An Analysis of the September 20, 2002, Indianapolis Tornado: Public Response to a Tornado Warning and Damage Assessment Difficulties

By

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Introduction

An anomalous date in the tornado record is September 20, which has, "the largest count for any day between the early summer and late spring (NSSFC Staff, 1980: 54)." The notorious Hurricane Beulah in Texas in 1967, which was a prolific producer of tornadoes, is responsible for many of the tornado reports on this date. Coincidentally, three tornadoes occurred in Indiana on September 20, 2002, with one hitting southern and eastern portions of Indianapolis in Marion County, Indiana (Appendix A: Fig. 1). The Indianapolis tornado had the longest track (a remarkable 112 miles) during this event, and it will be the subject of this study. Tornado paths longer than 100 miles are rare, with an average of almost one each year (Twisdale, 1982; Wilson & Morgan, 1971). This tornado proved to have the second longest track in Indiana's history. Pryor and Kurzhal (1997) claim that the more intense a tornado is, the more likely it is to have a long path length. The Indianapolis tornado also happened to be the most damaging tornado (F3; wind speeds of ~158-206 mph) during this outbreak (Appendix A: Fig.1).

This tornado provided an opportunity to study the effects of a tornado on an urbanized area. It is possible that the Fujita Scale does not describe urban types of damage effectively, which could lead to difficulties in the Fujita Scale damage assessment process. Also, urban dwellers might be faced with unique situations that affect their responses such as being in their cars, being at work, eating at restaurants, walking on the streets, or living in apartments. Since the tornado's path was so long, the focus of this study is only on the portion of the tornado's path in Marion County, Indiana (Appendix A: Fig. 2), which includes the city of Indianapolis.

The long-track tornado that is being studied caused enormous damages, affecting at least 313 buildings in Marion County, with a preliminary damage total of $36,605,800 for Marion County alone (Tan & Ellis, 2002). However, no fatalities or serious injuries were reported from this tornado, and only about 50 minor injuries were reported

(Schneider, 2002). Early warnings, rapid dissemination, and an overall prepared citizenry all seem to have contributed to the “miraculously” low number of casualties.

Study Area

Human Environment

Social factors can contribute as much or more to tornado vulnerability as the natural hazard occurrence (Blaikie et al., 1994). Therefore, risk is defined not only by the threat to people, but also by the product of cultural and social experiences (Kasperson, 1992). This is why it is important to understand the human environment as well as the physical environment when dealing with hazards. Boruff et al. (2003) illustrate how social vulnerability can amplify or decrease tornado vulnerability in the U.S. both spatially and temporally.

The total population of Marion County, Indiana in 2000 was 860,454 (USCB, 2002a). It has the highest population of any county in Indiana. The population density was 2172 persons per square mile in 2000. The city of Indianapolis is the 12th largest city in the U.S. based on population, but its population density ranked 183rd (USCB, 2002b). Population density is especially important when discussing tornado impacts because tornadoes typically affect a narrow swath rather than the entire county, and a high population density means more people are likely to be affected.

The median age of Marion County residents is 33.6 years old (USCB, 2000a). Only 11% of the population in Marion County is 65 years of age or older, but 26% of the county’s residents are under the age of 18. 7% of the population of Marion County consists of small children under the age of 5. Schmidlin (1993) has found that the very young (<5) and the elderly (>65) are at highest risk for death in tornadoes. Also, there are 157,908 persons over the age of 5 with disabilities in Marion County. These residents are particularly vulnerable to tornadoes because it is frequently more difficult for them to receive warnings and to respond to them.

There are slightly fewer males (48%) than females (52%) in Marion County, IN. The age and gender composition of Marion County is consistent with the state average for Indiana. However, the racial composition of the population in Marion County differs from the rest of Indiana. The black population is much higher in Marion County (24%) than it is for the entire state of Indiana (8%). The white population percentage for Marion County (71%) is thus lower than the average for the state of Indiana (88%). The Hispanic population is the third most common racial group in Marion County according to the 2000 Census, but they account for only 4% of the population in both Marion County and the state of Indiana. It has been suggested that both gender and ethnicity contribute to vulnerability to tornadoes.

There were 352,164 households in Marion County, IN in the year 2000, with an average of 2.39 persons per household. 53% of Marion County residents who are 15 years old or older have either never been married, are separated, are divorced, or are widowed (USCB, 2000b). Being unmarried or divorced has been shown to increase vulnerability to tornadoes, possibly due to where these persons frequently live (e.g. apartments, mobile homes) (Schmidlin et al., 1998).

Other factors that can contribute to vulnerability are income and education levels, which generally affect the type of home one can afford and possibly have an influence on preparedness levels. Illiteracy can make people particularly vulnerable (Pearce, 1994).

Generally, a low education level is related to a low income level and high vulnerability. The median household money income in 1999 for Marion County residents was $40,421, and the per capita money income was $21,789. Unfortunately, 11% of the population in Marion County lives below the poverty level. This is just slightly higher than the state average. 82% of Marion County residents over the age of 25 are high school graduates, and ¼ of the population over 25 years old has a bachelor's degree or higher education level. This level of college-educated residents is higher than the state average of 19%.

The population in Marion County is fairly mobile with only 47% of persons over the age of 5 living in the same house in 2000 as they were living in back in 1995. This is lower than the state average of 55%. 19% of Marion County residents lived in another county, state, or country in 1995 (USCB, 2000b). This affects preparedness because residents that are new to an area may not have the level of awareness that long-term residents have. 5% of Marion County residents were born outside of the United States, and 7% of residents over the age of 5 speak a language other than English at home. This affects preparedness levels and warning dissemination. Warnings are usually only broadcasted in English. These numbers are slightly higher than the state average.

Finally, the mean travel time to work for residents over the age of 16 is 23 minutes. Only 10% of households do not own a vehicle in Marion County (USCB, 2000b). Being in a vehicle reduces the likelihood of receiving warnings, and vehicles are not the best shelter choice during tornadoes. Unfortunately, automobile fatalities from tornadoes can occur in high numbers, particularly during rush hour times when traffic jams are more common as was true in Wichita Falls, Texas on April 10, 1979 (Glass et al., 1980).

Physical Environment

Marion County is located at the heart of the Indianapolis Metropolitan Statistical Area, and it contains the city of Indianapolis. Marion County, Indiana has an area of 396 square miles. The city of Indianapolis has the 9th largest land area of any city with a population over 100,000 in the U.S. (USCB, 2002b). Berz et al. (2001) claim that the potential for catastrophes increases greatly as economic activity is concentrated in large cities and industrial areas. Urban sprawl increases the probability that a city will be hit by a tornado because it increases the area of the city. Unfortunately, Indianapolis does lie in an area of frequent tornado occurrence. Pryor and Kurzhal (1997) discuss the tornado climatology of Indiana in detail.

In 2000, there were 387,183 housing units in Marion County. However, 32% of these housing units were in multi-unit structures, a much higher percentage than the state average of 19%. It is difficult to modify a multi-unit structure because more than one household is affected, and the occupants are often renters. The homeownership rate for Marion County is 59%, which is lower than the state average of 71%. This is probably due to the large number of apartments and renters in Marion County. People who rent their residences are also more vulnerable than homeowners because renters carry less insurance, and their residences are often not well constructed or maintained. Apartment managers often do not provide safe shelters for their tenants either. In addition, renters are frequently over-represented by the poor, the elderly, and the young (Pearce, 1994). 56% of Marion County's structures were built before 1970 (USCB, 2000b). Fortunately, mobile homes make up only 2% of the housing stock in Marion County (USCB, 2000b). Mobile homes are not safe during tornadic storms. However, the median value of owneroccupied housing units was $99,000, which was $4700 higher than the state average. Therefore, it is not difficult for a tornado to cause significant property damage values in Marion County.

Research Questions

1. What types of damage are seen in urban areas, and do these damage patterns have an effect on the Fujita Scale ranking of tornadoes?

2. How does the public receive, perceive, and react to tornado warning information?

Methodology

After driving to Indiana on September 23, 2002, the principal investigator began documenting the tornado's path with photographs and notes about the resultant damage. It is important to photograph damage before it can all be cleaned-up to get a realistic impression of what occurred. The pictures taken for this study were compared to index pictures of tornado damage patterns (Appendix A: Figure 3) taken by the tornado pioneer, Ted Fujita (Fujita, 1971) in order to estimate the Fujita Scale rating of the tornado at each photograph location. This information can then be mapped to determine the tornado's path and strength variations throughout Marion County (Appendix A: Figs. 4, 5, and 6).

In addition to damage assessment, this study determines if and how people heard about the tornado warnings and how they responded to the warnings. Therefore, public surveys were conducted at two different sites, one a major retail center on the south side of Indianapolis very close to the tornado's path (Appendix A: Fig. 4) and the other a mall on the east side of Indianapolis near the tornado's track (Appendix A: Fig. 5). On September 25, the survey was conducted at the south side site, and there were 29 participants. On September 26 and 27, surveys were conducted at the east side site with 48 and 25 participants, respectively. A copy of the survey used in this study is attached (Appendix D). The survey results were entered into a spreadsheet for analysis, and the χ^2 statistic was used to test for significance when appropriate. Again, quick response is necessary to ensure that respondents remember the event clearly, and the public is generally more eager to answer questions soon after a disaster.

After returning to Columbia on September 29, the 6 o'clock news reports from the NBC, CBS, ABC, and FOX affiliates in Indianapolis for September 20, 21, and 22 were ordered to study their coverage and obtain more information about the tornadoes. The National Weather Service Office in Indianapolis was also contacted, and they provided the original wording and times of the tornado warnings issued on September 20 (Appendix A: Figs. 7 and 8).

Sample Size and Characteristics

The public surveys in Indianapolis included 102 people. The majority of the respondents were female (64%), which is probably a result of the demographics of the customers at the survey sites at the time that the surveys were conducted. It is possible that men were more likely to be working or cleaning up debris at the time of the surveys. It was easily apparent that more women than men were entering the major retail center and the mall in Indianapolis during the daylight hours while the surveys were being conducted.

Also, most of the respondents were fairly young. For example, 67% of the respondents were between the ages of 18 and 47. Only 1/3 of respondents were over the age of 47 (Appendix A: Fig. 9). There were slightly more 18-27 year old respondents who were male and slightly more 28-57 year old respondents who were female (Appendix B). Again, this is probably a result of the demographic construction of the mall and retail center's customers.

The race of most respondents was white (75%), but almost ¼ (24%) of respondents were black. The racial gap was slightly larger for females than males (Appendix B), but the difference is not statistically significant, χ^2 (1,N=101)=0.34, $p>0.10$. Black respondents were generally younger than white respondents in this case (Appendix B). Again the demographic profile of the areas surveyed is probably responsible for these results, and the proportions agree with the statistics found for Marion County by the U.S. Census Bureau.

Almost half (49%) of the respondents indicated that they were very close (within 2 miles, but not hit) to the tornado (Appendix A: Figure 10). This makes sense because the survey sites were very close to the tornado's path, and most people probably lived near the survey sites. Only 10% of respondents indicated that the tornado hit their location. Also, only 9% of respondents were more than 10 miles away. Due to the proximity of the tornado, many respondents were very enthusiastic about taking the survey, and this is an opportunity to get vital information from the public that should not be missed.

Results

Fujita Scale Assessment

Narrative Account of Tornado Track

The tornado damage pictures and accompanying notes indicate a continuous damage path across southern and eastern Marion County, with damage ranging from F1 to F3 intensity on the Fujita Scale (Appendix A: Fig. 2). This agrees overall with the National Weather Service Assessment (Appendix A: Fig. 1), but the damage assessment in this study indicates smaller-scale variations in F-scale intensity and the shape of the tornado's swath of damage. The tornado's track in Marion County is divided into 3 segments from southwest to northeast as it moved through the county, and the damage path is described in Appendix C.

Damage Assessment Difficulties

Using the descriptions of characteristic damage types and the index pictures, it is fairly straightforward to rate tornado damage to houses on the Fujita Scale (Appendix A: Fig. 28). Damage to apartments is not very difficult to classify either (Appendix A: Fig. 29). However, it is possible that apartment buildings are more susceptible or less likely to be damaged by tornadoes than houses due to their size and construction as well as wind flow patterns around them. Wind engineering studies could address this issue.

The same can be said for businesses and factories (Appendix A: Fig. 30). The large-span roofs on factories probably make them more susceptible to wind damage in a similar manner as churches and gymnasiums. The vacant Pier 1 Imports store that was destroyed by this tornado was probably more susceptible to damage due to its type of construction and the glass walls that are common in these types of stores.

Damage to vehicles was more difficult to classify (Appendix A: Fig. 31). Vehicles are not typically damaged by tornadoes less than F1 in strength unless a limb falls on them. At F1 intensity, some cars are blown around on roads. When F2 winds are encountered some vehicles are lifted off the ground. Debris also poses a major hazard to vehicles by crushing them or breaking the windows (Appendix A: Fig. 31). Cars can be lifted and thrown by F3 tornadoes. This results in tremendous damages and terrifying situations. Debris can flatten cars and blow out all windows (Appendix A: Fig. 31). During this tornado a minivan with a mother and teenage daughter inside was rolled over several times through a parking lot at a shopping center while they prayed for their lives. Fortunately, they had on their seat belts and survived, and they were thankful to be alive. Another amazing story broadcast on local television in Indianapolis tells of a mother and her toddler son who were driving home ahead of the tornado. The mother realized the tornado was about to strike them, and she pulled into her church parking lot. She got in the back of the minivan and lay on top of her son. The tornado picked up the minivan and tossed it through the air for three blocks. Witnesses described seeing the minivan flying over several houses. Miraculously, the minivan landed on its wheels, and neither mother nor son was physically harmed.

Damage to trees was somewhat challenging to classify. In this case, there were usually buildings nearby to assess the damage, but in rural areas that are heavily wooded damage assessment could prove difficult. Damage below F3 is especially difficult to rate (Appendix A: Fig. 32) because it depends on so many variables (e.g. root depth, plant health, height, leaf mass, wind speed, and thickness of forest). Ecological models and biologists could improve damage classification with more research.

Many have noted problems with the Fujita Scale, and a symposium addressing its problems was held at the 2003 American Meteorological Society's Annual Meeting in Long Beach, CA. The Fujita Scale does not describe how to classify damage to many structures that are commonly found such as signs (Appendix A: Fig. 33), power lines, fences, small walls and borders, or streetlights (Appendix A: Fig. 34). It is also challenging to try to classify tornadoes based on odd debris that is found some distance from where it was originally located (Appendix A: Fig. 33). Of course if no damage indicators are present (e.g. corn fields), it is extremely difficult to determine the intensity of the tornado.

Damage assessment is often quite challenging. In urban areas, damage assessment is probably easier than usual because there are so many structures to compare to the index pictures, which are only structures. Some possible biases in urban areas are that the amount of debris created in urban areas during tornadoes could exacerbate the damage levels, and the types of buildings in urban areas (e.g. apartments, businesses, factories, restaurants, etc.) might not react to winds in the same manner as houses. Future research could improve the damage assessment process by addressing some of the problems discussed in this section.

Warning Dissemination, Shelter Decisions, and Public Awareness

The public survey results from Indianapolis indicate that most of the 102 respondents (47%) had no visual or audible cues to indicate that a tornado was nearby (Appendix A: Fig. 11). Of those that did see or hear tornado indicators, the most common cues were odd-colored or greenish clouds (31%), a loud, roaring sound (25%), or a funnel-shaped cloud (11%). Those respondents who were at a location that was struck by the tornado frequently experienced all of the visual or audible cues associated with tornadoes, except for hail or odd-colored clouds (Appendix B). They were the only group to likely have seen the funnel-shaped cloud associated with the tornado. However, ¼ to ½ of persons in all distance groups claimed to have experienced no sensory cues of the tornado. The respondents who were not hit by the tornado frequently saw odd-colored clouds. Besides those who were hit, respondents that were very close or not close often heard the roar of the tornado, too.

Fortunately, 81% of the 102 respondents were aware of the tornado warning in this case. Those least likely to be aware of the warning were either directly hit by the tornado, or they were more than 10 miles away from the tornado's path (Appendix B). Distance from the tornado did not significantly alter the tornado warning awareness level, χ^2 (1,N=102)=0.37, p>0.10. A minimal racial difference in tornado warning awareness existed with white persons being slightly less likely to be aware of the warning than black persons (Appendix B), but the difference was not statistically significant, χ^2 (1,N=101)=0.82, p>0.10. Also, female respondents were more likely to have been aware of the tornado warning than males (Appendix B) in this case, but again the difference was not statistically significant, χ^2 (1,N=102)=1.24, p>0.10. Finally, middle-aged respondents (age 28-57) were more likely to be aware of the warning than retirement-age (over 57) or young adult (18-27) respondents (Appendix B). However, the relationship between age and warning awareness was not statistically significant, χ^2 (2,N=102)=0.41, p>0.10, either.

Unfortunately, of the 83 respondents who were aware of the warning, only 31% felt that they were really in danger. Those who did not feel that they were in danger were much more likely to continue with business as usual (Appendix B). As expected, those that felt they were in danger when they heard the warning were less than 10 miles from the tornado's track (Appendix B), but the relationship between distance and awareness was not significant, χ^2 (1,N=83)=1.28, p>0.10. Most of these 83 people either heard about the warning from the tornado sirens sounding (70%) or from local television scrolls and news coverage (46%; this adds up to more than 100% because more than one answer could be chosen) (Appendix A: Fig. 12). However, the respondents that were most likely to perceive the threat of the tornado (>50% response) received the warning from NWS Weather Radio or a friend or relative (Appendix B).

Though the warning lead-time was between 20 and 40 minutes for Marion County, depending on what part of the county is considered, 22% of these 83 respondents reported less than 5 minutes to respond (Appendix B). However, many of the respondents (41%) who were aware of the warning did seek shelter immediately when they became aware of the tornado warning. Unfortunately, the second most common response to the tornado warning was to continue with business as usual (27%; again more than one answer could be chosen) (Appendix A: Fig. 14). Those most likely to seek shelter were within 20 miles of the tornado, but those who were very close to the path also were most likely to continue with business as usual (Appendix B). The relationship between distance from the tornado and shelter-seeking behavior was not statistically significant, χ^2 (1,N=102)=1.89, p>0.10. One frightening result of the survey is that 49% of the 102 respondents did not seek shelter at any time during this tornado, and only about half of those who did seek shelter had rehearsed their plan or gone to that shelter before. Being aware of the tornado warning did raise the chances of the respondent seeking shelter (Appendix A: Fig. 15), and the difference in proportions is significant, χ^2 (1,N=101)=4.52, p<0.05. The almost half of respondents who did seek shelter most commonly went to a basement (19%), an interior hallway (11%), or into a large building like a mall or Wal-Mart store (8%) (Appendix A: Fig.16). Females were more likely to seek shelter than males (Appendix A: Fig. 17), and the difference in proportions is significant, χ^2 (1,N=102)=3.21, p<0.10. Younger respondents were more likely to seek shelter than elderly respondents with 18-57 year olds being statistically more likely to seek shelter than those age 58 or older, χ^2 (1,N=102)=3.30, p<0.10 (Appendix A: Fig. 18). Middle-aged respondents (age 38-57) were likely to go to a basement. Also, black respondents were more likely to take shelter than white respondents, but the difference is not significant, χ^2 (1,N=101)=0.96, p>0.10. White persons who took shelter most often went to a basement, but black persons who took shelter most often went to a hallway (Appendix B). The respondents who where at a location that was struck by the tornado usually either never took shelter or they went to a basement (Appendix B). Those who went to a basement, large building, or bedroom were most likely to have rehearsed their plan before, but those who went to someone else's house or a vehicle were not likely to have practiced their plan before (Appendix B).

Of the 19 respondents who were not aware of the tornado warning, the most common reasons for not being aware of the warning were being in a car or being at work, respectively (Appendix A: Fig. 19). Most of these people were either never aware that there was a tornado threat, or they had less than 1 minute to respond when they did see or hear the tornado (Appendix A: Fig. 20). Therefore, 68% of them never responded to the tornado threat. This illustrates the importance of disseminating the warnings widely and effectively, and it indicates that we must improve warning notification processes at businesses and industries and in automobiles.

The respondents seemed to be most satisfied with the performance of the National Weather Service (63%), rescue personnel (54%), and the media (50%) during this tornado (Appendix A: Fig. 21). These groups should be commended for saving many lives. Most people (61%) thought everyone performed adequately during this tornado. Females (and white persons) were slightly more satisfied than males (and black persons) with all groups' responses, except for the public's, during this tornado (Appendix B). All age groups, especially the middle-aged were happy with the performance of the National Weather Service during this tornado. Young persons reported being satisfied with the rescue personnel slightly more often than older persons, but older respondents reported being satisfied with the media slightly more often than young respondents (Appendix B).

The respondents who did note some problems most often criticized the performance of the public (16%), the government (11%), and the media (7%) during this tornado (Appendix A: Fig. 22). Gender did not play a noticeable role in dissatisfaction of various groups during this tornado. The public was criticized by some respondents for making bad sheltering decisions, for causing massive traffic problems, for looting, and for apathy. White respondents were dissatisfied with the public's performance slightly more than black respondents (Appendix B). The government was most often criticized for not providing adequate shelter and assistance following the tornado, for keeping people out of their damaged homes, and for some decisions local schools made during the tornado. One respondent stated that children were crouched on the floor of a second-story hallway in a two-story school building that took a direct hit from the tornado. There was roof and water damage, but fortunately the children were not harmed. School officials should be instructed that children should always seek shelter on the lowest floor of the school during a tornado, and the sheltering plan should be practiced during tornado drills. Tornado drills also provide an opportunity to educate people about tornado facts and safety information. Black respondents were dissatisfied with the government's performance more often than white respondents (Appendix B). Also, young respondents were dissatisfied with the government's performance more often than older respondents (Appendix B). Finally, the media received some criticism, from white respondents (Appendix B), for hyping the event, for causing panic, and for insensitivity to victims. However, again the majority of people were satisfied with everyone's performance during this tornado.

Of the 102 respondents, approximately 30% could not correctly identify what a tornado watch means, and 21% could not correctly identify what a tornado warning means. The majority of respondents knew what both a tornado watch and warning meant, and knowing one raised the chance of knowing the other at a significant level, χ^2 (1,N=102)=22.80, p<0.005. However, the most frequent mistakes were not knowing what a tornado watch meant and switching the definitions of tornado watches and warnings (Appendix B). There is not much of a gender difference in the comprehension of the meaning of a tornado watch and warning (Appendix B), and the differences are not significant, χ^2 (1,N=102)=0.02 and χ^2 (1,N=102)=0.10, p>0.10, respectively. Both groups understood tornado warnings better than tornado watches. However, black respondents were less likely to understand the meaning of a tornado watch or warning (especially a tornado warning) than white respondents (Appendix A: Fig. 23), and both differences were significant (watch: χ^2 (1,N=102)=3.63, p<0.10; warning: χ^2 (1,N=101)=8.33, p<0.005). Alarmingly, 18-27 year olds were most likely to not understand what a tornado watch means (Appendix B). However, the difference in proportions was not quite significant, χ^2 (1,N=102)=2.36, p>0.10. This could mean that education efforts are decreasing or complacency is creating less awareness. Those aged 28-47 and 68-77 were most likely to know what a tornado watch means. Another frightening trend is that the youngest group (18-27) was least likely to know what a tornado warning means. 18-37 year olds were significantly less likely to know what a tornado warning meant than those age 38 or older, χ^2 (1,N=102)=3.68, p<0.10, (Appendix A: Fig. 24). It appears that education about tornadoes in public schools has either been recently reduced, or it is ineffective. This indicates that further public education and awareness campaigns, especially using the media, would be beneficial. These campaigns should particularly target young adults and the black population of Marion County.

22% of respondents had never been in a tornado drill, and almost the exact same number of respondents did not have a family emergency plan at home. However, having been in a tornado drill did not raise the likelihood of a person having a family emergency plan at home. Respondents over the age of 58 were least likely to have been in a tornado drill before (Appendix B), and this finding is significant, χ^2 (1,N=102)=13.403, p<0.005, (Appendix A: Fig. 25). However, young respondents (18-37) were least likely to have a family emergency plan at home (Appendix B), and this finding is significant also, χ^2

(1,N=101)=7.00, p<0.01, (Appendix A: Fig. 26). White respondents were less likely to report having been in a tornado drill at work than black respondents (Appendix B), and the difference is significant, χ^2 (1,N=101)=3.34, p<0.10, (Appendix A: Fig. 27). However, both groups usually had a family emergency plan at home (Appendix B), and the difference was not significant, χ^2 (1,N=101)=1.31, p>0.10. Again, education campaigns could target these age and racial groups to improve safety. There was not a gender difference in tornado drill participation or family emergency planning.

Conclusions

The Marion County, Indiana tornado of September 20, 2002 provided many lessons to improve tornado warning information and damage assessment procedures. The damage from this tornado illustrated that urban areas could have biased Fujita Scale estimates due to the types of structures present (e.g. factories, churches, restaurants, apartments) and the amount of airborne debris that is created. Certain types of damage such as damage to signs, fences, streetlights, and power lines were difficult to classify using the current Fujita Scale. Tree and vehicle damage proved difficult to rate also. This study illustrates that the Fujita Scale damage assessment is as much an art as a science, and it contains inherent subjectivity.

The public surveys conducted in Marion County indicated that many respondents (61%) who received the tornado warning did not take it seriously. The results also implied that disseminating warnings many different ways is crucial to reach the most people. Tornado sirens and local television stations proved to be extremely effective methods for disseminating the tornado warning in this case. This is an important finding because budgetary constraints are making some towns abandon future funding for tornado siren coverage. Also, the StormReady program, in which Marion County participates, appears to help reduce vulnerability to tornadoes via its requirements for entry into the program. Travelling, recreation, power outages, and working all seem to inhibit the warning dissemination process. Creative methods for reaching people in these situations should be devised. Finally, not being aware of a warning substantially decreased the time to respond to the tornado threat, which illustrates the importance of effective warning dissemination methods.

Other findings from the surveys were that 46% of Marion County residents did not seek shelter during this tornado. However, those who did seek shelter most often went to a basement or hallway as recommended during tornadoes. Warning awareness did increase shelter-seeking behavior, which further strengthens the point that warnings must be disseminated effectively, particularly since most respondents did not experience any sensory cues of the approaching tornado. Fortunately, most respondents did report having been in a tornado drill and having a family emergency plan at home.

Some recommendations to improve safety in Marion County during tornadoes is to emphasize the importance of seeking shelter, especially focusing on males and those ages 58 or older. Also, tornado drills need to include white persons and those age 58 and older more often in Marion County. Respondents who were age 18-37 should develop family emergency plans. Education campaigns in Marion County should target black residents and residents ages 18-37. These actions could ameliorate some of the problems that were displayed by the survey results after the September 20, 2002 tornado.

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Appendix A: Figures

Indiana Tornado Event Timeline

September 20, 2002

Updated 9/30/02

WATCHES

- Tornado Watch #693 issued at 11:30 AM EST until 5:00 PM EST
- Tornado Watch #695 issued at 12:35 PM EST until 6:00 PM EST

WARNINGS / EVENTS

TYPE of WARNING	COUNTY	WARNING VALID TIME	EVENT TIME	LEAD TIME	DURATION OF TIME IN COUNTY
	Posey		10:50		
Tornado	Pike	11:24-12:00	11:45	:21	11:35-11:37
Tornado	Knox	11:28-12:15	11:58	:29	11:37-11:58
Tornado	Daviess	11:39-12:45	11:50	:19	11:58-12:02
Tornado	Monroe	12:39-13:15	12:59	:20	12:59-13:05
Tornado	Morgan	12:42-13:45	13:17	:35	13:05-13:35
Tornado	Johnson	13:22-14:00	13:35	:15	13:35-13:42
Tornado	Marion	13:22-14:15	13:59	:39	13:42-14:03
Tornado	Hancock	13:46-14:30	14:05	:19	14:03-14:11
Svr Tstm	Hamilton	14:06-14:30	14:19	:13	14:11-14:13
Tornado	Madison	14:06-15:00	14:35	:23	14:13-14:54
Tornado	Delaware	14:44-15:30	15:05	:21	14:54-15:10
Tornado	Blackford	14:48-15:45	15:10	:22	15:10-15:20
Tornado	Henry	14:54-15:30	14:47	:00	14:47-14:58
Tornado	Rush	15:01-15:30	15:03	:02	15:03-15:04

Event Time and Lead Time elements are based on damage reports received during the event or when the tornado entered the county when damage reports are unavailable. Duration of Time in County is based upon analyzation of radar data.

Figure 1. September 20, 2002 tornado paths and intensities in Indiana (from NWSFO Indianapolis, IN, 2002). Note the location of Marion County.

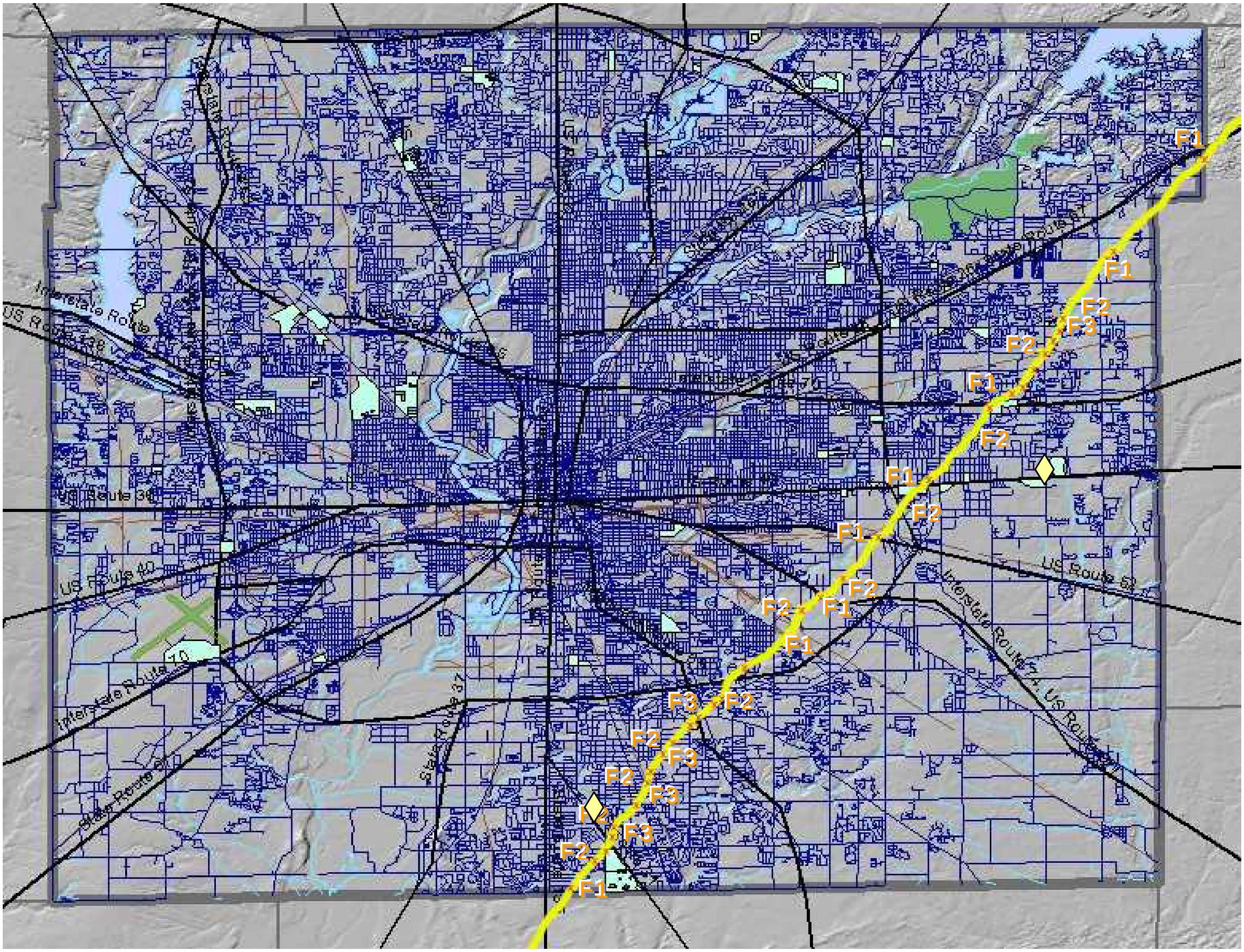

Figure 2. Map of Marion County, Indiana showing elevation (gray), bodies of water (light blue), Interstates and U.S. Highways (black), the local road network (navy blue), parks (dark green), shopping centers (light green), Indianapolis International Airport (green), the tornado path (yellow), Fujita Scale intensity assessment by author (orange), photograph locations (small red x's along tornado track), and sites where public surveys were conducted (light yellow diamonds).

Cat.	Damage Intensity	Est. Wind Speed	Damage Description	Photograph
F0	Light Damage	<73 mph	Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; signboards damaged.	None
F1	Moderate Damage	73-112 mph	Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off road.	
F2	Consider-able Damage	113-157 mph	Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.	
F3	Severe Damage	158-206 mph	Roofs and some walls torn off well-constructed houses, trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.	
F4	Devasta-ting Damage	207-260 mph	Well-constructed houses leveled; structure with weak foundations blown off some distance; cars thrown and large missiles generated.	
F5	Incredible Damage	261-318 mph	Strong frame houses lifted off foundations and swept away; automobile sized missiles fly through the air in excess of 100 meters (109 yards); trees debarked; incredible phenomena will occur.	

Figure 3. The Fujita Scale (Fujita, 1971).

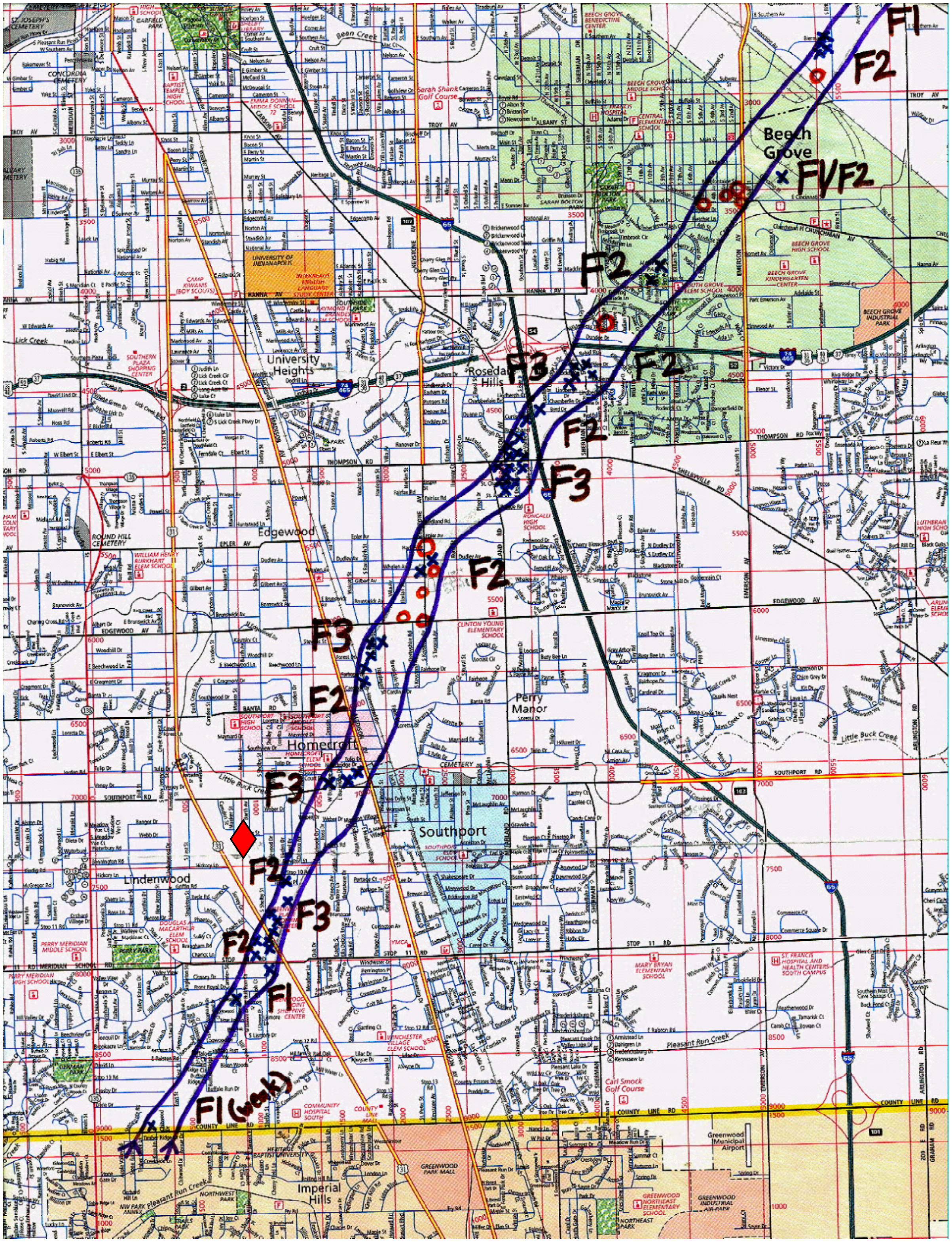

Figure 4. Tornado path (blue lines marking edges) determined by author, Fujita Scale intensity (brown) determined by author, photograph locations (blue x's), visual confirmation sites of damage with notes (orange circles), and survey site (red diamond) in southern Marion County. Base map from McNally (2000).

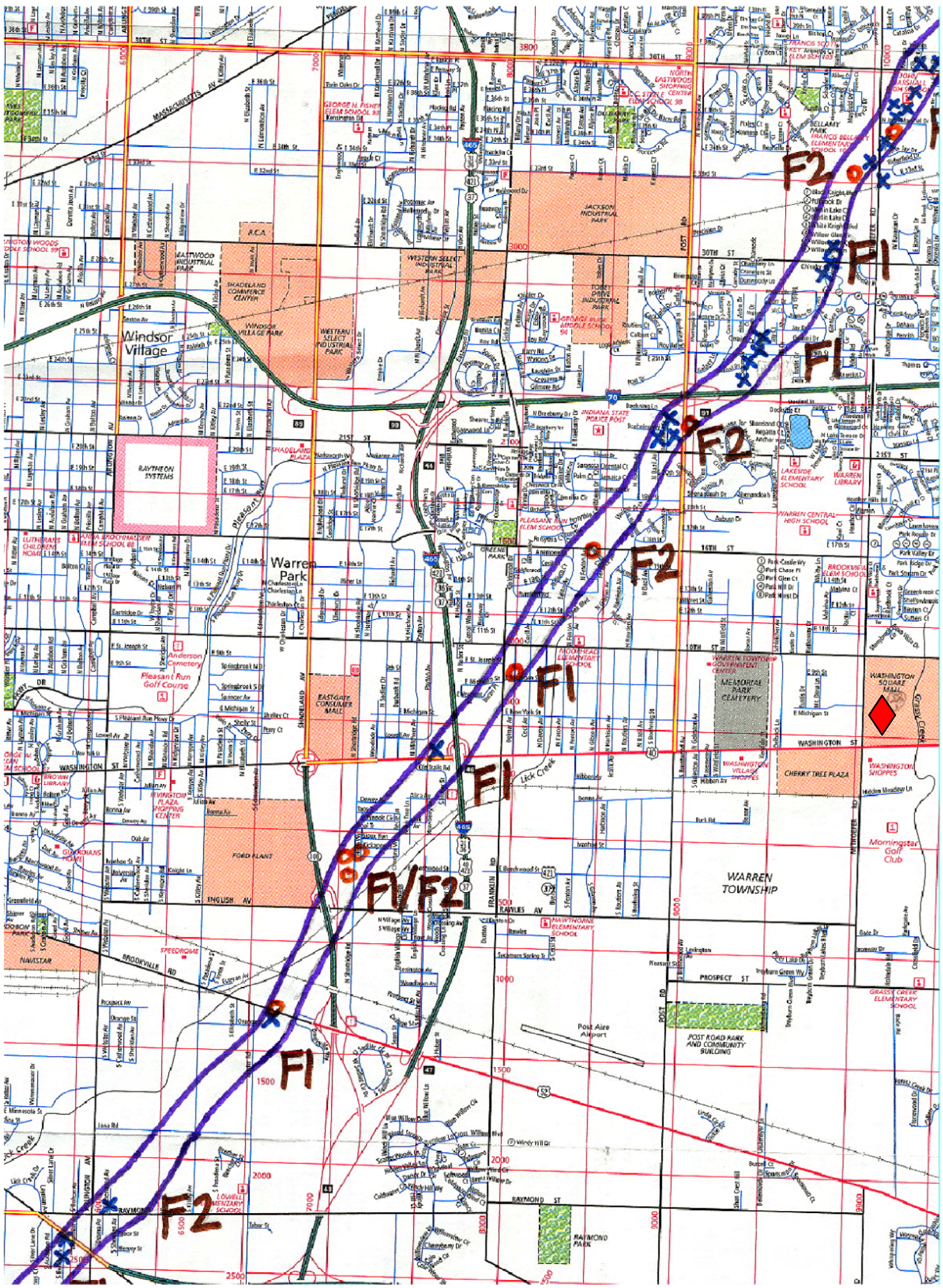

Figure 5. As in Fig. 4, except for eastern Marion County.

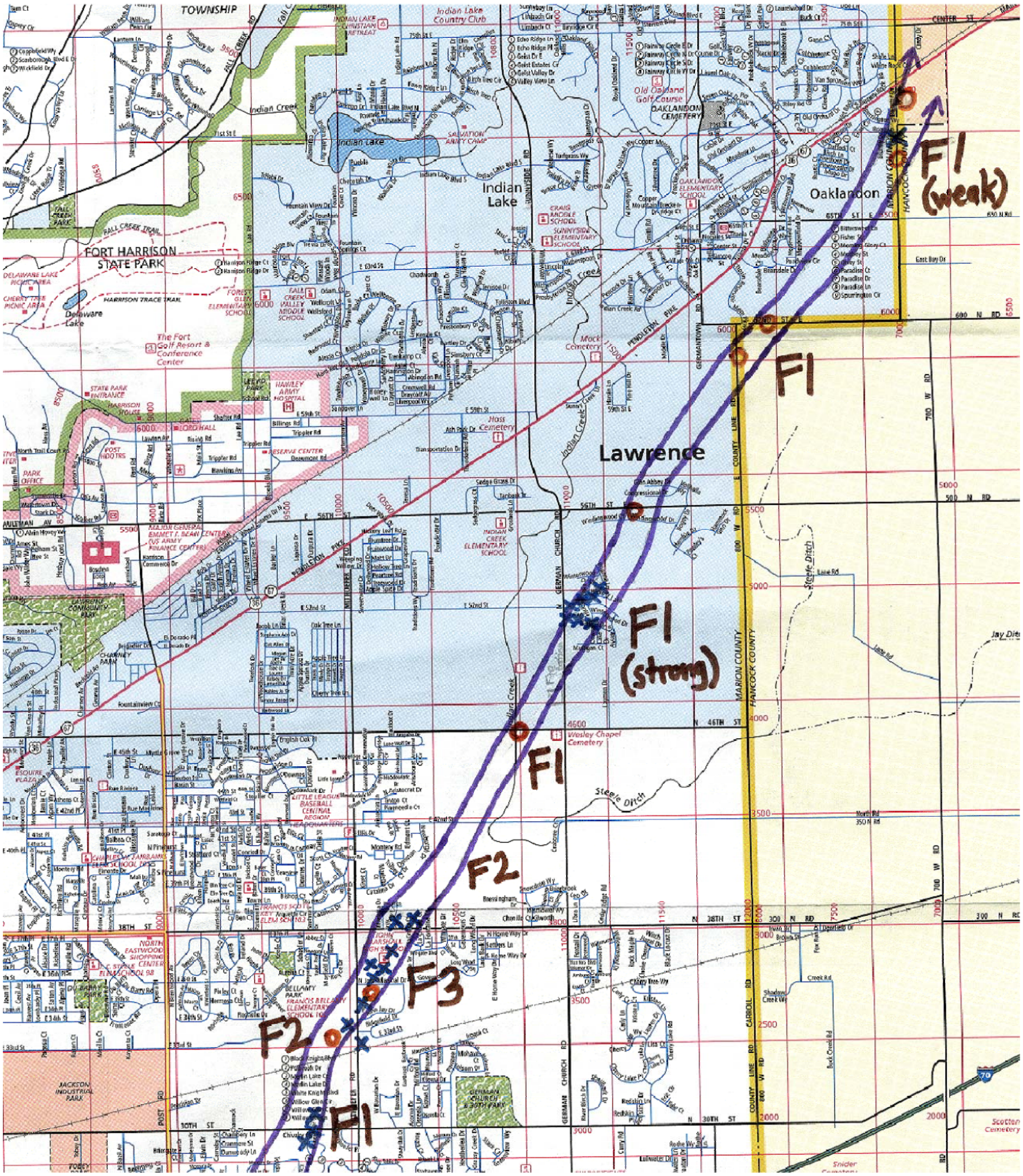

Figure 6. As in Fig. 4, except for northeastern Marion County, and no survey site.

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WFUS53 KIND 201822
INC081-097-201900-

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE INDIANAPOLIS IN
121 PM EST FRI SEP 20 2002

THE NATIONAL WEATHER SERVICE IN INDIANAPOLIS HAS ISSUED A

* TORNADO WARNING FOR...
  NORTHERN JOHNSON COUNTY IN CENTRAL INDIANA
  MARION COUNTY IN CENTRAL INDIANA
  THIS INCLUDES THE CITY OF INDIANAPOLIS

* UNTIL 200 PM EST

* AT 116 PM EST...AMATEUR RADIO WEATHER SPOTTERS REPORTED A
TORNADO   JUST SOUTH OF MARTINSVILLE...OR ABOUT 17 MILES NORTH OF
BLOOMINGTON...MOVING NORTHEAST AT 45 MPH.

* THE MOST DANGEROUS PART OF THE STORM IS EXPECTED TO BE NEAR...
  BARGERSVILLE AT 135 PM EST
  GREENWOOD AT 140 PM EST
  HOMECROFT AT 145 PM EST
  BEECH GROVE AT 150 PM EST
  INDIANAPOLIS AT 150 PM EST

THIS IS A LIFE THREATENING TORNADO EMERGENCY. IF YOU ARE IN THE PATH
OF THIS LARGE AND DESTRUCTIVE TORNADO...TAKE COVER IMMEDIATELY.

THE SAFEST PLACE TO BE DURING A TORNADO IS IN A BASEMENT. IF NO
BASEMENT IS AVAILABLE...GO TO THE LOWEST FLOOR OF THE BUILDING IN AN
INTERIOR HALLWAY OR ROOM. GET UNDER STURDY FURNITURE OR USE BLANKETS
OR PILLOWS TO COVER YOUR BODY.

IF IN MOBILE HOMES OR VEHICLES...EVACUATE THEM AND GET INSIDE A
SUBSTANTIAL SHELTER. IF NO SHELTER IS AVAILABLE...LIE FLAT IN THE
NEAREST DITCH OR OTHER LOW SPOT.

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NNNN
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Figure 7. Original tornado warning for Marion County (graciously provided by Mike Shartran from the NWSFO, Indianapolis, IN). Note time, places mentioned, and call-to-action statements.

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ZCZC INDTORIND
WFUS53 KIND 201858
INC097-201915-

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE INDIANAPOLIS IN
158 PM EST FRI SEP 20 2002

THE NATIONAL WEATHER SERVICE IN INDIANAPOLIS HAS ISSUED A

* TORNADO WARNING FOR...
  EASTERN MARION COUNTY IN CENTRAL INDIANA
  THIS INCLUDES THE CITY OF INDIANAPOLIS

* UNTIL 215 PM EST

* AT 152 PM EST...NATIONAL WEATHER SERVICE DOPPLER RADAR INDICATED A
  SEVERE THUNDERSTORM CAPABLE OF PRODUCING A TORNADO OVER WARREN
  PARK...OR ABOUT 5 MILES EAST OF INDIANAPOLIS...MOVING NORTHEAST AT
  50 MPH.

* THE MOST DANGEROUS PART OF THE STORM IS EXPECTED TO BE NEAR...
  RURAL NORTHEASTERN MARION COUNTY AT 210 PM EST

THE SAFEST PLACE TO BE DURING A TORNADO IS IN A BASEMENT. IF NO
BASEMENT IS AVAILABLE...GO TO THE LOWEST FLOOR OF THE BUILDING IN AN
INTERIOR HALLWAY OR ROOM. GET UNDER STURDY FURNITURE OR USE BLANKETS
OR PILLOWS TO COVER YOUR BODY.

IF IN MOBILE HOMES OR VEHICLES...EVACUATE THEM AND GET INSIDE A
SUBSTANTIAL SHELTER. IF NO SHELTER IS AVAILABLE...LIE FLAT IN THE
NEAREST DITCH OR OTHER LOW SPOT.



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NNNN
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Figure 8. As in Fig. 7, except for second warning.

Figure 9. Characteristic F1 (top row), F2 (middle row), and F3 (bottom row) damage to houses in Marion County (right two columns) as compared to Fujita's (1971) index pictures (left column). (The middle column is strong F1, F2, and F3 damage, and the right column is weak F1, F2, and F3 damage).

Figure 10. As in Fig. 28, except for apartments. (In this case, right column is weak F1, F2, and F3, and middle column is strong F1, F2, and F3 damage).

Figure 11. As in Fig. 28, except for businesses. (In this case, the middle column is weak F1, F2 and strong F3 damage, and the right column is strong F1, F2, and weak F3 damage).

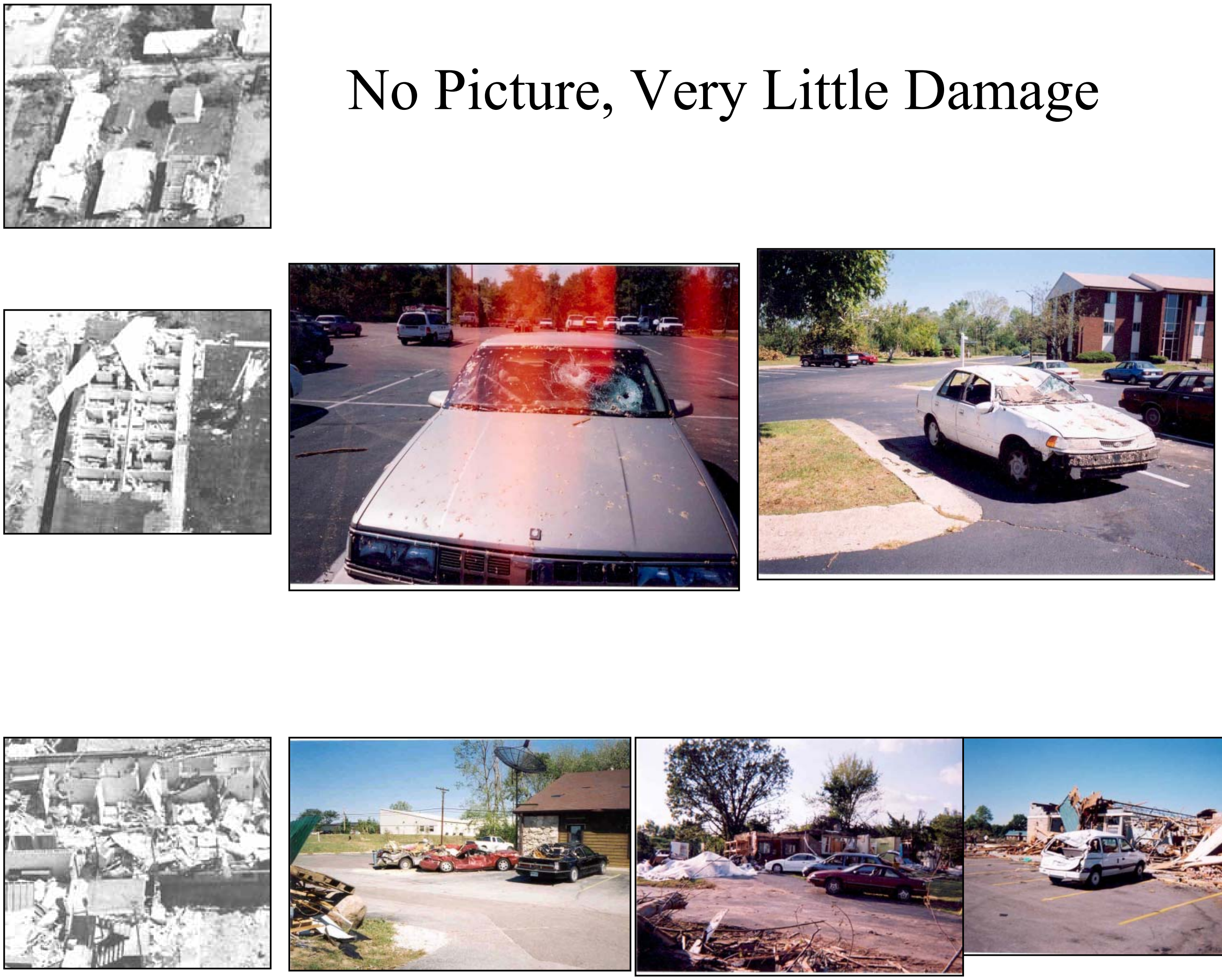

Figure 12. As in Fig. 28, except for vehicles. (No differentiation between weak and strong).

Figure 13. As in Fig. 28, except for trees. (No weak vs. strong columns in this case.)

Figure 14. Sign damage and airborne debris that are difficult to classify

Figure 15. Damage to power lines (top), streetlights (middle), and walls and fences (bottom) that are difficult to classify.

Appendix B: Tables

	Hit	Very Close	Close	Not Close	Far Away
Funnel Cloud	3 (30%)	7 (14%)	1 (3%)	0 (0%)	0 (0%)
Loud Roar	3 (30%)	16 (32%)	5 (15%)	2 (50%)	0 (0%)
Hail	1 (10%)	0 (0%)	3 (9%)	0 (0%)	0 (0%)
Odd-Colored Cloud	2 (20%)	17 (34%)	9 (27%)	2 (50%)	2 (40%)
None of the Above	3 (30%)	23 (46%)	18 (55%)	1 (25%)	3 (60%)
Other	3 (30%)	6 (12%)	7 (21%)	0 (0%)	0 (0%)

Table 1. Visual and audible cues in relation to proximity to the tornado's path (25% or greater responses highlighted in 25% increments).

	Hit	Very Close	Close	Not Close	Far Away
Aware of Warning	6 (60%)	44 (88%)	28 (85%)	3 (75%)	2 (40%)
Not Aware of It	4 (40%)	6 (12%)	5 (15%)	1 (25%)	3 (60%)

Table 2. Awareness of the tornado warning based on proximity to the tornado's path (25% or greater response highlighted in 25% increments).

	Hit	Very Close	Close	Not Close	Far Away
Felt Danger	2 (33%)	16 (36%)	8 (29%)	0 (0%)	0 (0%)
Did Not	3 (50%)	28 (64%)	15 (54%)	3 (100%)	2 (100%)
Not Sure	1 (17%)	0 (0%)	5 (18%)	0 (0%)	0 (0%)

Table 3. Feeling of danger by those aware of warning in relation to proximity to tornado's path (25% or greater response highlighted in 25% increments).

	Hit	Very Close	Close	Not Close	Far Away
Called Someone	0 (0%)	1 (2%)	2 (5%)	0 (0%)	2 (100%)
Looked Outside	1 (17%)	8 (18%)	7 (18%)	0 (0%)	0 (0%)
Sought Shelter	4 (67%)	20 (45%)	8 (21%)	1 (33%)	0 (0%)
Drove in Car	0 (0%)	1 (2%)	2 (5%)	0 (0%)	0 (0%)
More Information	3 (50%)	5 (11%)	7 (18%)	1 (33%)	0 (0%)
Business as Usual	1 (17%)	11 (25%)	9 (23%)	0 (0%)	0 (0%)
Took Pictures	0 (0%)	1 (2%)	0 (0%)	0 (0%)	0 (0%)
Other	0 (0%)	5 (11%)	1 (3%)	0 (0%)	0 (0%)

Table 4. Response to tornado warning based on proximity to tornado's path (25% or greater response highlighted in 25% increments).

	Hit	Very Close	Close	Not Close	Far Away
No Shelter	5 (50%)	22 (44%)	19 (58%)	2 (50%)	2 (40%)
Vehicle	0 (0%)	2 (4%)	0 (0%)	1 (25%)	2 (40%)
Basement	3 (30%)	8 (16%)	8 (24%)	0 (0%)	0 (0%)
Big Building	0 (0%)	7 (14%)	1 (3%)	0 (0%)	0 (0%)
Hallway	1 (10%)	9 (18%)	0 (0%)	1 (25%)	0 (0%)
Bedroom	0 (0%)	0 (0%)	2 (6%)	0 (0%)	0 (0%)
Another House	0 (0%)	0 (0%)	1 (3%)	0 (0%)	0 (0%)
Other	2 (20%)	3 (6%)	1 (3%)	0 (0%)	0 (0%)

Table 5. Shelter location in relation to proximity to tornado's path (25% or greater response highlighted in 25% increments).

	Aware	Not Aware
White	61 (79%)	16 (21%)
Black	21 (88%)	3 (13%)

Table 6. Warning awareness based on race (25% or greater response highlighted in 25% increments).

	Aware	Not Aware
Male	28 (76%)	9 (24%)
Female	55 (85%)	10 (15%)

Table 7. Warning awareness based on gender (25% or greater response highlighted in 25% increments).

	Aware	Not Aware
Age 18-27	25 (78%)	7 (22%)
Age 28-37	15 (88%)	2 (12%)
Age 38-47	16 (84%)	3 (16%)
Age 48-57	10 (83%)	2 (17%)
Age 58-67	6 (67%)	3 (33%)
Age 68-77	10 (91%)	1 (9%)
Over Age 77	1 (50%)	1 (50%)

Table 8. Warning awareness based on age (25% or greater response highlighted in 25% increments).

	Felt Danger	No Danger	Not Sure
Local TV	13 (34%)	22 (58%)	3 (8%)
Weather Channel	1 (50%)	1 (50%)	0 (0%)
NWS Weather Radio	3 (60%)	1 (20%)	1 (20%)
Friend	4 (57%)	3 (43%)	0 (0%)
Siren	20 (34%)	35 (60%)	3 (5%)
Emergency Official	1 (50%)	1 (50%)	0 (0%)
Other	9 (36%)	15 (60%)	1 (4%)

Table 9. Perception of threat based on source of warning information (25% or greater response highlighted in 25% increments).

	Felt Danger	No Danger	Not Sure
Called Someone	2 (50%)	2 (50%)	0 (0%)
Looked Outside	5 (29%)	12 (71%)	0 (0%)
Sought Shelter	14 (41%)	18 (53%)	2 (6%)
Drove in Car	3 (75%)	1 (25%)	0 (0%)
More Information	3 (19%)	11 (69%)	2 (13%)
Business as Usual	1 (5%)	19 (86%)	2 (9%)
Took Pictures	1 (100%)	0 (0%)	0 (0%)
Other	4 (57%)	3 (43%)	0 (0%)

Table 10. Warning response based on perception of threat of those aware of the warning (25% or greater response highlighted in 25% increments).

	Rehearsed	Not Rehearsed
Vehicle	0 (0%)	3 (100%)
Basement	12 (67%)	6 (33%)
Large Structure	4 (50%)	4 (50%)
Hallway	5 (45%)	6 (55%)
Bedroom	2 (100%)	0 (0%)
Another House	0 (0%)	1 (100%)
Other	3 (50%)	3 (50%)

Table 11. Rehearsed shelter plan based on shelter type (25% or greater response shaded in 25% increments).

	White	Black
Vehicle	3 (4%)	2 (8%)
Basement	16 (22%)	3 (12%)
Large Structure	8 (11%)	0 (0%)
Hallway	7 (9%)	4 (16%)
Bedroom	0 (0%)	2 (8%)
Another House	0 (0%)	1 (4%)
Other	3 (4%)	3 (12%)
No Shelter	39 (53%)	10 (40%)

Table 12. Shelter choice based on race (25% or greater response shaded in 25% increments).

	Sighted	Favorable	None of Above	Don't Know
Sighted	15 (58%)	64 (89%)	0 (0%)	2 (40%)
Favorable	13 (50%)	6 (8%)	0 (0%)	0 (0%)
Few Days	0 (0%)	0 (0%)	0 (0%)	1 (20%)
None of Above	0 (0%)	0 (0%)	1 (100%)	0 (0%)
Don't Know	0 (0%)	0 (0%)	0 (0%)	2 (40%)

Table 13. Respondents' understanding of tornado watches and warnings (25% or greater response shaded in 25% increments; 64 people got both answers correct).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Correct	17 (52%)	14 (82%)	16 (80%)	9 (75%)	6 (67%)	9 (82%)	1 (50%)
Incorrect	16 (48%)	3 (18%)	4 (20%)	3 (25%)	3 (33%)	2 (18%)	1 (50%)

Table 14. Respondents' understanding of a tornado watch by age (25% or greater response shaded in 25% increments).

	Male	Female
Correct	26 (68%)	46 (70%)
Incorrect	12 (32%)	20 (30%)

Table 15. Respondents' understanding of a tornado watch by gender (25% or greater response shaded in 25% increments).

	Male	Female
Correct	30 (81%)	51 (78%)
Incorrect	7 (19%)	14 (22%)

Table 16. Respondents' understanding of a tornado warning by gender (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Drill	31 (97%)	12 (71%)	15 (79%)	11 (92%)	6 (67%)	4 (36%)	1 (50%)
No Drill	1 (3%)	5 (29%)	4 (21%)	1 (8%)	3 (33%)	7 (64%)	1 (50%)

Table 17. Tornado drill participation based on age (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Plan	22 (69%)	12 (71%)	17 (89%)	11 (92%)	6 (75%)	11 (100%)	2 (100%)
No Plan	10 (31%)	5 (29%)	2 (11%)	1 (8%)	2 (25%)	0 (0%)	0 (0%)

Table 18. Family emergency plan based on age (25% or greater response shaded in 25% increments).

	White	Black
Drill	57 (74%)	22 (92%)
No Drill	20 (26%)	2 (8%)

Table 19. Tornado drill participation based on race (25% or greater response shaded in 25% increments).

	White	Black
Plan	59 (77%)	21 (88%)
No Plan	18 (23%)	3 (13%)

Table 20. Family emergency plan based on age (25% or greater response shaded in 25% increments).

	Male	Female
Rescue Personnel	19 (51%)	36 (55%)
Weather Service	19 (51%)	45 (69%)
Media	17 (46%)	34 (52%)
Public	11 (30%)	14 (22%)
Government	6 (16%)	12 (18%)

Table 21. Performance satisfaction by gender (25% or greater response shaded in 25% increments).

	White	Black
Rescue Personnel	42 (55%)	12 (50%)
Weather Service	50 (65%)	14 (58%)
Media	36 (47%)	14 (58%)
Public	20 (26%)	5 (21%)
Government	15 (19%)	3 (13%)

Table 22. Performance satisfaction by race (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Rescue Personnel	16 (50%)	13 (76%)	7 (37%)	9 (75%)	4 (44%)	5 (45%)	1 (50%)
Weather Service	18 (56%)	9 (53%)	14 (74%)	9 (75%)	5 (56%)	7 (64%)	2 (100%)
Media	12 (38%)	13 (76%)	7 (37%)	5 (42%)	5 (56%)	8 (73%)	1 (50%)
Public	7 (22%)	7 (41%)	2 (11%)	3 (25%)	1 (11%)	4 (36%)	1 (50%)
Government	2 (6%)	7 (41%)	2 (11%)	2 (17%)	0 (0%)	4 (36%)	1 (50%)

Table 23. Performance satisfaction by age (25% or greater response shaded in 25% increments).

	White	Black
Rescue Personnel	1 (1%)	0 (0%)
Weather Service	2 (3%)	0 (0%)
Media	7 (9%)	0 (0%)
Public	14 (18%)	2 (8%)
Government	5 (6%)	6 (25%)

Table 24. Performance dissatisfaction by race (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Rescue Personnel	1 (3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Weather Service	0 (0%)	1 (6%)	0 (0%)	1 (8%)	0 (0%)	0 (0%)	0 (0%)
Media	2 (6%)	1 (6%)	1 (5%)	2 (17%)	1 (11%)	0 (0%)	0 (0%)
Public	7 (22%)	2 (12%)	2 (11%)	2 (17%)	2 (22%)	1 (9%)	0 (0%)
Government	4 (13%)	3 (18%)	3 (16%)	1 (8%)	0 (0%)	0 (0%)	0 (0%)

Table 25. Performance dissatisfaction by age (25% or greater response shaded in 25% increments).

	Male	Female
White	27 (73%)	50 (77%)
Black	10 (27%)	14 (22%)

Table 26. Racial composition by gender of respondents (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
Male	14 (38%)	6 (16%)	5 (14%)	4 (11%)	4 (11%)	3 (8%)	1 (3%)
Female	18 (28%)	12 (18%)	14 (22%)	8 (12%)	5 (8%)	8 (12%)	1 (2%)

Table 27. Age of respondents by gender (25% or greater response shaded in 25% increments).

	18-27	28-37	38-47	48-57	58-67	68-77	Over 77
White	20 (26%)	11 (14%)	13 (17%)	11 (14%)	9 (12%)	11 (14%)	2 (3%)
Black	11 (46%)	6 (25%)	6 (25%)	1 (4%)	0 (0%)	0 (0%)	0 (0%)

Table 28. Age of respondents by race (25% or greater response shaded in 25% increments).

Appendix C: Narrative Description of Tornado Track

The following is a narrative description of the tornado's track and resulting damage as it moved northeastward through Marion County, Indiana:

Segment 1 (Figure 4)

The tornado entered Marion County from the southwest (Fig. 1) causing weak F1 (but mainly F0) damage around the Faith & Charity Assembly church on County Line Rd. as it exited Johnson County. The tornado continued producing F1 damage to trees and homes until it crossed Stop 11 Rd. where F2 damage began on the grounds of the Baxter YMCA. The tornado then produced F3 damage as it struck the main building on the Baxter YMCA grounds ripping off the roof and a wall of a classroom that had been evacuated just minutes before. A local news channel showed that the clock had stopped at 1:40 PM as the tornado hit this classroom. The tornado then crossed U.S. Highway 31 at the intersection with South Shelby St., damaging a Wendy's, Boston Market, and another local restaurant. The tornado continued moving northeast, striking Greenwood Place Shopping Center. Here the tornado heavily damaged a freestanding building containing a Shoe Carnival store and another local business, and it destroyed a vacant Pier 1 Imports store. The tornado tossed cars around in the parking lot (some occupied), and then struck the main portion of the shopping center damaging many businesses, particularly the Galyan's Sporting Goods store. The damage in this area was consistent with F3 types of damage, also.

As the storm continued to move northeast, F2 damage was sustained by a long building containing apartments and also by some houses. The tornado produced F3 damage to an apartment complex as it crossed Southport Rd. just west of the Madison Ave. intersection. A shopping center and some houses along Madison Avenue just north of the Southport Rd. intersection also sustained F3 damage. The tornado then did some F2 damage to several houses before crossing a railroad track and destroying a high-tension power line tower.

As the tornado struck Hardegan Street in southern Marion County, it produced F3 damage to a brick house, taking off the roof and some walls of the house and heavily damaging two vehicles parked there. F3 damage was also sustained by some homes along Edgewood Avenue, and this area was cluttered with debris. The tornado then continued northeastward, producing F2 damage along Keystone Avenue and Epler Avenue. The tornado damaged the roof and windows of Southport Middle School on Keystone Avenue, which was full of students at the time. Fortunately, nobody was harmed at the school, but the school did receive damage to the roof and windows.

Next, the tornado produced F3 damage to homes along St. Charles Place. The tornado then struck a shopping center, a bank, a vacant business, a restaurant, and a strip mall along Shelbyville Road, producing F3 damage and demolishing several vehicles. The tornado also damaged some law offices on Carson Avenue, and it heavily damaged the Parc Bordeaux Apartments complex. The storm then flattened a forest south of Curtis Drive as it crossed I-65 just south of its juncture with the I-74/I-465 loop. Debris was strewn across the interstate including trees, power lines, and building materials.

After crossing I-65, the tornado produced F2 damage to homes at the end of Byrd Drive and along Redfern Drive. It also heavily damaged a Village Pantry convenience store on Redfern Drive. The tornado then produced F3 damage at the Sawmill Apartments complex where many units were destroyed before it damaged some homes and trees on Meridee Drive. Then the tornado crossed the I-74/I-465 loop, and it heavily damaged several units in the Timbers Apartments complex.

Next, the tornado entered the township of Beech Grove producing F2 damage at Hartman Park. Many houses were damaged between Emerson Avenue and South 5th Avenue along Churchman Avenue. Trains and the depot at an Amtrak facility sustained strong F1 to weak F2 damage before the tornado exited Beech Grove Township. As the tornado continued northeastward inside the Indianapolis loop, trees, some houses, and outbuildings along Bierman Road sustained F2 damage.

Segment 2

The damage was in the F1 range along South Bolton Avenue to houses and street signs, as the storm crossed Southeastern Avenue. The tornado continued through southeastern Indianapolis producing F2 damage to homes along Arlington Avenue, Raymond Street, and South Catherwood Avenue. The damage again decreased to F1 level along Brookville Road where only signs and power lines were damaged. The tornado produced strong F1 to weak F2 range damage along North Shortridge Road just north of English Avenue, where it destroyed several mobile homes and toppled a radio transmission tower. The tornado went on to produce F1 damage along Washington Street to a car dealership before crossing the I-465 loop again.

After crossing the I-465 loop, the tornado continued producing F1 damage to homes and businesses. Homes were damaged along Belmar Avenue from 10th Street to East Michigan Street. At the intersection of 16th Street and North Fenton Avenue, the second floor of a house was destroyed, indicative of F2 damage. An office building, a Dollar Inn, and International Buffet along Boehning Street just north of 21st Street also sustained F2 damage. The tornado then crossed I-70 just east of the Post Road interchange.

After crossing I-70, the tornado produced F1 damage to homes along Saturn Drive, Andy Drive, and East 25th Street. The Indiana Assembly of God Korean Church and a factory on 30th Street just west of Mithoefer Road also sustained F1 damage. Other factories and businesses sustained F2 damage, including Lau Industries and the Finish Line factory, along Mithoefer Road between 30th Street and Park Davis Drive. One factory was heavily damaged, with parts of the roof and walls missing.

Segment 3

After crossing Mithoefer Road, the tornado produced F3 damage to the Amber Woods Apartment complex, which is a project-based Section 8 development for low-income housing. Eight buildings were destroyed in this complex, and 7 others were deemed uninhabitable due to a serious gas leak. 65 families were displaced for 8 months and 80 more families were displaced for 3 weeks (U.S. HUD, 2002). The local government received criticism for not allowing residents to retrieve their belongings here in a timely manner, and for not providing adequate shelter for those displaced by the tornado. Some residents were placed in hotels only to be kicked out days later to make room for racing fans that were coming into town.

Next, the athletic fields and parking lot of John Marshall High School were flattened and covered with debris. The school itself sustained some roof damage, but it narrowly averted a direct hit by the F3 tornado. The tornado then crossed North 38th Street damaging more apartments and destroying the Rock of Faith Church ($2,000,000 in damage) with its last F3 damage in Marion County.

The tornado crossed North 46th Street at the bridge over Indian Creek where trees and corn stalks were damaged and twisted. There was minor roof damage to a fire department building on North German Church Road. The tornado produced strong F1 damage in a golf community along Hickory Lake Drive and Sanabria Drive on the east side of North German Church Road. There was damage along 56th Street East at Windingwood Drive. F1 damage was noted at East County Line Road and 62nd Street East, south and east of their intersection. Finally, weak F1 damage to a golf driving range was noted at the intersection of Pendleton Pike and County Line Road as the tornado exited Marion County to the northeast.

Appendix D: Survey Form and Answers

University of South Carolina
Department of Geography
Hazards Research Lab

A tornado has recently struck this urbanized area. In order to hopefully reduce casualties and damages from future tornadoes, we would like to ask you a few brief questions. Please circle the number (or numbers) of your choice. You may have more than one answer to some questions. If you have any questions, feel free to ask me.

1. Approximately, how close were you to the tornado?

A. It struck my location (0 miles away)		10	10%
B. Very close	(less than 2 miles away, but not hit)	50	49%
C. Close	(2 – 10 miles away)	33	32%
D. Not very close	(10 – 20 miles away)	4	4%
E. Far away	(more than 20 miles away)	5	5%

2. Which of the following, if any, did you see associated with the tornado? (Please circle all those that apply)

A. Funnel-shaped cloud	11	11%
B. Loud, roaring sound	26	25%
C. Hail	4	4%
D. Odd-colored or greenish cloud	32	31%
E. None of the above	48	47%
F. Other: (Please specify) ________________________________	16	16%

(Mud Flying 1; Debris 8; Felt Like Brains Being Sucked Through Ears 1; Heavy Rain 7; Wind 6; Trees Bending 1; Crashing Sound 1)

3. Were you aware that the national Weather Service had issued a tornado warning for your area?

A. Yes	83	81%
B. No	19	19%
C. Don't Know	0	0%

If YES, then continue.
If NO or DON'T KNOW, then go to QUESTION #4.

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3a. How did you first hear about the tornado warning?

A.	Local TV news break-in or scroll at screen bottom. If so, please circle which station or stations (NBC, CBS, ABC, FOX, other____) (CBS 3; NBC 2; 1060 AM Radio 1)	38	46%
B.	The Weather Channel	2	2%
C.	National Weather Service weather radio	5	6%
D.	Friend or relative	7	8%
E.	Siren	58	70%
F.	Emergency official (e.g. police officer)	2	2%
G.	Other: (Please specify) ____________________________	25	30%

(Radio 13; Public in Library 1; Announcement on Intercom 6; Phone Call to Tour Bus 1; Clerk at Store 1; Internet (Weatherbug) 1; Teacher at College 1)

3b. Did you feel like you were *really* in danger after you heard the tornado warning?

A.	Yes	26	31%
B.	No	51	61%
C.	Not Sure/ Didn't Know	6	7%

3c. What was the length of time between when you became aware of the warning and when the tornado hit?

A.	Less than 5 minutes	18	22%
B.	6 – 10 minutes	10	12%
C.	11 – 15 minutes	12	14%
D.	16-20 minutes	8	10%
E.	More than 20 minutes	14	17%

(After it Hit 2; Adequate 2; Don't Know 17)

3d. How did you respond to the tornado warning?

A.	Called someone on the telephone	5	6%
B.	Looked outside	17	20%
C.	Sought shelter immediately	34	41%
D.	Got in my car and drove around	4	5%
E.	Sought more information (e.g. on internet, radio, or TV)	16	19%
F.	Continued with business as usual	22	27%
G.	Got my camera or video camera to capture the tornado on film	1	1%
H.	Other: (Please specify) _______________________________	7	8%

(Stayed on Bus 1; Covered Head 1; Pulled Off the Road 2; Moved Birds 1; Closed Windows 1; Put Cats Out 1)

SKIP TO QUESTION #5.

****

4a. Why do you think you were not aware of the tornado warning?

A. Sleeping	1	5%
B. At work or school	3	16%
C. Shopping	1	5%
D. In my car	5	26%
E. Eating	0	0%
F. At home (No TV or radio turned on)	1	5%
G. Siren did not sound	2	11%
H. Watching TV or radio (No weather warning broadcasted)	2	11%
I. Other: (Please specify) ______________________________	6	32%

(Complacency 1; Camping 1; In Movie Theater 1; On Airplane 1; Power Outage 2) (No Answer 1)

4b. Once you became aware of the tornado threat, how long did you have to react before the tornado hit?

A. Less than 1 minute	5	26%
B. 1 – 5 minutes	1	5%
C. 6 – 10 minutes	2	11%
D. 11 – 15 minutes	0	0%
E. 16 –20 minutes	0	0%
F. More than 20 minutes	0	0%

(After it Hit 1; Never Aware 7; No Answer 3)

4c. At any time, did you respond to the tornado threat?

A. Yes	5	26%
B. No	13	68%
C. Not Sure/ Don't Know	0	0%

(No Answer 1)

****

5. If you sought shelter during the tornado, where did you go?

A. Did not seek shelter	50	49%
B. In a ditch or culvert	0	0%
C. In a car or truck	5	5%
D. In an underground storm shelter	0	0%
E. In a bathtub	0	0%
F. In a basement	19	19%
G. Underneath a bridge	0	0%
H. In a large building (e.g. Wal-Mart, mall, church)	8	8%
I. In an interior hallway	11	11%
J. In the bedroom	2	2%
K. In someone else's house	1	1%
L. Other: (Please specify) ______________________________	6	6%

(In bathroom 3; Under computer desk 1; Doctor's office 1; In cooler at work 1)
(No Answer 2)

6. If you sought shelter, had you ever used this shelter before, or had you ever rehearsed this emergency plan?

A. Did not seek shelter	47	46%
B. Yes	27	26%
C. No	25	25%
D. Not sure/ Don't know	1	1%

(No Answer 2)

7. Which of the following describes the meaning of a tornado *watch*?

A. A tornado has been sighted or indicated by Doppler radar	26	25%
B. Conditions are favorable for the development of tornadoes	72	71%
C. There may be a risk of tornadoes in the next few days	0	0%
D. None of the above	1	1%
E. Not Sure/ Don't Know	5	5%

8. Which of the following describes the meaning of a tornado *warning*?

A. A tornado has been sighted or indicated by Doppler radar	81	79%
B. Conditions are favorable for the development of tornadoes	17	17%
C. There may be a risk of tornadoes in the next few days	1	1%
D. None of the above	1	1%
E. Not Sure/ Don't Know	2	2%

9. Have you ever been in a tornado drill at work or school?

A. Yes	80	78%
B. No	22	22%
C. Not Sure/ Don't Know	0	0%

10. Do you have a family emergency plan?

A. Yes	81	79%
B. No	20	20%
C. Not Sure/Don't Know	1	1%

11. Which of the following do you think performed *best* during this tornado?

A. Rescue personnel (e.g. police, EMS, firefighters)	55	54%
B. The National Weather Service (e.g. tornado warning not satisfactory)	64	63%
C. The media (e.g. local weatherman, TV scroll, live coverage, reporters)	51	50%
D. The public (e.g. panic, chaos, bad decisions)	25	25%
E. The government (e.g. providing assistance, shelter, reassurance)	18	18%

(Don't Know 2; No Answer 2)

12. Which of the following do you think performed *worst* during this tornado?

A. Rescue personnel (e.g. police, EMS, firefighters)	1	1%
B. The National Weather Service (e.g. tornado warning not satisfactory)	2	2%
C. The media (e.g. local weatherman, TV scroll, live coverage, reporters)	7	7%
D. The public (e.g. panic, chaos, bad decisions)	16	16%
E. The government (e.g. providing assistance, shelter, reassurance)	11	11%

(Don't Know 4; School Officials 1; No Answer 3; None of the Above 61)

13. Gender (optional)

A. Male	37	36%
B. Female	65	64%
C. No answer	0	0%

14. Age (optional)

A. 18 – 27 years old	32	31%
B. 28 – 37 years old	17	17%
C. 38 – 47 years old	19	19%
D. 48 – 57 years old	12	12%
E. 58 – 67 years old	9	9%
F. 68 – 77 years old	11	11%
G. Over 77 years old	2	2%
H. No answer	0	0%

15. Race (optional)

A. White, not Hispanic	77	75%
B. Black, not Hispanic	24	24%
C. Hispanic	0	0%
D. Asian / Pacific Islander	0	0%
E. Alaskan Native or Native American, not Hispanic	0	0%
F. Other: (Please specify) ____________________	0	0%
G. No answer	1	1%

16. May I have your telephone number for possible future follow-up questions on tornado safety (optional)? ______________________ Yes: 8 8%

Thank you for your participation. Hopefully the information that you have provided will help us reduce losses from future tornadoes. If you would like a copy of the results, please provide your name and address below.

Name: Yes: (28 27%)

Address: Yes: (30 29%)

Date:
Location:
Interviewer: