A LINEAR REFERENCING ANALYSIS OF TRAFFIC INCIDENTS AND LAND COVER CHANGES: A CASE STUDY FROM CULPEPER, ORANGE, AND SPOTSYLVANIA COUNTIES, VIRGINIA

by

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Geographic and Cartographic Sciences

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at George Mason University

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DEDICATION

I would like to dedicate this work to my wife, Tammy, and my children, JC and Andrew for enduring the lengthy process that has resulted in this work. Working on a Master's Thesis while working a full time job (which is located an hour and a half from your home) and trying to spend enough time with your family is a difficult task. I would just like to say thank you all so very much for your patience and understanding and just plain tolerating me through the whole process. I know it has not been easy for you all and I thank you.

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I am also thankful to the SANET team at the Center for Spatial Information Science at the University of Tokyo and especially Dr. Atsu Okabe for timely assistance with my questions when completing my analysis. I think this work has benefited greatly from the use of the SANET program.

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LIST OF ABBREVIATIONS

Commonwealth of Virginia Department of Motor Vehicles	DMV
Land Use/Land Cover	LULC
Linear Referencing System	LRS
National Oceanic and Atmospheric Administration	NOAA
Spatial ANalysis on a NETwork	SANET
Traffic Engineering Division	TED
United States Geological Survey	USGS
Virginia Department of Transportation	VDOT

ABSTRACT

A LINEAR REFERENCING ANALYSIS OF TRAFFIC INCIDENTS AND LAND COVER CHANGES: A CASE STUDY FROM CULPEPER, ORANGE, AND SPOTSYLVANIA COUNTIES, VIRGINIAA LINEAR REFERENCING ANALYSIS OF TRAFFIC INCIDENTS AND LAND COVER CHANGES: A CASE STUDY FROM CULPEPER, ORANGE, AND SPOTSYLVANIA COUNTIES, VIRGINIA

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George Mason University, 2013

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Traffic injuries and deaths are a sobering reality on roads throughout Virginia and the United States. Numerous traffic incident studies have been conducted focusing on the spatial distribution and clustering of the identified locations; however, many of these studies do not take into account other environmental factors that change over time (i.e. land cover and site characteristics) and that may have an effect on the number of incidents. In this research, a linear referencing and spatial statistical analysis is performed to identify correlations between changing land cover patterns, site characteristics, and traffic incident patterns along travel corridors within Culpeper, Orange, and Spotsylvania counties in central Virginia. Traffic incident data from 1990 to 2007 and land cover data was referenced to the road network to compute changes in distribution of incidents over the 18 year period. It should be understood that land cover

does not directly cause traffic incidents; rather the adjacent land cover is one of several factors that play a role in distracting drivers or increasing traffic volumes. The results show an increase in the number of incidents occurring within suburban and urban areas and a small increase in the overall fatally rate. In addition, the number of incidents in agricultural and forested land cover areas steadily increases over the time period, as well; however, the fatality rate decreases over time. By understanding the relationship between land cover changes, site characteristics, and traffic incidents, it is hoped that this information can be used in conjunction with traffic and land use planning to either prepare for future land use changes or to identify problem areas that may lead to increased traffic incidents.

INTRODUCTION

Traffic injuries and deaths impact nearly everyone and are a sobering reality on roads throughout Virginia and the United States with an average of 903 traffic related fatalities per year in Virginia (1990 to 2011) and a high of 1,071 fatalities in 1990 (DMV 2010, 2013). Over the past five years (2007-2011) traffic fatalities have declined to a twenty-one year-low, 740 in 2010; however, fatalities have increased to 756 in 2011 (**Figure 1**). In central and northern Virginia, commercial and residential development began dramatically transforming the rural countryside to an urban and suburban landscape during the mid-1990s. In Culpeper, Orange, and Spotsylvania counties, the population growth has exceeded 50% over the past twenty years (**Table 1**) with Spotsylvania and the City of Fredericksburg (combined) nearly doubling over the same time period (US Census Bureau 1990; 2000; 2010). With population growth, there is an increase in the number of vehicles, the number of daily commuting and shopping trips, and -- unsurprisingly -- the number of traffic incidents. In addition, there is a decrease in the forested and pastoral landscape which is replaced by shopping centers and moderate- to high-density residential developments. Transportation agencies attempt to understand why and where incidents are occurring so that the roads may be made safer for the traveling public (Li and Zhang 2008). One set of methods that can inform this type of research is linear referencing.

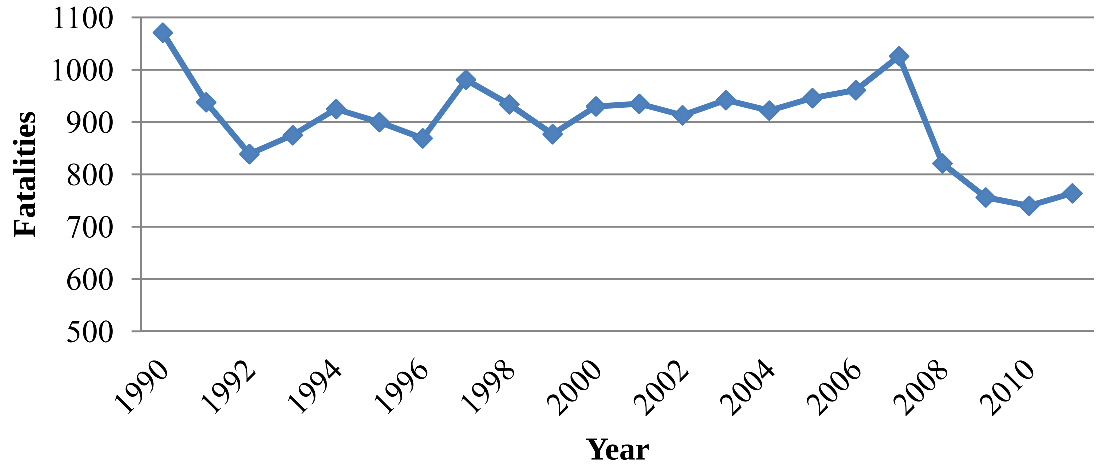

Figure 1. Commonwealth of Virginia Traffic-Related Fatalities, 1990 to 2011 (VDOT-TED 2007; DMV 2011) .

Table 1. Population Growth within Study Area from 1990 to 2010 (US Census Bureau 1990, 2000, 2010).

County	1990 Population	2000 Population	2010 Population	Percentage Growth
Spotsylvania	76,430	109,674	146,683	91%
Culpeper	27,791	34,262	46,689	70%
Orange	21,421	25,881	33,481	56%
Total	125,642	169,817	226,853	81%

Since the late 1990s, linear referencing has become a popular tool for conducting analysis of features along a network, especially road networks. State transportation agencies maintain a large amount of data that is referenced to the road network. This referencing system allows the user to measure the location of events based on its distance from the start node of an individual segment, or from other significant points on the network. This is important because there are numerous different ways to reference a point on the earth's surface, i.e. address, longitude/latitude, UTM coordinates; however, not all are easy to

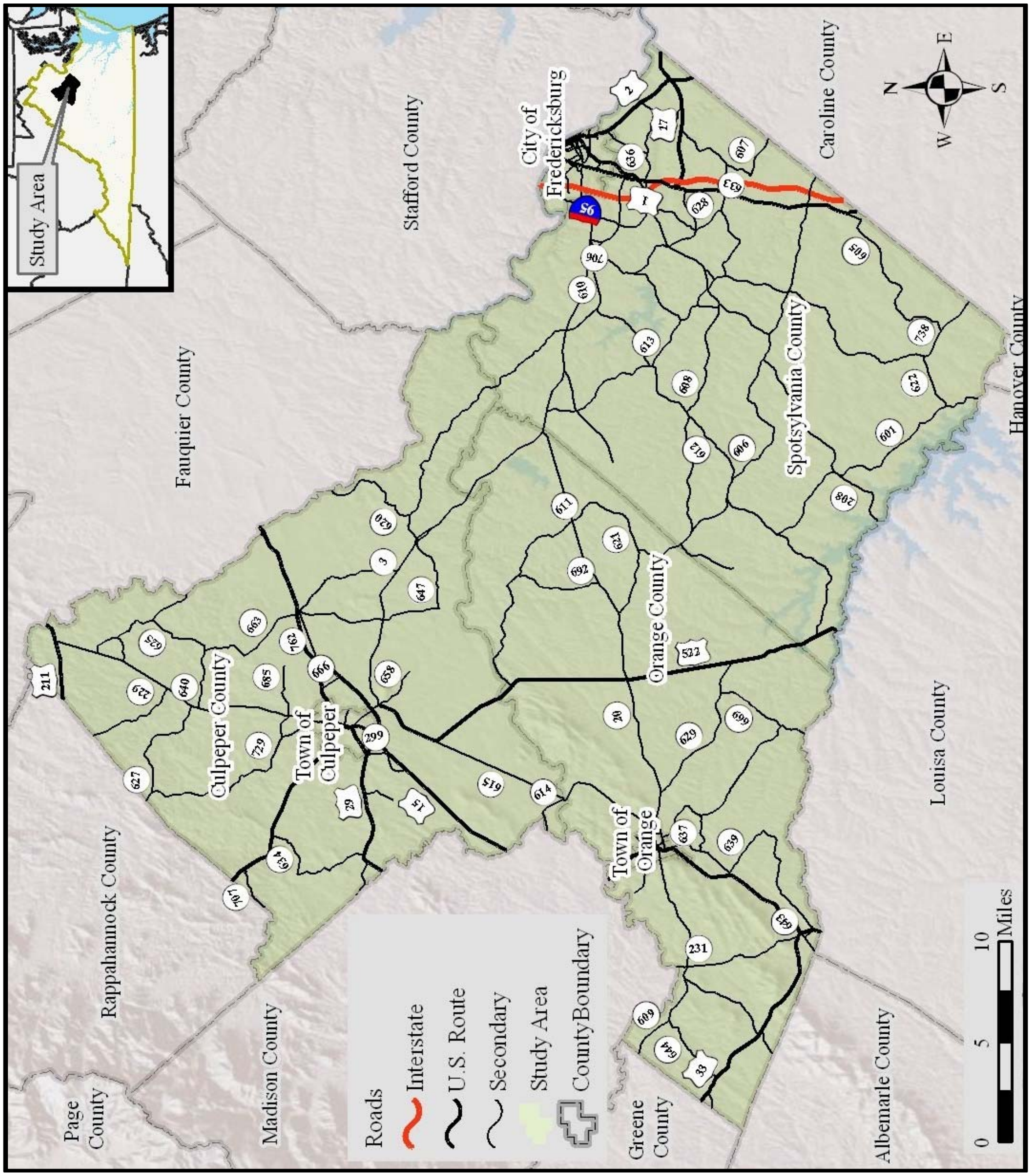

Figure 2. Location of the Study Area and Major Roads.

relate back to the real world locations. A Linear Referencing System (LRS) provides a datum upon which multiple variables can be referenced, and allows for spatial analysis of both spatial and non-spatial data in a GIS program. Point, polyline, and polygon data can all be symbolized along the linear reference system (Curtin, Nicoara, and Arifin, 1997; Durduran 2010a; Graettinger et al. 2009; Hallmark et al. 2003; Kiel and Pollack 1998; Kiel et al. 1999; Noronha and Goodchild 2000; Vonderohe and Hepworth 1997). For this project, the use of the linear referencing system will allow for land cover data and site characteristics to be analyzed with the locations of the reported traffic incidents. Curtin, Nicoara, and Arifin (2007) lay out a systematic method for setting up and utilizing a linear referencing method that will establish the basic methodology for this segment of the proposed research.

It is hypothesized that changes in land cover along the road networks, i.e. from rural to suburban or urban, will lead to an increase in the number of traffic incidents throughout the study area; however, there will not necessarily be an increase in the severity of incidents resulting in fatalities. With increased traffic and populations, the traffic incidents will result in fewer fatalities within these residential and commercial areas. It is expected that the increased populations will lead to an increase in the fatality in the rural agricultural and forested areas of the counties. A linear referencing system will identify potential correlations between traffic incidents and land cover. This research proposes to identify site characteristics that may produce an environment conducive to higher rates of incidents along a segment of roadway. It is anticipated that the results may be useful in guiding road improvements and development along potentially unsafe travel corridors.

The following section identifies and discusses the previous research in the field of traffic incident analysis and prevention. Section 3 identifies the data to be used for this research and Section 4 outlines the linear referencing and spatial analytic methodology used for the current study. The results of the research are presented in Section 5 and show an increase in suburban/urban land cover leading to more incidents, but an overall lower fatality rate. Conversely, the decrease in incident rates in the rural countryside (forested and agricultural land cover) is accompanied by a higher fatality rate. The conclusions and future research are outlined in the final sections of this study.

LITERATURE REVIEW

Traffic fatalities are one of the leading causes of deaths across the globe and in the United States. According to the National Highway Traffic Safety Administration, traffic incidents are the leading cause of death of individuals ranging from age 4 to age 34 and ranked ninth overall for all age groups with 43,667 deaths in 2005 (National Highway Traffic Safety Administration 2005). Even with numerous safety advances in automobiles over the past 50 years, traffic incidents, fatalities and related-injuries are a major problem here in the United States and in many other countries (Li and Zhang 2008). In Virginia, the mission statement for the VDOT states that they "will plan, deliver, operate and maintain a transportation system that is safe, enables easy movement of people and goods, enhances the economy and improves our quality of life" (VDOT 2012). Safety is one of the key goals of any transportation agency and in addition to the overall mission statement the VDOT also has a Strategic Highway Safety Plan mission statement that goes one step further "[t]o save lives and to reduce injuries from motor vehicle crashes in Virginia through the integration of education, enforcement, engineering, and emergency response actions" (Virginia's Surface Transportation Safety Executive Committee 2005). In the interest of safety, numerous studies have been conducted on the spatial distributions of traffic incidents focusing on the locations of high numbers of incidents, fatalities, or injuries (Hot Spot Analysis), cluster analysis (Ripley's

K and network K-Function), and relationships of traffic incidents to environmental and social characteristics.

Traffic Incident Research

The majority of the research to date on traffic incidents focuses on hot-spot cluster analysis of the physical location of the incident, utilizing statistical methodologies to determine if the incidents are clustered, dispersed, or randomly distributed (Prasannakumar et al. 2011). The typical research methodologies include the empirical Bayesian Methodology (Aguero-Valverde and Jovanis 2008; Huang, Abdel-Aty, and Darwiche 2010; L Li, Zhu, and Sui 2007; Linhua Li and Zhang 2008; Mitra 2009; Saccomanno, Fu, and Roy 2001; Song et al. 2006), Hot Spot Analysis with Getis-Ord statistic (Erdogan et al. 2008; Gundogdu 2010; Prasannakumar et al. 2011), Kernel density estimation and K-means Clustering (Anderson 2009), comparison to the Poisson distribution (Hadayeghi, Shalaby, and Persaud 2003; Ivan, Wang, and Bernardo 2000; Khattak, Wang, and Zhang 2010; Ossenbruggen 2001), network distance-weighted clustering and subtractive clustering attribute weighting (Polat and Durduran 2011), and an analysis of spatial and temporal clustering compared to spatiotemporal clustering of traffic incidents (Eckley and Curtin 2012). However, many of these statistical methodologies rely primarily on the numbers (fatal incidents, injury incidents, and total incidents) without taking into account other environmental, social, and economic variables that may have an impact on the distribution of traffic incidents (Gundogdu 2010). A few of these studies do look at time of day, time of season, and weather-related factors (Durduran 2010b; Erdogan et al. 2008; Levine, Kim, and Nitz 1995a; Polat and

Durduran 2011; Quddus 2008; Sukhai et al. 2011; Wang, Quddus, and Ison 2011). However, almost all of these studies focus primarily on the urbanized city centers and the immediate surroundings.

In several studies, there appears to be a correlation between traffic incidents and other variables, such as proximity to urban, suburban, and residential areas. Prasannakumar et al. (2011), utilize the Moran's I spatial autocorrelation statistic, the Getis-Ord Gi* statistic, and point Kernel density estimation to identify an increase in traffic incidents during the monsoon season and in close proximity to religious and educational institutions (typically considered urban or suburban) in Turkey. Levine, Kim, and Nitz 1995a; 1995b) conducted an analysis of traffic incidents in Hawaii, focusing on the spatial distribution of the incidents in relation to urban and suburban areas and looked at differences based on the day of the week and time of day. The results show more concentrated incidents in the vicinity of urban areas during daytime weekday hours and a more dispersed spatial pattern in the suburban areas. The incidents are more dispersed and typically more severe during the nighttime hours and on weekends.

Most spatial pattern analysis relies on Euclidean geometry and planar space to locate the individual phenomena based on its linear distance to other phenomena. Planar space relies on shortest distance paths between any two points to determine the relationship and potential clustering (Yamada and Thill 2004). Ripley's K (Ripley 1976) is primary common method used to identify clustering of spatial patterns; however, Yamada and

Thill (2004) showed that Ripley's K over-detects cluster patterns of phenomena that occur over a network, as it will cluster points that may be close together but are on separate roads (i.e. city blocks). Traffic incidents, however, occur on or adjacent to the roads and therefore require a network distance to analyze spatial patterns. Okabe and Yamada (2001) introduced a modification of Ripley's K for use on spatial analysis in network space, called the network K-function. The network K-function was later included in the SANET tool box for use in ArcGIS (Okabe et al. 2010). One drawback of the network K-function is that it is a test of randomness versus clustering, yet, it does not have the capability to identify actual locations of the clustering, or hot spots (Yamada and Thill 2004:157).

The Effect of Land Cover on Traffic Incidents

There have been fewer studies focusing more directly on the association of land cover changes and the rise in traffic incidents in the vicinity of urban areas. Austin, Tight, and Kirby (1997) introduced methods aside from simple incident clustering, leading to identifying potential trouble spots where the land use type was urban. This research looked at a deviance measure to see if the addition of specific variables leads to a significant change in the number of incidents. In another study focused on Hawaii, the researchers looked at the relationship of land use, demographics, and socio-economic variables on traffic incidents (Kim and Yamashita 2002; Kim, Brunner, and Yamashita 2006; Kim, Pant, and Yamashita 2010). Hadayeghi, Shalaby, and Persaud (2003) attempted to predict the number of incidents that will occur in planning zones of Toronto, Ontario based on the relationship of the socio-economic, demographic, and other transportation network data. These studies focus on comparisons with the Poisson distribution and negative binomial regression to identify the clustering of accidents and then look at the site characteristics. In the case of the study in Hawaii, the majority of the accidents occurred in urban areas, and the researchers therefore decided to focus only on those urban areas. A spatio-temporal analysis system was created by Shaw and Xin (2003) using GIS to identify patterns in land use interaction with transportation networks.

The interaction between land cover changes and traffic patterns is a dynamic relationship. This research offers a systematic analysis to look at the relationship of changes in land cover with changes in transportation variables over time. Khattak, Wang, and Zhang (2010) explore the possible association of land cover and the geometrics of the road with traffic incidents and secondary incidents as a result of driver distraction due to the original incident. The authors used negative binomial regression to model the frequencies of the traffic incidents, Kernel density analysis to identify hot spots, and the Chi-square test to determine if there is an association between the initial incidents and the secondary incidents. The results show a correlation between the frequency of traffic incidents in relation to the tested variables (including nearness to a school or larger shopping centers). Ivan, Wang, and Bernardo (2000) compared distributions to the Poisson regression models to analyze and predict traffic incidence based on multi- vs. single-vehicle, traffic densities, land cover, and time of day. The study shows a correlation between increased traffic and increased numbers of accidents and that increased numbers of entrances (i.e. driveways, parking lots, etc.) lead to more single-and multi-vehicle incidents. Another Hot Spot Analysis looked at the clustering of incidents based on kernel density estimation. The analysis also looked at the site characteristics of the hot spots to determine what might be the cause of the increase in incidents at each location, including time of year, land cover, and time of day (Erdogan et al. 2008). The authors used a Chi-square test to determine if the frequencies of accidents are significantly different and a Kernel Density estimation to identify clusters of accidents along the road network. With the results, site locations were analyzed and recommendations made to improve the safety of those areas seeing the most traffic incidents with fatalities and injuries.

Research Objective

All of the previous research identified in this literature review focuses on the urban and the suburban areas surrounding major cities, and with good reason since that is where the most incidents are occurring. However, as identified in a report from the U.S. General Accounting Office (2003), most of the fatal crashes in America are occurring on the rural roads. While the research discussed above adds important information about traffic incidents in urban and highly residential areas, none of the research examines the more rural areas where the traffic incidents may not be as concentrated, but typically result in more fatal incidents. The current research focuses on a rural-suburban area of central Virginia and looks to identify problem areas based not only on suspected clustering of a high number of accidents, but clustering of fatal accidents. This research is unique in that it will attempt to identify a pattern of traffic incident change over an 18-year time span associated with the change in the surrounding land cover over that time, associated with the sprawl of commercial and residential development into the countryside. The majority of the previous research focuses their studies on a narrower time period, typically less than four years.

DATA

This project will use data primarily from the Virginia Department of Transportation, the Commonwealth of Virginia Department of Motor Vehicles, the United States Geologic Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). All data are freely available to the public and most is accessible through each of the respective agency's websites.

Land Use/Land Cover Data

Land Use/Land Cover (LULC) data was acquired from NOAA's Coastal Change Analysis Program (C-CAP) and images from 1992, 1996, 2001, and 2006. The imagery is confined to the coastal areas of the United States. All imagery was acquired from the Landsat Thematic Mapper (TM) at a spatial resolution of 30 meters. The 1992 data is used as a baseline with the subsequent imagery to identify changes over time from 1992 to 1996, 1996 to 2001, and 2001 to 2006. The NOAA imagery excludes the far western portions of Culpeper and Orange counties (**Figure 3**) and was only included in the overall project area discussions.

For this study, the LULC data was divided into four general categories: Suburban/Urban, Agriculture, Forest, and Water. Each of the original NOAA categories was combined into one of the four categories (**Figure 4**). Due to the limited urban areas, both

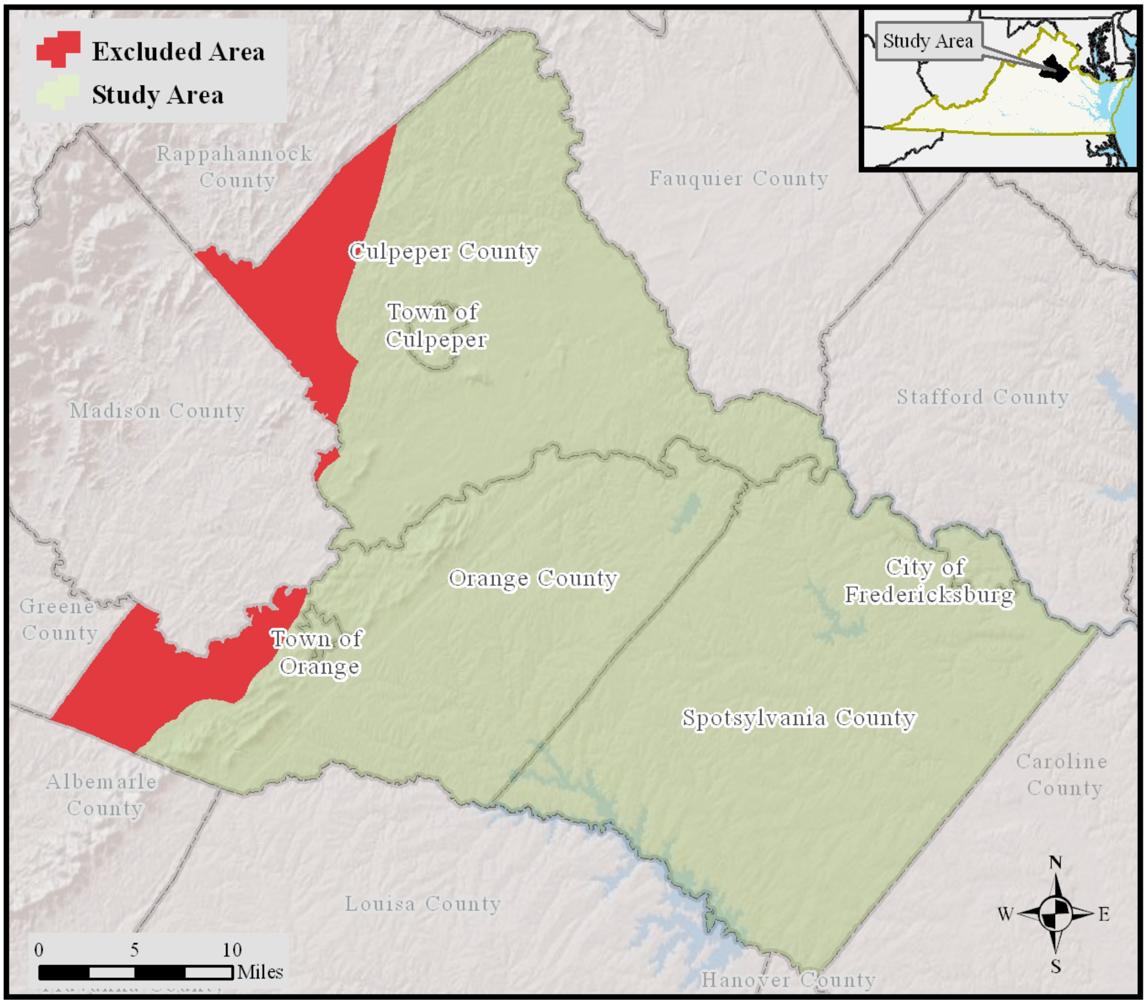

Figure 3. Detail of Project Area Depicting the Western Portion of Culpeper and Orange Counties not included in the Land Cover Data (NOAA 1992, 1996, 2001, 2006).

Suburban/ Urban	Agriculture	Forest	Water/ Wetland
•Developed, Open Space •Developed, Low Intensity •Developed, Medium Intensity •Developed, High Intensity •Bare Land	•Pasture/Hay •Cultivated Crops •Shrub/Scrub •Grassland/ Herbaceous	•Deciduous Forest •Evergreen Forest •Mixed Forest	•Open Water •Palustrine Forested Wetland •Palustrine Scrub/Shrub Wetland • Palustrine Emergent Wetland

Figure 4. Aggregation of Land Cover Categories (NOAA 1992, 1996, 2001, 2006; United States Geologic Survey 1992; 2001; 2006).

suburban and urban categories were combined into one category. The Suburban/Urban category included pixels identified as developed and bare land as most of the bare land is likely associated with clearing activities for future development. The Agriculture category included Pasture/Hay, Cultivated Crops, Shrub/Scrub, and Grassland/Herbaceous pixels. The Shrub/Scrub pixels was included in the agricultural category assuming that the shrub/scrub lands might be fallow agricultural fields that have not been used in the agricultural rotation for several years. The Forest category included all three categories labeled as different types of forest. The Water/Wetland included the open water and all the identified wetland pixels.

The original raster imagery was resampled to smooth the imagery with the Resample tool in ArcGIS. Upon initial review of the imagery, the roads were identified as low to medium intensity development (**Figure 5**), which would be problematic in the analysis, as incidents occurring on a rural secondary road may be identified as Suburban/Urban land cover. In order to smooth out the land cover pixels along the road network, pixels intersecting the road centerline were reclassified as “No Data”. The land cover image was resampled at a 90-meter resolution filling in the areas with “No Data” with the majority of the surrounding pixels. Finally, the data was smoothed at a 400 m resolution to get a representative view of the overall adjacent land cover attributes along the road network.

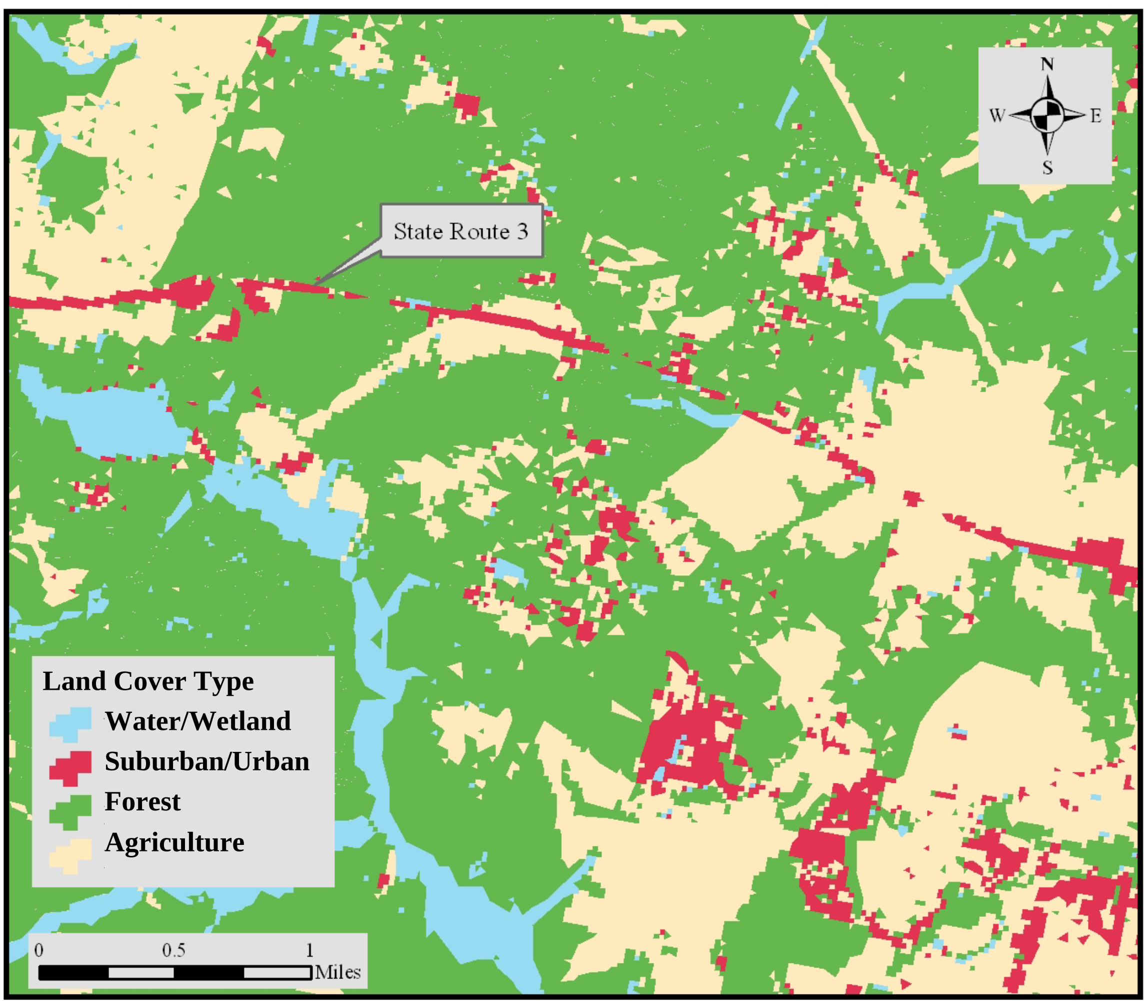

Figure 5. Detail of the NOAA Land Cover Data (NOAA 1992).

Traffic Incident Data

This research will look at traffic incidents occurring over an eighteen year time period (1990 to 2007) in Culpeper, Orange, and Spotsylvania counties. Within the study area, there were 38,879 incidents reported during the time period resulting in 542 fatalities and 22,971 injuries, averaging 30.1 fatalities and 1,276.2 injuries per year (**Table 2**). The traffic incident data was acquired from the Virginia Department of Transportation Traffic Engineering Division (VDOT-TED 2007). The traffic incident data includes information about the incident location, number of fatalities, number of injuries, type of incident, and weather and pavement conditions at the time of the incident. The traffic incident data is compiled by the Commonwealth of Virginia Department of Motor Vehicles (DMV) and the VDOT-TED generated the spatial database information for the traffic incidents based on the information contained in the traffic incident reporting that resulting in a fatality or

Table 2. Number of Fatalities, Injuries, and Non-Injury Incidents within the Study Area.

Incident Type	1990 - 1995	1996 - 2001	2002 - 2007	TOTAL
All Incidents	10,139	13,367	15,373	38,879
Incidents w/ Fatality	124	167	161	452
Number of Fatalities	146	200	196	542
Incidents w/ Injuries	4,364	5,373	5,402	15,139
Number of Injuries	6,786	8,205	7,980	22,971
Incidents w/ No Injuries	5,775	7,994	9,971	23,740

Source: (DMV 2010; VDOT-TED 2007)

injury or property damage greater than $1,500. The incident locations have an error of +/- 50 to 500 feet (VDOT-TED 2007). Incident locations within 0.1 mile (528 ft) have previously been determined to sufficient for traffic incident analysis on macroscopic study area (Li and Zhang 2008, 66; Li, Zhu, and Sui 2007, 278). Additional traffic incident data and statistics were also retrieved from Virginia's Department of Motor Vehicles (DMV 2010). The DMV data includes state-wide statistics about the number of fatalities, the number of injuries, and the death rate on Virginia roads compared to the United States.

The traffic incident data were divided into three 6-year time periods (1990 to 1995, 1996 to 2001, and 2002 to 2007), corresponding to the land cover data. The time period of 1990 to 1995 corresponds to the 1996 Land Cover image, as during this time the study area was just beginning to see large-scale development late in 1995 and 1996. The 2001 Land Cover image corresponds to the 1996 to 2001 time period where the majority of land cover change to suburban and urban areas occurred. Finally, the 2006 Land Cover image corresponds with the 2002 to 2007 time period, which precedes the downturn in the housing development market in the project area.

Road Network and Linear Referencing System

The VDOT road network is a linear referenced data set based on the Highway Traffic Record and Inventory System (HTRIS). The road network has been dynamically segmented where the number of lanes changes, at intersections with other roads on the network, or where at least one characteristic of the road changes. The measurement along the road network is based on the Official State Mileage (OSM), which is derived from HTRIS nodes and junctions. The VDOT's linear referencing system also includes information on speed limits, pavement width, number of lanes, shoulder width, and median width (VDOT-TED 2007). The road characteristics are based on the current road conditions and unfortunately do not represent the actual characteristics that may have been present during the 1990s or early 2000s. However, the majority of the new development results in new roads, so the data primarily limited in an accurate representation of those roads that may have been improved during the study time period.

The purpose of the linear referencing system used in the current study is to display traffic incident locations, site characteristics, and land cover as it changes through the three time periods. More importantly, the linear referencing allows overlay and spatial analysis of land cover and other highway variables along the road network. Since the majority of the roads in the project area are rural, a simple centerline road network will be the basis of the linear referencing system and will be segmented where the route number changes or where one of the other road characteristics change, i.e. shoulder width, surface width, speed limit, or median width. The measures along the route will be in miles and each event layer (i.e. Traffic Incidents and Land Cover) will be located along the routes. Linear referenced event layers for land cover and traffic incident locations were created with the Linear Referencing tools in ArcGIS and overlays were performed to identify those segments that changed over the three time periods and the number of incidents within each of the areas of change in land cover (ESRI 2011).

Aerial Imagery

Aerial imagery from 1994, 2001, and 2006 was used to identify changes in the roads corresponding to the three time periods. An overlay of the road network and the 1994 USGS digital orthophoto quadrangles were reviewed to identify and remove those roads that were not constructed prior to 1994. Similarly, another overlay was created with the road network and the 2001 and 2006 aerial imagery from the Commonwealth of Virginia identify and remove those roads that had yet to be constructed prior to the date of the aerial image (USGS 1994, Commonwealth of Virginia 2002, 2006).

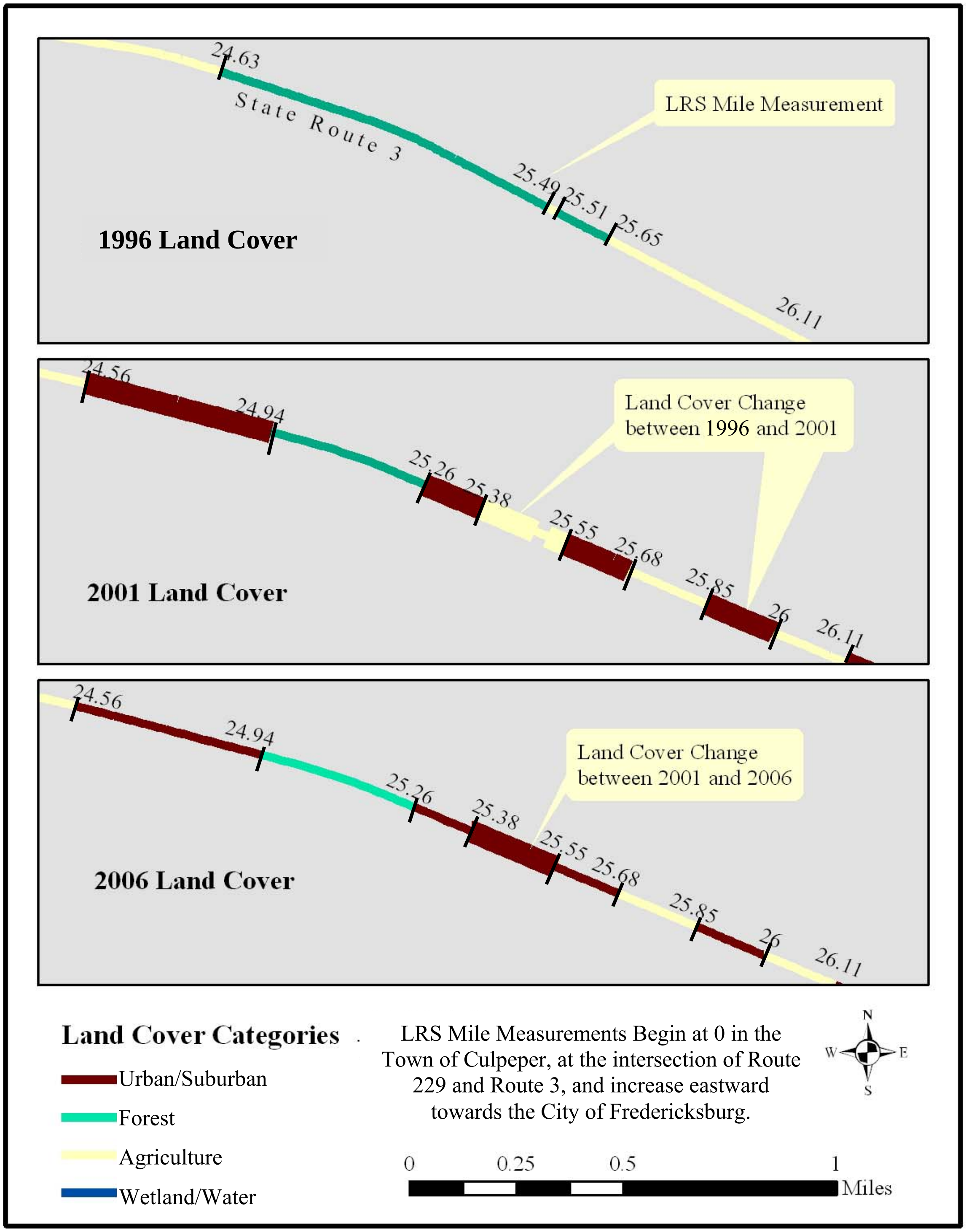

Figure 6. Linear Referencing Methods to Identify Change in Land Cover.

METHODOLOGY

The methodology will use the existing traffic incident data to identify land cover and road characteristics (i.e., lane width, speed limit) as variables that increase the chance for traffic incidents. As can be seen from the literature review, there are many methodologies that can be employed in the analysis of traffic incidents. For the current study, the methodology utilized includes creating the linear referencing system, deriving descriptive statistics, examining the data with the Chi-Square statistic, Multiple Regression Analysis, and analyzing clustering of fatalities with the Network K-Function in combination to identify changes in the patterns of traffic incidents in relation to the change in land cover over time. Prior to the analysis, the data required several steps of preprocessing in order to ensure consistency, the majority of which is discussed in the previous section (

Figure 7).

Linear Referencing System

The VDOT road network is the foundation for the analysis, with all the data being related to the road network, a detailed spatial analysis can be conducted. The LRS is based on the official state maintained road network, but also includes roads maintained by localities and some subdivision roads that have been accepted into state maintenance. Event layers were created along the road network for the Traffic Incidents (1990 to 1995,

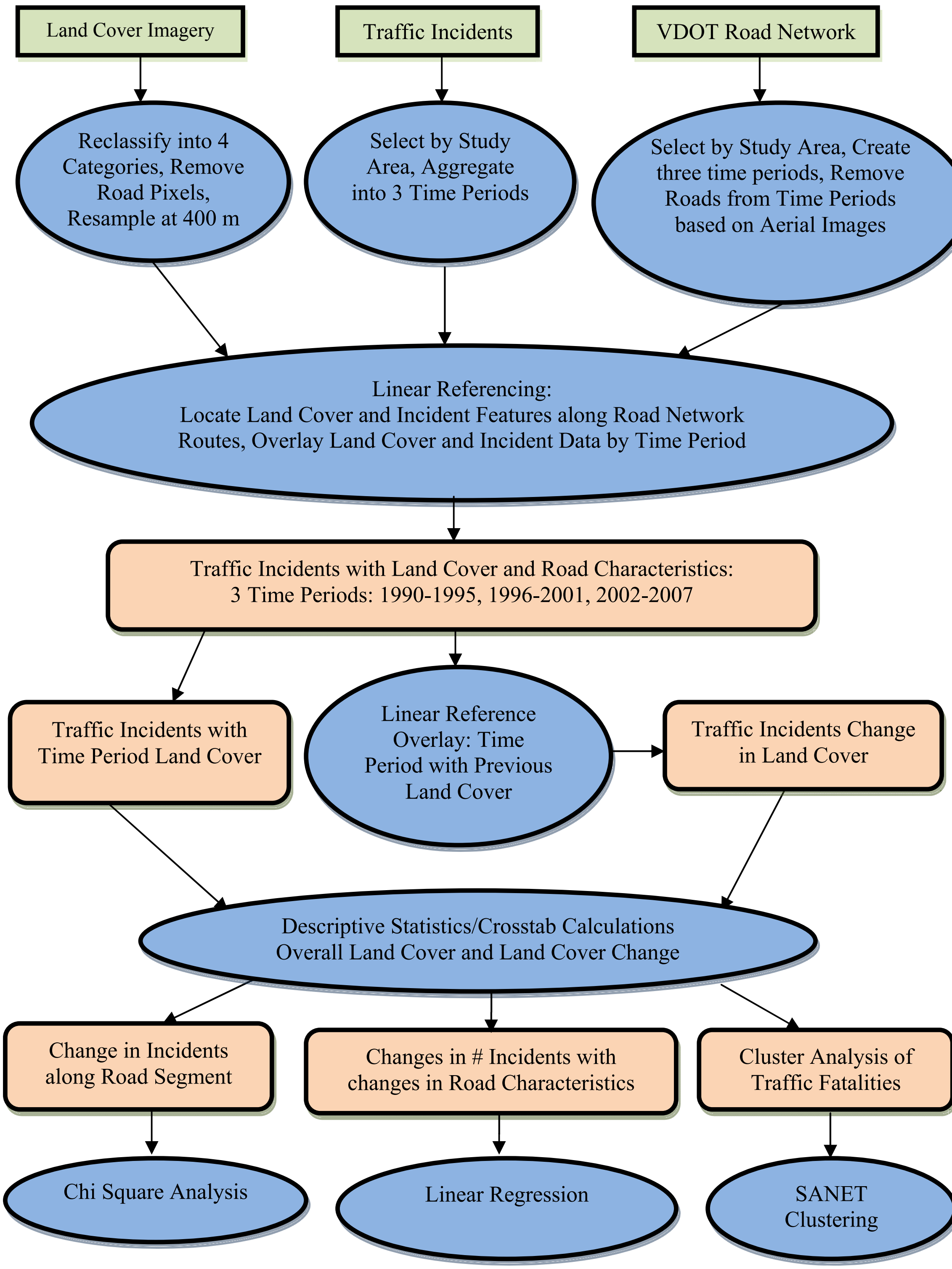

Figure 7. Methodology Flow Chart.

1996 to 2001, 2002 to 2007) and Land Cover data for each image date (1992, 1996, 2001, and 2006). An overlay of the traffic incident period with the corresponding image date (i.e. 1990 to 1995 with the 1996 image) generated a point layer identifying the incident location and the land cover information. The traffic incident layers and linear referenced data allowed for multiple descriptive statistics to be derived from the data and for spatial analysis of the change in land cover over time (See Tables in Results section). The land cover data in comparison with the LRS was used to determine which segments changed from one time period to the next (**Figure 8**). With these changed segments, the traffic incident data was selected to allow for statistical analysis focusing on the areas where the land cover has changed along the road segment between two time periods.

Descriptive Statistics

With tables and shapefiles generated through the linear referencing tools, cross-tab calculations were created to show the change in land cover acreage between the four land cover images acquired from NOAA (1992, 1996, 2001, 2006). The data included in the cross-tabulation tables for changes in land cover area includes overall totals by land cover, percentage by land cover, and change in percentage from previous year. Tables were also created to show the distribution of the different incident types (with fatality, with injury, no injury, and all incidents). These tables included similar information as the land cover change tables. Additional cross-tabulations were generated for the study area covered by the NOAA imagery (See Figure 3) focusing on the change in land cover as represented by the mileage along the road network between the three time periods.

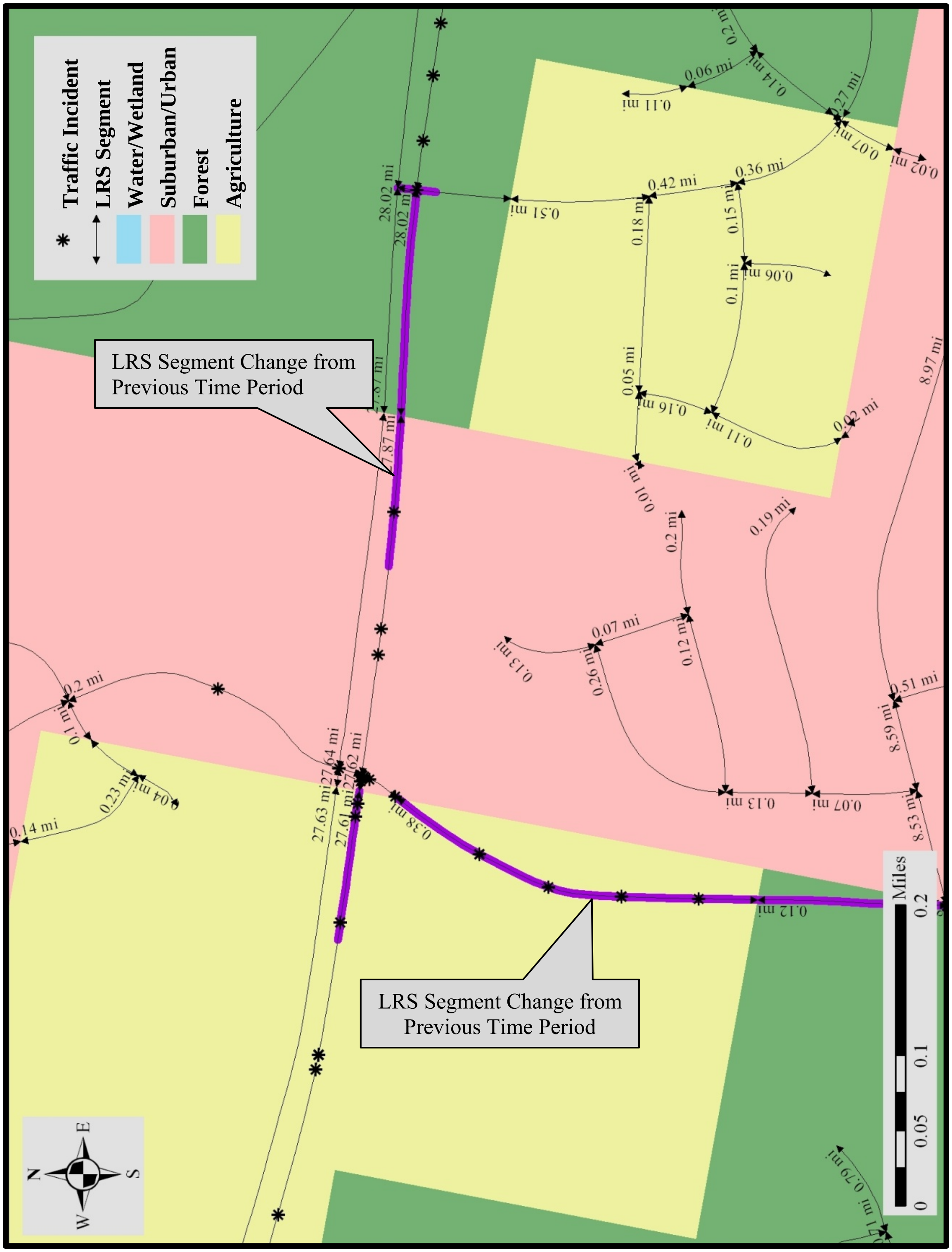

Figure 8. Detail of LRS Segments, Change in LRS Segments, and Traffic Incidents Depicting how the LRS is used to categorize each within the Underlying Land Cover Type.

Descriptive and spatial statistical methods have been used to identify patterns in the distribution of the traffic incidents in relation to land cover. Specifically, descriptive statistics were used to calculate the traffic incident rates for fatalities and injuries within each of the land cover categories for each of the time periods. The spatial statistics will identify patterns in the distribution of the traffic incidents in relation to land cover and changes in the land cover over time. The data was normalized by dividing each category by the miles of road present within the specific land cover or land cover change category and the road characteristic (i.e. 4 lane roads in Suburban/Urban areas or 4 lane roads in land cover from Forest to Suburban).

To get a general idea of the data, overall distributions for fatalities (**Figure 9**), injuries (**Figure 10**), and non-injury incidents (**Figure 11**) were derived by using the Point to Raster tool in ArcGIS. The data was aggregated into 600 meter square blocks, and the number of each variable within each block was summed. These figures depict the distribution of each variable over the 18 year time period and highlight several areas to further explore with additional statistical methods.

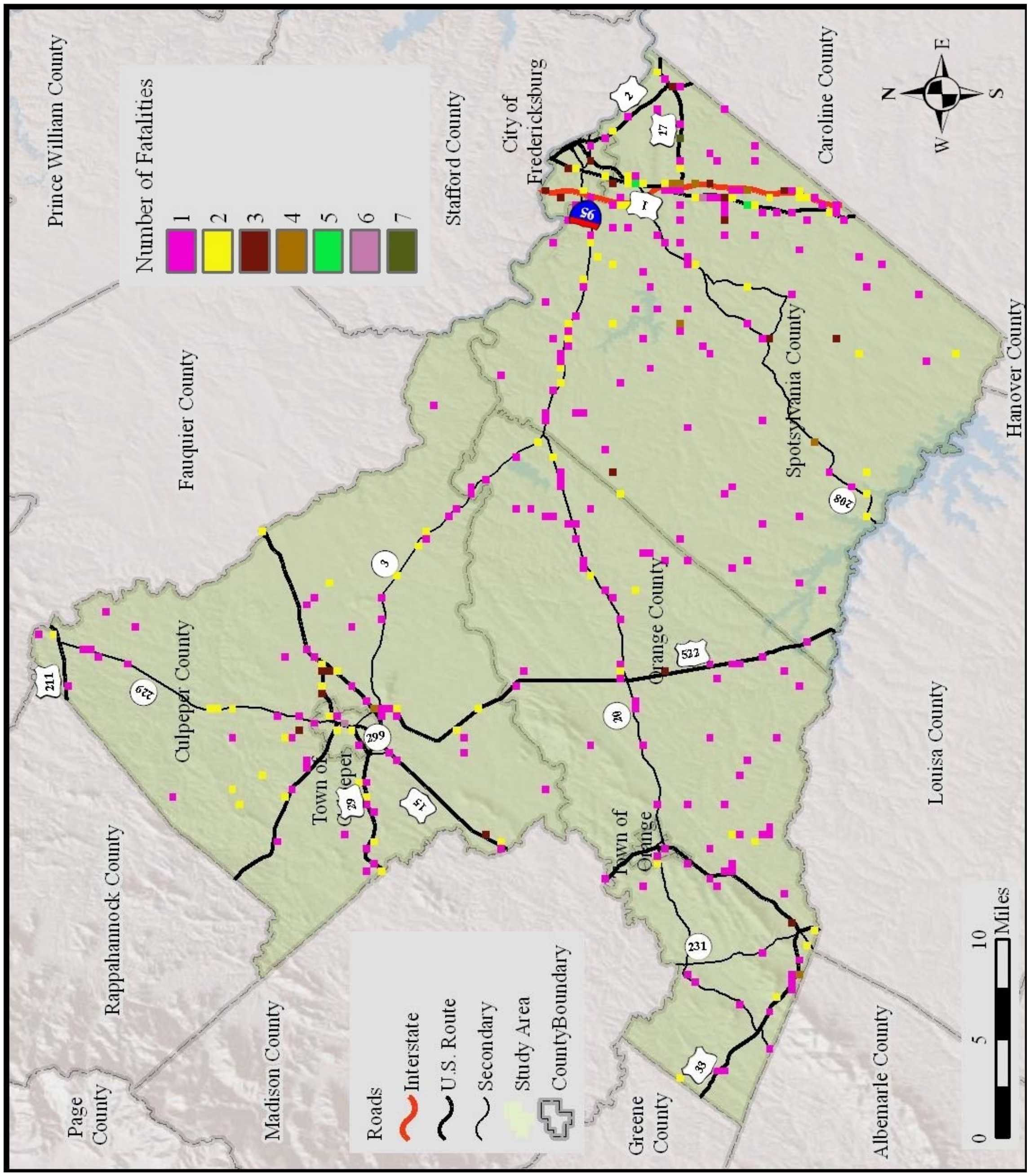

Figure 9. Distribution of Fatalities from 1990 to 2007 throughout the Study Area.

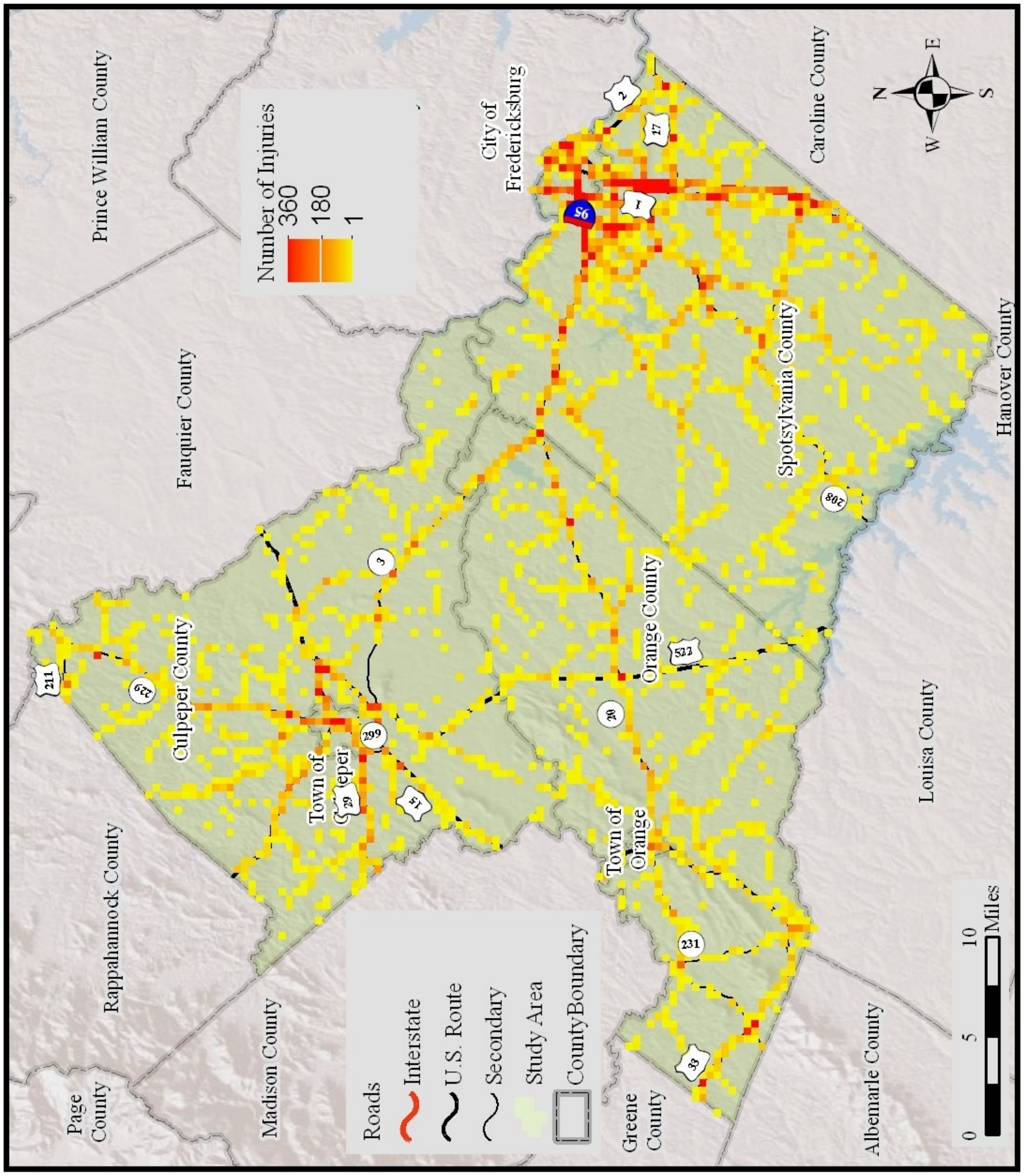

Figure 10. Distribution of Injuries from 1990 to 2007 throughout the Study Area.

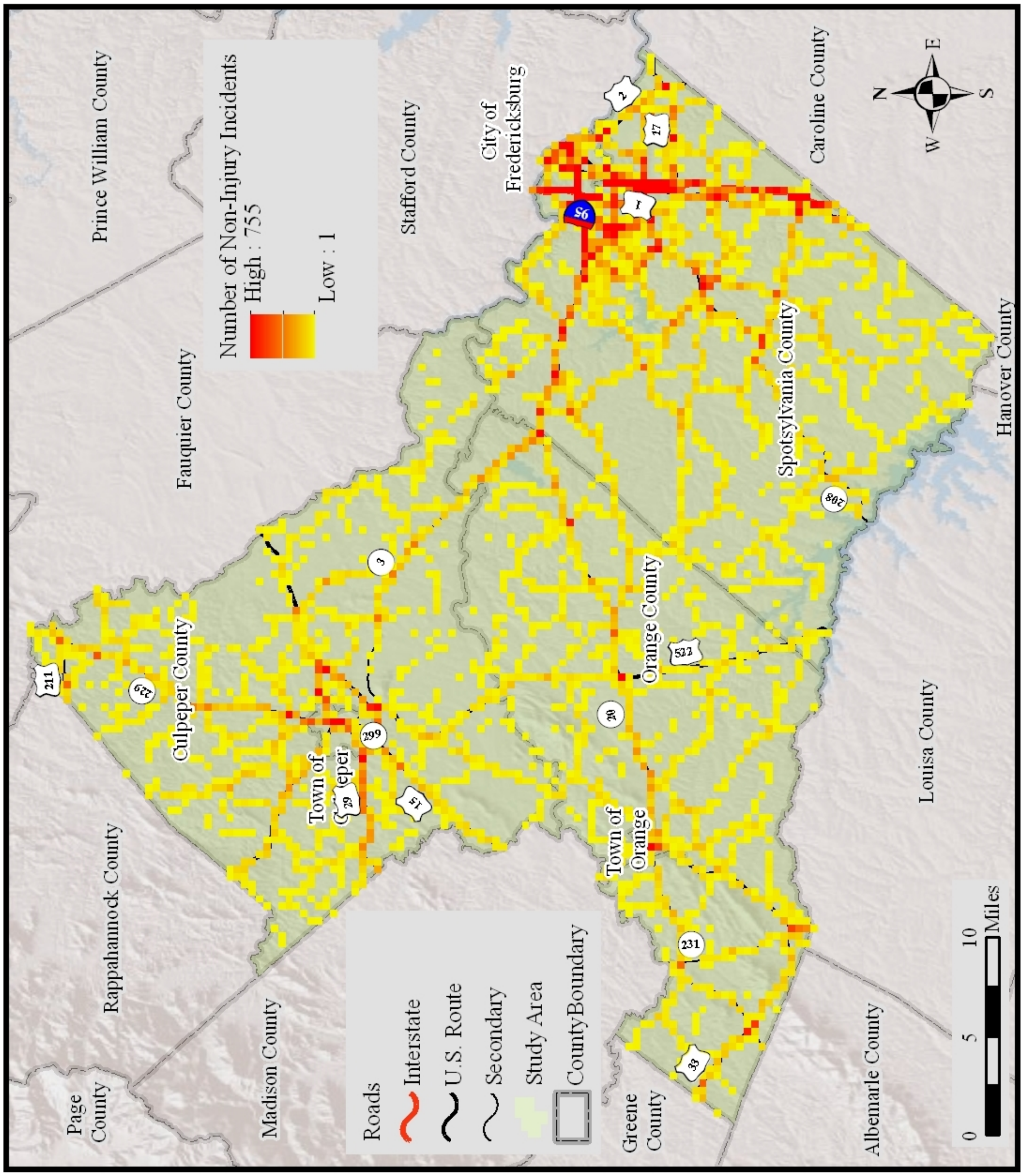

Figure 11. Distribution of Non-Injury Incidents from 1990 to 2007 throughout the Study Area.

Chi-Square Test Statistic

The Chi-Square statistic (X^2) is a method for evaluating the observed distribution (O_i) with respect to the expected distribution or relative frequency (E_i) for categorical values such as land cover (**Equation 1**). This statistic is used as a test for independence between the observed and expected values (Burt, Barber, and Rigby 2009:405-08). To begin the Chi Square Test, a null hypothesis (H_o) and an alternative hypothesis (H_a) are established. In the research presented here, those hypotheses are:

> H_o = the change in the number of incidents is statistically independent of the change in the land cover type.
>
> H_a = the change in the number of incidents is not statistically independent of the change in the land cover type. If the Chi-Square value is less than the critical value, the H_a hypothesis cannot be rejected and further studies would be required to determine the nature of the relationship.

Although, the Chi-Square statistic is often used to test the statistical significance of spatial relationships between multiple variables, there is no way to determine the direction or strength of the relationship between those variables (Berman 2007).

$$X^2 = \left[\sum_i \frac{(O_i - E_i)^2}{E_i}\right]$$

Equation 1. Chi Square Equation

The degrees of freedom (df), in the Chi Square statistic, accounts for the magnitude of the variables used in the analysis. In order to properly adjust for the number of independent variables, the Chi Square statistic uses:

$$df = (r-1)(c-1)$$

Equation 2. Calculation of Degrees of Freedom.

where r is the number of rows and c is the number of columns.

The variables used for the Chi-Square Statistic focus on the changing of the land cover type and the change in the number of incidents that occur within each particular land cover type. With the linear referencing system the road segments were identified as changing from one land cover type in 1996 to another type in 2001 (and between 2001 and 2006). The number of incidents on each road segment was also calculated with the linear referencing tools (locate features on road network). The land cover types in 1996 were located along the road network and this segmentation provided the basis for identifying the change in land cover types and the change in the number of incidents. The road segments were compared to the 2001 and the 2006 segments to determine which segments retained the same land cover and to identify those segments where a land cover change occurred.

The incidents on each road segment were calculated based on the 1996 road segment and the change from 1996 incidents to 2001 incidents. The change in incidents between 2001 and 2006 was also calculated similar to the 1996 to 2001 incidents. The change in incidents was categorized by High Negative, Negative, No Change, Positive, and High Positive. As the majority of the change in incidents clustered between -3 to 3, the categories created were High Negative ($n < -3$), Negative ($-3 <= n < 0$), No Change ($n = 0$), Positive ($0 < n <= 3$), and High Positive ($n > 3$).

Road Network Clustering (SANET)

The Ripley's K or the K-function (Ripley 1976; Haase 1995) is a widely used statistical analysis method for looking at the distribution of points within a geographic area. It is used in many different fields, from traffic incidents to agriculture, soil erosion, ecology, and others. Typically, Euclidian distance is used to measure the distance between points on the plane (Okabe and Yamada 2001). The K-function assumes an infinite plane limited by the largest maximum distance between the two furthest points. The distribution is only limited by the minimum enclosing rectangle or other user-defined study area. The results, in graph form, depict whether the data is clustered, dispersed, or random across incremental distance bands from each point without referencing any underlying network, i.e. transportation network. There is the possibility of the statistic to show clustering of incidents on two non-intersecting roads (i.e. parallel roads in a city).

This study will use Spatial Analysis along NETworks (SANET), a computer program developed by the Center for Spatial Information Science at the University of Tokyo. SANET is used to determine if the distribution of traffic fatalities is clustered, dispersed or random (Okabe and Kitamura 1996; Okabe and Okunuki 2001; Okabe, Okunuki, and Shiode 2006; Okabe and Satoh 2005; Okabe, Satoh, and Sugihara 2009; Okabe and Yamada 2001; Okabe, Yomono, and Kitamura 1995; Xie and Yan 2008; Yamada and Thill 2004). The SANET program utilizes the Ripley's K function and confines the spatial analysis along a user-defined network. This program and the Network K-Function are ideal for analyzing distributions of variables that occur along a road network and since traffic incidents are directly associated with the road network and do not occur randomly (Okabe and Yamada 2010).

The SANET program was used to analyze the clustering of fatal incidents within the project area. The Network K-Function uses the observed distribution and generates an expected distribution using a mean, an upper 5 percent, and a lower 5 percent to compare the observed distribution against. Attempts were made to look at the clustering of all incidents and injury-related incidents; however the program returned errors when attempting to analyze the clustering of 2,000 to 40,000 points. The fatality incidents totaled 542 fatalities and provided an adequate sample to run the SANET analysis. The parameters used in this study were 50 iterations, 500 meter interval, and 5 percent statistical significance.

Software Utilized

This research has utilized ArcGIS 10 (including Linear Referencing Tools and Spatial Statistics Tools) (ESRI 2010), Spatial Analysis along NETworks (SANET) Version 4.0 Beta (Okabe et al. 2006a, Okabe et al. 2006b, Okabe et al. 2010) and Microsoft Access and Excel programs to examine the distribution and potential clustering of traffic incidents, and to perform Chi-squared analysis.

RESULTS

The results section begins with a discussion of the overall change in land cover over the 18-year time period of the study. Included within this section are an analysis of the change in miles of road, the distribution of incidents, fatalities, and injuries across the study area, and the distribution of other road characteristics (shoulder width, surface width, posted speed limit, number of lanes, median width, and incident type) within each of the land cover types. Given the disparity in the miles of road within each land cover type (i.e. 353 to 480 miles of road in Suburban/Urban versus 870 to 904 miles in Agriculture) the distributions are normalized by dividing the sum per land cover type by the miles of road, thus resulting in number of incidents, fatalities, or injuries per mile. This overview discussion will provide a basis for discussing the road segments where land cover change occurred and the resulting change in incidents located along those segments. Linear referencing tools were used to locate land cover type and individual incidents along the road network. The analysis was then carried out using additional linear referencing and spatial analysis tools within ArcGIS 10.

Overall Land Cover

The project area has seen numerous changes in the rural landscape since 1990; those changes can be quantified by the changes in the acres covered by a particular land cover type. The overall area of land cover for the entire study area was derived from the four

NOAA LULC images (NOAA 1992, 1996, 2001, 2005). The individual land cover types were aggregated into Water/Wetland, Suburban/Urban, Forest, and Agriculture. Descriptive statistics about the land cover types were generated in ArcGIS, Microsoft Excel spreadsheets, and Microsoft Access database. The differences between the four time periods are presented in the following discussion and associated tables. The original LULC images have a 30 meter ground resolution; however, the metadata associated with the images suggest using at least a 90 meter ground resolution. However, as exhibited in Figure 5, many roads are categorized as Suburban/Urban even if they are surrounded by forest or open fields. Therefore, for the purposes of this study the pixels intersecting with the road centerlines were removed and resampled with the majority of the surrounding pixels, further the overall image was resampled to 180 meter ground resolution to negate errant pixels that may not represent the overall land cover or land cover type.

The project area is primarily a rural agricultural landscape separated by vast stands of forest; hence Forest and Agriculture dominate the land cover types throughout all four land cover images (**Table 3, Figure 12**). The suburban/urban category has increased from 24,945 acres to 33,536 acres over the 18 year time period, a 34.4 percent increase, primarily around the City of Fredericksburg and the Town of Culpeper. The largest increase in the Suburban land cover occurred between 1996 and 2001 (19.3 percent increase). Overall, there is an increase in Water/Wetland (7.9 percent) and a slight increase Agriculture (2.3 percent). The increase in Water/Wetland can most likely be attributed to better sensor detection of wetlands

Table 3. Distribution and Changes in Land Cover Type.

	Land Cover Type	Water/ Wetland	Suburban/ Urban	Forest	Agriculture	TOTAL
1992	Acres	31,582	24,945	365,644	256,935	679,106
	%	4.7	3.7	53.8	37.8	
1996	Acres	32,157	25,621	362,660	258,043	678,481
	%	4.7	3.8	53.5	38.0	
	% change	1.8	2.7	-0.8	0.4	
2001	Acres	33,992	30,554	341,461	262,171	668,178
	%	5.1	4.6	51.1	39.2	
	% change	5.7	19.3	-5.8	1.6	
2006	Acres	34,090	33,536	345,706	262,878	676,210
	%	5.0	5.0	51.1	38.9	
	% change	0.3	9.8	1.2	0.3	
Overall Change		7.9	34.4	-5.5	2.3	

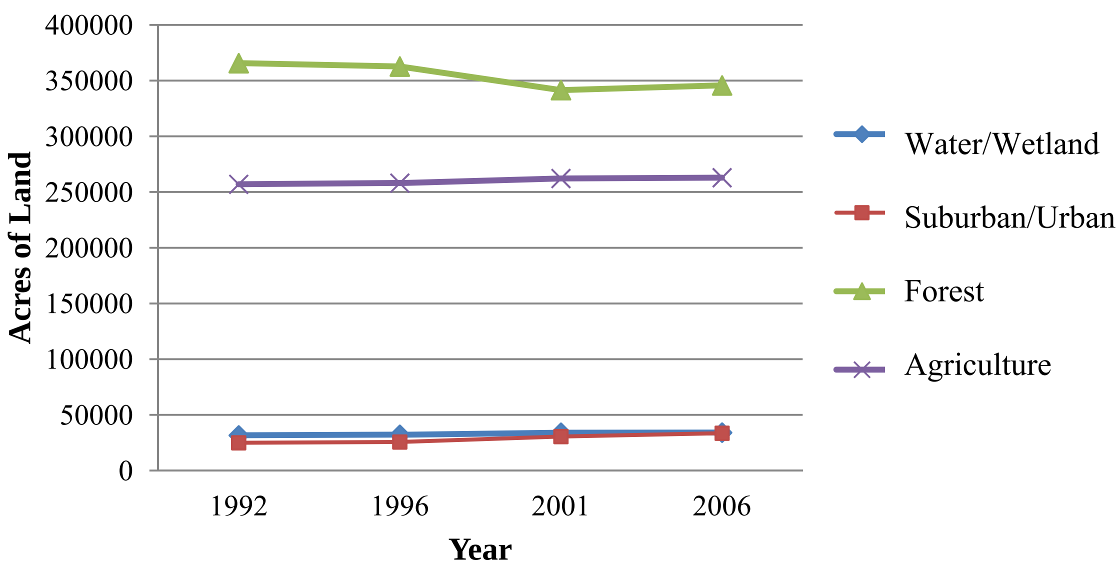

Figure 12. Change in Area of Land Cover Types.

most likely be attributed to better sensor detection of wetlands and the addition of several reservoirs located in close proximity to several roads in the project area (such as the Hunting Run Reservoir and Ni River Reservoir, both in western Spotsylvania County). The increase in Agriculture can likely be attributed to a conversion of forested areas to agricultural fields or pasture, and clearing for residential and commercial development. The overall pattern in the change of land cover types is a general increase in Water/Wetland and Agriculture, an overall decrease in Forest, a significant increase in Suburban/Urban land cover throughout the study time period. In Figure 12, the Water/Wetland and Suburban/Urban categories follow the same pattern across the three time periods. The difference in the acreage through the different time periods is attributed to the slightly different satellite coverage between the time periods, primarily along the western edge of the project area.

Overall Distributions

Miles of Road

The land cover data was located along the road network with linear referencing tools identifying specific land cover types along the road within each of the study time periods. As mentioned in the Methods section, the land cover pixels along the road network were removed and the majority of the surrounding land cover type was used to interpolate the land cover along the road. The project area consists of approximately 2,216 miles of roadway as of 2007 to 2011: including both state-maintained roads and locality maintained roads.

From 1992 to 1996, there are significant increases in the miles of road located within Suburban/Urban and Agriculture, while there is a drop in the miles of roadway in Forested areas (**Table 4, Figure 13**). As with the change in overall acres of land, this can be attributed to the conversion of forested tracts into residential developments, commercial shopping centers, and agriculture/pasture land. Water/Wetland areas make up less than 2 percent of the total in each of the time periods.

Distribution of Incidents

The number of incidents per acre illustrates how prevalent incidents are in the Suburban/ Urban areas, albeit not surprisingly, since this is where the majority of the traffic activity occurs (**Table 5**, **Figure 14, Figure 15**). Suburban/Urban areas produce 0.45 to 0.55 incidents per acre across the three time periods, with the highest occurrence in the 1996 to 2001 time period (**Table 6**). The next highest land cover type is Agriculture with a range of 0.011 to 0.016 incidents per acre. Since the land cover that is most clearly associated with traffic incidents (as shown in previous tables) is the Suburban/Urban, it is the conversion to this type of land cover that is of particular concern. The frequency of incidents is dominated by Suburban/Urban with nearly half of the incidents over all three time periods. Again, traffic incidents occur second most within Agriculture land ranging from 26 to 27 percent of the total number of

Table 4. Overall Miles of Road Network by Land Cover Type.

	Land Cover Type	Water/ Wetland	Suburban/ Urban	Forest	Agriculture	TOTAL
1992	Miles	24.07	353.14	806.01	887.16	2070.38
	% of Total	1.16	17.06	38.93	42.85	
1996	Miles	21.34	381.91	790.63	869.94	2063.82
	% of Total	1.03	18.51	38.31	42.15	
	% change	-11.34	8.14	-1.90	-1.94	
2001	Miles	22.07	445.43	814.81	898.02	2180.33
	% of Total	1.01	20.43	37.37	41.19	
	% change	3.42	16.63	3.06	3.23	
2006	Miles	23.99	479.78	808.17	904.40	2216.34
	% of Total	1.08	21.65	36.46	40.81	
	% change	8.70	7.71	-0.82	0.42	

Note: % of Total represents the Percentage of Road for each Time Period.

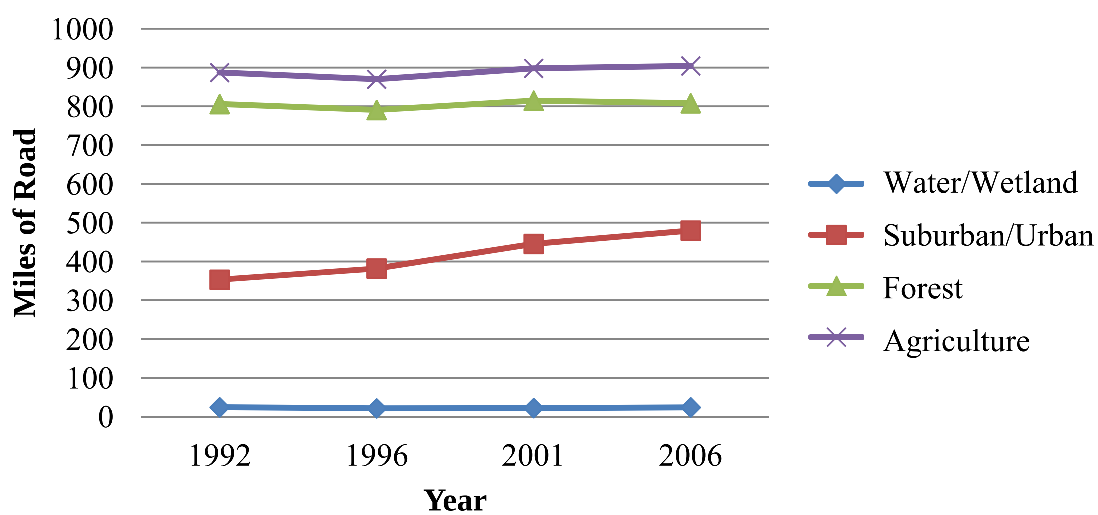

Figure 13. Change in Distribution of Miles of Road.

Table 5. Distribution of Incidents by Land Cover Type.

Time Period	1990-95		1996-2001			2002-07		
Land Cover Image	1996		2001			2006		
Land Cover Type	# incidents	% of total	# incidents	% of total	% change	# incidents	% of total	% change
Water/ Wetland	137	1.35	213	1.60	55.47	282	1.84	32.39
Suburban/ Urban	5174	51.10	7205	53.98	39.25	7941	51.75	10.22
Rural-Forest	2186	21.59	2704	20.26	23.70	3158	20.58	16.79
Agriculture	2628	25.96	3226	24.17	22.75	3964	25.83	22.88
Total	**10125**	**100**	**13348**	**100**		**15345**	**100**	

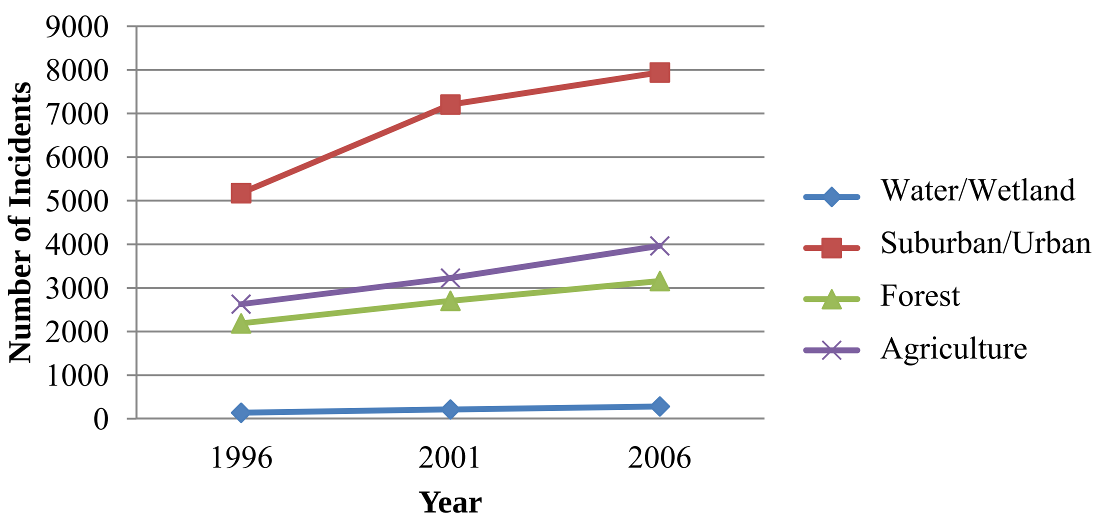

Figure 14. Distribution of Number of Incidents within the Study Area.

Table 6. Change in Incidents per Acre by Land Cover Type.

	Land Cover Type	Water/ Wetland	Suburban/ Urban	Forest	Agriculture	TOTAL
1996	Incidents	137	5174	2186	2628	10125
	Incident/ Acre	0.0041	0.2093	0.0057	0.0106	0.0146
2001	Incidents	213	7205	2704	3226	13348
	Incident/ Acre	0.0079	0.2546	0.0073	0.0127	0.0197
2006	Incidents	256	7844	3397	3853	15353
	Incident/ Acre	0.0094	0.2475	0.0093	0.0151	0.0226

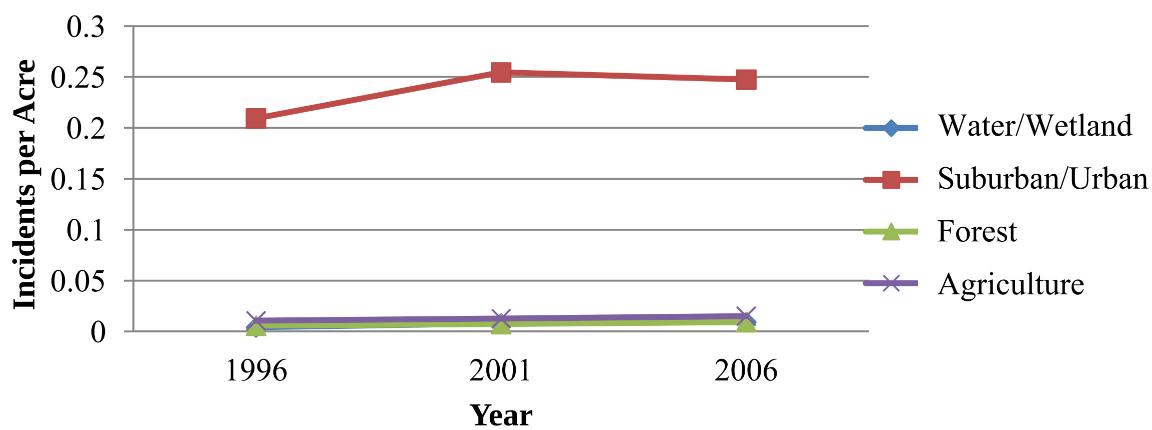

Figure 15. Change in Incident Rate per Acre of Land.

incidents. Incidents occurring within the Forest land cover type are only a few percentage points behind the Agriculture land. The result of the residential and commercial development boom in the project area is evident with the 36 percent increase in Suburban/Urban land cover between 1996 and 2001. The sharp increase in incidents within Wetland land cover types may be attributed to the increased accuracy in wetland detection; however, these incidents represent less than 2 percent of the total incidents.

Additional research on this topic would be required to understand any potential significance in this trend.

Fatality and Injury Rates

The incidence of fatalities shows a marked increase from 1996 to 2001 in both Suburban/Urban and Agriculture, while Water/Wetland shows a relatively low increase and Forest increase by only 9 percent. Both Suburban/Urban and Agriculture show continuous increase from 1990 to 2007. The majority of fatalities are occurring within the Rural areas from 1990 to 2001 (108 from 1990 to 1995 and 133 from 1996 to 2001). However, Suburban/Urban fatalities (n = 71), although less then Rural areas combined (117 fatalities), surpasses both Agriculture and Forest individually from 2002 to 2007. The biggest decline in fatalities occurs from 2002 to 2007 in the Forest areas (21 percent decrease), not including the Water/Wetland numbers (**Table 7**). Of particular note here, is the significant increase in fatalities in the 1996 to 2001 time period, a time of great population growth in the project area. With the disparity in miles of road and number of incidents within each land cover type, the fatality rate gives a better idea of the severity of the incidents by highlighting the number of fatalities in relation to the number of incidents (**Table 8**) and the number of injuries (**Table 9**).

Table 7. Distribution of Fatalities by Land Cover.

Time Period	1990-95		1996-2001			2002-07		
Land Cover Image	1996		2001			2006		
Land Cover Type	#	% of Total	#	% of Total	% change	#	% of Total	% change
Water/Wetland	2	1.37	6	3.03	200	7	3.59	-25.00
Suburban/Urban	36	24.66	59	29.80	63.89	71	36.41	22.22
Forest	61	41.78	67	33.84	9.84	56	28.72	-21.05
Agriculture	47	32.19	66	33.33	40.43	61	31.28	4.76
Total	**146**		**198**			**195**		

Note: # = Number of Fatalities and % change equals the change in fatalities from one time period to the next.

Table 8. Fatality Rates per 100 Incidents.

Time Period	1990-95	1996-2001		2002-07		1990-2007
Land Cover Image	1996	2001		2006		Total
Land Cover Type	Fatality Rate	Fatality Rate	% Change	Fatality Rate	% Change	Fatality Rate
Water/Wetland	1.46	2.82	92.96	2.73	-2.93	2.37
Suburban/Urban	0.70	0.82	17.69	0.91	10.54	0.82
Forest	2.79	2.48	-11.21	1.65	-33.47	2.29
Agriculture	1.79	2.05	14.40	1.58	-22.62	1.77

Note: Fatality Rate is calculated by Number of Fatalities (per Land Cover Type)/Number of Incidents (per Land Cover Type) multiplied by 100.

Table 9. Fatality Rates per 100 Injuries.

Time Period	1990-95	1996-2001		2002-07		1990-2007
Land Cover Image	1996	2001		2006		Total
Land Cover Type	Fatality Rate	Fatality Rate	% Change	Fatality Rate	% Change	Fatality Rate
Water/Wetland	2.41	5.36	122.32	6.86	28.10	5.05
Suburban/Urban	1.11	1.39	24.40	1.81	30.55	1.45
Forest	4.11	4.02	-2.23	3.06	-24.03	3.69
Agriculture	2.37	3.08	29.82	2.89	-6.09	2.79

Note: Fatality Rate is calculated by Number of Fatalities (per Land Cover Type)/Number of Injuries (per Land Cover Type) multiplied by 100.

The fatality rates mirror the fatality frequencies noted in Table 7. The calculation of the fatality rates in Table 8 identifies how many fatalities have occurred per 100 incidents (**Figure 16**). In other words, for every 100 incidents within the Suburban/Urban area from 1990 to 1995, there are 0.70 fatalities and 2.79 fatalities for every 100 incidents within the Forest area during the same time period. The fatality rate in Table 9 identifies the number of fatalities occurring per number of injuries within the respective land cover type (**Figure 17**). The fatality rates by injuries and incidents have similar patterns. In both distributions, the fatality rate increases steadily in the Suburban/Urban areas, remains considerably lower than the rates in Forest and Agriculture.

Also, in both distributions, Forest begins with the highest rate for 1996 and steadily declines through the time periods. Agriculture areas have an even distribution with

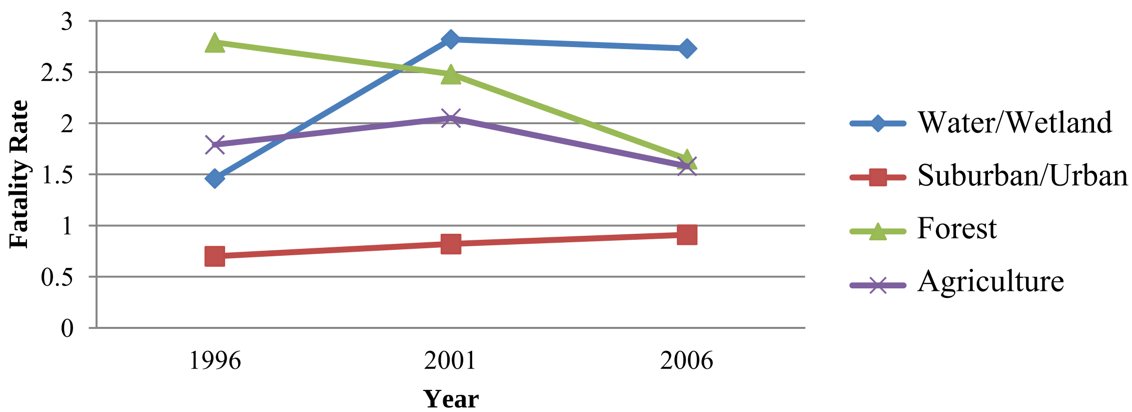

Figure 16. Fatality Rate per 100 Incidents.

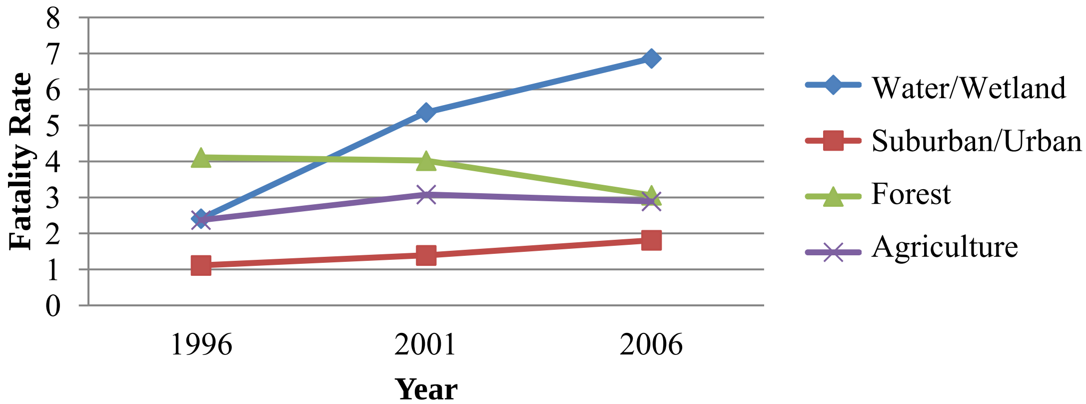

Figure 17. Fatality Rate per 100 Injuries.

a slight increase in 2001. Suburban/Urban and Agriculture show a continued increase in fatality rates over the time period, while Forest increases between 1996 and 2001 and decreases between 2002 and 2007. The fatality rates for Water/Wetland land cover appears to be inflated due to the relatively low number of incidents and injuries. The biggest increase in fatality rates occurred from 1996 to 2001 in Agriculture (nearly 40 percent) and in Suburban/Urban from 2002 to 2007 (31 percent). These data show that there are higher fatality rates within the rural areas based on the overall number of injuries; again the rates for the Water/Wetland areas are skewed representing a limited numbers of incidents.

When looking at the distribution of fatalities normalized by the number of miles of road within each land cover type (**Figure 18**), the distribution is nearly opposite of the raw distribution by incidents or injuries. Water/Wetland again is skewed based on few incidents and few miles of road. Suburban/Urban lands with a relatively lower number of

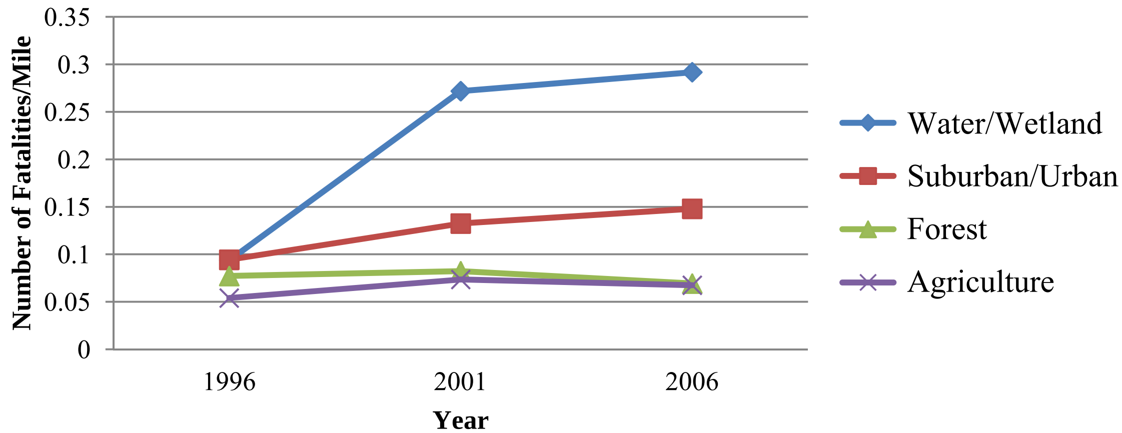

Figure 18. Distribution of Fatalities per Mile.

miles increase the significance of the fatalities per mile; while the larger mileage areas in the Forest and Agriculture drop to the bottom of the chart. Although rural areas account for more than 75 percent of the total roads in the project area and there are more fatalities, there are fewer fatalities per mile in the rural areas as opposed to the suburban areas.

As with the number of incidents, the distribution of injuries is dominated by the Suburban/Urban land cover consisting of more the 45 percent of all injuries across all three time periods. Agriculture comes in second with just under 30 percent and Forest is third with 22 to 24 percent (**Table 10**). The injuries increase between the first two time periods, as seen in previous figures and tables for overall incidents and fatalities. The injuries, however, decrease between the second and third time periods, even though the incidents continue a steady increase. The Injury Rate (**Table 11**) also shows a steady decrease in the number of injuries occurring although the number of incidents continues to increase.

Table 10. Distribution of Injuries by Land Cover.

Time Period	1990-95		1996-2001			2002-07		
Land Cover Image	1996		2001			2006		
Land Cover Type	#	%	#	%	% change	#	%	% change
Water/Wetland	83	1.22	112	1.37	34.94	102	1.28	-8.93
Suburban/Urban	3232	47.66	4258	52.05	31.75	3925	49.24	-7.82
Forest	1483	21.87	1666	20.36	12.34	1833	23.00	10.02
Agriculture	1983	29.24	2145	26.22	8.17	2111	26.48	-1.59
Total	**6781**		**8181**			**7971**		

Table 11. Change in Injury Rate per 100 Incidents.

Time Period	1990-95	1996-2001		2002-07	
Land Cover Image	1996	2001		2006	
Land Cover Type	Injury Rate	Injury Rate	% Change	Injury Rate	% Change
Water/Wetland	60.58	52.58	-13.21	39.84	-24.23
Suburban/Urban	62.47	59.10	-5.39	50.04	-15.33
Forest	67.84	61.61	-9.18	53.96	-12.42
Agriculture	75.46	66.49	-11.88	54.79	-17.60

Note: Injury Rate calculated by Number of Injuries/Number of Incidents within each land cover type and represents the number of injuries per 100 incidents.

Summary of Overall Land Cover Results

- Rural Forest land cover makes up over 50 percent of the total land cover
- The biggest change in land cover occurs within Suburban/Urban areas with an overall increase of 34 percent over the study time period and a 19 percent increase from 1996 to 2001.

- Miles of Road in Rural areas steadily, albeit slightly, decreases through the study time period, while the Suburban/Urban road mileage steadily increases by 7 to 16 percent (again largest increase is from 1996 to 2001).
- More than 50 percent of incidents occur in Suburban/Urban land cover and steadily increase over time.
- Only 20 to 25 percent of incidents occur in Forest and Rural Agriculture, respectively, and steadily increase over time.
- Rural fatalities dominate the study area through 2001 with a slight drop-off in 2006. Suburban/Urban fatalities steadily increase through the time periods, surpassing both rural categories in 2006.
- Fatality rates in rural land cover types are more than double the fatality rates in Suburban/Urban for 1996 and 2001, although rural fatality rates are slightly declining in 2006, yet still nearly double the Suburban/Urban.
- Although 50 percent of injuries occur within Suburban/Urban areas, the injury rates per 100 incidents between the three main land cover categories are within 12 percentage points with both Agriculture and Forest exceeding Suburban/Urban areas.

Other Road Characteristics

In an attempt to understand the causes and reasoning why incidents occur in one place versus another this research examines additional site/road characteristics. Among such characteristics is the general location of the incidents in relation to the associated land cover. To more fully understand why and where incidents have occurred, several road characteristics were also evaluated in this study (the number of lanes, road surface width, shoulder width, posted speed limits, and median width) to see what characteristics are prevalent where there are the most incidents or higher numbers of fatalities and injuries. Due to the disparity in the mileage of roads within different land cover types and different road characteristics, the calculations were also adjusted for miles of road.

Number of Lanes: The category for Number of Lanes was divided into three categories, 1) 2-Lane, 2) 4-Lane (with 5-Lane roads included), and 3) 6-Lane (with 3 lane roads included with the 6-Lane category and 5-Lane roads included with the 4-Lane category). The 3-Lane category is confined to Interstate 95 as the two directions are identified separately in the data. The 5-Lane category is confined to the urban areas and represents roads such as US Route 1 or US Route 17 which are 4-Lane roads with a center turn lane in some areas. The majority of the roads within the project area are 2-Lane roads (comprising 92 percent through all three time periods). The 4-Lane roads average 7.5 percent through the three time periods and covers primary and major secondary routes that have been widened to accommodate the growing population. As there is large disparity in the types of roads throughout the study area, the incidents per miles of road were calculated by dividing the number of incidents within each land cover type by the miles of road within that land cover type. This adds another level for the analysis to identify patterns in the data rather than just relying on the total numbers of road segments in each category.

The raw distribution of incidents and injuries by the number of lanes consistently declines as the number of lanes increases; however the distribution of fatalities is a little more evenly distributed among land cover types (not including Water/Wetland). One exception is the increase in fatalities within Suburban/Urban areas from 1996 to 2001 along 4-Lane roads. Also there are very few fatalities in the 6-Lane category, which may be due to the low number of miles within that category (**Table 12, Table 13, Table 14**). The 2-Lane roads (with the exception of the Water/Wetland category) dominates the distribution with over 64 percent within each time period which is more than double the 27 to 29 percent along 4-Lane roads.

The distribution of the number of incidents, fatalities, and injuries per mile appear to follow different patterns (**Figure 19, Figure 20, Figure 21**); however, a closer look at the numbers shows elevated values along 6-Lane roads due to relatively low number of miles with less than one mile in all categories except Suburban/Urban. The raw numbers showed a steady decrease as the number of lanes increased. In the per mile distribution, although there are clearly more incidents, injuries, and fatalities along 2-Lane roads, the pattern shows more incidents, fatalities, and injuries occurring per mile of road on 4-Lane roads than on 2-Lane roads. As mentioned above, the incidents, fatalities, and injuries along 6-Lane roads are elevated due to a total mileage less than one mile leading to an over-representation of incidents and injuries in Forest and Agriculture.

Overall, the Suburban/Urban category leads the other categories (not including Water/Wetland) in all time periods for incidents and injuries. In the distribution of fatalities, all three main land cover types are generally equal along 2-Lane roads, except in 2006 when Suburban/Urban increases slightly over the two rural categories. Rural-

Table 12. Distribution of Incidents by the Number of Lanes and Land Cover Type.

Number of Lanes	2		4		6		Total	Percentage
1996 Land Cover-Incidents								
Land Cover	#	Miles	#	Miles	#	Miles		
Water/Wetland	40	17.43	97	3.93	0	0.00	137	1.35
Suburban/Urban	2939	316.62	1645	61.69	590	3.77	5174	51.10
Forest	1547	742.56	616	47.67	23	0.50	2186	21.59
Agriculture	2177	828.16	449	41.75	2	0.24	2628	25.96
Sub-Total	6703	1904.77	2807	155.05	615	4.51	10125	
Percentage	66.20	92.27	27.72	7.51	6.07	0.22		
2001 Land Cover-Incidents								
Water/Wetland	75	17.92	138	4.15	0	0.00	213	1.60
Suburban/Urban	4001	374.43	2390	66.74	814	4.47	7205	53.98
Forest	1825	766.39	861	47.92	18	0.43	2704	20.26
Agriculture	2698	855.07	528	43.11	0	0.02	3226	24.17
Sub-Total	8599	2013.8	3917	161.92	832	4.93	13348	
Percentage	64.42	92.35	29.35	7.43	6.23	0.23		
2006-Land Cover-Incidents								
Water/Wetland	87	19.86	169	4.15	0	0.00	256	1.67
Suburban/Urban	4246	401.01	2621	74.49	977	4.47	7844	51.10
Forest	2324	760.50	1023	47.16	50	0.43	3397	22.13
Agriculture	3221	862.39	632	42.08	0	0.02	3853	25.10
Sub-Total	9878	2043.76	4445	167.88	1027	4.93	15350	
Percentage	64.35	92.2	28.96	7.57	6.69	0.22	100.00	
Total	25180		11169		2474		38823	
Percentage	64.86		28.77		6.37			

Table 13. Distribution of Fatalities by the Number of Lanes and Land Cover Type.

Number of Lanes	2	4	6	Total	Percentage
1996 Land Cover-Fatalities					
Water/Wetland	1	1	0	2	1.37
Suburban/Urban	20	16	0	36	24.66
Forest	45	16	0	61	41.78
Agriculture	38	9	0	47	32.19
Sub-Total	104	42	0	146	
Percentage	71.23	28.77	0.00		
2001 Land Cover-Fatalities					
Water/Wetland	4	2	0	6	3.03
Suburban/Urban	25	29	5	59	29.80
Forest	43	24	0	67	33.84
Agriculture	56	10	0	66	33.33
Sub-Total	128	65	5	198	
Percentage	64.65	32.83	2.53		
2006 Land Cover-Fatalities					
Water/Wetland	4	3	0	7	3.59
Suburban/Urban	43	28	0	71	36.41
Forest	48	8	0	56	28.72
Agriculture	47	14	0	61	31.28
Sub-Total	142	53	0	195	
Total	374	160	5	539	
Percentage	69.39	29.68	0.93		

Table 14. Distribution of Injuries by Number of Lanes and Land Cover Type.

Number of Lanes	2	4	6	Total	Percentage
1996 Land Cover-Injuries					
Water/Wetland	27	56	0	83	1.22
Suburban/Urban	1891	1031	310	3232	47.66
Forest	1049	416	18	1483	21.87
Agriculture	1597	383	3	1983	29.24
Sub-Total	4564	1886	331	6781	
Percentage	67.31	27.81	4.88		
2001 Land Cover-Injuries					
Water/Wetland	51	61	0	112	1.37
Suburban/Urban	2398	1434	426	4258	52.05
Forest	1179	476	11	1666	20.36
Agriculture	1784	361	0	2145	26.22
Sub-Total	5412	2332	437	8181	
Percentage	66.15	28.51	5.34		
2006 Land Cover-Injuries					
Water/Wetland	36	66	0	102	1.28
Suburban/Urban	2296	1212	417	3925	49.24
Forest	1263	555	15	1833	23.00
Agriculture	1751	360	0	2111	26.48
Sub-Total	5346	2193	432	7971	
Total	15322	6411	1200	22933	
Percentage	66.81	27.96	5.23		

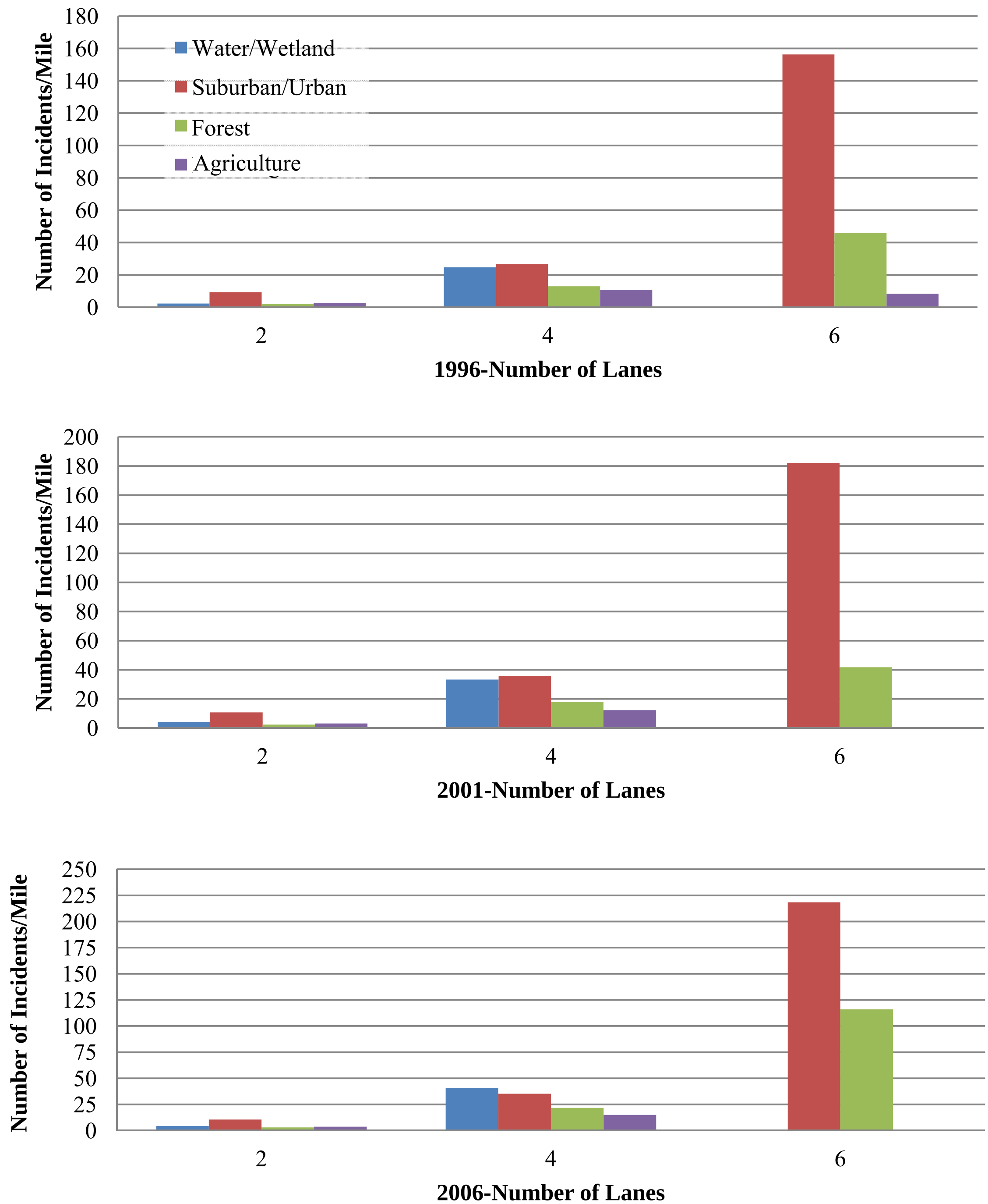

Figure 19. Distribution of Incidents by Number of Lanes per Miles of Road.

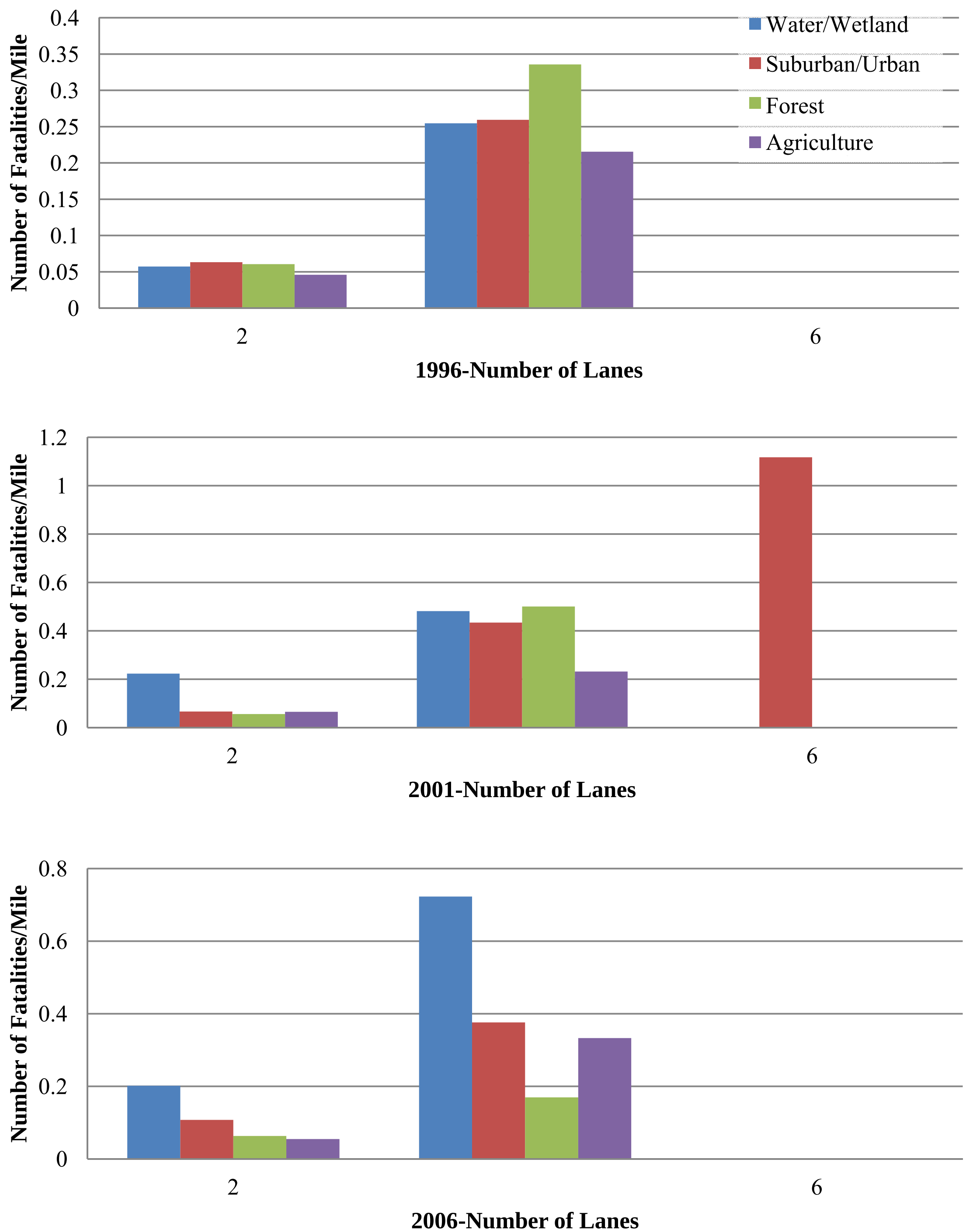

Figure 20. Distribution of Fatalities by Number of Lanes per Miles of Road.

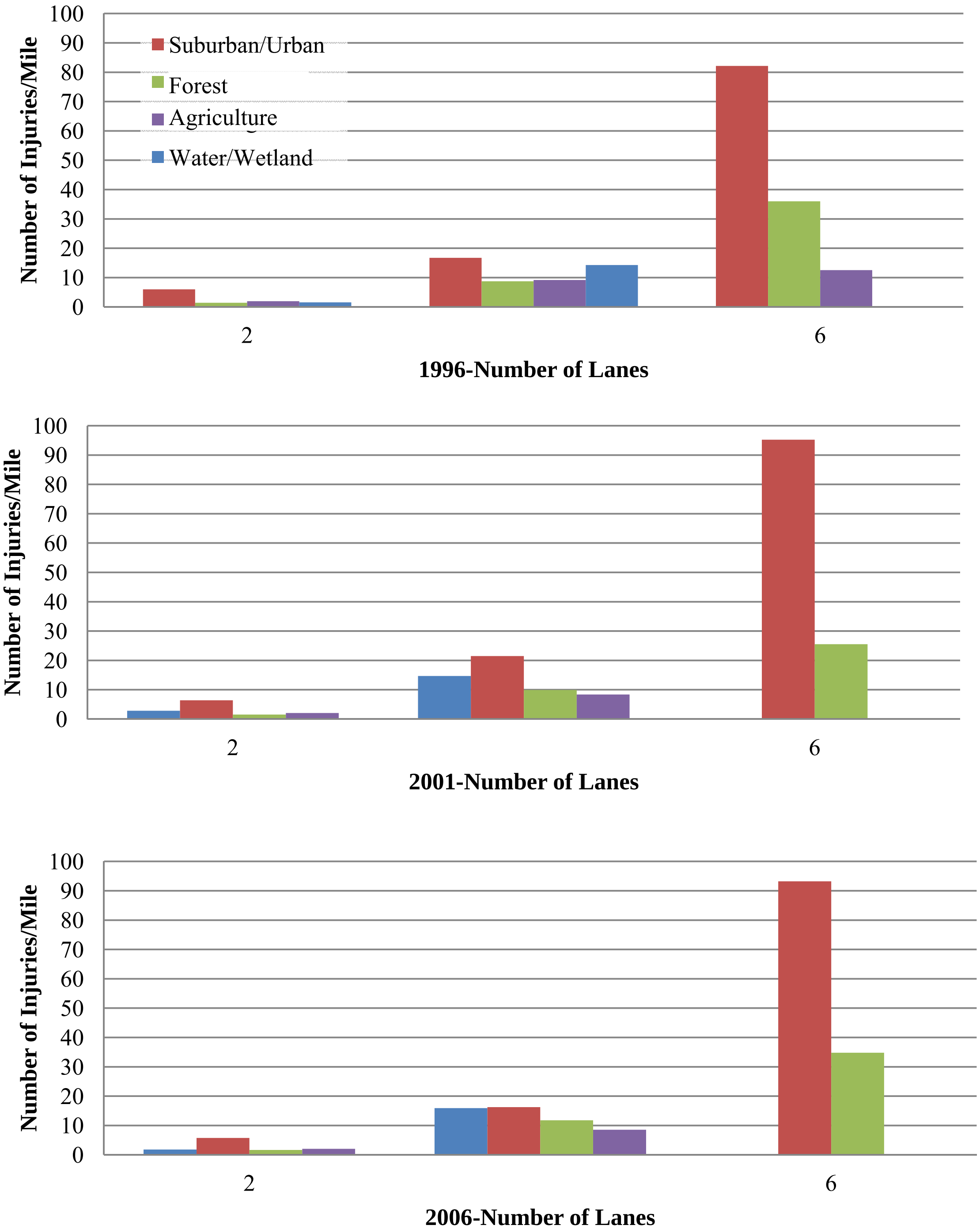

Figure 21. Distribution of Injuries by Number of Lanes per Miles of Road.

Forest leads Suburban/Urban fatalities along 4-Lane roads in 1996 and 2001. However, Suburban/Urban fatalities surpass the rural categories in 2006. The only fatalities on 6-Lane roads occurred in Suburban/Urban areas in 2001, while all other categories and years were 0. In the distribution of raw numbers 2-Lane incidents, fatalities, and injuries dominate the distribution, whereas in per mile distributions, the 4-Lane incidents, fatalities, and injuries dominate all three time periods. Translated this means that more incidents, fatalities, and injuries are occurring on the typically rural 2-Lane roads; however, more incidents, fatalities, and injuries per mile of roads are occurring in the typically suburban residential and urban areas of the study area.

Surface Width: Surface width was divided into three main categories: 1) n <= 18ft less than or equal to 18 ft, 2) 19 < n <= 24 ft, and 3) n > 24. These categories generally follow the rural and unimproved 2-lane roads (Category 1); improved rural, residential and suburban/urban areas (Category 2), and interstates, highways, and urban areas (Category 3), respectively. The distribution of incidents and injuries is dominated by Suburban/Urban, except along roads with a surface width less than or equal to 18 ft, which is dominated by Agriculture. Suburban/Urban fatalities rank behind both rural land cover categories on all roads except those with a surface width greater than 24 ft (**Table 15, Table 16, Table 17**). Without exception Forest and Agriculture incidents, fatalities, and injuries increase from less than 19 ft surface width to a surface width between 19 ft and 24 ft, and then all land cover categories decrease along roads with surface width greater than 24 ft. Conversely, within Suburban/Urban land cover, the incidents, fatalities, and injuries all increase with the increase in the surface width of the roads. For the most part, Water/Wetland also increases with the increase in surface width; except with fatalities with a limited numbers of instances.

An interesting pattern emerges when looking at the numbers normalized by miles of road in Suburban/Urban areas (**Figure 22, Figure 23, Figure 24**). Incidents, fatalities, and injuries all decline between Category 1 and Category 2 and increase significantly in Category 3. In other words, even though the raw numbers are increasing from the first category to the second, the frequency per mile is decreasing, which is due in part by the increase in the miles of road within Suburban/Urban areas that are greater than 18ft and less than 25 ft. This pattern is repeated in the distribution of fatalities in Water/Wetland, as well, but encompasses a small sample size. The general pattern for Water/Wetland, Forest, and Agriculture follow a steady increase from the first surface width category to the second surface width category. As the mileage decreases from the second category to the surface widths greater than 24 ft, the instances per mile increase significantly.

Suburban/Urban incidents and injuries are the most prevalent per mile of road through all categories and time periods; however there is a consistent drop in the incidents, fatalities, and injuries across all time periods. With Suburban/Urban incidents increasing nearly four time from Category 1 (n = 563) to Category 2 (n = 1940), the drop in incidents, fatalities, and injuries suggests that Category 2 roads are far more safer than the other two

Table 15. Distribution of Incidents by Surface Width and Land Cover Type.

Surface Width (ft)	n <= 18		18 < n > 24		n > 24		Total	Percentage
1996 Land Cover-Incidents								
Land Cover	#	Miles	#	Miles	#	Miles		
Water/Wetland	18	6.889	22	10.49	97	3.97	137	1.35
Suburban/Urban	563	46.35	1940	244.92	2671	90.81	5174	51.10
Forest	601	346.26	919	391.46	666	53.02	2186	21.59
Agriculture	803	424.89	1331	398.94	494	46.33	2628	25.96
Sub-Total	1985	824.4	4212	1045.81	3928	194.12	10125	
Percentage	19.60		41.60		38.80			
2001 Land Cover-Incidents								
Water/Wetland	20	6.86	55	10.74	138	4.47	213	1.60
Suburban/Urban	805	52.5	2611	293.28	3789	99.86	7205	53.98
Forest	712	335.04	1090	420.74	902	58.96	2704	20.26
Agriculture	960	433.39	1699	412.22	567	52.6	3226	24.17
Sub-Total	2497	827.79	5455	1136.97	5396	215.88	13348	
Percentage	18.71		40.87		40.43			
2006-Land Cover-Incidents								
Water/Wetland	26	7.34	61	11.59	169	5.08	256	1.67
Suburban/Urban	1098	54.46	2891	306.31	3855	119.2	7844	51.10
Forest	897	330.89	1417	422.53	1083	54.67	3397	22.13
Agriculture	1215	440.97	1960	412.45	678	51.09	3853	25.10
Sub-Total	3236	833.67	6329	1152.88	5785	230.03	15350	
Percentage	21.08		41.23		37.69		100.00	
Total	7718		15996		15109		38823	
Percentage	19.88		41.20		39.92			

Table 16. Distribution of Fatalities by Surface Width and Land Cover Type.

Surface Width (ft)	n <= 18	18 < n > 24	n > 24	Total	Percentage
1996 Land Cover-Fatalities					
Water/Wetland	1	0	1	2	1.37
Suburban/Urban	6	13	17	36	24.66
Forest	16	28	17	61	41.78
Agriculture	13	25	9	47	32.19
Sub-Total	36	66	44	146	
Percentage	24.66	45.21	30.14		
2001 Land Cover-Fatalities					
Water/Wetland	3	1	2	6	3.03
Suburban/Urban	8	14	37	59	29.80
Forest	14	27	26	67	33.84
Agriculture	13	43	10	66	33.33
Sub-Total	38	85	75	198	
Percentage	19.19	42.93	37.88		
2006 Land Cover-Fatalities					
Water/Wetland	1	3	3	7	3.59
Suburban/Urban	12	28	31	71	36.41
Forest	14	34	8	56	28.72
Agriculture	14	33	14	61	31.28
Sub-Total	41	98	56	195	
Percentage	21.03	50.26	28.72	100.00	
Total	115	249	175	539	
Percentage	21.34	46.20	32.47		

Table 17. Distribution of Injuries by Surface Width and Land Cover Type.

Surface Width (ft)	n <= 18	18 < n > 24	n > 24	Total	Percentage
1996 Land Cover-Injuries					
Water/Wetland	13	14	56	83	1.22
Suburban/Urban	377	1253	1602	3232	47.66
Forest	403	628	452	1483	21.87
Agriculture	563	1008	412	1983	29.24
Sub-Total	1356	2903	2522	6781	
Percentage	20.00	42.81	37.19		
2001 Land Cover-Injuries					
Water/Wetland	16	35	61	112	1.37
Suburban/Urban	464	1659	2135	4258	52.05
Forest	438	717	511	1666	20.36
Agriculture	616	1146	383	2145	26.22
Sub-Total	1534	3557	3090	8181	
Percentage	18.75	43.48	37.77		
2006 Land Cover-Injuries					
Water/Wetland	11	25	66	102	1.28
Suburban/Urban	613	1549	1763	3925	49.24
Forest	501	753	579	1833	23.00
Agriculture	622	1110	379	2111	26.48
Sub-Total	1747	3437	2787	7971	
Percentage	21.92	43.12	34.96	100.00	
Total	4637	9897	8399	22933	
Percentage	20.22	43.16	36.62		

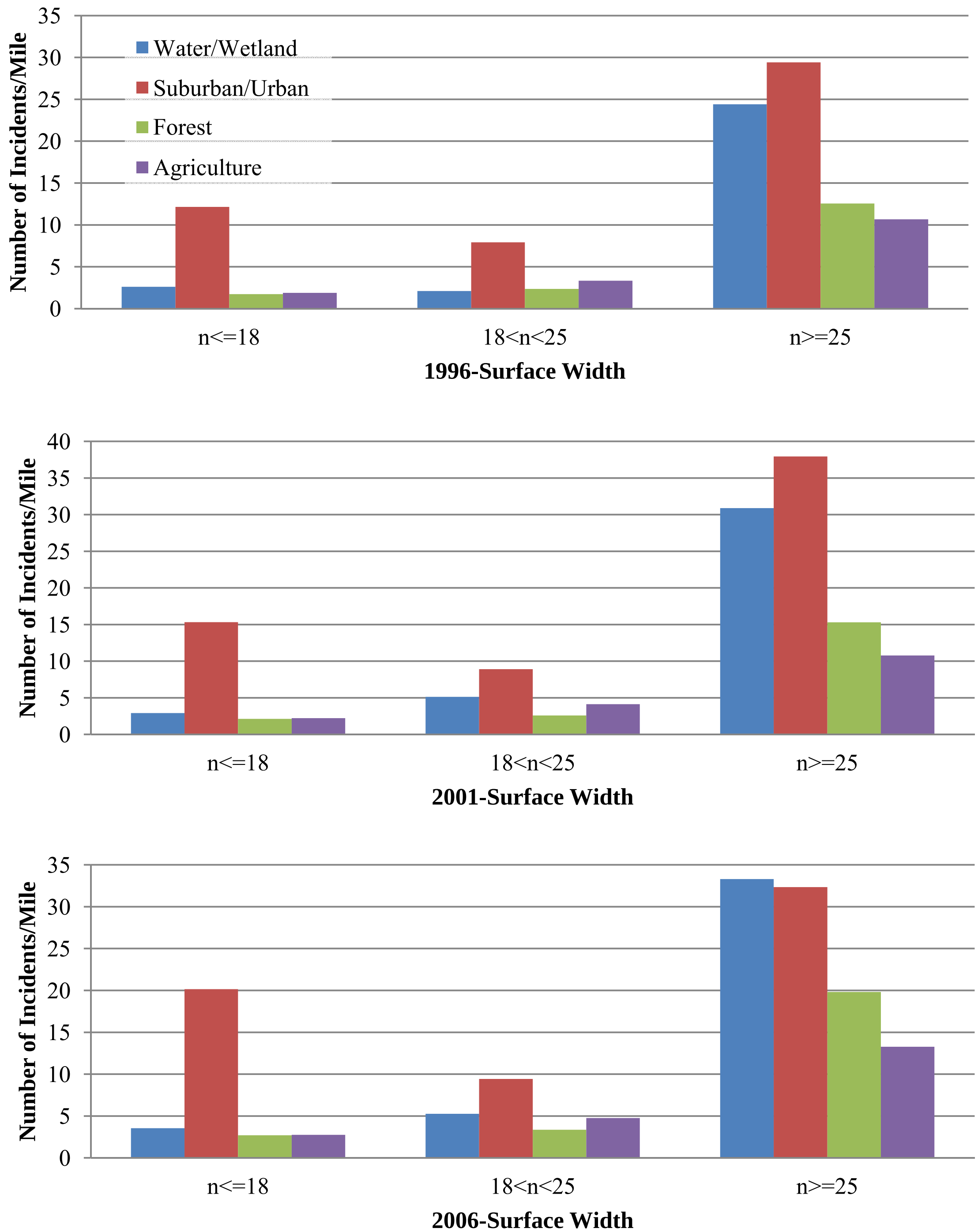

Figure 22. Distribution of Incidents by Surface Width per Miles of Road.

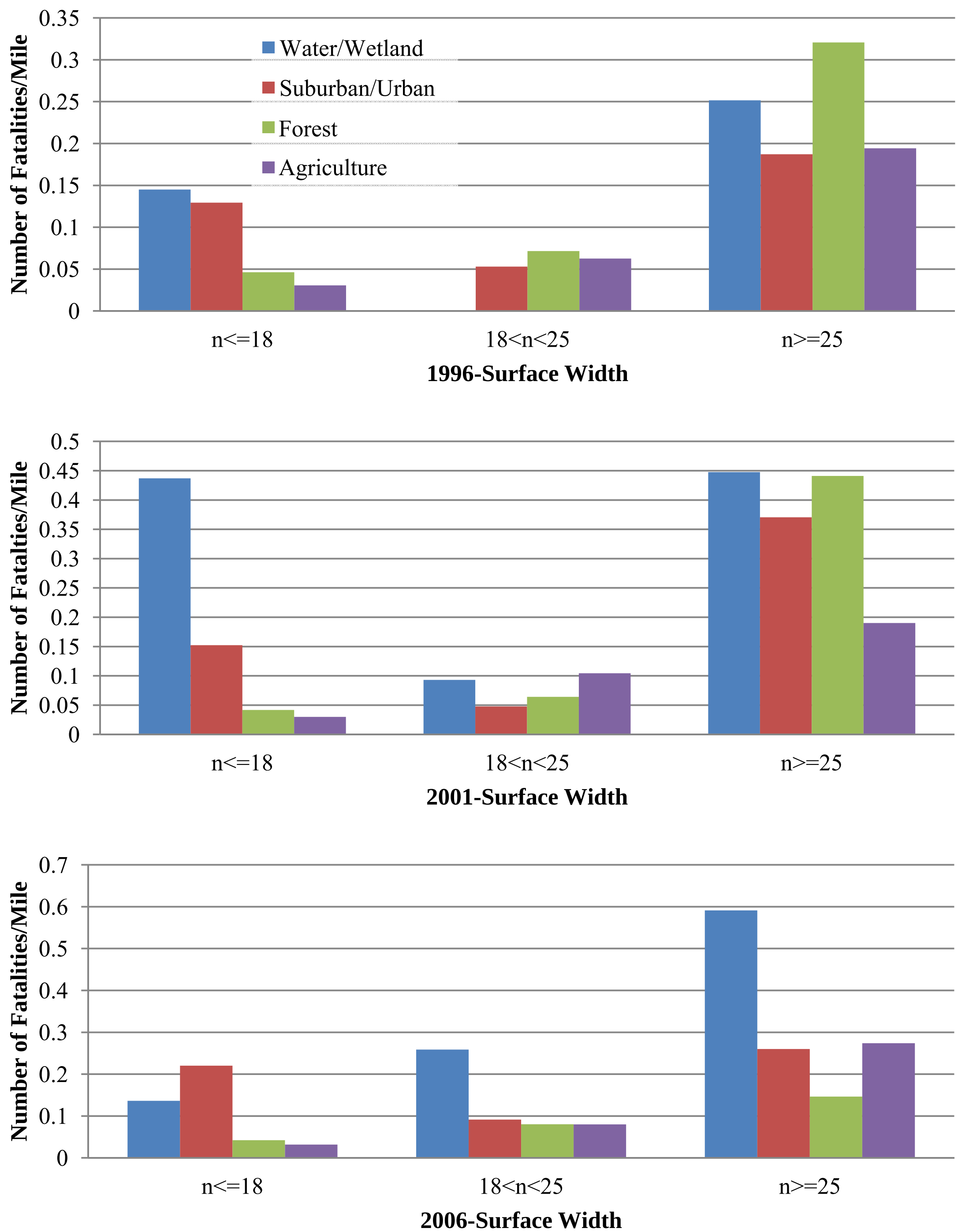

Figure 23. Distribution of Fatalities by Surface Width per Miles of Road.

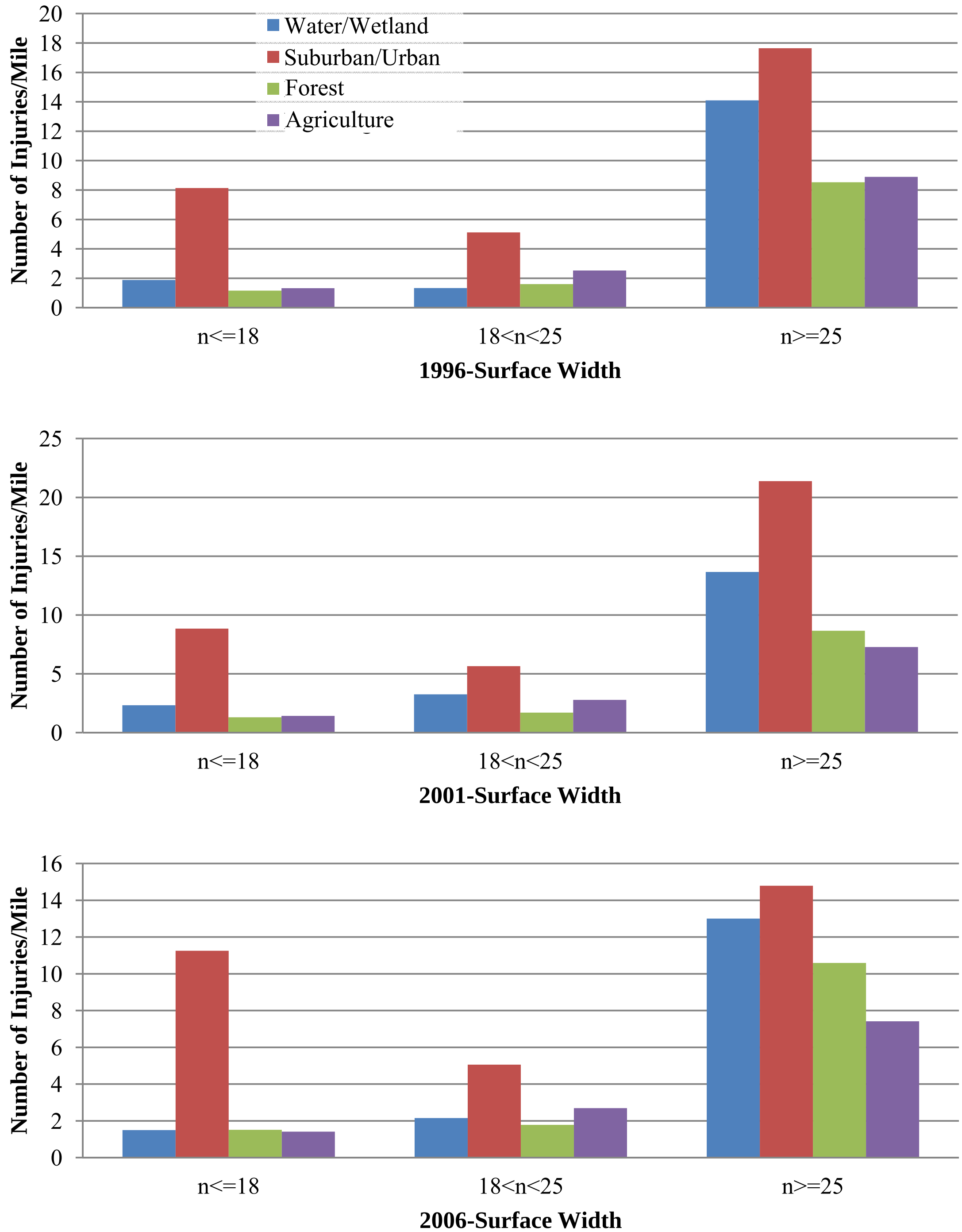

Figure 24. Distribution of Injuries by Surface Width per Miles of Road.

categories. The distribution of fatalities is slightly different with Suburban/Urban fatalities leading only on roads with surface widths less than 19 ft. On roads with surface widths from 19 ft to 24 ft, the three main categories are very close in fatalities per mile, with Forest leading in 1996, Agriculture leading 2001, and Suburban/Urban leading in 2006. On roads greater than 24 ft in width have more fatalities in 1996 and 200, while in 2006 Agriculture is slightly ahead of Suburban/Urban. The Suburban/Urban areas have significantly less mile of road than either rural category; therefore, the frequency of fatalities on roads less than 19 ft may be slightly skewed and would require additional research to explore this pattern.

Shoulder Width: Shoulder widths were divided into three categories: 1) n <= 2, 2) 2 < n <= 6ft, and 3) n > 6ft. Rural roads typically have shoulders less than 2 ft. Many of the residential and suburban areas have shoulders ranging from 2 to 6 ft (the definition of shoulder does not include curb and gutter or sidewalks). The interstates and other limited access highways typically have shoulders greater than 6 ft.

The majority of incidents and injuries are occurring along roads with shoulders less than 6 ft wide. Although the distribution is very close between Category 1 and Category 2, there is a pattern where there are more incidents and injuries occurring on roads with shoulders less than or equal to 2 ft in Suburban/Urban and Forest areas except in Agriculture where there are more incidents in areas with shoulders greater than 2 ft and less than 6 ft across all time periods (**Table 18, Table 19, Table 20**). However, in 2006

Suburban/Urban incidents on roads with shoulders less than or equal to 2 ft surpasses those incidents on roads with shoulders between 2 ft and 6 ft. For the most part, Fatalities also increase along roads with shoulders that are 2 ft or less to shoulders with 2 ft to 6 ft, with one exception in Suburban/Urban areas in 2001.

Similar to the previous discussion on Surface Widths, when the shoulder width increases from Category 1 to Category 2, there is a marked decrease in incidents, fatalities, and injuries across all time periods in Suburban/Urban land cover areas. For the rural land cover, the incidents, fatalities, and injuries typically increase with the increase in the shoulder widths, with a few exceptions in Forest fatalities and injuries (**Figure 25, Figure 26, Figure 27**). The Water/Wetland instances continue to represent a small portion of the data set and comparisons to the other land cover areas appear to be suspect. The per mile distribution of Suburban/Urban incidents, fatalities, and injuries are relatively high on roads with Shoulders less than or equal to 2 ft at least double of their counterparts on roads with shoulders between 2 ft and 6 ft. Roads with shoulders greater than 6 ft are comprise a significantly small portion of the total land cover change road segments (6 percent) and this continues to manifest in the charts with areas with fewer incidents, fatalities, and injuries coupling with relatively low road segment mileage leads to an inflated instances per mile. For both Forest and Agriculture the pattern for incidents and injuries is similar across all three time periods, a steady increase in numbers as the shoulder width increases (sometime with a small dip for the middle category. Fatalities begin with a slight increase between the first two categories;

Table 18. Distribution of Incidents by Shoulder Width and Land Cover Type.

Shoulder Width (ft)	n <= 2		2 < n <= 6		n > 6		Total	Percentage
1996 Land Cover-Incidents								
Land Cover	#	Miles	#	Miles	#	Miles		
Water/Wetland	100	6.99	28	11.76	9	2.61	137	1.35
Suburban/Urban	2892	104.51	1930	247.37	352	30.2	5174	51.10
Forest	1066	335.02	970	424.16	150	31.55	2186	21.59
Agriculture	896	374.15	1394	432.35	338	63.66	2628	25.96
Sub-Total	4954	820.66	4322	1115.65	849	128.03	10125	
Percentage	48.93	39.75	42.69	54.04	8.39	6.2		
2001 Land Cover-Incidents								
Water/Wetland	128	6.74	76	12.54	9	2.79	213	1.60
Suburban/Urban	3667	118.84	2904	292.41	634	34.39	7205	53.98
Forest	1379	331.93	1145	450.28	180	32.53	2704	20.26
Agriculture	1117	389.29	1697	445.32	412	63.6	3226	24.17
Sub-Total	6291	846.79	5822	1200.55	1235	133.3	13348	
Percentage	47.13	38.83	43.62	55.05	9.25	6.11		
2006-Land Cover-Incidents								
Water/Wetland	152	8.24	98	12.98	6	2.79	256	1.67
Suburban/Urban	3556	144.53	3657	299.09	631	36.34	7844	51.10
Forest	1581	322.96	1559	453.98	257	31.15	3397	22.13
Agriculture	1342	393.60	2046	447.87	465	63.03	3853	25.10
Sub-Total	6631	869.34	7360	1213.93	1359	133.31	15350	
Percentage	43.20	39.22	47.95	54.77	8.85	6.01	100.00	
Total	17876		17504		3443		38823	
Percentage	46.04		45.09		8.87			

Table 19. Distribution of Fatalities by Shoulder Width and Land Cover Type.

Shoulder Width (ft)	n <= 2	2 < n <= 6	n > 6	Total	Percentage
1996 Land Cover-Fatalities					
Water/Wetland	2	0	0	2	1.37
Suburban/Urban	17	17	2	36	24.66
Forest	22	34	5	61	41.78
Agriculture	18	22	7	47	32.19
Sub-Total	59	73	14	146	
Percentage	40.41	50.00	9.59		
2001 Land Cover-Fatalities					
Water/Wetland	1	4	1	6	3.03
Suburban/Urban	28	23	8	59	29.80
Forest	32	33	2	67	33.84
Agriculture	21	34	11	66	33.33
Sub-Total	82	94	22	198	
Percentage	41.41	47.47	11.11		
2006 Land Cover-Fatalities					
Water/Wetland	3	4	0	7	3.59
Suburban/Urban	29	35	7	71	36.41
Forest	15	29	12	56	28.72
Agriculture	19	31	11	61	31.28
Sub-Total	66	99	30	195	
Percentage	33.85	50.77	15.38	100.00	
Total	207	266	66	539	
Percentage	38.40	49.35	12.24		

Table 20. Distribution of Injuries by Shoulder Width and Land Cover Type.

Shoulder Width (ft)	n <= 2	2 < n <= 6	n > 6	Total	Percentage
1996 Land Cover-Injuries					
Water/Wetland	57	24	2	83	1.22
Suburban/Urban	1741	1263	228	3232	47.66
Forest	692	660	131	1483	21.87
Agriculture	673	1041	269	1983	29.24
Sub-Total	3163	2988	630	6781	
Percentage	46.65	44.06	9.29		
2001 Land Cover-Injuries					
Water/Wetland	61	49	2	112	1.37
Suburban/Urban	2051	1821	386	4258	52.05
Forest	836	739	91	1666	20.36
Agriculture	718	1119	308	2145	26.22
Sub-Total	3666	3728	787	8181	
Percentage	44.81	45.57	9.62		
2006 Land Cover-Injuries					
Water/Wetland	67	32	3	102	1.28
Suburban/Urban	1682	1986	257	3925	49.24
Forest	841	858	134	1833	23.00
Agriculture	720	1110	281	2111	26.48
Sub-Total	3310	3986	675	7971	
Percentage	41.53	50.01	8.47	100.00	
Total	10139	10702	2092	22933	
Percentage	44.21	46.67	9.12		

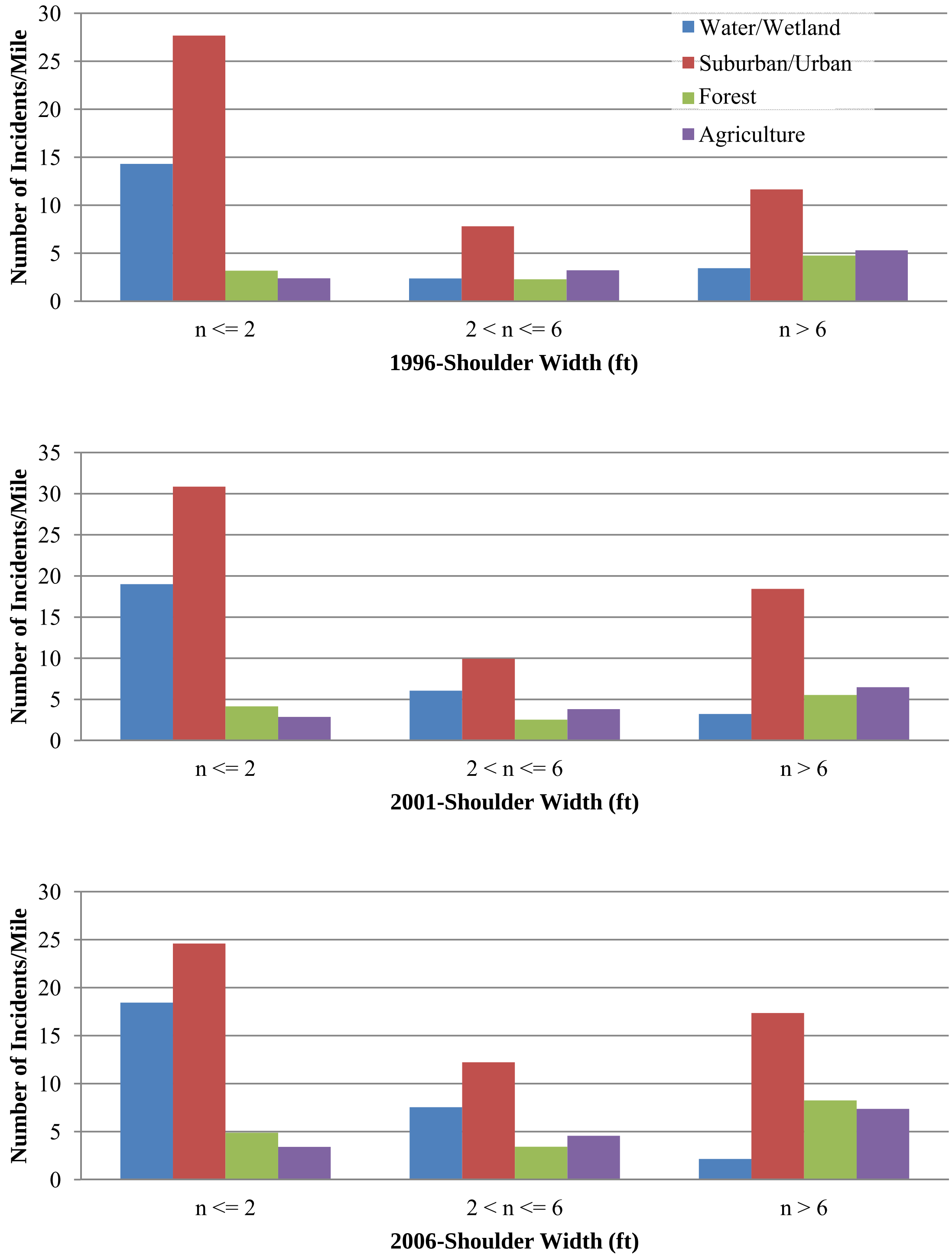

Figure 25. Distribution of Incidents by Shoulder Width per Miles of Road.

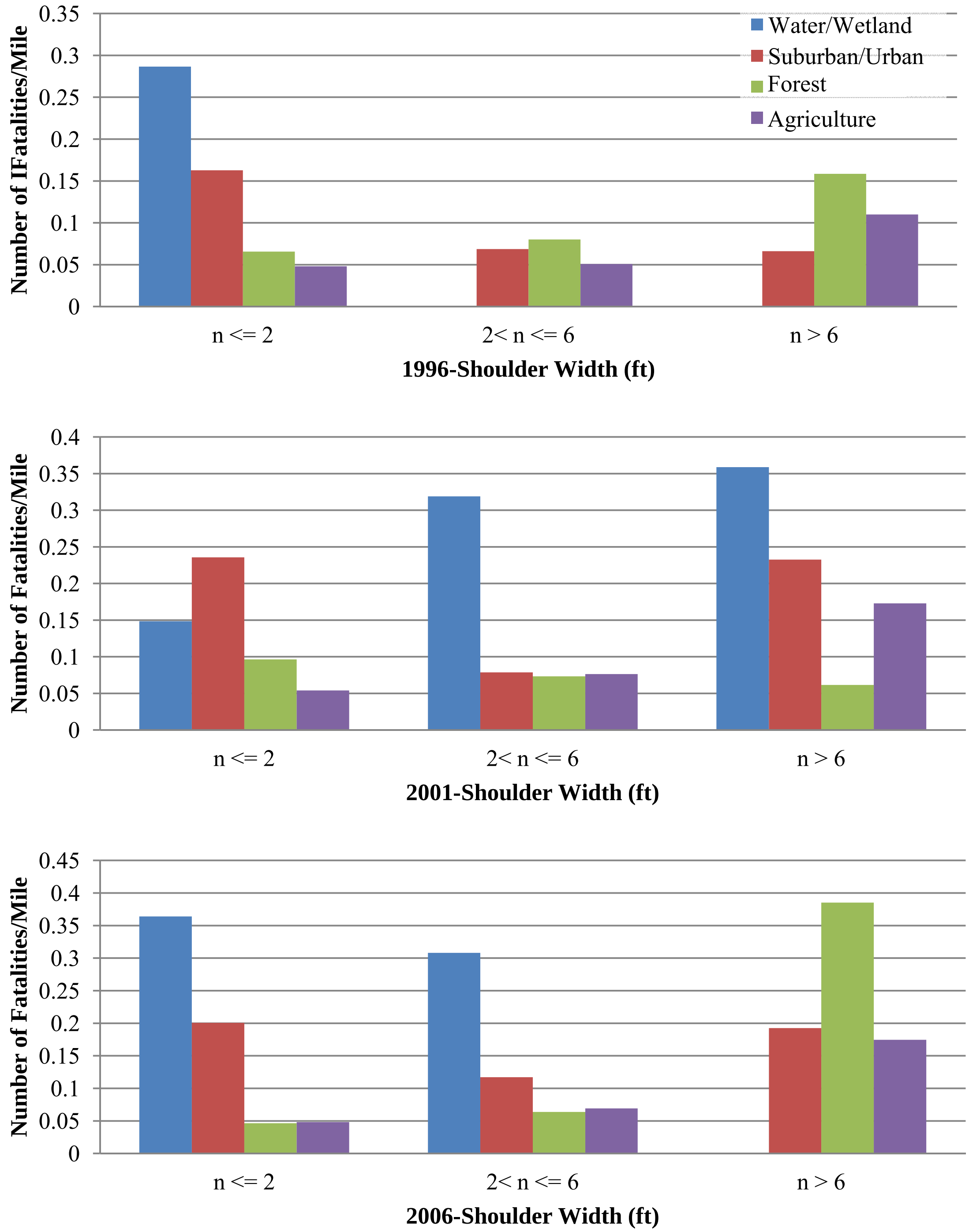

Figure 26. Distribution of Fatalities by Shoulder Width per Miles of Road.

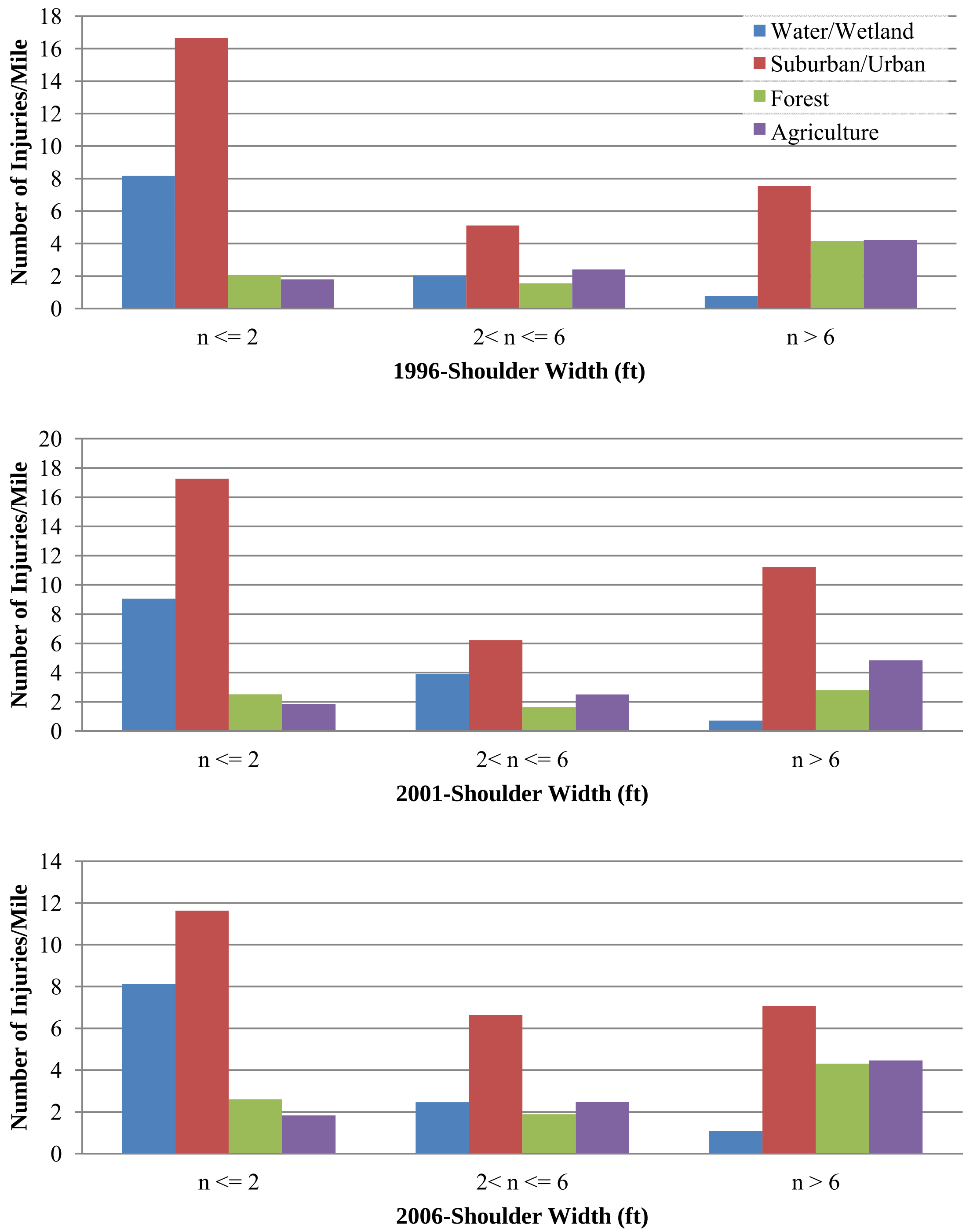

Figure 27. Distribution of Injuries by Shoulder Width per Miles of Road.

however, rise rather sharply on roads with shoulders greater than 6 ft except for Forest in 2001, where the fatalities decrease as shoulder width increases. The most incidents and injuries are occurring on roads with shoulders less than 7 ft wide across all land cover types. Fatalities appear to be more evenly distributed on little to no shoulder or larger shoulders with the main differences being which land cover type leads the category. Suburban/Urban fatalities lead both rural categories on roads with shoulders 2 ft or less. The three categories are somewhat even on the middle category, but Forest leads in fatalities on roads with shoulder greater than 6 ft in 1996 and 2006, while Suburban/Urban leads in fatalities in 2001.

Posted Speed: Posted Speed Limit was divided into four categories: 1) 30 miles per hour (mph) or less, 2) 35 to 45 mph, 3) 50 to 60 mph, and 4) greater than 65 mph. The first category corresponds generally to the town centers and the highly urban or commercialized areas. The second category generally covers residential and suburban areas on the outskirts of the town centers, as well as small communities along rural routes. The third category encompasses the rural highways, major secondary roads, and suburban/urban portions of the interstates; while the fourth category includes all interstates with speed limits of 65 or greater.

The distribution of incidents and injuries is dominated by Suburban/Urban land cover, where nearly half of all incidents and injuries occur within the Suburban/Urban land cover category. Forest and Agriculture each account for approximately 21 and 26 percent of the incidents and injuries, respectively (**Table 21, Table 22, Table 23**). The overall majority of the incidents are also occurring on roads with speed limits from 35 to 45 mph (69 percent) and a distant second on roads with a speed limit of 50 to 60 mph (20 percent). With the exception of fatalities, the general trend is upwards with the increase in the speed limit, with a drop in incidents and injuries occurring on roads with speed limits of 50 to 60 mph. The fatalities in the Suburban/Urban category have a generally increasing trend from 25 mph to 60 mph and then drop significantly with speed limits over 60 mph. The trend for Forest incidents, fatalities, and injuries follow a similar pattern across all three time periods. Forest begins with a general trend upwards through the first three categories and then spikes significantly when the speed limits reach 65 or more. Agriculture has a steady increasing pattern with the rise in speed limits; however, in Fatalities for 2006, Agriculture jumps to 1.4 fatalities per mile of road with speed limits greater then 60, more than 3x the next closest land cover type. This pattern is in stark contrast with the fatalities for Agriculture in 1996 and 2001, where each one drops to 0 for roads with speed limits greater than 60 (**Figure 28**, **Figure 29**, **Figure 30**).

Table 21. Distribution of Incidents by Posted Speed Limit and Land Cover Type.

Posted Speed Limit (mph)	n <= 30		35 to 45		50 to 60		n >= 65		Total	Percentage
1996 Land Cover-Incidents										
	#	Miles	#	Miles	#	Miles	#	Miles		
Water/ Wetland	3	2.76	113	15.06	14	3.17	7	0.37	137	1.35
Suburban /Urban	882	91.03	3515	237.86	577	40.67	200	12.53	5174	51.10
Forest	82	69.96	1545	570.12	454	143.70	105	6.96	2186	21.59
Agriculture	113	66.76	1568	559.03	936	241.85	11	2.52	2628	25.96
Sub-Total	1080	230.52	6741	1382.06	1981	429.38	323	22.37	10125	
Percentage	10.67	11.17	66.58	66.95	19.57	20.80	3.19	1.08		
2001 Land Cover-Incidents										
Water/ Wetland	6	2.77	191	14.83	14	4.10	2	0.37	213	1.60
Suburban/ Urban	883	102.23	5258	287.95	770	42.30	294	13.17	7205	53.98
Forest	92	83.41	1898	583.17	596	141.43	118	6.72	2704	20.26
Agriculture	112	71.96	1942	577.30	1163	246.84	9	2.11	3226	24.17
Sub-Total	1093	260.37	9289	1463.25	2543	434.67	423	22.37	13348	
Percentage	8.19	11.94	69.59	67.10	19.05	19.93	3.17	1.03		
2006-Land Cover-Incidents										
Water/ Wetland	11	2.82	220	16.73	17	4.09	8	0.37	248	1.62
Suburban/ Urban	763	105.82	6194	315.16	360	43.13	527	15.86	7317	47.67
Forest	120	80.79	2295	579.58	830	141.86	152	5.87	3245	21.14
Agriculture	141	73.53	2290	581.60	1409	247.89	13	1.47	3840	25.02
Sub-Total	1035	262.95	10999	1493.08	2616	436.97	700	23.58	15350	
Percentage	6.74	11.86	71.65	67.36	17.04	19.71	4.56	1.06	100	
Total	3208		27029		7140		1446		38823	
Percentage	8.26		69.62		18.39		3.72			

Table 22. Distribution of Fatalities by Posted Speed Limit and Land Cover Type.

Posted Speed Limit (mph)	n <= 30	35 to 45	50 to 60	n >= 65	Total	Percentage
1996 Land Cover-Fatalities						
Water/Wetland	0	2	0	0	2	1.37
Suburban/Urban	2	31	3	0	36	24.66
Forest	5	40	15	1	61	41.78
Agriculture	0	30	17	0	47	32.19
Sub-Total	7	103	35	1	146	
Percentage	4.79	70.55	23.97	0.68		
2001 Land Cover-Fatalities						
Water/Wetland	0	6	0	0	6	3.03
Suburban/Urban	9	45	4	1	59	29.80
Forest	1	44	20	2	67	33.84
Agriculture	1	34	31	0	66	33.33
Sub-Total	11	129	55	3	198	
Percentage	5.56	65.15	27.78	1.52		
2006 Land Cover-Fatalities						
Water/Wetland	1	4	2	0	7	3.59
Suburban/Urban	9	48	12	2	71	36.41
Forest	0	36	17	3	56	28.72
Agriculture	1	29	29	2	61	31.28
Sub-Total	11	117	60	7	195	
Percentage	5.64	60.00	30.77	3.59	100.00	
Total	29	349	150	11	539	
Percentage	5.38	64.75	27.83	2.04		

Table 23. Distribution of Injuries by Posted Speed Limit and Land Cover Type.

Posted Speed Limit (mph)	n <= 30	35 to 45	50 to 60	n >= 65	Total	Percentage
1996 Land Cover-Injuries						
Water/Wetland	3	69	5	6	83	1.22
Suburban/Urban	545	2203	377	107	3232	47.66
Forest	59	1008	354	62	1483	21.87
Agriculture	87	1146	744	6	1983	29.24
Sub-Total	694	4426	1480	181	6781	
Percentage	10.23	65.27	21.83	2.67		
2001 Land Cover-Injuries						
Water/Wetland	7	100	4	1	112	1.37
Suburban/Urban	628	3072	379	179	4258	52.05
Forest	70	1169	390	37	1666	20.36
Agriculture	72	1284	782	7	2145	26.22
Sub-Total	777	5625	1555	224	8181	
Percentage	9.50	68.76	19.01	2.74		
2006 Land Cover-Injuries						
Water/Wetland	1	95	6	0	102	1.28
Suburban/Urban	398	3120	195	212	3925	49.24
Forest	69	1186	518	60	1833	23.00
Agriculture	69	1241	797	4	2111	26.48
Sub-Total	537	5642	1516	276	7971	
Percentage	6.74	70.78	19.02	3.46		
Total	2008	15693	4551	681	22933	
Percentage	8.76	68.43	19.84	2.97		

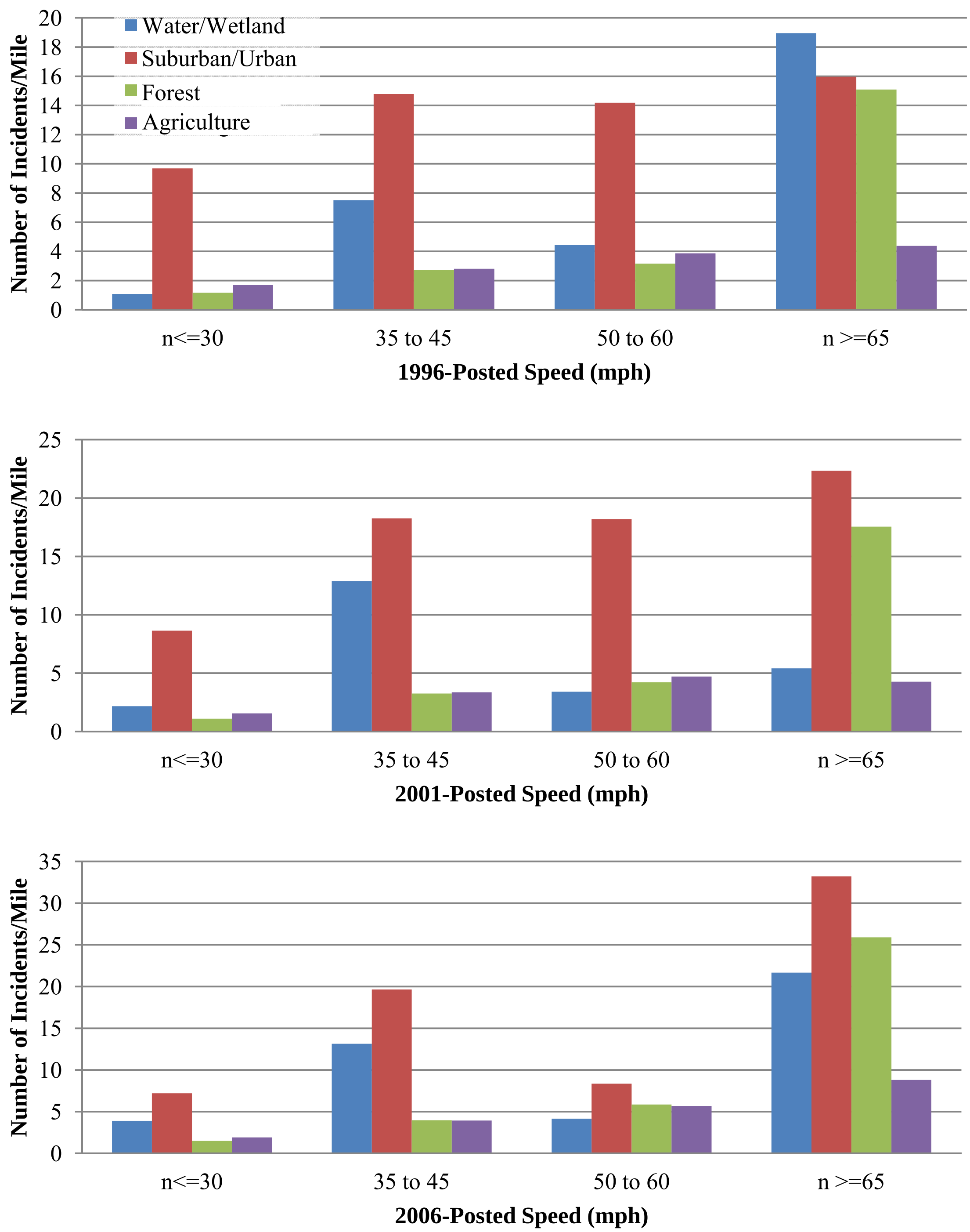

Figure 28. Distribution of Incidents by Posted Speed Limit per Miles of Road.

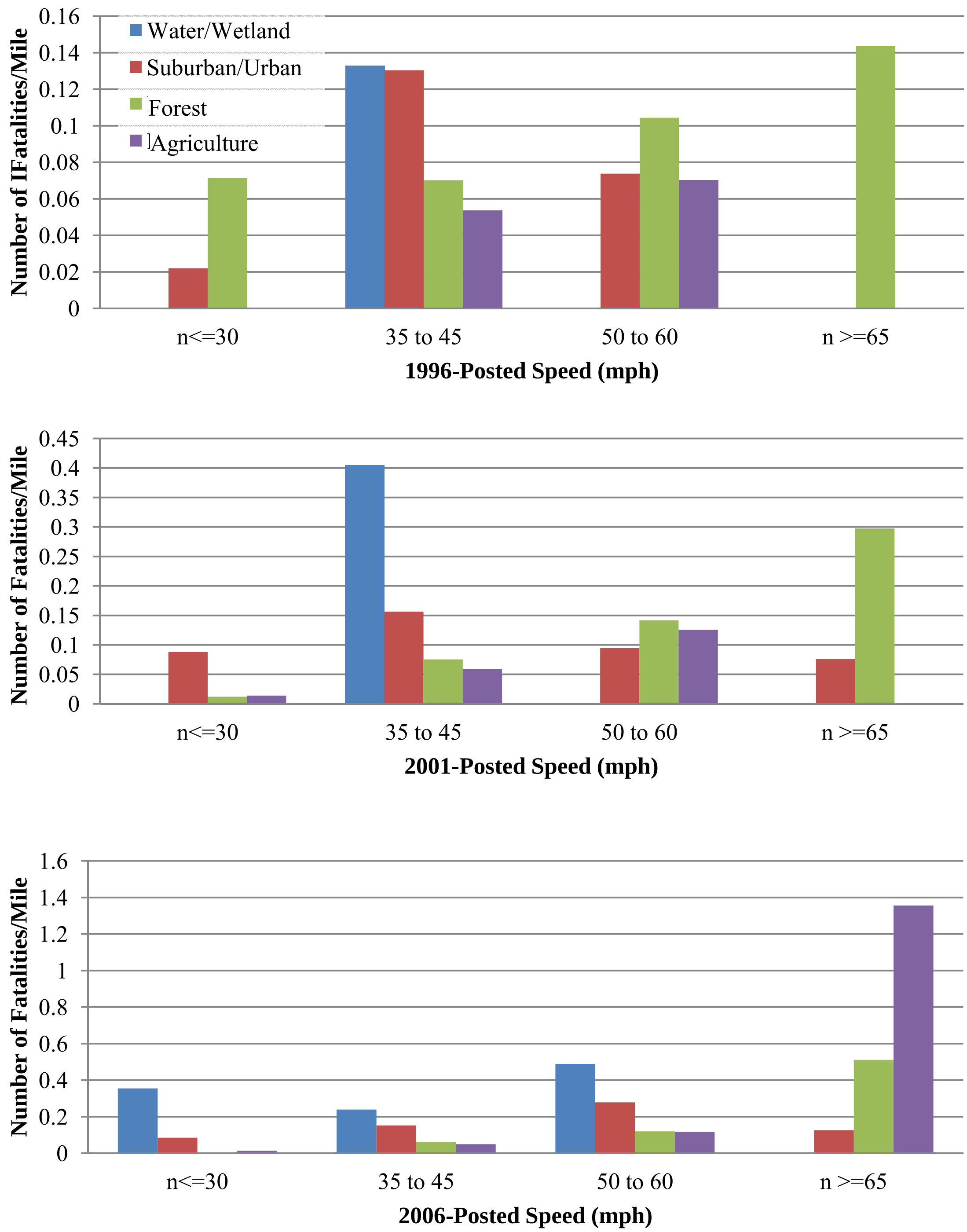

Figure 29. Distribution of Fatalities by Posted Speed Limit per Miles of Road.

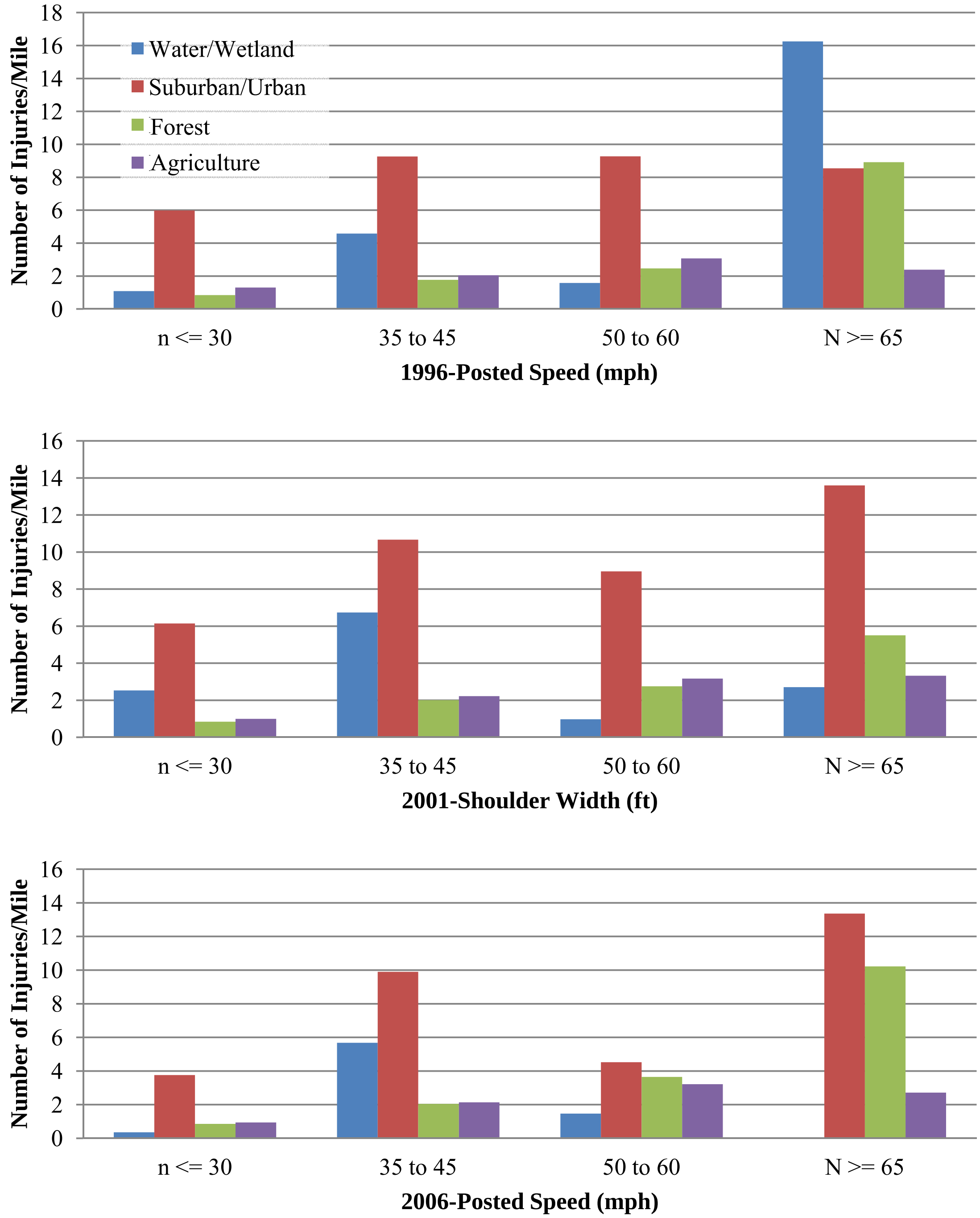

Figure 30. Distribution of Injuries by Posted Speed Limit per Miles of Road.

Median Width. The median width was divided into four categories, 1) 0 or no median, 2) $0 < n <= 20$, 3) $20 < n <= 40$, and 4) $n > 40$. Category 1 covers primarily all the rural roads (usually 2-Lanes); however, there are portions of major roads, such as Route 1, where there is no median as well. The second category covers the majority of the Suburban/Urban and residential areas as well as the other land cover types as they transition to the Suburban/Urban areas. The third category and fourth category could probably be combined; however, as it is divided here the third category includes the major primary roads and other Suburban/Urban areas while the fourth category includes primarily Interstate 95.

Similar to the distribution of incidents and injuries in previous discussions, Suburban/Urban land cover comprises nearly 50 percent of all incidents and injuries across all three time periods. Over 70 percent of all incidents, fatalities, and injuries are occurring on roads with no median which comprise approximately 92 percent of the roads within the project area. The remaining categories range between 8 to 10 percent of the incidents and injuries, while 15 percent of fatalities are occurring along roads with medians greater than 40 ft (such as interstates) and only 5 percent on roads with medians ranging from 20 to 40 ft in width (**Table 24, Table 25, Table 26**).

Although more than 70 percent of the incidents, fatalities, and injuries are occurring on roads with no medians, the highest per mile category for incidents and injuries is the along Suburban/Urban segments with medians less than 20 ft. Generally, the incidents

Table 24. Distribution of Incidents by Median Width and Land Cover Type.

Median Width (ft)	0		0 < n <= 20		20 < n <= 40		n > 40		Total	Percentage
1996 Land Cover-Incidents										
	#	Miles	#	Miles	#	Miles	#	Miles		
Water/ Wetland	49	17.57	1	0.53	8	0.55	79	2.70	137	1.35
Suburban/ Urban	3500	329.55	962	19.65	395	13.42	317	19.46	5174	51.10
Forest	1624	748.54	43	3.18	144	13.74	375	25.28	2186	21.59
Agriculture	2187	831	20	3.93	319	26.93	102	8.29	2628	25.96
Sub-Total	7360	1926.67	1026	27.30	866	54.63	873	55.73	10125	
Percentage	72.69	93.33	10.13	1.32	8.55	2.65	8.62	2.70		
2001 Land Cover-Incidents										
Water/ Wetland	95	18.07	4	0.51	4	0.99	110	2.53	213	1.60
Suburban/ Urban	4792	388.93	1468	22.17	498	20.37	447	21.93	7205	54.08
Forest	1927	772.63	48	4.67	202	11.84	526	23.93	2703	20.29
Agriculture	2720	856.56	31	7.09	367	23.54	83	14.41	3201	24.03
Sub-Total	9534	2036.19	1551	34.43	1071	56.74	1166	62.79	13322	
Percentage	71.57	92.97	11.64	1.57	8.04	2.59	8.75	2.87		
2006-Land Cover-Incidents										
Water/ Wetland	121	20.01	0	0.51	7	0.99	128	2.53	256	1.67
Suburban/ Urban	4977	416.59	1318	24.51	582	21.21	967	25.98	7844	51.23
Forest	2418	766.89	82	4.64	264	11.45	630	23.45	3394	22.17
Agriculture	3247	863.96	41	6.19	455	23.29	75	14.08	3818	24.93
Sub-Total	10763	2067.45	1441	35.85	1308	56.94	1800	66.04	15312	
Percentage	70.29	92.87	9.41	1.61	8.54	2.56	11.76	2.97	100	
Total	27657		4018		3245		3839		38759	
Percentage	71.36		10.37		8.37		9.90			

Table 25. Distribution of Fatalities by Median Width and Land Cover Type.

Median Width (ft)	0	0 < n <= 20	20 < n <= 40	n > 40	Total	Percentage
1996 Land Cover-Fatalities						
Water/Wetland	1	0	0	1	2	1.37
Suburban/Urban	25	1	2	8	36	24.66
Forest	50	0	2	9	61	41.78
Agriculture	39	0	4	4	47	32.19
Sub-Total	115	1	8	22	146	
Percentage	78.77	0.68	5.48	15.07		
2001 Land Cover-Fatalities						
Water/Wetland	4	0	1	1	6	3.03
Suburban/Urban	33	12	7	7	59	29.80
Forest	47	0	6	14	67	33.84
Agriculture	57	0	7	2	66	33.33
Sub-Total	141	12	21	24	198	
Percentage	71.21	6.06	10.61	12.12		
2006 Land Cover-Fatalities						
Water/Wetland	4	0	0	3	7	3.61
Suburban/Urban	47	8	12	4	71	36.60
Forest	50	0	2	4	56	28.87
Agriculture	47	1	9	3	60	30.93
Sub-Total	148	9	23	14	194	
Percentage	76.29	4.64	11.86	7.22	100.00	
Total	404	22	52	60	538	
Percentage	75.09	4.09	9.67	11.15		

Table 26. Distribution of Injuries by Median Width and Land Cover Type.

Median Width (ft)	0	0 < n <= 20	20 < n <= 40	n > 40	Total	Percentage
1996 Land Cover-Injuries						
Water/Wetland	38	1	0	44	83	1.22
Suburban/Urban	2244	532	288	168	3232	47.66
Forest	1118	36	117	212	1483	21.87
Agriculture	1607	20	272	84	1983	29.24
Sub-Total	5007	589	677	508	6781	
Percentage	73.84	8.69	9.98	7.49		
2001 Land Cover-Injuries						
Water/Wetland	61	1	1	49	112	1.37
Suburban/Urban	2891	764	349	254	4258	52.19
Forest	1238	33	151	244	1666	20.42
Agriculture	1804	15	249	54	2122	26.01
Sub-Total	5994	813	750	601	8158	
Percentage	73.47	9.97	9.19	7.37		
2006 Land Cover-Injuries						
Water/Wetland	46	0	2	54	102	1.28
Suburban/Urban	2694	543	295	393	3925	49.31
Forest	1305	38	167	323	1833	23.03
Agriculture	1778	28	260	34	2100	26.38
Sub-Total	5823	609	724	804	7960	
Percentage	73.15	7.65	9.10	10.10		
Total	16824	2011	2151	1913	22899	
Percentage	73.47	8.78	9.39	8.35		

occurring on segments with no median are consistent through the three time periods for each of the land cover types. Forest incidents increase with the median width increase, while Agriculture increases up to Category 3 and declines when medians become greater than 40 ft in 2001 and 2006. The distribution of incidents is very similar to the distribution of incidents (**Figure 31, Figure 32, Figure 33**).

With fatalities, the distribution changes with each time period and with each land cover type; however, there are a limited number of fatalities within categories other than Category 1 which may skew the distribution. Overall, the general trend is an increasing number of fatalities as the median width increases from Category 2 to 4. There are more Suburban/Urban fatalities occurring on roads with Category 1 and 2 medians through all three time periods and in Category 3 for 2006. In 1996, Agriculture fatalities are slightly above Suburban/Urban fatalities in Category 3 and clearly outnumber them in Category 4 in 1996 and in 2006. In 2001, Forest outnumbers the Suburban/Urban fatalities.

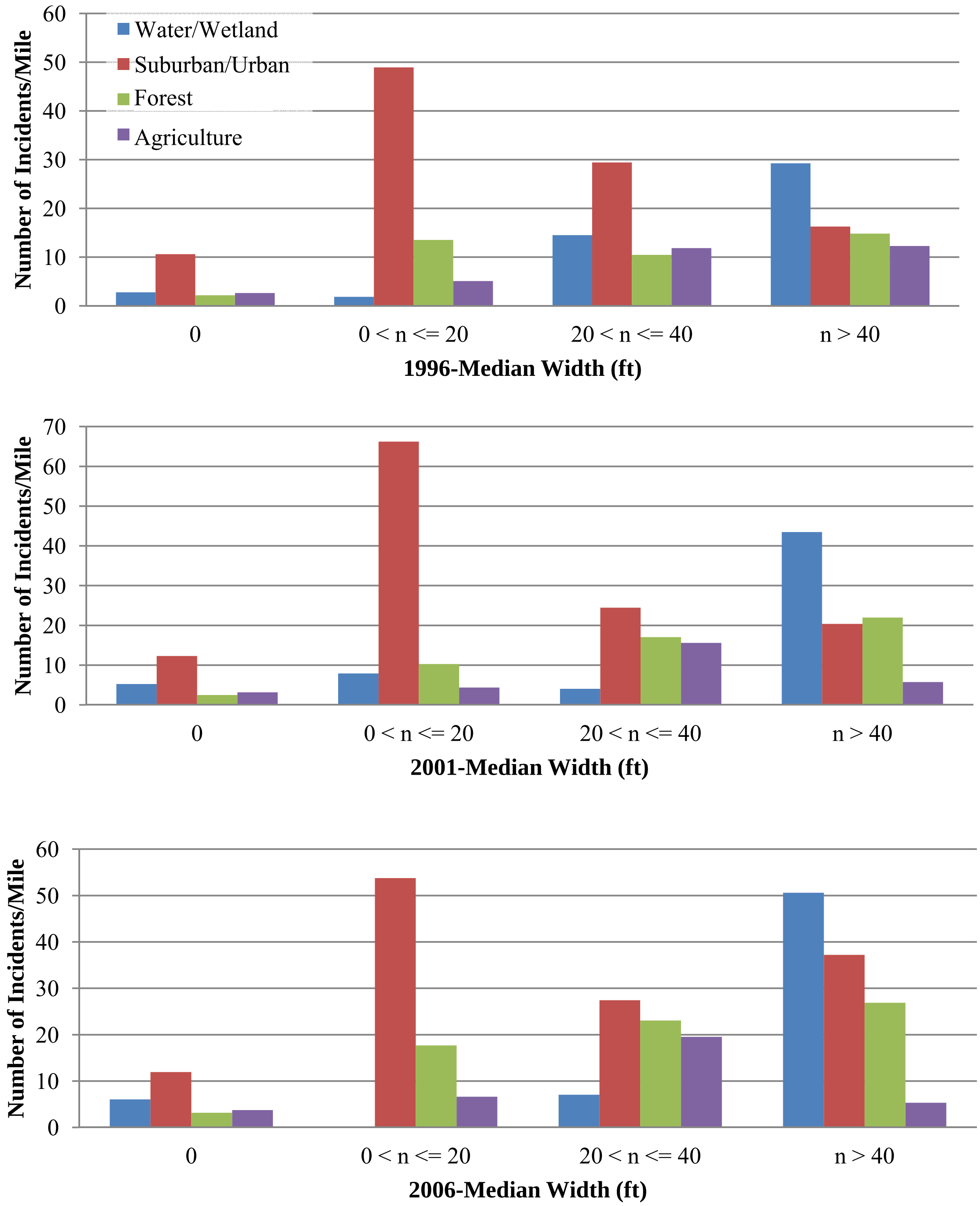

Figure 31. Distribution of Incidents by Median Width per Miles of Road.

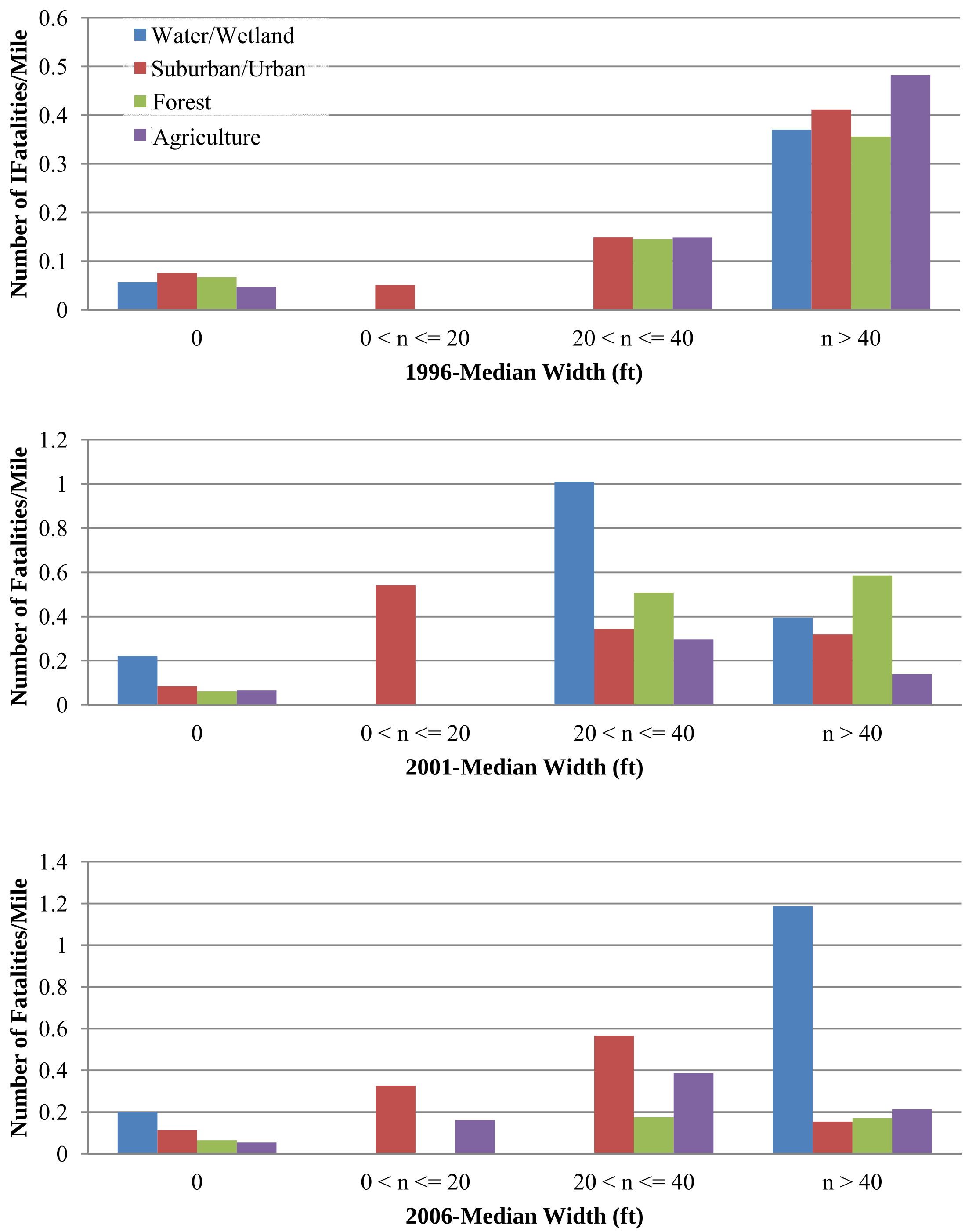

Figure 32. Distribution of Fatalities by Median Width per Miles of Road.

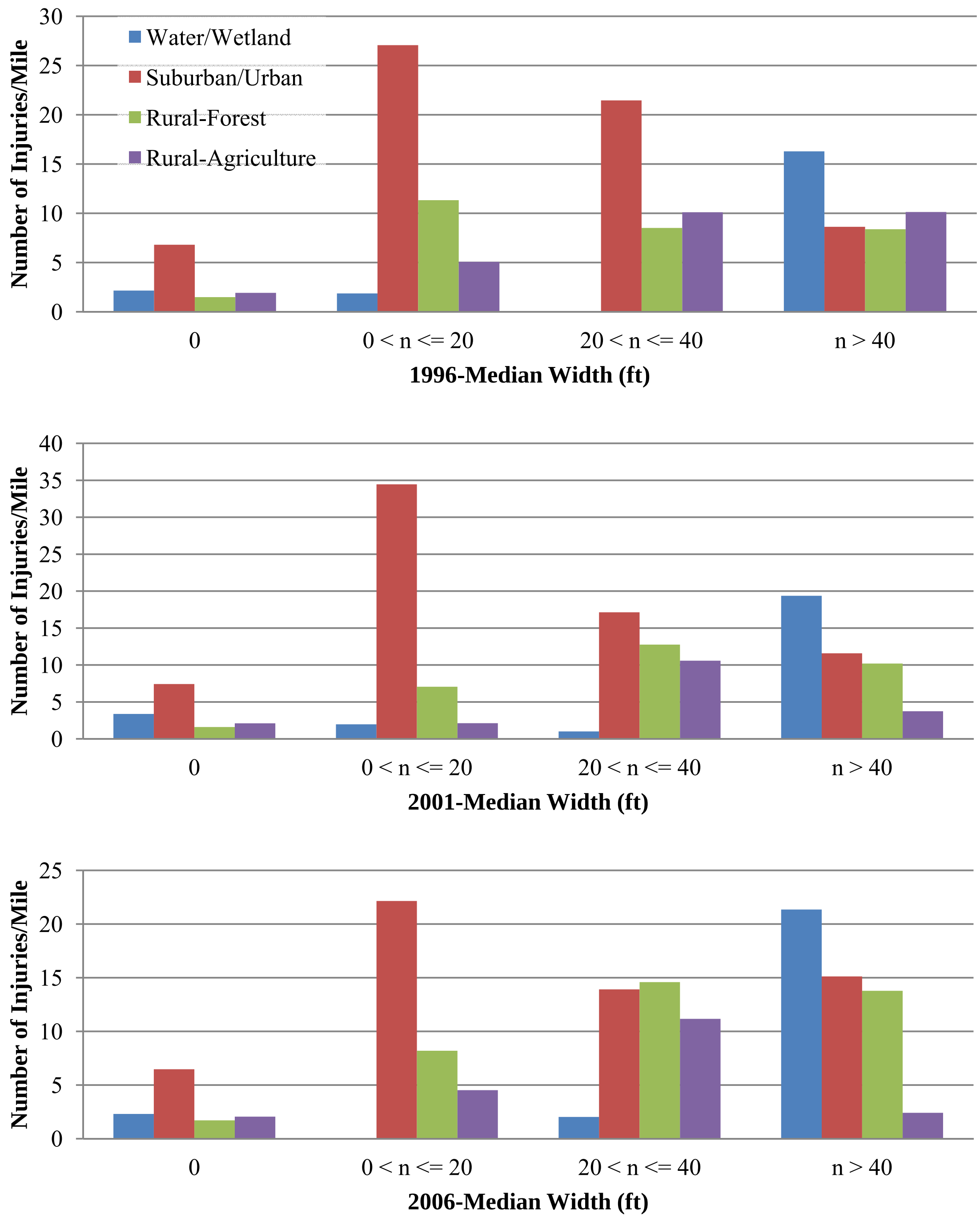

Figure 33. Distribution of Injuries by Median Width per Miles of Road.

Incident Type. The incident types were broken down into eight categories from the 10 to 12 categories used to report incidents by the Virginia State Police. The categories include Angle, Fixed Object, Sideswipe, Rear End, Head On, Animal, Non-Collision, and Other. The Fixed Object includes incidents reported as fixed object in road and fixed object off road, i.e. tree or telephone pole. The Sideswipe category includes Sideswipe-same direction and Sideswipe opposite direction. Rear End and Head On are singular categories in the VSP reporting and are self-explanatory. Animal includes both deer and any other animal. Non-Collision incidents can be defined as running off the road, rollover, cross median or centerline, fire, or equipment failure. The other category is the catch-all for incident types that do not fit in the above categories or make up a very small percentage of the overall incidents (less than 1 percent) and includes incidents involving trains, pedestrians, and where no incident type was noted (DMV 2007).

The distribution of incident types follows the general trend of many of the previous categories but is not related directly to the road characteristics. There are four main categories that the incidents fall into: Angle, Fixed Object, Sideswipe, and Rear End. The majority of the incidents and injuries occur in the Suburban/Urban areas, where the majority of the traffic is located. The Fatalities are dominated by Forest in 1996 and are more evenly distributed among the three main land cover categories in 2001 and 2006 (**Figure 34, Figure 35, Figure 36**).

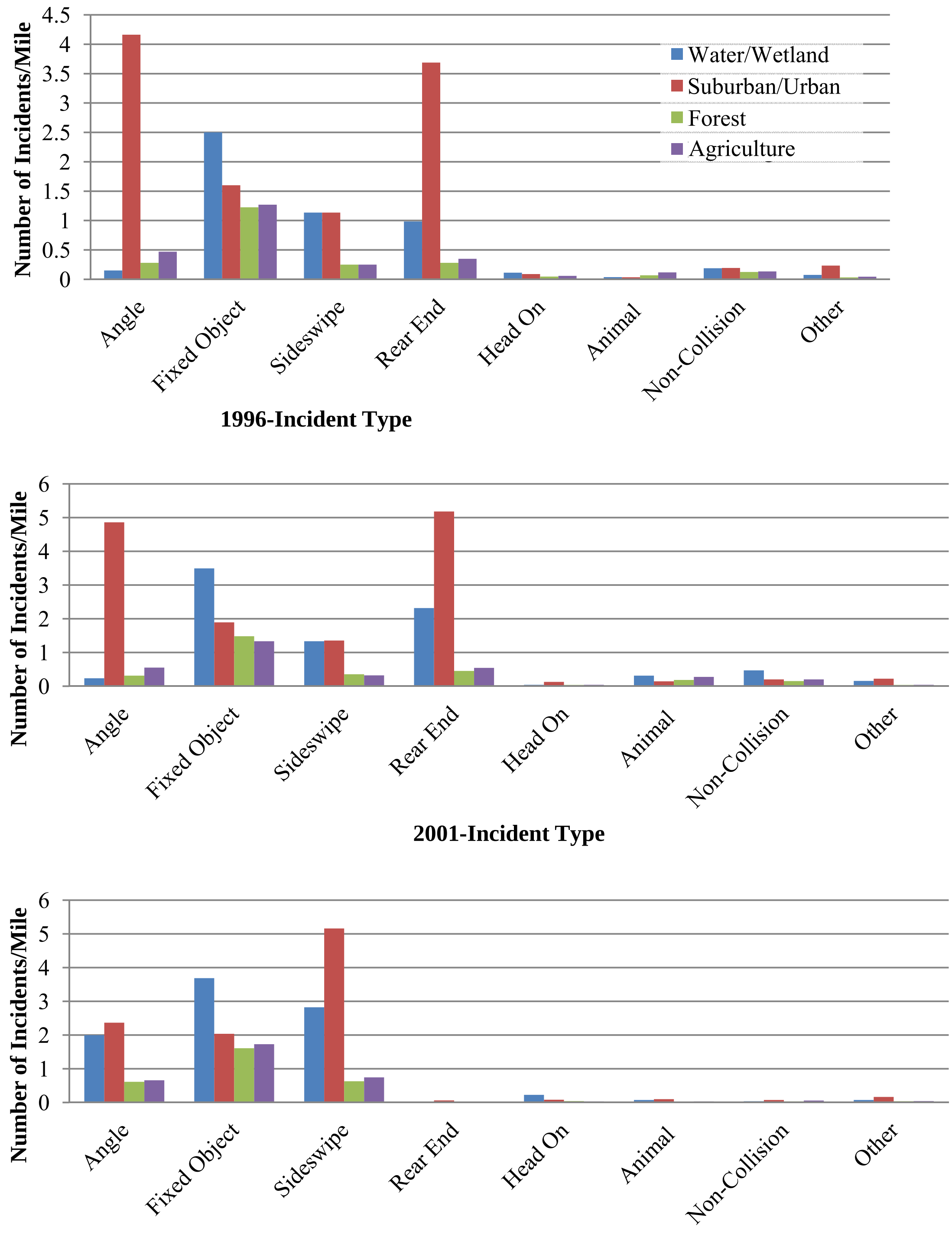

Figure 34. Distribution of Incidents by Incident Types per Miles of Road.

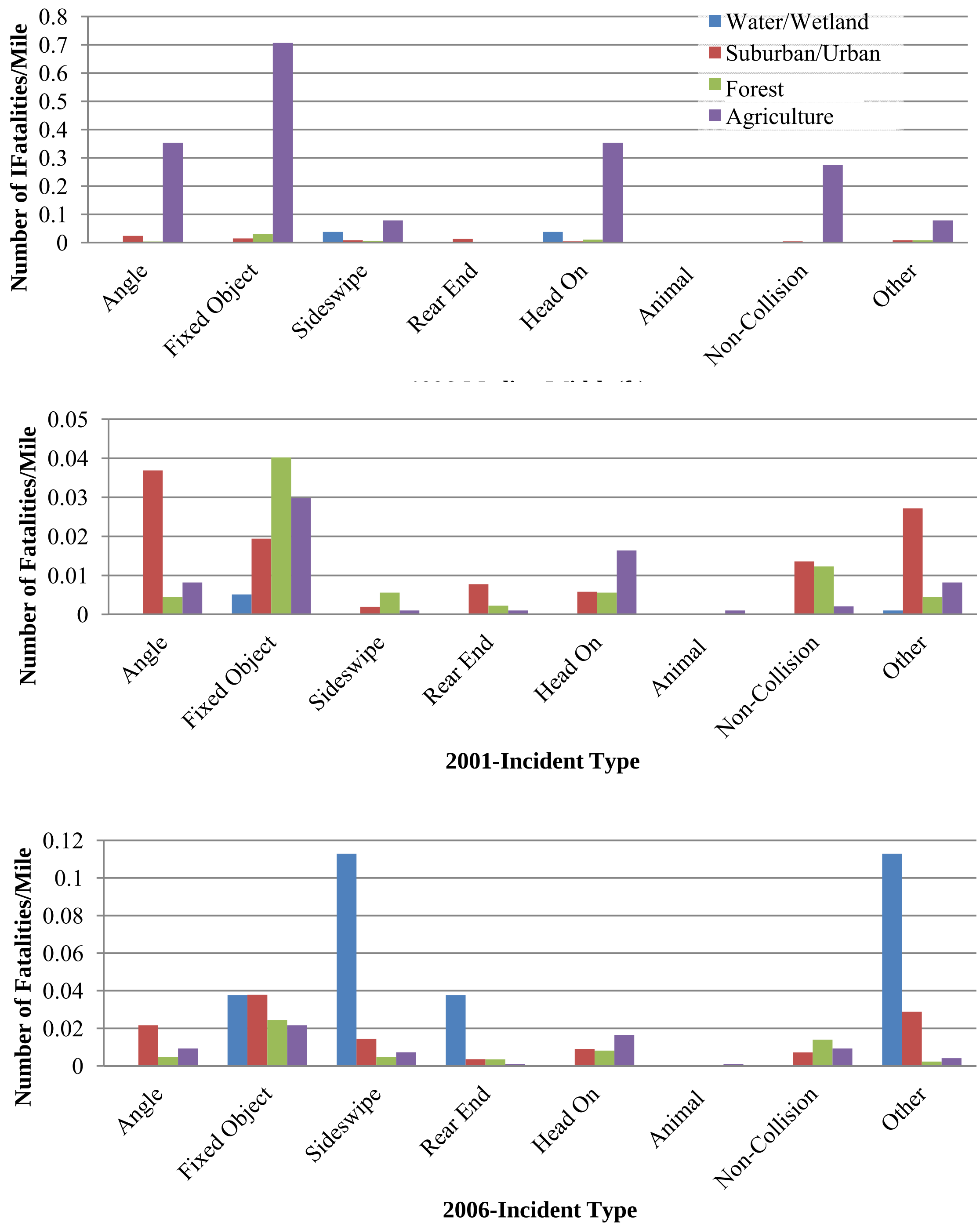

Figure 35. Distribution of Fatalities by Incident Type per Miles of Road.

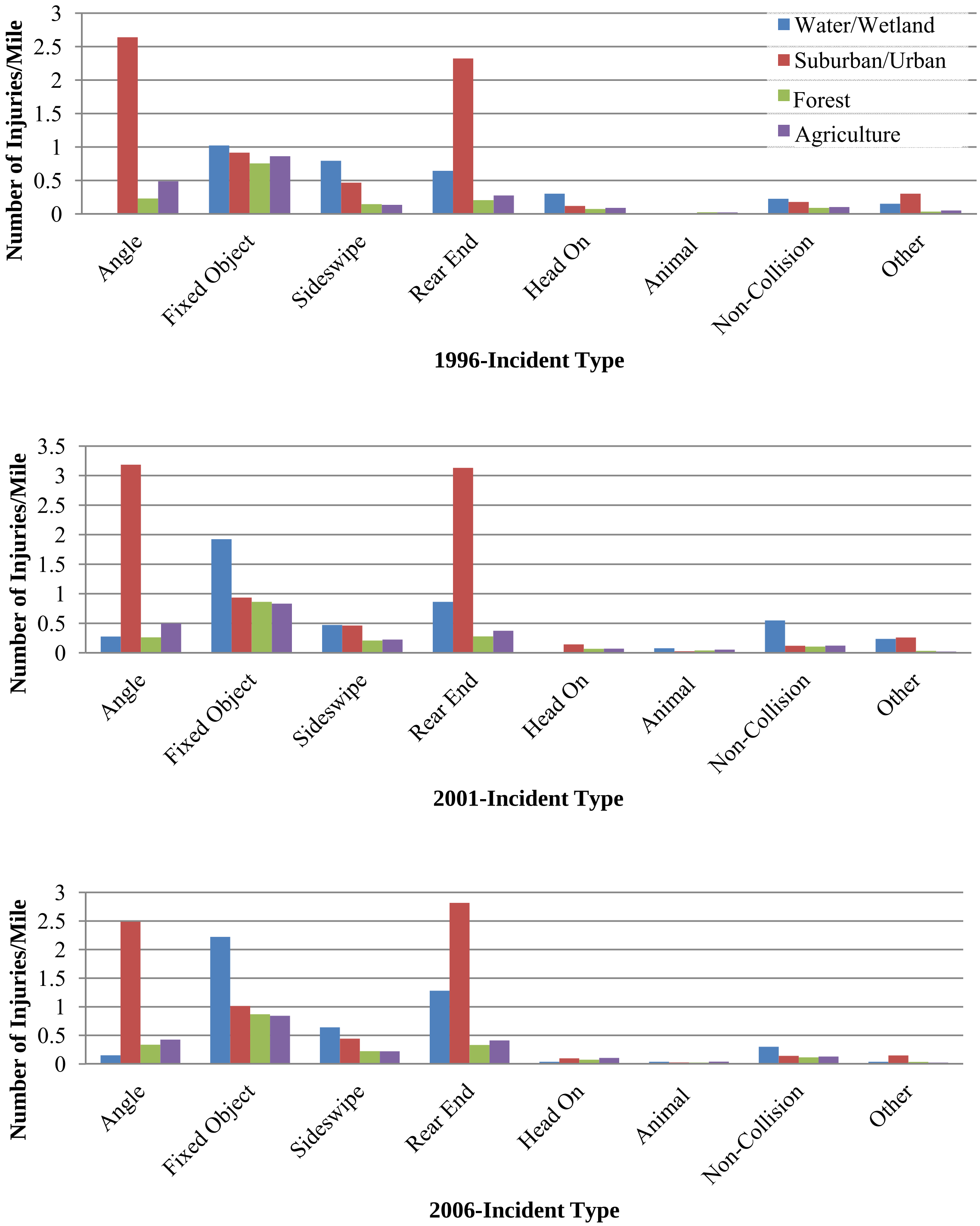

Figure 36. Distribution of Injuries by Incident Type per Miles of Road.

Summary of Results for Other Road Characteristics

- Number of Lanes: More than 64 percent of traffic incidents, fatalities, and injuries are occurring on 2-Lane roads, which make up 92 percent of the total mileage of roads. However, incidents and injuries per mile increase significantly with the increase in the number of lanes, due to lower miles of road with six lanes. Fatalities per mile are highest on 4-Lane roads throughout, and specifically in Forest areas (1996 and 2001) and Suburban-Urban areas in 2006.
- Surface Width: The majority of incidents and injuries are occurring on roads with surface widths greater than 18 ft and less than 24; although roads with surface widths greater than 24 ft are only 3 to 4 percentage points behind. Fatalities, however, are more prevalent on roads between 18 and 24 ft wide (46 percent). Looking at the distributions per mile, more incidents per mile are occurring on roads with surface widths greater than 24 ft. Generally, for Suburban/Urban More fatalities overall have occurred in Forest (n =184, 34.14 percent); although Suburban/Urban fatalities (n = 166, 30.78 percent) have been increasing over the study time period, increasing from 36 in 1996 to 71 in 2006. Still, Forest and Agriculture (n = 174, 32.28 percent) outnumber Suburban/Urban incidents.
- Shoulder Width: Roads with shoulder widths less than 2 ft and between 2 ft and 6 ft have similar numbers of incidents and injuries. Fatalities are more prevalent on roads with shoulder widths between 2 ft and 6 ft wide. Forest and Agriculture fatalities outnumber Suburban/Urban fatalities in 1996 and 2001, while Suburban/Urban fatalities surpass both rural categories in 2006. Per mile

distributions of Suburban/Urban incidents, fatalities, injuries are in the majority on roads with shoulders less than 2 ft.

- Posted Speed: The overwhelming majority of incidents, fatalities, and injuries occur on roads with speed limits between 35 and 45 mph. For the most part the distribution of incidents, fatalities, and injuries are higher on roads with speed limits from 35 to 45 mph and greater than 65 mph. Of particular note, the Forest (1996, 2001) and Agriculture (2006) spike in fatalities based primarily on the low number of miles.
- Median Width: More than 70 percent of the incidents, fatalities, and injuries are occurring along roads with no median. However, with the per mile distributions, Suburban/Urban incidents and injuries are more prevalent on roads with medians greater than 0 ft but less than 20 ft. Fatalities, on the other hand, are more prominent on roads with no median; although per mile distributions fluctuate between the other three categories.
- Incident Type: The majority of the incident types are Angle, Fixed Object, Side-Swipe, and Rear End. Angle, Side-Swipe, and Rear End are more prevalent in Suburban/Urban areas and Fixed Objects are more numerous in rural areas. Per mile distributions of Angle and Rear End incidents and injuries are significantly higher in Suburban/Urban in 1996 and 2001, whereas Sideswipe increases more than twofold in 2006.

Land Cover Change

Using the different land cover time periods (1992, 1996, 2001, 2006), this study identifies those segments of the road network, with linear referencing tools, where the land cover changes from one type to another. Additionally, the incidents and associated land cover change for each time period are analyzed to see if any patterns emerge in the types of land cover change with incidents and road characteristics.

As shown in the previous section, the Water/Wetland category comprises less than 2 percent of the total incidents and less than 5 percent of the total area of the project area. Therefore, for the remainder of the study, the Water/Wetland category will not be included in this discussion. Also, the change from Suburban to Forest or Suburban to Agriculture is less likely to occur over a relatively short time period (six years) and appears to be the result of technical differences between the different images, as the mileage within these areas decline significantly by 79 percent and 66 percent respectively across the study time period (**Table 27**). The majority of the area and incidents identified in these categories are associated with Interstate 95 and therefore do not actually represent a change from suburban to agriculture or suburban to forest but rather a refined identification of the land cover types with more modern satellite imagery. Therefore these categories will also be excluded from the subsequent discussions and analysis. The focus of the following analysis will be on the areas of change from Agriculture to Suburban, Agriculture to Forest, Forest to Suburban, and Forest to Agriculture.

Table 27. Change in Miles of Road within Land Cover Types.

Time Period	1990 to 1995		1996 to 2001		2002 to 2007		Total	
Land Cover Image	1996		2001		2006		1990 to 2006	
Land Cover Change	Length (Miles)	% of Total	Length (Miles)	% of Total	Length (Miles)	% of Total	Total Miles	% of Total
Suburban-Forest	15.33	5.28	8.05	5.74	0.76	1.19	24.15	4.88
Suburban-Agriculture	15.95	5.50	3.95	2.82	0.61	0.95	20.51	4.15
Forest-Suburban	36.79	12.67	38.50	27.47	24.70	38.46	99.99	20.21
Forest-Agriculture	95.89	33.03	43.28	30.88	17.42	27.13	156.58	31.65
Agriculture-Suburban	23.16	7.98	19.33	13.79	9.5	14.80	51.99	10.51
Agriculture-Forest	103.22	35.55	27.06	19.31	11.23	17.48	141.50	28.60
Total	**290.33**		**140.16**		**64.22**		**494.71**	

Miles of Road

The previous overall discussion of the distribution of incidents, fatalities, and injuries forms a basis to examine the same distribution within along the road segments where the land cover types changed between the time periods. The following discussion is based on the segments of land cover change along the road network.

The change in land cover along each road segment was determined by looking at the change in land cover from 1992 image to 1996 image to determine the 1996 land cover change, 1996 image to 2001 image for the 2001 land cover change, and 2001 image to 2006 image for the 2006 land cover change. The land cover types were located along the road network with linear referencing tools to facilitate the analysis. The overall distribution (**Figure 37**) shows a steep decrease in the miles of roads changing from Forest to Agriculture and Agriculture to Forest, dropping by 75 and 73 percent respectively from 1996 to 2001 and then 44 and 42 percent from 2001 to 2006. The change from Forest to Suburban and Agriculture to Forest is also a declining trend but not as steeply. Looking at the percentage of the time period totals, a different pattern emerges (**Figure 38**). The change from Forest to Suburban increases from a 5 percent in 1996 to 38 percent in 2006, but the total mileage also drops from 290 miles in 1996 to 64 miles in 2006. The change from Agriculture to Suburban increases from 8 percent to 15 percent, while the changes from Agriculture to Forest (36 to 17 percent) and Forest to Agriculture (33 to 27 percent) decline from 1996 to 2006, although not as significantly as the drop depicted in Figure 30. This suggests that the majority of the changes have been from forest to suburban.

Distribution of Incidents

The distribution of incidents occurring along the road segments of land cover change generally follows the distribution of the overall incidents, with the majority of incidents located along the road segments changing to Suburban/Urban areas (**Table 28**). The numbers of incidents drop steadily across the three time periods, except for road segments changing from Forest to Suburban, where the distribution is more evenly distributed (**Figure 39**). However, the number of fatalities is steadily decreasing as there is a steady decrease in the total mileage of roads changing from one land cover type to another. Two alternative ways to look at the changing distributions is by percentages and

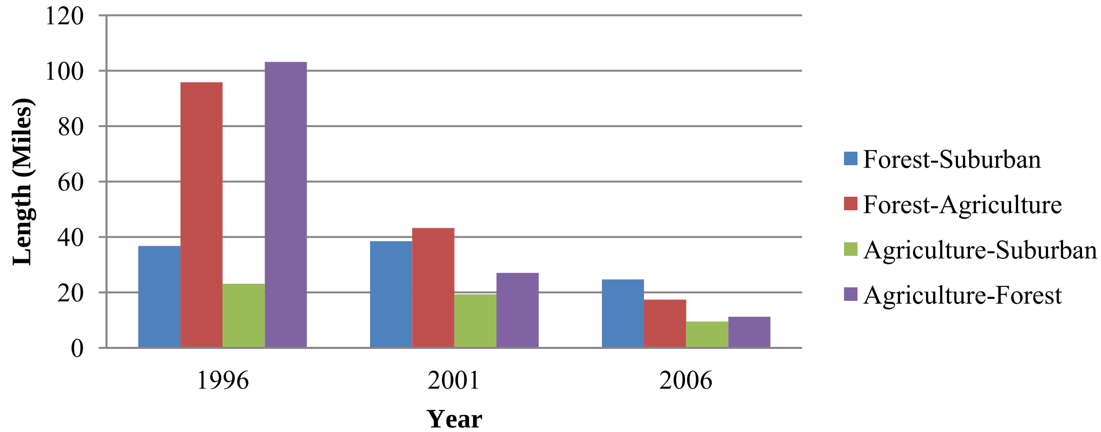

Figure 37. Distribution of Changes in Land Cover Type by Length of Road.

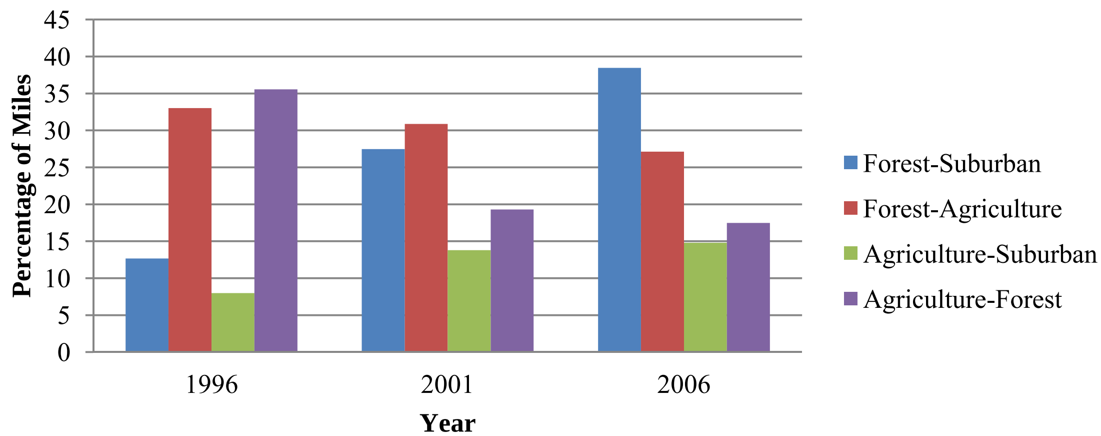

Figure 38. Distribution of Change in Land Cover Type by Percentage of Change in Yearly Totals.

Table 28. Distribution of Incidents along Land Cover Change Road Segments.

Time Period	1990 to 1995			1996 to 2001			2002 to 2007		
Land Cover Image	1996			2001			2006		
Land Cover Change	#	% of Total	# per Miles	#	% of Total	# per Miles	#	% of Total	# per Miles
Suburban-Forest	76	6.49	4.96	72	9.94	8.94	6	1.49	7.88
Suburban-Agriculture	110	9.39	6.90	17	2.35	4.30	7	1.73	11.53
Forest-Suburban	217	18.53	5.90	258	35.64	6.70	200	49.50	8.10
Forest-Agriculture	306	26.13	3.19	133	18.37	3.07	46	11.39	2.64
Agriculture-Suburban	177	15.12	7.64	150	20.72	7.76	85	21.04	8.94
Agriculture-Forest	285	24.34	2.76	94	12.98	3.47	60	14.85	5.34
Total	1171			724			404		

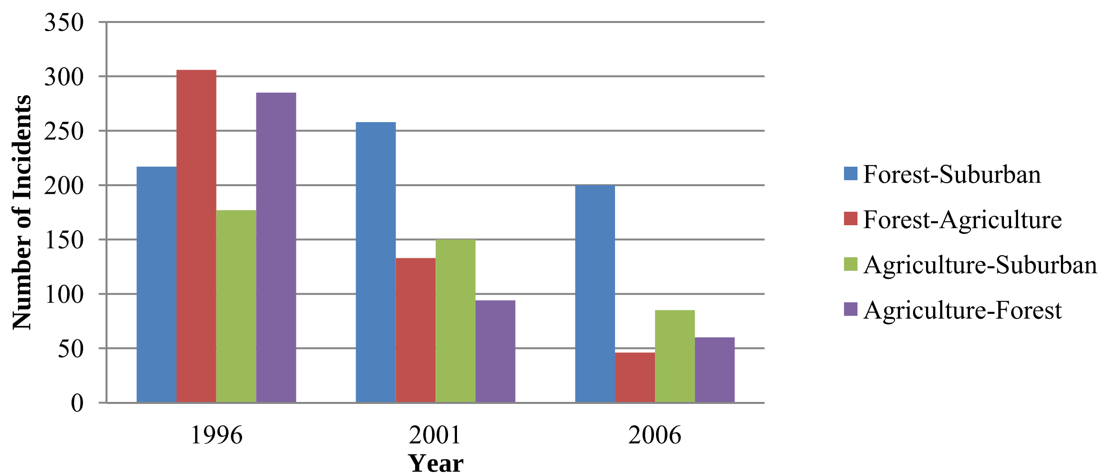

Figure 39. Distribution of Incidents along Land Cover Change Road Segments.

normalizing the numbers by dividing the raw numbers by the miles of road within the land cover category. Looking at the change in percentages (**Figure 40**) of incidents a different pattern emerges. The incidents occurring on road segments changing from Agriculture to Forest or Forest to Agriculture decline over the study time period, while changes from Forest to Suburban increases significantly from 18 percent to 50 percent and the change for Agriculture to Suburban is more modest from 15 percent to 21 percent. The land cover change with the most incidents is the change from Forest to Suburban, accounting for 26 percent of the incidents from 1990 to 1995 and over 63 percent in from 1996 to 2007. The land cover change that produces the second most incidents is the change from Agriculture to Suburban land cover.

The distribution of incidents normalized by mileage (**Figure 41**), is similar to the percentages in the change from Forest to Suburban (steady increase) and Forest to Agriculture (steady decrease). The differences are highlighted by the majority of incidents per mile along roads changing from Agriculture to Suburban and the change from Agriculture to Forest is steadily increasing, whereas it was decreasing in the distribution of percentages.

It would appear that the normalized distribution gives a more accurate picture of the distribution incidents as the two main categories (Forest to Suburban and Agriculture to Suburban) both have approximately 8 incidents per mile, where as the percentages show them with approximately 50 percent and 20 percent of the total number of incidents,

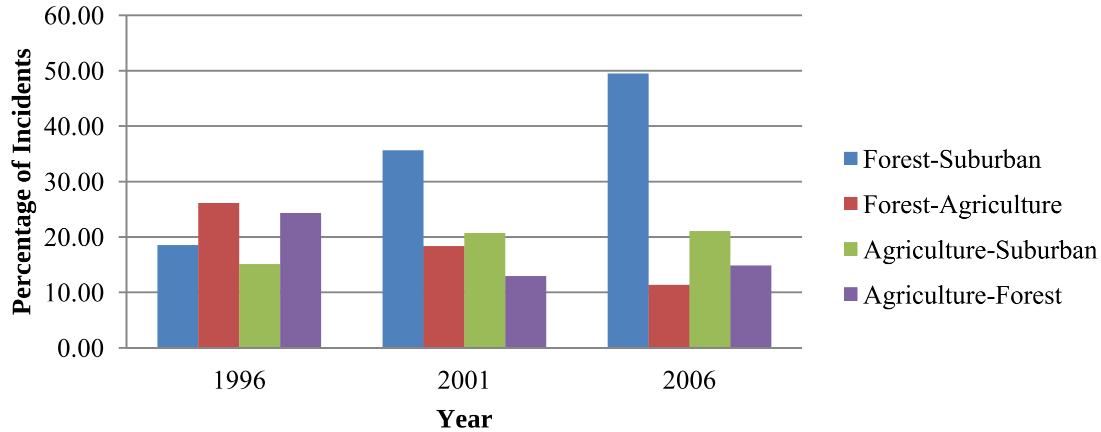

Figure 40. Distribution of Percentage of Incidents along Land Cover Change Road Segments.

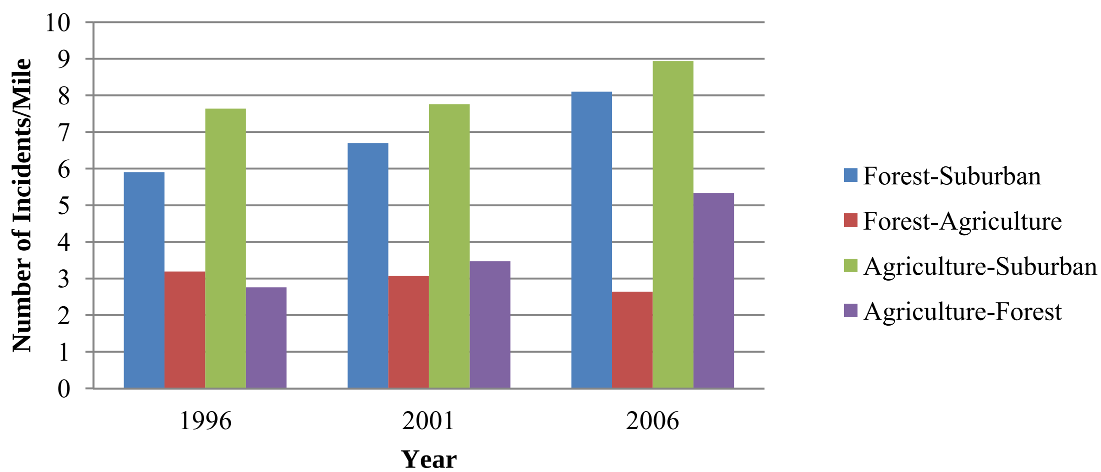

Figure 41. Distribution of Incidents per Miles of Road along Land Cover Change Segments.

respectively. However, the miles of road categorized as Forest to Suburban is nearly 2 times more than Agriculture to Suburban (throughout all three time periods), therefore, with the total number of incidents in relation to mileage. It would seem apparent that the category with the most miles would have the most incidents, but in order to compare the four different categories on the same basis, it is necessary to normalize by dividing the number of incidents, fatalities, and injuries by the mileage of roads within each category, similar to the previous section on overall land cover change. This is the methodology used for the remaining discussion on the road segments with land cover change.

Fatality and Injury Rates

Given the limited number of fatalities, a discussion of fatality rates along road segments where the land cover changed beyond the raw numbers in the table below (**Table 29**) , would have little meaning as the sample is extremely low for 2001 and 2006 time periods. With normalization of the fatalities, several categories with less than 1 mile of road segments show elevated numbers (even greater than the actual number) of fatalities per mile. For example, with the change from Suburban to Agriculture there are two fatalities and the miles of road segments is 0.61 miles. The result is 3.27 fatalities per mile of road segments which is more than the actual total of fatalities.

The distribution of injuries (**Table 30, Figure 42, Figure 43**) is similar to the distribution of incidents, with Forest to Suburban and Agriculture to Suburban steadily increasing across the three time periods and with Forest to Suburban dominating the totals in 2001

Table 29. Distribution of Fatalities along Land Cover Change Road Segments.

	1990 to 1995			1996 to 2001				2002 to 2007			
Land Cover Image	1996			2001				2006			
Land Cover Type	#	Rate	# per Miles	#	Rate	# per Miles	% Change	#	Rate	# per Miles	% Change
Suburban-Forest	3	0.04	0.20	1	0.02	0.12	-66.67	0	0	0	-100
Suburban-Agriculture	3	0.03	0.19	4	0.36	1.01	33.33	2	0.5	3.29	-100
Forest-Suburban	6	0.03	0.16	2	0.01	0.05	-66.67	1	0.01	0.04	-50
Forest-Agriculture	4	0.01	0.04	0	0	0	-100	3	0.09	0.17	100
Agriculture-Suburban	2	0.01	0.09	0	0	0	-100	0	0	0	0
Agriculture-Forest	4	0.01	0.04	0	0	0	-100	0	0	0	0
Total	22			7				6			

Note: Fatality Rate is calculated by Number of Fatalities/Number of Incidents per land cover type.

Table 30. Distribution of Injuries along Land Cover Change Road Segments.

Time Period	1990 to 1995			1996 to 2001				2002 to 2007			
Land Cover Image	1996			2001				2006			
Land Cover Type	#	%	# per mile	#	%	# per mile	% Change	#	%	# per mile	% Change
Suburban-Forest	57	6.88	3.72	51	12.32	6.33	-10.53	3	1.64	3.94	-94.12
Suburban-Agriculture	67	8.08	4.20	11	2.66	2.79	-83.58	4	2.19	6.59	-63.64
Forest-Suburban	131	15.8	2.49	139	33.57	3.61	6.11	78	42.62	3.16	-43.88
Forest-Agriculture	239	28.83	3.56	89	21.50	2.06	-62.76	33	18.03	1.89	-62.92
Agriculture-Suburban	122	14.72	5.27	75	18.12	3.88	-38.52	43	23.50	4.52	-42.67
Agriculture-Forest	213	25.69	2.06	49	11.84	1.81	-77.00	22	12.02	1.96	-55.10
Total	829	100		414	100			183	100		

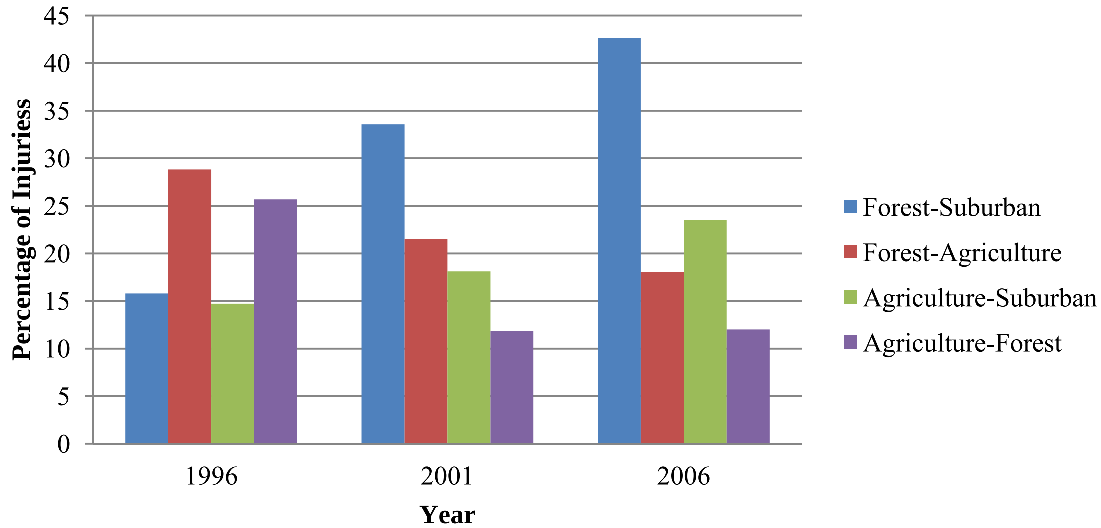

Figure 42. Change in Land Cover Injuries along Road Segments (Percentage).

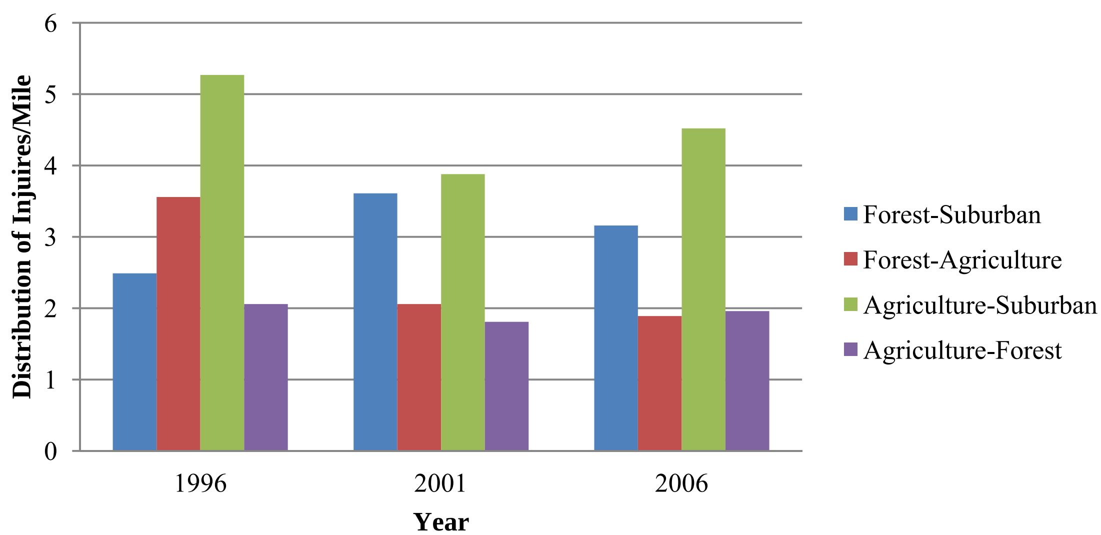

Figure 43. Distribution of Injuries by Miles of Road.

and 2006. In addition, Agriculture to Forest and Forest to Agriculture are trending downward. Looking at the normalized distribution of injuries, Agriculture to Suburban surpasses Forest to Suburban in all three categories, albeit relatively close in 2001. In both charts, Forest to Agriculture has a declining trend, although more pronounced with the distribution of percentages.

Land Cover Change Summary

- The change in miles of road is dominated by the change from Agriculture to Forest and from Forest to Agriculture in 1996 (however this can most likely be attributed to better satellite imagery and sensors).
- From 1996 to 2001, the greatest change in land cover change in miles of roads occurs from Forest to Agriculture and Forest to Suburban. In 2006, Forest to Suburban again ranks at the top. This is consistent with the rise in the commercial and residential development during the late 1990s.
- More incidents occur along roads changing from Forest to Agriculture and Agriculture to Forest in 1996 and then drop significantly in subsequent time periods. Incidents on roads changing from Forest to Suburban remain steady across all three time periods and are significantly higher than the other three categories.
- The distribution of incidents per mile shows that both suburban categories are nearly double the two rural categories.
- There are too few fatalities within land cover change along miles to draw meaningful conclusions with the data.

- Injuries per mile are dominated by the two suburban categories, except for 1996 where Forest to Agriculture surpasses Forest to Suburban incidents.

Other Road Characteristics

The other road characteristics where calculated from those road segments where the land cover type changed from one time period to the next. Only those incidents that occurred along these segments are included in this discussion. Crosstab calculations were generated to identify the numbers of incidents, fatalities, and injuries occurring along each road segment. Additionally, the numbers of incidents, fatalities, and injuries were normalized by dividing each by the mileage of roads within each category of land cover change and the other road characteristics. The tables for the numbers of incidents occurring within each road characteristic category will include the Suburban-Forest and Suburban-Agriculture land cover changes to more accurately discuss the numbers and percentages of the four main categories. These two categories will not be discussed as the make up a relatively small percentage of the overall totals. As in the previous discussion, 1996 is used to refer to the first time period, 1990 to 1995, and the land cover image from 1996. The second time period, 1996 to 2001 is referred to as 2001 in the following discussion which correlates with the land cover image from 2001. The third time period, 2002 to 2007, is referred to as 2006 to correspond with the land cover image as well.

Number of Lanes: The majority of incidents are occurring on 2-Lane roads comprising 62 percent of the total land cover change incidents; however, in 2006, incidents on 4-Lane roads (63 percent) surpass 2-Lane incidents which fall to 36 percent. There are very few incidents occurring on 6-Lane roads which are likely a result of the relatively low miles of road segments (**Table 31, Table 32, Table 33**).

The general pattern for number of lanes is low per mile rate along 2-Lane and 6-Lane roads and a high per mile rate along 4-Lane roads for incidents, fatalities, and injuries (**Figure 44**, **Figure 45**, **Figure 46**). There are a few exceptions primarily with the Forest-Suburban, Agriculture-Suburban, and Agriculture-Forest where there is another increase from 4-Lanes to 6-Lanes; however these changes are primarily due to the low miles of road segments, all of which are less than 0.31 which inflates the number of incidents, fatalities, and injuries. The overwhelming majority of incidents are along 2-Lane road segments; however, there is also an equal majority of the miles of road segments which leads to a lower per mile rate. With fewer miles of road segments categorized as 4-Lane, there is a higher rate for incidents, fatalities, and injuries as compared to the 2-Lane roads.

The distribution of fatalities generally follows the overall distributions with the majority of fatalities per mile occurring on 4-lane roads and with very few occurring on 2-lane roads and none occurring on 6-lane roads during the time periods. The majority of fatalities are occurring in areas where the land cover changes from Forest to Suburban and secondly from Agriculture to Suburban. In 2006, the change from Agriculture to

Table 31. Distribution of Incidents by Number of Lanes and Land Cover Change.

Incidents	Number of Lanes							
Land Cover Change	2		4		6		Total	Percentage
1996 Land Cover Change-Incidents								
	#	Miles	#	Miles	#	Miles		
Suburban-Forest	60	13.42	16	1.92	0	0	76	6.49
Suburban-Agriculture	95	13.86	13	1.97	2	0.12	110	9.39
Forest-Suburban	104	29.33	107	7.34	6	0.11	217	18.53
Forest-Agriculture	224	91.59	82	4.29	0	0	306	26.13
Agriculture-Suburban	82	18.41	91	4.44	4	0.31	177	15.12
Agriculture-Forest	217	99.83	54	3.19	14	0.20	285	24.34
Sub-Total	782	266.44	363	23.15	26	0.74	1171	
Percentage	66.78	91.77	31.00	7.97	2.22	0.25		
2001 Land Cover Change-Incidents								
Suburban-Forest	17	5.72	47	2.33	0	0	64	10.19
Suburban-Agriculture	11	3.52	3	0.43	0	0	14	2.23
Forest-Suburban	143	34.55	60	3.88	3	0.07	206	32.80
Forest-Agriculture	109	41.53	20	1.75	0	0	129	20.54
Agriculture-Suburban	110	17.13	22	1.92	4	0.28	136	21.66
Agriculture-Forest	60	26.28	19	0.78	0	0	79	12.58
Sub-Total	450	128.72	171	11.09	7	0.35	628	
Percentage	71.66	91.84	27.23	7.91	1.11	0.25		
2006-Land Cover Change-Incidents								
Suburban-Forest	0	0	6	0.76	0	0	6	1.49
Suburban-Agriculture	0	0	7	0.61	0	0	7	1.73
Forest-Suburban	17	18.49	183	6.21	0	0	200	49.50
Forest-Agriculture	41	16.55	5	0.88	0	0	46	11.39
Agriculture-Suburban	53	8.17	32	1.33	0	0	85	21.04
Agriculture-Forest	36	10.36	24	0.86	0	0	60	14.85
Sub-Total	147	53.57	257	10.65	0	0	404	
Percentage	36.39	83.41	63.61	16.89	0.00	0	100	
Overall Total	1379	448.74	791	44.89	0	1.09	2203	
Overall Percentage	63.55	90.71	36.45	9.07	0	0.22		

Table 32. Distribution of Fatalities by Number of Lanes and Land Cover Change.

Fatalities	Number of Lanes				
Land Cover Change	**2**	**4**	**6**	**Total**	**Percentage**
1996 Land Cover Change-Fatalities					
Suburban-Forest	2	1	0	3	13.64
Suburban-Agriculture	2	1	0	3	13.64
Forest-Suburban	2	4	0	6	27.27
Forest-Agriculture	4	0	0	4	18.18
Agriculture-Suburban	1	1	0	2	9.09
Agriculture-Forest	4	0	0	4	18.18
Sub-Total	15	7	0	22	
Percentage	68.18	31.82	0.00		
2001 Land Cover Change-Fatalities					
Suburban-Forest	0	1	0	1	20.00
Suburban-Agriculture	2	0	0	2	40.00
Forest-Suburban	1	1	0	2	40.00
Forest-Agriculture	0	0	0	0	0.00
Agriculture-Suburban	0	0	0	0	0.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	3	2	0	5	
Percentage	60.00	40.00	0.00		
2006 Land Cover Change-Fatalities					
Suburban-Forest	0	0	0	0	0.00
Suburban-Agriculture	0	0	0	0	0.00
Forest-Suburban	0	2	0	2	33.33
Forest-Agriculture	1	0	0	1	16.67
Agriculture-Suburban	2	1	0	3	50.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	3	3	0	6	
Total	21	12	0	33	
Percentage	63.64	36.36	0.00	100	

Table 33. Distribution of Injuries by Number of Lanes and Land Cover Change.

Injuries	Number of Lanes				
Land Cover Change	**2**	**4**	**6**	**Total**	**Percentage**
1996 Land Cover Change-Injuries					
Suburban-Forest	47	10	0	57	6.88
Suburban-Agriculture	58	6	3	67	8.08
Forest-Suburban	75	55	1	131	15.80
Forest-Agriculture	165	74	0	239	28.83
Agriculture-Suburban	57	61	4	122	14.72
Agriculture-Forest	163	46	4	213	25.69
Sub-Total	565	252	12	829	
Percentage	68.15	30.40	1.45		
2001 Land Cover Change-Injuries					
Suburban-Forest	16	26	0	42	11.57
Suburban-Agriculture	7	2	0	9	2.48
Forest-Suburban	98	18	1	117	32.23
Forest-Agriculture	73	10	0	83	22.87
Agriculture-Suburban	65	4	2	71	19.56
Agriculture-Forest	31	10	0	41	11.29
Sub-Total	290	70	3	363	
Percentage	79.89	19.28	0.83		
2006 Land Cover Change-Injuries					
Suburban-Forest	0	3	0	3	1.64
Suburban-Agriculture	0	4	0	4	2.19
Forest-Suburban	3	75	0	78	42.62
Forest-Agriculture	31	2	0	33	18.03
Agriculture-Suburban	27	16	0	43	23.50
Agriculture-Forest	14	8	0	22	12.02
Sub-Total	75	108	0	183	100.00
Total	930	430	15	1375	751.37
Percentage	67.64	31.27	1.09		

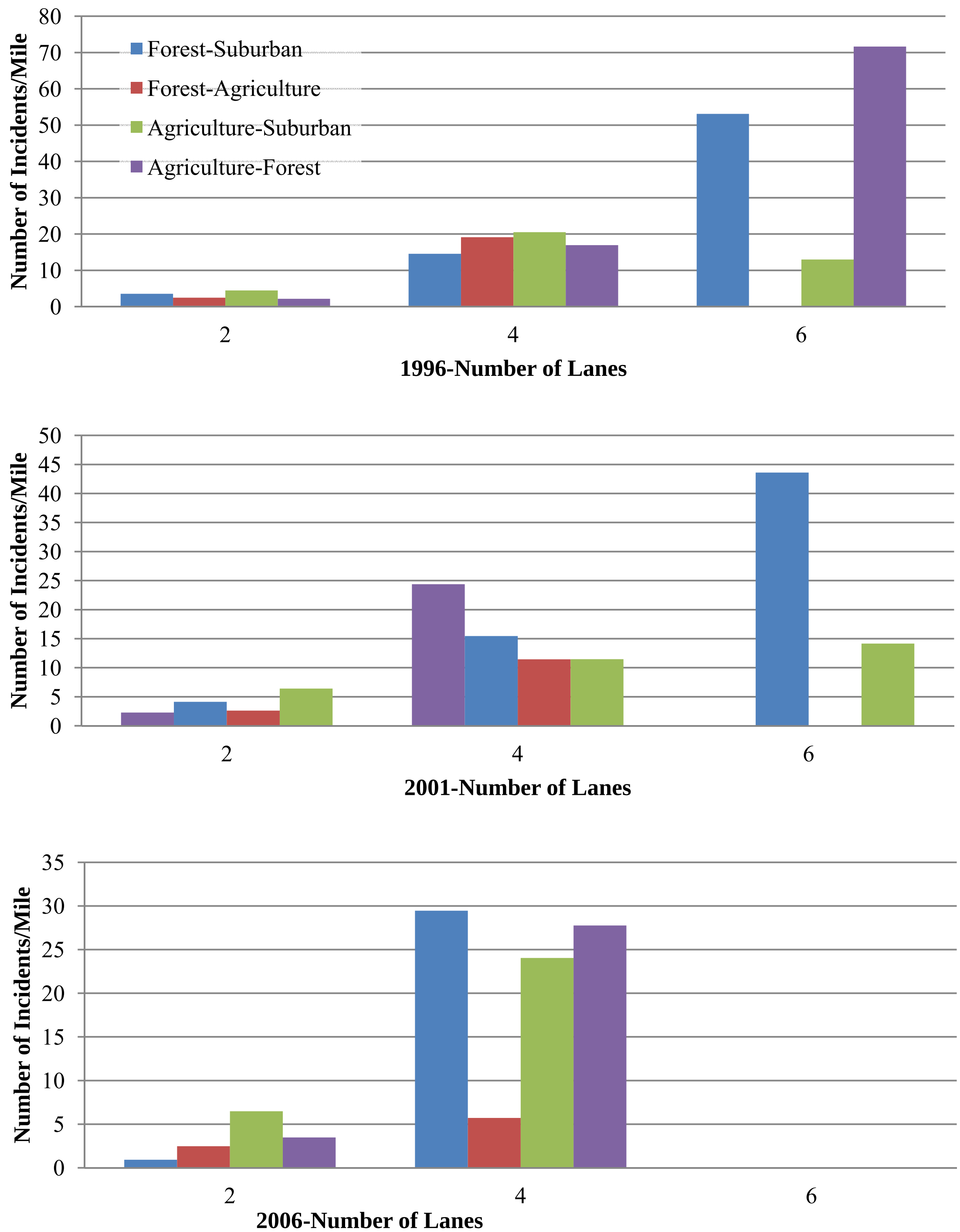

Figure 44. Distribution of Incidents by Number of Lanes per Miles of Road.

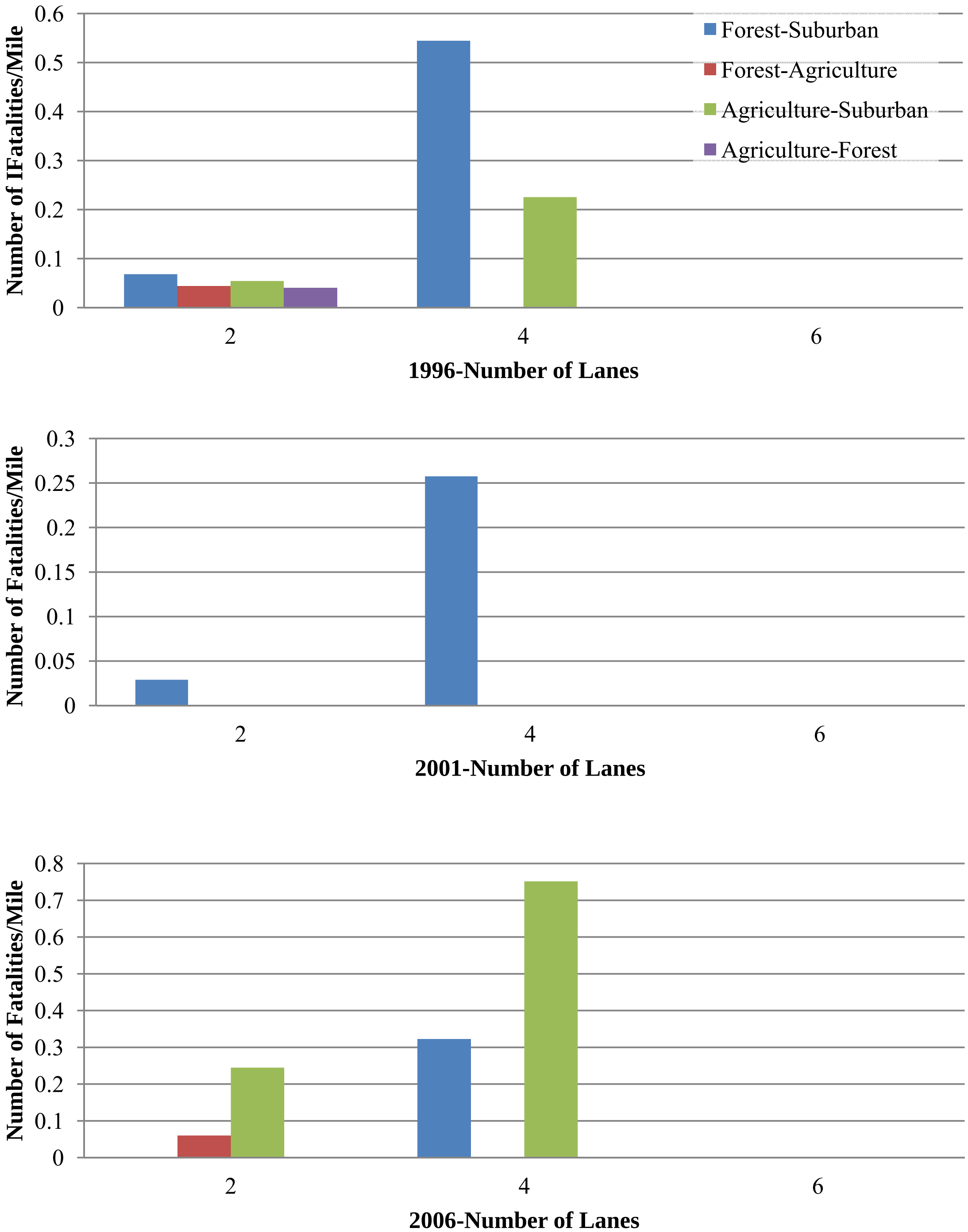

Figure 45. Distribution of Fatalities by Number of Lanes per Miles of Road.

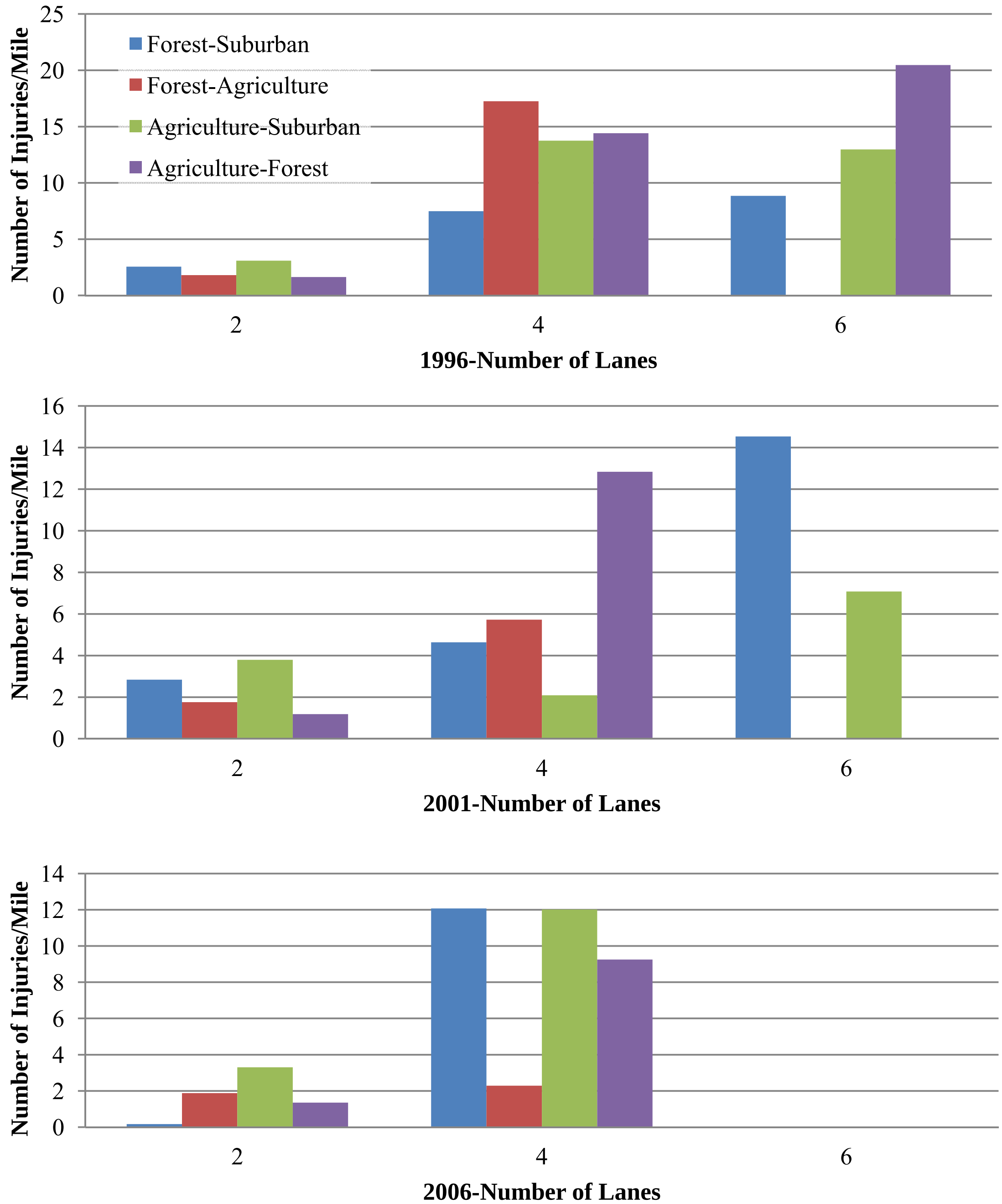

Figure 46. Distribution of Injuries by Number of Lanes per Miles of Road.

Suburban produces the highest fatalities rate with approximately with 0.75 fatalities per mile of road. However, these numbers are with a small number of overall fatalities and any patterns would need to be studied with a larger sample size to validate.

Surface Width: The majority of incidents, fatalities, and injuries are occurring on road segments with surface widths of 19 to 24 ft and comprise 50 percent of incidents, fatalities, and injuries. This corresponds with the higher miles of road segments within the same road width. Through the three time periods there is a change in the dominant land cover type. In 1996, Forest-Agriculture and Agriculture-Forest incidents are more numerous than those changing to Suburban; however, Forest-Suburban and Agriculture-Suburban dominate the following two time periods with Forest-Suburban making up more than 40 percent of the incidents and injuries (**Table 34, Table 35, Table 36**).

The distribution of incidents, fatalities, and injuries per mile is dominated by surface widths greater than 25 ft. The distribution also increases with the increase in the surface width of the road. No specific land cover change dominates throughout the three time periods; however, Forest-Suburban displays a consistent increase with increase in surface width across all three time periods for incidents, fatalities, and injuries. The highest incident per mile is found within Agriculture-Suburban (1996) and Agriculture-Forest (2001, 2006), both on surface widths greater than 24 ft. The highest fatalities per mile are found within Forest-Suburban (1996, 2001) and Agriculture-Suburban (2006), again along segments with surface widths greater than 24 ft. The highest injuries per mile is

Table 34. Distribution of Incidents by Surface Width and Land Cover Change.

Incidents	Surface Width (ft)							
Land Cover Change	n <= 18		18 < n < 25		n >= 25		Total	Percentage
1996 Land Cover Change-Incidents								
	#	Miles	#	Miles	#	Miles		
Suburban-Forest	9	2.03	50	11.02	17	2.29	76	6.49
Suburban-Agriculture	21	2.98	64	10.54	25	2.42	110	9.39
Forest-Suburban	14	5.26	86	23.35	117	8.18	217	18.53
Forest-Agriculture	81	48.01	135	42.67	90	5.20	306	26.13
Agriculture-Suburban	37	5.17	39	12.81	101	5.18	177	15.12
Agriculture-Forest	76	52.78	138	46.42	71	4.02	285	24.34
Sub-Total	238	116.23	512	146.82	421	27.27	1171	
Percentage	20.32	40.04	43.72	50.57	35.95	9.39		
2001 Land Cover Change-Incidents								
Suburban-Forest	0	0.78	17	4.88	47	2.39	64	10.19
Suburban-Agriculture	1	1.03	10	2.01	3	0.91	14	2.23
Forest-Suburban	23	4.81	117	27.85	66	5.83	206	32.80
Forest-Agriculture	43	21.25	66	19.39	20	2.63	129	20.54
Agriculture-Suburban	25	2.68	73	14.10	38	2.55	136	21.66
Agriculture-Forest	22	12.41	38	13.69	19	0.96	79	12.58
Sub-Total	114	42.96	321	81.92	193	15.28	628	
Percentage	18.15	30.65	51.11	58.45	30.73	10.90	100	
2006-Land Cover Change-Incidents								
Suburban-Forest	0	0	0	0.18	6	0.58	6	1.49
Suburban-Agriculture	0	0.32	0	0.15	7	0.14	7	1.73
Forest-Suburban	5	2.04	8	8.23	187	14.43	200	49.50
Forest-Agriculture	24	10.98	17	5.36	5	1.08	46	11.39
Agriculture-Suburban	0	0.19	44	4.84	41	4.48	85	21.04
Agriculture-Forest	11	5.70	24	4.21	25	1.32	60	14.85
Sub-Total	40	19.24	93	22.96	271	22.03	404	
Percentage	9.90	29.95	23.02	35.75	67.08	34.29	100	
Overall Total	348	178.43	899	251.70	240	64.58	1487	
Overall Percentage	23.40	36.07	60.46	50.88	16.14	13.05		

Table 35. Distribution of Fatalities by Surface Width and Land Cover Change.

Fatalities	Surface Width (ft)				
Land Cover Change	n <= 18	18 < n < 25	n >= 25	Total	Percentage
1996 Land Cover Change-Fatalities					
Suburban-Forest	0	1	2	3	17.65
Suburban-Agriculture	0	2	1	3	17.65
Forest-Suburban	0	2	4	6	35.29
Forest-Agriculture	3	1	0	4	23.53
Agriculture-Suburban	1	0	1	2	11.76
Agriculture-Forest	2	2	0	4	23.53
Sub-Total	1	12	4	17	
Percentage	5.88	70.59	23.53		
2001 Land Cover Change-Fatalities					
Suburban-Forest	0	0	1	1	40.00
Suburban-Agriculture	0	2	0	2	40.00
Forest-Suburban	0	1	1	2	0.00
Forest-Agriculture	0	0	0	0	0.00
Agriculture-Suburban	0	0	0	0	0.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	0	3	2	5	0.80
Percentage	0.00	60.00	40.00		
2006 Land Cover Change-Fatalities					
Suburban-Forest	0	0	0	0	0.00
Suburban-Agriculture	0	0	0	0	0.00
Forest-Suburban	0	0	2	2	33.33
Forest-Agriculture	0	1	0	1	16.67
Agriculture-Suburban	0	0	3	3	50.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	0	1	5	6	
Percentage	0.00	16.67	83.33		
Overall Total	1	16	11	28	
Overall Percentage	3.57	57.14	39.29		

Table 36. Distribution of Injuries by Surface Width and Land Cover Change.

Injuries	Surface Width (ft)				
Land Cover Change	n <= 18	18 < n < 25	n >= 25	Total	Percentage
1996 Land Cover Change-Injuries					
Suburban-Forest	10	34	13	57	6.88
Suburban-Agriculture	8	45	14	67	8.08
Forest-Suburban	8	65	58	131	15.80
Forest-Agriculture	60	101	78	239	28.83
Agriculture-Suburban	33	20	69	122	14.72
Agriculture-Forest	46	116	51	213	25.69
Sub-Total	165	381	283	829	
2001 Land Cover Change-Injuries					
Suburban-Forest	0	16	26	42	11.57
Suburban-Agriculture	0	7	2	9	2.48
Forest-Suburban	9	86	22	117	32.23
Forest-Agriculture	27	46	10	83	22.87
Agriculture-Suburban	13	50	8	71	19.56
Agriculture-Forest	12	19	10	41	11.29
Sub-Total	61	224	78	363	
2006 Land Cover Change-Injuries					
Suburban-Forest	0	0	3	3	1.64
Suburban-Agriculture	0	0	4	4	2.19
Forest-Suburban	0	2	76	78	42.62
Forest-Agriculture	17	14	2	33	18.03
Agriculture-Suburban	0	26	17	43	23.50
Agriculture-Forest	8	5	9	22	12.02
Sub-Total	25	47	111	183	
Overall Total	281	536	117	934	
Overall Percentage	30.09	57.39	12.53		

found within Forest-Agriculture (1996) and Agriculture-Forest (2001, 2006) along surface widths greater than 24 ft. Another pattern emerges, Agriculture-Suburban roads with medians between 19 and 24 ft are increasing in incidents and injuries per mile with time, while the others have slight fluctuations (**Figure 47, Figure 48, Figure 49**).

Shoulder Width: The majority of the road segment mileage has shoulders between 2 and 6 ft wide, comprising 50 to 58 percent of the total segment mileage (**Table 37, Table 38, Table 39**). Shoulder widths less than 2 ft, although comprising the majority of all the roads in the project area, make up only 43 percent of the all land cover change segments but are in the majority with 67 percent in the 2006. Road segments with shoulders greater than 6 ft only consist of 5 to 6 percent throughout the study period.

In the discussion of the overall distribution of incidents based on shoulder width, traffic incidents, fatalities, and injuries all decrease fairly significantly as the shoulder width increases. That same pattern does not hold up within the areas of land cover change. Instead, the incidents and injuries mirror each other through all three time periods with a general increase in rates per mile, except for Forest-Suburban incidents and injuries in 1996 which decreases with the increase in shoulder width. The general pattern per mile is a higher rate along roads with shoulders greater than 6 ft, especially Agriculture-Suburban, Agriculture-Forest and Forest-Suburban (but only in 2001) (**Figure 50, Figure 51, Figure 52**). There seems to be a general pattern of fewer incidents, fatalities, and injuries on those roads with shoulders greater than 2 feet and less than 6 feet. Of course, this pattern does not hold up across all three time periods for all categories. The pattern

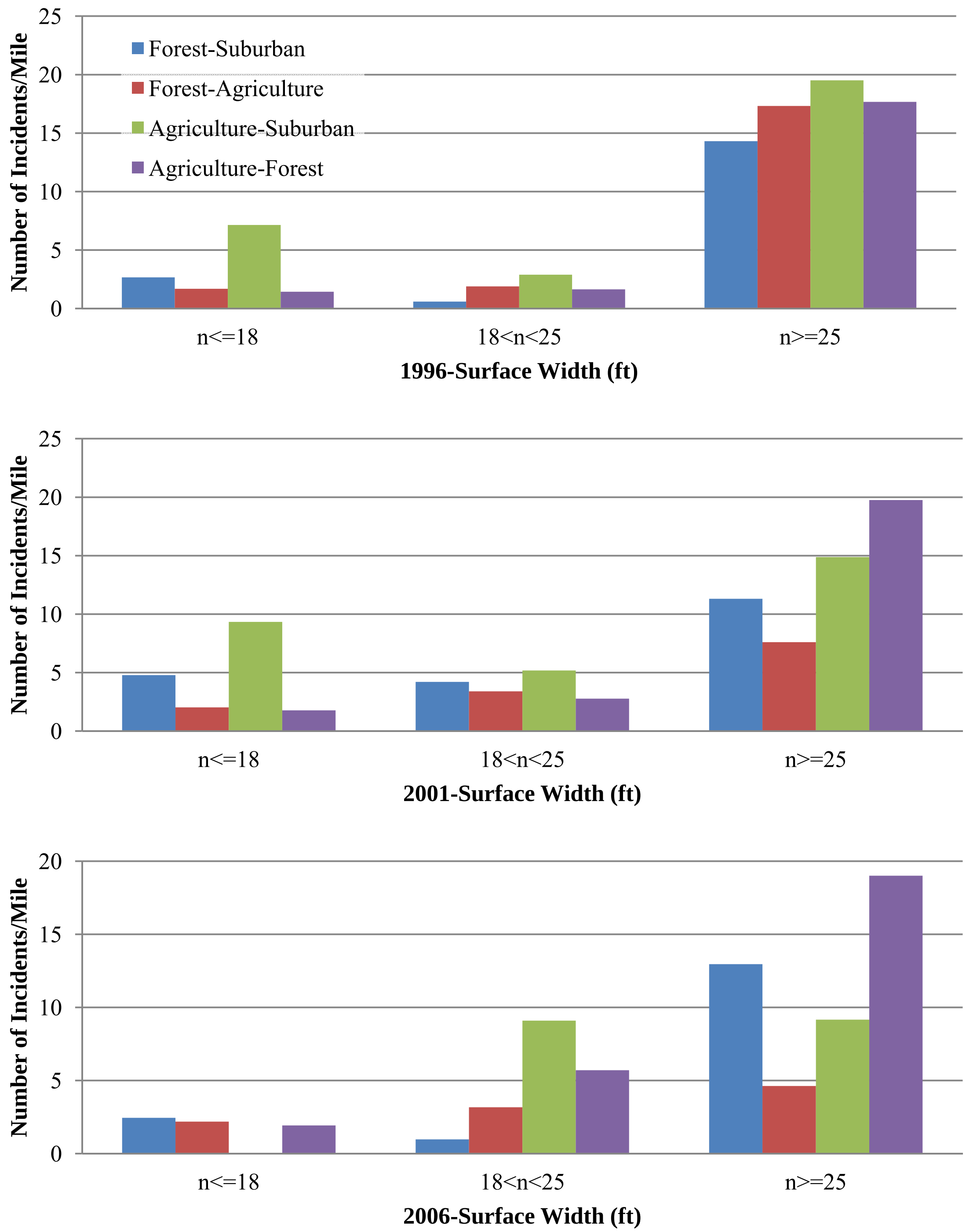

Figure 47. Distribution of Incidents by Surface Width per Miles of Road.

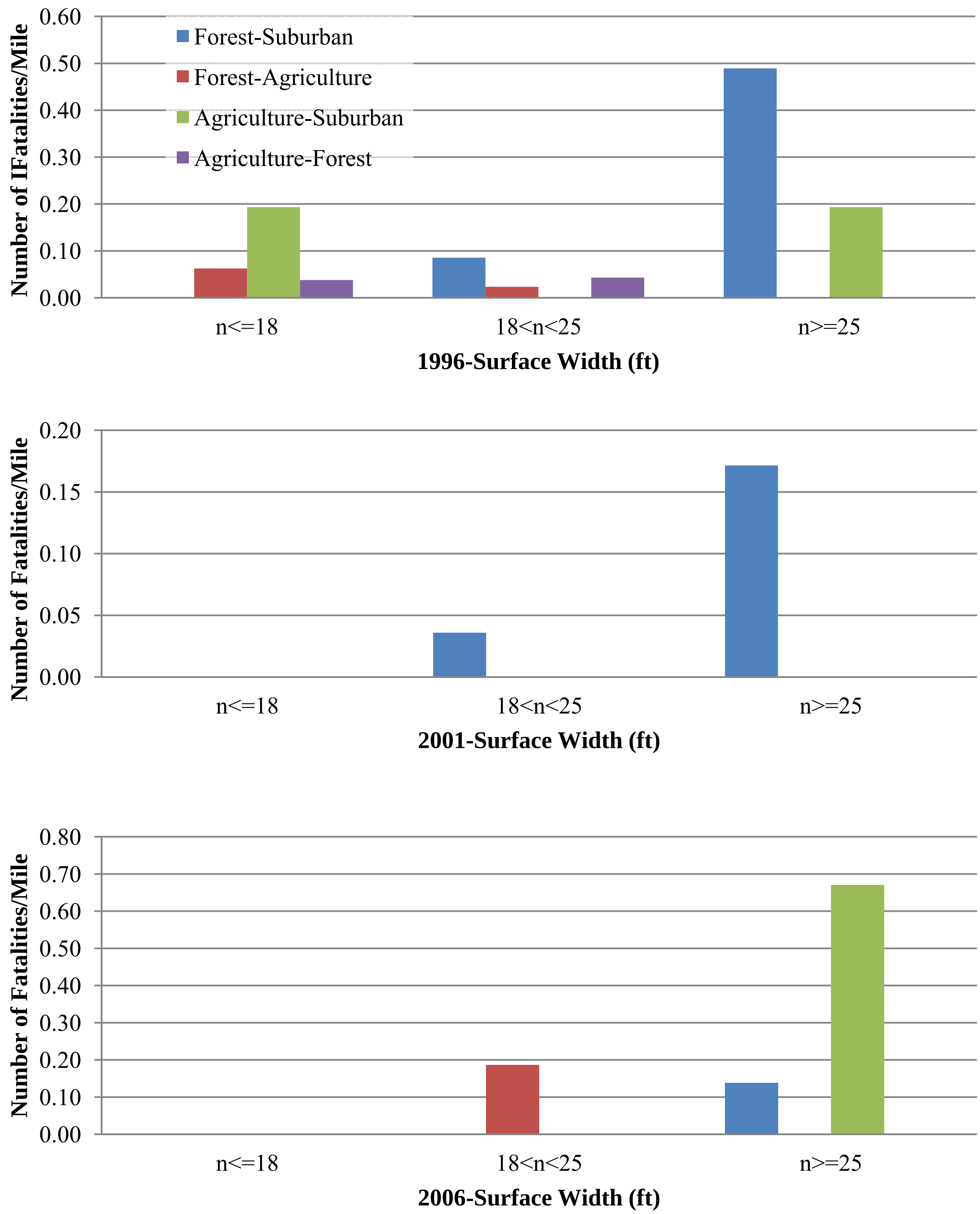

Figure 48. Distribution of Fatalities by Surface Width per Miles of Road.

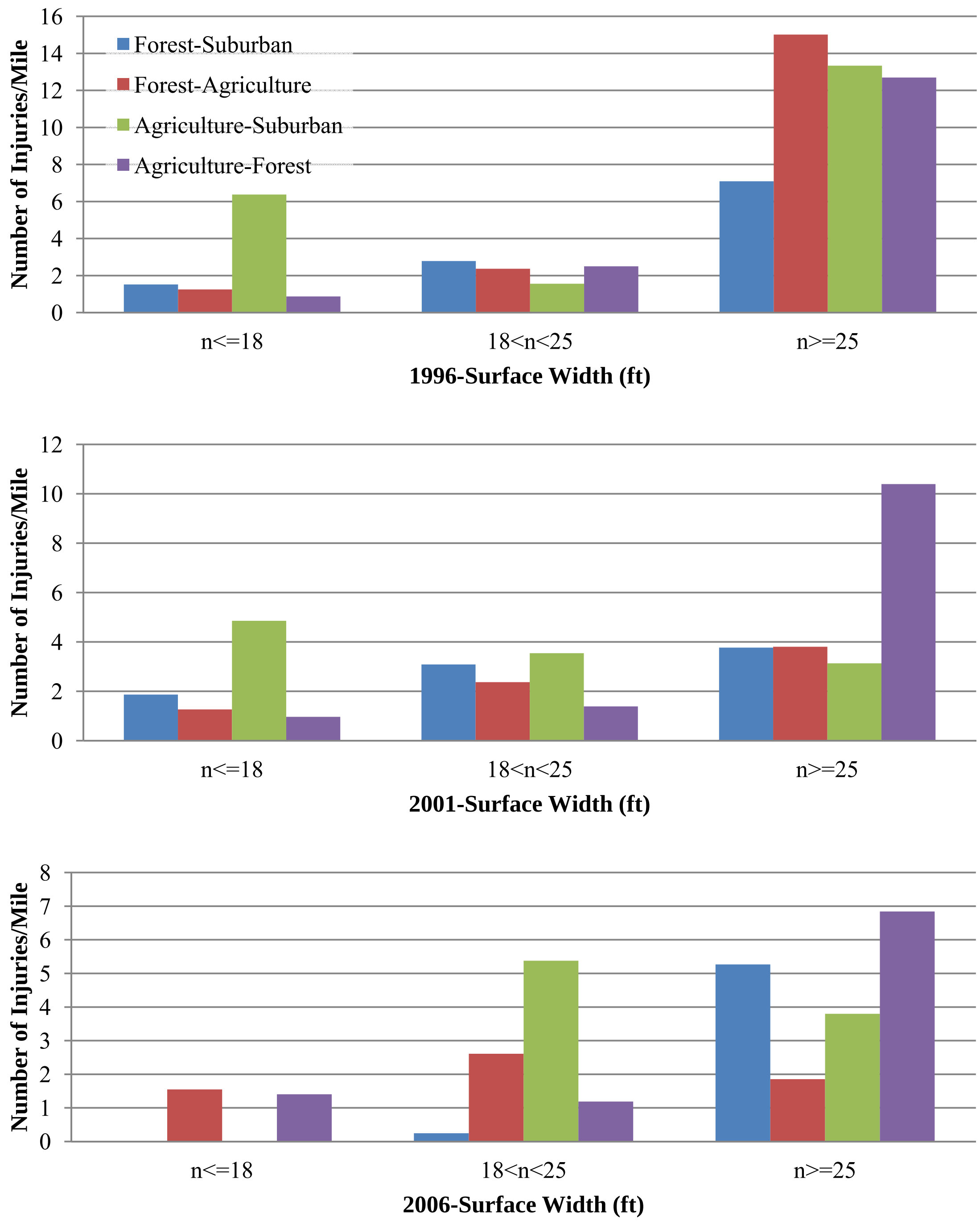

Figure 49. Distribution of Injuries by Surface Width per Miles of Road.

Table 37. Distribution of Incidents by Shoulder Width and Land Cover Change.

Incidents	Shoulder Width (ft)							
Land Cover Change	n <= 2		2 < n <= 6		n > 6		Total	Percentage
1996 Land Cover Change-Incidents								
	#	Miles	#	Miles	#	Miles		
Suburban-Forest	41	4.15	26	9.73	9	1.46	76	6.49
Suburban-Agriculture	39	4.37	52	8.47	19	3.10	110	9.39
Forest-Suburban	127	8.23	74	24.51	16	4.05	217	18.53
Forest-Agriculture	93	45.24	192	46.91	21	3.74	306	26.13
Agriculture-Suburban	61	7.44	84	12.72	32	3.00	177	15.12
Agriculture-Forest	133	51.97	130	47.84	22	3.41	285	24.34
Sub-Total	494	121.39	558	150.17	119	18.76	1171	
Percentage	42.19	41.81	47.65	51.73	10.16	6.46		
2001 Land Cover Change-Incidents								
Suburban-Forest	40	1.54	24	5.72	8	0.79	72	9.94
Suburban-Agriculture	1	1.46	12	2.19	4	0.30	17	2.35
Forest-Suburban	52	8.62	139	26.93	67	2.94	258	35.64
Forest-Agriculture	60	22.71	65	19.48	8	1.09	133	18.37
Agriculture-Suburban	65	5.06	56	12.59	29	1.68	150	20.72
Agriculture-Forest	24	12.06	50	14.21	20	0.79	94	12.98
Sub-Total	242	51.45	346	81.12	136	7.59	724	
Percentage	33.43	36.71	47.79	57.88	18.78	5.41		
2006-Land Cover Change-Incidents								
Suburban-Forest	4	0.29	0	0.18	2	0.29	6	1.49
Suburban-Agriculture	0	0.32	7	0.29	0	0.00	7	1.73
Forest-Suburban	174	18.55	26	4.60	0	1.55	200	49.50
Forest-Agriculture	33	11.52	9	5.38	4	0.53	46	11.39
Agriculture-Suburban	25	6.32	32	2.49	28	0.70	85	21.04
Agriculture-Forest	30	6.44	30	4.39	0	0.40	60	14.85
Sub-Total	266	43.43	104	17.32	34	3.47	404	
Percentage	65.84	67.62	25.74	26.97	8.42	5.41		
Total	1002	216.27	1008	248.62	289	29.82	2299	
Percentage	43.58	43.72	43.85	50.26	12.57	6.03		

Table 38. Distribution of Fatalities by Shoulder Width and Land Cover Change.

Fatalities	Shoulder Width (ft)				
Land Cover Change	n <= 2	2 < n <= 6	n > 6	**Total**	**Percentage**
1996 Land Cover Change-Fatalities					
Suburban-Forest	2	1	0	3	13.64
Suburban-Agriculture	1	2	0	3	13.64
Forest-Suburban	3	3	0	6	27.27
Forest-Agriculture	3	1	0	4	18.18
Agriculture-Suburban	2	0	0	2	9.09
Agriculture-Forest	2	2	0	4	18.18
Sub-Total	13	9	0	22	
Percentage	59.09	40.91	0.00		
2001 Land Cover Change-Fatalities					
Suburban-Forest	1	0	0	1	14.29
Suburban-Agriculture	0	2	2	4	57.14
Forest-Suburban	0	2	0	2	28.57
Forest-Agriculture	0	0	0	0	0.00
Agriculture-Suburban	0	0	0	0	0.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	1	4	2	7	
Percentage	14.29	57.14	28.57		
2006 Land Cover Change-Fatalities					
Suburban-Forest	0	0	0	0	0.00
Suburban-Agriculture	0	0	0	0	0.00
Forest-Suburban	1	1	0	2	33.33
Forest-Agriculture	1	0	0	1	16.67
Agriculture-Suburban	2	0	1	3	50.00
Agriculture-Forest	0	0	0	0	0.00
Sub-Total	4	1	1	6	
Total	18	14	3	35	
Percentage	51.43	40.00	8.57	100	

Table 39. Distribution of Injuries by Shoulder Width and Land Cover Change

Injuries	Shoulder Width (ft)				
Land Cover Change	n <= 2	2 < n <= 6	n > 6	**Total**	**Percentage**
1996 Land Cover Change-Injuries					
Suburban-Forest	35	19	3	57	6.875754
Suburban-Agriculture	16	45	6	67	8.082027
Forest-Suburban	73	48	10	131	15.80217
Forest-Agriculture	73	152	14	239	28.82992
Agriculture-Suburban	31	62	29	122	14.71653
Agriculture-Forest	84	100	29	213	25.69361
Sub-Total	312	426	91	829	
Percentage	37.64	51.39	10.98		
2001 Land Cover Change-Injuries					
Suburban-Forest	19	23	9	51	12.31884
Suburban-Agriculture	0	9	2	11	2.657005
Forest-Suburban	30	77	32	139	33.57488
Forest-Agriculture	36	41	12	89	21.49758
Agriculture-Suburban	26	37	12	75	18.11594
Agriculture-Forest	10	29	10	49	11.83575
Sub-Total	121	216	77	414	
Percentage	29.23	52.17	18.60		
2006 Land Cover Change-Injuries					
Suburban-Forest	1	0	2	3	1.639344
Suburban-Agriculture	0	4	0	4	2.185792
Forest-Suburban	62	16	0	78	42.62295
Forest-Agriculture	27	4	2	33	18.03279
Agriculture-Suburban	9	19	15	43	23.49727
Agriculture-Forest	17	5	0	22	12.02186
Sub-Total	116	48	19	183	100
Total	549	690	187	1426	779.23497
Percentage	38.50	48.39	13.11		

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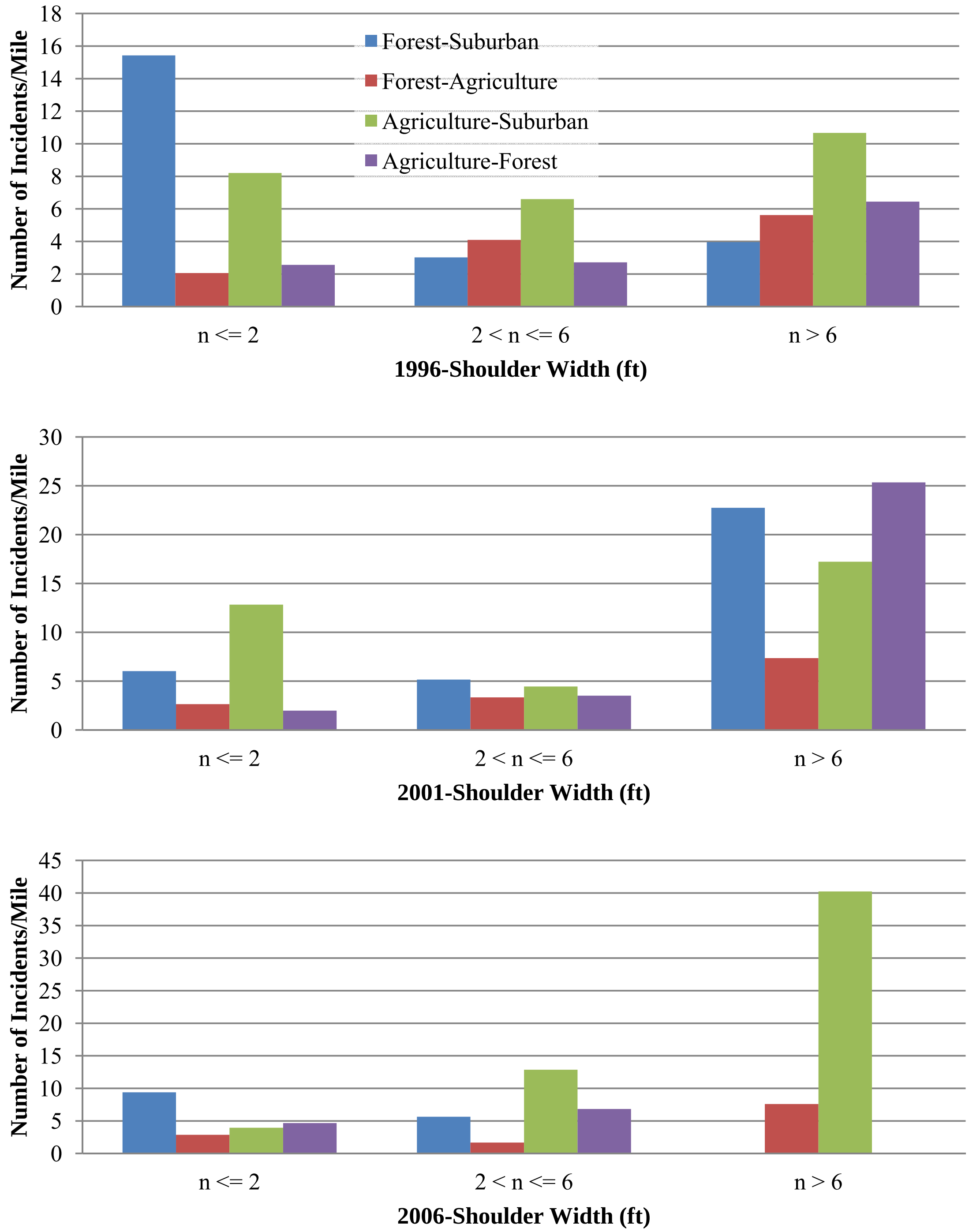

Figure 50. Distribution of Incidents by Shoulder Width per Miles of Road.

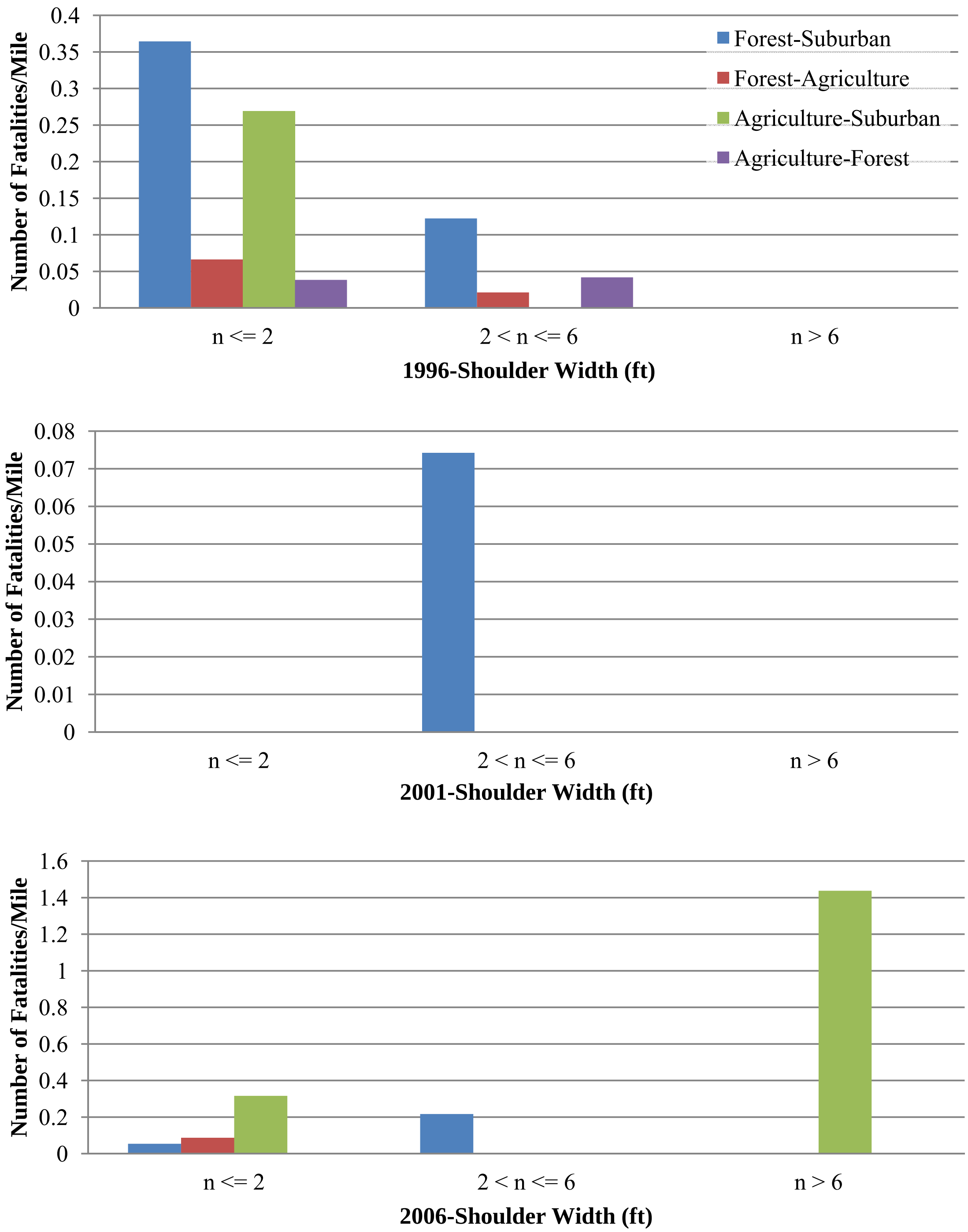

Figure 51. Distribution of Fatalities by Shoulder Width per Miles of Road.

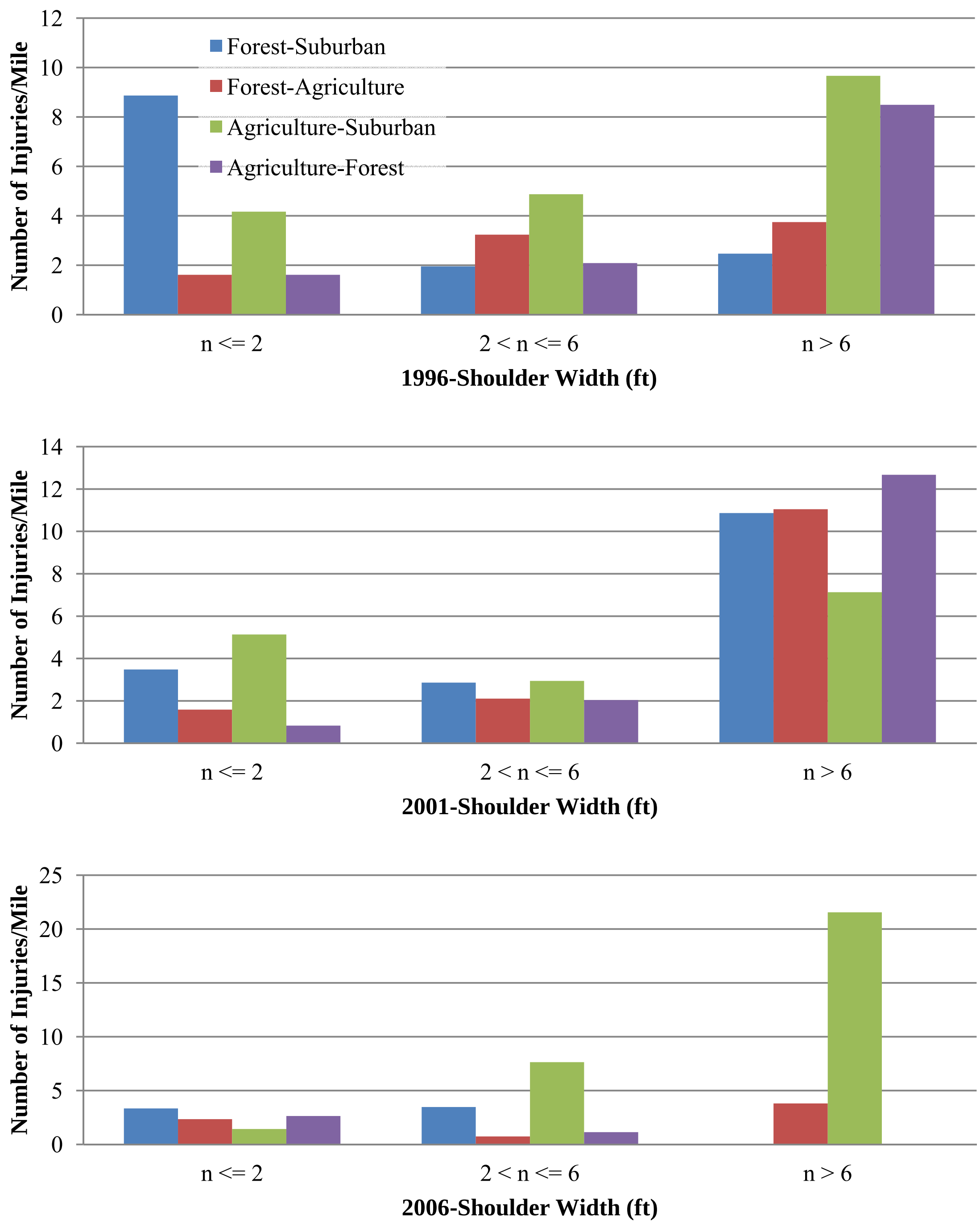

Figure 52. Distribution of Injuries by Shoulder Width per Miles of Road.

is very different than the overall trends discussed in the earlier section. The distribution of fatalities is limited by the low number of fatalities; however, there is a declining trend in 1996 with the increase in shoulder width and slight variations across the different shoulder widths in 2006 with a lone outlier in Agriculture-Suburban. There was only one category with fatalities in 2001 and the chart depicts that very clearly.

Posted Speed Limit: The distribution of incidents, fatalities, and injuries within land cover change areas generally follows the distribution of the overall incidents and injuries with the majority located within those areas that changed to Suburban land cover. The overwhelming majority of incidents are occurring within the Posted Speed Limit of 35 to 45 mph, with the majority occurring in Forest to Suburban land cover from 2001 to 2006, although Forest-Agriculture and Agriculture-Forest are in the majority during 1996 **(Table 40, Table 41, Table 42).**

Distributions per mile for the incidents, fatalities, and injuries are slightly different than the distribution of the raw numbers. The two land cover changes to Suburban (Forest-Suburban and Agriculture-Suburban) dominate the charts (**Figure 53, Figure 54, Figure 55**); however, the highest rate per mile is within the speed limit from 50 to 60 mph, instead of 35 to 45 mph. Also, for the 1996 time period, Agriculture-Forest is nearly five times greater than the next highest rate in incidents and nine times greater for injuries; however, the mileage for Agriculture-Forest with speed limits greater than 60 mph are less than 1 (0.13) which causes the exaggerated number.

Table 40. Distribution of Incidents by Posted Speed Limit and Land Cover Change.

Incidents	Posted Speed Limit (mph)									
Land Cover Change	n<=30		35 to 45		50 to 60		n >=65		Total	Percentage
1996 Land Cover Change-Incidents										
	#	**Miles**	**#**	**Miles**	**#**	**Miles**	**#**	**Miles**		
Suburban-Forest	3	2.24	56	10.96	14	1.84	3	0.29	76	6.49
Suburban-Agriculture	7	2.50	69	9.65	34	3.47	0	0.32	110	9.39
Forest-Suburban	37	5.71	128	25.08	16	3.53	36	2.47	217	18.53
Forest-Agriculture	4	6.26	182	67.62	120	21.83	0	0.17	306	26.13
Agriculture-Suburban	25	4.40	81	13.42	49	4.35	22	0.99	177	15.12
Agriculture-Forest	13	6.90	181	73.32	77	22.87	14	0.13	285	24.34
Sub-Total	89	28.01	697	200.04	310	57.89	75	4.38	1171	
Percentage	7.60	9.65	59.52	68.90	26.47	19.94	6.40	1.51		
2001 Land Cover Change-Incidents										
Suburban-Forest	3	1.16	41	5.41	6	0.96	14	0.52	64	10.19
Suburban-Agriculture	2	1.02	7	1.94	5	0.97	0	0.02	14	2.23
Forest-Suburban	5	5.59	164	30.97	22	1.19	15	0.75	206	32.80
Forest-Agriculture	3	2.43	106	31.34	20	9.50	0	0.00	129	20.54
Agriculture-Suburban	15	3.03	103	13.50	16	2.38	2	0.43	136	21.66
Agriculture-Forest	1	2.33	49	19.84	29	4.88	0	0.00	79	12.58
Sub-Total	29	15.57	470	103.00	98	19.87	31	1.72	628	
Percentage	4.62	11.11	74.84	73.49	15.61	14.18	4.94	1.22		
2006 Land Cover Change-Incidents										
Suburban-Forest	0	0.14	4	0.46	2	0.15	0	0.00	6	1.49
Suburban-Agriculture	0	0.15	3	0.46	4	0.00	0	0.00	7	1.73
Forest-Suburban	1	2.22	140	20.72	15	0.28	44	1.48	200	49.50
Forest-Agriculture	0	1.37	33	12.05	13	4.01	0	0.00	46	11.39
Agriculture-Suburban	1	1.66	49	6.52	15	0.70	20	0.63	85	21.04
Agriculture-Forest	2	0.44	39	8.52	19	2.27	0	0.00	60	14.85
Sub-Total	4	5.98	268	48.72	68	7.41	64	2.11	404	
Percentage	0.99	9.32	66.34	75.86	16.83	11.54	15.84	3.28		
Total	122	49.57	1435	351.77	476	85.17	170	8.20	2203	
Percentage	5.54		65.14		21.61		7.72			

Table 41. Distribution of Fatalities by Posted Speed Limit and Land Cover Change.

Fatalities	n<=30	35 to 45	50 to 60	n >=65	Total	Percentage
1996 Land Cover Change-Fatalities						
Suburban-Forest	0	2	0	1	3	13.64
Suburban-Agriculture	0	2	1	0	3	13.64
Forest-Suburban	0	4	2	0	6	27.27
Forest-Agriculture	0	4	0	0	4	18.18
Agriculture-Suburban	0	2	0	0	2	9.09
Agriculture-Forest	1	3	0	0	4	18.18
Sub-Total	1	17	3	1	22	
Percentage	4.55	77.27	13.64	4.55		
2001 Land Cover Change-Fatalities						
Suburban-Forest	0	1	0	0	1	20.00
Suburban-Agriculture	0	0	2	0	2	40.00
Forest-Suburban	0	2	0	0	2	40.00
Forest-Agriculture	0	0	0	0	0	0.00
Agriculture-Suburban	0	0	0	0	0	0.00
Agriculture-Forest	0	0	0	0	0	0.00
Sub-Total	0	3	2	0	5	
Percentage	0.00	60.00	40.00	0.00		
2006 Land Cover Change-Fatalities						
Suburban-Forest	0	0	0	0	0	0.00
Suburban-Agriculture	0	0	0	0	0	0.00
Forest-Suburban	0	1	1	0	2	33.33
Forest-Agriculture	0	1	0	0	1	16.67
Agriculture-Suburban	0	2	1	0	3	50.00
Agriculture-Forest	0	0	0	0	0	0.00
Sub-Total	0	4	2	0	6	
Total	1	24	7	1	33.00	
Percentage	3.03	72.73	21.21	3.03		

Table 42. Distribution of Injuries by Posted Speed Limit and Land Cover Change.

Injuries	n<=30	35 to 45	50 to 60	n >=65	Total	Percentage
1996 Land Cover Change-Injuries						
Suburban-Forest	0	47	7	3	**57**	6.88
Suburban-Agriculture	4	43	20	0	**67**	8.08
Forest-Suburban	31	69	8	23	**131**	15.80
Forest-Agriculture	1	127	111	0	**239**	28.83
Agriculture-Suburban	12	54	46	10	**122**	14.72
Agriculture-Forest	9	118	74	12	**213**	25.69
Sub-Total	57	458	266	48	**829**	
Percentage	6.88	55.25	32.09	5.79		
2001 Land Cover Change-Injuries						
Suburban-Forest	3	26	6	7	**42**	11.57
Suburban-Agriculture	0	5	4	0	**9**	2.48
Forest-Suburban	2	92	19	4	**117**	32.23
Forest-Agriculture	1	61	21	0	**83**	22.87
Agriculture-Suburban	9	56	5	1	**71**	19.56
Agriculture-Forest	1	26	14	0	**41**	11.29
Sub-Total	16	266	69	12	**363**	
Percentage	4.41	73.28	19.01	3.31		
2006 Land Cover Change-Injuries						
Suburban-Forest	0	1	2	0	**3**	1.64
Suburban-Agriculture	0	3	1	0	**4**	2.19
Forest-Suburban	0	51	14	13	**78**	42.62
Forest-Agriculture	0	24	9	0	**33**	18.03
Agriculture-Suburban	0	23	8	12	**43**	23.50
Agriculture-Forest	1	17	4	0	**22**	12.02
Sub-Total	1	119	38	25	**183**	
Percentage	0.55	65.03	20.77	13.66		
Total	74	843	373	85	**1375**	
Percentage	5.38	61.31	27.13	6.18		

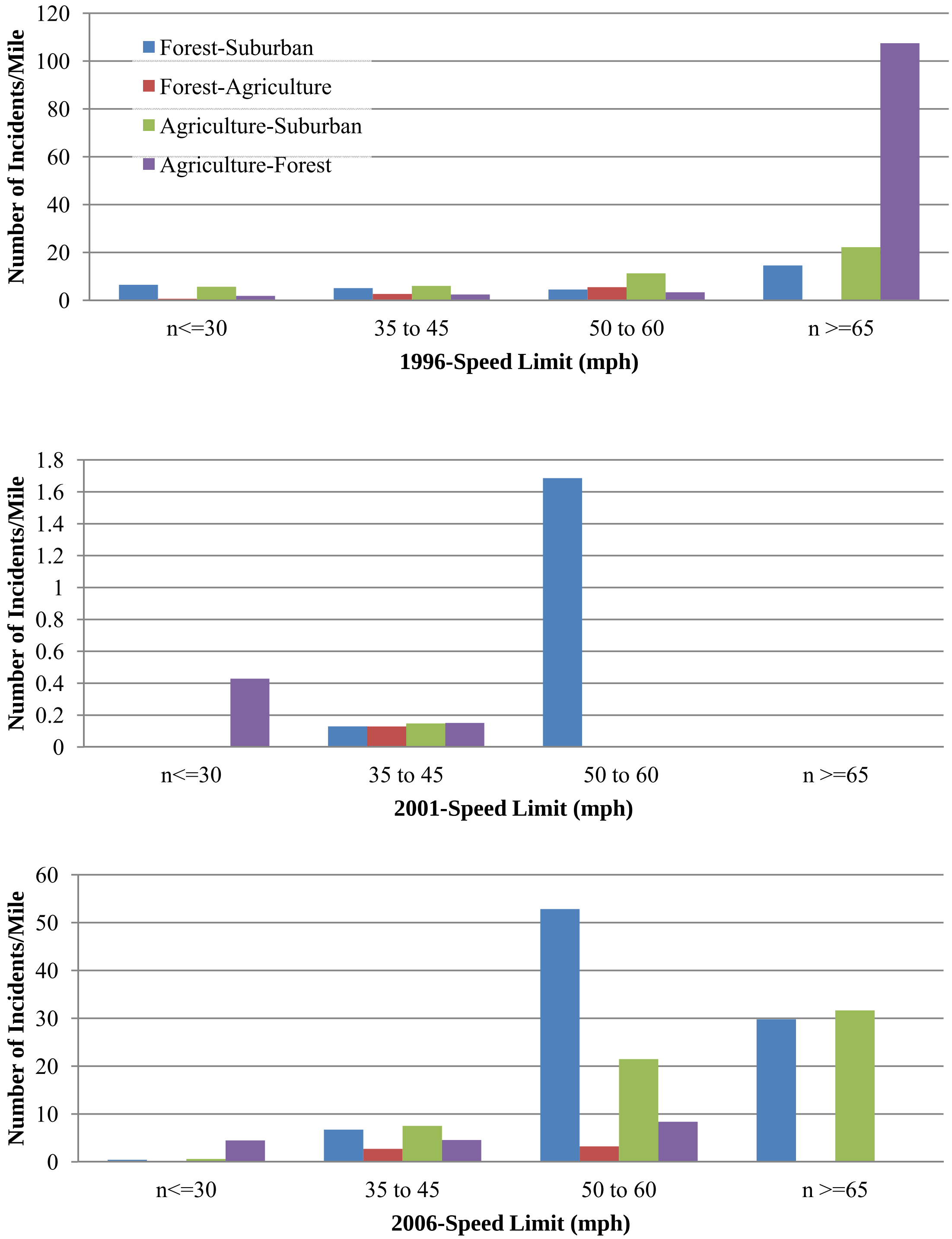

Figure 53. Distribution of Incidents by Posted Speed Limit per Miles of Road.

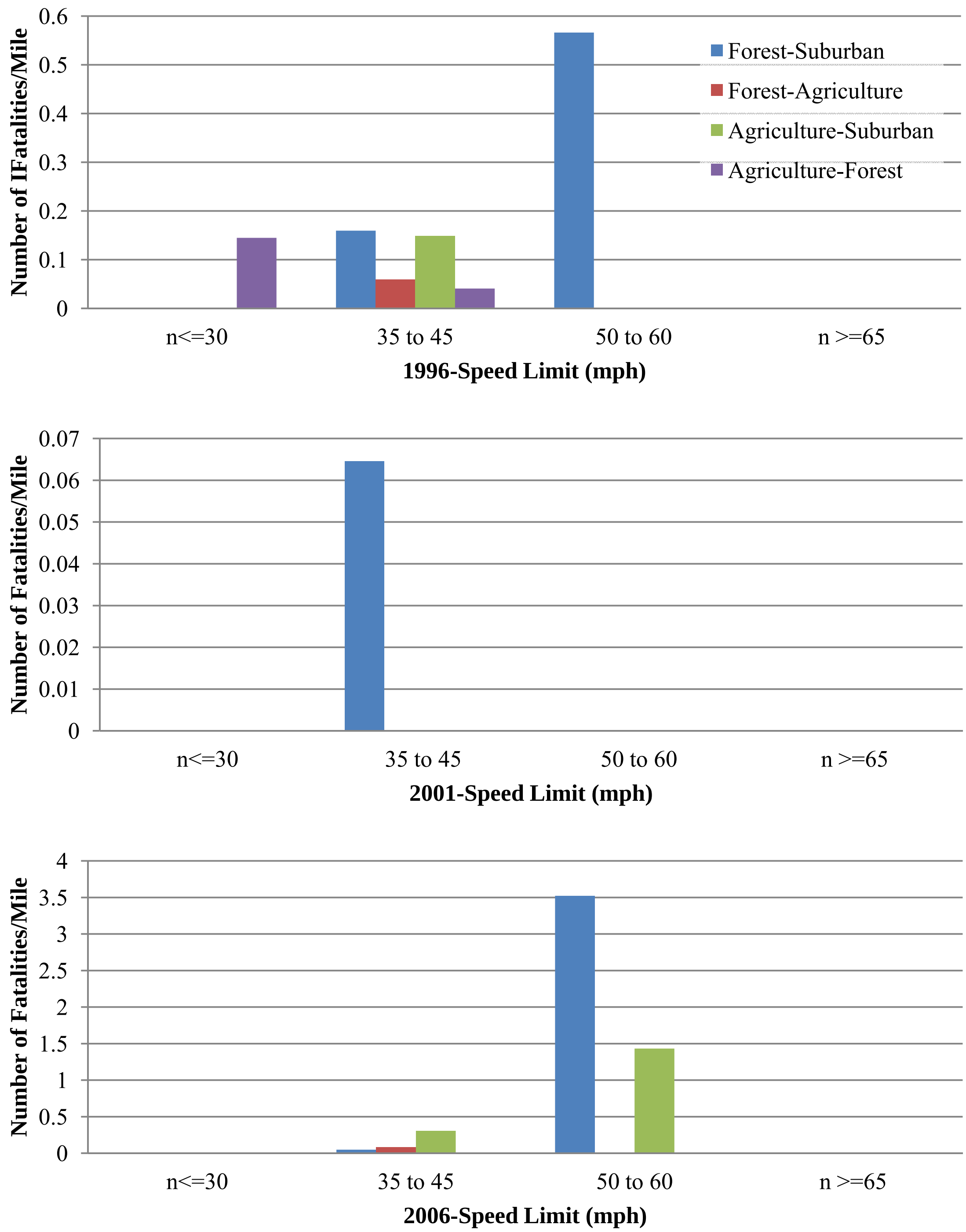

Figure 54. Distribution of Fatalities by Posted Speed Limit per Miles of Road.

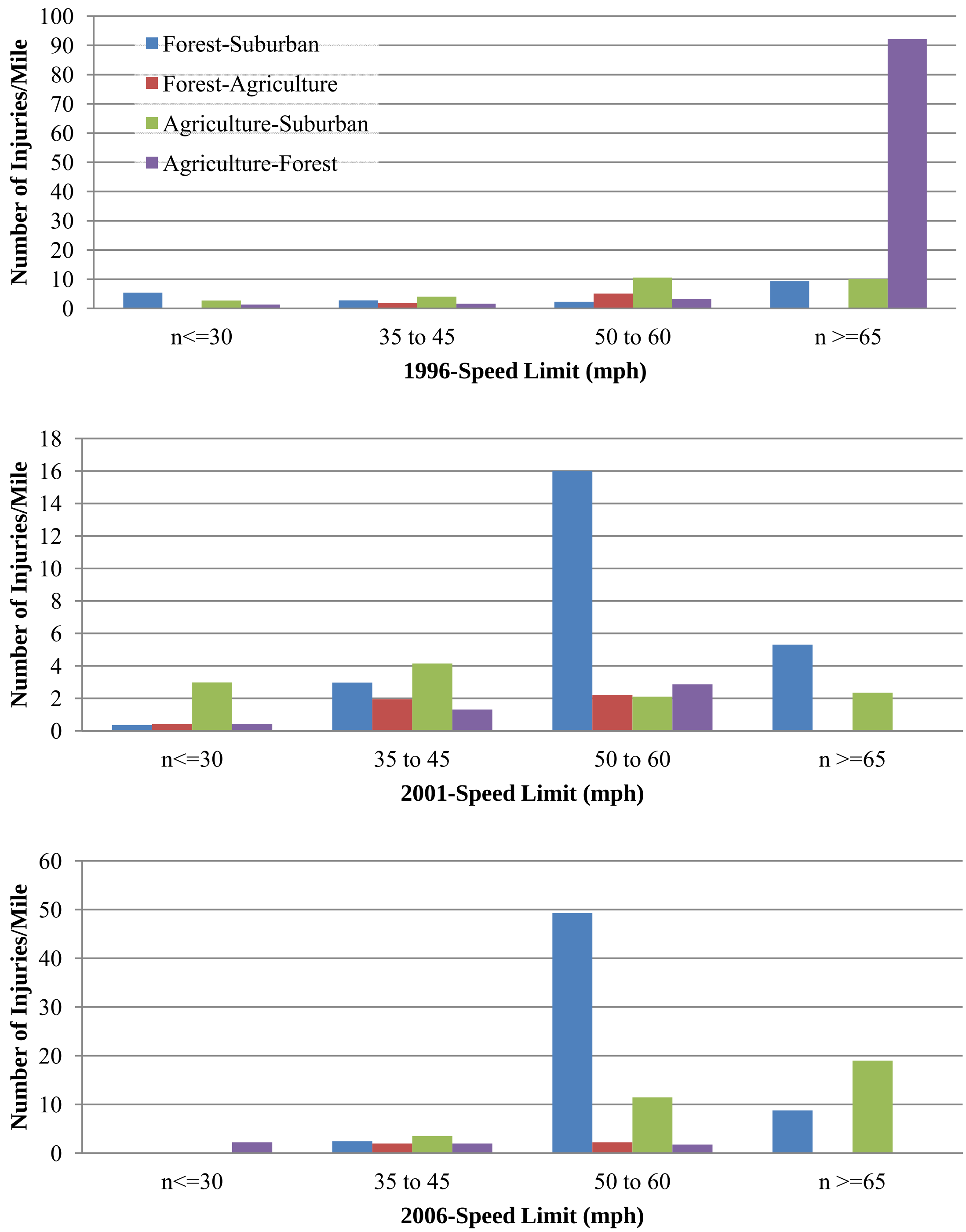

Figure 55. Distribution of Injuries by Posted Speed Limit per Miles of Road.

Median Width: The incidents occurring along roads with no median appears to be the least likely location throughout all three time periods, however, as **Table 43, Table 44,** and **Table 45** shows there are far more incidents occurring on roads with no medians than those with medians (n =1451, total incidents 2203). However, as seen in previous discussions the overwhelming mileage of roads in the rural portions of the project area is quadruple the number of roads within the suburban areas. While there is less mileage and higher incidents on the road segments changing from Forest and Agriculture to Suburban, the likelihood of an incident occurring within an area changing to suburban is much higher than an area than an area that remains rural.

Through the first two time periods there is a general increase in the numbers of incidents and injuries as the width of the median increases up to 40 ft and a general drop in incidents and injuries on roads with medians greater than 40 ft. In 2006, there is a more pronounced increase from 20 ft to more than 40 ft in all land cover types except Agriculture to Forest. Conversely, there is a decrease in incidents from 1996 to 2006 in road segments with a median less than 20 ft. The incidents and injuries follow a similar pattern; however, the fatalities are limited in the sample size and the pattern may or may not be real. With fatalities there is an increase in the numbers with the increase in median width. Although in 1996 roads with medians greater than 40 ft had the most fatalities, in both 2001 and 2006 fatalities are most prominent in the 20 to 40 ft category falling off to 0 in the greater than 40 ft median category.

Table 43. Distribution of Incidents by Median Width and Land Cover Change.

Incidents	Median Width (ft)									
Land Cover Change	0		0 < n <= 20		20<n<=40		n>40		Total	Percentage
1996 Land Cover Change-Injuries										
	#	**Miles**	**#**	**Miles**	**#**	**Miles**	**#**	**Miles**		
Suburban-Forest	61	13.62	0	0.05	4	0.67	11	0.99	76	6.49
Suburban-Agriculture	100	13.98	8	0.73	1	0.77	1	0.54	110	9.39
Forest-Suburban	123	30.47	10	0.98	15	1.10	69	4.23	217	18.53
Forest-Agriculture	224	91.99	2	0.16	56	2.32	24	1.41	306	26.13
Agriculture-Suburban	85	18.95	17	1.14	38	1.27	37	1.80	177	15.12
Agriculture-Forest	227	100.59	14	0.51	12	1.27	32	0.91	285	24.34
Sub-Total	820	269.59	51	3.57	126	7.39	174	9.89	1171	
Percentage	70.03	92.82	4.36	1.23	10.76	2.54	14.86	3.41		
2001 Land Cover Change-Injuries										
Suburban-Forest	19	5.88	4	0.29	5	0.55	36	1.33	64	10.19
Suburban-Agriculture	13	3.66	0	0.01	1	0.27	0	0.02	14	2.23
Forest-Suburban	146	34.85	7	0.89	34	0.88	19	1.87	206	32.80
Forest-Agriculture	112	41.91	0	0.49	5	0.59	12	0.29	129	20.54
Agriculture-Suburban	122	17.93	4	0.32	2	0.55	8	0.53	136	21.66
Agriculture-Forest	60	26.57	0	0.00	12	0.25	7	0.24	79	12.58
Sub-Total	472	130.80	15	1.99	59	3.10	82	4.27	628	
Percentage	75.16	93.33	2.39	1.42	9.39	2.21	13.06	3.05		
2006 Land Cover Change-Injuries										
Suburban-Forest	0	0.32	0	0.00	2	0.15	4	0.29	6	1.49
Suburban-Agriculture	7	0.61	0	0.00	0	0.00	0	0.00	7	1.73
Forest-Suburban	17	19.94	2	0.65	19	1.31	162	2.80	200	49.50
Forest-Agriculture	41	16.68	0	0.00	5	0.74	0	0.00	46	11.39
Agriculture-Suburban	49	7.94	8	1.05	8	0.22	20	0.29	85	21.04
Agriculture-Forest	45	10.79	0	0.00	0	0.15	15	0.29	60	14.85
Sub-Total	159	56.28	10	1.70	34	2.57	201	3.67	404	
Percentage	39.36	87.64	2.48	2.65	8.42	4.01	49.75	5.71		
Total	1451	456.68	76	7.26	219	13.06	457	17.83	2203	
Percentage	65.86	92.29	3.45	1.47	9.94	2.64	20.74	3.60		

Table 44. Distribution of Fatalities by Median Width and Land Cover Change.

Fatalities	Median Width (ft)					
Land Cover Change	**0**	**0 < n <= 20**	**20<n<=40**	**n>40**	**Total**	**Percentage**
1996 Land Cover Change-Fatalities						
Suburban-Forest	2	0	0	1	3	13.64
Suburban-Agriculture	3	0	0	0	3	13.64
Forest-Suburban	3	0	0	3	6	27.27
Forest-Agriculture	4	0	0	0	4	18.18
Agriculture-Suburban	1	0	0	1	2	9.09
Agriculture-Forest	4	0	0	0	4	18.18
Sub-Total	17	0	0	5	22	
Percentage	77.27	0.00	0.00	22.73		
2001 Land Cover Change-Injuries						
Suburban-Forest	0	0	0	1	1	20.00
Suburban-Agriculture	2	0	0	0	2	40.00
Forest-Suburban	1	0	1	0	2	40.00
Forest-Agriculture	0	0	0	0	0	0.00
Agriculture-Suburban	0	0	0	0	0	0.00
Agriculture-Forest	0	0	0	0	0	0.00
Sub-Total	3	0	1	1	5	
Percentage	60.00	0.00	20.00	20.00		
2006 Land Cover Change-Injuries						
Suburban-Forest	0	0	0	0	0	0.00
Suburban-Agriculture	0	0	0	0	0	0.00
Forest-Suburban	0	0	2	0	2	33.33
Forest-Agriculture	1	0	0	0	1	16.67
Agriculture-Suburban	0	2	1	0	3	50.00
Agriculture-Forest	0	0	0	0	0	0.00
Sub-Total	1	2	3	0	6	
Total	21	2	4	6	33	
Percentage	63.64	6.06	12.12	18.18		

Table 45. Distribution of Injuries by Median Width and Land Cover Change.

Injuries	Median Width (ft)					
Land Cover Change	0	0 < n <= 20	20<n<=40	n>40	Total	Percentage
1996 Land Cover Change-Fatalities						
Suburban-Forest	49	0	4	4	57	4.87
Suburban-Agriculture	61	5	1	0	67	5.72
Forest-Suburban	86	2	7	36	131	11.19
Forest-Agriculture	165	2	56	16	239	20.41
Agriculture-Suburban	58	10	38	16	122	10.42
Agriculture-Forest	171	4	15	23	213	18.19
Sub-Total	590	23	121	95	829	
Percentage	71.17	2.77	14.60	11.46		
2001 Land Cover Change-Fatalities						
Suburban-Forest	20	4	3	15	42	11.57
Suburban-Agriculture	9	0	0	0	9	2.48
Forest-Suburban	98	2	12	5	117	32.23
Forest-Agriculture	79	0	2	2	83	22.87
Agriculture-Suburban	69	2	0	0	71	19.56
Agriculture-Forest	31	0	7	3	41	11.29
Sub-Total	306	8	24	25	363	
Percentage	84.30	2.20	6.61	6.89		
2006 Land Cover Change-Fatalities						
Suburban-Forest	0	0	2	1	3	1.64
Suburban-Agriculture	4	0	0	0	4	2.19
Forest-Suburban	3	0	15	60	78	42.62
Forest-Agriculture	31	0	2	0	33	18.03
Agriculture-Suburban	27	1	3	12	43	23.50
Agriculture-Forest	16	0	0	6	22	12.02
Sub-Total	81	1	22	79	183	
Total	977	32	167	199	1375	
Percentage	71.05	2.33	12.15	14.47		

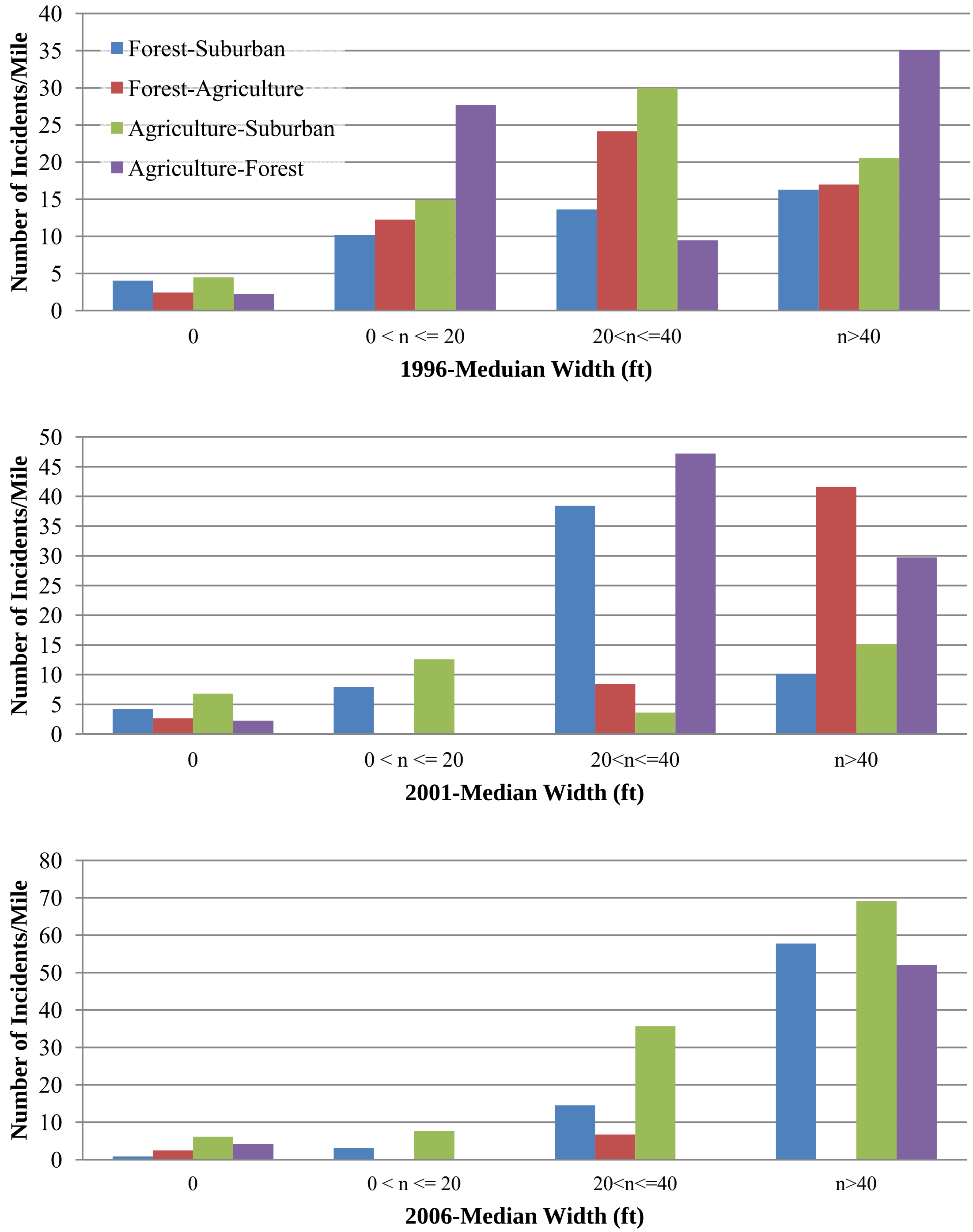

Figure 56. Distribution of Incidents by Median Width per Miles of Road.

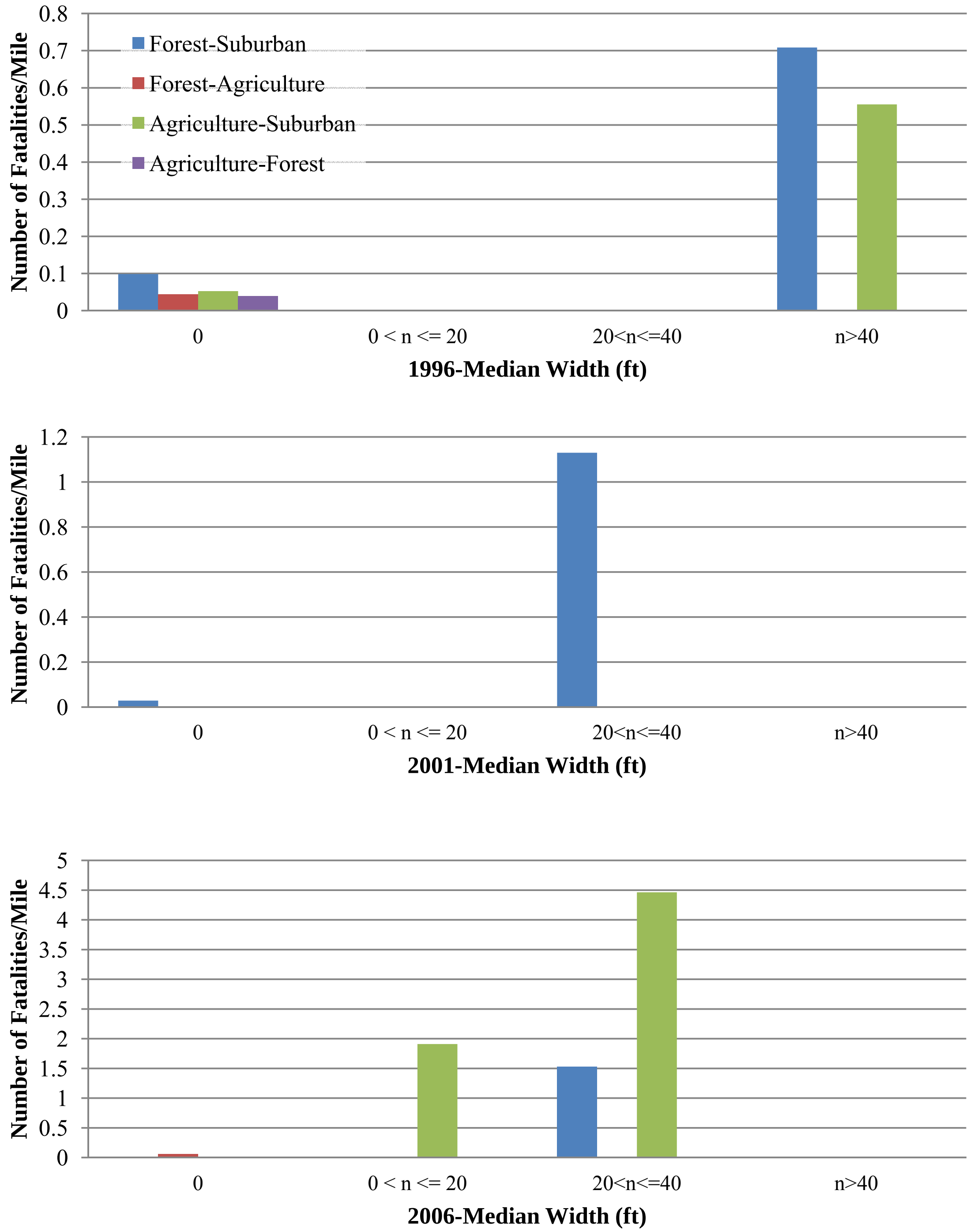

Figure 57. Distribution of Fatalities by Median Width per Miles of Road.

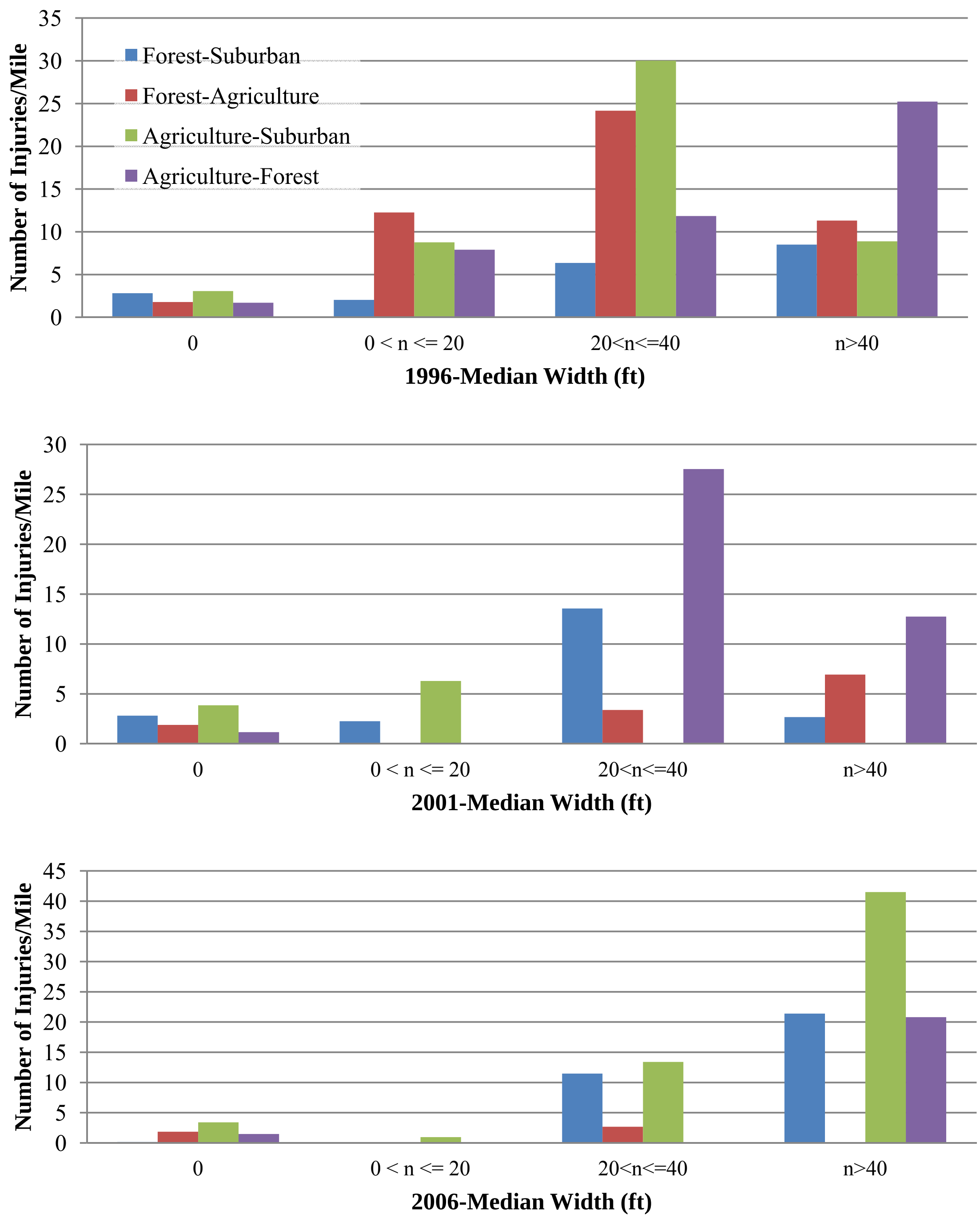

Figure 58. Distribution of Injuries by Median Width per Miles of Road.

Incident Type: The most incidents types occurring within the project area are Fixed Object incidents (40.8 percent of overall total) with Rear End incidents (21.2 of the overall total) coming in second with approximately 50 percent less than Fixed Object incidents. Angle incidents were the second most prevalent incident type in 1996 with just three more incidents than Rear End incidents; however overall Angle incidents make up only 15.8 percent of the overall total. Sideswipe incidents (10.9 percent of overall total) are a distant fourth while the remaining categories each make up less than 5 percent of the overall total (**Table 46, Table 47, Figure 48**).

Through the three time periods, the distribution of incident types per mile of road (**Figure 59**) is dominated by Forest-Suburban and Agriculture-Suburban. This pattern could be the result of the larger number of incidents occurring within suburban areas or the result of there being more miles of road located within the rural forested and agricultural areas. The raw numbers in Table 46 show a slightly more dispersed pattern across the four main land cover categories (not including the Suburban-Forest and Suburban-Agriculture). Although the Forest-Agriculture and Agriculture-Forest categories are nearly double the Forest-Suburban and Agriculture- Suburban in 1996, the Forest-Suburban incidents increase to 32 percent of the total in 2001 and 50 percent in 2006 (total number of incidents), although the distribution by miles of road shows a closer to distribution of Forest-Suburban and Agriculture-Suburban.

Throughout all three time periods, the most prevalent incident types in both Table 46 and Figure 59 are the Fixed Object, Rear End, and Angle incidents (in descending order). Fixed Object incidents dominate across all land cover types and all time periods with Rear End incidents coming in second across all time periods and land cover types.

The distribution of fatalities (**Table 47, Figure 60**), albeit skewed with limited numbers, generally follows the distribution of incidents with Forest to Suburban and Agriculture to Suburban accounting for the most fatalities. Fixed Objects also account for the most fatalities.

The distribuiton of injuries by incident types also follows the distribution of the overall incidents (**Table 48, Figure 61**). Changes to Suburban is less than those incidents changing to Forest or Agriculture in 1996, but increases through the next two time periods. The incident types are the same with Fixed Objects comprising the majority.

Table 46. Distribution of Incidents by Incidents Types across Land Cover Change Categories.

Incidents	Incident Types							
Land Cover Change	Angle	Fixed Object	Sideswip e	Rear End	Head On	Anim al	Non-Collision	Othe r
1996 Land Cover Change-Incidents								
Suburban-Forest	9	32	6	17	2	4	3	3
Suburban-Agriculture	26	28	18	28	0	4	4	2
Forest-Suburban	33	75	33	55	3	1	14	3
Forest-Agriculture	60	161	20	27	5	15	15	3
Agriculture-Suburban	40	63	19	48	0	0	6	1
Agriculture-Forest	38	171	22	28	4	7	14	1
Sub-Total	206	530	118	203	14	31	56	13
2001 Land Cover Change-Incidents								
Suburban-Forest	2	27	9	17	0	3	5	1
Suburban-Agriculture	1	2	2	5	0	2	1	1
Forest-Suburban	61	57	29	39	2	10	6	2
Forest-Agriculture	12	57	11	27	1	9	10	2
Agriculture-Suburban	27	40	13	44	1	5	5	1
Agriculture-Forest	10	41	7	8	2	8	3	0
Sub-Total	113	224	71	140	6	37	30	7
2006-Land Cover Change-Incidents								
Suburban-Forest	1	2	1	1	0	1	0	0
Suburban-Agriculture	3	4	0	0	0	0	0	0
Forest-Suburban	11	61	33	77	0	8	4	6
Forest-Agriculture	0	33	2	1	2	6	1	1
Agriculture-Suburban	9	22	8	36	3	4	2	1
Agriculture-Forest	5	23	7	10	1	9	5	0
Sub-Total	29	145	51	125	6	28	12	8
Total	348	899	240	468	26	96	98	28

Table 47. Distribution of Fatalities by Incident Types across Land Cover Change Categories.

Fatalities	Incident Types							
Land Cover Change	**Angle**	**Fixed Object**	**Sideswipe**	**Rear End**	**Head On**	**Animal**	**Non-Collision**	**Other**
1996 Land Cover Change-Fatalities								
Suburban-Forest	0	3	0	0	0	0	0	0
Suburban-Agriculture	1	2	0	0	0	0	0	0
Forest-Suburban	0	2	2	0	1	0	1	0
Forest-Agriculture	0	2	0	0	0	0	2	0
Agriculture-Suburban	0	0	1	1	0	0	0	0
Agriculture-Forest	0	3	1	0	0	0	0	0
Sub-Total	1	12	4	1	1	0	3	0
2001 Land Cover Change-Fatalities								
Suburban-Forest	0	1	0	0	0	0	0	0
Suburban-Agriculture	0	0	0	0	0	0	0	2
Forest-Suburban	0	0	0	2	0	0	0	0
Forest-Agriculture	0	0	0	0	0	0	0	0
Agriculture-Suburban	0	0	0	0	0	0	0	0
Agriculture-Forest	0	0	0	0	0	0	0	0
Sub-Total	0	1	0	2	0	0	0	2
2006 Land Cover Change-Fatalities								
Suburban-Forest	0	0	0	0	0	0	0	0
Suburban-Agriculture	0	0	0	0	0	0	0	0
Forest-Suburban	1	0	0	1	0	0	0	0
Forest-Agriculture	0	1	0	0	0	0	0	0
Agriculture-Suburban	0	1	0	0	0	0	0	2
Agriculture-Forest	0	0	0	0	0	0	0	0
Sub-Total	1	2	0	1	0	0	0	2
Total	2	15	4	4	1	0	3	4

Table 48. Distribution of Injuries by Incident Types across Land Cover Change Categories.

Incidents	Incident Types							
Land Cover Change	Angle	Fixed Object	Sideswipe	Rear End	Head On	Animal	Non-Collision	Other
1996 Land Cover Change-Injuries								
Suburban-Forest	14	17	2	14	6	0	0	4
Suburban-Agriculture	28	12	10	12	0	0	3	2
Forest-Suburban	26	36	22	29	4	0	10	4
Forest-Agriculture	66	117	12	19	7	3	11	4
Agriculture-Suburban	24	33	21	38	0	0	4	2
Agriculture-Forest	27	120	12	25	10	2	15	2
Sub-Total	185	335	79	137	27	5	43	18
2001 Land Cover Change-Injuries								
Suburban-Forest	4	18	0	16	0	1	3	0
Suburban-Agriculture	0	0	1	8	0	0	0	0
Forest-Suburban	41	33	9	24	3	2	4	1
Forest-Agriculture	14	38	6	19	2	1	3	0
Agriculture-Suburban	11	20	3	30	2	1	2	2
Agriculture-Forest	3	24	3	3	2	2	4	0
Sub-Total	73	133	22	100	9	7	16	3
2006 Land Cover Change-Injuries								
Suburban-Forest	2	1	0	0	0	0	0	0
Suburban-Agriculture	2	2	0	0	0	0	0	0
Forest-Suburban	8	22	11	32	0	0	4	1
Forest-Agriculture	0	23	2	0	6	0	2	0
Agriculture-Suburban	9	10	3	16	4	0	1	0
Agriculture-Forest	2	10	0	2	0	4	4	0
Sub-Total	23	68	16	50	10	4	11	1
Total	281	536	117	287	46	16	70	22

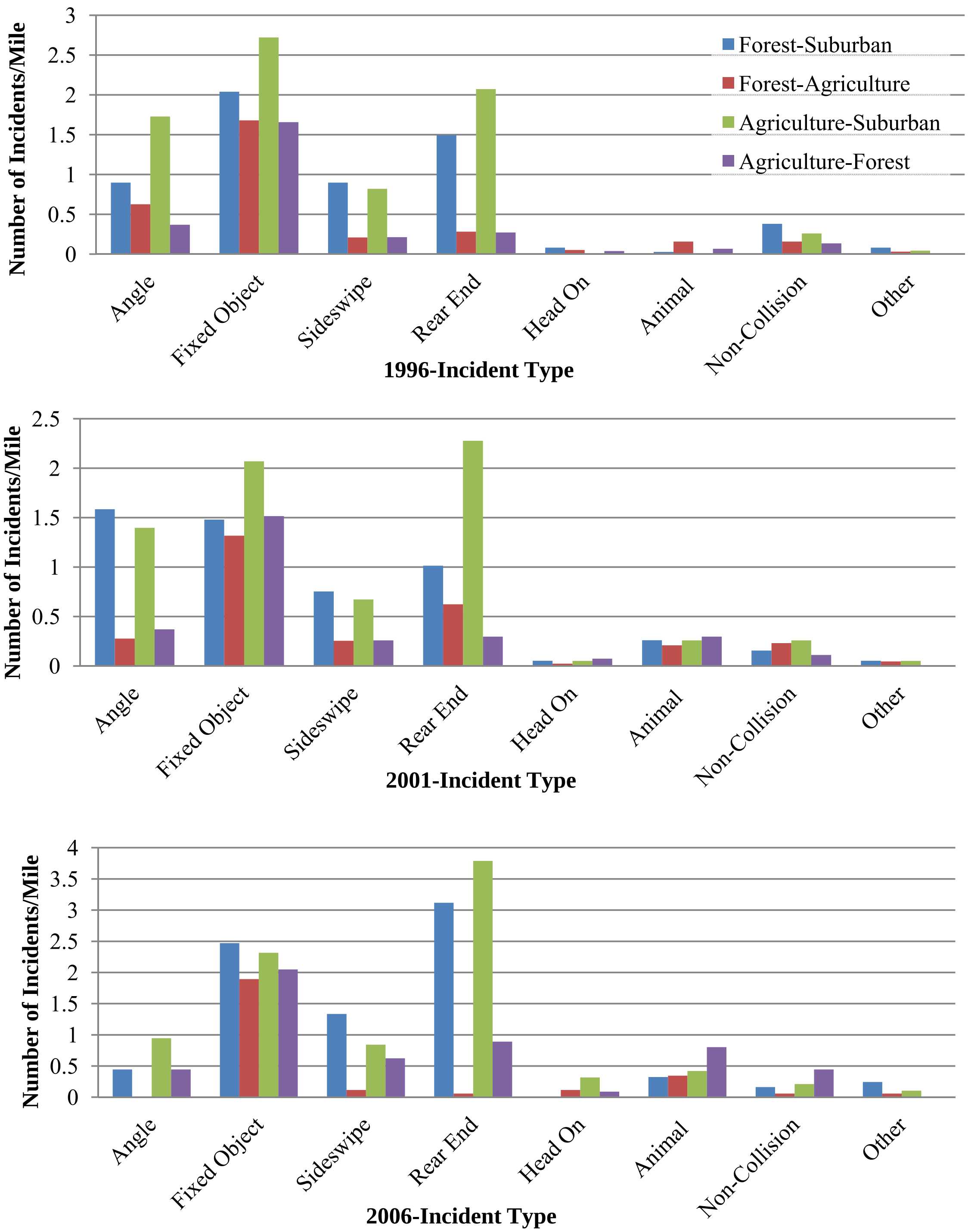

Figure 59. Distribution of the Number of Incidents by Incident Type.

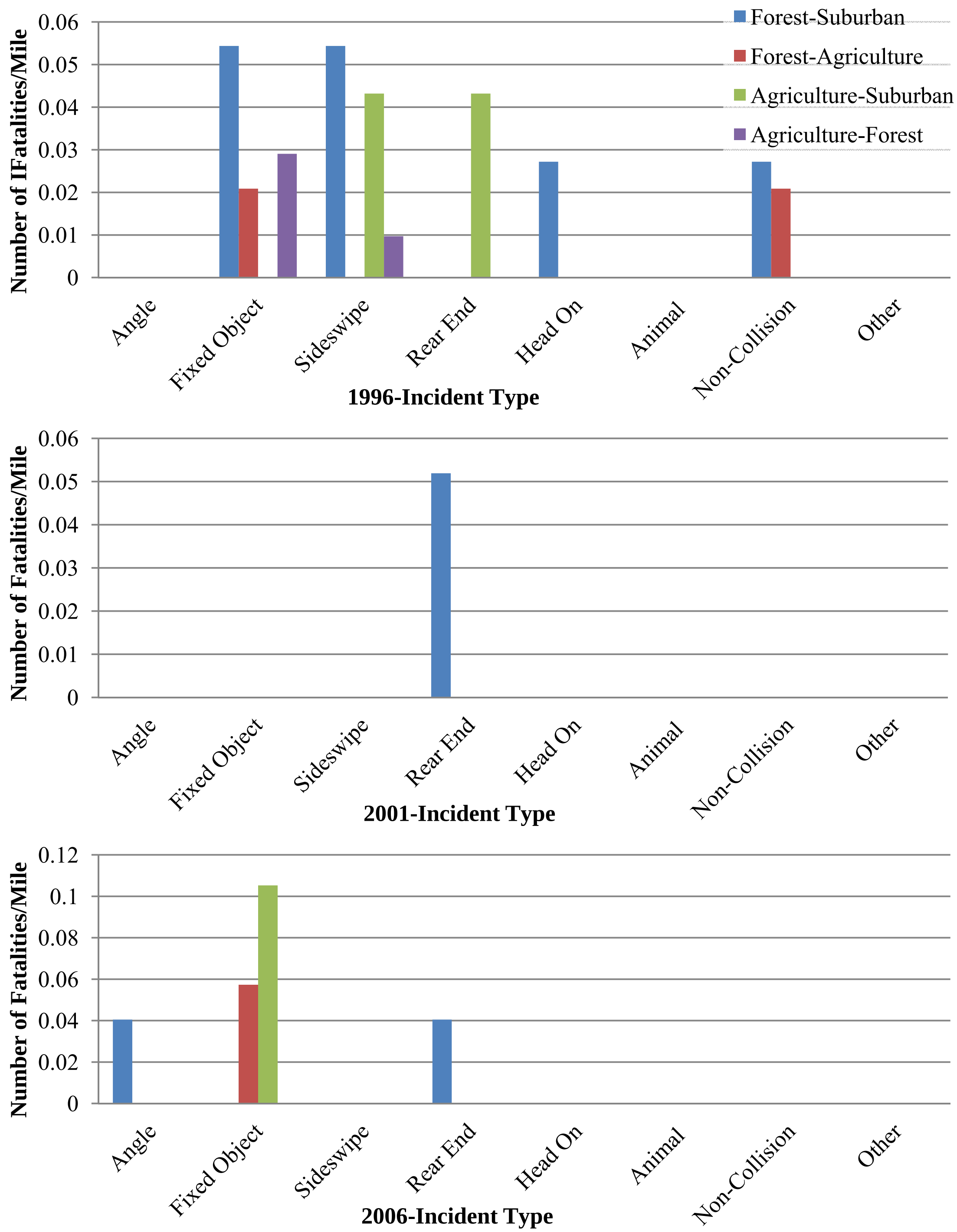

Figure 60. Distribution of the Number of Fatalities by Incident Type.

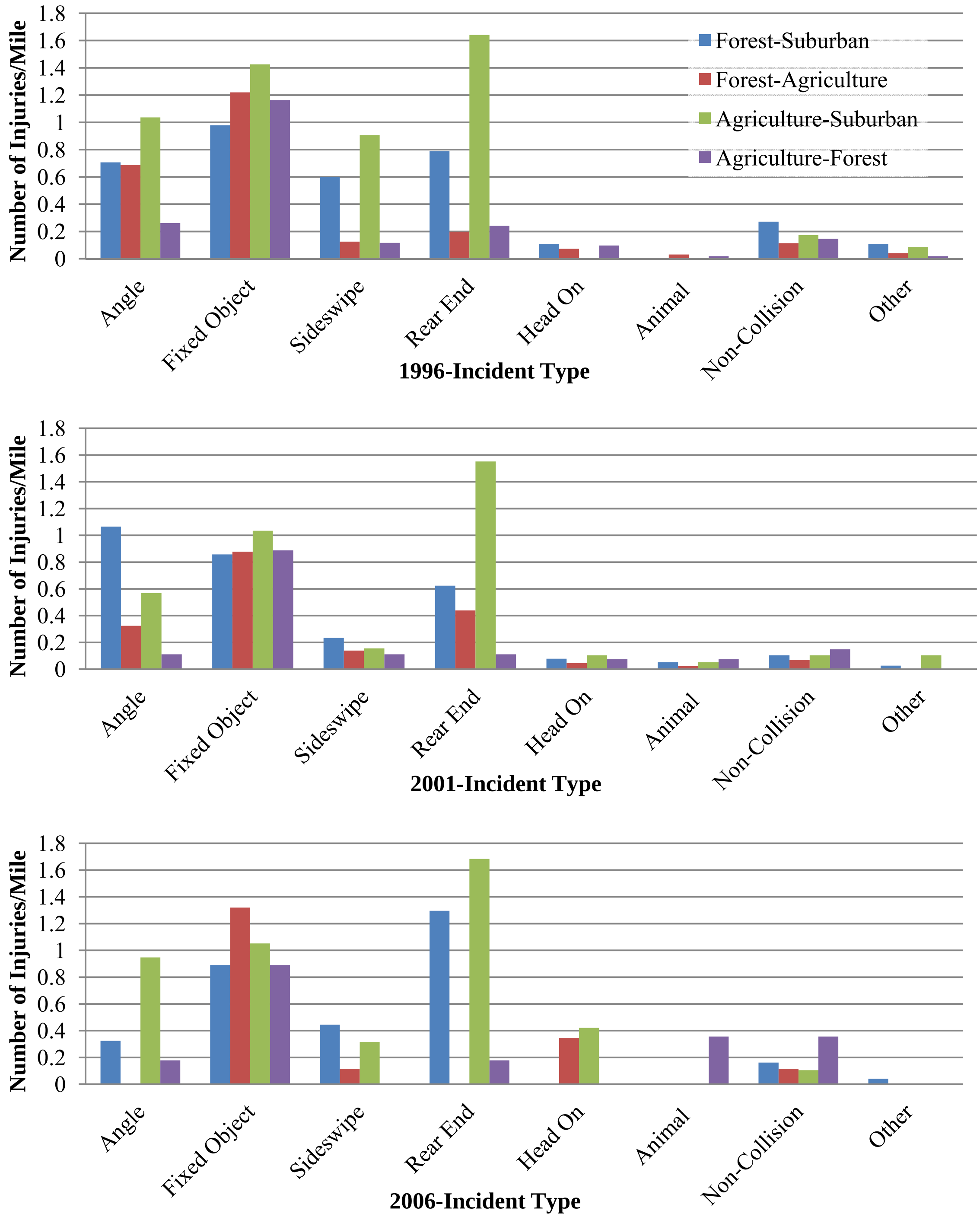

Figure 61. Distribution of the Number of Injuries by Incident Type.

Summary of Land Cover Change Road Characteristics

- Number of Lanes: Roads with two lanes, similar to the overall land cover, comprises over 60 percent of the incidents, fatalities, and injuries; however, increases to over 70 percent for Incidents and nearly 80 percent for injuries in 2001. The per mile distributions show higher rates of incidents, fatalities, and injuries along roads with four lanes, except for a couple of anomalies on six lane roads: Agriculture-Forest (Incidents 1996, Injuries 1996) and Forest-Suburban (Incidents 1996, 2001; Injuries 2001).
- Surface Width: In the first two time periods, incidents, fatalities, and injuries are most prevalent along roads with an overall surface width between 18 ft and 24 ft. In 2006, incidents and injuries increase on roadways with a width greater than 24 ft. Per mile distributions of incidents are similar to the Number of Lanes, with the larger road surface width having the higher incidents per mile, surface widths greater than 24 ft. However, in 2006, the mid-range surface width shows higher incident per mile than previous time periods. Although the fatalities are relatively low, the higher per mile rates are occurring on those areas changing from rural to suburban.
- Shoulder Width: Within land cover change, incidents and injuries on roads with a shoulder width greater than 2 ft and less than 6 ft outnumber the other categories in 1996 to 2001. However, roads with shoulders less than 2 ft surpass the second category and to equal nearly two-thirds of the incidents and injuries. The per mile distributions show a few high numbers for roads with shoulders less than or equal

to two feet but generally decreases or remains similar to roads with shoulders between 2 and 6 ft before increasing significantly on roads with shoulders greater than 6 ft.

- Posted Speed Limit: The majority of incidents, fatalities, and injuries are occurring on roads where the speed limit is between 35 to 45 mph. The second most of each occurs on roads with speed limits between 50 and 60 mph. The per mile distribution of posted speed limits offers a different picture. The highest per mile incidents and injuries are Agriculture-Forest with speed limits greater than or equal to 65 ft in 1996 and Forest-Suburban with speed limits from 50 to 60 mph in 2001 and 2006. In 2006, though, Agriculture-Suburban increases to near equal incidents as Forest-Suburban and surpasses the injuries per mile. The Fatalities per mile are similar with the highest rates for incidents and injuries occurring at the 50 to 60 mph in 1996 and 2006, while speed limits of 35 to 45 mph are the only fatalities in 2001.
- Median Width: The overwhelming majority of incidents, fatalities, and injuries are occurring on roads with no median. The per mile distribution is much less clear, however. There is a general increasing trend with the increase in median width, but this may be a result of the lower miles of road in the higher median width categories.
- Incident Types: Similar to the distribution of overall land cover incident types, the change in land cover results in higher frequencies of Fixed Object, Rear End,

Angle, and Sideswipe incidents. All four can be associated with suburban/urban areas; however, Fixed Object is also indicative of rural areas.

Chi-Square Statistic Analysis and Results

Change in Number of Incidents

The Chi-Square is a statistical test of independence that analyzes two or more categorical variables from a simple random sample to determine if the variables are independent of one another. For the Chi-Square analysis, the change in the number of incidents along each road segment was calculated based on the number of incidents identified along the segment during the previous time period. The numbers include the change in number of incidents from the three main land cover changes. The change in incidents from Forest to Agriculture ranged from -13 to 12, from Forest to Suburban ranged from -33 to 53, and from Agriculture to Suburban ranged from -56 to 17. Based on the distribution of numbers, five categories were derived to correspond to the change in number of incidents: High negative < -3, Negative -3 < = n < 0, No Change = 0, Positive = 0 < n < = 3, High Positive >3. The sum of the number of segments falling within each category was calculated and added to the Chi-Square table (**Table 49**).

The H_o Hypothesis states that the change in land cover is independent of the increase/decrease in the number of incidents occurring on the roads. Alternately, the H_a Hypothesis states that the two variables are not independent of one another and one variable can help predict the value of the second variable. The lower the p-value the less likely the two variables are independent of one another. Using the CHITEST in Microsoft Excel, the Chi-Square analysis is computed based on the difference in the observed and expected change in incidents and returns probability value that the data are independent. Based on the results (**Table 49**) the p-value (or probability) = 0.0000393, which suggests that there is a strong correlation between the observed and expected numbers with a less than 0.0000393 percent chance that two variables are independent of one another. In other words, the two categorical variables appear to be strongly related to one another which may allow for the prediction of incidents within areas of certain land cover changes. Additionally, the X^2 = 34.1 which is greater than the p-value for 8 degrees of freedom at a significance level of 0.95 which can be interpreted that the null hypothesis can be

Table 49. Chi-Square Analysis of Change in Number of Incidents by Land Cover Type.

Observed	High Negative	Negative	No Change	Positive	High Positive	Totals
Forest-Agriculture	15	43	41	23	6	128
Forest-Suburban	19	22	18	34	26	119
Agriculture-Suburban	18	24	35	19	17	113
Totals	52	89	94	76	49	360
Expected	**High Negative**	**Negative**	**No Change**	**Positive**	**High Positive**	**Totals**
Forest-Agriculture	18.49	31.64	33.42	27.02	17.42	128
Forest-Suburban	17.19	29.42	31.07	25.12	16.20	119
Agriculture-Suburban	16.32	27.94	29.51	23.86	15.38	113
Totals	52	89	94	76	49	360
CHITEST Results	df = 8			p-value: 0.0000393		
CHIDIST Results	X^2 = 34.1			p-value: 0.0000		

rejected as there appears to be significant relationship between the change in land cover and the change in the number of incidents. The nature of the relationship between the two variables, however, cannot be determined through this test.

Severity of Incidents

The severity of an incident is ranked by the type of fatalities and injuries that occur. There were five categories created to rank the severity of the incidents, this ranking loosely follows the severity measure used by the VDOT. The five categories are (from most severe to least severe): 1) Pedestrian Fatality, 2) Vehicular Fatality, 3) Pedestrian Injury, 4) Vehicular Injury, and 5) No Injury. The results of the five categories leads to two values of 0 in the Chi-Square matrix table, therefore, the severity categories were changed to 2) Fatality, 4) Injury, and 5) No Injury. Based on this ranking, the Chi-Square analysis was conducted to determine if the severity can be correlated with the change in land cover types (**Table 50).** Based on the CHITEST in Excel, the probability value is 0.00384, suggesting that there is a 0.38 percent chance the two variables are independent of one another, conversely, the test suggests that the severity of the incidents is directly related to the land cover change in the vicinity of the incident; however, the nature of that relationship cannot be determined by the Chi-Square Test. With degrees of freedom of 4, the Chi-Square (X^2) value is 15.5 which exceeds the probability value of 9.488 at the significance level of 0.95, further corroborating the rejection of the null hypothesis with the CHITEST above. Based on these two Chi-Square analyses, the change in land cover and the severity of the incidents appear to have a significant relationship.

Table 50. Chi-Square Analysis of Severity of Incidents by Land Cover Type.

Severity	2	4	5	Totals
Observed Land Cover Change				
Forest-Agriculture	6	224	261	491
Forest-Suburban	8	213	403	624
Agriculture-Suburban	4	155	240	399
Totals	18	592	904	1514
Expected Land Cover Change				
Forest-Agriculture	5.84	191.99	293.17	491
Forest-Suburban	7.42	243.99	372.59	624
Agriculture-Suburban	4.74	156.02	238.24	399
Totals	18	592	904	1514
CHITEST Results	df: 4	p-value 0.00384		
CHIDIST Results	$X^2 = 15.5$	p-value: 0.00381		

The significance of the Chi-Square test shows that there is significant relationship between the change in land cover and severity of incidents with the change in the number of incidents. The exact nature of this relationship is not fully expandable with these results and would require additional analysis to understand the relationship; therefore a multiple regression analysis was also conducted with the change in land cover and the change in number of incidents.

Spatial Analysis along NETworks

Given that traffic incidents occur along or adjacent to road networks, it would follow that any spatial analysis of traffic incidents should be confined to the road network and ignore those areas where there is no possibility of a traffic incident occuring. As described in the Methods section, the typcial K-Function tends to over-represent point data along a road network as clustered. Figure 62 depicts the extreme clustering of fatal incidents within the project area. Attempts were made to analyze incidents, fatalities, and injuries within the three time periods, looking at individual years, and even 6 months; however, the program continually failed to calculate sample sizes larger than approximately 500 incidents. Therefore the Network K-Function analysis focuses on the fatalities within each of the three time periods each totaling less than 200.

The Global auto K Function method in SANET is a test of complete spatial randomness (CSR) or that each fatal accident is completely random and the location of one fatality has no affect on the location of the other fatalities and the locations of each of the fatal incidents is uniformly distributed across the network without regard to additional factors, including other incidents. The tool creates a distribution based on the mean shortest-path distance and the upper and lower 5th percntile. When the distribution exceeds the upper 5th perctentile, the data points are cluster; conversely if they fall below the lower 5th percentile, the data points are dispersed. When the data points fall between the upper and lower 5th percentile, the data points exhibit complete spatial randomness (SANET Team 2012; Okabe and Sugihara 2012).

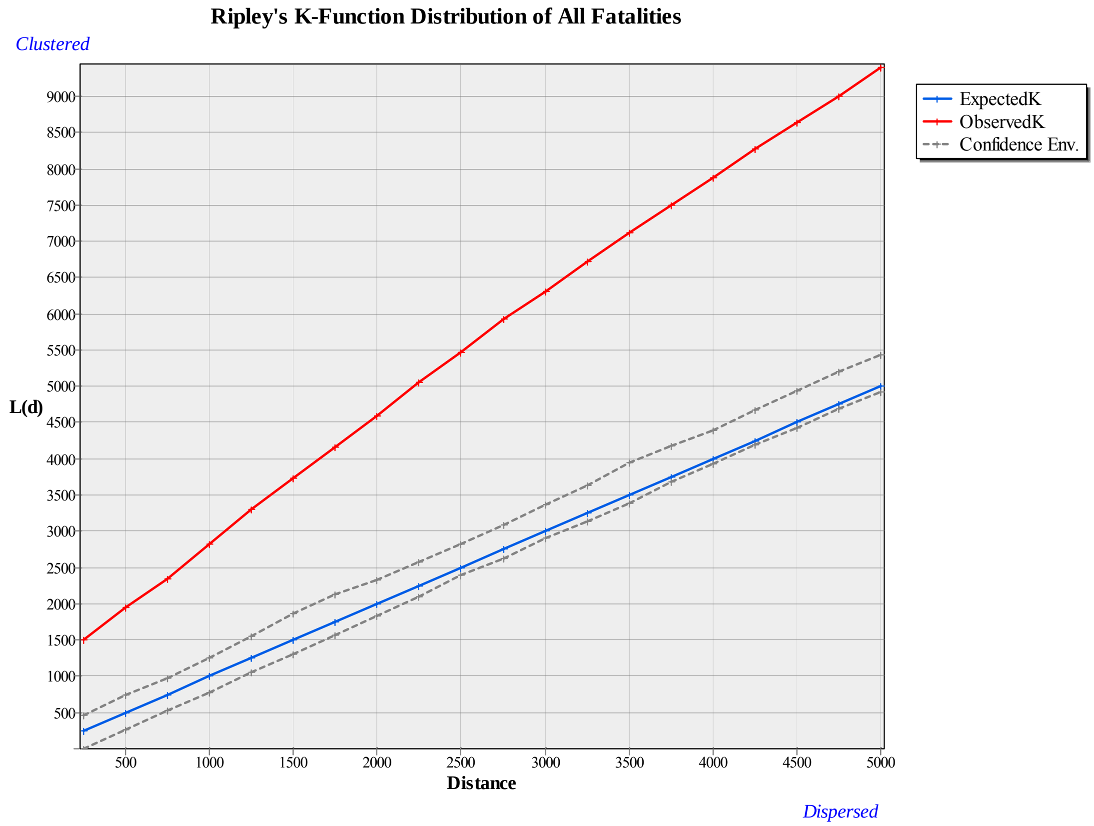

Figure 62. Multi-Distance Spatial Cluster Analysis Tool in ArcGIS Distribution of all Fatalities.

In the K-Function graphs, the observed values are depicted in blue and the expected values are divided into three categories, Mean, Upper 5 percent and Lower 5 percent. When the obsserved exceeds the Expected Upper 5% lines, then the distribution is considered clustered (Yamada and Thill 2004). The parameters used in the K-Function analysis for the fatalities for each time period where 50 iterations at a 500 meter interval with a 5 percent confidence/significance level (**Figure 63, Figure 64, Figure 65**).

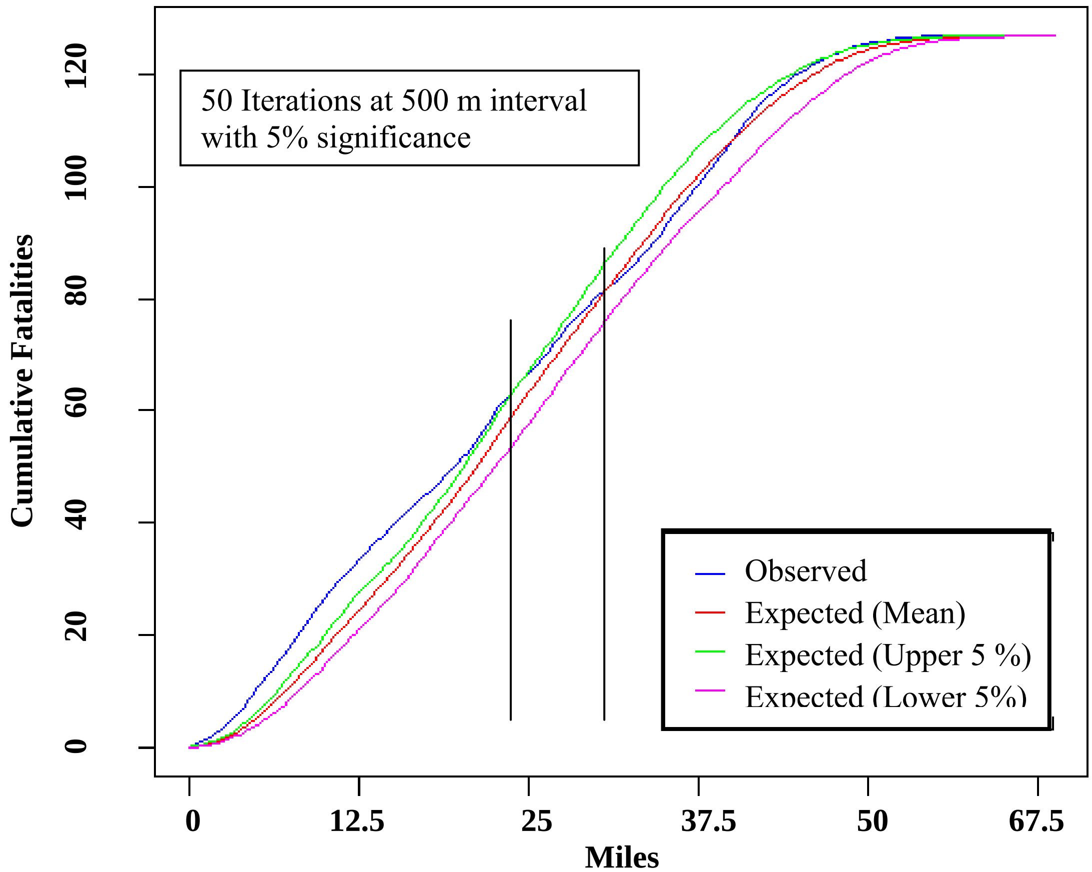

Figure 63. Global Auto-Correlation K-Function of Fatalities from 1990 to 1995.

There were 124 incidents resulting in 146 fatalities from 1990 to 1995. The distribution of those fatalities appear to be significantly clustered at less than 20 miles, here the observed incidents are at the greatest distance above the Expected (Upper 5%), especially in the range of approximately 8 miles to 15 miles. The fatal incidents fall below the Expected (Upper 5%) around 25 miles and below the Expected (Mean) near 30 miles. At distances greater than 30 miles, the Observed fluctuates with the mean before coinciding with the Expected (Upper 5%) near 2000 m. Nearly half of the incidents (n = 60), appear to be significantly clustered, while the other half of the incidents do not.

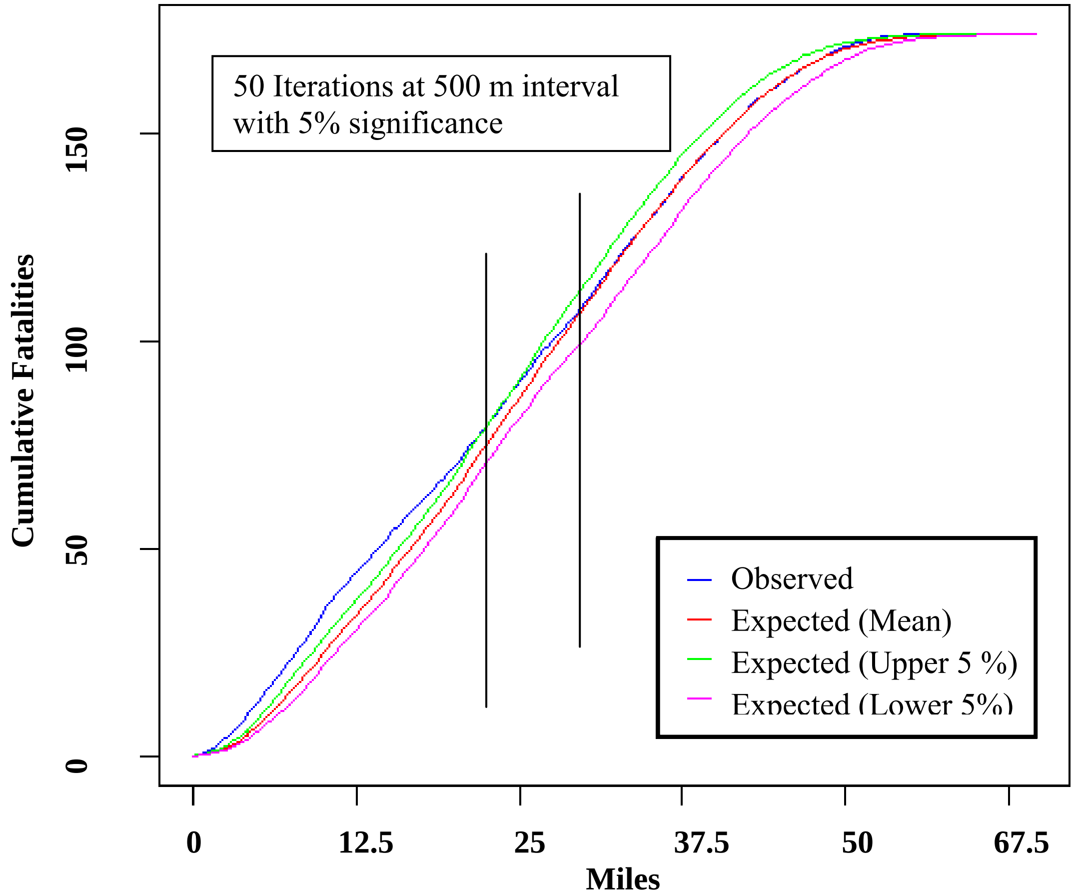

Figure 64. Global Auto-Correlation K-Function of Fatalities from 1996 to 2001.

There were 167 incidents resulting in 200 fatalities from 1996 to 2001. The distribution of the fatalities (similar to the previous) appears to be significantly clustered between 5 miles and 20 miles, where the observed incidents are at the greatest distance above the Expected (Upper 5%). The fatal incidents fall below the Expected (Upper 5%) around 22 miles and below the Expected (Mean) near 30 miles and continue to follow the mean beyond 50 miles. Approximately one-third of the fatal incidents (n = 60), appear to be significantly clustered, while two-thirds of the incidents are not clustered.

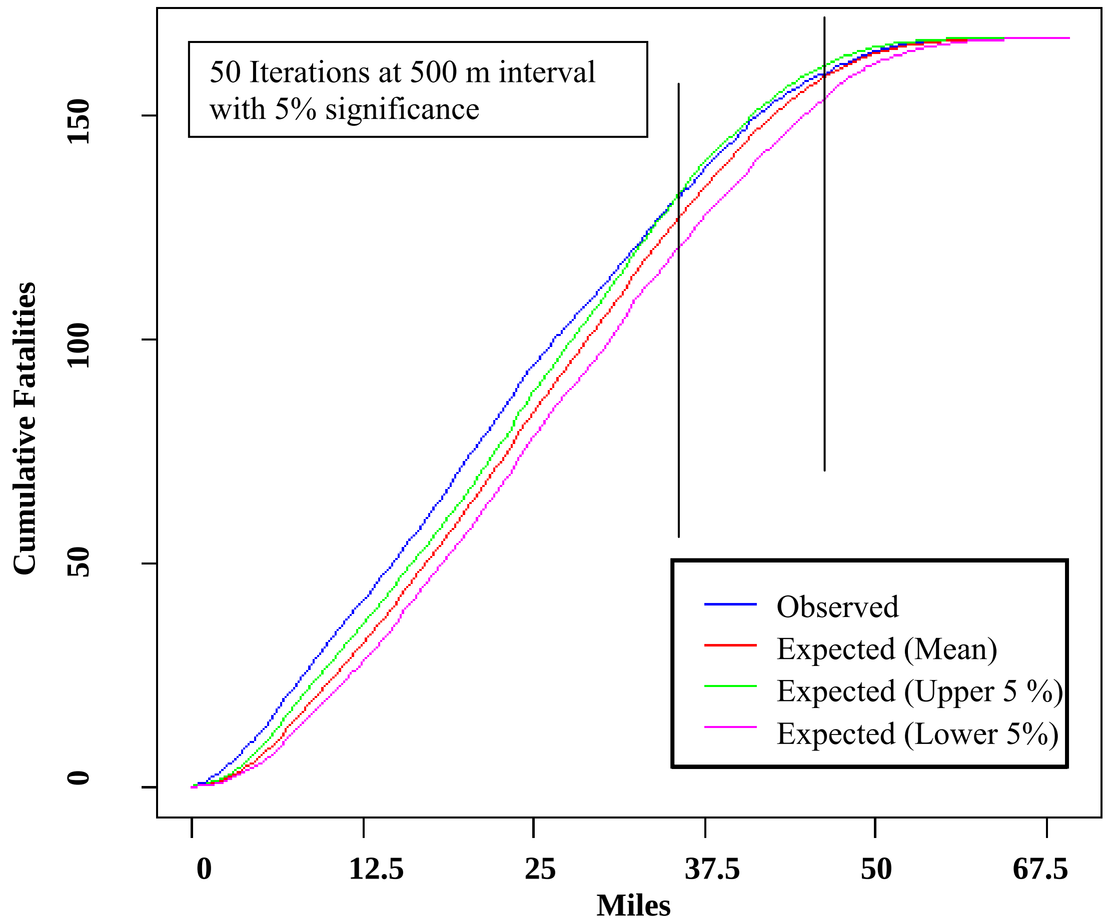

Figure 65. Global Auto-Correlation K-Function for Fatalities from 2002 to 2007.

There were 161 incidents resulting in 196 fatalities from 1996 to 2001. The distribution of the fatalities is different from the previous in that they appear to be significantly clustered between 5 miles to 30 miles, where the observed incidents are at the greatest distance above the Expected (Upper 5%). The fatal incidents fall below the Expected (Upper 5%) around 37 miles and below the Expected (Mean) near 45 miles and continue to follow the mean beyond 50 miles. Approximately 120 fatal incidents appear to be significantly clustered, and only one-fourth do not appear to be clustered.

Although SANET does not allow for the geographical display of the location of any of the fatality clustering, using ArcGIS tools (including linear referencing) density of fatalities per segment was created to show where potential clustering may be occurring (**Figure 66, Figure 67, Figure 68**). The density of fatalities through the three time periods also shows the increase in deadly incidents occurring in the rural areas of the project area. In Figure 66, the fatalities are concentrated along I-95 and the around the urban centers in each of the counties. There are localized fatalities throughout the rural countryside in each county with very few locations of more than one fatal incident. During the late 1990s, with the increase in development, there is an increase in the fatal road segments and an increase in the number of segments with multiple fatalities. Finally, in the third time period, there is a significant increase in the segments experiencing multiple fatalities clustering along State Route 3, State Route 20, and State Route 522. In addition, there are more multiple fatality segments on the secondary roads along these two primary routes through the study area. Interstate 95 continues to be a problem area for fatalities, as well.

The SANET results show that there is a clustering of traffic fatalities, in combination with the ArcGIS maps, the clusters can be identified with the Kernel Density tool in ArcGIS. The locations of road segments are identified and the lines are weighted by the number of fatalities occurring during the time period.

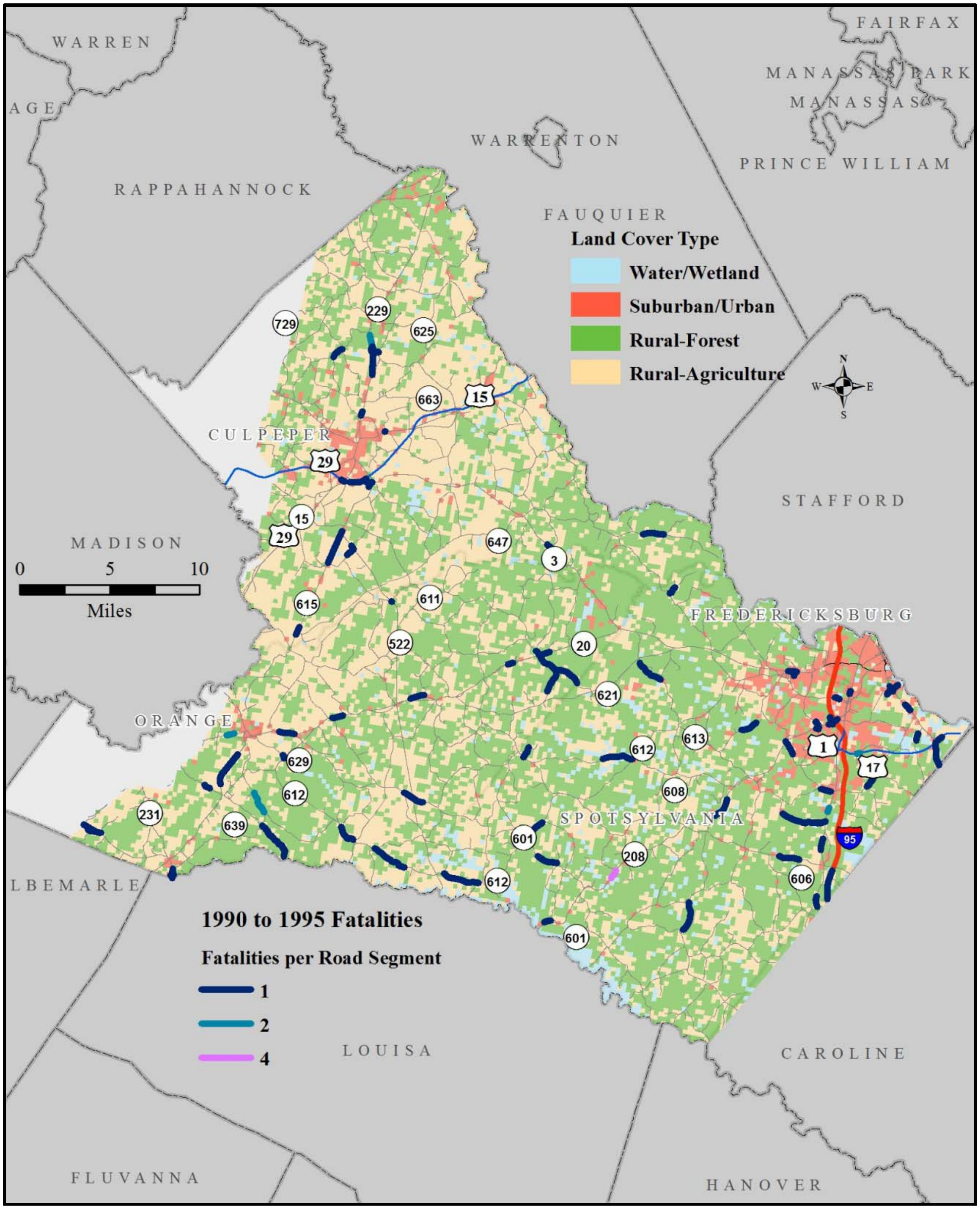

Figure 66. Distribution of Number of Fatalities (1990 to 1995) Per Road Segment.

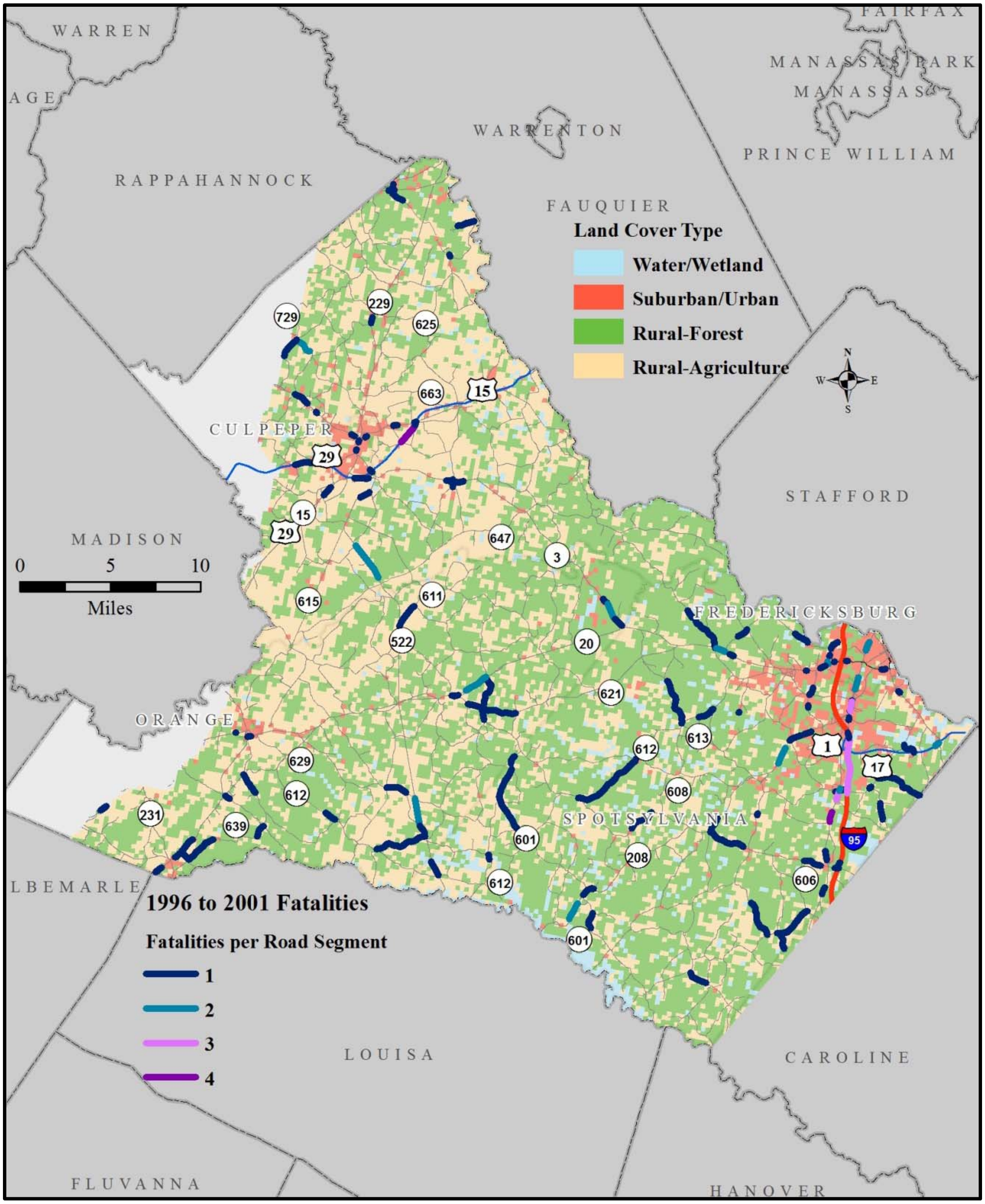

Figure 67. Distribution of Number of Fatalities (1996 to 2001) Per Road Segment.

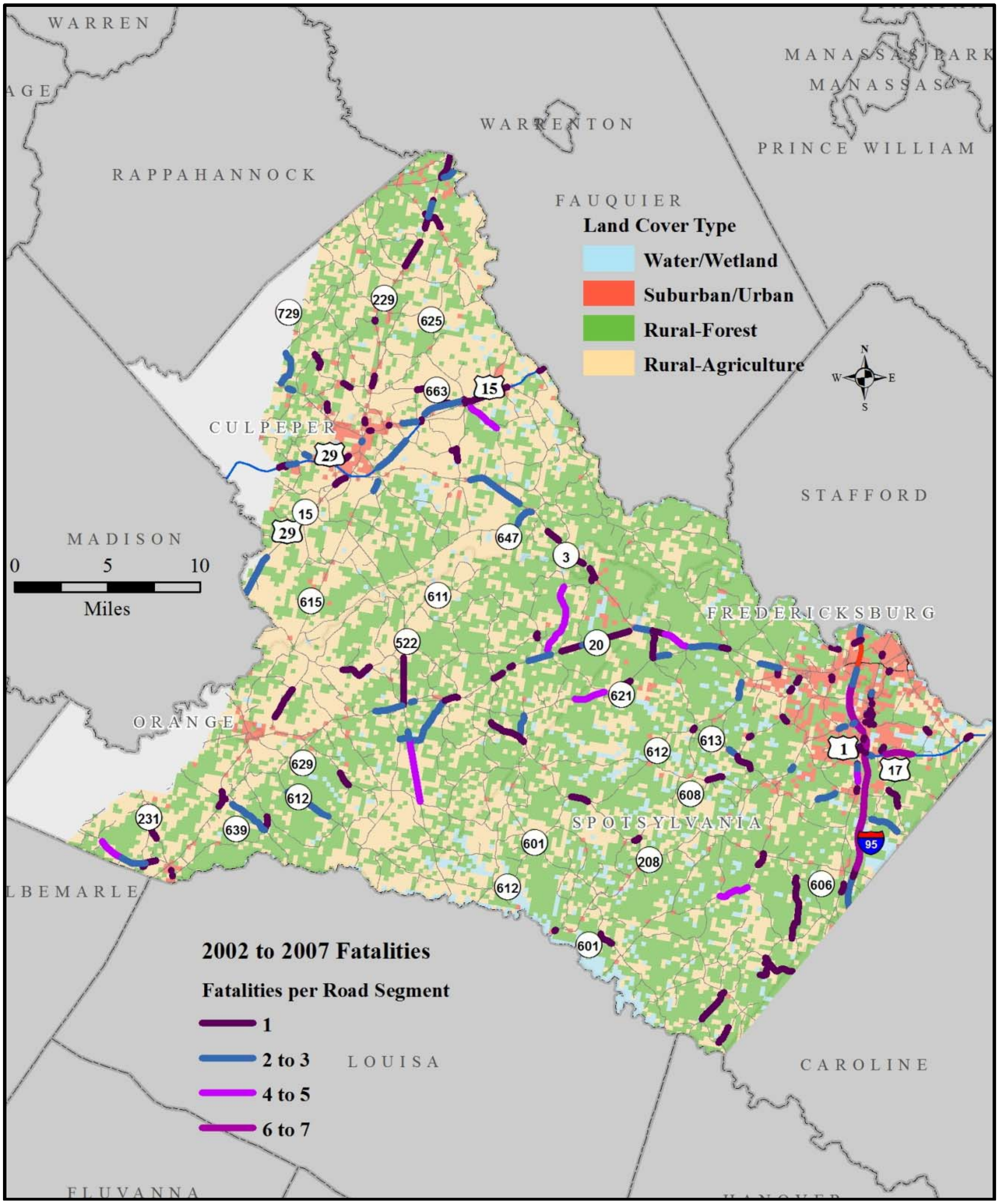

Figure 68. Distribution of Number of Fatalities (2002 to 2007) Per Road Segment.

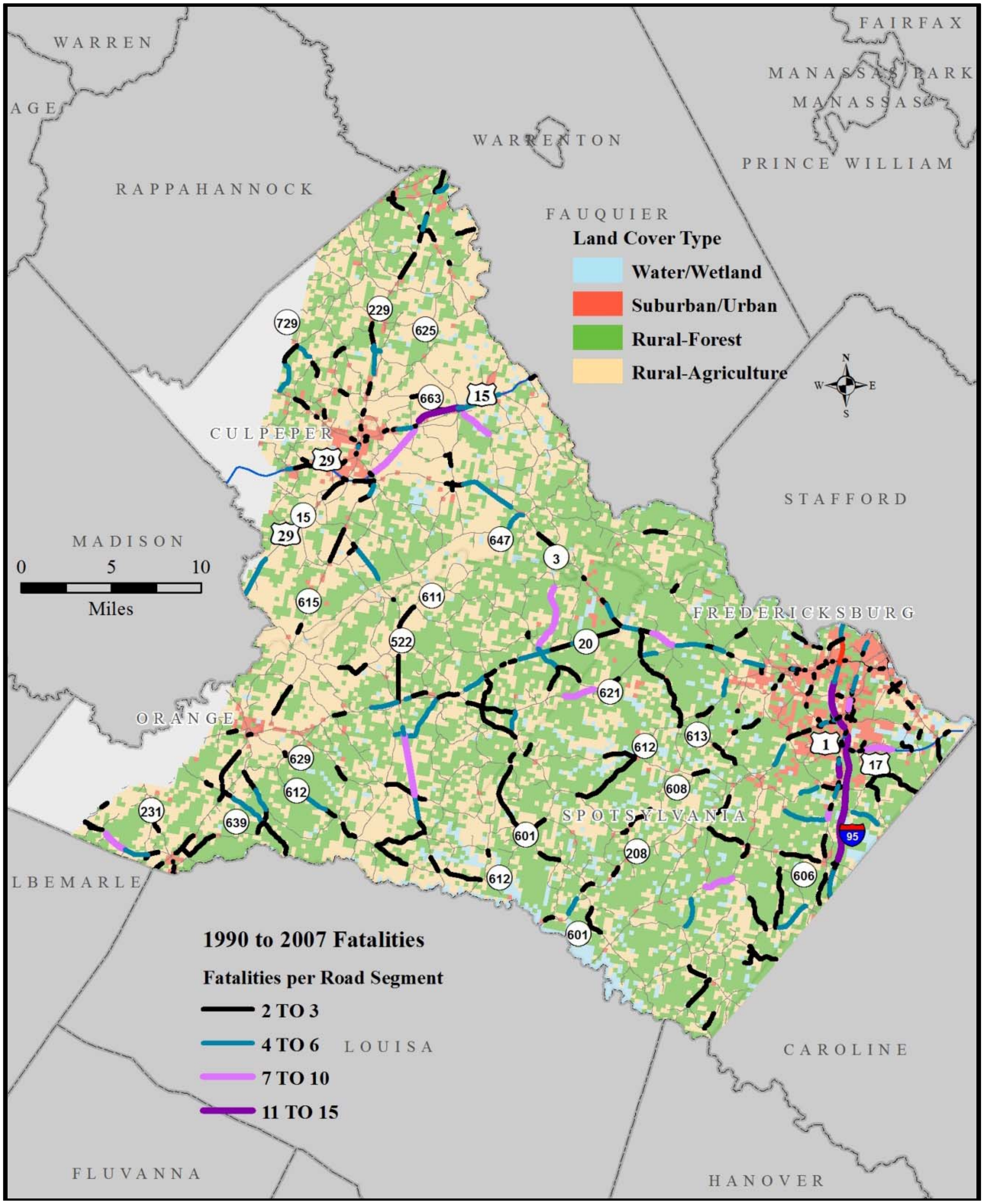

Figure 69. Distribution of Number of Fatalities (1990 to 2007) Per Road Segment.

CONCLUSIONS

The primary purpose of this study was to determine whether the change from rural land cover to suburban and urban land cover lead to more incidents. Secondly, the study attempted to identify characteristics of the roads that may lead to more incidents, fatalities, and injuries. Thirdly, although more incidents may be occurring on suburban and urban roads the fatality rates were hypothesized to continue to be higher along the rural roads while decreasing in suburban and urban areas.

In the Suburban/Urban area the number of incidents increases by more than 53 percent and comprises over 50 percent of the total incidents through all three time periods while only covering five percent or less of the total acreage of the study area. The number of incidents in Suburban/Urban areas is nearly double that of either rural category throughout all three time periods. The increase in incidents is a direct result of the increase in population in conjunction with the increased commercial and residential development in the study area. The distribution of injuries follows the distribution of incidents across all three time periods.

Based on the numbers of incidents and injuries, traffic incidents are most prevalent on two lane roads with surface widths typically greater than 18 ft, shoulder widths less than or equal to 6 ft, speed limits between 35 to 45 mph and with no median. This profile is primarily indicative of suburban roads. The suburban roads typically will consist of two to four lanes and the improved two lane roads will be up to 24 ft wide while four lane roads will be double. Also, suburban roads will typically have some type of shoulder up to 6 ft, speed limits ranging from 35 to 45 mph. Medians are usually only found within the commercialized area; however, the primary routes will have areas with and without medians (US Route 1, State Route 3, State Route 20, and US Route 17). Although the majority of the unimproved rural roads are typically 2-Lane roads that are less than approximately 18 ft wide with little to no shoulders and no medians with speed limits of 55 mph with some posted at 45 mph in Spotsylvania County and closer to the suburban commercial and residential developments, with the development of the rural countryside these rural roads have been improved to 20 to 24 ft wide.

With the rise in commercial and residential development, the rural landscape of the project area was transformed, the change in land cover echoes that change. Overall the two biggest changes identified are from forest to suburban and from forest to agriculture. Not surprising, the majority of the incidents and injuries are found along those road segments that have changed from a forest land cover to a suburban one, while the other three main categories (Forest-Agriculture, Agriculture-Suburban, and Agriculture-Forest) fluctuate with similar numbers. Per mile distribution of incidents and injuries are two times as numerous along those road segments changing to suburban land cover as those changing to a rural land cover category.

Incident types also suggests that the majority of the incidents are occurring within suburban areas as Angle, Sideswipe, and Rear End incidents comprise three of the top four incident types. The other incident type is Fixed Object, which can be associated with either rural areas or suburban areas, i.e. trees, telephone poles, traffic light pole, etc. The distribution of incident types across land cover types is similar for both numbers of incidents, fatalities, and injuries as the per mile distributions, with slight variations.

This research confirms that the majority of the incidents are occurring in commercial and residential suburban areas of the project area. Also, when the land cover changes from the forest to suburban, the traffic incidents increase significantly. The Chi-Square test for independence shows a strong correlation between the changing land cover types and the change in the number of incidents occurring along those road segments; unfortunately the exact type of relationship cannot be determined through the Chi-Square test alone. The multiple regression analyses identified the results of the change in incidents along road segments with a change in land cover as not occurring by chance. In addition, it shows that Shoulder Width, Incident Count, and potentially Median Width are significant variables in the changing number of incidents along those road segments.

The current research also identifies specific road characteristics that appear to be related to the increase in incidents in certain land cover types. The analysis of the overall land cover and the land cover change between the three time periods identified those characteristics of the road that lead to a higher frequency of incidents:

Overall Land Cover

- Number of Lanes: two lane roads - 64 percent
- Surface Width: 18ft to 24 ft - 41 percent, greater than 25 ft - 39 percent
- Shoulder Width: 2 ft or less - 46 percent, 2 ft to 6 ft - 45 percent
- Posted Speed Limit: 35 to 45 mph - 70 percent
- Median Width: no median - 70 percent

Land Cover Change

- Number of Lanes: Total: two lane roads - 64 percent. Time Periods: two lane roads - 70 percent (1996 to 2001), four lane roads - 64 percent (2006).
- Surface Width: Total: 18ft to 24 ft - 60 percent. Time Periods: 18ft to 24 ft - 47 percent (1996 to 2001), greater than 25 ft - 67 percent (2006).
- Shoulder Width: 2 ft or less - 44 percent, 2 ft to 6 ft - 44 percent
- Posted Speed Limit: 35 to 45 mph - 65 percent
- Median Width: no median - 66 percent

The fatalities within the study area are one of the greatest concerns to the general public, local governments, and state agencies. Although, they cannot control the distracted or drunk drivers, one thing that can be done is look at the environmental factors associated with the location of fatal incidents. The majority of the fatal incidents occur in the rural areas; combined there have been 358 fatalities (66.42 percent) in the rural areas compared to only 166 fatalities (30.8 percent) within the suburban and urban areas. As discussed above, the suburban/urban incidents comprise over 50 percent of the incidents within the project area; however, 66 percent of the fatalities are occurring in the rural areas. Based on fatality rates per number of incidents, a person is more than twice (2.29 fatalities per 100 incidents) as likely to have a fatal incident in Forest area and nearly twice (1.77 fatalities per 100 incidents) as likely to be involved in a fatal incident in Agriculture area than be in a fatal incident in a Suburban/Urban setting (0.80 fatalities per 100 incidents). However, looking at the land cover change, the fatality rates for both Forest and Agriculture have declined 40.86 percent and 11.73 percent, respectively, while the fatality rate in Suburban/Urban has increased by 30 percent over the study time period. Of the areas changing from one land cover to another type, the change from Forest to Suburban appears to lead to the most incidents; however, both the change from Forest and Agriculture to Suburban leads to similar frequencies of fatalities.

The fatalities differ from the distribution of incidents and injuries only slightly. The majority of the fatalities are occurring on two lane roads with surface widths between 19 and 24 ft and shoulder widths between 2 and 6 ft. Similar to the incidents, fatalities are also primarily along roads with no medians and posted speed limits between 35 and 45 mph. Looking at the distributions per mile of road, with few exceptions the suburban road segments have a higher fatality frequency with fewer miles of road.

The SANET analysis of the fatal incidents identifies 50 percent or more clustering between 5 to 30 miles, following the sprawl along the major routes in the study area. As the clustering expands from 5 to 20 miles in 1996 to 5 to 30 miles in 2006, it follows the expansion of the fatalities in the rural areas outside of the suburban/urban areas. Utilizing the Kernel Density tool in SANET, gives a visual representation of the clustering. Not surprisingly, the clustering of incidents are located in and around the three major urban areas (City of Fredericksburg and the towns of Culpeper and Orange); throughout the study time period, however, the incidents begin to extend out from the urban centers along the major roads in the areas, State Routes 3 and 20, US Routes 1, 17, and 29, and of course along Interstate 95. This coincides with the expansion of commercial and large scale residential developments in the study area. With this strong correlation between land cover change and incidents, if one or more of the road characteristics identified of having a propensity to increase traffic incidents, then perhaps in the planning process of future development changes can be made to those new or improved roads in the vicinity of the new development to help decrease the likelihood of an incident barring human error or that the incident will result in a fatality.

In conclusion, the rise in commercial and residential development within central Virginia lead to one of several unintended consequences, more traffic-related incidents, fatalities, and injuries. This study has shown that there is significant correlation between the change in land cover and the change in the number of incidents. The majority of the traffic incidents and injuries are occurring in suburban and urban areas; however, there are still more fatalities occurring in the rural areas of the study area. The road characteristics associated with the rising traffic incidents typically included two lane roads with a surface width less than 24 ft, no medians, and shoulder widths less than 6 ft. Additionally, the majority of the incidents within the study area are occurring at posted speed limits greater than 35 mph to 45 mph. Ideally, this information could be used to help transportation planning agencies and localities design roads or improve existing roads to limit the number of incidents. Although there is no fix for human error, there is a possibility to widen roads, create a clear zone free of trees and other immovable objects, and add medians where feasible to help keep a distracted driver from becoming a traffic incident or traffic fatality. That is where the analysis of road characteristics in this study plays an important role, by identifying those areas that result in more fatal incidents, future road construction and improvements can be guided by the results to insure safer roads for the traveling public.

FUTURE DIRECTIONS

Further research on specific problem areas, such as around the large shopping center developments and in the vicinity of moderate to high density housing developments may help to shed more light on the correlation between the change in land cover and the change in the numbers and severity of incidents. This methodology could be tested in other regions of Virginia to see if the same patterns emerge.

Another potential research topic would be to analyze the location of traffic incidents correlate the location of incidents with the Level of Service (LOS) of the roads. Level of Service is calculated by the flow of traffic in comparison to the posted speed limit, the closer (or above) the free flow speed is to the posted speed limit the higher the LOS (LOS A is maximum free flow). With traffic congestion the free flow speeds begin to fall and the level of service is graded from B to F, with D, E, and F being areas of concern. A future study could look at the incidents to see if they are occurring on roads with a low LOS. Additionally, if historic traffic information on LOS is available, incidents on a road with a poor LOS that has been widened and improved could be looked at to identify improvements in the number or severity of incidents occurring on the same road with different LOS ratings.

The basis of this research could be used in more highly urbanized areas such as Northern Virginia or Hampton Roads to see if this pattern is replicated without the larger rural areas. Also, the same method could be used in more rural areas of Virginia to see if the rural patterns are replicated. Additionally, since the beginning of this project 2011 traffic data has become available and 2012 data will be available in the coming months. Using the data from 2008 to 2012 would be helpful to see if the patterns identified in the current research continue or decrease with the economic recession that began in 2008. Although there was a decline in fatalities from 2007 to 2010, there has been an increase in fatalities over the past two years.

Another avenue of research would be to focus on areas of improved roads by looking at the pattern of traffic incidents in the years preceding the improvements and then compare the traffic incident patterns in the succeeding years. This has the potential to identify those improvements that help to reduce the number of incidents, fatalities, and injuries (Elias and Shiftan 2011).

Another potential research questions that could be added to the current study could include looking at single vehicle incidents versus multiple vehicle incidents, as single vehicle incidents may be more indicative of rural settings. Additionally, looking at differences in time of day and weather related conditions may also provide additional information as to why and where incidents, fatalities, and injuries are occurring.

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CURRICULUM VITAE

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