Tornado Hazard Risk Analysis:
A Report for Rutherford County Emergency Management Agency

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August 12, 2003

PART 3

III. Cost Analysis

In this section, we will discuss the question of how much structural damage a tornado would do if it occurred in a specific location.

Structural Damage

Suppose a particular structure is in the path of a tornado. The amount of damage done to the structure depends on the strength of the tornado as well as the method of construction used. For example, a mobile home will be almost destroyed by an F2 tornado, while a brick home will suffer less dramatic damage. If the tornado were rated an F4, even the brick home would not escape destruction. Since it would be impossible because of time and cost constraints to completely classify every structure by its construction type, five categories were chosen. These categories are those used in the Dallas-Fort Worth Tornado report. [13] They are Mobile Home, Single-Family Home, Apartment Unit, Commercial, and Industrial. Within each construction category and for each intensity rating, proportions were chosen that represent the average reduction in the value of the structure if it were struck by a tornado. Dr. James Henry, middle Tennessee tornado expert, suggested small modifications in the Dallas-fort worth structural damage proportions, resulting in Table 6.

Table 6. Proportion of Reduction to Structure Value by Building Type and F-Scale

	F1	F2	F3	F4	F5
Mobile Home	50%	100%	100%	100%	100%
Single Family Home	10%	80%	90%	100%	100%
Apartment Unit	10%	80%	90%	100%	100%
Commercial	10%	45%	80%	95%	100%
Industrial	10%	80%	95%	100%	100%

Examining Table 6's percentages reveal differences in damage levels for the different intensities and for different structure types. The numbers in columns for F1 and F2 reflect the facts that mobile homes are especially vulnerable to tornadoes and that in an F2 tornado, roofs will generally be torn off structures. Comparing the Commercial structure row with the other structure types reflects that commercial buildings are more likely than other types to be constructed using materials, such as reinforced concrete, which withstand high winds well. As an example of how Table 6 is used, consider the value in the F3 column and the single-family home row. This value indicates that if a $100,000 home were struck by an F3 tornado, the appraised value would be reduced by 90%, resulting in a new value of $10,000.

These proportions in Table 6 are average values that do not take into account factors such as whether the home was made of brick or of siding and how well the roof was attached to the home. Note also that this is the proportion reduction in the value of the structure, since we may assume that the value of the land under the structure is not affected by a tornado.

It is also important to remember that a tornado is classified by the highest amount of damage done to any structure in its path, so that an F4 tornado will leave behind structures damaged at the levels F0 through F4. Kruse et al. found the following probabilities of damage levels for an F4 tornado. [7]

Table 7. Probability of Damage Levels for an F4 Tornado

F-level	Probability of Damage at F-level in Tornado Classified as F4
0	0.35
1	0.09
2	0.14
3	0.26
4	0.16
5	0.00

These values came from closely studying tornadoes one tornado outbreak. Perhaps future studies will calculate these values for larger numbers of tornados and give us more confidence in these numbers. However, since no other estimates of these probabilities were found in the literature, they were the ones used. Because we lack similar tables for F1, F2, and F3 tornados, we decided to use proportional probabilities in those cases. For example, we will assume that if the tornado is classified as an F3, the number in the fourth row will be set to zero, and the other probabilities will be scaled accordingly. These probabilities are combined with the proportion of reduction to structural value in Table 6. For example, if the sample tornado path is an F4, and the structure is a single-family home, the predicted damage will be

$$0.35*0\%+0.09*10\%+0.14*80\%+0.26*90\%+0.16*100\%+0*100\%=51.5\%.$$

Performing similar calculations for all of the different construction types and F-levels, we obtain Table 8.

Table 8. Modified Proportion of Reduction to Structure Value by Building Type and F-Scale.

	F1	F2	F3	F4
Mobile Home	10%	32%	53%	61%
Single Family Home	2%	21%	42%	52%
Apartment Unit	2%	21%	42%	52%
Commercial	2%	12%	33%	43%
Industrial	2%	21%	44%	53%

Since we were unable to classify our Rutherford County Structure by building type, we found the average percent reduction to value for each F-scale. Table 9 shows the percents used to calculate loss by f-scale.

Table 9. Average Proportion of Reduction to Structure Value by F-scale

	F1	F2	F3	F4
Average Proportion Reduction to Structure Value	3.6%	21.4%	42.8%	52.2%

For each simulated path, Rutherford County OIT expert Ms. Barbara Seivers used the county tax assessor's database and identified the parcels and the corresponding improved value of each parcel in the path. Improved values do not include land values as we are assuming that land values will not be substantially reduced by tornado damage. Considering the time and computing limitations we were very pleased to be able to match 90% of the parcels with their assessed value. The total value of all parcels in a given path was then multiplied by the percentage of value reduction for the corresponding F-scale as shown in Table 9 to determine the total expected damage for each path. These estimated damages for each F-scale and each location are shown in Table 10.

Table 10. Damage Estimates for Simulated Paths

Location	*Tornado Intensity*	*Total Number of Parcels in the Path*	*Total Value of the Parcels in the Path*	*Expected Damages*
Location 1	**F1**	275	$36,665,600	$1,466,624
Murfreesboro	**F2**	558	$94,768,000	$19,901,280
	F3	1316	$165,535,200	$71,180,136
	F4	1327	$166,909,700	$86,793,044
Location 2	**F1**	891	$85,889,800	$3,435,592
Murfreesboro	**F2**	549	$110,001,700	$23,100,357
	F3	659	$74,680,600	$32,112,658
	F4	1751	$244,174,800	$126,970,896
Location 3	**F1**	183	$38,643,500	$1,545,740
Smyrna & La Vernge	**F2**	150	$25,609,500	$5,377,995
	F3	147	$28,732,400	$12,354,932
	F4	412	$58,087,900	$30,205,708

It is clear that tornado damage cost estimates are very much path dependent. For example, an F1 tornado with a 1 mile by 200 yard path hit Smyrna on June 2, 1998 and caused about $1.8 million dollars (year 2002) worth of damage, while an F2 with a 5 mile by 400 yard path hit Smyrna on January 24, 1997 and caused a little over half a million dollars (year 2002), and an F3 caused less than $200,000 (year 2002) damage in Rutherford County on April 3, 1974. The damage estimates in this project are assuming paths located in populated areas, with substantial government, business and residential structures in the simulated path areas. The paths were selected in these populated areas to help provide worst-case scenarios. The paths were not selected because they were more or less likely than any other paths in Rutherford County.

Future Research

The typical path width was not entered as a parameter in the modeling process, and the resulting simulated path widths are approximately four times wider on average than the maximum actual tornadoes of the specified F-scale that had previously struck Rutherford County. For a crude estimate of the reduction in the loss, would be approximately one forth of the values produced in the Table 10. This component of the modeling process is one that should be examined further.

To improve the modeling process, a next step would be to develop a three-dimensional model of the simulated tornado paths. Three-dimensional modeling would take into account the terrain of the property. Such modeling would be more labor and const intensive than the two-dimensional modeling used in this project. Another labor intensive next step in the modeling would be to simulate hundreds of paths throughout the county and to match those paths with the county tax assessor database to determine the estimated property value n each of the hundreds of paths. Then we would be able to find average and interval estimates for loss. To further refine the loss for each path, we could match the structure type with parcel data and use the percentage reduction to value based on structure type instead of assuming an average structure proportion reduction.

Conclusions

In this paper, we have examined the risk of the hazard of tornadoes with a focus on the relative risk and costs for Rutherford County, Tennessee. Using historical data on tornado occurrence and loss for the nation and state of Tennessee, we were able to see the relative risk for Rutherford County. Using this historical data and mathematical modeling we simulated tornado paths of possible future tornadoes in Rutherford County. The starting places of these simulated tornadoes were not selected because they were more or less likely than any other starting places. Instead, they were selected as populated areas with high risk of structural damage and thus costs associated with damage caused by a tornado. Two simulated paths were concentrated in the city of Murfreesboro and one was in the adjacent cities of Smyrna and La Vergne. Based on these simulated paths a cost analysis was conducted to estimate the potential damage that would be caused if a tornado were to actually hit the area. Tables are provided which give the percent damage of a structure for different building types.

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Appendix A.

U.S. Reported Tornadoes and Average Number of Deaths per Year

1961-1990

State	Average Number of Tornadoes per Year	Average Number of Deaths per Year	Average Number of Tornadoes Per 10,000 Sq Mi
Alabama	23	6	4.53
Alaska	0	0	0
Arizona	4	0	0.35
Arkansas	21	5	3.95
California	4	0	0.26
Colorado	24	0	2.32
Connecticut	1	0.13	2.05
Delaware	1	0	5.18
Florida	52	2	9.59
Georgia	21	1	3.61
Hawaii	1	0	1.56
Idaho	2	0	0.24
Illinois	27	5	4.86
Indiana	23	7	6.41
Iowa	35	0	6.25
Kansas	36	2	4.65
Kentucky	10	3	2.52
Louisiana	27	2	6.07
Maine	2	0	2.22
Maryland	3	0.07	3.05
Massachusetts	3	0	3.83
Michigan	18	3	3.16
Minnesota	19	2	2.39
Mississippi	26	10	5.51
Missouri	27	2	3.92
Montana	5	0	0.34
Nebraska	36	0.7	4.70
Nevada	1	0	0.09
New Hampshire	2	0	2.22
New Jersey	3	0	4.02
New Mexico	9	0	0.74
New York	5	0	1.06
North Carolina	14	2	2.87
North Dakota	20	0	2.39
Ohio	16	5	3.90
Oklahoma	47	3	6.85
Oregon	1	0	0.10
Pennsylvania	10	2	2.23
Rhode Island	0.23	0	2.22
South Carolina	10	1	3.31
South Dakota	28	0	3.69
Tennessee	12	3	2.91

State	Average Number of Tornadoes per Year	Average Number of Deaths per Year	Average Number of Tornadoes Per 10,000 Sq Mi
Texas	137	8	5.23
Utah	2	0	0.24
Vermont	1	0	1.08
Virginia	6	0	1.51
Washington	1	0	0.15
West Virginia	10	1	3.31
Wisconsin	21	1	3.86
Wyoming	11	0	1.13

Source: http://www.erh.noaa.gov/er/cae/svrwx/tornadobystate.htm

Appendix B. Rutherford County Tornado Historical Data

Year	Month	Day	Time	Latitude	Long-itude	F-Scale	Path Length (miles)	Path Width (yards)	Dead	Injured	Property Damage Cost in 2002 $	Location
1877	April	18	11:00 PM			F4	40	500	10	50		Lewis, Maury, Williamson, Davidson, Rutherford counties
1883	April	22	12:00 PM			F3		200	1	2		Southern part of Rutherford county
1890	March	27	9:30 PM			F2	10		0			Fosterville to SE of Murfreesboro
1900	Nov.	20	6:00 PM			F3	25	200	9	40		Williamson, Davidson, Rutherford counties
1909	April	29	11:15AM			F3	40		2	20		Williamson, Wilson, Rutherford counties
1913	March	13	2:30 PM			F3	50		7	15		Giles, Marshall, Rutherford counties
1921	March	24	4:00 PM			F2			0	3		5 miles SE of Murfreesboro
1921	April	16	5:00 AM			F2			0	3	$151,950	Rutherford, Cannon counties
1925	March	18	5:45 PM			F3	20		1	9	$310,800	Williamson, Rutherford counties
1925	March	18	6:10 PM			F3	12		2	15		Bedford, Rutherford counties
1926	Nov.	26	5:00 AM			F2	2		0	0		Florence
1935	March	25	7:00 PM			F3	22		1	15	$198,450	Rutherford, Cannon counties
1955	May	12	5:58 PM	35°50'N	86°23'W	F1	0	20	0	0	$169,000	Near Murfreesboro
1957	January	22	6:30 PM	35°42'N	86°24'W	F1	0	3	0	0	$161,250	Christiana
1963	March	11	4:20 PM	35°44'N	86°32'W	F2	2	100	0	5	$148,000	Versailles
1966	April	12	12:00 PM	35°56'N	86°10'W	F1	1	73	0	0	$14,000	Milton
1974	April	3	5:10 PM	35°50'N	86°26'W	F3	16	100	0	0	$736,000	Rutherford, Wilson counties
1976	Feb.	17	11:15 PM	35°57'N	86°37'W	F1	7	440	0	2	$797,500	Williamson, Rutherford counties
1976	Feb.	17	11:15 PM	36°01'N	86°35'W	F1	6	440	0	0	$797,500	Rutherford, Wilson counties
1980	March	24	12:30 PM	35°51'N	86°23'W	F2	2	150	0	2	$550,000	Murfreesboro to Oak Hill
1980	April	8	10:46AM	35°48'N	86°31'W	F1	1	50	0	0	$55,000	Overall Springs
1984	May	7	1:30 AM	35°59'N	86°32'W	F1	0	50	0	0	$43,500	Near Smyrna
1984	May	7	7:00 AM	35°51'N	86°25'W	F1	0		0	0	$0	Murfreeesboro

Appendix B Continued. Rutherford County Tornado Historical Data

Year	Month	Day	Time	Latitude	Long-itude	F-Scale	Path Length (miles)	Path Width (yards)	Dead	Injured	Property Damage Cost in 2002 $	Location
1995	January	28	3:55 PM	35°45'N	86°33'W	F1	3	50	0	0	$59,500	Rockvale
1995	May	18	3:55 PM	35°45'N	86°39'W	F0	8	75	0	4	$119,000	Eagleville to Rockvale
1997	January	24	4:37 PM	35°59'N	86°32'W	F2	5	440	0	0	$565,000	Smyrna
1997	January	24	5:00 PM	35°47'N	86°30'W	F4	7	300	0	18	$5,311,000	Murfreesboro to Barfield
1998	June	2	2:15 AM	35°57'N	86°30'W	F1	1	200	0	0	$1,776,000	Smyrna
1999	August	12	4:00 PM	35°58'N	86°33'W	F0	0.1	5	0	0	$0	Smyrna
2000	March	25	5:20 PM	35°45'N	86°39'W	F0	0.1	6	0	0	$0	Eagleville
2000	May	24	11:50 PM	35°59'N	83°32'W	F0	0.4	10	0	0	$0	Smyrna
2001	Feb.	25	1:20 AM			F0	0	10	0	0	$0	Smyrna
2001	October	24	7:20 PM			F0	0	6	0	0	$0	La Vergne
2002	April	28	6:34 AM	35°45'N	86°22'W	F3	3.2	350	0	37	$2,300,000	Murfreesboro

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Source for inflation factor - consumer price index: http://www.bls.gov/cpi/

Appendix C: Rutherford County Tennessee, Gum Road Tornado Path