Natural Disaster Survey Report

DISASTROUS FLOODS ON THE TRINITY, BRAZOS, COLORADO, AND GUADALUPE RIVERS IN TEXAS

December 1991 - January 1992

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service, Silver Spring, Maryland

Cover: Flooded homes in the Valley Lodge subdivision in Simonton, northwest Fort Bend County, Texas, on the Brazos River. Photograph courtesy Rod Hooks of the Houston Post.

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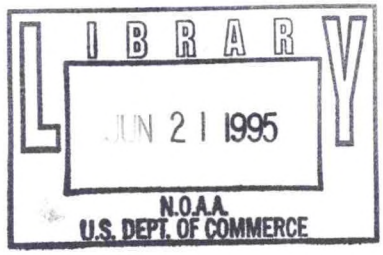

U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
Dr. D. James Baker, Administrator

National Weather Service
Dr. Elbert W. Friday, Jr., Assistant Administrator

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FOREWORD

The National Weather Service (NWS), one of the major line offices of the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), has broad federal responsibility to provide public forecasts and warnings of weather and river conditions for the protection of life and property and in support of the Nation's commerce. NOAA conducts a survey of major natural disasters to thoroughly assess the performance of its warning system in all aspects, from data collection and assimilation through creation and dissemination of products and, ultimately, including effective user response. This report of the survey team's findings regarding the disastrous floods of the south-central United States in 1991 and 1992 identifies opportunities to improve NOAA's weather and flood warning system, not only in the affected region but throughout the Nation.

The survey team was sent to the region affected by major flooding in January 1992. The team visited NWS offices that provide flood warning service to the affected region. They interviewed numerous officials and representatives of the print and broadcast media.

The survey team deserves thanks for its efforts in compiling this report, but I would like to express the special gratitude of the NWS to the numerous Federal, State, and local officials and media representatives in Texas who helped the survey team. Having provided admirable service to the public through this disastrous flood event, you also aided the survey team to evaluate NOAA's warning services.

Elbert W. Friday, Jr.
Assistant Administrator
for Weather Services

PREFACE

Quite possibly the most voluminous flooding in the recorded history of the State of Texas occurred during late December 1991 and into January 1992. Virtually the entire eastern half of the State experienced significant flooding, though four major river basins were hardest hit: the Trinity, the Brazos, the Colorado, and the Guadalupe. Several locations along these and numerous other rivers and streams observed record stages or flows, while at least six major reservoirs also set new elevation and/or storage records. The flooding claimed at least 13 lives and caused damages (primarily agricultural) estimated at close to $100 million. A NOAA disaster survey team assembled for its first meeting in Fort Worth, Texas, on the afternoon of January 5, 1992. All aspects of weather and flood warning systems--from data acquisition to user response--were surveyed to determine NOAA's effectiveness and to recommend improvements if deficiencies were found. This report gives the results and findings of the survey team.

The survey team consisted of the following individuals:

Robert Mahler, Team Leader and Deputy Director, Environmental Research Laboratory, Boulder, Colorado

Robert Tibi, Chief, Hydrologic Services Division, Western Region Headquarters, National Weather Service, Salt Lake City, Utah

Charles Hoffeditz, Hydrologic Services Division, Office of Hydrology, National Weather Service Headquarters, Silver Spring, Maryland

Andy Anderson, Meteorologist in Charge/Area Manager, Lubbock Weather Service Forecast Office, Lubbock, Texas

Kevin Stewart, P.E., Special Consultant and Flash Flood Program Manager, Urban Drainage and Flood Control District, Denver, Colorado

Dean Braatz, Hydrologist in Charge, North Central River Forecast Center, Minneapolis, Minnesota

José Garcia, Warning Coordination Meteorologist, Amarillo Weather Service Office, Amarillo, Texas

Pat Slattery, NOAA Public Affairs Officer, Central Region Headquarters, National Weather Service, Kansas City, Missouri

Background and overview information on the hydrologic situation, which appears in Chapter 1, was contributed by Scott Kroczynski of the Hydrometeorological Information Center, Office of Hydrology, Silver Spring, Maryland.

Descriptions of the meteorological conditions and forecasts, which are presented in Chapter 2, were contributed by Bruce Sullivan, Chuck Hodges, and Paul Kocin of the Meteorological Operations Division, National Meteorological Center, Camp Springs, Maryland.

The team was divided into two groups during parts of the survey so that the wide geographic area of interest could be covered efficiently. One group, composed of Mahler, Garcia, Slattery, and Stewart, concentrated on the lower river basins in Texas. The other group, composed of Tibi, Hoffeditz, Braatz, and Anderson, concentrated on the upper basins. During the week, the two teams coordinated their progress by meetings and telephone calls. The entire survey team met in Fort Worth and San Antonio on Sunday, January 5, through Tuesday, January 7. The survey team conducted its field work on Monday, January 6, through Friday, January 10.

The consensus of the survey team was that, overall, NOAA provided good, high-quality services throughout this event. Successful features of NOAA's services program, as well as recommendations for improvement, are discussed in subsequent sections of this report.

Robert J. Mahler
Team Leader

EXECUTIVE SUMMARY

Most of Texas experienced an abnormally wet year during 1991. Every month, except March and November, had generally normal or above-normal precipitation. August-October 1991 were particularly wet across the northeast quarter of Texas. During October, the Dallas/Fort Worth Airport recorded 9.32 inches of rainfall--well over three times the normal amount of 2.47 inches. Numerous locations in and around Dallas received over 12 inches in October, while some locations reported nearly 15 inches. Following a somewhat dry November, precipitation increased again in December, significantly across the eastern half of the State. The first week of December brought moderate precipitation but was followed by heavy precipitation across the region during the second week. Then, in just a 6-day period December 18-23, excessive rainfall occurred over a huge area of Texas. Nearly one-half of the State received 4 or more inches of rain.

All of these conditions induced one of the most voluminous floods recorded in the history of the State of Texas during late December 1991 into January 1992. Virtually the entire eastern half of the State experienced significant flooding, though four major river basins were hardest hit: the Trinity, the Brazos, the Colorado, and the Guadalupe. Several locations along these and numerous other rivers and streams observed record stages or flows, while at least six major reservoirs also set new elevation and/or storage records. The counties most heavily damaged were concentrated along the Trinity, Brazos, Colorado, and Guadalupe Rivers and their tributaries. At least 13 deaths were attributed to the flooding, while evacuations numbered in the hundreds. Major economic losses occurred in the agricultural industry as hundreds of thousands of acres of farmland were inundated by floodwaters. Additionally, considerable damage was done to roads, bridges, culverts, and the like, as well as to several water and sewage treatment plants. Businesses and residences were also affected, bringing an estimate of total damages at close to $100 million.

A NOAA disaster survey team traveled around the affected area visiting several weather offices and interviewing numerous officials, representatives of the media, and the public. Its purpose was to assess the effectiveness of the overall hydrologic forecast and flood warning system and to make recommendations to improve the system. In doing so, it is necessary to differentiate between the performance of the NWS employees and the inherent deficiencies in the technologies available to the employees responsible for providing the services. The performance of the NWS employees was admirable. Their exemplary efforts were truly worthy of recognition and praise for they clearly demonstrated how team efforts and devotion to providing service to the public is characteristic of the high level of professionalism that has been a long-standing tradition in the NWS during events of this nature. The disaster survey team also found that the NWS offices have maintained a good relationship with emergency operation center officials and with the media. The media received and distributed the NWS watches and warnings in sufficient time for the public to take appropriate action to protect lives and property. While significant amounts of property were damaged and/or lost,

individuals were able to take advantage of the timely warnings and remove their possessions. As is frequently the case, most of the deaths that occurred were due primarily to individuals driving into moving waters which then swept their vehicles downstream.

Some difficulties were encountered in forecasting the lower Brazos River. Several forecasts indicated the rivers would rise higher or would crest sooner than they did. Even though flood stage was reached 2 days later than was originally predicted, the flood did exceed flood stage as forecasted; and homeowners in the area had sufficient time to remove their belongings. Most of the deficiencies identified by the survey team, and especially those experienced on the lower Brazos River, resulted from inadequate technological capabilities within the current forecast and warning system. While the overall quality and accuracy of the forecasts were high, those for the lower Brazos River can be significantly improved through implementation of more sophisticated procedures for forecasting flood waves. These techniques for forecasting flood waves, such as the Dynamic Wave Model, use more detailed model physics to predict water levels and velocities at multiple locations and to account for the reduced velocity of the flood wave as the river spreads out over extensive low-lying areas such as the farmland adjacent to the Brazos River. In large measure, most of the identified deficiencies will be corrected as part of the NWS modernization and associated restructuring. A summary of all the findings and recommendations resulting from this disaster report can be found in Appendix A.

ABBREVIATIONS AND ACRONYMS

AFOS	Automation of Field Operations and Services
ALERT	Automated Local Evaluation in Real-Time
ASAP	AFOS SHEF Automatic Processing system
ASOS	Automated Surface Observing System
AVN	AViatioN model
AWIPS	Advanced Weather Interactive Processing System
BF	Bankfull Stage
C	Celsius
CADAS	Centralized Automatic Data Acquisition System
CS	Caution Stage
CST	central standard time
EBS	Emergency Broadcast System
ECMWF	European Center for Meteorology and Weather Forecasting model
E-19	Description and history of a river forecast point (WS Form E-19)
ETA	Greek letter that identifies mesoscale model under development by NMC
F	Fahrenheit
FS	Flood Stage
gpm	geopotential meters
GOES	Geostationary Operational Environmental Satellite
HDRain	Hourly digital rainfall
HIC	Hydrologist in Charge
HSA	hydrologic service area
LARC	Limited Automatic Remote Collector
LFM	Limited Area Fine Mesh Model
LFWS	local flood warning system
mb	millibar
MIC	Meteorologist in Charge
MRF	Medium Range Forecast (model)
NCCF	NOAA Central Computer Facility
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar (WSR-88D)
NGM	Nested Grid Model
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSRFS	NWS River Forecast System
NWWS	NOAA Weather Wire Service (CONTEL)
PC	personal computer
QPF	quantitative precipitation forecast

RACES	Radio Amateur Civil Emergency Services
RDC	Regional Distribution Circuit (of the AFOS system)
RFC	River Forecast Center
RJE	remote job entry
SH	Service Hydrologist
SHEF	Standard Hydrometeorological Exchange Format
SHIMS	Service Hydrologist Information Management System
UKMET	United Kingdom Meteorology office model
UTC	Universal Coordinated Time
VAS	VISSR Atmospheric Sounder
VDUC	VAS Data Utilization Center
VISSR	Visible Infrared Spin Scan Radiometer
WARFS	Water Resources Forecasting System
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WGRFC	West Gulf River Forecast Center
WPM	Warning Preparedness Meteorologist (Under the NWS modernization and associated restructuring, this position will become Warning Coordination Meteorologist.)
WS	Warning Stage
WSFO	Weather Service Forecast Office
WSI	Weather Services, Inc.
WSMO	Weather Service Meteorological Observatory
WSO	Weather Service Office
WSR-88D	Weather Surveillance Radar-1988 Doppler (NEXRAD)
WSR-57	Weather Surveillance Radar-1957 (non-Doppler technology)

CHAPTER 1
BACKGROUND AND OVERVIEW OF HYDROLOGIC SITUATION

1.1 Introduction

Quite possibly the most voluminous flood in the recorded history of the State of Texas occurred during late December 1991 into January 1992. Virtually the entire eastern half of the State experienced significant flooding, though four major river basins were hardest hit: the Trinity, the Brazos, the Colorado, and the Guadalupe. Several locations along these and numerous other rivers and streams observed record stages or flows, while at least six major reservoirs also set new elevation and/or storage records. The flooding claimed at least 13 lives and caused damages (primarily agricultural) estimated at close to $100 million.

1.2 Antecedent Conditions

Much of the eastern half of Texas had experienced an abnormally wet year during 1991. Since the beginning of calendar year 1991, only 2 months had precipitation significantly below normal across eastern Texas: March and November. Every other month had generally normal or above-normal precipitation. August-October 1991 were particularly wet across the northeast quarter of Texas. As an example, during October the Dallas/Fort Worth Airport recorded 9.32 inches of rainfall, which was well over three times the normal amount of 2.47 inches. Numerous locations in and around Dallas received over 12 inches, while some locations reported nearly 15 inches. Ironically, October began as one of the driest months on record at Dallas and across much of northeastern Texas, with little or no precipitation until the last week of the month. November 1991 was abnormally dry across most of this same area. Again, using Dallas/Fort Worth as an example, only 1.04 inches of rainfall was recorded there in November, which was 0.72 inch below normal. It is interesting to note that the dry November did allow for some improvement in the hydrological conditions across eastern Texas. One unanswered question which arises from this fact is: What effect would a wet or even normal November have had on the December flooding? At any rate, eastern Texas entered into December with above-average soil moisture content as well as above-average streamflow conditions (see Figure 1). These soil-moisture and streamflow conditions were the result of persistent, above-normal precipitation throughout much of 1991, including a very wet October.

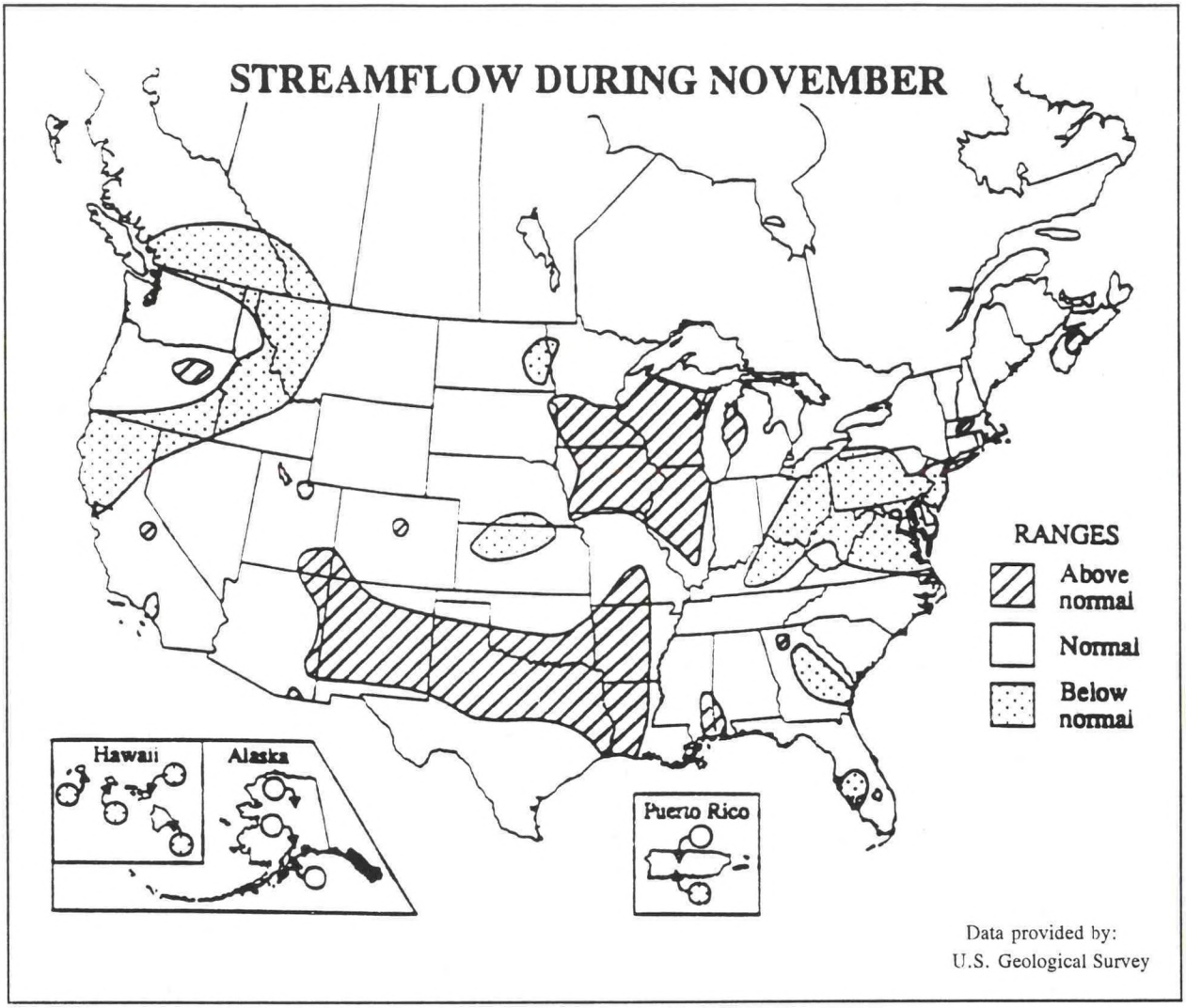

Figure 1. *National streamflow conditions, November 1991.*

1.3 Flooding in December 1991

Following the dry November, precipitation increased significantly across the eastern half of Texas in December. While moderate precipitation occurred during the first week of December, heavy precipitation occurred across the region during the second week. Then, during the period December 18-23, excessive rainfall occurred over a huge area of Texas, as evidenced by the fact that nearly one-half of the State received 3 or more inches of rain (see map on page 7).

Using the isohyetal map on page 7, a rough calculation was made to derive the volume of rain which fell during the period December 18-23. From this calculation, it is estimated that nearly 53 million acre-feet of water fell, which is comparable to the entire reservoir storage

system of the State of California (approximately 60 million acre-feet). Using Dallas/Fort Worth again as an example, 8.75 inches of rain fell during December--more than five times the December normal of 1.67 inches. This was the wettest December on record at Dallas/Fort Worth, which contributed to making 1991 the wettest year on record (since 1898) with a total of 53.54 inches recorded (average is 29.46 inches). With hydrologic conditions being wetter than normal from previous rainfall, especially in October, the large volume of December rainfall (particularly December 18-23) almost immediately began to run off, creating widespread flash flooding[1]. As soils became nearly saturated, and with most small streams and rivers running full or flooded, the relentless rains finally led to widespread major river flooding across much of eastern Texas. The river flooding generally peaked during the last week of December, but flooding continued well into January. As previously stated, the flooding was most significant along the Trinity, Brazos, Colorado, and Guadalupe Rivers and their tributaries.

1.4 Impact of the Flooding

Figure 2 shows the counties in the flood-stricken region that were declared Federal disaster areas. This figure clearly shows that the counties most heavily damaged were concentrated along the Trinity, Brazos, Colorado, and Guadalupe Rivers and their tributaries. At least 13 deaths were attributed to the flooding, while evacuations numbered into the hundreds. Major economic losses occurred in the agricultural industry as hundreds of thousands of acres of farmland were inundated by floodwaters. Additionally, considerable damage was done to roads, bridges, culverts, and the like, as well as to several water and sewage treatment plants. Businesses and residences were also affected, bringing an estimate of total damages at close to $100 million.

1.5 Overview of NWS Services

The disaster survey team findings indicate that, overall, the NWS did well in providing watches and warnings for the event even though there were some problems with the forecasts for the lower Brazos River, which are detailed in Chapter 5 of this report. The media received NWS watches and warnings and passed them on with sufficient time for the public to take appropriate action. While significant amounts of property were damaged and/or lost, many people were able to take advantage of the timely warnings to remove their possessions. There were 13 deaths. As is frequently the case, most of the deaths were due to individuals driving into fast-moving floodwaters which swept their vehicles downstream.

Despite the overall high quality of services provided by the NWS during this event, the survey team has developed a number of recommendations to further improve and enhance services. These recommendations are contained in more detailed discussions in the chapters which follow and are repeated in summary fashion in Appendix A for convenience.

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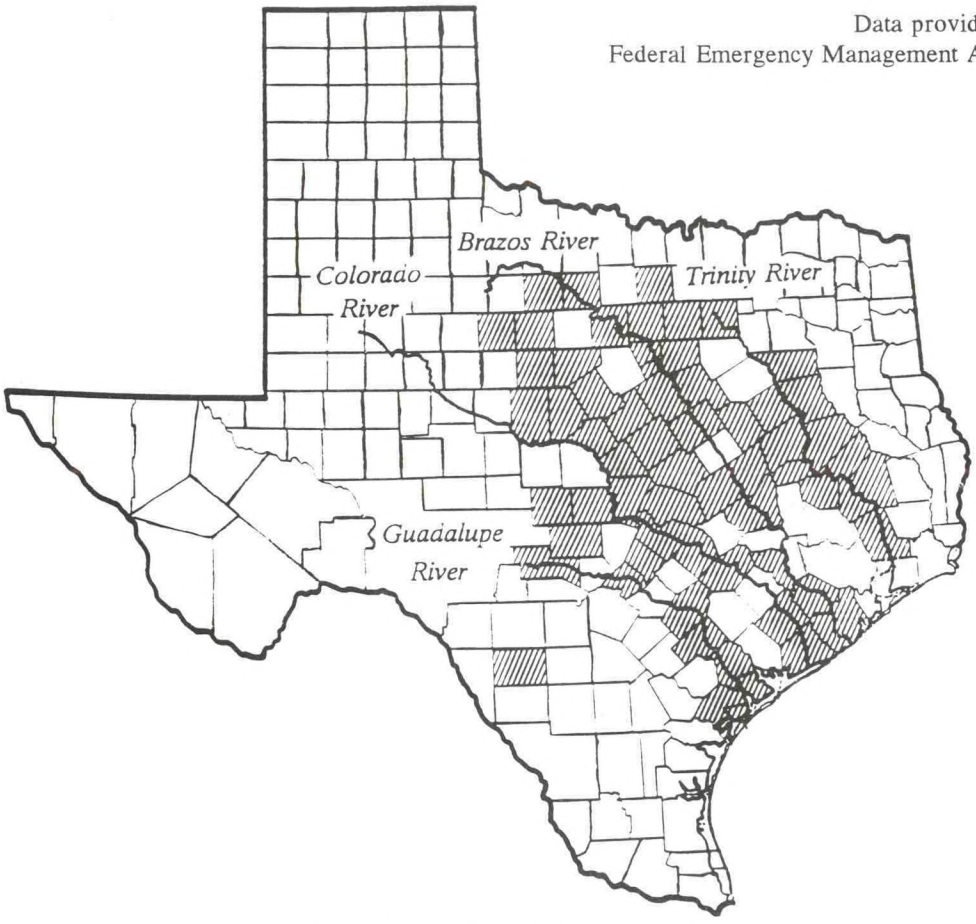
[1] Flash flooding develops rapidly as a result of intense precipitation and generally is of relatively short duration. Typically, small streams and urban areas are affected. When these conditions persist over prolonged periods of time, the cumulative effect can lead to significant flooding of major river systems. This is precisely what occurred from mid-December into early January across eastern Texas.



Counties Declared for Individual Assistance

Anderson	Coryell	Jones	Refugio
Aransas	Dallas	Kerr	Robertson
Austin	Dewitt	Lampasas	San Jacinto
Bastrop	Eastland	Leon	Shackelford
Bell	Fayette	Liberty	Somervell
Bosque	Fort Bend	Limestone	Tarrant
Brazoria	Freestone	Llano	Throckmorton
Brazos	Gillespie	Madison	Travis
Brown	Gonzales	Mason	Trinity
Burleson	Hamilton	Matagorda	Victoria
Burnet	Hays	McLennan	Walker
Calhoun	Henderson	Milam	Wharton
Callahan	Hill	Mills	Williamson
Coleman	Hood	Palo Pinto	Wise
Comal	Houston	Parker	Young
Comanche	Johnson	Polk	Zaval

Figure 2. *Texas counties declared Federal disaster areas (shaded) as a result of the December 1991-January 1992 flood event. (Declared counties are listed alphabetically.)*

1.6 NWS Modernization Plans

Although the focus of this report is the evaluation of NWS services during the flooding in December 1991, it is appropriate to comment briefly on the likely impact of known plans for NWS modernization on the ability of the NWS to improve its services for future similar events. The new Next Generation Weather Radar (NEXRAD), referred to as Weather Surveillance Radar-1988 Doppler (WSR-88D), will use an advanced, multistage precipitation processing system to provide high-resolution precipitation estimates. This precipitation processing system will use real-time data from ground-based gages, such as the new Automated Surface Observing System (ASOS), to provide adjustments to biases in radar precipitation estimates. Use of WSR-88D precipitation estimates will remove much of the uncertainty in rainfall amounts and locations that plague the delivery of accurate flood and flash flood warnings. Full national implementation and acceptance of the new WSR-88D network is expected to be completed in the 1996-1997 time frame. Early in a flood event, especially, there is the greatest opportunity to provide sufficient lead-time to maximize effective response by citizens to the warning. In a similar vein, the delivery speed of more accurate warning products could increase with the ability of the planned Advanced Weather Interactive Processing System (AWIPS) to integrate radar, satellite, and surface data sources; to analyze the assimilated data; and to quickly present results to the forecaster. It is obvious that longer lead-time products for water facility (reservoir) operations have the potential to improve flood control. The advanced technology for the planned Water Resources Forecasting System (WARFS) program can provide longer lead-time water management products that are not part of current NWS hydrologic services except on an experimental/prototype basis. Finally, the NWS plans to staff River Forecast Centers (RFC) for nominal 16-hours-per-day operations that will provide improved support throughout extended floods, such as this event.

1.7 Findings and Recommendations

Finding 1-1: The NWS plans for modernization and restructuring (including technological programs such as WSR-88D, AWIPS, and ASOS; staffing realignment; and enhanced WARFS) offer substantial opportunities to improve services for future major flooding events of this nature.

Recommendation 1-1: Continued effort must be made to keep the NWS modernization plans and implementation of new technology on schedule and to accelerate them wherever possible.

CHAPTER 2
METEOROLOGICAL CONDITIONS AND GUIDANCE

2.1 Introduction

A rainfall event of historical proportions occurred across central and eastern Texas during a 6-day period December 18-23, 1991. An area of rainfall greater than 3 inches extended across most of east Texas from the Red River southward to near Corpus Christi. Precipitation amounts exceeded 10 inches over south-central Texas, with several locations receiving over 15 inches (see Figure 3). While the southern plains are often deluged by flood-producing rainfall, the areal extent of the excessive rains that fell on December 18-23 dwarfed most of the more common events, led to widespread flooding, and established new monthly rainfall records. Additional rainfall events occurred within the 2 weeks prior to this episode. These preceding events likely contributed to high antecedent streamflow conditions, such that less than 2 inches of rain in a 3-hour period were necessary to initiate flash flooding in several Texas zones on the day before the heavy rains began. Normally, higher rainfall rates are necessary to initiate flash flooding.

2.2 Meteorological Conditions

An excessive rainfall event plagued much of south-central Texas during the period December 18-23, 1991. Figure 4 depicts the daily rainfall totals for the 6-day period. The event began on December 17 with generally light, 24-hour rainfall amounts totaling 0.50-1.00 inch over portions of central and south-central Texas, ending 1200 UTC, December 18, 1991. Rainfall amounts dramatically increased the following day, December 19, with a large 1-inch area encompassing much of the south-central portions of Texas. Areas to the south of San Antonio were hardest hit, with up to 8 inches reported. More pronounced, heavy rainfall occurred on December 20 with an area greater than 2 inches that stretched from central Oklahoma southward to south-central Texas. Over 5 inches fell to the east of San Angelo, while up to 8 inches fell in the San Antonio and Austin areas.

The peak rainfall occurred on December 21 as the axis of heaviest rain shifted southeastward with a 150-mile-wide area of greater than 2 inches of rain falling east of a line from Mineral Wells to Eagle Pass. From a hydrological point of view, this was a worse-case scenario as the excessive rainfall storm maxima moved downstream in the direction of the floodwater runoff of 8-12 inches of rain that fell on previous days.

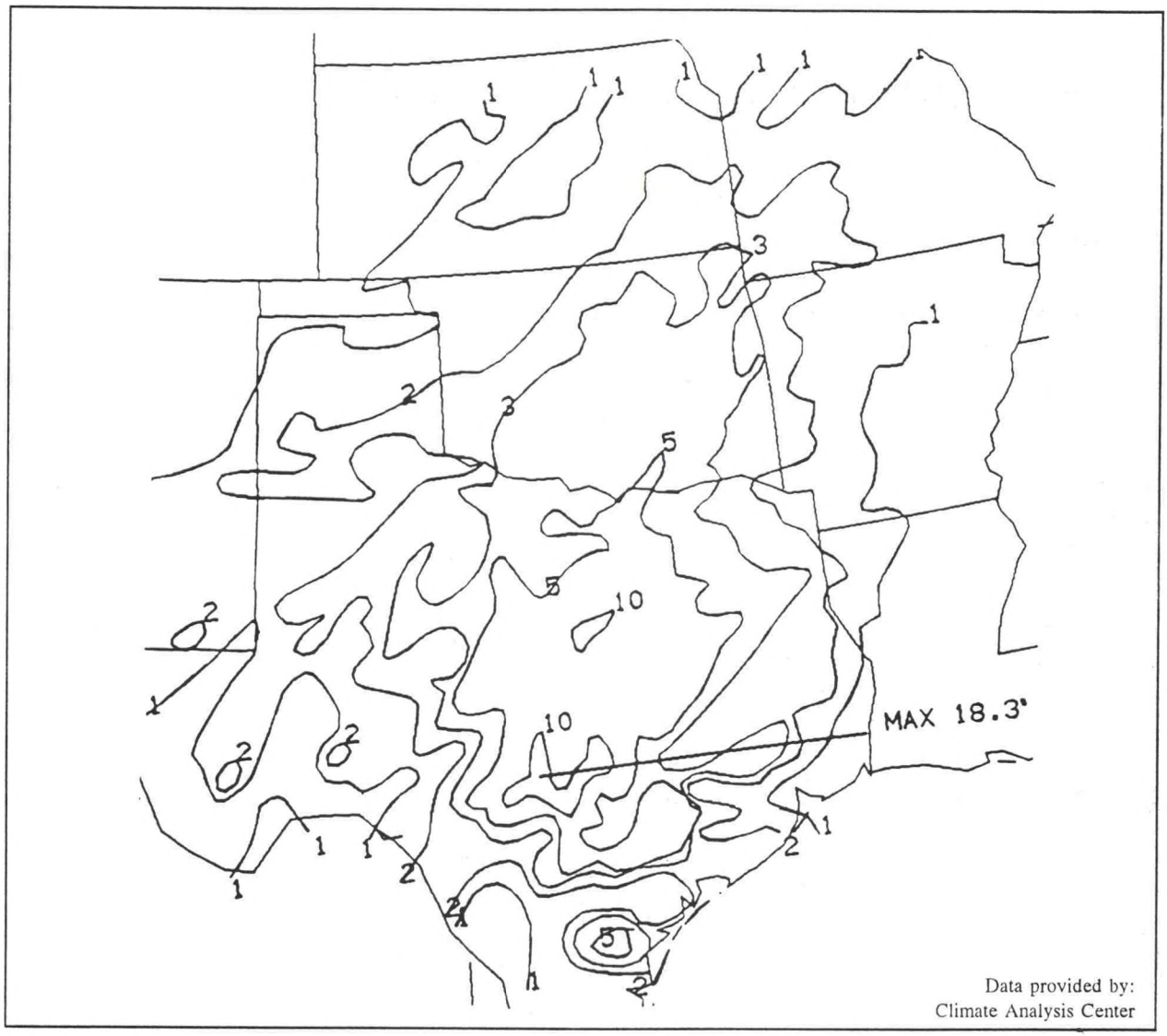


Figure 3. *Total precipitation (in inches), December 18-23, 1991.*

The southeastward shift of maximum rainfall continued the next day with a band 60-90 miles wide of greater than 2 inches from Galveston Bay to south Texas. The area of maximum rainfall continued to shift in the general direction of river flow. Although the areal extent of heavy rainfall had decreased by this time, there were still reports of excessive rain--with over 4 inches west of Houston and near Victoria and with nearly 7 inches close to Corpus Christi. This major rainfall event began to wind down by December 23 with general amounts of 0.50-1.00 inch falling in central and northeast Texas.

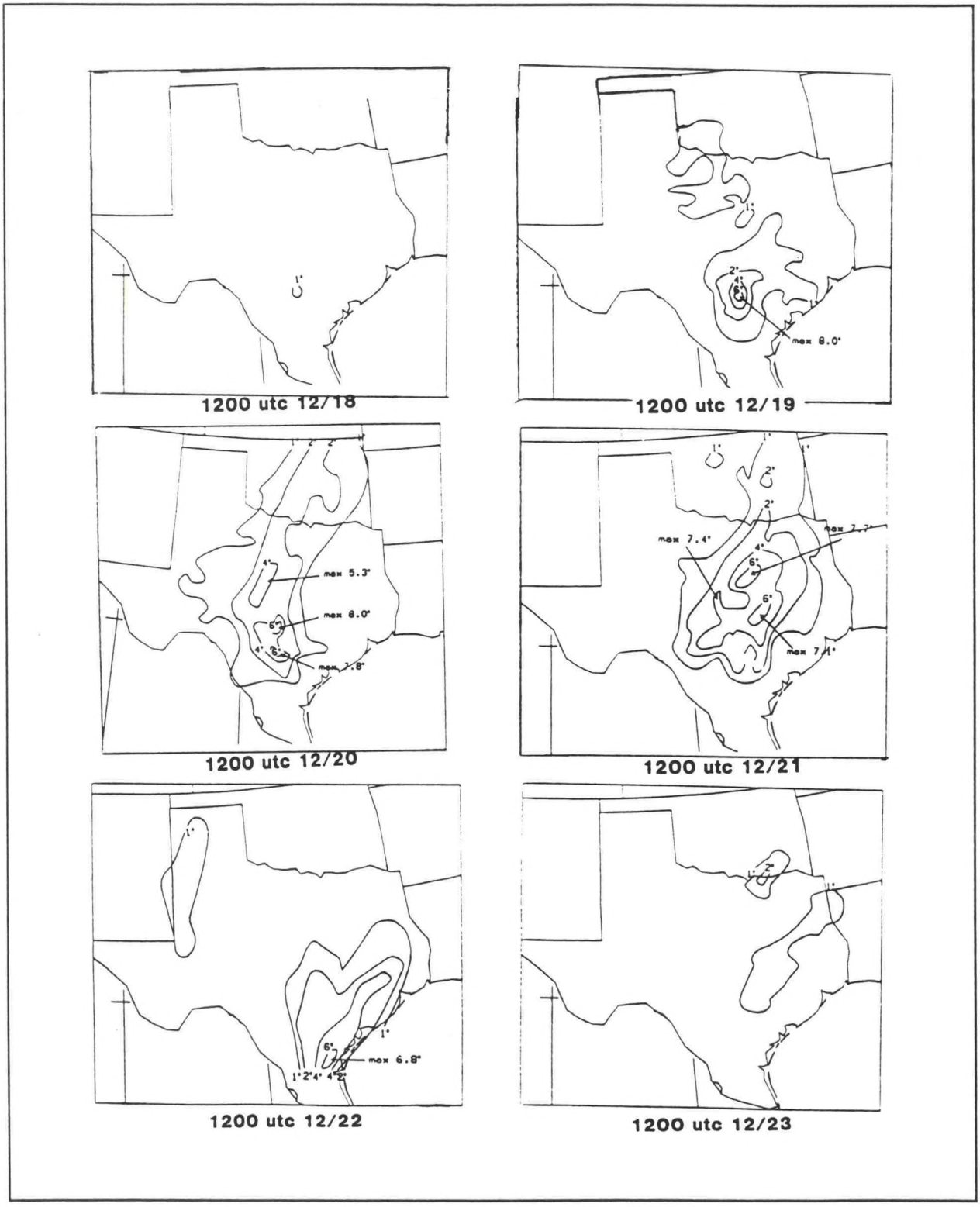


Figure 4. *Daily rainfall totals ending at 1200 UTC, December 18-23, 1991.*

Analyses of 500-mb Flow Fields:

An examination of the 500-mb flow field December 18-23 (see Figure 5) depicts the evolution of a closed low in the southwest United States. The 500-mb Limited Area Fine Mesh Model (LFM) analysis for 1200 UTC, December 18, shows a high-amplitude pattern with a long-wave trough moving onto the West Coast, a long-wave ridge from south Texas to the northern plains, and a fast, confluent flow over the northeast. By 1200 UTC, December 19, a long-wave ridge was building along 132W, while a powerful jet was diving along the western side of the upper trough (note the 120-knot, north-northwesterly wind at San Francisco). In addition, strong height falls were occurring at the base of the trough with a 130-gpm, 12-hour height fall reported at Desert Rock in southern Nevada. These parameters, along with the light southeast wind at Desert Rock, suggested a closed low was forming. By 1200 UTC, December 20, the 500-mb analysis depicted a closed and nearly cutoff 500-mb low just southwest of Yuma, Arizona. The flow over Texas had been slowly backing over the last 48 hours and was generally south-southwest at about 55 knots. The 500-mb closed low continued to drop slowly south and was over Baja by 1200 UTC, December 21. Flow over Texas continued to be from the south-southwest around 30-50 knots. By 0000 UTC, December 22, strong 12-hour height falls of 70-80 gpm along the Oregon and California coast signaled the arrival of a long-wave trough along 132W (not shown). By this time, the wavelength between the next Pacific Coast trough and the closed low over Baja was sufficiently close to begin forcing the Baja low eastward. Large height falls of 60-90 gpm were over Texas by 1200 UTC, December 22, as the closed low moved to central New Mexico. At this time, the heaviest rainfall had shifted eastward in Texas and was along the immediate coastline. The remnants of the closed low moved to near Weather Service Office (WSO) Kansas City by 1200 UTC, December 23, while the flow over Texas was westerly; and the heaviest rainfall moved offshore.

Analyses of 850-mb Flow Fields:

The six-panel chart shown in Figure 6 depicts the 850-mb LFM analyses at 24-hour intervals from 1200 UTC, December 18, to 1200 UTC, December 23. The 850-mb analysis for 1200 UTC, December 18, shows a shortwave trough moving onto the Pacific Northwest coast. The midsection of the country, at this time, was dominated by a high-amplitude ridge with the ridge axis running from the western Gulf of Mexico northward into southern Canada. Low-level flow over Texas was light (10-15 knots) from the south, with 850-mb dew points ranging from 10 °C along the Texas coast to 3-6 °C over central and north-central Texas. By 1200 UTC, December 19, a closed low had formed over southern Nevada, while the upper ridge had shifted eastward over the Mississippi Valley. The presence of the closed low and upper ridge combined to increase the southerly inflow over Texas to 30-35 knots. A weak, east-west thermal boundary was situated across the south-central part of the State where favorable 850-mb inflow combined to produce up to 8 inches of rainfall in the San Antonio area on this, the first significant heavy-rainfall day.

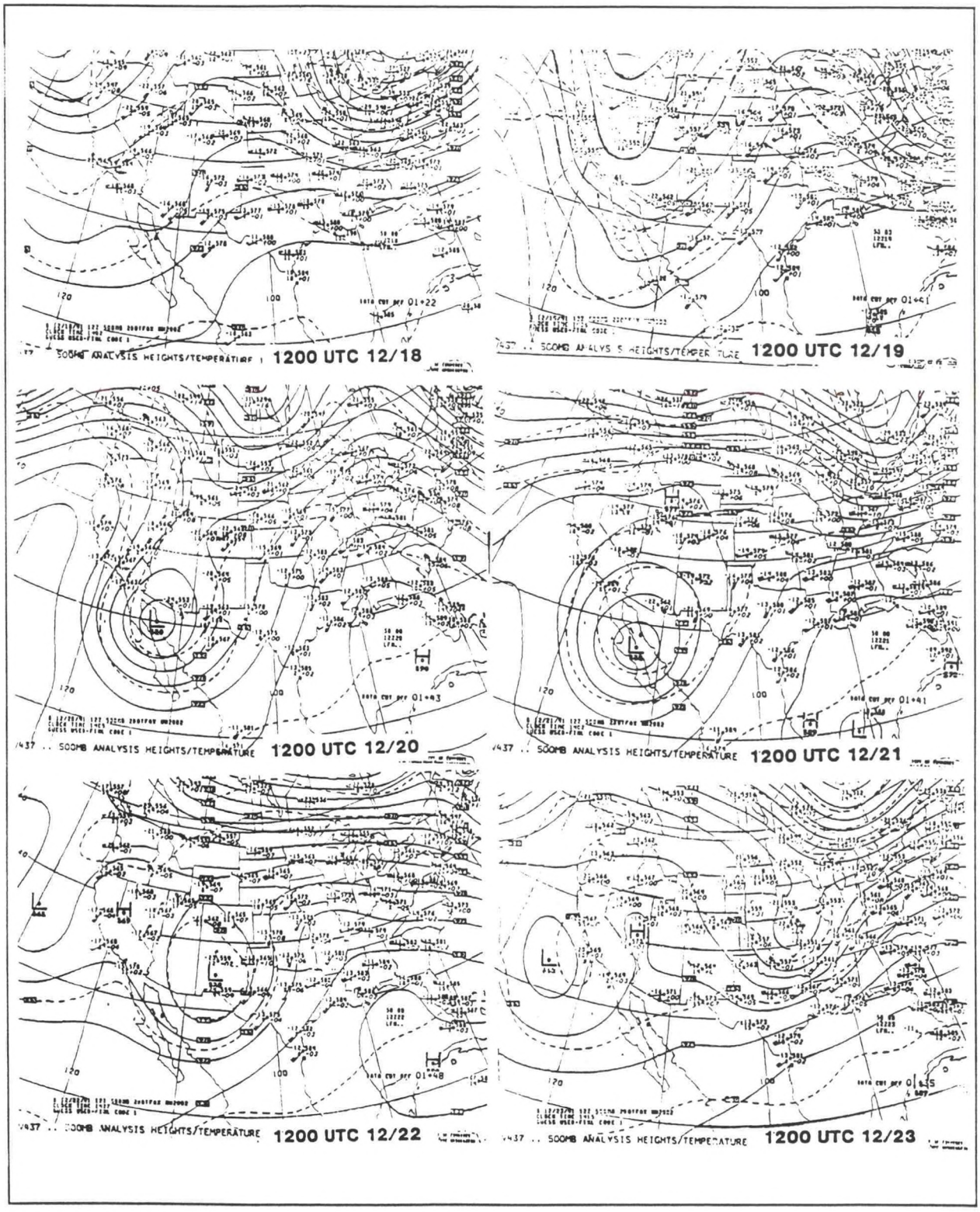


Figure 5. *500-mb LFM analysis, December 18-23, 1991.*

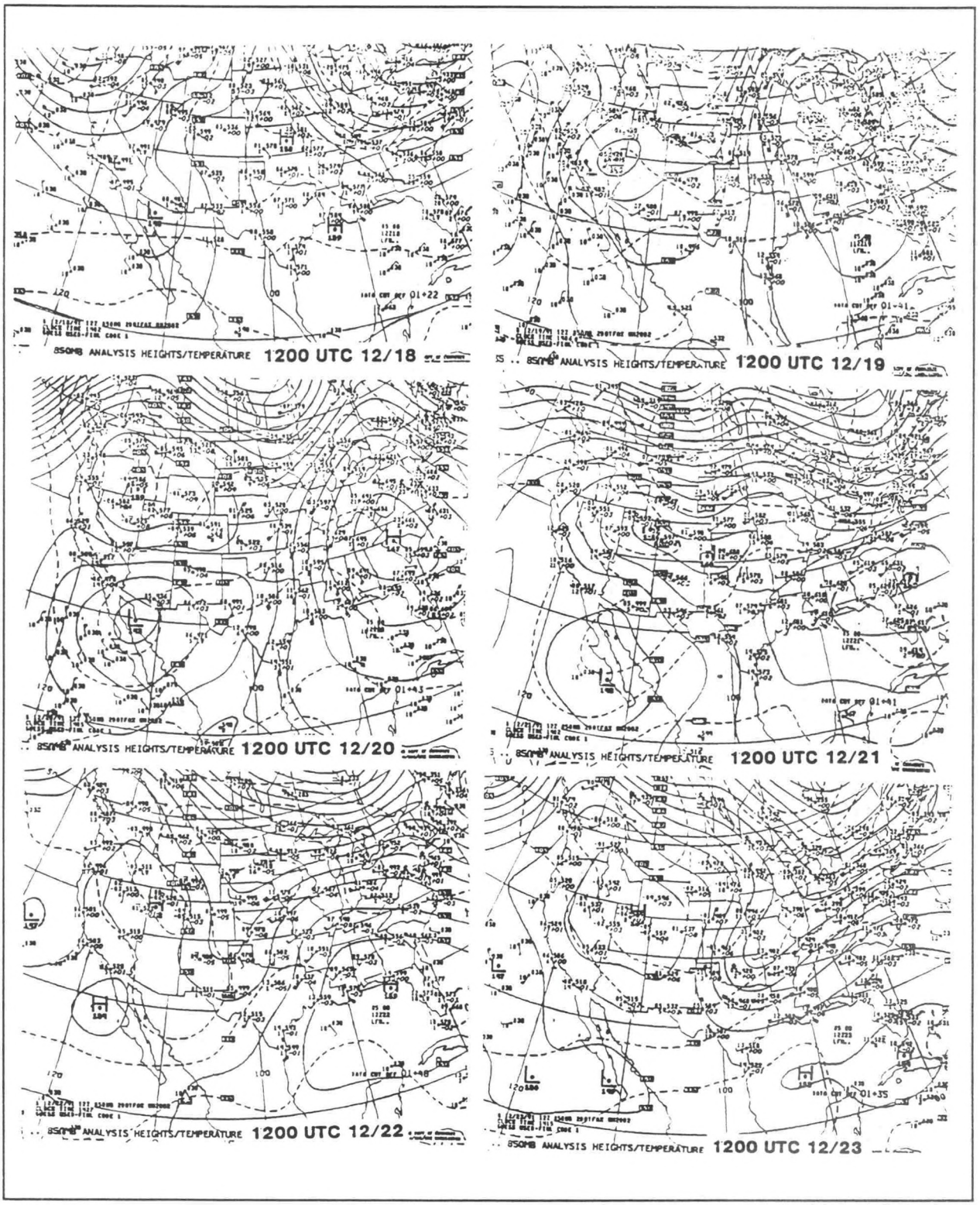


Figure 6. *850-mb LFM analysis, December 18-23, 1991.*

The inflow over southern Texas continued to increase and by 1200 UTC, December 20, was an impressive 45 knots at WSO Brownsville. At the same time, an 850-mb front was setting up from just south of WSO El Paso northeastward to southern Kansas. This 850-mb front corresponded well to the increase in precipitation from the San Angelo/Abilene areas northeastward through Oklahoma. By 1200 UTC, December 21, the 850-mb front extended from southwest Missouri through northeast Texas and southwestward to the Big Bend area.

Inflow in south Texas was not as impressive as the previous day but was still southerly around 20-30 knots. By 1200 UTC, December 22, phasing of a northern stream shortwave and the remains of the closed low in the southwest resulted in an open trough along the lee of the Rockies. In southern Texas, the 850-mb inflow remained southerly; but the upstream flow had veered to a more westerly component, thus shifting the axis of heaviest rain to the immediate coastline. The following morning an elongated, positive-tilt trough stretched from the Great Lakes into Texas. Flow was westerly and northwesterly over most of Texas, with drier, cooler air invading all but the southern portion of the State.

Analyses of Surface Fields:

On the morning of December 18, a decaying stationary front stretched east-west across eastern Texas, while a coastal trough formed along the Texas coast. A widespread area of mainly light rain covered much of eastern Texas, with temperatures ranging from the 40s in the north to the lower 60s in the south. By that evening, the coastal trough had worked inland and a warm frontogenesis was analyzed over the Big Bend region. By early morning on December 19, a warm front extended across southern Texas. Very heavy rains in and around San Antonio fell close to the warm frontal boundary. Meanwhile, a huge 1,045-mb anticyclone was situated over northern Ohio. The return flow from the anticyclone helped establish a broad southeasterly fetch across much of Texas. The warm front remained nearly stationary across south Texas during the day separating warm, humid air over south Texas (dew points close to 70 °F) from cooler, moist air to the north (temperature and dew points in the 40s). By the evening of December 19, a wind-shift line was forming from Midland toward Wichita Falls, separating northeast winds across west Texas from southeast flow to the east of the wind-shift line.

This wind-shift line remained stationary over the next 12 hours and by 1200 UTC, December 20, extended from Abilene northward through western Oklahoma and south-central Kansas. To the south, the warm front cut across central Texas with widespread rain from southwest Oklahoma to south-central Texas. During the day, a cold front, moving east from the Rockies, combined with the wind-shift line and formed a nearly north-south front from eastern Kansas to south-central Texas by 0000 UTC, December 21. The heaviest rain fell along and to the east of this front. By the following morning, the cold front had subsided slowly to the southeast across eastern Texas, with temperatures mainly in the 40s to the west of this front and the 60s and 70s to the east of the front. By the evening, the front had become stationary along the Texas coast with rain and thunderstorms developing along this boundary. By the morning of December 22, the stationary front had retreated inland as a

warm front as the upper low began to lift out from the southwestern United States. Low pressure over Colorado had developed in response to the upper low. Over the next 12 hours, the Colorado low moved to southwest Kansas; and drier air began to enter Texas from the west, ending the rains across much of western and central Texas. The warm front over southern Texas became a cold front and shifted back to the coast. By the morning of December 23, dry air filtered in over most of Texas bringing an end to the heavy rains.

2.3 Meteorological Explanation for Rainfall on December 20-21, 1991

Synoptic Scale:

The 500-mb analysis for 0000 UTC, December 21 (see Figure 7a), shows a slowly southward-sinking closed low about 100 miles south of Arizona. This was the midpoint of the most widespread rainfall day where 4-7 inches fell from south of the Dallas/Fort Worth metropolitan areas to south of San Antonio (see Figure 3). The 500-mb flow over Texas had steadily backed over the past 3 days and was generally 30-55 knots from the southwest providing a moist, mid-level flow from the Pacific. No appreciable height falls were evident over Texas; and, in fact, heights were rising as a result of a subtropical upper ridge building across the Gulf of Mexico.

The 200-mb analysis at 0000 UTC, December 21 (see Figure 7b), shows a closed low just south of Arizona with southwesterly diffluent upper flow over Texas. An anticyclonically curved jet streak is situated south-southwest to north-northeast across Texas with the favorable right-entrance region centered over the Deep South. It has been shown that the right-rear quadrant of an anticyclonically curved jet is the favored region for enhanced upward motion (Beebe and Bates, 1955). It, no doubt, played a significant role in the heavy rainfall during December 20-21. The analysis also indicates that another significant jet streak would soon translate out of Mexico, although the lack of supportive upper air data out of Mexico casts some uncertainty into the strength and timing of the jet. The left-exit region of this jet combined with the right-entrance region of the upper jet over the middle Mississippi Valley. It likely formed a significant upper-level jet couplet and resultant transverse-circulation pattern (described by Uccellini and Kocin, 1987) that helped sustain the strong, large-scale, vertical-motion field over Texas.

A strong, 850-mb ridge had settled off the coast of South Carolina by 0000 UTC, December 21, resulting in a moist, southerly return flow as high as 45 knots over eastern Texas (see Figure 7c). Low-level moisture was abundant, with 850-mb dew points of 10-13 °C south of a line from near Del Rio to Longview, Texas. A well-marked thermal boundary bisected the state from the Big Bend to northeast Texas with cool, dry, northerly flow on the poleward side of this boundary and warm, moist, southerly flow on the equatorial side. The 850-mb inflow was somewhat weaker than the previous day, but speed convergence and overrunning of the low-level thermal boundary remained relatively strong and continued to enhance vertical motions.

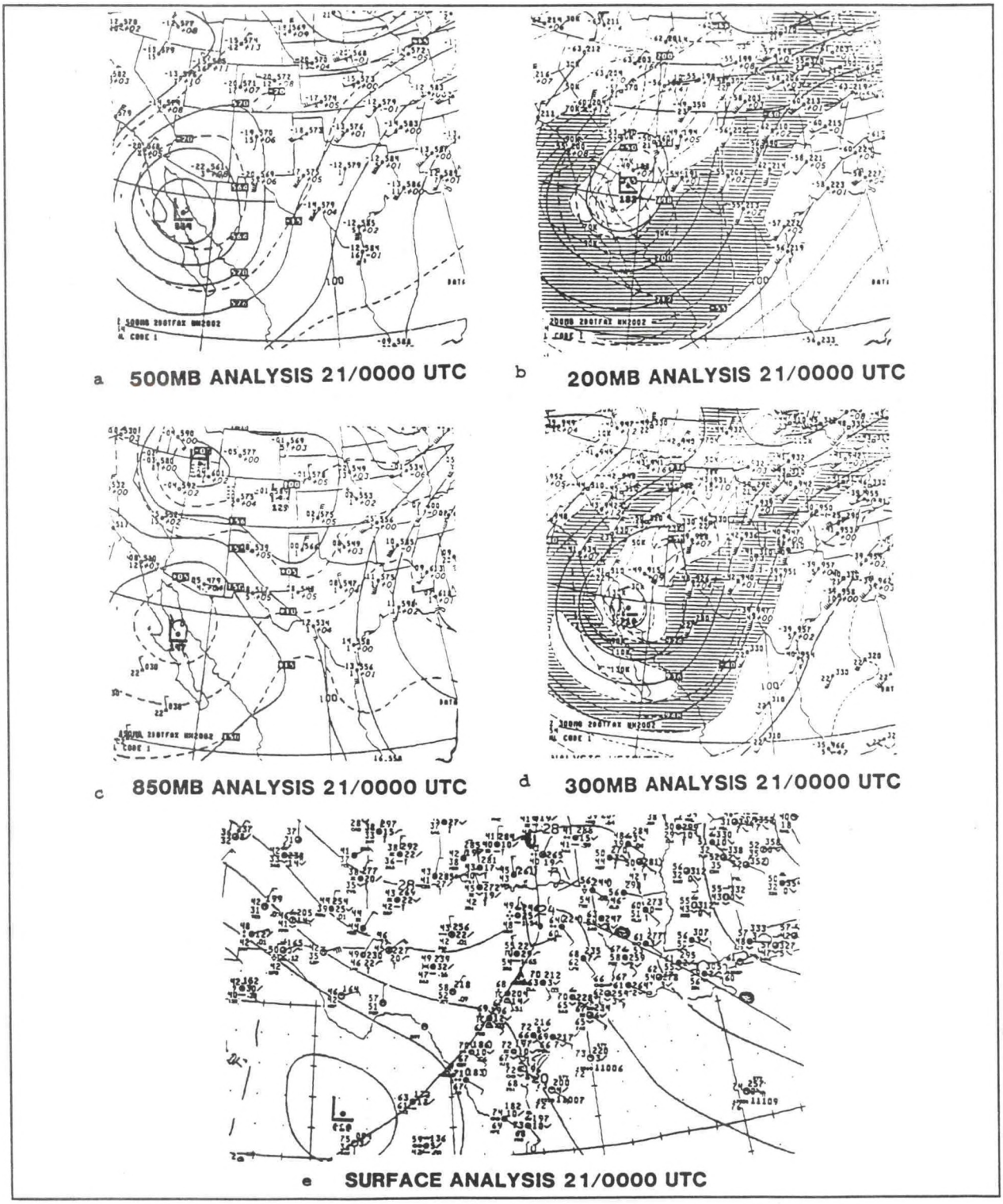


Figure 7. *Synoptic analysis for 0000 UTC, December 21, 1991: (a) 500 mb, (b) 200 mb, (c) 850 mb, (d) 300 mb, and (e) surface analysis.*

The surface chart from 0000 UTC, December 21 (see Figure 7e), shows an inverted isobaric pattern over Texas with a quasi-stationary frontal boundary stretching from Tulsa, Oklahoma, to a weak wave near Tyler, Texas. This front then extended southwest to just north of Laredo, Texas. In addition, an old and diffuse warm front extended northwest-southwest through Louisiana, marking the northern boundary of relatively warm, moist air. The initial front over Texas was an extremely important low-level feature as it provided a strong, thermal overrunning zone and helped to focus the influx of moist, mid- to upper-60s dew points. The fact that the front was nearly stationary (despite implied strong, low-level, warm advection on this day) was crucial to the excessive nature of the rainfall since it acted as a boundary which focused convection and overrunning precipitation repeatedly over the same area.

Comparison to Established Heavy Rain/Flash Flood Patterns:

The meteorological factors contributing to the excessive rainfall December 20-21 reveal that the situation was a near-classic, Maddox synoptic scale flood event (Maddox et al., 1979). A simple, composite schematic of this type of excessive rainfall event is shown in Figure 8.

Similarities between the **TEXAS** event and a **SYNOPTIC** event:

1. Surface:

   a. a quasi-stationary front oriented NNE-SSW
   b. mid- to upper-60s dew points

2. Upper Flow:

   a. 500-mb flow basically parallel to the surface boundary
   b. little veering in winds from 850 mb to 300 mb and little increase in wind speeds

Differences between the **TEXAS** event and a **SYNOPTIC** event:

1. 500 mb: The Texas event 500-mb pattern was closed and farther west than a Maddox synoptic event early in the occurrence (by 22/1200 UTC, the 500-mb pattern is very similar to Maddox schematic).

2. Surface: Surface pressures were rather high for the Texas event (about 1,020 mb versus 1,009 mb for a typical synoptic event).

3. Climatology: The Texas event occurred in late December, while most synoptic events occur in spring or fall.

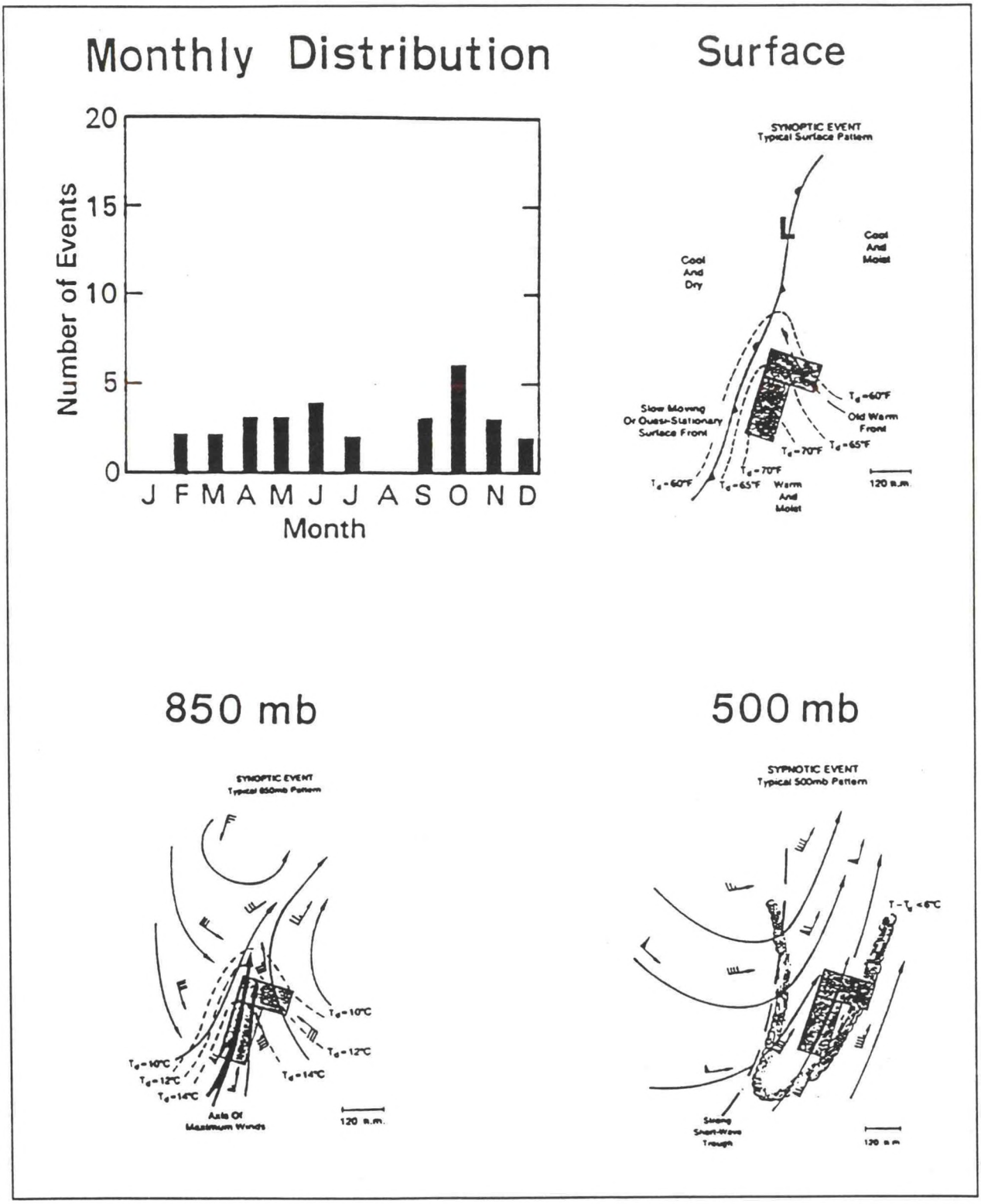


Figure 8. *Composite schematic of excessive rainfall.*

2.4 Objective and Subjective Guidance Provided by the National Meteorological Center (NMC)

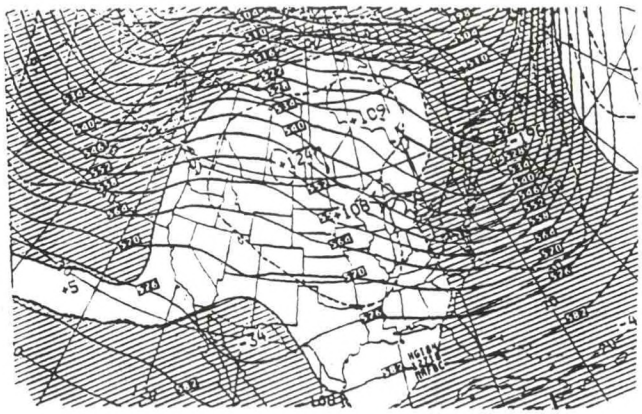
Medium-range forecasts (MRF) are issued once a day and verified 3, 4, and 5 days after the issue time. The primary objective model available to forecasters is the U.S.-developed MRF model which provides hemispheric circulation and moisture forecasts out to 5 days and beyond. Surface and 500-mb height field forecasts are also available from two highly competitive European forecast models: the European Center for Meteorology and Weather Forecasting (ECMWF) model and the United Kingdom Meteorology Office (UKMET) model. The MRF model is generated once a day at 0000 UTC, while the UKMET model is run at both 0000 and 1200 UTC. The ECMWF model is produced only at 1200 UTC and thus is always 12 hours older than the MRF when received.

The first substantial indication of a significant pattern change that would affect the southern tier of states appeared in the medium-range guidance package produced on December 15, 1991. All three medium-range models routinely available to NMC forecasters (the MRF, ECMWF, and UKMET) predicted the development of a split in the mean upper flow pattern over the eastern Pacific and the evolution of an important precipitation-producing southern storm track into the southwestern United States (see Figure 9). The major question at that time was how intense the southern storm track would be. The ECMWF and UKMET models were more emphatic in establishing the southern jet, while the MRF was channeling much of its energy northward into Canada over the persistent upper ridge that was anchored over the western states.

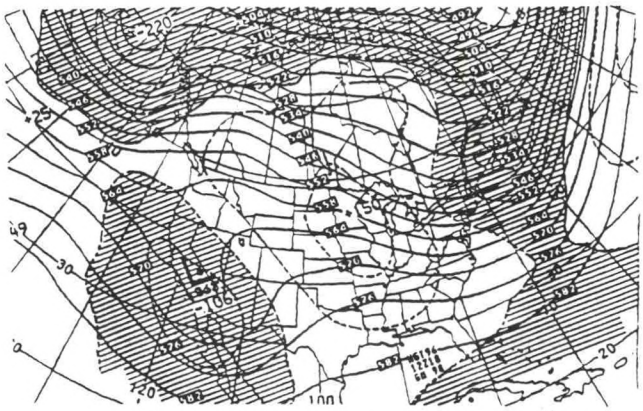
The subjective MRFs, although accepting the evolution of a split-flow pattern, hesitated going toward the more intense ECMWF and UKMET solutions given the more northern MRF forecast which had maintained good continuity from its earlier runs. Nonetheless, the subjective forecasts acknowledged the potential for development of strong, overrunning rains in Texas by Day 5. The accompanying hemispheric discussion issued at 1800 UTC on December 15 emphasized:

> "...the prospects of a significant rainfall event developing over the southern plains toward the western Gulf Coast Region, as southern track of upper trough should ensure plenty of subtropical moisture influx."

The subsequent model runs produced at 0000 UTC, December 16 (1200 UTC, December 15, in the case of the ECMWF), continued to show a more energetic and stronger southern stream leading toward a significant upper trough over the southwestern United States. While the medium-range models were at odds as to the placement and strength of the eventual closed low, downstream signals bolstered forecast confidence on the likelihood of heavy precipitation over parts of Texas. The following medium-range discussion issued at 1930 UTC, December 16, states:



MRF 00 UTC 12/15/91



ECMWF 12 UTC 12/14/91

UK 00 UTC 12/15/91

Figure 9. *500-mb mean charts, 0-5 days.*

> "Plenty of inflow develops between falling pressure over the western states and high pressure holding in over the east coast states by mid-period...giving locally heavy overrunning convective rains to east Texas and the lower Mississippi Valley."

Medium-range model guidance became more in agreement as the major event approached, indicating a distinct separation of the southern stream upper trough as the northern branch of the polar jet became displaced well north into Canada. Meanwhile, a large surface polar high-pressure system was forecast to sink toward the southeast United States and provide an unusually strong fetch of south and southeasterly winds into Texas, supplying warm, moist air to the region. Thus, the medium-range discussion issued at 1930 UTC, December 17, emphasized:

> "Potential flood situation from convective overrunning developing east Texas/lower Mississippi Valley days 2-3...repeat MCC activity over the same areas could give very excessive rainfall."

The hemispheric discussion issued at 1800 UTC the same day stated:

> "...a prolonged heavy rainfall event can be expected for the entire 3- to 5-day period and some areas could see 4-6 inches per day."

The generally favorable agreement among later runs of the medium-range models involving major closed low development through the southwestern United States and northern Mexico carried through into the short-range period, although major timing differences continued. The short-range period covers those forecasts, both model and subjective, that verify 1 and 2 days after issue time. Numerical model guidance available to NMC forecasters include the LFM model (Environmental Research Laboratory), the nested grid model (NGM) (Regional or Regional Analysis and Forecast System), and the AViatioN (AVN) models, which provide information on circulation trends, stability, precipitation, and other useful fields. The LFM is processed first and thus is the official "early-look" model. The AVN model is the same spectral model as the MRF model, except that it has an earlier cutoff time and a little less data. The NGM is run soon after the LFM, which usually provides forecasters the opportunity to examine it in detail as opposed to the AVN model which, because of its later run time, often affords forecasters little more than a quick comparison to the other model solutions. Because of this timing and its superior physics and resolution in comparison to the LFM, the NGM is normally viewed as the primary guidance for atmospheric circulation trends. During the past year, a new experimental model, the ETA, with improvements to model terrain, increased vertical resolution, and smaller grid spacing, has become increasingly available through NMC's Visible Infrared Spin Scan Radiometer (VISSR) (satellite) Atmospheric Sounder (VAS) Data Utilization Center (VDUC) system. More recently, several forecast fields from the ETA model have become accessible via a personal computer (PC) workstation. Several statistical model fields are also available as guidance, including LFM and NGM model output statistics. Short-range model solutions captured the

initial development of the strong upper trough and closed low through the southwestern United States and eventually into the vicinity of Baja, Mexico, like their medium-range counterparts. Model solutions had difficulty forecasting the intensity and speed at which the mid-level and upper-level systems would move out toward the northeast. Likewise, both objective and subjective guidance underestimated the magnitude of the heavy precipitation at the early stages of the event through 1200 UTC, December 19. The strength of the lower tropospheric ridge over the southeastern United States and the resultant low-level warm advection and inflow were underforecast. Lack of Mexican upper air data, in addition to sparse data over the eastern Pacific and Gulf of Mexico, undoubtedly contributed to a less-than-satisfactory model performance over Texas.

The NMC Forecast Branch prepares subjective quantitative precipitation forecast (QPF) guidance packages five times per day. These packages offer 6-hour and 24-hour isohyetal forecasts, along with excessive rainfall outlooks, all in the form of graphics and corresponding forecast discussions (heavy snow guidance forecasts are also prepared but are not an issue here). The discussions are intended to be used as a companion to the graphics and to offer forecast reasoning and indications of possible confidence as well as to discuss numerical model differences.

Since this was a long-term rainfall event, the following discussion will focus on the 24-hour QPFs, the excessive rainfall outlooks, and the corresponding narratives. The 24-hour forecasts include Days 1 and 2 and are issued about 1100 UTC daily, while an update is issued about 1830 UTC.

Both objective and subjective guidances were underforecast during the initial onset of the precipitation event, quite possibly a result of limited upstream data from Mexico and the eastern Pacific as well as the Gulf of Mexico. Subsequent subjective precipitation issuances showed a dramatic improvement in both the volume and location of the significant rainfall areas over the objective model precipitation forecasts. Given the challenge of significant model differences through the 0000 UTC, December 19, model runs, with the NGM ejecting the upper low too quickly to the east (which would have an impact on the duration of the heavy rainfall event in Texas and parts of Oklahoma), the QPF discussion issued 1030 UTC, December 19, pointed out:

> "...potential exists for a long-duration excessive rainfall event for the southern plains and central-eastern Texas, where precipitation amounts may be measured in feet before the event winds down. All the ingredients are there, including high precipitable water values, extremely favorable low-level inflow, and divergence aloft between the polar and subtropical jets."

Figure 10 shows both the subjective and objective 24-hour QPF ending 1200 UTC, December 20. Note the superior quantitative and location improvements subjective guidance provided over model forecasts, with the Day 1 forecasts most nearly correct in placement of the two observed precipitation maxima over central Texas.

The next widespread heavy rain followed on December 20 (all hydrologic reports and guidances verify for the 24-hour period ending 1200 UTC, December 21). Day 1 objective precipitation guidance from all the models placed the main precipitation emphasis near the central Oklahoma/Texas border along the Red River, even though model circulation patterns remained quite diverse between them (see Figure 11). Although the NGM was correct in emphasizing the heavy rains along the low-level convergence maximum, it had erroneously displaced this boundary too far north by eroding the shallow cold air at the surface (a known characteristic model error). While the LFM had a similar precipitation depiction, it often errs by limiting convective potential, especially near frontal boundaries, and instead saturates a majority of its moisture as "overrunning" precipitation.

The subjective Day 1 QPF guidance issued for that same day provided vastly superior quantitative and location adjustments (see Figure 12) by recognizing the slower movement of the upper low (a result of the strongest upper-level winds still digging on the west side of the storm) and the lack of a significant upstream shortwave trough to eject the system more rapidly eastward. The Day 1 and Day 2 QPF discussion issued at 1030 UTC, December 20, stated:

> "Slow-moving 500-mb lows such as this one have a history of producing very heavy and sustained rainfall. On December 3 and 4 of 1982, a similar slow-moving system brought 10-inch-or-better rains for 2 consecutive days over the Mississippi Valley. The low-level jet is farther west in this case and the heaviest precipitation looks like it will be over Texas. Still, the December 1982 case indicates how much rainfall potential this system has. Two-day rain totals could be in the 10- to 15-inch range."

The 0000 UTC December 21 model run of the NGM had a good handle on the upper low through the subsequent 36 hours as it began to lift out of northern Mexico. However, strong convection (which developed as a result of the favorable, low-level convergence) helped reinforce the convergence boundary over the southeast Texas coast. This convergence maintained the heaviest rains near the Texas coast as the main dynamical effects from the upper low in the form of good height falls and strong, upper-level jet diffluence finally came into play. This result was in contrast to most objective model guidance that suggested heavier rains, and the low-level frontal boundary would lift northward away from the Texas coast.

Subjective guidance and reasoning was again more correct indicating in the NMC-issued QPF discussion (issued at 1900 UTC, December 20, 1991) that:

> "[T]he excessive rainfall pattern in Texas is probably most tied to the low-level convergence pattern that has no reason to move until the upper low arrives early Sunday."

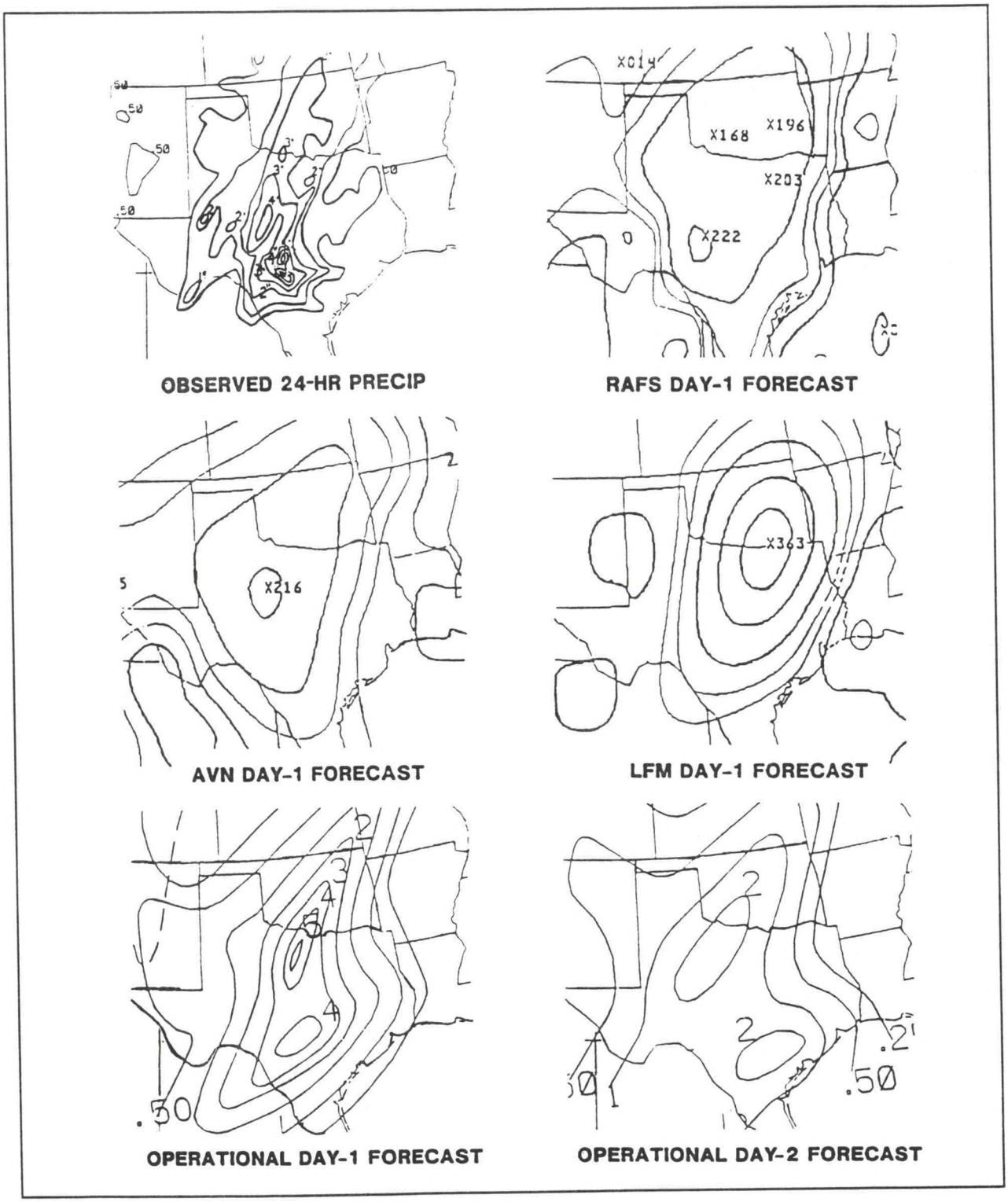


Figure 10. *Subjective and objective 24-hour quantitative precipitation forecasts and observed precipitation ending 1200 UTC, December 20, 1991.*

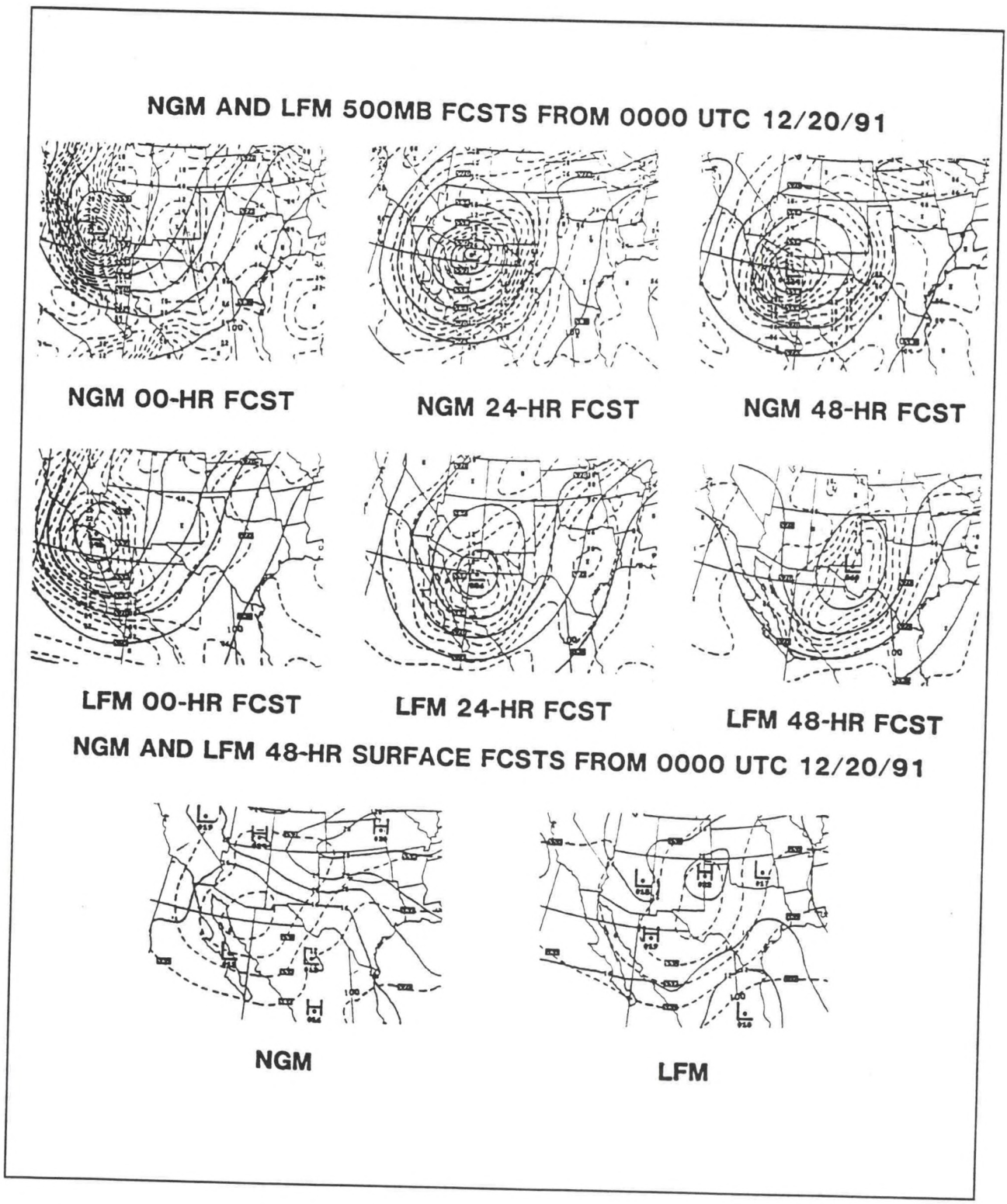


Figure 11. *NGM and LFM 500-mb and surface forecasts from 0000 UTC, December 20, 1991, model run.*

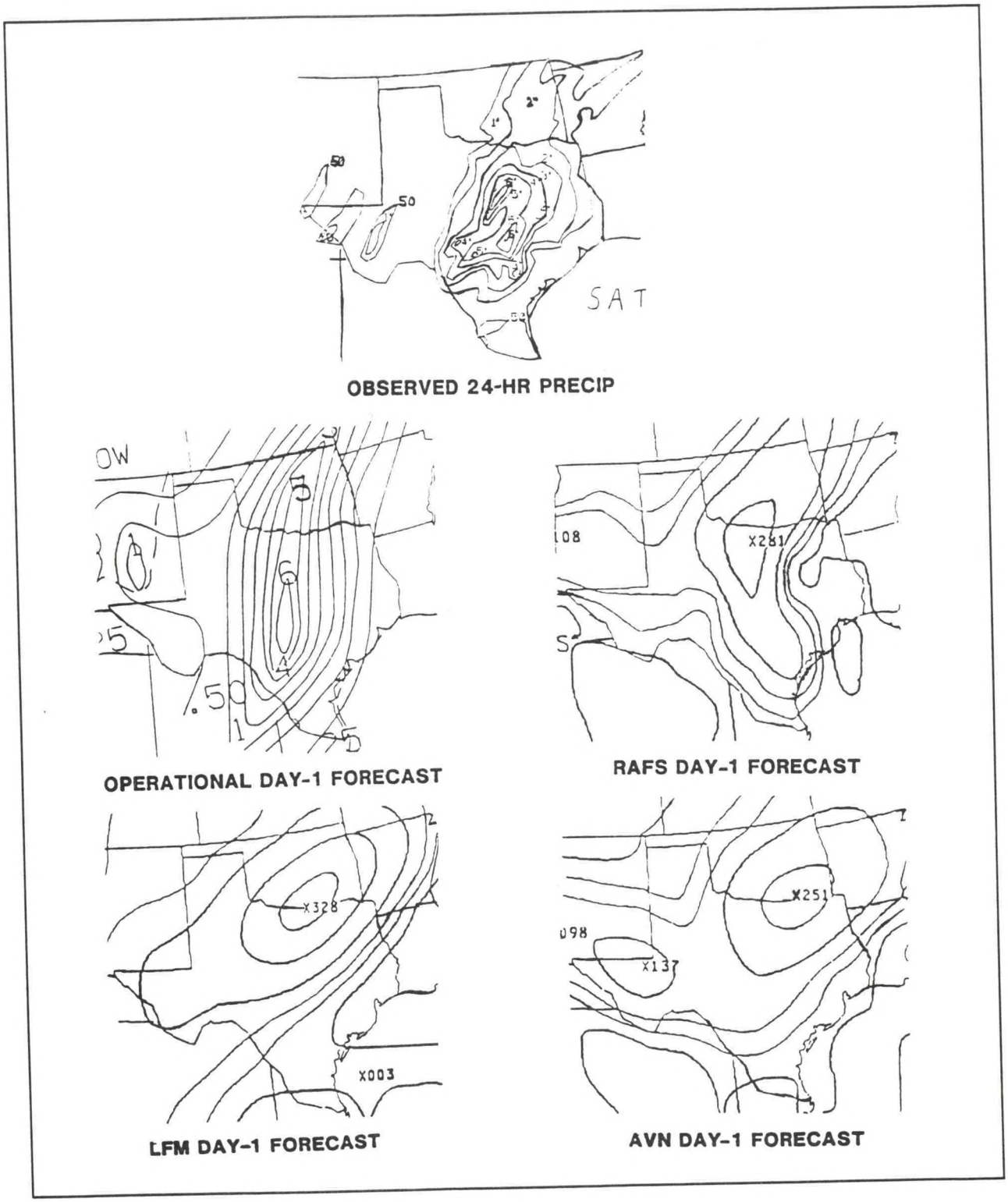


Figure 12. *Subjective and objective 24-hour quantitative precipitation forecasts and observed precipitation ending 1200 UTC, December 21, 1991.*

Even though NMC QPF guidance had the axis of heavier rain displaced to the northwest of where the heaviest actually occurred on that particular day, the objective model guidance was dismal by comparison (see Figure 13).

Day 2 manual and AVN QPF forecasts from the most prolific rainfall period of December 21-23 are shown for comparison in Figure 14. Note the significant improvements to objective model guidance on December 22 and December 23.

The QPF section of NMC also issues excessive rainfall guidance, providing details of when and where rainfall might exceed the flash flood guidance values issued by the RFCs. This product is issued at least three times per day covering standard 24-, 21-, and 15-hour periods valid at 1200 UTC the following day.

Unscheduled discussions and graphics are issued at any time as conditions warrant. When rainfall is expected to exceed 5 inches within a given period, a special hatched area is depicted. Figure 15 shows the initial 24-hour excessive rainfall outlook covering the most prolific rainfall day ending 1200 UTC, December 21, and the series of adjustments made to the outlooks ending 1200 UTC, December 22, when it became clear that the heaviest rains would concentrate toward the southeast Texas coast. Note the 12-hour special excessive rainfall outlook that adjusted the heavy rain threat to the Texas coast where the axis of the heaviest rains occurred.

The NGM most closely captured the weakening rainfall trend during the following 24-hour period ending 1200 UTC, December 23. Although one precipitation axis was nearly correct in northeast Texas, amounts were generally underforecast. Subjective forecasts indicated heavy rains would fall across eastern Texas, but they erred on the high side as a result of weaker-than-forecast inflow from the western Gulf of Mexico.

2.5 Summary of NMC Guidance

The NMC provided high-quality, long-term and short-term guidance during this event. Considering the diverse model guidance and the lack of quality upstream upper air data over data-void areas, NMC forecasters continued to emphasize the serious flood potential over the southern plains and provided highly accurate, short-term precipitation guidance.

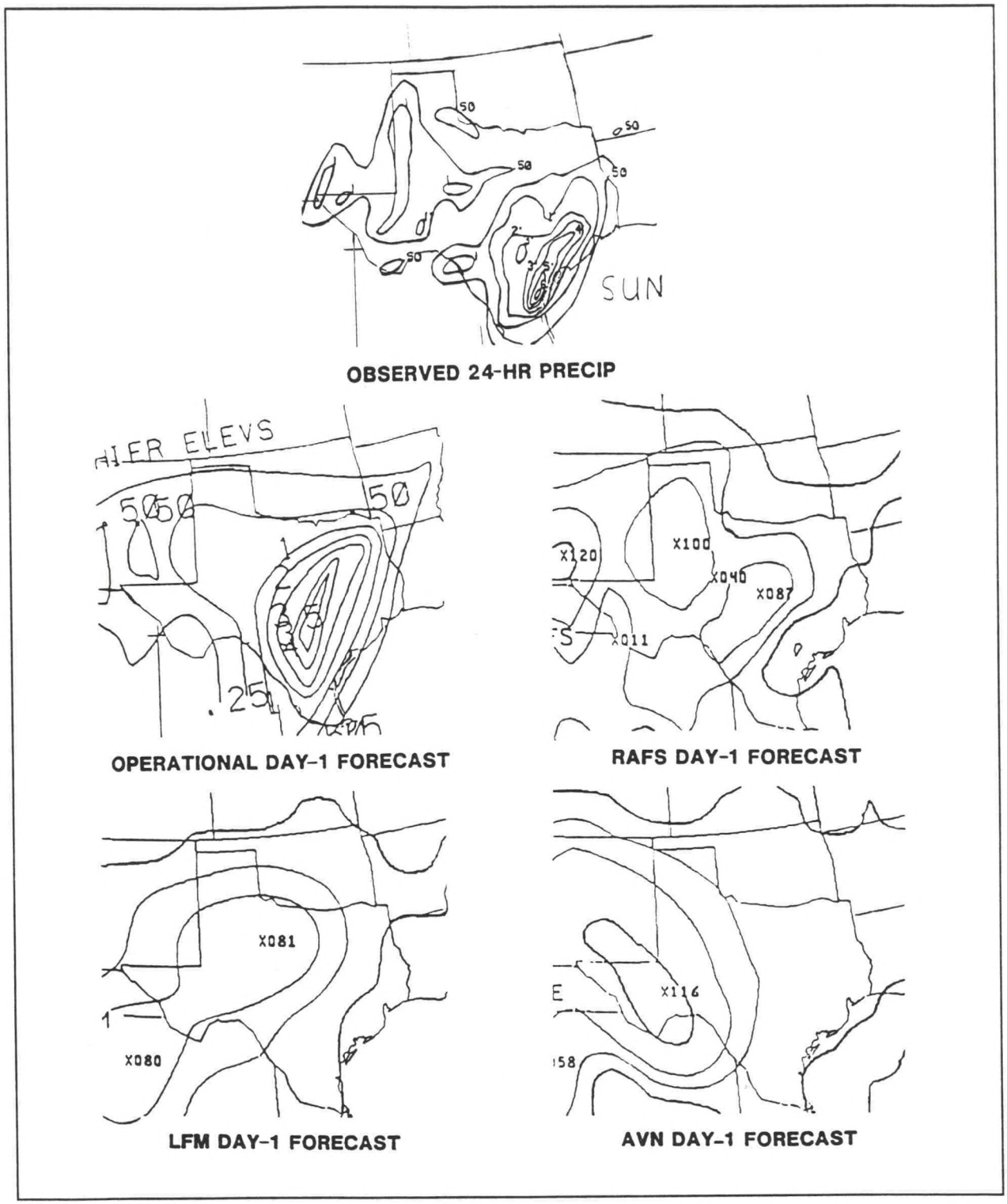


Figure 13. *Subjective and objective 24-hour quantitative precipitation forecasts and observed precipitation ending 1200 UTC, December 22, 1991.*

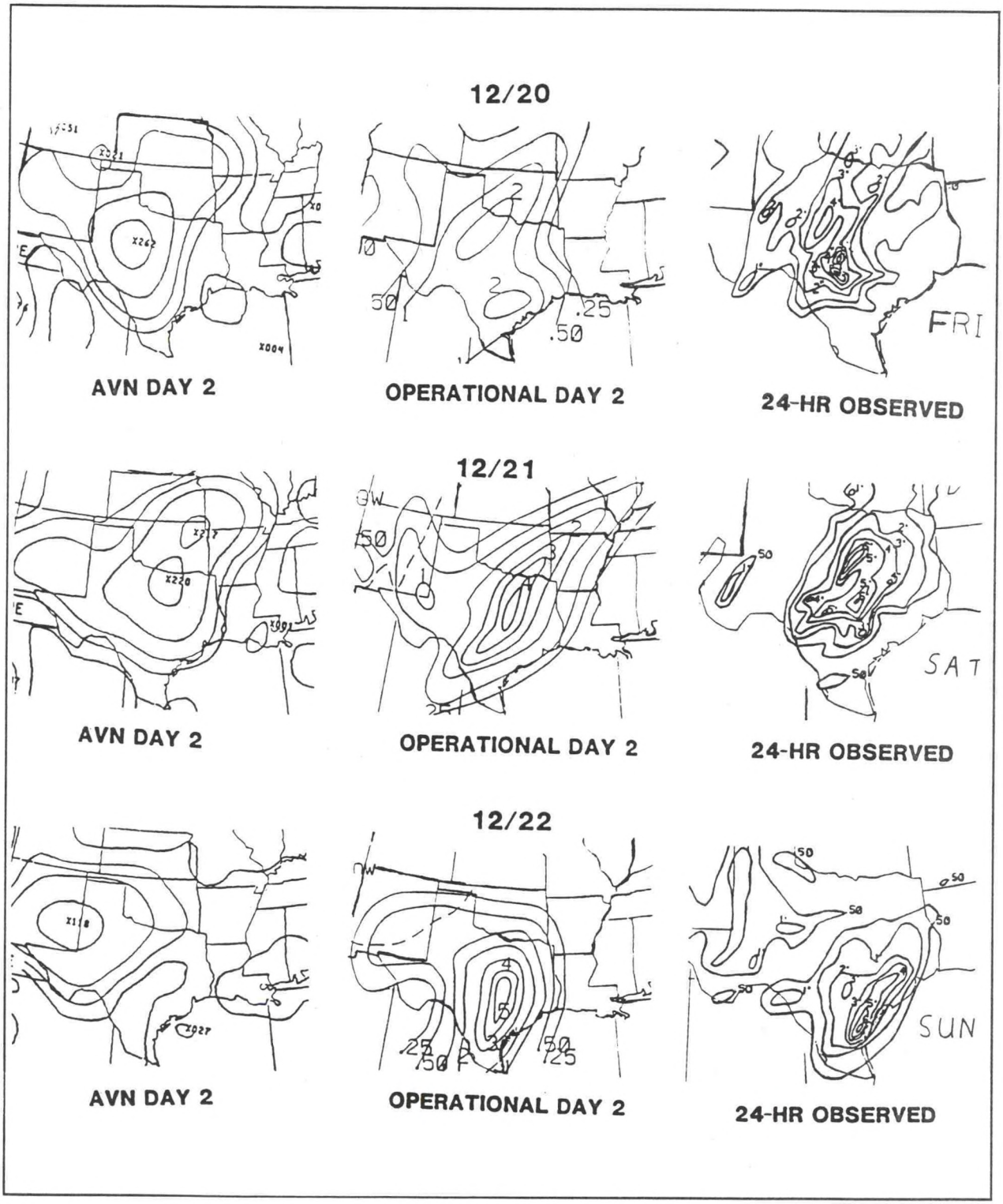


Figure 14. *Subjective and objective Day 2 quantitative precipitation forecasts and observed precipitation ending 1200 UTC, December 20-22, 1991.*

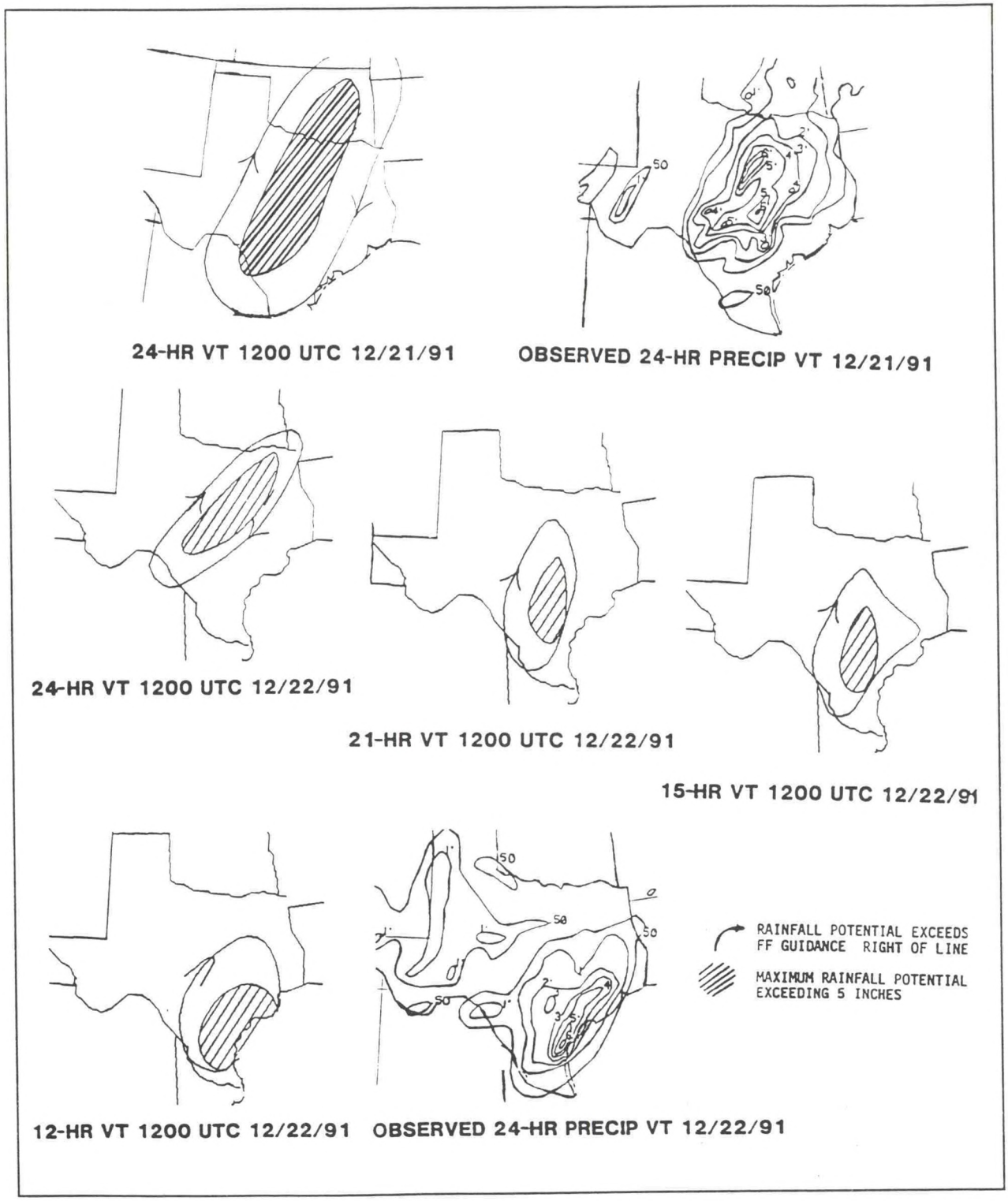


Figure 15. *Subjective excessive rainfall forecasts and observed precipitation ending 1200 UTC, December 21-22, 1991.*

2.6 Activities of the National Environmental Satellite, Data, and Information Service (NESDIS) Synoptic Analysis Branch

The NESDIS Synoptic Analysis Branch supports the NOAA Flash Flood Program by providing specialized satellite analyses to Weather Service Forecast Offices (WSFO) using the Interactive Flash Flood Analyzer.

As rainfall accumulations approach flash flood thresholds (as defined by the NWS RFCs), satellite precipitation estimates are disseminated to the WSFOs through the Automation of Field Operations and Services (AFOS) system. These AFOS messages provided a short narrative discussion (including trends) and included a tabular listing of "maximum" accumulated precipitation at the county level.

During the Texas floods, Synoptic Analysis Branch meteorologists spent 59 staff hours monitoring the situation and preparing estimates. They issued a total of 26 satellite-precipitation estimates for Texas and Oklahoma. Maximum satellite estimates totaled 7.3 inches over central Texas for the 24-hour period ending 1200 UTC on December 21 (6.5 inches were observed) and 6.5 inches over southeast Texas for the 24-hour period ending 1200 UTC on December 22 (6.8 inches were reported).

2.7 References

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CHAPTER 3
DATA ACQUISITION, COMMUNICATIONS, AND FACILITIES

3.1 Introduction

This chapter discusses data sources and data acquisition procedures, communications, and facilities used by most offices. Specific areas are highlighted where appropriate.

The flood event occurred over a large portion of Texas and involved a total of nine NWS operational offices. The nine offices included one RFC, West Gulf RFC; two WSFOs, Fort Worth and San Antonio; and four WSOs, Houston, Victoria, Austin, and Waco. In addition, two Weather Service Meteorological Observatories (WSMO) were involved, Stephenville and Hondo.

There are many data sources and acquisition methods used in the Hydrology Program by NWS field offices. Some of the data sources are automated; most are not. The acquisition methods of obtaining data consist of a combination of automatic and manual procedures. A complicating factor is that most of the automated data sensors used in the Hydrology Program are owned, operated, and managed by agencies other than the NWS.

3.2 West Gulf River Forecast Center (WGRFC)

The WGRFC obtains the bulk of its precipitation data from the Cooperative Hydrologic Network. Cooperative observers manually measure precipitation routinely once a day at approximately 7 a.m. The report is then input by the observer into an automated collection system through a touch-tone telephone. The touch-tone minicomputers in the Fort Worth and San Antonio WSFOs receive the telephone messages and code the data into Standard Hydrometeorological Exchange Format (SHEF)-coded products approximately every 30 minutes during the morning hours and then transmit the products to the AFOS system. WSFOs, WSOs, and RFCs all receive the information over the Southern Region Regional Distribution Circuit (RDC). The WGRFC has SHEF-coded data automatically posted in the National Weather Service River Forecast System (NWSRFS) Version 5.0 preprocessed database via AFOS and the AFOS SHEF Automatic Processing (ASAP) system.

Data collection platforms report stage and precipitation data directly through the NOAA Geostationary Operational Environmental Satellite (GOES), and the information is automatically posted within the NAS9000 system at the NOAA Central Computer Facility (NCCF) and into the NWSRFS Version 5.0 preprocessor database. Automated Local

Evaluation in Real-Time (ALERT) data, precipitation, stages, and reservoir pool elevations from the Lower Colorado River Authority are coded into SHEF for 6-hour periods using a report writer on the computers. WSO Austin calls the Lower Colorado River Authority system using the AFOS auxiliary backup terminal, transfers the data to the backup terminal, edits the text for errors, and transmits the SHEF product to AFOS at about 7:30 a.m. each day. Some ALERT and most unofficial reports are verbally called into the Fort Worth and San Antonio WSFOs and WGRFC. Handcoding data into a SHEF product is necessary using AFOS header RR1. The product is then sent over AFOS. The WGRFC receives these SHEF-coded products locally, and the information is automatically posted in the NWSRFS Version 5.0 database using ASAP. Many remote river and rainfall data collection sites have Limited Automatic Remote Collectors (LARC) installed for telemetry purposes. Opportunities exist for additional LARCs to be installed that would provide increased coverage at river gaging stations operated by the U.S. Geological Survey. However, the data reports from these telephone reporting telemetry systems are sometimes missing during flooding events. It is frequently difficult to determine the details of the missing data problem which includes sensor failures, bad telephone lines, busy telephone signals (a cooperator may be calling the site at the same time), etc.

NWSRFS Version 5.0 is the operational forecast procedure that runs on the NAS9000 at the NCCF in Suitland, Maryland. RFCs have dedicated communication lines to the NAS9000 using remote job entry (RJE) to submit operational jobs and return model output.

Recent years have seen more automation of hydrologic data collection. However, there are still a considerable number of manual observations being taken as well as manual transfer of telephone data. Offices are encouraged to work toward total automation--from sensing the precipitation or stage at the gaging site to dissemination over NWS circuits--and for automatic model input. The following list provides a snapshot of station status at the time of the disaster as defined in WGRFC NWSRFS Version 5.0 procedures:

Total River Gages	598
Number of DCP River Gages	286
Number of Centralized Automatic Data Acquisition System (CADAS) River Gages	22
Number of Other Automated River Gages	64
Total Automated River Gages	372
Percent Automated	62%
Total Precipitation Gages	2,157
Automated Precipitation Gages	1,035
Percent Automated	48%
Total Defined Stations	2,365

During this event, the WGRFC had some problems with missing data from river gages. During the period of the flood, 27 percent of the 6 a.m. river stage observations were missing. About half of the river gages in the WGRFC area have backup observers. However, contacting the backup observers, and the time required for them to take the reading, can result in lengthy delays. In most cases, the backup observer only provides one reading a day. While this is "better than nothing," more frequent readings are very desirable during a critical flood episode. Also, finding backup observers is becoming increasingly difficult; and a lengthy delay often occurs in attempting to find a replacement once a backup observer quits.

The WGRFC produces the river forecasts that serve as input for the public river forecast products that are prepared by the San Antonio and Fort Worth WSFOs and issued to the public. This RFC product is distributed internally on AFOS to the WSFOs who prepare the public forecast that is released over the communications circuits to the public. The WGRFC prepares river forecast products for each WSFO. Each of these forecast products contain forecasts for a series of forecast points along one or more rivers within the WSFO's area of responsibility. The individual forecast for each river forecast point contains three groups of information as defined below:

1. The name of the forecast point; in parentheses, the elevation of the Flood Stage (FS); and, depending upon the actual forecast point, the elevation of the Bankfull Stage (BF), Caution Stage (CS), and Warning Stage (WS).

2. The 6 a.m. stage (today).

3. The forecast.

Often, the forecast value provided by the WGRFC contains only one value. This, in addition to the 6 a.m. stage, only gives the user two data points to provide the public with decision-making information. Sometimes the time of the forecast is only indicated as to the day (e.g., RISING TO NR 28 FT SAT) with no information as to the time of the day.

In this event, the RFC forecasts were distributed over AFOS directly to the WSFOs. Thus, the WSOs did not have an opportunity to see the river forecasts provided by the WGRFC. In at least one instance, a review of the guidance data by the WSOs prior to the issuance of the WSFO river forecast product might have prevented questionable data from being included in the public product.

3.3 WSFOs, WSOs, WSMOs

There were few major data acquisition, communications, and facilities problems at the WSFOs, WSOs, and WSMOs during this flood episode, except for the river gage problems discussed previously and some minor (mainly equipment) problems at several NWS offices that are detailed later in this chapter. For the most part, the CONTEL NOAA Weather Wire Service (NWWS), NOAA Weather Radio (NWR), AFOS, and the Radar and Upper Air Systems remained operational and performed within current specifications.

However, emergency managers, the media, and other officials in the rural areas often mentioned their inability to receive the NWR broadcasts. Some had attempted to install outside antennas to improve signal strength. Also, smaller communities and rural counties often do not, or cannot, take advantage of other existing communication systems. For many, the CONTEL NWWS is too costly. In addition, many are well outside the radio range of NWR. The Texas Law Enforcement Telecommunication System is invaluable, but generally only the local sheriff and/or police office have access to that system.

There were communication outlets for city or county emergency managers in the rural areas. In more than one instance, the emergency manager was dependent on receiving NWS watches and warnings by telephone from the local law enforcement entity. The hard copy of the communication would be picked up later. If the proper local official did get the warning, intracounty communications systems often existed to fan the warning information out to appropriate local government agencies. Thus, for many rural areas, the problem seems to be the initial timely receipt of warning information.

Consistent praise was heard from State and local emergency managers, law enforcement offices, and NWS offices for the role played by radio and television in disseminating NWS watches and warnings and general flood and flash flood information. Many officials stated that the flow of information from the media was so frequent that they felt the public should have had at least a general knowledge of the continuing flood and flash flood problems.

Many NWS offices also praised the contribution of their storm spotters, especially those with amateur radio capabilities. While these spotter groups most often activate during severe thunderstorm and tornado events, good rainfall and flood information was provided to several NWS offices by spotter groups. However, it was also clear that access to more real-time rainfall information would be invaluable to the warning process.

While there were no major problems with data acquisition, communications, and facilities at NWS offices, some problems did occur. However, the incidents which follow did not have a significant impact on NWS forecast and warning operations during this event. Given the age and increasing maintenance demands of some NWS equipment, especially the 30-plus-year-old WSR-57 network radars, more equipment failures would not have been surprising.

3.3.1 WSFO San Antonio and WSOs and WSMOs in the South Texas Forecast Area

The lack of Mexican surface observations and upper air data continues to be a problem for all southern Texas NWS offices, but especially for WSFO San Antonio. Satellite data were invaluable in providing at least some information on systems moving out of Mexico into south Texas. The rainfall estimates derived from satellite data provided to the WSFO were excellent and were used in the warning decision process.

On Saturday, December 21, the AFOS line between San Antonio and Lubbock WSFOs was not operating properly for about 45 minutes (between 11 a.m. and noon). WSMO Hondo and all south Texas WSOs, except Austin, were able to dial into the Systems Monitoring and Coordination Center. Since WSO Austin is the WSFO's backup for warnings, WSFO San Antonio asked WSFO Fort Worth to issue several warnings for them during this 45-minute period.

No radar outages occurred during this event. However, four film canisters for the WSR-57 radar at WSMO Hondo proved defective. Thus, only a limited number of radar pictures are available for this event in the south-central Texas area covered by the Hondo WSR-57 network radar.

3.3.2 WSFO Fort Worth and WSOs and WSMOs in the North-Central and Northeast Texas Forecast Area

The WSR-57 network radar at WSMO Stephenville reported some frequency drift at times during the event, but this did not have any significant impact on overall forecast and warning operations.

3.4 Findings and Recommendations

Finding 3-1: The precipitation gages in the cooperative network are sparse, especially in rural areas of most large watersheds in the WGRFC area of responsibility. This low density of gages, combined with missing data from many cooperative observers on many days during this event, resulted in a significant problem with insufficient precipitation data. NEXRAD-generated rainfall data, using a 4 km x 4 km grid, is being implemented. The first such WSR-88D will be installed at Houston. A NEXRAD Principle User Processor is also scheduled for the WGRFC that will provide radar display capability.

Recommendation 3-1: The implementation of planned modernization and associated restructuring hardware must not falter. Interactive forecast workstations capable of running hydrologic models and inputting WSR-88D gridded precipitation data must be provided in the period prior to AWIPS.

Finding 3-2: In accordance with office policy, the WGRFC river forecast products were routed on AFOS only to the WSFOs. Thus, the WSOs involved in this flood episode never saw the RFC forecast prior to the issuance of the public river forecast products from the WSFOs. It should also be noted that all RFC forecast products will be distributed on the Family of Services circuits in the NWS modernization and associated restructuring.

The reason given for this WGRFC policy is that the data in the product is information for the WSFOs to use in formulating their public river forecast products. There was some concern that the WSOs might release these forecasts instead of waiting for the WSFO product that would contain the river forecasts for media and public release. However, if the WSOs had received the RFC's forecast over AFOS, in at least one instance, based upon the personal knowledge of the WSO staff, an unlikely stage forecast could have been brought to the attention of the WSFO or RFC. The stage forecast could possibly have been corrected prior to public release.

Recommendation 3-2: RFC forecasts are presently considered internal products (not for transmission to the public) and should be transmitted on AFOS with (as a minimum) RDC routing in order for these products to be (1) available as reference by offices other than just the Hydrologic Service Area office (e.g., WSOs, Regional Headquarters, and the Hydrologic Information Center in the Office of Hydrology) and (2) archived on the AFOS Service Records Retention System. A heading should be added to the product that indicates the data are "for internal use only." The WGRFC should also take steps to prepare for distribution of their forecasts on the Family of Services as a result of modernization (see also Finding and Recommendation 3.6).

Finding 3-3: The lack of meteorological data from Mexico is a continuing problem. In this instance, it was mainly a problem for WSFO San Antonio but also operationally affects NWS offices all along the U.S./Mexico border. During this flood episode, satellite was the only source of real-time meteorological data for Mexico that was available to WSFO San Antonio.

Recommendation 3-3: The NWS should investigate ways to improve the receipt of Mexican hydrometeorological data.

Finding 3-4: Data from the national river gaging networks in the United States continue to deteriorate, and there is a decline in the number of sites being funded. During the 20-year period from 1970 through 1989, a total of 39 river gages were taken out of operation that the WGRFC had been using in their forecast system in the State of Texas. In 1991, the WGRFC was using data from a total of 598 gages. Budgets for maintenance of existing gaging stations have diminished in recent years, and interagency response for restoring normal data availability has slowed. Each year the NWS increasingly relies on cooperating agencies for operational data. In view of the NWS's modernization and associated restructuring efforts (i.e., major advances from the use of WSR-88D precipitation data and interactive forecast procedures in the RFCs), the national impact on river stage data becomes increasingly significant. Major lifesaving and economic benefits are possible with prudent budgeting and interagency cooperation. Other

technical advances in systems and forecast procedures in the near future will require significantly more reliable data collection and a quicker response for restoring malfunctioning river gages.

Recommendation 3-4: The NWS and cooperating hydrologic agencies must become more imaginative and enterprising in order to devise budgeting plans for maintaining, restoring, and expanding river gaging networks.

Finding 3-5: One of the most (if not the single most) serious problems encountered in river forecasting is inaccurate or missing river stage observations. In a review of the 6 a.m. stage values used as model input for river forecasting during the period December 18, 1991, to January 5, 1992, it was found that 27 percent of the river stage observations were either not available or reported as missing. There are several reasons for missing data (e.g., automatic data collection system malfunction, no manual report collected, lack of backup observers, etc.). It was estimated from NWS staff interviews that nearly one-half of the river gages critical to flood forecast preparations failed at some point during this flood event. This situation was recognized by both the WGRFC and the Fort Bend County Office of Emergency Management in Richmond, Texas.

Recommendation 3-5: The NWS Hydrologic Service Area offices should aggressively explore further opportunities for obtaining backup river gage observations from cooperating agencies (e.g., emergency management offices, flood control districts, or river authorities). They should also actively seek assistance in the collection of stage data when and if failures occur with automated stream gage equipment and, when practical, share costs for backup observers at critical flood-producing sites. This form of data collection is sometimes more desirable than having volunteer observers who may be unavailable on weekends and during large flood events. Local emergency management agencies have the most interest in the flood forecast process and benefit most by cooperating in data collection for improved forecasts. Furthermore, the NWS should, wherever possible, maximize capabilities to access and share available data from local flood warning systems (e.g., ALERT).

Procedures also need to be developed to restore the flow of data from automated river gages whenever missing data are detected.

Finding 3-6: Forecasts issued by the WGRFC contain three groups of information for each forecast point as defined below:

1. The name of the forecast point; in parentheses, the elevation of the Flood Stage; and, depending upon the actual forecast point, the elevations of the Bankfull Stage, Caution Stage, and Warning Stage.
2. The 6 a.m. stage (today).
3. The forecast.

Often, the forecast value provided by the WGRFC contains only one value. This, in addition to the 6 a.m. stage, only gives the user two data points to provide the public with decision-making

information. Sometimes the time of the forecast is only indicated as to the day (e.g., RISING TO NR 28 FT SAT) with no information as to the time of day. These messages are also somewhat difficult to understand, especially for the casual user. Modernization plans are for RFC forecasts to be distributed on the Family of Services, and improvements in the way they are worded are desirable. WGRFC forecasts contain no information regarding QPF.

Recommendation 3-6: It would be desirable for the WGRFC to provide additional forecast data values in the river forecast products. Typically, river forecast products are released near midday; therefore, it would be extremely valuable for the users to have forecast information for 6 p.m. on the day of the forecast as well as for 6 a.m. the following day. If possible, forecasts should also be provided for 6 p.m. the following day. This would lend itself nicely to a tabular forecast product and would enable users to better understand how fast the rivers are changing. Tabular forecasts will also be easier for the casual user to understand which will be important since modernization calls for these products to be available to a wide range of users on the Family of Services circuit. Some consideration should also be given to providing additional information, even if it is subjective, with regard to how the forecast would change based upon future rainfall. (See also Finding and Recommendation 3-2.)

Finding 3-7: Rainfall data from many cooperative observers were missing on several days. The lack of sufficient storm rainfall information for the area during this event limited the ability of the WGRFC staff to accurately provide river forecasts. The forecasters, unfortunately, just did not have the most up-to-date spatial and temporal precipitation information. The NWS is in the process of implementing NEXRAD, which will provide Hourly Digital Rainfall (HDRain) products for use in hydrologic forecasting.

Recommendation 3-7: It is recommended that these products be implemented as soon as practicable for river forecasting in the WGRFC area of responsibility.

Finding 3-8: The touch-tone system, which is used in the collection of precipitation and stream gage data from cooperative observers, does not have any software to check on data quality.

Recommendation 3-8: The NWS should add software to the touch-tone system to do quality checks on the data and reduce the time required for manual checking of precipitation and river stage data.

Finding 3-9: LARCs are used frequently as a river stage telemetry system. Many U.S. Geological Survey gages have no telemetry, and opportunities exist for adding LARCs to provide increased coverage at sites where U.S. Geological Survey gages are located. LARCs also proved their versatility by computer contact and telephone voice readout both in the office and at home. LARCs are reasonably effective telemetry devices for river stage data. During this event, only 62 percent of the river gages in the WGRFC area were automated.

Recommendation 3-9: Expanding the LARC program should be a high priority of the NWS.

CHAPTER 4
PREPAREDNESS

4.1 Introduction

This chapter deals with both the internal and external preparedness efforts of the NWS directly related to the flood event of December 1991. The disaster survey team did extensive research in this area, considering the number of NWS offices involved in distributing information for the flood and flash flood events of late December 1991. The disaster survey team poured over many preparedness contact forms, mailing lists, telephone contact logs, and internal documents, such as drills, warning lists, and preparedness manuals. These sources, together with information provided by those interviewed during and following the on-site survey, are the basis for this chapter.

4.2 Internal Preparedness Actions

The disaster survey team found that all NWS offices (WSO, WSFO, RFC) perform internal preparedness actions regularly. Each office maintained and updated call lists to key external contacts. These contacts generally consisted of primary county dissemination points but also included other major external users, such as emergency managers and river and water authorities. In this way, each office could directly contact officials who were involved in life and property decision-making processes. This contact could have been missed or delayed, but each office had taken the time to update call lists at least once during the year before the flooding event.

Each office also prepared and maintained local station reference manuals on warning/hydrology programs. The manuals generally consisted of information and procedures related to the issuance of severe weather warnings as well as river and river flooding products. Some hydrology reference manuals included E-19 descriptions and histories of river forecast points (WS Form E-19), information on how to interpret E-19s, and instructions on calling up automated data. The hydrology reference manuals were especially important at Fort Worth and San Antonio WSFOs since forecasters at these offices were expected to understand and carry out many hydrology duties. These reference manuals helped to prepare forecasters for situations when the Service Hydrologist (SH) was not available, and they had to effectively answer questions related to hydrology. Hydrology reference manuals were found to a much lesser extent at the WSO level.

The WGRFC did not maintain a running call log; however, all other offices prepared call logs and warning checklists. The advanced preparation of these items played an important part during the flood/flash flood event, because incoming information and problems were

effectively logged. Warning checklists also ensured that proper dissemination points were contacted and provided an accountability of when warnings were issued. Without these prepared items, it would have been difficult to review the operations of the NWS following this event.

The nature of internal preparedness at the RFC was different from that of the field offices who deal with the public, the media, and the issuance of warnings. Generally, internal preparedness activities are more limited at the RFC. The RFC hydrologists depended on previously established forecast procedures and existing databases when dealing with flooding. Missing data from one or, as often in this case, several precipitation gages are routinely dealt with through estimation procedures during the forecast process. Nonetheless, these procedures and databases were developed before the flood event and thus considered an effective preparedness effort. Another internal preparedness effort by the WGRFC was the maintenance of excellent contact with SHs, WSOs, and cooperative agencies. If these contacts had not been maintained and nurtured, communication and coordination during the flood event would have been nonexistent. Also, the WGRFC was essentially internally prepared for this flood event because of the 1990 heavy rain/flood event. Flooding on the Trinity, Red, and Arkansas Rivers (over 1 year prior to this event), and a subsequent NOAA disaster survey, contributed to the preparations that were made by the WGRFC for the magnitude of flooding during this event.

A final internal preparedness effort was noted in the evaluation of training needs. Most field offices conducted river/flash flood preparedness drills during the year before the flooding event. At least one office conducted its drill within a 2-year period prior to the flooding. The WSO at Houston did not conduct specific river/flash flooding drills. Still, the Houston office, with its emphasis on hurricanes, did include coastal surge flooding in its hurricane drills. The SHs did conduct hydrologic drills with their respective WSFO staffs. These drills were very important since they allowed forecasters to become familiar with flood and river products, general river/tributary systems, and data collection sources. As a result, forecasters at the WSFOs seemed to have a good understanding of hydrologic problems in their areas of responsibility. The disaster survey team found that, generally, this type of training was not applied at the WSO level by the SH but should have been. Under the proposed modernization and associated restructuring of the NWS, WSOs will not exist and all Weather Forecast Offices (WFO) will have a Hydrologic Program. However, some WFO offices will operate without an on-site SH.

4.3 External Preparedness Efforts

The disaster survey team found that all NWS units performed extensive external preparedness activities. Each office made hundreds of contacts with the media, emergency management officials, water and river management authorities, volunteer and professional groups, and other State and local government agencies, as well as the public. External preparedness efforts were largely accomplished through direct meetings with these groups. The disaster

survey team found that Warning Preparedness Meteorologists (WPM), Meteorologists in Charge (MIC), and SHs all made conscientious efforts to meet various individuals and groups who were involved in the dissemination and warning decision-making process. External preparedness was also accomplished through informal telephone conversations, newsletters, letters, and memos.

Since the NWS depends greatly on the electronic and news media to distribute its forecasts and watches and warnings information, ongoing preparedness efforts with external groups are extremely important. All NWS offices visited by the disaster survey team reported having excellent relations with the media in their areas. These relationships were verified by the positive response the team found when interviewing various media outlets. Preparedness efforts were generally accomplished by providing the media with information and interviews on NWS operations. The effort of MICs, WPMs, and SHs to keep the media informed about ongoing and upcoming operations paved the road for the media to seek out the NWS as an authority concerning the river and flash flooding of late December 1991. Judging by the media responses for this event, the NWS accomplished the necessary preparedness contacts prior to the event by its continuing efforts to nurture these contacts.

Some river and flash flooding did occur in areas with a large Hispanic population. This group depended mostly on Spanish-speaking radio, television, and newspapers for their weather information. The disaster survey team found that the NWS office in San Antonio maintained excellent relationships with Hispanic media in part because of the bilingual abilities of several staff members. However, contact with the Hispanic media was done on a lesser scale at other NWS offices.

The RFC's coordination efforts with the field offices was superb and additionally put the RFC in contact with other local governmental agencies. The disaster survey team noted that among the RFC's contacts, the U.S. Army Corps of Engineers and the Lower Colorado River Authority were two of the agencies that the RFC worked with very well during this event. Many local NWS offices also had similar contacts with local agencies. Subsequently, the close relationships of other water agencies with the RFC expanded the field of expertise to draw on during the coordination process. As a result, the RFC was able to prepare and coordinate procedures and lines of communication between themselves and these important river authorities.

Preparedness contacts with emergency management officials were done by all WSOs and WSFOs. Contacts with these individuals were ongoing and often resulted in several meetings over the course of a year. MICs and WPMs were the main NWS contact points. The disaster survey team found that SHs were also heavily involved in preparing emergency managers for river and flash flooding events. The preparation accomplished by SHs occurred in large part because of their responsibilities in establishing river observing networks. The disaster survey team found that sometimes WPMs were also coordinating efforts with these same emergency management officials. As a result, some emergency

managers were confused about the river warning/flash flood warning process and where the information originated.

Under the modernized NWS, a full-time Warning Coordination Meteorologist (WCM) will alleviate some preparedness and coordination problems that the part-time WPM typically encounters. The WCM will devote more time to personal one-on-one interaction with individuals in the hazards community. In addition, the WCM will coordinate with the NWS Hydrology Program. Consequently, future WCMs and SHs should work closely in preparing the emergency management community for hydrology/severe weather warning programs.

Preparedness contacts with emergency managers played a key role during the late December flooding of 1991. In almost every interview conducted by the disaster survey team, emergency management officials were impressed with the one-on-one cooperation and coordination exhibited by the NWS and accomplished through preparedness efforts. For instance, most emergency managers had no qualms about contacting their local NWS offices during the event. This was simply the result of a one-on-one working relationship with a specific individual in the office. Often, emergency managers knew that they could contact the SH directly to learn about river flooding. The disaster survey team found only one instance where an emergency manager did not call his local NWS office. As a result, the emergency manager complained to the media about the river forecasts. A review of preparedness-contact forms indicated that this manager had not received any direct contact during the year prior to the flooding. Had a personal preparedness visit occurred, the emergency manager might have known whom to contact directly and may have been at ease in doing so.

One criticism received by the disaster survey team from MICs and WPMs was that because of NWS budget restrictions and the resulting freeze on travel during the summer of 1991, direct preparedness contact prior to the flooding was somewhat limited. This may have accounted for the lack of contact with the emergency manager who complained to the media. The NWS did keep in touch with some of these managers through newsletters and formal letters, but personal interaction has always been a more effective preparedness tool.

All WSO/WSFO offices were involved in the development and training of spotter networks. The disaster survey team found that several offices used spotter networks as well as State of Texas Radio Amateur Civil Emergency Services (RACES) networks during this flood event of late December 1991. WPMs and MICs have done an excellent job of developing, maintaining, and preparing these networks for flood/severe weather events. The WSO at Austin and the WSFO at Fort Worth established excellent amateur radio and emergency management spotter networks. These networks were utilized during this flood event. The spotter network in the San Antonio area consisted of existing rainfall observers and emergency management spotter networks. This office could benefit from the development of a RACES or other amateur radio network to supplement critical information used in the flood/flash flood warning decision-making process.

One final area of external preparedness is public education. The disaster survey team found that the WGRFC did not have a public education program, but the WSOs and WSFOs performed numerous activities related to public education and preparedness. While most of this education was related to severe storms, flooding and flash flooding were included in most educational talks. Discussions with WPMs and MICs revealed that river flooding was generally covered at a far lesser degree. This may be one reason why some users were confused over terms that were applied to river flooding, e.g., flood crest versus flood wave. Another revelation was that the public was not generally aware that the NWS had the responsibility for warnings and river forecasts. Additionally, the disaster survey team found that the media and public were confused about the working relationship between the NWS, emergency managers, and river authorities.

4.4 Findings and Recommendations

Finding 4-1: Some NWS users were confused by, or misunderstood, some terms (such as flood crest and flood wave) which related to river flooding.

Recommendation 4-1: WPMs, MICs, and SHs should educate users on the use of terms related to river flooding. Also, the NWS should reevaluate how certain confusing terms are used and in what context.

Finding 4-2: The public may not have understood the role of the NWS in the issuance of warnings and river forecasts.

Recommendation 4-2: WPMs and MICs should continue to make a concentrated effort to educate all users about the NWS, including providing information about what the NWS does and what products it is responsible for. In addition, it would be helpful for the media to see and understand NWS local partnerships and their important roles in the warning/safety process.

Finding 4-3: Some WSOs did not have copies of hydrology preparedness manuals and E-19s on rivers within their county warning areas.

Recommendation 4-3: WSOs should be provided with a copy of the Hydrologic Services Manual for the Hydrologic Service Area. WSO staff members should have training provided by SHs on interpretation of E-19s. These items would help the staff at WSOs to deal more effectively with the public and the media when calls come in to them rather than having to refer all questions to the SH.

Finding 4-4: The WGRFC did not maintain prepared call/coordination logs.

Recommendation 4-4: The WGRFC should prepare call/coordination logs, especially during major floods. These logs ensure that key communications and the times they occur are

accounted for. Prepared call logs also provide important event information for both internal and external reviews of operations.

Finding 4-5: River/flash flood drills were not conducted annually at all NWS offices.

Recommendation 4-5: Each office should conduct, at least once a year, a river/flash flood drill for its area of responsibility as stated in Weather Service Operations Manual Chapter A-17. The drill should specifically address problems of heavy rain flooding and river flooding not associated with severe weather. In addition, these drills should involve outside groups, such as emergency managers, flood control districts, and river authorities. Any groups that operate local flood warning systems should specifically be targeted.

Finding 4-6: SHs prepared and conducted excellent training for forecasters at their offices, but limited attention was provided to the WSOs.

Recommendation 4-6: Hydrologic training should be provided by the SH to personnel at the WSO level. Local officials involved in the flood warning system should also be invited to attend.

Finding 4-7: Few NWS offices maintained significant contact with the Hispanic media. This resulted in a reduced ability to reach that segment of the population. Most Hispanic media outlets have bilingual employees; therefore, it is not necessary that the NWS contact point be proficient in Spanish.

Recommendation 4-7: To properly serve the Hispanic population, the NWS needs to make a conscious preparedness effort with the Hispanic media.

Finding 4-8: Close interaction between the RFC and Hydrologic Service Area offices resulted in good preparedness contacts with key river authorities.

Recommendation 4-8: RFCs should cultivate and maintain contacts with WSOs as well as with WSFOs. These contacts are a valuable resource for interaction with State and local river authorities.

Finding 4-9: Direct preparedness contacts by the SHs with emergency managers helped to provide that group with important information and expertise during the flood event.

Recommendation 4-9: External preparedness contacts by SHs should be coordinated with WPMs and MICs. River flood and flash flood programs often go hand in hand. Therefore, the SH should be invited to meetings between emergency management officials and WPMs/MICs. These coordinated visits would help both the NWS and the emergency management officials to understand the warning and dissemination communication chain.

Finding 4-10: Direct personal preparedness contact with emergency managers helped to establish one-on-one coordination relationships. These relationships resulted in excellent two-way communication during the flooding event.

Recommendation 4-10: Future NWS budgets should make specific allowances for preparedness contacts and travel. However, in times of fiscal austerity, WPMs and MICs should continue, and possibly increase, direct contact with the hazards community through written and personal telephone communication. Emergency managers should be encouraged to also accept the responsibility of contacting the NWS to schedule meetings and to confer on communication and weather problems.

Finding 4-11: Existing spotter networks did not include all possible sources of information.

Recommendation 4-11: WPMs/MICs should seek out and consider the development of other reliable information networks for use in the warning process. Development or refinement of amateur radio spotter networks for use in river flood events, as well as severe thunderstorm events, would be beneficial.

CHAPTER 5
HYDROLOGIC WARNING SERVICE--RIVER FLOODING

5.1 Introduction

This chapter presents the results of the survey team review of river flood forecast services for the Trinity, Brazos, Colorado, and Guadalupe River Basins. It is organized by type of NWS office (RFC and WSFO), giving a brief description of findings for each. Chronologies of the river forecasts issued for Fort Worth and San Antonio hydrologic service areas (HSA) are contained in Appendix B and Appendix C, respectively. Specific findings and recommendations are located in Sections 1.7, 3.4, 4.4, and 5.4.

5.2 RFC Operations

The WGRFC in Fort Worth, Texas, the first-echelon office responsible for forecasting flood levels, was the sole RFC involved in the December 1991-January 1992 record flood event. The WGRFC interfaced with two WSFOs: one at Fort Worth, Texas, and the other at San Antonio, Texas. Each WSFO has HSA responsibility to interpret RFC forecasts and disseminate flood statements and warnings; to handle data collection and quality control; and to interact with interagency contacts, media, emergency management agencies, and the general public.

The WGRFC issued hydrologic forecasts for the Trinity, Brazos, Colorado, Guadalupe, and Lavaca River Basins plus their related tributaries. Drainage basins along the Interstate 35 corridor from Dallas/Fort Worth to San Antonio, Texas, endured more than a 1-week period of rainfall. Significant precipitation totals over 12 inches occurred near San Antonio and ranged 6-7 inches moving northward toward Dallas/Fort Worth. Heaviest amounts fell December 20-22, 1991, creating runoff that produced major flooding over central and coastal areas of Texas and continued as streams neared their mouths on the Gulf of Mexico. Figure 16 shows these areas of disastrous floods in Texas. Rain returned to the Texas coast December 23-27, 1991, compounding near-record flooding already in existence over the coastal areas of the State.

The Colorado River experienced major flooding in headwater reservoirs that topped previous record levels dating back to the 1950s. Table 5-1 shows flood crests that occurred during the event. Downstream, the Colorado River flows through Austin, Columbia, and Wharton, Texas, where major flooding continued to affect most river communities and farmland. The Guadalupe River flooded portions of Gonzales, Cuero, and Victoria, Texas.

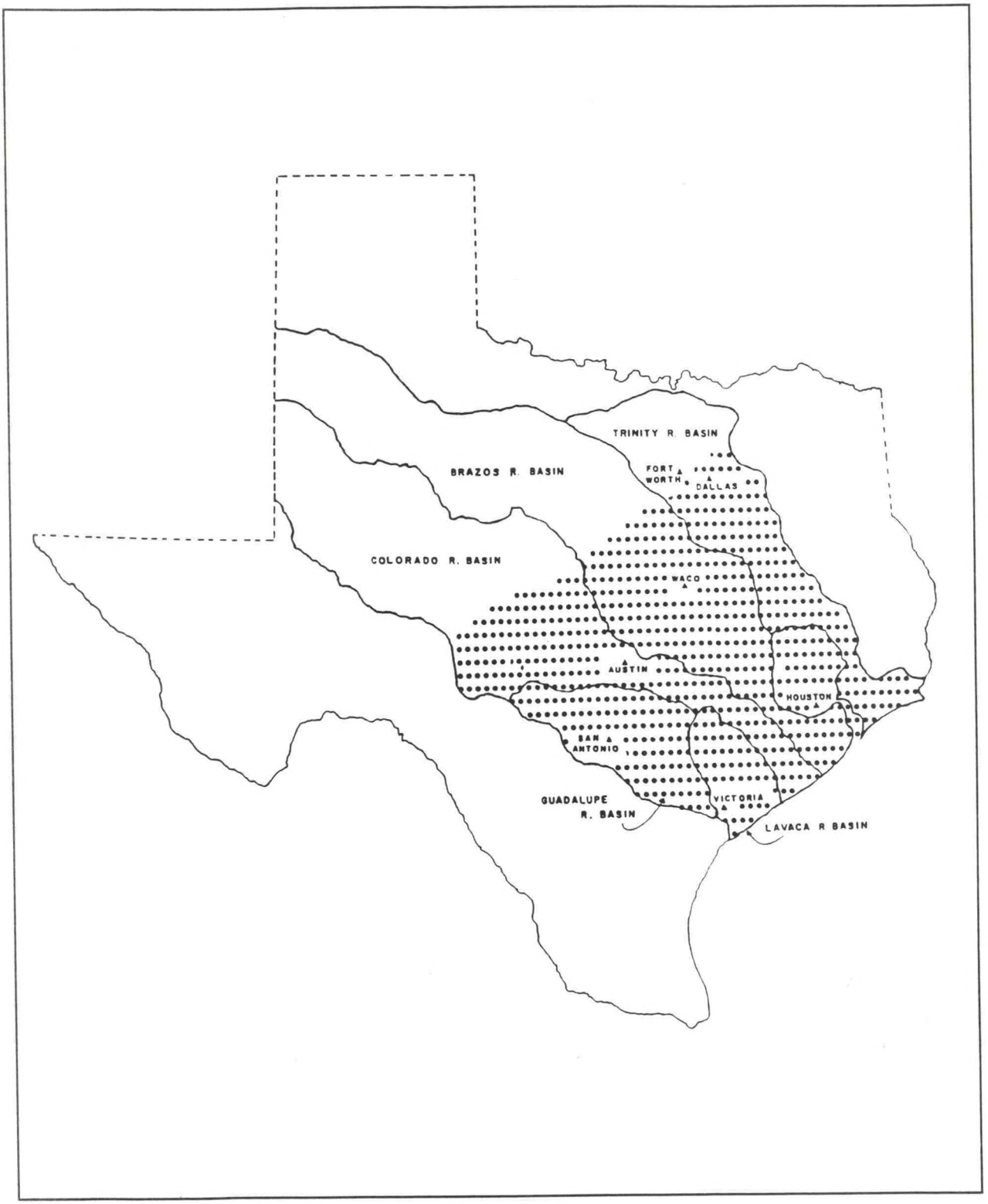

Figure 16. *Texas area of disastrous floods, December 1991.*

Table 5-1. *Flood crests for Texas during the December 1991 major flood event.*

River/Station (FS)*	Crest (ft.)	Date of Crest	Previous Record	Date of Record
Colorado River				
Bastrop (30)	37.48	12/22/91	34.45	10/29/60
San Gabriel River				
Rockdale (30)	35.58	12/21/91	32.91	7/27/79
Little River				
Little River (30)	39.41	12/21/91	42.85	5/17/65
Rockdale (27)	37.98	12/21/91	35.67	6/15/81
Cameron (30)	38.57	12/21/91	53.20	9/10/21
Navasota River				
Easterly (19)	27.51	12/22/91	27.13	5/2/44
Bryon (12)	17.80	12/23/91	16.57	4/29/66
Brazos River				
Highbank (35)	30.78	12/22/91	42	12/1913
Bryan (40)	43.40	12/23/91	54.0	9/12/21
Washington (45)	47.95	12/26/91	33.6	1/24/68
Hempstead (50)	53.03	12/28/91	56.1	12/9/13
Richmond (48)	49.80	1/1/92	53.6	6/6/29
North Bosque River				
Hico (19)	23.27	12/21/91	27.6	5/23/52
Clifton (32)	38.34	12/21/91	34.88	10/4/59
Valley Mills (36)	44.5	12/21/91	43	5/1908
Leon River				
Hamilton (26)	35.02	12/20/91	38.4	5/1908
Gatesville (22)	34.87	12/21/91	35	5/1908
Nolan River Blum (24)	31.55	12/20/91	35	5/08/22
Cowhouse Creek				
Pidcoke (38)	44.5	12/20/91	40.1	10/04/59
Lampasas River				
Kempner (na)	35.0	12/20/91	45(e)	10/1873
Chambers Creek				
Rice (24)	32.57	12/21/91	None	Records begin 1984

*FS is flood stage
(e) is estimate

To the north, the Trinity River (which originates near Fort Worth) and the Brazos River (which flows through Waco) were partly contained by reservoirs, which prevented catastrophic flooding on those streams in central Texas. Several of these reservoirs reached record levels as shown in Table 5-2. Near-record flooding did occur downstream on the Brazos River at Hempstead, Texas.

Table 5-2. *New record pool elevations for Texas during the December 1991 and January 1992 major flood event.*

River/Lake	Pool Elevation	Date
Colorado River		
Lake Buchanan	1,021.39	12/20/91
Lake Travis	710.23	12/26/91
Brazos River Basin		
Aquilla Creek		
Aquilla Lake	551.89	12/24/91
Bosque River		
Lake Waco	488.48	12/24/91
Leon River		
Belton Reservoir	621.17	12/30/91
Lampasas River		
Stillhouse Hollow	649.22	01/09/92

The WGRFC issues hydrologic forecasts and crests when significant runoff response on rivers and streams approaches bankfull stages. During periods when river flows are low, no active forecasting is necessary except for recreational advisories. Staffing at the WGRFC normally is between 7 a.m. and 4 p.m., Monday through Friday. On weekends and holidays, staffing is from 8 a.m. to 12 p.m. Additional staffing, when required during evenings and weekends, is handled on an as-needed basis. Overtime is paid to employees for extra hours worked in these situations. During this flood event, the WGRFC was staffed evenings until 10 p.m. December 20-22, 1991; until 8 p.m. on December 23, 1991; and from 7 p.m. to 9 p.m. on December 26, 1991. Early morning arrival of staff occurred at 6 a.m. December 21-23, 1991. Extra hours worked by the WGRFC during this period totaled 31 hours overtime, 29 hours holiday pay, and 159 hours compensatory time. Annual leave was canceled for all staff members for December 19-23, 1991. Selected staff were allowed annual leave commencing on December 24, 1991, and thereafter.

Some difficulties were encountered in forecasting the lower Brazos River, especially the forecast points located at Washington, Texas, and near Hempstead, Texas. Several forecasts indicated the rivers would rise higher or would crest much sooner than they did. The initial forecast for Washington that was issued midday Saturday, December 21, 1991, was for the river to rise over flood stage (45 feet) Sunday night, December 22, 1991. The river gage reading at that time at Washington was 15.7 feet. On Sunday, December 22, 1991, the forecast was for the stage to be higher and that it would occur later. The forecast on Monday, December 23, 1991, also indicated a delay in the crest. Flood stage was reached Tuesday, December 24, 1991, and the river crested at 47.95 feet at 3 p.m. on Thursday, December 26, 1991.

Similarly, the forecast for Hempstead that was also initially issued midday Saturday, December 21, 1991, was for the river to rise over flood stage (50 feet) Monday night, December 23, 1991. On Sunday, December 22, 1991, the forecast for Hempstead was revised for a higher stage that would occur later. The forecast issued Monday, December 23, 1991, again indicated a delay in the crest. Flood stage was reached Wednesday, December 25, 1991, and the river crested at 53.03 feet at 7 a.m. on Saturday, December 28, 1991. Even though at both locations flood stage was reached 2 days later than was predicted, the flood did exceed flood stage as forecasted and homeowners in the area had sufficient time to remove their belongings. Forecasts for the Brazos River at Richmond, Texas, and other forecast points further down the river were also predicted to reach flood stage sooner than actually occurred. The public had been very adequately warned in advance that the flood would occur and had taken steps to protect life and property but had expected flood stage to be reached earlier.

One previous flood approaching the magnitude of this one occurred in early December 1913. The forecast model that was in place to forecast the Brazos River at Washington and Hempstead was calibrated with previous available conditions. However, all of the data and information from the 1913 flood are not available for use in calibrating the forecast model. Consequently, the calibrations were at the edge of their limits, which subsequently contributed to the erroneous forecasts. Also, more complete information on the distribution of rainfall over the river basins, which will be available from NEXRAD, would have provided more precise information to the hydrologic runoff model.

More sophisticated procedures for forecasting flood waves do exist--procedures which are better able to accurately forecast conditions at or even beyond the conditions in the historical record. These procedures, such as the Dynamic Wave Model, use more detailed model physics to predict water levels and velocities at multiple locations and to account for the reduced velocity of the flood wave as the river spreads out over extensive low-lying areas such as the farmland adjacent to the Brazos River. This more advanced model can even account, with some success, for scour and fill that occurs in the river bottom during high flows. Unfortunately, the Dynamic Wave Model is very time-consuming to implement. Much data, including cross-sections of the river at various locations, need to be assembled to calibrate the model and put it into operational use. Advanced models of other hydrologic

processes, which compute the volume of precipitation runoff entering the river systems, also exist but require similar investments to be installed uniformly. The increased staffing that is necessary to implement these advanced modeling and forecasting capabilities for floods such as those that recently occurred in Texas have been included in the modernization plans for the WGRFC. NWS modernization plans, when fully implemented, will provide significant improvements to our flood forecasting services. As indicated previously, one of the most noteworthy improvements will occur from the high-resolution precipitation estimates that will be made available from NEXRAD for higher levels of processing and analysis in the AWIPS. This new information will greatly assist forecasters in the determination of the amount of water that will be added to the river systems. AWIPS will provide the higher levels of data processing and forecast analysis required to effectively use the NEXRAD data operationally.

It has been a practice for staff of the WGRFC to keep forecast aids at their residences. The purpose is to quickly respond when HSA offices or other offices request new or updated forecasts. When an updated or new forecast is provided over the telephone from the hydrologist's home, the office logs are subsequently updated. It was reported to the survey team that this procedure was employed during this flood event on several occasions.

Both the Fort Worth WSFO and the Lake Control Unit of the U.S. Army Corps of Engineers Fort Worth District are collocated with the WGRFC. This arrangement has many positive advantages. Management contacts emphasized considerable interaction between staffs when coordinating data and forecasts. Speedy transfer of information is possible with xerox copies made and hand carried to the collocated offices. Response from comments indicates that an excellent relationship exists among the three staffs. Coordination with the San Antonio WSFO is basically accomplished by telephone with early forecast information for the preparation of public-released forecasts and warnings transferred by fax. In addition, the WGRFC often has direct contact with various river authorities. Referrals to the Hydrologist in Charge (HIC) at the WGRFC for hydrologic information include emergency management officials, county judges, media, public and private organizations, etc.

The WGRFC follows the policy that the Deputy HIC is responsible for daily operational procedures while given hydrologists are assigned responsibilities for data collection, quality control, and forecast product issuance. It was pointed out to the survey team that hydrologists normally rotate among basin assignments. One river basin had been assigned to one individual forecaster for over 2 years. No clearly established policy was found to exist for quality review of forecasts or rotation of the assignment responsibilities to other river basins. All hydrologists may be assigned procedures development duties, but most assignments are directed to trainees or interns. Forecasts prepared at the WGRFC are sent by fax (or hand carried in the case of WSFO Fort Worth) directly to an HSA office after initial contact is made. The WGRFC has 15 river forecast product identifiers provided for its use (reference Southern Region's Regional Operations Manual Letter S-11-91, dated September 16, 1991, filed with Weather Service Operations Manual Chapter E-42). In the recent flood event, only two of these product identifiers were used.

The WGRFC, like other RFCs, is connected to the NAS9000 mainframe computer at the NCCF. For a week and a half, the WGRFC requested "HYDCRIS," which is a high-priority job status reserved for emergency flood forecasting operations. The HIC reported outstanding support with batch-retrieval jobs during this critical period. Later, when operations returned to running normally, support for retrieving batch jobs rated barely acceptable to poor. Occasions were noted when long job queues meant turnaround times of 30-40 minutes or more. The result delayed forecast preparations and release of products to the HSA offices. A single line printer slowed the process by acting as a bottleneck. Hydrologists were often waiting for hydrograph printouts before forecasts could be prepared and released. Early on, the WGRFC used a simple PC-based interactive procedure to model the Guadalupe, which is a fast-responding river. It was estimated by WGRFC staff that 1½-2 hours could be realized in quicker releases of hydrologic forecasts if the NWS RFCs all had the capability of an interactive forecast system such as the one being installed on pre-AWIPS equipment at the Arkansas-Red Basin RFC in Tulsa, Oklahoma. The new technology and workstations would likely have played a large, positive support role for the WGRFC, which issued over 860 flood forecasts in 12 days and 105 forecasts in a single day.

5.3 WSFO Responsibilities

River forecasts for this event were provided by the WGRFC to the San Antonio and Fort Worth WSFOs, which are assigned HSA responsibilities. Each of these HSA offices is responsible for receiving the river forecasts from the WGRFC and for creating forecasts for release to the public.

WSFO Fort Worth's HSA responsibility includes the headwaters of the Trinity River downstream to, and including, Lake Livingston. WSFO San Antonio has HSA responsibility downstream below Lake Livingston through Goodrich, Texas, to the Gulf of Mexico. WSFO Fort Worth's HSA responsibility on the Brazos River Basin includes reaches below Aspermont 13N (Salt Fork); Aspermont near Double Mt. Fork; and Roby (Clear Creek) downstream to, and including, Youngsport (Lampasas) and Belton Dam (Little River); then downstream to Highbank, Texas, on the main channel of the Brazos River; and the headwaters of the Navasota River down to Limestone Dam. WSFO San Antonio has responsibility on the Brazos River below Highbank, including the Navasota Basin below Limestone Dam and other Brazos River tributaries above Hempstead, Texas, downstream to the Gulf of Mexico. WSFO Fort Worth has HSA responsibility for the Colorado River Basin below points at Robert Lee (Colorado) and San Angelo (Concho) downstream to, and including, the San Saba River to, but not including, Buchanan Dam. WSFO San Antonio's HSA responsibility on the Colorado River includes the reach from Buchanan Dam and tributaries to Wharton, Texas, and the Gulf of Mexico. WSFO San Antonio has HSA responsibility for the entire Guadalupe River and its tributaries, downstream to the Gulf of Mexico, and the Lavaca River Basin along the Texas coastal plain (see Figure 17 for a map of Texas HSA responsibilities). HSA offices produce plain-language river statements or warnings for dissemination over media circuits for public release. WSFOs also have the responsibility for issuing flash flood watches for their forecast areas, and both WSFOs and WSOs have flash flood warning responsibility for their areas of county warning responsibility.

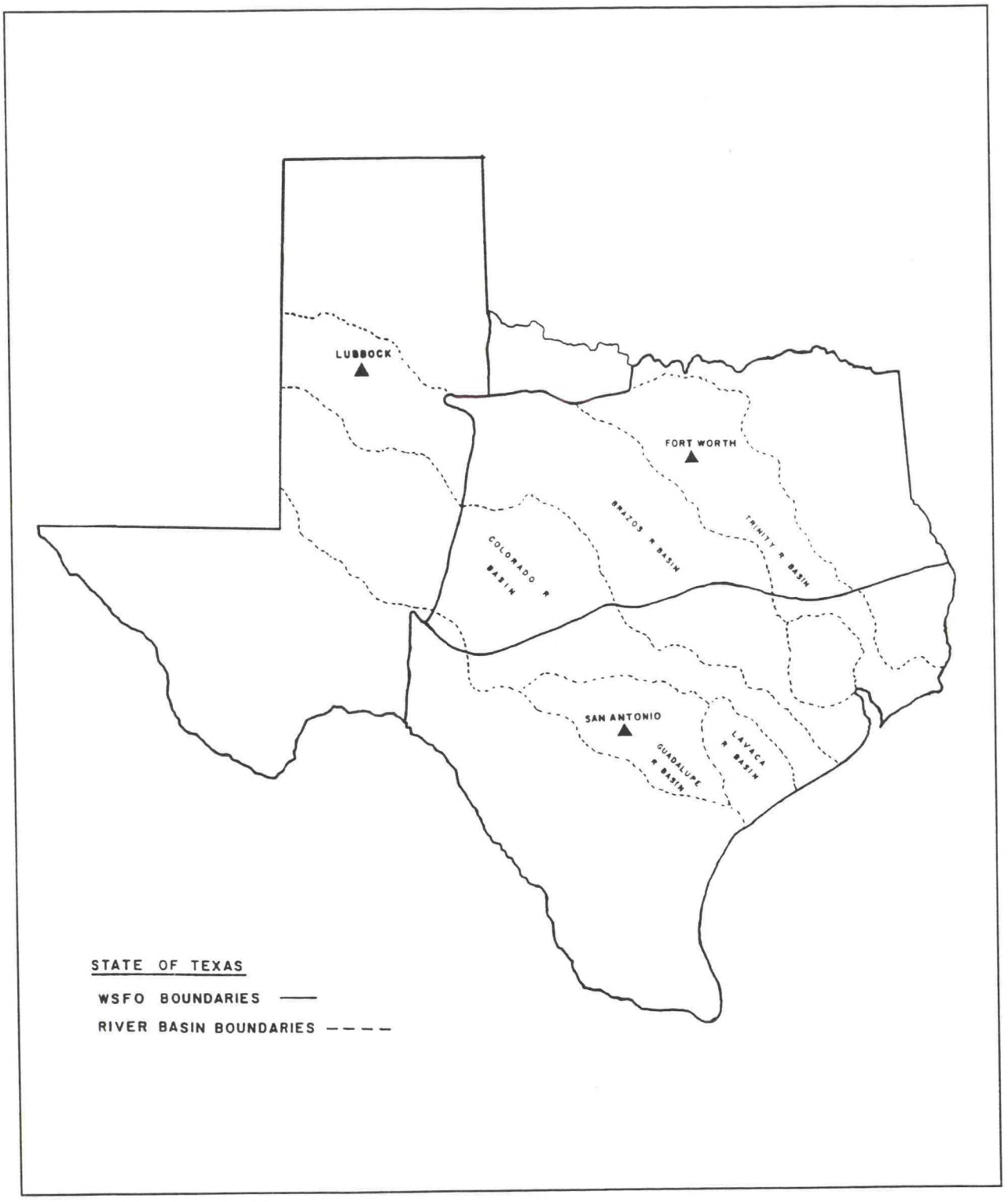

Figure 17. *Texas hydrologic service areas of responsibility during December 1991 flood event.*

STATION I.D.: DWYT2
DATUM: -5.92'
STATION NAME: DEWEYVILLE
RIVER NAME: SABINE
ORDER: 005
LOCATION: 2.4 MI NORTH OF RULIFF; AT DOWNSTREAM SIDE OF BRIDGE ON ST. HIGHWAY 12
PERIOD OF RECORD: OCTOBER 1924 TO CURRENT
RECORD FOR PERIOD OF RECORD: 29.98' (121,000 CFS) 5/22/53 (ADJUSTED TO CURRENT DATUM)
RECORD OUTSIDE PERIOD OF RECORD: 32.2' 5/1884
GAGE TYPE AND SOURCE OR OBSERVER: MANOMETER RIVER DATA THROUGH SATELLITE DCP (NMCRRATX2), WIRE WEIGHT. SABINE RIVER AUTHORITY THROUGH TOUCHTONE SYSTEM, LARC.
EQUIPMENT TYPE AND MAINTENANCE OFFICES: BUBBLER TYPE MANOMETER, WIRE WEIGHT GAGE AND STEVENS 7000 RECORDER. USGS HOUSTON (JIM FISHER) 8-526-6667-55. LARC - ET AT BPT.
AGENCIES TO COORDINATE WITH OR WARN: SABINE RIVER AUTHORITY 409-746-2111.
RFC FORECAST POINT: YES
REFERENCE LEVELS:
23' - BANKFULL STAGE
24' - FLOOD STAGE
25' - LOWEST ROADS BESIDE RIVER FLOOD
25' - 27' LOWEST HOMES BETWEEN DEWEYVILLE AND RIVER FLOOD - IN INDIAN LAKES AND RIVER OAKS SECTIONS.
27' - FIRST HOMES IN DEWEYVILLE
29' - DEWEYVILLE ISOLATED - MOST OF TOWN FLOODED.
29.15' - JULY 6, 1989 - ESTIMATED 50 HOMES FLOODED - SOME IN EDGE OF DEWEYVILLE - RIVER INUNDATED ALL LOOPS IN CHANNEL SO IT WAS MORE THAN A MILE WIDE NEAR DEWEYVILLE.
29.98' - 121,000 CFS - FLOOD OF RECORD - 5/22/1953 (CURRENT DATUM)
32.20' - RECORD FLOOD OUTSIDE PERIOD OF RECORD 5/1884
FLOOD FORECAST REFERENCE LEVELS ---
24' MINOR
26' MODERATE
27' MAJOR
28' NR FLOOD OF RECORD
29.98' FLOOD OF RECORD

Figure 18. *Example of E-19 reference material.*

The hydrologic situation for this flood event has already been described in previous chapters. By the morning of December 19, 1991, it was evident that a major flood event was on the horizon. The WSFO Fort Worth office had issued a flood potential outlook product (FTWESFFTW) at 4:10 p.m. on the previous afternoon, and the rains that fell overnight were sufficient for the WSFO San Antonio office to issue a flood warning (SATFLWSAT) very early (4:25 a.m. CST) on the morning of December 19, 1991. By the end of the day, several flood warnings had been issued by both San Antonio and Fort Worth.

Flood warnings and statements continued to be prepared and disseminated throughout the flood by both the Fort Worth and San Antonio HSA offices. For both of these offices, the SH was primarily responsible for creating the warnings and statements. While the methods that are used by the HSA offices to prepare the flood warnings and statements vary somewhat, generally the text is prepared by using the river forecast (issued by the WGRFC) and by cross-referencing information contained within Weather Service River Gaging Station (WS Form E-19) forms. The "E-19 reference material" file (example shown in Figure 18), developed by the San Antonio HSA office, contains one "page" of pertinent information for each forecast point. The Service Hydrologist Information Management System (SHIMS) is being implemented within the Southern Region to computerize the E-19 process.

The disaster survey team found that the public, emergency management officials, and other federal agencies were kept well informed on the progress of the flood. On one occasion, reports indicated difficulty in finding the forecast for a specific location because the forecast that was released to the public was too lengthy. The Fort Bend County Emergency Management Office reported that the forecasts were changed often and, furthermore, that the early forecasts were, on occasion, too high. Many times river stage data from automated equipment were not available to the WGRFC, sometimes due to equipment failure. County employees, however, were at times manually taking observations in order to augment NWS forecasts to the public with the most up-to-date conditions.

5.4 Findings and Recommendations

Finding 5-1: The public forecast products (and the forecast products that were issued by the WGRFC) often were lengthy, containing forecasts for many basins and many individual forecast points within a basin, which made it difficult to find the specific forecast for an individual point.

Recommendation 5-1: It would be beneficial to all users if forecast products could be made shorter in length, especially for smaller basins. This may require additional AFOS product identifiers from the RFCs but, in all circumstances, would enable users to more readily locate specific forecasts that they are most concerned about.

Finding 5-2: The WGRFC routinely follows the practice of preparing forecasts in the morning based upon 6 a.m. stage observations. These forecasts are then hand carried or faxed to the HSA offices whereupon the WGRFC sends the forecasts via AFOS, site addressed to the appropriate HSA office. The WGRFC also provides updated forecasts via voice telephone or fax to HSA offices. In the case of WSFO Fort Worth HSA, forecasts (as well as updates and revisions) are frequently just hand carried to the office (which is just next door). Cooperative agencies and the Hydrometeorologic Information Center's access to these products is limited to either faxing or telephone transfer. These activities are inefficient and lack timeliness in reaching numerous users of these products. Furthermore, site addressing of these forecast products on AFOS does not allow them to be archived in the Service Records Retention System.

Recommendation 5-2: All forecasts, including revised and updated forecasts, should be transmitted on AFOS with an RDC routing so that they (1) are available to the HSA offices, (2) reach the Service Records Retention System for official archiving, and (3) are officially available to others in the AFOS database. The Southern Region should officially discourage the use of fax transmissions as a primary means for dissemination of official forecasts.

Weather Service Operations Manual Chapter E-42 should be amended to discuss the archival of official forecasts at the Service Records Retention System. User instructions that are provided in the AFOS Handbook Series on how to ensure that forecasts reach the Service Records Retention System need to be refined.

Finding 5-3: Delays occurred in the forecast process that were due to the time it takes for computer forecast runs to print out the information which forecasters use to make the actual river forecast. Commonly termed "job stacking" by the forecasters, the delays were a combination of low-speed printers and outdated RJE equipment that ties the WGRFC to the host mainframe computer (NCCF located in Suitland, Maryland) where the computer runs are made to produce the forecasts. The WGRFC requested the NCCF to use the NAS9000-designated "Critical Flood Day" procedure for its computer operations as provided for by NMC. This procedure ran for 1-1/2 weeks during the period when record floods were occurring. Later, when this procedure was turned off, batch turnaround was stacking jobs 30-40 minutes on the printer adding 1-1/2 to 2 hours to the normal time it takes to prepare forecasts. The NWS is implementing an interactive forecast system for forecast preparation as part of the modernization and associated restructuring of the NWS which could reduce this time delay.

Recommendation 5-3: Schedules indicate that most RFCs will not be receiving interactive forecast capability until the middle to late 1990s. There is good evidence that most of the 1-1/2 to 2 hours lost in batch operations can be regained by using the interactive forecast capability. This will allow for more timely forecasts to be released to the public and cooperating agencies. High priority needs to be placed on implementing the interactive forecast capability in each RFC in order to provide the public with timely warning services.

Finding 5-4: WGRFC hydrologists assigned the evening duty return home after normal office hours and are called at their home should the HSA office need hydrologic support and/or advice for rising streams due to heavy nighttime rainfalls. Often these RFC forecasters will prepare a forecast from information taken home and information provided over the telephone from the HSA office that requests support. Forecasts are logged at the RFC after the RFC forecaster returns to work the next day. These forecasts normally are not sent over AFOS. The requirement for this type of service is not frequent, but several meteorologists indicated that they would feel much more secure if they knew someone was available in the RFC, should the need arise, to discuss a specific situation. This is especially true when complex rainfall occurrences and near-record flows are potential or are occurring. While it is recognized that the WGRFC had a short staff during this event, the potential for improved service would probably have outweighed the disadvantage.

Recommendation 5-4: It is a positive sign when HSA staff call the RFC hydrologist at home after hours. This high level of professionalism has long-standing tradition in the NWS even though the WGRFC did not maintain 24-hour operation (in the RFC) during this flood event. The WGRFC should revisit the practice of not providing a forecaster on duty in the RFC during the night when major flooding is in progress.

When HSA offices receive reports of heavy nighttime rainfall, and updated river forecasts from the RFC are not immediately available, the HSA office should immediately issue a statement to the effect that the additional rainfall could possibly cause changes to the forecast and further state that an updated river forecast will be provided shortly.

River forecast products from the RFC need immediate dissemination on AFOS over the RDC for all need-to-know field offices and cooperating agencies. The latest observed stage (e.g., 6 a.m. observed stages for morning forecasts, noon observed stages for afternoon forecasts, and 6 p.m. observed stages for evening forecasts) should also be provided with the river forecast to indicate where the river stage is at present relative to any and all forecast values.

The staffing increase for the WGRFC, as outlined in the "Hydrometeorological Service Operations for the 1990's" plan, should be implemented without delay. These NWS modernization and associated restructuring plans, currently being implemented, will provide for extended hours at the RFCs. This 7-days-per-week operation will greatly increase the level of hydrologic support during periods of prolonged heavy rains and riverine flooding.

Finding 5-5: Public flood warnings contained statements indicating that flooding would be more severe than what was forecasted if additional heavy rainfall occurred. The WGRFC used the NMC QPF to determine the potential for heavy rainfall; however, no attempt was made by the RFC to run hydrologic contingency forecasts based on NMC QPF products. Furthermore, the WGRFC received no requests from HSAs for this type of QPF-enhanced hydrologic products. All involved stated that NMC provided excellent support for the QPF statements and estimated rainfall amounts. Emphasis on QPF-enhanced hydrologic forecast products has increased in recent years. Some RFCs in various areas of the United States are

now, and have been for several years, using QPF values produced by NMC and the WSFOs in their hydrologic forecast areas. Other RFCs continue to study the use of QPF as input to hydrologic forecast models.

Recommendation 5-5: All RFCs should pursue the use of QPF in the preparation of hydrologic forecasts.

Finding 5-6: On one occasion, a river forecast was issued for Hempstead on the Brazos River by the WGRFC for a stage above 70 feet which would have been over 10 feet greater than the flood of record (56.1 feet).

Recommendation 5-6: RFC forecasts that exceed flood of record should be reviewed carefully prior to being released. The intent of this review should be to examine the likelihood of the forecast being outside a reasonable range of possibilities with respect to forecasts that are also about to be issued for adjacent points on the same river.

Finding 5-7: Difficulties were encountered by the staff of the WGRFC in forecasting some of the forecast points on the lower Brazos River. Some of the early forecasts exceeded the flood of record by more than 10 feet. The most influential contributor to forecasts on the lower Brazos River is the routed water from upstream points. The WGRFC uses a Lag and K routing technique for this purpose. The forecast model was calibrated with previous conditions and available data. These calibrations were at the edges of their limits, which subsequently contributed to the erroneous forecasts. Mathematically sophisticated forecasting techniques that are specifically designed to handle situations such as those encountered on the Brazos River have been developed and continue to be enhanced by the NWS Hydrologic Research Laboratory. The best model currently available is known as the Dynamic Wave Model. It is designed to model the movement of a flood wave through a river system and provide predicted water level information at various locations along the river system. Furthermore, this model will compute the average velocity of the flood wave, which often will be significantly reduced as the water spreads out over wide floodplain areas (such as the farmland adjacent to the Brazos River).

Recommendation 5-7: The WGRFC should take steps to implement the Dynamic Wave Model on the Brazos River.

Finding 5-8: Some Weather Service Form E-19s (Report on River Gage Station) were found to be quite out of date (close to 10 years old). Furthermore, several of these old E-19s had multiple flood stage values (with different dates--possibly the dates when flood stages were changed) on the page that shows the staff gage. Additional confusion occurred in finding crests for individual flood events labeled "flood stage" rather than "flood crest." The SHIMS is available to computerize the E-19 process.

Recommendation 5-8: The Fort Worth, San Antonio, and the new Houston HSA offices should go through each of their E-19s and develop a priority list that would be used to

update all E-19s in their service areas. When the E-19s are updated, page 9 that shows the staff gage should have only the current flood stage shown. Flood crests for individual flood events need to be identified with an occurrence date, but there should be only one flood stage value. Flood stage, referring to the level where damage actually begins to occur within a specific reach of the river, should stand out for quick reference. Form E-19s also need to be provided to the WGRFC and WSOs for maximum utility during flood emergencies.

Finding 5-9: The E-19 reference material file developed by the Service Hydrologist at San Antonio (see Figure 18) contains all of the pertinent information needed to prepare a public forecast from an RFC forecast as well as the additional information to collect river stage data.

Recommendation 5-9: It is recommended that these types of files be created for forecast points by other HSA offices.

Finding 5-10: Based on information gathered from the WGRFC official forecast point worksheets, which indicate sites where crest forecasts are prepared by the WGRFC, not all stations have a listed flood stage.

Recommendation 5-10: The RFC should check to ensure that flood stages are listed on its forms. A check of all E-19s should be made to determine appropriate flood stages. Where flood stage values are found to be missing on the WGRFC official forecast point worksheets, E-19s need to be obtained from the appropriate HSA office. If E-19s are not available from the HSA office, the Service Hydrologist needs to create one and provide a copy to the RFC.

Finding 5-11: Hydrologists at the WGRFC are assigned procedures development and forecast responsibilities for forecast points within given river basins. One river basin had been assigned to one individual forecaster for over 2 years. No clearly established policy was found to exist for quality review of forecasts or rotation of the assignment responsibilities to other river basins.

Recommendation 5-11: The WGRFC is encouraged to routinely rotate forecasters from one basin to another in order to broaden their expertise on all basins. Senior staff should work more directly with journey level and junior staff through the development and forecast process to more fully utilize their skills and technical knowledge. This will also add a dimension of quality review to the procedures used in daily forecast operations.

Finding 5-12: Users perceived from WGRFC products that hydrologic models worked well during this flood period. Recently, 2 man-years were spent revising and redeveloping model procedures on the Brazos River. In view of widespread, recent record flooding and new hydrologic knowledge, operational forecast procedures need further review as stated by WGRFC staff. The WGRFC uses its version of the antecedent precipitation index model to determine runoff; it runs the Sacramento Soil Moisture Accounting model in parallel on the Trinity River.

Recommendation 5-12: The RFCs should provide updated model parameters as soon as possible after major flood events. As resources permit, calibration of additional models should be encouraged. NWSRFS allows flexibility to use several options of the antecedent precipitation index and the Sacramento Soil Moisture Accounting models. Resources, both in staffing levels and computer systems, should be maintained in the RFCs to provide for the greatest possible development activity, which will bring additional quality to public forecasts.

Finding 5-13: Hydrologic forecasts prepared at the WGRFC were generally found to be long, contained several references to crests or flood stages in one statement, and did not always specify a date for the crest to occur. It was found that considerable confusion existed from the terms that were used in the forecasts. These terms included phrases such as "RISING OVR..., RISING TO..., CONT RISING TO OVR...," etc. Days (e.g., MONDAY), rather than dates, were used to indicate the crest's occurrence. No standard format was found for preparing river forecast products nor were there any guidelines for using forecast terminology.

Recommendation 5-13: Confusion over WGRFC hydrologic products can be addressed with the preparation of a standard, general-use river forecast format that employs short, concise terminology and utilizes date labels for crest occurrence. Use of confusing terms or phrases, (i.e., "RISING TO...," etc.) should be discontinued. For slow-rising floods, a 3-day stage forecast on the rising and falling limbs of the hydrograph should be provided in the river forecast. The hydrologist should code a forecast for a crest to occur at a specific time, thereby providing the greatest lead-time possible. The crest forecast should indicate whether or not QPF is used in making the prediction. Mention of this fact in the river forecast is practiced by other RFCs. All NWS field offices served by the WGRFC should be provided with a copy of the standard river forecast format and a list of terminology and common phrases used for individual forecasts. Examples of each category in the terminology list should also be provided for greater understanding. The HSA offices should provide the descriptive interpretation for hydrologic forecasts released to the media and the public.

CHAPTER 6
HYDROLOGIC WARNING SERVICE--FLASH FLOODING

6.1 Introduction

This chapter presents the results of the disaster survey team's review of the small stream, urban, and flash flood forecast services provided by the NWS offices with county warning areas of responsibility in north-central, northeast, and south Texas. The body of the chapter is a chronological description of the flood and a general description of NWS services. A detailed chronology of products generated by each responsible NWS office is contained in Appendices D through I. Specific findings and recommendations are contained in section 6.5 in this chapter.

Widespread, sporadic rain covered a large portion of the eastern half of Texas during December 18-22, 1991. Somewhat unique was the fact that much of the rain was produced by stratiform systems with occasional pockets of convection reinforcing the already moderate-to-heavy rain. Rainfall totals of 6-10 inches were common, and unofficial reports of up to 17 inches were reported in the San Antonio area during the 5-day period.

The heavy rain followed an already wet fall. The ground was well saturated and runoff was high. The result was widespread flooding over large areas lasting several days. Numerous roads and highways were closed or barricaded and, as has been the case in past floods in this part of Texas, many normally tranquil, low-water crossings turned deadly.

6.2 WSFO Flash Flood Watch Responsibilities

The Fort Worth and San Antonio WSFOs are responsible for issuing public forecasts and flash flood watches in the eastern half of Texas where most of the flash flooding occurred. The WSFOs and their WSOs are responsible for issuing flash flood warnings and statements for their respective county warning areas.

WSFOs Fort Worth and San Antonio both recognized the potential for heavy rain, as evidenced by the content of their state forecast discussions and public forecasts. WSFO Fort Worth issued a flood potential outlook for its forecast area of north-central and northeast Texas at 4:10 p.m., Wednesday, December 18, 1991, calling attention to the likelihood of heavy rain and the potential for flooding.

The first flash flood watch was issued by WSFO San Antonio at 2 a.m., December 19, 1991, for an area of south-central and south Texas, west of a line from College Station to Cuero to Beeville to Laredo. WSFO Fort Worth issued that office's first flash flood watch shortly

afterward at 4 a.m. for the western two-thirds of north-central Texas. While these flash flood watches would occasionally be extended in time and be reshaped to cover different areas, the watches would remain in effect until the afternoon of Sunday, December 22, 1991. The flash flood watch from WSFO Fort Worth was finally cancelled at 7:35 p.m. on December 22, and the watch from WSFO San Antonio was cancelled shortly thereafter at 8:15 p.m. Thus, large areas of the eastern half of Texas were under a flash flood watch for 4 days.

6.3 WSFO and WSO Warning Services

There were 13 deaths attributed to this prolonged episode of heavy rain and flooding, and 11 of the 13 deaths were clearly due to flash floods.

During this event, the WSOs responded with numerous flash flood warnings and statements. There was an almost constant flow of flood and flash flood information from the NWS during the height of the heavy rain and flooding. In the 4-day period, 102 flash flood warnings were issued by the WSFOs and WSOs in the eastern half of Texas. Most of these warnings were timely and issued well in advance of flooding and the flood-related deaths. The duration of the flooding was so long that many warnings were extended in time at least once.

All flash flood warnings and statements contained "call-to-action" and safety statements. The most often used statement dealt with the dangers of driving into floodwaters of unknown depth. Unfortunately, these statements and other safety advice passed on by the NWR and the news media either were not received, were not understood, or were ignored. Too often motorists did not perceive danger and thus made poor decisions that resulted in death. However, these deaths represent only a small fraction of the number of motorists who attempted to cross flooded, low-water crossings and other floodwaters. Reports from law enforcement and emergency managers indicate that hundreds of people saved themselves, or were rescued, after being forced to abandon their vehicles in floodwaters.

6.4 Fatalities and NWS Issuances

The following text details the relevant issuances of public products from NWS offices and the circumstances under which deaths occurred. Flash flood watches from either WSFO Fort Worth or WSFO San Antonio were in effect in the areas and dangerous situations were discussed prior to all flood-related deaths.

WSO Waco

About 9-9:30 p.m., Friday, December 20, two deaths by drowning occurred when a female and her 6-year-old daughter drove into Meridian Creek at Highway 6 in Bosque County

about 45 miles northwest of Waco. The road leading to the bridge across Meridian Creek was barricaded. A deputy sheriff's vehicle was parked in front of the barricade and several other cars were stopped on the road. The adult victim drove off the road onto the grass in order to bypass the cars, sheriff's vehicle, and the barricade. People at the scene indicated that once past the barricade the driver stopped, got out of the car, looked at the water, got back into the car, drove off into the flooded creek, and was swept away. The deputy sheriff estimated the water depth in the creek at that time at about 12 feet.

There were other reports around the Waco area of people driving into flooded creeks or low-water crossings and either escaping or being rescued. Warnings were in effect at this time.

WSFO San Antonio

On Friday, December 20, three people were drowned between 4 a.m. and 6 a.m. when a 31-year-old female drove into a low-water crossing on Highway 55 and Little Hackberry Creek in Edwards County. The driver had apparently crossed there less than 1 hour earlier only to be turned back by the flooding Nueces River near the Real-Edwards County line. The two passengers in the vehicle were a 2-year-old male and a 1-year-old female. It is not known if the driver was trying to drive through the low-water crossing or did not see the floodwater because of darkness.

A flash flood warning for Edwards and Real counties was issued at 10:54 p.m., December 19, valid until 6:30 a.m., December 20.

A 14-year-old male drowned at about 11:30 a.m., December 22, when he and his companion fell into Leon Creek in Bexar County. Reports indicate that the two young men had been playing along the creek.

A flood warning for Leon Creek was issued at 4:50 p.m., December 21; and a flash flood warning for Bexar County was issued at 6:13 a.m., December 22, and reissued at 11:15 a.m., valid until 6 p.m.

WSO Austin

In Hays County, a 17-year-old female drowned at about 6:30 p.m., December 20, after her car was swept away while trying to cross a flooded bridge. Her passenger was later rescued as she clung to a tree. The driver apparently had crossed the bridge earlier and was on her way back. She drove around cars that were stopped at the bridge, and there were reports that some people asked her not to try to cross.

Emergency management officials stated that other vehicles were washed off roads in Hays County, but the occupants either escaped or were rescued. Flood warnings were in effect; and, in at least one of these cases, the road was barricaded.

There were two deaths by drowning in Travis County. A 59-year-old male was found in a field near a low-water crossing on Farm Road 973. His death was attributed to either drowning or exposure. The time of death was estimated to be 9 p.m., December 20. A 52-year-old male drowned during the night of December 20 or early morning hours of December 21. Officials thought he may have been sleeping in or near a culvert along Shoal Creek in Travis County.

A flash flood warning for Travis County was issued at 4:52 p.m., December 20, valid until 8 p.m. The warning was reissued twice; first at 7:57 p.m., valid until 11 p.m., and again at 10:45 p.m., valid until 12:45 a.m., December 21. Another flash flood warning for Travis County was issued at 3:51 a.m., December 21, valid until 7:30 a.m. This warning was reissued at 7:11 a.m. and was valid until 12:15 p.m.

Two separate incidents claimed three victims in Milam County. Around 9-10 p.m., December 20, two males, ages 52 and 42, drowned near Farm Road 2027 and Pond Creek. Three males drove into the water, stopped, and began wading. The survivor, who was rescued later clinging to a tree, indicated that the three of them were wading some distance from their pickup truck. The water began to rise, and they were unable to get back to the truck before being swept away. The fatality from the second incident was a 54-year-old male who drowned between 11 p.m. and midnight that same evening. He was apparently trying to cross Alligator Creek on Farm Road 484 when his vehicle was swept away.

A flash flood warning was issued for Milam County at 9:28 p.m., December 20, and was valid until 12:30 a.m., December 21.

WSO Houston

A 50-year-old male drowned after falling into White Oak Bayou in Harris County about 6 p.m., December 21. It is not known if this death was directly related to high water.

An existing flood and flash flood watch was extended to cover Harris County at 10:04 a.m., December 21. Flash flood statements were issued during the day, which discussed the heavy rain and potential for flooding.

6.5 Findings and Recommendations

Finding 6-1: An alarming number of people attempt to drive through flooded, low-water crossings and/or floodwaters of unknown depth. For years the NWS and others have stressed the danger of these actions, but too often the message does not produce the desired results. Milam County Judge Roger Hasham felt that many people, who are accustomed to hearing the preparedness statements that accompany flash flood warnings, very likely do not pay attention to them or, more likely, do not think the advice applies to themselves and their situations. The judge stated that people need visual reminders of the dangers of driving

through floodwaters. He felt that television stations should have materials available for use during periods of heavy rain that graphically demonstrate the dangers of floodwaters. He also felt that NWS preparedness presentations should include the same visual material.

Recommendation 6-1: The NWS must continue to strengthen all preparedness efforts with regard to motorists and flash floods and also to look for new approaches to emphasize the dangers. NOAA and the NWS should develop radio and television spots that graphically demonstrate the dangers, especially to motorists, of floodwaters. The same type of material should be furnished to all NWS offices for use in their warning and preparedness work.

Finding 6-2: Many local officials did not know that the NWS was involved in river forecasting. River authorities were inundated with calls from the public, media, and emergency management coordinators seeking river information. As a result of its experience during the flood, the Brazos River Authority is seriously considering establishing an information unit to handle the demands for river information during future flood events.

Recommendation 6-2: The NWS should give increased visibility to its river forecasting program, especially in those parts of the country where river flooding can be a significant problem. Information concerning the NWS's hydrologic role should be a part of all pertinent preparedness and emergency planning programs. The NWS should also take steps to expand the public information role for RFCs during times of serious flooding.

Finding 6-3: People living near the coast had difficulty relating the river forecasts at a gage to their specific locations. Many coastal residents are familiar with hurricane storm surge forecasts that are given in mean sea level but had difficulty translating the river forecasts into meaningful information for their situations.

Recommendation 6-3: The NWS should explore the possibility of providing river flood forecasts for coastal areas in both mean sea level and in the traditional gage forecasts.

Finding 6-4: The two SHs in this episode performed extremely well; however, during a flood event of this magnitude and duration, the WSFO SH can be overwhelmed. By working long hours, the SH can easily become too tired and stressed to perform with top effectiveness, even with the help of the WSFO staff.

Recommendation 6-4: During long-duration flood events, the MIC should consider requesting a backup hydrologist to the affected WSFO from an office not impacted by the flooding. The backup hydrologist could provide valuable assistance to the SH and the WSFO staff during critical periods. This option should only be pursued if other knowledgeable members of the HSA staff are not available to back up the SH.

CHAPTER 7
COORDINATION, DISSEMINATION, AND USER RESPONSE

7.1 Introduction

This chapter provides an assessment of both internal and external coordination and dissemination activities that occurred during the flood event. In addition, the chapter reviews the effectiveness of NWS forecast products and the corresponding user response by emergency managers, the news media, and the general public. Numerous interviews were conducted with NWS staff, and all NWS office staffs were extremely helpful in collecting pertinent materials for review by the disaster survey team. In gathering data from other sources, the survey team interviewed and collected printed material from a representative cross-section of the user community. Selected interviews were based on recommendations provided by key NWS staff involved with the event, by reviews of relevant newspaper articles, and by other contacts known to survey team members. Unplanned interviews were also conducted with citizens whenever possible. A substantial number of media contacts were made and special efforts were made to meet with local emergency managers, response agencies, and other local/regional authorities involved with emergency services or local flood warning system (LFWS) operations.

Forecasts developed by the WGRFC were disseminated to the public by WSFOs utilizing NWWS, NWR, telephone, and, in at least one known instance, fax. With few exceptions, the forecasts were judged by the user community as being thorough, timely, and accurate.

7.2 Internal Coordination and Dissemination

For the purpose of this chapter, "internal" communications refer to information exchange conducted between NWS offices (WSFO, WSO, RFC) and within a specific NWS office. The degree of coordination between the WSFOs, WSOs, and WGRFC was very impressive. When another office called for assistance, the responses were always prompt and professionally handled. For example, when WSFO San Antonio experienced temporary problems with AFOS, WSFO Fort Worth assisted with product dissemination. Another example involved the WGRFC, upon request, providing direct assistance to WSO Waco. While this action received some minor criticism because the SH was not party to these discussions, it should be noted that the SHs at both WSFOs were being worked excessively due to the magnitude of the event. All offices interviewed were very complimentary of their co-workers in other offices.

While the Texas NWS offices should receive high marks and congratulations for their internal coordination efforts during the December flooding, it is not possible for an event of this duration and extent to pass without some problems being noted. The hydrology program at WSFO San Antonio has earned a high degree of respect throughout the State, and a lot of credit goes to the SH. The service provided was very noteworthy. However, it was apparent that the SH was relied on to personally provide most of the hydrologic river services, and an excessive amount of overtime was logged by the SH. Efforts should be made to provide additional training to the other staff members and also to provide them with additional hydrologic knowledge so that when flood situations of this magnitude occur, the burden can be more evenly shared.

One instance of questionable coordination and judgment occurred at WSO Houston. The incident involved a river forecast for the Brazos River received from WSFO San Antonio for release to the public. The individual handling the information noted that the predicted gage height was more than 10 feet higher than any previous forecast and believed this to be a possible error. Since WSOs are not responsible for making hydrologic forecasts, a decision was made to issue the statement. Controversy resulted and negative newspaper articles followed. While this isolated incident was not the only source of controversy with regard to Brazos River forecasts, it is probable that some of the negative press could have been avoided if the WSO had questioned WSFO San Antonio or contacted the WGRFC directly prior to releasing the public statement. Under the NWS modernization plans, WSO Houston will assume a "modernized" WFO configuration; and an SH will be available to deal directly with hydrologic questions such as this.

The WGRFC prepared many timely forecasts to support the WSFOs and WSOs; however, certain deficiencies were noted by the disaster survey team. For example, at no time during the event did the HIC call for 24-hour operations. On certain occasions, when assistance was requested, hydrologists on call had to make decisions from their homes at odd hours using available decision aids and telephone links to data sources. This practice was previously found to have occurred in a similar disaster report regarding floods on the Trinity, Red, and Arkansas Rivers in May of 1990. The recommendation at that time was that "RFCs should remain open during potentially dangerous flood situations." The disaster survey team also noted that the WGRFC does not keep any written record or log of specific actions taken or of phone calls. A paper trail would be helpful in troubleshooting problems.

7.3 External Coordination and Dissemination

For the purpose of this chapter, "external" communications refer to information exchange between NWS offices and outside parties. The importance of two-way communications will be reviewed in this section with particular emphasis placed on coordination which occurred between the NWS and local agencies prior to the issuance of a public forecast, advisory, or warning. It should be noted that a wide variety of communication methods are used among outside agencies to coordinate and disseminate critical weather and flood information (e.g.,

fax, Texas Law Enforcement Telecommunication System, two-way radio, amateur radio, telephone, and personal contact). Not all of these methods are available to NWS offices. In some cases, this leaves NWS personnel at a disadvantage; in other cases, practices have proven mutually beneficial.

In discussing external communications, it is important to recognize that the capabilities of users vary widely. For example, some users are technically qualified to make their own flood predictions and provide direct support to NWS offices. Some of these users may also participate in the dissemination of flood-related information to the public. One example would be an organization which operates an ALERT system that collects and analyzes real-time data from a local network of automated rain, stream level, and weather sensors. In many cases, the ability of these groups to observe rainfall and recognize flash flood potential can exceed that of the WSFO or WSO. Such organizations may also be able to evaluate meteorological data and QPF products which are not considered public forecast products. Other users rely exclusively on the NWS for technical support, forecasts, and warning dissemination. The NWS should recognize the strengths and limitations of each cooperating agency and be flexible in its manner of providing support.

The following paragraphs provide specific examples of external communications and operations that occurred during the Texas flood disaster.

Brazos River Authority

The disaster survey team found that the Brazos River Authority has a very close working relationship with the WGRFC, with the telephone as its primary means of communications. River forecasts and reservoir releases are routinely coordinated. This relationship has obviously developed over time and is an excellent example of two-way cooperation.

Lower Colorado River Authority

The Lower Colorado River Authority is another good example of two-way cooperation with the preparation of river forecasts. Since it is responsible for flood control operations at Lake Travis, it has become a key agency for disseminating NWS forecast information to the public. This is also true of a number of other river authorities. The result is that the public does not really know where the forecasts come from. The Lower Colorado River Authority, other river authorities, and many local government agencies in Texas have real-time access to rainfall and streamflow data from an LFWS, such as the ALERT system. NWS offices in Texas are currently limited to dial-up computer/modem access. This places NWS forecasters at a disadvantage with respect to immediate notification of alarm levels and other features, particularly for areas having high flash flood potential. Unless the local agencies initiate relaying alarm information to NWS offices, delays can result in issuing critical weather information to the public.

Upper Guadalupe River Authority

The Upper Guadalupe River Authority and Kerr County Emergency Management officials have a good working relationship with WSFO San Antonio with the telephone as their primary manner of exchanging information. The LFWS and local communication network in this county was found by the disaster survey team to be extremely efficient. The State Department of Public Safety is an active player in the LFWS. The fax is used extensively among the various agencies to relay messages and tabular data reports generated by the automated system. WSFO San Antonio is included in the fax dissemination. During the heavy precipitation period on December 20, numerous fax communications were sent by the Emergency Management officials to the WSFO San Antonio, but it was after normal working hours. Those reports went unnoticed by WSFO staff because the fax machine was not located in the forecaster work area. After hearing no response, a phone call was finally placed to the WSFO; and a flash flood warning was issued shortly thereafter. It is clear from this scenario that there is room for improvement.

Cities of Arlington and Grand Prairie

Both cities are accustomed to working directly with NWS staffs at WSFO Fort Worth and at the WGRFC. Continual coordination was maintained throughout the December flooding event. However, an incident occurred on the Trinity River which caused some controversy within the City of Grand Prairie. Grand Prairie has a residential subdivision which was damaged by fast-rising Trinity River floodwater early in the morning of December 21, 1991. This area sustained flood damages in 1990, and, most recently, flooding occurred again in October of 1991, which again alerted residents to their flood-loss potential and prompted them to be prepared to take protective actions, if necessary.

Very early in the afternoon on December 20, 1991, the WGRFC forecast the Trinity River at Grand Prairie to flood. The public flood warning was issued at 1:55 p.m. by WSFO Fort Worth and highlighted the fact that people should be very cautious of this potentially dangerous flood situation. WSFO Fort Worth then revised the forecast at 2 p.m. that afternoon and simultaneously provided a relationship to the flood that had occurred a few months earlier. This is often practiced by the NWS so that people in the affected area can better understand how the forecasted flood compares to a recent previous flood event.

The WGRFC updated the flood forecast at 3:50 p.m. on the afternoon on December 20 and indicated then that the stage was expected to rise to a higher level than had been earlier predicted. The resulting public flood warning issued at 4:20 p.m. stated, in addition, that the flood would exceed the previous October flood. The WSFO Fort Worth staff was also in telephone contact with the emergency manager from the City of Grand Prairie who, in turn, was working with the local fire and police departments. Grand Prairie fire and police department officials were working directly with residents in the community advising them of the situation that afternoon and evening.

Late that night, the emergency manager from the City of Grand Prairie contacted the WGRFC to see if any change had been made in the forecast for the Trinity River at Grand Prairie. The WGRFC responded that no revision had been made to the forecast since there was no new data upon which to base a change. Heavy rain continued into the night, and very early in the morning (about 3 a.m.) water levels in the Trinity River at Grand Prairie exceeded those forecasted the previous evening. It was later determined that sometime after midnight water began to flow over the emergency spillway from Lake Arlington. Lake Arlington is a source for drinking water for the City of Arlington and discharges into a tributary of the Trinity River upstream of Grand Prairie. The spillway at Lake Arlington is uncontrolled and therefore has no operator at the lake. In addition, there is no sensor for determining when water overflows the emergency spillway at the lake. Arlington city officials were busy warning the affected citizens within their jurisdiction of the danger. However, the added heavy rainfall and subsequent excessive flow over the Lake Arlington emergency spillway caused additional problems to the people in both Arlington and Grand Prairie. During the early morning hours of December 21, 1991, the Trinity River stage at Grand Prairie exceeded that which was forecasted on the afternoon of December 20, 1991, by 2 feet. The NWS became aware of the situation and provided a revised forecast at 4:05 a.m. on Saturday, December 21, 1991. The early Saturday morning forecast was for the Trinity River at Grand Prairie to continue to rise to around 33 feet by late morning. The river crested that day at 33.1 feet.

This incident illustrates the importance of good coordination, not only within the NWS but also between local governments and adjacent communities affected by the same flooding problem. It also points out the importance of (1) access to good quality, real-time data and (2) the need to continue education in assessing hydrologic problems. The flow over the emergency spillway at Lake Arlington was a rare occurrence; it had occurred only once prior to this event--in 1957. Had information of the emergency spillway flow been available at the time, forecast adjustments could have been made; and Grand Prairie could have been notified of the additional problem. Fortunately, the community was forewarned of a flood in progress on the Trinity River, even though the magnitude of the flooding was greater than they had expected.

City of Austin

Austin has one of the largest and best run LFWSs in the country. The availability of real-time data proved extremely valuable, particularly during the rainfall that produced flash floods in the late afternoon on Friday, December 20. The late afternoon thunderstorm, which produced the heavy precipitation, arrived unexpectedly, at least from the city's perspective. Considering the magnitude of flash flooding which occurred that evening in Austin, the disaster survey team questioned how well two-way communications worked between the City of Austin and the NWS preceding the event.

After reviewing the contents of the flash flood watches, warnings, and statements issued on the afternoon of December 20 by WSFO San Antonio and WSO Austin, the survey team

found that NWS flash flood watches had been issued and were in effect at the time. Unfortunately, key personnel in the city did not expect the late afternoon thunderstorm which produced the very heavy precipitation and caused the flash flooding. The long-term nature of the event and the large numbers of watches and warnings issued throughout the day for neighboring counties may have contributed to some missed communications and/or passive responses during the developing stages of the thunderstorm. Another possible contributing factor was that the heavy precipitation began immediately after normal working hours on the Friday preceding Christmas. Clearly, increased communication and exchange of information are needed. Memorandums of Understanding that address the details of information exchange need to be developed between the NWS and local cooperating agencies to minimize the potential for communication failures. They also need to be critiqued and routinely updated following each flood event.

City of San Antonio

The disaster survey team toured San Antonio's LFWS and Emergency Operations Center. Although the December flooding in that city was not considered very serious, this location was a point of interest to the survey team due to its proximity to WSFO San Antonio and also its history of related deaths from flash floods at low-water crossings. The Emergency Operations Center was well organized for interagency coordination, including communications with the NWS. An emergency manager for the city made one very important observation pertinent to this survey: Even though relations between the city and the NWS are very good, increased one-on-one contacts are needed to maintain the good relationship. The emergency manager pointed out to the disaster survey team the importance of being able to associate a face with a name. The manager also suggested that new NWS staff make themselves known to appropriate officials as soon as possible and that all NWS staff be encouraged to make routine visits and phone contacts.

Fort Bend County

This county was the point of much controversy with respect to flood forecasts for the lower reaches of the Brazos River. The County Emergency Management Center had no direct access to NWS forecasts. Hard copies of NWS forecasts were being relayed to the Center via fax from a friend at the City of Houston offices. Local sources of flooding information were considered more current than NWS forecasts, but it was unclear how much local data was in fact relayed to the NWS. The Emergency Management officials believe that the fax is the most efficient means of disseminating hard-copy flood information and would like to see it used more.

U.S. Army Corps of Engineers Lake Control Unit

The Lake Control Unit is uniquely collocated with the WGRFC and has an excellent working relationship with them. External coordination between these groups is convenient--a walk down the hall. This type of interaction will change, however, when the WGRFC is relocated

in conjunction with the NWS modernization and associated restructuring plans. Special efforts will be needed to maintain this level of coordination.

WGRFC staff suggested that the fax be used as the first means of disseminating river forecasts, followed by AFOS dissemination. A policy issue needs to be addressed here, but it is clear that the fax has become a very popular communication tool that cannot be ignored. Regardless of what types of communication devices are used, either voice or digital transfers of hard-copy products, communications always have the potential of being the weakest link in the "warning system." While the NWS is the agency responsible for providing the watches and warnings, the NWS is only one part of the complete "warning system." Communicating dangerous weather situations to the public occurs in a variety of ways. Furthermore, emphasis must be placed on developing and maintaining effective, two-way communication with cooperating agencies, such as the U.S. Army Corps of Engineers Lake Control Unit, since they often provide valuable information for the forecast process. In the design of these communications systems, user capabilities and flexibility should be considered. What seems to be missing most often is a "wake-up call" that would prompt priority dissemination of critical information to key individuals. A communication of this type could be initiated by either NWS staff or a local cooperator.

7.4 NWS Services to the Media

The disaster survey team made contact with the media in Dallas, Fort Worth, San Antonio, Austin, Houston, Seguin, and Wharton to obtain reactions to NWS performance during the flooding episodes. Included were metropolitan daily newspapers; smaller local newspapers; Spanish language newspapers; television newsrooms and weather departments; radio station newsrooms and weather departments; Spanish broadcast television and radio stations; and a locally operated, automated Gospel station that dispenses weather bulletins. The contacts represented the spectrum of media in east Texas.

Media people were unanimous in their support of NWS efforts and were especially complimentary of the spirit of cooperation exhibited at local NWS offices (WSFOs, WSOs, and WGRFC) throughout the flood events. In all of the media contacts, there were no criticisms of NWS actions, attitudes, or cooperation with media representatives. There were a few contacts who mentioned some minor changes they would like to see in products, but those proved to be the exception and came mostly from smaller radio stations that had no weather staffs. The station's lack of familiarity with NWS operations and lack of sophistication in disseminating weather statements seemed to be a key ingredient in the requests for minor changes in the products.

The following comments were typical of the media contacts:

Anita Baker, Assistant City Editor, *Fort Worth Star Telegram*: *"We have worked with Skip Ely at the Fort Worth office for some time, and he has always set a tone of being cooperative. The people there are always helpful and go out of their way to help us out. The information they give us is always clear and precise, and they do a great job of explaining things that are complex or difficult to follow."*

Dan Potter, Meteorologist, WBAP Radio, Dallas: *"There is very good cooperation between the National Weather Service and the media in this market. I recall that we called [the WSFO] for an on-air interview, and they gladly provided us with the tapes we needed. I recall other markets where the level of cooperation was much less than here in Dallas/Fort Worth."*

Steve LaNore, Meteorologist, KENS TV 5, San Antonio: *"I have to applaud the immediacy of the warning information we received from the NWS.... From a public relation's standpoint, we find the Weather Service people to always be helpful and courteous and to conduct themselves in a very professional manner."*

Kevin Harboreth, KWED Radio, Seguin (San Antonio office contact): *"The people at the San Antonio office have always been real good about making sure their information was clear and explaining things in detail when we have questions."*

Andres Morin, Meteorologist, KWEX TV 41, San Antonio (Spanish broadcast station): *"The watches and warnings were given us by the Weather Service well in advance, but people are people and sometimes they don't listen to what they're told."*

Troy Kimmel, Meteorologist, KVUE TV 24, Austin: (Mr. Kimmel was so impressed with the efforts of the Austin staff that he tracked the survey team down and called from the American Meteorological Society meeting in Atlanta to give his opinion.) *"I could not commend the National Weather Service in Austin more. They kept the station operating through the night and were giving continuous updates on what was happening. About the time of the Shoal Creek peak, I got a call from [MIC] Lou Withrow advising me of a serious situation with that creek. That call meant a whole lot--that he felt the need to personally contact the media to let them know what was coming up."*

Janet Evans, News Director, KLBH Radio, Austin: *"I've always been very pleased with all the aspects of the Austin office, and that is true in severe weather situations. We did many live broadcasts from the [WSO] and the staff there was always very cooperative and helpful to us. They should be complimented for their efforts."*

Scott Wright, Reporter, *Austin American Statesman*: *"The local Weather Service has always been very cooperative with us. They give us forecast information that goes well beyond what is on the recording. The staff always goes out of its way to help us and answer any questions we have."*

Joe Noland, Assistant News Director; Roland Galvan, Meteorologist; KPRC TV 2, Houston: *"We stayed informed of conditions through our [NOAA] Weather Wire Service and with frequent phone calls to the local [NWS] office. The people there were always very accommodating of us, even when they were busy. The Weather Service and the river authorities made it very clear to our reporters that the rise of the [Brazos] river here would be slow. Everybody knew it was going to go out of its banks a full 10 days before it did. The Brazos flood was a new thing, and I think people got complacent. I don't think the downriver people took the warnings seriously."*

A complete listing of the contacts made by the disaster survey team is given in Appendix J. Appendix K describes the media interviews and their individual responses.

The WGRFC and all of the WSOs and WSFOs in the affected area reported high levels of media inquiry, both over the telephone and in person. Many of the calls were handled by the San Antonio SH, who received numerous compliments for his cooperation and the timeliness of his information. Local MICs also were actively involved in working with the media--holding news conferences and making phone calls to media contacts to warn them of impending dangerous situations.

One slightly disturbing fact was revealed during the disaster survey team's contact with media outlets and in eliciting opinions from media personnel. At all NWS offices, telephone contact lists were provided to the disaster survey team for the purpose of conducting the survey. In some instances, telephone numbers provided were not working or were no longer in service. That caused a minor inconvenience for the survey team in getting current numbers from the phone company; but, more important, it indicated a lack of communication between NWS offices and the media. Telephone numbers can change on short notice, but the frequency of encountering nonworking numbers raises some doubt about the effectiveness of outside office communication. To keep up the best media relations, NWS offices have to initiate occasional contact. While lack of having current phone numbers generated minor inconvenience for the survey team, the delay in the NWS offices establishing contact with the media could be serious in an emergency situation.

7.5 Media Contacts with Other Agencies

Much of the flood information to the media was provided by personnel from other government agencies and private services. The Lower Colorado River Authority, the Austin Office of Emergency Management, the Brazos River Authority, and numerous small county

emergency preparedness agencies were in frequent contact with the media. The many "officials" providing information to the public at times caused confusion because of different data sets and terminology used. The private agencies deferred questions on flood forecasts to personnel at the WGRFC or at the WSOs and WSFOs.

The overall media attitude was one of cooperation with both the NWS and private sources, and very little friction or animosity was generated. One point of controversy, which was reported in *Houston Post* articles, was that some difficulties were encountered by emergency management officials in Fort Bend County. These difficulties were effectively eliminated when data were shared between the emergency management officials and the SH at WSFO San Antonio. The Emergency Manager, who was cited in the articles, said that he could find no fault with the NWS throughout the flood events. "The media tried to get me to say [confusion over river levels and crest arrival] was the Weather Service's fault, but it wasn't their fault," he said.

7.6 Direct User Services

The survey team found substantial differences between the levels of public interaction and direct individual service provided by various NWS offices in the flood-affected areas. That was to be expected because of staffing, geographical, and other local differences and also because of the availability of river authorities and emergency preparedness agencies in dealing with the public. All the differences were well within established policy guidelines of the NWS. Obviously, user satisfaction was greatest in those incidents where the NWS has the resources to provide greater personal contact.

NWR provided a useful source of direct contact between NOAA and the people who use it. Nearly all the radio and television stations and the newspapers contacted used NWR as a backup, if not primary, information source of weather information. The effectiveness of NWR to the public was limited in some areas, especially in the remote, hilly areas that were, unfortunately, often the sites of flash flooding. Since more widespread use of NWR would have positively impacted more people, perhaps surveys of users and nonusers should be made to determine how the service could be made available to more people and could prompt increased user interest.

7.7 Public Awareness of NWS Forecast Services

The public, and even some affected local officials, have an incomplete picture of the mandate of the NWS. While the affected agencies and individuals were generally pleased with the flood forecasts and warning services, many were not aware that the forecasts and warnings were issued by the NWS. For example, in the Austin area, the Lower Colorado River Authority was recognized by the public as the source of flooding information; but, in reality, it was only releasing official NWS forecasts. It should be noted, however, that the Lower

Colorado River Authority cooperated with the NWS and WGRFC in developing river forecast products.

River basin authorities, public works agencies, local emergency managers, and other officials are generally aware of the NWS role but not all have a clear understanding of how the WGRFC fits into the picture or what the specific responsibilities of a WSFO or WSO are. Coordination with these groups could be improved if local agencies would define the responsibilities of each NWS office in their emergency action plans. The written plan should clearly distinguish between riverine and flash flooding scenarios and acknowledge which NWS offices are responsible for originating and disseminating the forecast and warning information for each type of event. NWS officials could offer assistance in this area. Through this process, the public would attain a much better understanding of the NWS role since much of the media activity during flood emergencies is with local emergency service and public works organizations.

7.8 User Response

The NWS special weather statements, flood advisories, flash flood watches, flash flood warnings, and river forecasts undoubtedly saved lives and prevented millions of dollars in damages as farmers and other citizens responded in a timely fashion to reduce losses by floodproofing their property and by relocating personal possessions and livestock. The dissemination of forecasts on the flooding was excellent.

With a few minor exceptions, and one temporary major exception, virtually all individuals and media outlets interviewed by the survey team concerning flooding of the Brazos, Colorado, Guadalupe, and Trinity Rivers and small tributary streams were pleased with the information provided by the NWS. In the one temporary major exception, the disaster survey team found there was a complaint about some forecasts on the Brazos River but subsequently determined that the emergency management officials were not in direct contact with the local NWS office. A review of preparedness-contact forms indicated that direct contact had not been made in at least a year prior to the flooding. Had a personal preparedness visit occurred, the emergency manager would have had a direct NWS contact which may have mitigated the problem. Subsequent to the complaint, the emergency manager initiated coordination with the NWS and stated that "communication between the National Weather Service and local emergency management offices is a must if we expect the weather service to give realistic forecasts on river flooding."

Most of the public were unaware that forecasts and statements originated from the NWS, crediting them rather to the electronic media or the river authorities. Unfortunately, the disaster survey team obtained no data that allowed it to estimate damage reduction as a direct result of NWS forecasts and warnings. A special study would be needed to quantify averted damages for the 1991 Texas flooding or for any future flood event of similar magnitude.

Such an effort could produce data of great value to NOAA and be of widespread interest to the disaster preparedness community.

More favorable public reactions and an increased awareness of NWS responsibilities could result if NWS offices work more closely with local media contacts to keep the public informed of the complexities involved in predicting large floods like this Texas disaster.

7.9 Findings and Recommendations

Finding 7-1: The SH plays a critical role both preceding and during major riverine and flash flood events. During long-duration riverine flood events, like this one, the SHs are often relied on to personally provide most hydrologic river services. Current staffing of WSFOs only provides for one SH per office which, in the case of Texas, means that two individuals are responsible for providing hydrologic support for their respective offices and corresponding HSA offices.

Recommendation 7-1: Continue to develop, improve, and maintain high-quality hydrologic training programs for meteorologists. Lead forecasters need to be familiar with known flood problem areas within their areas of responsibility and be confident with recognizing critical rainfall thresholds that cause problems. Continue to pursue the modernization plans which call for WFO forecasters having the resources, knowledge, skills, and responsibilities for routinely assessing flood as well as flash flood problems and issuing, as appropriate, all necessary public hydrologic watches and warnings.

Finding 7-2: An error in judgment at WSO Houston caused public controversy that could have been avoided. The incident involved a river forecast from the WGRFC for the Brazos River that was received from WSFO San Antonio for release to the public. The individual handling the information noted that the predicted gage height was more than 10 feet higher than any previous forecast and believed this to be a possible error. A simple phone call to either WSFO San Antonio or the WGRFC could have quickly resolved the matter.

Recommendation 7-2: All NWS staff involved with disseminating public forecasts and warnings should be reminded and encouraged to review and question suspect information received from another office before releasing it to the public.

Finding 7-3: During major riverine flooding, a high level of coordination needs to be maintained with RFC staff. This is difficult to achieve with an office that is not staffed 24 hours a day. The WGRFC did not implement its option to conduct 24-hour staffing operations during the flooding period in question. This practice occurred previously as found in a similar disaster report regarding floods on the Trinity, Red, and Arkansas Rivers in May of 1990. The recommendation at that time was that "RFCs should remain open during potentially dangerous flood situations."

Recommendation 7-3: Implement the recommendations of past flood surveys and have RFCs provide written procedures for approval by the Regional Office and NWS Headquarters that set forth criteria for 24-hour staffing. These procedures should be flexible between regions, since the hydrologic characteristics of river basins vary considerably. RFC staff should be the originating authors.

Finding 7-4: The technical capabilities of local and regional cooperating agencies vary considerably. Technically qualified users have different needs than nontechnical users; but the importance of good, two-way communications is common to both. Special efforts are needed to improve links with the various organizations, and key individuals need to be identified.

Recommendation 7-4: NWS offices should obtain copies of local emergency action plans and work with key agencies to improve internal procedures. In refining NWS operational procedures, address the differing needs of users by recognizing individual capabilities. The importance of personal contact should be emphasized, and Memorandums of Understanding should be developed where none currently exist and routinely updated where they do exist. The WPM and SH should work closely together when making personal contacts relative to local flood warning programs.

Finding 7-5: NWS offices are somewhat handicapped with respect to evaluating available, real-time data from local flood-detection networks, such as the ALERT systems. LFWS operators have a definite advantage over NWS forecasters by instantly knowing when critical rainfall and river-level thresholds are exceeded. This type of information is not always relayed to the WSFO or WSO, since it is often difficult to do so every time an alarm level is exceeded.

Recommendation 7-5: WSFOs should be provided with the means to directly process data from automated gaging systems within their HSA offices or to develop the capability of automatically being immediately notified when alarm levels are exceeded.

Finding 7-6: The media complimented the accuracy and timeliness of NWS forecasts throughout this event. The admiration was stronger from the television and radio stations with more sophisticated weather departments; but the small, rural stations were also complimentary.

Finding 7-7: Telephone inquiries, at times, taxed the resources of NWS offices, especially at the San Antonio office where the SH received frequent calls. Even then, when the SH was unable to give immediate attention to media calls, they were understanding of his tremendous work load and held no animosity for having to occasionally wait for information for their news reports.

Recommendation 7-7: Additional resources, including personnel support, should be made available to help handle public affairs and excess telephone calls during prolonged flood events.

Finding 7-8: The level of accuracy and timeliness in disseminating NWS flood statements, warnings, and forecasts was in direct relation to the radio and television station's level of sophistication and frequency of contact with the NWS. The radio and television stations that gave serious attention to weather news also provided immediate dissemination of flood statements.

Recommendation 7-8: The NWS should continue its support of field office educational efforts to teach station managers, reporters, and other users the speed with which NWWS can provide weather statements. Local NWS managers should organize seminars to train new media personnel and to reinforce past training in the coordination and dissemination of weather information by the NWS.

Finding 7-9: The NWS and the Lower Colorado River Authority recently completed a cooperative effort to automatically produce a daily hydrologic message containing data from the Lower Colorado River Authority hydrometeorological sensor network. The Lower Colorado River Authority used a database and a report writer on a Digital Equipment Corporation MicroVAX computer to produce the message in the SHEF code. The generated message is stored as a file on the MicroVAX. After the message has been generated, the WSO in Austin, Texas, calls the Lower Colorado River Authority MicroVAX and downloads the file to its AFOS Auxiliary Backup Terminal. The WSO quality controls the message, adds additional hydrologic data, if needed, and transmits the message on the AFOS circuit. The WGRFC receives the data and also automatically enters the data into its forecast model. Over 90 percent of the message is generated and encoded in a completely automated process. This automation effort has resulted in a significant reduction of field personnel time that would have been required for manual data entry.

Recommendation 7-9: NWS offices vested with HSA responsibility should investigate the possibility of having their cooperative river authorities and local flood control agencies enter into similar cooperative efforts.

Finding 7-10: Water flowed over the emergency spillway from Lake Arlington and discharged into a tributary of the Trinity River upstream of Grand Prairie. The spillway at Lake Arlington is uncontrolled and has no operator at the lake. In addition, there is no sensor for determining when water overflows the emergency spillway. Extremely heavy rainfall and the subsequent excessive flow over the Lake Arlington emergency spillway caused problems to the people in both Arlington and Grand Prairie during the early morning hours of December 21, 1991.

Recommendation 7-10: The communities of Grand Prairie and Arlington should consider sharing resources for installation of a Local Flood Warning System that includes event precipitation gages and an alarm system on the emergency spillway of Lake Arlington.

APPENDIX A
SUMMARY OF FINDINGS AND RECOMMENDATIONS

This appendix is provided as a convenient summary of all the findings and recommendations developed throughout the body of this report.

CHAPTER 1: BACKGROUND AND OVERVIEW OF HYDROLOGIC SITUATION

Finding 1-1: The National Weather Service (NWS) plans for modernization and restructuring, including technological programs such as Weather Surveillance Radar 1988 Doppler (WSR-88D), Advanced Weather Interactive Processing System (AWIPS), and the Automated Surface Observing System; staffing realignment; and enhanced Water Resources Forecasting System (WARFS), offer substantial opportunities to improve services for future major flooding events of this nature.

Recommendation 1-1: Continued effort must be made to keep the NWS modernization plans and implementation of new technology on schedule and to accelerate them wherever possible.

CHAPTER 2: METEOROLOGICAL CONDITIONS AND GUIDANCE

No findings and recommendations.

CHAPTER 3: DATA ACQUISITION, COMMUNICATIONS, AND FACILITIES

Finding 3-1: The precipitation gages in the cooperative network are sparse, especially in rural areas of most large watersheds in the West Gulf River Forecast Center (WGRFC) area of responsibility. This low density of gages, combined with missing data from many cooperative observers on many days during this event, resulted in a significant problem with insufficient precipitation data. Next Generation Weather Radar (NEXRAD)-generated rainfall data, using a 4 km x 4 km grid, is being implemented. The first such WSR-88D will be installed at Houston. A NEXRAD Principle User Processor is also scheduled for the WGRFC that will provide radar display capability.

Recommendation 3-1: The implementation of planned modernization and associated restructuring hardware must not falter. Interactive forecast workstations capable of running hydrologic models and inputting WSR-88D gridded precipitation data must be provided in the period prior to AWIPS.

Finding 3-2: In accordance with office policy, the WGRFC river forecast products were routed on the Automation of Field Operations and Services (AFOS) only to the Weather Service Forecast Offices (WSFO). Thus, the Weather Service Offices (WSO) involved in this flood episode never saw the River Forecast Center (RFC) forecast prior to the issuance of the public river forecast products from the WSFOs. It should also be noted that all RFC forecast products will be distributed on the Family of Services circuits in the NWS modernization and associated restructuring.

The reason given for this WGRFC policy is that the data in the product is information for the WSFOs to use in formulating their public river forecast products. There was some concern that the WSOs might release these forecasts instead of waiting for the WSFO product that would contain the river forecasts for media and public release. However, if the WSOs had received the RFC's forecast over AFOS, in at least one instance, based upon the personal knowledge of the WSO staff, an unlikely stage forecast could have been brought to the attention of the WSFO or RFC. The stage forecast could possibly have been corrected prior to public release.

Recommendation 3-2: RFC forecasts are presently considered internal products (not for transmission to the public) and should be transmitted on AFOS with (as a minimum) regional distribution circuit (RDC) routing in order for these products to be (1) available as reference by offices other than just the Hydrologic Service Area office (e.g., WSOs, Regional Headquarters, and the Hydrologic Information Center in the Office of Hydrology) and (2) archived on the AFOS Service Records Retention System. A heading should be added to the product that indicates the data are "for internal use only." The WGRFC should also take steps to prepare for distribution of their forecasts on the Family of Services as a result of modernization (see also Finding and Recommendation 3.6).

Finding 3-3: The lack of meteorological data from Mexico is a continuing problem. In this instance, it was mainly a problem for WSFO San Antonio but also operationally affects NWS offices all along the U.S./Mexico border. During this flood episode, satellite was the only source of real-time meteorological data for Mexico that was available to WSFO San Antonio.

Recommendation 3-3: The NWS should investigate ways to improve the receipt of Mexican hydrometeorological data.

Finding 3-4: Data from the national river gaging networks in the United States continue to deteriorate, and there is a decline in the number of sites being funded. During the 20-year period from 1970 through 1989, a total of 39 river gages were taken out of operation that the

WGRFC had been using in their forecast system in the State of Texas. In 1991, the WGRFC was using data from a total of 598 gages. Budgets for maintenance of existing gaging stations have diminished in recent years, and interagency response for restoring normal data availability has slowed. Each year the NWS increasingly relies on cooperating agencies for operational data. In view of the NWS's modernization and associated restructuring efforts (i.e., major advances from the use of WSR-88D precipitation data and interactive forecast procedures in the RFCs), the national impact on river stage data becomes increasingly significant. Major lifesaving and economic benefits are possible with prudent budgeting and interagency cooperation. Other technical advances in systems and forecast procedures in the near future will require significantly more reliable data collection and a quicker response for restoring malfunctioning river gages.

Recommendation 3-4: The NWS and cooperating hydrologic agencies must become more imaginative and enterprising in order to devise budgeting plans for maintaining, restoring, and expanding river gaging networks.

Finding 3-5: One of the most (if not the single most) serious problems encountered in river forecasting is inaccurate or missing river stage observations. In a review of the 6 a.m. stage values used as model input for river forecasting during the period December 18, 1991, to January 5, 1992, it was found that 27 percent of the river stage observations were either not available or reported as missing. There are several reasons for missing data (e.g., automatic data collection system malfunction, no manual report collected, lack of backup observers, etc.). It was estimated from NWS staff interviews that nearly one-half of the river gages critical to flood forecast preparations failed at some point during this flood event. This situation was recognized by both the WGRFC and the Fort Bend County Office of Emergency Management in Richmond, Texas.

Recommendation 3-5: The NWS Hydrologic Service Area offices should aggressively explore further opportunities for obtaining backup river gage observations from cooperating agencies (e.g., emergency management offices, flood control districts, or river authorities). They should also actively seek assistance in the collection of stage data when and if failures occur with automated stream gage equipment and, when practical, share costs for backup observers at critical flood-producing sites. This form of data collection is sometimes more desirable than having volunteer observers who may be unavailable on weekends and during large flood events. Local emergency management agencies have the most interest in the flood forecast process and benefit most by cooperating in data collection for improved forecasts. Furthermore, the NWS should, wherever possible, maximize capabilities to access and share available data from local flood warning systems (e.g., Automated Local Evaluation in Real-Time (ALERT)).

Procedures also need to be developed to restore the flow of data from automated river gages whenever missing data are detected.

Finding 3-6: Forecasts issued by the WGRFC contain three groups of information for each forecast point as defined below:

1. The name of the forecast point; in parentheses, the elevation of the Flood Stage; and, depending upon the actual forecast point, the elevations of the Bankfull Stage, Caution Stage, and Warning Stage.
2. The 6 a.m. stage (today).
3. The forecast.

Often, the forecast value provided by the WGRFC contains only one value. This, in addition to the 6 a.m. stage, only gives the user two data points to provide the public with decision-making information. Sometimes the time of the forecast is only indicated as to the day (e.g., RISING TO NR 28 FT SAT) with no information as to the time of day. These messages are also somewhat difficult to understand, especially for the casual user. Modernization plans are for RFC forecasts to be distributed on the Family of Services, and improvements in the way they are worded are desirable. WGRFC forecasts contain no information regarding quantitative precipitation forecast (QPF).

Recommendation 3-6: It would be desirable for the WGRFC to provide additional forecast data values in the river forecast products. Typically, river forecast products are released near midday; therefore, it would be extremely valuable for the users to have forecast information for 6 p.m. on the day of the forecast as well as for 6 a.m. the following day. If possible, forecasts should also be provided for 6 p.m. the following day. This would lend itself nicely to a tabular forecast product and would enable users to better understand how fast the rivers are changing. Tabular forecasts will also be easier for the casual user to understand which will be important since modernization calls for these products to be available to a wide range of users on the Family of Services circuit. Some consideration should also be given to providing additional information, even if it is subjective, with regard to how the forecast would change based upon future rainfall. (See also Finding and Recommendation 3-2.)

Finding 3-7: Rainfall data from many cooperative observers were missing on several days. The lack of sufficient storm rainfall information for the area during this event limited the ability of the WGRFC staff to accurately provide river forecasts. The forecasters, unfortunately, just did not have the most up-to-date spatial and temporal precipitation

information. The NWS is in the process of implementing NEXRAD, which will provide Hourly Digital Rainfall (HDRain) products for use in hydrologic forecasting.

Recommendation 3-7: It is recommended that these products be implemented as soon as practicable for river forecasting in the WGRFC area of responsibility.

Finding 3-8: The touch-tone system, which is used in the collection of precipitation and stream gage data from cooperative observers, does not have any software to check on data quality.

Recommendation 3-8: The NWS should add software to the touch-tone system to do quality checks on the data and reduce the time required for manual checking of precipitation and river stage data.

Finding 3-9: Limited Automatic Remote Collectors (LARC) are used frequently as a river stage telemetry system. Many U.S. Geological Survey gages have no telemetry, and opportunities exist for adding LARCs to provide increased coverage at sites where U.S. Geological Survey gages are located. LARCs also proved their versatility by computer contact and telephone voice readout both in the office and at home. LARCs are reasonably effective telemetry devices for river stage data. During this event, only 62 percent of the river gages in the WGRFC area were automated.

Recommendation 3-9: Expanding the LARC program should be a high priority of the NWS.

CHAPTER 4: PREPAREDNESS

Finding 4-1: Some NWS users were confused by, or misunderstood, some terms (such as flood crest and flood wave) which related to river flooding.

Recommendation 4-1: Warning Preparedness Meteorologists (WPM), Meteorologists in Charge (MIC), and Service Hydrologists (SH) should educate users on the use of terms related to river flooding. Also, the NWS should reevaluate how certain confusing terms are used and in what context.

Finding 4-2: The public may not have understood the role of the NWS in the issuance of warnings and river forecasts.

Recommendation 4-2: WPMs and MICs should continue to make a concentrated effort to educate all users about the NWS, including providing information about what the NWS does and what products it is responsible for. In addition, it would be helpful for the media to see and understand NWS local partnerships and their important roles in the warning/safety process.

Finding 4-3: Some WSOs did not have copies of hydrology preparedness manuals and E-19s on rivers within their county warning areas.

Recommendation 4-3: WSOs should be provided with a copy of the Hydrologic Services Manual for the Hydrologic Service Area. WSO staff members should have training provided by SHs on interpretation of E-19s. These items would help the staff at WSOs to deal more effectively with the public and the media when calls come in to them rather than having to refer all questions to the SH.

Finding 4-4: The WGRFC did not maintain prepared call/coordination logs.

Recommendation 4-4: The WGRFC should prepare call/coordination logs, especially during major floods. These logs ensure that key communications and the times they occur are accounted for. Prepared call logs also provide important event information for both internal and external reviews of operations.

Finding 4-5: River/flash flood drills were not conducted annually at all NWS offices.

Recommendation 4-5: Each office should conduct, at least once a year, a river/flash flood drill for its area of responsibility as stated in Weather Service Operations Manual Chapter A-17. The drill should specifically address problems of heavy rain flooding and river flooding not associated with severe weather. In addition, these drills should involve outside groups, such as emergency managers, flood control districts, and river authorities. Any groups that operate local flood warning systems should specifically be targeted.

Finding 4-6: SHs prepared and conducted excellent training for forecasters at their offices, but limited attention was provided to the WSOs.

Recommendation 4-6: Hydrologic training should be provided by the SH to personnel at the WSO level. Local officials involved in the flood warning system should also be invited to attend.

Finding 4-7: Few NWS offices maintained significant contact with the Hispanic media. This resulted in a reduced ability to reach that segment of the population. Most Hispanic media outlets have bilingual employees; therefore, it is not necessary that the NWS contact point be proficient in Spanish.

Recommendation 4-7: To properly serve the Hispanic population, the NWS needs to make a conscious preparedness effort with the Hispanic media.

Finding 4-8: Close interaction between the RFC and Hydrologic Service Area offices resulted in good preparedness contacts with key river authorities.

Recommendation 4-8: RFCs should cultivate and maintain contacts with WSOs as well as with WSFOs. These contacts are a valuable resource for interaction with State and local river authorities.

Finding 4-9: Direct preparedness contacts by the SHs with emergency managers helped to provide that group with important information and expertise during the flood event.

Recommendation 4-9: External preparedness contacts by SHs should be coordinated with WPMs and MICs. River flood and flash flood programs often go hand in hand. Therefore, the SH should be invited to meetings between emergency management officials and WPMs/MICs. These coordinated visits would help both the NWS and the emergency management officials to understand the warning and dissemination communication chain.

Finding 4-10: Direct personal preparedness contact with emergency managers helped to establish one-on-one coordination relationships. These relationships resulted in excellent two-way communication during the flooding event.

Recommendation 4-10: Future NWS budgets should make specific allowances for preparedness contacts and travel. However, in times of fiscal austerity, WPMs and MICs should continue, and possibly increase, direct contact with the hazards community through written and personal telephone communication. Emergency managers should be encouraged to also accept the responsibility of contacting the NWS to schedule meetings and to confer on communication and weather problems.

Finding 4-11: Existing spotter networks did not include all possible sources of information.

Recommendation 4-11: WPMs/MICs should seek out and consider the development of other reliable information networks for use in the warning process. Development or refinement of amateur radio spotter networks for use in river flood events, as well as severe thunderstorm events, would be beneficial.

CHAPTER 5: HYDROLOGIC WARNING SERVICES--RIVER FLOODING

Finding 5-1: The public forecast products (and the forecast products that were issued by the WGRFC) often were lengthy, containing forecasts for many basins and many individual forecast points within a basin, which made it difficult to find the specific forecast for an individual point.

Recommendation 5-1: It would be beneficial to all users if forecast products could be made shorter in length, especially for smaller basins. This may require additional AFOS product identifiers from the RFCs but, in all circumstances, would enable users to more readily locate specific forecasts that they are most concerned about.

Finding 5-2: The WGRFC routinely follows the practice of preparing forecasts in the morning based upon 6 a.m. stage observations. These forecasts are then hand carried or faxed to the Hydrologic Service Area (HSA) offices whereupon the WGRFC sends the forecasts via AFOS, site addressed to the appropriate HSA office. The WGRFC also provides updated forecasts via voice telephone or fax to HSA offices. In the case of WSFO Fort Worth HSA, forecasts (as well as updates and revisions) are frequently just hand carried to the office (which is just next door). Cooperative agencies and the Hydrometeorologic Information Center's access to these products is limited to either faxing or telephone transfer. These activities are inefficient and lack timeliness in reaching numerous users of these products. Furthermore, site addressing of these forecast products on AFOS does not allow them to be archived in the Service Records Retention System.

Recommendation 5-2: All forecasts, including revised and updated forecasts, should be transmitted on AFOS with an RDC routing so that they (1) are available to the HSA offices, (2) reach the Service Records Retention System for official archiving, and (3) are officially available to others in the AFOS database. The Southern Region should officially discourage the use of fax transmissions as a primary means for dissemination of official forecasts.

Weather Service Operations Manual Chapter E-42 should be amended to discuss the archival of official forecasts at the Service Records Retention System. User instructions that are provided in the AFOS Handbook Series on how to ensure that forecasts reach the Service Records Retention System need to be refined.

Finding 5-3: Delays occurred in the forecast process that were due to the time it takes for computer forecast runs to print out the information which forecasters use to make the actual river forecast. Commonly termed "job stacking" by the forecasters, the delays were a combination of low-speed printers and outdated remote job entry equipment that ties the WGRFC to the host mainframe computer (NOAA Central Computer Facility (NCCF) located in Suitland, Maryland) where the computer runs are made to produce the forecasts. The WGRFC requested the NCCF to use the NAS9000-designated "Critical Flood Day" procedure for its computer operations as provided for by the National Meteorological Center (NMC). This procedure ran for 1-1/2 weeks during the period when record floods were occurring. Later, when this procedure was turned off, batch turnaround was stacking jobs 30-40 minutes on the printer adding 1-1/2 to 2 hours to the normal time it takes to prepare forecasts. The NWS is implementing an interactive forecast system for forecast preparation as part of the modernization and associated restructuring of the NWS which could reduce this time delay.

Recommendation 5-3: Schedules indicate that most RFCs will not be receiving interactive forecast capability until the middle to late 1990s. There is good evidence that most of the 1-1/2 to 2 hours lost in batch operations can be regained by using the interactive forecast capability. This will allow for more timely forecasts to be released to the public and cooperating agencies. High priority needs to be placed on implementing the interactive forecast capability in each RFC in order to provide the public with timely warning services.

Finding 5-4: WGRFC hydrologists assigned the evening duty return home after normal office hours and are called at their home should the HSA office need hydrologic support and/or advice for rising streams due to heavy nighttime rainfalls. Often these RFC forecasters will prepare a forecast from information taken home and information provided over the telephone from the HSA office that requests support. Forecasts are logged at the RFC after the RFC forecaster returns to work the next day. These forecasts normally are not sent over AFOS. The requirement for this type of service is not frequent, but several meteorologists indicated that they would feel much more secure if they knew someone was available in the RFC, should the need arise, to discuss a specific situation. This is especially true when complex rainfall occurrences and near-record flows are potential or are occurring. While it is recognized that the WGRFC had a short staff during this event, the potential for improved service would probably have outweighed the disadvantage.

Recommendation 5-4: It is a positive sign when HSA staff call the RFC hydrologist at home after hours. This high level of professionalism has long-standing tradition in the NWS even though the WGRFC did not maintain 24-hour operation (in the RFC) during this flood

event. The WGRFC should revisit the practice of not providing a forecaster on duty in the RFC during the night when major flooding is in progress.

When HSA offices receive reports of heavy nighttime rainfall, and updated river forecasts from the RFC are not immediately available, the HSA office should immediately issue a statement to the effect that the additional rainfall could possibly cause changes to the forecast and further state that an updated river forecast will be provided shortly.

River forecast products from the RFC need immediate dissemination on AFOS over the RDC for all need-to-know field offices and cooperating agencies. The latest observed stage (e.g., 6 a.m. observed stages for morning forecasts, noon observed stages for afternoon forecasts, and 6 p.m. observed stages for evening forecasts) should also be provided with the river forecast to indicate where the river stage is at present relative to any and all forecast values.

The staffing increase for the WGRFC, as outlined in the "Hydrometeorological Service Operations for the 1990's" plan, should be implemented without delay. These NWS modernization and associated restructuring plans, currently being implemented, will provide for extended hours at the RFCs. This 7-days-per-week operation will greatly increase the level of hydrologic support during periods of prolonged heavy rains and riverine flooding.

Finding 5-5: Public flood warnings contained statements indicating that flooding would be more severe than what was forecasted if additional heavy rainfall occurred. The WGRFC used the NMC QPF to determine the potential for heavy rainfall; however, no attempt was made by the RFC to run hydrologic contingency forecasts based on NMC QPF products. Furthermore, the WGRFC received no requests from HSAs for this type of QPF-enhanced hydrologic products. All involved stated that NMC provided excellent support for the QPF statements and estimated rainfall amounts. Emphasis on QPF-enhanced hydrologic forecast products has increased in recent years. Some RFCs in various areas of the United States are now, and have been for several years, using QPF values produced by NMC and the WSFOs in their hydrologic forecast areas. Other RFCs continue to study the use of QPF as input to hydrologic forecast models.

Recommendation 5-5: All RFCs should pursue the use of QPF in the preparation of hydrologic forecasts.

Finding 5-6: On one occasion, a river forecast was issued for Hempstead on the Brazos River by the WGRFC for a stage above 70 feet which would have been over 10 feet greater than the flood of record (56.1 feet).

Recommendation 5-6: RFC forecasts that exceed flood of record should be reviewed carefully prior to being released. The intent of this review should be to examine the likelihood of the forecast being outside a reasonable range of possibilities with respect to forecasts that are also about to be issued for adjacent points on the same river.

Finding 5-7: Difficulties were encountered by the staff of the WGRFC in forecasting some of the forecast points on the lower Brazos River. Some of the early forecasts exceeded the flood of record by more than 10 feet. The most influential contributor to forecasts on the lower Brazos River is the routed water from upstream points. The WGRFC uses a Lag and K routing technique for this purpose. The forecast model was calibrated with previous conditions and available data. These calibrations were at the edges of their limits, which subsequently contributed to the erroneous forecasts. Mathematically sophisticated forecasting techniques that are specifically designed to handle situations such as those encountered on the Brazos River have been developed and continue to be enhanced by the NWS Hydrologic Research Laboratory. The best model currently available is known as the Dynamic Wave Model. It is designed to model the movement of a flood wave through a river system and provide predicted water level information at various locations along the river system. Furthermore, this model will compute the average velocity of the flood wave, which often will be significantly reduced as the water spreads out over wide floodplain areas (such as the farmland adjacent to the Brazos River).

Recommendation 5-7: The WGRFC should take steps to implement the Dynamic Wave Model on the Brazos River.

Finding 5-8: Some Weather Service Form E-19s (Report on River Gage Station) were found to be quite out of date (close to 10 years old). Furthermore, several of these old E-19s had multiple flood stage values (with different dates--possibly the dates when flood stages were changed) on the page that shows the staff gage. Additional confusion occurred in finding crests for individual flood events labeled "flood stage" rather than "flood crest." The Service Hydrologist Information Management System (SHIMS) is available to computerize the E-19 process.

Recommendation 5-8: The Fort Worth, San Antonio, and the new Houston HSA offices should go through each of their E-19s and develop a priority list that would be used to update all E-19s in their service areas. When the E-19s are updated, page 9 that shows the staff gage should have only the current flood stage shown. Flood crests for individual flood events need to be identified with an occurrence date, but there should be only one flood stage value. Flood stage, referring to the level where damage actually begins to occur within a

specific reach of the river, should stand out for quick reference. Form E-19s also need to be provided to the WGRFC and WSOs for maximum utility during flood emergencies.

Finding 5-9: The E-19 reference material file developed by the SH at San Antonio (see Figure 18) contains all of the pertinent information needed to prepare a public forecast from an RFC forecast as well as the additional information to collect river stage data.

Recommendation 5-9: It is recommended that these types of files be created for forecast points by other HSA offices.

Finding 5-10: Based on information gathered from the WGRFC official forecast point worksheets, which indicate sites where crest forecasts are prepared by the WGRFC, not all stations have a listed flood stage.

Recommendation 5-10: The RFC should check to ensure that flood stages are listed on its forms. A check of all E-19s should be made to determine appropriate flood stages. Where flood stage values are found to be missing on the WGRFC official forecast point worksheets, E-19s need to be obtained from the appropriate HSA office. If E-19s are not available from the HSA office, the SH needs to create one and provide a copy to the RFC.

Finding 5-11: Hydrologists at the WGRFC are assigned procedures development and forecast responsibilities for forecast points within given river basins. One river basin had been assigned to one individual forecaster for over 2 years. No clearly established policy was found to exist for quality review of forecasts or rotation of the assignment responsibilities to other river basins.

Recommendation 5-11: The WGRFC is encouraged to routinely rotate forecasters from one basin to another in order to broaden their expertise on all basins. Senior staff should work more directly with journey level and junior staff through the development and forecast process to more fully utilize their skills and technical knowledge. This will also add a dimension of quality review to the procedures used in daily forecast operations.

Finding 5-12: Users perceived from WGRFC products that hydrologic models worked well during this flood period. Recently, 2 man-years were spent revising and redeveloping model procedures on the Brazos River. In view of widespread, recent record flooding and new hydrologic knowledge, operational forecast procedures need further review as stated by WGRFC staff. The WGRFC uses its version of the antecedent precipitation index model to

determine runoff; it runs the Sacramento Soil Moisture Accounting model in parallel on the Trinity River.

Recommendation 5-12: The RFCs should provide updated model parameters as soon as possible after major flood events. As resources permit, calibration of additional models should be encouraged. The NWS River Forecast System allows flexibility to use several options of the antecedent precipitation index and the Sacramento Soil Moisture Accounting models. Resources, both in staffing levels and computer systems, should be maintained in the RFCs to provide for the greatest possible development activity, which will bring additional quality to public forecasts.

Finding 5-13: Hydrologic forecasts prepared at the WGRFC were generally found to be long, contained several references to crests or flood stages in one statement, and did not always specify a date for the crest to occur. It was found that considerable confusion existed from the terms that were used in the forecasts. These terms included phrases such as "RISING OVR..., RISING TO..., CONT RISING TO OVR...," etc. Days (e.g., MONDAY), rather than dates, were used to indicate the crest's occurrence. No standard format was found for preparing river forecast products nor were there any guidelines for using forecast terminology.

Recommendation 5-13: Confusion over WGRFC hydrologic products can be addressed with the preparation of a standard, general-use river forecast format that employs short, concise terminology and utilizes date labels for crest occurrence. Use of confusing terms or phrases, (i.e., "RISING TO...," etc.) should be discontinued. For slow-rising floods, a 3-day stage forecast on the rising and falling limbs of the hydrograph should be provided in the river forecast. The hydrologist should code a forecast for a crest to occur at a specific time, thereby providing the greatest lead-time possible. The crest forecast should indicate whether or not QPF is used in making the prediction. Mention of this fact in the river forecast is practiced by other RFCs. All NWS field offices served by the WGRFC should be provided with a copy of the standard river forecast format and a list of terminology and common phrases used for individual forecasts. Examples of each category in the terminology list should also be provided for greater understanding. The HSA offices should provide the descriptive interpretation for hydrologic forecasts released to the media and the public.

CHAPTER 6: HYDROLOGIC WARNING SERVICE--FLASH FLOODING

Finding 6-1: An alarming number of people attempt to drive through flooded, low-water crossings and/or floodwaters of unknown depth. For years the NWS and others have stressed the danger of these actions, but too often the message does not produce the desired

results. Milam County Judge Roger Hasham felt that many people, who are accustomed to hearing the preparedness statements that accompany flash flood warnings, very likely do not pay attention to them or, more likely, do not think the advice applies to themselves and their situations. The judge stated that people need visual reminders of the dangers of driving through floodwaters. He felt that television stations should have materials available for use during periods of heavy rain that graphically demonstrate the dangers of floodwaters. He also felt that NWS preparedness presentations should include the same visual material.

Recommendation 6-1: The NWS must continue to strengthen all preparedness efforts with regard to motorists and flash floods and also to look for new approaches to emphasize the dangers. The National Oceanic and Atmospheric Administration and the NWS should develop radio and television spots that graphically demonstrate the dangers, especially to motorists, of floodwaters. The same type of material should be furnished to all NWS offices for use in their warning and preparedness work.

Finding 6-2: Many local officials did not know that the NWS was involved in river forecasting. River authorities were inundated with calls from the public, media, and emergency management coordinators seeking river information. As a result of its experience during the flood, the Brazos River Authority is seriously considering establishing an information unit to handle the demands for river information during future flood events.

Recommendation 6-2: The NWS should give increased visibility to its river forecasting program, especially in those parts of the country where river flooding can be a significant problem. Information concerning the NWS's hydrologic role should be a part of all pertinent preparedness and emergency planning programs. The NWS should also take steps to expand the public information role for RFCs during times of serious flooding.

Finding 6-3: People living near the coast had difficulty relating the river forecasts at a gage to their specific locations. Many coastal residents are familiar with hurricane storm surge forecasts that are given in mean sea level but had difficulty translating the river forecasts into meaningful information for their situations.

Recommendation 6-3: The NWS should explore the possibility of providing river flood forecasts for coastal areas in both mean sea level and in the traditional gage forecasts.

Finding 6-4: The two SHs in this episode performed extremely well; however, during a flood event of this magnitude and duration, the WSFO SH can be overwhelmed. By working

long hours, the SH can easily become too tired and stressed to perform with top effectiveness, even with the help of the WSFO staff.

Recommendation 6-4: During long-duration flood events, the MIC should consider requesting a backup hydrologist to the affected WSFO from an office not impacted by the flooding. The backup hydrologist could provide valuable assistance to the SH and the WSFO staff during critical periods. This option should only be pursued if other knowledgeable members of the HSA staff are not available to back up the SH.

CHAPTER 7: COORDINATION, DISSEMINATION, AND USER RESPONSE

Finding 7-1: The SH plays a critical role both preceding and during major riverine and flash flood events. During long-duration riverine flood events, like this one, the SHs are often relied on to personally provide most hydrologic river services. Current staffing of WSFOs only provides for one SH per office which, in the case of Texas, means that two individuals are responsible for providing hydrologic support for their respective offices and corresponding HSA offices.

Recommendation 7-1: Continue to develop, improve, and maintain high-quality hydrologic training programs for meteorologists. Lead forecasters need to be familiar with known flood problem areas within their areas of responsibility and be confident with recognizing critical rainfall thresholds that cause problems. Continue to pursue the modernization plans which call for WFO forecasters having the resources, knowledge, skills, and responsibilities for routinely assessing flood as well as flash flood problems and issuing, as appropriate, all necessary public hydrologic watches and warnings.

Finding 7-2: An error in judgment at WSO Houston caused public controversy that could have been avoided. The incident involved a river forecast from the WGRFC for the Brazos River that was received from WSFO San Antonio for release to the public. The individual handling the information noted that the predicted gage height was more than 10 feet higher than any previous forecast and believed this to be a possible error. A simple phone call to either WSFO San Antonio or the WGRFC could have quickly resolved the matter.

Recommendation 7-2: All NWS staff involved with disseminating public forecasts and warnings should be reminded and encouraged to review and question suspect information received from another office before releasing it to the public.

Finding 7-3: During major riverine flooding, a high level of coordination needs to be maintained with RFC staff. This is difficult to achieve with an office that is not staffed 24 hours a day. The WGRFC did not implement its option to conduct 24-hour staffing operations during the flooding period in question. This practice occurred previously as found in a similar disaster report regarding floods on the Trinity, Red, and Arkansas Rivers in May of 1990. The recommendation at that time was that "RFCs should remain open during potentially dangerous flood situations."

Recommendation 7-3: Implement the recommendations of past flood surveys and have RFCs provide written procedures for approval by the Regional Office and NWS Headquarters that set forth criteria for 24-hour staffing. These procedures should be flexible between regions, since the hydrologic characteristics of river basins vary considerably. RFC staff should be the originating authors.

Finding 7-4: The technical capabilities of local and regional cooperating agencies vary considerably. Technically qualified users have different needs than nontechnical users; but the importance of good, two-way communications is common to both. Special efforts are needed to improve links with the various organizations, and key individuals need to be identified.

Recommendation 7-4: NWS offices should obtain copies of local emergency action plans and work with key agencies to improve internal procedures. In refining NWS operational procedures, address the differing needs of users by recognizing individual capabilities. The importance of personal contact should be emphasized, and Memorandums of Understanding should be developed where none currently exist and routinely updated where they do exist. The WPM and SH should work closely together when making personal contacts relative to local flood warning programs.

Finding 7-5: NWS offices are somewhat handicapped with respect to evaluating available, real-time data from local flood-detection networks, such as the ALERT systems. LFWS operators have a definite advantage over NWS forecasters by instantly knowing when critical rainfall and river-level thresholds are exceeded. This type of information is not always relayed to the WSFO or WSO, since it is often difficult to do so every time an alarm level is exceeded.

Recommendation 7-5: WSFOs should be provided with the means to directly process data from automated gaging systems within their HSA offices or to develop the capability of automatically being immediately notified when alarm levels are exceeded.

Finding 7-6: The media complimented the accuracy and timeliness of NWS forecasts throughout this event. The admiration was stronger from the television and radio stations with more sophisticated weather departments; but the small, rural stations were also complimentary.

Finding 7-7: Telephone inquiries, at times, taxed the resources of NWS offices, especially at the San Antonio office where the SH received frequent calls. Even then, when the SH was unable to give immediate attention to media calls, they were understanding of his tremendous work load and held no animosity for having to occasionally wait for information for their news reports.

Recommendation 7-7: Additional resources, including personnel support, should be made available to help handle public affairs and excess telephone calls during prolonged flood events.

Finding 7-8: The level of accuracy and timeliness in disseminating NWS flood statements, warnings, and forecasts was in direct relation to the radio and television station's level of sophistication and frequency of contact with the NWS. The radio and television stations that gave serious attention to weather news also provided immediate dissemination of flood statements.

Recommendation 7-8: The NWS should continue its support of field office educational efforts to teach station managers, reporters, and other users the speed with which NWWS can provide weather statements. Local NWS managers should organize seminars to train new media personnel and to reinforce past training in the coordination and dissemination of weather information by the NWS.

Finding 7-9: The NWS and the Lower Colorado River Authority recently completed a cooperative effort to automatically produce a daily hydrologic message containing data from the Lower Colorado River Authority hydrometeorological sensor network. The Lower Colorado River Authority used a database and a report writer on a Digital Equipment Corporation MicroVAX computer to produce the message in the Standard Hydrometeorological Exchange Format (SHEF) code. The generated message is stored as a file on the MicroVAX. After the message has been generated, the WSO in Austin, Texas, calls the Lower Colorado River Authority MicroVAX and downloads the file to its AFOS Auxiliary Backup Terminal. The WSO quality controls the message, adds additional hydrologic data, if needed, and transmits the message on the AFOS circuit. The WGRFC receives the data and also automatically enters the data into its forecast model. Over

90 percent of the message is generated and encoded in a completely automated process. This automation effort has resulted in a significant reduction of field personnel time that would have been required for manual data entry.

Recommendation 7-9: NWS offices vested with HSA responsibility should investigate the possibility of having their cooperative river authorities and local flood control agencies enter into similar cooperative efforts.

Finding 7-10: Water flowed over the emergency spillway from Lake Arlington and discharged into a tributary of the Trinity River upstream of Grand Prairie. The spillway at Lake Arlington is uncontrolled and has no operator at the lake. In addition, there is no sensor for determining when water overflows the emergency spillway. Extremely heavy rainfall and the subsequent excessive flow over the Lake Arlington emergency spillway caused problems to the people in both Arlington and Grand Prairie during the early morning hours of December 21, 1991.

Recommendation 7-10: The communities of Grand Prairie and Arlington should consider sharing resources for installation of a Local Flood Warning System that includes event precipitation gages and an alarm system on the emergency spillway of Lake Arlington.

APPENDIX B

RIVER FLOOD PRODUCTS ISSUED BY WEATHER SERVICE FORECAST OFFICE FORT WORTH

Date	Time	Location
12/18/91	1025	Sulphur, Sabine, Neches, and Trinity Rivers.
12/19/91	0920	Trinity River.
12/19/91	1115	Sulphur, Cypress, Sabine, Neches, and Trinity Rivers.
12/19/91	2135	Trinity River.
12/20/91	1145	Sulphur, Cypress, Sabine, Neches, and Trinity Rivers and Pecan Bayou.
12/20/91	1355	Trinity River.
12/20/91	1400	Trinity River.
12/20/91	1515	Brazos, Leon, and Bosque Rivers.
12/20/91	1620	Trinity and San Saba Rivers and Pecan Bayou.
12/20/91	2114	Trinity River (Lake Worth).
12/20/91	2140	Brazos River.
12/21/91	0405	Trinity River.
12/21/91	0830	Trinity River.
12/21/91	1100	Sulphur River and Cypress Creek.
12/21/91	1215	Sabine, Neches, and Trinity Rivers.
12/21/91	1330	Brazos, Leon, Bosque, and Colorado Rivers.
12/21/91	1545	Trinity River.
12/21/91	2100	Trinity River.
12/22/91	1040	Sulphur River and Cypress Creek.
12/22/91	1150	Trinity River.
12/22/91	1220	Sabine and Neches Rivers.
12/22/91	1230	Brazos, Leon, Bosque, and Colorado Rivers.
12/22/91	1300	Trinity River.
12/22/91	1300	Sabine and Neches Rivers.
12/22/91	1525	San Saba River.
12/23/91	1100	Sulphur River and Cypress Creek.
12/23/91	1125	Brazos, Leon, Bosque, and Colorado Rivers.
12/23/91	1155	Trinity River.
12/23/91	1230	Sabine and Neches Rivers.
12/23/91	1450	Trinity River.
12/24/91	0930	Trinity River.
12/24/91	1000	Sulphur River and Cypress Creek.
12/24/91	1120	Brazos and Leon Rivers.
12/24/91	1140	Trinity River.

APPENDIX B (continued)

Date	Time	Location
12/24/91	1210	Sabine and Neches Rivers.
12/25/91	1020	Sulphur River and Cypress Creek.
12/25/91	1040	Brazos and Leon Rivers.
12/25/91	1125	Sabine, Neches, and Angelina Rivers.
12/25/91	1205	Trinity River.
12/26/91	1020	Sulphur River and Cypress Creek.
12/26/91	1100	Brazos and Leon Rivers.
12/26/91	1150	Trinity River.
12/26/91	1235	Sabine, Neches, and Angelina Rivers.
12/27/91	1010	Sulphur River and Cypress Creek.
12/27/91	1205	Trinity River.
12/27/91	1230	Sabine, Neches, Angelina, and Brazos Rivers.
12/28/91	1155	Sulphur River and Cypress Creek; Sabine, Neches, Angelina, and Brazos Rivers.
12/28/91	1220	Trinity River.
12/29/91	1045	Sulphur River and Cypress Creek; Sabine, Neches, and Angelina Rivers.
12/29/91	1055	Trinity River.
12/30/91	1120	Sulphur River and Cypress Creek; Sabine, Neches, and Angelina Rivers.
12/30/91	1130	Trinity River.
12/30/91	1200	Sulphur River and Cypress Creek; Sabine, Neches, Angelina, and Trinity Rivers.

APPENDIX C

RIVER FLOOD PRODUCTS ISSUED BY WEATHER SERVICE FORECAST OFFICE SAN ANTONIO

Date	Time	Location
12/19/91	0425	Olmos and Salado Creeks.
12/19/91	0710	San Antonio River.
12/19/91	0850	Guadalupe River and Geronimo Creek.
12/19/91	1155	Sabine, Trinity, and Navasota Rivers.
12/19/91	1230	Guadalupe and San Antonio Rivers; Salado and Cibolo Creeks.
12/20/91	0200	Medina River.
12/20/91	0525	Guadalupe, Medina, and Frio Rivers and Seco Creek.
12/20/91	0730	Medina and Guadalupe Rivers.
12/20/91	0825	Pedernales River.
12/20/91	0925	Pedernales River.
12/20/91	1330	Guadalupe, San Antonio, Colorado, Llano, and Pedernales Rivers; Cibolo and Sandy Creeks.
12/20/91	1500	Sabine, Trinity, and Navasota Rivers.
12/20/91	2300	Colorado, Llano, Pedernales, and Guadalupe Rivers; Barton, Walnut, and Onion Creeks.
12/21/91	0115	Blanco River.
12/21/91	0400	Medina River.
12/21/91	0850	Pedernales and Colorado Rivers.
12/21/91	1010	Pedernales, Colorado, and San Marcos Rivers.
12/21/91	1140	Colorado River.
12/21/91	1520	Brazos, Navasota, Little, San Gabriel, Colorado, Pedernales, Llano, Blanco, San Marcos, Guadalupe, Sabine, and Trinity Rivers.
12/21/91	1650	Leon Creek.
12/21/91	1759	Lavaca River.
12/21/91	2140	Navasota River.
12/21/91	2240	Guadalupe and San Antonio Rivers.
12/21/91	2335	Guadalupe and San Antonio Rivers.
12/22/91	0945	Guadalupe River.
12/22/91	1450	Brazos, Navasota, Little, San Gabriel, Colorado, Pedernales, Llano, Blanco, San Marcos, Guadalupe, Sabine, and Trinity Rivers.
12/23/91	0750	Colorado, San Marcos, and Guadalupe Rivers.
12/23/91	0815	Brazos, Navasota, and Trinity Rivers.
12/23/91	1410	Sabine, Neches, Brazos, Navasota, Little, San Gabriel, Trinity, San Jacinto, and San Bernard Rivers; Village and Davidson Creeks; Pine Island Bayou.

APPENDIX C (continued)

Date	Time	Location
12/23/91	1412	Colorado, Lavaca, Navidad, San Marcos, Guadalupe, Llano, San Antonio, Nueces, Frio, Atascosa, and Mission Rivers.
12/24/91	0715	Colorado, Lavaca, Navidad, San Marcos, Guadalupe, Llano, San Antonio, Nueces, Frio, Atascosa, and Mission Rivers.
12/24/91	0720	Sabine, Neches, Brazos Navasota, Little, San Gabriel, Trinity, San Jacinto, and San Bernard Rivers; Village and Davidson Creeks; Pine Island Bayou.
12/24/91	1435	Colorado, San Marcos, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.
12/24/91	1525	Sabine, Neches, Brazos, Navasota, Little, San Gabriel, Trinity, San Jacinto, and San Bernard Rivers; Village and Davidson Creeks; Pine Island Bayou.
12/25/91	1240	Sabine, Neches, Trinity, San Bernard, Brazos, Little and Navasota Rivers; Village Creek; Pine Island Bayou.
12/25/91	1345	Colorado, San Marcos, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.
12/26/91	0840	Brazos and Trinity Rivers.
12/26/91	0905	Trinity, Brazos, Colorado, Guadalupe, and San Antonio Rivers.
12/26/91	1345	Sabine, Neches, Trinity, San Bernard, Brazos, Little and Navasota Rivers; Village Creek; Pine Island Bayou.
12/26/91	1425	Colorado, San Marcos, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.
12/27/91	0750	Sabine, Neches, Trinity, San Bernard, Brazos, Little, and Navasota Rivers; Village Creek; Pine Island Bayou.
12/27/91	0820	Colorado, San Marcos, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.
12/27/91	1005	Sabine, Neches Trinity, San Bernard, Brazos, Little, and Navasota Rivers; Village Creek; Pine Island Bayou.
12/27/91	1230	Canyon Lake.
12/27/91	1255	Sabine, Neches, Trinity, San Jacinto, San Bernard, Brazos, and Navasota Rivers; Village, Cypress, and Peach Creeks; Pine Island Bayou.
12/27/91	1340	Colorado, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.
12/27/91	1445	Sabine, Neches, Trinity, San Jacinto, San Bernard, Brazos, and Navasota Rivers; Village, Cypress, and Peach Creeks; Pine Island Bayou.
12/28/91	1135	Brazos River.

APPENDIX C (continued)

Date	Time	Location
12/28/91	1330	Sabine, Neches, Trinity, San Jacinto, Brazos, and Navasota Rivers; Village, Cypress, and Peach Creeks; Pine Island Bayou.
12/28/91	1420	Colorado, Guadalupe, San Antonio, Nueces, Frio, and Atascosa Rivers.

APPENDIX D

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE FORECAST OFFICE SAN ANTONIO December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/19/91	FFW	0127C	FLASH FLOOD WARNING	Eastern Bexar County; 1 inch/hr at RND.
	FFA	0200C	FLASH FLOOD WATCH	Flash flood watch through today west of line from College Station/Cuero/Beeville/Laredo; influx of gulf moisture and upper trough to the west.
	FFW	0256C	FLASH FLOOD WARNING	Flash flood warning until 6 a.m. for Bexar, southern Comal, southern Kendall; water rising in low areas as heavy rains continue.
	FFS	0332C	FLASH FLOOD STATEMENT	Flash flood statement; metro streets flooded; Interstate 35 downtown closed (construction site); roads in Olmos basin closed.
	FFS	0432C	FLASH FLOOD STATEMENT	Flash flood statement to summarize closed roads around San Antonio; river flooding and rainfall.
	FFW	0606C	FLASH FLOOD WARNING	Extended flash flood warning until 9:15 a.m. for Bexar, Comal, and Kendall Counties.
	FFS	0636C	FLASH FLOOD STATEMENT	Flash flood statement summarizing flash flood warnings, river flood warnings, road closures.
	FFS	0636C	FLASH FLOOD STATEMENT	Update summary of watches, warnings.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFW	0823C	FLASH FLOOD WARNING	Flash flood warning extended until 2 p.m. for Bexar, Comal, Kendall; heavy rains continue; low-lying areas to remain flooded; rivers to remain flooded.
	FFW	0851C	FLASH FLOOD WARNING	Flash flood warning for Guadalupe County; roads beginning to flood due to recent/continuing, heavy rains.
	FFS	0855C	FLASH FLOOD STATEMENT	Flash flood statement summarizing watches, warnings; no relief in sight.
	FFS	1000C	FLASH FLOOD STATEMENT	Update summary of watches, warnings; little or no letup in sight.
	FFS	1125C	FLASH FLOOD STATEMENT	Update summary of watches, warnings; many roads closed; rainfall update: little change expected next few days.
	FFS	1225C	FLASH FLOOD STATEMENT	Update summary of watches, warnings; many roads closed; rainfall update: some relief possible late afternoon, otherwise, wet weather through Saturday.
	FFS	1315C	FLASH FLOOD STATEMENT	Update summary of watches, warnings; many roads closed; rainfall update: some relief possible late afternoon, otherwise, wet weather through Saturday.
	FFW	1349C	FLASH FLOOD WARNING	Flash flood warning extended until 6 p.m. for Bexar, Comal, and Guadalupe Counties; rains up to 7 inches in some areas with flooding continuing.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1415C	FLASH FLOOD STATEMENT	Update summary of watches, warnings; many roads closed; rainfall update: some relief possible late afternoon, otherwise, wet weather through Saturday.
	FFA	1530C	FLASH FLOOD WATCH	Flash flood watch extended through tonight northwest of line from Austin/San Antonio/Eagle Pass; deep, unstable moisture; upper disturbance approaching from the west.
	FFW	1803C	FLASH FLOOD WARNING	Flash flood warning extended until 9 p.m. for Bexar and Comal Counties; moderate rains continue over these counties, and low areas still flooded.
	FFS	1909C	FLASH FLOOD STATEMENT	Update on warnings, watches, radar, general weather conditions.
	FFW	2029C	FLASH FLOOD WARNING	Flash flood warning for Bandera, Kendall, and Kerr Counties until 6:30 a.m.; heavy rains over counties; roads are being closed.
	FFW	2052C	FLASH FLOOD WARNING	Flash flood warning until midnight for western Bexar County; locally heavy rain over that area.
	FFW	2254C	FLASH FLOOD WARNING	Flash flood warning until 6:30 a.m. for Edwards and Real Counties; heavy rain increasing in that area.
	FFW	2356C	FLASH FLOOD WARNING	Flash flood warning until 6:30 a.m. for Kinney and Uvalde Counties; repeat radar echoes across that area.
12/20/91	FFS	0140C	FLASH FLOOD STATEMENT	Flash flood statement; update on watches, warnings, radar, road closures; main focus of heavy rain over western/central Hill County.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFW	0305C	FLASH FLOOD WARNING	Flash flood warning Bexar and Medina Counties until 9 a.m. Heavy rains indicated by radar over those areas; 3-5 inches of rain possible this morning.
	FFA	0400C	FLASH FLOOD WATCH	Flash flood watch through today northwest of line from College Station to Laredo.
	FFS	0545C	FLASH FLOOD STATEMENT	Flash flood statement; summary of watches, warnings, river warnings, radar, and road closures.
	FFW	0617C	FLASH FLOOD WARNING	Flash flood warning Bandera, Kendall, and Kerr Counties until 9:15 a.m.; 1-3 inches of rain falling over already flooded areas.
	FFS	0730C	FLASH FLOOD STATEMENT	Flash flood statement; summary of watches, warnings, rainfall, road closures.
	FFS	0957C	FLASH FLOOD STATEMENT	Flash flood statement; summary of flash flood watches/warnings, river flood warnings.
	FFS	1038C	FLASH FLOOD STATEMENT	Flash flood statement; summary of road closures in warned counties.
	FFS	1038C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings, river flooding, radar summary.
	FFS	1248C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings, river flooding, radar summary.
	FFW	1348C	FLASH FLOOD WARNING	Flash flood warning until 8 p.m. for flooded low areas and continued rain over that area.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1450C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings, river floodings, rainfall totals, radar summary, safety rules.
	FFA	1530C	FLASH FLOOD WATCH	Flash flood watch through tonight northwest of line from Eagle Pass/ San Antonio/Austin.
	FFW	1711C	FLASH FLOOD WARNING	Flash flood warning until 8 p.m. for Bexar, Comal, Guadalupe Counties; additional heavy rains falling over saturated/flooded areas.
	FFA	1847C	FLASH FLOOD WATCH	Flash flood watch extended eastward into Huntsville area.
	FFW	2104C	FLASH FLOOD WARNING	Flash flood warnings until 6 a.m. for Bandera, Edwards, Kendall, Kerr, Real Counties; moderate to heavy rains over these already saturated counties.
	FFS	2202C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings, rainfall.
	FFW	2330C	FLASH FLOOD WARNING	Flash flood warning until 3:30 a.m. for Uvalde County; line of very heavy rain moving into county.
	FFW	2347C	FLASH FLOOD WARNING	Flash flood warning until 6 a.m. for Comal County; heavy rains continue over this already saturated area.
12/21/91	FFW	0251C	FLASH FLOOD WARNING	Flash flood warning until 10 a.m. for Kinney and Uvalde Counties; heavy rain continues over already flooded areas.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFS	0330C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings, river flood warnings, radar, safety rules.
	FFA	0400C	FLASH FLOOD WATCH	Flash flood watch expanded southward and extended through the day. Cold front and convergence moving southward. New watch northwest of an Eagle Pass/Karnes City/Anderson line.
	FFW	0613C	FLASH FLOOD WARNING	Flash flood warning until 11:15 a.m. for Atascosa, Bandera, Bexar, Comal, Guadalupe, Kendall, Kerr, Kinney, Medina, Real and Uvalde Counties; satellite and radar estimates show additional inch has fallen and continues over already flooded areas.
	FFS	0815C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood warnings/watches, river flooding, rainfall totals since midnight, weather synopsis.
	FFW	0840C	FLASH FLOOD WARNING	Flash flood warning until 1:45 p.m. for Webb County; heavy rains and Interstate 35 being closed; 2-inch rains reported.
	FFA	0857C	FLASH FLOOD WATCH	Flash flood watch expanded southward through today; new area north of Del Rio/Laredo/Corpus Christi/Victoria/Houston/Newton; rainfall sagging southward.
	FFS	1012C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood warnings/watches; list of river heights.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFW	1041C	FLASH FLOOD WARNING	Flash flood warning (issued by WSFO Fort Worth for WSFO San Antonio) for McMullen County; 2-3 inches of rain beginning to cause flooding of low areas and roads.
	FFW	1115C	FLASH FLOOD WARNING	Flash flood warnings (issued by WSFO Fort Worth for WSFO San Antonio, due to communications failure in south Texas) extended until 6 p.m. for Atascosa, Bandera, Bexar, Comal, Guadalupe, Kendall, Kerr, Kinney, Medina, Real and Uvalde Counties; continued heavy rains over already flooded areas.
	FFS	1250C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood watches/warnings; flooding in Webb and McMullen has ended; many rivers, streams, low areas in other counties will continue for a few more hours.
	FFS	1430C	FLASH FLOOD STATEMENT	Flash flood statement; summary update of flash flood warnings/watches, river/creek flooding.
	FFA	1553C	FLASH FLOOD WATCH	Flood/flash flood watch extended through tonight along north of a Laredo/Corpus Christi/Galveston/ Port Arthur line; surface front and upper-level trough moving across area tonight.
	FFS	1845C	FLASH FLOOD STATEMENT	Flash flood statement; all flash flood warnings in San Antonio County area expired; flash flood watch continues; no rain falling in area at present.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFA	2025C	FLASH FLOOD WATCH	Flood/flash flood watch expanded to include all of south Texas (added the lower valley); slow-moving cold front and upper trough moving across area.
12/22/91	FFA	0400C	FLASH FLOOD WATCH	Flood/flash flood watch removed northwest sections and extended through the day; new area south of an Eagle Pass/Junction line; main rains sagging southward and some clearing from the north; cold front in central and southern zones and upper trough moving across area will continue threat today.
	FFW	0603C	FLASH FLOOD WARNING	Flash flood warning until 10 a.m. for Gonzales County; over 1 inch of rain has fallen past 3 hours over already flooded area.
	FFA	0800C	FLASH FLOOD WATCH	Flood/flash flood watch redefined to exclude western and southern sections of south Texas; new area is east of Burnet/San Antonio/ Beeville/Palacios; secondary front has cleared areas to the west as upper low moves northeastward.
	FFS	0800C	FLASH FLOOD STATEMENT	Flash flood statement updating status of flash flood watches/warnings, rivers, radar, synopsis.
	FFW	0939C	FLASH FLOOD WARNING	Flash flood warning for Gonzales County until 3:45 p.m.; sheriff reports that flooding continues over much of the County; travel is dangerous.
	FFS	1115C	FLASH FLOOD STATEMENT	Flood/flash flood statement; summary update of flash flood watches/ warnings, river flooding.

APPENDIX D (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1305C	FLASH FLOOD STATEMENT	Flood/flash flood statement; summary update of flash flood watches/warnings; portions of the flash flood watch canceled west of line from Austin/Lockhart/ Seguin/Jourdanton; some low-lying areas in canceled region will remain temporarily flooded as waters slowly subside.
	FFA	1435C	FLASH FLOOD WATCH	Flood/flash flood watch area revised and extended through tonight, now along and east of a College Station/Victoria line. Cold front moving into southeast Texas tonight.
	FFS	1602C	FLASH FLOOD STATEMENT	Flood/flash flood statement; summary update of flood/flash flood watches/warnings for Gonzales expired; river flood summary.
	FFS	2015C	FLASH FLOOD STATEMENT	Flash flood watch discontinued; no additional heavy rains will add to already flooded areas; many rivers (listed) in flood at record to near-record levels.

APPENDIX E

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE OFFICE AUSTIN December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/19/91	FFSAUS	0550C	FLASH FLOOD STATEMENT	90 percent of area covered with rain which, in past days, has saturated soils; locally heavy rains expected to produce flash flooding.
	FFSAUS	0800C	FLASH FLOOD STATEMENT	Overnight rains 1-2 inches; no problems yet; additional heavy rains may produce flooding.
	FFSAUS	0840C	FLASH FLOOD STATEMENT	Flash flood watch continues; heavy rains San Marcos to Wimberly; Hays County should listen for additional bulletins.
	FFWAUS	1000C	FLASH FLOOD WARNING	Warning for Hays County; moderate to heavy rains continue, flooding of low-lying areas likely to begin soon.
	FFSAUS	1030C	FLASH FLOOD STATEMENT	Flash flood warning for Hays; road closures listed.
	FFSAUS	1215C	FLASH FLOOD STATEMENT	Flash flood warning for Hays County extended until 2:45 p.m.
	FFSAUS	1400C	FLASH FLOOD STATEMENT	Warning until 2:45 p.m. for Hays County; rain totals, road closures.
	FFWAUS	1434C	FLASH FLOOD WARNING	Warning for Hays County extended until 5:30 p.m.; flooded low areas and moderate rains continue.
12/20/91	FFSAUS	0115C	FLASH FLOOD STATEMENT	Heavy rains forming over Hill County, San Antonio/ Fredericksburg; some flooding may be developing.

APPENDIX E (continued)

Date	Type	Time	Issuance	Remarks
	FFWAUS	0418C	FLASH FLOOD WARNING	Warning until 8:15 a.m. for Burnet, Gillespie, and Llano; unofficial amounts of 4-7 inches; additional 3-5 inches possible.
	FFWAUS	0750C	FLASH FLOOD WARNING	Warning until 10 a.m. for Lampasas, Mills, San Saba, Burnet, Gillespie, and Llano; many low areas flooded, and rains continue to develop over area.
	FFWAUS	1001C	FLASH FLOOD WARNING	Warnings extended until 2 p.m. for Lampasas, Mills, San Saba, Burnet, Gillespie, and Llano; many low areas flooded, and moderate rains continue.
	FFWAUS	1359C	FLASH FLOOD WARNING	Warnings until 6 p.m. for Lampasas, Mills, San Saba, Gillespie, and Llano Counties; rain continues over already flooded areas.
	FFWAUS	1652C	FLASH FLOOD WARNING	Flash flood warning until 8 p.m. for Hays, Travis, and Williamson Counties.
	FFSAUS	1720C	FLASH FLOOD STATEMENT	Flash flood warning updates; very heavy rains falling over Travis, Williamson, and Hays Counties.
	FFWAUS	1754C	FLASH FLOOD WARNING	Warning until 8 p.m. for Lampasas, Mills, and Gillespie Counties; flooding of numerous low areas continues.
	FFSAUS	1805C	FLASH FLOOD STATEMENT	Flash flood warning update; extremely dangerous situation developing, with creeks rising and rush-hour traffic heavy.

APPENDIX E (continued)

Date	Type	Time	Issuance	Remarks
	FFWAUS	1957C	FLASH FLOOD WARNING	Warning until 11 p.m. for Lampasas, Mills, Gillespie, Hays, Travis, and Williamson Counties; major flooding occurring and heavy rains expected to persist for the next few hours.
	FFSAUS	2015C	FLASH FLOOD STATEMENT	Flash flood warnings continue, evacuations being necessary, shelters being opened.
	FFWAUS	2128C	FLASH FLOOD WARNING	Warning for Bastrop, Lee, and Milam Counties until 12:30 a.m.; very heavy rains shifting eastward on that area.
	FFWAUS	2245C	FLASH FLOOD WARNING	Warning until 12:45 a.m. for Hays and Travis Counties; heavy rains continuing over these already flooded areas.
12/21/91	FFWAUS	0325C	FLASH FLOOD WARNING	Warning for western Bastrop, Burleson, Lee, Milam, and Caldwell Counties; very heavy rains flooding low areas and closing roads.
	FFWAUS	0351C	FLASH FLOOD WARNING	Warning extended until 7:30 a.m. for Lampasas, Blanco, Burnet, Hays, eastern Llano, Travis, and Williamson Counties. Heavy rains continue over already flooded areas.
	FFWAUS	0711C	FLASH FLOOD WARNING	Warnings extended until 12:15 p.m. for Lampasas, Bastrop, Blanco, Burnet, Caldwell, Lee, Hays, and Travis Counties; flooding still being reported and heavy rains continue.
	FFSAUS	1201C	FLASH FLOOD WARNING	Warnings for all counties in Austin area expired; however, many low areas, rivers, and streams will remain flooded for several hours.

APPENDIX E (continued)

Date	Type	Time	Issuance	Remarks
	FFSAUS	1745C	FLASH FLOOD STATEMENT	Rain has ended west of Austin over Hill County.
12/22/91	FFWAUS	0733C	FLASH FLOOD WARNING	Warning for Hays, Travis, and Williamson Counties until 10:30 a.m.; strong thunderstorms across those areas; ground already saturated with some areas still flooded.
	FFWAUS	1203C	FLASH FLOOD WARNING	Warning for Burleson and Milam Counties until 2 p.m.; heavy rain falling; county officials report many roads flooded.

APPENDIX F

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE OFFICE HOUSTON December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/21/91	SPSHOU	0716C	SPECIAL WEATHER STATEMENT	Heavy rains reaching the Greater Houston area.
	FFSHOU	1310C	FLASH FLOOD STATEMENT	2-3 inches of rain over some counties with water over roads.
12/22/91	FFWHOU	1435C	FLASH FLOOD WARNING	Warning for southern Colorado County until 5:30 p.m. Sheriff reports water over some roads; heavy rains moving toward county.

APPENDIX G

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE OFFICE BROWNSVILLE December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/21/91	FFWBRO	1818C	FLASH FLOOD WARNING	Flash flood warning until 10:15 p.m. for Jim Hogg and Zapata Counties; radar indicates very heavy rains over that area.
	FFSBRO	2050C	FLASH FLOOD STATEMENT	Flash flood warnings expired; flash flood watch continues; thunderstorms decreasing.

APPENDIX H

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE FORECAST OFFICE FORT WORTH December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/18/91	ESF	1610C	FLOOD POTENTIAL OUTLOOK	Potential heavy rainfall and flood situation developing across north Texas in the late-week period.
	SPS	1630C	SPECIAL WEATHER STATEMENT	Potential heavy rainfall and flood situation developing across north Texas in the late-week period.
12/19/91	FFA	0400C	FLASH FLOOD WATCH	Flash flood watch for today for the western two-thirds of north Texas.
	FFS	0605C	FLASH FLOOD STATEMENT	A large area of light to moderate rain over much of north Texas.
	FFS	0720C	FLASH FLOOD STATEMENT	Widespread patches of light to moderate rain over much of north Texas.
	FFS	0755C	FLASH FLOOD STATEMENT	Widespread patches of light to moderate rain over all of north Texas.
	FFS	1020C	FLASH FLOOD STATEMENT	Widespread patches of light to moderate rain over all of north Texas.
	FFA	1020C	FLASH FLOOD WATCH	The flash flood watch extended through today and tonight for the western two-thirds of north Texas. Radar continued to show widespread patches of light to moderate rain over all of north Texas.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1320C	FLASH FLOOD STATEMENT	Weather radar showed widespread patches of light to moderate rainfall across all of north Texas. Heavy rainfall is expected over north Texas this afternoon as another upper-level disturbance moves over the area.
	FFS	1440C	FLASH FLOOD STATEMENT	Weather radar showed widespread patches of light to moderate rainfall across all of north Texas. The heavier areas of rain were expanding in coverage.
	FFS	1600C	FLASH FLOOD STATEMENT	Radar showed widespread patches of light to moderate rainfall across the northern two-thirds of north Texas.
	FFS	1750C	FLASH FLOOD STATEMENT	Weather radars indicated an area of mostly light rain with a few embedded, heavier showers over that portion of north-central and northeast Texas, generally to the north of a line from Abilene to Eastland to Waxahachie to Tyler.
	FFS	1930C	FLASH FLOOD STATEMENT	Radars indicated scattered areas of mostly light rain with a few heavier showers over north-central Texas.
	FFS	2310C	FLASH FLOOD STATEMENT	Weather radars indicated rain had decreased across northeast Texas.
12/20/91	FFS	0118C	FLASH FLOOD STATEMENT	A flash flood watch remains in effect tonight for the west half of north Texas.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFA	0340C	FLASH FLOOD WATCH	The flash flood watch has been extended and redefined to include all of the central and west part of north Texas today. 1-3 inches of rain have been common across the central and west part of north Texas over the past 24 hours. An additional 2-4 inches, along with isolated 5-inch amounts, are possible across the watch area today.
	FFS	0700C	FLASH FLOOD STATEMENT	Flash flood watch remains in effect.
	FFW	0750C	FLASH FLOOD WARNING	Flash flood warning effective until 11:45 a.m., CST, for Erath County. High-water crossing isolated portions of Farm to Market Road 914.
	FFW	0826C	FLASH FLOOD WARNING	Effective until 1:30 p.m., CST, for Parker and Tarrant Counties.
	FFW	0838C	FLASH FLOOD WARNING	Effective until 1:45 p.m., CST, for Hood, Johnson, and Somervell Counties.
	FFS	0915C	FLASH FLOOD STATEMENT	Flash flood warnings are in effect for several counties in north-central Texas.
	FFW	0923C	FLASH FLOOD WARNING	Effective until 2:30 p.m., CST, for Hamilton County. Numerous creeks and streams out of banks.
	FFS	1025C	FLASH FLOOD STATEMENT	Flash flood warnings are in effect for several counties in north-central Texas. Between the hours of 6 a.m. and 9 a.m., rainfall totals have been heavy at some locations in north-central Texas.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFW	1157C	FLASH FLOOD WARNING	Effective until 5 p.m., CST, for Erath County. Heavy rains are continuing. More heavy rains expected this afternoon.
	FFW	1246C	FLASH FLOOD WARNING	Effective until 5:45 p.m., CST, for Collin and Denton Counties. More heavy rains are expected throughout the afternoon.
	FFS	1315C	FLASH FLOOD STATEMENT	Flash flood warnings continue for several counties in north-central Texas. Heavy rainfall forced creeks, streams, and rivers out of their banks. Many urban areas are reporting street flooding. A trailer park in Haltom City was evacuated.
	FFW	1323C	FLASH FLOOD WARNING	Effective until 5:30 p.m., CST, for Fannin, Grayson, Hood, Johnson, Parker, Somervell, and Tarrant Counties. Flash flooding and moderate to occasionally heavy rain continuing.
	FFW	1400C	FLASH FLOOD WARNING	Effective until 6 p.m., CST, for Wise County. Flooding occurring on rural roads. Moderate to locally heavy rain will continue to increase flash flood problems.
	FFA	1410C	FLASH FLOOD WATCH	Flash flood watch extended and will be in effect for the rest of today and tonight.
	FFW	1425C	FLASH FLOOD WARNING	Effective until 5:30 p.m., CST, for Dallas and Hamilton Counties.
	FFS	1500C	FLASH FLOOD STATEMENT	Flash flood warnings continue for several counties in north-central Texas. This is a serious flood situation.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1635C	FLASH FLOOD STATEMENT	Flash flood warnings continue for several counties in north-central Texas. Some of these warnings will likely be extended.
	FFW	1731C	FLASH FLOOD WARNING	Effective until 9:30 p.m., CST, for Collin, Dallas, Denton, Erath, Hamilton, Hood, Johnson, Parker, Somervell, Tarrant, and Wise Counties. Flash flood warnings extended because of continuing high water problems.
	FFS	1810C	FLASH FLOOD STATEMENT	Flash flood warnings extended for several counties in north-central Texas.
	FFS	1920C	FLASH FLOOD STATEMENT	Flash flood warnings continue.
	FFW	1951C	FLASH FLOOD WARNING	Effective until 1 a.m., CST, for Ellis and Rockwall Counties. Numerous roads and low-water crossings reported under water.
	FFS	2020C	FLASH FLOOD STATEMENT	Flash flood warnings continue. Radars indicated rain over north-central Texas decreased to mostly light rain with a few moderate showers. Moderate to heavy rain continued over northeast Texas.
	FFS	2020C	FLASH FLOOD STATEMENT	Flash flood statement corrected to replace Kaufman County with Rockwall for flash flood warning.
	FFW	2035C	FLASH FLOOD WARNING	Effective until 6:30 a.m., CST, for Fannin County.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFW	2131C	FLASH FLOOD WARNING	Effective until 6:30 a.m., CST, for Collin, Dallas, Denton, Erath, Freestone, Hamilton, Hood, Johnson, Navarro, Parker, Somervell, and Tarrant Counties. Law enforcement officials report numerous roads, streets, and low-lying areas flooded.
	FFA	2155C	FLASH FLOOD WATCH	Flash flood watch in effect for much of north Texas redefined to include northeast Texas and is in effect for all of tonight.
	FFW	2315C	FLASH FLOOD WARNING	Effective until 7:15 a.m., CST, for Kaufman, Anderson, Hopkins, Rains, and Van Zandt Counties. Weather radars indicated a broad area of moderate to occasionally heavy rain over a large part of northeast and central Texas.
	FFS	2345C	FLASH FLOOD STATEMENT	Flash flood watch has been defined to include northeast Texas.
12/21/91	FFW	0103C	FLASH FLOOD WARNING	Effective until 8 a.m., CST, for Ellis, Rockwall, Cherokee, Henderson, Smith, and Wood Counties. Law enforcement agencies reported a number of roads closed due to high water.
	FFS	0130C	FLASH FLOOD STATEMENT	Flash flood warnings extended for Ellis and Rockwall Counties until 8 a.m.
	FFS	0230C	FLASH FLOOD STATEMENT	Flash flood warnings remain in effect.
	FFS	0330C	FLASH FLOOD STATEMENT	Flash flood warnings remain in effect. A few areas of heavy rain were embedded within the moderate rain area in northeast Texas.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFA	0425C	FLASH FLOOD WATCH	The flash flood watch for much of north Texas redefined. The watch is for that part of north Texas east of a Sherman/ Weatherford/Stephenville/ Brownville/Brady line. The Dallas/Fort Worth Metroplex, Waco, Brownwood, and Tyler are included in the watch.
	FFS	0500C	FLASH FLOOD STATEMENT	Flash flood warnings remain in effect.
	FFS	0600C	FLASH FLOOD STATEMENT	Watch remains in effect. Flash flood warnings remain in effect.
	FFW	0642C	FLASH FLOOD WARNING	Effective until 12 noon, CST, for Dallas, Freestone, Hamilton, Navarro, Parker, and Tarrant Counties. Flash flood warnings for these counties continued.
	FFW	0726C	FLASH FLOOD WARNING	Effective until 12 noon, CST, for Anderson County. Warning extended.
	FFS	0740C	FLASH FLOOD STATEMENT	Flash flood warnings have been extended.
	FFW	0809C	FLASH FLOOD WARNING	Effective until 12 noon, CST, for Cherokee, Henderson, and Smith Counties. Warnings extended.
	FFS	0910C	FLASH FLOOD STATEMENT	Flash flood warnings continue in parts of north Texas.
	FFS	0910C	FLASH FLOOD STATEMENT	Correction to Para 2. Flash flood warnings continue in parts of north Texas.
	FFS	1020C	FLASH FLOOD STATEMENT	Flash flood warnings continue in parts of north Texas.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFW	1155C	FLASH FLOOD WARNING	Effective until 3 p.m., CST, for Freestone, Navarro, Anderson, Cherokee, Henderson, and Smith Counties. Rain continues to fall across the warning area.
	FFS	1305C	FLASH FLOOD STATEMENT	Flash flood warnings continue in parts of north Texas but canceled for the Metroplex.
	FFS	1410C	FLASH FLOOD STATEMENT	Dangerous flood situation still exists over parts of north Texas.
	FFS	1520C	FLASH FLOOD STATEMENT	All flash flood warnings have expired for north Texas. Problems still exist on area roads and low spots. A flash flood watch remains in effect.
	FFA	1600C	FLASH FLOOD WATCH	Flash flood watch for north Texas redefined and extended through tonight and tomorrow for all of north Texas.
	FFS	1815C	FLASH FLOOD STATEMENT	Flash flood watch is in effect. Early this evening no significant rainfall was over north-central Texas. Rain will likely redevelop late tonight from the west and continue spreading east through Sunday.
	FFS	2330C	FLASH FLOOD STATEMENT	Scattered patches of rain had developed over Hill County and were moving northeast toward north-central Texas.
12/22/91	FFS	0100C	FLASH FLOOD STATEMENT	Light rain continued to develop over southwest portions of north-central Texas.
	FFS	0200C	FLASH FLOOD STATEMENT	Flash flood watch is in effect tonight and Sunday.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFS	0300C	FLASH FLOOD STATEMENT	Flash flood watch is in effect tonight and Sunday.
	FFS	0400C	FLASH FLOOD STATEMENT	Light rain continued to develop over Hill County and western portions of north-central Texas.
	FFS	0630C	FLASH FLOOD STATEMENT	Showers and thunderstorms continue to develop across north Texas.
	FFS	0745C	FLASH FLOOD STATEMENT	Flash flood watch canceled for that portion of north Texas west of a Wichita Falls/Brownwood/ San Saba line.
	FFS	0900C	FLASH FLOOD STATEMENT	Rain and isolated thunderstorms continue over north Texas.
	FFS	1015C	FLASH FLOOD STATEMENT	Rain and isolated thunderstorms continue over north Texas.
	FFS	1115C	FLASH FLOOD STATEMENT	Flash flood watch continues in effect this afternoon for eastern portions of north Texas. Flash flood watch redefined to include that portion of north Texas east of a Bonham/Kaufman/Grosbeck line. This includes the cities of Tyler, Longview, Paris, and Lufkin.
	FFS	1115C	FLASH FLOOD STATEMENT	Correction of issuance time.
	FFS	1230C	FLASH FLOOD STATEMENT	Rain ending over west sections of north Texas. Light to moderate rain with isolated thunderstorms over most of northeast Texas.
	FFS	1230C	FLASH FLOOD STATEMENT	Correction.

APPENDIX H (continued)

Date	Type	Time	Issuance	Remarks
	FFS	1345C	FLASH FLOOD STATEMENT	Rain is ending over most of north-central Texas. Areas of light to moderate rain with isolated thunderstorms continued over northeast Texas.
	FFS	1455C	FLASH FLOOD STATEMENT	Strong thunderstorms have developed over parts of east Texas.
	FFS	1600C	FLASH FLOOD STATEMENT	Thunderstorms have decreased in intensity over northeast Texas. A flash flood watch remains in effect until 6 p.m.
	FFS	1650C	FLASH FLOOD STATEMENT	Thunderstorms continue to decrease in intensity over northeast Texas.
	FFA	1755C	FLASH FLOOD WATCH	Flash flood watch for tonight for the southeast part of north Texas. The watch is within an area bounded by a Marshall/Tyler/ Crockett line. Some of the cities in the watch area are Lufkin, Jacksonville, Henderson, Center, and Carthage.
	FFS	1935C	FLASH FLOOD STATEMENT	Flash flood watch for the southeast part of north Texas canceled.

APPENDIX I

FLASH FLOOD PRODUCTS ISSUED BY WEATHER SERVICE OFFICE WACO December 18-22, 1991

Date	Type	Time	Issuance	Remarks
12/18/91	SPSACT	1309C	SPECIAL WEATHER STATEMENT	Widespread light rain across much of central and south-central Texas.
12/19/91	FFSACT	1040C	FLASH FLOOD STATEMENT	Flash flood watch in effect for much of central and south-central Texas through tonight.
	FFSACT	1230C	FLASH FLOOD STATEMENT	Flash flood watch in effect. Weather radar continued to show light rain with a few embedded, heavier showers.
12/20/91	SPSACT	0340C	SPECIAL WEATHER STATEMENT	Flash flood watch in effect for all of central Texas.
	SPSACT	0435C	SPECIAL WEATHER STATEMENT	Flash flood watch in effect through today for all of central Texas and parts of south-central Texas. Rain showers on the increase.
	SPSACT	0533C	SPECIAL WEATHER STATEMENT	Rain showers were continuing to the west of a Dallas/Waco/Taylor line.
	SPSACT	0533C	SPECIAL WEATHER STATEMENT	Correction.
	SPSACT	0633C	SPECIAL WEATHER STATEMENT	Flash flood watch in effect through today. Some areas in central Texas have already received 2 inches of rainfall.
	SPSACT	0730C	SPECIAL WEATHER STATEMENT	Flash flood watch in effect through today.

APPENDIX I (continued)

Date	Type	Time	Issuance	Remarks
	SPSACT	0945C	SPECIAL WEATHER STATEMENT	Flash flood watch in effect through today. Waco weather radar showed light rain with a few embedded, heavier showers. Rainfall in excess of 5 inches over the past 24 hours.
	FFWACT	1034C	FLASH FLOOD WARNING	Effective until 2:30 p.m., CST, for Bosque and Coryell Counties. Most low-water crossings impassable. Residents along the north Bosque River, Leon River, and Cowhouse Creek should take immediate action.
	FFSACT	1045C	FLASH FLOOD STATEMENT	Numerous reports of flooding.
	FFWACT	1102C	FLASH FLOOD WARNING	Effective until 5 p.m., CST, for Hill County. Waco weather radar indicated heavy rains beginning to move into the northern portions of Hill County.
	FFSACT	1200C	FLASH FLOOD STATEMENT	Numerous reports of road closures received.
	FFWACT	1416C	FLASH FLOOD WARNING	Effective until 8:15 p.m., CST, for Bosque and Coryell Counties. Numerous reports of water over roads and road closures have been received. Additional flooding likely.
	FFSACT	1445C	FLASH FLOOD STATEMENT	Bosque County: numerous roads under water; Highway 22 closed. Coryell County: water over many rural roads; car swept off the road at Leon River. Numerous road closures near Blum. Residents along the north Bosque River in Bosque County are urged to seek higher ground.

APPENDIX I (continued)

Date	Type	Time	Issuance	Remarks
	FFWACT	1628C	FLASH FLOOD WARNING	Effective until 12:30 a.m., CST, for Bell, Bosque, Coryell, Hill, and McClennan Counties. Large area of moderate to heavy precipitation continues over the western parts of central Texas.
	FFSACT	1655C	FLASH FLOOD STATEMENT	River flood warning is in effect through tonight for the Brazos, Bosque, and Leon Rivers in central Texas. Waco weather radar continued to show light rain with embedded, heavier showers and thunderstorms over most of central Texas. In McLennan County, water was reported over Interstate 35.
	FFSACT	1905C	FLASH FLOOD STATEMENT	Numerous road closures. Persons trapped on rooftops by flood waters of the Bosque River.
	FFSACT	1905C	FLASH FLOOD STATEMENT	Correction for time.
12/21/91	FFWACT	0006C	FLASH FLOOD WARNING	Effective until 4:15 a.m., CST, for Bell, Bosque, Coryell, Hill, and McLennan Counties. Light to moderate rain with isolated heavy showers continue over most of central Texas.
	FFSACT	0120C	FLASH FLOOD STATEMENT	Reports from sheriffs' departments throughout central Texas have many road closures as well as stranded motorists; rural communities cut off due to water over many roadways. The north Bosque River (Bosque County) will continue to rise through the night. The Leon River is over its banks in Coryell County. Flooding/flash flooding to continue through the night and morning hours.

APPENDIX I (continued)

Date	Type	Time	Issuance	Remarks
	FFWACT	0419C	FLASH FLOOD WARNING	Effective until 7:15 a.m., CST, for Bosque, Coryell, Hill, and McLennan Counties. Radar continued to show moderate to heavy rains over the warned area.
	FFSACT	0430C	FLASH FLOOD STATEMENT	Many reports of flooded roadways and closed highways have been received. This is a very serious flooding event across a large part of Texas. Residents along the north Bosque River in Bosque County urged to evacuate to higher ground. The river will continue to rise through the night. The Leon River is more than 10 feet over its banks in Coryell County at Gatesville.
	FFSACT	0645C	FLASH FLOOD STATEMENT	Rain continued widespread over most of central and south-central Texas. Many reports of flooded roadways and closed highways.
	SPSACT	0845C	SPECIAL WEATHER STATEMENT	Waco weather radar showed a large area of rain, moderate showers, and a few thunderstorms with heavy rain throughout much of central Texas. Many reports of flooded roadways and closed highways continue to be received.
	SPSACT	1025C	SPECIAL WEATHER STATEMENT	Waco weather radar showed a large area of rain, moderate showers, and a few thunderstorms with heavy rain throughout much of central Texas. Many reports of flooded roadways and closed highways continue to be received.

APPENDIX I (continued)

Date	Type	Time	Issuance	Remarks
	SPSACT	1328C	SPECIAL WEATHER STATEMENT	Many reports of flooded roadways and closed highways continue to be received. The Department of Public Safety reports that nearly all roads in Bosque County are flooded.
	SPSACT	1520C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect through tonight for the north Bosque River, the Leon River, and the Brazos River. A flash flood watch is in effect through tonight for all of central and south-central Texas.
	SPSACT	2057C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect. A flash flood watch is in effect.
	SPSACT	2320C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect. A flash flood watch is in effect.
	FFSACT	2340C	FLASH FLOOD STATEMENT	Waco weather radar showed a large area of rain, moderate showers, and thunderstorms with heavy rain throughout central parts of south-central Texas.
12/22/91	SPSACT	0120C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect. A flash flood watch is in effect.
	SPSACT	0332C	SPECIAL WEATHER STATEMENT	Numerous showers and a few thunderstorms with heavy rain were moving north out of south Texas.
	SPSACT	0635C	SPECIAL WEATHER STATEMENT	Thunderstorms with heavy rain developing rapidly in a band from just west of Grandview to Meridian to south of Kileen. The thunderstorms were part of a larger area moving out of west and south Texas.

APPENDIX I (continued)

Date	Type	Time	Issuance	Remarks
	SPSACT	0725C	SPECIAL WEATHER STATEMENT	Thunderstorms with heavy rain were in a band from west of Itasca to Waco to Moody.
	SPSACT	0948C	SPECIAL WEATHER STATEMENT	Waco weather radar showed numerous light to moderate showers and scattered thunderstorms with heavy rain throughout much of central Texas.
	SPSACT	1115C	SPECIAL WEATHER STATEMENT	Waco weather radar continued to show numerous areas of light rain with a few embedded showers and thunderstorms. Serious flood conditions continue to persist along the Brazos, Leon, and Navasota Rivers. The flash flood watch has been canceled.
	SPSACT	1310C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect. The flash flood watch has been canceled.
	SPSACT	1440C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect through tonight for the Bosque, Leon, Brazos, and Navasota Rivers. Reports from Brazos County show evacuations may occur on a large scale all along the Brazos River as the river is continuing to rise through parts of Brazos and Robertson Counties.
	SPSACT	1545C	SPECIAL WEATHER STATEMENT	River flood warnings are in effect through tonight for the Bosque, Leon, Brazos, and Navasota Rivers.
12/23/91	SPSACT	0635C	SPECIAL WEATHER STATEMENT	Major flooding along the Brazos River in Brazos County.

APPENDIX J
DISASTER SURVEY TEAM CONTACTS

- **West Gulf River Forecast Center**

  Dave Morris, Hydrologist in Charge
  John Croslin, Deputy Hydrologist in Charge
  Jerry Nunn, Hydrologist

- **Weather Service Forecast Office Fort Worth**

  Skip Ely, Meteorologist in Charge
  Ernest Cathey, Service Hydrologist
  Michael Mach, Warning Preparedness Meteorologist

- **Weather Service Forecast Office San Antonio**

  Al Drumont, Meteorologist in Charge
  Jimmy Ward, Deputy Meteorologist in Charge
  John Patton, Service Hydrologist
  Mario Valverde, Warning Preparedness Meteorologist

- **Weather Service Office Austin**

  Louis Withrow, Meteorologist in Charge
  Jim Dugan, Warning Preparedness Focal Point

- **City of Austin, Office of Emergency Management**

- **Lower Colorado River Authority**

- **Upper Guadalupe River Authority**

  Bernie Burns
  Captain Ray Cooks

- **Weather Service Office Waco**

  William Weaver, Officer in Charge
  Bruce Byers, Coop Student

APPENDIX J (continued)

- **Weather Service Office Houston**

  Scott Kaiser, Acting Meteorologist in Charge
  Ron Stagno, Warning Preparedness Meteorologist

- **Fort Bend County, Office of Emergency Management**

  Melvin Speed, Emergency Manager

- **NWS Southern Region Headquarters**

  Harry Hassel, Regional Director
  Bill Proenza, Deputy Regional Director
  Dave Reed, Acting Regional Hydrologist

- **Hayes County**

  A.D. Carroll, Fire Marshal and Emergency Manager

- **Milan County**

  Judge Roger Hashim, County Judge
  Tom Chambelein, Office of Emergency Management

- **U.S. Army Corps of Engineers, Belton Dam**

  Murray McCarley, Park Ranger
  Rod Steiger, Park Ranger
  Robert Chapman, Project Manager

- **Brazos River Authority**

  Sheryl Franklin, Water Resource Division Manager

- **Center For Disease Control**

  Scott Lillibridge

APPENDIX J (continued)

- **Fredericksburg, Gillespie County, Office of Emergency Management**

  Paul Hanneman, Coordinator
  Louis Loch, Retired Emergency Manager

- **U.S. Army Corps of Engineers, Lake Control Unit, Fort Worth**

  Doug Perrin, Chief of Upper Basins, Lake Control Unit

- **Texas State Office of Emergency Management, Austin**

  Robert Lansford and eight staff members

- **Texas Department of Public Safety**

  Officer Wardlow

Dallas/Fort Worth

Anita Baker, *Fort Worth Star Telegram*, (817) 390-7410
Brad Barton, KRLD Radio, News/Weather Director, (214) 263-3283
Mike Berger, TV 4 (CBS), Meteorologist, (214) 720-4413
Troy Dungan, WFAA Television, Meteorologist, (214) 748-9631
Steve Mace, KLIF Radio, News Director, (214) 787-1570
Dan Potter, WBAP Radio, Program Director, (817) 654-6100

APPENDIX J (continued)

San Antonio

Brad Branson, KKYX Radio, News Director, (512) 690-1925
Patricio Espinoza, KVDA TV 60, News Director, (512) 340-8862
Don Ferguson, KGNV Radio, News Director, (512) 625-7311
Jim Forsythe, WOAI Radio (EBS), News Director, (512) 736-9700
Kevin Harboreth, KWED Radio, Office Manager, (512) 379-2234
Steve LaNore, KENS TV 5, Weather Staff, (512) 366-5000
Andres Morin, KWEX TV 41, Meteorologist, (512) 227-4141
Mike Pesina, KSAT TV 12, Weather Staff, (512) 351-1200
J. D. Rose, KNAF Radio, Program Director, (512) 997-2198
San Antonio Express News, (512) 828-3784
Mike Sterle, KMOL TV 4, Weather Staff, (512) 226-4444
Olene Stone, *San Antonio Light*, Assistant City Editor, (512) 271-2716

Austin

Mike Clay, KTVV TV 36, Meteorologist, (512) 476-3636
Jack Church, KTBC TV 7, Meteorologist, (512) 476-7777
Janet Evans, KLBJ Radio, News Director, (512) 832-4000
Doc Holiday, KEYI Radio, Program Director, (512) 328-1035
Troy Kimmel, KVUE TV 24, Meteorologist
Bob Rose, KVUE TV 24, Meteorologist, (512) 459-6521
Fred Switzer, KTAE Radio, Program Director, (512) 352-3631
Brad Wheelis, KVET Radio, Reporter, (512) 495-1300
Scott Wright, *Austin American Statesman*, (512) 445-3500

Houston

Ed Brandon, KTRK TV 13, Weatherman, (713) 666-0713
Neil Frank, KHOU TV 11, Meteorologist, (713) 526-1111
Doug Freelander, *Houston Post*, Staff Reporter, (713) 840-5600
Roland Galvan, KPRC TV 2, Meteorologist
Joe Noland, KPRC TV 2, Assistant News Director, (713) 771-4631

Wharton

Unnamed Disc Jockey, KANI Radio

APPENDIX K
DISASTER SURVEY MEDIA RESPONSES

Description of Media Interviews:

As part of the investigation into the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) actions during the late December 1991 floods in Texas, contacts were made with media sources in four metropolitan areas and in certain rural areas impacted by the floodwaters. Interviews were made by telephone calls in the Dallas/Fort Worth area on January 6; in the San Antonio area on January 7; in the Austin area on January 8; and in the Houston area on January 10, 1992. All interviews were done by telephone except for visits to Radio Station KANI in Wharton, Television Station KPRC TV 2 in Houston, and the *Houston Post* newspaper.

Contacts at each electronic media location were asked a set of 13 questions to determine the timeliness and perceived effectiveness of NWS forecasts, watches, and warnings throughout the flood events which lasted more than 1 week. Contacts with the print media were asked more general questions about overall NWS cooperation and effectiveness. The questions for the electronic media were the following:

1. How does your station receive warnings from the NWS and from which office do they originate?

2. Do you get weather information from other sources?

3. Were forecasts, watches, and warnings of the impending floods issued well enough in advance?

4. Did the watches and warnings from the NWS contain sufficient information to accurately inform your audience of the possible dangers and the areas involved?

5. How long after you receive a watch or warning from the NWS does it take to get it on the air?

6. Was the information passed along to the public through a live break-in of programming or with a crawl message on the screen?

7. Was there any aspect of the communications from the NWS with which you were particularly pleased or displeased?

APPENDIX K (continued)

8. Is there anything you would recommend to improve communication?

9. What is your perception of the timeliness and effectiveness of the watches and warnings?

10. Is the information you receive from the NWS clear and understandable or does it require interpretation?

11. Have you received any response from the public that would indicate public satisfaction or dissatisfaction with the NWS watches and warnings and overall information?

12. Does your station subscribe to NOAA Weather Wire Service (NWWS)?

13. Is there a NOAA Weather Radio (NWR) receiver at your station and, if so, where is it located?

A complete list of media contacts for Dallas/Fort Worth, San Antonio, Austin, Houston, and Wharton can be found in Appendix J.

Individual Interview Responses:

Dallas/Fort Worth

Anita Baker, *Fort Worth Star Telegram*: Baker is an Assistant Metro Editor in the Fort Worth office. According to her, the paper works almost exclusively with the Fort Worth Weather Service Forecast Office (WSFO). "*Star Telegram* reporters," she said, "have always relied on the WSFO as a source of accurate and honest information." Especially noting Meteorologist in Charge (MIC) Skip Ely for setting the cooperative tone, Baker said personnel at the Fort Worth WSFO have always been cooperative with reporters and that staff members go out of their way to provide assistance and answers to questions. She said all staff members made certain that information given to reporters was clear and precise and that all aspects of the flooding were well explained.

APPENDIX K (continued)

Brad Barton, KRLD Radio: Barton explained that KRLD gets its NWS information from NWWS, which is equipped with a tone alarm that has to be shut off manually. An NWR receiver in the control room serves as a backup to NWWS. The station had formerly used AccuWeather but discontinued that service some time back. Contacts are also kept with area law enforcement warning systems and Dallas emergency preparedness, but weather information is derived solely from the NWS.

Watches and warnings are always received well in advance of threatening events, according to Barton, although he could not recall the exact time lapse on the flood events. The station airs any watches at the first available break, which is no longer than the weather updates done every 10 minutes. Warnings, which are Emergency Broadcast Service (EBS) messages, go on the air immediately.

Barton said the only problem he had with communications was that lists of locations involved sometimes become confusing. He admitted that he was not clear about river flood advisories and statements and would like to see some of them consolidated for specific areas rather than listed individually. He said he had noticed that severe storm watches from the National Severe Storm Forecast Center would occasionally get to the station after activity had already started.

As far as public opinion, Barton said he knew the station's listeners were certainly interested in weather news but that he had heard of no adverse opinions about the NWS's handling of the floods.

Dan Potter, WBAP Radio: Potter said his station has a triple-redundant system, with NWWS as the primary source of warnings. The station also has an NWR receiver and uses Associated Press Wire as a backup. A new computer system allows the station to have warnings on the air within 30 seconds. The station employs three staff meteorologists who share duties with a local television station.

Potter said watches and warnings were issued well in advance of any flooding and that ensuing statements were clear and concise and should have been invaluable to the public in determining degrees and areas of danger. He said statements during the period in question were even more specific than others he had received. He also praised the frequent rate of updated information put out by the NWS. Potter said there was very good cooperation between his station and NWS personnel at WSFO Fort Worth, much better than he recalled in other areas he has worked. "WSFO staffers gave on-air interviews and provided many tapes for station use," he said.

APPENDIX K (continued)

Steve Mace, KLIF Radio: KLIF is an EBS transfer station and receives warning information from the NWWS. An NWR receiver is located centrally in the newsroom and Associated Press Wire serves as a backup. He said watches and warnings were issued well in advance, and his station aired them within seconds of issuance from the NWS. Calling the Fort Worth WSFO one of the best, he especially complimented the jobs done with river tables and dissemination of information after events were over. He said he would have liked to have seen a little more case-by-case chronology to help with the station's development of sidebar stories and also more frequent use of city names rather than county areas.

Mace said KLIF had received several calls from listeners who were appreciative of the station's warnings and noted that listeners do not differentiate between the radio station and the NWS.

Troy Dungan, WFAA TV 8: Dungan said WFAA gets warning information from NWWS, and the station also subscribes to Kavoris Met-Pak. An NWR receiver is monitored in the master control room. He said watches and warnings were issued well in advance and updates were timely and informative; the station normally uses a crawl script and gets warnings on the air within 2-3 minutes and watches a little longer, depending upon the situation. He was completely satisfied with NWS services--both from a weather and a news standpoint.

Mike Berger, TV 4: Berger said his station gets warnings from NWWS and also uses Weather Services, Inc. (WSI) satellite database. The station has no NWR receiver but does employ its own spotters. He said watches and warnings were issued well in advance; watches were put on a crawl script within 1 minute or less, and warnings generally aired within 5 minutes. Berger was also highly complimentary of the WSFO staff and cited excellent cooperation and good relationships between his station and the WSFO.

<u>San Antonio</u>

Jim Forsythe, WOAI Radio (EBS Station): The station gets weather information from NWWS and also has two full-time meteorologists with an in-house setup and an NWR receiver and uses Associated Press Wire for a second backup. Warnings are broadcast immediately and watches go on at each half-hour newscast.

Forsythe said he had heard of no comments from the public about NWS actions, which he interpreted to mean the public was satisfied.

Patricio Espinosa, KVDA TV 60 (Spanish Station): The station issues weather statements based on information received by fax and by the Associated Press Wire, although Espinosa

sidestepped the question when asked where the faxed material originated. The station uses a crawl script to get weather/flood information on the air. Because of the need to translate statements, it usually takes about 10 minutes to get watches and warnings on the air but sometimes takes up to 15-20 minutes. The only suggestion Espinosa had was to have statements come from NWS offices already in Spanish.

Mike Pesina, KSAT TV 12: The station gets its weather information from WSI and has an NWR receiver on the meteorologist's desk as a backup. Warnings are aired immediately and watches as soon as they can get on, both on a crawl script.

Pesina said he had gotten some feedback and that viewers expressed satisfaction with the timeliness and content of watches and warnings. His only recommendation was for a more open line in the event of severe weather, with someone on the WSFO staff available to talk to the station's meteorology department and reporters.

Bob Branson, KYYX Radio: Weather information is received on NWWS with backup by Associated Press Wire. As an EBS station, it is policy to get warnings on the air immediately. Branson said his staff was completely satisfied with NWS assistance and guidance, and what little public feedback he had was also complimentary.

Branson's only recommendation was a better explanation of how the river crests were moving slowly and were not walls of water roaring downstream. He said he couldn't fault the NWS because people didn't understand explanations given but suggested that a little more support might have helped.

Steve LaNore, KENS TV 5: The station uses NWWS and has a WSI satellite downlink and NWR backup. There is also dial-up access to WSI. LaNore was complimentary of the WSFO staff and especially mentioned the professionalism and courtesy of the staff.

Kevin Harboreth, KWED Radio, Sequin, Texas: Weather information is received through Associated Press Wire, and the station depends on WSFO San Antonio to call during severe weather, although there is an NWR receiver in the control room that the station often relays live to its audience. Harboreth was very complimentary of the staff and had only one suggestion. He said a few statements about levels of the Guadalupe River did not include the normal stage at first.

J. D. Rose, KNAF Radio, Fredricksburg, Texas: Weather information is received through NWWS, and the station also uses information from the Weather Channel. Rose had no complaints about the flood incidents and said he was satisfied that the NWS did a good job of issuing warnings.

APPENDIX K (continued)

Olene Stone, *San Antonio Light*: Stone said cooperation was very good for her reporters seeking flood news. She noted one occasion when a reporter was put off for a couple of hours but added that she realized the work load on NWS staff prevented an immediate response.

Mike Sterle, KMOL TV 4: Information is taken from NWWS and a WSI backup. Warnings are aired immediately with a crawl script. Sterle, who is a forecaster for a nearby Air Force installation, was complimentary of NWS statements and cooperation but had one minor criticism. He noted that flash flood watches and warnings would be reissued (actually updated) for a few hours at a time for many areas during several days of rain. He said the Air Force issued 12-hour and 18- to 24-hour statements to simplify matters. (Note: This does not take into consideration that the NWS had a much broader area to cover.)

Don Ferguson, KGNV Radio, New Braunfels, Texas: Weather information is taken from Associated Press Wire, although an NWR receiver is located in the station's newsroom. As an EBS station, warnings (usually taken directly from NWR) are aired immediately. Ferguson was highly complimentary of the WSFO staff, from both weather and news perspectives. He did have a couple of suggestions: (1) The WSFO could have used more rainfall reports from the public and suggested the staff should have requested phone-in totals. He mentioned that he called the WSFO to advise of a 4-inch rain at one point--the staff didn't seem to be aware of that amount of rainfall. (2) He could have used more information on the San Marcos River and Cibolo Creek.

Ferguson did say the station would probably subscribe to NWWS if the cost was lower.

Andres Morin, KWEX TV 41 (Spanish Station): The station receives its weather information from AccuWeather graphics and uses the Weather Channel as a backup source. Morin was complimentary of actions by WSFO San Antonio during the flood but said that many people chose to ignore the watches and warnings. He said he had gotten some feedback and that the public seemed to be pretty well satisfied with NWS performance, although there was some grumbling about Emergency Management.

APPENDIX K (continued)

Austin

Janet Evans, KLBH Radio: The station gets its warning information from NWWS and has an NWR receiver in the newsroom. Warnings are put on the air immediately and watches go on regular news logs twice an hour. The station's reporters also did several live forecasts/reports from the Weather Service Office (WSO). Evans expressed total satisfaction with the timeliness and usefulness of watches and warnings, adding that she would like to see more locally produced radar summaries and more cities added to warning lists. She said input from the public had been very positive, both toward the station and the NWS. She also said she would like a copy of the final report, if possible.

Brad Wheelis, KVET Radio: The station uses Associated Press Wire as its primary source of watches and warnings, although an NWR receiver is located in the newsroom. (Wheelis was unaware of a delay in transmitting warnings from the NWS through Associated Press Wire.) He said warnings were usually issued within 10 minutes of receipt, at the first opportune spot for a voice break-in. He was pleased with the overall quality and timeliness of watches and warnings. He said he would like to see some of the weather statements put more into layman's terms than are currently used.

Wheelis' only complaint through the whole series of flash floods and floods: "The only thing I can think of is that when I noticed the rain was coming down (during rush hour December 20), it would have been nice to have seen it predicted."

Wheelis said he had no negative input from the public toward his station or the NWS and added that several people doing interviews with his news staff had expressed appreciation for the station doing its job.

Scott Wright, *Austin American Statesman*: Wright was highly complimentary of the WSO Austin staff, stating that NWS staffers always went out of their way to cooperate and answer any questions he or other reporters might have.

Fred Switzer, KTAE Radio, Taylor, Texas: The station receives its watches and warnings from an NWR receiver with Associated Press Wire used as a backup. Warnings are broadcast almost immediately when received.

Switzer was highly complimentary of the WSO staff and said his station had received numerous calls from people, all of whom said the NWS had done a very good job, both with the flash flooding events and the river floods.

APPENDIX K (continued)

Doc Holiday, KEYI Radio: KEYI has no weather department but monitors an NWR receiver in the control room to issue watches and warnings. Station employees also monitor CNN and the Weather Channel and the station subscribes to Associated Press Wire services. Watches and warnings are aired at the first opportunity to break into programming.

Holiday said the information from the NWS proved to be of great help in issuing warnings and helping reporters gather information, and he was especially grateful for upriver information.

Mike Clay, KTVV TV 36: The station gets its warning/watch information from NWWS and has a WSI hookup as a backup. Warnings get on the air within 1-2 minutes and watches within 5 minutes. A crawl script is used in most cases, although the station broke into live broadcasting at times during flash flooding. Clay said warnings were given well in advance and noted that WSO Austin issued the first flash flood watch before any rain had started. Clay said he had nothing but good comments on the station's actions and that he had to give credit for that to the NWS. The only problem he saw was that some radio stations (those without weather departments) were heard repeating old (bad) information during the flooding.

Jack Church, KTBC TV 7: The station gets its warnings from NWR and also subscribes to WSI and a private company called Weather Check System. He said watches and warnings were issued well in advance and that statements were aired within 5 minutes using a crawl script. The station also used live programming breaks several times.

Citing excellent cooperation with the city's Emergency Operations Center staff, the NWS, and the media, Church said the only problem area he saw was that precise locations were sometimes lacking in outlying counties.

Bob Rose and Troy Kimmel, KVUE TV 24: The station gets weather statements from NWWS and has a domestic data circuit (a new service) from Kavoris. An NWR receiver with tone alert is located in the office and Associated Press Wire is used in the newsroom. The station does live program breaks for warnings within 5 minutes of receipt with follow-up text on a crawl script.

Rose and Kimmel (who called from the American Meteorological Society Convention) were highly complimentary of WSO Austin, and Kimmel noted a phone call from the MIC, Lou Withrow, to notify him of a "serious situation."

Both men mentioned one area of concern--a lack of communication between the Lower Colorado River Authority and the NWS. Both said they were receiving faxes of Colorado River data that the Lower Colorado River Authority was not making available to the NWS. The station relayed that information to WSO Austin. Both also said many of the station's viewers use NWR and that it had proved invaluable for getting information to the public.

Houston

Dave Freelander, *Houston Post*: Freelander is one of three reporters who covered the floods in the Houston area. Freelander wrote only one article, but it was the one article in which the NWS received criticism--from the Fort Bend County Emergency Management. The article stated that the county was having problems because the NWS had issued bad flood forecasts based on outdated models.

Freelander said his impression was that the Fort Bend County Emergency Management was experiencing difficulties during the event which prompted the comment critical of the NWS. Freelander said he dealt with the county judges for Fort Bend and Brazoria Counties (the people in charge of emergency management) and that the judges had no criticism of the NWS.

Freelander said the information he and other *Post* reporters had received from the NWS was helpful and informative. He also mentioned that the NWS did a very good job explaining the complexities of the slow-moving floods and why the water was moving much more slowly than previously expected. He also repeated an opinion common to media people--that such widespread rain and flooding had never before been simultaneously experienced on the four rivers involved and that records weren't adequate to accurately forecast exactly what each of the rivers would do.

Joe Noland and Roland Galvan, KPRC TV 2: With a full meteorology staff, KPRC TV gets its NWS information from NWWS and makes frequent phone calls to NWS offices in Houston and San Antonio.

Galvan said one problem he noticed was that the dissemination of up-to-date information was confusing to the public at times because of the wide range of weather expertise at the radio stations who were issuing bulletins. That confusion, he said, led to some animosity between the public and emergency preparedness officials.

Noland said his opinion was that public animosity arose because many rural county emergency officials didn't know what they were doing and that he could not blame the NWS for any bad feelings or bad information. He said the biggest part of the problem was that

people did not take the flood forecasts and warnings seriously. The station led with a flood story and did live shots of flooding every day for 3 weeks, according to Noland. That level of coverage, along with NWS bulletins, let people know at least 10 days in advance that the floods were coming. He said he thought any discrepancies in river levels and crests were minor points that had plenty of time for correction.

Noland did note one large discrepancy (a flood level 15 feet higher than any of record that WSO Houston commented on) and also that there was concern about the confusion over when flood crests would arrive at specific points. He was complimentary of the NWS for its assistance in providing information used in a Christmas Day segment on how flood forecasts are made. The segment noted the complications and cited many outdated records and changes in terrain that caused additional difficulty.

The consensus of Galvan and Noland was that the NWS did a very good job in predicting flood levels, passing on warnings, and cooperating with the media to provide accurate information. Both also agreed with the opinion that "nothing of that magnitude had been seen on the Brazos in so long, nobody really knew what it would do" and that "existing records weren't accurate to help NWS hydrologists give completely accurate predictions."

Neil Frank, KHOU TV 11: As former director for the National Hurricane Center for 13 years, Frank probably had a better understanding of the complexities of river forecasting than other media sources. He said there was no modern precedent for the volume of water involved and that the models used were not designed to handle three or four rivers flooding simultaneously.

One problem Frank noted was that the public expected to see walls of water that are related with most floods and that possibly the NWS and the media did not sufficiently emphasize the severity of the flooding and the volume of water involved.

Ed Brandon, KTRK TV 13: KTRK uses NWWS and South Texas Weather Wire with backup information coming from Zephyr, a system provided by Alden Electronics in Massachusetts.

Brandon said the only public dissatisfaction he heard was in the accuracy of when floods would reach certain places. He added that the public wasn't upset with the NWS but with local emergency managers. Since those agencies make decisions and statements based on NWS forecasts, the NWS must accept some blame for the confusion. He said late crests drew most of the complaints but that the public was informed as to the severity of the flooding. He thought that under the circumstances (an unprecedented flood event) the NWS did a good job.

APPENDIX K (continued)

Wharton

KANI Radio: KANI is an automated Gospel station that issues weather watches and warnings in the Wharton, Texas, area. A single disc jockey was on duty, who did not want to give her name. She said any questions would have to be answered by the station manager, who spreads her time between three such stations. This disc jockey did not know how warnings were received or which NWS office was the station's source. She knew, however, that the station did put out weather warnings.

Public Comments:

Several residents of the flooded areas were interviewed by the disaster survey team, and the comments for the most part were positive for the NWS. One exception occurred in the initial response of a taxi driver in Austin. His reply to an inquiry by the survey team as to how well the NWS performed during the floods was that he felt "they" did very well. However, in further discussion, he revealed that he was referring to emergency managers rather than to the NWS. In fact, he wasn't sure just how the NWS was involved in anything during the flooding. This comment was typical of many residents who responded, that is, any compliments and/or complaints were directed at local emergency managers rather than at the NWS.

Conclusions:

After visiting with contacts at media outlets, reading more than a dozen articles in local newspapers, and visiting with the general public and with NWS personnel, the consensus of the disaster survey team was that the NWS received much positive and very little negative press. Media people were unanimous in their support of NWS efforts and were especially complimentary of the spirit of cooperation exhibited at local NWS offices. Whether they were contacting WSOs, WSFOs, or the RFC, all voiced appreciation for the NWS.

The public perception was somewhat different in that most did not associate the NWS with the floods. This may indicate a need for the NWS to better publicize itself but also raises a matter of principle: Should the NWS be more concerned with putting out timely, clear, and accurate forecasts and warnings or with making sure the public is aware of the origin of those warnings? If the goal is assuring public safety, NWS personnel performed admirably during the Texas floods, as reported by the media. If the goal is agency recognition, there was not much success.

APPENDIX K (continued)

This flood disaster has provided all NWS offices involved with the flood event an excellent opportunity to improve already good media relations and to improve public perception of their roles. The NWS could work with the media to prepare lengthy newspaper articles, complete with graphics, and also radio and television reports that explain in detail what happened to each of the major rivers, smaller local creeks, and bayous during the flood event. If no media sources suggest such an approach, NWS personnel should make the suggestion to the media. Two purposes can be filled: (1) the NWS can gain public recognition and awareness; and (2) the public can be educated on flood safety, which could help to save lives in a future event.

Although there is no way for the NWS to force radio stations to standardize their methods of receiving warnings, an educational effort should be mounted to show station managers and staffs that the NWWS provides much faster warnings than does Associated Press Wire. There seemed to be a lack of understanding of that fact among many radio station operators.

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Brazos River flooding, Thomsons Oil Field, southeast Bend County, Texas. Photograph courtesy Mel Speed of the Fort Bend County Emergency Management Office.