U.S. Department of the Interior
U.S. Geological Survey

PREPARED IN COOPERATION WITH THE
PUERTO RICO AQUEDUCT AND SEWER AUTHORITY

Flood of September 22, 1998, in Arecibo and Utuado, Puerto Rico

WATER-RESOURCES INVESTIGATIONS REPORT 01-4247

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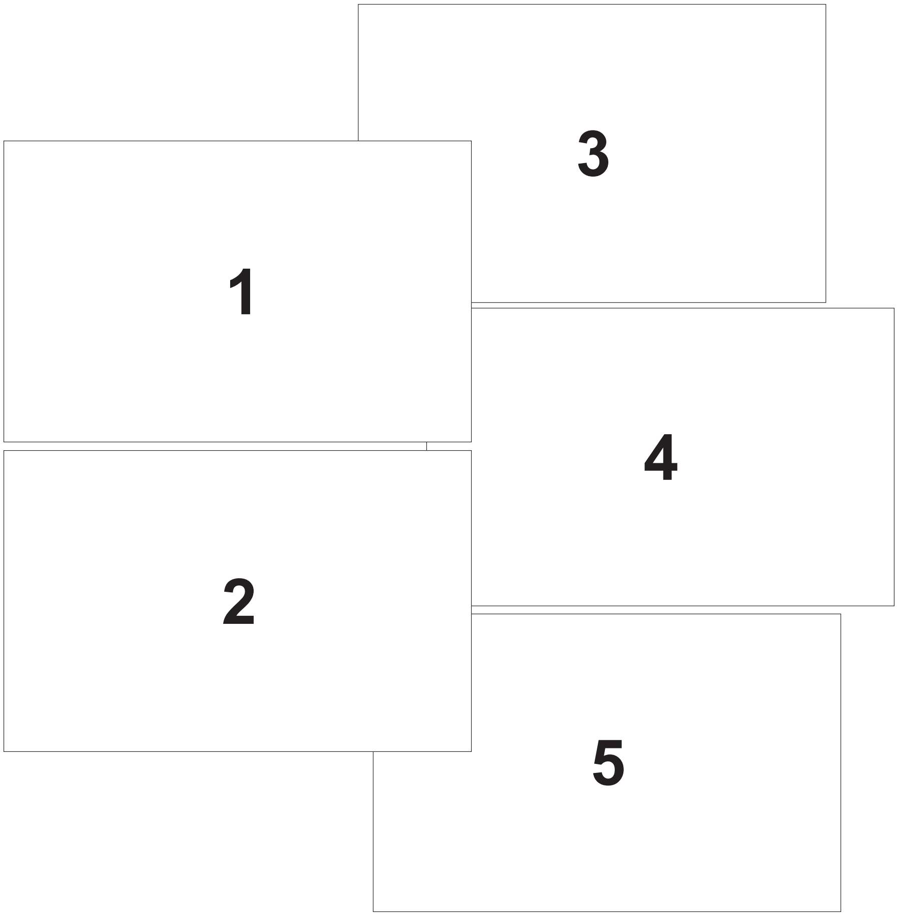

1. House damaged by floodwaters from the Río Viví in downtown Utuado, Puerto Rico. Photograph by Heriberto Torres-Sierra, September 1998, USGS.

2. High concentration of debris near the spillway of the Dos Bocas Dam, Arecibo, Puerto Rico. Note the container stuck on dam piers. Photograph by Heriberto Torres-Sierra, September 1998, USGS.

3. Road damaged from flooding in downtown Utuado, Puerto Rico. Photograph by Heriberto Torres-Sierra, September 1998, USGS.

4. Victor Rojas Avenue bridge destroyed by floodwaters from the Río Grande de Arecibo near downtown Arecibo, Puerto Rico. Photograph by Richard M.T. Webb, September 1998, USGS.

5. Aerial view of low-lying areas of downtown Arecibo inundated by floodwaters from the Río Grande de Arecibo, Arecibo, Puerto Rico. Photograph by Richard M.T. Webb, September 1998, USGS.

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By Heriberto Torres-Sierra

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San Juan, Puerto Rico: 2002

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

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

For additional information write to:

District Chief
U.S. Geological Survey
GSA Center, Suite 400-15
651 Federal Drive
Guaynabo, Puerto Rico 00965

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225

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CONVERSION FACTORS, DATUMS, ACRONYMS, and TRANSLATIONS

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

Datums

Horizontal Datum - Puerto Rico Datum, 1940 Adjustment

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)-a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called “Seal Level Datum of 1929.”

Acronyms used in this report

PRASA	Puerto Rico Aqueduct and Sewer Authority
USGS	U.S. Geological Survey

Translations

de	of
Grande	Large
Lago	Lake (in Puerto Rico, also reservoir)
Municipio	approximately the same as county
Río	River

Flood of September 22, 1998, in Arecibo and Utuado, Puerto Rico

By **Heriberto Torres-Sierra**

Abstract

Hurricane Georges made landfall on the southeastern part of Puerto Rico during September 21, 1998. Georges, with maximum sustained winds of 185 kilometers per hour and gusts to 240 kilometers per hour, produced 24-hour total rainfall amounts of 770 millimeters on the island's mountainous interior. Severe flooding affected almost half of the island's 78 municipios during September 21-22, 1998. The most affected municipios were Adjuntas, Aguada, Aguadilla, Añasco, Arecibo, Cayey, Ciales, Comerío, Barceloneta, Dorado, Jayuya, Manatí, Mayagüez, Morovis, Orocovis, Patillas, Toa Alta, Toa Baja, and Utuado. The combination of strong winds, intense rainfall and severe flooding caused widespread property damages. More than 20,000 houses were destroyed and more than 100,000 houses sustained damage. Floodwaters and landslides destroyed or damaged many bridges and roads throughout the island.

Records indicate that Hurricane Georges induced flood discharges in the Río Grande de Arecibo Basin that were the largest on record. Floodwaters inundated urban and rural areas, affecting urban subdivisions, businesses, vehicles, bridges, roads, and high-tension electric power lines. To define the extent and depth of inundation, more than 280 high-water marks were identified and surveyed in Arecibo and Utuado. In addition estimates of flood magnitude and frequency were made at selected gaging stations, and flood profiles were developed for certain stream reaches. Flooding was most severe in the towns of Arecibo and Utuado. In Arecibo, the most affected communities were the rural area of San Francisco, the urban subdivisions of Martell, Nolla, and Arecibo Gardens, and the low-lying areas of downtown Arecibo. In these areas, the water depths ranged from 0.6 to 1.8 meters. In Utuado, floodwaters from the Río Viví and the Río Grande de Arecibo inundated the downtown area affecting homes, public facilities, and businesses. In the urban subdivision of Jesús María Lago, the depth of flooding exceeded 2.5 meters. Frequency analysis indicates that flood-peak discharges equaled or exceeded the 100-year recurrence interval at five streamflow-gaging stations in the Río Grande de Arecibo Basin.

Sumario

El huracán Georges penetró por la parte sureste de Puerto Rico el 21 de septiembre de 1998. Georges, con vientos máximos sostenidos de 185 kilómetros por hora y ráfagas de hasta 240 kilómetros por hora, produjo lluvias que totalizaron 770 milímetros en 24 horas en el interior montañoso de la isla. Durante el 21 y el 22 de septiembre de 1998, inundaciones severas afectaron casi la mitad de los 78 municipios de la isla.

Los municipios más afectados fueron Adjuntas, Aguada, Aguadilla, Añasco, Arecibo, Cayey, Ciales, Comerío, Barceloneta, Dorado, Jayuya, Manatí, Mayagüez, Morovis, Orocovis, Patillas, Toa Alta, Toa Baja y Utuado. La combinación de vientos fuertes, lluvias intensas e inundaciones severas ocasionó daños a la propiedad en toda la región afectada. Más de 20,000 residencias fueron destruidas y más de 100,000 residencias sufrieron daños. Las inundaciones y los deslizamientos de tierra destruyeron o dañaron muchos puentes y carreteras a través de toda la isla.

Los archivos indican que el huracán Georges generó las mayores descargas de inundación que se hayan registrado en la cuenca del Río Grande de Arecibo. Las crecidas inundaron áreas urbanas y rurales, afectando urbanizaciones, negocios, vehículos, puentes, carreteras y líneas de energía eléctrica de alta tensión. Para definir la extensión y la profundidad de las inundaciones, se identificaron y se midieron más de 280 marcas de niveles máximos de inundación en Arecibo y en Utuado. Además se estimó la magnitud y la frecuencia de la inundación en estaciones fluviométricas seleccionadas y se definieron perfiles de inundación a lo largo de ciertos tramos de ríos específicos. Las inundaciones más severas ocurrieron en los pueblos de Arecibo y Utuado. En Arecibo, las comunidades más afectadas fueron el área rural de San Francisco, las áreas urbanas de Martell, Nolla y Arecibo Gardens, y las áreas bajas del centro del pueblo de Arecibo. En estas áreas, la profundidad de inundación fluctuó entre 0.6 y 1.8 metros. En Utuado, las crecidas del Río Viví y del Río Grande de Arecibo inundaron el área central del pueblo y afectaron hogares, instalaciones públicas y negocios. En la urbanización Jesús María Lago, la profundidad de la inundación excedió 2.5 metros. Análisis de frecuencia indican que las descargas máximas de inundación igualaron o excedieron el intervalo de 100 años de recurrencia en cinco estaciones fluviométricas en la cuenca del Río Grande de Arecibo.

INTRODUCTION

During the afternoon of Monday, September 21, 1998, Hurricane Georges made landfall in the vicinity of the towns of Yabucoa and Humacao on the southeastern part of Puerto Rico (fig. 1). Hurricane Georges traversed the island of Puerto Rico as a Category 3 hurricane (Saffir-Simpson Scale) with maximum sustained winds of 185 kilometers per hour (km/h) and gusts to 240 km/h. Hurricane Georges has been classified as the most destructive hurricane to strike the island of Puerto Rico since Hurricane San Ciprian in 1932. Moderate to severe floods were produced by intense rainfall generated by the passage of Hurricane Georges over the mountainous central region of the Island. As much as 770 millimeters (mm) of rain fell on the municipio of Jayuya during a 24-hour period (fig. 2), and floods affected almost all of the island's 78 municipios. The most severe flooding occurred within the basins of the Río Grande de Arecibo (at the towns of Adjuntas, Arecibo, Jayuya, and Utuado), the Río de la Plata (at the towns of Cayey, Comerío, Toa Alta, Toa Baja, and Dorado), the Río Grande de Manatí (at the towns of Orocovis, Morovis, Ciales, Manatí, and Barceloneta), the Río Grande de Patillas (at the town of Patillas), the Río Grande de Añasco (at the towns of Añasco and Mayagüez) and the Río Culebrinas (at the towns of Aguada and Aguadilla) (fig. 3).

The floods within the basin of the Río Grande de Arecibo exceeded the documented historical floods of 1970 and 1975 in Jayuya and Utuado (Johnson and Carrasquillo, 1982; Johnson and others, 1982) and of 1928 and 1954 in Arecibo (Hickenlooper, 1968). Downtown areas of Adjuntas, Arecibo, Jayuya and Utuado were extensively damaged by the floodwaters of the Río Grande de Arecibo and its tributaries. The flood along the lower reach of the Río Grande de Añasco also exceeded the floods of 1928 and 1975 in Añasco and Mayagüez (Fields, 1971; Johnson and Quiñones-Aponte, 1982). In the towns of Añasco and Mayagüez, some areas were inundated by the floodwaters of the Río Grande de Añasco for the first time this century.

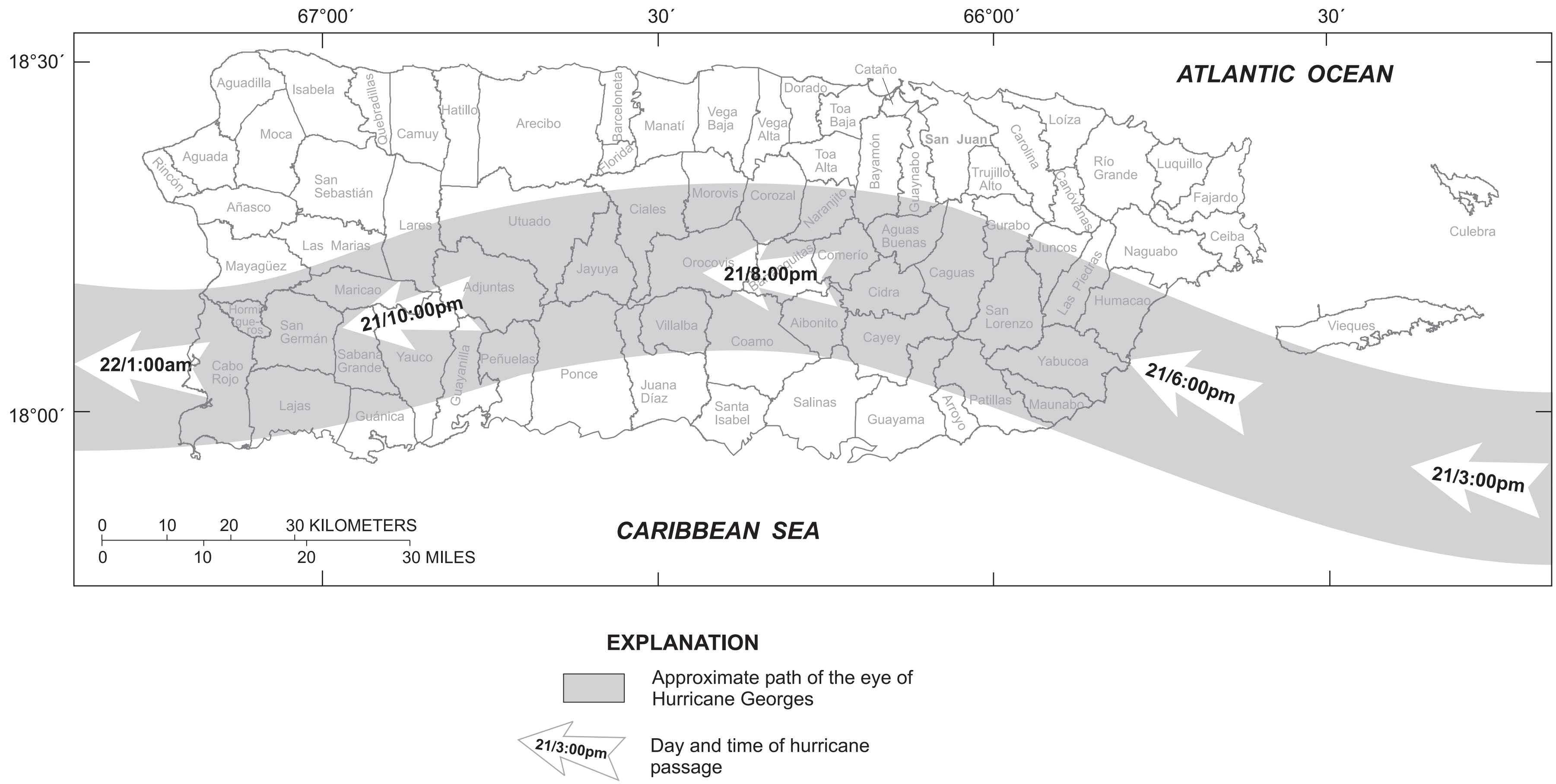

Figure 1. Track of Hurricane Georges across Puerto Rico during September 21-22, 1998.

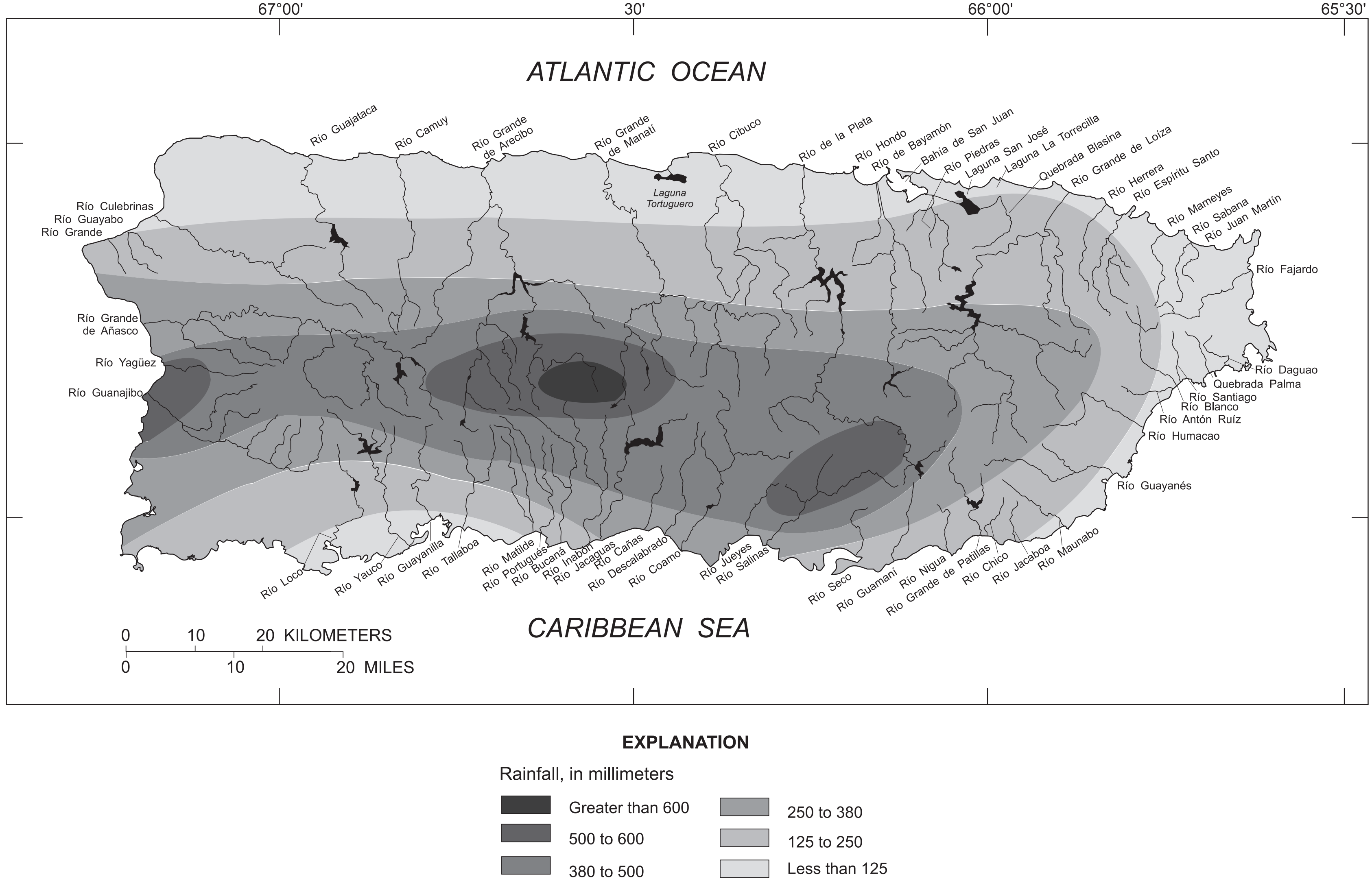

Figure 2. Cumulative rainfall over Puerto Rico during September 21-22, 1998 (compiled by the National Weather Service, San Juan, Puerto Rico).

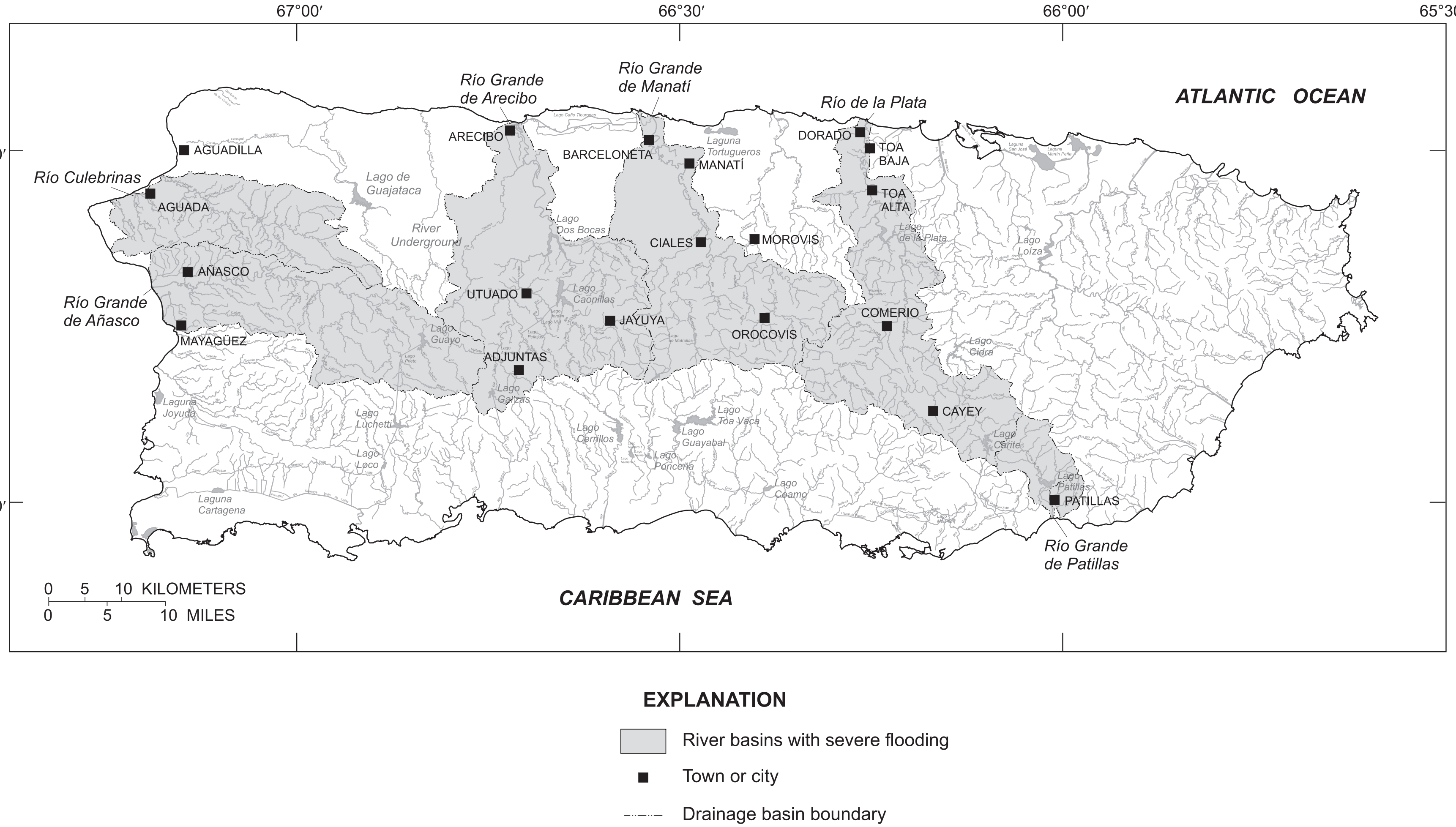

Figure 3. River basins in Puerto Rico where flooding was most severe during September 21-22, 1998.

This report, prepared by the U.S. Geological Survey (USGS) in cooperation with the Puerto Rico Aqueduct and Sewer Authority (PRASA), documents the extent of the September 22 Río Grande de Arecibo flood in the Arecibo and Utuado area. High-water marks and flood-discharge data obtained by USGS personnel immediately after the flood are the principal sources of data for this report. Additional information was obtained from interviews with residents who live or work in the study area. The information provided in this report can be of value and interest to engineers, developers, planners, and government officials, and can be used for flood-plain regulation, land-use planning, highway bridge and culvert design and for designing flood-control structures.

RÍO GRANDE DE ARECIBO DRAINAGE BASIN

The Río Grande de Arecibo drains a basin in the northern slopes of the Cordillera Central in the north-central part of Puerto Rico (fig. 4). The Río Grande de Arecibo drainage basin at its headwaters includes the municipios of Adjuntas, Ciales, Jayuya, and Utuado and the municipio of Arecibo near its mouth at the coast. The Río Grande de Arecibo originates in the municipio of Adjuntas at the confluence of the Río Cidra and the Río Vacas and flows in a northerly direction through a narrow incised valley near the town of Utuado. At downtown Utuado, the Río Viví, a major tributary with a drainage area of 43 square kilometers (km^2), joins the Río Grande de Arecibo. The drainage area of the Río Grande de Arecibo just downstream of the confluence with the Río Viví is 167.9 km^2. Approximately 2.0 kilometers (km) north (downstream) of Utuado, the Río Grande de Arecibo flows into the Lago Dos Bocas reservoir where it joins the Río Caonillas and the Río Limón. The Río Grande de Arecibo has a drainage area of about 440 km^2 at Dos Bocas dam. North of the Dos Bocas dam, the Río Grande de Arecibo meanders through about 16 km of a deeply entrenched alluvial valley, flanked on both sides by karst terrane, before reaching the coastal plain, where it joins the Río Tanamá, and discharges into the Atlantic Ocean at Arecibo. The contributing drainage area of the Río Grande de Arecibo between the Dos Bocas dam and the river's mouth on the Atlantic Ocean is indeterminate, because most of the surface drainage is through cavernous limestone.

FLOOD HISTORY

Severe floods have affected the Arecibo and Utuado areas at least eight times during the period from 1899 to 1998. Floods that have inundated sizable areas, and for which some water-surface elevation data are available, occurred in 1899, 1928, 1932, 1954, 1975, 1985, 1996, and 1998. However, accurate water-surface profiles were determined only for the floods of October 13, 1954, and September 22, 1998, in the lower Río Grande de Arecibo valley at Arecibo and for the floods of September 16, 1975, and September 22, 1998, in the Río Viví and Río Grande de Arecibo at Utuado. Flood elevation and extent for the September 22, 1998, flood in the lower valley of the Río Grande de Arecibo cannot be compared with floods prior to 1985 because the flood plain has been substantially modified. Among the most hydraulically significant changes is the construction of the new Highway PR-10 causeway that constrains the flood flow in the Río Grande de Arecibo to the east side of the highway and diverts part of the flood flow in the Río Tanamá to the west side of the highway (plate 1). The Highway PR-22 causeway is another structure that could impact the extent of flooding by increasing the water-surface elevation.

FLOOD DISCHARGE

During the September 22, 1998 flood, the USGS collected peak stage and discharge information from 122 gaging stations throughout Puerto Rico. Only 12 of these streamflow-gaging stations were damaged or destroyed by the storm. High-water marks were surveyed shortly after the event to determine peak stages and discharges at sites where recording instruments failed or were damaged during the flood. In the Río Grande de Arecibo Basin, two of the nine gaging stations operating in the basin were destroyed by the floodwaters: station 50024950, Río Grande de Arecibo below Utuado and station 50028400, Río Tanamá at Charco Hondo (fig. 4). Recording instrument damage also affected data acquisition at the streamflow-gaging stations of 50025155 on the Río Saliente at Coabey near Jayuya and 50026025 on the Río Caonillas at Paso Palma.

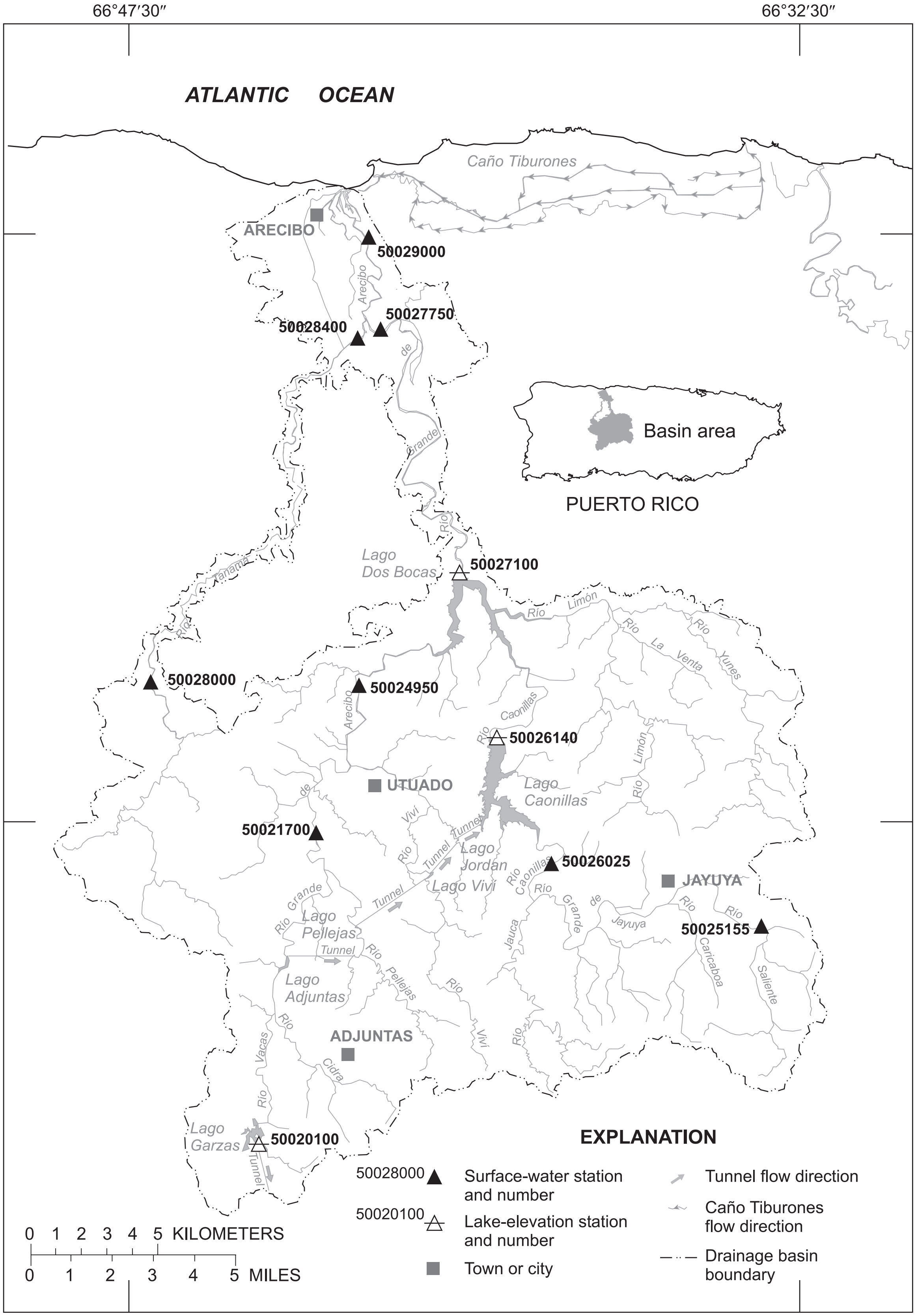

Figure 4. Río Grande de Arecibo drainage basin and U.S. Geological Survey stream- and lake-gaging stations.

Flood-discharge data for the September 22, 1998 flood, in Arecibo and Utuado were obtained for seven gaging stations within the Río Grande de Arecibo drainage basin. Stage and discharge hydrographs for the Río Grande de Arecibo above Utuado (50021700) and for the Río Tanamá near Utuado (50028000) are shown in figure 5. Previously recorded peak discharges were exceeded at all seven gaging stations. Peak discharges were obtained using indirect discharge measurement techniques (slope-area measurements) at the Río Grande de Arecibo below Utuado and the Río Saliente at Coabey near Jayuya gaging stations (stations 50024950 and 50025155, respectively). The peak discharge at the Río Caonillas at Paso Palma gaging station (50026025) was estimated using peak stage data collected near the gage and the stage-discharge relation for this gaging station. Flood stages, discharges, recurrence intervals, and other information pertinent to these gaging stations are summarized in table 1. For purposes of comparison, the table also includes the recorded stage, discharge, and recurrence interval of the highest recorded peak discharges prior to September 21-22, 1998. All gaging stations, except the gaging station in the Río Saliente (50025155), registered the peak stage during the early morning of September 22. At the Río Saliente at Coabey near Jayuya gaging station, the peak stage occurred on September 21 shortly before midnight.

Peak discharges were also computed for flood flow over the spillways at the Caonillas and Dos Bocas dams. The principal source of data used to compute the peak discharges over the spillways were the flood stage data collected near the dams immediately after the flood and the theoretical spillway discharge rating for each reservoir. The peak discharge of the Río Caonillas over the spillway at the Caonillas dam was computed to be 1,330 cubic meters per second (m^3/s), and the peak discharge of the Río Grande de Arecibo over the spillway at the Dos Bocas dam was computed to be 3,260 m^3/s. The computed peak discharge of the Río Grande de Arecibo at the Dos Bocas dam (drainage area 440 km^2) was transferred downstream to the Río Grande de Arecibo above Arecibo gaging station (50027750) on the basis of drainage area using a procedure described by López and others (1979), resulting in a peak discharge estimate of 3,330 m^3/s. This procedure was also used to transfer the peak discharge of 666 m^3/s at the Río Tanamá near Utuado gaging site (station 50028000) downstream to the Río Tanamá at Charco Hondo gaging station (station 50028400), resulting in a peak discharge estimate of 778 m^3/s.

FLOOD PROFILE

A flood profile shows the water-surface elevation referenced to a datum (mean sea level) and a horizontal distance along a base line. The base line, and therefore the profile, are not confined to the configuration of the channel, but follow a smoother path along the flood plain in the general direction of the flood flow. Flood profiles can be defined from actual high-water mark elevations or by computer analysis. Normally the profiles include the location and elevation of bridges, culverts, and other constraining structures along the channel.

The flood profile for the Río Grande de Arecibo during the flood of September 22, 1998, in the lower valley near Arecibo is shown in figure 6. Flood profiles for the Río Grande de Arecibo and the Río Viví for the flood of September 22, 1998, at Utuado are shown in figures 7 and 8, respectively. No comparison can be made with flood profiles of previously documented floods because substantial structural modifications have occurred in the flooded areas of Arecibo and Utuado.

The profiles are referenced to an arbitrary base line shown on plates 1 and 2. All elevations shown in the study area are referenced to mean sea level datum. Reference marks used in the study were established by USGS personnel at selected points throughout the study area (tables 2 and 3, plates 1 and 2, respectively).

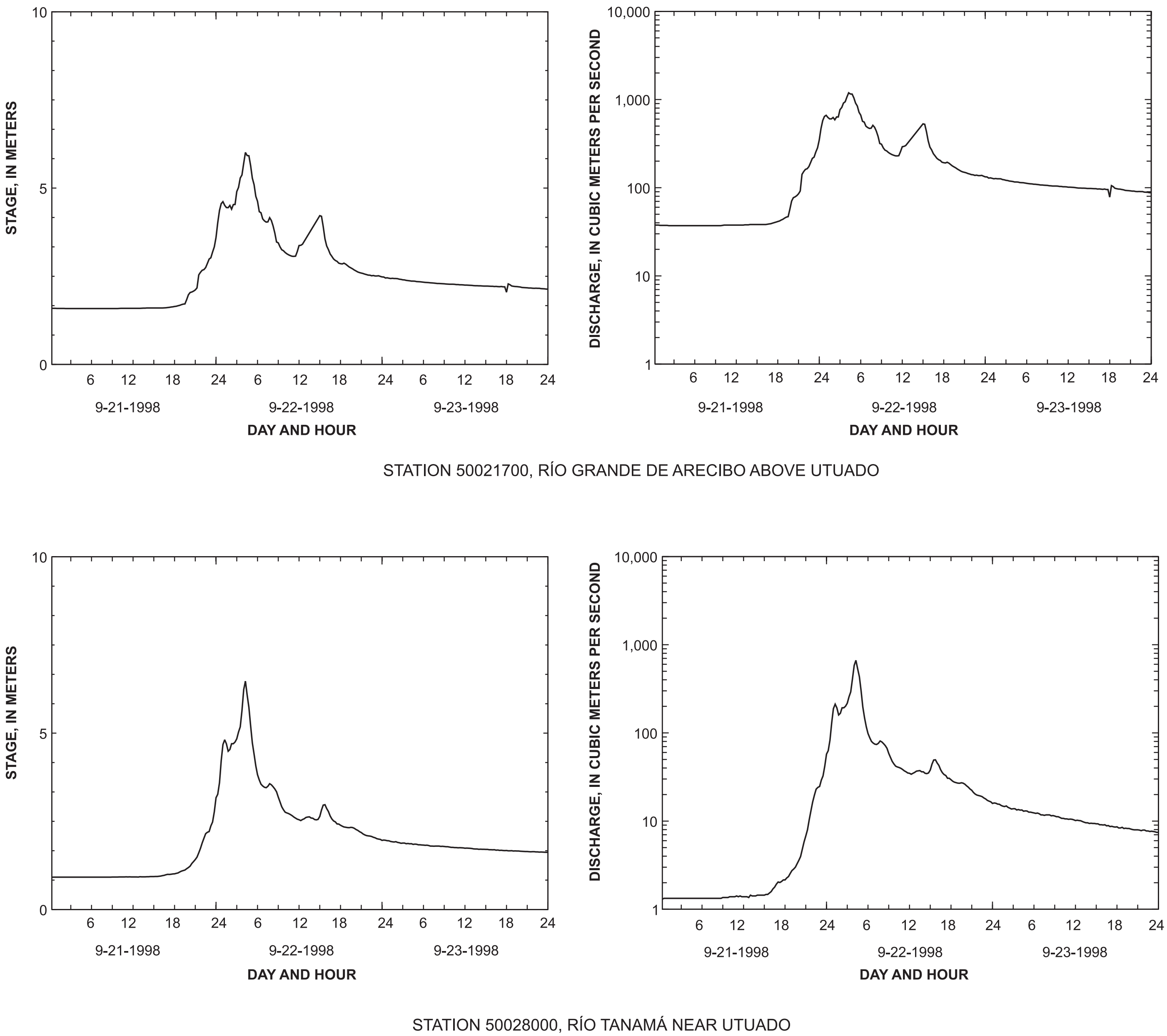

Figure 5. Stage and discharge hydrographs for the Río Grande de Arecibo above Utuado (50021700) and the Río Tanamá near Utuado (50028000) gaging stations during September 21-23, 1998.

Table 1. Summary of peak stages and discharges prior to and during flood of September 22, 1998, at selected U.S. Geological Survey streamflow-gaging stations within the Río Grande de Arecibo Basin, Puerto Rico

[km^2, square kilometer; m, meter above an arbitrary datum; m^3/s, cubic meter per second; ---, not determined; >, greater than]

Station number	Station name[1]	Drainage area (km^2)	Period of record (water year)	Maximum prior to September 1998			Maximum in September 1998			
				Date	Peak stage (m)	Peak discharge (m^3/s)	Day	Peak stage (m)	Peak discharge (m^3/s)	Estimated recurrence interval (years)
50021700	Río Grande de Arecibo above Utuado	93.2	1989-98	10/06/92	4.17	481	22	6.01	1,290	>[2]100
50024950	Río Grande de Arecibo below Utuado	170	1996-98	09/10/96	5.80	733	22	10.03	[3]2,160	>[4]100
50025155	Río Saliente at Coabey near Jayuya	24.0	1989-98	09/10/96	5.88	410	21	6.07	[3]524	[2]50
50026025	Río Caonillas at Paso Palma	98.3	1995-98	09/10/96	7.96	626	22	9.49	1,020	>[4]100
50027750	Río Grande de Arecibo above Arecibo	451	1982-98	05/18/85	5.55	1,300	22	[5]5.33	[6]3,330	[7]---
50028000	Río Tanamá near Utuado	47.7	1960-98	05/18/85	5.32	346	22	5.56	666	>[2]100
50028400	Río Tanamá at Charco Hondo	[8]149.2	1969-71 1981-98	05/18/85	5.47	425	22	7.49	[6]778	[2]100

[1] Station locations are shown in figure 4.

[2] Recurrence interval determined from flood-frequency relation based on weighted average of the peak discharges.

[3] Peak discharge computed by means of indirect discharge measurements.

[4] Recurrence interval determined from flood-frequency relation based on regional regression equations (Choquette, 1988; Ramos-Ginés, 1999).

[5] Peak stage affected by structural modifications in flood plain near gaging station.

[6] Peak discharge was estimated by transferring peak discharge from an upstream site, using technique described by López and others (1979).

[7] No flood-frequency relation was developed for this gaging station because streamflow is regulated by the upstream reservoirs of Caonillas and Dos Bocas.

[8] Approximately 101.5 km^2 of this drainage area is in karst terrane and about 91.7 km^2 of this karst area does not contribute directly to surface runoff. Contributing drainage area in the karst encompassed about 9.8 km^2 of immediate surface drainage area along the stream course.

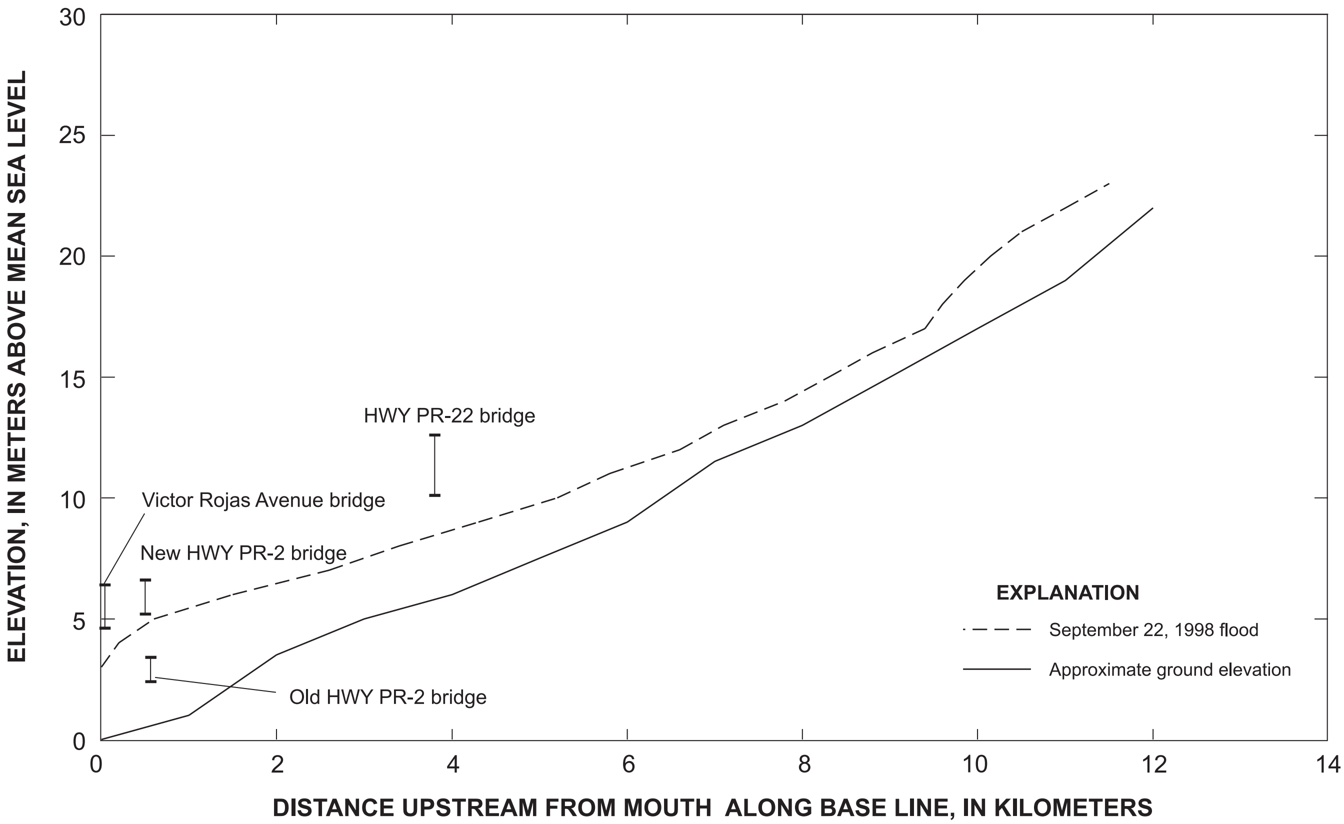

Figure 6. Flood profile of the Río Grande de Arecibo near Arecibo during September 22, 1998. The location of the flood profile is shown in plate 1.

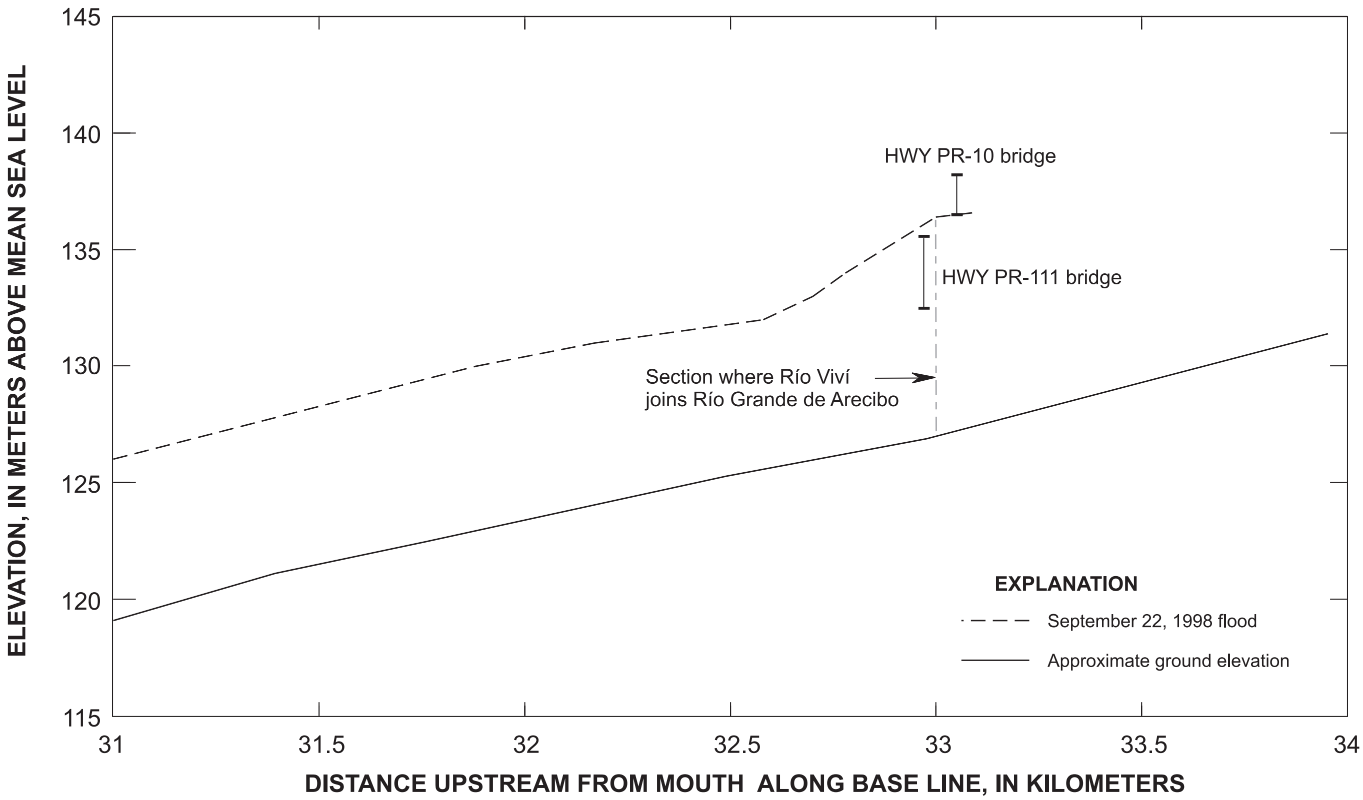

Figure 7. Flood profile of the Río Grande de Arecibo at Utuado during September 22, 1998. The location of the flood profile is shown in plate 2.

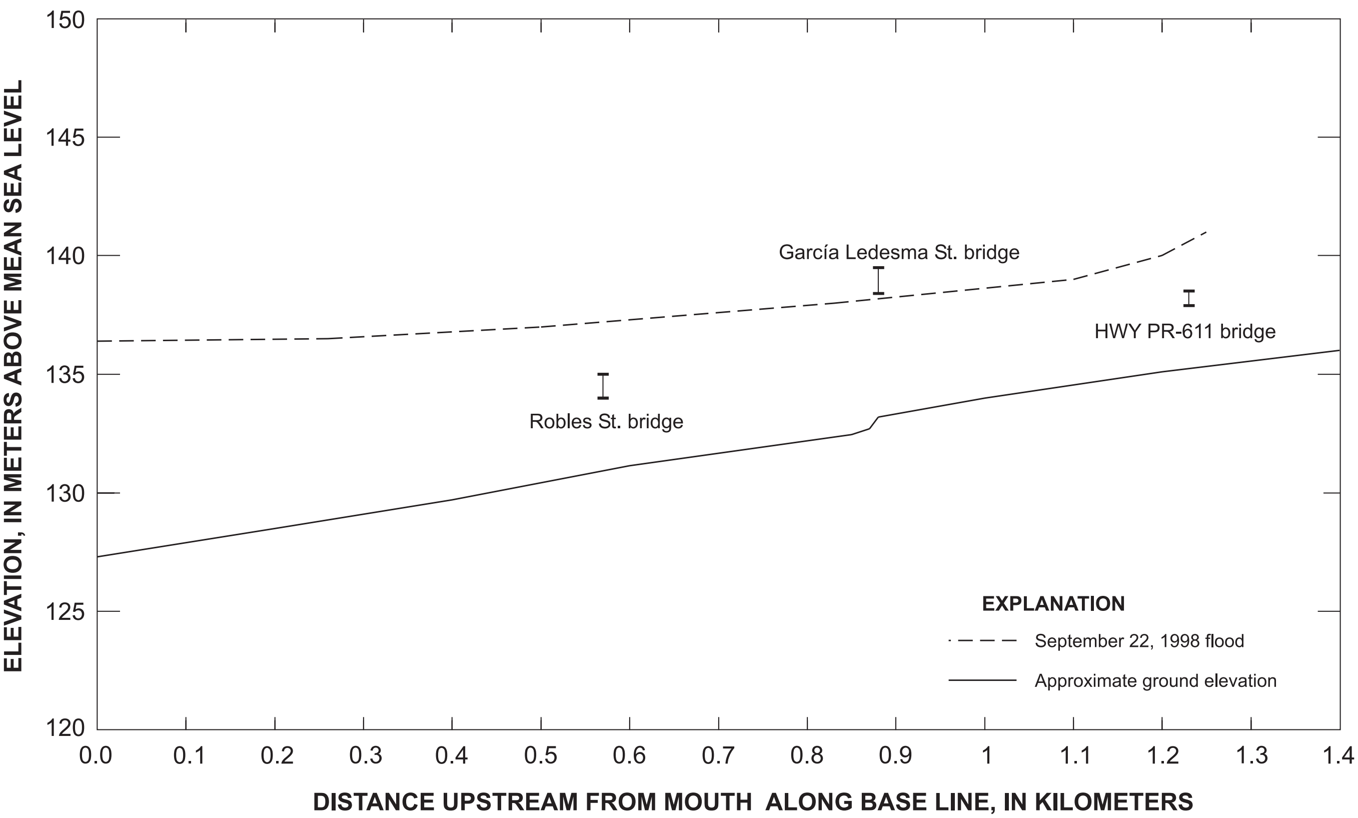

Figure 8. Flood profile of the Río Viví at Utuado during September 22, 1998. The location of the flood profile is shown in plate 2.

Table 2. Flood reference marks established by the U.S. Geological Survey in the Arecibo study area, Puerto Rico

Reference mark number (plate 1)	Elevation, in meters above mean sea level	Latitude	Longitude	Site description
RM 1	3.54	18º28'13.60"	66º42'35.44"	Standard U.S. Geological Survey disk stamped *Flood Mark*, set flush in left upstream side of culvert headwall on south lanes of Highway PR-2, km 74.5, south of new bridge over Río Grande de Arecibo on north lanes of Highway PR-2, about 150 meters southwest of road entrance to Barrio Islote, Arecibo.
RM 2	2.49	18º28'05.80"	66º43'20.12"	Chiseled square, painted orange, set on northwest end of median of Esmeralda Street, at intersection with Constitution Avenue (also known as Antonia Martell Avenue), Reparto Martell, Arecibo.
RM 3	12.06	18º27'23.64"	66º41'47.36"	Standard U.S. Geological Survey disk stamped *Flood Mark*, set flush in northwest end of concrete barrier of overpass bridge on north lanes of Highway PR-2, km 72.3, near Central Cambalache, Arecibo.
RM 4	9.69	18º26'58.18"	66º43'02.13"	Chiseled square, painted orange, set on center of median about 2.5 meters south of north end of median of Highway PR-10, at intersection with access road to Barrio Higuillales, Arecibo.
RM 5	3.80	18º26'56.87"	66º43'06.08"	Chiseled square, painted orange, set on northeast corner of west triangular islet which directs traffic from Highway PR-2 to the south on Domingo Ruíz Avenue, Barrio Domingo Ruíz, Arecibo.
RM 6	13.76	18º26'34.82"	66º41'50.10"	Standard U.S. Geological Survey disk stamped *Flood Mark*, set flush in east end of concrete barrier at downstream side of bridge on south lanes of Highway PR-22, km 72.6, Arecibo.
RM 7	11.13	18º25'46.67"	66º42'31.95"	Standard U.S. Geological Survey disk stamped *Flood Mark*, set flush in center of median about 5.5 meters north of south end of median of Highway PR-10, at intersection with Highway PR-651, Arecibo.
RM 8	14.49	18º25'33.02"	66º41'05.30"	Chiseled square, painted orange, set on right upstream side of culvert headwall of abandoned irrigation channel on Highway PR-656, about 6.0 meters east from the southeast corner of fence of the PRASA Bajadero no. 1 well, Barrio Bajadero, Arecibo.
RM 9	17.60	18º25'18.14"	66º42'20.72"	Chiseled square, painted orange, set on north end of concrete barrier at upstream side of bridge over Río Tanamá on Highway PR-10, Arecibo.
RM 10	18.51	18º24'26.57"	66º41'06.51"	Chiseled square, painted red, set on third step of stair to the chlorination chamber of PRASA Carreras I and Carreras II wells, Highway PR-656, Barrio Carreras II, Arecibo.
RM 11	23.85	18º23'39.86"	66º41'23.60"	Chiseled square, painted orange, set on downstream side of culvert headwall on Highway PR-123, km 76.1, Barrio Carreras I, Arecibo.
RM 12	20.41	18º23'39.57"	66º40'51.31"	Chiseled square, painted orange, set on top of wingwall at right downstream side of bridge over Río Grande de Arecibo on Highway PR-656, Sector Jurutungo, Barrio Carreras II, Arecibo.

Table 3. Flood reference marks established by the U.S. Geological Survey in the Utuado study area, Puerto Rico

Reference mark number (plate 2)	Elevation, in meters above mean sea level	Latitude	Longitude	Site description
RM 1	122.30	18º17'07.20"	66º42'10.23"	Chiseled square, painted orange, set on west side of concrete base of the northernmost power pole (power pole no. 2477) in front of Puerto Rico Electric Power Authority Substation at end of Rolando Cabañas Avenue, San José, Utuado.
RM 2	126.64	18º16'53.91"	66º42'26.37"	Chiseled square set on fourth step of entrance to the ticketing area of the Jorge “Peco” González basketball court, Rolando Cabañas Avenue, San José, Utuado.
RM 3	130.51	18º16'45.76"	66º42'40.30"	Chiseled square set on right upstream side of culvert headwall on Highway PR-123, km 56.5, Utuado.
RM 4	130.53	18º16'23.28"	66º42'33.63"	Chiseled square set on sidewalk in front of garage entrance of house no. 57, Rolando Cabañas Avenue, Utuado.
RM 5	135.66	18º16'15.91"	66º42'43.10"	Chiseled square set on south side of concrete base of *Walgreens* sign stand south of Walgreens drug store parking lot on Highway PR-123, Utuado.
RM 6	133.06	18º16'14.79"	66º42'37.56"	Chiseled square set on north side of manhole outside ring, in front of house no. B-1, Street B, Barriada Nueva, Utuado.
RM 7	135.81	18º16'06.24"	66º42'31.86"	Chiseled square set on right upstream abutment of new bridge over Río Grande de Arecibo on Highway PR-10, about 4.0 meters upstream of bridge and about 1.0 meter downstream of old Highway PR-10 bridge abutment, Utuado.
RM 8	136.28	18º16'06.17"	66º42'13.75"	Chiseled square set on southwest end of concrete barrier at upstream side of bridge over Río Viví on Robles Street, Peréz Matos, Utuado.

FLOOD FREQUENCY

The relation of the annual maximum discharge to probability of exceedance or recurrence intervals is herein referred to as a flood-frequency relation. Probability of exceedance is the chance of a given flood magnitude being exceeded in any given year. For example, a 50-year flood has the probability of 0.02 (2 percent) of being exceeded in any given year. A recurrence interval is the reciprocal of exceedance probability and is the average number of years between exceedances for a long period of record. A 50-year flood can be expected to occur on the average of once in 50 years, or two times in 100 years. This does not mean that floods occur at uniformly distributed time intervals: a flood with a 50-year recurrence interval can be exceeded more than twice in the same year, or it can occur in consecutive years.

The flood-frequency relation at a particular site can be derived by means of two approaches, depending on whether the site is gaged or ungaged (Thomas, 1987). At a gaged site, two peak-discharge estimates are available, one from the frequency curves based on the flood-peak data and the other computed from the regression equations based on climatic and physical basin characteristics. An analysis of flood frequency based on records collected at one gaging station is an indication of what happened at that particular site during a specific period of time. Such a record is only a small sample of long-term flood characteristics, and therefore, may not be a good basis for predicting what will happen in the future, even at that same site. A frequency curve based on regional characteristics of climate, topography, and other physical properties is widely believed to be more reliable than one solely based on flood experiences at a particular site. Another estimate would be to combine the estimates (Choquette, 1988). Combining the estimates provides a regional adjustment to the gaged record. The combination of the estimates results in a weighted average of the peak discharges. By combining the gaged record, regression peak-discharge estimates, and record length, errors at sites with short record lengths are reduced, providing an improved estimate of peak discharge. At ungaged sites, the method using regional regression equations based on climatic and physical basin characteristics is used to compute peak discharges for selected recurrence intervals (Thomas, 1987).

Recurrence intervals for the September 22, 1998 flood peaks, presented in this report were determined by using Bulletin 17B procedures (Hydrology Subcommittee of Interagency Advisory Committee on Water Data, 1982) and the USGS flood-frequency report for streams in Puerto Rico (Ramos-Ginés, 1999). Flood-frequency relations for gaging stations within the Río Grande de Arecibo Basin that have 10 or more years of record were derived by combining the flood-frequency estimates based on gaged records with those based on regression equations. Flood-frequency relations based on gaged records were defined following computational guidelines described in Bulletin 17B. These guidelines recommend the use of the Pearson Type III distribution with log transformation of the data (log-Pearson Type III distribution) as a base method for flood-flow frequency studies. The procedures do not cover basins where flood flows are appreciably altered by reservoir regulation. Bulletin 17B provides numerous analytical alternatives that may produce different estimates of frequency. Estimates generated in this study are based upon decisions about the representativeness of sample data, outliers, historic information, and skew coefficients. Alternate decisions by another analyst may provide different flood-frequency values. In order to obtain a weighted average of the peak discharge at each gaging station, the flood-frequency estimate based on observed peak discharge data was combined with the estimate based on the regional regression equations derived by Ramos-Ginés (1999) for unregulated streams in Puerto Rico.

Flood-frequency relations for recurrence intervals of 2, 5, 10, 25, 50, and 100 years were derived for the Río Grande de Arecibo above Utuado (50021700), Río Saliente at Coabey near Jayuya (50025155), Río Tanamá near Utuado (50028000), and Río Tanamá at Charco Hondo (50028400). Figures 9-12 show the flood-frequency curves based on gaged records (log-Pearson Type III distribution), regional regression equations, and weighted average for each of those gaging stations. Figures 9-12 also show the upper and lower 95 percent confidence limit curves for the gaged record flood-frequency curves and the uncertainty standard error limits (+ and -) for the relations based on regional regression equations.

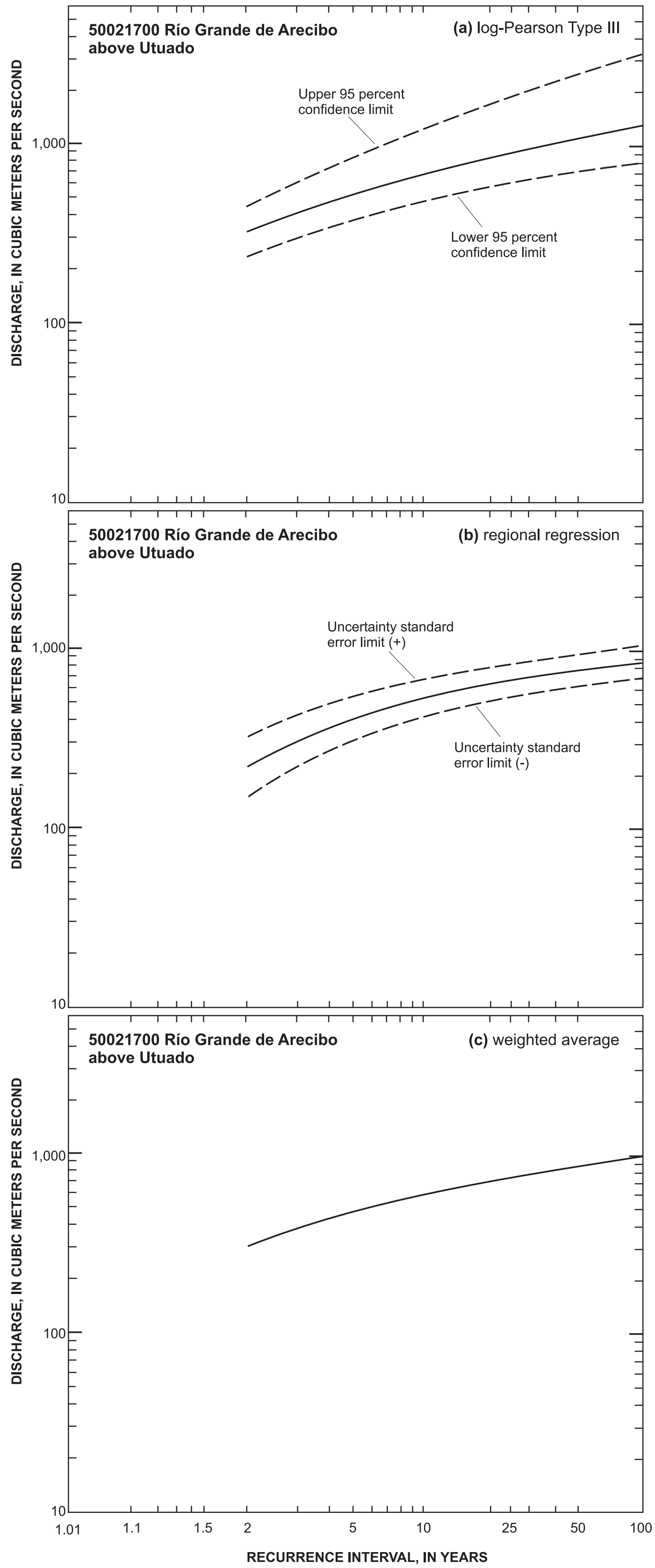

Figure 9. Flood-frequency curves for Río Grande de Arecibo above Utuado (50021700) based on (a) log-Pearson Type III distribution, (b) regional regression analysis, and (c) weighted average peak-discharge estimate. Station location shown in figure 4.

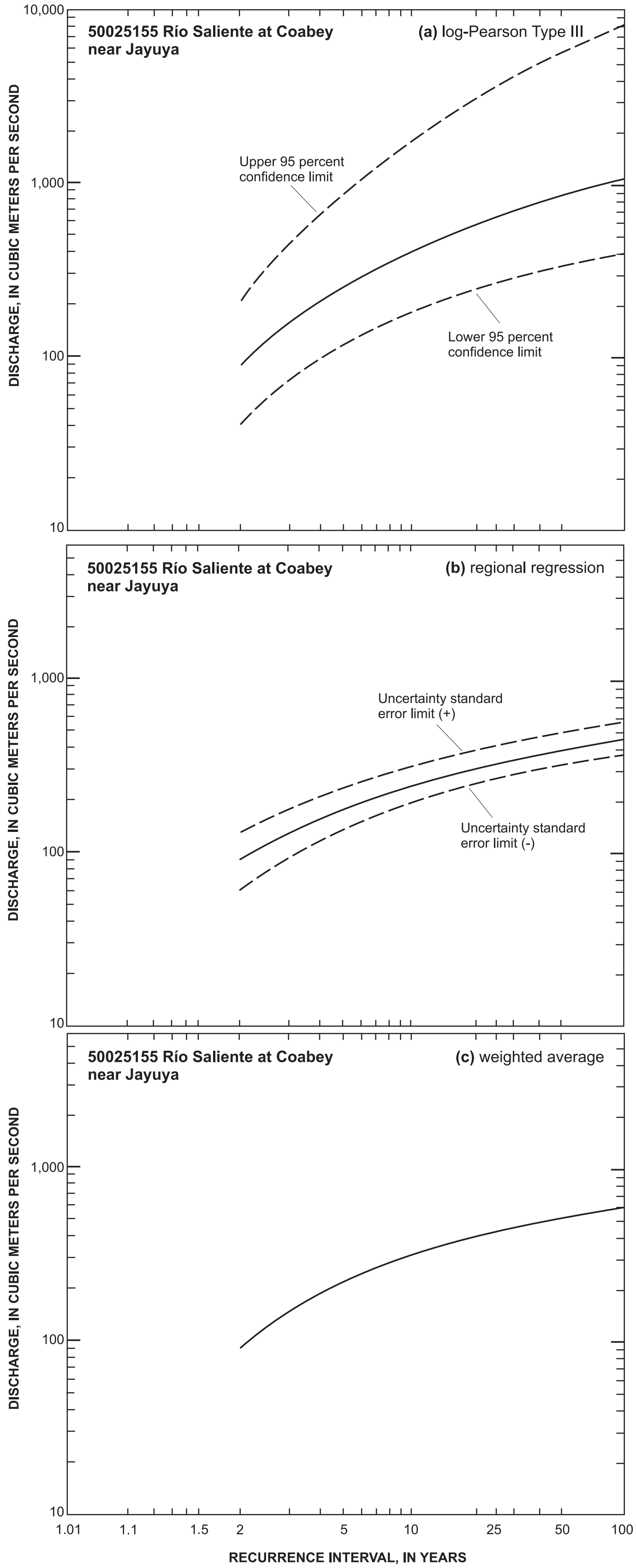

Figure 10. Flood-frequency curves for Río Saliente at Coabey near Jayuya (50025155) based on (a) log-Pearson Type III distribution, (b) regional regression analysis, and (c) weighted average peak-discharge estimate. Station location shown in figure 4.

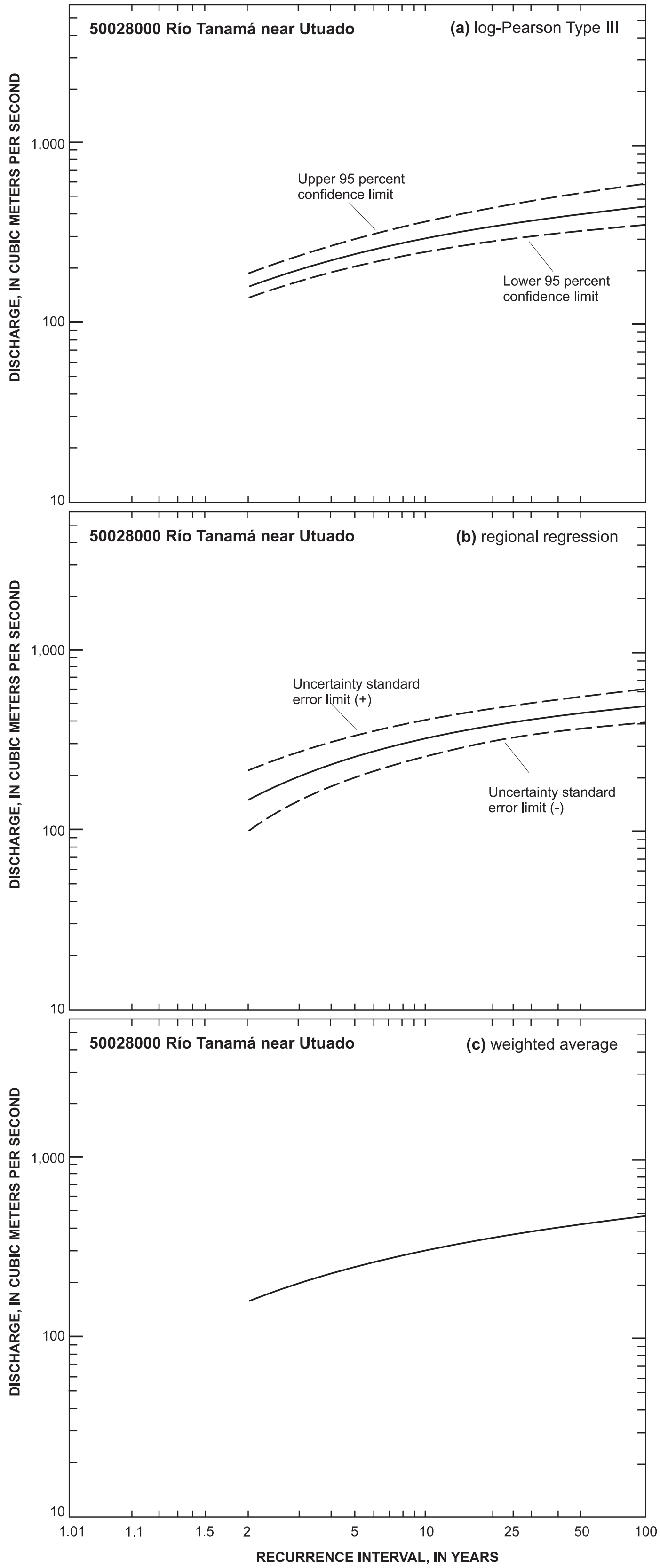

Figure 11. Flood-frequency curves for Río Tanamá near Utuado (50028000) based on (a) log-Pearson Type III distribution, (b) regional regression analysis, and (c) weighted average peak-discharge estimate. Station location shown in figure 4.

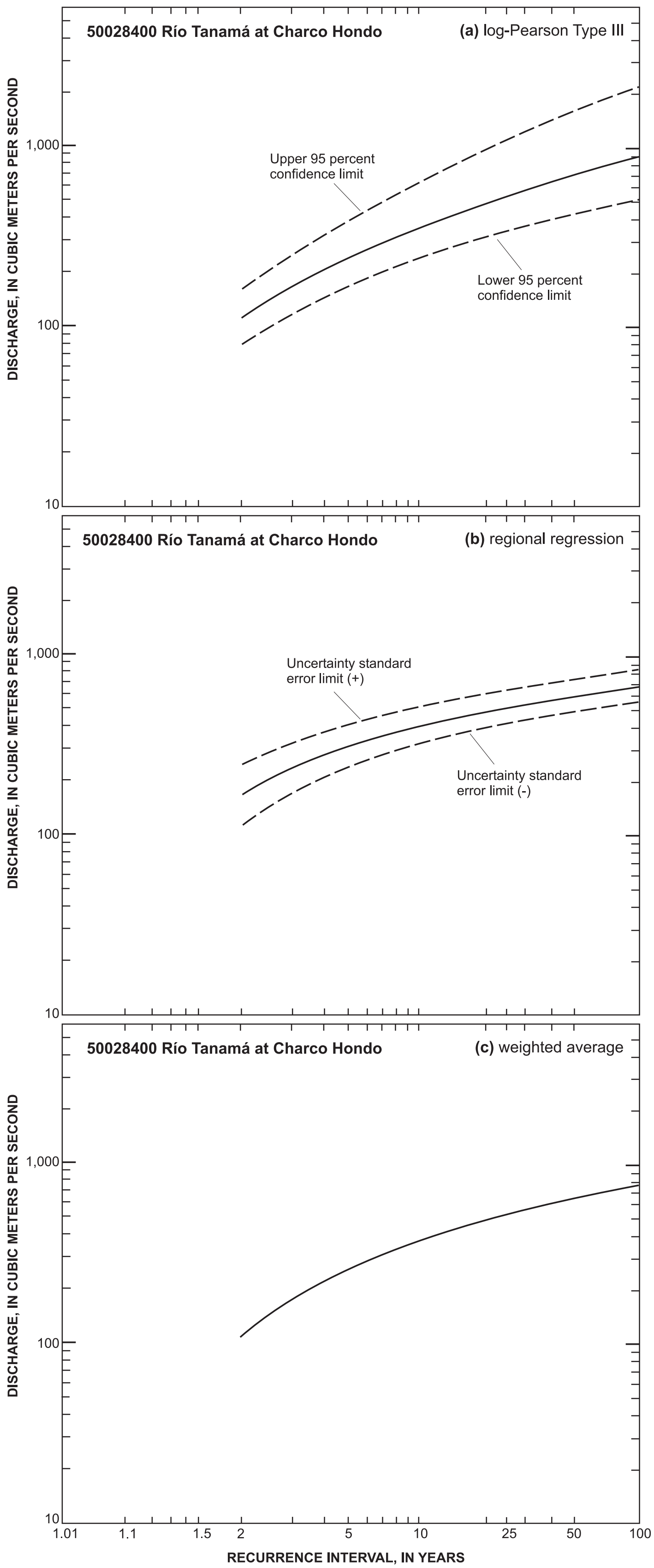

Figure 12. Flood-frequency curves for Río Tanamá at Charco Hondo (50028400) based on (a) log-Pearson Type III distribution, (b) regional regression analysis, and (c) weighted average peak-discharge estimate. Station location shown in figure 4.

The length of records for the Río Grande de Arecibo below Utuado (station 50024950) and the Río Caonillas at Paso Palma (station 50026025) were insufficient to determine a flood-frequency relation using the guidelines described in Bulletin 17B, which requires at least 10 years of record. Therefore, multiple-regression equations derived from the regional analysis for streams in Puerto Rico were used to determine a flood-frequency relation for these two gaging stations (Ramos-Ginés, 1999) (figs. 13 and 14, respectively). This analysis, based mainly on the drainage area and mean annual rainfall of the basin, was used to estimate the peak discharges for floods of 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. The accuracy of streamflow information obtained by regression of a flow characteristic, such as a 50-year flood, is appraised by estimating the standard error of the flow characteristic. The standard error of estimate of the regression provides a standardized measure of the uncertainty of the prediction. The standard error of estimate of the regression equations developed by Ramos-Ginés (1999) for the streams of Puerto Rico ranges from +46.2 to -31.6 percent, whereas those of López and others (1979) range from +61 to -38 percent.

The Caonillas and Dos Bocas reservoirs, located 23.3 and 16.7 km, upstream of the Arecibo gaging station (50027750), substantially reduce flood flows. Because streamflow at this gaging station is regulated, no flood-frequency relation was developed.

The flood frequency analyses indicated that the September 22, 1998 flood, within the Río Grande de Arecibo Basin was primarily a 100-year or greater event. Of the six gaging stations analyzed, the 100-year recurrence interval was exceeded in four cases and equaled in one (table 1). The 100-year recurrence interval was exceeded at the gaging stations of Río Grande de Arecibo above Utuado (50021700), Río Grande de Arecibo below Utuado (50024950), Río Caonillas at Paso Palma (50026025), and Río Tanamá near Utuado (50028000). Flood-peak discharge that equaled the 100-year recurrence interval was recorded at the Río Tanamá at Charco Hondo (50028400). The recurrence interval of the September 22, 1998 flood, within the Río Grande de Arecibo Basin varied across the flooded area according to the magnitude and duration of the rainfall events that caused the flooding.

FLOODED AREAS

More than 280 high-water marks were recovered and level-surveyed in the areas inundated by the Río Grande de Arecibo and the Río Tanamá in Arecibo and by the Río Grande de Arecibo and the Río Viví in Utuado. The flood boundaries were delineated using the high-water marks and field inspection of the flooded areas immediately after the flood. Information obtained from interviews with local residents was also used to define the flood boundaries. The boundaries shown on plates 1 and 2, are approximate and may not include areas where shallow flooding occurred. Floodwaters pooling at storm-water drains may have inundated some areas outside the mapped flood boundaries.

In terms of extent of flooding, the September 22, 1998 flood, was one of the largest ever recorded in the Arecibo and Utuado areas. In Arecibo, floodwaters from the Río Grande de Arecibo and the Río Tanamá inundated large urban and rural areas along the lower Río Grande de Arecibo alluvial valley. The most severely affected areas were the rural areas of San Francisco, Charco Hondo, and Los Caños, the urban subdivisions of Martell, Nolla, and Arecibo Gardens, and the low-lying areas of downtown Arecibo. Water as deep as 1.8 m was recorded at the urban subdivision of Martell. In others areas the water depths ranged from 0.6 to 1.6 m. A levee built after the 1975 floods to protect the urban subdivision of Jesús María Lago from the Río Grande de Arecibo floodwaters was partially destroyed by the flood causing inundation of this housing area to depths exceeding 2.5 m.

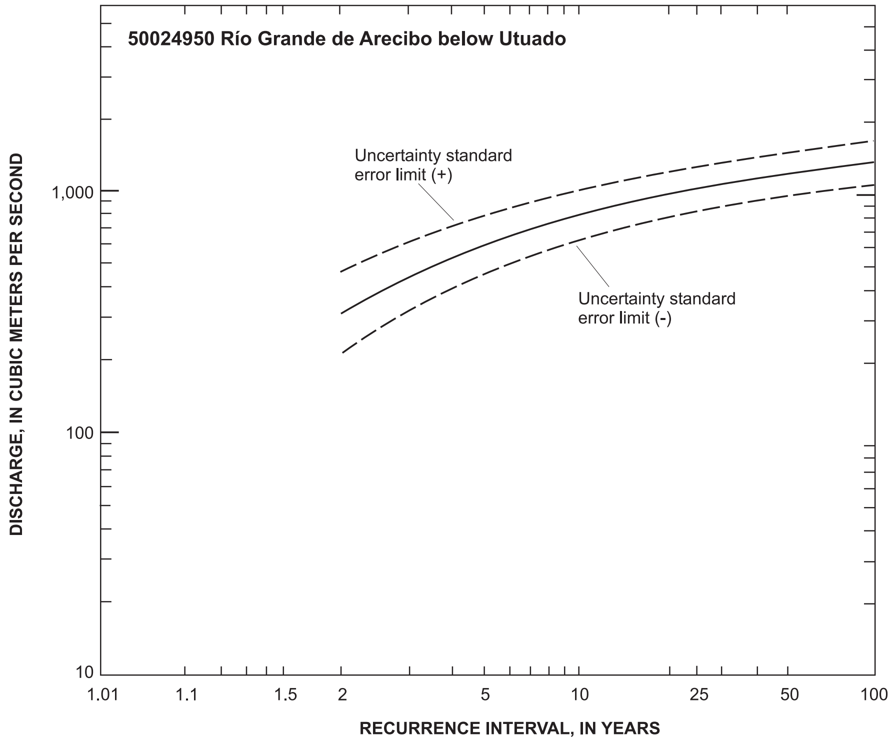

Figure 13. Flood-frequency curve for Río Grande de Arecibo below Utuado (50024950) based on regional regression analysis. Station location shown in figure 4.

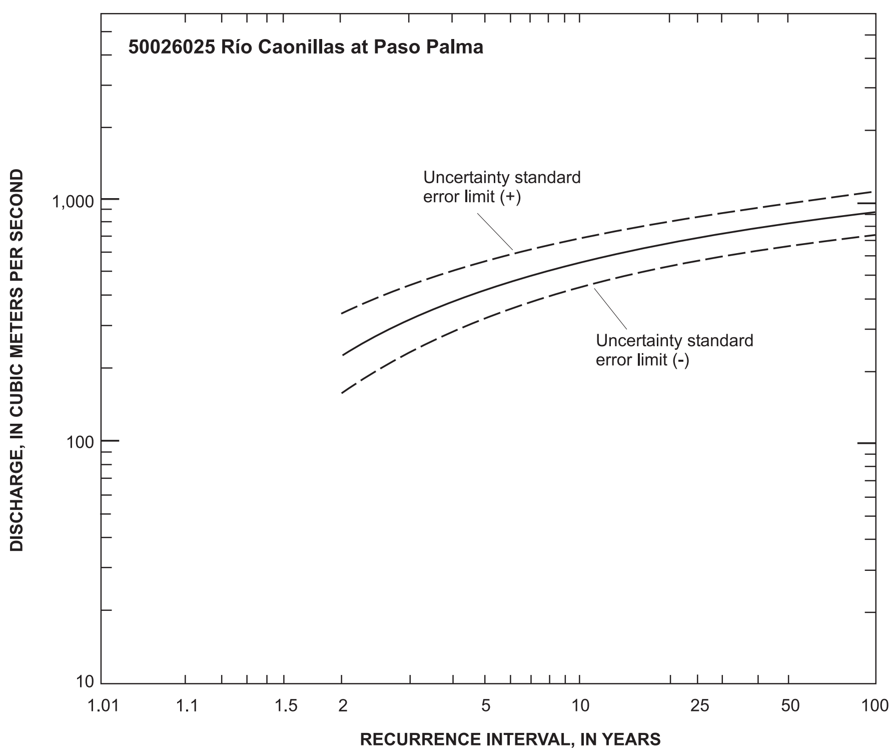

Figure 14. Flood-frequency curve for Río Caonillas at Paso Palma (50026025) based on regional regression analysis. Station location shown in figure 4.

WATER-SURFACE CONTOURS

The water-surface contours shown on plates 1 and 2 are based on the elevation of high-water marks surveyed after the flood of September 22, 1998. These contours represent equal elevations of the water surface and are perpendicular to the direction of flow. Obstructions to the flow, such as dense vegetation, man-made obstacles (buildings, roads, bridges), and variations in valley width can affect the shape of the contours. The approximate depth of flooding at any point in the inundated area can be estimated by subtracting the ground elevation (contour) from the water-surface elevation (contour). Intermediate estimates of depth can be obtained by interpolation.

SUMMARY

During September 21-22, 1998, severe floods affected almost half of Puerto Rico's 78 municipios. These floods were produced by intense rainfall generated by the passage of Hurricane Georges over the mountainous central region of the Island. A 24-hour total rainfall of as much as 770 mm was recorded in the municipio of Jayuya. The most severe flooding occurred in areas along the Río Grande de Arecibo, Río de la Plata, Río Grande de Manatí, Río Grande de Patillas, Río Grande de Añasco, and Río Culebrinas. Flood discharges on the Río Grande de Arecibo and the Río Grande de Añasco were the largest on record.

Floods along the Río Grande de Arecibo and its tributaries were particularly severe at the towns of Arecibo and Utuado. In Arecibo, floodwaters from the Río Tanamá and Río Grande de Arecibo inundated homes, businesses, and public facilities. In many homes, the floodwaters reached a depth of 1.8 meters. Downtown Utuado was inundated by the floodwaters of the Río Viví and the Río Grande de Arecibo. Water depths exceeding 2.5 meters were recorded at the urban subdivision of Jesús María Lago.

To define the extent and depth of inundation, more than 280 high-water marks were identified and surveyed in the flooded areas of Arecibo and Utuado. Flood-frequency analyses indicated that the September 22, 1998 flood, within the Río Grande de Arecibo Basin was primarily a 100-year or greater event.

The information presented in this report may be used by local and Federal agencies to define the flood plain extent and evaluate flood risk. Systematic mapping of flood depth and extent is also important for planning flood-plain use, and particularly for defining no-build zones. These studies are essential for developing safe and cost-effective design criteria for hydraulic structures, especially highway culverts, bridges, and flood-control structures.

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