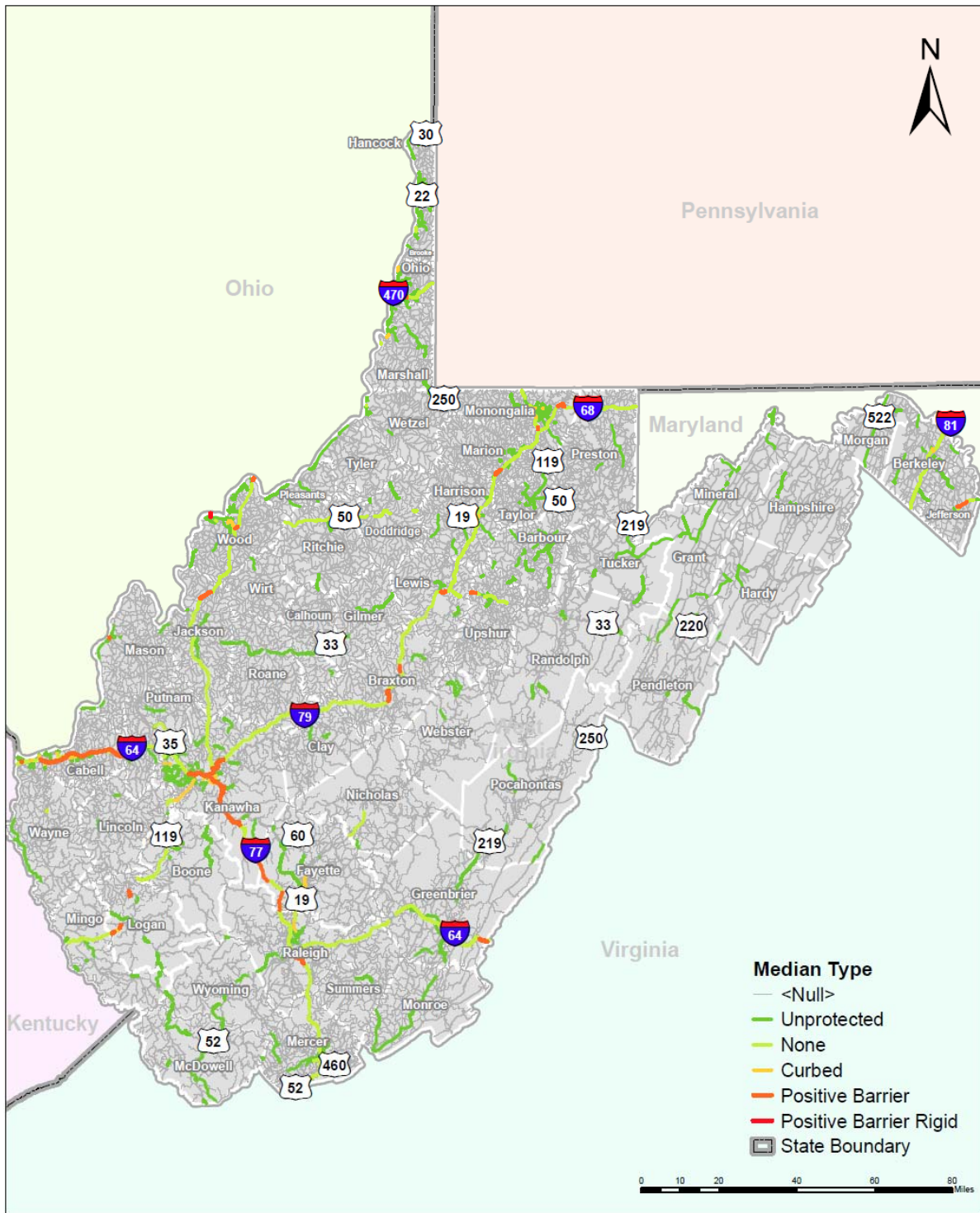
Figure 7-5 Median Types by Segment from Roadway Inventory Log

Median Width

The median width data in the RIL is summarized in Table 7-7 and mapped in Figure 7-6. Similar to the median type, there are both null values and zero values in the database. Since an Interstate cannot have a width of zero, it is assumed that the null values in this case indicate missing data since 6.2% of the Interstate has a null value. Similar to the lane width, it was not feasible to manually enter all of the missing values due to the amount of effort involved. Therefore this variable was not included in the modeling effort. It might be expected that higher median widths would be associated with locations that have grass or wooded medians and might attract more deer to the roadway. These road types would also likely have high speed limits, which also have a positive relationship with DVC based on other studies, so it may be difficult to separate the effects of those two variables.

Table 7-7 Median Width Range by Sign System from Roadway Inventory Log

Map Group	Median Width	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	71.8	2923.6	3179.6	28335.8	6.2%	45.2%	46.0%	49.9%
2	0	-	675.6	525.3	423.5	-	10.4%	7.6%	0.7%
3	1 - 28	127.7	112.5	26.8	1.9	10.9%	1.7%	0.4%	0.0%
4	30 - 49	662.3	152.1	-	-	56.8%	2.4%	-	-
5	50 - 70	164.2	-	-	-	14.1%		-	-
6	80 - 99	69.9	7.7	-	-	6.0%	0.1%	-	
Total LRS Mileage		1166.7	6468.1	6911.4	56755.2				

Figure 7-6 Median Widths by Segment from Roadway Inventory Log

Shoulder Type

The shoulder type information in the RIL is listed by sign system in Table 7-8 and mapped in Figure 7-7. A brief analysis of this data indicated that it was not usable due to 86.1% of the US Routes containing a null value. Regardless, it is unclear what, if any, relationship the type of shoulder would have with DVC occurrence. If it is a paved or stabilized shoulder and a driver swerves to avoid a deer, they may be more likely to maintain control and not crash. Therefore, roadways with those types of shoulders and wider shoulders may have lower DVCs.

Table 7-8 Shoulder Type Designation by Sign System from Roadway Inventory Log

Map Group	Shoulder Type	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	11.7	3331.4	3365.2	28522.7	1.1%	86.1%	91.5%	99.2%
2	None	-	4.7	2.4	37.8		0.1%	0.1%	0.1%
3	Surfaced - Bit con	1084.2	152.8	58.3	9.1	98.9%	3.9%	1.6%	0.0%
4	Surfaced Shou - Port Cem	-	18.6	-	-		0.5%		
5	Stabilized Shoulder	-	282.0	201.5	151.1		7.3%	5.5%	0.5%
6	Combination Shoulder	-	32.8	11.3	8.6		0.8%	0.3%	0.0%
7	Earth Shoulder	-	12.9	14.6	10.8		0.3%	0.4%	0.0%
8	Barrier Curb_no sho in front	-	36.2	24.3	21.0		0.9%	0.7%	0.1%
Total LRS Mileage		1096.0	3871.5	3677.6	28761.2				
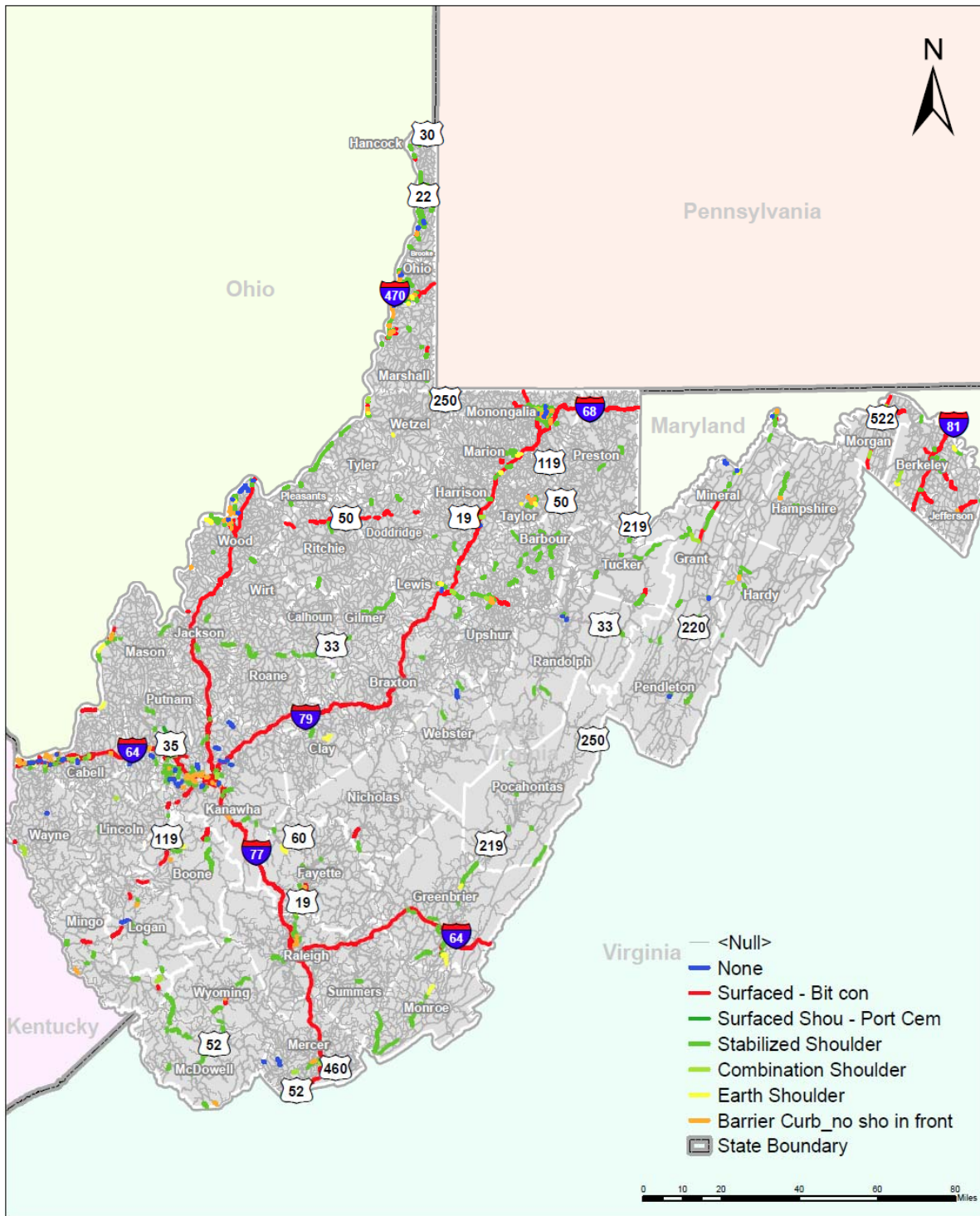
Figure 7-7 Shoulder Types by Segment from Roadway Inventory Log

Left and Right Shoulder Width

The width of the left shoulder and right shoulder by sign system are listed in Table 7-9 and Table 7-10, mapped in Figure 7-8 and Figure 7-9. Since the majority of the US Route data is null for both left and right shoulder width (87.1% and 86.1%), this data was not used in the modeling effort due to the amount of effort to manually process it. The left shoulder width would not be as critical to the analysis process as the median width, but unfortunately neither are usable. Increases in right shoulder width might result in a fewer DVCs, particularly on WV and County Routes because the driver's field of vision would be increased, which would allow them to see deer sooner and react more quickly. Wider shoulders also give the driver more room to recover if they swerve to miss a deer.

Table 7-9 Left Shoulder Width Range by Sign System from Roadway Inventory Log

Map Group	Shoulder Width Left	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	11.7	3648.8	3631.6	28701.1	1.1%	87.1%	92.1%	99.2%
2	0 - 2	395.1	109.9	38.6	59.8	36.1%	2.6%	1.0%	0.2%
3	3 - 4	239.6	98.2	7.4	0.2	21.9%	2.3%	0.2%	0.0%
4	5 - 8	447.2	14.6	-	-	40.8%	0.3%		
5	9 - 12	2.3	-	-	-	0.2%			
Total LRS Mileage		1096.0	4029.4	3943.9	28939.3				

Table 7-10 Right Shoulder Width Range by Sign System from Roadway Inventory Log

Map Group	Shoulder Width Right	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	11.7	3331.4	3365.2	28657.3	1.1%	86.1%	91.5%	98.7%
2	0 - 2	-	136.6	72.4	134.6		3.5%	2.0%	0.5%
3	3 - 4	-	81.5	94.7	77.4		2.1%	2.6%	0.3%
4	5 - 8	287.9	192.9	119.1	22.4	26.3%	5.0%	3.2%	0.1%
5	9 - 12	796.4	129.0	26.2	4.1	72.7%	3.3%	0.7%	0.0%
Total LRS Mileage		1096.0	3871.5	3677.6	28761.2				
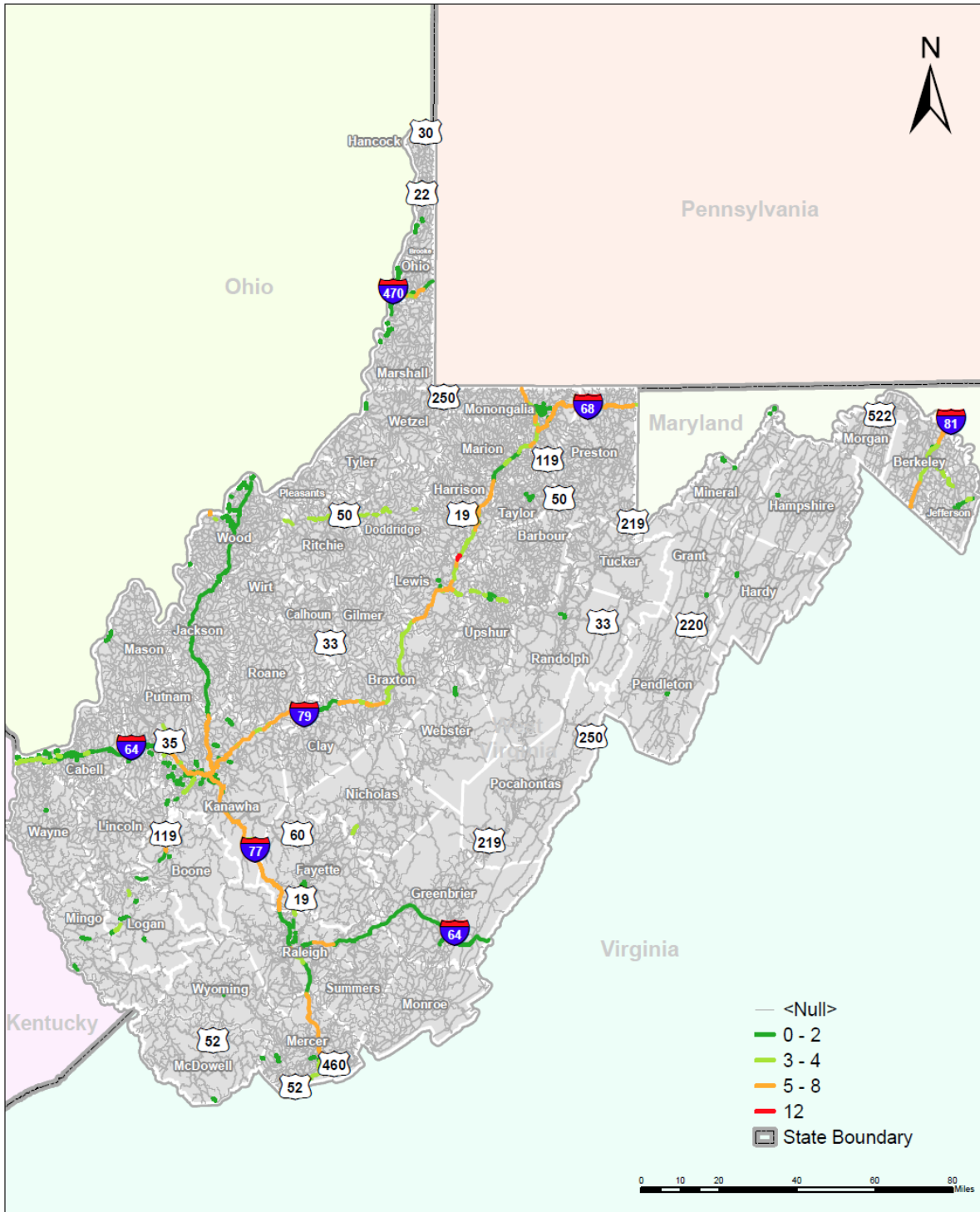
Figure 7-8 Left Shoulder Width by Segment from Roadway Inventory Log

Figure 7-9 Right Shoulder Width by Segment from Roadway Inventory Log

Number of Combined Through Lanes

The number of combined through lanes in both directions (ignores presence of auxiliary turn lanes on segment) by sign system is listed in Table 7-11 and mapped in Figure 7-10. There are minimal null values in this data set. This variable will likely capture characteristics similar to the roadway functional classification, but it was included in the analysis.

For the modeling effort, this attribute was treated as a two-level categorical variable. The first level was all roads with three lanes or less and the second level was all roads with more than four lanes. Three lane roads are predominantly two-lane roads with a center two-way left-turn lane. Therefore, the first level is generally two-lane roads and the second level is multi-lane roads.

Table 7-11 Number of Combined Thru Lanes by Sign System from Roadway Inventory Log

Map Group	Number of Through Lanes	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	1.1	327.1	-	341.8	0.1%	8.4%		1.2%
2	1	-	7.1	4.0	1.9		0.2%	0.1%	0.0%
3	2	2.6	2675.1	3533.8	28407.3	0.2%	69.1%	94.7%	98.8%
4	3	1.8	20.6	3.8	1.3	0.2%	0.5%	0.1%	0.0%
5	4	892.5	814.6	187.3	8.2	81.4%	21.0%	5.0%	0.0%
6	5	109.7	26.0	1.6	-	10.0%	0.7%	0.0%	
7	6	80.3	1.2	1.3	0.6	7.3%	0.0%	0.0%	0.0%
8	7	8.0	-	-	-	0.7%			
Total LRS Mileage		1095.9	3871.5	3731.8	28761.1				
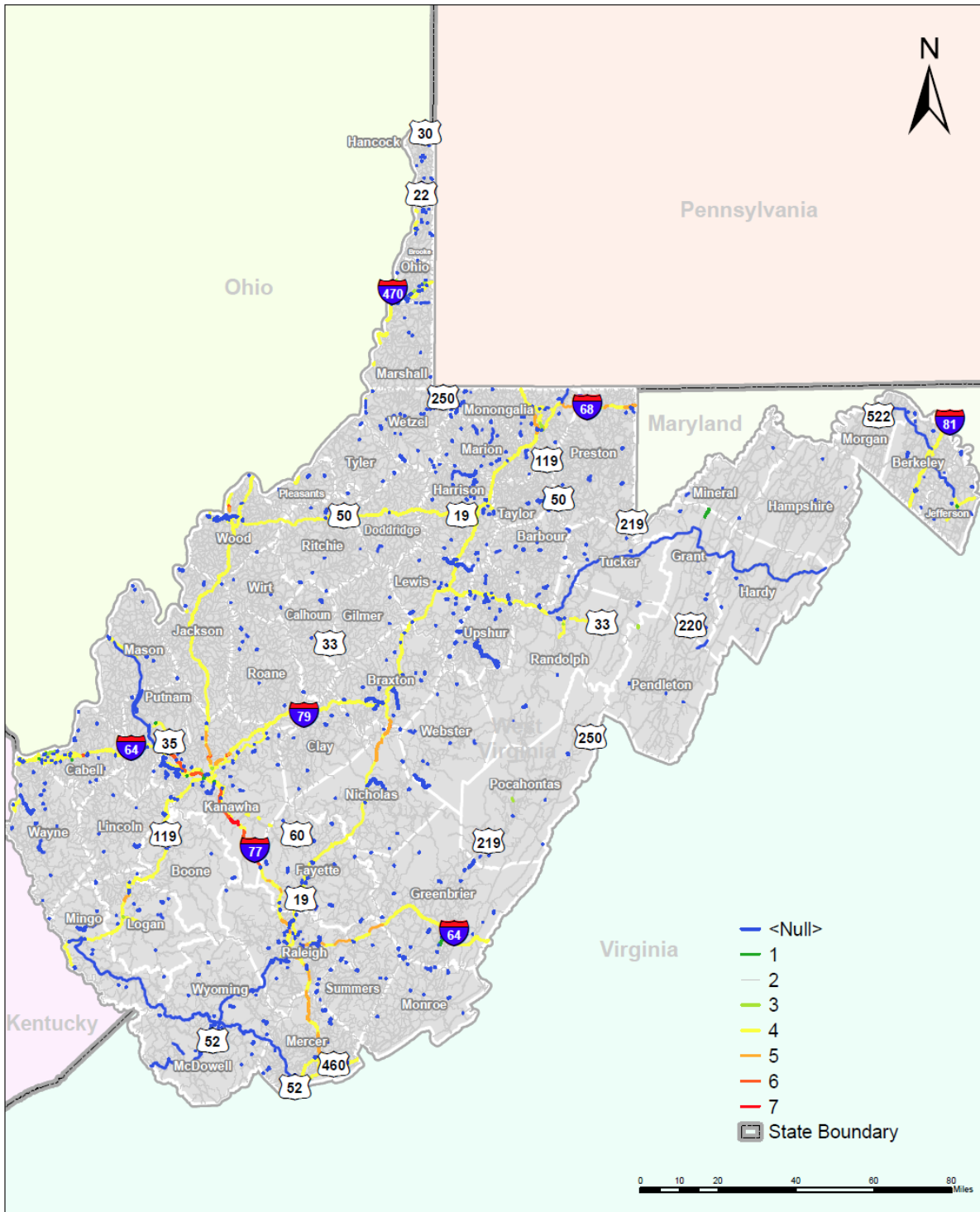
Figure 7-10 Number of Through Lanes by Segment from Roadway Inventory Log

Roadway Functional Classification

The Federal Highway Administration uses roadway functional classifications to convey the purpose of the roadway and guide the design parameters of the roadway. The functional classification by sign system is summarized in Table 7-12 and mapped in Figure 7-11. There were null values for the Interstate and US Route that could have been manually filled in, although finding out the true designation would be difficult. This classification is more of a planning designation that dictates speed limits, lane widths, median widths, shoulder design, and other parameters that are already being captured in the data set with much more detail. Therefore, due to the difficulty in obtaining the data to update this variable and the fact that its usefulness would be limited, it was not included in the analysis.

Table 7-12 Roadway Functional Class by Sign System from Roadway Inventory Log

Map Group	Functional Class	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	\<Null\>	1.1	327.9	-	341.9	0.1%	9.3%		1.2%
2	Principal Arterial - Interstate - Rural	727.9	-	-	-	66.5%			
3	Principal Arterial - Other - Rural	-	1388.0	420.2	-		39.2%	11.3%	
4	Minor Arterial - Rural	-	998.8	768.6	51.2		28.2%	20.6%	0.2%
5	Major Collector - Rural	-	412.8	1991.0	3377.1		11.6%	53.4%	11.9%
6	Minor Collector - Rural	-	-	2.5	2181.1			0.1%	7.7%
7	Local - Rural	-	2.2	13.2	20833.4		0.1%	0.4%	73.3%
8	Principal Arterial - Interstate - Urban	367.0	-	-	-	33.5%			
9	Principal Arterial - Freeways or Expressways- Urban	-	17.8	-	-		0.5%		
10	Principal Arterial - Other - Urban	-	366.1	175.0	7.5		10.3%	4.7%	0.0%
11	Minor Arterial - Urban	-	340.3	335.0	178.3		9.6%	9.0%	0.6%
12	Collector - Urban	-	17.4	23.3	479.7		0.5%	0.6%	1.7%
13	Local - Urban	-	0.3	3.0	1310.8		0.0%	0.1%	4.6%
Total LRS Mileage		1094.9	3543.6	3731.8	28419.2				
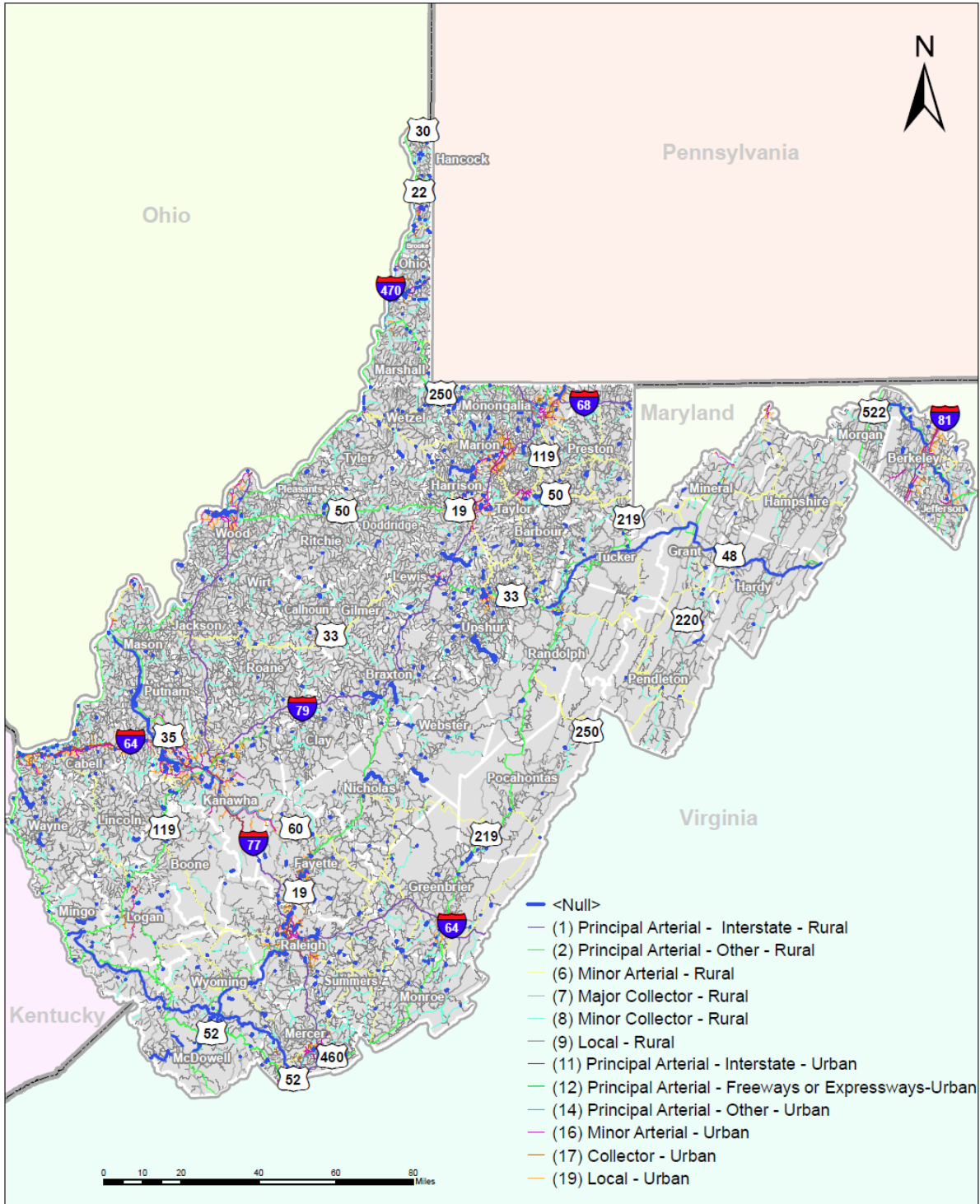
Figure 7-11 Roadway Functional Classification by Segment from Roadway Inventory Log

Rural/Municipal & Rural/Urban Designations (Population)

There are two fields in the RIL that capture whether the road is in a populated area. The first is referred to in the RIL as Rural/Municipal, which indicates whether the road is in an incorporated municipality and if it is, the population of that municipality. The breakdown of population range by sign class is listed in Table 7-13 and mapped in Figure 7-12. Another field in the RIL is called Rural/Urban and simply captures if the roadway is in a Rural area (population less than 5,000), an Urban area (population 5,000-49,999), or an Urbanized area (population greater than 50,000). The breakdown of this three level category is shown in Table 7-6 and mapped in Figure 7-13. The Rural/Urban variable was determined to be more valuable to the modeling because whether an area is incorporated wouldn't impact the occurrence of DVCs. An area's population is the primary measure to be obtained, so the Rural/Urban variable was used and the null values were removed from the analysis.

In the modeling effort, the Rural/Urban variable was treated as a three-level categorical variable, with Rural being "low population" and Urbanized being "high population". The behavior of this variable is difficult to interpret. As shown on the map, the urbanized areas include the inner city of large areas where you wouldn't expect to see deer because there is no habitat. The urban areas would be smaller towns and outside of large cities that might border deer habitat and attract more deer.

Table 7-13 Rural/Municipal Designation by Sign System from Roadway Inventory Log

Map Group	Rural/ Municipal	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	1.1	327.8	0.0	341.9	0.1%	8.5%	0.0%	1.2%
2	Not w/in an incorporated municipality	957.5	3045.1	3360.6	27728.1	87.4%	78.7%	90.1%	96.4%
3	< 2,500	26.9	163.9	153.4	408.5	2.5%	4.2%	4.1%	1.4%
4	2,500 - 4,999	26.1	91.0	70.9	120.1	2.4%	2.4%	1.9%	0.4%
5	5,000 - 9,999	5.7	39.4	28.2	48.7	0.5%	1.0%	0.8%	0.2%
6	10,000 - 24,999	5.4	102.8	40.1	55.6	0.5%	2.7%	1.1%	0.2%
7	25,000 - 49,999	17.8	54.2	42.3	38.5	1.6%	1.4%	1.1%	0.1%
8	50,000 - 99,999	55.5	47.3	36.2	19.9	5.1%	1.2%	1.0%	0.1%
	Total LRS Mileage	1096.0	3871.5	3731.7	28761.2				

Table 7-14 Rural/Urban Designation by Sign System from Roadway Inventory Log

Map Group	Rural/ Urban	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	\<Null\>	1.1	327.8	0.0	341.9	0.1%	8.5%	0.0%	1.2%
2	Rural (< 5,000)	727.9	2802.1	3195.5	26442.9	66.4%	72.4%	85.6%	91.9%
3	Urban (5,000 - 49,999)	98.3	384.5	220.3	880.1	9.0%	9.9%	5.9%	3.1%
4	Urbanized (50,000+)	268.7	357.1	316.0	1096.3	24.5%	9.2%	8.5%	3.8%
Total LRS Mileage		1096.0	3871.5	3731.8	28761.2				
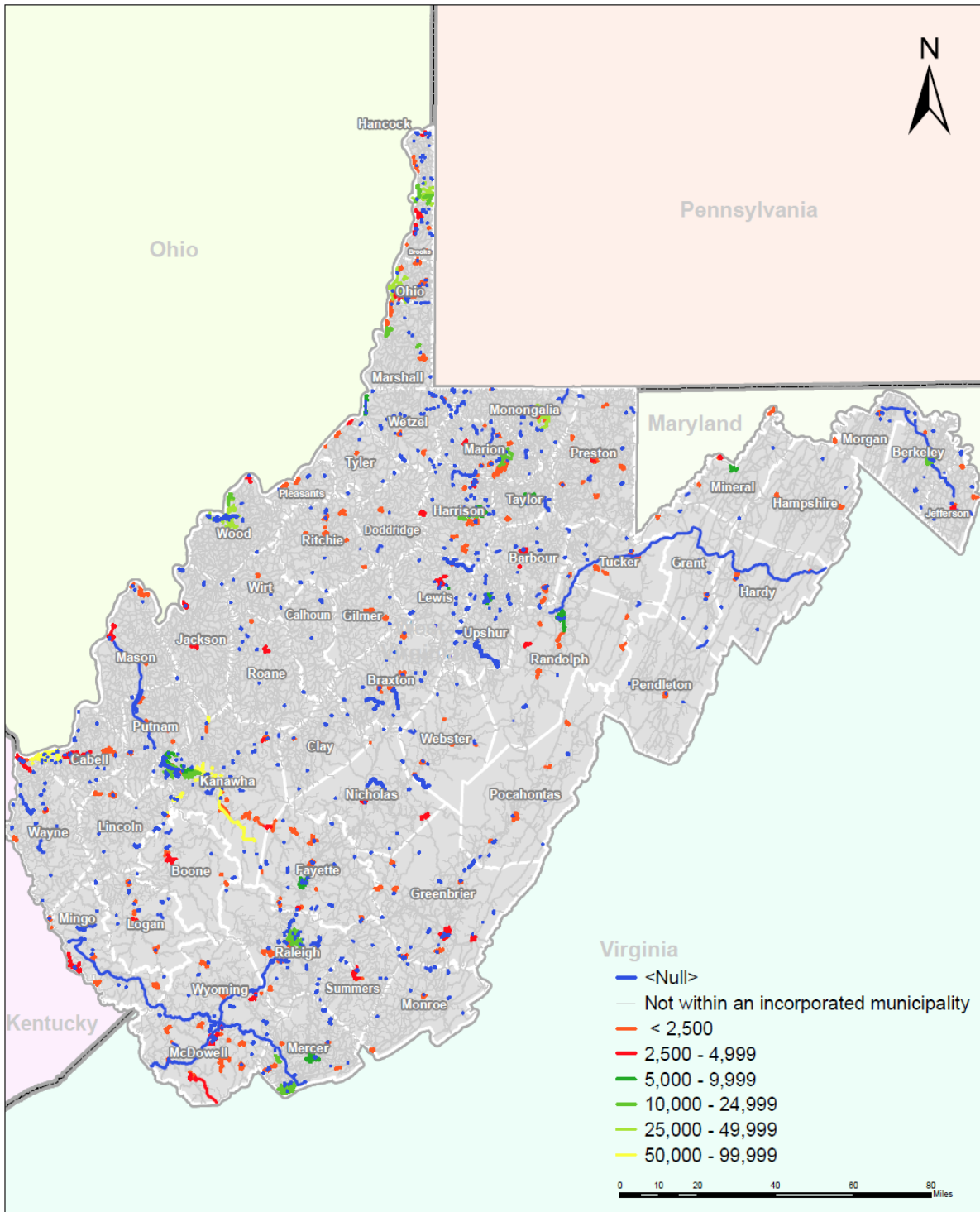
Figure 7-12 Rural/Municipal Designation by Segment from Roadway Inventory Log
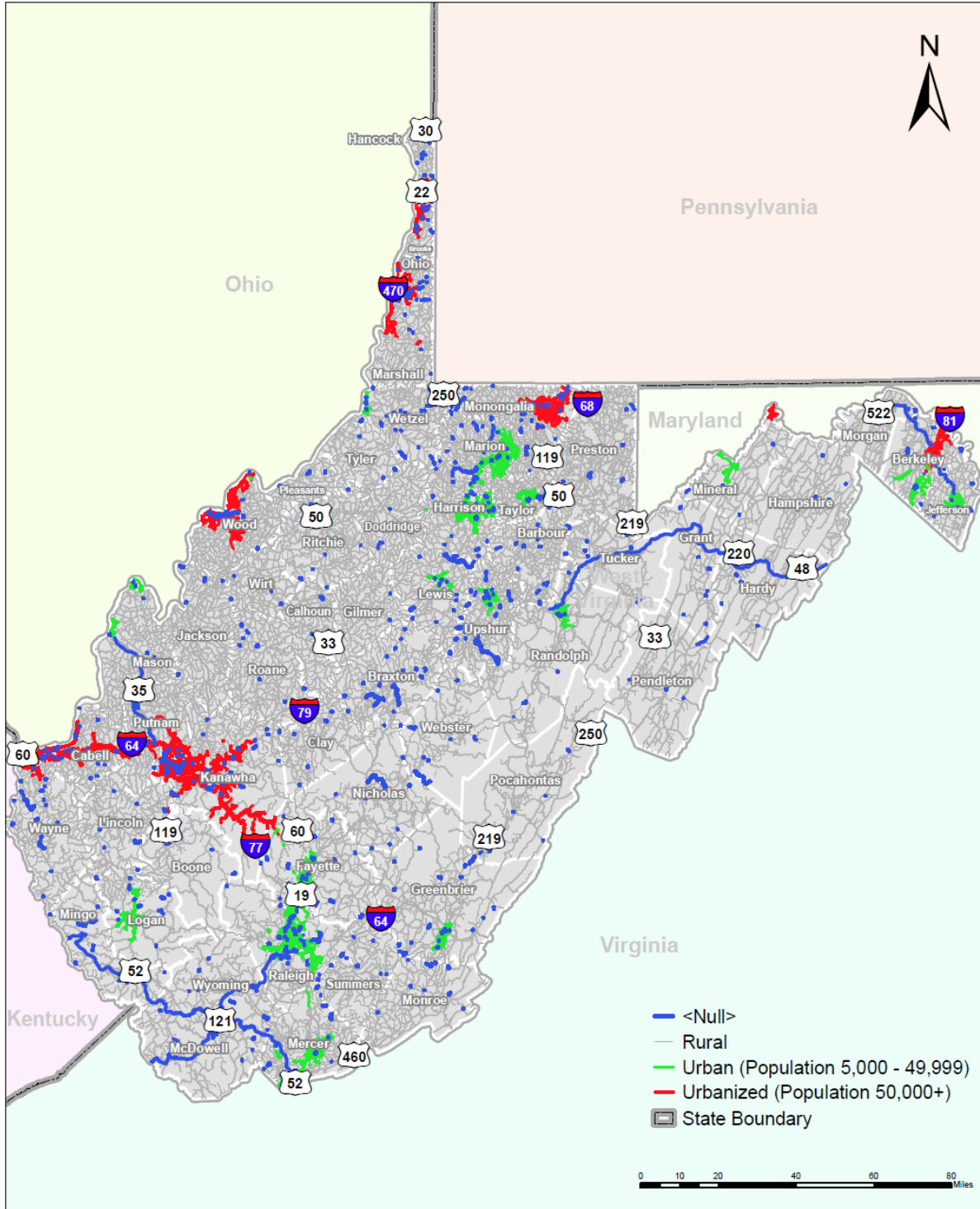
Figure 7-13 Rural/Urban Designation by Segment from Roadway Inventory Log

Road Surface Type

The road surface type by sign system is listed in Table 7-15 and mapped in Figure 7-14. Given that the majority of the Interstate, US Route, and WV Routes in this database are asphalt or concrete, there isn't much information that could be derived from this that would affect DVC occurrence. There is nothing about the roadway type that would attract or deter deer. The type of road is more of an indication of the function it serves, but there is already a roadway functional classification variable that is being used.

Table 7-15 Road Surface Type by Sign System from Roadway Inventory Log

Map Group	Road Surface Type	Sign System				Percentage of Sign System Total Mileage			
		1 Inter.	2 US	3 WV	4 County	1 Inter.	2 US	3 WV	4 County
1	<Null>	1.1	327.1	-	341.8	0.1%	8.4%		1.2%
2	Primitive Road	-	-	-	1236.3				4.3%
3	Unimproved	-	-	-	1623.2				5.6%
4	Graded And Drained Road	-	-	-	1.6				0.0%
5	Soil Surface Road - Dirt	-	-	-	20.8				0.1%
6	Gravel/Stone	-	-	2.6	7585.7			0.1%	26.4%
7	Bit. Surface Treated Road	-	-	5.0	3586.7			0.1%	12.5%
8	Mixed Bituminous Road < 7" Combined Thickness	-	-	1.1	481.2			0.0%	1.7%
9	Mixed Bituminous Road > 7" Combined Thickness	-	-	0.1	2.9			0.0%	0.0%
10	Bituminous Penet. Road < 7" Combined Thickness	-	-	-	1.2				0.0%
11	Bituminous Penet. Road >7" Combined Thickness	-	0.0	0.1	-		0.0%	0.0%	
12	Asphalt	757.2	3199.1	3647.7	13811.4	69.1%	82.6%	97.7%	48.0%
13	Concrete	337.7	345.2	74.9	64.0	30.8%	8.9%	2.0%	0.2%
14	Brick	-	0.1	0.4	4.2		0.0%	0.0%	0.0%
	Total LRS Mileage	1096.0	3871.5	3731.8	28761.2				
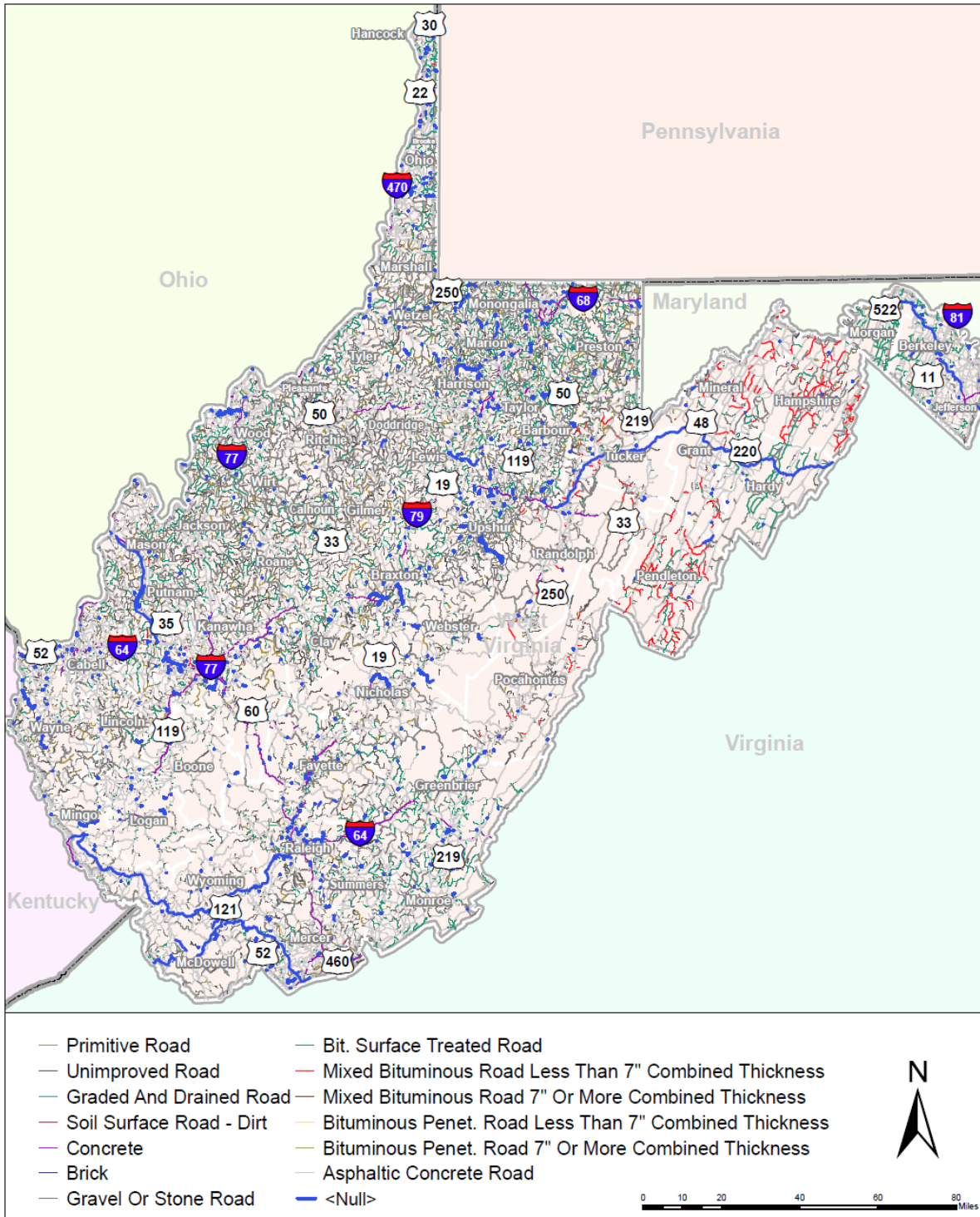
Figure 7-14 Road Surface Type by Segment from Roadway Inventory Log

7.2.4. <u>Distance to Water</u>

Deer movements can be affected by the location of water. A roadway that is between a deer habitat and a water source may experience frequent crossing activity. GIS data was obtained from the WV Department of Environmental Protection (wetlands) and U.S. Geological Society (hydrography) that represents the locations of water bodies in West Virginia. All types of water bodies are included in the data set, including rivers, streams, lakes, reservoirs, wetlands, and marshes. Within these types, the water body can also be classified as perennial (holds water throughout the year), intermittent (holds water during wet portions of the year), and ephemeral (holds water only during and immediately after rain events). For this analysis, the shortest distance to the nearest water body type was calculated and assigned to each 2.0-mile segment. Figure 7-15 illustrates a map of each segment's distance to the nearest water body of any type. Due to the distribution of values in the data, a log transformation was conducted to obtain a more normally distributed data set. This variable was treated as a continuous variable. The expected relationship is that the closer the roadway is to a source of water, the more likely there will be deer activity and the DVC rate would be higher. Future analysis could investigate distances to specific water body types since there was minimal variation among this variable across roadway segments.
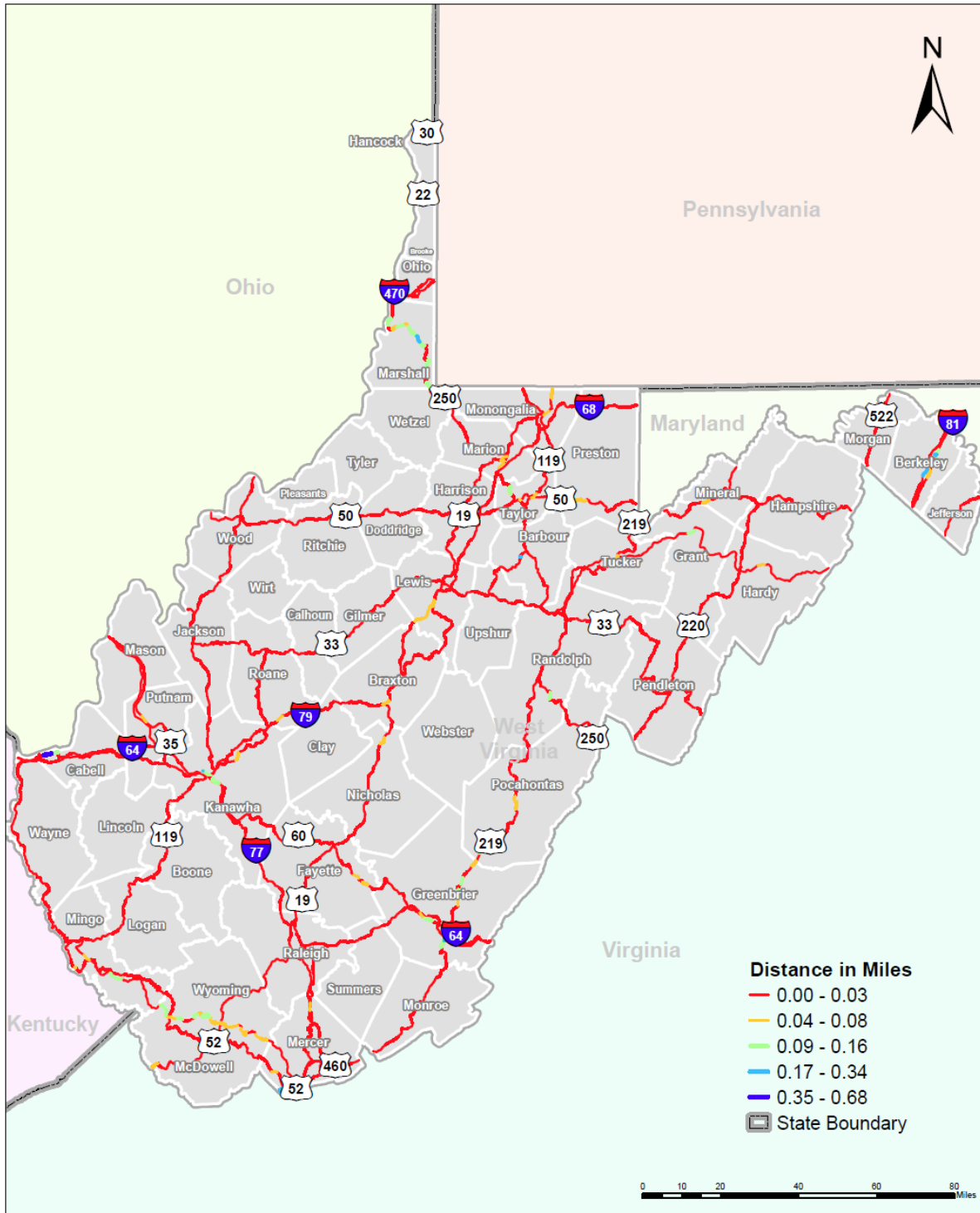
Figure 7-15 Distance to Nearest Water Body by Segment

7.2.5. Roadway Curvature

Sight distance can impact how much time a driver has to see and react to a deer in the road. Therefore, including a variable in the analysis that explains roadway curvature is desirable. Since the WVDOT RIL does not contain roadway curvature data, a surrogate measure was calculated from the GIS roadway shapefiles that are part of the Linear Reference System. The calculation was a ratio of the actual segment distance to the shortest distance between the segment endpoints. The ArcGIS "sinuosity ratio" tool was used to conduct this calculation. The calculation is performed in 2 dimensions, so elevation (and therefore vertical curvature) is not accounted for. If the ratio is 1.0, the road segment is a straight line (tangent). As the amount of curvature increases, so does the ratio. This ratio may not be a true indicator of poor sight distance because a segment could have a single large radius curve (likely not reducing sight distance) or many smaller radius curves (likely reducing sight distance) and have the same ratio. The calculated ratios ranged from 1.0-7.5. In the modeling effort, the ratio was treated as a continuous variable, where the expectation is that higher values would correspond to locations with higher DVC rates. Figure 7-16 illustrates a map of the ratios assigned to each segment.
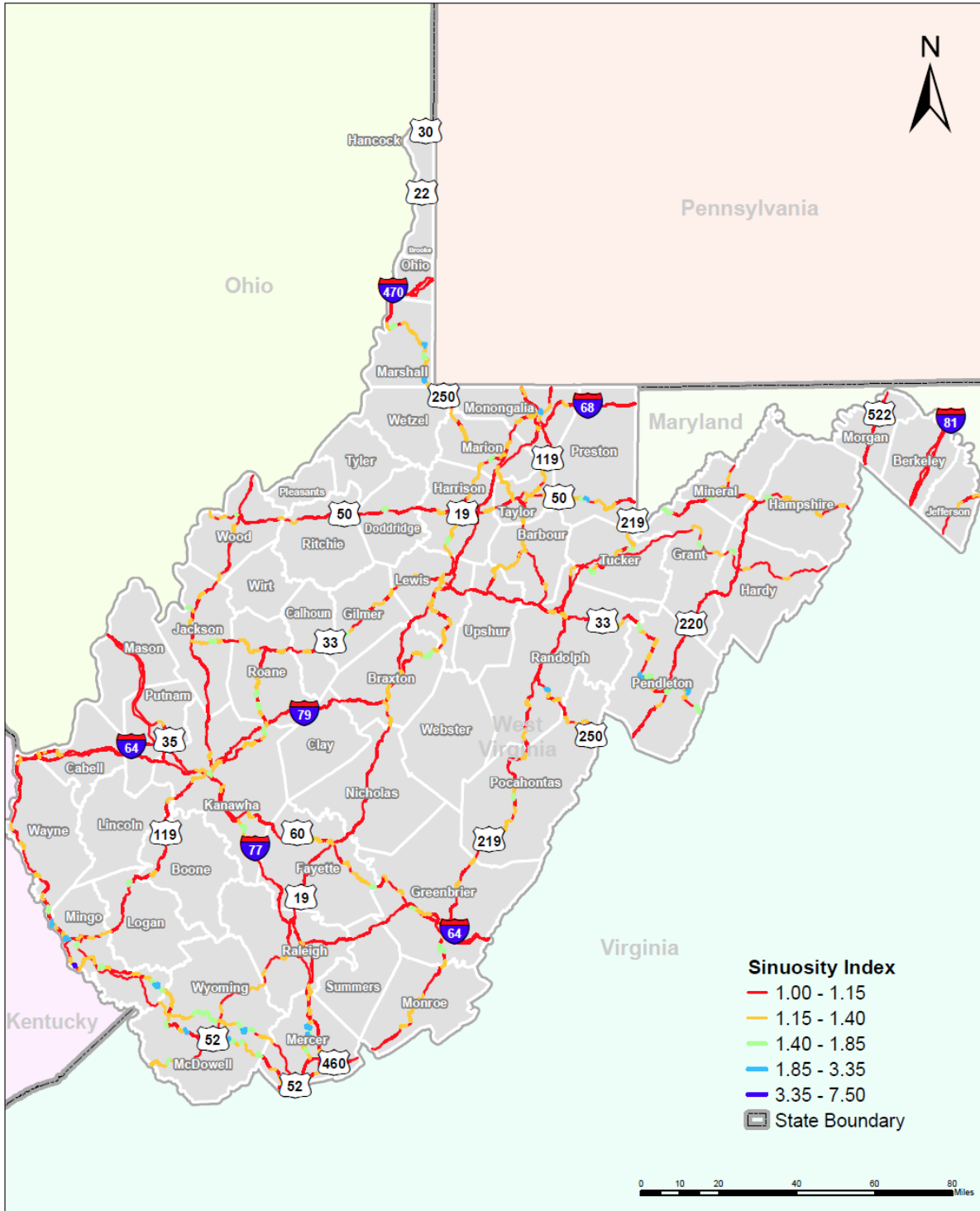
Figure 7-16 Roadway Curvature (Ratio) by Segment

7.2.6. <u>Roadside Slope</u>

Road segments that are in a steep cut or fill section might experience fewer deer crossings due to the deer being physically unable (or unwilling) to climb up or down the incline. Since roadside slope data was not available in the WVDOT RIL, a surrogate measure was calculated from the 2003, 3-meter digital elevation model (DEM) elevation from the U. S. Geological Society using the ArcGIS Slope algorithm. The slope analysis identified the maximum rate of change in elevation between each 3-meter cell and its eight neighboring cells. The slopes were calculated for all pixels along each 2.0-mile segment for a total width of 60 meters (30 meters on each side of the road). It was assumed that deer would be deterred by slopes exceeding 60 degrees (uphill or downhill). Therefore, the number of pixels exceeding 60 degrees along each segment were used to calculate a percentage of the area that was steep and this was treated as a continuous variable. Figure 7-17 illustrates a map of the percentage of the segment buffer area with a slope exceeding 60°.

Figure 7-17 Percentage of Roadside Slope Exceeding 60° by Segment

7.3. DVC Regression Modeling

As stated previously, the modeling effort was only conducted for segments on Interstates and US Routes due to the availability and reliability of data, particularly the WVDOT RIL, for the other roadway types. There were a total of 1,150 segments on Interstate and US Routes with complete data (i.e., no missing values) and 698 segments have at least one observed crash (61%). 160 segments were eliminated from the analysis because of a missing data field.

Certain regression models are more appropriate than others when the majority of segments have a value of zero, such as the zero-inflated negative binomial (ZINB) model. Another approach to handle an excessive amount of zeroes is to use a hurdle model. A hurdle model is a two-step process where the first model generates a zero or a positive value (i.e., no crash or crash). If the value is positive, the "hurdle is crossed" and a second model is estimated to determine the distribution of the positive values (i.e., number of crashes). For this modeling effort, the second model was only applied to the segments where a crash was observed. While many regression models were estimated, the results presented here focus on the negative binomial (NB), zero-inflated negative binomial (ZINB), two-step hurdle, and generalized additive negative binomial (GANB).

7.3.1.   Model 1 - Negative Binomial NB

An NB model was estimated using various combinations of variables. The objective of this model is to estimate the total number of DVCs on the segment, using the observed crashes as the dependent variable. The optimal model and significant variables are shown in Table 7-16. The model was evaluated using the nine combined land use categories based on the WVDNR recommendation, the landscape diversity index based on the nine WVDNR groups, and the landscape diversity index based on the alternative six groups. The Akaike information criterion (AIC) value can be used to evaluate the relative quality of statistical models, with lower values indicating a better model. The NB model using the diversity index of the six groups was the best of the three. Therefore, the landscape diversity used here and in the remaining models is the one based on the six groups discussed in Section 7.2.2. The AADT, landscape diversity, and slope are continuous variables. The Urban, Urbanized, and number of lanes are indicator variables, so the presence of that characteristic on a segment will have an impact corresponding to the estimated sign on the DVC estimate. The coefficients that are positive indicate that an increase in that variable will result in an increase in the expected frequency on a segment. All variables have a positive relationship with the DVC frequency, except for the slope. This is expected since increasing the slope should decrease deer crossings and DVCs.

Table 7-16 Negative Binomial Model Results

Variable	Coefficient	Std. Error	p-value
Intercept	-12.74	0.52	< 2e-16
AADT	+0.54	0.06	< 2e-16
fRU (Urban)	+0.21	0.11	0.05
fRU (Urbanized)	+0.20	0.10	0.05
fLanes (>= 4)	+0.16	0.11	0.13
Div (Landscape Diversity)	+0.51	0.23	0.02
Slope	-0.04	0.01	2.69e-12
		AIC	3910.749

7.3.2. <u>Model 2 - Zero-Inflated Negative Binomial (ZINB)</u>

The ZINB model is utilized when there is an abundance of segments where the variable being modeled is zero. The results of the optimal ZINB model are shown in Table 7-17. Based on the AIC value, this model performs very similar to the negative binomial model.

Table 7-17 Zero-Inflated Negative Binomial Model Results

Variable	Coefficient	Std. Error	p-value
Intercept	+2.25	3.71	0.54
LAADT	-1.00	0.41	0.01
fRU(Urban)	-12.06	257.46	0.96
fRU(Urbanized)	+0.79	1.03	0.44
fLanes(>=4)	+0.15	1.14	0.88
Div	-6.28	3.02	0.03
Slope	+0.07	0.03	0.03
Intercept	-11.47	0.64	< 2e-16
LAADT	+0.43	0.07	1.85e-09
fRU(Urban)	+0.19	0.11	0.07
fRU(Urbanized)	+0.27	0.11	0.01
fLanes(>=4)	+0.22	0.12	0.06
Div	+0.23	0.24	0.33
Slope	-0.03	0.00	4.84e-07
AIC			3910.912

7.3.3.   Model 3: Two-Step Hurdle

The hurdle model was estimated using a variety of regression types. The optimal model utilized the binomial model for step 1 to determine presence and absence and a zero-truncated negative binomial (NB) model for step 2 to estimate the quantity. The results of the models from both steps are shown in Table 7-18. The top model is the presence/absence model and the bottom model estimates the quantity.

Table 7-18 Hurdle Negative Binomial Model Results

Variable	Coefficient	Std. Error	p-value
Intercept	-14.77	0.92	< 2e-16
LAADT	+0.75	0.11	6.16e-12
fRU(Urban)	+0.93	0.29	0.001
fRU(Urbanized)	+0.02	0.23	0.912
fLanes(>=4)	+0.17	0.22	0.440
Div	+1.02	0.48	0.036
Slope	-0.05	0.01	2.67e-
Intercept	-11.43	0.76	< 2e-16
LAADT	+0.40	0.08	2.85e-06
fRU(Urban)	+0.07	0.13	0.56
fRU(Urbanized)	+0.31	0.13	0.01
fLanes(>=4)	+0.24	0.14	0.08
Div	+0.32	0.29	0.27
Slope	-0.03	0.01	2.00e-05
AIC			3898.183

7.3.4. Model 4: General Additive Negative Binomial

To model the deviation from the NB model that may be due to the spatial autocorrelation, a nonparametric non-linear modeling technique was applied on the spatial coordinates (i.e., latitude and longitude) of the road segments as an additive part to the parametric NB model. This method assumes that the amount of DVCs on each road segment is not only influenced by the environmental variables, but also by the amounts of DVCs on nearby road segment, given that DVCs are spatially clustered (*145*). The contribution of the spatial structure of DVCs can be modeled by an isotropic thin plate regression spline, and added from the residuals defined by the NB model. The results of the optimal model are shown in Table 7-19.

Table 7-19 General Additive Negative Binomial Model Results

Variable	Coefficient	Std. Error	p-value
Intercept	-11.23	0.56	< 2e-16
LAADT	0.37	0.06	5.92e-09
fRU(Urban)	0.45	0.11	7.57e-05
fRU(Urbanized)	-0.08	0.12	0.46
fLanes(>=4)	0.07	0.11	0.50
Div	0.16	0.23	0.48
Slope	-0.015	0.01	0.01
		AIC	3738.378

7.3.5.   Model Comparison

Figure 7-18 illustrates a comparison of the actual (observed) DVCs and estimated DVCs (fitted) for each model. A red line was fit to each plot to indicate the trend: the closer to the black diagonal line, the better estimation. Based on the AIC values and these plots, GANB appears to be the best model among the four models.

(a)   Negative Binomial

(b) Zero Inflated Negative Binomial

(c) Hurdle Model

(d) GANB
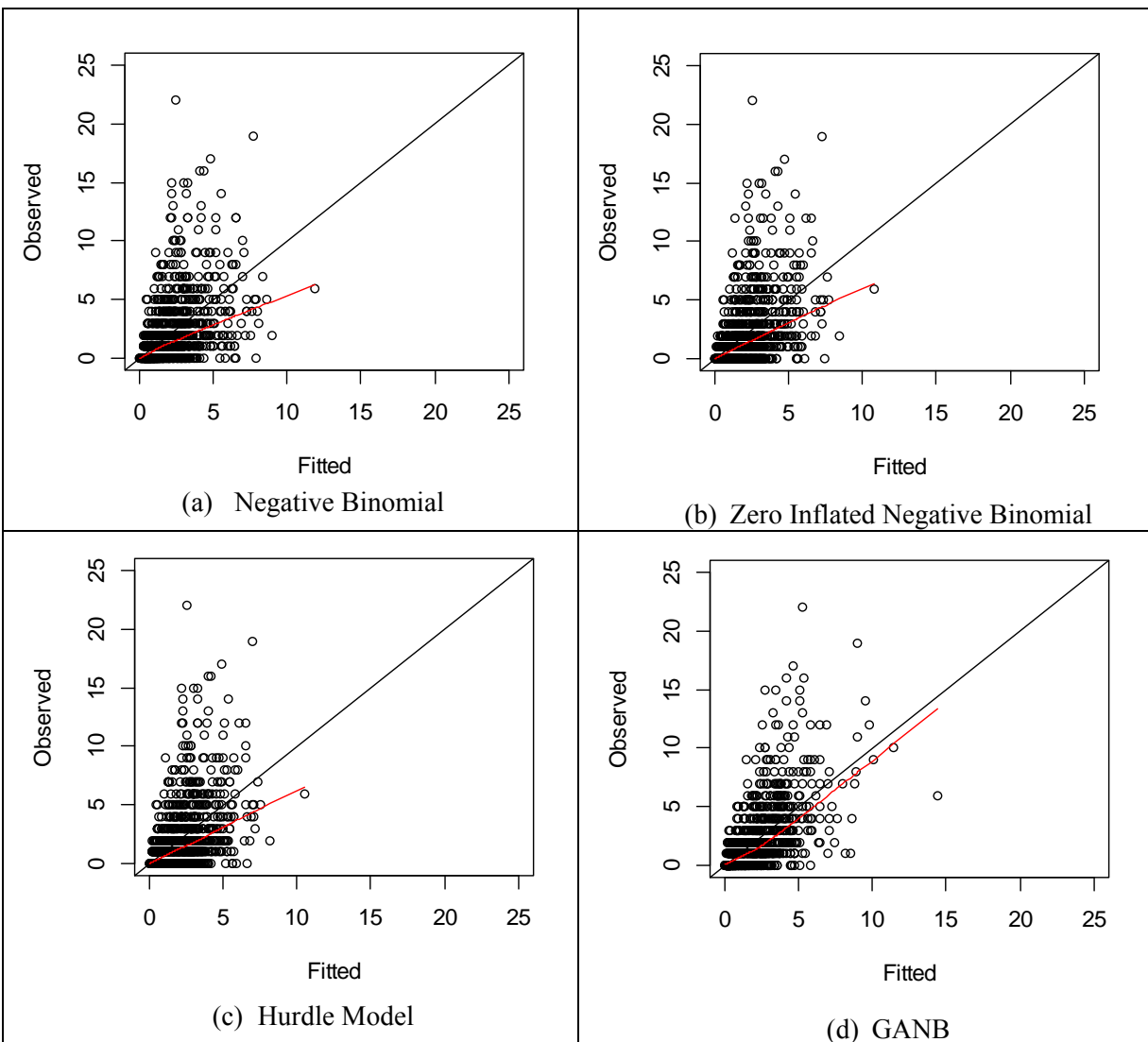
Figure 7-18 Comparison of Models

7.4. Roadway Characteristic Correlation Discussion

Based on the optimal models developed in the previous section, the general relationship between DVC and the characteristics modeled are summarized in Table 7-20, along with the AIC values for each model. Notice there is general agreement among the signs of the coefficients and some of the variables analyzed weren't significant in any of the optimal models. The GANB model had the lowest AIC value, which suggests that it is the best model of the four. In that model, the AADT and landscape diversity have a positive correlation with the DVC frequency. Road segments with high DVC count are also positively correlated with having four or more lanes and being located in an area with population of 5,000-49,999. Road segments in an area with a population above 50,000 and having a steep slope on the side of the road are correlated with low frequency DVC (or no DVC).

Table 7-20 Summary of DVC and Characteristic Relationships

Variable	Model 1 Neg Bin	Model 2 ZINB Pres	Model 2 ZINB Abund	Model 3 Hurdle Pres	Model 3 Hurdle Abund	Model 4 GANB
National Land Cover Data						
Landscape Div Index (6 comb)	+	-	+	+	+	+
AADT	+	-	+	+	+	+
Speed Limit > 50 mph						
Positive Median Barrier						
Functional Classification						
Urban Area (5,000-49,999 pop.)	+	-	+	+	+	+
Urbanized Area (>50,000 pop.)	+	+	+	+	+	-
4 or more lanes	+	+	+	+	+	+
Distance to Water						
Roadway Curvature						
Roadside Slope > 60°	-	+	-	-	-	-
AIC Value	3910.749	3910.912		3898.183		3738.378

(blank) Not included in optimal model
+ Positive Relationship
- Inverse Relationship

7.5. Summary and Recommendations

In this work, four types of models – negative binomial, zero-inflated negative binomial, two-step hurdle, and generalized additive negative binomial – were developed to understand the factors affecting DVCs. Based on the AIC values, all four models performed very similarly, but the generalized additive performed the best, accounting for spatial relationships among the segments.

The significant variables in the models and the signs of their coefficients seemed logical. As the AADT and landscape diversity increased, the expectation of a DVC increased. The presence of steep slopes on the side of the road reduced the expectation that a deer would be hit on a segment. The researchers believe there is further scope for improving the model predictions by accounting for the interaction variables, however it is also likely that there are causes that can't be explained by the data being used, such as deer population.

The modeling effort could be greatly enhanced if more complete and reliable roadway data were available in GIS format, particularly the data contained in the RIL. Many of the roadway characteristics that were modeled in other studies and found to be significant could not be included in this study, such as sight distance (forward and to the side), geometric curvature, and shoulder width. The AADT estimates need to be reliably completed for all roadways within the state to facilitate a more reliable crash rate calculation.

The model developed is probably not adequate to use for prediction purposes, but this shouldn't be necessary as long as police crash records are utilized for hotspot analysis. The amount of effort to complete the modeling effort again in the future should be less than the effort required in this study as long as the missing data fields in the RIL are completed. If it is desirable to model the carcass data, a future effort could focus on the analysis of counties with a high percentage of DOT-12 records with route and milepost, then apply that model to estimate carcasses in other counties.

8. WILDLIFE-VEHICLE COLLISION MITIGATION FUNDING SOURCES

8.1. Overview

This section of the report addresses the following objective of the study.

10. Identify possible funding sources at the local, state, and federal level for DVC mitigation implementation.

There are a variety of sources for funding the reduction of WVCs in West Virginia. These sources include a mix of traditional transportation programs, as authorized in the latest transportation act, MAP-21 (Moving Ahead for Progress in the 21st Century Act), Public Law 112-141 (23 USC, §101 et seq.). For the first time in a surface transportation bill, MAP-21 provided explicit language to use program funds to reduce WVC in a wide variety of highway programs. MAP-21 also included a new program for broad scale highway mitigation, called programmatic mitigation plans. This new provision for statewide mitigation planning could be explored by WVDOT as it seeks to reduce DVCs statewide.

In addition to MAP-21 programs, depending on the highway mitigation project, there may be opportunities to leverage traditional transportation funding with funding from other non-transportation agency funds or with interested non-transportation partners. Since reducing WVCs can provide additional benefits beyond those provided for improving motorist safety; partners may be interested in co-funding WVC mitigation for the collateral benefits for wildlife conservation, the protection of threatened or endangered species, improved habitat and ecological connectivity resulting from some WVC mitigation infrastructure (i.e., wildlife underpasses), or reduced costs for motor vehicle collision insurance. Such benefits reach well beyond the realm of transportation safety, providing WVDOT the opportunity to develop new partnerships that tap the resources of non-transportation partners.

To generate the greatest variety of funding opportunities, partnerships for DVC reduction projects may require a mix of federal, state, and local agencies as well as non-profit organizations and individuals. This is a result of the many different grant programs that could be tapped for highway mitigation as well as the restrictions that often apply on the type of recipients that can receive funding from corporate and private philanthropy. Thus a mix of federal, state, local, private individuals and/or non-profit organizations working together will help maximize the programs and sources of funding that can be utilized to implement WVC mitigation. Following are a list of potential funding sources, or examples of funding sources. For the different funding categories, many of the different categories could be tapped if multi-

stakeholder partnerships are developed for WVC mitigation projects and their implementation, monitoring, research and outreach.

8.2. <u>National Transportation Funding Sources</u>

MAP-21 authorizes the funding of a variety of surface transportation programs for federal fiscal years 2013 and 2014. It is the shortest duration transportation law in recent memory and is the first highway authorization enacted since 2005. It was signed by President Obama on July 6, 2012. It is the first U.S. transportation law to explicitly define as one of its targets - the reduction in the number of motorist collisions with wildlife. Some programs also describe projects eligible for funds including those that improve connectivity among habitats disrupted by roads. These provisions are incorporated into various programs for state, federal, metropolitan, and tribal agencies (*146*). The following sections include the programs with their funding amounts that can be used to reduce DVCs in West Virginia.

8.2.1.   <u>WVDOT Programs and Funds</u>

Surface Transportation Program (STP)
Nationwide, the STP program is authorized at $10.0B for fiscal year (FY) 2013 and $10.1B for FY 2014. In FY 2013, West Virginia had available $57,248,047 in funds for its STP (*147*). Eligible projects under the STP include highway and transit safety infrastructure improvements and programs, installation of safety barriers and nets on bridges, hazard eliminations, projects to mitigate hazards caused by wildlife, and railway-highway grade crossings.

Highway Safety Improvement Program (HSIP)
West Virginia received an initial $26,440,963 in FY 2013 for its HSIP program (*148*). Eligible highway safety improvement projects include the addition or retrofitting of structures or other measures to eliminate or reduce crashes involving vehicles and wildlife. These funds are typically allocated based on crash rate and crash severity prioritization through benefit-cost analysis. Therefore, DVC hotspots would be competing with all other crash types for funding.

Transportation Alternatives Program (TAP)
The national TAP set aside for FY 2013, after rescission, was $807,142,480 of which West Virginia received $6,833,221 (*149*). TAP provides funding for programs and projects defined as transportation alternatives, including on- and off-road pedestrian and bicycle facilities, infrastructure projects for improving non-driver access to public transportation and enhanced mobility, community improvement

activities, and environmental mitigation; recreational trail program projects; and safe routes to school projects. Funding from TAP can be used for a program or project activity to reduce vehicle-caused wildlife mortality or to restore and maintain connectivity among terrestrial or aquatic habitats. It is clear that WVC reduction mitigation projects will be in stiff competition with other local needs for TAP's limited funds.

8.2.2. TIGER Discretionary Grants

Originally TIGER grants were administered by the FHWA as part of the American Recovery and Reinvestment Act of 2009 (the "Recovery Act"). They were competitive grants that could be awarded directly to state, county or city governments for surface transportation projects. The granting program under the Recovery Act was completed in 2012. Then, in 2013, as part of the Full-Year Continuing Appropriations Act of 2013 (Public Law 113-6, March 26, 2013), the program was continued. TIGER in 2013 was similar to the Recovery Act program and FHWA distributed $474M for competitive surface transportation projects across the nation. It is unclear if future appropriations will fund the program, but if so, WVDOT highway projects that include DVC reduction mitigation and infrastructure could be proposed for TIGER funding.

8.2.3. Highway Traffic Safety Grants

This grant program is administered by the National Highway Traffic Safety Administration (NHTSA). NHTSA is seeking $561.5M for this grant program in FY 2014 (*150*). Given the high level of DVC rates in various areas of West Virginia, this grant program has the potential to help identify and address this key cause of accidents on West Virginia highways.

8.2.4. Eco-Logical Competitive Grants

Eco-Logical is the FHWA's ecosystem approach to consider and protect natural resources using an integrated approach to transportation planning and projects. In the past, there have been 15 grants totaling $1.4M provided to explore different facets of Eco-Logical (*151*). Now the needs for Eco-Logical research will be incorporated in to the Strategic Highway Research Program (SHRP 2). Future SHRP 2 competitive grants may be sought by WVDOT once DVC planning is completed and project implementation is ready. SHRP 2 grants are primarily for funding projects designed to provide the tools needed to implement the Eco-Logical approach.

8.2.5.   <u>Non-state Agency Transportation Programs</u>

WVDOT may choose to work with metropolitan and federal land management agencies to cooperatively address the reduction of DVCs. The following programs are directed to WVDOT's potential partners, but the programs could be utilized to emphasize and potentially fund DVC mitigation efforts.

Metropolitan Transportation Planning Program (MPP)
Metropolitan planning organizations in West Virginia were apportioned $1,651,709 for MPP in FY2013 (*152*) A long-range transportation plan under this section shall include a discussion of types of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the plan. For metropolitan authorities to complete their mitigation plans they must be in consultation with Federal, State, and tribal wildlife, land management, and regulatory agencies. Therefore, there may be ample opportunity for MPPs developed in West Virginia to include mitigation for wildlife along high DVC road segments in metropolitan and suburban areas.

Federal Lands Transportation Program
This section of MAP-21 has three programs that include WVC mitigation as well as habitat connectivity provisions: One of these three, the Tribal Transportation Program, cannot be used in West Virginia due to the absence of tribal reservations. However, the Federal Lands Transportation Program and the Federal Lands Access Program could be tapped in partnership with federal land management agencies.

- <u>Federal Lands Transportation Program (FLTP)</u>. The FLTP helps improve multi-modal access within national parks, forests, wildlife refuges, Bureau of Land Management (BLM) lands, and U.S. Army Corps of Engineers (USACE) facilities. The FLTP funding is authorized at $300M for both FY 2013 and FY 2014. The National Park Service gets the majority of the funding, $240M each year, the US Fish and Wildlife Service gets $30M each year and the remaining is competitively apportioned to the BLM, USACE and the US Forest Service. The FLTP focuses on the transportation infrastructure owned and maintained by Federal land management agencies. Funding from this program can be used to pay for environmental mitigation in, or adjacent to, federal land open to the public to improve public safety and reduce vehicle-caused wildlife mortality while maintaining habitat connectivity; or to mitigate damage to wildlife, aquatic organism passage, habitat, and ecosystem connectivity, including the costs of constructing, maintaining, replacing, or removing culverts and bridges. The FLTP provides a great opportunity

for WVDOT to work with federal land management partners; however, it is the only program that Congress put a cap of $10M per fiscal year for eligible activities.

- Federal Lands Access Program (FLAP). The FLAP complements FLTP by providing funds to improve transportation facilities that provide access to, are adjacent to, or are located within federal lands. It has been authorized for funding for both FY 2013 and FY 2014 at $250M per year. FLAP supplements state and local resources for public roads, transit systems, and other transportation facilities, with an emphasis on high-use recreation sites and economic generators. Funding from this program can be used to pay for environmental mitigation in or adjacent to federal land to improve public safety and reduce vehicle-caused wildlife mortality while maintaining habitat connectivity.
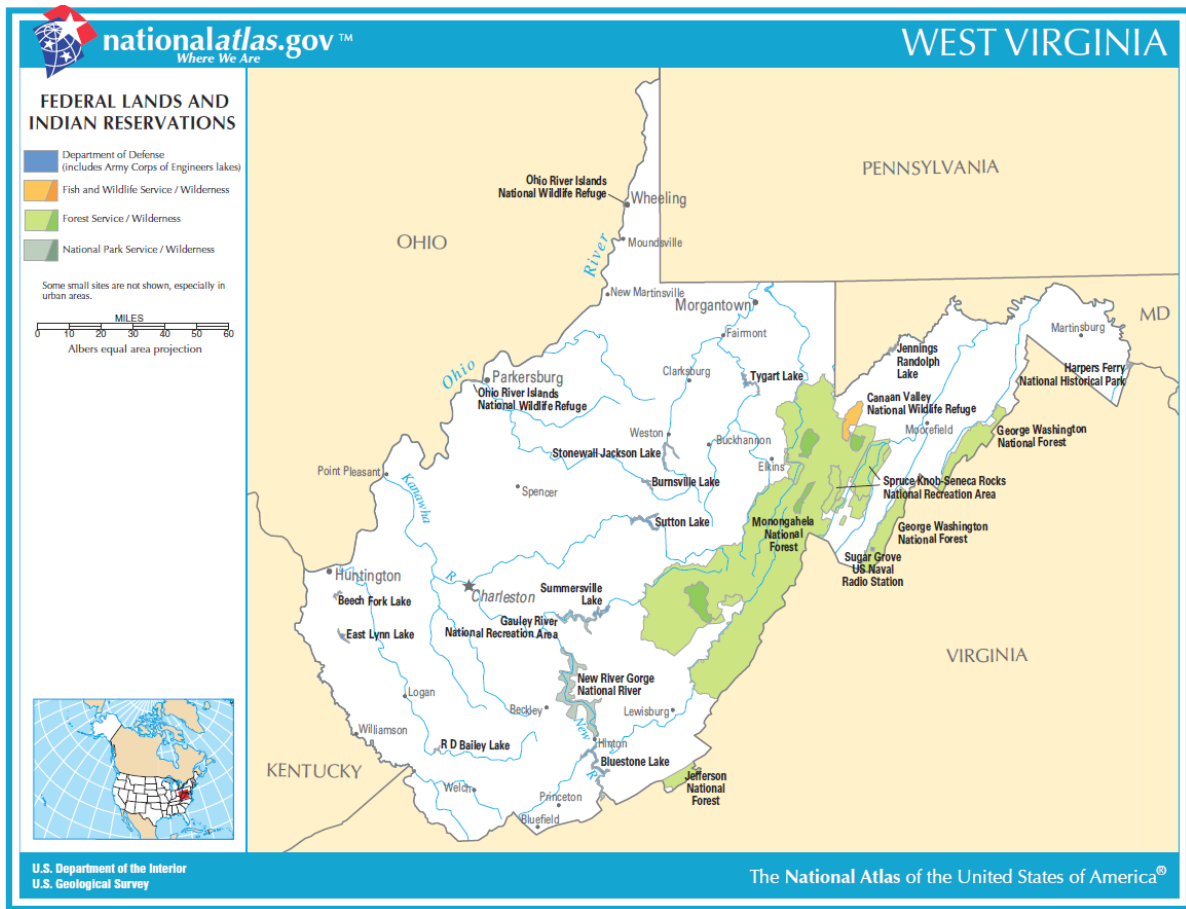
Figure 8-1 Federal Lands in West Virginia

8.2.6.   New Potential Transportation Funding in MAP-21

A new section in MAP-21 authorizes states and metropolitan planning organizations (MPOs) to develop programmatic mitigation plans. This is section 1311 of MAP-21 and it has no precedent in previous

transportation acts. It provides no funding authority to the states or MPOs to develop the mitigation plans. Due to the novelty and newness of the provision, as of January 2014, the FHWA has not included the section in any rulemaking to develop regulations for its deployment nor has the agency posted any guidelines for its use. The FHWA has provided a six part question and answer sheet on its website regarding the program (*153*).

There are currently no examples of how states or MPOs are using the new mitigation planning provisions. However, MAP-21 allows the programmatic mitigation plans to be developed on a regional, ecosystem, watershed, or statewide scale and could encompass multiple environmental resources within a defined geographic area or may focus on a specific resource, such as aquatic resources, parkland, or wildlife habitat. Thus, the WVDOT could take advantage of this new provision by developing a statewide DVC mitigation program. Such a plan may be advantageous to define the extent of WVDOT's commitment for DVC mitigation, have locations and measures already identified and allow DVC mitigation to proceed regardless of whether a highway construction or re-construction project is slated for a particularly problematic road segment with high DVC rates. Thus, the potential to bank DVC mitigation appears to be possible under this program.

8.3. National Non-transportation Potential Funding Sources

The U.S Fish and Wildlife Service (USFWS) administers a variety of natural resource grant programs for state agencies. To employ these grant monies for DVC mitigation, the WVDOT would need to work in partnership with the West Virginia Division of Natural Resources (WVDNR) – Wildlife Section to seek funding for mutually agreeable projects. A cooperative highway DVC mitigation project, such as a wildlife underpass with fencing, could have additional benefits other than motorist safety, such as the conservation of non-ungulate species that would also use the infrastructure to safely pass under busy highways. Thus locations that are high in DVCs and are areas where species that are priorities for the WVDNR are co-located could be beneficial to both organizations. Following are examples of USFWS grants that could be made available for joint WVDOT-WVDNR wildlife mitigation projects (*154*).

- Conservation Grants. This program provides funds to implement conservation projects for listed (as threatened or endangered under the Endangered Species Act (ESA)) and non-listed species.
- Cooperative Endangered Species Conservation Fund. This provides assistance for the conservation of listed, candidate or proposed species under the ESA.

8.4. Private Philanthropy

According to the National Philanthropic Trust, 88% of U.S. households give to charity and individuals are the largest source of philanthropy. Americans gave over $298B in 2011. In the same year, corporate giving was much smaller at $14.5B and foundations were in the middle with contributions at over $41.6B (*155*).

Conserving wildlife and improving human safety have the potential to garner philanthropic support, particularly if DVC mitigation projects are developed with a variety of components: construction, monitoring, research, education and/or community outreach. This is usually most successful when there are many partners involved in the project. It often requires a non-profit organization (having Internal Revenue Service 501c3 status) that can receive tax deductible contributions for the partners. While transportation infrastructure is generally financed through a combination of local, state or federal funding, private foundation philanthropy can increase funding efficiency by helping to leverage or match public funds for research, education, and outreach efforts. Most private philanthropy is focused on granting to non-profit organizations; thus, in order for WVDOT wildlife mitigation to receive private funding, it will be important to collaborate with non-profit organizations.

8.4.1.   Private Grant-making Foundations

The National Fish and Wildlife Foundation was created by the U.S. Congress in 1984 and manages many different wildlife grants programs. It is one of the largest conservation grant-makers in the world and has a variety of federal, corporate and private foundation partners. They provide grants through a competitive process and usually seek to match their funds with non-federal monies (*156*). There are 72 conservation programs listed on its website, several of these have the potential to align with reducing WVCs in West Virginia if partnerships are formed by WVDOT and other entities.

For West Virginia highways that pass through National Forest lands, the National Forest Foundation (NFF) may provide opportunities to partner on WVC mitigation projects that support forest conservation needs as well. (*157*). The NFF was also chartered by the U.S. Congress. The NFF's grant programs include those that contribute to local conservation and on-the-ground projects.

Other wildlife and animal welfare foundations contribute to organizations seeking to conserve wildlife in West Virginia on a regular basis. A search for grants via the paid research service www.bigdatabase.com that has information on the top 20,000 foundations in the U.S., using two keywords "West Virginia" and

"wildlife", listed 65 private foundation funding sources. This does not guarantee that they would fund WVDOT DVC reduction projects or their monitoring and outreach. However, it does demonstrate diverse interest in wildlife conservation by private foundations for West Virginia wildlife resources.

8.4.2. Corporate Philanthropy

Hundreds of America's corporations have a history of philanthropy and often give directly through their community relations programs or have created their own foundation. In addition, depending on the company, they may have employee contribution match programs, provide in-kind gifts or provide volunteers for projects. WVC mitigation projects could be eligible to receive support from corporate environmental, community or conservation programs. Obvious partners would be automobile or automobile parts manufacturers, the auto insurance industry or outdoor sports companies. Some examples of corporations that may be interested in West Virginia DVC reduction projects that might not be so obvious include:

- CSX is a transportation corporation with philanthropic interests for personal safety, community safety and the environment. Thus their interests could align with future WVC mitigation projects. The corporation welcomes requests for support on a regular basis via their website.

- Plum Creek provides grant support in locations of corporate operations. This includes the following West Virginia counties: Fayette, Greenbrier, Nicholas, Pocahontas, Randolph and Webster. Their corporate philanthropy includes funds for environmental stewardship and awareness as well as improving the quality of life in the communities where they operate.

- The American Electric Power (AEP) Foundation was formed in 2005 to supplement the corporate philanthropy of AEP and its regional utilities. Its grant-making focus is on communities served by its utilities or where facilities are sited (*158*). In the past it has provided funds to such conservation organizations as Trout Unlimited, Jane Goodall Institute and the Rob and Bessie Welder Wildlife Conservation Foundation.

8.4.3. Organizations and Individuals

There may be many organizations and individuals that the WVDOT may find to have common interests with as wildlife mitigation projects arise. Clearly some organizations may be more aligned than others. Following are just a few examples of possible conservation partners interested in DVC mitigation.

- Whitetails Unlimited (WU). WU is a membership organization that supports many different facets of conserving natural resources with a focus on the whitetail deer. Since 1982 it has spent over $18M on habitat and more than $7M on research. (*159*). Since DVCs are a major source of

mortality to whitetail deer, there may be many locations across the state that WVDOT has the opportunity to partner with WU where they find common cause.

- Wildlife Forever. Wildlife Forever (WF) is a 501c (3) non-profit that touts itself as "America's Leading All-Species Conservation Charity". WF has four conservation areas that align with WVC reduction projects: wildlife management, habitat, education and research (*160*). It has supported projects in all fifty states since its formation over 20 years ago.
- The Conservation Fund. This organization has protected areas in all fifty states over the last thirty years. It may be of interest for the portions of its conservation program that may align favorably with reducing WVC mitigation sites. It has supported the development of many green infrastructure plans, such as one for Jefferson County, WV through the Freshwater Institute (*161*).

There are many other potential non-profit partners that could team with WVDOT on a project, depending on the location, the species of concern, and other aspects of individual mitigation projects. Likely partners will become more evident as projects are developed.

8.5. Examples of Funding Partnerships

Simple reliance on existing transportation program funds to meet the needs of reducing DVCs across West Virginia will not be sufficient to address all the locations that may require mitigation. Therefore, solutions that create partnerships that draw from a variety of resources will be necessary for expanding successful DVC mitigation in the future. Many wildlife mitigation projects have been successful around the U.S. by creating a project that allows a variety of government agencies, non-profit organizations and individuals to contribute to its success. Following are a list of examples of recent highway mitigation projects that have relied on many different people, organizations and funds brought together for the common goal of conserving wildlife and making roads safer for motorists. The following examples are from the western U.S., given some of these states have been constructing wildlife mitigation structures to reduce WVCs since the 1970s. . Although not necessarily focused on white-tailed deer, these case studies demonstrate that whatever the species of interest are in the particular landscape, it is the convergence of interests that helped make the project successful.

8.5.1. Montana: Highway 206 in the Flathead Valley

Local ranch owners were keen on a wildlife crossing and fencing that would benefit their livestock when the Montana Department of Transportation (MDT) was in the midst of a slope flattening project on Highway 206. The installed mitigation was focused on the safe passage of ungulates such as elk, white-tail deer and mule deer, as well as other native wildlife and ranch livestock. As a result, a 9-foot high by

13-foot wide by 60-foot long underpass and fencing was installed. A conservation easement for 80 acres was put on the lands adjacent to the crossing site by ranchers Jay and Sandy Whitney. The funding for the $165,000 wildlife mitigation project was paid for by a fundraising drive that netted contributions from the Whitneys, Flathead County Commissioners, American Wildlands, Yellowstone to Yukon Conservation Initiative, Wildlife Land Trust, Northern Rockies Conservation Cooperative, Friends of the Wild Swan, Swan View Coalition, Montana Backcountry Hunters and Anglers, 16 individuals and ranches, the Montana Department of Fish, Wildlife and Parks and topped off by a Community Transportation Enhancement Program grant (*57*). Such a broad convergence of interest for safety and wildlife conservation and willing landowners who made a major contribution to the effort was a recipe for its success.

8.5.2.   Utah: US Highway 89 near Kanab in Kane County

This $2.5M wildlife mitigation project is a system of fencing and underpasses intended to slash the roadside carcass count and make the road safer for motorists. The 12-mile section of roadway has approximately 100 WVCs with mule deer each year. This particular herd migrates across state borders, so it is of joint interest to both Utahans and Arizonans. In partnership with Utah and Arizona state wildlife agencies, sportsmen, Kane County and the Grand Staircase-Escalante National Monument (GSENM), the Utah Department of Transportation (UDOT) has adapted four existing culverts and built three new ones specifically for wildlife on this stretch of highway east of Kanab. It includes 8-foot fencing connecting all the structures and keeping deer from the road surface (see Figure 8-2). Wildlife organizations contributing to the project included the Arizona Deer Association, Mule Deer Foundation and Sportsmen for Fish and Wildlife (SFW) (*162*). The funding sources and amounts for this project are listed in Table 8-1. The partners have not only helped construct the mitigation but also are funding post-construction monitoring of the crossings' effectiveness and the reduction of WVCs. This is considered an exemplary partnership that is being highlighted by the Western Governors' Association for its Wildlife Corridors and Crucial Habitats Initiative.

Table 8-1. Funding Breakdown of WVC Mitigation Project on US 89 in Kane County, Utah

Source	Amount
Arizona Game and Fish Department and Sportsmen	$130,000
Utah Department of Wildlife Resources and Sportsmen	$100,000
GSENM: FHWA Public Roads Grant	$1,525,000
GSENM: Cultural Resources Staff Support	$10,000
UDOT R-4 Transportation Enhancement	$625,000
Kane County (estimated)	$125,000
SFW Signs & Fence Maintenance (estimated)	$2,000
Partnership Total	$2,517,000

Figure 8-2 Wildlife Mitigation on US 89 in Kane County, Utah.
(Photo credit: Patti Cramer/UDOT/USU/UDWR/AZFG.)

8.5.3. Colorado: Highway 9 south of Kremmling

A $46M widening and realignment project is slated for a 10-mile section of Highway 9 which includes 5 wildlife underpasses and exclusionary fencing. This highway segment had 455 wildlife mortalities over an eight year period, mostly mule deer (*163*). The Colorado Department of Transportation (CDOT) and local communities have wanted to complete this project for nearly a decade. In early 2013, CDOT announced a new process to release funds in a more efficient manner, called Responsible Acceleration of Maintenance and Partnerships (RAMP) (*164*). This new partnership program allowed local governments, groups and individuals to raise 20% of the project to match 80% federal funds, and for it to be moved

forward by CDOT. A major donation of $4.9M by the Blue Valley Ranch located adjacent to the project area spearheaded the process of meeting the match. The Citizens for a Safe Highway 9 committee was created and completed a fundraising drive and netted the necessary funds through a mix of contributors. They included $931,000 in individual and organizational pledges, a $250,000 donation from Summit County and $3.1M contribution from Grand County. The project's success hinged on a citizens group that led the fundraising effort and a local landowner who could donate a significant portion of the necessary matching funds.

8.5.4. Arizona: Pima County Corridors and Crossings

Citizens of Pima County successfully sought to create a Regional Transportation Authority (RTA) to address regional transportation planning and funding (*165*). The RTA was approved by voters and funded by a 0.5% sales tax for 20 years. As a result, a portion of the tax revenue, $45M, has been set aside to protect and enhance wildlife connectivity across the county's road system. It allows for funding of design and construction of wildlife crossings for future road projects and retrofitting of existing highways (*166*). The RTA has supported 16 research or construction projects for wildlife totaling over $21M in expenditures (*167*). The newest project to tap these funds is scheduled to build wildlife crossings over and under State Route 77 and Oracle Road (see Figure 8-3), of which $8.23M was approved for its implementation by the RTA. Nationally, this is the first time ever that a sales tax increase has been approved by citizens to help reduce wildlife-highway conflicts and improve connectivity.

Figure 8-3 Rendering of a Wildlife Overpass on the Arizona SR 77 project
(Courtesy of the Arizona Department of Transportation)

8.5.5.   Wyoming: Teton County Highways

A non-profit organization, the Jackson Hole Wildlife Foundation (JHWF) developed a campaign coined "Give Wildlife a Brake®" to support the reduction of WVCs in Teton County, WY. They organized WVC citizen data collectors and set up a web-based system to encourage recording carcasses along the county's highways and now have a hotline to phone in wildlife mortality information. Supported by donations from community members, JHWF bought 6 portable dynamic message signs (DMS) for the WY Department of Transportation (WYDOT) to deploy where wildlife-traffic conflicts occur (see Figure 8-4). JHWF and WYDOT have signed a Memorandum of Understanding to outline the terms of the use of the DMS. Each DMS cost approximately $16,000 each (*168*). JHWF also purchased two fixed radar signs that are deployed by WYDOT along a problematic WVC stretch of WY Highway 390 to let motorists know how fast they are traveling. It also is programmed to reduce the posted speed from 45 mph to 35 mph from dusk to dawn. The non-profit group has also bought two DMS for Grand Teton National Park for use on its roads where high incidences of wildlife and vehicle traffic occur.   Wyoming DOT carcass data indicate that this mitigation effort would also help reduce crashes with mule deer and white tail deer that frequent this area of the Snake River Valley in Jackson Hole.

Figure 8-4 Dynamic Message Sign on WY Highway 390
(Photo credit: Rob Ament/WTI)

8.5.6.   Washington: U.S. Highway 097 Alternate Route

The US Highway 097 Alternate Route was a safety project completed by the Washington Department of Transportation (WSDOT), north of Wenatchee, WA. It is another example of collaboration between a transportation agency and many private organizations interested in protecting wildlife. The project included 9-miles of 8-foot tall fence to protect wildlife (*169*). The final cost of this multi-phase project was $2.8 M. Table 8-2 lists the funding sources and amounts. It was primarily a collision reduction project intended to make the highway safer for motorists. However, it also included wildlife fencing to protect the lives of mule deer and bighorn sheep (*170*). The project included the installation of one-way gates to let wildlife escape the roadway in the event they are trapped between the fences on each side of the roadway (see Figure 8-5).

Table 8-2. Funding Breakdown of WVC Mitigation Project on US 097 near Wenatchee, WA

Funding Source	Amount
Wenatchee Sportman's Association	$10,000
Seattle Sportsmen Conservation Foundation	$10,000
Washington State, Foundation for North American Wild Sheep	$10,000
State Farm Insurance	$5,000
Mt. Vernon Mule Deer Foundation	$2,132
Central Washington Mule Deer Foundation	$1,036
Woodinville Mule Deer Foundation	$1,032
Washington State Bowhunters	$1,000
Washington Department of Fish & Wildlife	$462,000
WSDOT Funds	$948,670
Federal Highway Administration	$1,280,000

Figure 8-5 Wildlife Escape Gate on U.S. Highway 097A near Wenatchee, WA
(Photo credit: WSDOT)

8.6. Summary and Recommendations

To accomplish a robust program of future DVC mitigation projects across West Virginia, it will be incumbent on WVDOT to seek a wider source of funding than that provided by traditional transportation programs. Experience in other states demonstrates that creating partnerships with allies that mutually benefit from WVC mitigation creates opportunities to tap individual, organizational, foundation and non-transportation agency sources of support.

To attract the widest variety of funding from federal, state, local, and private interests it is recommended to:

- Convene a working group of allies to focus on DVC mitigation and seek priority projects that are attractive not only to WVDOT, but to others.
- Assure there are knowledgeable people that are familiar with what is needed for competitive grants to succeed with private foundations and corporations.
- If a working group for DVC mitigation is successfully formed, contemplate assigning a WVDOT employee as a coordinator to facilitate meetings, communications, joint activities and fundraising.

9. SUMMARY

9.1. Discussion of Objectives

Referring back to the ten objectives for this project presented at the beginning of this report, the majority of them were completed, but perhaps not to the level that was anticipated at the outset of the project due to unforeseen hurdles. The following summarizes the findings related to each objective as well as any corresponding recommendations.

9.1.1. Objective 1

Determine the site characteristics and other variables, inclusive of all roadway types (e.g. local routes, arterials, Interstates, etc.) that national and regional studies have shown to contribute to DVCs.

Many DVC studies have been performed that evaluated the relationship of roadway, traffic, landscape, and environmental characteristics on the frequency of DVCs.

- Roadway. In general, over 89% of WVCs occur on two-lane roads whereas only 52% of all crashes (all types) occur on two-lane roads. DVCs are associated with relatively low road density. This is logical as higher road densities may not leave enough available habitat for deer to live in. While there is a shortage of data, concrete median barriers (e.g., Jersey barriers) may be a contributing factor to WVCs. While these barriers may reduce the likelihood that animals will try to cross the road (i.e. they may increase the barrier effect of roads and traffic), they may also cause the animals to spend more time on the road as they are trying to cross the barriers. While two-lane roads that have been upgraded with wider lanes, wider shoulders, and increased sight distance have improved overall safety, they tend to have an increase in WVCs. An increase in design speed of the highways was identified as the most likely explanation for the increase in WVCs. Interestingly, the vast majority (91.7%) of all WVCs occur on straight road sections with long sightlines than road sections with curves and shorter sight lines. This could be attributed to the relative frequency of these road types.

- Traffic. While it seems intuitive that higher traffic volumes result in higher numbers of DVCs, several authors have suggested the relationship between traffic volume and DVCs may be quite complex. As traffic volume increases, WVCs may increase initially, but when traffic volume reaches high levels, fewer animals attempt to cross the road, resulting in fewer DVCs. This means that at higher traffic volumes, DVCs may decrease, while the barrier effect of the road and traffic

may increase (i.e., animals intentionally avoid due to fear). Though evidence is scarce, the probability of DVCs declines notably with speed limits below 45 mph.

- Landscape and Habitat. White-tailed deer occur in a wide variety of habitat types. Nonetheless, previous studies have associated DVC locations with certain landscape elements and with deer population density parameters. The location of DVCs is, in general, positively associated with edge habitat (transition cover-open habitat), proximity to forest, high landscape diversity, water, and to some degree also with development (houses), but only if sufficient green is mixed in with the houses and no physical barriers are present. Proximity of houses may also provide deer with shelter from human hunters and other predators. Larger areas of forest tend to be associated with fewer DVCs than mixed landscapes with abundant edge habitat. The effect of grasslands and croplands can be complex and partially depends on the proximity of cover (forest). Linear features (ridges, gullies) can lead deer to roads, but DVCs can also occur elsewhere in relatively high numbers.

- Deer Population. Not surprisingly, high deer density is generally associated with higher numbers of DVCs. However, driver behavior, road location, and other factors can still produce high DVCs in difference to relative deer density.

9.1.2. Objective 2

Identify and evaluate available DVC mitigation technologies and techniques.

DVC mitigation is classified in two general groups: 1) measures intended to modify human behavior and 2) measures intended to modify deer behavior.

- Modification of Human Behavior. The DVC mitigation measures intended to modify human behavior include posted speed limit reductions, standard signage, enhanced signage, temporal signage, animal detection systems, vehicle-based warning systems, roadway lighting, and removal of vegetation from the road right-of-way.

- Modification of Deer Behavior. The DVC mitigation measures intended to modify deer behavior include mirrors and reflectors installed in the right-of-way, acoustic devices on cars, deer population reduction methods, and barriers along highways. There is no evidence that mirrors, reflectors, or acoustic devices are effective at modifying the deer behavior and are not considered viable mitigation methods. Deer population reduction methods have been shown to be effective, but the programs must be sustained in order to successfully reduce the herd sizes and impact

DVCs. Wildlife fencing is considered to be the most effective mitigation for DVCs and should be used in conjunction with safe crossing opportunities and proper fence end treatments.

9.1.3. Objective 3

Evaluate and summarize the current practices used in West Virginia for addressing DVCs issues.

Other than the standard deer crossing signs installed along roadways throughout the state and efforts by the WVDNR to control deer population, the only other documented DVC mitigation strategy used in West Virginia has been wildlife fencing installed on a portion of US 33.

- Location. When US 33 from I-79 to Elkins, WV was upgraded to a four-lane divided highway in 1991 (from Lorentz to Buckhannon) and 1994 (from Buckhannon to Elkins), wildlife fencing was installed along sections of the roadway in an effort to prevent deer from crossing the roadway. This recommendation was a result of a 3-year study initiated on I-79 by the WVDNR in 1974. The fencing begins approximately 8.2 miles east of the I-79 interchange and continues on both sides of the road for approximately 4.7 miles. Standard height right-of-way fencing is installed for the next 1.6 miles on both sides of the roadway, likely due to the presence of the interchange with US 119 in Buckhannon. The wildlife fencing was then installed for the next 14.4 miles on both sides of the roadway. The four-lane section of US 33 continues another 12.8 miles toward Elkins with standard right-of-way fencing.

- Effectiveness. Deer-vehicle crash data from police reports were analyzed for this entire segment of US 33 for the period covering 2008-2012. There were a total of 24 DVCs reported along the entire 41.7 mile segment. Of those, only 3 crashes occurred along the 19.1 miles of wildlife fencing and the other 21 occurred along the 22.6 miles that had no fencing or standard right-of-way fencing. The crash rates on segments without wildlife fencing was 4.8 DVCs per hundred million vehicle miles, which is six times higher than those segments with wildlife fencing, which had a crash rate of 0.8.

9.1.4. Objective 4

Identify DVC mitigation policies and practices, or parts thereof, from other state transportation and wildlife management agencies that would be applicable to West Virginia.

State transportation and wildlife management agencies in states bordering West Virginia were interviewed over the phone to obtain information regarding their policies, practices, and mitigation usage

related to DVC. No new mitigation measures were identified through the interviews that were not already discussed in the literature review. It appears that the role of natural resource management agencies is to control deer population size through public hunting. The implementation of roadside mitigation measures depends on the transportation agencies. While general crash data analyses are standard to identify and prioritize road sections that may require mitigation, DVCs do not rise as a high priority because relatively few of these collisions result in human injuries and fatalities. DVCs would be better represented in the analyses if they also included vehicle repair costs, or more fundamentally, also included deer carcass removal data to account for under-reporting. This would then lead to more recognition of the DVC impact and the associated allocation of funding. However, it would involve a shift from primarily human injuries and fatalities to a more general monetary analysis. Some agencies are considering modifying their analysis process to allow for more emphasis on DVCs.

The funding of effective mitigation measures currently comes from federal sources, and implementation of these mitigation measures is typically restricted to (re)construction projects. Funding of roadside based mitigation measures is currently regarded as insufficient. In general there seems to be no high level coordination between transportation agencies and natural resource management agencies. Better coordination may lead to more population size reduction efforts through hunting in areas with high DVC numbers. It may also lead to a shift to more effective mitigation measures as wildlife managers may be better informed about wildlife behavior and management tools than most engineers.

9.1.5.   Objective 5

Summarize and rate the available mitigation technologies, countermeasures, policies, practices etc. that would apply to West Virginia and that should be considered for implementation and further study.

The recommendation for mitigation measures in West Virginia are based on what measures have been shown to be effective in previous documented research or show promise for effectiveness based on inconclusive data. The researchers consider wildlife fencing in combination with wildlife underpasses and overpasses the most robust mitigation measure. As long as relatively long road sections are mitigated ($\geq$3 miles), DVCs can be expected to be reduced by at least 80%. Animal detection systems also have the potential to reduce DVCs substantially, but many projects involving these systems suffer from technical and management problems. In addition, the effectiveness of animal detection systems in reducing DVC is less predictable than the effectiveness of wildlife fencing in combination with wildlife underpasses and

overpasses. Wildlife culling by sharpshooters or controlled urban archery hunts may also be successful in locations with high concentrations of deer and DVCs as long as the culling programs are sustained over a number of years. Other mitigation recommendations for West Virginia are summarized in Table 2-10 and Table 2-11 in the body of the report.

9.1.6. Objective 6

Evaluate national reports on DVC ranking methods and the statistics used for validity.

Based on national information provided by both State Farm Insurance and the Insurance Institute for Highway Safety, motorists in West Virginia are at a higher risk of being involved in DVCs than most states; despite the fact that West Virginia ranks from 11th to 17th in terms of total DVC estimates. These two annual reports base risk on the DVC per number of licensed drivers in the state. This study also evaluated roadway mileage, number of registered vehicles, and vehicle miles traveled as measures for normalization. Furthermore, these metrics were broken down into rural-only components to eliminate bias that occurs in states with large urbanized areas.

West Virginia still ranks first in all normalized comparisons that were drawn from the national data, except roadway mileage, before removing the urban portion of the normalizing data. When removing the large urban areas from all states, West Virginia's ranking drops, but is still in the top 5-11. Unfortunately, there is not a valid and reliable measure for performing state-by-state comparisons, although vehicle miles traveled is the most logical because it directly estimates driver exposure.

Recommendation: Any national DVC rankings and estimates should be used for informational and public education purposes only and not for decision-making purposes. The state-to-state ranking methods based on normalized rates (rather than total counts) do not adequately account for various factors that would actually cause state-to-state variations.

9.1.7. Objective 7

Evaluate and summarize the DVC data that has been collected in West Virginia and the collection methods used.

WVC data are typically used to answer questions that relate to changes in numbers over time and spatial distribution (i.e., the location of hotspots for WVCs). It is important that the WVC data have been

collected with consistent search and reporting effort over time for trend analyses and over the geographical area of interest for hotspot analyses. Police crash report data and carcass removal data collected by road maintenance crews are more likely to have the required search and reporting effort over a long time period (multiple years) and large geographical areas (e.g. a state).

At the outset of this project, it was anticipated that the carcass data reported by the WVDOT Daily Work Report – Form DOT-12 would be the main data used in the hotspot and modeling analysis because it was the data source with the highest quantity that included location information (approximately 13 times more carcass records than police DVC reports). However, after the data was reviewed, it is was clear that not all maintenance crews were recording the location information consistently, if at all. After evaluating all available data sources that contained specific crash location information, it was decided that the police crash report data would be utilized for the hotspot analysis and modeling. The location information recorded in the police crash reports contained problems that were corrected as much as possible based on the information provided. There were 6,833 DVC police reports from 2008-2012 and 90% of those had usable location information for the modeling and hotspot analysis. The location and frequency of the carcass data and police report data were analyzed to evaluate correlations, but none were found (most likely due to the deficiencies in the data).

Analysis of the West Virginia police crash report data from 2008-2012 revealed that the majority of the crashes were reported in October and November, crashes were evenly distributed across each weekday, and most crashes occurred at night. The majority of drivers involved in a DVC had a West Virginia driver's license. However, the percentage of out-of-state drivers involved in a DVC was 6% higher than the percentage of out-of-state drivers involved in all crash types in West Virginia (22% compared to 16%). There were a total of 12 fatalities that resulted from a DVC (five on US routes, four on WV routes, and 3 on County routes), which is less than 1% of all fatal crashes (of all crash types) during that 5-year period.

Since safety-related DOT funding is based on monetary benefits, projects that reduce severe crashes tend to get the highest priority. The crash types with the highest percentage of overall fatalities in West Virginia are drivers hitting other vehicles for various reasons (31%), vehicle rollovers (16%), vehicles running off the road and hitting trees and embankments (13% and 7%), and vehicles hitting pedestrians (7%). Since most DVCs involve property damage only, it is unlikely that a DVC mitigation project would get prioritized over locations with other crash types with higher severities.

Recommendations: In order to facilitate future DVC analysis to identify hot spots and model roadway and habitat characteristics, it is recommended that the DVC data collection processes be improved. It is important for law enforcement agencies completing crash reports to collect GPS coordinates of the crash site to ensure the most accurate representation of the location. Since the quantity of carcasses picked up far exceeds the number of crashes reported, it would be ideal if the WVDOT maintenance crews could record the location of carcasses picked up in a consistent and detailed manner. While it might not be feasible for them to utilize GPS devices to record coordinates, the crews are familiar enough with the milepost numbering schemes along the routes in their jurisdiction to record those to a high degree of accuracy. It would also be beneficial to specifically add a check box on the police crash report form for the officer to indicate that a deer was involved. A free-form text box was previously added where the officer could indicate the type of animal after checking that an animal was a contributing factor. However, querying the free-form field for all variations of deer descriptions will always yield inaccuracies

9.1.8.   Objective 8

Conduct a Geographic Information System (GIS) analysis of DVCs in West Virginia to identify and rank hotspots, if the available data is adequate.

The West Virginia roadway network was divided into 2-mile segments for hotspot analysis with the DVCs from police crash reports assigned. Hotspots were identified based on total DVC count along the 2-mile segment as well as crash rate along the 2-mile segment, which accounts for the traffic volume.

- Ranking based on count. After the frequencies were assigned to the segments, HIGH frequency segments are defined as segments that experienced 13 or more crashes over the 5 year period, MEDIUM frequency is defined as segments that experienced 3-12 crashes, and LOW frequency is defined as segments that experienced 1-2 crashes. There are a total of 3,128 Interstate, US Route, and WV Route segments statewide, which result in 0.6% of them being high, 16.9% medium, and 31.2% low. Therefore, 51.3% of the Interstate, US Route, and WV Route segments in the state did not have a documented DVC. The high DVC threshold of 13 per two-mile segment over five years (1.3 per mile per year) is slightly less than the "High" threshold applied in an Iowa study (1.75 per mile per year). The general locations of the High segments are the eastern panhandle, the Summersville area in the central part of the state, the Parkersburg area in the western part of the state, and the Kanawha River Valley near Winfield in the western part of the state. The highest observed count was 22 on US-19 in Nicholas County.

- Ranking based on crash rate. In addition to ranking segments by the total number of reported crashes, they were also ranked by the crash rate (crashes per hundred million vehicle miles traveled), which normalizes the data based on annual average daily traffic (AADT), number of years analyzed, and segment length. There are 3-10 segments that are visibly higher than the rest of the segments, with crash rates above 130 DVC per hundred million vehicle miles traveled. The majority of the top 35 sites are WV Routes, where the AADT values are much lower than the Interstates and US Routes. There are no Interstate segments in the top 35. Only two of the segments that were identified as hotspots in the previous section based on raw count are on this list: WV-62 in Mason County (ranked #2 by count and #3 by rate) and WV-9 in Jefferson County (ranked #11 by count and #20 by rate).   The highest observed crash rate was 327 crashes per hundred million vehicle miles, which occurred on WV-20 in Summers County.

Recommendations: Due to some concerns with the validity of the AADT data for some roadway segments, the raw count hotspots were considered to be the more reliable list, although the ranked list by crash rate is certainly a useful tool. If a decision is made to implement mitigation, both the count and crash rate should be considered. The research team provided suggested mitigation for the highest segments based on raw count to serve as implementation examples. The process to select the segments for mitigation as well as the type of mitigation will involve a more extensive process that examines the severity of the crashes, the locations of the crashes along the segment, the site characteristics, and funding availability. Once a segment has been identified for mitigation, it is recommended that a before and after study be conducted to evaluate the mitigation effectiveness. The use of static segment lengths for the hotspot analysis is not necessarily the preferred method, but it was the only option based on the current WVDOT LRS. A recommendation for WVDOT is to complete the continuous LRS mapping in order to facilitate the application of more dynamic hotspot analysis techniques. It is also recommended that the AADT data be further evaluated to ensure that data is being collected and estimated for as many roadway segments as possible.

9.1.9. Objective 9

Model probable DVC locations across West Virginia to identify roadway, landscape, environmental, and traffic characteristics that contribute to DVC, if available data is adequate.

Regression analysis was performed to examine the relationship of DVC presence and frequency with possible contributing factors. Since statewide DVC data was used, there wasn't a need to develop a

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model for prediction. Instead, the goal of the model was to identify roadway, landscape, environmental, and traffic characteristics that might be correlated to location with high DVCs. West Virginia data sets that could be converted to GIS layers were sought for this analysis and were primarily available from the U.S. Geological Society and the WVDOT Roadway Inventory Log (RIL). There were are a total of 1,150 segments on Interstate and US Routes with complete data (i.e., no missing values) and 698 segments have at least one observed crash (61%). There were 160 segments that were eliminated from the analysis because of a missing data field.

In this study, four types of models – negative binomial, zero-inflated negative binomial, two-step hurdle, and generalized additive negative binomial (GANB) – were developed to understand the factors affecting DVCs. Based on the Akaike information criterion (AIC) values, all four models performed very similarly, but the GANB yielded the best results, accounting for spatial relationships among the segments. The variables in the GANB model and the signs of their coefficients were reasonable. As the AADT and landscape diversity increased, the expectation of a DVC increased. The presence of steep slopes on the side of the road reduced the expectation that a deer would be hit on a segment. Compared to rural areas, urban areas (defined as small towns and suburban areas around large cities) have higher expectation of crashes, while urbanized areas (defined as large city centers) have a lower expectation of crashes.

Recommendations: The modeling effort could be greatly enhanced if more complete and reliable roadway data were available in GIS format, particularly the data contained in the WVDOT RIL. Many of the roadway characteristics that were modeled in other studies and found to be significant could not be included in this study, such as sight distance (forward and to the side), geometric curvature, and shoulder width. The AADT estimates need to be reliably completed for all roadways within the state to facilitate a more reliable crash rate calculation.

9.1.10. Objective 10

Identify possible funding sources at the local, state, and federal level for DVC mitigation implementation.

There are a number of mitigation funding sources available at the federal and state levels. However, each funding source has different funding amounts and project requirements, so some effort is necessary to locate the appropriate funding for the appropriate project. Other states are creating partnerships among

public transportation agencies, natural resource management agencies and wildlife-related private entities to help fund mitigation projects.

Recommendations: To accomplish a robust program of future DVC mitigation projects across West Virginia, it will be incumbent on WVDOT to seek a wider source of funding than that provided by traditional transportation programs. Experience in other states demonstrates that creating partnerships with allies that mutually benefit from DVC mitigation creates opportunities to tap individual, organizational, foundation and non-transportation agency sources of support. To attract the widest variety of funding from federal, state, local, and private interests it is recommended to: (a) convene a working group of allies to focus on DVC mitigation and seek priority projects that are attractive not only to WVDOT, but to others, (b) assure there are knowledgeable people that are familiar with what is needed for competitive grants to succeed with private foundations and corporations, and (c) contemplate assigning a WVDOT employee as a coordinator for a working group to facilitate meetings, communications, joint activities and fundraising.

9.2. **Summary of Recommendations**

Throughout the report, a few recommendations were made regarding improved data collection and data processing capabilities. Those recommendations are summarized here.

9.2.1.   Deer-Vehicle Collision Data Collection (Carcass Data)

The carcass data collected by WVDOT maintenance crews could be a great source of data for modeling DVC collisions. The total number of carcass records far outweighed the police crash report data, but the consistency of how the data was collected across the state was too inconsistent to use the data. For example, not all crews would record route and milepost information for the carcasses picked up, which is essential for identifying hotspots. If WVDOT wants to invest the time and effort into collecting high quality location information when carcasses are picked up, there are tools that can be utilized. However, it would likely require additional training and monitoring. Furthermore, conveying the importance of the data collection and how it is being used to mitigate problem to the crews would likely provide additional motivation to collect better quality data.

9.2.2. Deer-Vehicle Collision Data Collection (Police Crash Reports)

The crash report data analyzed in this study also had problems with location information. The majority of the records had location information, but it was often assigned to the nearest intersection or whole milepost. This makes identification of the specific hotspot challenging. Officers should be encouraged to record GPS coordinates of the specific crash locations, which will eliminate any bias in the data. This applies to DVCs as well as all crash types, in general. While the importance of this location information is likely covered by various training courses and supervisors, perhaps dissemination of reports such as this one illustrating how the data is ultimately used would serve as reinforcement.

9.2.3. Data for Deer-Vehicle Collision Modeling

There was incomplete data in the WVDOT Roadway Inventory Log (RIL), which hindered modeling efforts to examine correlations between DVCs and other roadway and traffic characteristics. There were other roadway data that seemed available in other states, but not in West Virginia. This data included roadway curvature (horizontal and vertical) and sight distances. The AADT information in the RIL also seemed unreliable for some segments and was missing for other segments. WVDOT should consider tagging their AADT data to indicate its reliability. It would be useful for the data user to know whether the AADT was a direct observation of traffic counts or if it was estimated from historical counts and nearby segments of similar characteristics. Finally, the conversion of the linear reference system to have continuous mileposts (across county lines) will be beneficial for implementing more sophisticated hotspot analysis techniques.

9.3. Future Work

The following items are recommended for future work related to this project.

9.3.1. Sliding Window Hotspot Analysis

Once the WVDOT converts to the continuous LRS system for the roadway network, a sliding window hotspot analysis should be conducted with a sensitivity analysis of the window size. This may better yield hotspot segments.

9.3.2. Carcass Data Analysis

The WVDOT carcass removal data for a few counties appeared to have a high percentage of records that contained route and milepost information. Once the WVDOT RIL file is completed for Interstates, US Routes, WV Routes, and County Routes, perhaps a prediction model can be developed from the carcass data for a few counties and applied to the other counties. These hotspots could be compared to those identified from the crash reports.

9.3.3. Crash data analysis.

Once the WVDOT RIL file is fully updated, the modeling analysis should be conducted with the crash report data in an attempt to estimate a better regression model from the data.

9.3.4. DVC Mitigation Pilot Study

The following locations were selected from the High frequency DVC segments based on DVC count for mitigation consideration. It is highly recommended that a before and after study be conducted with any future mitigation efforts in order to quantify the effectiveness of the strategies and contribute to the overall body of knowledge in this area. Depending on the frequency of crash reports on the segments selected for mitigation, it may be worthwhile to conduct a focused data collection effort to ensure sufficient data is collected.

I-64 Nitro to Cross Lanes

The segment on I-64 from milepost 45.39 to 47.66 ranked 3rd on the list with 19 DVCs over the 5 year period. However, the crash rate was only 7.3 due to the volume of vehicles using this segment between Cross Lanes and Nitro. Figure 9-1 depicts a hotspot map similar to the one presented before, but it has been enhanced with the CWD data, carcass data, and deer crossing signs along this corridor. Interestingly, there were no carcasses reported on this segment by WVDOT maintenance crews. Only two of the crashes involved an occupant injury.

The mitigation recommended for this location would be wildlife fencing with safe crossing opportunities. The fencing could be extended from the Nitro interchange at Exit 45 to the Cross Lanes interchange at Exit 47 with proper end treatments at those locations to minimize the chance of deer entering the roadway at those locations. This is depicted in Figure 9-2 as red lines adjacent to the roadway. Furthermore, there is an opportunity to provide at least one safe crossing opportunity under an existing bridge structure.

Ideally, other crossings would be provided closer to the Cross Lanes exit. Figure 9-3 shows photos of the bridge structure and underneath. The underpass serves 40th Street traffic, but it also has a creek and enough vegetation on the south side that it could serve as a wildlife underpass.

WV-62 near Leon

Another High frequency location that is suggested for mitigation is WV-62 in the vicinity of milepost 4.25 and 6.25. This segment ranked 2nd on the list with 19 DVC and a crash rate of 254.9 per hundred million vehicle miles, the highest rate on the High frequency list based on count. Figure 9-4 depicts a hotspot map similar to the one presented before, but it has been enhanced with the CWD data, carcass data, and deer crossing signs along this corridor. The crashes seem to be clustered in one area with only one carcass picked up. Four of the crashes resulted in an injury to a vehicle occupant.

This two-lane roadway in a somewhat rural area seems suitable for wildlife fencing. Existing access roads should be equipped with cattle guards, grates, or electric mats to keep deer out of the roadway. Due to the terrain in this area, it will be difficult to provide structures for safe crossings. Therefore, a gap in the fence in conjunction with an animal detection system could be considered.

US-19 Through Summersville

There were three segments of US 19 in the vicinity of Summersville that were rated as High frequency. These sections are depicted in Figure 9-5. Milepost 10.32-12.33 was ranked 1st with 22 DVC. Milepost 14.34-16.36 was ranked 9th with 15 DVC. Milepost 4.23-6.29 was ranked 12th with 14 DVC. Figure 9-6 depicts a hotspot map similar to the one presented before for the segment from milepost 4.23-6.29, but it has been enhanced with the CWD data, carcass data, and deer crossing signs along this corridor. The crashes appear to be spread out along the corridor with only one resulting in an occupant injury. There also appear to be a number of carcasses that were reported in the area.

Installing wildlife fencing along this segment of roadway would be challenging with the number of access roads, but this would be the most effective solution to reduce the DVCs. It is likely that there are adequate opportunities to provide safe crossings given the terrain in this area. Additional roadway lighting along this divided highway may be another option to improve visibility for motorists. Considering this is an urban area, perhaps this location would be suitable for an urban area deer hunt to reduce the size of the deer herd in this area.
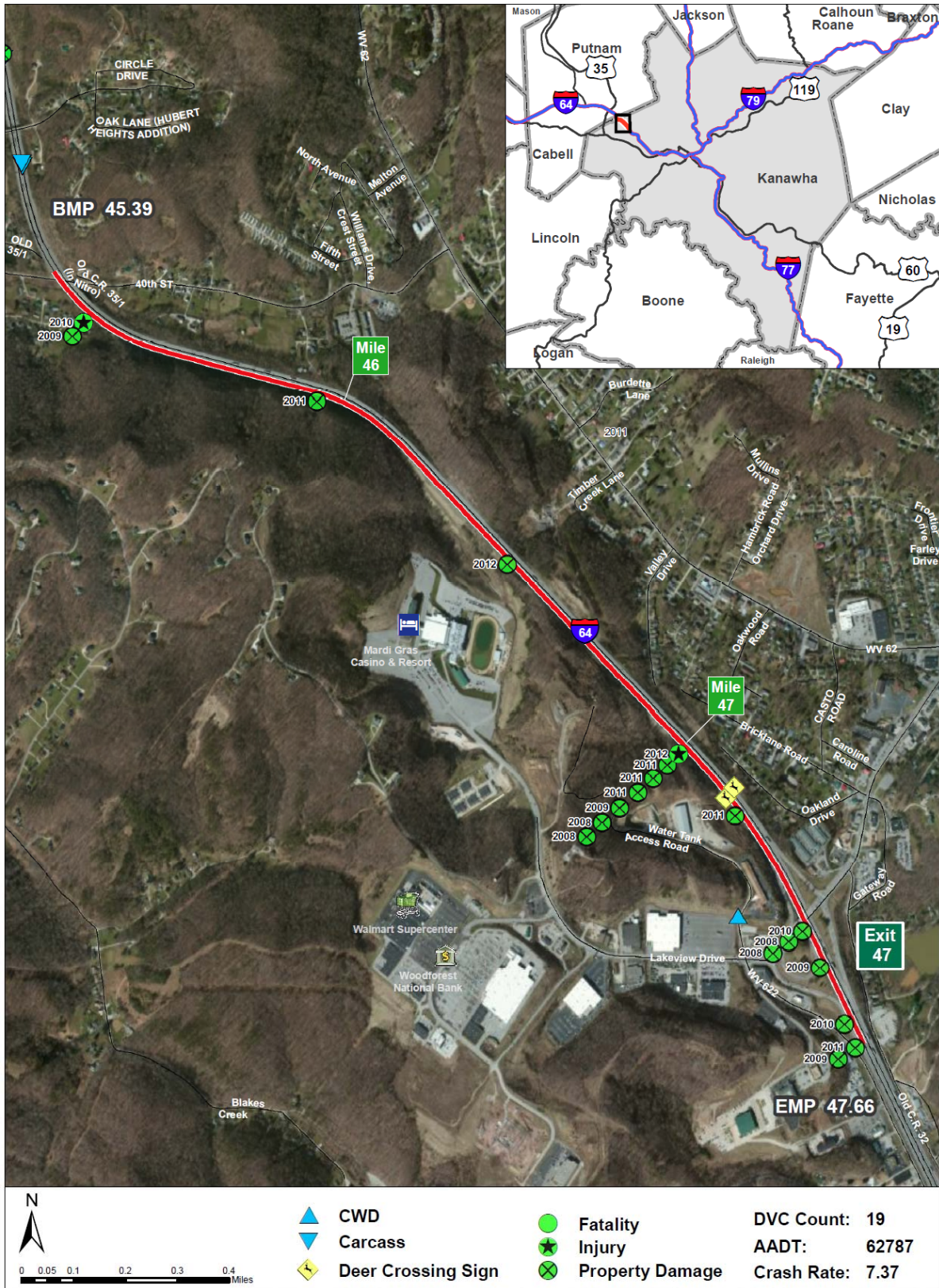
Figure 9-1 Enhanced Hotspot Map for I-64 from Nitro to Cross Lanes
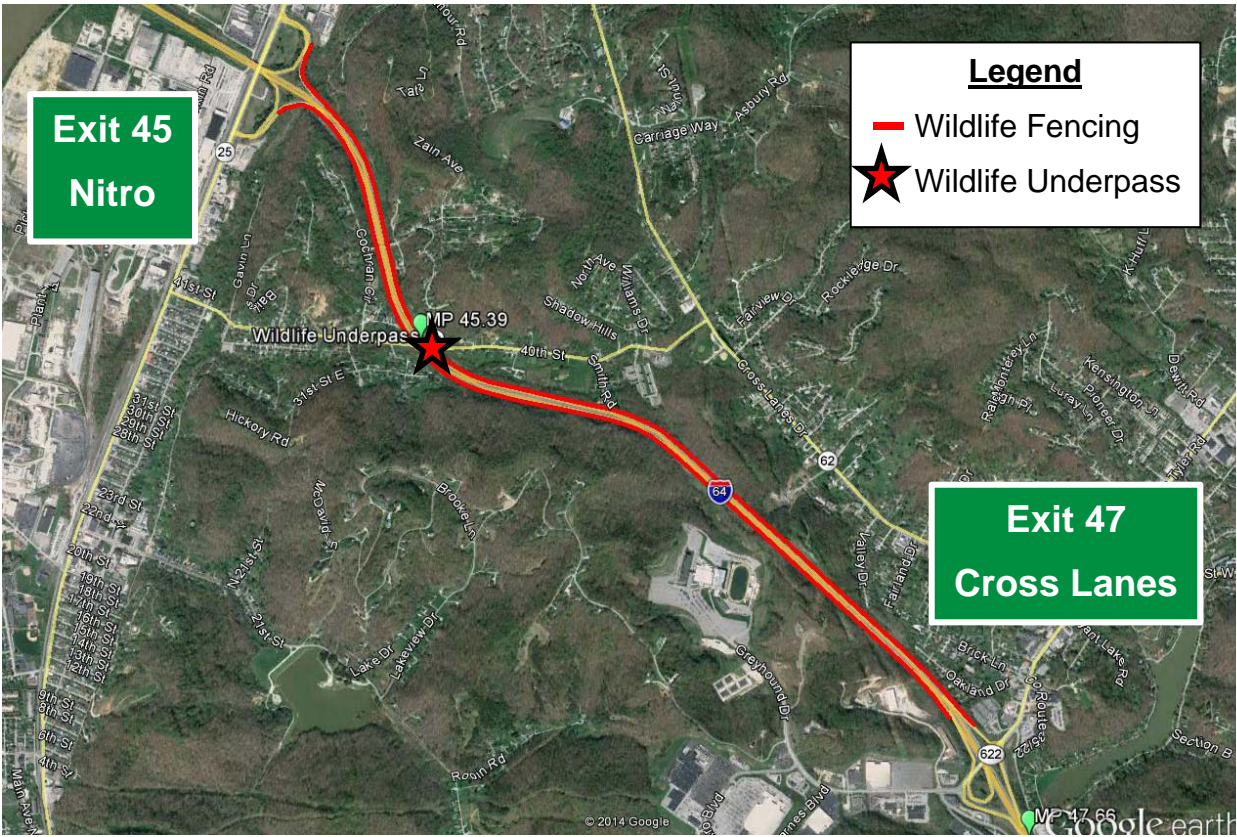
Figure 9-2 Suggested DVC Mitigation Plan – I-64 from Nitro to Cross Lanes

(a) North Side of Underpass

(b) South Side of Underpass

(c) I-64 Overpass Aerial View

Figure 9-3 Existing I-64 Bridge to Convert into a Safe Crossing
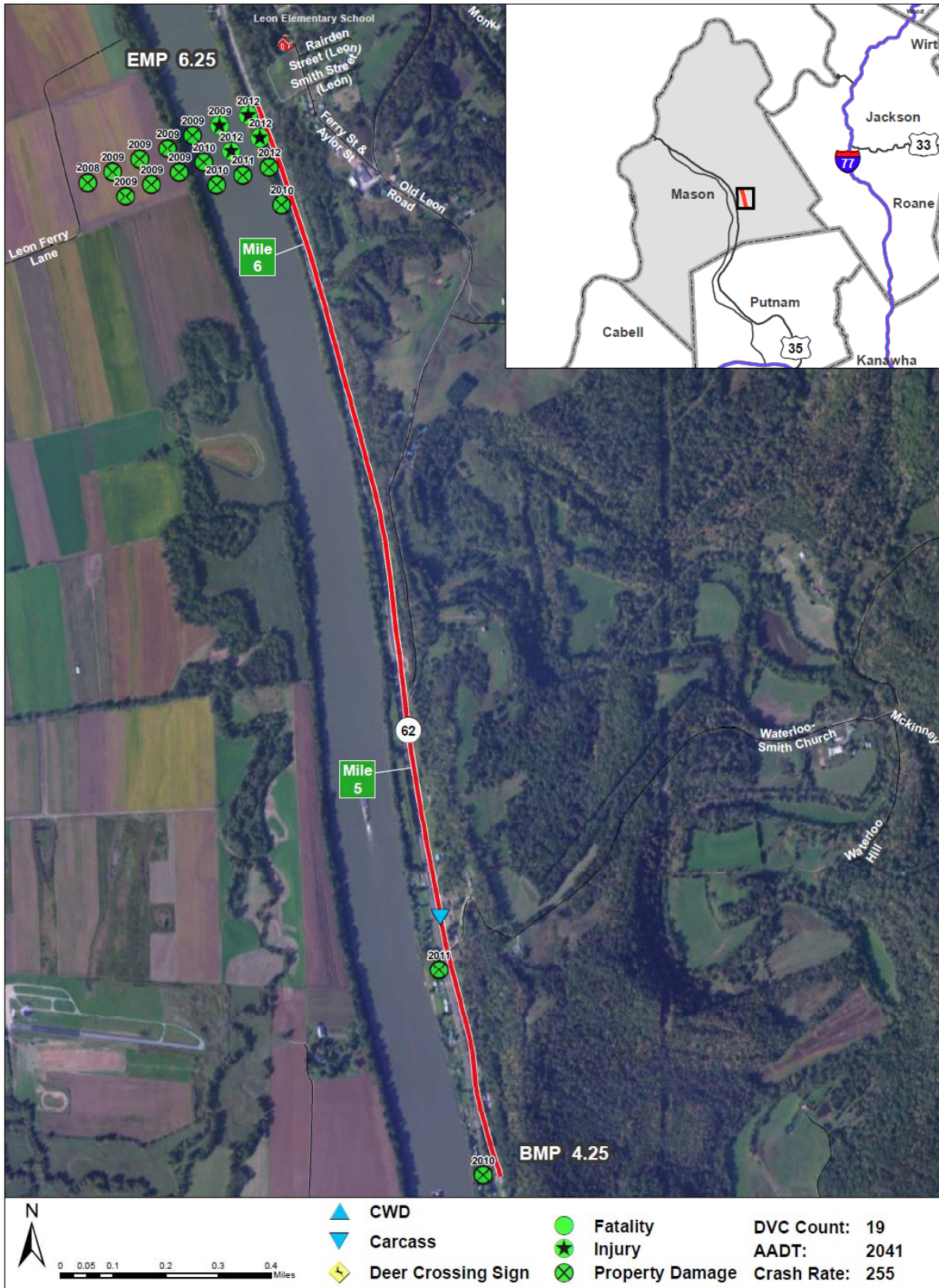
Figure 9-4 Enhanced Hotspot Map for WV-62 near Leon
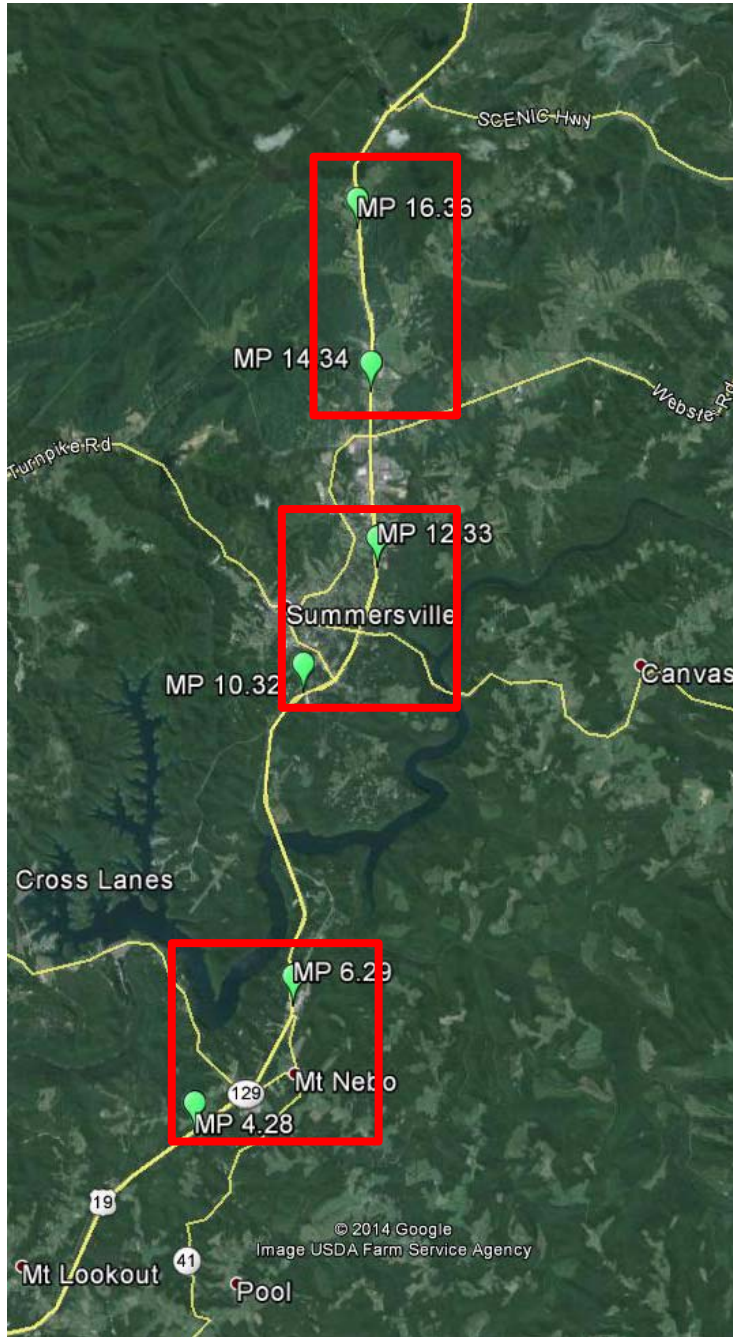
Figure 9-5 Top Ranked Segments on US-19 near Summersville
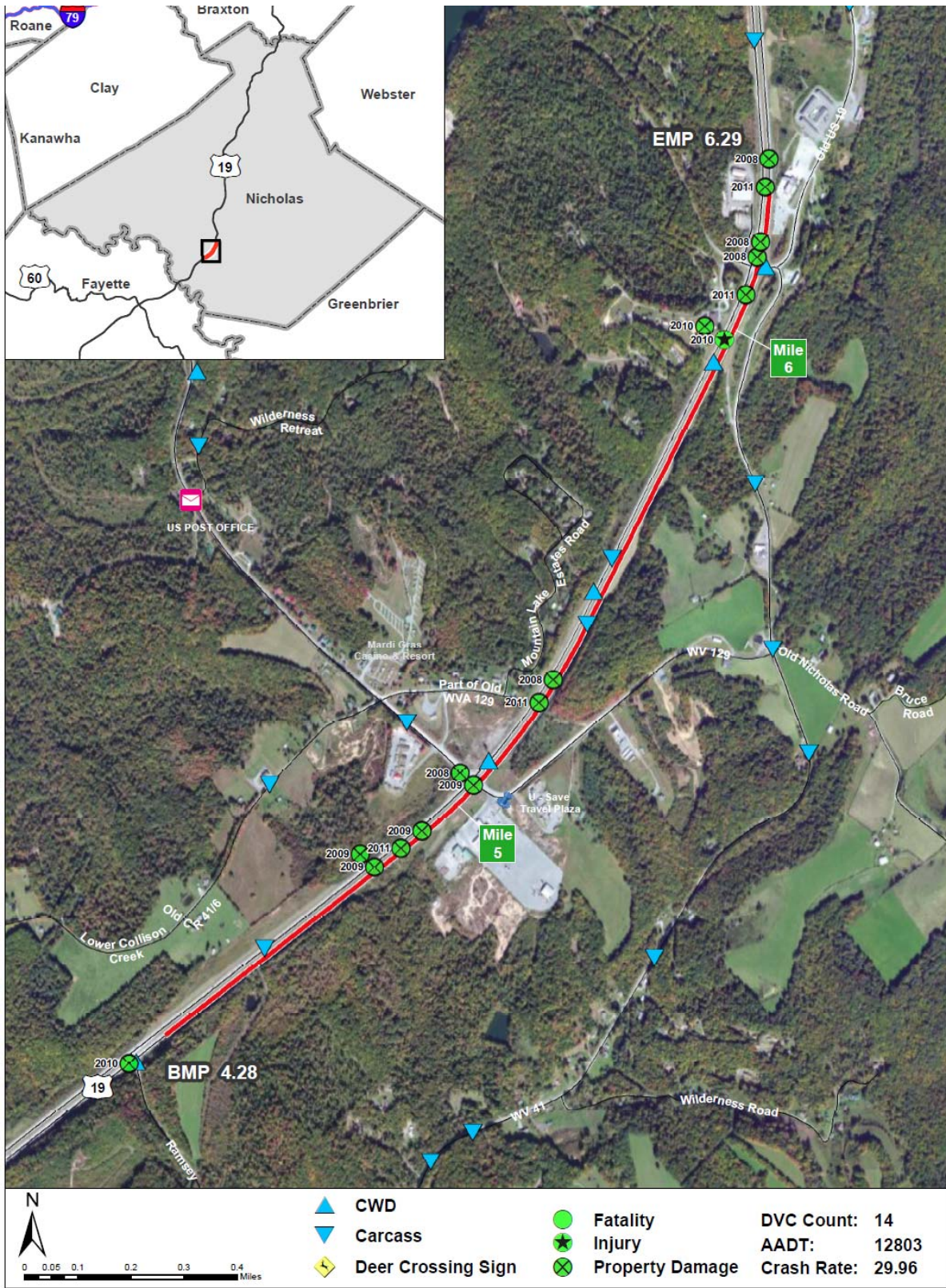
Figure 9-6 Enhanced Hotspot Map for US-19 near Summersville

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168   Personal Communication, Lydia Dixon, JHWF, 1/29/14

169   online at: http://www.wsdot.wa.gov/projects/us97a/wildlifefence/ [accessed 31 January 2014]

170   Kelly McAllister, Personal Communication, WSDOT, 1/29/14

APPENDIX

APPENDIX A.   **<u>DVC MITIGATION MATRIX (<i>13</i>)</u>**

Measure	Votes Received Recommended	Further Research	Not Recommended
Mitigations that attempt to influence driver behavior			
Public information and education		7	
Standard wildlife warning signs		2	
Large, nonstandard wildlife warning signs	1	5	
Seasonal wildlife warning signs		7	
Roadside animal detection systems (RADS)		2	5
In-vehicle (veh.) warnings: RADS to on-board			
In-veh. warning: on-board animal detectors			7
Increase visibility: roadway lighting		7	
Increase visibility: vegetation removal		7	
Increase visibility: wider road striping			
Reflective collars (buffalo)			
Reduce traffic volume on road network			
Seasonal closure			
Reduce speed by reducing posted speed limit		6	1
Reduce speed by traffic calming	1	5	1
Wildlife crossing guards	4	3	
Mitigations that attempt to influence animal behavior or population size			
Deer reflectors and mirrors		1	5
Audio signals in row or deer whistles		1	6
Olfactory repellants		3	4
Deer flagging models		1	6
Hazing		2	5
Investigate deicing alternatives	1	4	2
Intercept feeding		2	5
Influence species/nutritional value in ROW		5	1
Expanded median		4	2
Mitigations that seek to reduce wildlife population size			
Wildlife culling	2	4	1
Wildlife relocation		1	6
Anti-fertility treatment		3	4
Habitat alteration	1	3	3
Mitigations that attempt to physically separate animals from the roadway			
Wildlife fencing	6	1	
Boulders fence	2	5	
Long tunnels and long bridges	2	4	1
Underpasses and overpasses	2	4	1
Underpasses/overpasses and fencing	4	1	

APPENDIX B. <u>**WVDOT TRAFFIC ENGINEERING DIRECTIVE 215**</u>

October 1, 1993

TRAFFIC ENGINEERING DIRECTIVE

215

SUBJECT: **DEER CROSSING SIGNS**

The purpose of this Directive is to establish a criteria for the installation of DEER CROSSING sign assemblies.

DEER CROSSING sign assemblies may be installed when Division of Highways records (computerized central office accident data and/or reports compiled by County, APD, or Interstate Maintenance Organizations) or Department of Commerce, Labor & Environmental Resources (which includes the Division of Natural Resources and the Division of Tourism & Parks) records indicate that one of the following conditions are satisfied:

(1)   For any one year there should be at least seven deer killed per mile.

(2)   For any two or more year period, there should be at least five deer per mile, per year killed.

All DEER CROSSING sign assemblies shall contain a DEER CROSSING symbol and shall also include a mileage plaque (W7-3A) in increments of 1/4, 1/2, 1, 2 or 3 miles. If a continuous deer crossing area extends beyond 3 miles, then additional sign assemblies should be installed every 3 miles.

Ken F. Kobetsky, Director
Traffic Engineering Division

APPENDIX C.   PHONE INTERVIEW RESPONSES – TRANSPORTATION

Pennsylvania
Girish (Gary) Modi Chief, Highway Safety and Traffic Operations Division Pennsylvania Department of Transportation (PennDOT) gmodi@pa.gov 717-783-1190

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

    Crash data, including with deer, are analyzed by each district to identify and prioritize road sections that may require action to reduce crashes.

2. If yes,

    a. What are they?

    For deer:
    1. Signs
    2. Deer fencing
    3. Test with an animal detection system

    b. How is their implementation location identified?

    This is based on crash data. PennDOT is preparing a more systematic approach on how to identify and prioritize road sections that may qualify for mitigation for deer-vehicle collisions.

    c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

    The schedule for identification and prioritization processes currently is dependent on the district.

    d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

    In general, crash data is what guides safety measures, independent of other activities.

    e. How is it funded and who provided funding?

    So far it is some maintenance funds (but these are too limited) and also Federal Hwy safety funds. There are opportunities in MAP21.

    f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

    1. Signs: effectiveness unknown
    2. Deer fence: effectiveness unknown
    3. Animal detection system: had technological difficulties (unreliable).

3. If no,

    a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

    Yes, see above.

    b. Is the lack of implementation due to funding, perceived as minor problem, or other?

    Maintenance funding is too limited; this is a problem.
    PennDOT is preparing a strategic approach to deer-vehicle collisions, including funding sources.

4. Cooperation with DNR:

    Currently no systematic cooperation, perhaps in future.

Maryland
Cedric Ward Director, Office of Traffic & Safety Maryland Department of Transportation cward@sha.state.md.us (410) 787-5814

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?
   Yes. Note: deer crash and deer carcass data are available.
2. If yes,
   a. What are they?
      Above a certain threshold deer-warning signs are installed.
      Public safety messages
      No wildlife fencing.
      Some existing structures may be used by deer.
      Occasional new wildlife underpass
   b. How is their implementation location identified?
      Signs: based on crash and carcass data. Threshold for sign: >5 deer hit per 0.5 mi/yr.
   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?
      Signs are installed when thresholds are met.
   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?
      Wildlife underpasses only considered for new roads or major road reconstruction.
   e. How is it funded and who provided funding?
      Signs: maintenance budget.
      Underpass: overall major roadway project; federal funds.
   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?
      No, the effectiveness of signs and underpasses is not monitored.
3. If no,
   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?
      Not really, but perhaps a strategic safety plan should be revisited to include other approaches for deer. On the other hand the limited funds and mitigation are based on human fatalities, and deer-vehicle collisions do not result in many human fatalities.
   b. Is the lack of implementation due to funding, perceived as minor problem, or other?
      Maintenance funding is too limited; this is a problem.
      PennDOT is preparing a strategic approach to deer-vehicle collisions, including funding sources.
4. Cooperation with DNR:
   Not aware of coordination.

Virginia
Bridge M. Donaldson Senior Research Scientist Virginia Center for Transportation Innovation and Research Virginia Department of Transportation Bridge.Donaldson@VDOT.Virginia.gov (434) 293-1922

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

   Currently there are not standardized policies or practices; though they are needed. There has been some research into collisions and mitigation for wildlife, which is a first step. These include:

   1. Wildlife use of multi-functional underpasses before and after fencing (retrofitting existing structures), effect of road length fenced.

   2. Study large mammal presence adjacent to highways before implementing mitigation.

   3. Deer carcass composting.

2. If yes,

   a. What are they?

   1. Currently each district has its own procedures regarding deer-vehicle collisions, including identification and prioritization of hotspots.

   2. Retrofitting existing structures including wildlife fencing

   3. Sometimes a new structure is made wider to make it more suitable for wildlife.

   b. How is their implementation location identified?

   Typically based on deer-vehicle crash data.

   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

   Project by project basis.

   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

   e. How is it funded and who provided funding?

   Funding is per district but research funding also contributes.

   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

   1. Wildlife monitoring of selected structures takes place

   2. There are issues with the quality of deer-vehicle collision data (crash data and carcass removal data). This makes evaluation of the effectiveness of the mitigation measures troublesome.

3. If no,

   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

   1. Discussion about implementing animal detection system along smart road I64.

   2. Implementing a better data collection program through the use of Pocket PC or cell phone app..

   b. Is the lack of implementation due to funding, perceived as minor problem, or other?

   Big problem; insufficient funds to implement mitigation measures.

4. Cooperation with DNR:

   Yes, there is cooperation with the state natural resource management agency.

   1. Info sharing

   2. Argue for providing also safe crossing opportunities if wildlife fence is proposed..

Kentucky
Tracy Lovell Kentucky Transportation Cabinet Tracy.lovell@ky.gov (502) 782-5534

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

    Yes.

2. If yes,

    a. What are they?

    1. Standard wildlife warning signs (deer signs).

    2. Intensive mowing practices in right-of-way (3x/yr) for increased visibility to drivers, though regrowth may also attract deer.

    3. Existing box culverts (for drainage and cattle) are sometimes also used by deer.

    4. Deer population size reduction.

    5. Experiment with dehydrated sewer sludge on right-of-way vegetation was conducted; potential scent deterrent for deer, not effective though.

    Note: Experiments with deer carcass composting were abandoned (attracted too many vultures, too labor and equipment intensive). Now incinerators are used: clean and efficient.

    b. How is their implementation location identified?

    Based on crash and carcass removal data.

    c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

    Decentralized identification and prioritization of road sections that may require mitigation for deer-vehicle collisions; 12 Hwy districts. It is up to the individual districts to conduct the analyses. These analyses include all types of crashes, not just deer-vehicle collisions.

    d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

    Signs are implemented independent of scheduled road reconstruction.

    e. How is it funded and who provided funding?

    Traffic operation and maintenance funds.

    f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

    There has been no research or monitoring of the effectiveness of wildlife warning signs.

3. If no,

    a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

    No other measures discussed other than signing, except for:

    1. Seed mix and mowing practices right-of-way

    2. Scent treatment of vegetation in right-of-way that is supposed to scare deer away.

    3. Perhaps over design drainage structures so that they are more suitable for wildlife.

    No specific measures have been discussed for elk in eastern Kentucky.

    b. Is the lack of implementation due to funding, perceived as minor problem, or other?

4. Cooperation with DNR:

    No process for coordination.

    There may be some involvement during the design process.

Ohio
Matt Perlik Assistant Environmental Administrator Ohio Department of Transportation Matt.Perlik@dot.state.oh.us 614-466-1937

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?
Yes.
2. If yes,
   a. What are they?
    1. Deer signs
    2. Special project: Nelsonville Bypass project through Wayne National Park incorporated higher fencing and deer jump outs
   b. How is their implementation location identified?
    Signs: it's pretty much copied from the national MUTCD and there's no specific guidance on a methodology for placing them
   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?
    Deer signs: standard procedures
    Fences, jump-outs on project by project basis.
   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?
    Deer signs: stand-alone process
    Fences, jump-outs tied to (re)construction
   e. How is it funded and who provided funding?
    No Response
   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?
    Ongoing study with sound/light emitters.
3. If no,
   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?
    Yes: Office of Systems Planning & Program Management has a pilot study ongoing with Jaffa Technologies 'DeerDeter' (sound and Light Emitter in right-of-way).
   b. Is the lack of implementation due to funding, perceived as minor problem, or other?
    The focus so far has probably been on other safety issues.
4. Cooperation with DNR:
   No Response.

APPENDIX D.   <u>**PHONE INTERVIEW RESPONSES – NATURAL RESOURCE**</u>

<u>**AGENCIES**</u>

Pennsylvania
Christopher Rosenberry, PhD Pennsylvania Game Commission chrosenber@pa.gov (717) 582-2988

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

   No, but they do have surveys in each district (each about 200 sq mi) and ask people about wildlife-human conflicts. Deer-vehicle collisions are one of the conflicts that are often identified. This includes questions about:

   Do you want deer numbers to stay the same, reduced or increased?

   At district level: never "too many deer". At local level sometimes "too many deer", including too many deer-vehicle collisions. In some cases local deer population size is reduced through increased public hunting pressure. Increase in public hunting is the primary way for the game commission to reduce deer-human conflicts, including deer-vehicle collisions.

2. If yes,
   a. What are they?
   b. How is their implementation location identified?
   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?
   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?
   e. How is it funded and who provided funding?
   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

3. If no,
   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

      No, but yes for elk. 2-3 yrs ago there was a cooperation with PennDOT to install a variable message sign for elk. There were about 6 elk-vehicle collisions/yr. In the meantime elk population a bit reduced through hunting. Not known if sign was effective at reducing collisions..
   b. Is the lack of implementation due to funding, perceived as minor problem, or other?

      A few years ago there was talk about an animal detection system for the elk. However, the costs were considered too high. Since then not much discussion about elk-vehicle collisions.

4. Cooperation with DOT:

   Occasionally, see e.g. elk signs.

Maryland
Brian Eyler Wildlife & Heritage Service Maryland DNR beyler@dnr.state.md.us (301) 842-0332

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

   Yes

   1. Deer-vehicle collision numbers are monitored in cooperation with state DOT.

   2. Tag is issued to people who have had a collision with a deer.

   3. Hunting success parameters (general numbers, buck harvest) are monitored.

2. If yes,

   a. What are they?

      1. Increase in hunting tags issued in areas (counties) where deer-vehicle collisions are high.

      2. Hunting is mostly public hunting, in some cases there are "managed hunts" (safety course completed, assigned stands).

      3. In some other cases sharpshooting by professional shooters is applied.

   b. How is their implementation location identified?

      Deer-vehicle collision data are part of the information used to decide on deer hunting tags issued.

   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

      Not associated with highway projects.

   e. How is it funded and who provided funding?

      1. Hunting tags and Pittman-Robertson act.

      2. Professional sharpshooters: e.g. paid for by the county, Maryland Park Service, private home owner association..

   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

      Some state parks had deer population size reduced. There appeared to be fewer deer-vehicle collisions after the population size reduction.

3. If no,

   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

      No roadside mitigation.

   b. Is the lack of implementation due to funding, perceived as minor problem, or other?

      Problems are:

      1. Access to hunters (often no access on private land).

      2. Hunter numbers (too few hunters).

4. Cooperation with DOT:

   There is coordination with State Highway Administration.

   1. Share database deer-vehicle collisions

   2. If fencing is proposed then there is contact about also providing for safe crossing opportunities.

   3. State Hwy Admin does not request deer population reduction.

Virginia

Nelson Lafon
Virginia Department of Game & Inland Fisheries
Nelson.lafon@dgif.virginia.gov mailto:Bridge.Donaldson@VDOT.Virginia.gov
(540) 569-0023

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

    Yes

2. If yes,

    a. What are they?

    1. Per county human-deer conflict data: collisions, agricultural damage, residential garden damage, lyme disease. Leads to "cultural carrying capacity". Response by the agency is to increase public hunting pressure (more doe tags).
    2. In some cases a city (police department) will hire sharpshooters for local deer population reduction.
    3. Kill permits can be issues to city, police, farmers etc. to reduce deer-vehicle collisions or crop damage.

    b. How is their implementation location identified?

    Area based. Based on human-conflict data.

    c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

    Human – wildlife conflict data are part of standard practices, as well as response to reduce deer population size.

    d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

    Specific project, not related to road reconstruction or new construction.

    e. How is it funded and who provided funding?

    Public hunting funded through license sales and Pittman–Robertson Act
    Sharpshooting through local taxes (cities)

    f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

    Mixed success. Blacksburg and Lynchburg have kept good data on culling and deer-vehicle collisions and have had a marked reduction in deer-vehicle collisions since reducing deer population through sharpshooting.
    More problematic in urban areas where there is more private land or small parcels and fragmented landownership (no hunting access).

3. If no,

    a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

    b. Is the lack of implementation due to funding, perceived as minor problem, or other?

    Reduced hunter numbers and limited access to land for hunters is a problem and limits the ability of the agency to reduce the deer population size.
    Better DVC data are needed: current data are geographically variable in search and reporting effort (especially carcass removal data).

4. Cooperation with DOT:

    Yes, but mostly in an advisory role.
    1. Fairfax County Parkway: 2 wildlife underpasses
    2. Rt 17 upgrade in SE VA: bear-vehicle collisions were an issue. Potential modifications to existing bridges, potential fencing. Multi-functional underpasses.
    3. Ashton I64 Stanton-Charlottesville: monitoring wildlife movements near road to plan for mitigation (fencing, crossing structures).

Kentucky
Gabe Jenkins Big Game Program Coordinator Kentucky Department of Fish and Wildlife Resources Gabriel.jenkins@ky.gov (800) 858-1549

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?
   Yes.
2. If yes,
   a. What are they?
      1. Management recommendations per deer management district
      2. Number of hunting tags issued (per county).
      3. Type of hunting tags issued (more doe tags if deer population size reduction is desired)
   b. How is their implementation location identified?
      Through involvement of the public:
      1. Deer-vehicle collision data
      2. Agricultural damage
      3. Harvest trends.
   c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?
      Project by project basis when a problem is suspected. If there are no complaints by the public no specific investigation of deer-vehicle collision data takes place.
   d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?
   e. How is it funded and who provided funding?
      1. Hunting tag fees.
      2. Pittman–Robertson Act
   f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?
      Appears to result in fewer deer-vehicle collisions.
      In one particular area, in cooperation with the DOT:
      1. Increase in hunting tags
      2. Increase visibility along roadside for drivers.
      Appears to have resulted in a decrease in deer-vehicle collisions..
3. If no,
   a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?
      Only through reducing deer population size is specific areas.
      However, for elk (another species than deer), wildlife fencing has been discussed.
   b. Is the lack of implementation due to funding, perceived as minor problem, or other?
      Deer-vehicle collisions appear to be declining over the last few years as a result of:
      1. Hunters killing relatively large numbers of deer.
      2. Increase in visibility along roadside (clearance of shrubs and trees).
4. Cooperation with DOT:
   Yes, there is coordination in areas where many deer-vehicle collisions occur.
   There is no established procedure for coordination; coordination happens as needed.
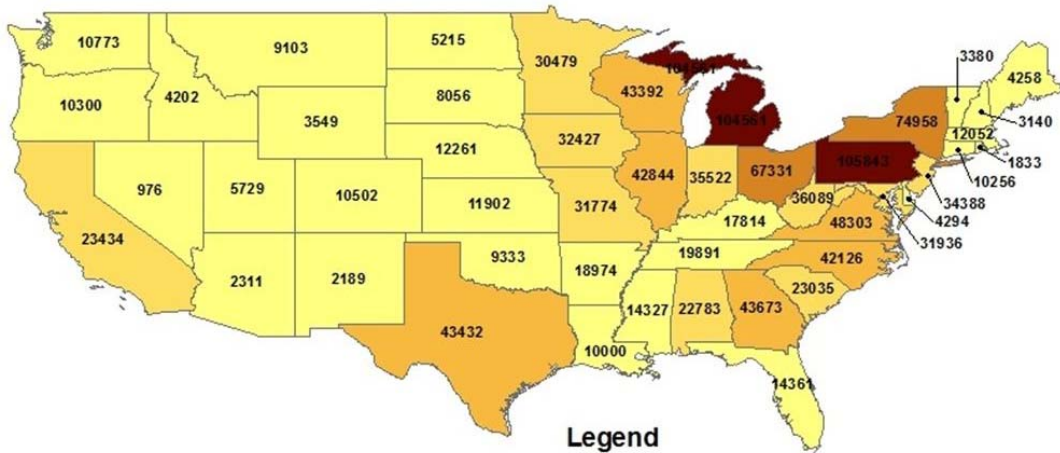   *There may be some involvement during the design process.*

Ohio
Mike Tonkovich, PhD Ohio Division of Natural Resources Mike.tonkovich@dnr.state.oh.us (740) 589-9930

1. Does your agency have policies and/or practices that are specifically implemented to reduce deer-vehicle collisions?

    Yes

    Note: Crashes were used as an index of the deer population size until end 1990s. Now people who hit a deer are no longer required to include a crash report of the collision to their insurance company, so more recently the number of reported deer crashes is no longer a good indicator of deer population size.

2. If yes,
    a. What are they?

        1. Public info on increased risk in rutting season when most collisions occur.
        2. Reduction in deer population size in selected areas. These areas are mostly identified through surveys among farmers. This is not based on deer-vehicle collisions, though there is likely a correlation.
        3. No roadside on the ground mitigation measures.

    b. How is their implementation location identified?

        Surveys among farmers; opinions on deer population size

    c. Is it done on a project-by-project basis or are the practices incorporated into all projects (such as planting types)?

        Public info, surveys among farmers, and deer population size reduction are standard practice

    d. Is the implementation a specific mitigation project or is it incorporated into an existing project that has another purpose (such as roadway widening)?

        Public info, surveys among farmers, and deer population size reduction are standard practice

    e. How is it funded and who provided funding?

        Standard budgets

    f. Have the effectiveness of the mitigation efforts been quantified? Have any been successful/unsuccessful?

        1. Press releases during rut: effectiveness unknown.
        2. Deer population size reduction: probably leads to fewer deer-vehicle collisions, but it is not measured or analyzed.

3. If no,
    a. Has there been any interest or discussion about implementing deer-vehicle collision mitigation?

        Is not on the radar; not perceived as a specific task.

    b. Is the lack of implementation due to funding, perceived as minor problem, or other?

        Not really a problem.

4. Cooperation with DOT:
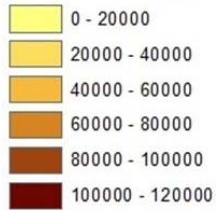
    No regular coordination with the DOT.

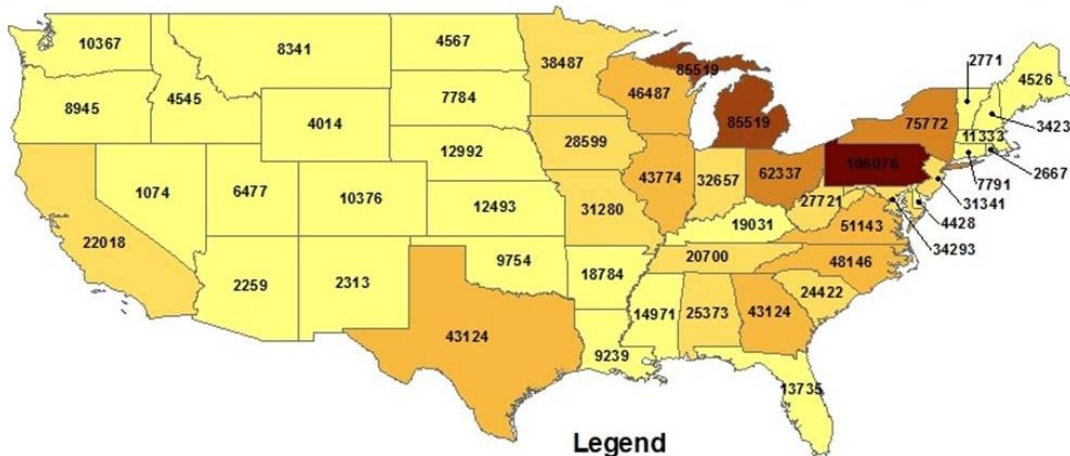**APPENDIX E.**   <u>**NATIONAL DVC COMPARISON MAPS**</u>

Map 1 (2008)

State values: 10773, 9103, 5215, 30479, 3380, 4258, 10300, 4202, 3549, 8056, 43392, 104561, 74958, 3140, 32427, 12052, 1833, 12261, 104561, 67331, 105843, 10256, 976, 5729, 10502, 11902, 31774, 42844, 35522, 36089, 34388, 23434, 17814, 48303, 4294, 31936, 2311, 2189, 9333, 18974, 19891, 42126, 43432, 14327, 22783, 43673, 23035, 10000, 14361

WV RANKED 11TH

Legend

2008
DVC Estimates (State Farm)

- 0 - 20000
- 20000 - 40000
- 40000 - 60000
- 60000 - 80000
- 80000 - 100000
- 100000 - 120000

Map 2 (2010)

State values: 10367, 8341, 4567, 38487, 2771, 4526, 8945, 4545, 4014, 7784, 46487, 85519, 75772, 3423, 28599, 11333, 2667, 12992, 85519, 62337, 106076, 7791, 1074, 6477, 10376, 12493, 31280, 43774, 32657, 27721, 31341, 22018, 19031, 51143, 4428, 34293, 2259, 2313, 9754, 18784, 20700, 48146, 43124, 14971, 25373, 43124, 24422, 9239, 13735

WV RANKED 17TH

Legend

2010
DVC Estimates (State Farm)

- 0 - 20000
- 20000 - 40000
- 40000 - 60000
- 60000 - 80000
- 80000 - 100000
- 100000 - 120000

WV RANKED 16TH

Legend

2011
DVC Estimates (State Farm)

- 0 - 20000
- 20000 - 40000
- 40000 - 60000
- 60000 - 80000
- 80000 - 100000
- 100000 - 120000

Legend

2008

DVC Rate per 10000 Licensed Drivers

- 0 - 45
- 45 - 90
- 90 - 135
- 135 - 180
- 180 - 225
- 225 - 270

WV RANKED 1ST

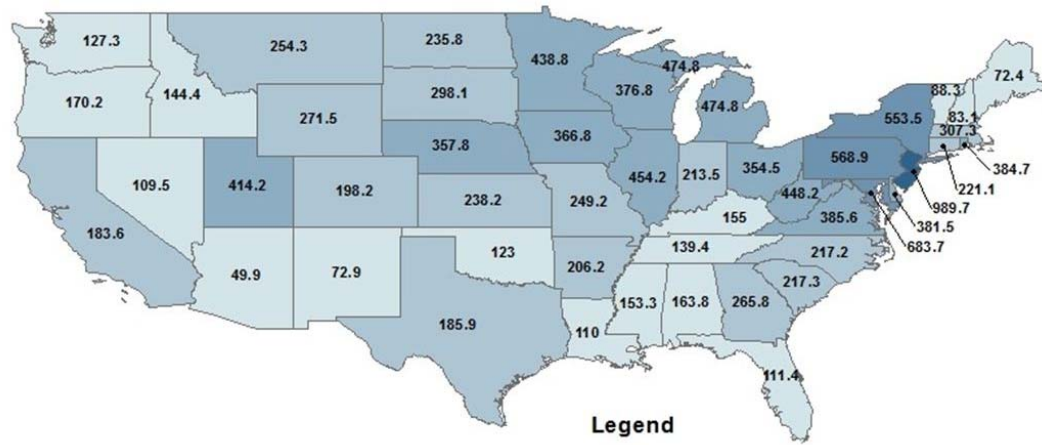**Legend**

2008

DVC Rate per 10000 Rural Licensed Drivers

- 10 - 200
- 200 - 400
- 400 - 600
- 600 - 800
- 800 - 1000
- 1000 - 1200

WV RANKED 6TH

WV RANKED 1ST

Legend

2010

DVC Rate per 10000 Licensed Drivers

- 0 - 40
- 40 - 80
- 80 - 120
- 120 - 160
- 160 - 200
- 200 - 240

WV RANKED 7TH

Legend

2010

DVC Rate per 10000 Rural Licensed Drivers

- 0 - 175
- 175 - 350
- 350 - 525
- 525 - 700
- 700 - 875
- 875 - 1050

Map 1

Legend

2011

DVC Rate per 10000 Licensed Drivers

- 0 - 45
- 45 - 90
- 90 - 135
- 135 - 180
- 180 - 225
- 225 - 270

WV RANKED 1ST

State values:
20.7, 127.3, 93.6, 124.5, 138.6, 54.6, 48.5, 33, 42.5, 88.1, 146.9, 126.6, 138.6, 71.6, 35.1, 18.7, 26.7, 93.7, 137.4, 131.4, 32.8, 7, 34.7, 31.3, 78.4, 85.6, 61.7, 51.8, 84.8, 251.9, 95.8, 52.2, 69.3, 88.5, 10.6, 76.5, 5.8, 17.4, 50.9, 103.7, 53, 73.6, 77.5, 30, 32, 83.1, 68.6, 66.1, 10.1

Map 2

Legend

2011

DVC Rate per 10000 Rural Licensed Drivers

- 0 - 175
- 175 - 350
- 350 - 525
- 525 - 700
- 700 - 875
- 875 - 1050

WV RANKED 7TH

State values:
129.5, 288.5, 233.3, 465.8, 545.1, 79.1, 174.1, 144.3, 338.9, 424.3, 545.1, 590.2, 89.4, 88.3, 232.7, 249.9, 381.9, 615.6, 287.8, 120, 368.3, 226, 348.7, 535.6, 187.8, 384.1, 273.2, 980.9, 209.8, 304, 289.4, 491.3, 390.2, 415, 57.3, 77.3, 150.6, 236.5, 183.9, 691, 196.3, 157.8, 164, 167.4, 265.1, 217.1, 230.1, 119.2, 114.7

WV RANKED 38TH

Legend
2011
Licensed Drivers, FHWA (10000 Drivers)
- 0 - 400
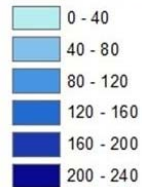- 400 - 800
- 800 - 1200
- 1200 - 1600
- 1600 - 2000
- 2000 - 2400
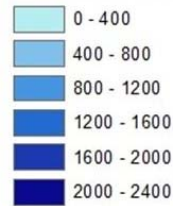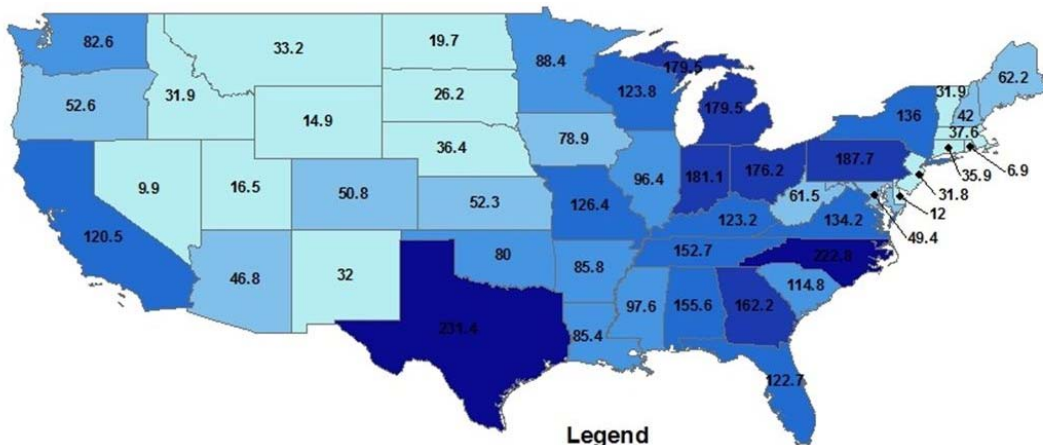
WV RANKED 27TH

Legend
2011
Rural Licensed Drivers, FHWA (10000 Drivers)
- 0 - 40
- 40 - 80
- 80 - 120
- 120 - 160
- 160 - 200
- 200 - 240
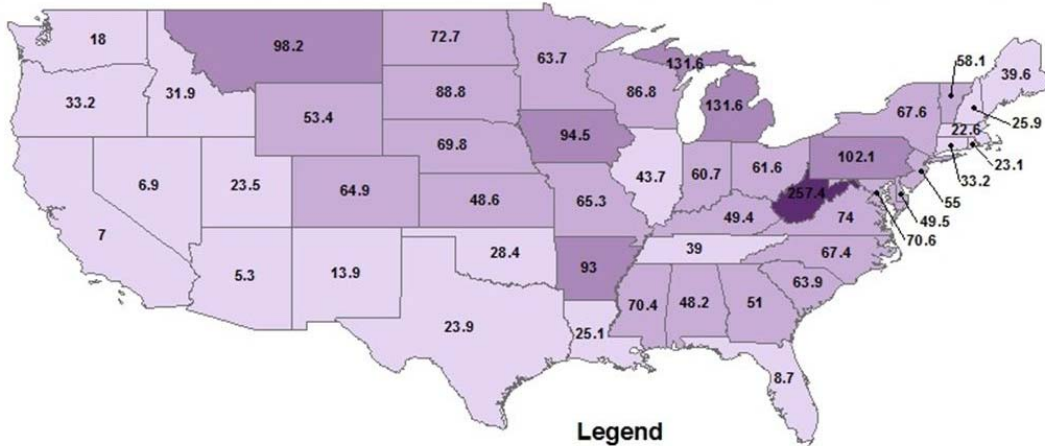
WV RANKED 1ST

Legend

2008

DVC Rate per 10000 Registered Vehicles

- 0 - 45
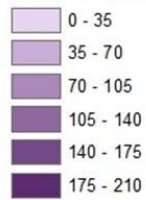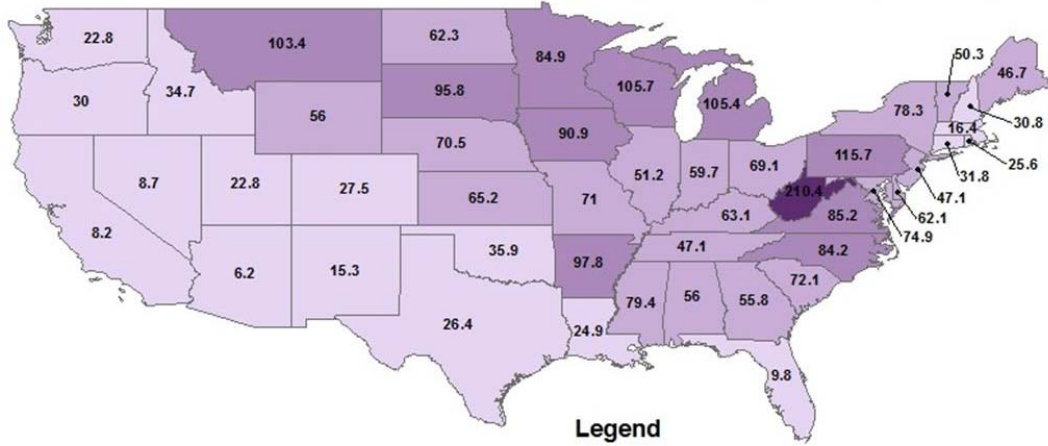- 45 - 90
- 90 - 135
- 135 - 180
- 180 - 225
- 225 - 270

WV RANKED 1ST

Legend

2010

DVC Rate per 10000 Registered Vehicles

- 0 - 35
- 35 - 70
- 70 - 105
- 105 - 140
- 140 - 175
- 175 - 210

WV RANKED 1ST

Legend

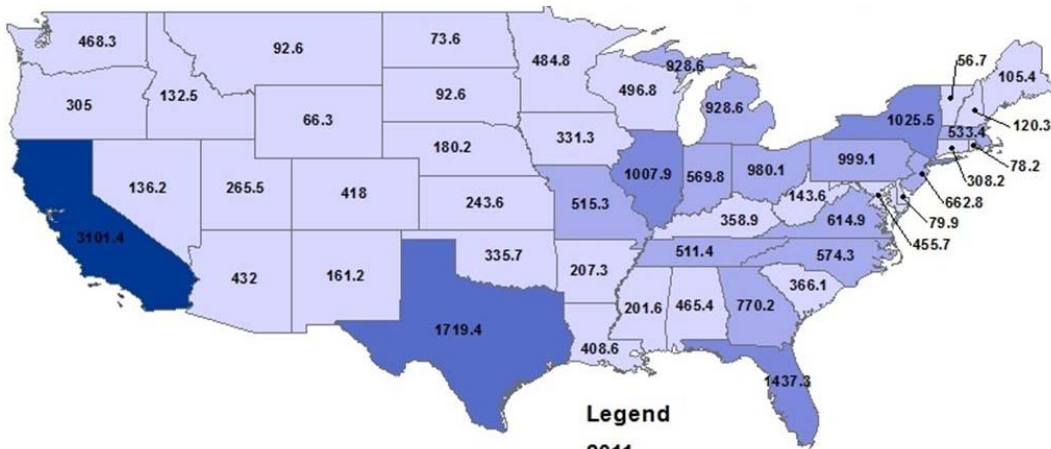2011

DVC Rate per 10000 Registered Vehicles

- 0 - 40
- 40 - 80
- 80 - 120
- 120 - 160
- 160 - 200
- 200 - 240
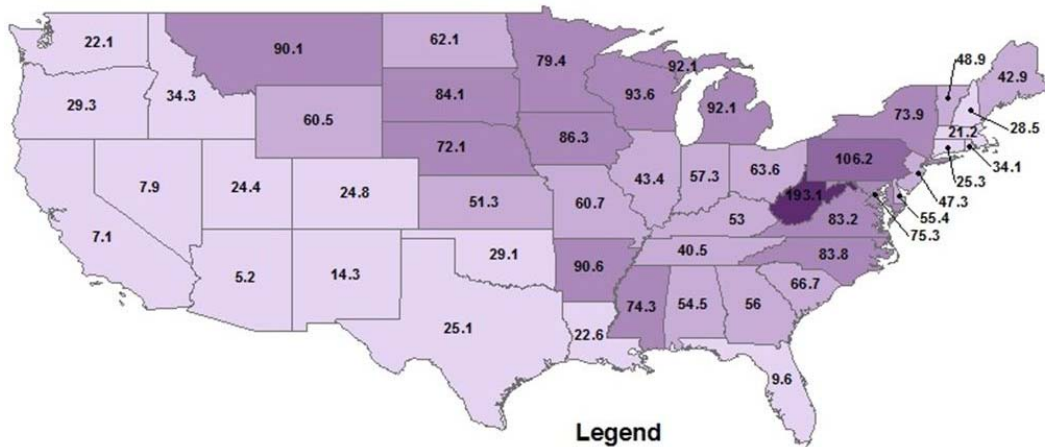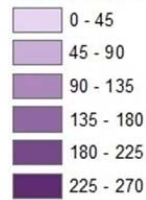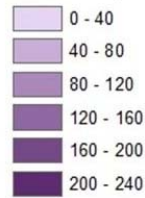
WV RANKED 37TH

Legend

2011

Registered Vehicles, FHWA (10000 Vehicles)
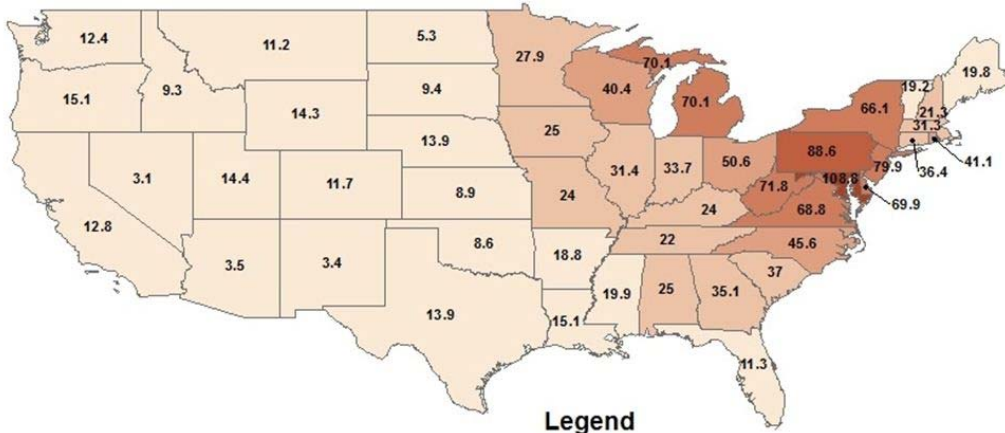
- 0 - 500
- 500 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 2500
- 2500 - 3000
- 3000 - 3500

Legend
2008
DVC Rate per 100 Roadway Miles
0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120

WV RANKED 2ND

Legend
2008
DVC Rate per 100 Rural Roadway Miles
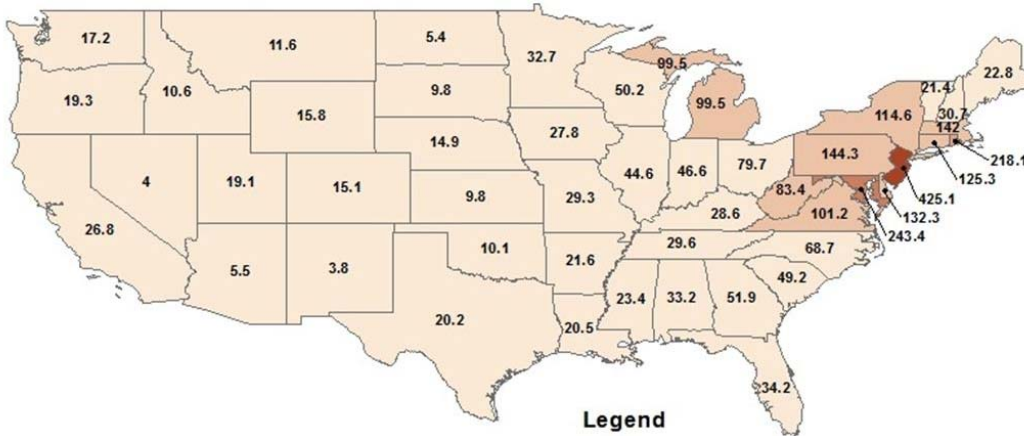0 - 80
80 - 160
160 - 240
240 - 320
320 - 400
400 - 480

WV RANKED 10TH

Legend

2010

DVC Rate per 100 Roadway Miles

- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120

WV RANKED 4ᵀᴴ

Legend

2010

DVC Rate per 100 Rural Roadway Miles

- 0 - 80
- 80 - 160
- 160 - 240
- 240 - 320
- 320 - 400
- 400 - 480

WV RANKED 11ᵀᴴ

Legend
2011
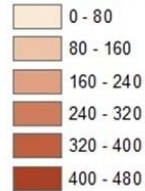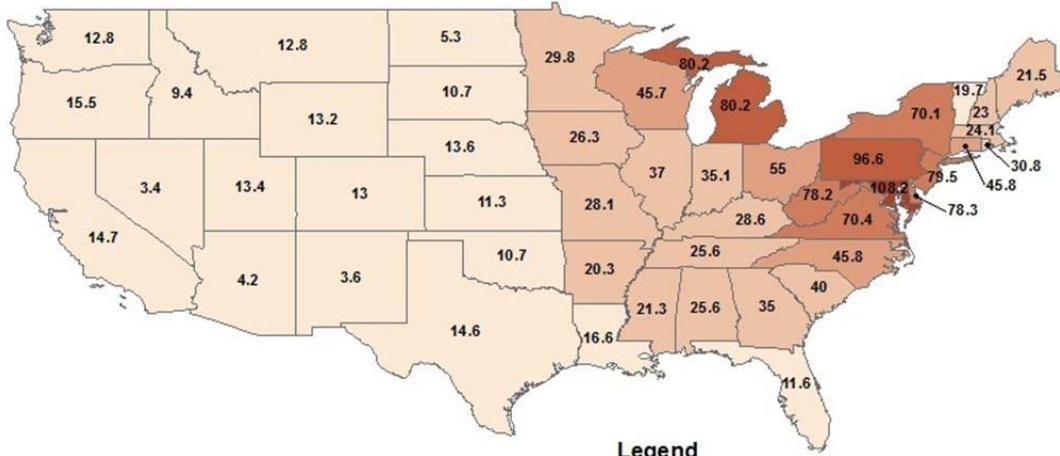DVC Rate per 100 Roadway Miles
0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120

WV RANKED 6TH
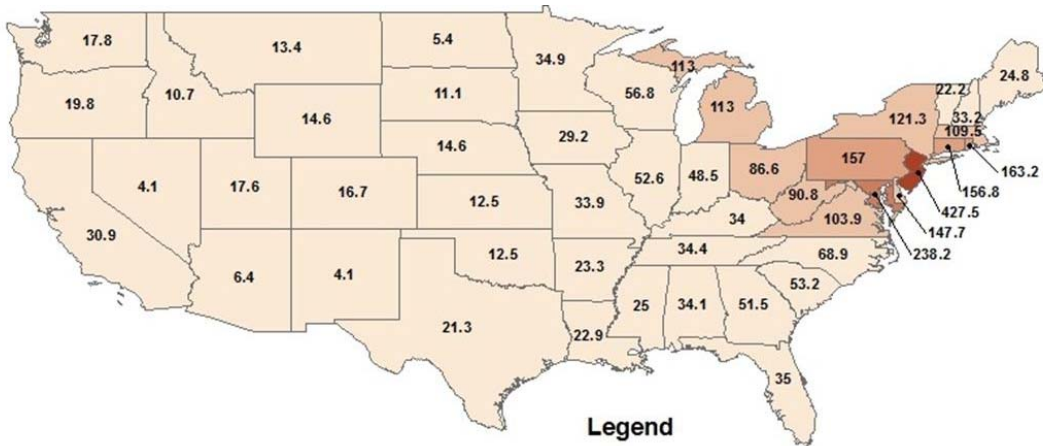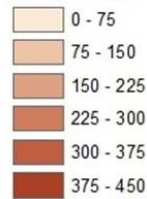
Legend
2011
DVC Rate per 100 Rural Roadway Miles
0 - 75
75 - 150
150 - 225
225 - 300
300 - 375
375 - 450

WV RANKED 11TH

Map 1 — Public Roadway Miles, FHWA (2011):

83822, 74793, 86842, 138164, 121969, 14437, 22864, 59151, 48771, 82447, 114963, 121969, 114574, 16085, 28105, 93653, 114383, 139519, 123192, 119685, 36248, 6490, 35061, 45124, 88353, 140653, 96988, 21391, 38625, 39242, 172139, 130360, 79184, 74378, 6337, 31526, 64308, 68378, 112873, 94207, 105653, 100068, 66024, 75080, 101575, 122917, 311249, 61327, 121702

WV RANKED 38TH

Legend

2011

Public Roadway Miles, FHWA

- 0 - 50000
- 50000 - 100000
- 100000 - 150000
- 150000 - 200000
- 200000 - 250000
- 250000 - 300000
- 300000 - 350000

Map 2 — Rural Public Roadway Miles, FHWA (2011):

60059, 71698, 84932, 117885, 86596, 12824, 19867, 46237, 43000, 79492, 92537, 66157, 11147, 25468, 102986, 86596, 7988, 28622, 34463, 68883, 127532, 107827, 98226, 70171, 78209, 73620, 1225, 33275, 6252, 81877, 66588, 50391, 7296, 41594, 60480, 96673, 87069, 69975, 70197, 3361, 14323, 64107, 76416, 83548, 49623, 213725, 44466, 40288

WV RANKED 37TH

Legend

2011

Rural Public Roadway Miles, FHWA

- 0 - 40000
- 40000 - 80000
- 80000 - 120000
- 120000 - 160000
- 160000 - 200000
- 200000 - 240000

Legend

2008

DVC Rate per 100 million Vehicle miles Traveled

	0 - 30
	30 - 60
	60 - 90
	90 - 120
	120 - 150
	150 - 180

WV RANKED 1ST

Legend

2008

DVC Rate per 100 million Rural Vehicle miles Traveled

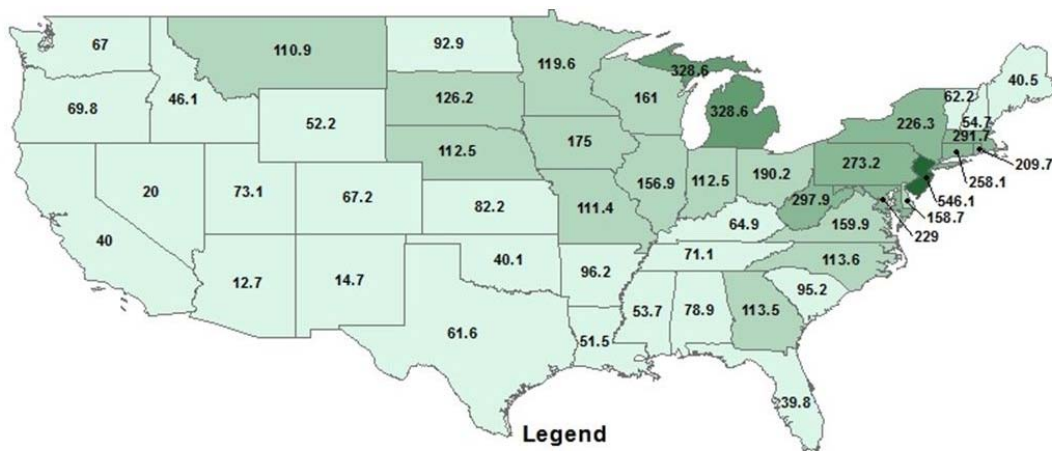|	
	0 - 100
	100 - 200
	200 - 300
	300 - 400
	400 - 500
	500 - 600

WV RANKED 3RD

Appendix   261

WV RANKED 1ST

Legend

2010

DVC Rate per 100 million Vehicle miles Traveled

- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 125
- 125 - 150

WV RANKED 6TH

Legend

2010

DVC Rate per 100 million Rural Vehicle miles Traveled

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500

Legend
2011
DVC Rate per 100 million Vehicle miles Traveled

- 0 - 30
- 30 - 60
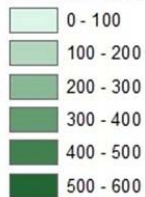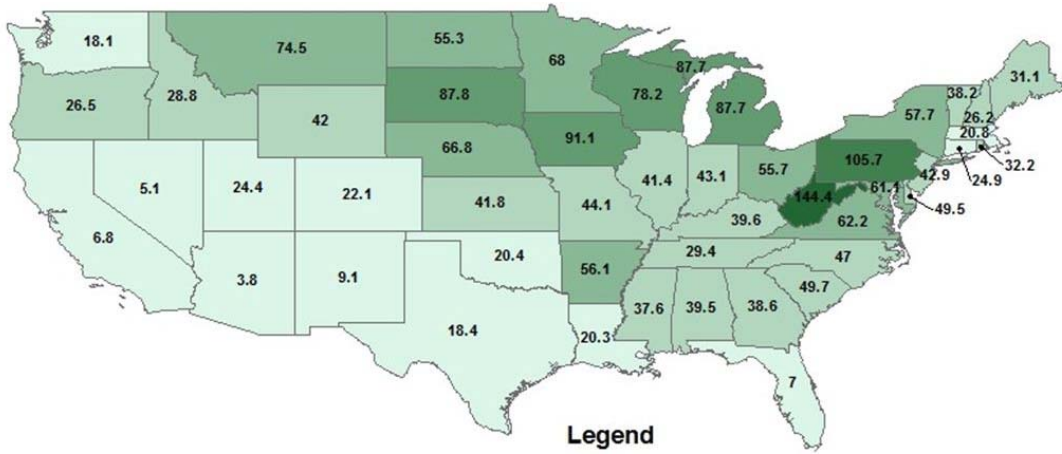- 60 - 90
- 90 - 120
- 120 - 150
- 150 - 180

WV RANKED 1ST

Legend
2011
DVC Rate per 100 million Rural Vehicle miles Traveled

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500

WV RANKED 4TH

Legend

2011

VMT, FHWA (100 million miles)

Color	Range
	0 - 500
	500 - 1000
	1000 - 1500
	1500 - 2000
	2000 - 2500
	2500 - 3000
	3000 - 3500

WV RANKED 38TH

Legend

2011

Rural VMT, FHWA (100 million miles)

Color	Range
	0 - 120
	120 - 240
	240 - 360
	360 - 480
	480 - 600
	600 - 720
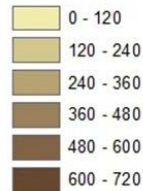
WV RANKED 33RD

APPENDIX F. <u>**WEST VIRGINIA CRASH REPORT (PAGE 1)**</u>

State of West Virginia Uniform Traffic Crash Report
Crash Data

DOH Form: 17-c
Revised: 02/2007

Crash Record Number: _____ **Reporting Agency's Record Number:** _____ **Page** ___ **of** ___

# of Vehicles Involved: ___ **# of Non-Motorists Involved:** ___ **# of Fatal Injuries:** ___ **# of A B or C Injuries:** ___

Date / Time of Crash: ___ / ___ **Date / Time Crash Reported:** ___ / ___ **Time of Arrival:** ___

County: ___ **Municipality or Place of Crash:** ___ **GPS Coordinates:** ___ ___

Latitude   Longitude

Highway Class:
- ○ Interstate ○ US ○ WV
- ○ County/HARP ○ City Street ○ State Park / Forest Road
- ○ Private Road ○ Private Property/Off-Roadway ○ Other

Supplemental Designation:
- ○ Not Applicable ○ Spur ○ North ○ East ○ Truck Route ○ Other
- ○ Alternate ○ Ramp ○ South ○ West ○ Toll

Route: ___ / ___ **Milepost:** ___ **Ramp:** ___ **Street:** ___

Other Description of Location: ___ **Intersecting Street:** ___

Relation to Junction / Junction Type:
- ○ Non-Junction ○ Junction, Non-Interchange Area ○ Junction, Interchange Area
  - ☐ Intersection
  - ☐ Intersection-Related
  - ☐ Interstate to Interstate
  - ☐ Railroad Grade Crossing #: ___
  - ☐ Median Crossover-Related
  - ☐ Business or Residential Driveway/Alley Access
  - ☐ Other Non-Interchange
  - ☐ Thru Roadway
  - ☐ Merge/Diverge Area
  - ☐ Intersection
  - ☐ Intersection-Related
  - ☐ Entrance / Exit Ramp
  - ☐ Other Part of Interchange

Intersection Type:
- ○ 4-Way Intersection
- ○ T Intersection
- ○ Y Intersection
- ○ Intersection as Part of Interchange
- ○ Traffic Circle / Roundabout
- ○ 5-Point or More

Manner of Collision:
- ○ Single Vehicle Crash
- ○ Rear End
- ○ Head-On
- ○ Sideswipe, Same Direction
- ○ Sideswipe, Opposite Direction
- ○ Rear-to-Side
- ○ Rear-to-Rear

- ○ Angle (Front to Side) Same Direction   OR
- ○ Angle (Front to Side) Opp. Direction   OR
- ○ Right Angle   OR
- ○ Angle - Direction Not Specified

Environmental Contributing Circumstances (Select Up to 3):
- ☐ None
- ☐ Weather Conditions
- ☐ Physical Obstruction(s)
- ☐ Glare
- ☐ Animal(s) in Roadway Type: ___
- ☐ Other: ___

Weather (Select Up to 2):
- ☐ Clear ☐ Rain ☐ Blowing Snow ☐ Other
- ☐ Cloudy ☐ Sleet, Hail, or Freezing Rain ☐ Severe Crosswinds
- ☐ Fog, Smog, Smoke ☐ Snow ☐ Blowing Sand, Soil, Dirt

Lighting:
- ○ Daylight ○ Dawn
- ○ Dark - Lighted ○ Dusk
- ○ Dark - Not Lighted ○ Other ___

Roadway Surface Condition:
- ○ Dry ○ Slush ○ Mud, Dirt, Gravel, Sand
- ○ Wet ○ Ice / Frost
- ○ Snow ○ Water (Standing / Moving)

Location of First Harmful Event:
- ○ On Roadway ○ Roadside ○ In Parking Lane or Zone ○ Outside of Right-of-Way
- ○ Shoulder ○ Gore ○ Off Roadway, Location Unknown
- ○ Median ○ Separator ○ Unknown

Roadway Surface Type: ○ Asphalt ○ Concrete ○ Gravel ○ Dirt ○ Brick ○ Other: ___

First Harmful Event:
- ○ Overturn / Rollover
- ○ Fire / Explosion
- ○ Immersion
- ○ Jackknife
- ○ Cargo / Equipment Loss or Shift
- ○ Fell / Jumped from Motor Veh
- ○ Thrown or Falling Object
- ○ Other Non-Collision

COLLISION WITH:
- ○ Pedestrian
- ○ Pedalcycle
- ○ Railway Vehicle
- ○ Animal
- ○ Motor Vehicle in Transport
- ○ Parked Motor Vehicle
- ○ Work Zone / Maintenance Equip
- ○ Other Non-Fixed Object
- ○ Impact Attenuator / Crash Cushion

- ○ Bridge Overhead Structure
- ○ Bridge Pier or Support
- ○ Bridge Rail
- ○ Culvert
- ○ Curb
- ○ Ditch
- ○ Embankment
- ○ Guardrail Face
- ○ Guardrail End
- ○ Cable Median Barrier

- ○ Concrete Traffic Barrier
- ○ Other Traffic Barrier
- ○ Tree (Standing)
- ○ Utility Pole/Light Support
- ○ Traffic Sign Support
- ○ Traffic Signal Support
- ○ Other Post, Pole, or Support
- ○ Fence
- ○ Mailbox
- ○ Other Fixed Object

APPENDIX G.   <u>**WVDOT DOT-12 FORM**</u>

WEST VIRGINIA
DEPARTMENT OF TRANSPORTATION
Form DOT-12 (Rev. 11/98)

DAILY WORK REPORT		ACCOUNTING INFORMATION			
		1	2	3	4
Date:	RECEIVING ORG.				
	AUTH./ E.D. NO				
Home Ore:	ACTIVITY CODE				
	"N" OR "P"				
DOCUMENT CONTROL	ROUTE NUMBER				
Number: Type:	BEG. MILE POST				
	END. MILE POST				
MAINT: UNITS ACCOMPLISHED / WORK ORDER NO.					
MAINT: UNITS OF MEASURE / TYPE OF WORK					

EMPLOYEE NAME	SOCIAL SECURITY	WAGE CODE	HOURS REPORTED			
			1	2	3	4
	TOTAL HOURS REPORTED					

EQUIPMENT DESCRIPTION	E.D. NO.	END. METER & STATUS	HOURS OR MILES REPORTED			
			1	2	3	4
	TOTAL HOURS/MILES REPORTED					

INVENTORY DESCRIPTION	ORG. LOC.	CLASSIFICATION CLASS - TYPE - SUB.	INVENTORY USAGE BY UNITS			
			1	2	3	4
	TOTAL UNITS REPORTED					

Prepared By: Approved By: Entered Into System By:

APPENDIX H.   <u>**REGRESSION PLOTS OF CRASH REPORTS VS. CARCASS DATA**</u>

Hampshire

Nicholas

Mason

Fayette

Braxton

Pleasants

Taylor

Clay

Jefferson

Greenbrier

Wayne

Harrison

Wirt

Tyler

Monroe

Hancock

Webster

Calhoun
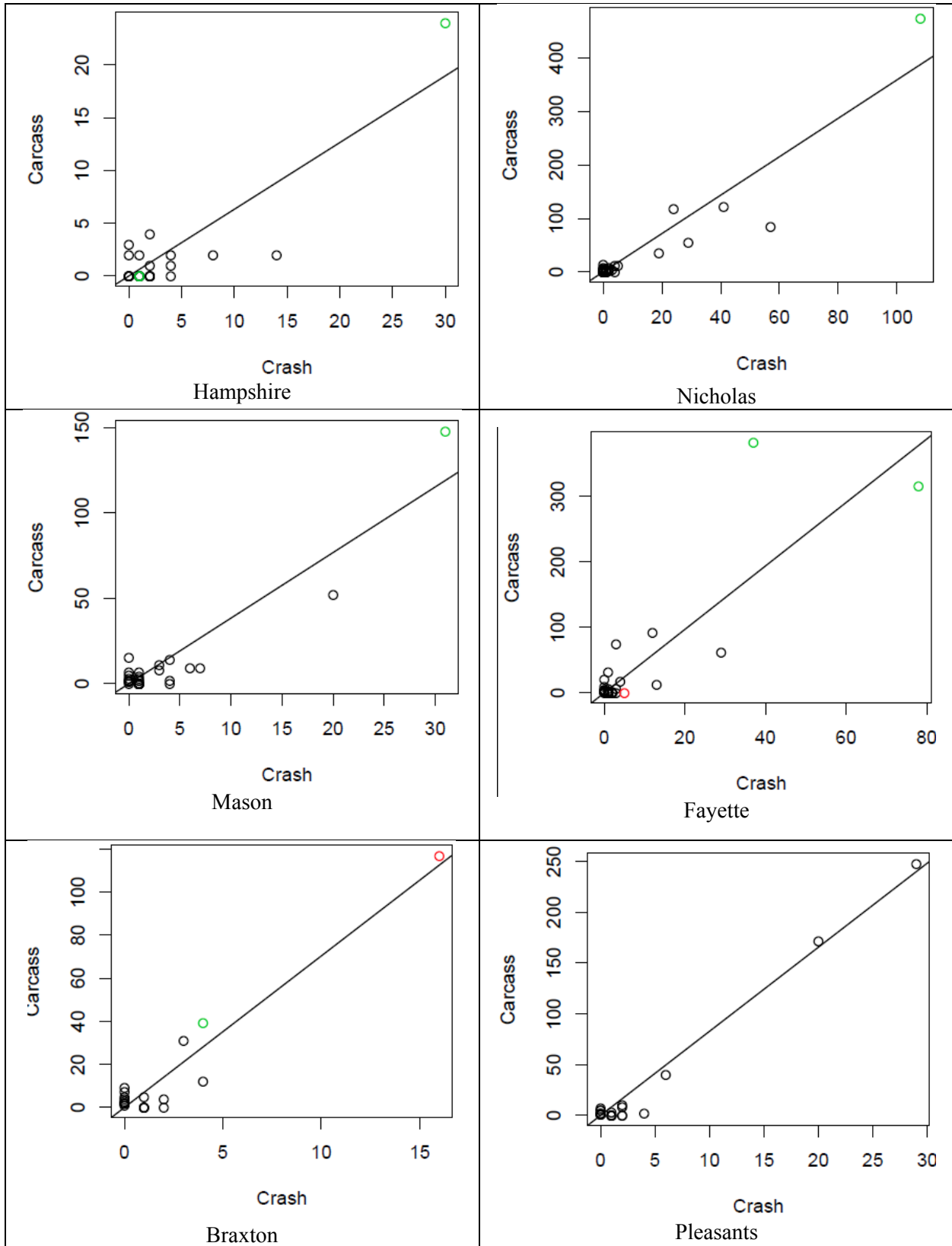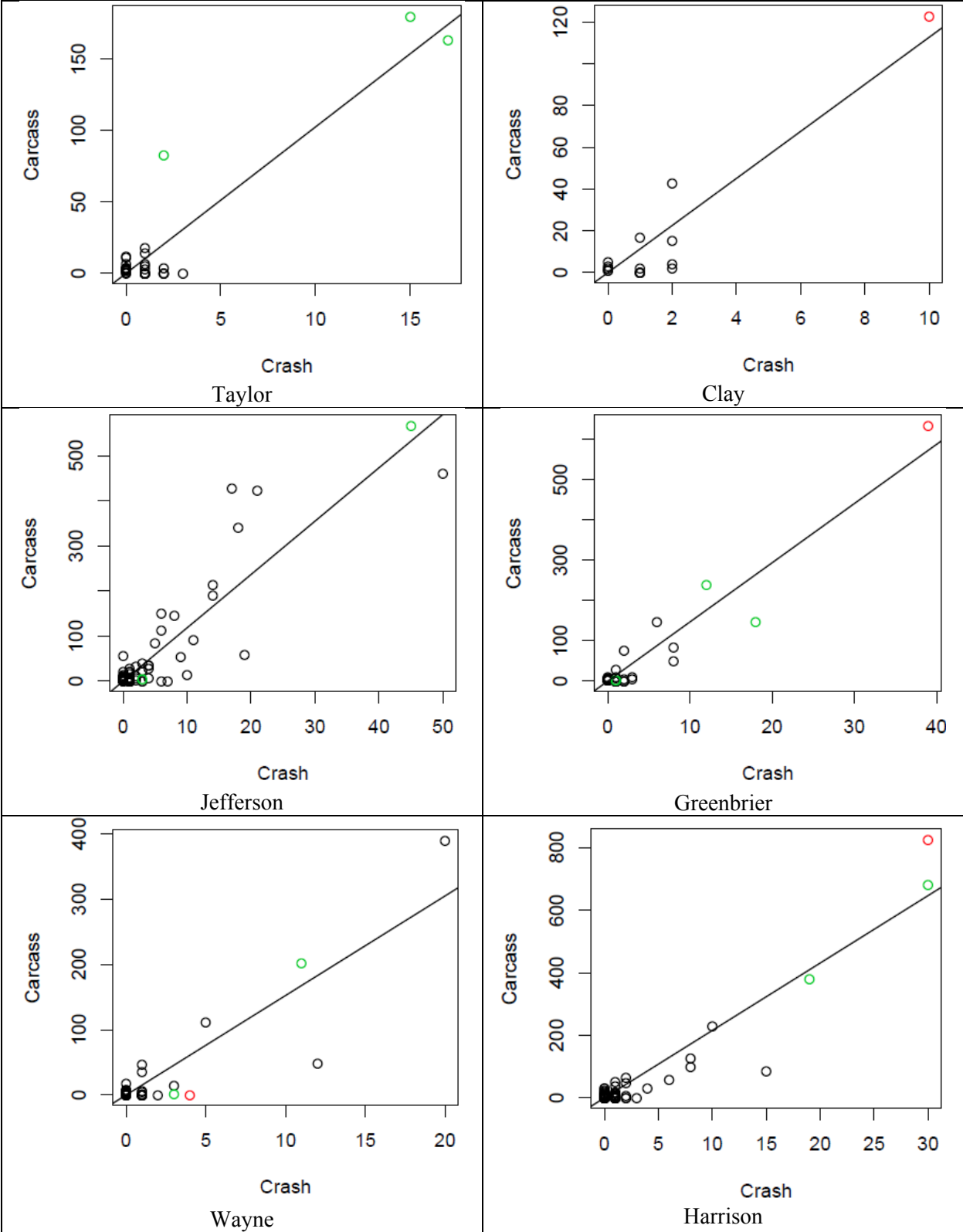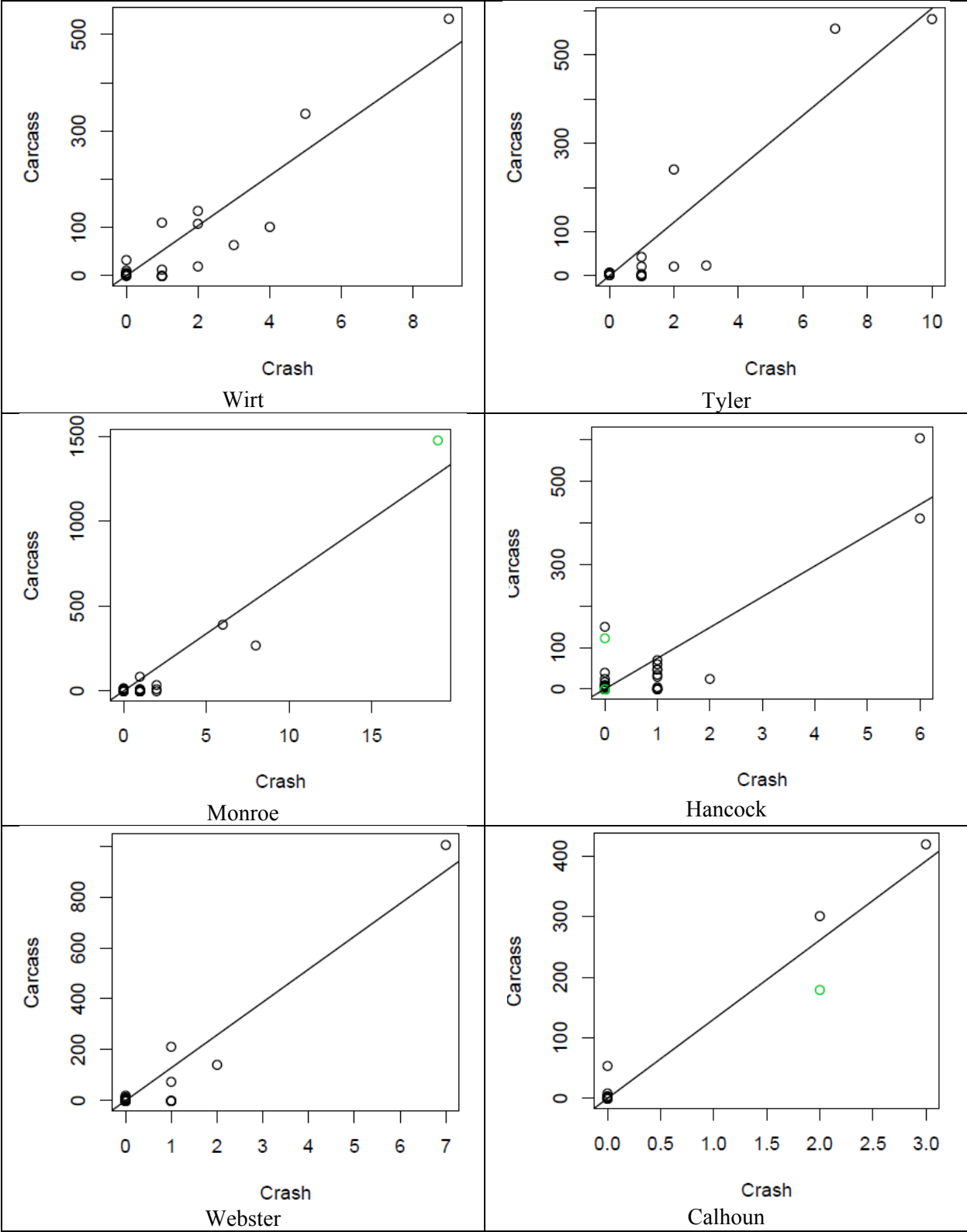
APPENDIX I.   <u>**ARCGIS DATA PROCESSING**</u>

<u>Block statistics (Raster):</u>

1. Create a buffer of 200 meters for each road segments. The land-use type of an area, which the road segment travels through, is determined by the most common land cover within the 200 meters buffer.

2. Loop process through each segment:

    a. Clip NLCD (National Land Cover Dataset) to a road segment's buffer. The result is a segment_NLCD raster.

    b. Look at the segment_NCLD raster table, we will see two fields: Value and Count

        i. Value represents for the type of land cover at a certain cell in the raster

        ii. Count is a number of cells that has the same value in a whole raster

    Discussion: we want to pick the "Value" that has the most "Count" (or the most common land cover type which a road segment cut through).

    Process:

    Count, Value are both integer and Value is always below 100. Therefore, the comparison of "New Count" (equal to Count + Value/100) is similar to the comparison of Count. The "New Count" allows us to pick Value with the highest Count and still represents the Value (land cover type) in its decimal part. For example: 100.11 means that Value of 11 has 100 Counts (or there are 100 pixels have the value of 11).

    c. In ArcGIS, we add a new field for "New Count" and calculate it based on following equation: "New Count" = Count + Value/100

    d. Use statistics tool to pick out the highest "New Count" of the segment_NCLD and write it to a .csv file. Each segment_NCLD raster will have 2 records, ID of a road segment and "New Count", in the same row.

3. Move to next segment by loop process

The output of block statistics model is a .csv file (able to read as an excel file) which includes two columns and multiple rows. One column is a road segment ID which will be used to link the .csv table back to road segment features in ArcGIS. The other column is "New Count" which will be separate later in ArcGIS to achieve the land cover value (it is the most common land cover value of a segment).

Average Sharing (Vector):

(Apply for AADT assignment)

Overview: A road segment may share its part with several AADT segments with different AADT values (2 futures dataset actually overlap on each other). We want to assign a single AADT value for the road segment according to these AADT values and the length of sharing parts.
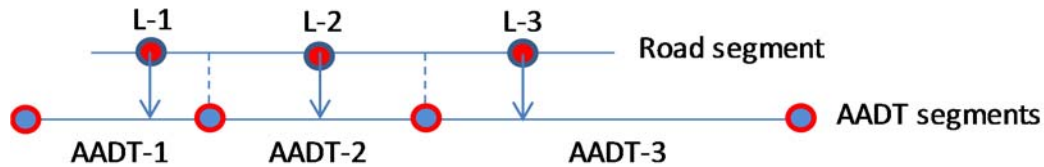
The equation to calculate the road segment's AADT is:

$$\text{AADT} = ((\text{AADT-1} * \text{L-1}) + (\text{AADT-2} * \text{L-2}) + (\text{AADT-3} * \text{L-3})) / (\text{L-1} + \text{L-2} + \text{L-3})$$

With:

L-1, L-2, L-3 : smaller parts of a road segment corresponding to shares between a road segment and AADT segments => L-1 + L-2 + L-3 = L (length of a road segment)

AADT-1, -2, -3 : relative AADT values of AADT segments 1, 2, and 3

Process:

1. Trim a road segment into smaller part in corresponding to shares between it and AADT segments.
   a. Convert vertex of AADT segments into point (both ends: start and end point)
   b. Trim a road segment by AADT end points => a road segment turn in to three smaller segments (L-1,-2,-3) which still keep the original road segment ID.
2. Assign AADT values for all small road segments
   a. Add "Length" field to the road segment layer (now contain small segments) and calculate segment length
   b. Convert a road segment into point (each point represents a small road segment). The output is a point layer with all attributes as the road segment layer.
   c. Spatial join AADT segments to the point layer to achieve AADT value for the points
3. Calculate average AADT by equation above
   a. Add "AADT_Length" field to point layer and calculate following value:
      AADT_Length = AADT * Length
   b. AADT and Length are both achieved from previous processes.
   c. Summary point table by road segment ID, use SUM with AADT_Length field.


Appendix 275

By the end of this process, we have a summary table that contains the sum values of AADT*Length of all smaller segment sharing the same original segment ID [call Sum(AADT*Length)]. This is the numerator of the equation.

d. Relate the original road segment attribute with the summary table by ID, and add a new field for average AADT values. An average AADT equals to Sum(AADT* Length)/segment Length

Majority Sharing (Vector):

(Apply for Speed Limit – SPL assignment)

Overview: A road segment may share its part with several SPL segments with different SPL values (2 futures dataset actually overlap on each other). We want to assign a SPL value of the feature with share the longest part with the road segment.
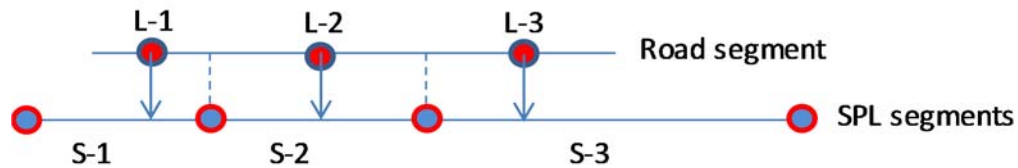
Process:

1. Same as Average Sharing method
2. Same as Average Sharing method until the points get SPL values.
3. Pick SPL value with the longest shared segment.
   a. Create a new field "ID_SPL" = ID + "_" + SPL
   b. Summary "ID_SPL", use SUM for segment length, average for ID (equal to segment ID), average for SPL – Table 1
   c. Create "ID_Length" field = ID + "_" + Length
   d. Summary "ID_SPL", use MAX for SUM segment length (from previous process), average for AVE_ID (average ID from previous process) => the ID remains the same. – Table 2
   e. Create "ID_Length" field = ID + "_" + Length
   f. Relate Table 2 with table 1 by "ID_Length" to achieve SPL value
   g. Link table 2 (which has segment ID and SPL value) back to segment layer