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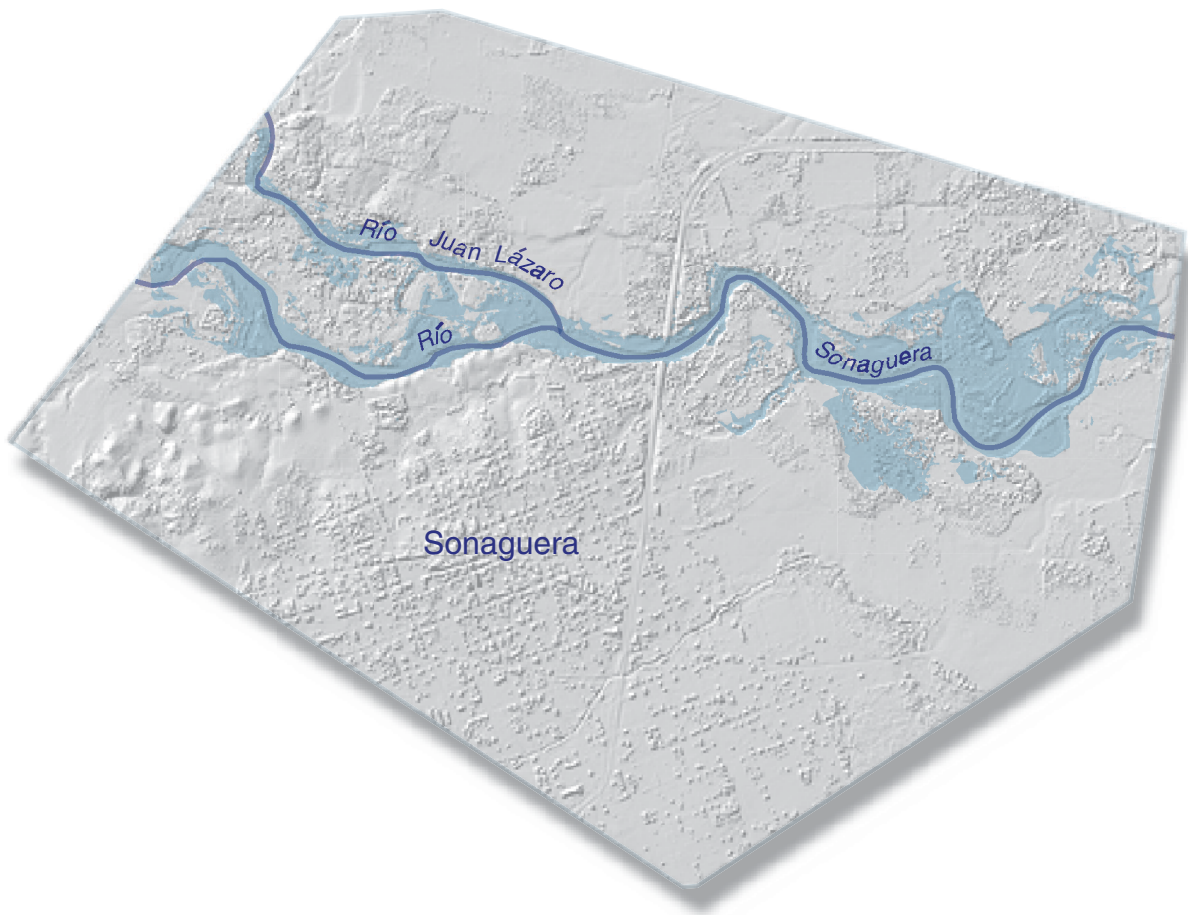
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Fifty-Year Flood-Inundation Maps for Sonaguera, Honduras

U.S. Geological Survey Open-File Report 02-260

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

U.S. GEOLOGICAL SURVEY

Open-File Report 02-260

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

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

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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 Sonaguera that would be inundated by a 50-year flood of Río Sonaguera and its tributary, Río Juan Lázaro. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of Sonaguera 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 an estimated 50-year-flood on Río Sonaguera and Río Juan Lázaro at Sonaguera were determined 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 and a ground survey at the bridge. There are no nearby long-term stream-gaging stations on Río Sonaguera or Río Juan Lázaro; therefore, the 50-year-flood discharge for Río Sonaguera above the confluence with Río Juan Lázaro, 194 cubic meters per second; for Río Juan Lázaro at its mouth, 168 cubic meters per second, and for Río Sonaguera at the downstream end of the study area, 282 cubic meters per second; were estimated using a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation.

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 in 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 Sonaguera that would be caused by a 50-year flood of Río Sonaguera and Río Juan Lázaro.

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 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 profile, and (3) 50-year-flood inundation maps for Río Sonaguera and Río Juan Lázaro at Sonaguera 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 (2002). Water-surface elevations along Río Sonaguera and Río Juan Lázaro were calculated using a HEC-RAS, 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 the model were developed from a LIDAR topographic survey of Sonaguera and ground surveys at the bridge. Because of the high cost of obtaining the LIDAR elevation data, the extent of mapping was limited to areas of high population where flooding is expected to cause the worst damage. The findings in this report are based on the condition of the river channel and floodplains on March 12, 2000, when LIDAR data were collected, and January 15, 2001, when the bridge was surveyed.

Acknowledgments

DESCRIPTION OF STUDY AREA

The study area includes Río Sonaguera, which flows in an easterly direction near the northern boundary of the city of Sonaguera, and Río Juan Lázaro, which empties into Río Sonaguera just north of Sonaguera. The headwaters of both of these rivers are in the Montaña Mico Blanco range. The study area includes the channel and flood plains of Río Sonaguera and Río Juan Lázaro from approximately 1 kilometer (km) upstream to 2 km downstream from Sonaguera (figure 1).

The streambed material consists primarily of sand and gravel with a few small cobbles. The main channel banks and floodplains are generally covered with dense trees and brush. Much of the overbank area has been cultivated as orange orchards. During Hurricane Mitch, it was reported that the river did not flood the town, but it was bankful and there was concern about erosion of the stream bank into residential areas (Carlos Alberto Morazan, mayor of Sonaguera, oral commun., October 1999).
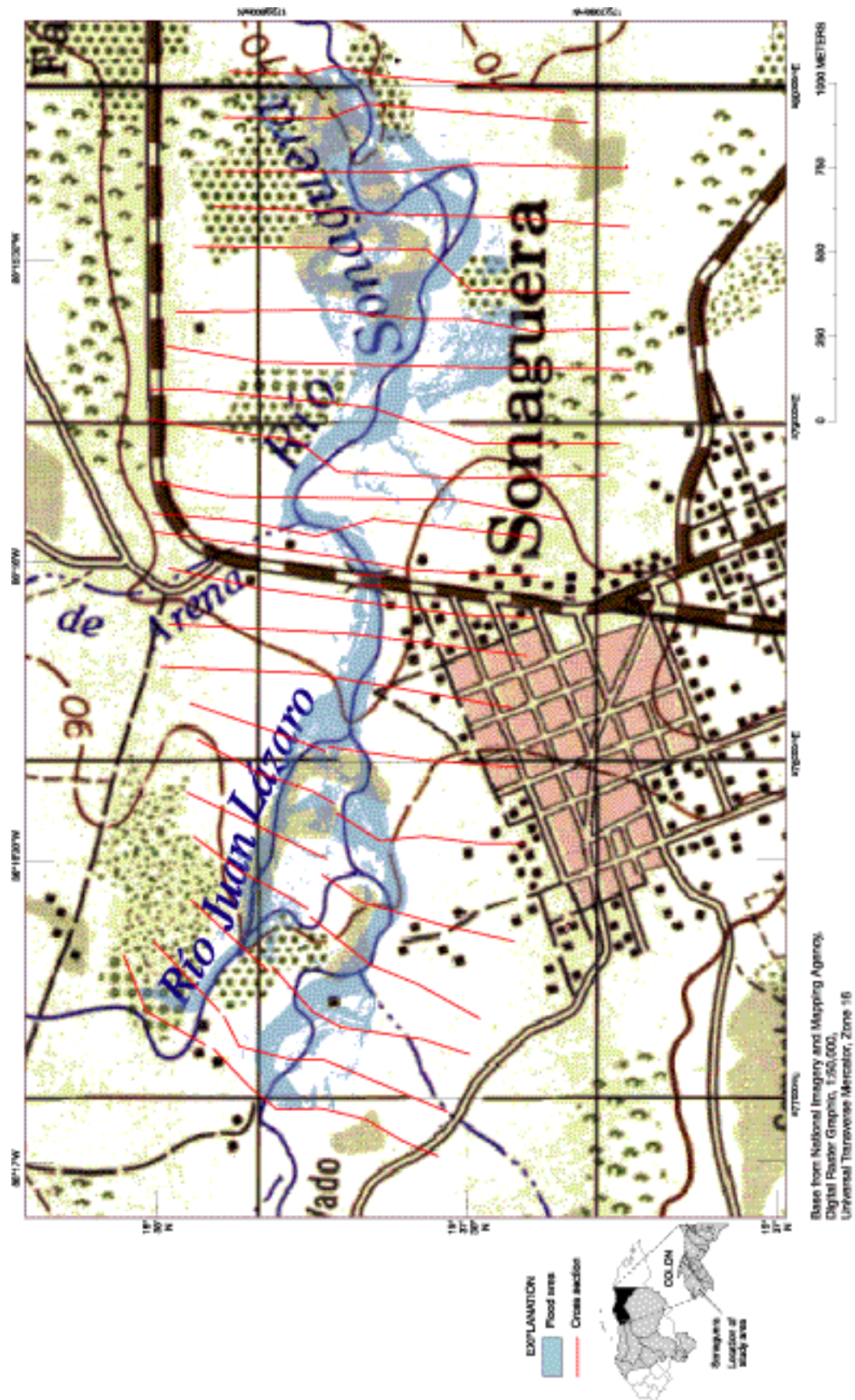
Figure 1. Map showing Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Sonaguera at Sonaguera, Honduras.

FIFTY-YEAR FLOOD DISCHARGE

There are no long-term streamflow records for either Río Sonaguera or Río Juan Lázaro. Therefore, the 50-year flood discharges were estimated (table 1) 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.

Drainage areas (table 1) were determined 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). Mean annual precipitation (table 1) was determined 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 50-year-flood discharges estimated from equation 1 are given in table 1 for the Sonaguera study area. The sum of the 50-year-flood discharges at the confluence of the two streams is greater than the discharge of the outflow because 50-year floods are not likely to occur simultaneously on all streams.

Table 1. Drainage area, mean annual precipitation, and estimated discharge for the 50-year flood for Río Sonaguera and Río Juan Lázaro at Sonaguera, Honduras

[**Abbreviations**: km^2, square kilometers; mm, millimeters; m^3/s, cubic meters per second]

Stream reach	Drainage area (km^2)	Mean annual precipitation (mm)	50-year-flood discharge (m^3/s)
Río Sonaguera upstream of Río Juan Lázaro	40.3	1,681	194
Río Juan Lázaro	26.6	1,897	168
Río Sonaguera downstream of Río Juan Lázaro to downstream end of study area	72.7	1,774	282

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 numerical, 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 12, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 1,285 points in the Sonaguera study area. The mean difference between the two sets of elevations is 0.029 meter, and the standard deviation of the differences is 0.110 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 TINs 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 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 in October, 1999, indicated that the bridge on the main road through Sonaguera was the only bridge that needed to be surveyed for inclusion in the HEC-RAS model. The geometry of that bridge was surveyed in January 2001.

Most hydraulic calculations of flow in channels and overbank areas require an estimation 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 profiles. Roughness coefficients (Manning's *n*) for Río Sonaguera and Río Juan Lázaro were estimated from field observations and digital photographs taken during January 2001 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 ranged from 0.030 to 0.040, and the *n* values estimated for the floodplain areas ranged from 0.040 to 0.060.

Step-backwater computations require a water-surface elevation 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 as a boundary condition. A water-surface elevation of 72.49 meters at cross section 0.068, the farthest downstream cross-section on the Río Sonaguera step-backwater model, was estimated by a slope-conveyance computation assuming an energy gradient of 0.002. The energy gradient 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. At the mouth of the upper Río Sonaguera and the mouth of the Río Lázaro, the boundary condition is the 50-year-flood water-surface elevation at the first downstream cross section (cross section 2.556) with the assumption that flow is subcritical. Since the 50-year flow would probably not occur simultaneously for both rivers, the boundary condition and the water-surface elevations for the lower portion of the Río Lázaro are probably a little high.

The step-backwater model provided estimates of water-surface elevations at all cross sections for the 50-year discharge (table 2 and figures 2 and 3).

Table 2. Estimated water-surface elevations for the 50-year flood on Río Sonaguera and Río Juan Lázaro at Sonaguera, Honduras

[**Cross-section stationing**: distance upstream from an arbitrary point near the 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^3/s, cubic meters per second]

| Cross-section stationing (km)	50-year peak flow (m^3/s)	Minimum channel elevation (m)	Average velocity (m/s)	Water-surface elevation (m)
Río Sonaguera				
4.123	194	79.75	1.85	81.74
3.916	194	78.80	2.33	80.93
3.720	194	78.61	2.10	80.24
3.483	194	77.48	2.38	79.24
3.316	194	76.85	1.62	79.03
3.101	194	76.11	1.62	78.75
2.814	194	74.96	3.48	77.55
Mouth of Río Juan Lázaro				
2.556	282	74.16	1.40	77.62
2.415	282	74.23	1.81	77.41
2.317	282	73.86	3.41	76.74
2.253	282	73.17	1.31	76.73
2.248 (Bridge)				
2.233	282	73.17	1.33	76.71
2.181	282	73.66	1.41	76.65
2.063	282	73.33	2.25	76.36
1.870	282	72.95	2.49	76.02
1.718	282	72.89	2.65	75.68
1.441	282	72.28	1.72	75.32
1.292	282	72.03	1.48	75.16
1.135	282	71.89	1.39	75.06
0.854	282	71.33	3.67	73.91
0.670	282	70.82	1.26	74.13
0.490	282	70.39	2.37	73.76
0.194	282	69.83	2.80	72.77
0.068	282	69.67	1.85	72.49
Río Juan Lázaro				
1.295	168	78.15	2.60	80.57
1.071	168	77.32	2.59	79.86
0.884	168	77.11	2.98	78.98
0.679	168	76.14	1.50	78.85
0.504	168	75.68	2.67	78.32
0.347	168	75.30	2.20	78.05
0.218	168	74.80	2.76	77.62
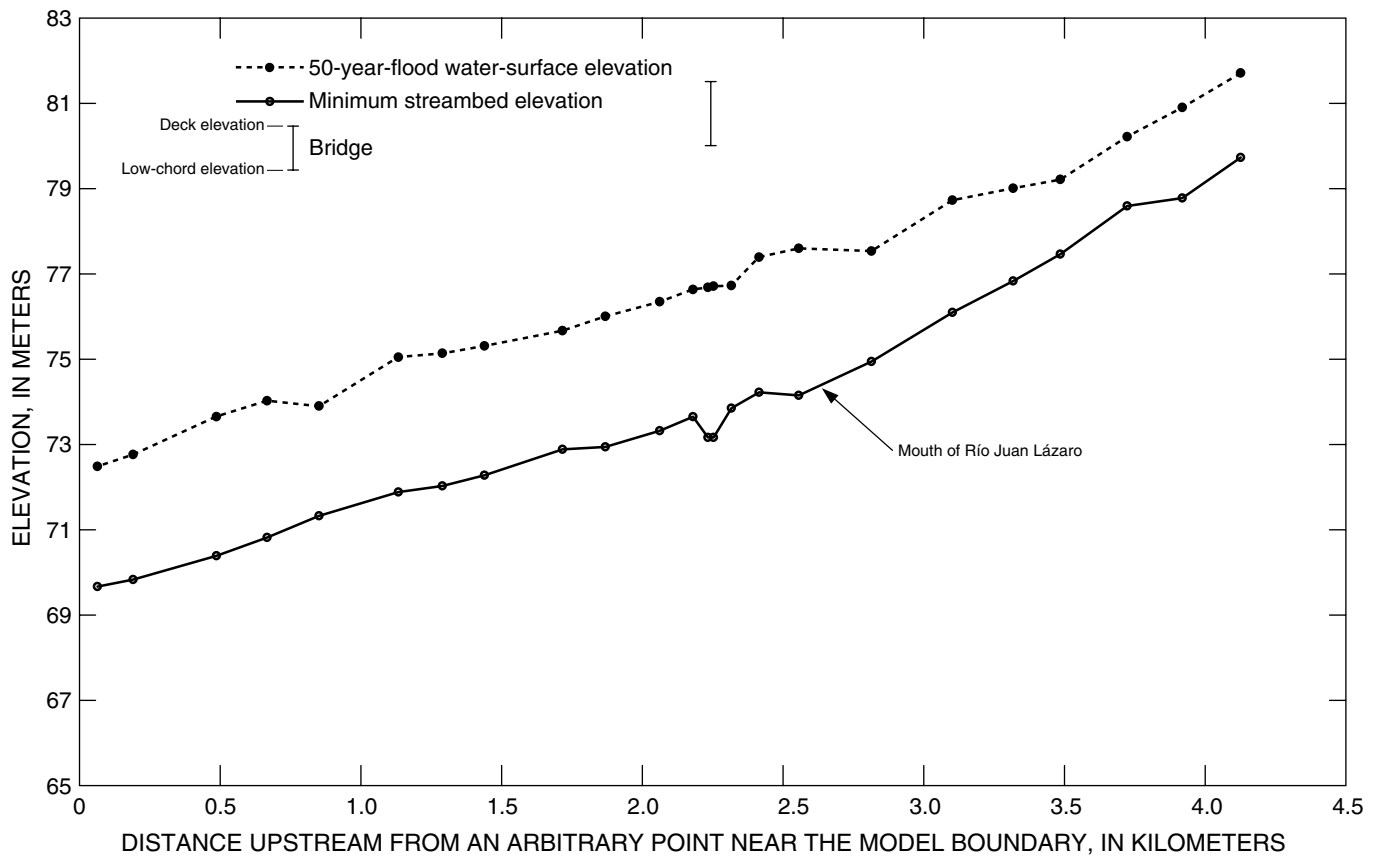
Figure 2. Graph showing Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Sonaguera at Sonaguera, Honduras.
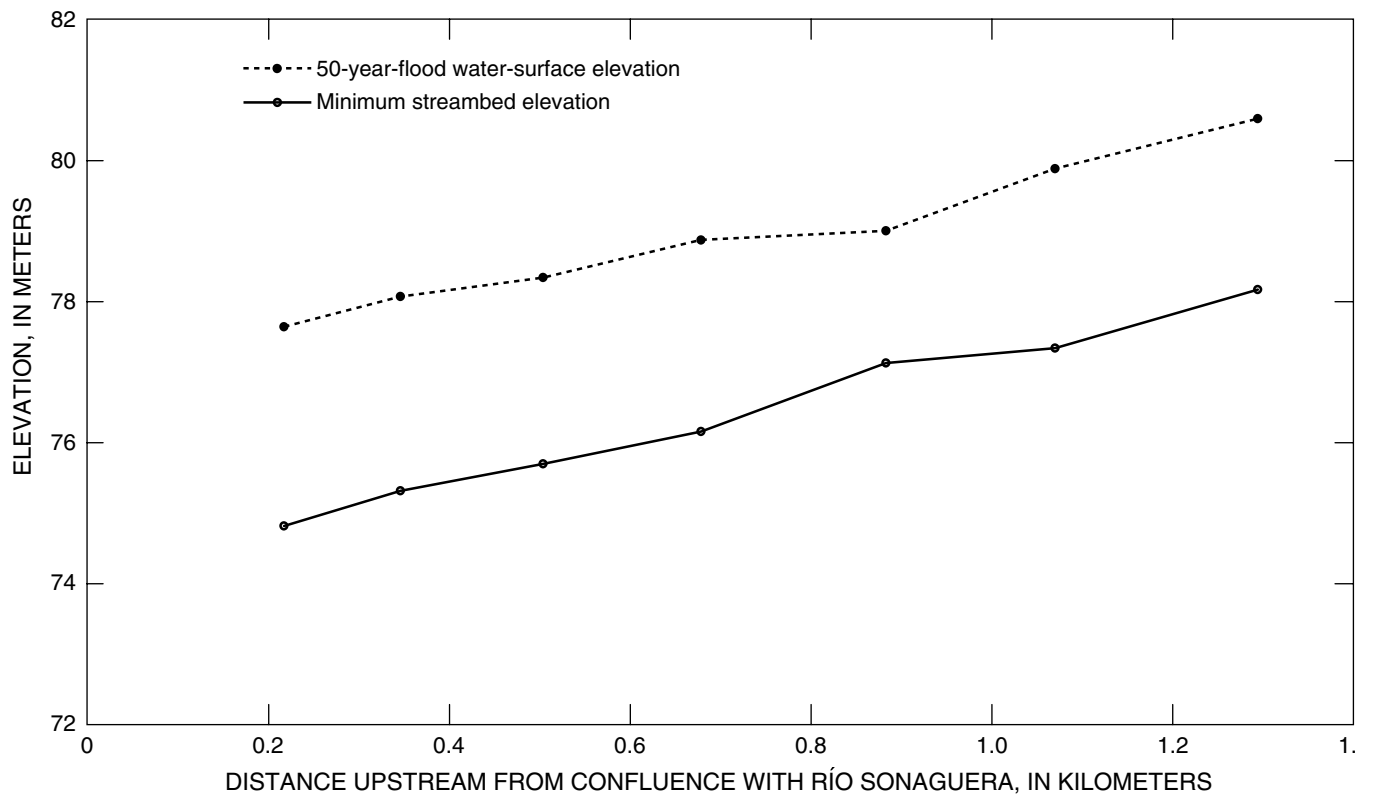
Figure 3. Graph showing Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Juan Lázaro at Sonaguera, Honduras.
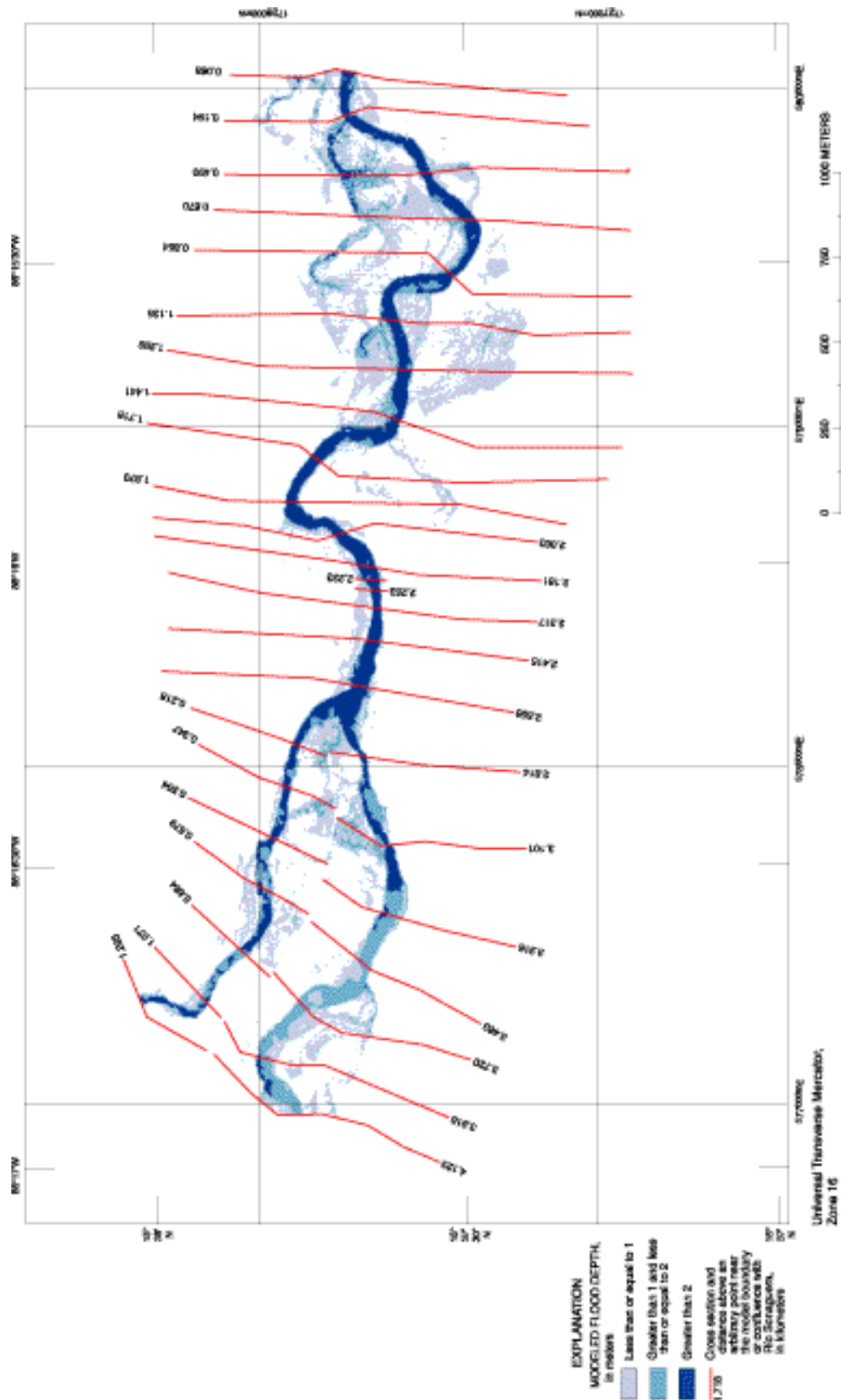
FIFTY-YEAR FLOOD-INUNDATION MAPS

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 Sonaguera for a 50-year-flood on Río Sonaguera and Río Juan Lázaro (figure 4) was computed by subtracting the topographic TIN from the water-surface elevation TIN to produce a grid with a cell size of 2 meters. There is little area of inundation outside of the main channel south of the upper Río Sonaguera reach, which might flood the main populated areas of Sonaguera. The city appears to be perched high enough above the river to avoid flooding. Most of the flooding of the overbank areas occurs in the area between the upper Río Sonaguera reach and the Río Lázaro reach and in the lower Río Sonaguera reach below cross section 1.718. This flooding affects mostly agricultural lands next to the river. In the lower Río Sonaguerra where flooding of the overbanks occurs during the 50-year flood, the water surface elevations are only slightly above the main-channel banks. Reducing the flood discharge slightly or raising the elevation of the main-channel banks would alleviate most of the flooding. The size of the highway bridge opening is more than adequate to convey the 50-year flood.

The blue lines depicting the Río Sonaguera and Río Juan Lázaro channels on the digital raster graphics map used as the base map for figure 1 lie 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 base map was created, especially those flows 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 Sonaguera and Río Juan Lázaro floodplain. This tool can reasonably separate high-hazard from low-hazard areas in the floodplain, to minimize future flooding losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location will affect the area and depth of inundation. Also, encroachment into the floodplain with structures or fill will reduce the flood-carrying capacity and thereby increase the potential height of floodwaters, and may increase the area of inundation.

Figure 4. Map showing Depth of inundation for the 50-year flood and location of cross sections on Río Sonaguera at Sonaguera, 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 Sonaguera 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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