

Service Assessment

South Texas Floods

October 17-22, 1998



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



Cover: San Antonio, Texas, fire department rescuing a man who had been trapped on top of his car for 2 hours Saturday morning, October 17, 1998. (Photograph by Morris Goen/*San Antonio Express-News* Staff Photographer. Copyright © 1998 *San Antonio Express-News*.)

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U.S. DEPARTMENT OF COMMERCE

William M. Daley, Secretary

National Oceanic and Atmospheric Administration

D. James Baker, Administrator

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John J. Kelly, Jr., Assistant Administrator



Preface

Torrential rains over south and southeast Texas during the weekend of October 17-18, 1998, led to widespread and deadly flooding. A total of 31 people died during this event, and property damage estimates approached three quarters of a billion dollars.

The event occurred within areas served by three National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) field forecast offices and by one NOAA/NWS River Forecast Center. Due to the magnitude of this flood event, a Service Assessment Team was assembled to examine all aspects of the warning services provided by NWS offices to the citizens and public officials of the areas affected.

This Service Assessment highlights successful operational procedures and identifies shortcomings noted during this event. Findings and recommendations are presented which will be used in our ongoing efforts to continually improve NWS services for the citizens of this country.

A handwritten signature in black ink, appearing to read "John J. Kelly, Jr.", is positioned above the typed name.

John J. Kelly, Jr.
Assistant Administrator for Weather Services
February 1999

Acronyms

AWIPS	Advanced Weather Interactive Processing System
CDT	Central Daylight Time
cfs	cubic feet per second
CWA	County Warning Area
DCP	Data Collection Platform
EMWIN	Emergency Managers Weather Information Network
FFA	Flash Flood Watch
GBRA	Guadalupe-Blanco River Authority
GOES	Geostationary Operational Environmental Satellite
HAM	Amateur Radio Operator
HPC	Hydrological Prediction Center
HSA	Hydrologic Service Area
HWO	Hazardous Weather Outlook
LAG/K	Lag and K Hydrologic Routing Procedure
LCRA	Lower Colorado River Authority
LMRFC	Lower Mississippi River Forecast Center
MIC	Meteorologist in Charge
NCEP	National Centers for Environmental Prediction
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NWRSAME	NOAA Weather Radio Specific Area Message Encoder
NWS	National Weather Service
NWSFO	NEXRAD Weather Service Forecast Office
NWSO	NEXRAD Weather Service Office
NWSRFS	National Weather Service River Forecast System
NWWS	NOAA Weather Wire Service
QPF	Quantitative Precipitation Forecast
ROML	Regional Operations Manual Letter
SFD	State Forecast Discussion
SHEF	Standard Hydrometeorological Exchange Format
SPC	Storm Prediction Center
SRH	Southern Regional Headquarters
USGS	U.S. Geological Survey
WGRFC	West Gulf River Forecast Center

Service Assessment Team

This Service Assessment Team was formally activated on October 26, 1998, with all team members traveling to Texas on October 27. The team remained in Texas through November 1, collecting information pertaining to the flooding from a wide variety of sources, both within and outside the NWS. Before leaving Texas, the team completed the first draft of the report. After completion of the field work, the team continued to gather and review information before preparing the final version of this Service Assessment.

The team was comprised of the following individuals:

Stephen Harned *Team Leader*, Meteorologist In Charge (MIC), Next Generation Weather Radar (NEXRAD) Weather Service Forecast Office (NWSFO) Raleigh, North Carolina

David Reed Hydrologist In Charge, Lower Mississippi River Forecast Center (LMRFC), Slidell, Louisiana

Larry Eblen Warning Coordination Meteorologist, NWSFO Austin/San Antonio, Texas

Treste' Huse Service Hydrologist, NEXRAD Weather Service Office (NWSO) Rapid City, South Dakota

Curtis Carey Southern Region Headquarters (SRH), Public Affairs Officer, Ft. Worth, Texas

The team would like to thank those people with the following entities who took the time to be interviewed by team members while in Texas. Valuable information was gathered during these interviews.

NOAA/NWS Offices

West Gulf River Forecast Center (WGRFC)

NWSFO Austin/San Antonio

NWSO Houston/Galveston

NWSO Corpus Christi

State of Texas

Assistant State Emergency Coordinator

County Emergency Managers

Bexar, Caldwell, Dewitt, Gonzales, Guadalupe, Jackson, **Wilson**

City Emergency Managers

Luling, New Braunfels, San Antonio

River Authorities

Guadalupe-Blanco River Authority (GBRA)

Lavaca-Navidad River Authority

Lower Colorado River Authority (LCRA)

Federal Officials

U.S. Geological Survey (USGS) -- Austin

USGS -- San Antonio
Corps of Engineers -- Canyon Lake

Other City/County/State Officials

Gonzales City Manager
Gonzales City Police Chief
Hays County Fire Marshal
Hays County Sheriff
Seguin Fire Chief
Victoria County Judge
Victoria City Fire Chief

Media

San Antonio Express-News
KSAT-TV -- San Antonio
KMOL-TV -- San Antonio
KWEX-TV (Spanish Language) -- San Antonio
KAVU-TV -- Victoria
KVET/KASE Radio -- Austin

Other valuable contributors include:

Larry Wenzel, Hydrometeorological Technician, NWS Headquarters, Office of Hydrology,
Silver Spring, Maryland
Linda Kremkau, Technical Editor, NWS Headquarters, Office of Meteorology, Silver Spring,
Maryland

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Overview

During the weekend of October 17-18, 1998, torrential rains fell over south and southeast Texas. Up to 22 inches of rain fell which first resulted in deadly flash flooding from San Antonio to Austin followed by record breaking river floods along several south Texas rivers the following week. Based on provisional data from the USGS, which is subject to revision, the flood peak for this event was the highest known peak stage at 15 locations. Tragically, a total of 31 people died during the event (26 drownings, 2 tornado deaths, 2 heart attacks, and 1 electrocution/drowning). At least 17 of the drowning victims were in vehicles which were either driven into water or were swept away by rapidly rising water. Preliminary property damage estimates approached three quarters of a billion dollars.

The event occurred within the county warning areas (CWA) of three NOAA/NWS field forecast offices (NWSFO Austin/San Antonio, NWSO Houston/Galveston, NWSO Corpus Christi) and within the West Gulf River Forecast Center's (WGRFC's) area of responsibility. The potential for extremely heavy rainfall was anticipated by all offices and by the Hydrometeorological Prediction Center (HPC) and the Storm Prediction Center (SPC) of the National Centers for Environmental Prediction (NCEP).

When the heavy rains began in the CWAs of NWSFO Austin/San Antonio and NWSO Houston/Galveston, both offices began issuing needed flash flood warnings. When the flash flooding evolved into river flooding, the WGRFC provided good river stage forecasts for the San Antonio, Lavaca, Navidad, Colorado, San Bernard, Brazos, and San Jacinto Rivers. However, stage height and timing problems occurred with the forecasts for the Guadalupe River below Seguin.

The Rain Event

All ingredients for extremely heavy rains came together over south Texas the morning of Saturday, October 17. A strong upper level trough (figure 1) and surface front were approaching from the west while a persistent low-level southeast flow of very moist air (dew points in the mid 70s) covered south Texas (figure 2). Additionally, a plume of moist mid and high level air was streaming across the area from Hurricane Madeline off the west coast of Mexico (figure 3).

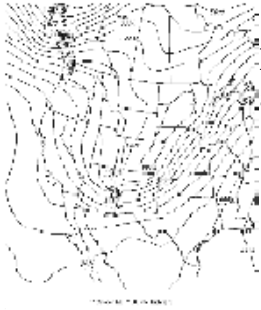


Figure 1. Strong 500 millibar trough approaching Texas from the west at 7 a.m. CDT, Saturday, October 17, 1998.



Figure 2. Surface station plot at 7 a.m. CDT, Saturday, October 17, 1998, showing persistent southeast flow of very moist air feeding into south Texas.

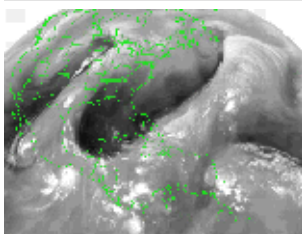


Figure 3. Geostationary Operational Environmental Satellite (GOES)-8 water vapor image at 7 a.m. CDT, Saturday, October 17, 1998, showing a plume of moist mid and high level air streaming across south Texas from Hurricane Madeline located off the west coast of Mexico. (Courtesy of the National Environmental Satellite, Data, and Information Service)

By late Friday, October 16, and early Saturday, October 17, it had become apparent the ingredients for the heavy rain were coming together for the weekend. The only part of the puzzle missing was what triggering mechanism would initiate the heavy rain. Forecasters were keying

on the cold front to the west, which would arrive in south Texas late Saturday or Saturday night, as being the most likely trigger. The 2:35 a.m. Eastern Daylight Time, Saturday, October 17, Quantitative Precipitation Forecast (QPF) Discussion issued by NCEP's HPC began with the headline "...EXCESSIVE RAINS ARE POSSIBLE OVER THE CENTRAL TEXAS HILL COUNTRY LATER THIS AFTERNOON INTO TONIGHT...."

The 3:30 a.m. Central Daylight Time (CDT),⁽¹⁾ Saturday, October 17, State Forecast Discussion (SFD) issued by NWSFO Austin/San Antonio focused on "MODERATE TO STRONG CONVERGENCE ALONG THE FRONT..." due in the area Saturday night, October 17, or early Sunday, October 18, as being the likely focus for heavy rains. The office did issue a flash flood watch (FFA) early Saturday morning for south-central and southeast Texas through the entire weekend since conditions were conducive for the development of heavy rain.

Between midnight and 4 a.m. Saturday morning, October 17, scattered showers and thunderstorms formed over south Texas well ahead of the front. There was little organization to the convection until around 5 a.m. At that time, the convection became concentrated over northern Bexar County (San Antonio) and developed explosively. The intense convection rapidly spread to the northeast and reached the Travis County (Austin) area within 2 hours while the southwest portion of the complex remained anchored over northern San Antonio. The reason for this intense development 12 hours before the front reached the area is not evident at this time. Research efforts to determine the cause of this explosive development are beyond the scope of this Service Assessment. Both upper air and surface data sources are scarce west and south of San Antonio. If forecasters had access to additional data early Saturday morning, October 17, they would have had a better chance of identifying the mesoscale forcing features contributing to the early organization of the intense convection.

The front arrived Saturday night, October 17, and supported continued intense convection to the east and south of the initial heavy rain location. As the leading edge of the convection entered the NWSO Houston/Galveston's CWA, several tornadoes were spawned and were followed by torrential rains. By Sunday, October 18, the heaviest rains were confined to the NWSO Corpus Christi's CWA along the coastal bend of Texas where several more inches fell.

As the initial flood wave moved down the rivers Saturday night and Sunday, October 17-18, up to a foot of additional rain fell on the drainages. When the event ended, over 22 inches of rain had fallen over south and southeast Texas, with many areas receiving over 1 foot of rain.

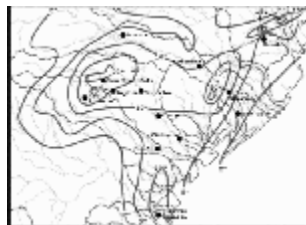


Figure 4. Total rainfall amounts over south Texas for the period October 17-21, 1998.
(Courtesy of the NOAA/NWS LMRFC)

The Flooding

Initially, the event consisted of widespread flash flooding in the urban areas of San Antonio and Austin and along the eastern edge of the hill country in the Interstate Highway 35 corridor between the two cities. Austin and San Antonio are about 80 miles apart. By Saturday night, October 17, the flash flooding had moved to the south and east closer to the coast.

By late Sunday, October 18, the heavy rains had tapered off, and the event then became a major river flood affecting seven river basins, draining approximately 10,000 square miles (figure 5). Based on provisional data from the USGS, between October 17 and 22, record stages were measured at 15 sites (appendix A). These numbers may be revised by the USGS as they complete their field work before publishing the official record stage heights for this flood event.



Figure 5. South Texas river basins that experienced major flooding from October 17-22, 1998. (Courtesy of the NOAA/NWS LMRFC)

Warning and Forecast Performance

Except for the river forecasts along the Guadalupe River south of Seguin, warning and forecast services were good. All field offices, HPC, and SPC were anticipating the potential for heavy rainfall over south Texas for the weekend. NWSO Houston/Galveston recognized that the developing situation had many similarities to the disastrous October 1994 flooding in southeast Texas and issued an effective heavy rain outlook statement Friday afternoon, October 16. NWSO Corpus Christi issued a "South Texas Hazardous Weather Outlook" (HWO) at 6 a.m. Saturday, October 17, highlighting heavy rain expected across south Texas during the day.

Although heavy rainfall was expected, a review of the QPFs issued by HPC and the three field offices for the 24-hour period from Saturday morning to Sunday morning, October 17-18, showed that the rainfall was significantly underestimated by all. The maximum amount forecasted was 4 inches, however, this amount fell within the first few hours of the event Saturday morning, October 17. During the day Saturday, the WGRFC did prepare an updated QPF which attempted to incorporate the early, intense rainfall. However, although the forecasted amounts were higher, the placement of the heaviest QPF rainfall was west of where it actually fell. QPF forecasts for this event from all sources provided little assistance to the WGRFC hydrologists. The magnitude of the rain which fell overwhelmed QPF contributions to the river forecast demands of this event.

The survey team was impressed with the performance of the NWSFO Austin/San Antonio staff early Saturday morning, October 17, when the heavy rains developed. The midnight shift personnel recognized that the extreme rains had begun earlier than expected and issued a series of well written flash flood warnings. Between Saturday morning and Monday afternoon, October

17-19, NWSFO Austin/San Antonio issued a total of 163 flash flood warnings. There were no unwarned flash flood events, and the average lead time for the warnings was 48 minutes.

Although the loss of life was tragic, NWSFO Austin/San Antonio had flash flood warnings in effect more than 4 hours before the first flooding related death was reported. Media and emergency managers in the flash flood region praised the quick work of the NWSFO Austin/San Antonio forecasters and felt the NWS service had been excellent.

NWSO Houston/Galveston issued 60 flash flood warnings, and NWSO Corpus Christi issued 29 flash flood warnings during the event. Neither office had any unwarned flash flood events. The average lead time for the flash flood warnings was 1 hour 44 minutes for NWSO Corpus Christi and 1 hour 13 minutes for NWSO Houston/Galveston.

When the WGRFC recognized Saturday morning that a significant and very dangerous event was underway several hours earlier than had been expected, they went to 24-hour operations and remained on 24-hour operations through Friday evening, October 23. The WGRFC issued over 700 site-specific predictions of river stages reaching or exceeding flood stage during the flooding event. These forecasts were issued to the public by NWSFO Austin/San Antonio and NWSOs Houston/Galveston and Corpus Christi.

In addition to providing forecasts to the NWS offices for public dissemination, the WGRFC was in frequent contact with water resource agencies in Texas, especially the GBRA and the LCRA, to coordinate forecasts and share data. Both the GBRA and the LCRA spoke favorably of WGRFC's enhanced forecast coordination and communications during this event after the WGRFC recognized the magnitude and severity of the flood.

Input received from the NWS offices, river authorities, and emergency management officials indicated the WGRFC forecasts were good for the points along the Colorado, San Bernard, Brazos, San Jacinto, Lavaca, Navidad, and San Antonio Rivers. However, problems arose with the stage forecasts for the Guadalupe River below Seguin. For the Guadalupe River, the river stage forecasts prepared by the WGRFC during the flood were generally too low and the crests occurred sooner than was forecast.

The river crested at 51.7 feet at Gonzales (flood stage 31 feet) at 6 p.m. Sunday night, October 18. The river forecast for Gonzales, issued to the public at 5:05 p.m. Saturday, October 17, from NWSFO Austin/San Antonio and based on WGRFC forecasts, predicted a crest of 45 to 46 feet Monday night, October 19. This was updated at 1:25 p.m. Sunday, October 18, to indicate a crest of 51 to 52 feet late Sunday night.

The river crested at 49.8 feet at Cuero (flood stage 20 feet) at 1 a.m. Tuesday morning, October 20. By mid-morning on Monday, October 19, the river had risen above the previous USGS flood of record of 41.8 feet (September 1, 1981). The USGS believes the highest historical stage previously reached at Cuero was 44.3 feet on July 2, 1936, during a period when no USGS measurement was available. This mark was reached during this flood by early Monday afternoon, October 19.

The 5:05 p.m. Saturday, October 17, forecast for Cuero, issued by NWSFO Austin/San Antonio and based on WGRFC forecasts, predicted a rise to 37 feet by midweek. This was updated at 1:25 p.m. Sunday, October 18, to indicate an expected crest of 40 to 41 feet on Wednesday, October 21. This forecast remained in effect until 11:45 a.m. Monday, October 19, when the forecast was updated to predict a crest of 44 to 45 feet for Monday night.

Although the river was rising rapidly and ahead of schedule early Monday morning, October 19, no forecast updates were issued for Cuero until late Monday morning. The USGS gage at Cuero remained in service during the flood; however, the WGRFC believed the gage was malfunctioning when it indicated the extremely rapid and unprecedented rises. Early in the flood, WGRFC received a manual observation at Cuero 1.5 feet less than the USGS gage report. The USGS had a stream gaging crew on the bridge at Cuero during the flood measuring the flow of the river. This crew had cell phones but did not relay their readings to the WGRFC or any NWS office. This input would have confirmed the gage readings and assisted in adjusting the downstream river forecasts.

As the river rose rapidly at Cuero Monday morning, October 19, local officials and citizens had to quickly accelerate evacuation actions. They had been expecting the crest to occur on Wednesday, October 21.

The Guadalupe crested at Victoria (flood stage 21 feet) at 33.85 feet at 2 p.m. Tuesday afternoon, October 20. At 1:30 a.m. Sunday, October 18, NWSO Corpus Christi issued a flood warning for the Guadalupe from above Victoria to San Antonio Bay. This was issued by NWSO Corpus Christi to give officials and citizens of the lower Guadalupe River as much warning time as possible. This warning clearly stated major flooding was expected. At 11:30 a.m. Sunday, October 18, NWSO Corpus Christi issued a flood warning for Victoria based on forecasts received from the WGRFC. This forecast called for a near record crest of between 30 and 31 feet for Thursday, October 22. This forecast was updated at 12:45 p.m. Monday, October 19, to indicate a crest of 31 feet early Wednesday, October 21. At 9:50 p.m. Monday, October 19, an updated forecast called for the crest to reach 31.3 feet between midnight and 6 a.m. Wednesday, October 21. The 9:25 a.m. Tuesday, October 20, forecast updated the crest to be between 34 and 36 feet and to occur between midnight and 6 a.m. Wednesday, October 21.

The USGS has determined that the intense rainfall produced flows along the Guadalupe far exceeding previously known events. Based on preliminary calculations, the USGS estimates the peak discharge at Cuero was around 400,000 cubic feet per second (cfs). (This estimate could be revised by the USGS after more information and data are reviewed and considered before the final computation is determined.) The previous record flow occurred on September 1, 1981, when 132,000 cfs was measured.

Since USGS gages upstream from Cuero at New Braunfels, Luling, and Gonzales were knocked out of service as the flood waters moved downstream, the WGRFC was not able to determine that the amount of water heading down the Guadalupe was approximately three times the previous known maximum. Had the upstream gages been designed to withstand an extreme flood, stage data would have been available for a longer period of time during this event. This

additional stage data would have provided valuable information to the WGRFC concerning the magnitude of this flood.

The WGRFC used Lag/K routing procedures and USGS rating curves to provide guidance for forecasting the height of the river as the flood moved downstream. The Lag/K routing procedure is an empirical procedure to simulate the movement of a flood crest downstream and is based on historical data. The USGS rating curves correlate streamflow and stage height. The rating curve and the Lag/K routing procedure being used for Cuero were based on the previous measured flow of record of 132,000 cfs. Although the rating curve and the Lag/K procedure for Cuero were extrapolated to higher flows, they did not reflect the extreme nature of this event.

The WGRFC did not update the forecast for Cuero from Sunday afternoon to midday Monday, October 18-19, because, with the limited information available, they considered the Sunday afternoon forecast valid.

The river warning messages, based on WGRFC forecasts and issued to the public by NWSFO Austin/San Antonio and NWSO Corpus Christi, all stressed a major, disastrous flood was heading down the Guadalupe.

Emergency managers in the Guadalupe River Basin and the media in the San Antonio area indicated that in this very serious situation, they needed more frequent and accurate river forecast information.

During the flood, the WGRFC only provided the height and timing of the expected crest. The media and the public required more detailed river stage information, such as the time rivers are expected to reach flood stage or how quickly rivers are expected to rise.

NWS Products

The NWS offices performed an outstanding job issuing well worded warnings and forecasts during this event. The seriousness of the situation was well depicted in the issuances. Following are the best examples of the wording used.

NWSFO Austin/San Antonio

From Flash Flood Warning issued at 8:27 a.m. Saturday, October 17:

"...THIS IS A VERY DANGEROUS SITUATION! RUNOFF WILL BE RAPIDLY FLOODING LOW LYING AREAS, STREETS, STREAMS, CREEKS AND RIVERS. MANY ROADWAYS WILL BE CLOSED DUE TO THE HEAVY RAINFALL AND DRIVING IS NOT RECOMMENDED ACROSS THESE COUNTIES FOR THE NEXT SEVERAL HOURS...."

From Short Term Forecast issued at 9:03 a.m. Saturday, October 17:

"...EXTREMELY DANGEROUS FLOODING IS OCCURRING... NUMEROUS ROADS, STREETS AND HIGHWAYS ARE CLOSED DUE TO VERY HIGH WATER OVER ROADWAYS! TRAVEL IS DISCOURAGED, STAY HOME, DO NOT TRY TO DRIVE UNTIL WEATHER AND TRAVEL CONDITIONS IMPROVE LATER TODAY! ...MORE IS COMING! CONDITIONS IN SAN ANTONIO ARE LIFE-THREATENING!"

From Flash Flood Statement issued at 10:24 a.m. Saturday, October 17:

"...THIS IS A VERY DANGEROUS AND LIFE-THREATENING FLOOD SITUATION...YOU SHOULD NOT ATTEMPT TRAVEL THIS MORNING OR EARLY AFTERNOON...STAY HOME UNLESS FLOOD WATERS THREATEN YOUR LOCATION AND YOU ARE FORCED TO EVACUATE TO HIGHER GROUND...."

NWSO Corpus Christi

From River Flood Statement issued at 12:45 a.m. Monday, October 19:

"TORRENTIAL RAINFALL ACROSS SAN ANTONIO RIVER BASIN WILL RESULT IN MAJOR FLOODING FROM ABOVE GOLIAD TO THE GUADALUPE RIVER CONFLUENCE. DISASTROUS AND RECORD-SETTING FLOODING IS OCCURRING UPSTREAM...ALL RESIDENTS FROM ABOVE GOLIAD TO SAN ANTONIO BAY SHOULD TAKE IMMEDIATE ACTION TO PROTECT LIFE AND PROPERTY. LISTEN TO LOCAL EMERGENCY PERSONNEL AND FOLLOW THEIR RECOMMENDATIONS."

From River Flood Warning issued at 9:25 a.m. Tuesday, October 20:

"... *DISASTROUS AND LIFE-THREATENING FLOODING IS OCCURRING IN VICTORIA***"**

*****LARGE NUMBER OF CITY BLOCKS IN VICTORIA WILL BE UNDER WATER AS THE GUADALUPE RIVER CONTINUES TO RISE***"**

PERSONS...ALONG THESE AREAS [lower Guadalupe River and surrounding creeks and streams] SHOULD TAKE ALL PRECAUTIONS TO PROTECT LIFE AND PROPERTY...."

NWSO Houston/Galveston

From River Flood Statement issued at 10:40 a.m. Tuesday, October 20:

"...THIS IS A DANGEROUS...LIFE THREATENING SITUATION AND EVERY PRECAUTION SHOULD BE TAKEN TO AVOID LOSS OF LIFE AND PROPERTY. MASSIVE FLOODING IS EXPECTED IN THE CITY OF WHARTON. ...MOTORISTS SHOULD AVOID WATER COVERED ROADS AND FIND ALTERNATE ROUTES...."

Response from Emergency Management and Media Customers

Except for those customers along the Guadalupe River south of Seguin who had to respond to a record high flood crest earlier than expected, response was generally positive. Those in the areas first hit felt that the NWSFO Austin/San Antonio responded quickly and effectively to the unfolding event. The Bexar County Emergency Manager said no deaths were attributed to a lack of warning and evacuation recommendations contained in the warnings were very effective. The problems experienced by those on the Guadalupe River responding to this massive flood were due to river forecast or external infrastructure (e.g., telephone service) problems resulting from the unprecedented magnitude of this flood.

Public Response

Most of the loss of life occurred when vehicles either were driven into high water or were swept away by rapidly rising waters. Strong outreach efforts have been undertaken by NWSFO Austin/San Antonio over the span of many years to educate the public about the life-threatening dangers of driving into or playing in high waters. These efforts have been closely coordinated with the media and emergency managers. The city of San Antonio fines people who drive around street barriers and motorists who must be rescued from high waters.

Infrastructure Events at NWSFO Austin/San Antonio

The NWSFO Austin/San Antonio facility was in the midst of the extreme flooding and for a period of time was completely isolated by flood waters rapidly flowing across the fields surrounding the building. Water levels came within a foot of entering the building. All telephone and data link communications were lost from 8:55 p.m. Saturday, October 17, to

1:21 a.m. Sunday, October 18, due to the flooding. NWSFO Austin/San Antonio personnel exercised great ingenuity by using amateur radio operators (HAMs) and cell phones to inform surrounding offices that backup was needed. All backup offices responded, and all NWSFO Austin/San Antonio products were issued as required. The communications outage was transparent to customers.

Unrelated to the flooding, the NOAA Weather Wire Service (NWWS) suffered a nationwide outage between 7:50 a.m. and 8:45 a.m. Saturday morning, October 17. Eight flash flood warnings were issued during the outage and were not transmitted over the NWWS.

Facts, Findings, and Recommendations

Observations

FACT: Based on provisional data from the USGS gathered during the flooding, 15 locations within the Guadalupe, San Antonio, San Jacinto, Colorado, and Lavaca River basins recorded flood peaks which represented the highest known peak stages. These numbers may be revised by the USGS as they conduct additional field studies.

Finding 1: There were unusually rapid rises, primarily below Seguin, on the Guadalupe River during the event. Questions arose at the WGRFC concerning whether the river gage readings on the Guadalupe River at Cuero were accurate during the rapid rise. The WGRFC had received a manual reading at Cuero 1.5 feet lower than the USGS gage reported early in the flood. The USGS had personnel taking flow measurements on the Guadalupe River at Cuero during the flood. These crews had cell phones but did not relay their readings to any NWS office. These measurements would have provided valuable information regarding the accuracy of the gage readings.

Recommendation 1a: The WGRFC and NWSFO Austin/San Antonio should meet with the USGS in Austin to develop better coordination methods.

Recommendation 1b: At the national level, the USGS and the NWS should agree on procedures to improve real-time data coordination.

Finding 2: Early in the flood event, NWSFO Austin/San Antonio was unable to access by telephone the USGS data collection platforms (DCP) on the Guadalupe River at New Braunfels and the Blanco River at Wimberly. NWSFO Austin/San Antonio uses these DCPs to receive real-time river stage height information.

Recommendation 2: NWSFO Austin/San Antonio needs to ascertain why needed data was not available and take steps to ensure the data is accessible during flood events.

RFC Models and Guidance

FACT: During the flood event, WGRFC was open 24 hours a day from 6 a.m. Saturday, October 17, through 10 p.m. Friday, October 23. During this period, WGRFC issued over 120 forecast products, including over 700 site-specific predictions of river stages reaching or exceeding flood stage.

FACT: QPF forecasts issued by HPC and the three field offices significantly underestimated the rainfall for the 24-hour period from Saturday morning to Sunday morning, October 17-18. The WGRFC prepared an updated QPF forecast to incorporate the early, intense rain of Saturday morning. Although the forecasted amounts were higher, the placement of the heaviest QPF rainfall was west of where it actually fell. The QPF for this event from all sources provided little assistance to the WGRFC hydrologists. The magnitude of the rainfall overwhelmed QPF contributions to the river forecast demands of this event.

FACT: The river stage forecasts on the Guadalupe River below Seguin were generally too low and the crests occurred sooner than were forecast.

FACT: The USGS has preliminarily determined that the peak discharge at Cuero during this event was around 400,000 cfs. (This estimate could be revised by the USGS after more information and data are reviewed.) The previous measured flow of record was 132,000 cfs.

Finding 3: The Guadalupe River below Seguin crested earlier and higher than WGRFC models predicted.

Recommendation 3a: Using discharge data from this flood obtained from the USGS, the WGRFC should update the LAG/K routing procedures and rating curves used on the Guadalupe River.

Recommendation 3b: WGRFC should determine whether a hydraulic routing technique is appropriate for use on the Guadalupe River and other similar rivers in the WGRFC area.

Finding 4: Emergency managers in the Guadalupe River Basin and the media in the San Antonio area require more frequent updates of river forecasts and flood warnings.

Recommendation 4a: The WGRFC should update forecasts and issue river forecast products at least every 12 hours, or more frequently as needed, for all locations where a river is rising and is forecasted to be above flood stage. This update cycle should continue until the river has crested.

Recommendation 4b: NWS should consider requiring more frequent updates of River Forecast Center's products during floods as a national policy.

Finding 5: WGRFC issues plain language forecasts which contain the crest stage (e.g., 34 feet) or a crest stage range (e.g., 34-35 feet) and the date and time the crest is expected. There is no information about when the river will reach flood stage or how quickly the river is expected to rise. The media and the public need additional information, such as when a river is expected to go above flood stage, prior to the crest.

Recommendation 5: WGRFC should issue all river forecasts in time series format in Standard Hydrometeorological Exchange Format (SHEF) for use in formatting NWSFO/NWSO products to inform the public of the timing of river rises.

Local Offices Warnings/Forecasts

FACT: NWSFO Austin/San Antonio issued 163 flash flood warnings, NWSO Houston/Galveston issued 60 flash flood warnings, and NWSO Corpus Christi issued 29 flash flood warnings during the event.

FACT: Eleven deaths occurred in the city of San Antonio. All deaths were the result of attempts to drive through flooded streets and roads. NWSFO Austin/San Antonio had flash flood warnings in effect over 4 hours before the first flooding related death was reported. NWS Austin/San Antonio issued 57 flood and flash flood watches, warnings and statements concerning Bexar County (San Antonio) from Saturday morning through Sunday noon, October 17-18. The San Antonio media and emergency managers complimented the NWS support in this event.

FACT: NWSO Houston/Galveston issued a "Heavy Rain Outlook" at 3:11 p.m. Friday, October 16, and at 4:30 a.m. Saturday, October 17, highlighting the potential of heavy rains over

southeast Texas over the weekend. NWSO Corpus Christi issued a "South Texas Hazardous Weather Outlook" at 6 a.m. Saturday, October 17, highlighting heavy rain expected across south Texas during the day.

Finding 6: Highlighting the potential for heavy rains by the issuance of an outlook by NWSFOs/NWSOs several hours before a flash flood watch is issued is an effective method to increase awareness of a potentially serious flood situation. Presently, the issuance of heavy rain outlooks is optional.

Recommendation 6: Regions should review their policies regarding heavy rain outlooks and consider requiring their issuance when conditions warrant.

FACT: NWSFO Austin/San Antonio routinely issues a "Hazardous Weather Outlook" twice daily to highlight any expected hazardous weather (including heavy rain) during the following 24 hours. Each outlook contains prepackaged information concerning scheduling of the product and sources for receiving this and other outlooks.

FACT: SRH instructions (SRH ROML [Regional Operations Manual Letter] S-11-97, May 27, 1997) indicate the HWO should include a statement referring customers to adjacent office's products for more detailed information for nearby areas. Examples in the ROML imply the referencing information should only be one or two lines in length.

Finding 7: The amount of the prepackaged information contained in each NWSFO Austin/San Antonio HWO detracts from the message of the day information contained within the product. The routine issuance of the HWO reduces the impact of the message when significant events are expected.

Recommendation 7: After consultations with customers, NWSFO Austin/San Antonio should consider issuing their HWO only when significant events, such as heavy rains, are expected. In addition, the amount of prepackaged information should be reduced.

FACT: The use of strongly worded statements was noted by the media and emergency managers as an effective way to communicate the severity of the flooding. The following statements were repeatedly used by the media in warning the public.

-- "Major life-threatening flood."

-- "This is an extremely dangerous situation."

-- "Most flood fatalities occur by driving into low water crossings. Do not drive into low water crossings."

-- "Evacuate the _____ area."

Systems

FACT: The Advanced Weather Interactive Processing System (AWIPS) was used very successfully by NWSO Houston/Galveston. The river basin responsibilities were split between two people working at two different AWIPS workstations. With the "Hydroview" capability, they were able to quickly and efficiently assess the situation at hand, monitor the progress of the flood, quality control the forecasts, and provide timely customer services. With AWIPS, the MIC estimated they were able to issue the river forecasts from 1 to 2 hours ahead of the issuance times noted during previous floods of this magnitude.

Communications

FACT: HAM radio operators played a key role in passing NWS messages and warnings during this event. Approximately 80 HAMs maintained a week-long 24-hour network of communications which involved NWS, Red Cross, Salvation Army, and numerous emergency management staffs. In at least one instance, an experienced operator noted the emergency management staff in a nearby community had not become aware of the need for immediate evacuation along a rapidly rising creek and took it upon himself to warn the staff. His quick reaction and the staff's immediate start of evacuation saved lives.

FACT: At 8:55 p.m. Saturday, October 17, NWSFO Austin/San Antonio lost all telephone communications due to the flooding in the vicinity of the office. The staff used cell phones and HAM radio communications to request the surrounding NWS offices assume backup responsibilities for NWSFO Austin/San Antonio products. All offices performed the extra duties in an excellent manner. During the outage, NWSFO Austin/San Antonio relayed warning information to the backup offices via HAM radio links. Communications were restored at 1:21 a.m. Sunday, October 18.

FACT: Outside users who were aware of the communications outages praised all NWS offices involved with the backup. They indicated the backup was transparent to them, worked very effectively, and resulted in no diminished service.

Internal and External Coordination

FACT: Internal coordination during the event was conducted effectively based on interviews with the WGRFC, NWSFO Austin/San Antonio, and NWSOs Houston/Galveston and Corpus Christi.

FACT: The WGRFC provided an increased level of forecast coordination and data exchange with the river authorities, especially the LCRA and the GBRA, during the flood event. The GBRA and the LCRA spoke favorably of WGRFC's enhanced forecast coordination and communications with them after the WGRFC recognized the magnitude and severity of this event.

FACT: Flooding is by far the leading cause of weather-related deaths in the Bexar County and the Greater San Antonio area. An early 1980's study conducted by NWSFO San Antonio

reviewed approximately 30 years of weather-related deaths across all of south Texas. The study determined that approximately 80 percent of the drownings involved vehicles trying to cross flooded low areas. Most other drowning victims were children and young adults being swept away by flood waters while walking along or playing in flooded creeks and streams. These dangers are emphasized strongly in all outreach programs and during warnings and watches.

FACT: The city of San Antonio fines \$200 to any driver traveling around a street barrier. In addition, everyone in a vehicle who must be rescued is fined \$400. Still, this has not eliminated the problem of flood deaths. The city is looking for additional methods, including the use of more effective barriers, to prevent people from driving into flood waters.

FACT: NWSFO Austin/San Antonio ensures that flood education is the major thrust of all of its outreach efforts, both in the Bexar County/San Antonio area and across the CWA. All education and training programs, including spotter training, public safety and school informational talks, include a discussion of the flood threat. Flooding is identified as the major cause of weather-related deaths and is depicted with very graphic slides and video films. Safety rules are strongly emphasized. Surveys are undertaken by the office after each significant flood event to document the threat and provide additional audiovisual material for subsequent training programs. Spotter training and public education programs had been conducted in each of the flood-affected counties during 1998 prior to this flood.

FACT: Emergency managers interviewed were complimentary of NWSFO Austin/San Antonio's outreach/education efforts in the area, including the spotter training, community outreach programs through clubs organizations, school safety programs, and tours of the NWS office. Interviews the office conducts with the media were also noted as important education efforts.

FACT:

Many Victoria and Calhoun County officials working the flood event were well versed in NWS flood operations as a result of a very effective NWSO Corpus Christi-sponsored flood conference held for those officials earlier in 1998.

Finding 8: The WGRFC has worked with the LCRA and the GBRA to evaluate the need for additional river forecast locations, and selected sites are scheduled to be added to the WGRFC forecast system. Additional forecast locations may still be required to complement those planned.

Recommendation 8: The WGRFC and service hydrologists from NWSFO Austin/San Antonio and NWSO Houston/Galveston and the hydrologic focal point from NWSO Corpus Christi should meet with river authorities to discuss additional river forecast locations.

FACT: The headwaters of the Lavaca and Navidad Rivers are in Lavaca and Fayette Counties in the NWSFO Austin/San Antonio CWA. The rivers then flow into Jackson County in the NWSO Houston/ Galveston CWA. The San Antonio Hydrologic Service Area (HSA) includes all forecast locations on the Lavaca and Navidad Rivers, including the locations in Jackson County.

Finding 9: Jackson County receives river warning and forecast information from NWSFO Austin/San Antonio. All other hazardous weather information is provided by NWSO Houston/Galveston. The Jackson County Emergency Manager would like to receive all hazardous weather information, including river warning and forecast information, from NWSO Houston/Galveston.

Recommendation 9: SRH should coordinate with customers in Jackson County to see if Jackson County would be better served by transferring HSA responsibility from NWSFO Austin/San Antonio to NWSO Houston/Galveston.

FACT: NWSFO Austin/San Antonio has been a strong advocate of HAM radio operators' usage by emergency managers. The office has conducted an aggressive program to encourage HAM radio expansion through south-central Texas, increasing activity from two networks covering three counties in 1994 to seven networks covering 26 counties in 1998.

FACT: Interviews with emergency management officials in Bexar County and San Antonio revealed they received warnings and forecasts. However, there were cases where telephone lines were overloaded making it difficult for emergency managers to contact NWSFO Austin/San Antonio.

Finding 10: Emergency managers in the NWSFO Austin/San Antonio CWA could not call into the office at times during the flood because phone lines were either busy or out of service due to flood waters surrounding the office.

Recommendation 10: NWSFO Austin/San Antonio should continue its efforts to expand HAM radio communications by contacting each emergency manager in their CWA to re-emphasize the value of using HAMS for communications with the NWS during major, disruptive events.

FACT: After the telephone circuits in Victoria became saturated, NWSO Corpus Christi was able to maintain critical communications with the Emergency Operations Center in Victoria with the help of HAM radio operators.

FACT: Extensive local and national media interviews were conducted by the local NWS offices and the regional public affairs officer. A news release on the record flooding was released to the Texas Associated Press and local media in San Antonio. An "Opinion-Editorial" (OPED) letter from the Southern Region Director was released to San Antonio, New Braunfels, Austin, Corpus Christi, and Fort Worth newspapers.

FACT: A KOA campground located along the Salada Creek approximately 4 miles east of downtown San Antonio was evacuated as a direct result of a personal call from the service hydrologist at NWSFO Austin/San Antonio.

Finding 11: Several people interviewed in the NWSFO Austin/San Antonio CWA were not aware of the NOAA Weather Radio (NWR) Specific Area Message Encoder (SAME) technology.

Recommendation 11: NWSFO Austin/San Antonio should add information explaining SAME technology on the current locally produced NWR brochure.

Dissemination

Finding 12: At 7:50 a.m. Saturday, October 17, the NWWS suffered a nationwide outage and was out until 8:45 a.m. Eight flash flood warnings issued during this period by NWSFO Austin/San Antonio were not disseminated over the NWWS.

Recommendation 12: NWS Headquarters should determine the reason for the 55-minute outage on October 17 and whether the eight flash flood warnings were re-transmitted when NWWS service was restored.

FACT: City and county officials, as well as members of the emergency management and emergency response community in the San Antonio area, complained about the NOAA Weather Radio 2000 synthesized voice. They could not clearly understand what was being said.

Finding 13: Several individuals interviewed expressed concern regarding the NOAA Weather Radio 2000 artificial voice. It is viewed as difficult to understand.

Recommendation 13: NWS should determine what steps are necessary to replace the current artificial voice with a voice more natural sounding and easier to understand.

FACT: The NWR alarm awakened the emergency managers for both Bexar County and San Antonio early Saturday morning, October 17.

Response

FACT: The mayor of New Braunfels, on behalf of the city council, sent a letter of appreciation to the staff of NWSFO Austin/San Antonio. Included in the letter were "*...thank you sincerely for your invaluable assistance in response to the worst flood in our community's history*" and "*...convey our deep appreciation to all the staff there who gave so generously of themselves during this catastrophic event. The expertise of the National Weather Service helped tremendously. Thank you sincerely.*"

FACT: The Bexar County Emergency Manager said the evacuation recommendations in the flood warnings were very effective.

FACT: According to the Bexar County Emergency Manager, no deaths were attributed to a lack of warning.

1. All other times listed in this Service Assessment are CDT.

Appendix A

Locations where October 1998 Flood Peak Represented Highest Known Peak Stage¹

Peak Stages for the October 1998 Flood Event Included¹⁽¹⁾

Location	Peak Stage (ft)	Significance of Flooding
SAN JACINTO RIVER BASIN		
Cypress Creek at Katy-Hockley Road near Hockley, TX	63.51	Highest peak stage since before 1960 and 0.02 feet higher than 2nd highest peak stage in 1994. Second highest peak discharge since station was installed in 1975.
COLORADO RIVER BASIN		
Onion Creek near Driftwood, TX	24.91	Highest peak stage and peak discharge since station was installed in 1980 and about 7.4 feet higher than 2nd highest peak stage on June 9, 1997. Flood on May 28, 1929, probably many feet higher.
LAVACA RIVER BASIN		
Sandy Creek at Louise, TX	32.70	Highest peak stage and peak discharge since station was installed in 1978 and about 4.2 feet higher than 2nd highest peak stage on Oct. 19, 1994.
GUADALUPE RIVER BASIN		
Guadalupe River at New Braunfels, TX	35.08	Highest peak stage and peak discharge for period of record (1915-1927 and 1974-present). About 10.2 feet higher than 2nd highest peak stage on Sept. 10, 1921.
Plum Creek at Lockhart, TX	23.09	Highest peak stage and probably highest peak discharge since before 1905 and about 1.1 feet higher than 2nd highest peak stage in June 1936.
Guadalupe River at Gonzales, TX	50.44	Highest peak stage and peak discharge since station was installed in 1978 and about 11.6 feet higher than 2nd highest peak stage on June 24, 1997.
Guadalupe River at Cuero, TX	49.8	Highest peak stage and peak discharge since before 1900 and about 5.7 feet higher than 2nd highest peak stage on July 2, 1936.
Guadalupe River at Victoria, TX	33	Highest peak stage and peak discharge since before 1833 and about 1.8 feet higher than 2nd highest peak stage on July 3, 1936.
SAN ANTONIO RIVER BASIN		
San Antonio River at Mitchell Street at San Antonio, TX	12.43	Highest peak stage and peak discharge since station was installed in 1993 and about 4.5 feet higher than 2nd highest peak stage on Oct. 8, 1994. Probably highest peak since 1921.
San Antonio River at	36.15	Highest peak stage and peak discharge since station was

Loop 410 at San Antonio, TX		installed in 1990 and about 4 feet higher than 2nd highest peak stage on July 15, 1990. Probably highest peak since 1921.
Salado Creek (Lower Station) at San Antonio, TX	23.00	Highest peak stage and peak discharge since before 1941 and 3.2 feet higher than 2nd highest peak stage on Sept. 27, 1973.
Leon Creek at IH 35 at San Antonio, TX	28.52	Highest peak stage and peak discharge since station was installed in 1984 and 4 feet higher than 2nd highest peak stage on June 22, 1997.
San Antonio River near Elmendorf, TX	64.2	Highest peak stage and peak discharge since before 1900 and 3.2 feet higher than 2nd highest peak stage in 1946.
Cibolo Creek at Selma, TX	35.4	Highest peak stage and peak discharge since before 1869 and 5.7 feet higher than 2nd highest peak stage on June 22, 1997.
Cibolo Creek near Falls City, TX	40	Highest peak stage and peak discharge since before 1890 and 4.6 feet higher than 2nd highest peak stage on Sept. 28, 1973.

1. http://tx.usgs.gov/alert/oct_floods_98.html on January 7, 1999. Data are subject to revision.