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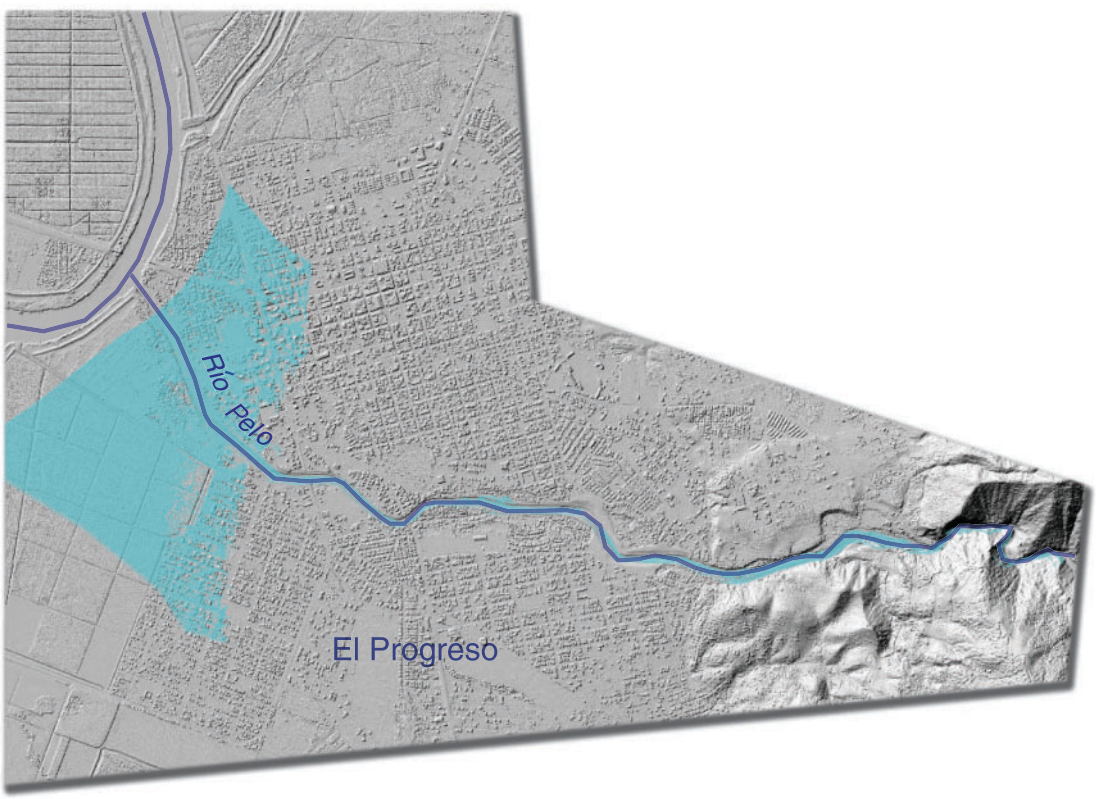
Fifty-Year Flood-Inundation Maps for El Progreso, Honduras

U.S. Geological Survey Open-File Report 02-252



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By David L. Kresch, Mark C. Mastin, and Theresa D. Olsen

U.S. GEOLOGICAL SURVEY

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Tacoma, Washington
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of the 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the municipality of El Progreso that would be inundated by a 50-year flood of Río Pelo. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of El Progreso as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the flood inundation in much more detail than is possible using the maps in this report.

Water-surface elevations for a 50-year-flood on Río Pelo at El Progreso were estimated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer program. The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of the area. There are no nearby long-term stream-gaging stations on Río Pelo; therefore, the 50-year-flood discharge for Río Pelo, 235 cubic meters per second, was estimated using a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The drainage area and mean annual precipitation estimated for Río Pelo at El Progreso are 47.4 square kilometers and 1,920 millimeters, respectively.

INTRODUCTION

In late October 1998, Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country's resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the "Great Hurricane" of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable flood-hazard maps of Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents and describes the determination of the area and depth of inundation in the municipality of El Progreso that would be caused by a 50-year flood of Río Pelo.

The 50-year flood was used as the target flood in this study because discussions with the USAID and the Honduran Public Works and Transportation Ministry indicated that it was the most common design flood used by planners and engineers working in Honduras. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equalled or exceeded once every 50 years.

Purpose, Scope, and Methods

This report provides (1) results and summary of the hydrologic analysis to estimate the 50-year-flood discharge used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharge at cross-sections along the stream profile, and (3) 50-year-flood inundation maps for Río Pelo at El Progreso showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharge, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2001). Water-surface elevations along Río Pelo were calculated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer model; and maps of the area and depths of inundation were generated from the water-surface elevations and topographic information.

The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of El Progreso and ground surveys of two bridges. Because of the high cost of obtaining the LIDAR elevation data, the extent of mapping was limited to areas of high population density where flooding is expected to cause the worst damage. The findings in this report are based on the conditions of the river channel and floodplains on March 4, 2000, when the LIDAR elevation data were collected, and March 20–21, 2000, when the bridges were surveyed.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; Roger Bendeck, a Honduran interpreter, for being an indispensable guide, translator, and instrument man during our field trips; and Nelly Solimán de Anariva of the El Progreso mayor's office, who gave us important local insights into the hydrology of and historical flooding along Río Pelo and allowed us access to the river during our field surveys.

DESCRIPTION OF STUDY AREA

Río Pelo flows through the middle of the southeastern section of El Progreso and then along the west boundary of the municipality. The study area includes the river channel and floodplains of Río Pelo from approximately 2 kilometers (km) upstream from El Progreso to Río Pelo's mouth at Río Ulua (figure 1). The study area did not include the river channel and floodplains of Río Ulua, which flows along the northwestern extent of El Progreso. However, because low lying areas in that part of El Progreso have historically been flooded by Río Ulua floodflows, the 50-year-flood stage of Río Ulua at the mouth of Río Pelo was used as the downstream boundary condition for the analyses of a 50-year flood on Río Pelo. The headwaters of Río Pelo are in the Montaña de Mico Quemado.

In October 1999, a U.S. Army Corps of Engineers project to dredge channel sediment deposited during the Hurricane Mitch flood was nearing completion. The dredging project extended from near the mouth of Río Pelo to the bridge about 3.7 kilometers upstream. A uniform floodplain terrace was carved out of the channel banks. Grasses were planted in some locations to stabilize the barren slopes of the reworked channel. By January 2001, it was noted during a field survey visit that only a sparse amount of low, brushy vegetation had invaded the channel.

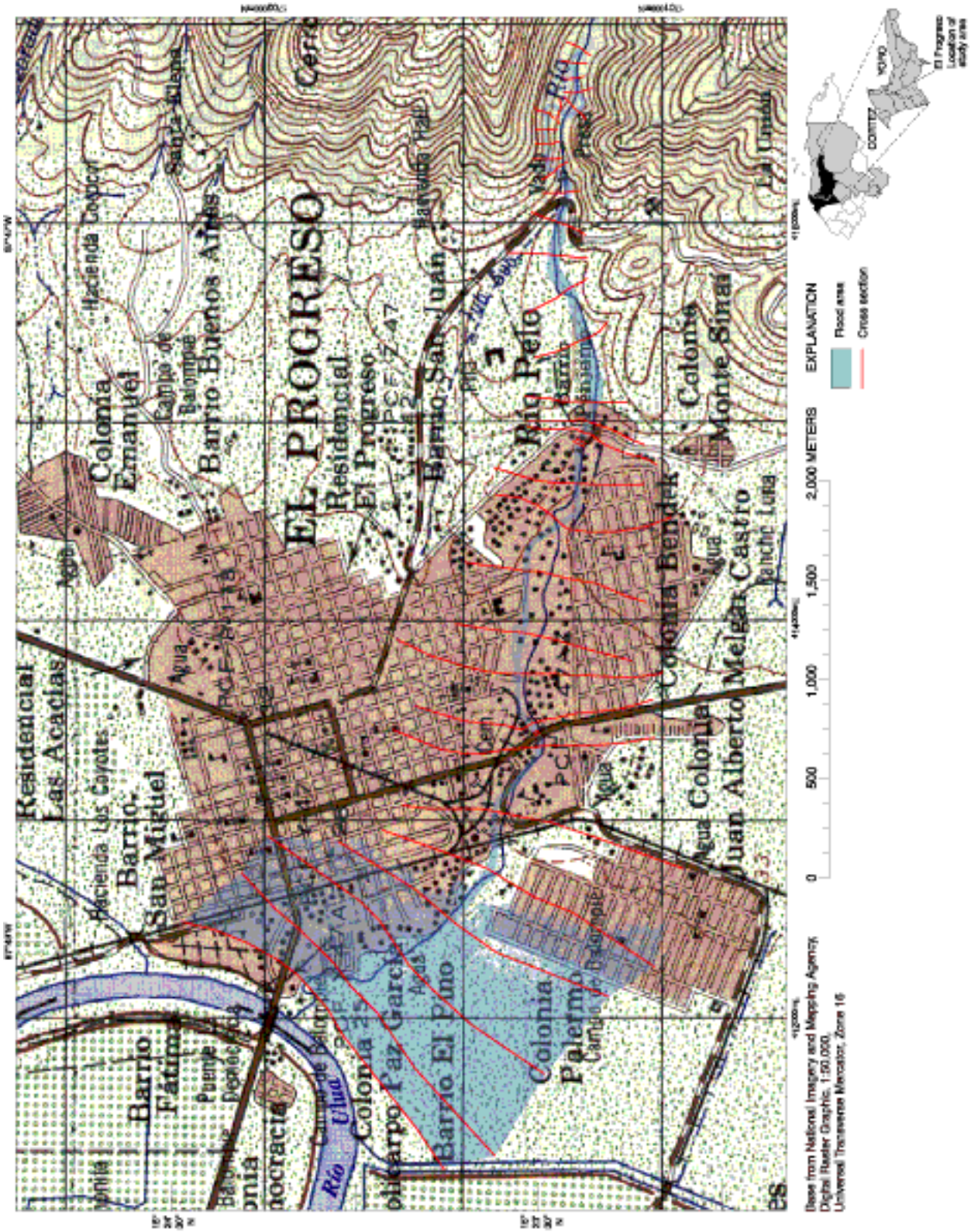

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Pelo at El Progreso, Honduras.

The streambed material ranges from sand and gravel to cobbles and small to medium boulders. As part of the dredging project, some bank armor in the form of medium to large boulders was placed along the outside bends in the lower portion of the channel cross section.

FIFTY-YEAR FLOOD DISCHARGE

There are no long-term streamflow records for Río Pelo. Therefore, the 50-year-flood discharge was estimated using the following regression equation, which was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record, that relates the 50-year peak flow with drainage basin area and mean annual precipitation (Mastin, 2001).

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\ , \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent

The drainage area of Río Pelo at El Progreso was determined to be 47.4 km^2 using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution from the U.S. National Imagery and Mapping Agency (David Stewart, USGS, written commun., 1999). The mean annual precipitation over the Río Pelo drainage basin was determined to be 1,920 mm using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997–1998, p. 15). The DEM and mean annual precipitation map also were used to determine the drainage area (20,600 km^2) and mean annual precipitation (1,630 millimeters) of Río Ulua at the mouth of Rio Pelo.

The 50-year-flood discharges estimated from equation 1 for Río Pelo at El Progreso and Río Ulua at the mouth of Rio Pelo are 235 and 6,500 m^3/s, respectively.

WATER-SURFACE PROFILES OF THE 50-YEAR FLOOD

Once a 50-year flood discharge has been estimated, a profile of water-surface elevations along the course of the river can be estimated for the 50-year flood with a step-backwater model, and later used to generate the flood-inundation maps. The U.S. Army Corps of Engineers HEC-RAS modeling system was used for step-backwater modeling. HEC-RAS is a one-dimensional, steady-flow model for computing water-surface profiles in open channels, through bridge openings, and over roads. The basic required inputs to the model are stream discharge, cross sections (geometry) of the river channels and floodplains perpendicular to the direction of flow, bridge geometry, Manning's roughness coefficients (n values) for each cross section, and boundary conditions (U.S. Army Corps of Engineers, 1998).

Cross-section geometry was obtained from a high-resolution DEM created from an airborne LIDAR survey. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 4, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 539 points in the El Progreso study area. The mean difference between the two sets of elevations is 0.100 meter, and the standard deviation of the differences is 0.112 meter. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a "bare earth" elevation representation of the floodplain. The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution. The coverage was then processed into a triangular irregular network (TIN) GIS coverage. Cross sections of elevation data oriented across the floodplain perpendicular to the expected flow direction of the 50-year-flood discharge (figure 1) were obtained from the TIN using HEC-GeoRAS, a pre- and post-processing GIS program designed for HEC-RAS (U.S. Army Corps of Engineers, 2000). The underwater portions of the cross sections cannot be seen by the LIDAR system. However, because the LIDAR surveys were conducted during a period of extremely low flows, the underwater portions were assumed to be insignificant in comparison with the cross-sectional areas of flow during a 50-year flood; therefore, they were not included in the model.

A reconnaissance visit to the study area was made on October 20, 1999, to determine whether there were any bridges over Río Pelo that needed to be surveyed for inclusion in the HEC-RAS model. As a result of that visit, the geometry of two bridges; the bridge on the highway heading south out of El Progreso located about 2.1 km upstream from the mouth of Río Pelo, and a city-street bridge located about 3.7 km upstream from the mouth, was surveyed during a March 20–21, 2000, field visit.

Most hydraulic calculations of flow in channels and overbank areas require an estimate of flow resistance, which is generally expressed as Manning's roughness coefficient, *n*. The effect that roughness coefficients have on water-surface profiles is that as the *n* value is increased, the resistance to flow increases also, which results in higher water-surface elevations. Roughness coefficients for the moderately steep downstream reach of Río Pelo (cross sections 0.179 to 2.617), where the channel slope is less than 1 meter per 100 meters of stream channel, were estimated from digital photographs taken during the reconnaissance of October 20, 1999, from field observations and digital photographs taken during the field visit on March 20–21, 2000, to survey the geometry of the two bridges, and from computer displays of shaded-relief images of the LIDAR-derived DEM before the vegetation removal filter was applied. The *n* values estimated for the main channel of the downstream reach of Río Pelo ranged from 0.035 to 0.050, and the *n* values estimated for the floodplain areas ranged from 0.060 to 0.080.

Manning's *n* values for the steep upstream reach of Río Pelo (cross sections 2.935 to 6.083), where the channel slope exceeds 2 meters per 100 meters of stream channel, were calculated using an equation for estimating roughness coefficients for steep streams (Jarrett, 1985, p.35). The *n* values estimated for the main channel of the upper reach of Río Pelo ranged from 0.064 to 0.151, and the *n* values estimated for the floodplain areas ranged from 0.060 to 0.080.

Step-backwater computations require a water-surface elevation as a boundary condition at either the downstream end of the stream reach for flows in the subcritical flow regime or at the upstream end of the reach for flows in the supercritical flow regime. Initial HEC-RAS simulations indicated that the flow in the downstream reach of Río Pelo would be in the subcritical flow regime. Therefore, the boundary condition used was a water-surface elevation at cross section 0.179, the farthest downstream cross section in the Río Pelo step-backwater model. The water-surface elevation at the mouth of Río Pelo during high flow conditions on Río Ulua is controlled by the water-surface elevation of Río Ulua at the mouth of Río Pelo. In October 1999, when the flood level of the Río Ulua at Chinda gaging station, located about 26 km upstream from El Progreso, peaked at about flood stage, the stage of Río Ulua near the mouth of Río Pelo is estimated to have been about 26 meters. The flow in Río Pelo at the time of the Río Ulua flooding was estimated to be only about 5 m^3/s. The peak stage of 26 meters near the mouth of Río Pelo, which is about 1 meter higher than the 50-year-flood level of Río Pelo at its mouth without the effects of concurrent flooding on Río Ulua, caused shallow flooding near the west boundary of El Progreso along Río Ulua.

It is probably unlikely that a 50-year flood on Río Ulua, which drains about 20,600 km^2, would occur at the same time as a 50-year flood on Río Pelo, which drains only 47.4 km^2. However, because such an eventuality is possible and would result in worse flooding than that caused by just a 50-year flood on Río Pelo, the downstream boundary condition used was the 50-year-flood water-surface elevation on Río Ulua at the mouth of Río Pelo. A HEC-RAS model of Río Ulua beginning 1.9 kilometers downstream from the mouth of Río Pelo was used to estimate the Río Ulua 50-year-flood elevation. The 50-year-flood discharge of Río Ulua was estimated from equation 1 to be 6,500 m^3/s using a mean annual precipitation of 1,630 millimeters. The topographic information available to define the Río Ulua cross sections used in the HEC-RAS model was limited mostly to the main channel, which is bounded by levees. These cross sections were insufficient to allow water-surface profiles with various starting elevations to converge because all the profiles were above the Río Ulua levee, which has an elevation of about 30 meters near the mouth of Río Pelo. Once the levee is overtopped water-surface elevations are not likely to increase substantially because the Río Ulua floodplain is extremely wide. Therefore, the 30-meter elevation of the top of the levee was considered to be a reasonable estimate of the 50-year-flood water-surface elevation and was used as the downstream boundary condition for the Río Pelo HEC-RAS model.

The Río Pelo HEC-RAS model was also run without the effects of concurrent flooding on Río Ulua. The boundary condition for this run, 25.01 meters, was estimated by a slope-conveyance computation assuming an energy gradient of 0.0027, which was estimated to be equal to the slope of the main channel bed. The computed water-surface elevations at the first few cross sections upstream may differ from the true elevations if the estimated boundary condition elevation is incorrect. However, if the error in the estimated boundary condition is not large, the computed profile asymptotically approaches the true profile within a few cross sections.

The step-backwater model provided estimates of water-surface elevations at all cross sections for the 50-year-flood discharge on Río Pelo (table 1 and figure 2). The water-surface elevations estimated for the 50-year-flood on Río Pelo without the effects of concurrent flooding on Río Ulua are given in table 2. Comparison of tables 1 and 2 show that the backwater effects of Río Ulua extend only about 1.5 kilometers upstream on Río Pelo. However, higher Río Ulua flood levels, such as those produced during Hurricane Mitch, may affect flood levels farther upstream on Río Pelo. The peak stage of Río Ulua at Chinda during Hurricane Mitch was about 11.5 meters above flood stage.

Table 1. Estimated water-surface elevations for the 50-year-flood concurrent with a flood stage of 30 meters on Río Ulua near the mouth of Río Pelo, for cross sections along Río Pelo at El Progreso, Honduras

[Peak flow for the 50-year flood is 235 cubic meters per second. **Cross-section stationing**: distance upstream from model boundary or river confluence; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
6.083	143.85	3.78	146.91
5.994	139.86	4.05	143.74
5.912	137.28	3.38	140.63
5.839	134.35	3.31	138.23
5.735	130.22	3.67	135.05
5.626	126.22	4.64	128.98
5.521	118.36	2.16	124.22
5.429	115.40	5.66	120.74
5.356	107.50	10.11	110.19
5.273	106.71	2.36	110.79
5.189	103.47	4.71	107.68
5.064	89.17	6.44	92.76
4.899	83.34	2.27	86.34
4.731	77.64	2.41	80.84
4.510	73.07	2.25	76.09
4.237	66.69	2.84	70.21
3.919	59.68	2.75	63.47
3.817	58.23	3.04	61.32
3.758	56.42	3.57	59.26
3.711	54.20	2.59	57.93
3.708 (bridge)			
3.696	54.20	3.43	57.17
3.490	49.52	2.87	53.67
3.254	44.49	4.30	46.91
2.935	36.56	3.00	41.36
2.617	35.21	2.83	39.25
2.403	34.41	3.08	37.55
2.123	32.07	3.48	35.24
2.073	31.80	3.42	34.99
2.070 (bridge)			
2.058	31.80	5.63	33.87
1.995	31.53	4.06	34.00
1.591	28.15	3.67	30.94
1.291	26.65	2.51	30.05
0.970	25.05	1.17	30.04
0.662	23.90	0.76	30.02
0.347	23.09	0.66	30.01
0.179	22.59	0.63	30.00

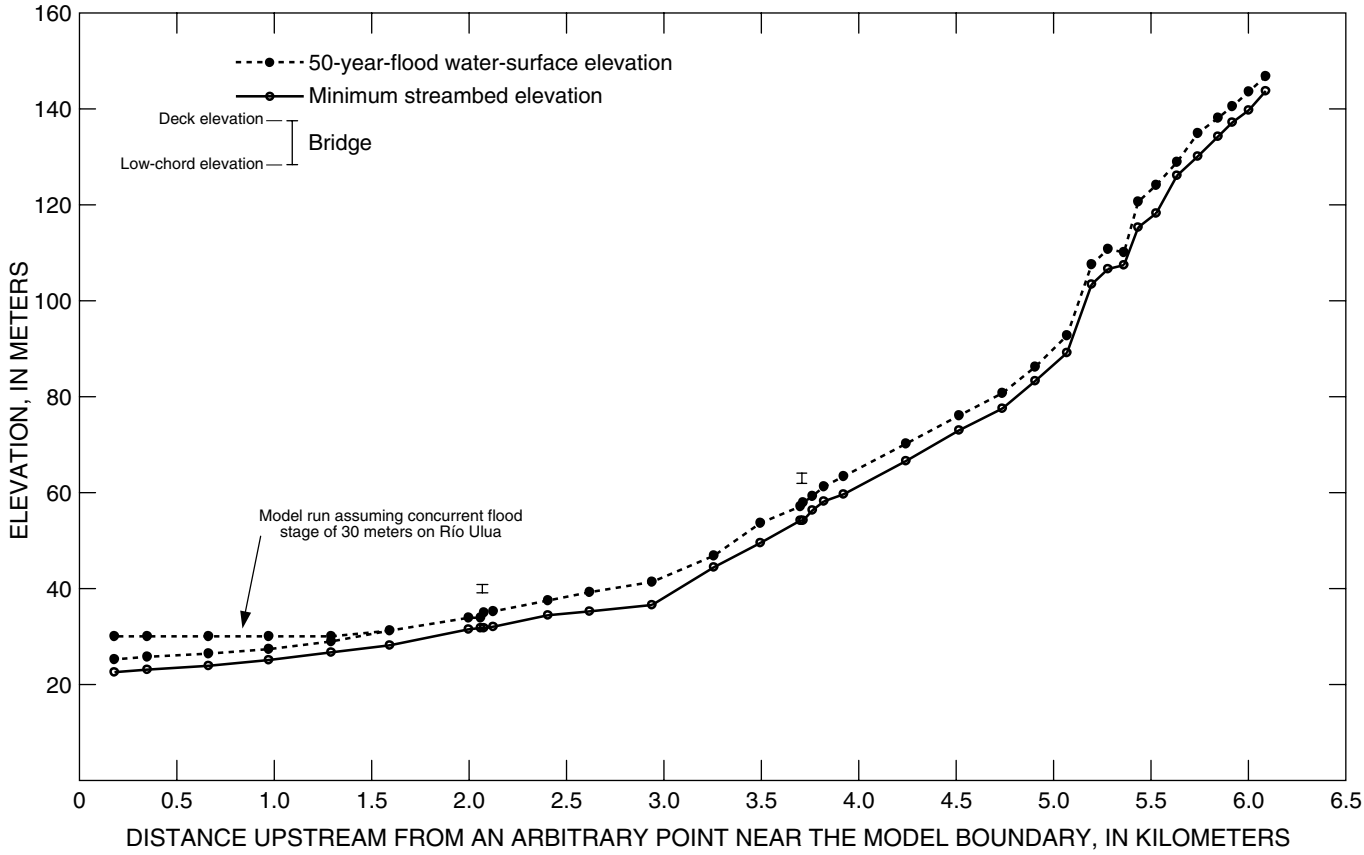

Figure 2. Water-surface profiles, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Pelo at El Progreso, Honduras.

Table 2. Estimated water-surface elevations for the 50-year-flood, without concurrent flooding on Río Ulua, for cross sections along Río Pelo at El Progreso, Honduras

[Peak flow for hte 50-year flood is 235 cubic metets per second. **Cross-section stationing**: distance upstream from an arbitrary point near the model boundary; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
6.083	143.85	3.78	146.91
5.994	139.86	4.05	143.74
5.912	137.28	3.38	140.63
5.839	134.35	3.31	138.23
5.735	130.22	3.67	135.05
5.626	126.22	4.64	128.98
5.521	118.36	2.16	124.22
5.429	115.40	5.66	120.74
5.356	107.50	10.11	110.19
5.273	106.71	2.36	110.79
5.189	103.47	4.71	107.68
5.064	89.17	6.44	92.76
4.899	83.34	2.27	86.34
4.731	77.64	2.41	80.84
4.510	73.07	2.25	76.09
4.237	66.69	2.84	70.21
3.919	59.68	2.75	63.47
3.817	58.23	3.04	61.32
3.758	56.42	3.57	59.26
3.711	54.20	2.59	57.93
3.708 (bridge)			
3.696	54.20	3.43	57.17
3.490	49.52	2.87	53.67
3.254	44.49	4.30	46.91
2.935	36.56	3.00	41.36
2.617	35.21	2.83	39.25
2.403	34.41	3.08	37.55
2.123	32.07	3.48	35.24
2.073	31.80	3.42	34.99
2.070 (bridge)			
2.058	31.80	5.63	33.87
1.995	31.53	4.22	33.93
1.591	28.15	3.16	31.25
1.291	26.65	4.19	28.93
0.970	25.05	2.79	27.44
0.662	23.90	2.43	26.48
0.347	23.09	2.23	25.72
0.179	22.59	2.38	25.28

FIFTY-YEAR FLOOD-INUNDATION MAPS

The results from the step-backwater hydraulic model were processed by the computer program HEC-GeoRAS to create GIS coverages of the area and depth of inundation for the study area. The GIS coverage of area of inundation was created by intersecting the computed water-surface elevations with the topographic TIN that was produced from the LIDAR data. This coverage was then overlain on an existing 1:50,000 topographic digital raster graphics map (figure 1) produced by the National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). Depth of inundation at El Progreso for a 50-year-flood on Río Pelo (figure 3) was computed by subtracting the topographic TIN from a computed water-surface elevation TIN to produce a grid with a cell size of 2 meters.

The blue line depicting the centerline of the Río Pelo channel on the digital raster graphics map used as the base map for figure 1 lies outside the 50-year-flood boundaries at some locations. This probably results from changes in the river course as a result of flood flows that occurred after the map was created, especially those that resulted from Hurricane Mitch.

The flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Pelo floodplain. This tool can reasonably separate high-hazard from low-hazard areas in the floodplain to minimize future flood losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location can affect the area and depth of inundation. Also, encroachment into the floodplain with structures or fill will reduce flood-carrying capacity and thereby increase the potential height of floodwaters, and may also increase the area of inundation.

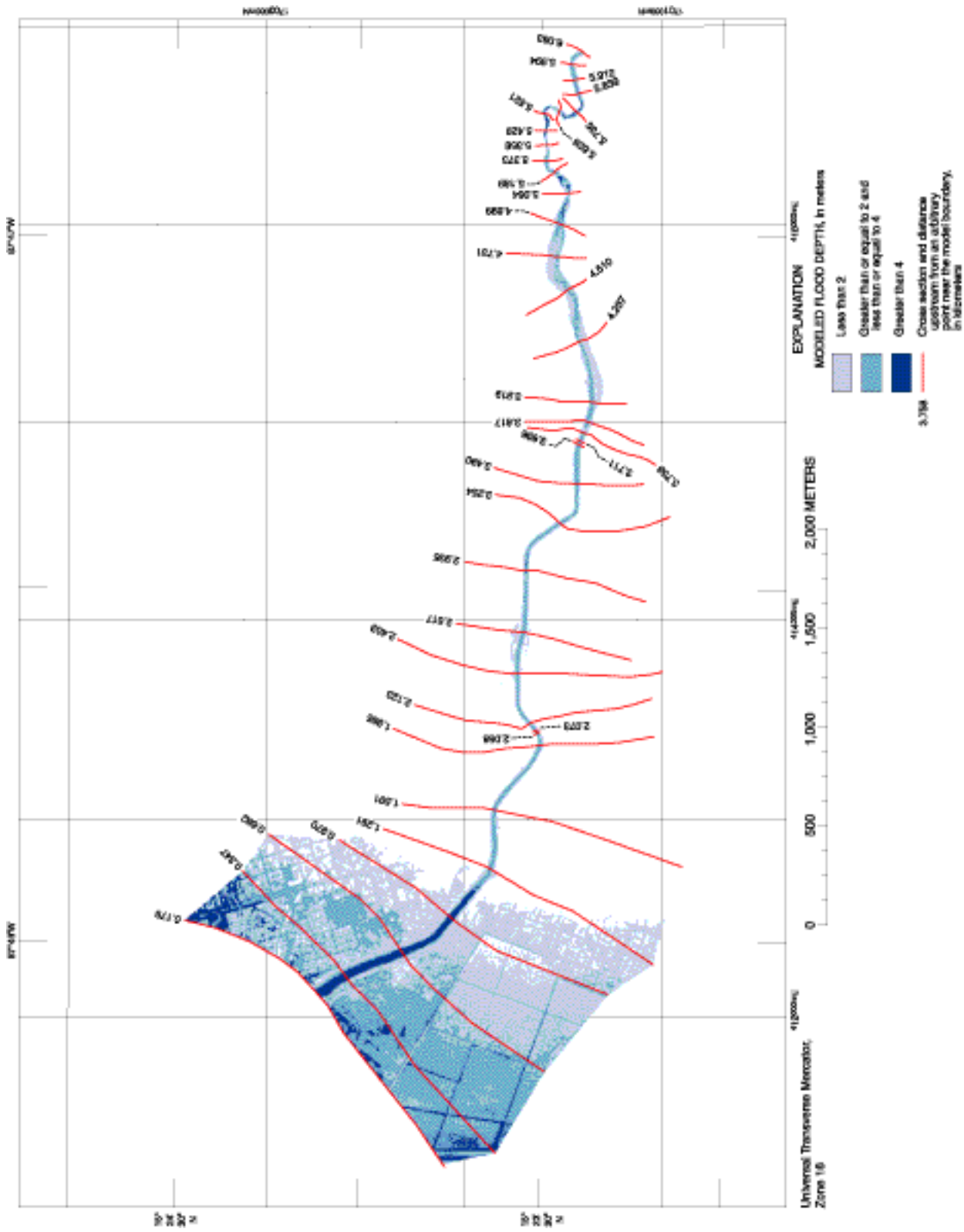

Figure 3. Depth of inundation of the 50-year flood and location of cross sections on Río Pelo at El Progreso, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 3 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the El Progreso municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 3. The GIS project will also allow users to overlay other GIS coverages over the inundation and flood-depth boundaries to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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