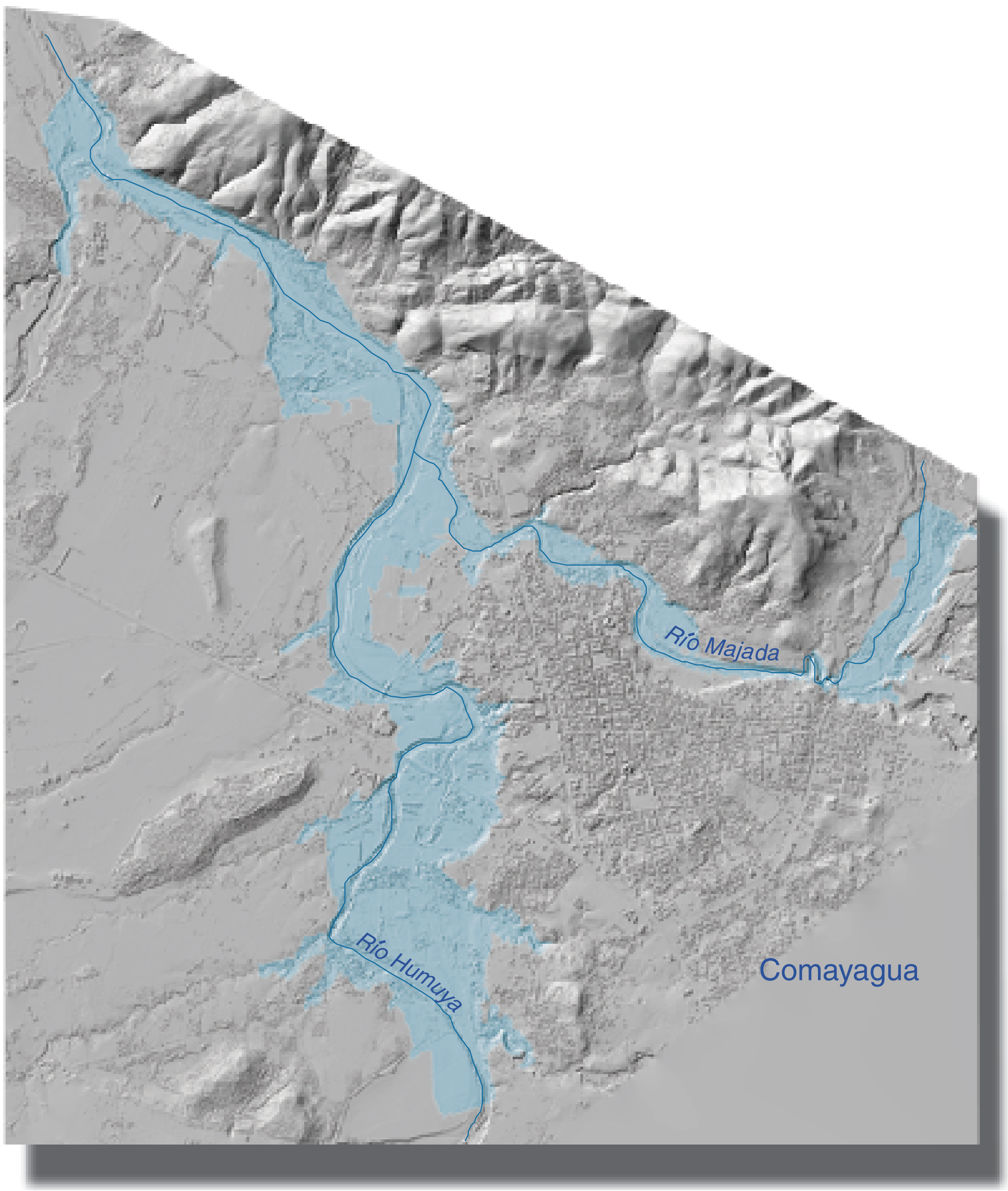
Prepared in cooperation with the U.S Agency for International Development

Fifty-Year Flood-Inundation Maps for Comayagua, Honduras

U.S. Geological Survey Open-File Report 02-251



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U.S. Department of the Interior
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Fifty-Year Flood-Inundation Maps for Comayagua, Honduras

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

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-251

Prepared in cooperation with the
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Tacoma, Washington
2002

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Information Services
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Box 25286, Federal Center
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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 Comayagua that would be inundated by 50-year floods on Río Humuya and Río Majada. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of Comayagua 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 50-year-floods on Río Humuya and Río Majada at Comayagua 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.

The 50-year-flood discharge for Río Humuya at Comayagua, 1,400 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 reasonableness of the regression discharge was evaluated by comparing it with drainage-area-adjusted 50-year-flood discharges estimated for three long-term Río Humuya stream-gaging stations. The drainage-area-adjusted 50-year-flood discharges estimated from the gage records ranged from 946 to 1,365 cubic meters per second. Because the regression equation discharge agrees closely with the high end of the range of discharges estimated from the gaging-station records, it was used for the hydraulic modeling to ensure that the resulting 50-year-flood water-surface elevations would not be underestimated.

The 50-year-flood discharge for Río Majada at Comayagua (230 cubic meters per second) was estimated using the regression equation because there are no long-term gaging-stations on this river from which to estimate the discharge.

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 (mm) 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 Comayagua that would be caused by 50-year floods on Río Comayagua and Río Majada.

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 equaled 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 discharges used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharges at cross sections along the stream profiles, and (3) 50-year-flood inundation maps for Río Humuya and Río Majada at Comayagua showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharges, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2002). Water-surface elevations along Río Humuya and Río Majada 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 Comayagua and ground surveys at two bridges. Because of the high cost of obtaining 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 channels and floodplains on March 10, 2000, when the LIDAR data were collected, and March 18, 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 representatives of the mayor's office, who gave us important local insights into the hydrology of and historical flooding along Río Humuya and Río Majada and allowed us access to the rivers during our field surveys.

DESCRIPTION OF STUDY AREA

Río Humuya flows in a northerly direction near the western boundary of Comayagua, and Río Majada, a Río Humuya tributary, flows in a northwesterly direction along the northern boundary of Comayagua. Río Humuya, which originates in the Montaña de Yerba Buena to the south, has a moderately steep gradient through the study reach. Río Majada, which flows from the Montaña de Comayagua to the east, has a steep slope throughout the study reach. The study area includes the channel and floodplains of Río Humuya from approximately 2 kilometers (km) upstream to 4 km downstream from Comayagua, and the channel and floodplains of Río Majada from approximately 1 km upstream from Comayagua to its mouth at Río Humuya (figure 1).

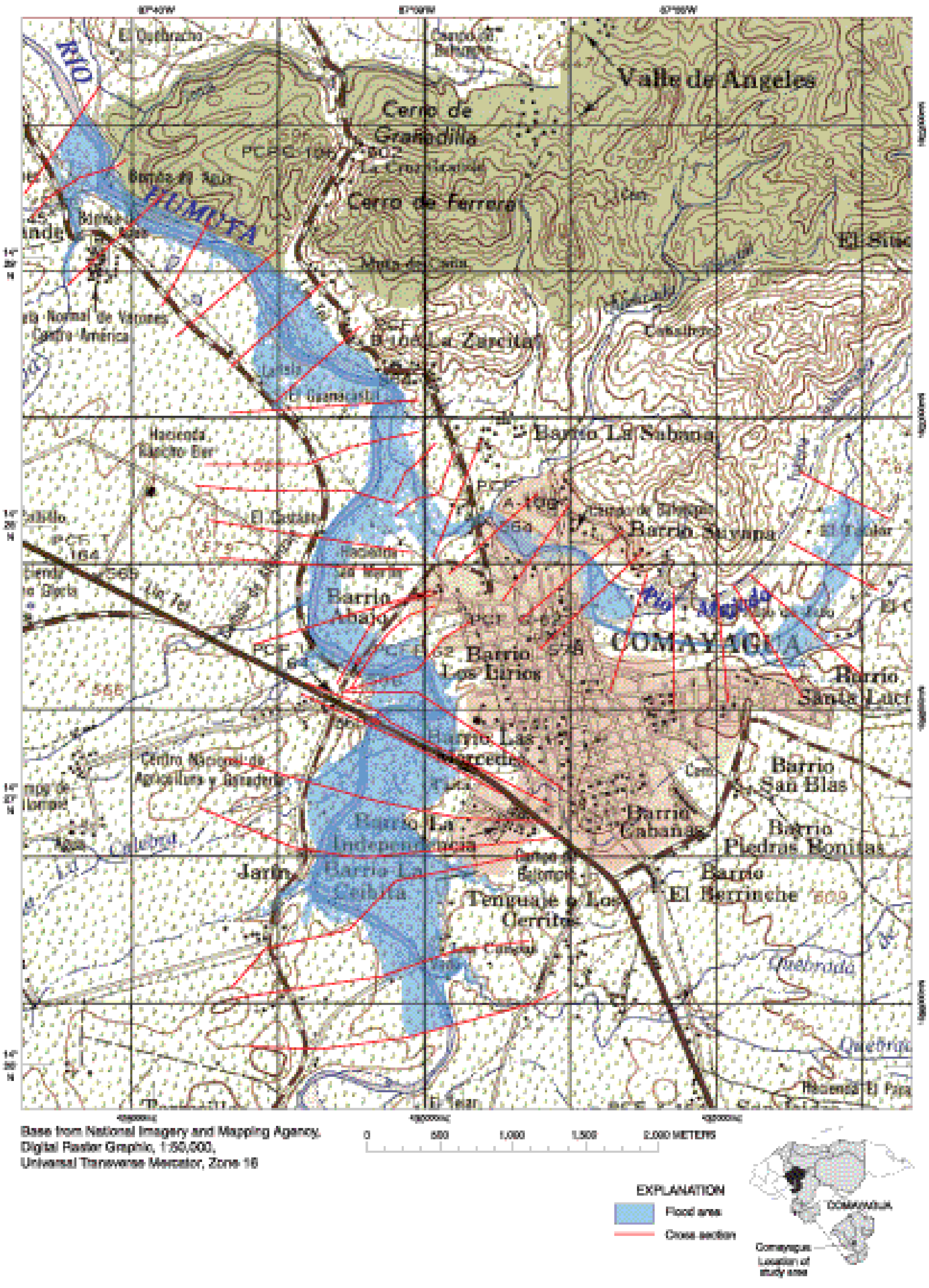

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Humuya and Río Majada at Comayagua, Honduras.

The Río Humuya streambed material consists primarily of sand and gravel with some cobbles. The Río Majada streambed material consists primarily of gravel with some cobbles and a few small to medium boulders. The main channel banks and floodplains of both Río Humuya and Río Majada are generally covered with dense vegetation.

FIFTY-YEAR FLOOD DISCHARGE

Estimates of 50-year-flood discharges for Río Humuya and Río Majada were made 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 to drainage basin area and mean annual precipitation (Mastin, 2002).

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

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 areas of the Río Humuya and Río Majada river reaches in the study area were computed 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 river reach drainage basins was calculated 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 drainage area, mean annual precipitation, and 50-year-flood discharge estimated from equation 1 for each river reach are shown below.

River reach	Drainage area (km^2)	Mean annual precipitation (mm)	50-year discharge (m^3/s)
Río Humuya upstream from Río Majada	1,480	1,493	1,360
Río Majada	59	1,591	230
Río Humuya downstream from Río Majada	1,542	1,497	1,400

These discharges were used in the computation of the 50-year-flood water-surface profiles.

The 50-year-flood discharges for Río Humuya estimated from the regression equation were compared for reasonableness with 50-year discharges estimated using frequency analyses of streamflow records from three Río Humuya gaging stations operated by Secretaría de Recursos Naturales y Ambiente (SERNA), the national natural resource agency in Honduras. The length of record, drainage area, 50-year peak flow determined by frequency analysis of the annual peak-flow discharges, and weighted 50-year peak flow for each of these gaging stations are as follows.

Gaging station name	Length of record (years)	Drainage area (km^2)	50-year peak flow estimated by indicated method	
			Frequency analysis (m^3/s)	Regression weighted average (m^3/s)
Río Humuya en Las Higueras	30	1,117	632	685
Río Humuya en La Encantada	38	2,058	918	963
Río Humuya en Guacamya	21	2,621	2,386	2,320

The weighted discharges are the weighted averages of the discharges estimated using frequency analysis and the regression equation. The weights used in computing the weighted discharges were inversely proportional to the variance of the individual estimates. Weighted averages generally provide better estimates of true flood discharges than those determined from either a flood-frequency analysis or a regression equation alone.

The ratios of the drainage area of Río Humuya at Comayagua to the drainage area at each of the streamflow stations were used to estimate 50-year-flood discharges for Río Humuya at Comayagua from the 50-year peak flows at the gaging stations. The drainage-area-adjusted 50-year-flood discharges thus determined from the gaging-station discharges are as follows.

Gaging station name	50-year flood discharge (m^3/s)
Río Humuya en Las Higueras	946
Río Humuya en La Encantada	722
Río Humuya en Guacamya	1,365

The discharges estimated for Río Humuya at Comayagua from the “en Las Higueras” and “en La Encantada” gaging-station records are considerably less than the discharges estimated from the regression equation (1,360 m^3/s to 1,400 m^3/s), but the discharge determined from the “en Guacamya” record agrees closely with the regression results. Therefore, the discharges estimated by the regression equation were used for the hydraulic modeling to ensure that the resulting 50-year-flood water-surface elevations would not be underestimated. If the 50-year-flood discharges estimated from the “en Las Higueras” and “en La Encantada” gaging-station records are more representative of the true 50-year-flood discharge of Río Humuya at Comayagua, then the true water-surface elevations would probably be significantly lower than those calculated in this study.

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 10, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 1,091 points in the Comayagua study area. The mean difference between the two sets of elevations is 0.143 meter, and the standard deviation of the differences is 0.089 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 field visit of the study area on October 23, 1999, indicated that two bridges over Río Humuya at Comayagua needed to be surveyed for inclusion in the HEC-RAS model. The geometry of those bridges was surveyed on March 18, 2000. The only Río Majada bridge visited during the field visit on October 23, 1999, was one located about midway between cross-sections 0.833 and 1.343. That bridge was not surveyed for inclusion in the HEC-RAS model because a visual observation indicated that it probably would not cause any significant contraction of flood flows. Computer displays of shaded-relief images of the LIDAR-derived DEM before any vegetation removal filter was applied indicate that there is a bridge of about equal size between cross-sections 1.688 and 2.061, and two bridges, located just upstream from cross-sections 2.061 and 2.751, that appear to be much smaller. Because it is unknown if any of these bridges would constrict flood flows, the water-surface elevations computed by the model may be too low upstream of these bridges.

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 were estimated from field observations and digital photographs taken during the field visits on October 23, 1999, and March 18, 2000, and from computer displays of shaded-relief images of the LIDAR-derived DEM before the vegetation removal filter was applied. The *n* value estimated for the main channel of the Río Humuya was 0.035, and the *n* values estimated for the floodplain areas ranged from 0.045 to 0.065. The *n* value estimated for the main channel of Río Majada was 0.040, and the *n* values estimated for the floodplain areas ranged from 0.050 to 0.065.

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 Río Humuya would be in the subcritical flow regime. Therefore, the boundary condition used was a water-surface elevation at cross section 0.346, the farthest downstream cross-section in the Río Humuya step-backwater model. This elevation, 546.89 meters, was estimated by a slope-conveyance computation assuming an energy gradient of 0.00274, 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 discharges (tables 1-2, and figures 2-3). The computed flood elevations in the lower reach of Río Majada may be a little high because it is unlikely that 50-year floods would occur simultaneously on both Río Majada and Río Humuya. The water-surface elevation at Río Humuya bridge cross-section 6.912 is above the low chord elevation of the bridge. Although the model did not indicate that the bridge was causing a significant constriction of flow, even a minor increase in the flood elevation at the bridge could cause the bridge to be overtopped, which could easily result in the failure of the bridge.

Table 1. Estimated water-surface elevations for the 50-year-flood on Río Humuya at Comayagua, Honduras

[Peak flow for the 50-year flood is 1,360 cubic meters 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)
9.615	555.97	2.34	562.88
9.132	555.40	1.59	562.74
8.601	554.97	1.47	562.36
7.948	554.12	1.76	561.77
7.462	553.03	2.15	561.04
6.956	552.96	3.14	560.30
6.922	552.21	3.10	560.28
6.912 (bridge)			
6.902	552.21	3.23	560.03
6.850	552.45	3.39	559.88
6.482	552.11	1.92	559.80
6.145	551.65	2.82	559.34
5.718	551.32	3.35	558.47
5.675	550.14	3.75	558.24
5.665 (bridge)			
5.655	550.14	3.82	558.12
5.612	551.61	4.12	557.87
5.268	551.15	3.26	557.31
4.851	550.49	2.86	556.80
4.661	550.38	2.75	556.40
4.255	549.92	3.46	555.31
3.827	550.34	3.07	553.99
3.560	548.64	2.60	553.59
2.965	547.68	3.23	552.13
2.555	545.88	2.75	551.46
2.166	544.75	2.36	550.93
1.722	544.62	4.43	549.20
1.312	543.92	2.73	548.58
0.829	542.64	1.85	548.22
0.346	541.27	3.83	546.89

Table 2. Estimated water-surface elevations for the 50-year-flood on Río Majada at Comayagua, Honduras

[Peak flow for the 50-year flood is 230 cubic meters per second. **Cross-section stationing**: distance upstream from confluence with Río Humuya; **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)
5.318	617.58	2.73	619.17
4.816	607.30	3.40	609.17
4.352	599.25	1.93	600.96
4.026	593.64	2.85	595.63
3.399	583.19	4.63	586.80
3.069	580.50	4.31	583.06
2.751	577.00	3.60	579.30
2.389	573.69	2.57	575.60
2.061	569.51	3.30	572.29
1.688	565.83	3.28	568.06
1.343	562.88	2.44	564.57
0.833	557.70	1.70	560.38
0.475	554.98	3.11	557.10
0.244	552.75	1.85	555.59

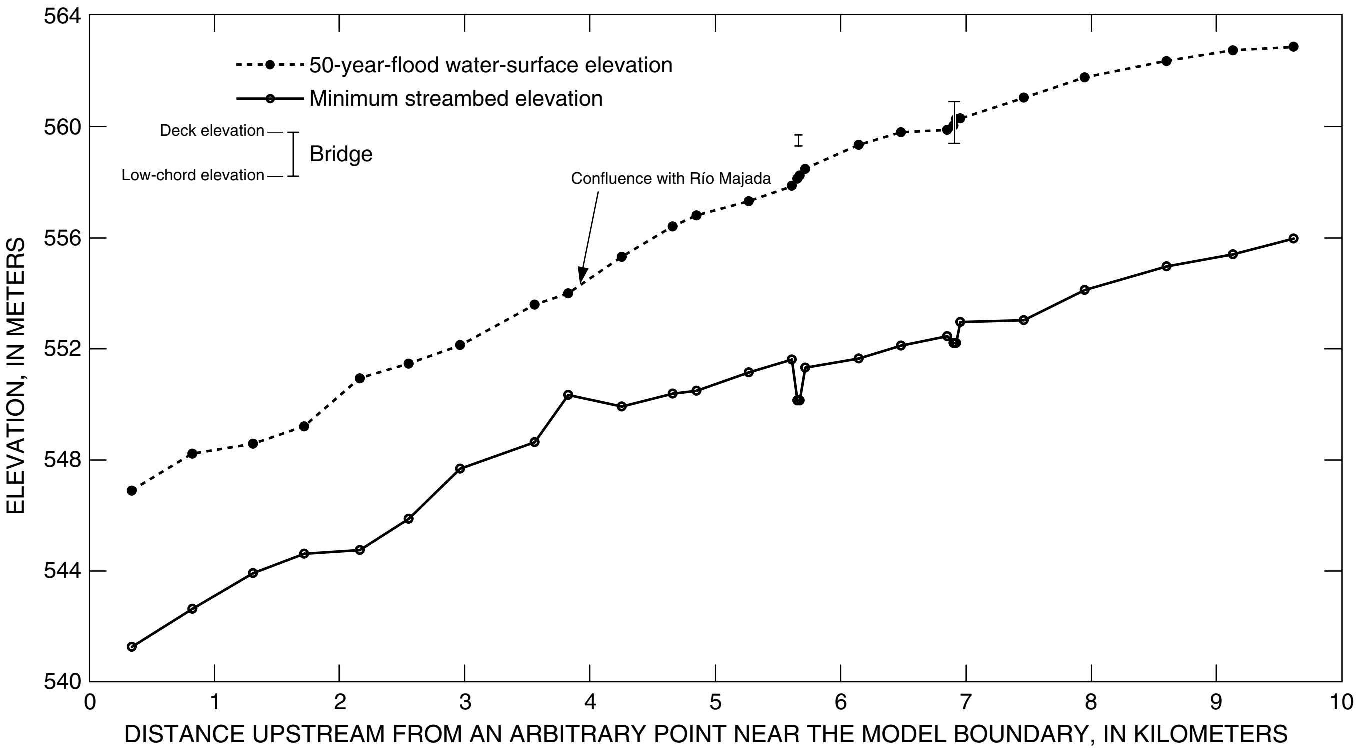

Figure 2. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Humuya at Comayagua, Honduras.

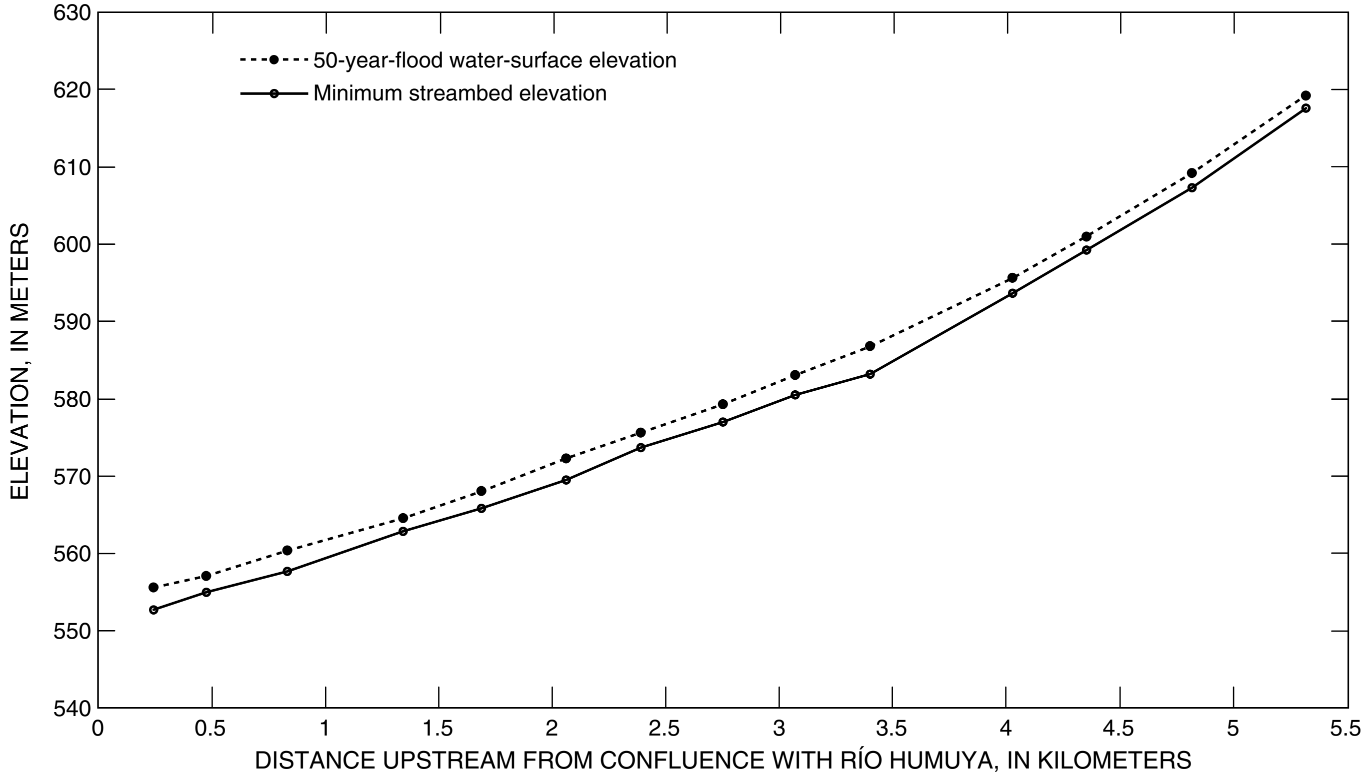

Figure 3. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Majada at Comayagua, Honduras.

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 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 Comayagua for 50-year-floods on Río Humuya and Río Majada (figure 4) 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 flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Humuya and Río Majada floodplains. 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 floodplains 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.

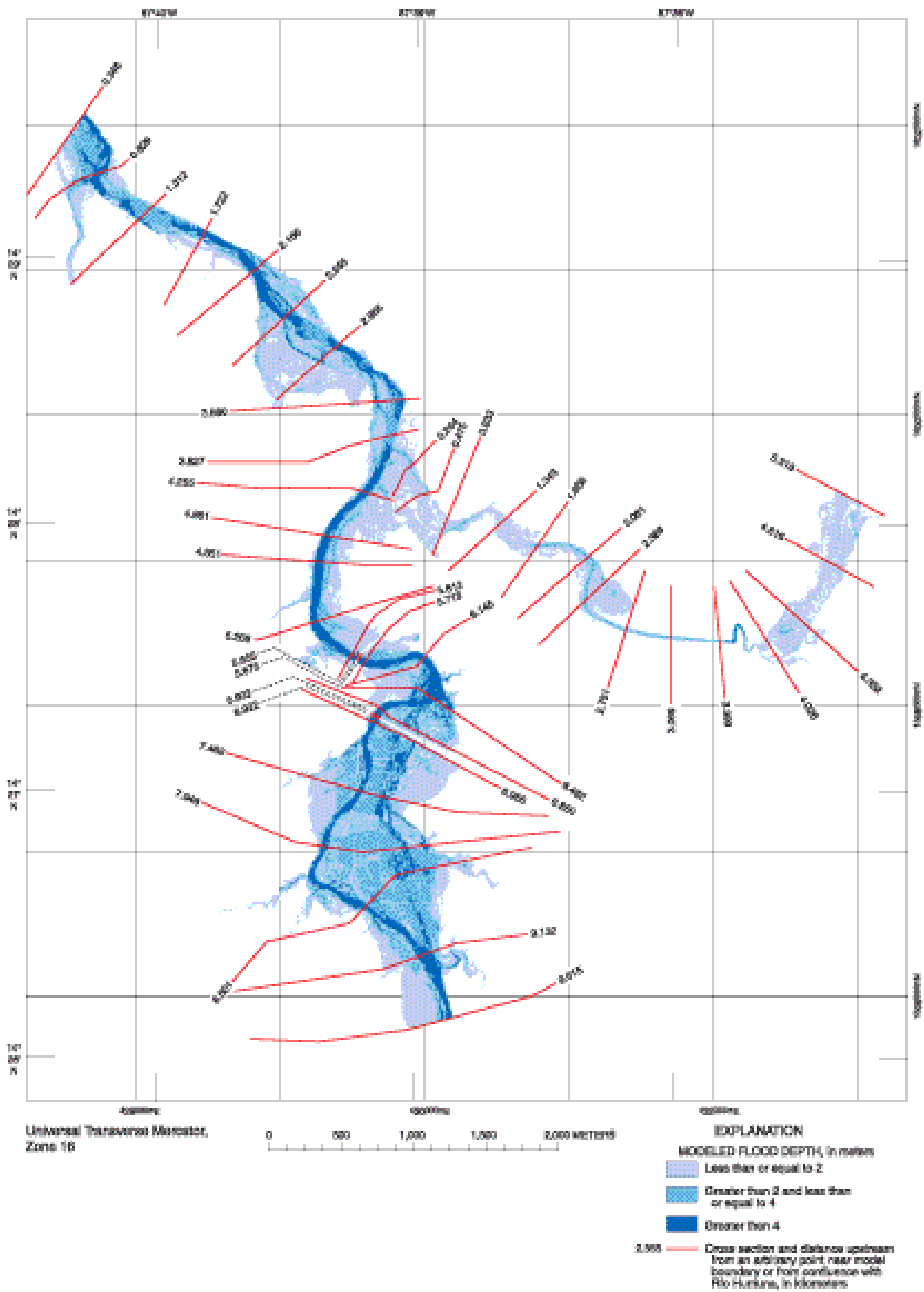

Figure 4. Depth of inundation of the 50-year flood and location of cross sections on Río Humuya and Río Majada at Comayagua, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 4 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 Comayagua municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 4. 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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