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A GIS FLOOD INUNDATION MAP BASED ON A DYNAMIC WAVE (FLDWAV) SIMULATION OF THE OCTOBER, 1998 FLOOD ON THE LOWER GUADALUPE RIVER, TEXAS

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ABSTRACT

A GIS based flood inundation map has been developed to show the areal extent of the October, 1998 flood on the Lower Guadalupe River. In October, 1998, extreme rainfall occurred over this drainage basin causing catastrophic flooding. The resulting flood is considered to be one of the most recent hydrologically significant events to have occurred within the State of Texas.

Following the flood, the National Weather Service dynamic wave model (FLDWAV) was utilized to reconstruct the event. The maximum water surface elevations computed by FLDWAV were input into GIS to map the areal extent of this flood. These computed elevations were a very close approximation to the actual high water elevations which occurred during the flood at locations where river gauge information was available.

Knowledge gained from this study is being incorporated into the flood forecasting mission of the National Weather Service, West Gulf River Forecast Center, located in Fort Worth, Texas. This investigation demonstrates the potential in displaying the results of FLDWAV in a GIS environment to depict the approximate areal extent of major floods. Emergency management officials will have the opportunity to use this information as a planning tool in projecting potential flood impacts on their communities. Results demonstrate how river forecast centers might also develop first hand knowledge on what impacts their flood forecasts will have on various communities. Currently, National Weather Service river forecasts only provide stage projections at selected river points. Flood inundation mapping allows the extent of a flood to be depicted over an entire river drainage.

INTRODUCTION

The October, 1998 flood devastated parts of southeast Texas. Tragically, 31 people died. More than 10,000 homes and businesses were either destroyed or heavily damaged by flood water. Over 10,000 people were displaced, and thousands of animals drowned. Approximately 1 billion dollars in flood-related damages occurred from this flood event with an estimate of 116 million dollars attributed to the Guadalupe River Basin (AAS, 1998), (GBRA, 1999), (TWR, 2000). River flows associated with this flood were of such magnitude that they greatly exceeded the 100-year peak discharge at several locations (USGS, 1998). This flood is considered to be one of the most significant hydrologic events to have occurred within the State of Texas in recent history.

From the morning of October 17 and continuing well into October 18, torrential rainfall occurred over a large area of south central and southeast Texas. During this storm, substantial areas of both the Guadalupe and San Antonio River basins received widespread rainfall amounts of 20 inches, increasing to 30 inches in localized areas. The distribution of rainfall for this event is shown in Fig. 1.

The flood began on Saturday morning, October 17, as widespread flash flooding in the urban areas of Austin and San Antonio, and between these two cities along the eastern edge of the Texas Hill Country. By Saturday evening, the flash flooding had moved southeast toward the Texas Gulf Coast. From Saturday night into Sunday, up to a foot of additional rain fell on these same drainages as the initial flood wave moved southeastward in the downstream direction. By late Sunday, October 18, the heavy rain had tapered off. This event had now become a major river flood impacting seven Texas river basins with a total drainage area of approximately 10,000 square miles (NWS, 1998). The Guadalupe River was one of these basins and is the subject of this study.

The intense rainfall from this event produced record flows at various points along the Guadalupe River, shattering flows from previously known events. These locations, shown in Fig. 2, include the river gauges at Gonzales, Cuero and Victoria, which crested at stages of 50.44, 50.35, and 34.04 ft, respectively, with corresponding flows of 340,000, 473,000, and 466,000 cubic feet per second (cfs), respectively (Slade and Persky, 1999). The river flow at the Gonzales gauge was much greater than the 100-year peak discharge. The river flow at both the Cuero and Victoria gauges was 3-4 times greater than the 100-year peak discharge (USGS, 1998).

The rainfall event also impacted tributaries associated with the Guadalupe River. On Sandies Creek near Westhoff, the peak stage was 28.80 ft with a corresponding flow of 36,200 cfs. This was considered the 15-year peak discharge. Unfortunately, no river gauge was available for the Peach Creek near Dilworth river site. Therefore, topographic maps, information from observers concerning the areal extent of the flooding, and hydrologic and hydraulic techniques were employed to estimate a peak flow of 200,000 cfs at this location (Morris and Shultz, 1999, 2000).

Several towns along the Guadalupe River were inundated. In New Braunfels, many homes were washed off their foundations. In Seguin, Gonzales, and Victoria, several homes were flooded. The town of Cuero was the most seriously impacted, with a large percentage of the town being inundated. Numerous homes located on the west side of Cuero were either damaged and/or destroyed. Several of these homes were washed off their foundations and eventually across Highway 87. The flood, however, did not inundate the main part of the downtown business district but did reach the western edge (GBRA, 1999), (NWS, 1999), (Patton, 1998).

STUDY AREA

This study encompasses the Lower Guadalupe River drainage which is located in southeast Texas (Fig. 2). The upstream locations of the study area are the Guadalupe River at Gonzales and two tributaries, Peach Creek near Dilworth, and Sandies Creek near Westhoff. The downstream location is the Guadalupe River at Victoria. The intermediate location is the Guadalupe River at Cuero.

PROJECT SCOPE

The scope of this project consisted of two components: (1) development of a hydraulic simulation using FLDWAV on the Lower Guadalupe River for the October, 1998 flood, and (2) integration of the maximum water surface elevations computed by FLDWAV into a GIS environment to develop the flood inundation maps.

DYNAMIC WAVE (FLDWAV) SIMULATIONS

FLDWAV is a one-dimensional physically based unsteady hydraulic flow model which takes into account the physical properties of a flood wave as it propagates downstream in a river channel. FLDWAV solves a set of unsteady flow equations simultaneously to obtain the discharge and water surface elevations at each previously defined cross-section location along a river reach. FLDWAV was developed at the Hydrologic Research Laboratory of the National Weather Service, located in Silver Spring, Maryland (Fread and Lewis, 1998).

Following the October, 1998 flood, hydraulic simulations were conducted on the Lower Guadalupe River using FLDWAV. The use of a dynamic wave model, such as FLDWAV, is especially advantageous for this region due to the wide floodplains associated with this river system.

FLDWAV requires the use of both upstream and downstream boundary conditions. The upstream boundary condition consisted of flow hydrographs, measured in cubic feet per second, for the river gauges located at the Guadalupe River at Gonzales; and two tributaries, Peach Creek near Dilworth, and Sandies Creek near Westhoff. The downstream boundary condition was the stage hydrograph, measured in feet, for the river gauge located at the Guadalupe River at Victoria. The Guadalupe River at Cuero lies between the upstream and downstream locations. A schematic diagram showing the layout of these river gauges and tributaries in relation to the Lower Guadalupe River System is illustrated in Fig. 3.

Both stage and stream flow data were obtained for most of these locations from the U.S. Geological Survey (USGS). The flow hydrographs for the Westhoff, Cuero, and Victoria gauges were complete and required no adjustments. The flow and stage hydrographs at Gonzales, however, consisted of missing data since the gauge went out of service during the rising limb of the hydrograph. Because of this, the hydrograph was reconstructed using available hourly discharge data, peak flow estimates from USGS indirect measurements, and the approximate time peak flow occurred. Unfortunately, no river gauge was available for the Dilworth location. As a result, topographic maps, information from observers concerning the areal extent of the flood, and hydrologic and hydraulic synthetic techniques, were used to derive the peak flow and corresponding flow hydrograph. (Morris and Shultz, 1999, 2000)

FLDWAV also requires the use of cross-section data at numerous locations along both the main river channel and tributaries, located within the study area. Cross-section data was derived for the FLDWAV model using USGS 7.5 minute (1:24000 scale) quadrangles.

Using stage and flow hydrographs along with cross-section data, FLDWAV was executed. Flow hydrographs at the upstream locations (i.e. Gonzales, Dilworth, and Westhoff) were hydraulically routed through each river reach downstream to Cuero and Victoria. The FLDWAV model was then calibrated so the simulated elevation hydrographs made a favorable comparison to the observed elevation hydrographs at locations where stream gauge data was available. During the computational process, stage values were converted to elevations based on the datum of each streamgauge.

INCORPORATION OF FLDWAV INTO GIS

Maximum water surface elevations computed by FLDWAV were incorporated into a GIS environment to develop the flood inundation maps. Two software packages, HEC-RAS and HEC-GeoRAS, were utilized as a framework for this project in order to incorporate the results computed by FLDWAV into GIS.

HEC-RAS (Hydrologic Engineering Center-River Analysis System) was developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) in Davis, California. HEC-RAS performs one-dimensional steady and unsteady flow hydraulics (USACE-HEC, 1998). HEC-GeoRAS is an ArcView GIS extension designed to process geospatial data for use in HEC-RAS (USACE-HEC, 2000). The HEC-GeoRAS extension was developed through a Cooperative Research and Development Agreement between the Environmental Systems Research Institute, Inc. (ESRI) and the Hydrologic Engineering Center (Maidment and Snead, 2000).

ArcView GIS, in conjunction with the HEC-GeoRAS extension, was used to process 30 meter digital elevation model (DEM) data into a format which could be incorporated directly into HEC-RAS. In the next step HEC-RAS was utilized to hydraulically model the Lower Guadalupe River, computing the maximum water surface elevations at each cross-section location along the river system. These results were then incorporated back into ArcView GIS through the HEC-GeoRAS extension. Finally, these results computed by HEC-RAS were replaced with the maximum water surface elevations computed by FLDWAV in order to develop the flood inundation map for the Lower Guadalupe River, based on FLDWAV simulations.

RESULTS

The final results for both the dynamic wave (FLDWAV) and GIS flood inundation map components of this investigation are discussed below.

DYNAMIC WAVE (FLDWAV)

Hydraulic simulations computed by using FLDWAV were calibrated so simulated elevation hydrographs compared quite favorably with observed elevation hydrographs at locations where stream gauge data was available. The location of these sites (Gonzales, Dilworth, Westhoff, Cuero, and Victoria) are shown in Figure 2.

In the discussion below, the statistical terms root mean square error (RMSE) and average arithmetic error (BIAS) are defined as follows. BIAS is the mean value from a data series of differences, simulated - observed; RMSE is the square root of the mean value of a data series of squared differences (Maidment, 1993). A negative value of BIAS indicates the simulated stages are consistently smaller than the observed stages; a positive value is the reverse.

Gonzales. At Gonzales, the observed elevation hydrograph compared quite well with the simulated hydrograph (see Fig 4). The RMSE was 0.78 feet with a BIAS of -0.07 feet. The computed peak elevation was within 0.94 feet of the observed peak. This difference (computed - observed) is 2.5% of the 37.41 foot observed rise from baseflow to crest elevation. These results are very good considering the extreme nature of this flood event.

Dilworth. For Dilworth, only the simulated hydrograph is depicted in Fig. 5. Unfortunately, no stream gauge was available at this location thereby necessitating the use of hydrologic and hydraulic techniques in conjunction with an estimated high water elevation to estimate a peak flow and corresponding hydrographs. Following the execution of FLDWAV, a difference of 3.38 feet was computed between the estimated high water mark and the simulated elevation. This difference is 8.2% of the 41.3 foot observed rise from baseflow to crest elevation. These results are very reasonable in light of (1) the unavailability of stream gauge data at this location and (2) the extreme magnitude of flows associated with this record breaking catastrophic flood event.

Westhoff. At Westhoff, peak flow and corresponding surface runoff were small when compared to magnitudes estimated on both the mainstem of the Guadalupe River and Peach Creek drainages. Therefore, the impact of flows from Sandies Creek was minimal for this flood event. The observed elevation hydrograph provided a reasonable representation when compared with the simulated hydrograph (see Fig 6). The RMSE was 1.67 feet with a BIAS of -1.15 feet. The computed peak elevation was within 0.23 feet of the observed peak. This difference is 0.9% of the 25.85 foot observed rise from baseflow to crest elevation.

Cuero. At Cuero, the observed elevation hydrograph compared quite well with the simulated hydrograph (see Fig 7). The RMSE was 1.17 feet with a BIAS of 0.00 feet. The difference between the observed peak elevation and computed peak was 0.45 feet. This difference is 1% of the 45.19 foot observed rise from baseflow to crest elevation. These results are excellent considering the extreme nature of this flood event.

Victoria. At Victoria, only the observed stage hydrograph is shown in Figure 8. FLDWAV uses this observed stage hydrograph as the downstream boundary condition for the entire river reach for the computational procedures within the dynamic wave model.

GIS FLOOD INUNDATION MAPS

A flood inundation map was developed for the October, 1998 flood on the Lower Guadalupe River using maximum water surface elevations computed by FLDWAV. These computed elevations are very close to the actual high water elevations which occurred during the flood at the few locations where river gauge information was available.

During this flood, the towns of Gonzales, Cuero and Victoria suffered adverse impacts due to high water. The extent of the maximum water elevation computed by FLDWAV was determined for the towns of Cuero and Victoria. This information was not determined for Gonzales due in part to the location of the river gauge downstream of the main part of town and the fact that this location was one of the upstream boundary conditions for the FLDWAV model.

The flood inundation map for Cuero (Fig. 9) shows the approximate areas of the western and southern parts of Cuero which were inundated with flood water. This map also shows the approximate sections of the main highway (US 77A, US 183, US 87) which were impacted.

The flood inundation map for Victoria (Fig. 10) shows the approximate areas of Victoria which were inundated with flood water. Because the stream gauge located in Victoria is the downstream boundary condition of the model, FLDWAV can only estimate areas of inundation upstream of the gauge. Areas inundated with flood water downstream of the gauge were estimated based on peak stage data at the gauge and from USGS 7.5 minute (1:24000 scale) quadrangles showing areas of inundation as estimated by the USGS.

CONCLUSION

The October, 1998 flood is considered to be one of the more recent significant hydrologic events to impact the State of Texas. Maximum water surface elevations computed by a dynamic wave model (FLDWAV) were used to develop a GIS based flood inundation map for the Lower Guadalupe River Basin showing the areal extent of this flood.

Results from this investigation are being incorporated into the flood forecasting activities of the National Weather Service - West Gulf River Forecast Center. GIS based flood simulations using FLDWAV show great potential as a planning tool for emergency officials in projecting potential flood impacts on their communities. River forecast centers will also have guidance as to the impact their flood forecasts will have on various communities. Currently, National Weather Service river forecasts only provide stage projections at selected river points. Flood inundation mapping demonstrates that the extent of a flood can be depicted over an entire river drainage.

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Rainfall Distribution Map

Southeast Texas

October 17-18, 1998

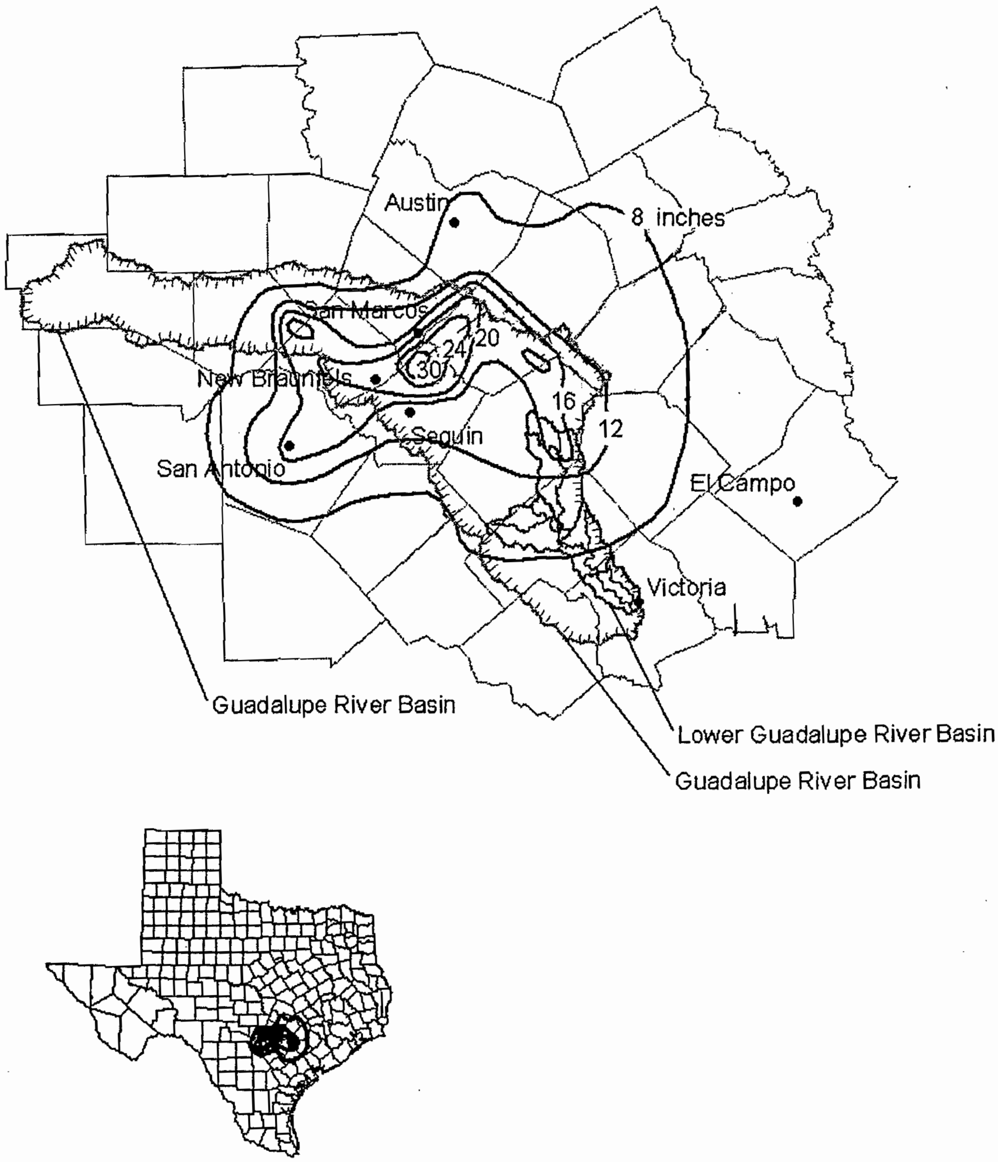


Figure 1. Rainfall Distribution Map

Location Map

Lower Guadalupe River Basin

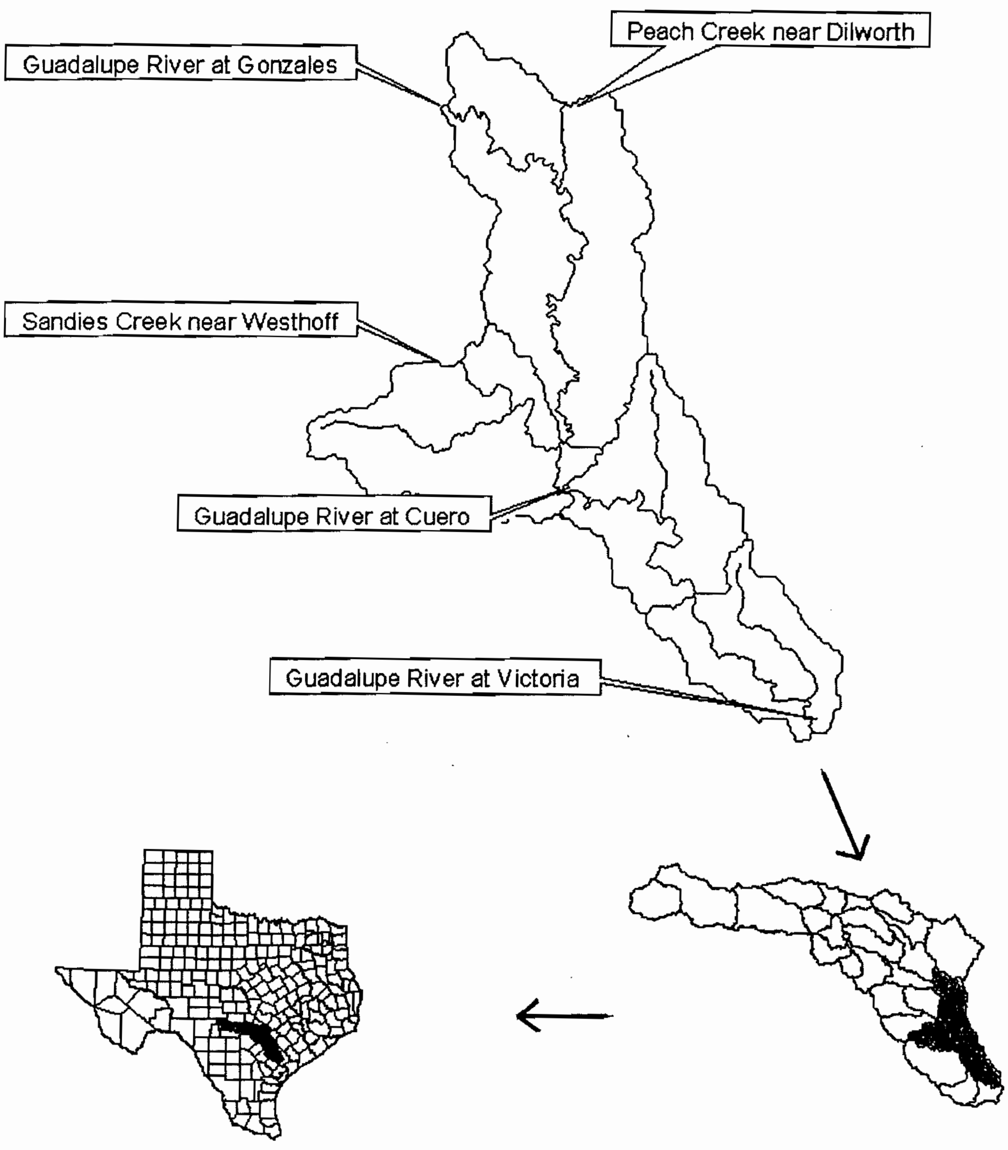


Figure 2. Location Map

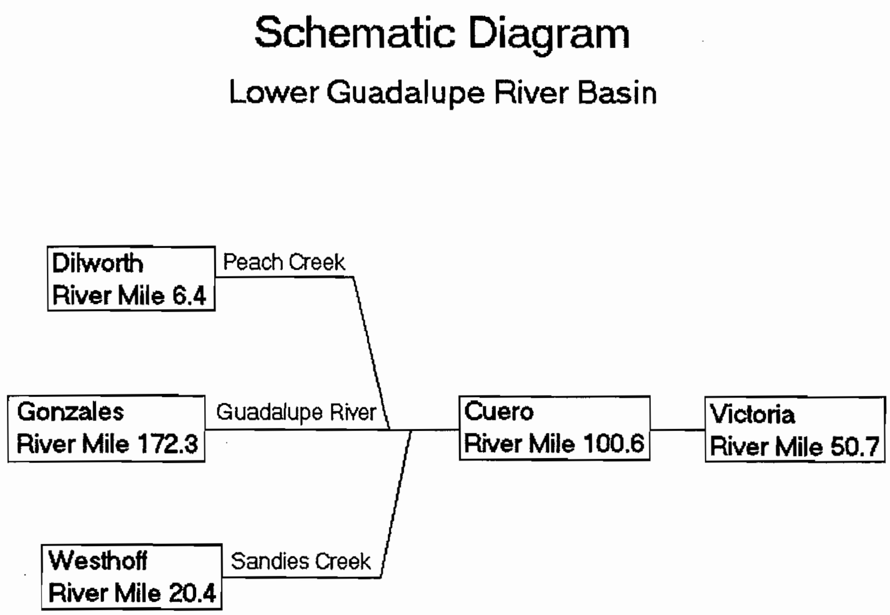


Figure 3. Schematic Diagram

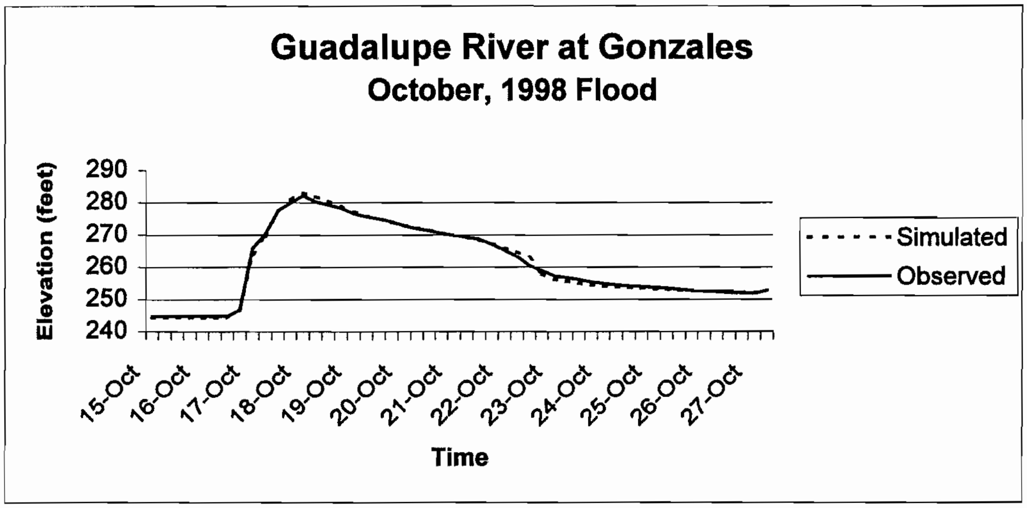


Figure 4. Elevation Hydrograph – Guadalupe River at Gonzales

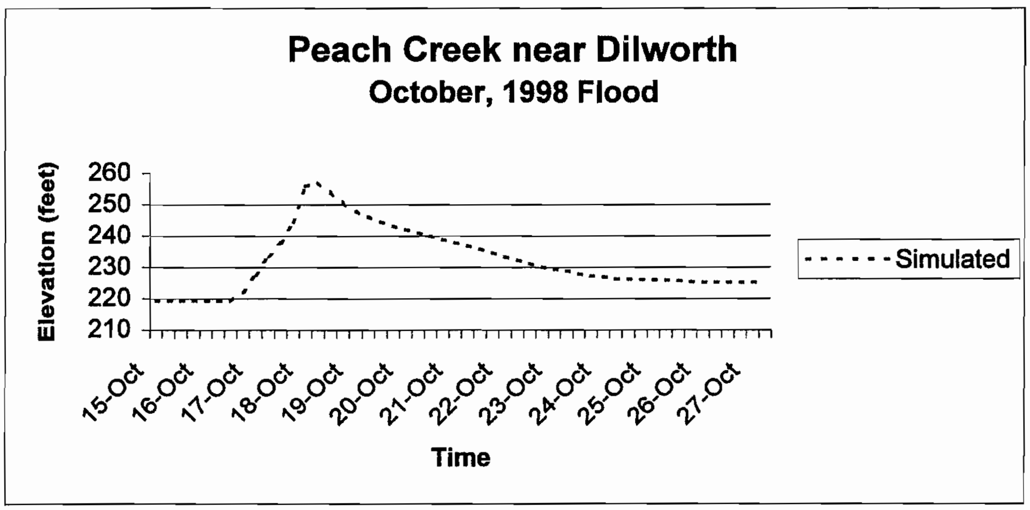


Figure 5. Elevation Hydrograph – Peach Creek near Dilworth

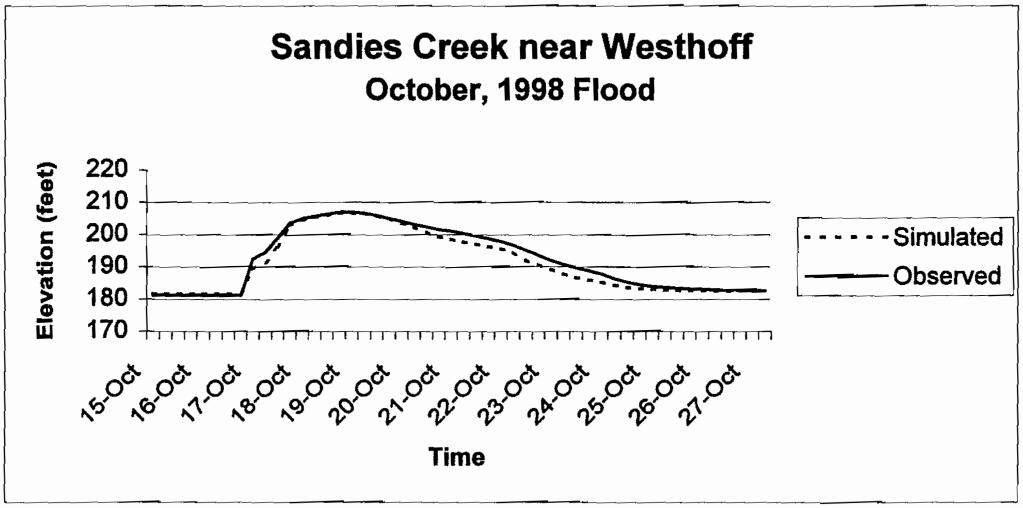


Figure 6. Elevation Hydrograph – Sandies Creek near Westhoff

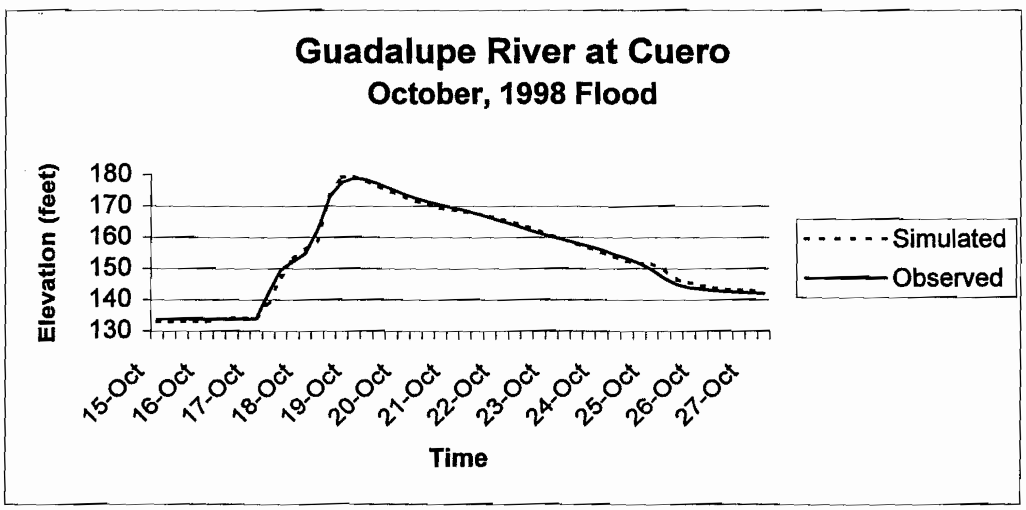


Figure 7. Elevation Hydrograph – Guadalupe River at Cuero

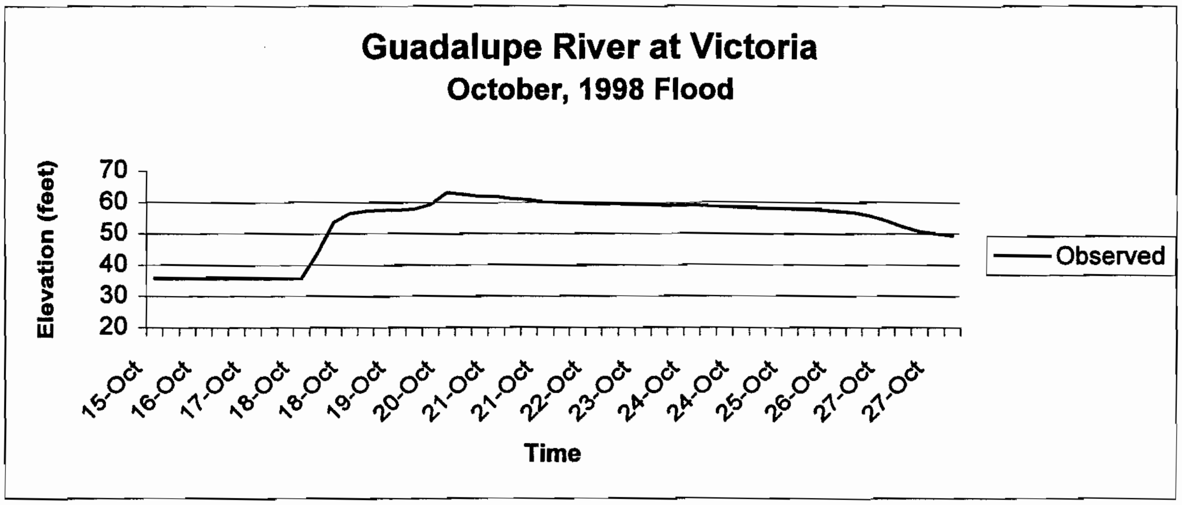
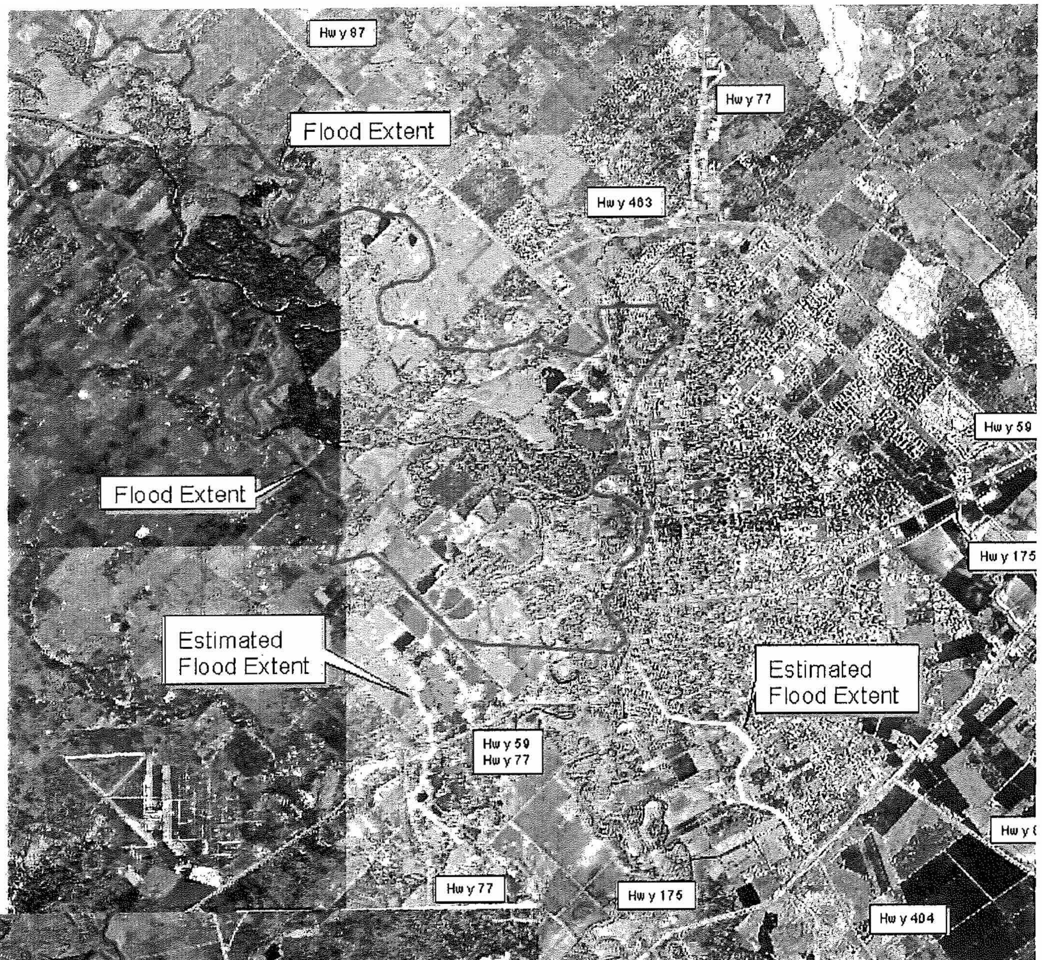


Figure 8. Elevation Hydrograph – Guadalupe River at Victoria

Figure 10. Flood Inundation Map
Victoria, Texas
October, 1998 Flood
Lower Guadalupe River
Maximum Water Surface Elevation
Dynamic Wave Model Simulation
(FLDWAV)



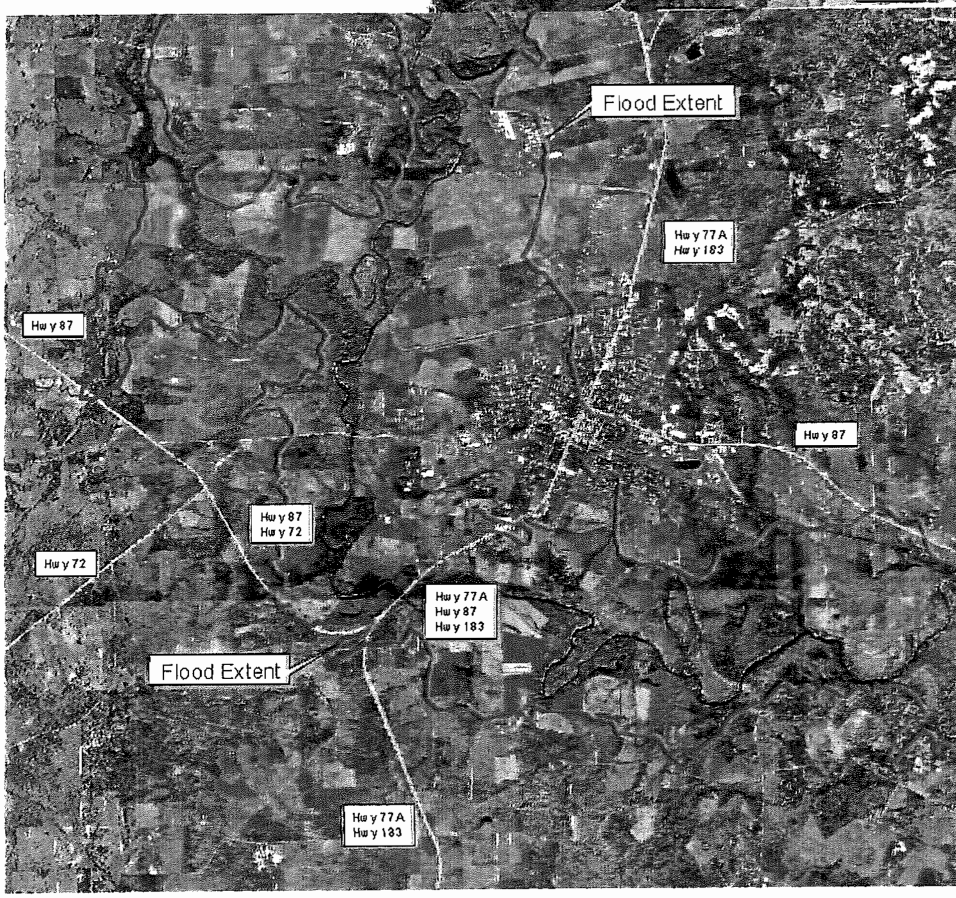


Figure 9. Flood Inundation Map
Cuero, Texas
October, 1998 Flood
Lower Guadalupe River
Maximum Water Surface Elevation
Dynamic Wave Model Simulation
(FLDWAV)