A HISTORICAL GEOGRAPHIC ASSESSMENT OF DROWNING INCIDENTS IN AUTOMOBILES DURING TEXAS FLOODS, 1950 – 2004

THESIS

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Master of SCIENCE

by

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DEDICATION

I dedicate this thesis to my sister, Beth.

Though she has left this Earth before me, the memory of her spirit still inspires and encourages me in all I do.

ACKNOWLEDGEMENTS

I would like to thank Patrick for encouraging me to return to school and take the road less traveled by studying something that truly interests me. I appreciate the support and patience of all of my family, especially Patrick, Bruno, Carlo, Felix, Zelda, Mum, Pat, and Charlie. I would also like to thank all of the babysitters who made my attendance at school possible. Additionally, I would like to thank Steven Gray for taking an interest in my study and helping with the data collection and all my friends who allowed me to vent when I was under pressure.

My gratitude goes out to my committee members: Dr. Earl for his helpful suggestions and his amiability and Dr. Giordano for challenging my thinking. I would like to give a special thanks to my adviser and chair, Dr. Tiefenbacher, for his immense patience in answering my interminable questions and pushing me to do better when I felt like what I had was good enough.

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CHAPTER I

INTRODUCTION

The purpose of this research is to answer the following two questions: What is the historical spatial distribution of drowning incidents caused by motorists' interactions with flooded roadways in Texas? and What factors contribute to the pattern? This research will cover the period since 1950, the approximate beginning of the modernization of automobiles and roadways (Bardou et al. 1982), and will conclude with 2004, the last complete year for which data were available for reports of automobile incidents involving drowning deaths in Texas.

The following questions will provide a basis upon which the primary two questions can be answered:

- How many people have drowned by way of automobile interaction with a flooded roadway during the specified time period?
- How did the rate of deaths change over the study period?
- Where did these incidents occur?
- How far from their homes were the victims when they drowned?
- What were the characteristics of the roads where the deaths occurred?
- What additional factors are mentioned in the incident reports?

The history of drowning associated with the entrapment of automobiles in flooded roadways helps us to better understand the contribution of drivers to such events. The general components of this type of disaster are nature, technology, and people and their interactions. More specifically, the natural environment includes the characteristics of the physical environment upon which the roads are built and the distribution and rate of precipitation that leads to high runoff rates. The technologies involved are the automobiles, the roads and signage, and the rest of the built environments (land uses) that surround the roads and contribute to roadway flooding. The human dimension of this hazard includes the driver, the driver's judgment, and the driver's actions, abilities, and decisions behind the wheel.

Automobiles and roadways have changed greatly over the past half of century. Technological advances and the passage of time have brought the public comfort in their use (Slovic et al. 1979). Under normal circumstances this elevated level of comfort may be viewed positively. However, when heavy storms occur comfort should be replaced with caution and vigilance, but often it is not.

Texas is a region that has a history of severe flooding (Slade and Patton 2003). Additionally, over the past twenty-five years the population in Texas has grown by twenty-five percent. During this time period, road use has increased by ninety-five percent, but the road capacity has only been increased by eight percent (Texas Department of Public Safety 2006). The combination of the above factors signifies the potential hazardousness of Texas roadways.

CHAPTER II

BACKGROUND

With the exception of fires, "floods are the most common and widespread natural hazard" (FEMA 2005). Flooding is the deadliest natural hazard in the United States (NOAA 2005). Texas is one of the most flood-prone regions in the United States (Leopold et al. 1964) (Figure 1) and has a long record of documented automobile-flood accidents (Slade and Patton 2003, NCDC 2005).

An average of 140 people in the United States have died each year because of flooding over the past 30 years (NOAA 2005). From 1994 through 2003, at least 156 people drowned in floods in Texas alone. The vast majority of these deaths could have been avoided if drivers had backed up instead of driving into flooded streets, roads or underpasses. "Each year about 15 Texans drown driving into floodwaters flowing across roadways or beneath underpasses" (Governor's Division of Emergency Management for the State of Texas 2005).

The majority of fatalities caused by flooding have happened in automobiles; most of these deaths could have been avoided (Coates 1999, NOAA 2005, Texas Department of Public Safety 2005). Drivers and pedestrians alike often do not recognize the great risk they take trying to cross or drive through a flooded roadway and thus ignore

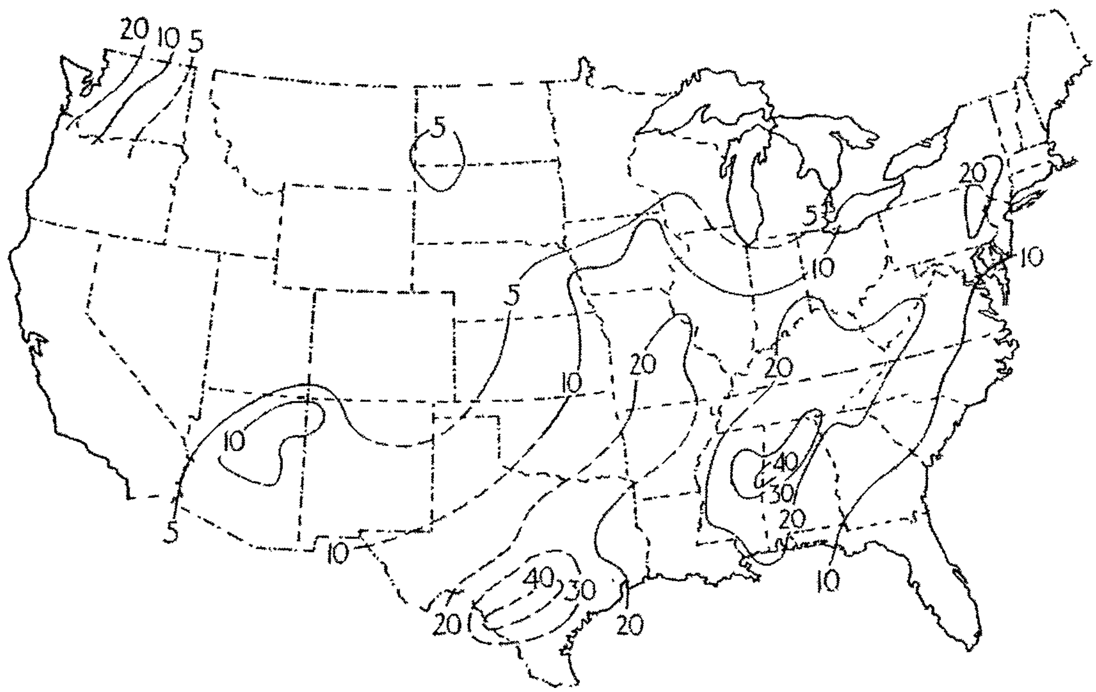

Figure 1. Flood Potential: The 10 –year Flood in Thousands of Cubic Feet Per Second from Drainage Basins of 300 Square Mile Area (Leopold et al. 1964).

warnings or barriers. It is difficult to judge the depth of the water or the speed of the current from outside the water. Many people do not realize it takes less than two feet of water to float most vehicles (Figure 2)(NOAA 2005, USGS 2005), and a great number of deaths during flood events are the result of risky behavior (Jonkman and Kelman 2005).

According to Slovic (1987), the average citizen uses intuition to judge and respond to a hazard. He terms this intuition "risk perception." In the case of making the decision to enter a flooded roadway in an automobile, this judgment must occur instantaneously, if there is time for it at all. Over the past half-century people have become increasingly comfortable with the cars they drive and the roads upon which they drive. When people become comfortable with a technology, they may not perceive the risks associated with its use as great (Slovic et al. 1979). Additionally, different groups interpreting the same hazardous event may have different understandings of what the risks are and different measures of their probability.

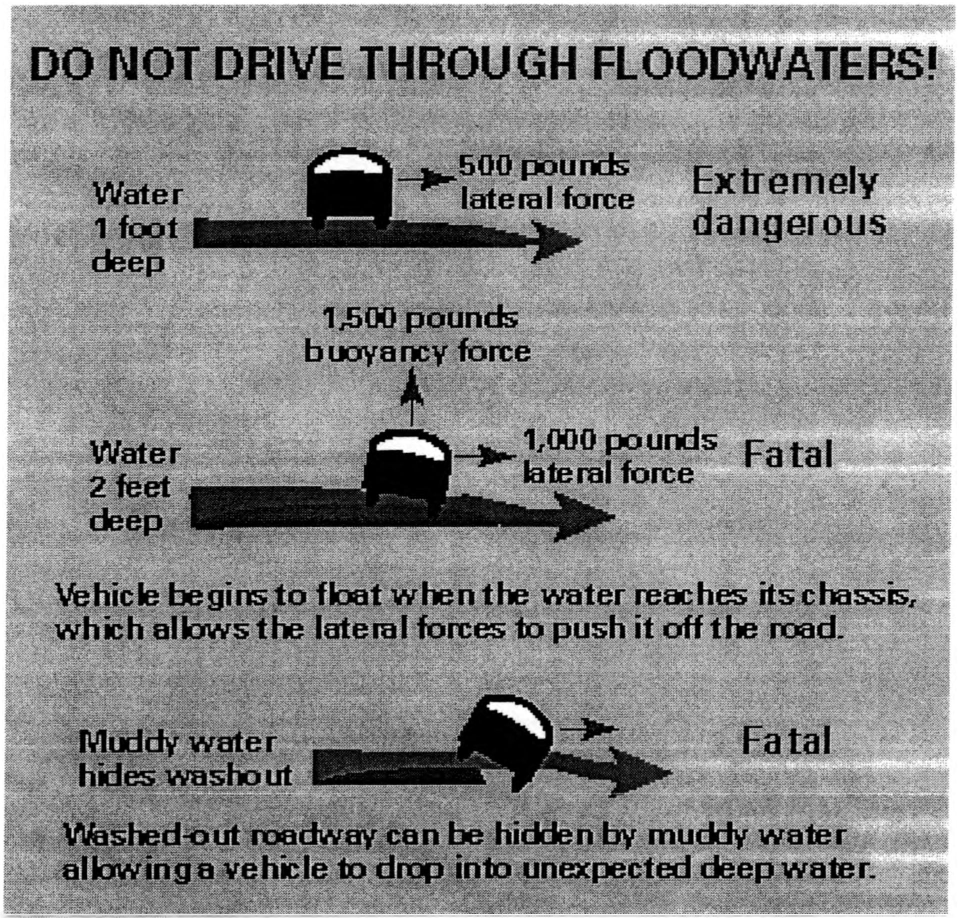

Figure 2. Graphic from United States Geological Survey (USGS 2005).

CHAPTER III

RELATED RESEARCH

Palm (1990) defines hazards as "risks embedded in the environment." Burton, Kates, and White (1978) suggest that a natural hazard is the interaction between a natural event and the human-use system. Smith (1992) reinforces that idea by proposing that natural hazards are the overlap between the physical processes of the earth and human activity and invention. Tobin and Montz (1997) define a natural hazard as the potential interaction between humans and extreme natural events. They differentiate between a hazard and a disaster - a hazard is the potential or likelihood of an event; whereas a disaster is the actual occurrence of an event. According to Palm (1990), deaths caused by automobile interactions with flooded roadways can be considered a "micro-scale" hazard or disaster, meaning that it impacts an individual person or a small collection of people.

Like many hazards, this particular hazard cannot be solely defined as a natural hazard or a technological hazard, but a complex combination of the two. Keating (1975) suggests that technology has consistently been identified as a contributor to environmental problems. Smith (1992) states, "most hazards have both natural and technological components." Showalter and Myers (1994) assert, natural disasters and technology coexist and can combine to create even larger disasters. These events are sometimes referred to as "na-tech" events (Showalter and Myers 1994). It has become commonly accepted among hazards researchers that technology plays a great role in the loss of lives and livelihoods during natural events (Burton et al. 1978, Mitchell 1990, Showalter and Myers 1994, Tobin and Montz 1997). Some of the greatest losses have occurred when human activities coincide with extreme processes. For example, when an earthquake occurs in a populated area, it is usually the destruction of technology that causes the highest rate of mortality. This is the case in such instances as buildings collapsing in earthquakes and tornadoes and gas lines rupturing that cause deadly fires. Additionally, the ruin of infrastructure frequently disrupts and changes the lives of individuals after a disaster.

In order to fully consider the factors associated with the hazard of a motorist drowning during a flood event, we must also acknowledge the human dimension. Not only are people the ones who created the technology of roads and automobiles, but they are also the ones that are "in control" of the decisions involved when driving during a flood event. Beginning in the 1970s, steps have been taken to explain the human role in natural hazards (Tobin and Montz 1997), and since then many hazards researchers have come to view the human dimension as significant in hazards of all kinds (Blaikie 1985, Mitchell 1990, Tobin and Montz 1997, Wisner et al. 2004). Burton et al. (1978) suggest that nature alone is neutral and only becomes hazardous when it intersects with man. Man's inventions can be added here as well.

Risk

People accept a certain level of risk anytime they engage in a potentially hazardous activity such as driving in an automobile (Musselwhite 2005). It is commonly pointed out that principal judgments about acceptable risk involve two components (Lowrance 1976). The first is empirical, an attempt to identify and measure risk associated with some course of action. The second is normative, an attempt to decide on reasonable grounds whether the risks of the action are warranted, given the alternatives (Von Magnus 1984). The normative approach addresses the question of what actions individuals are willing to take part in, given the perceived benefits of engaging in a particular risk. In this study, the normative evaluation may be another way to explain why individuals are willing to engage in potentially risky behavior in environments where they are relatively comfortable. This assurance has a perceived benefit (i.e. they arrive at their destination quicker than if they were to take another route). Conversely, individuals may be uncomfortable, or might have a negative perception of involving themselves in the alternative behavior, which in this case would involve taking a longer route to their destination, exacerbated by the fact that that route might be less familiar and therefore more risky.

To obtain information about risk/benefit preferences that can be considered rational, it would be necessary to disregard observed willingness to take risks under conditions where the individuals are not likely to be performing well (Von Mangus 1984). It can therefore be assumed that willingness to take risks involves a certain level of comfort (or familiarity). This comfort comes from routine or commonplace involvement with the environment where the individual may be confronted with risk.

Past research has shown that in the course of normal daily activities people unavoidably risk death, injury, or loss (Fried 1970, Wildavsky 1979). Driving an automobile involves possibly encountering a number of risks in an otherwise familiar context. Fried admits that the reasons why judgments are made are difficult to pin down, but he believes that all risky judgments involve rational elements. While decisions to get behind the wheel of an automobile cannot be said to be continuously "normal" across all situations, it could be said that they are not irrational in any obvious sense. The benefits of the action are clearly worth the possible costs of engaging in risky behavior. For the purpose of this study, this would indicate that, wherever a fatality occurred, drivers involved in drowning incidents either saw no other possible alternative, or viewed the perceived benefit of crossing better than the option of finding another route.

Hazards Models

Many researchers have created models to represent the factors contributing to hazards, and these can be applied to a variety of hazard events (Mitchell et al. 1989, Tobin and Montz 1997, Cutter et al. 2003). These examples do a good job of modeling hazards in general, but a more focused model is needed in order to help recognizes details that are important when it comes to the discussion of hazards and disasters that occur as separate incidents such as the drowning incidents caused by vehicles that get trapped in flood waters. Such models may disregard or generalize context, and context is crucial in determining an outcome of an event at a particular location (Tobin and Montz 1997).

In order to fully understand the factors that contribute to drowning incidents caused by automobile interactions with flooded roadways, it was necessary to develop an event-specific model. This type of contextual model considers all components that contribute to a specific hazard and helps to identify those that are unique to the event (Figure 3).

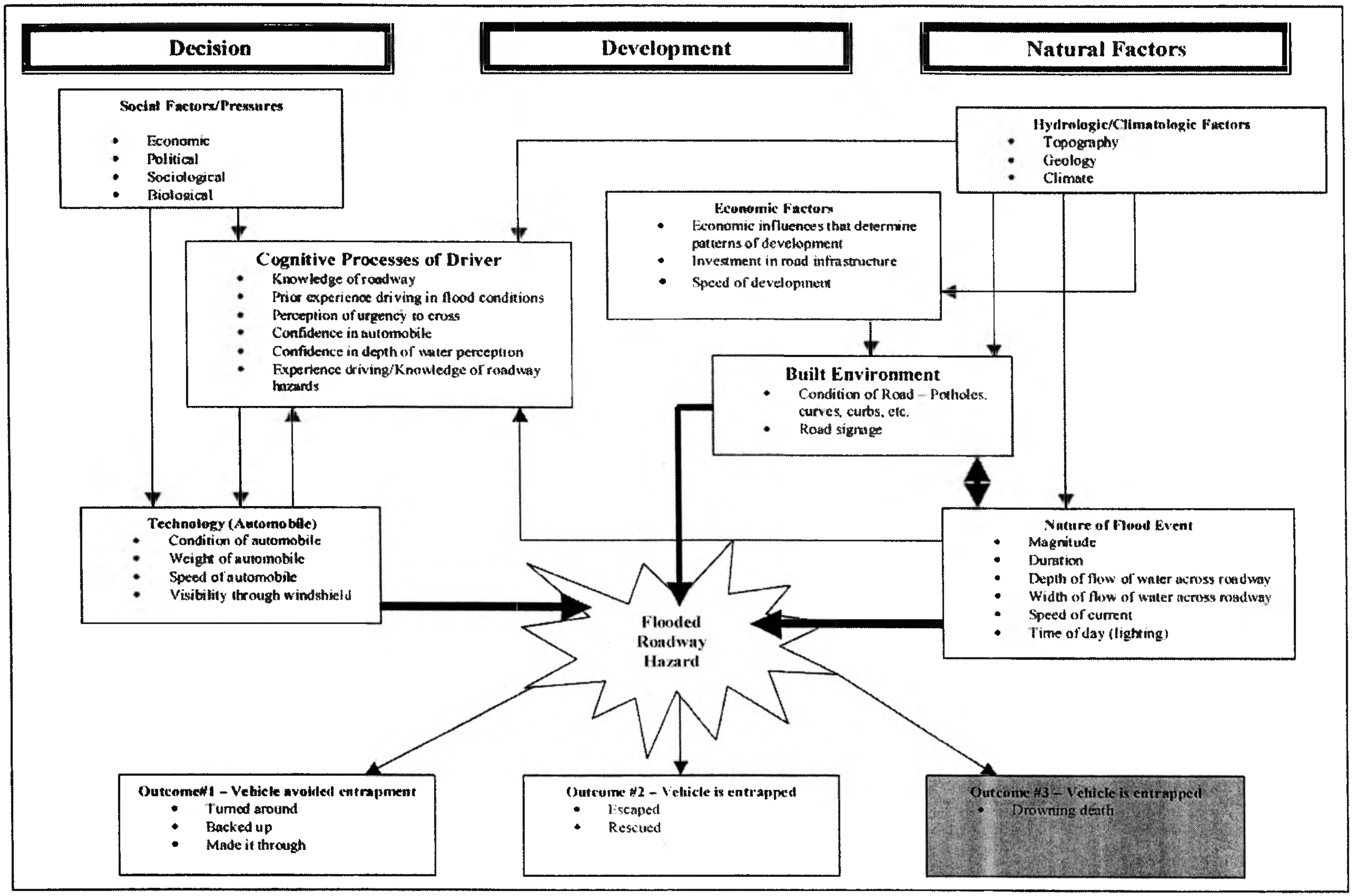

Figure 3. Contextual Model for Drowning Incidents in Automobiles during Flood Events.

Description of Model

The contextual model for drowning incidents in automobiles during flood events is valuable for identifying the factors that were most often associated with the drowning incidents. This model is broken down into three major components: decision, development, and natural factors. The thin arrows in the model indicate influences and the thick arrows indicate interactions.

Beginning with the "decision" component, social factors or pressures seem to influence a driver's cognitive processes during driving and in the choice to use the technology. The cognitive processes of the driver also influence the use and choice of technology. Additionally, characteristics of the technology (condition and type of automobile) may influence the cognitive processes of the driver. Within the "development" component of the model, economic factors influence spatial patterns of the built environment, and the built environment eventually interacts with the technology and the flood event. Under the "natural factors" component, the short-term and long-term hydrologic and climatologic factors have bearing on the cognitive processes of the driver, the economic factors of development, the built environment, and the nature of the particular flood event. The nature of the flood event itself influences the cognitive processes of the driver and interacts with the built environment. This interaction produces flooded roadways.

The final interaction represented in this model occurs between the technology (which contains the human), the built environment, and the flood event. This interaction contains all of the factors that lead to the flooded roadway hazard. This hazard has three potential outcomes. The first is that the driver avoids getting trapped in the water either by turning the vehicle around or passing it through the flooded roadway. The second possibility is that the vehicle is trapped, but the occupant(s) is(are) either able to escape or is(are) rescued. The third possible outcome is that the vehicle is trapped and the occupant(s) drown.

CHAPTER IV

METHODOLOGY

To determine the total number of incidents along with event details, a search was made of the National Climatic Data Center Storm Events database and the Spatial Hazard Events and Losses Database for the United States database year by year from 1950 through the end of 2004 for the state of Texas (NCDC 2005, SHELDUS 2005). All floods that caused at least one death were noted. The details of each flood were then searched to determine whether the death(s) occurred in an automobile. These data sets yielded reports of the numbers of deaths, causes of deaths, and locations associated with each event. Additionally, regional online newspapers were searched using the Newsbank – Texas Newspapers database, the Dallas Morning News Historical Archive (1885 – 1977), and the NewsBank Retrospective (1970 – 1991) database to identify heavy rain and flood events that produced drowning deaths. These sources were crosschecked with the flood event list from the U.S. Geological Survey Open-file Report 03-193 to identify all events. The most complete set of data was developed through iterations of these searches.

The contextual, event-specific model was used to identify the factors that were most often associated with these incidents. It was then employed in conjunction with the incident reports and newspaper articles, to determine the factors were most frequently detailed in reports. I compiled this information into a database containing the following information:

- the year, month, and day of each flood event
- the county and/or city where the incident occurred
- the nearest roadway intersection where the incident occurred
- the location of residence of the driver/motorist
- the distance between location of incident and residential address
- the number of deaths per incident
- the sex of driver
- age of driver
- the vehicle type (i.e. car, truck, van, etc…)
- event details
- and the source of data

The above variables were used to look for temporal and spatial patterns in flood-related deaths on roadways. Large-scale maps were used to determine whether these locations were in urban or rural areas and the level of development that surrounded these areas. When needed, historical maps (contemporaneous to each event) were found through the Virtual Map Library of the University of Texas at Arlington.

To determine whether there is a relationship between the number of incidents per county by decade, the population of the counties by decade, and the number of floods per decade, a linear regression was performed.

Additionally, a sample field survey of the eight locations of drowning incidents in 2004 helped determine the quality, characteristics, and design of the roadways. The roads with the most recent incidents were chosen because they are less likely to have undergone changes since the events happened.

This survey assessed the following:

- Visibility of the water crossing (Was the crossing visible at enough distance for the driver be able to stop on a slick road?)
- Signage (Were visible, permanent warning signs posted so that a driver who uses the road frequently would know of the potential flood hazard?)
- Construction (Does the road have guardrails? Curbs? Shoulders?)
- Number of lanes
- Type of road surface (dirt or asphalt?)
- Presence or absence of water at crossing (When it is not raining, would a driver recognize that the area has water that could potential flood the roadway?)
- Traffic rate/frequency under "normal" conditions
- Apparent relief (topography) in area around low water crossing
- Level of development (urban, suburban, rural...)
- General road density in the area around low water crossing (Are there roads in the area that offer alternative routes for drivers?)

CHAPTER V

RESULTS

A total of 216 deaths caused by automobile interactions with flooded roadways in Texas during the time period from the beginning of 1950 to the end of 2004 have been documented. These drowning deaths occurred in 140 separate incidents. Breaking these incidents down by decade gives a clearer view of the change over time (Figure 4). The number of incidents remains relatively low and consistent from the 1950s through the 1980s. After that there is a sharp increase in the 1990s. Though the five year span of the years 2000 – 2004 are only half of a decade, it is apparent that if the incidents continue to increase at the same rate the number will surpass the previous decade.

When the number of incidents makes a sharp increase in the decade of the 1990s, some patterns in the distribution of incidents among counties begin to emerge (Figures 5 - 10). Three main areas around which the majority of incidents are clustered can be discerned. The clusters surround the large metropolitan areas of Dallas-Fort Worth, Austin-San Antonio, and Houston, the cities that have consistently showed the greatest increase in population over the past half century (Figures 5- 10).

A linear regression was performed to determine whether there is a relationship between the number of incidents per county by decade, the population of the counties by

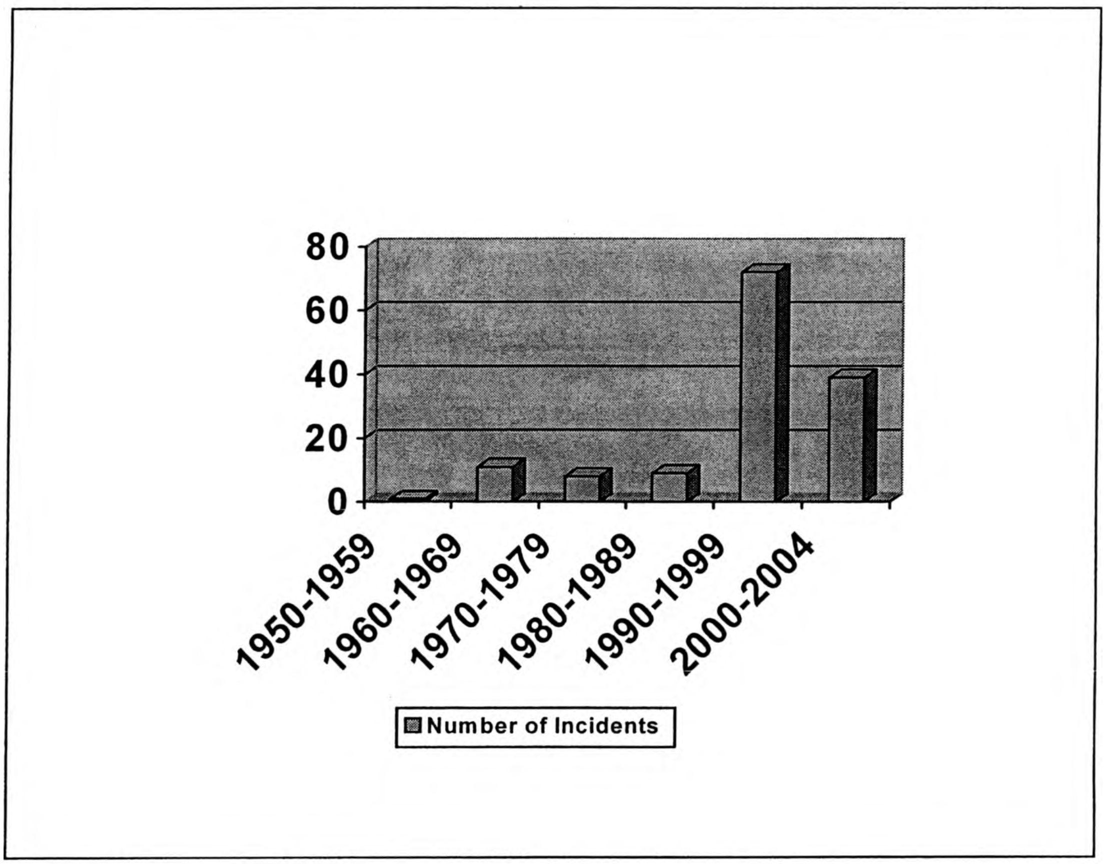

Figure 4. Number of Drowning Incidents in Automobiles on Texas Roadways, by Decade.

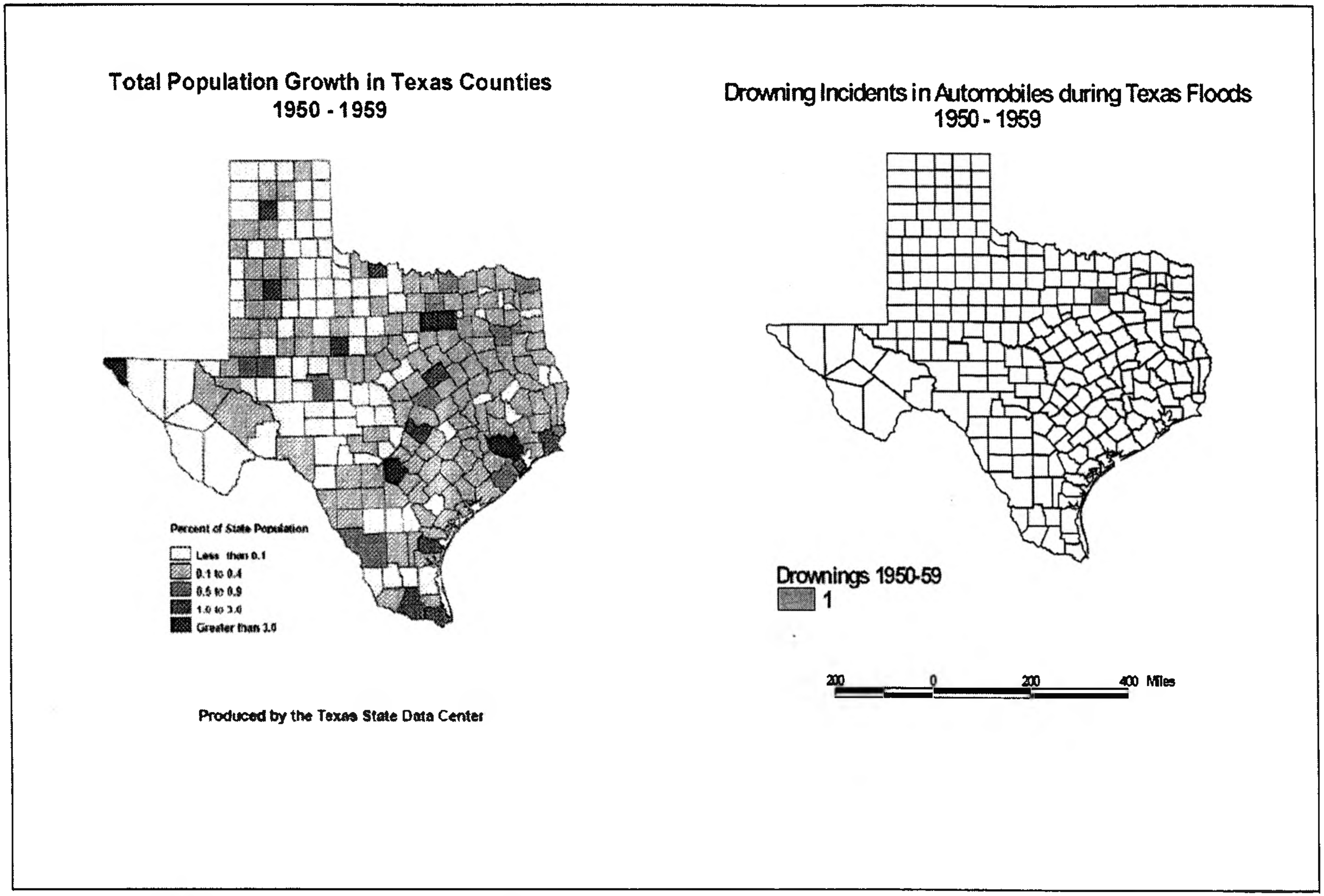

Figure 5. Comparison maps of Texas population and automobile related drowning incidents in the 1950s.

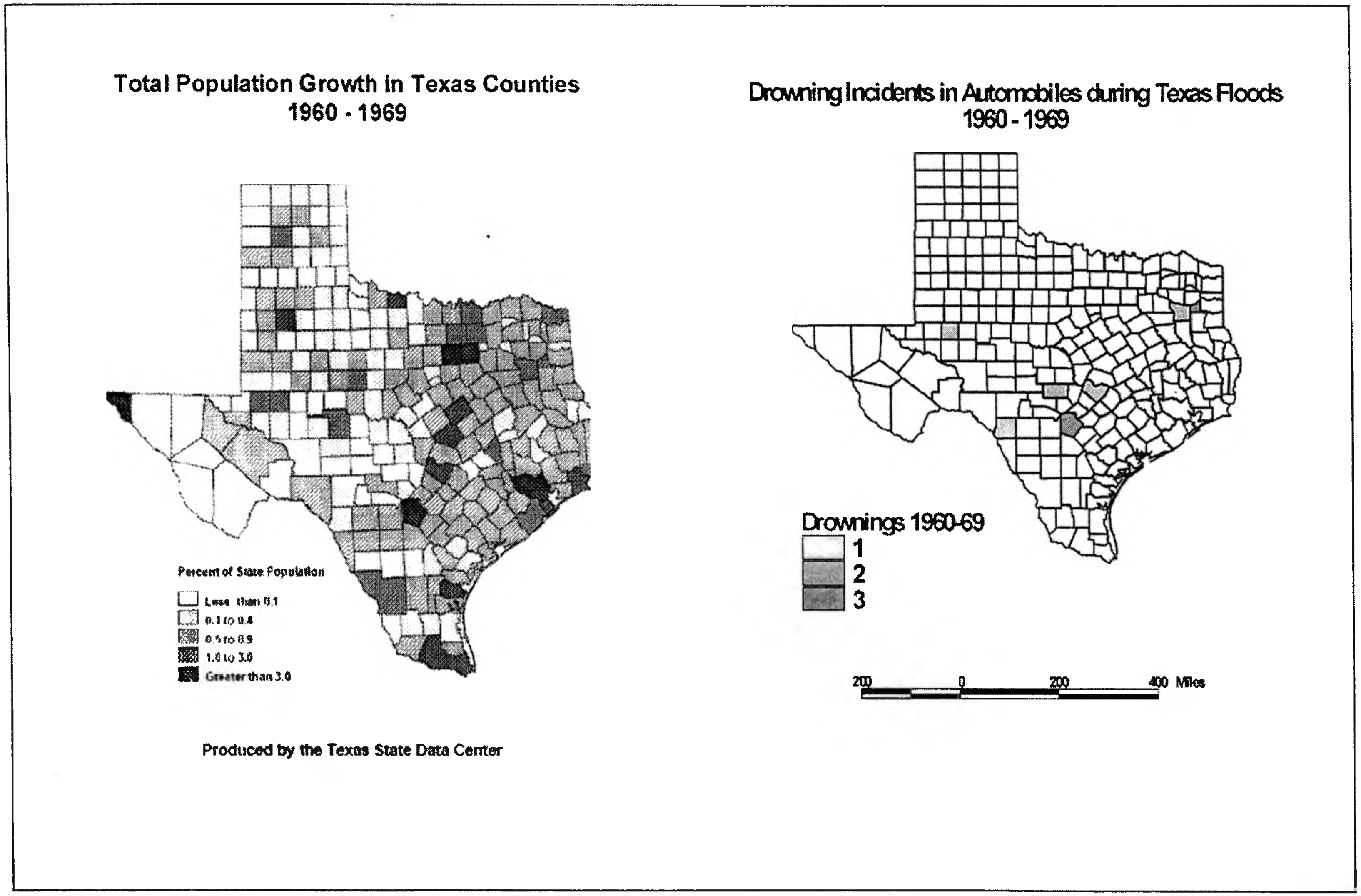

Figure 6. Comparison maps of Texas population and automobile related drowning incidents in the 1960s.

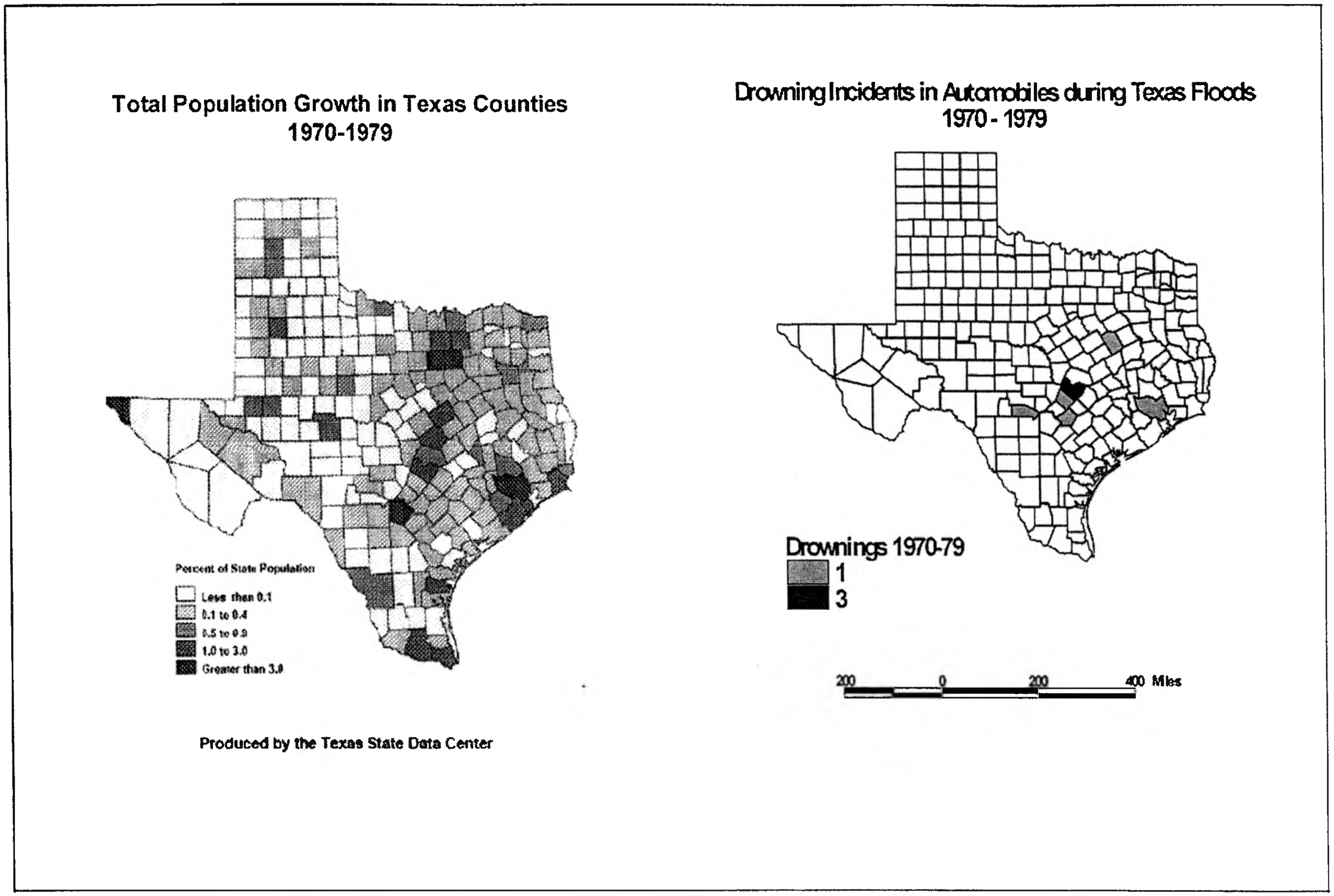

Figure 7. Comparison maps of Texas population and automobile related drowning incidents in the 1970s .

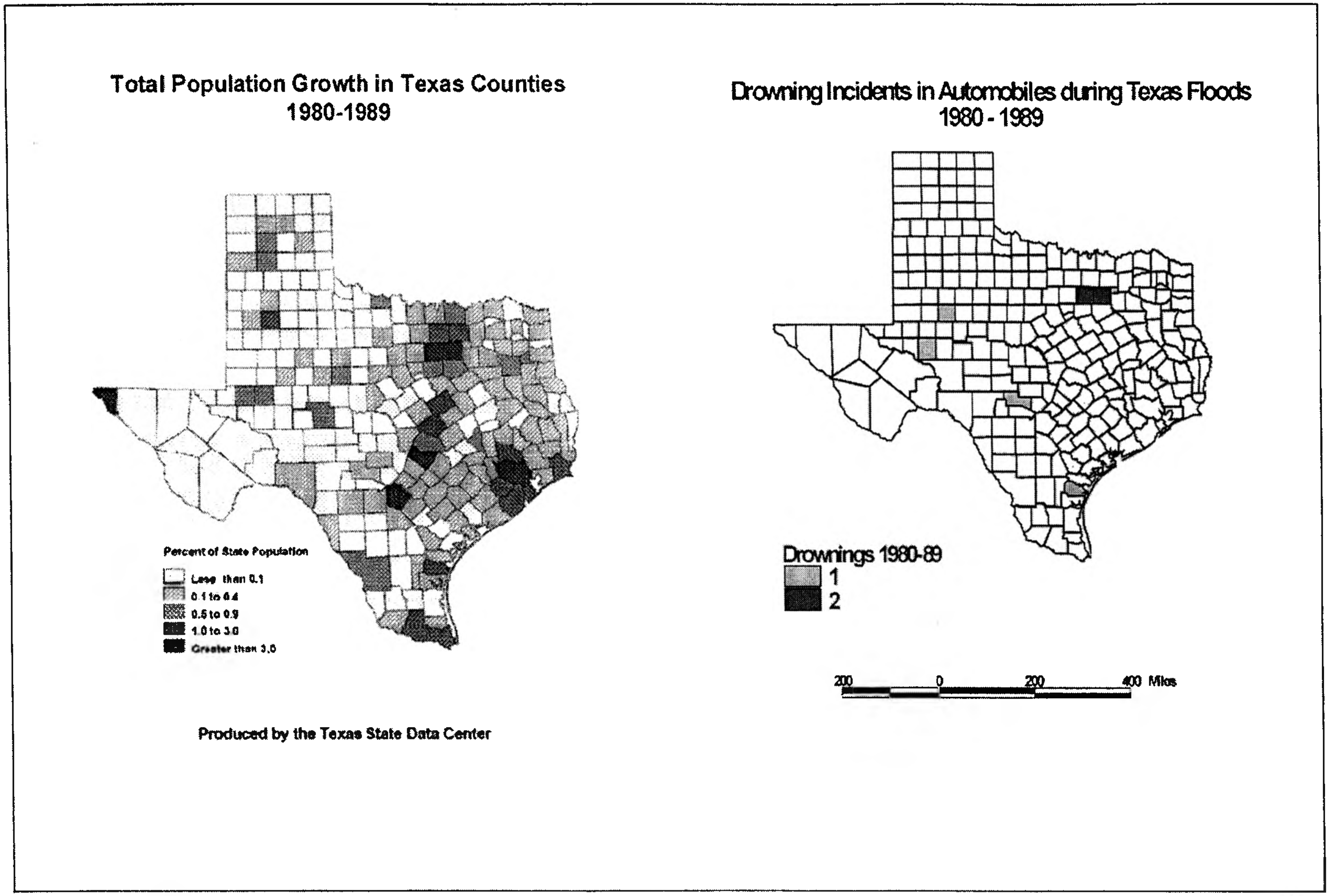

Figure 8. Comparison maps of Texas population and automobile related drowning incidents in the 1980s.

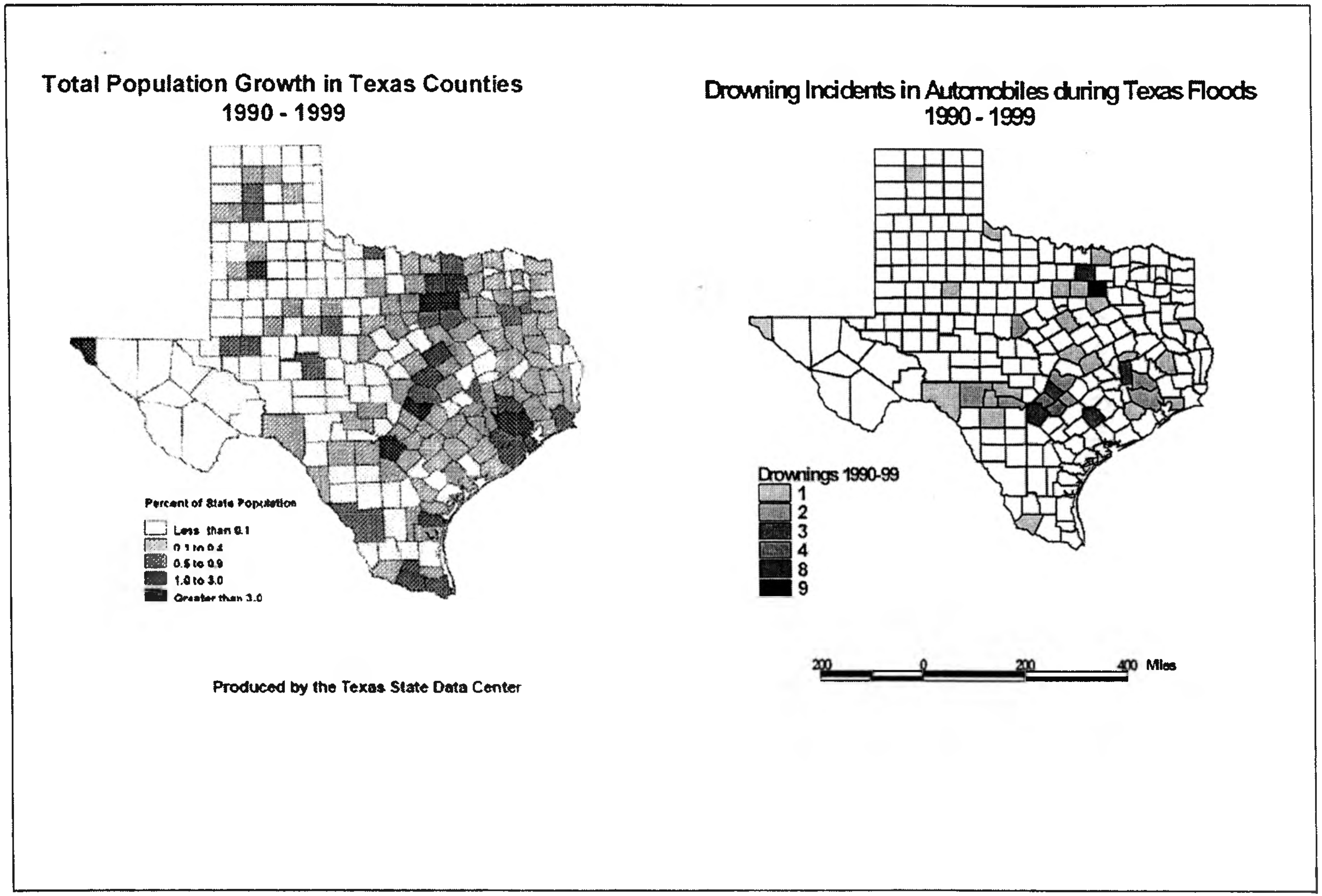

Figure 9. Comparison maps of Texas population and automobile related drowning incidents in the 1990s.

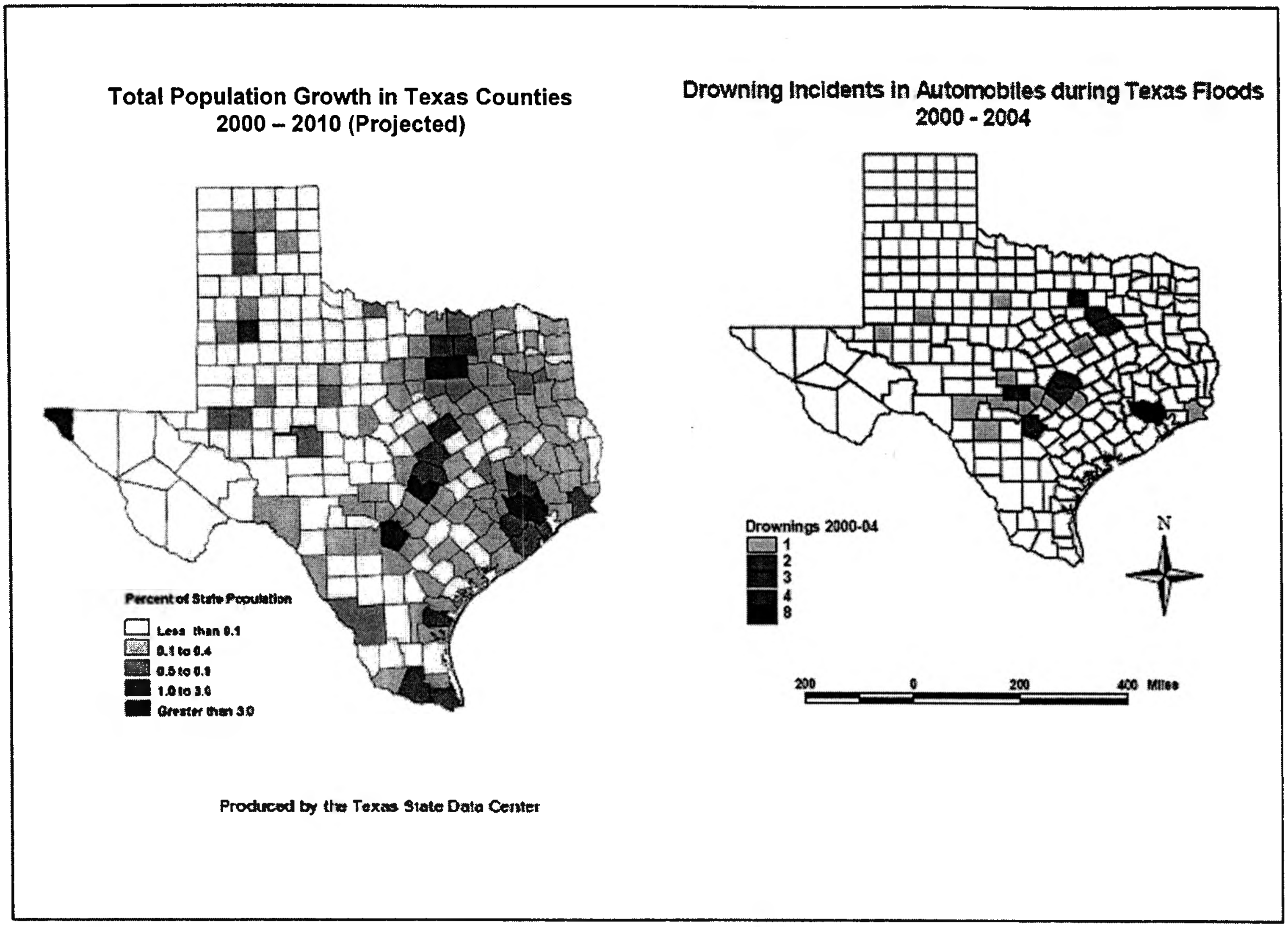

Figure 10. Comparison Maps of Texas Population and Automobile Related Drowning Incidents 2000 – 2004.

decade, and the number of floods per decade. The dependent variable was the number of incidents, and the independent variables were the county populations by decade and the number of floods per county per decade. While it would have been valuable also to use the number of drivers per county by decade, the miles of roads per county by decade, and the number of vehicles per county by decade, these data were not available.

The results of the regression (Table 1) show the F statistic to be 8.095 with a significance level of .000, so the null hypothesis, stating that there is no relationship between the two, can be rejected. Additionally, the output shows an R square value of 0.231, which accounts for only a small portion of the variability between the variables. Therefore, it can be concluded that while there is a relationship between the number of incidents per county by decade, the population of the counties, and the number of floods per county per decade that relationship is weak.

Of the 140 incidents, the probable roadway familiarity was determined for thirty-eight of the drivers (or 27 percent of the total). Of these thirty-eight drivers, twenty-seven (71 percent of the subset) were considered familiar with their driving environment and eleven (29 percent of the subset) were not.

To draw the preceding conclusions, some assumptions were made based on context clues from reports and articles. When the location of residence was in the same subdivision or within three blocks of the location of the drowning, roadway familiarity was assumed. Roadway familiarity was assumed when an article or report stated that the person was near their home. Also, familiarity was assumed when the driver was on the way to or from work, except in one case where the victim's son specifically stated that

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.480
R Square	0.231
Adjusted R Square	0.202
Standard Error	1.374
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	30.577	15.289	8 095	0 001
Residual	54	101.984	1.889		
Total	56	132.561			

Table 1. Output from Regression of Relationship Between the Number of Incidents Per County by Decade and the Population of the Counties

his mother had just started a new job and was not familiar with the roads in the area. In one case, a teenage girl was reported to have been within sight of her school when the incident occurred. This case was included with the tabulations of those who were familiar with the roadway.

Another potential determinant of roadway familiarity is distance between the residence and the location of the drowning incident. When both locations were available and explicit, the distance between the two was calculated. It was possible to determine the distance in twenty-seven cases. Four of those led to the classification of the driver as "unfamiliar" with the roadway. This assumption was made when the driver was forty miles or more from their home. The other twenty-three cases were not officially classified as familiar or not. The results of the mileage calculations follow (Figure 11).

The relative setting (urban or rural) was available for 109 of the 140 incidents (78 percent of the total). Of these, forty-eight (44 percent) of the incidents occurred in urban settings and sixty-one (56 percent) occurred in rural settings.

In 2004 nine motorists died on flooded roadways in the state of Texas. These incidents occurred at eight different sites (Table 2). Of these eight sites, the visibility of the water crossing can be considered "good" (during the daytime and in fair weather) for a driver who is approaching the area and going the speed limit on five of the roads. At the times when the incidents occurred, signs were posted on four of the eight roads warning of a flood danger. However, one of these signs was small and only stated that the area is flood-prone, making no mention of the potential for water on the road. Two of the roads had no curbs, shoulders, or guardrails to help prevent a car from washing off of

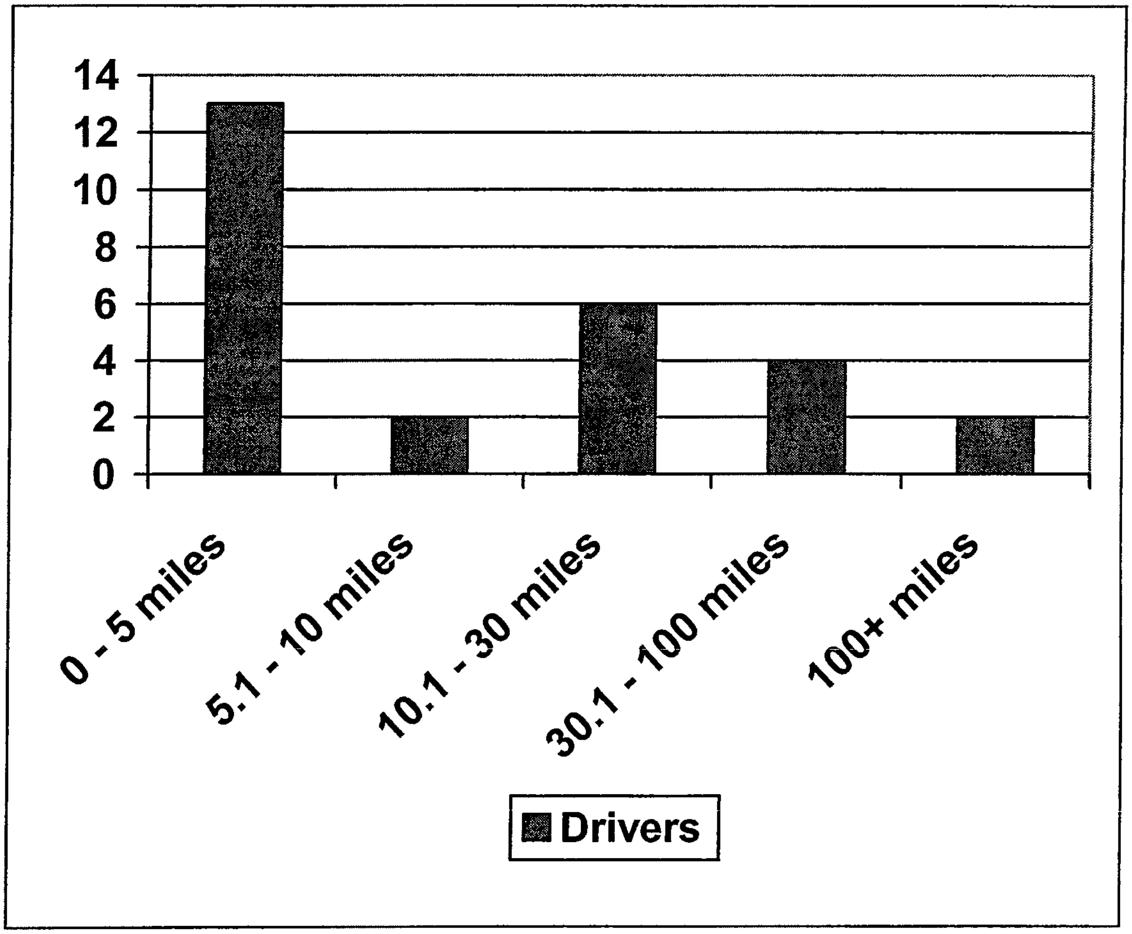

Figure 11. Distance between Location of Residence and Location of Drowning.

Site #	Visibility	Signage	Construction	Number of Lanes in Each Direction	Road Surface	Water at Site When Not Raining	"Normal" Traffic Rate	Surrounding Topography	Level of Development	Alternative Routes
1	Good	Posted after incident	× curbs × shoulders √ guardrail	1	Asphalt	Shallow	Slow	Generally flat	Suburban bordering rural (poor community)	Inconvenient
2	Good	None	× curbs × shoulders √ guardrails	1	Asphalt	Shallow	Medium	Generally flat	Rural Interstate	No
3	Fair	One small rectangular sign stating, "Flood Prone Area"	× curbs × shoulders × guardrails	1	Asphalt	Shallow	Slow	Generally flat	Suburban bordering rural (poor community)	Inconvenient
4	Good	None	× curbs √ shoulders √ guard rails	2	Asphalt	Flowing	Medium	Generally flat	Suburban	Inconvenient
5	Fair	None	× curbs × shoulders √ guardrails	1	Asphalt	Shallow	Slow	Generally flat	Urban	Convenient
6	Good	Flashing lights, warning signs stating, "Watch for water on road"	× curbs × shoulders √ guardrails (put in after event)	1	Asphalt	Very shallow	Medium	Very slight hill on one side of water crossing	Urban	Convenient
7	Poor	Gates, warning signs stating, "One lane bridge" and "Road subject to flooding"	× curbs × shoulders × guardrails	1	Asphalt	Flowing	Slow	Generally flat	Rural	Inconvenient
8	Good	Flashing lights, warning sign stating, "Watch for water on road"	√ curbs × shoulders √ guardrails	2	Asphalt	Dry	Heavy	Generally flat	Urban	Convenient

Site Locations:

1 Intersection of Butler and McClure streets in southeast Fort Worth (Tarrant County)
2 Mile marker 228 on the east side service road of Interstate 45 in Corsicana (Navarro County)
3 Intersection of Post Oak Creek and Bunert St. in Corsicana (Navarro County)
4 Intersection of Red Oak Creek and Ovilla Road in Ovilla (Ellis County)
5 Rush Creek near the 1900 block of N Peyeco Drive in Arlington (Tarrant County)
6 Intersection of McNeel Road and Overbrook Drive in San Antonio (Bexar County)
7 Intersection of Post Road and the Blanco River just south of Kyle (Hays County)
8 Lorence Creek at the 14700 block of Henderson Pass in San Antonio (Bexar County)

Table 2. Characteristics of Roadways Where Incidents Occurred.

the road. Six of the roads had only one lane in each direction and the other two had two lanes. All of the roads were constructed of standard asphalt. Only two of the roads intersected with water bodies that were flowing under "normal" conditions. The other six had a minimal amount of water that may not be obvious to a driver when the weather is fair. In all cases, the land surrounding the creeks or rivers is generally flat. Three of these incidents occurred in urban settings, three occurred in suburban settings, and two occurred in rural settings. Only one of these sites had no alternative routes.

Using the event-specific model and available data, it was evident there are a multitude of factors that contributed to these drowning incidents. With the data collected through the previously mentioned sources it was possible to examine four additional factors that may have contributed to these drowning incidents: time of day the incident occurred, driver's age, driver's sex, and vehicle type.

One factor studied to determine its likelihood of being a contributor to these fatalities is the time of day the incident occurred. By looking at the time of day it is possible to get an idea about how much natural lighting was available. This influences the driver's ability to determine how much water was on the roadway and therefore make a judgment before entering the flooded roadway. Other factors influence visibility (i.e. glare from sun or streetlights, amount of rain on windshield, and curves in the roadway), but by determining the potential amount of natural lighting the first step is made in solving this equation.

Three divisions were established for classifying the time of the incidents: daytime, nighttime, and dawn/dusk. Out of 140 incidents, data was available to verify the time of day for forty-four (or 31 percent of the total) of the incidents. Eleven incidents (25 percent) occurred during daylight hours, six occurred at either dawn or dusk (14 percent), and twenty-seven incidents (61 percent) occurred when it was dark outside.

The known sex was available for 98 of the 140 (70 percent of the total) drivers involved in drowning incidents in automobiles on flooded roadways in Texas from 1950 – 2004. Of these, 57 (58 percent) were male and 41 (42 percent) were female. Ages were available for 62 of the drivers (44% of the total). When examining the combination of the age and sex of the drivers, the evidence reinforces that male drivers were the majority of those who had become entrapped when crossing flooded roadways (Figure 12). For five of the eight age groups it was found that males were in the majority, in two of the age groups females were, and in one they tied.

In 99 out of the 140 cases (71 percent) the type of vehicle involved in the incident was reported in the newspaper article or incident report. The vehicles reported were as follows: sixty-nine cars, twenty-one trucks, four SUVs, three vans, one bus, and one tractor. Of the nine incidents that occurred in 2004 four of the vehicles reported were cars, three were trucks, and one was an SUV. Considering that over half of the vehicles involved in 2004 were comparatively larger, it will be interesting to see if the involvement of larger vehicles in these events becomes a trend over the next decade.

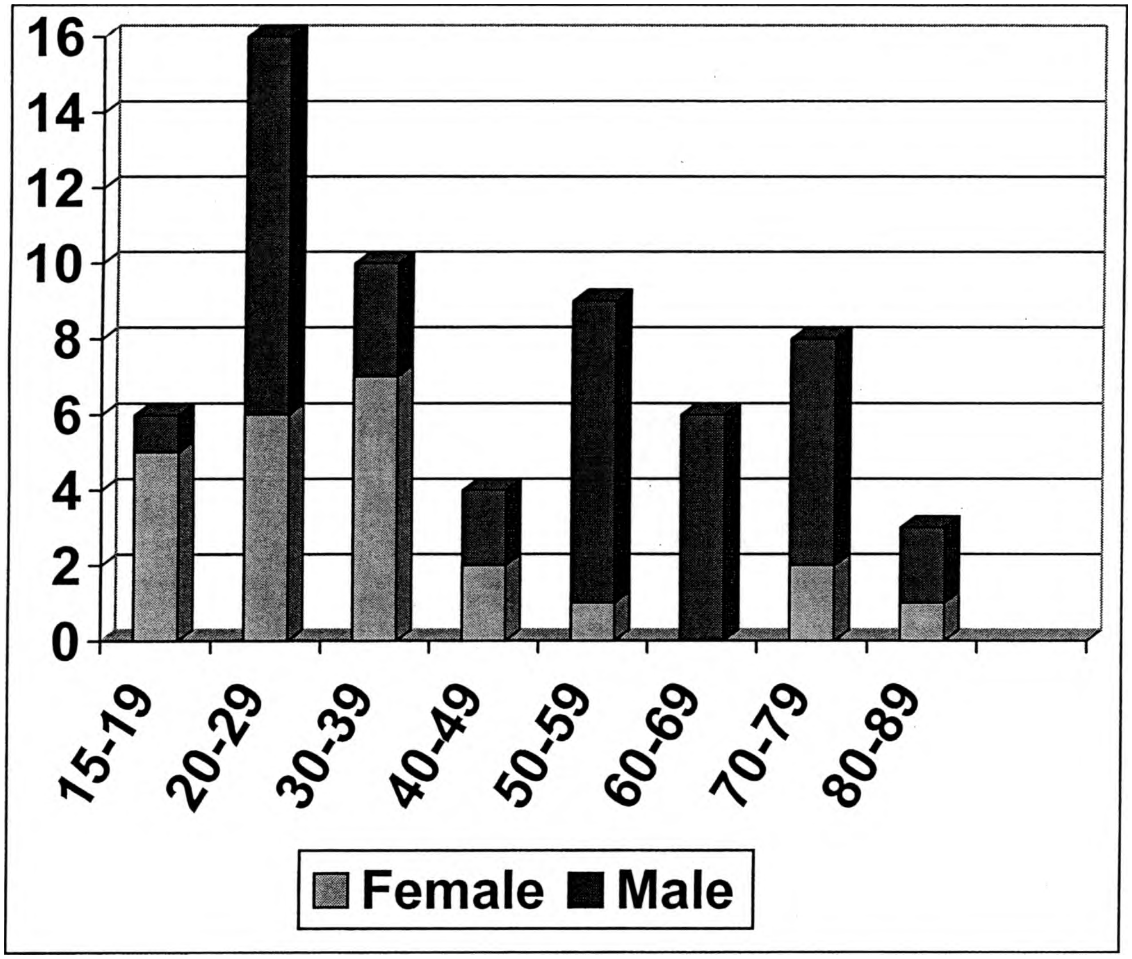

Figure 12. Age of Drivers (in Years) by Sex.

CHAPTER VI

DISCUSSION AND CONCLUSION

Discussion

When mapping the data, clusters of incidents appear around large metropolitan areas in the 1990s. There are four hypotheses (isolated or in combination) that may explain this distribution. The first being, with its 79,535 centerline miles (miles traveled in a one-way direction regardless of the number of lanes in a roadway), Texas has the largest road system of any state in the United States (Federal Highway Administration 2004, Texas Department of Transportation 2005). Surrounding the urban areas mentioned above, these roadways are dense and traveled with more frequency than they are elsewhere in the state. More roadways allow for more areas where water will cross the road. Second, with the population increase in these areas there are now more drivers on the roads. More drivers on the roads signify a higher probability of those drivers engaging in any type of driving incident. Third, these highly developed urban areas are places with a tremendous amount of impervious cover, which prohibits absorption of rainwater, especially during flash flood events. This not only adds to the water on the roadways where the rain falls, but the run-off also adds water to any surrounding areas that are at lower elevations. Therefore, a higher volume of water equals more flooded roadways. Finally, news media is often spatially biased (Brooker-Gross 2003). The areas that are showing more of these incidents are also areas that would have better/more media resources to cover such events.

Over half of all the incidents occurred within ten miles of the driver's home and just less than half (13 of the 27 or 48 percent of those for whom mileage could be obtained) occurred within five miles of the victim's residence. It is reasonable to infer that when people were familiar with their driving environment they were more likely to engage in the types of known risks that lead to deaths on flooded roadways.

The majority of the roadway characteristics were not consistent across all sites. One characteristic that did remain constant was the surrounding landscape was generally flat with the only visible depressions being the slopes of the creek or riverbeds, which makes it likely that all run-off from a large area is collecting in these beds. Additionally, the majority of these creeks and rivers have very shallow water under "normal" conditions. Therefore, it is logical that even a driver that is familiar with the area might be surprised by the run-off flooding the road during a heavy rainstorm.

Four additional factors that may have contributed to these drowning incidents were identified: time of day the incident occurred, driver's age, driver's sex, and vehicle type. Three divisions were established for classifying the time of the incidents: daytime, nighttime, and dawn/dusk. Out of 140 incidents, data was available to verify the time of day for forty-four (or 31 percent of the total) of the incidents. Eleven incidents (25 percent) occurred during daylight hours, six occurred at either dawn or dusk (14 percent), and twenty-seven incidents (61 percent) occurred when it was dark outside. It can be concluded that the darkness played a role in these drowning incidents.

By breaking the ages into groups at ten-year intervals, it can be concluded that deaths at flooded roadways do not vary much by age. Though, a sharp rise in incidents can be seen in the 20s age group when compared to all other age groups (Figure 12.). This peak is aligned with reports that show that younger drivers are more likely to drive with an increased level of risk (Baxter et al. 1990, Musselwhite 2005).

The majority of drivers involved in these incidents being male might be explained through a study that has found women show a tendency towards risk aversion, compared to males in the same age groups (Levin et al. 1988). Musselwhite's (2005) and Baxter's (1990) research reveals that males are more likely than females to drive with an increased level of risk. This study supports their conclusions. However, it is interesting to note that of the six people younger than twenty, five cases involved female drivers and only one case involved a teenage boy.

The majority of vehicles involved in these accidents were cars. This may be due to the limited visibility and poor perception of the water depth from the height of a car. Despite this, it is never wise to drive any vehicle through a flooded road segment.

Conclusion

This study found that roadway familiarity and time of day were factors that likely contributed to the occurrence of these incidents, while roadway characteristics, sex of the driver, and age of the driver were not likely to have been key contributing factors.

Ensuring public safety during flood events involves identifying the population of the individuals involved as well as determining the underlying processes that contribute to such events. The focus of this research was to study the factors that contribute to flood-related mortality incidents involving automobiles in Texas. To be able to address populations that are susceptible to this type of event, we must definitively examine the salient issues that remain the most constant throughout time and across events. This study has done so by examining the locations where these incidents have occurred, the characteristics of the drivers that have been involved in these incidents, and the characteristics of the roadways where these incidents have occurred. This analysis details these pertinent issues in an effort to curb automobile-related mortality rates during future events.

Future Research

This study identifies factors that contribute to the drowning deaths of motorists on flooded roadways in Texas. However, in addition to the testing done to determine a relationship between the number of incidents per county by decade, the population of the counties, and the number of floods per county per decade, it would be valuable to add the miles of roads per county by decade, the number of vehicles per county by decade, and the number of drivers by county by decade to the regression, if those data can be found.

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VITA

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