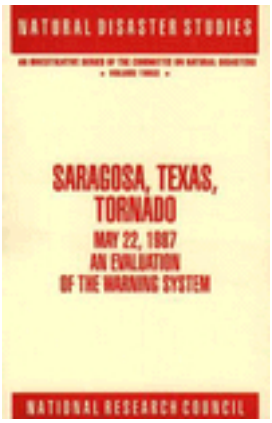

Saragosa, Texas, Tornado May 22, 1987: An Evaluation of the Warning System

Committee on Natural Disasters, Division of Natural Hazard Mitigation, National Research Council

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Volume Three

Saragosa, Texas, Tornado May 22, 1987

An Evaluation of the Warning System

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For:

Committee on Natural Disasters
Division of Natural Hazard Mitigation
Commission on Engineering and Technical Systems
National Research Council

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An Investigative Series of the Committee on Natural Disasters

The Committee on Natural Disasters and its predecessors, dating back to the committee that studied the 1964 Alaska Earthquake, have conducted on-site studies and prepared reports reflecting their findings and recommendations on the mitigation of natural disaster effects. Objectives of the committee are to:

—record time-sensitive information immediately following disasters;
—provide guidance on how engineering and the social sciences can best be applied to the improvement of public safety;
—recommend research needed to advance the state of the art in the area of natural disaster reduction; and
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Acknowledgments

The authors would like to acknowledge the kind assistance of the residents and local authorities of Saragosa, who made this report possible.

Glossary of Abbreviations

AFOS	automation of field operations and services
AP	Associated Press
AWIPS	Advanced Weather Interactive Processing System
CDT	central daylight time
DPS	Department of Public Safety
EBS	Emergency Broadcast System
EOC	Emergency Operating Center
LETS	Law Enforcement Teletype System
LI	lifted index
MDT	mountain daylight time
MIC	meteorologist in charge
NAWAS	National Warning System
NOAA	National Oceanic and Atmospheric Administration
NSSFC	National Severe Storms Forecast Center
NWR	NOAA Weather Radio
NWS	National Weather Service
NWWS	NOAA Weather Wire Service
PPI	planned position indicator
TSN	Texas State Network
UPI	United Press International
VIP	video integrator processor
WSFO	Weather Service Forecast Office

Contents

Executive Summary

Many valuable lessons can be learned from the conduct of postdisaster reconnaissance studies of natural disasters. They provide the opportunity to collect highly perishable data for assessing the extent to which state-of-the-art knowledge or technology has been implemented and they provide the information needed to develop methods of overcoming obstacles to implementation. Such studies can also identify future research needs. Depending on the nature of a natural disaster and its effects on a community, each reconnaissance effort may result in a special emphasis on one or more aspects of the natural disaster reduction process.

The primary purpose of this report is to combine the information provided by respondents to a postdisaster survey (see Chapter 5) with the facts surrounding the May 22, 1987, Saragosa tornado in order to understand and evaluate the severe weather warning procedures used in Reeves County, Texas. The intent of this evaluation is to determine ways of adjusting existing warning systems and better prepare the citizens, public officials, and news media in Reeves County, as well as in every city, county, and township where severe weather threatens lives and property.

The small community of Saragosa, Texas, was devastated by a violent multiple-vortex tornado between 8:15 and 8:20 p.m. CDT on Friday, May 22, 1987. (All references to time in this report except where noted otherwise are to central daylight time [CDT]). Thirty people were killed and 121 were injured in this unincorporated town of 428 residents located in sparsely populated Reeves County in southwest Texas. The town hall, post office, two churches, a school, and half the town's homes were destroyed.

Tornadoes are rare in southern Reeves County. Records indicate that there were 20 tornadoes from 1950 through 1986. Prior to the 1987 event, no tornado-related fatalities had occurred in Saragosa since 1916, when

recordkeeping began. Even this violent tornado was short lived, with a path length of 3 miles and a width of one-half mile.

A severe thunderstorm watch was in effect for Reeves County from 3:45 to 10:00 p.m. The National Weather Service (NWS) office at Midland issued a tornado warning for south-central Reeves County at 7:54 p.m., valid until 9:00 p.m. Other warnings and statements mentioning Reeves County were issued by the NWS office at Midland during the afternoon prior to the tornado.

Major radio and television stations in the Midland/Odessa area promptly broadcast the tornado warning. The radio station in Pecos, 30 miles north of Saragosa, transmitted the warning in both Spanish and English. Midland/Odessa television stations began to display a severe thunderstorm watch symbol in a lower corner of the television screen when watches and warnings were first issued in mid-afternoon.

These actions likely saved lives but unfortunately did not prevent a disaster. The extreme devastation caused by the tornado left many residents with little time to react and few safety options to seek. Twenty-two of the 30 deaths occurred in the town's community center, Saragosa Hall, where 70 to 100 people were attending a Head Start graduation exercise. Even though warnings were broadcast by radio and television stations, they did not reach the people at the hall. Rather, the people at the hall were warned of the approaching tornado by a man who ran in to pick up his son. There were also reports of people driving through town honking their horns. During the 1 to 2 minutes before the tornado hit, there were many instances of people demonstrating knowledge of tornado safety rules by taking proper protective actions.

Despite the extensive warning dissemination efforts, which are documented in this report, the overall warning system in Saragosa failed to reach most of the residents of Saragosa and those at the community center in time for them to take effective safety measures. This communication failure indicates that warnings, to be effective, require either a common shared culture or adaptation of the warning system to multicultural social contexts. In Saragosa neither requirement was satisfied.

The Saragosa community center was considered one of the strongest structures in the town. Even with the best warning system, a community needs a safe haven. Given the strength of the tornado, there were few safe places in Saragosa that evening. Proper provisions in building design and construction should be incorporated in reconstructing the community.

Six months after the Saragosa event, on November 15, B. E. Aguirre—the senior author of the present study—performed postdisaster reconnaissance on another tornado, this time in Palestine, Texas. The latter, which draws a number of similar observations as those from the Saragosa tornado with respect to technical ability to detect tornadoes, advance issuance of warnings, and failure of warning dissemination, is included as Appendix F.

1

The Tornado and Its Effects

POSTDISASTER SURVEY

The findings presented in this report were obtained by a National Weather Service (NWS) team dispatched to Saragosa immediately after the disaster and during a subsequent visit by the senior author of this report. The NWS survey team interviewed four people from Midland, five from Odessa, seven from Pecos, and nine from the Saragosa and Balmorhea areas. The senior author began his interviews on June 1. He conducted most in Spanish. A survey of newspaper articles on the disaster was made to develop questions and to double-check information collected during the field work. Questions about any warnings received by survivors were prepared for use during the field interviews,[1] but they did not prove to be very useful since most of the survivors questioned received no warning of the tornado.

Interviews were conducted with the family heads of 10 of the 51 households untouched by the tornado. Despite efforts to locate those whose homes were destroyed, only three family heads could be located and interviewed; the others had moved out of town. Interviews were also conducted with three adults who were at the community center when the tornado struck; the county surveyor; a deputy sheriff who was involved in the rescue operations; the general manager of the local radio station; the Spanish-language radio operator at work during the evening of the disaster; the general managers of the water, electricity, and telephone companies serving Saragosa; and the clerk of the county court.

THE SETTING

Saragosa is a small unincorporated town in the southern part of Reeves County in southwest Texas. The county is vast in size but sparsely popu

lated. Its economy is based on agriculture (beef, dairy cattle, cotton, grains, alfalfa, pecans); mineral production (oil, gas, sand, gravel); and tourism. Pecos (population 13,429 as of April 1986), which is 32 miles northeast of Saragosa, is the county seat.

Reeves County is a "western style" tourist area in the Trans-Pecos region of Texas. The local climate is semiarid (average annual precipitation, 12 inches), with low humidity. The dominant physical features of the local terrain are rolling to hilly plains. The Davis Mountains are to the south. Reeves County is bordered on the northeast by Loving and Ward counties, on the southeast by Pecos County, on the southwest by Jeff Davis County, on the west by Culberson County, and on the north by the state of New Mexico.

The precise population of Saragosa at the time of the tornado is unknown. Newspaper accounts of the disaster by Reeves County officials give different estimates. The best available estimate, based on the number and average size of households in the town, is close to 400 people. All but two families in Saragosa are of Mexican descent and between 50 and 80 percent speak Spanish only. Most of the adults work on neighboring ranches and farms or in service establishments in Pecos and the surrounding towns.

THE TORNADO

The records for Reeves County report 20 tornadoes from 1950 through 1986. No tornado-related fatalities are listed from 1916 (when recordkeeping began) to 1986. The lack of tornado-related casualties may be attributed to the low population density of the county. Some local people also believe that the proximity of the Davis Mountains, less than 20 miles south and west of Saragosa, may have been a deterring factor for tornado development in the southern part of the county. In June 1938 Saragosa was severely damaged by a tornado. It was then rebuilt 2 miles to the southwest in what is known as the Riverside area. This was the site that was struck by the May 22, 1987, tornado (Wright, unpublished manuscript, 1989).

On May 22, 1987, a violent multiple-vortex tornado struck Saragosa between 8:15 and 8:20 p.m.[2] Thirty people were killed and 121 injured. Twenty-two of the deaths occurred in Saragosa Hall (see Appendix A). Sixteen of the people killed were not Saragosa residents. The fatalities that did not occur in the hall included three in a frame house, four in mobile homes, and one in an automobile. All but two of the 30 people who died were Hispanic. Damage estimates ranged from $7.1 million to $8.7 million. The buildings on the extreme east and west edges of the town suffered only minor damage (see Figure 1).

The tornado formed about 1 mile southwest of Saragosa near Interstate Highway 10 and moved northeast into town. When the tornado initially

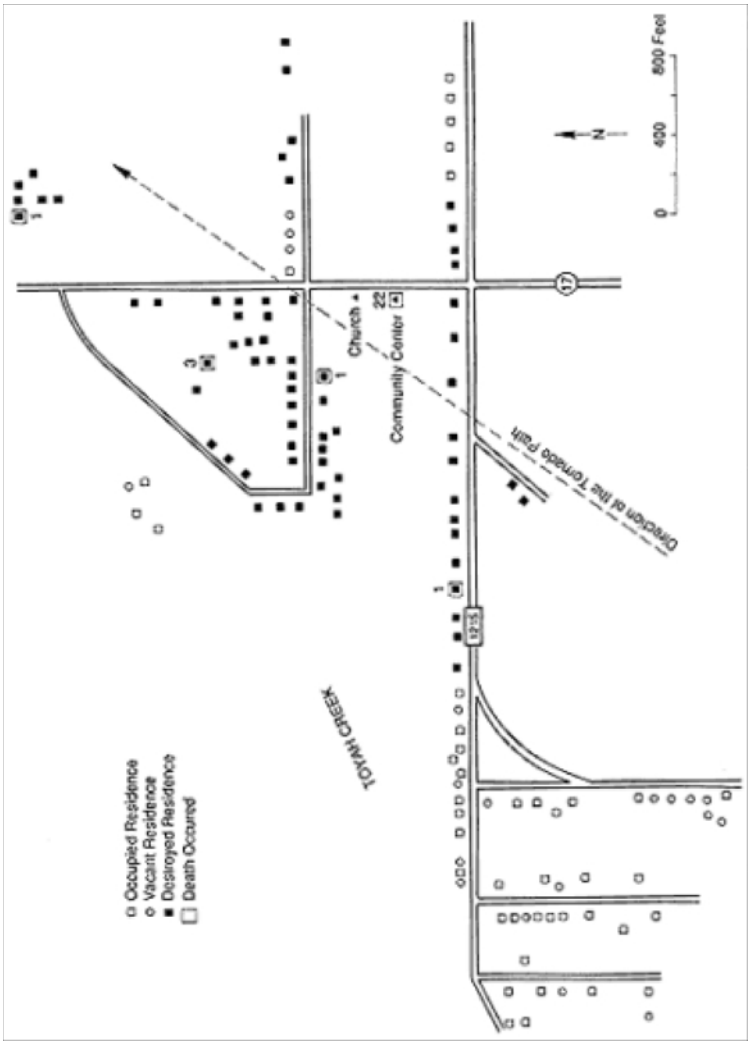

Figure 1
Path and impact of the Saragosa tornado.

touched down it was fairly weak, with a track width of less than 100 yards. As it moved into town, it quickly strengthened into a large multiple-vortex tornado. This sequence is verified by the tornado track and damage pattern, pictures of the tornado moving into town, and eyewitness reports of "three tornadoes moving in a circle."

The most intense part of the tornado moved through the central section of town and approached Highway 17, then curved to take a more north-northeast course and weakened slightly. It then followed the highway until lifting. The path length was about 3 miles, with a maximum width of 0.5 to 0.6 miles (see Figure 2). Movement of the tornado was estimated to be near 30 mph, although the parent thunderstorm was moving slowly to the northeast. The path of the tornado is reflected in the distribution of destruction. Indeed, the spatial distribution of the tornado's destruction and the deaths it caused can be summarized by a near straight line on the map in Figure 1.

The most intense damage, F4 in strength, occurred over most of the residential and business area of Saragosa. This damage occurred throughout an area three-fourths of a mile long and one-fourth of a mile wide.

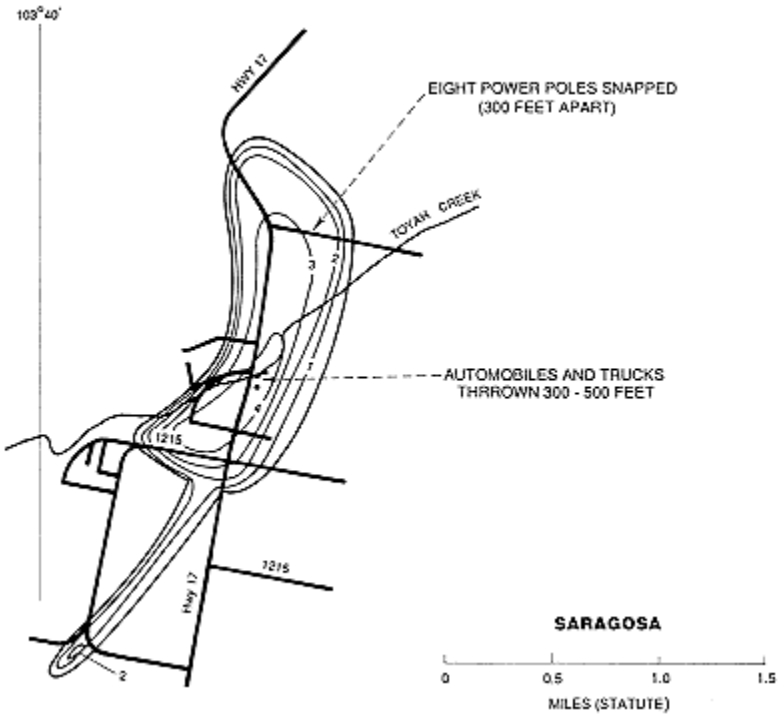

Figure 2
Path of the tornado.

Structures in the tornado's path were totally destroyed, and no interior walls were left standing. The tornado's force hurled automobiles into buildings and houses; several were found in an open field 300 to 500 feet east of Highway 17.

The tornado developed out of a storm complex that had been active since mid-afternoon over much of Reeves County. Travelers on Highway 17, approaching Saragosa from the north prior to the tornado, reported driving through heavy rain and occasional hail and observed several funnel clouds.

THE DAMAGE

A graduation ceremony at Saragosa Hall for Head Start children from Saragosa and neighboring Balmorhea started at 7 p.m. on the evening of the disaster. Survivors estimate that 80 to 100 people were attending the ceremony (see Appendix B). Twenty children were on the stage. In the audience were 30 to 40 children, their parents, and other adults.

Saragosa Hall had an area of approximately 2,500 square feet (50 × 50 feet). The south wall and entryway were made of steel-reinforced concrete, while the remainder of the building was frame construction. Most of the hall was destroyed, and the south concrete wall collapsed.

During the graduation ceremony, the space inside the community center was divided into three areas—the stage area, the area adjacent to the stage where the audience was seated, and a refreshments area behind the audience. According to survivors who responded to the postdisaster survey and individuals involved in the rescue efforts, the majority of the victims were killed while seeking refuge by leaning against the walls of the hall. Those who remained in the middle of the hall, and those who found shelter under the refreshment tables, survived. Parents also shielded their children with their bodies.

THE WARNING SYSTEM (OR ABSENCE OF IT)

Despite the lengthy record of official tornado warnings (see Appendix E), most of the survey respondents received no warning of the approaching tornado. The exceptions were two respondents who saw the warning on English-language television programs. For a number of reasons, the majority of the residents of Saragosa did not perceive the weather to be life threatening or dangerous.

Absence of Bad Weather

The weather conditions in Saragosa during the afternoon of May 22 and shortly before the tornado struck were normal. There was no rain, and the

wind was calm. The survey respondents said they could see rain in the direction of Pecos (northeast), but the sky was clear over Saragosa and in the opposite direction (southwest, toward Balmorhea). In the absence of bad weather, people went about their business in the usual way. None of the survey respondents had previous experience with tornadoes.

Absence of Clear Geographical References

The emergency weather announcements on radio and television made reference to geographical locations in Reeves County that were not relevant to the Spanish-speaking people of Saragosa. Two of the survey respondents said they saw the official emergency weather announcements on television but were unclear if the warnings applied to them. The vast size and sparse population of Reeves County probably contributed to the ineffectiveness of the announcements in eliciting widespread protective responses. The broad geographic locations used in the emergency weather announcements were difficult to interpret by the people of Saragosa. The announcements would have been more effective if they had included the names of the towns at greatest risk.

Absence of Public Warning Systems

There were no sirens, emergency public warning system, or disaster awareness program in Saragosa on the day of the tornado. Every survey respondent stated that a warning was not directly communicated to the citizens of Saragosa by public officials or community leaders. The survey respondents did not receive warnings from police and sheriff's officers, firefighters, highway patrol officers, or representatives of other official agencies.

The reasons for this lack of contact between Saragosa officials and citizens are not clear. It was probably caused by the absence of disaster awareness and planning alluded to earlier, the urgency of the impending disaster (there was at most 20 to 22 minutes to learn of the danger), and the lack of a tradition of public service to the people of Saragosa. Saragosa is unincorporated, and its citizens believed that the absence of warnings by officials mirrors the structure of social stratification in the county. One survey respondent complained that Saragosa had been systematically ignored by public agencies; it will be interesting to see if this issue becomes an important source of controversy during the reconstruction of the town.

The tornado warnings that the survey respondents did receive came from people who saw the tornado approaching and alerted their family and neighbors. In addition, motorists along Highway 17 alerted citizens to the approaching danger by honking their horns. These warnings were taken seriously and were effective in eliciting protective actions. However, they

occurred very close to the time the tornado hit (in most instances less than 2 minutes), so the range of safety options available was quite limited. Those alerted at the last minute either stayed in their houses, moved to a neighbor's house that they perceived as being safer than their own, or tried to escape the tornado by car. A number of motorists along Highway 17 sought shelter beneath a bridge overpass where Highway 17 and Interstate 10 intersect. Many drivers demonstrated correct safety procedures and abandoned their vehicles for drainage ditches along the road. At least one car stopped at a tavern in Saragosa, and the passengers sought shelter inside. The tavern lost its roof, but the occupants survived.

Although no official warning reached Saragosa Hall, the people there were warned of the approaching tornado by a man who rushed into the building, grabbed his son, and fled in his car. It appears that the consensus of the others was to remain in the hall since they thought, justifiably, that it was one of the best-built and strongest buildings in Saragosa. Indeed, most of the houses in Saragosa are made of adobe or have wood frames; there were very few substantial housing structures. Clearly, adequate public shelters and warning systems utilizing sirens or other means of warning diffusion are needed. Neighbor-to-neighbor warnings cannot be the only public method of alerting citizens to impending hazardous weather.

Absence of Warning on Cable Television

The English-language television stations broadcast the tornado warnings. However, the citizens of Saragosa acquired cable television service only 5 months earlier. The cable service includes Univision, the popular Spanish-language channel. Reportedly, during the evening of the tornado many of the televisions in Saragosa were tuned to this channel. However, Univision did not carry warnings of the tornado, as did the local television stations. Many lives might have been saved if emergency weather announcements had been transmitted on the Univision channel. An effort to see what can be done to provide this service to the Hispanic community is definitely needed.

Absence of Pretranslated Warnings

The local radio station in Pecos serves the town of Saragosa. On the evening of the disaster, the station's operators broadcast weather warnings in Spanish and English. The radio operators were able to respond almost immediately to the impending threat of the tornado. The Spanish-language operator who participated in the emergency broadcasting estimates that the first warning was broadcast by 8:00 p.m. and that emergency warnings in both languages went out every 6 minutes thereafter. Since the tornado

struck Saragosa about 8:20 p.m., it is probable that the Spanish-language radio emergency warnings were broadcast three times before the electricity was cut off and radio reception was blocked in Saragosa.

The radio operator on duty cannot remember with certainty how he translated the emergency tornado warning he received from the NWS office in Midland. The emergency weather messages he received were teletyped in English, so he had to translate them into Spanish first. He thinks that he probably said "aviso de tornado," followed by the rest of his translation of the message. An accurate translation of the tornado warning was rendered difficult. The urgent need to get the message on the air, coupled with the necessity of selecting the correct Spanish words to convey the technical content of the message (for instance, the difference between watch and warning had to be preserved in translation), caused some confusion.

In retrospect, the radio operator's use of "aviso" probably was not correct, for the word means to "give news, advice, or information." The technical meaning of the word "warning," representing a "materialized, impending disaster," has no direct translation into Spanish, and its meaning is not conveyed by "aviso." Perhaps a phrase such as "¡cuidado! peligro de tornado" (translation: caution ... danger from tornado) would have been more appropriate.

It would be a significant improvement if emergency weather announcements could be translated and made a part of disaster preparedness programs available to Spanish-language radio operators throughout the country. Standardized, officially approved, Spanish-language translations would make it easier for Spanish-language radio operators to maintain uniformity, exactness, and accuracy with the meaning of the original English-language messages.

In their report on American minority citizens confronted by natural disasters, Perry et al. (1983) found that their Mexican-American respondents preferred radio over newspapers and television as a source of disaster preparedness information. This finding adds credence to the necessity of effective emergency weather radio messages for the Hispanic community in the United States.

NOTES

1. Questionnaire is available from B. E. Aguirre on request.

2. Determination of tornado damage is based on the Fujita scale. A tornado is defined as a small-scale columnar vortex, often originating from a cumulonimbus that causes damage of scale F0 or higher. The Saragosa tornado was rated R (207 to 260 mph according to the Fujita scale).

2

Tornado Preparedness Activities

The NWS office in Midland is responsible for issuing severe weather warnings and administering disaster preparedness for 17 counties in the south plains of west Texas and in one county in the extreme southeast corner of New Mexico (see Figure 3). Successful preparedness programs consist of both organizational and individual training and education. Organizational training in severe storm identification is necessary for an effective warning system, while individual education is essential to prepare citizens for severe weather conditions. Organizational activities are designed to encourage emergency operations plans, storm-reporting networks, and effective dissemination of warnings. While these activities are being conducted, individuals must be made aware of safety measures for self-protection.

PUBLIC AWARENESS WEEK

The NWS office in Midland and the local news media have drawn the public's attention to severe weather with "Severe Weather Awareness Week in the Permian Basin." The second annual weather awareness event was held the week of February 22, 1987 (see Appendix C). In conjunction with weather awareness week, the meteorologist in charge (MIC) in Midland sponsored a severe weather workshop for media representatives on February 12, 1987. Workshop participants also included emergency management and law enforcement agencies and amateur radio storm spotters. The workshop focused on improved understanding of the problems participants encountered during severe weather situations. During the workshop, public education material was distributed to the media. The workshop increased public awareness through numerous severe weather programs by Midland/Odessa radio and television stations. It also improved coordination of operational efforts

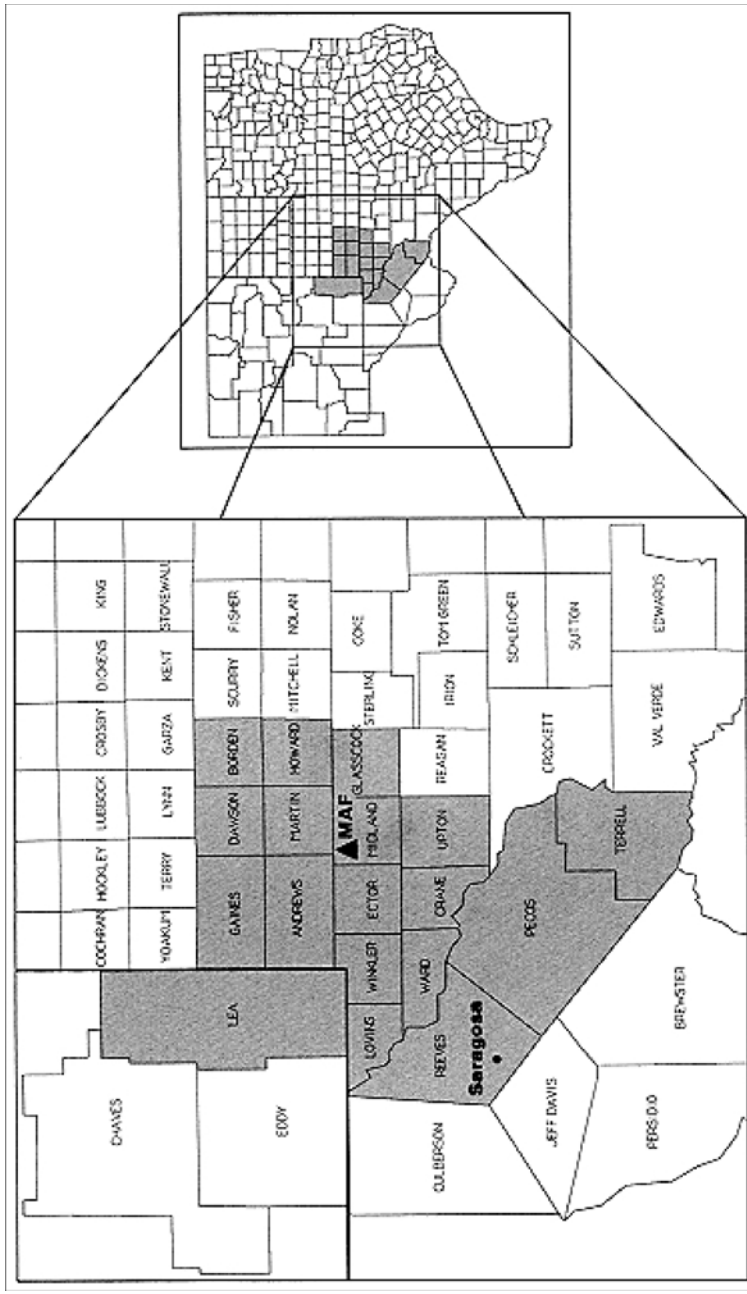

Figure 3
County warning area of WSO Midland, Texas.

among participants. Unfortunately, media representatives from small rural stations did not attend the workshop. Small staffs and low budgets often prohibit their participation.

An example of the interest in public awareness is demonstrated by KOSA-TV, Channel 7. KOSA-TV has made available to viewers an 11 × 17 inch, double-sided, weather safety sheet. Included on the sheet are tornado, lightning, and severe thunderstorm safety rules; definitions of the terms *tornado watch* and *tornado warning*; and a description of weather symbol displays and weather "crawls" (messages broadcast along the bottom of the television screen) used during coverage on severe weather.

STORM SPOTTER TRAINING

Severe storm spotters are a first line of defense against severe weather, and spotter training has received much attention at the NWS office in Midland. During each of the past 3 years, NWS Midland preceded each severe weather season with spotter training in each county seat during the months of January, February, and March. Reeves County was no exception, with spotter training on March 6, 1985 (8 attendees); March 11, 1986 (49 attendees); and March 10, 1987 (26 attendees). The last meeting included officials from the Texas Highway Department, the Pecos and Monahans police departments, the Reeves County Sheriff's Department, teachers, and several concerned citizens.

HAMFESTS

In addition to county-by-county severe storm spotter training, each March the NWS office in Midland participates in a regional "hamfest" with a spotter training session geared toward amateur (ham) radio operators. A *hamfest* is a gathering of amateur radio operators to swap equipment; discuss radio communications, equipment, and operating procedures; and meet other radio operators. Hamfests, particularly larger regional gatherings such as the one held in Midland, attract amateur radio operators from many miles around. A hamfest provides an excellent opportunity to train a geographically dispersed group of operators as volunteer severe storm spotters. In fact, the two amateur radio storm spotters who reported the rotating wall cloud on May 22 had taken part in several of these training sessions.

The amateur radio operators of southwest Texas are a valuable resource for the NWS. These radio operators are usually called to action by the NWS Midland staff when severe weather is anticipated in the Permian Basin area. On the afternoon of May 22, the amateur radio operators were alerted by the NWS Midland office around 4:30 p.m. and opened their station at the NWS office at 4:50 p.m.

The effectiveness of amateur radio operators in the Permian Basin is due in large part to a network of operators called the "West Texas Connection" (see Figure 4). "The Connection," which is the brainchild of Jim Jeffries, an amateur radio operator from Odessa, is the name given to the interconnection of multiple amateur radio repeaters throughout the Permian Basin. A radio repeater allows amateurs to use their VHF-FM frequencies (144.00 to 148.00 MHz) beyond its normal line-of-sight limitation.

Typically, a repeater on a tall tower or building will achieve a range of 50 miles. By connecting various repeaters to a hub repeater 5 miles south of Odessa, the ham radio operators have expanded their coverage to well over 200 miles. This is particularly valuable to the NWS office in Midland, where warning service must be provided for such a vast area.

No formal organization of amateurs exists for the entire Permian Basin,

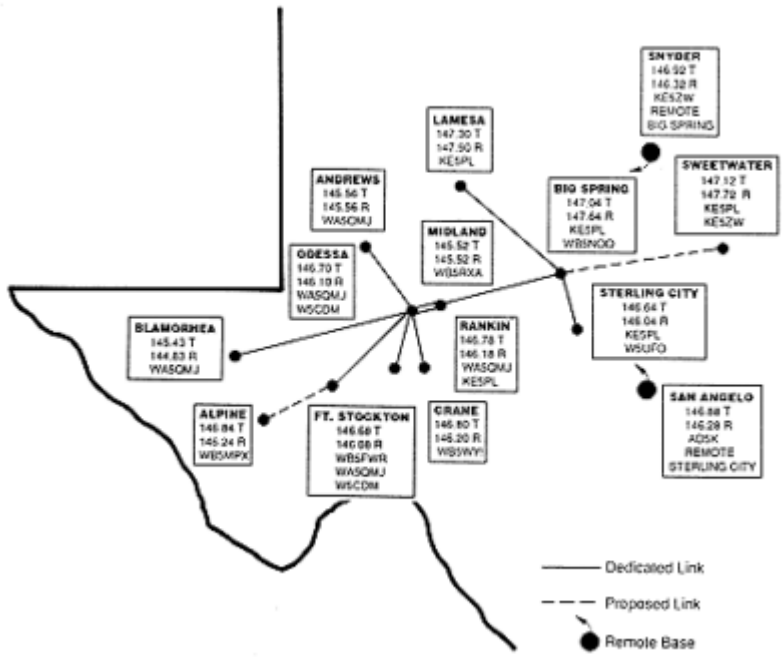

Figure 4
The "West Texas Connection."

but the extent of aerial coverage delivered by "The Connection" provides a cohesive mechanism for linking spotters. Whenever severe weather affects the Permian Basin area, amateurs report weather conditions through repeaters directly into the NWS office in Midland. Jeffries and those who assist him volunteer their time, equipment, and finances to maintain "The Connection."

SUMMARY

Severe storm spotter training and severe weather preparedness are high-priority functions for the NWS's Midland office. The office works effectively with the local media, volunteer storm spotters, and area amateur radio operators who have constructed a vast communications network. All are invaluable resources in severe weather forecasting. The office is active in drawing public attention to severe weather threats and to safety measures designed to protect life.

3

Tornado Warning Activities

WARNING ISSUANCE FROM VARIOUS SOURCES

The upper-air sounding from the NWS Midland office at 7:00 a.m. on Friday, May 22, 1987, showed the air mass over southwest Texas to be highly convectively unstable. The lifted index (LI)[1] on the morning Midland sounding was minus 6. The early morning West Texas Forecast Discussion issued by the National Weather Service Forecast Office at Lubbock at 3:41 a.m. noted the 24-hour LI prog[2] of more than minus 6 in its southern zones (see Appendix D). The 9:15 a.m. West Texas Forecast Discussion[3] again brought attention to the possibility of thunderstorms in the Lubbock forecast area. The forecaster described the weather situation as looking "like a good aftn and eve for tstms ... even ... some severe." The same message was carried in the afternoon forecast discussion sent at 3:08 p.m.

The Convective Outlook[4] issued by the National Severe Storms Forecast Center (NSSFC) (see Appendix D) at 1:43 a.m., and valid for the 24 hours beginning at 7:00 a.m., included a large section of west Texas in the area of slight risk of severe thunderstorms. Reeves County was just outside the slight-risk area. The Convective Outlook, updated at 2:12 p.m., shifted the slight-risk area westward to include Reeves County.

Severe thunderstorm watch no. 114, issued at 3:11 p.m. and valid from 3:45 p.m. until 10:00 p.m., encompassed a large portion of eastern New Mexico and parts of west Texas. The supplementary aerial outline derived from that watch, which specified the individual counties in the watch, included Reeves County.

The first radar indication of a severe storm in Reeves County was noted by Midland radar at 3:20 p.m. at 244 degrees, 108 nautical miles from Midland (or 20 miles northwest of Balmorhea) with a maximum top of

50,000 feet and a video integrator processor (VIP)[5] 6 core. Hail was reported. The NWS office in Midland issued a severe thunderstorm warning at 3:24 p.m. for southwest Reeves County, valid until 4:30 p.m. (see Appendix D). At 3:30 p.m. a call was made to the Pecos Department of Public Safety (DPS) advising it of the warning and requesting reports of severe weather. At 3:45 p.m. a severe weather statement and radar summary were issued that headlined the severe thunderstorm warning for the county. A special weather statement at 4:10 p.m. included a report from the DPS of 1.75-inch hail in the southwest part of the county. By 4:35 p.m., radar indicated the thunderstorm top had fallen to 37,000 feet from its earlier top of 50,000 feet. A 4:50 p.m. severe weather statement and radar summary again highlighted the severe thunderstorm watch; detailed the location of five very heavy thunderstorms, including one near Toyah, which is 22 miles northwest of Saragosa; and repeated the report of golfball-size hail in the county.

A second NSSFC Mesoscale Discussion[6] for Texas and New Mexico at 5:31 p.m. continued to focus on the area around Lubbock. It noted that very strong moisture convergence was located with a cell along the New Mexico and Texas border due west of Lubbock "with minus 10 surface lifted index feeding into it from the south."

The Reeves County storm maintained itself with little movement and by 6:05 p.m. was back to 44,000 feet. The 6:41 p.m. radar summary from the NWS office in Midland showed the storm to have a maximum top of 51,000 feet with a VIP 5 core. The 6:50 p.m. severe weather statement and radar summary mentioned very heavy thunderstorms at several locations, including south and west of the city of Pecos. The statement highlighted the watch and several warnings and mentioned that very heavy thunderstorms would continue to develop throughout the evening.

By 7:20 p.m. the storm had become a supercell with the maximum top displaced directly over the sharpest reflectivity gradient on the inflow side of the storm. The storm had a VIP 6 core to 21,000 feet and a VIP 5 core to 31,000 feet. The NWS Midland staff initiated a call to the Pecos DPS office at 7:26 p.m. to request information on the thunderstorm between Saragosa and Toyah. At 7:37 p.m. the NWS issued a combined severe thunderstorm and flash-flood warning for southern Reeves County valid until 9:45 p.m. The warning located the storm 15 miles southwest of Pecos (or 15 miles northwest of Saragosa), moving slowly to the northeast.

Amateur radio storm spotters reported a rotating wall cloud 4 miles west of Balmorhea on Interstate 10 at 7:46 p.m. and 2 miles west of Balmorhea at 7:48 p.m. These reports, together with radar clues, led to the issuance of a tornado warning for south-central Reeves County at 7:54 p.m. (see Appendix D). The warning message located the thunderstorm 10 miles southwest of Pecos and included a call-to-action statement that described the storm as

dangerous and advised that proper tornado safety measures be taken. A call was made to the Reeves County Sheriff's Department in Pecos at 7:55 p.m. advising the department of the tornado warning.

The county's Emergency Operating Center (EOC) at Pecos was activated by the emergency management coordinator around 8:00 p.m. after receipt of the tornado warning. The EOC is activated for tornado warnings but not normally for severe thunderstorm or flash flood warnings.

The two tornado reports logged in the NWS Midland's severe weather logs came from storm spotters and from the Pecos DPS. The logs show some confusion in the communication of reports since one report was for the area 4 miles west of Balmorhea and the other was for the area 4 miles east of Balmorhea. The DPS report came from a public safety officer who was filling up his vehicle's gas tank at a bulk gas plant at the 210-mile marker on Interstate 10.

Following the initial warnings and reports of the tornado, the NWS issued a severe weather statement at 8:20 p.m. headlining the tornado warning for south-central Reeves County. The statement described the tornado report and noted movement to the east at 30 mph. Another severe weather statement issued at 8:30 p.m. again highlighted the tornado warning. It stated that a tornado was reported at a local school. A third severe weather statement at 8:40 p.m. continued to headline the tornado warning and again reported substantial damage in Saragosa.

A new report of a funnel cloud 28 miles west of Fort Stockton from the Reeves County Sheriff's Department prompted an NWS tornado warning at 9:04 p.m. valid until 10:00 p.m., for southern Reeves and western Pecos counties. The warning noted that this was the same storm that had produced fatalities in Saragosa. The NWS Midland office issued several more warnings and statements throughout Friday night. (See Appendix E for a chronology of severe storm warning releases.)

NOTES

1. The LI refers to a relative measure of instability in the atmosphere expressed as a numerical value. It is arrived at by lifting a parcel of air dry adiabatically to its point of saturation and then along the moist adiabat to some reference pressure level such as 500 or 300 millibars. At that reference level, the temperature of the lifted parcel is compared to the ambient air temperature to arrive at an index value.
The adiabatic process refers to the thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system. A specific lapse rate (i.e., the rate of decrease of temperature with height for a specific air parcel) is associated with the assumption of a dry or saturated condition of the air parcel.

2. "Prog" refers to a 24-hour forecast chart of projected lifted indexes.

3. The West Texas Forecast Discussion is a message prepared four times daily

by the Lubbock Weather Service Forecast Office (WSFO) to describe current meteorological reasoning concerning present and anticipated weather. These discussions relate present synoptic-scale weather situations to numerical guidance outlining the forecasters' reasoning for the content of the upcoming forecast package. All WSFOs prepare these discussions, which are a vehicle for forecast coordination.

4. A Convective Outlook is a message routinely prepared by the NSSFC outlining areas where thunderstorms are expected, including areas where thunderstorms may reach severe limits. It encompasses the entire 48 contiguous states and is used as guidance by WSFOs.

5. VIP is the digital video integrator and processor equipment used on NWS radars. It was developed to meet requirements for continuous quantitative data output. The radar video signals resulting from precipitation echoes are integrated in 1-nautical-mile segments over a range of 115 nautical miles and displayed on the radar planned position indicator (PPI) in a step function intensity modulated sequence. The VIP (or, more accurately, DVIP) processes the output of the radar's logarithmic receiver to produce up to six levels of intensity data corresponding to preselected categories of estimated rainfall rates. This permits the constant monitoring of echo intensities, within the six categories, with each rotation of the radar antenna.

6. A Mesoscale Discussion is an unscheduled discussion prepared by the NSSFC describing meteorological factors related to existing mesoscale features. It focuses on a small area that moves as weather systems move.

4

Tornado Warning Dissemination

Severe weather information was generally well disseminated in the Reeves County and Midland/Odessa areas the day of the devastating tornado. The most effective methods of delivering weather forecasts and warnings were the National Oceanic and Atmospheric Administration's (NOAA) weather wire, commercial television, and a radio station in Pecos. The nearest NOAA weather radio transmitter is near Odessa, but its range cannot reach Reeves County or Saragosa. Several outstanding cases of delivering weather information to area residents were noted.

NOAA WEATHER WIRE SERVICE

The size of Texas and the number of NWS offices in the state entering data necessitate three NOAA Weather Wire Service (NWWS) circuits. The West Texas NWWS is headed by the Lubbock National Weather Service Forecast Office. Prior to divestiture of the telephone industry in 1984, there were 100 subscribers to the West Texas NWWS. It is estimated that there are about 56 subscribers now. Some subscribers have discontinued the service for various reasons, including cost of the system due to tariff increases, the slow speed of the archaic circuit (only 75 words per minute/56.9 baud), and service from other sources, such as high-speed news wire services from the Associated Press (AP), United Press International (UPI), Texas State Network news (TSN),[1] and private meteorological information sources. In October 1985, TSN began passing, via satellite, the NWWS information to its 148 affiliate stations throughout Texas at no additional cost. All three major television networks in the Midland/Odessa area have NWWS. An independent television station in Odessa does not subscribe to

NWWS. The Emergency Broadcast System (EBS)/CPCS-1 station in Midland uses TSN/NWWS as does the KIUN-AM/KPTX-FM radio station in Pecos, 30 miles north of Saragosa.

LAW ENFORCEMENT TELETYPE SYSTEM

Another key dissemination system in Texas is the Department of Public Safety's (DPS) Law Enforcement Teletype System (LETS). From the DPS headquarters center in Austin, all DPS offices, county sheriff's offices, and police departments have a drop on this circuit. A special AFOS (automation of field operations) asynchronous line[2] from NWS Austin sends Texas severe weather watches, warnings, and statements to the DPS headquarters in the state capital. A drop on this circuit exists at the DPS and sheriff's offices in Pecos.

NOAA WEATHER RADIO

Of the 27 NOAA Weather Radio (NWR) transmitter sites in Texas, the one closest to Saragosa is near Odessa. However, its signal does not reach Saragosa, which is about 90 miles southwest of Odessa (see Figure 5). NWR is monitored by television channels 2, 7, 9, and 24; the EBS station in Midland; and KKKK-FM in Odessa. TV-9 displays the Midland NWS radar image and carries the NWR broadcast between its sign-off time around midnight and its sign-on time at 6:15 a.m.

EMERGENCY BROADCAST SYSTEM

A meeting to establish EBS operational areas in west Texas was held on April 19, 1978, in Midland. The designated EBS CPCS-1 station for the Midland area was and still is KCRS-AM.

A postdisaster visit was made to KCRS. Because no log seems to exist of the times that EBS may have been activated on Friday, May 22, it was not possible to verify whether EBS had been activated for the 7:54 p.m. tornado warning for Reeves County although KCRS stated that EBS was activated for the 7:54 p.m. tornado warning for south-central Reeves County. Interviews with several radio and television personnel indicated that while EBS was activated for other warnings during this event, they did not recollect EBS activation for the 7:54 p.m. tornado warning. Nevertheless, due to the redundancy of dissemination of the tornado warning and to the close monitoring by media personnel, the apparent lack of EBS activation probably had no serious adverse impact in this case. KCRS subscribes to both TSN and NWWS, but the station's wire service unit does not have a "bell feature"[3] when warnings are received.

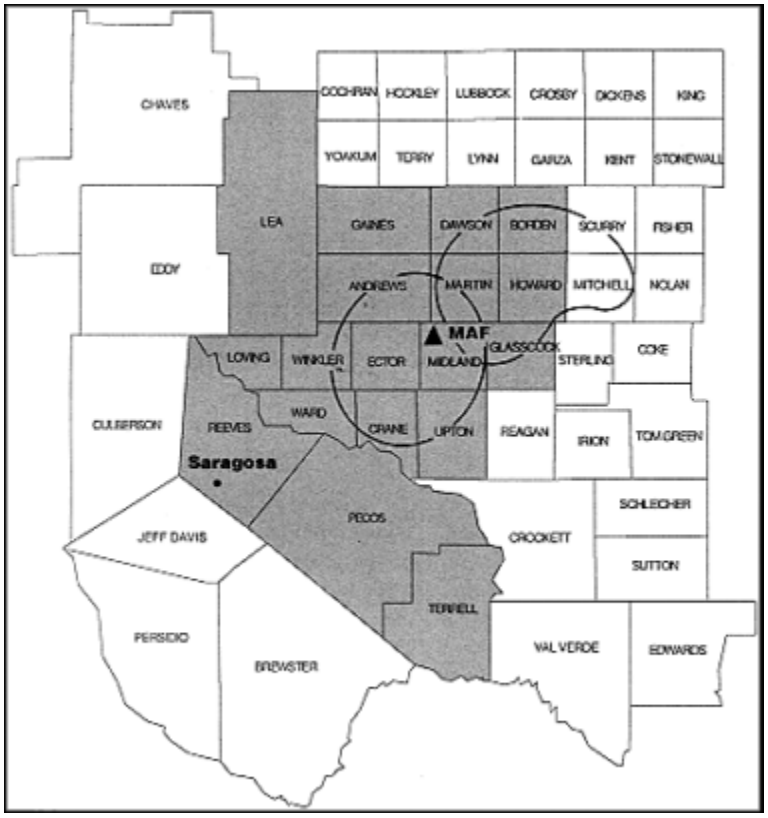

Figure 5
NOAA weather radio coverage—Midland/Odessa and Big Spring transmitters.

TELEVISION AND THE CABLE SYSTEM

Television signals from Odessa and Midland reach the Saragosa area. Television and newspaper accounts indicated the operation of a very basic cable television system in Saragosa that had 40 to 45 subscribers. Most cable subscribers were probably watching Univision, the popular Spanish-language entertainment station. Cable stations do not carry severe weather warning messages.

Television stations 2, 7, 9, and 24 display a warning symbol in a lower-screen corner when a severe thunderstorm or tornado watch or warning is in effect, and they use "crawls" or live cut-ins, as necessary, to disseminate

NWS warnings. "Spots" are occasionally run to tell viewers what the symbols mean.

KMID TV, Channel 2, the Midland ABC station, carried a severe weather statement on the screen at 7:10 p.m. At 8:03 p.m. the 7:54 p.m. tornado warning crawl for south-central Reeves County was repeated followed by a weather cut-in from 8:11 to 8:13 p.m. Tornado warning crawls are normally shown on screen twice, back to back, and are repeated every 15 minutes.

KOSA-TV, Channel 7, the CBS affiliate in Odessa, carries weather crawls at 10-minute intervals for tornado warnings and 20-minute intervals for tornado watches and severe thunderstorm warnings. The station has a drop on NWS Midland's WSR-57 weather radar using a Kavouras system.[4]

At 3:00 p.m., KOSA began its weather news breaks. These breaks are 30-second live cut-ins by the station's weathercaster with the latest weather information. The normal 30-second break was lengthened to I minute on the 3:00 p.m. broadcast, which highlighted the high potential for severe weather. Live cut-ins were made throughout the afternoon and night at 3:35, 4:02, 7:50, 8:01, 8:30, 8:49, and 9:16 p.m. The 7:50 cut-in featured the severe thunderstorm and flash flood warning, and the 8:01 and 8:30 cut-ins highlighted the tornado warning.

The NBC station, KTPX-TV, Channel 9, ran the 3:30 p.m. warning issued by NWS Midland as well as the 7:37 and 7:54 p.m. warnings. A live update was given at 8:01 p.m. explaining the tornado sighting by spotters, the wall cloud report, radar indications, and the need for people to be alert. The tornado warning was broadcast via a crawl at 8:21 p.m.

KPEJ-TV, Channel 24, the independent television station in Odessa, has no news or weather staff. Its broadcast signal does not reach the Saragosa area of Reeves County. The station provides viewers with weather information obtained from NWR and EBS. During the evening of May 22, the station ran several weather crawls and displayed the severe weather watch and warning symbols on the screen.

RADIO

Radio stations in Odessa do not serve Reeves County. KJJT-FM in Odessa is a Spanish-language station operating from 6:00 a.m. to 8:45 p.m. daily. It is doubtful that coverage reaches the Saragosa area. Moreover, for undetermined reasons the only source of weather information used by station personnel is local television, and, unfortunately, the personnel on duty the night of the Saragosa tornado did not notice any tornado warnings on television and thus did not broadcast any.

Saragosa is served by KIUN-AM and KPTX-FM in Pecos. The KIUN program is conducted in Spanish from 7 to 10 p.m. Programming on the

night of the tornado was in Spanish and English. KPTX is English only. Interviews with the manager and radio operator on duty the night of the storm indicated that the station did provide warning dissemination service during the tornado.

KIUN-AM is a 1,000-watt station, and KPTX-FM is a 3,000-watt station. KIUN has emergency power and also has NWWS via TSN. The station monitors KCRS in Midland for EBS information. Station personnel also monitor police reports on a scanner. There is no logbook showing the times that warnings were provided on the AM/FM stations, but interviews with the radio operator on duty indicate that they were broadcast almost immediately upon receipt of the announcements.

Around 7:37 p.m. the KIUN radio operator on duty heard at least two reports on the station's police radio scanner, one from a DPS trooper when he called in his spotter report while at the 210-mile marker on Interstate 10 and a second for help in Saragosa. The 7:54 p.m. tornado warning was broadcast about 8:00 p.m. in Spanish and English along with many tornado safety rules. The safety rules were taken from NWS Midland literature. Several days after the disaster KIUN allotted 30 minutes to "slowly" repeat weather safety rules.

The radio operator on duty at the KPTX (broadcasting in English only) frequently broke in during the broadcast of a baseball game to give the latest weather information, including the severe thunderstorm and flash flood warning between 7:37 and 7:45 p.m.

SIRENS

In mid-1986 free surplus siren systems were offered to the towns of Saragosa, Balmorhea, and Toyah. Each town was responsible for installation and maintenance of the system. Saragosa never responded to the offer; Balmorhea and Toyah accepted. The emergency management director for Pecos and Reeves County believes that Saragosa's unincorporated status and the absence of a city government may have contributed to the lack of response.

PECOS DEPARTMENT OF PUBLIC SAFETY

The Pecos DPS office receives weather information over high-speed LETS equipment. The DPS dispatcher broadcasts severe weather information to all DPS units as soon as possible. NWS Midland called the Pecos DPS by telephone to say that it was going to issue the severe thunderstorm and flash flood warning at 7:37 p.m. and to solicit information about the storm.

PECOS/REEVES COUNTY EMERGENCY MANAGEMENT OFFICE AND SHERIFF'S OFFICE

Warnings are received in the Emergency Management Office in Pecos via DPS radio, with hard copies available from the DPS or Reeves County sheriff's office. The EOC office often calls the sheriff or DPS office to request information about warnings and other matters. The sheriff's office has the DPS LETS teletype circuit and did receive the 7:54 p.m. tornado warning. According to the sheriff's office, 16 mobile units were on duty to spot storms. A deputy county sheriff in Balmorhea and a DPS trooper were also trying to get closer to the storm. The sheriff was the first to arrive in Saragosa after the tornado and provided the first word on the disaster to the sheriff's office.

NATIONAL WARNING SYSTEM

There are an estimated 50 National Warning System (NAWAS)[5] drops in Texas, including the Pecos DPS office and NWS Midland. Due to the size of the state and the number of users, the circuit is not always used for severe weather purposes. Additionally, the effectiveness of the LETS system circumvents the need to use NAWAS routinely. NWS Midland did not encounter communication problems with LETS and did not use NAWAS in the Saragosa tornado.

SUMMARY

Information collected on the Saragosa disaster shows that there were many activities connected with the dissemination of weather announcements about the storm throughout the region. These weather announcements probably elicited the desired protective responses from people threatened by the storm. Information on severe weather was distributed by the television stations in Midland and Odessa and by radio station KIUN/KPTX in Pecos. People in Saragosa who were watching noncable television programs or listening to KIUN/KPTX had opportunities throughout the afternoon to become aware of the storms and of the tornado warning for south-central Reeves County. Nevertheless, despite the dissemination activities all indications are that most of the residents of Saragosa were unaware of the impending danger. If the ultimate criterion in judging the effectiveness of Saragosa's warning system is whether the tornado warning reached those at risk, it must be concluded that the warning system failed.

Overall, the dissemination system in the major metropolitan areas functioned well. It proved more difficult to reach people in rural areas, especially unincorporated communities like Saragosa. While the Midland and

Odessa EBS plan appears to be adequate, procedures at the CPCS-1 station may need to be reviewed and strengthened. NOAA weather radio adequately serves the Odessa, Midland, and Big Spring areas but not distant communities such as Saragosa. Fortunately, TSN provided a major public service in distributing Texas weather wire data to its 148 affiliate stations, including KIUN in Pecos. The TSN is an extremely valuable asset that should be replicated in all states.

NOTES

1. TSN is a network of commercial radio broadcasters across Texas. It provides a variety of information services to its affiliates, including weather information received from the NWWS.

2. AFOS refers to the computer equipment used in NWS offices for the storage and retrieval of weather information as well as the composition of alphanumeric weather products. The asynchronous line refers to a communications outlet or port that permits the distribution of warning and forecast products to outside users.

3. The bell feature refers to the capability to sound an alarm on receiving printers with certain warning and watch products.

4. The Kavouras system is a private enterprise that furnishes NWS radar data to other external users. The service is provided via equipment at each NWS radar site that processes the radar signal and allows the data to be accessed by other agencies or firms.

5. The NAWAS is a hotline-restricted telephone system used by federal, state, and local authorities for rapid communication of critical information. In Texas users include all NWS and DPS offices.

5

Observations Recommendations, and Conclusions

OBSERVATIONS

A number of observations were made from the study conducted by the reconnaissance team:

- A severe thunderstorm watch issued by the National Severe Storms Forecast Center had been in effect for Reeves County since 3:45 p.m. Since mid-afternoon NWS Midland issued warnings and statements that detailed severe storms in the county. The tornado warning lead time was in excess of 20 minutes, which is significantly better than can be expected with the current state of tornado detection technology.
- The positive and quick reaction by the news media was due in part to a close working relationship with NWS Midland. Personal visits by NWS meteorologists to radio stations throughout the warning areas, especially those in rural areas, is an effective part of the dissemination and warning process.
- Significant warning dissemination service was provided by the Pecos radio station KIUN-AM/KPTX-FM. The 7:37 p.m. severe thunderstorm and flash flood warning and the 7:54 p.m. tornado warning were broadcast in both Spanish and English, as were the safety rules. The warnings were also broadcast by KPTX-FM in English. All Midland and Odessa television stations display relevant severe thunderstorm or tornado watch and warning symbols in a lower comer of the television screen when appropriate. This technique is an effective means of alerting the public to the threat of severe weather, but it is utilized by only a small percentage of the television stations nationwide.
- The hours devoted to amateur radio storm spotter training proved invaluable. The tornado warning issued at 7:54 p.m. was partly based on two

reports of "rotating wall clouds" from NWS-trained SKYWARN storm spotters. The decision to warn apparently was made almost simultaneously by NWS Midland's radar operators and the meteorologist in charge (MIC), who was working with the on-station SKYWARN amateur radio operators. The amateur radio operators' reports clearly enhanced the MIC's confidence that a warning was required. Amateur radio operators have consistently demonstrated a dedication and willingness to serve the public and have continued to be excellent severe storm spotters. The presence of an amateur radio operator in the weather office provided almost instant relay of information from spotters in the field. This volunteer group makes a significant contribution to the NWS warning program.

- NOAA Weather Radio (NWR) indirectly provided warnings for Saragosa through the major television stations in Midland/Odessa and the EBS station in Midland, all of which have NWR receivers, many with the warning alarm feature. NWR supplements and complements the weather wire service. Even though the warning tone is not sounded for Reeves County because it is not in the service area of the Odessa transmitter, all warnings issued by NWS Midland for its county warning area are placed on NWR.
- Many people in Saragosa were aware of basic tornado safety rules, and many individuals took proper protective actions. While it is difficult to estimate the number of people who are alive as a result, the death toll would have been higher had fewer individuals reacted properly. Discussions with survivors clearly indicated that last-minute protective measures did save lives and reduced injuries.
- Since 1975, when some of the first organized tornado awareness weeks were begun, NWS offices have promoted public education about weather hazards. These mass media campaigns as well as group and individual awareness and educational efforts have a cumulative effect in raising the consciousness level of the public.
- The Law Enforcement Teletype System (LETS) is extremely efficient at distributing NWS tornado watch and warning information to local law enforcement offices and emergency operating centers in those states where a direct tie exists between the LETS and the AFOS communication systems. In the NWS Southern Region such ties exist in Texas and Oklahoma, and the interface has proven invaluable for the rapid relay of NWS warning information. During the Saragosa event, the Department of Public Safety (DPS) office in Pecos and the Reeves County sheriff's office received NWS tornado watch and warning information from the Texas LETS.
- Only 20 tornadoes were reported in Reeves County from 1950 through 1986, with no tornado fatalities listed from 1916 through 1986. This may relate to the close proximity of the Davis Mountains. The rapid development of this strong tornado so close to the Davis Mountains warrants further study.

- Most residents of Saragosa are Hispanic; many speak only Spanish. An increased effort is needed to provide bilingual and Spanish-language broadcast stations with appropriate preparedness materials. Local Spanish-language television programming is a popular and growing media in the southwestern United States. The NWS should assist with preparing materials to reach the region's significant Hispanic population.

RECOMMENDATIONS

- The need for multiethnic/multilingual warning procedures should be recognized, and such procedures should be developed and tested, for their applicability as well as their improvement, at the earliest possible time.
- State-level policies should be developed to implement emergency planning and responses in unincorporated areas because these areas are typically overlooked in the planning efforts of neighboring jurisdictions yet are not large enough to sustain a sufficient preparedness program on their own.
- Warning dissemination through both regular and cable television systems, especially ethnic channels, by displaying severe thunderstorm or tornado watch and warning symbols in the lower corner of the television screen should be implemented, particularly to reach unincorporated areas in sparsely populated rural counties.
- Proper building design and construction provisions should be incorporated into future construction practices.
- More precision is needed in preparing warning messages for areas at high risk. The NWS should translate its warning messages into different languages to facilitate dissemination of the information to more people.
- NWS offices should continue to work closely with local news media to achieve two purposes: (1) to encourage, advise, and assist in the understanding of and prompt dissemination of NWS watches and warnings and (2) to encourage, advise, and assist with the broadcast of educational preparedness information designed to increase public awareness and preparedness.
- The NWS should continue as well as enhance, where necessary, severe storm spotter training efforts. A special focus should continue to be placed on groups with mobile communications capabilities, such as police and fire departments, highway patrol officers, and amateur radio operators.
- The NWS should continue to make possible the direct connection of LETS or LETS-type circuits to its internal communication system (AFOS and subsequently AWIPS[1]) to encourage and promote rapid distribution of public safety information to law enforcement and emergency management agencies.

CONCLUSION

Perhaps one of the most significant aspects of the Saragosa disaster is what it teaches about what can go wrong even with a sophisticated warning system. The most accurate and timely warnings might not be effective without coordination with local news media and public officials, training of storm spotters, and an ongoing culturally sensitive public awareness effort. Another important lesson to be learned from this disaster is that in the United States the effectiveness of warnings depends on either a common shared language and culture or adaptation of the warning system to a multilingual/multicultural social structure. Public policies and programs to lessen the destructive effects of natural disasters need to examine the cultural heterogeneity of the population they serve and to adjust their services accordingly. As Perry (1987) has indicated, officials in charge of disaster preparedness planning need to develop ethnic profiles of the communities they serve to maximize the effectiveness of their services.

Despite considerable social scientific work on warnings (see Drabek, 1986, pp. 70–99, for a thorough review of the literature), very little is known about the ways in which the dimensions of warning systems (e.g., initial responses, message quality, confirmation and coalescing behavior, and organizational and community responses) are affected by the ethnic and racial characteristics of target populations. This dearth of social science work on the interrelationships between dimensions of ethnicity and disaster-related experiences is documented in Perry's (1987) exhaustive review of the literature.

The first major study of disaster experiences of American minority citizens is that by Perry et al. (1983), but much remains to be done in this area. There is a special need for holistic analyses of the social organization and culture of ethnic communities and the meaning of disaster preparedness in these communities. Perry et al.'s study shows the importance of some elements of ethnic culture and society and argues for the systematic assessment of these matters in future studies of warning effectiveness and response. Their arguments clearly are reinforced by the postdisaster study team's observations of this May 1987 tornado in Saragosa.

NOTE

1. AWIPS (Advanced Weather Interactive Processing System), a new system for communicating and displaying weather data under development by the NWS for its operations in the 1990s.

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Appendix A

TABLE A-1 Summary of Deaths in the Saragosa Tornado

Sex	Age	Location
F	34	Frame house
F	14	Frame house
F	2	Frame house
F	77	Mobile home
F	46	Mobile home
M	70	Mobile home
F	63	Mobile home
F	66	Saragosa Hall
F	71	Saragosa Hall
M	27	Saragosa Hall
F	24	Saragosa Hall
M	25	Saragosa Hall
M	1	Saragosa Hall
M	35	Saragosa Hall
M	28	Saragosa Hall
M	57	Saragosa Hall
F	53	Saragosa Hall
F	25	Saragosa Hall
M	11 mo.	Saragosa Hall
F	30	Saragosa Hall
F	8 mo.	Saragosa Hall
F	31	Saragosa Hall
M	33	Saragosa Hall
F	49	Saragosa Hall
M	54	Saragosa Hall
F	48	Saragosa Hall
M	1	Saragosa Hall
F	30	Saragosa Hall
F	46	Saragosa Hall
F	17	Vehicle

Appendix B

Eyewitness Accounts

Presented below are accounts of the Saragosa tornado from eyewitnesses and others as communicated to NWS Survey Team members. To maintain their confidentiality, the respondents are identified only as citizens.

The night of the tornado *Citizen One* (a public official) was enroute to Saragosa Hall; he was running late. From Balmorhea he saw a dark cloud and used his sheriff's radio to put all units on standby. He proceeded to Saragosa and arrived moments after the tornado had struck. Saragosa Hall was destroyed, and he saw Citizen Two coming out carrying two crying children. There was rain and hail. He heard that someone had run into the hall and yelled a warning about the approaching tornado.

Citizen Two was assisting with the graduation exercise at Saragosa Hall. She observed that the wind was blowing very hard. The windows in the hall were high, so it was hard to see outside. One of the parents went outside and returned saying that a tornado was coming. The time was 8:10 to 8:15 p.m. Citizen Two stayed inside the hall and told people to move toward the walls. The children who had been on the stage were taken off and put under tables and against the walls; many were shielded by adults. None of the 4- and 5-year-old children participating in the graduation exercise were killed.

Citizen Two thought those in the hall had about a minute or so to protect themselves, some getting under tables by the south wall. She remembered thinking that the roof and windows would go, but she did not expect the south concrete walls to fall. She knew everyone was in great danger when the walls started to crack and crumble. She also mentioned that people in

the area listen to radio station KIUN-AM. She was unaware of earlier warnings in the day for Ward and Ector counties. After she considered attempting to escape by automobile, she remembered that in a tornado staying inside was the proper action to take.

The NWS Survey Team spoke to *Citizen Three* at the American Red Cross's temporary shelter in Balmorhea, Texas. Citizen Three was in Saragosa Hall the night of the tornado and had lost family members. She said there was no warning of the tornado, that all at once the building shook and then the walls fell. Citizen Three does not speak English, so she did not understand the warning shouted in English by one of the parents who had been outside and seen the tornado coming. Citizen Three said that she watches television stations 2, 7, and 9 in Saragosa and that she listens to a Pecos radio station. She knew the tornado safety rules about getting out of one's car and lying down in a ditch or, if in a building, getting under a strong table.

Citizen Four is a Balmorhea teacher. From the east side of Balmorhea, he observed what he called a "wild" cloud, a torn, ragged base underneath the thunderstorm. The "wild" cloud was rotating. He thought the time was about 8:15 p.m. He recalled hearing a "roaring" sound, which he described as being like a train, though no trains run anywhere near Balmorhea or Saragosa. According to his clock, the power failed in Balmorhea at 8:20 p.m.

Citizen Four stated that after the "wild" cloud and "roaring" sound there was heavy rain and golfball-size hail at his location. Then there was a second "wild" cloud but no rotation to it. He also related a report from some people he knew who were returning to Balmorhea from Pecos via Highway 17 through Saragosa. There were three individuals driving north to south through Saragosa. They saw the tornado and described it as "a wide mass that just [sat] down" after a funnel cloud had been "sucked" up into the thunderstorm. They stopped at a bar on the north side of Saragosa and went inside, where they got under a pinball machine. The building lost its roof and walls, and their car flipped over in the parking lot.

Citizen Five and his wife, daughter, and mother were traveling south on Highway 17 toward Saragosa on their way from Midland to Fort Davis. Five miles north of Saragosa they encountered rain and golfball-size hail; 4 miles north they noticed a V-shaped cloud to the west. Three miles north of Saragosa they saw a funnel cloud for about 20 seconds. At this point, Citizen Five turned back and headed north toward Pecos but then realized it was the wrong way to go since the storm seemed to be moving in that direction. He turned around again and headed back south. The funnel cloud then seemed to have dissipated.

One to 2 miles north of Saragosa he observed another funnel cloud closer to the ground and to the west. He and his family rode through Saragosa and saw people looking at the storm. When they got to Interstate 10 about 3

miles south of Saragosa, they saw a thin vertical tornado that swelled to a larger one in a few seconds. It seemed to touch down north of Interstate 10. There was no rain or wind yet.

The tornado then just dropped. Citizen Five then drove to the Interstate 10 underpass and directed his whole family into a ditch. He realized it might not be safe there, but that it was probably safer than being in the car. Soon there was rain and wind. A "blue mess" was the appearance to the north (in the direction of Saragosa). He estimated that another 10 to 15 people were also under the underpass. Some were in their cars and others were not.

Citizen Six's father had a mobile home near the bridge on Highway 17 in Saragosa. He tried to take shelter in a nearby frame home as the tornado approached, but the house was locked, so he returned to the mobile home. The mobile home was destroyed, killing his father and seriously injuring his mother. Both of Citizen Six's arms were broken.

At least five people took shelter under a nearby bridge and all walked away after the tornado. Citizen Six stated that his family did not have time to reach the bridge. He remembers a car going up and down the street honking its horn before the tornado hit. The driver then got out and took shelter under the Highway 17 bridge. Citizen Six described the storm as three distinct tornadoes, each about the size of a football field moving in a circle.

Citizen Seven had finished taking photographs of the graduation ceremony at Saragosa Hall when he began to leave. Upon exiting the hall he saw and photographed a funnel cloud southwest of Saragosa. The funnel went up and dissipated three times. The fourth time it came all the way down to the ground. People who were arriving at the hall late or leaving early saw the approaching tornado. Citizen Seven remembers that a man ran inside the hall and shouted that a tornado was coming. He estimated that the people in the hall had a 60- to 90-second warning. He also estimated that 70 to 80 people were in the hall. When the verbal warning was given, most stayed inside. After taking several pictures of the tornado, he left by car, driving north.

Appendix C

Preparedness Activities Related to Reeves County, Texas, by NWS Midland

Documented preparedness activities in Reeves County from 1985 to 1987 are described below.

1985

January 16

"Day of Killer Tornadoes" film shown at safety meeting of 15 employees of Superior Oil Company, Pecos, Texas.

March 6

Visits to KIUN/KPTX in Pecos, KERB in Kermit, and KVKM in Monahans. Discussed severe weather season and severe weather warning dissemination.

Spotter training session in Pecos; 8 attendees.

May 1 and 3

Tornado film loaned to Valero Oil Company shown at two safety meetings of 14 employees in Monahans and 16 in Pecos.

June 3

Tornado film loaned to Valero Oil Company and shown to 11 employees in Pecos.

August 25

Visit to KIUN station manager in Pecos.

1986

March 11

Spotter training session at community center in Pecos; 49 attendees. Session was announced in letter sent to officials in January.

April 20–26

Severe Weather Awareness Week in the Permian Basin of west Texas.

1987

February 12

Media Workshop held at the Midland City Hall, including news media and emergency management officials from throughout the county warning area of Midland.

February 22–28

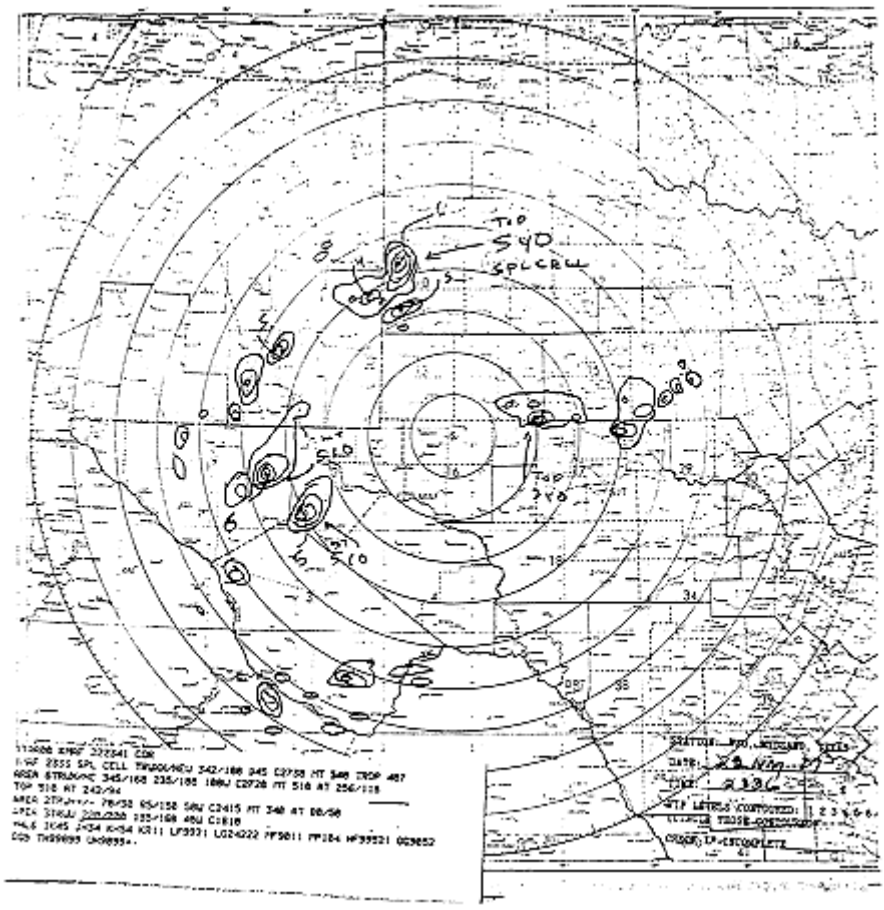
Severe Weather Awareness Week in the Permian Basin.

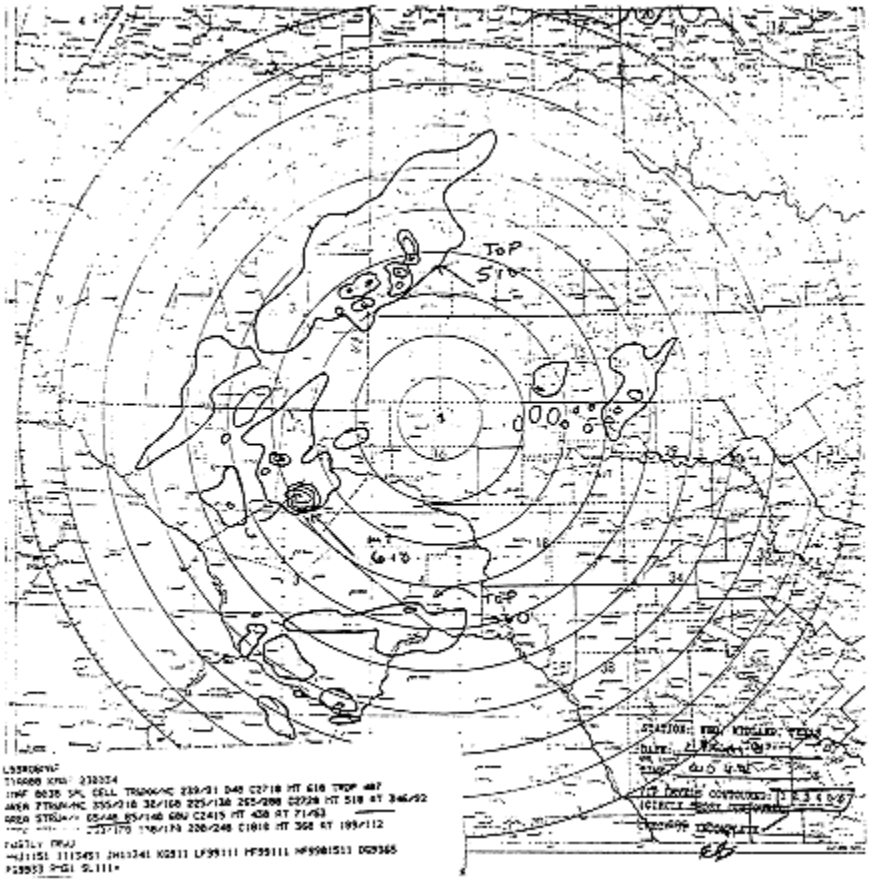
April 10

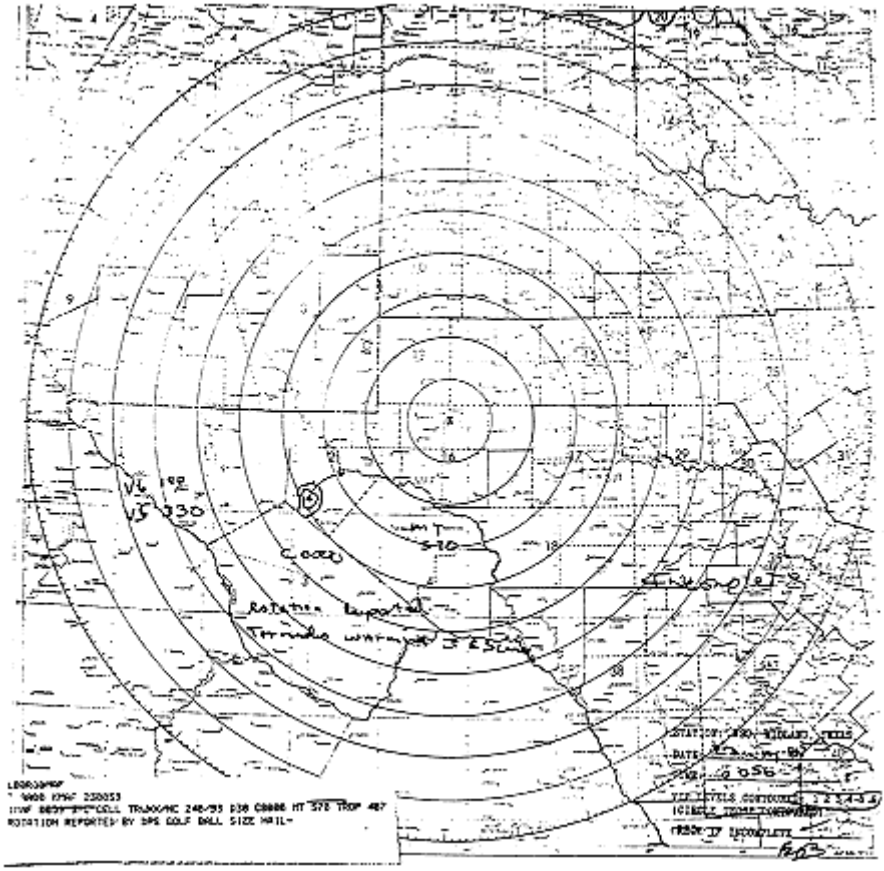
Spotter training session at the community center in Pecos, Texas; 26 attendees.

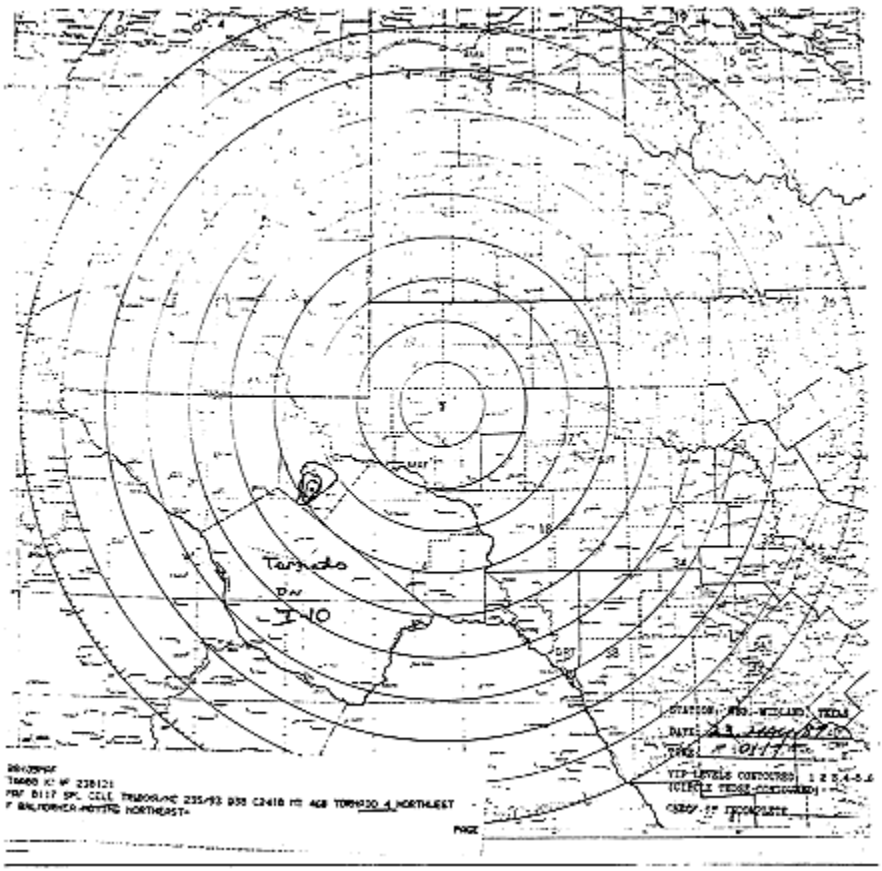
Appendix D

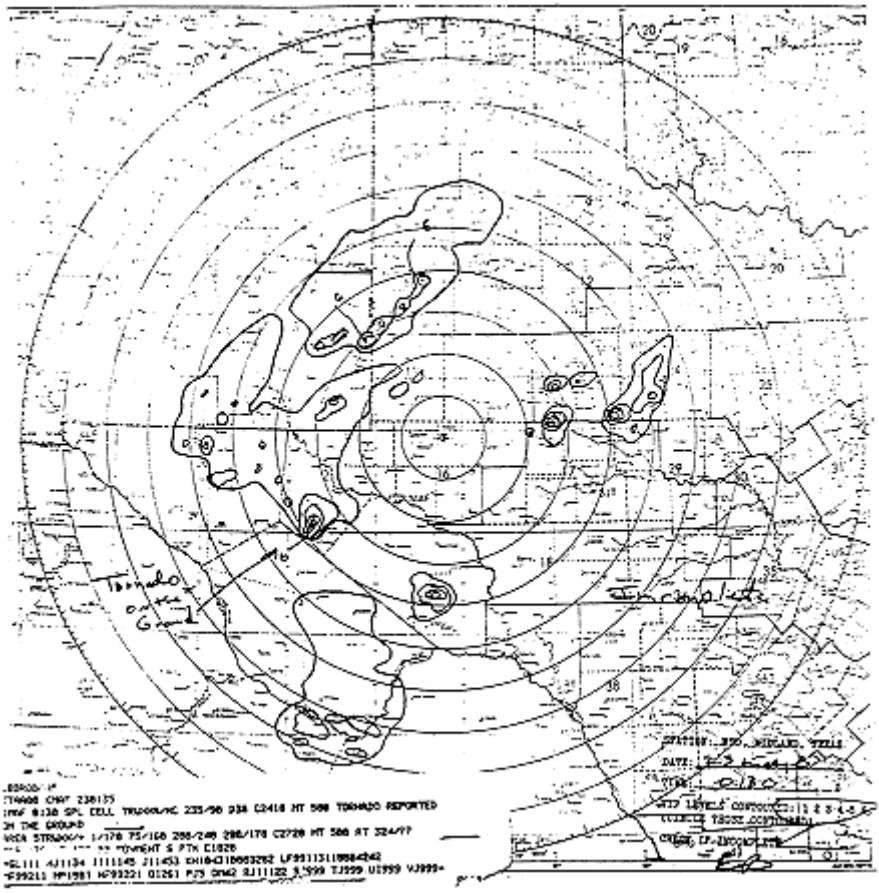
Meteorological Information on the Saragosa Tornado

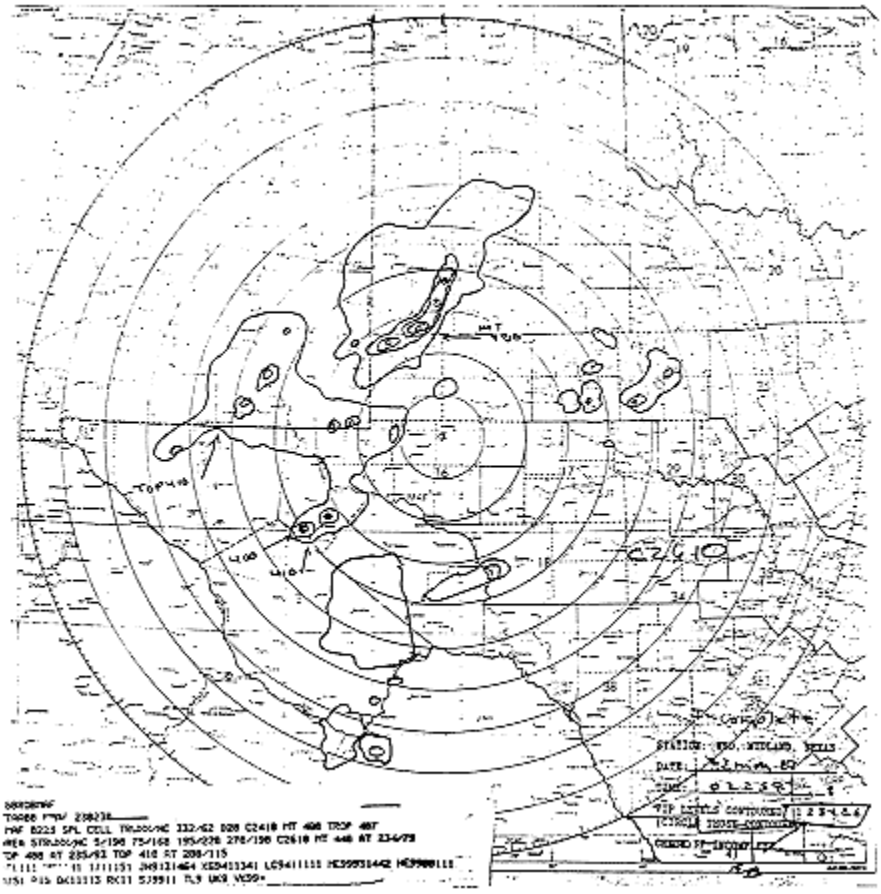


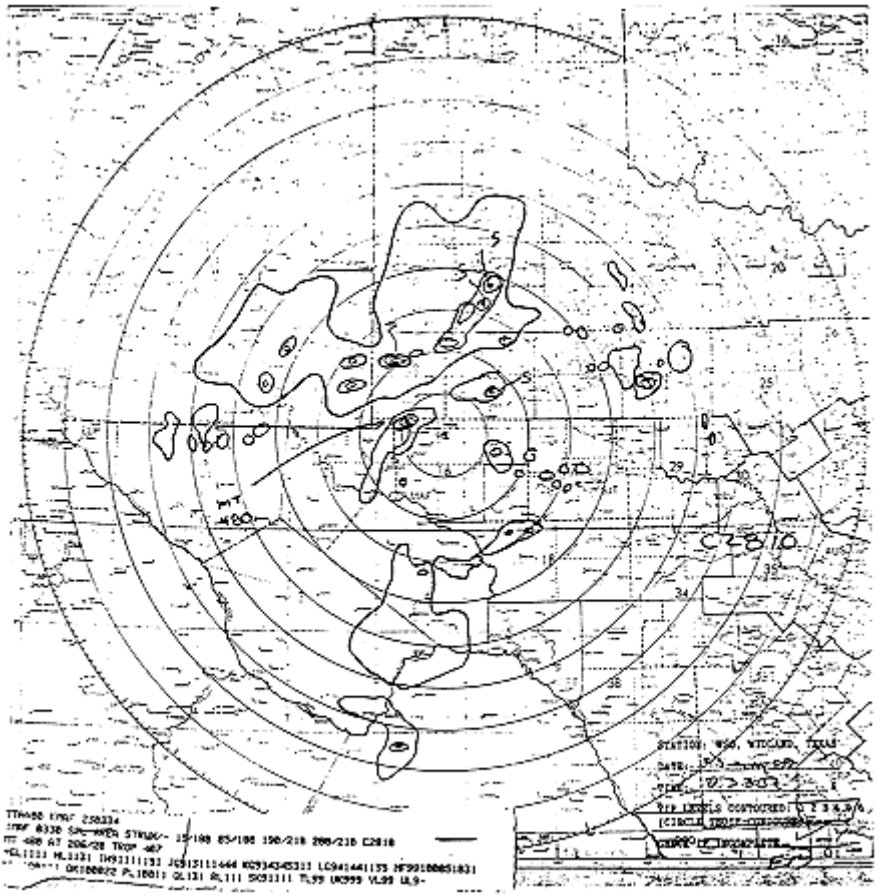


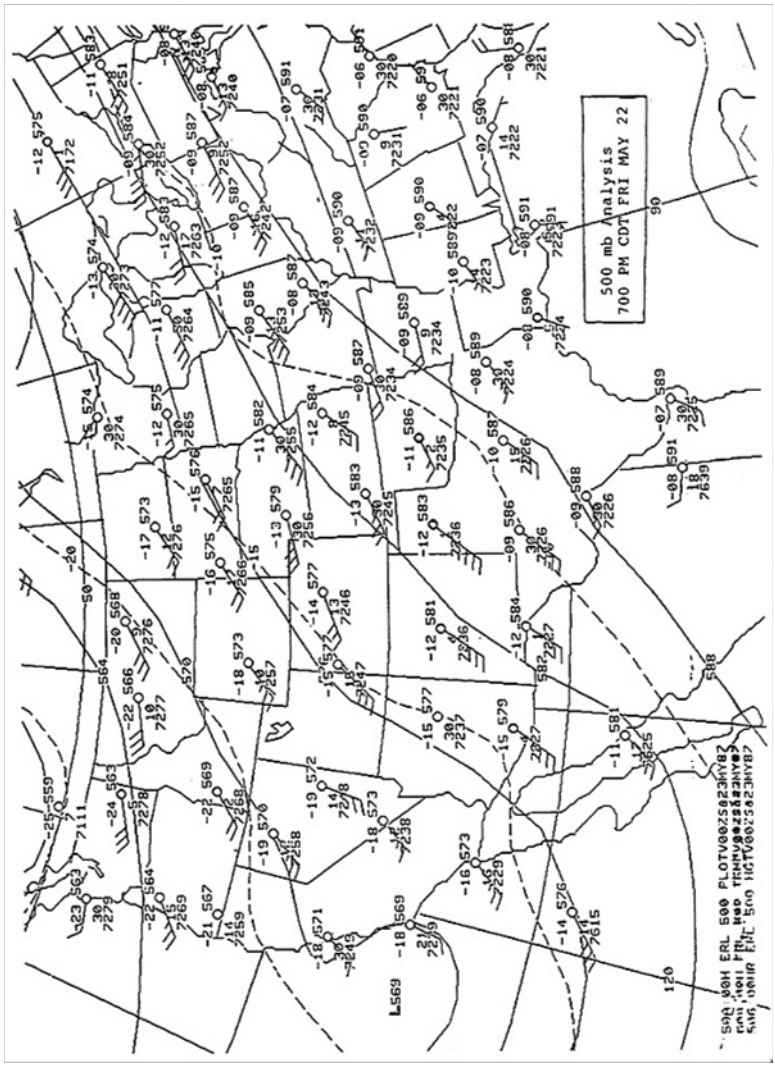


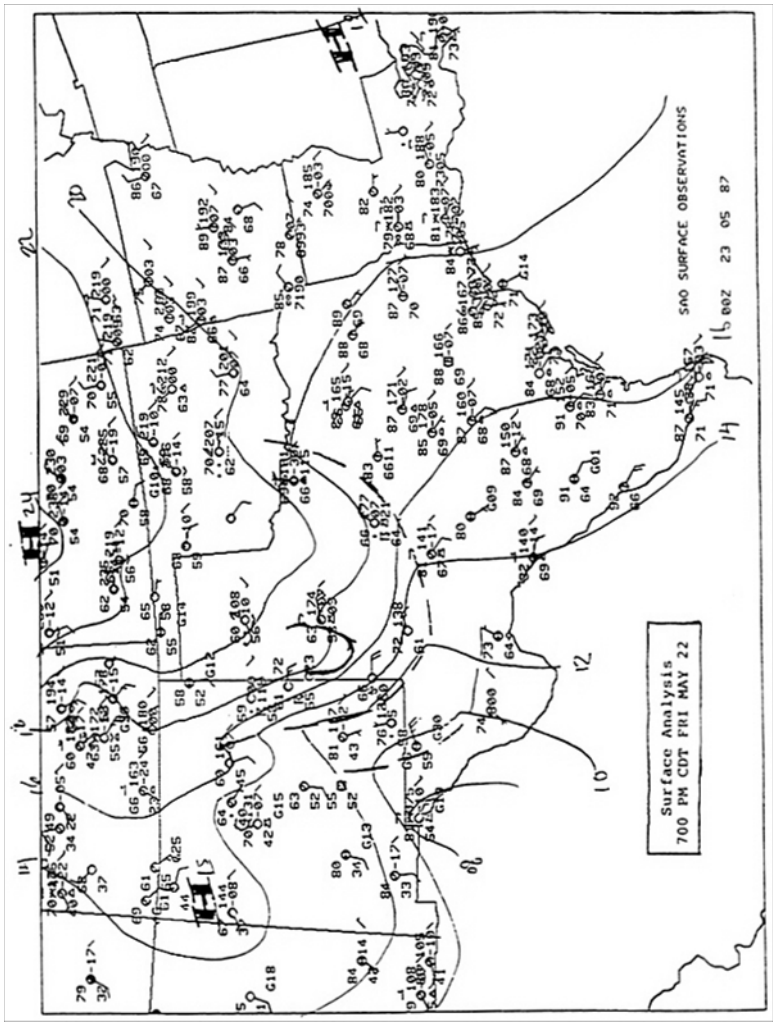












Appendix E

Chronology of Releases on West Texas Weather Wire

(All times are central daylight time [CDT].)

FRIDAY, MAY 22, 1987

3:11 p.m.

Severe thunderstorm watch no. 114 valid from 3:45 p.m. to 10:00 p.m. for a large portion of eastern New Mexico and parts of west Texas.

Aerial outline for severe thunderstorm watch no. 114 with listing of counties in northwest and southwest Texas. Aerial outline included Reeves County (Saragosa).

3:24 p.m.

Severe thunderstorm warning (LBBSVRMAF) valid until 4:30 p.m. for southwest Reeves County. Warning based on radar indication of severe thunderstorm with hail at 3:20 p.m., 20 miles northwest of Balmorhea.

3:45 p.m.

Severe weather statement and radar summary (LBBSVSMAF) headlined Reeves County warning and severe thunderstorm watch with general description of shower and thunderstorm activity in southwest Texas and southeast New Mexico.

4:10 p.m.

Special weather statement (LBBSPSMAF) included report at 3:55 p.m. of 1.75-inch hail in southwest Reeves County.

4:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) included headline for severe thunderstorm watch. Mentioned very heavy thunderstorm near Toyah (Reeves County) and report of golfball-size hail in Reeves County.

5:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) highlighted severe thunderstorm watch and described several very heavy thunderstorms across west Texas and southeast New Mexico. Mentioned that very heavy thunderstorms should continue to develop throughout the evening with the likelihood of large hail, strong gusty winds, heavy rains, and frequent lightning.

5:51 p.m.

Tornado watch no. 118 valid from 6:30 p.m. to midnight for portions of west Texas did not include Reeves County; watch area to the northeast of Reeves County.

6:34 p.m.

Severe thunderstorm warning (LBBSVRMAF) valid until 8:30 p.m. for northern Lea County, New Mexico, based on report of 0.75-inch hail at Tatum, New Mexico, and radar indication of severe thunderstorm across northern Lea County. Actual warning issued in mountain daylight time (MDT).

6:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) headlined severe thunderstorm watch, severe thunderstorm warning for north Lea County, New Mexico, and tornado warning for Cochran and Hockley counties (last warning issued by NWS Forecast Office in Lubbock). Mentioned very heavy thunderstorm in west Texas, south and west of the city of Pecos (Reeves County). Issue time of statement transmitted incorrectly as 5:50 p.m.

6:59 p.m.

Flash flood warning (LBBFFWMAF) valid until 8:00 p.m. MDT for northern Lea County, New Mexico. Thunderstorms in northern Lea County produced some highway flooding along Highway 380 near Cochran and 1.5-inch hail in the vicinity of Tatum.

7:37 p.m.

Severe thunderstorm and flash flood warning (LBBFFWMAF) valid until 9:45 p.m. for southern Reeves County. Radar indicated a severe thunderstorm 15 miles southwest of Pecos moving slowly northeast.

7:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) headlined severe thunderstorm watch and severe thunderstorm warning for Reeves County. Mentioned a very heavy thunderstorm in Reeves County southwest of Pecos.

7:54 p.m.

Tornado warning (LBBTORMAF) valid until 9:00 p.m. for southcentral Reeves County. Warning basis was given as radar indication of tornado activity 10 miles southwest of

Pecos. Warning included excellent call-to-action statement describing a "dangerous storm situation" and specifying proper tornado safety actions. (The NWS Survey Team later found that the radar operator used the leading edge of the storm for location reference.)

8:20 p.m.

Severe weather statement (LBBSVSMAF) headlined tornado warning for southcentral Reeves County and detailed report of tornado 4 miles west of Balmorhea on Interstate 10 (south-southwest of Saragosa) at 210-mile marker with movement east at 30 mph.

8:30 p.m.

Severe weather statement (LBBSVSMAF) headlined tornado warning for southcentral Reeves County and relayed report of tornado over Saragosa moving northeast at 30 mph. Damage and injuries reported at a local school and emergency personnel ordered to the area.

8:40 p.m.

Severe weather statement (LBBSVSMAF) again headlined tornado warning until 9:00 p.m. for southcentral Reeves County. Tornado reported moving through Saragosa at 8:37 p.m. with substantial damage reported.

8:55 p.m.

Severe weather statement and radar summary (LBBSVSMAF) headlined severe thunderstorm watch and reported a tornado northwest of Balmorhea at 8:35 p.m. moving northeast at 10 mph.

8:58 p.m.

Severe weather statement (LBBSVSMAF) headlined tornadoes and funnel clouds. At 8:57 p.m. a funnel cloud was reported 28 miles west of Fort Stockton. Repeated the 8:37 p.m. report that a tornado had moved through Saragosa. Report added that fatalities and substantial damage had been reported by Reeves County sheriff's department.

9:04 p.m.

Tornado warning (LBBTORMAF) valid until 10:00 p.m. for western Pecos and southern Reeves County. A funnel cloud was sighted by the Reeves County sheriff's office 28 miles west of Fort Stockton. This is the same storm that produced fatalities in Saragosa. Included call-to-action statement on proper tornado safety precautions.

9:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) headlined tornado watch for the Permian Basin and South Plains. Described very heavy thunderstorm activity across southwest Texas, including Reeves County south of Pecos.

10:25 p.m.

Special weather statement (LBBSPSMAF) discussed very heavy thunderstorms in the Midland and Odessa areas.

10:50 p.m.

Severe weather statement and radar summary (LBBSVSMAF) again headlined the tornado watch (no. 118) and described very heavy thunderstorms in southwest Texas.

11: 15 p.m.

Flash flood warning (LBBFFWMAF) valid until 1: 15 a.m., Saturday, for northern Ector County. Radar indicated slow-moving thunderstorms in northern Ector County that produced some street and highway flooding.

Note: Statements and warnings were continued into the early morning hours of Saturday, May 23; however, the severe weather was east of Reeves County and the Saragosa area by then.

Appendix F

Palestine, Texas, Tornado—November 15, 1987*

DISASTER RESPONSE

The city of Palestine, Texas, in Anderson County, is approximately 120 miles southeast of Dallas. On Sunday, November 15, 1987, a tornado hit the city at about 3:05 p.m. The tornado was part of a larger storm system that destroyed scores of homes and businesses, killed 10 people, and injured approximately 160 others in central and eastern Texas. Among the places hardest hit by tornadoes as were:

- Giddings, Lee County—a tornado destroyed an electric power station, damaged 35 homes, and injured eight persons in mostly black and Mexican neighborhoods in northeast Giddings.
- Caldwell, in adjacent Burleson County—a tornado killed two persons, injured 12, and damaged or destroyed 42 residences.
- Madison County—two people were killed and two were injured.
- Jacksonville, Cherokee County (25 miles northeast of Palestine)—two people died and 75 were injured.
- Whitehouse, Smith County—two people died and four were injured.

The tornado's path through the western part of Palestine was on average 4 miles long and one-half mile wide. It followed U.S. Highway 79 for almost 2 miles through the center of town. In Palestine (population 18,153) the Westwood subdivision bore the brunt of the damage. Fifty-one persons were injured, and one man was killed in his trailer home in the Scrougeout Community in southwest Anderson County. The tornado heavily damaged

* Prepared by B. E. Aguirre, Texas A&M University.

A. M. Story Elementary School and moderately damaged George Washington Elementary School and two churches (Lakeview Conference Center of the United Methodist Church and Camp Zion Baptist Church), as well as, according to city officials' accounts, 128 homes and 86 businesses (many of them fronted Palestine Avenue—Highway 79—from the Westwood area to Loop 256 and north to Highway 287). The city's industrial park suffered heavy damage. City officials variously estimated the damage at between $8 million and $15 million. Elsewhere in the county 65 residences were damaged, especially along the southern part of Harcrow Road, FM 1990, and Texas 294.

The number of fatalities probably would have been much higher had the tornado struck earlier in the day on Sunday or if it had occurred during a working day. For example, according to press reports, more than 350 people had just left the Lakeview Conference Center when the tornado touched down and heavily damaged 75 percent of the facilities (estimated damage $2.5 million, *Palestine Herald Press*, November 16, Sec. B, p. 2). Camp Zion Baptist Church was completely demolished; earlier in the day about 50 people had attended worship services there. Westside Assembly of God, which sustained moderate damage, had worship services earlier in the day for about 100 people (*Palestine Herald Press*, November 17, Sec. B, p. 6).

WARNING DISSEMINATION

The author was interested in finding out how many people in the sections of Palestine struck by the tornado had been warned about the seriousness of the approaching bad weather and about the likelihood and actual occurrence of tornadoes. Because of lack of resources, it was not possible to survey a representative sample of the population to find an answer to this question. Thus, the observations made below are provisional, based on what the author found during his visit to the city.

Similar to the Saragosa event, warnings about the strong probability that a tornado would strike Palestine were given well in advance of the time of impact. According to press reports, a spokesperson for the National Weather Service mentioned that a tornado watch had been issued for Anderson County at 8:45 a.m. on Sunday and that a tornado warning was issued at 2:55 p.m. The sheriff received a call at 2:05 p.m. from the Fort Worth National Weather Station warning him to expect very high winds, heavy rains, and probable tornadoes in southern Anderson County by 3:00 p.m. that afternoon. This warning was extremely accurate, missing the actual time of tornado impact by 5 minutes.

Although given well in advance, to the extent that the author could verify during his visit, the warning did not reach the citizens of Palestine. Ac

cording to the sheriff, he did not have the means to use the information at his disposal to warn people in the county. He had only two deputies on duty that afternoon, and there were no mechanisms in place to effectively disseminate warnings in the county. The sheriff knew but could not tell his fellow citizens what was expected to happen.

Radio station KLIS in Palestine was very active in broadcasting weather information the day of the disaster. It gave severe weather warnings throughout the day and began Emergency Broadcasting Service (EBS) at 2:48 p.m., after the station manager received a call from the weather station at Fort Worth, Texas, informing him that a tornado was approaching Palestine from the southeast. KLIS was knocked off the air by a tornado at 3:08 p.m., after approximately 15 minutes of EBS. It is unknown how many and what kind of people in the county heard the warnings broadcast by KLIS. In this study the author did not find anyone who was warned through the radio broadcast.

There is some circumstantial evidence that the warnings did not reach a significant proportion of the people of Palestine. Accounts in the press bear this out. For instance, the *Palestine Herald Press* (Monday, November 16, 1987, p. 10a) reported that "Dexton Shores, pastor of First Hispanic Baptist Church, rode out the storm with his wife and two sons in their small frame house Sunday. 'It was just a complete surprise—we had no warning at all,' he said." Another article stated that "E. R. Thompson, 74, was asleep on the couch of the living room of his home at 205 West Point Tap Road next to the Texas Animal Health Commission when the wind shattered the windows of his home."

The author asked a number of people who were working in businesses along U.S. 79 the afternoon of the tornado if they had been warned; none had. A case in point is the story in the *Palestine Herald Press* (November 16, Sec. B, p. 1) of a woman who called her place of work on U.S. 79 to warn her unsuspecting fellow workers. "My husband is a policeman and had called home to warn me," she explained. Her call arrived just as the business was being demolished by the tornado. This story is interesting because it shows that when an effective system of warning the public is absent the information becomes privatized and dependent on preexisting social relationships. Segments of the public are warned; others are left out.

This point can be illustrated another way. The author interviewed people in 15 Westwood households located in the path of the tornado. People in 10 of the households received no warning. In the remaining households only one person mentioned that at 10:00 a.m. he heard on television that thunderstorms were possible for Palestine. He received no other warning, however, and was watching a football game when the electricity went out and the tornado struck. A man in another household had a similar experience. His daughter

called him during the morning and told him that the town was under a tornado watch, but he received no other warning and was watching a football game on television when the tornado struck. People in the other three households were the only ones who knew about the approaching tornado. They learned about it through their police scanners, which they listened to on a regular basis. To most people the tornado was a complete surprise. People learned of the danger by the noise of thunder and hail, the high wind, increasing darkness, the change in air pressure felt in their ears, and the electricity going off as the tornado moved through town.

CONCLUDING REMARKS

In Palestine, as in Saragosa, cable television blocked the dissemination of the warning. People were watching football games in Dallas and Atlanta, and those stations did not broadcast the tornado warning for Palestine. It is surprising to note from the author's preliminary findings that the local radio station was so ineffective. A much larger survey of the town's population is needed to ascertain the facts with greater accuracy and to evaluate the effects of social class on relative use of radio. Perhaps the reason that radio was so ineffective is that Westwood is a predominantly working-class, blue collar subdivision of the city of Palestine whose residents tend to listen less frequently to radio broadcasts. It is possible that better-off residents of other subdivisions of the city heeded the radio warnings to a much greater extent.

Perhaps effective warning dissemination is a much more difficult problem than this author originally thought. In Saragosa, the author emphasized the cultural factors that blocked warning dissemination, but apparently cultural differences are only one of a number of factors contributing to the problem, which can be identified as our society's seeming inability to use the considerable hazard predictive knowledge available to protect human lives. The author would argue that the present emphasis on weather research and on ways (e.g., through the development of more sophisticated radar) to increase the lead time between hazard detection and warning dissemination is valuable but sorely incomplete. Even with an hour's lead time, as in Palestine—which is extraordinary in the case of tornadoes—warning dissemination can break down at the county and city levels. It may be that increasing lead time in the future will not, in the end, protect lives in the absence of effective social and communications arrangements at the local and community/county levels.

Methods for improving warning dissemination should be a top national priority. Demonstration projects are needed in areas of high tornado risk to assess how alternative means of dissemination work in practice. Such demonstration projects would have to be closely monitored and evaluated for

effectiveness by a central funding agency to ensure that the results could be compared and would complement each other. The results of these demonstration efforts should facilitate recommendations for national policy in this area. It is this author's recommendation that the National Research Council consider creating a panel of scholars in the field of disaster research to develop the technical specifications for such demonstration projects.