



## *Service Assessment*

# **Tropical Storm Allison Heavy Rains and Floods Texas and Louisiana June 2001**



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

**Cover:** The photograph shows severe flooding in downtown Houston, Buffalo Bayou, Texas, on June 9, 2001. (Courtesy of Harris County Flood Control District/Steve Fitzgerald)



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**September 2001**

**U.S. DEPARTMENT OF COMMERCE  
Donald L. Evans, Secretary**

**National Oceanic and Atmospheric Administration  
Scott B. Gudes, Acting Administrator**

National Weather Service  
John J. Kelly, Jr., Assistant Administrator

# **Preface**

Tropical Storm Allison was the most costly tropical storm in U.S. history. While the storm impacted a large part of the country, worst hit was southeast Texas and southern Louisiana. In these two areas alone, there were 24 fatalities and more than \$5 billion in damage.

Due to the magnitude of this flooding event, a service assessment team was dispatched to examine the warning and forecast services provided by the National Weather Service (NWS) to emergency managers, flood control/public works agencies, and the public in southeast Texas and southern Louisiana. Service assessments provide a valuable contribution to our ongoing efforts to improve the quality and timeliness of our products and services for the protection of life and property. Findings and recommendations from this assessment will help to improve techniques, products, and services.

**John J. Kelly, Jr.**  
**Assistant Administrator**  
**for Weather Services**

**September 2001**

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# Service Assessment Team

This service assessment team was activated on June 15, 2001. The Weather Forecast Office (WFO) Houston/Galveston, Texas, briefed the team on June 18. Team members visited Southern Region Headquarters (SRH), River Forecast Centers (RFCs), WFOs, Hydro-meteorological Prediction Center (HPC), and various emergency management, flood control, and broadcast media outlets. In addition, telephone interviews were conducted with a number of internal and external organizations. The team comprised the following individuals.

- Larry Mooney**      *Team Leader*, Meteorologist in Charge (MIC), WFO Denver/Boulder, Colorado
- Julie Adolphson**      Science and Operations Officer, WFO Northern Indiana, Syracuse, Indiana
- John Feldt**      Hydrologist in Charge (HIC), Southeast River Forecast Center, Peachtree City, Georgia
- Peter Gabrielsen**      Deputy Chief, Hydrologic Services Division, NWS Eastern Region Headquarters, Bohemia, New York
- Ken Graham**      Meteorologist in Charge, WFO Corpus Christi, Texas
- Jeff Orrock**      Warning Coordination Meteorologist, WFO Newport/Morehead City, North Carolina
- Kevin Stewart**      Professional Engineer (Chair, National Hydrologic Warning Council), Urban Drainage and Flood Control District, Denver, Colorado
- Ron Trumbla**      National Oceanic and Atmospheric Administration (NOAA) Public Affairs Specialist, NWS SRH, Fort Worth, Texas

Other valuable contributors include:

- William Lerner**      NWS Headquarters, Office of Climate, Water, and Weather Services, Silver Spring, Maryland
- Linda Kremkau**      NWS Headquarters, Office of Climate, Water, and Weather Services, Silver Spring, Maryland

The team would like to thank the individuals from the following organizations who took time to talk with team members.

**NWS Offices**

WFO Houston/Galveston, TX  
WFO Lake Charles, LA  
WFO New Orleans/Baton Rouge, LA  
Center Weather Service Unit, Houston, TX  
Spaceflight Meteorology Group, Houston, TX  
Lower Mississippi River Forecast Center (LMRFC), Slidell, LA  
West Gulf River Forecast Center (WGRFC), Fort Worth, TX  
NWS Southern Region Headquarters (SRH), Fort Worth, TX  
Hydrometeorological Prediction Center (HPC), Camp Springs, MD  
Tropical Prediction Center (TPC), Miami, FL

**State Emergency Managers**

Texas Division of Emergency Management (TDEM)  
Louisiana Office of Emergency Preparedness

**County/Parish Emergency Managers**

Galveston County, TX	Harris County, TX
Houston County, TX	Jefferson, County, TX
Montgomery County, TX	Polk County, TX
East Baton Rouge Parish, LA	

**City Emergency Managers**

Friendswood, TX	Houston, TX
Pasadena, TX	City of Baton Rouge, LA

**Other Officials**

Harris County Flood Control District  
Jefferson County Drainage District No. 6  
Louisiana State University, Southern Regional Climate Center  
Louisiana Office of State Climatology

**Media**

KHOU-TV, Houston, TX	KTRK-TV, Houston, TX
KPRC-TV, Houston, TX	KXLN-TV, Houston, TX
KRIV-TV, Houston, TX	WBRZ-TV, Baton Rouge, LA
KTRH-Radio, Houston, TX	

# Acronyms

AFD	Area Forecast Discussion
ALERT	Automated Local Evaluation in Real-Time
AWIPS	Advanced Weather Interactive Processing System
CWA	County Warning Area
DEM	Division of Emergency Management
EAS	Emergency Alert System
EMWIN	Emergency Managers Weather Information Network
HCM	Hydrometeorological Coordination Message
HIC	Hydrologist in Charge
HMD	Hydrometeorological Discussion
HPC	Hydrometeorological Prediction Center
LMRFC	Lower Mississippi River Forecast Center
MANS	Media Alert Notification System
MAP	Mean Areal Precipitation
MIC	Meteorologist in Charge
MSL	Mean Sea Level
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
OEM	Office of Emergency Management
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
ROC	Regional Operations Center
SRH	Southern Region Headquarters
TDEM	Texas Division of Emergency Management
TPC	Tropical Prediction Center
WFO	Weather Forecast Office
WGRFC	West Gulf River Forecast Center
WSR-88D	Weather Surveillance Radar-1988 Doppler





Neighborhood flooding near Interstate 10, Houston, Texas. (Courtesy of Harris County Flood Control District/Steve Fitzgerald)



Cars and trucks stranded on Interstate 10, west of downtown Houston, Texas. (Courtesy of Paige Morrison)

# **Service Assessment Report**

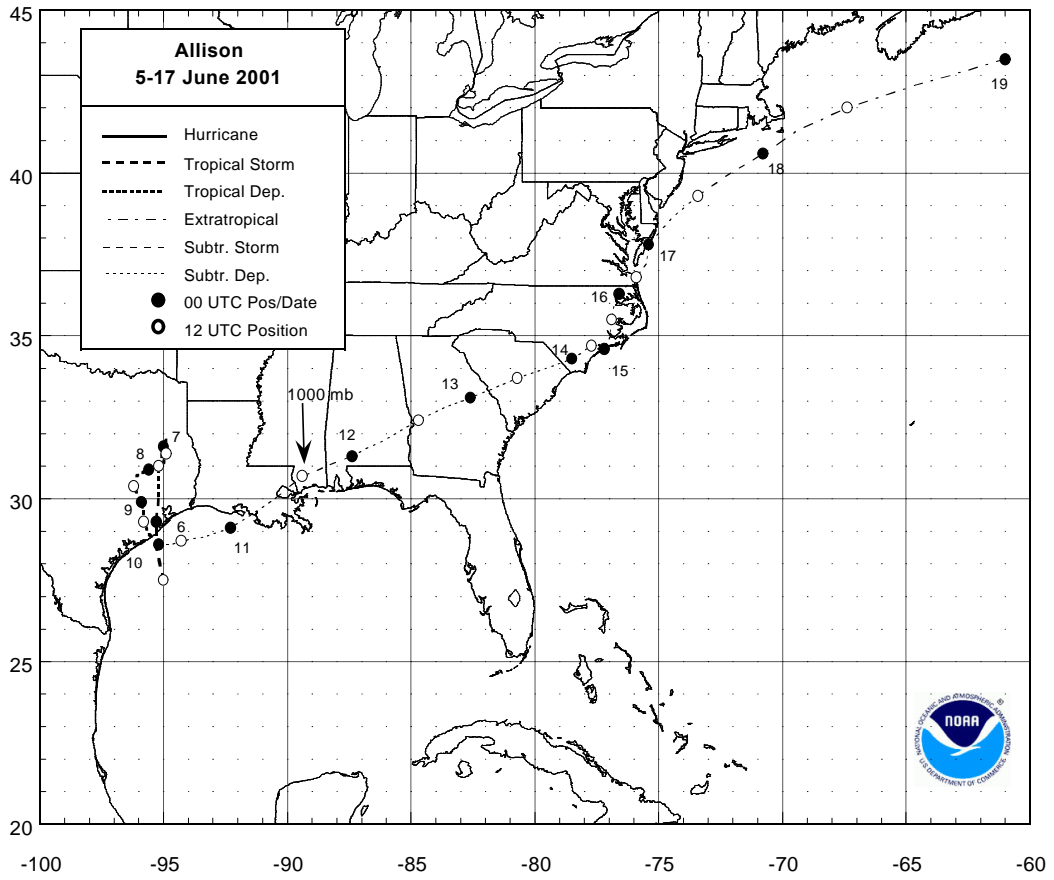
## **Introduction**

Tropical Storm Allison produced severe storms, torrential rainfall, and associated flooding across the southern and eastern sections of the United States from June 5 to June 18, 2001. After making landfall near Galveston, Texas, on June 5, the storm moved inland to near Lufkin, Texas. Allison drifted back into the Gulf of Mexico on June 9, turned to the northeast, and made landfall again on June 10 near Morgan City, Louisiana. After causing 24 deaths in Texas and Louisiana, Allison moved across southern Mississippi, southern Alabama, southwest Georgia, and northern Florida, causing 9 more deaths. By mid-week, Allison stalled over North Carolina and produced more heavy rainfall and flooding before tracking northeast along the DelMarVa Peninsula and moving off the New England coast on June 18. Seven additional deaths occurred in Pennsylvania and one in Virginia. Figure 1 shows the path of Tropical Storm Allison, and Figure 2 shows the associated rainfall.

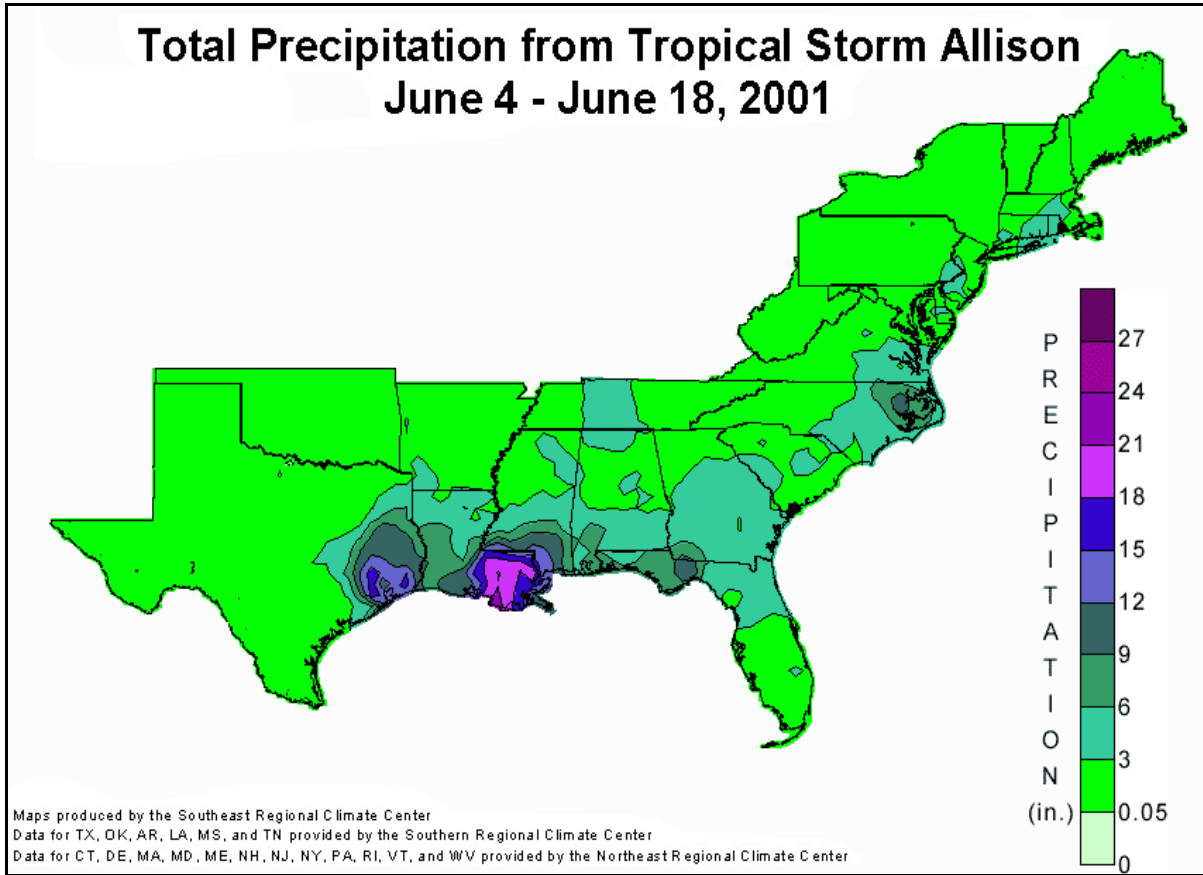
Tropical Storm Allison caused more damage than any tropical storm in U.S. history, with estimates in excess of \$5 billion. Most of the damage and fatalities (22) occurred in Houston, Texas. Storm rainfall totals peaked at 36.99 inches (Port of Houston) in Texas and 29.86 inches (Thibodaux) in Louisiana. Since this was the area of extreme rainfall and greatest impact in terms of damage and fatalities, the report focuses on NWS performance in southeast Texas and southern Louisiana.

## **Overview**

Tropical Storm Allison began as a disorganized area of thunderstorms in the southwest Gulf of Mexico. On June 5, the NWS's Tropical Prediction Center (TPC) declared the system a tropical storm. Of particular interest is that Allison made landfall twice. The storm first struck Galveston Island, Texas, on June 5, drifted back over the Gulf of Mexico, and the remnants of Allison made landfall again over southern Louisiana on June 10. During this period, torrential rainfall caused tremendous flooding along the Texas and Louisiana Gulf coasts. Rainfall storm totals from Allison are listed in Appendix A.



**Figure 1.** Track of Tropical Storm Allison, June 5-17, 2001. (NOAA/NCEP/TPC)



**Figure 2.** Tropical Storm Allison rainfall totals. (Courtesy of the Southeast Regional Climate Center)

## Texas

A high pressure system east of the Florida peninsula acted to steer the cyclone northward, prompting the evacuation of the west end of Galveston Island, an area not protected by the seawall which was constructed after the Galveston hurricane of 1900. Allison made its initial landfall on Galveston Island during the evening of June 5. Allison drifted north to Lufkin, about 120 miles north of Houston. During this time, the Houston area received 4 to 6 inches of rain with isolated totals of 8 to 10 inches.

During the night of June 5-6, heavy rains deluged northwest Jefferson and Orange Counties near the Louisiana border. Six to 10 inches of rain fell in less than 5 hours, flooding homes, closing streets, and stalling hundreds of cars in China, Beaumont, Nome, and Vidor. The remnants of Tropical Storm Allison's circulation center remained well defined between two high pressure areas, allowing the center to drift south and west to near Huntsville (about 60 miles north of Houston) during the day on June 7. Additional heavy rain, 8 to 12 inches, occurred over the Sugarland-Stafford area of Fort Bend and Harris Counties, west and southwest of Houston, flooding streets and homes. Without a strong steering current, Allison drifted farther southwest toward the Gulf of Mexico, and continued to draw in additional moisture. During the early morning hours of June 8, a band of heavy rain moved over Beaumont. Although up to 10 inches of rain fell, it was in areas previously spared, resulting in only minor flooding. The center of circulation was now between College Station and Huntsville drifting slowly southwest.

The combination of daytime heating and copious moisture set the stage for heavy and persistent rain over the Houston area on the night of June 8-9. Thunderstorms formed over the western side of the Houston area and rapidly intensified as they moved east. Flash flooding began rapidly during the afternoon rush hour and became widespread by dark. Between June 8-9, five of the six major bayou systems experienced severe flooding, some to record levels. All major interstates were closed due to flooding. Two-thirds of Harris County (Houston) received over 10 inches of rain. Amounts ranged from 2 inches in the extreme west to more than 20 inches in northeast Houston. Greens Bayou received more than 26 inches of rain in about 10 hours. Figure 3 is a map of the rainfall totals during the heaviest period of rain.

During this portion of the event, 22 people were killed and more than 45,000 homes and businesses flooded. More than 70,000 vehicles were flooded. Ten of the fatalities occurred either in a vehicle or while fleeing a vehicle. Six deaths resulted while walking in flood waters, and three from electrocution. The 45-building Texas Medical Center complex suffered damages of \$2 billion and included the loss of decades of medical research records and experiments. Large-scale patient evacuations occurred and medical services were disrupted for several days due to power outages. The underground portions of downtown Houston were flooded. In addition to the 22 deaths in Houston, a man was killed while swimming in a drainage ditch at

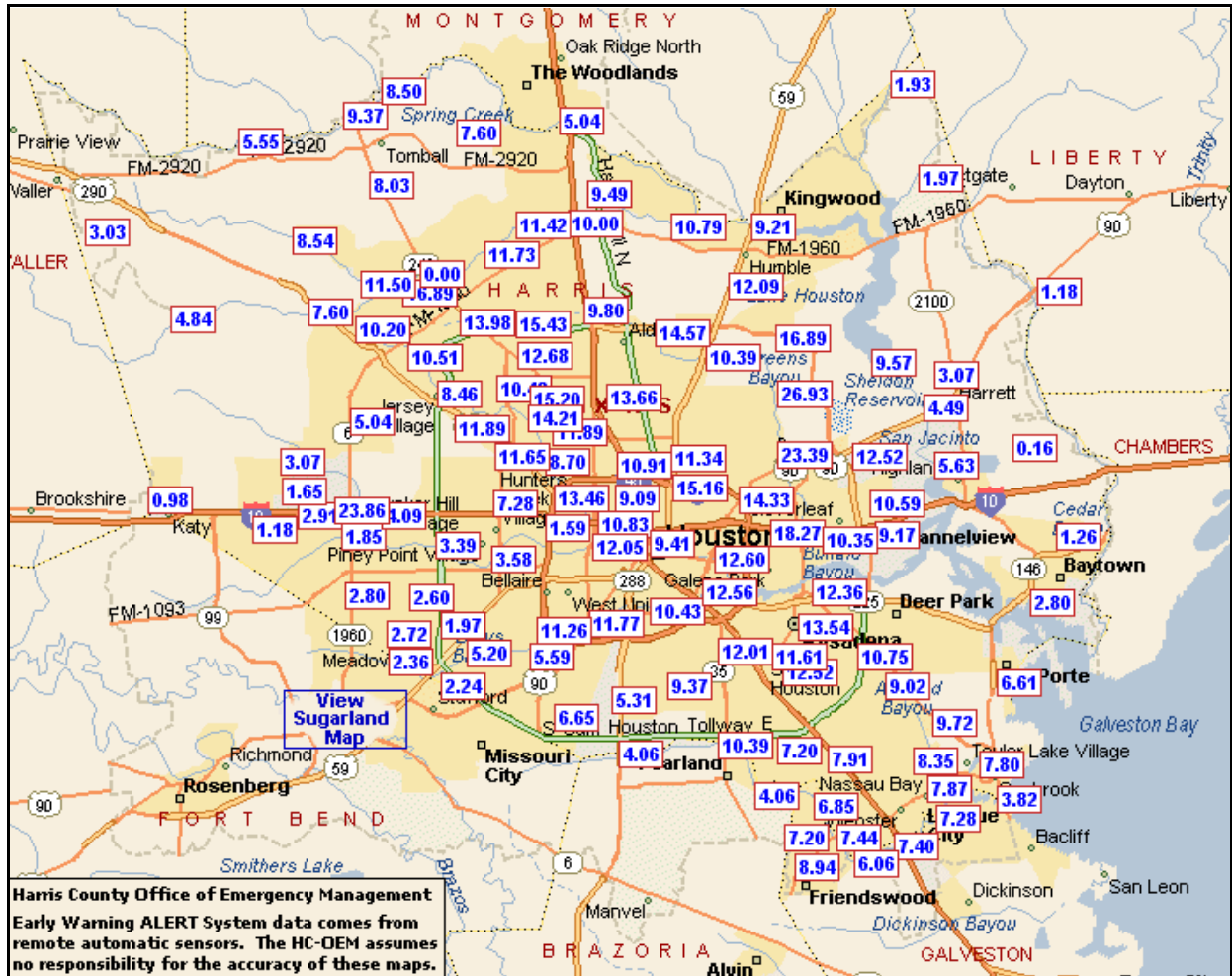


Figure 3. Harris County ALERT precipitation totals from 6 p.m., June 8, through 4 a.m., June 9. (Courtesy of Harris County OEM)

Mauriceville (Orange County), Texas, on June 9. (See Appendix B for the list of Texas and Louisiana fatalities directly attributed to Tropical Storm Allison.)

## **Louisiana**

The remnants of Allison drifted off the middle Texas coast during the evening of June 9. By midday on June 10, the center was still offshore about 70 miles south-southwest of Cameron, Louisiana, and moving to the east-northeast. Allison moved inland near Morgan City on the early evening of June 10. Tracking north of New Orleans across Lake Pontchartrain, the center of Allison exited Louisiana around dawn on June 11.

In terms of storm rainfall totals and area impacted, Allison ranks among the worst to hit Louisiana in the past 100 years. The greatest storm total was 29.86 inches at Thibodaux (30 miles northeast of Morgan City). Salt Point in St. Mary Parish recorded 27.55 inches of rain, and Baton Rouge had 19.15 inches.

The most significant flooding occurred on June 6-7. Much of the city of Thibodaux was flooded when 15.16 inches of rain fell in 24 hours. Dozens of homes were evacuated in Lafayette, Iberia, St. Mary, and Vermilion Parishes. Deep water submerged Highways 90 and 182 in this region for more than 12 hours. In East Baton Rouge Parish, flooding resulted in the evacuation of 1,800 residents and flooded 1,000 homes. Over 2,000 homes were flooded in Livingston, Lafourche, St. Tammany, and Ascension Parishes. This was the most significant flooding of the Amite and Comite Basins since 1983. Fifty homes were flooded in Jefferson Parish. About 75 people were evacuated from their homes in south Slidell during the early morning of June 11. Despite numerous reports of people stranded in their vehicles, no flood deaths occurred in Louisiana. The only fatality occurred near Zachary when a small tornado caused a tree to fall onto a vehicle, killing its occupant (see Appendix B). Damage in excess of \$50 million has been attributed to Allison in Louisiana.

## **Warning and Forecast Services**

### **National Centers**

The National Centers for Environmental Prediction (NCEP) provides forecast product guidance to RFCs, WFOs, and other NWS field offices. Of the nine centers comprising NCEP, the Tropical Prediction Center and the Hydrometeorological Prediction Center were most involved in providing services during Tropical Storm Allison in Louisiana and Texas.



## Tropical Prediction Center

The TPC monitors the movement and strength of tropical weather systems, provides official NWS forecasts, and issues associated coastal watches and warnings for the United States.

On May 21, the TPC observed a tropical wave off the west coast of Africa and tracked it across the Atlantic and the Yucatan Peninsula. It moved into the Bay of Campeche on the evening of June 4. The 4:30 a.m., Central Daylight Time (CDT),<sup>1</sup> June 5, Tropical Weather Outlook issued by TPC indicated no tropical storm development was expected. By 7 a.m., the TPC analysis of satellite imagery and surface observations suggested the presence of a surface low about 120 nautical miles south of Galveston, Texas. Data Buoy 42002 (240 nautical miles southeast of Sabine, Texas) was out of service during the passage of the weather system that was to later become Tropical Storm Allison. A replacement buoy became operational on August 21. Had this buoy been in service, the development of Tropical Storm Allison might have been detected earlier. A post storm review by TPC states, "Determination of a closed surface low pressure system was delayed by at least 6 hours as a result of Buoy 42002 not reporting due to its previous collision with a ship." The service assessment team agrees with this opinion.

The possibility of tropical development was first mentioned by TPC in a Special Tropical Disturbance Statement issued at 7:45 a.m., June 5. This statement cautioned heavy rains and tropical storm force winds would be spreading onto the mid and upper Texas coast and coastal Louisiana later in the day if development continued. Around 1 p.m., weather information from another buoy 60 nautical miles south of Freeport, Texas, and observations from an Air Force Reserve reconnaissance flight confirmed a circulation 80 nautical miles south-southwest of Galveston.

The initial Tropical Storm Warning for Allison was issued in a special advisory at 2 p.m. for the area from Sargent, Texas, to Morgan City, Louisiana, where the broad circulation was expected to make landfall that evening, June 5. Tides were predicted to be 2 to 4 feet above normal with maximum winds around 60 miles per hour (mph). Locally heavy rainfall up to 5 inches was predicted.

At 4 p.m., June 5, when the storm was centered 35 miles south of the Houston/Galveston area, the TPC forecast included the possibility of isolated rainfall amounts up to 8 inches. Heaviest rainfall and strongest winds in a tropical storm are normally near the center. In the 7 p.m. advisory, TPC warned the weather associated with Allison was not near the center but rather north, east, and southeast. Because heavy rain was already spreading into southeast Texas and southern Louisiana, and little movement of the storm had been detected, the forecast called for isolated rainfall totals to 10 inches.

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<sup>1</sup> All times listed in this service assessment are CDT.

At 10 p.m., June 5, Allison's center was 20 miles southwest of Galveston. TPC emphasized the strong winds (now weakened from 60 mph to 45 mph) and the heavy rain were well to the north and east. Ten inches of rain had fallen at a few locations in southeast Texas, and additional amounts of 4 to 5 inches with isolated amounts to 10 inches were still possible.

At 5 a.m., June 6, TPC issued its last public advisory on Allison when coastal warnings were discontinued. The threat of heavy rain was highlighted in this advisory even though Allison had weakened to a tropical depression and all tropical storm warnings were discontinued. Consistent with operational protocol, responsibility for preparing storm summaries on Allison was transferred from TPC to HPC.

HPC continued to issue storm summaries for the next 3 days. On the evening of June 9, the remains of Allison moved back across the Texas coast into the Gulf of Mexico and a new low-level circulation developed. As part of its marine warning and forecast responsibilities, TPC issued a Gale Warning for the northeast Gulf of Mexico about 3 hours prior to Allison reaching subtropical storm status. (A subtropical storm is one occurring in lower latitudes but has characteristics of both tropical cyclones and storms occurring farther north.) Normally, TPC would have again assumed responsibility for advisories on Allison. However, since HPC had been issuing these storm summaries for the past 3 days, the gale force winds were expected to be of short duration, and most of the storm's circulation remained over land, a coordinated decision was made to have HPC continue issuing storm summaries.

The onset of tropical storm force winds along the upper Texas coast occurred within 3 hours of the issuance of the Tropical Storm Warning. Rainfall forecasts in TPC products were effectively coordinated with HPC, the WFOs, and the RFCs. Rainfall amounts of 4 to 5 inches with isolated amounts of 8 to 10 inches were forecast. Observed totals were generally in the 4- to 6-inch range in the Houston area with isolated amounts of 8 to 10 inches in eastern Harris County. Tides observed in Texas were within the 2- to 4-foot above normal range predicted when the Tropical Storm Warning was issued.

### **Hydrometeorological Prediction Center**

HPC's mission is to provide forecast, guidance, and analysis products and services to support the public forecast activities of the NWS and its customers.

During Tropical Storm Allison, HPC forecasters provided accurate guidance to WFOs and RFCs. Updated Quantitative Precipitation Forecasts (QPFs) were made outside of the regularly scheduled issuance times. The morning HPC QPF on June 5 called for rainfall to exceed 5 inches in southeast Texas. A WFO Houston/Galveston forecaster indicated this was important input into his decision to issue the initial Flash Flood Watch at 10:30 a.m. This watch was issued more than 3 hours before Allison reached tropical storm strength and 6 hours in advance of the onset of flash flooding. Guidance from HPC to WFO Houston/Galveston on June 9 enabled the WFO to determine the threat was over and terminate the Flash Flood Watch

sooner than expected. The WFO Houston/Galveston MIC stated, “*kudos are in order*” for HPC assistance.

Another forecast product widely used by field personnel is the Excessive Rainfall Potential Outlook, which identifies areas where rainfall is expected to exceed amounts that will produce flash flooding. Areas expected to receive 5 inches or more of rain are depicted on this graphical product as a hatched area. Figure 4 is the Excessive Rainfall Potential Outlook issued by HPC at 12:25 p.m. on Friday, June 8, which correctly highlighted the overnight flash flood event that claimed 22 lives in Houston.

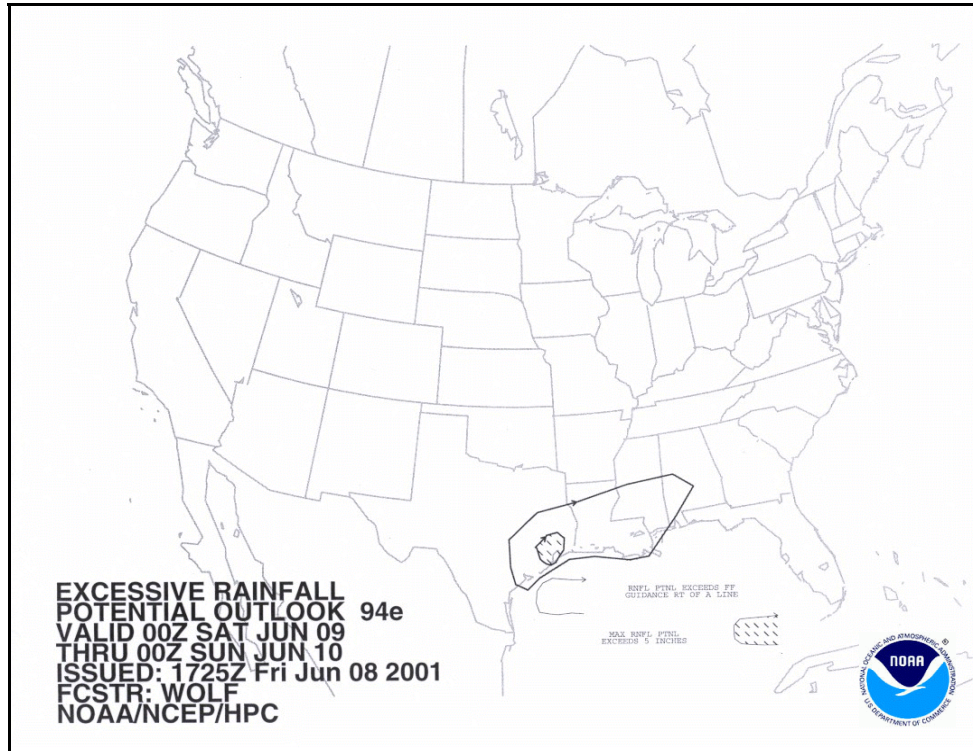
Frequent coordination calls were made from HPC to affected offices. A West Gulf River Forecast Center (WGRFC) contingency forecast for major flooding on Buffalo Bayou (24 hours before the event) was a direct result of coordination between the HPC and the WGRFC. WFO forecasters also noted excellent coordination calls with HPC.

Figure 5 compares the HPC QPF forecasts versus actual rainfall. The map on the top (Figure 5a) is the total rainfall from HPC’s forecasts for the period June 5 to June 12. The map on the bottom (Figure 5b) is the actual precipitation from radar estimates and rainfall measurements for the same period. The comparison of HPC’s cumulative QPF forecasts to the rainfall totals for June 5 to June 12 documents a high level of accuracy and strong performance by HPC forecasters. In fact, during June 2001, HPC set several new records for accuracy in its QPF program (see Appendix C).

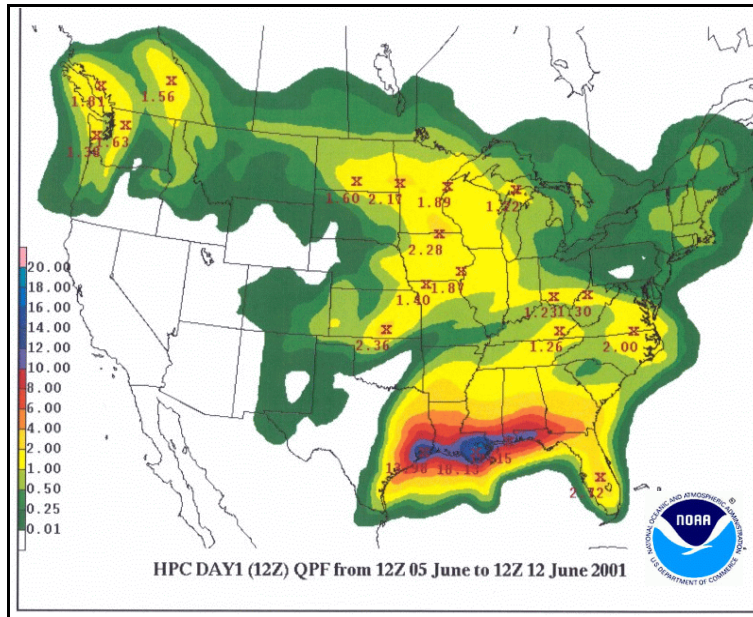
After assuming responsibility for Allison from the TPC on June 6, the HPC issued 48 storm summaries (one every 6 hours) which provided information on storm position, watch/warning status, rainfall, forecasts, and historical information.

## **River Forecast Centers**

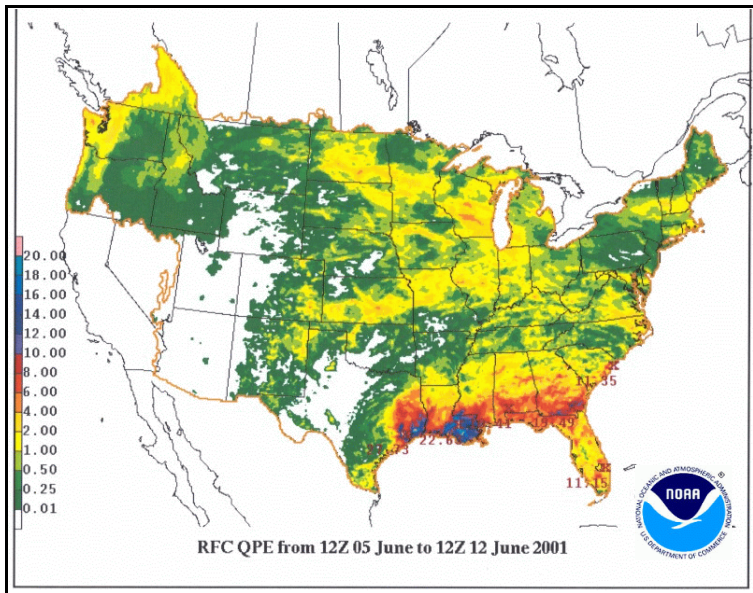
The RFCs are tasked with providing timely river stage and flood forecasts, radar and rainfall analyses, and hydrological expertise to WFOs, water management agencies, and state emergency managers. The RFCs responsible for river and flood forecast services with respect to Allison’s heavy rain and resultant flooding were the West Gulf RFC (WGRFC) in Fort Worth, Texas, and the Lower Mississippi RFC (LMRFC) in Slidell, Louisiana. RFCs are not normally staffed 24 hours a day.



**Figure 4.** HPC Excessive Rainfall Potential Outlook issued at 12:25 p.m., June 8, 2001. (NOAA/NCEP/HPC)



**Figure 5a.** HPC Cumulative Quantitative Precipitation Forecasts. (NOAA/NCEP/HPC)



**Figure 5b.** Mean Areal Precipitation Estimates. (NOAA)

**Figure 5.** Comparison of HPC QPF forecasts versus actual rainfall.

## **West Gulf River Forecast Center**

Recognizing the seriousness of the hydrologic event, the WGRFC began 24-hour operations on June 5. This extended coverage was provided to ensure partners and customers had continuous access to the RFC during a critical situation and provided a continuous flow of flood forecasts and updates.

There was ongoing telephone coordination with WFOs Houston/Galveston and Lake Charles, HPC, San Jacinto River Authority, Trinity River Authority, Texas Division of Emergency Management (TDEM), SRH Regional Operations Center (ROC), and the Federal Emergency Management Agency. Hydrometeorological Coordination Messages (HCMs) and telephone calls were the primary methods used to communicate with WFOs. HCMs contain specific information regarding adjustments to radar rainfall estimates, hydrometeorological analysis, and potential for both short- and long-term river impacts. A total of 23 HCMs were issued and several provided “heads-up” notice for the serious flooding potential.

The WGRFC produces an experimental River Flood Watch that is disseminated to the public by the WFOs. This experimental product provided information that highlighted the likelihood of a major flood. Thirteen WGRFC river flood watches were produced with an average lead time to crest of 36 hours. In the case of the San Jacinto River, the experimental River Flood Watch resulted in a lead time of almost 48 hours.

Another example of WGRFC’s response was issuance of several non-routine graphical products on the offices’ Internet page, including 24-hour rainfall totals derived from radar rainfall estimates and rain gauge measurements.

Radar estimated precipitation data was adequate throughout most of the event. When a minor underestimation was observed, WGRFC forecasters coordinated with affected WFOs, adjusted the data, and thereby improved accuracy of precipitation estimates to customers and partners. Early on June 9, a communication connection between a private vendor and the Internet failed, severing access to Southern Region field offices. As a result, Harris County ALERT (Automated Local Evaluation in Real-Time) rainfall data was not received at the WGRFC. An ALERT system is a local network of rainfall and stream gauges that provides real-time precipitation and water level measurements in support of local flood warning decisions. These data would have more precisely calibrated WGRFC precipitation estimates, resulting in a more accurate knowledge of where and how much rainfall had occurred. Working through SRH, the vendor restored Internet service by late morning on June 9.

Forecasting proved to be difficult for some small rivers/bayous that rose rapidly to record levels. Forecasts for Buffalo Bayou at Shepherd Drive in Houston underforecast the river stage by 6 to 12 feet with little or no lead time. Also, the forecasts for the West Fork of the San Jacinto River near Conroe were not accurate. Both software and procedural problems have been identified by the WGRFC and the NWS Office of Hydrologic Development as contributing to

these inaccuracies. RFCs employ forecast procedures that use data from past floods. When extreme rainfall occurs resulting in record floods, how a river responds becomes less predictable. How rainfall is distributed over a basin also affects how a river responds. With Allison, rainfall was concentrated at the lower end of the basin, and the RFC did not have a precedent for adjusting its procedure. For Buffalo Bayou, the time interval used for the forecast model was set at 6-hour time steps. A 3-hour interval is needed for basins that respond rapidly during heavy rainfall. A software problem existed in the model used to generate the forecasts for the West Fork of the San Jacinto River. **(Finding 1)**

During Allison, contingency forecasts showed potential for compensating for weaknesses in forecast procedures during extreme or unprecedented rainfall and flood events. Contingency forecasts are made based on potential “worst case” situations. On June 7, a contingency forecast called for a major flood at Buffalo Bayou 24 hours before the event. Another such forecast for Sour Lake on Pine Island Bayou called for a crest that verified within a half foot. For 16 forecast points, the average 24-hour crest forecast error was less than a foot.

## **Lower Mississippi River Forecast Center**

The LMRFC provided outstanding service to its customers and partners. This included specific guidance for river and flash flooding as well as operational support to emergency managers and the U.S. Geological Survey.

The LMRFC began 24-hour operations on June 5. Normally, the LMRFC uses 12-hour QPF to derive its river forecasts. During Allison, the RFC did expand usage of the QPF to 24 hours when conditions warranted. For longer range contingency forecasts, a special 48-hour QPF was used. These contingency forecasts were the basis for river flood watches issued by the WFOs at the suggestion of the LMRFC. During the event, the LMRFC issued Hydrometeorological Discussions (HMDs) on a more frequent basis. River forecasts were updated every 6 hours and QPF every 12 hours. Coordination of QPF forecasts was accomplished through conference calls with HPC and the WFOs.

The LMRFC directly coordinated with East Baton Rouge Emergency Management, Louisiana State Climatologist, and state emergency management officials in Texas and Louisiana. Extensive coordination also occurred with the mayor of Baton Rouge during times of critical decision making. There was extensive interaction with WFOs New Orleans/Baton Rouge and Lake Charles. The LMRFC also coordinated with interests along the flooded Amite River.

Rainfall in excess of 20 inches produced moderate to major flooding at seven LMRFC river forecast points. The LMRFC provided excellent lead times for these locations. For rivers in the Lake Pontchartrain drainage, lead times to flood stage ranged from 18 hours at two of the forecast points to 31 hours at three other sites. For the two forecast points in the Calcasieu Basin, the lead times to flood stage were 18.5 hours; and 2 days, 11.5 hours; respectively.

The LMRFC Web site was used extensively by State Climatologist Jay Grymes who stated, *“when I am asked about the most useful sites available for monitoring Louisiana weather, the LMRFC is among the very first I mention.”* A graphical version of the HMD on the RFC Web site was well received by customers. Normally, the LMRFC posts all river forecasts in both graphical and text format on its Web site one hour after the forecast is sent to the WFOs. In response to customer feedback, this delay was reduced to 30 minutes during this event to provide information faster to customers.

## **Weather Forecast Offices**

WFOs are responsible for issuing timely meteorological and hydrological warnings, watches, forecasts, and statements for their areas of responsibility. They are the primary NWS contact point for state and local officials, the news media, and the general public. Southeast Texas and southern Louisiana are served by WFOs Houston/Galveston, Lake Charles, and New Orleans/Baton Rouge.

### **WFO Houston/Galveston, Texas**

WFO Houston/Galveston provided outstanding service to its customers and maintained an exceptional level of cooperation with its partners. The threat of heavy rain was initially mentioned in the morning forecast issued at 4:30 a.m. on June 5. This was 12 hours before the heavy rains began. Recognizing that the storm had the potential to produce a significant weather event, the WFO issued a Hazardous Weather Outlook at 5:19 a.m. The Outlook mentioned the threat of rainfall up to 3 inches. The initial Flash Flood Watch for Houston/Harris County was issued at 10:30 a.m., calling for rainfall totals along and east of Highway 59 to exceed 5 inches with isolated amounts to 8 inches. At 1:38 p.m., a Coastal Flood Warning was issued for tides of 4 to 5 feet from High Island to Freeport. This included coastal sections of Galveston Bay.

A High Wind Warning was issued for the area east of a Conroe-Livingston line at 3:27 p.m., June 5. By late afternoon, the WFO began issuing a series of flash flood and river flood warnings, extending well into June 6. The WFO issued a Hurricane Local Statement at 7:25 p.m., calling for overnight rainfall totals of 7 to 14 inches in northern Galveston and Harris Counties.

Overnight rainfall totals ending on the morning of June 6 were in the 4- to 6-inch range with isolated amounts of 8 to 10 inches in eastern Harris County. Observed tides were within the forecasted range.

The Flash Flood Watch was extended on Wednesday, June 6, and remained in effect for all or portions of southeast Texas until late Sunday afternoon, June 10. A River Flood Watch was issued at 10:39 a.m. on June 6. Flash flood and river flood warnings continued to be issued throughout this period as well.



As early as Wednesday, June 6, WFO Houston/Galveston forecasters increased the likelihood of rain in the forecast for Friday and Saturday, June 8-9, in anticipation of another period of excessive rainfall. In the Thursday afternoon, June 7, Area Forecast Discussion (AFD), the forecaster cautioned “CANNOT RULE OUT SEVERAL MORE ROUNDS OF 5 TO 10 INCH RAINFALL EVENTS...OVER THE WEEKEND.” In the AFD issued at 3:37 a.m., Friday, June 8, the forecaster cautioned the storm could produce more heavy rain through Saturday night, June 9, and some of the thunderstorms could be severe. This was stated again in the 5:05 a.m. extension of the Flash Flood Watch, forecasting rainfall in excess of 10 inches and emphasizing this was a potentially dangerous situation. A number of flash flood warnings were issued in the early morning of June 8 for counties surrounding Harris County. Meanwhile, a break in the precipitation and cloud cover over metropolitan Houston was just a precursor for the most significant round of Allison’s rains. In the mid-morning forecast discussion, the forecaster warned, “THIS HEAVY RAIN EVENT IS NOWHERE NEAR FROM BEING OVER.” The combination of afternoon heating and a strong surge of moisture still feeding into the area enhanced the risk of thunderstorm development. An early afternoon update characterized the situation as a “DANGEROUS FLASH FLOOD THREAT” and advised the forecast of greater than 10 inches might have to be increased before the night was over.

By late Friday afternoon, June 8, rain began to fall again in Houston. At 4:25 p.m., an Urban Small Stream Flood Advisory was issued for Harris County as rainfall was expected to cause flooding of streets and feeder roads near the Texas Medical Center, Bush Intercontinental Airport, and other locations throughout the county. At 5:10 p.m., a Flash Flood Warning was issued for Harris County and specifically mentioned the areas that were later flooded extensively along I-45, Highway 59, and Highway 288. The Flash Flood Warning remained in effect until midnight, Saturday, June 9.

Warnings and statements for Harris County stated clearly this was a very dangerous flood situation and urged people not to travel in the county until the flood threat had passed. Subsequent statements and warnings provided specific information on expected or existing locations of flooding. An example of the detail and seriousness of the flood threat can be seen in the 7:12 p.m., June 8, statement issued by the WFO. It noted, “THE HARRIS COUNTY EMERGENCY MANAGER REPORTS FLOODING AT I-10 AND JOHN RALSTON... SOUTHWEST FREEWAY AT WESTPARK...NORMANDY AT I-10...AND WIDESPREAD STREET FLOODING OVER THE EAST SIDE OF HOUSTON. THIS IS A VERY DANGEROUS SITUATION! TRAVEL IS NOT RECOMMENDED.” The 7:55 p.m. extension of the Flash Flood Warning stated, “MUCH OF HOUSTON INSIDE LOOP 610 HAS RECEIVED 3 TO 5 INCHES OF RAINFALL...MORE IS ON THE WAY. DO NOT TRAVEL IN HARRIS COUNTY UNTIL THIS FLOOD THREAT HAS PASSED.”

The most intense rainfall in Houston occurred between 11 p.m., Friday, June 8, and 4 a.m., Saturday, June 9. At times, the hourly rainfall rates exceeded 5 inches an hour. Twenty-four-hour rainfall totals in the Houston area averaged just under 10 inches. An ALERT rain

gauge in the Greens Bayou area reported more than 28 inches in the 24 hours ending at 7 a.m., Saturday, June 9. Figure 2 shows the rainfall distribution across the Houston metropolitan area.

Flash and river flood warnings and statements were issued throughout Saturday, June 9, in the Houston county warning area (CWA) as forecasters continued to stress the flood danger. By late Sunday afternoon, June 10, the flash flood threat finally ended in the Houston service area. Figure 6 shows Allison's rainfall storm totals for June 4-10 for the Houston area.

Between June 5 and June 10, WFO Houston/Galveston experienced 39 flash flood events in its service area and issued 99 flash flood warnings. All of the events were included in a warning for an accuracy of 100 percent. Nine warnings had no subsequent flash flood event associated with them for a false alarm rate of 9 percent. This performance was outstanding when compared to national performance during 2000 (accuracy was 86 percent and false alarm rate was 38 percent). The average lead time was 40 minutes.

The Weather Surveillance Radar-1988 Doppler (WSR-88D) experienced an outage on Friday, June 1, and the WFO electronics staff worked over the weekend to restore operations. Media partners commented that this effort was helpful and appreciated. Partners and customers were also impressed by the quality of the rainfall data. The radar was switched into tropical rainfall mode during the late afternoon on June 5. Minor biases were noted and adjustments made in coordination with the WGRFC.

The WFO Houston/Galveston staff is capable of activating the pagers of key emergency managers and government officials in their area. With Allison's rapid formation, the WFO pager system was a vital notification method for the emergency management community. This capability was used throughout the event to provide rapid dissemination of new information.

The WFO relied on its Internet connection to monitor data from the Harris County Office of Emergency Management (OEM) ALERT system. WFO access to this system was lost early on the morning of June 9 when the Internet service provider experienced an outage. No significant impact resulted as the WFO was already in frequent telephone contact with the OEM and the Harris County Flood Control District. This interaction was critical during June 8-9 when the main threats were from urban flash flooding and the rapid flooding of the bayous.

Because of the small size of the bayous in the Houston area, most are not included in the WGRFC forecast system. WFO Houston/Galveston derived forecasts for the bayous and small basins by tapping the expertise of the engineers at the Harris County Flood Control District, using ALERT data, and interpreting their local radar information. Harris County has initiated a project to develop new forecast tools for these small basins and has invited NWS participation in this effort. The NWS Advanced Weather Interactive Processing System (AWIPS) Release 5.1.2 includes a site-specific hydrologic model which can be used for small-gauged basins.

**(Finding 2)**

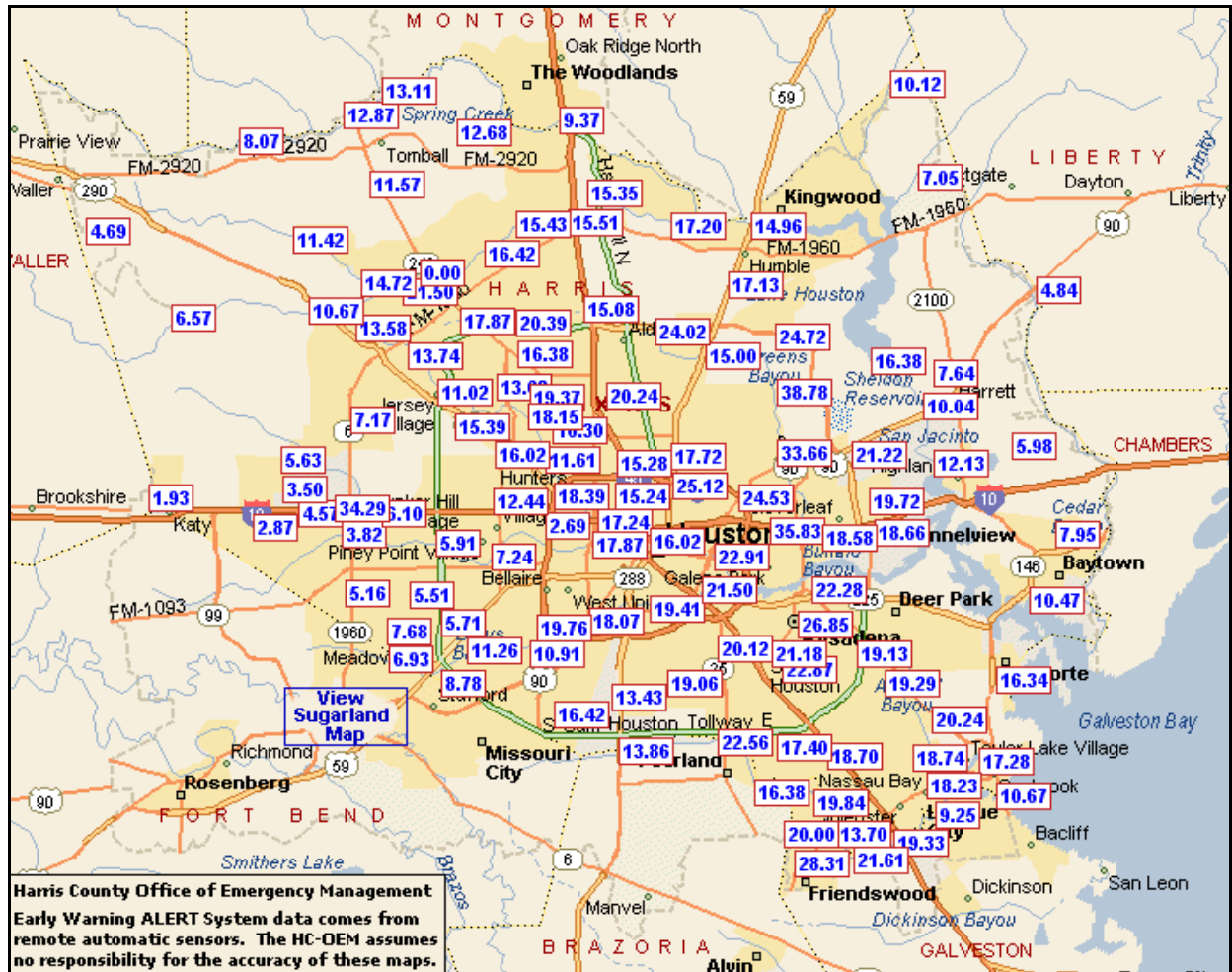


Figure 6. Harris County OEM rainfall storm totals, June 4-10, 2001. (Courtesy of Harris County OEM)

The WGRFC generates Mean Areal Precipitation (MAP) averages from radar rainfall estimates and observed rainfall measurements. Currently, coverage of this product does not include the Houston metropolitan area. MAP estimates would have been useful for assessing the flood risk and supplementing the analysis where gauges exist. **(Finding 3)**

The WFO was well staffed during this extended event. The administrative support assistant came in on June 9 to augment the operations staff and provide critical communications support. An amateur radio operator collected valuable reports from the flooded areas and was prepared to provide backup communications with key partners if needed.

The assessment team learned that excellent working relationships exist between WFO Houston/Galveston and its partners and customers. During Allison, these relationships resulted in close cooperation and effective two-way exchange of information. A strong performance by the WFO produced a high level of customer satisfaction and praise. Montgomery County Emergency Manager Jim Strong stated, *“This was the best prediction of flooding that we have received in 10 years...Bill Read and his staff nailed it.”* David Lamb, Houston County Emergency Manager, had *“nothing but praise”* for the WFO. Jim White, Emergency Management Coordinator for Harris County, described his organization’s relationship with the WFO as *“extremely good.”* A similar response was provided by Craig McDowell, Emergency Manager for the City of Houston. Bob White of the City of Houston OEM stated there was *“good information flow throughout the event...no surprises.”* Mr. White also noted, *“NWS uses urban and small stream flood advisories real effectively.”* He also expressed appreciation for the WFO’s willingness to include information from the OEM in its messages.

Media partners responded with favorable comments as well. Ed Brandon of KTRK-TV stated, *“I thought their performance was superb. They were quick to respond and pretty explicit about the severity of the event.”* This was echoed by Frank Billingsly at KPRC who stated, *“WFO Houston never let its guard down. I thought the office did an excellent job of conveying the severity and urgency of the event.”* Hector Villarreal of KXLN simply commented, *“The NWS did the job for us.”*

## **WFO Lake Charles, Louisiana**

WFO Lake Charles served its customers in an excellent manner during this historic flood event. A Special Weather Statement issued by WFO Lake Charles early on Monday, June 4, cautioned heavy rains were possible on Tuesday, June 5. This information was included again in an early morning statement on June 5, followed around noon by a very detailed statement on local impact. It noted, **“HEAVY RAIN BANDS WILL MOVE NORTHWARD FROM THE COAST. RAINFALL AMOUNTS OF 3 TO 5 INCHES WILL BE POSSIBLE BY WEDNESDAY MORNING. AT THIS TIME...RIVER LEVELS WILL RISE TO NEAR FLOOD STAGE.”** These actions occurred well before the formation of Tropical Storm Allison and the onset of heavy rain. On the afternoon of June 5, the WFO issued a Flash Flood Watch for all of the counties and parishes it serves. The lead time was 18 hours.

Between June 6 and June 10, the WFO Lake Charles CWA experienced 16 flash flood events. Only one of the events was not preceded by a warning for an accuracy of 94 percent. The WFO issued 47 flash flood warnings. Eleven of these had no subsequent flooding event associated with them, for a false alarm rate of 24 percent. Lead time averaged 24 minutes. Flash flood warnings contained detailed information for partners and customers. To increase feedback, WFO Lake Charles included a phone number in its warning messages to report flooding. A staff member was assigned to handle these calls.

The Jefferson County Drainage District No. 6 operates an ALERT system in southeast Texas. While some ALERT data is periodically faxed to WFO Lake Charles by the District, no Web site or other real-time connection exists for the WFO to access this data. The WFO is working with the District to obtain this data on a continuous basis.

The NOAA Weather Radio (NWR) transmitter site at Lafayette was flooded on Wednesday, June 6. The system remained off the air until flood waters had receded and a repairman could get to the site. Operations resumed on the evening of Sunday, June 10. During this period, critical warning information was disseminated via normal media outlets, the Emergency Alert System (EAS), etc. Some overlap coverage was provided by the NWR transmitter in Morgan City, Louisiana. The MIC has taken action to minimize the recurrence of this outage.

The WFO coordinated well with the WGRFC and LMRFC and provided timely river flood warnings for the Calcasieu River. During the event, the WFO contacted Jefferson County Emergency Management on a routine basis and also exchanged information with the Drainage District. Both of these agencies relied heavily on the WFO Web site for radar and other products. The overall coordination effort with partners was extensive and effective. Users were very complimentary. Cecil Peltier, Assistant District Manager of the Jefferson County Drainage District No. 6, stated, the NWS did an “*excellent job.*” Darlene Koch, Jefferson County Emergency Manager, was very complimentary about overall services and coordination provided by WFO Lake Charles. She stated she can “*always rely on NWS.*”

In May, more than 300 elected officials, emergency service, and media representatives attended a Hurricane Workshop. The key topic was response. Additional workshops were held at other locations in the WFO service area.

WFO staff focal points are used to manage the office hydrology program with assistance provided by the Service Hydrologist at WFO New Orleans/Baton Rouge.

## **WFO New Orleans/Baton Rouge, Louisiana**

WFO New Orleans/Baton Rouge issued an initial Flash Flood Watch for most of southeast Louisiana at 7:30 p.m. on Tuesday, June 5. This was about 16 hours before the first flooding in Terrebonne Parish and up to 21 hours prior to flooding in other southeast Louisiana

parishes. At 10:52 p.m., June 5, a River Flood Watch was issued for the Amite and Comite Rivers. The threat to the Amite, Comite, and smaller rivers draining into Lake Pontchartrain was again highlighted in a Flash Flood/Flood Watch issued at 10:54 a.m. on June 6. All of these rivers flooded within 72 hours.

Between June 5 and June 11, WFO New Orleans/Baton Rouge issued 87 flash flood warnings for the Louisiana portion of its service area. Thirty were not followed by a flash flood event, for a false alarm rate of 34 percent. Thirty flash flood events occurred in the WFO service area in Louisiana. Five were not preceded by a Flash Flood Warning, for an accuracy of 83 percent. The average lead time was 39 minutes.

WFO New Orleans/Baton Rouge issued over 140 river flood warnings and statements during a 7-day period. These flood warnings and statements included forecasts for up to 15 locations along the river. At times, multiple warnings were issued for as many as 13 forecast points on three different basins. On a few occasions, the interval was excessive between the LMRFC's issuance of river forecasts and WFO New Orleans/Baton Rouge's issuance of river flood warnings and statements. At an emergency management meeting sponsored by the Amite River Basin Commission in July, there was strong customer support for more rapid dissemination of river forecasts and warnings. In response, the WFO New Orleans/Baton Rouge MIC and the LMRFC HIC have identified procedural changes and training requirements that will address this need and reduce lag time between the LMRFC and WFO issuances. **(Finding 4)**

The WFO coordinated extensively with state and local partners during the event, logging over 60 coordination calls. Following Allison, the mayor of Baton Rouge noted in a letter to the WFO, *"The abundance of information your office provides continues to aid our response community in decision making as we work to ensure our common goal—public safety."*

In addition, the WFO coordinated closely with HPC on rainfall forecasts. A Flash Flood Decision Tree developed by WFO New Orleans/Baton Rouge proved valuable during the event and was used to make adjustments to the QPF forecasts.

## **Southern Region Headquarters**

SRH provides supervisory, administrative, operational, and technical oversight and support to the WFOs and RFCs in its area of responsibility. The Regional Operations Center (ROC) is a component of SRH and serves as a coordination and support unit for field offices. During significant weather events, the ROC is staffed 24 hours a day and provides a variety of services, including communication system support, field office coordination services, media, and interagency support.

During the period of heaviest rainfall associated with Allison, the ROC helped provide a larger picture of the event. Services included:

- C Twice-a-day hydrometeorological briefings to the Texas DEM
- C Coordination and support to field offices as requested
- C A wide variety of media interviews.

Local media interviews were handled by the respective field office, while national and international media interviews were conducted by SRH/ROC staff and the NOAA Public Affairs Specialist assigned to SRH. Interviews were provided to CNN, CNN.com, MSNBC, CNBC, ABC World News Tonight, and GHTV-London. The WFOs indicated this assistance was valuable since it allowed them to focus their support to local media and other partners.

Jack Colley, Assistant State Coordinator for the Texas DEM, stated, “*Southern Region Headquarters and River Forecast Center participation in our conference calls was essential to deploying resources and ensuring the safety of recovery workers.*” The Texas DEM State Coordinator, Tom Millwee, was also very appreciative of the assistance provided by SRH and the WFOs in Texas.

## **Partner and Customer Coordination and Response**

The effectiveness of the weather and flood warning system is dependent on close coordination, cooperation, and a clear consistent message among the various agencies responsible for public safety. This includes the NWS, emergency management community, flood control/public works agencies, the media, and state and local governments.

### **Emergency Management and Flood Control/Public Works Agencies**

Coordination between NWS offices and partners in emergency management and flood control/public works agencies was excellent. This cooperative effort extended beyond the normal WFO-local emergency manager relationship to include RFCs, SRH, the Louisiana Office of Emergency Preparedness, and TDEM. It was evident to the assessment team that over an extended period of time, a high level of respect and trust had been built up between the NWS and these partners.

Most of the emergency managers interviewed participated in annual NWS workshops, had prior interactions with the WFOs, and were aware of the full suite of products available to them. As a result, they were proactive in monitoring weather conditions and the WFOs’ AFDs and statements, and were not caught off guard by the heavy rainfall. These preparedness activities paid off once a Tropical Storm Warning for Allison was issued. Within an hour of issuance, the mayor of Galveston called for a voluntary evacuation of the west end of Galveston Island since that area is not protected by the seawall. The issuance of the warning, subsequent

conference calls, and follow-up statements resulted in activation of many Emergency Operation Centers.

Emergency management partners were aggressive in making NWS information available to local decision makers and the public. In Houston, the Harris County Appraisal District operates an Emergency Managers Weather Information Network (EMWIN) with the cooperation of Harris County OEM, the Texas National Guard, and the NWS. The NWS provides a data stream via satellite of national and local NWS text and graphic products. The Houston EMWIN system captures this signal and re-broadcasts the information over VHF radio frequencies. With a simple radio receiver and personal computer, the information can be displayed and subsequently provided to other users or the public via the Internet. The system also has pager activation capabilities.

The Internet site operated by the Harris County OEM was a major contributor to the success of the warning effort in southeast Texas. This site was a “one-stop” point for information and coordination. It provided immediate access to real-time and historic rainfall and river stage information; links to EMWIN, local radar, and news media outlets; rapid exchange of information among local governments; and awareness and safety information. Harris County also supports an e-mail list server, the Media Alert Notification System (MANS), which provides the latest information to more than 140 media outlets in the Houston area.

With the cooperation of a Lake Charles Mutual Aid Association and the local emergency manager, WFO Lake Charles can immediately broadcast NWS warning information over the Mutual Aid Association’s radio system to 100 major business and government organizations. Mutual aid organizations in Baton Rouge and Beaumont also disseminate NWS information and collect reports of hazardous weather. Other examples of assistance include Friendswood, Texas, where the emergency management office re-broadcasts NWR programming on a city-owned AM radio station. In Polk County, Texas, about 200 NWRs were distributed to key locations such as hospital and schools. In Pasadena, Texas, the emergency manager used an e-mail notification system and personal briefings to provide weather information as well as its expected impact information to all city officials.

Both the Harris County OEM and the Harris County Flood Control District expressed a strong need for river forecasts to be issued in reference to Mean Sea Level (MSL). **(Finding 5)**

## **Broadcast Media**

Upon assuming responsibility for Allison from TPC, the HPC had to support the significant requirements of the national news media. While this transition placed heavy demands upon HPC resources, it was accomplished in an effective manner that impressed the news media.

WFO Houston/Galveston held a Hurricane Workshop in May 2001 for local media, providing details on NWS products and dissemination. After the Allison floods, television



stations were complimentary, stating the workshop before the hurricane season gave them a much clearer understanding and appreciation of the WFO's operations and products. Workshops held by WFO Lake Charles received similar praise and results.

The Houston broadcast media indicated WFO Houston/Galveston was very accessible and user friendly prior to and during the flood event. Frank Billingsly of KPRC in Houston noted there was an *“open line of communication to the WFO at all times.”* Products were described as timely and informative, and addressed the appropriate level of concern for the growing threat to life and property. Hector Villarreal of KXLN in Houston stated, *“All the watches and warnings were concise and precise. I could read them right off the copy.”*

All of the media interviewed used the AFD on a daily basis and found it a valuable tool, providing insight into the severity of the event. They were also impressed with the reliability and accuracy of WSR-88D rainfall estimates. During the height of the event in Houston, the intensity of the rain disrupted the microwave signal from the vendor that provided data and warning products to one of the television stations. The station immediately went to the NWS Internet site to obtain WSR-88D data and NWS products. The television meteorologist at Baton Rouge indicated the Internet was a critical part of his operations.

Some weathercasters expressed a desire for more information on road closings. Others noted the information came so quickly there was little time to explain what was happening and provide safety information. Two interviewees expressed a preference for the use of the word “Warning” rather than “Advisory” for urban street flooding. One television station noted the written text format of river flood warnings and statements was too cumbersome for rapid television dissemination.

Several emergency managers noted the media was very proactive at covering the event and relaying NWS information to the public on the seriousness of the situation. Jennifer Shields Hawes, City of Pasadena Emergency Manager, stated, *“the media had continuous coverage of the event and provided a lot of safety information to the public.”*

The EAS is a voluntary effort on the part of the broadcast media to ensure rapid relay and dissemination of critical life-saving information. There was widespread cooperation from the media, and the EAS was activated in both Louisiana and Texas, ensuring wide dissemination of warning messages.

## **Public**

There were no flood related deaths from Allison during the first 3 days of the event. With the onset of torrential rainfall on the evening of Friday, June 8, the first fatality in Texas occurred. Most of the 22 deaths in Houston occurred from around midnight to the early morning hours of Saturday, June 9.

In Houston, three people died in their homes by electrocution. Seven drowned in their vehicles. Two of these deaths occurred after the rainfall ended on Sunday afternoon, June 10. A couple's vehicle was swept off a bridge while they were trying to reach their daughter who was isolated by flood waters but in no danger. Nine people died while on foot; three of these when flood waters forced them to flee their vehicles. Two residents at an assisted living facility drowned after getting separated from a group of patients and staff who were walking between the nursing home and a nearby hospital. A woman died when she went to move her car from a flooded parking garage four floors below ground in a high-rise building. In addition to the 22 deaths in Houston, a man was killed while swimming in a drainage ditch at Mauriceville (Orange County), Texas, on June 9 (see Appendix B).

It is difficult to understand why there were 22 fatalities on June 8-9. Sunshine returned to Houston on the morning and early afternoon of June 8, and WFO Houston/Galveston was clearly concerned about a possible drop in the public's perception of the flood risk as several of its messages stressed the threat had not ended. The ground was saturated from the previous days' rains and had limited ability to absorb additional rainfall. With the bayous and creeks already full of water, the rainfall that night produced almost instantaneous flooding. While heavy rains are not unusual in Houston, many individuals have not experienced intense rainfall rates of 4 to 5 inches an hour. In this case, the water spread outside the traditional flood plain into areas that may never have flooded before. The flooding of areas outside of the historical flood plains and inexperience with sustained excessive rainfall rates of 4 to 5 inches an hour are factors that were in place on June 8-9 when most of the fatalities occurred. With the exception of the two deaths on Sunday afternoon, June 10, all of the Houston fatalities perished while a Flash Flood Warning was in effect. Other than rapidly flowing water in a ditch, there was no flash flood threat in Orange County when the man died.

The sole fatality in Louisiana occurred at 6:30 a.m., June 7, about 3 miles north-northwest of Zachary, Louisiana. A small tornado blew a tree onto a vehicle occupied by a 70-year-old man (see Appendix B). No warning was in effect at that time.

# Facts

## Introduction

**FACT:** Tropical Storm Allison caused more damage than any tropical storm in U.S. history, with estimates in excess of \$5 billion.

**FACT:** Storm rainfall totals peaked at 36.99 inches (Port of Houston) in Texas and 29.86 inches (Thibodaux) in Louisiana.

## Overview

**FACT:** In Houston, Texas, 22 people were killed and more than 45,000 homes and businesses flooded. More than 70,000 vehicles were flooded. In addition, a man was killed while swimming in a drainage ditch at Mauriceville (Orange County), Texas, on June 9.

**FACT:** In terms of storm rainfall totals and area impacted, Allison ranks among the worst to hit Louisiana in the past 100 years.

**FACT:** In Louisiana, the only fatality occurred near Zachary when a small tornado caused a tree to fall onto a vehicle, killing its occupant.

## Warning and Forecast Services

**FACT:** Rainfall forecasts in TPC products were effectively coordinated with HPC, the WFOs, and the RFCs. Rainfall amounts of 4 to 5 inches with isolated amounts of 8 to 10 inches were forecast. Observed totals were generally in the 4- to 6-inch range in the Houston area with isolated amounts of 8 to 10 inches in eastern Harris County.

**FACT:** The Excessive Rainfall Potential Outlook issued by HPC at 12:25 p.m. on Friday, June 8, correctly highlighted the overnight flash flood event that claimed 22 lives in Houston.

**FACT:** The comparison of HPC's cumulative QPF forecasts to the rainfall totals for June 5 to June 12 documents a high level of accuracy and strong performance by HPC forecasters.

**FACT:** Rainfall in excess of 20 inches produced moderate to major flooding at seven LMRFC river forecast points. The LMRFC provided excellent lead times for these locations. For rivers in the Lake Pontchartrain drainage, lead times to flood stage ranged from 18 hours at two of the forecast points to 31 hours at three other sites. For the two forecast points in the Calcasieu Basin, the lead times to flood stage were 18.5 hours; and 2 days, 11.5 hours; respectively.

## **Weather Forecast Offices**

**FACT:** As early as Wednesday, June 6, WFO Houston/Galveston forecasters increased the likelihood of rain in the forecast for Friday and Saturday, June 8-9, in anticipation of another period of excessive rainfall. In the Thursday afternoon, June 7, Area Forecast Discussion (AFD), the forecaster cautioned “CANNOT RULE OUT SEVERAL MORE ROUNDS OF 5 TO 10 INCH RAINFALL EVENTS...OVER THE WEEKEND.”

**FACT:** Between June 5 and June 10, WFO Houston/Galveston experienced 39 flash flood events in its service area and issued 99 flash flood warnings. All of the events were included in a warning for an accuracy of 100 percent. Nine warnings had no subsequent flash flood event associated with them for a false alarm rate of 9 percent. This performance was outstanding when compared to national performance during 2000 (accuracy was 86 percent and false alarm rate was 38 percent). The average lead time was 40 minutes.

**FACT:** Excellent working relationships exist between WFO Houston/Galveston and its partners and customers. During Allison, these relationships resulted in close cooperation and effective two-way exchange of information. A strong performance by the WFO produced a high level of customer satisfaction and praise.

**FACT:** A Special Weather Statement issued by WFO Lake Charles early on Monday, June 4, cautioned heavy rains were possible on Tuesday, June 5. On the afternoon of June 5, the WFO issued a Flash Flood Watch for all of the counties and parishes it serves. The lead time was 18 hours.

**FACT:** Between June 6 and June 10, the WFO Lake Charles CWA experienced 16 flash flood events. Only one of the events was not preceded by a warning for an accuracy of 94 percent. The WFO issued 47 flash flood warnings. Eleven of these had no subsequent flooding event associated with them, for a false alarm rate of 24 percent. Lead time averaged 24 minutes.

**FACT:** Between June 5 and June 11, WFO New Orleans/Baton Rouge issued 87 flash flood warnings for the Louisiana portion of its service area. Thirty were not followed by a flash flood event, for a false alarm rate of 34 percent. Thirty flash flood events occurred in the WFO service area in Louisiana. Five were not preceded by a Flash Flood Warning, for an accuracy of 83 percent. The average lead time was 39 minutes.

**FACT:** Jack Colley, Assistant State Coordinator for the Texas DEM, stated, “*Southern Region Headquarters and River Forecast Center participation in our conference calls was essential to deploying resources and ensuring the safety of recovery workers.*”

## **Partner and Customer Coordination and Response**

**FACT:** Coordination between NWS offices and partners in emergency management and flood control/public works agencies was excellent. This cooperative effort extended beyond the normal WFO-local emergency manager relationship to include RFCs, SRH, the Louisiana Office of Emergency Preparedness, and TDEM.

**FACT:** The Internet site operated by the Harris County OEM was a major contributor to the success of the warning effort in southeast Texas. This site was a “one-stop” point for information and coordination. It provided immediate access to real-time and historic rainfall and river stage information; links to EMWIN, local radar, and news media outlets; rapid exchange of information among local governments; and awareness and safety information. Harris County also supports an e-mail list server, the Media Alert Notification System (MANS), which provides the latest information to more than 140 media outlets in the Houston area.

**FACT:** The Houston broadcast media indicated WFO Houston/Galveston was very accessible and user friendly prior to and during the flood event.

**FACT:** The flooding of areas outside of the historical flood plains and inexperience with sustained excessive rainfall rates of 4 to 5 inches an hour are factors that were in place on June 8-9 when most of the fatalities occurred. With the exception of the two deaths on Sunday afternoon, June 10, all of the Houston fatalities perished while a Flash Flood Warning was in effect.



Interstate 10 North Loop, Houston, Texas. (Courtesy of Harris County Flood Control District/ Steve Fitzgerald)

# Findings and Recommendations

## Warning and Forecast Services

**Finding 1:** Forecasting proved to be difficult for some small rivers/bayous that rose rapidly to record levels. Forecasts for Buffalo Bayou at Shepherd Drive in Houston underforecast the river stage by 6 to 12 feet with little or no lead time. Also, the forecasts for the West Fork of the San Jacinto River near Conroe were not accurate. Both software and procedural problems have been identified by the WGRFC and the NWS Office of Hydrologic Development as contributing to these inaccuracies.

**Recommendation 1a:** The WGRFC, with the assistance of the NWS Office of Hydrologic Development, should make the necessary software corrections and implement procedural changes needed for small basins that respond rapidly during heavy rainfall. These changes should be made by April 1, 2002.

**Recommendation 1b:** Regions should evaluate RFC procedures for small basins that respond rapidly during heavy rainfall. RFCs should be tasked with changing procedures where inadequate.

## Weather Forecast Offices

**Finding 2:** Because of the small size of the bayous in the Houston area, most are not included in the WGRFC forecast system. Harris County has initiated a project to develop new forecast tools for these small basins and has invited NWS participation in this effort. The NWS Advanced Weather Interactive Processing System (AWIPS) Release 5.1.2 includes a site-specific hydrologic model which can be used for small-gauged basins.

**Recommendation 2a:** The WFO Houston/Galveston MIC and the WGRFC HIC should meet with the appropriate Harris County officials to determine the NWS role in the project. Once the NWS role is determined, progress will be tracked through the follow-up service assessment reporting process.

**Recommendation 2b:** Once the AWIPS site-specific hydrologic model is deployed in Build 5.1.2, WFO Houston/Galveston should determine what contribution this model would make to local flood warning operations.

**Finding 3:** The WGRFC generates Mean Areal Precipitation (MAP) averages from radar rainfall estimates and observed rainfall measurements. Currently, coverage of this product does not include the Houston metropolitan area. MAP estimates would have been useful for assessing the flood risk and supplementing the analysis where gauges exist.

**Recommendation 3a:** The WGRFC should extend the MAP analysis across the Houston metropolitan area to the Texas coast.

**Recommendation 3b:** Regions should evaluate MAP coverage in their regions. RFCs should be tasked with extending MAP coverage where inadequate.

**Finding 4:** On a few occasions, the interval was excessive between the LMRFC's issuance of river forecasts and WFO New Orleans/Baton Rouge's issuance of river flood warnings and statements. At an emergency management meeting sponsored by the Amite River Basin Commission in July, there was strong customer support for more rapid dissemination of river forecasts and warnings. In response, the WFO New Orleans/Baton Rouge MIC and the LMRFC HIC have identified procedural changes and training requirements that will address this need and reduce lag time between the LMRFC and WFO issuances.

**Recommendation 4:** The WFO New Orleans/Baton Rouge MIC, with the assistance of the LMRFC HIC, should develop and implement a plan to change WFO procedures and provide training to staff to ensure rapid dissemination of river forecasts and river flood warnings.

## **Partner and Customer Coordination and Response**

**Finding 5:** Both the Harris County OEM and the Harris County Flood Control District expressed a strong need for river forecasts to be issued in reference to Mean Sea Level (MSL).

**Recommendation 5:** WFO Houston/Galveston should provide river stages in MSL in river flood warnings and statements.



# Best Practices

## 1. Contingency River Forecasts

Both the LMRFC and WGRFC issued contingency river forecasts based on worst case precipitation forecasts. In several cases, these forecast the onset of major flooding well in advance of the event. The contingency forecasts were also the basis for several river flood watches.

## 2. Internal River Flood Watch

The WGRFC produces an experimental River Flood Watch that is disseminated to the public by the WFOs. This experimental product provided information that highlighted the likelihood of a major flood. Thirteen WGRFC river flood watches were produced with an average lead time to crest of 36 hours. In the case of the San Jacinto River, an experimental River Flood Watch resulted in a lead time of almost 48 hours.

## 3. Phone Number in Warning Messages

To increase feedback, WFO Lake Charles included a phone number in its warning messages to report flooding. A staff member was assigned to handle these calls.

## 4. Flash Flood Decision Tree

A Flash Flood Decision Tree developed by WFO New Orleans/Baton Rouge proved valuable during the event and was used to make adjustments to the QPF forecasts.

## 5. Southern Region Headquarters/Public Affairs Assistance with Interviews

Local media interviews were handled by the respective field office, while national and international media interviews were conducted by SRH/ROC staff and the NOAA Public Affairs Specialist assigned to SRH. This assistance allowed the WFOs to focus their support to their local media and other partners where life-saving dissemination was critical.

## 6. WFO Pager System

The WFO Houston/Galveston staff is capable of activating the pagers of key emergency managers and government officials in their area. With Allison's rapid formation, the WFO pager system was a vital notification method for the emergency management community. This capability was used throughout the event to provide rapid dissemination of new information.



National Guardsmen leading a truck through a flooded Houston, Texas, neighborhood.  
(Courtesy of Jason Hinkel, Galveston County Office of Emergency Management, and Wayne Brown, Risk Manager for Galveston County)

# Appendix A

## Tropical Storm Allison Rainfall Storm Totals (Inches)

### **Southeast Texas Reports from WFOs Houston/Galveston and Lake Charles**

Port of Houston (Harris County)	36.99	Pennington (Houston County)	15.60
Beaumont Research (Jefferson County)	27.24	Tomball Hooks Airport (Harris County)	15.02
Pearland Clover Fld. (Brazoria County)	21.41	Hunstville (Walker County)	13.01
Houston Hobby Airport (Harris County)	20.84	Segno (Polk County)	12.99
Deer Park (Harris County)	20.50	Sugarland Airport (Fort Bend County)	12.17
Westbury (Harris County)	19.53	Newton (Newton County)	12.08
League City, NWS (Galveston County)	19.41	Alvin (Brazoria County)	11.23
Conroe (Montgomery County)	17.48	Baytown (Harris County)	9.83
Bush Intercontinental (Harris County)	16.48	Galveston (Galveston County)	9.77

### **Harris County Office of Emergency Management ALERT System**

Greens Bayou at Mt. Houston Pkwy	38.78	Garners Bayou at Beltway 8	24.72
Hunting Bayou at I-10	35.83	Buffalo Bayou at Turning Basin	22.91
Greens Bayou at Ley Road	33.66	Clear Creek at Telephone Road	22.56
Cowart Creek at Baker (Friendswood)	28.31	Greens Bayou at Bammel N Houston	20.39
Vince Bayou at W. Ellaine	26.85	Brays Bayou at Stella Link	19.76
Hunting Bayou at Lockwood	25.12	Buffalo Creek at Milam	16.02

**Southern Louisiana Reports from WFOs New Orleans/Baton Rouge and Lake Charles**

Thibodaux (Lafourche Parish)	29.86	Folsom (Saint Tammany Parish)	19.66
Salt Point (Saint Mary Parish)	27.55	Convent (Saint James Parish)	19.59
Slidell, NWS (Saint Tammany Parish)	21.35	Baton Rouge (East Baton Rouge Parish)	19.15
Gretna/Terrytown (Jefferson Parish)	21.30	St. Francisville (West Feliciana Parish)	19.11
Morgan City (Saint Mary Parish)	20.96	Paradis (Lafourche Parish)	18.45
Reserve (Saint John The Baptist Parish)	20.62	Bogalusa (Washington Parish)	17.66
Breaux Bridge (Saint Martin Parish)	20.13	Jackson (East Feliciana Parish)	17.11
Pontchatoula (Tangipahoa Parish)	20.03	New Orleans Int'l (Jefferson Parish)	14.33

# Appendix B

## Texas and Louisiana Fatalities Directly Attributed to Tropical Storm Allison

### Houston, Texas

<i>Date</i>	<i>Cause</i>	<i>Age</i>	<i>Gender</i>	<i>Circumstances</i>
6/8/01	Drowning	70	Male	In automobile
6/8/01	Drowning	38	Male	Fleeing flooded automobile
6/8/01	Drowning	34	Female	Fleeing flooded automobile
6/8/01	Drowning	21	Male	Unknown
6/9/01	Drowning	22	Male	Pickup washed into underpass
6/9/01	Electrocution	53	Female	Grabbed an antenna
6/9/01	Electrocution	30	Male	Grabbed person holding antenna
6/9/01	Drowning	57	Male	Van overturned in flood waters
6/9/01	Drowning	23	Male	Walking to friend's house
6/9/01	Drowning	65	Male	Homeless man found under bridge
6/9/01	Drowning	37	Male	Vehicle swept off bridge
6/9/01	Drowning	32	Male	Walking
6/9/01	Drowning	62	Male	Evacuation of assisted care facility
6/9/01	Drowning	55	Female	Evacuation of assisted care facility
6/9/01	Drowning	21	Male	Fleeing vehicle; rescue attempt failed
6/9/01	Drowning	35	Female	Walking
6/9/01	Drowning	44	Male	Walking
6/9/01	Drowning	52	Male	Last seen in car
6/9/01	Electrocution	45	Female	Holding iron cord
6/9/01	Drowning	42	Female	Wall of water slammed into elevator
6/10/01	Drowning	71	Male	Truck washed into ditch
6/10/01	Drowning	69	Female	Truck washed into ditch

**Mauriceville, Texas**

06/9/01	Drowning	30s	Male	Swimming in a ditch
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**3 Miles North of Zachary, Louisiana**

6/7/01	Trauma	70	Male	Small tornado knocked down tree on vehicle
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## Appendix C

### HPC Forecast Operations Branch Monthly QPF Threat Scores 24-Hour Day 1 Forecast June 2001

Precipitation Threshold	HPC Threat Score	Best Model Threat Score
0.5 inch	.333	.296 (ETA)
1.0 inch	.235	.198 (ETA)
2.0 inch	.201	.128 (ETA)
3.0 inch	.205	.015 (Aviation)

For the four increments of rainfall on the left, the table above shows a comparison of the HPC threat scores with the best threat score of the NCEP numerical forecast models. The threat score is based on the overlap between the forecast and observed areas of precipitation greater than the threshold precipitation value. If there is no overlap between the forecast and observed areas, the threat score has a value of 0, and if there is complete overlap (a perfect forecast), the value is 1. The scores are for the first 24 hours of the QPF forecast.

The HPC scores for each of the four thresholds are record high values for the month of June. The 3-inch score in June was mainly associated with Allison's rains.