Flood of September 10, 1996, in Bayamón, Puerto Rico

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ABSTRACT

Hurricane Hortense made landfall on the southwestern part of Puerto Rico during the early morning of September 10, 1996. Hortense, with maximum sustained winds of 130 kilometers per hour, produced 24-hour total rainfall amounts of nearly 560 millimeters on the island's mountainous eastern interior. Severe flooding affected almost half of the island's 78 municipalities on September 10, 1996. The most affected municipalities were Barceloneta, Bayamón, Canóvanas, Carolina, Dorado, Loíza, San Juan, and Toa Baja. The floods caused loss of life and widespread property damages. Eighteen people died as a consequence of the floods and landslides which resulted from intense rainfall. Floodwaters and landslides destroyed or severely damaged roads and more than 1,000 houses.

Flood discharges on the Río de Bayamón, at Bayamón, were the largest on record. Floodwaters inundated urban and rural areas, affecting urban subdivisions, businesses, vehicles, bridges, roads, and high-tension lines. The flood was most severe in the rural area of Parcelas Juan Sánchez and the urban subdivision of Versalles and Santa Rosa, where water reached depths of about 2.7, 2.2, and 2.0 meters, respectively. More than 235 high-water marks were recovered and level-surveyed in the areas inundated by the Río de Bayamón.

INTRODUCTION

During the early morning of September 10, 1996, Hurricane Hortense made landfall on the southwestern part of Puerto Rico (fig. 1). During its passage, Hurricane Hortense produced intensive rainfall over Puerto Rico, principally over the eastern half of the island. Cumulative 24-hour rainfall totals ranged from less than 100 mm in the western half of Puerto Rico to nearly 560 mm on the peaks of the Sierra de Luquillo and Sierra de Cayey in the eastern half of the island (fig. 2). Extremely heavy rainfall was reported in the towns of Cayey, Caguas, Comerío, Gurabo, Orocovis, and San Lorenzo.

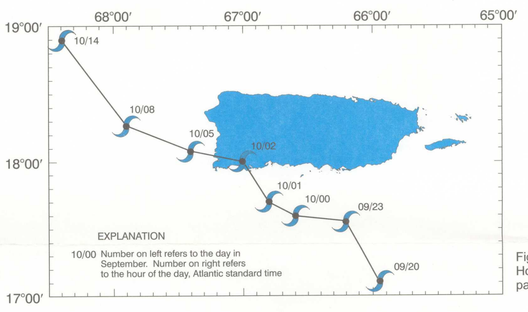

Figure 1. Track of Hurricane Hortense across the southwestern part of Puerto Rico.

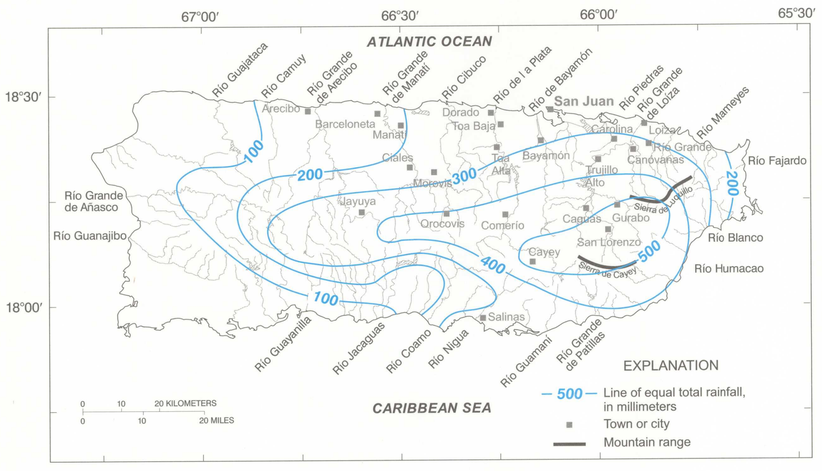

Figure 2. Cumulative rainfall over Puerto Rico during September 9-10, 1996 (Source: Rainfall data compiled by the National Weather Service).

The rains caused moderate to severe floods in most of the towns in the mountainous interior and along coastal areas in the north-central and southeastern parts of Puerto Rico. These floods affected almost half of the island's 78 towns. The most severe flooding occurred within river basins north of the insular hydrologic divide: the Río Grande de Manatí (at the towns of Orocovis, Morovis, Ciales, Manatí, and Barceloneta), the Río de la Plata (at the towns of Cayey, Comerío, Toa Alta, Toa Baja, and Dorado), the Río de Bayamón (at the town of Bayamón), the Río Piedras (at the city of San Juan), and the Río Grande de Loíza (at the towns of San Lorenzo, Gurabo, Caguas, Trujillo Alto, Carolina, Canóvanas, Loíza, and Río Grande) (fig. 3). Significant flooding also occurred at Jayuya, near the geographic center of the island; at Arecibo, on the north-central coast; and at Salinas, on the south-central coast.

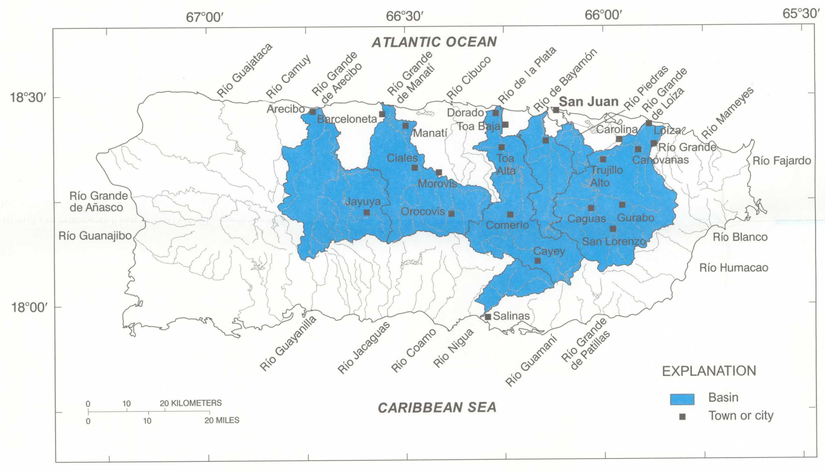

Figure 3. River basins in Puerto Rico where flooding was most severe during September 10, 1996.

Floodwaters inundated downtown areas and neighborhoods. Fifteen people drowned as floodwaters inundated their homes or swept away their vehicles when they attempted to cross flooded bridges and roads. Three more people died as a consequence of landslides that buried their homes. More than 1,000 houses were destroyed or severely damaged by floodwaters and landslides (Federal Emergency Management Agency, written commun., 1996). Many landslides occurred on the slopes of the island's mountainous interior. Several towns were isolated for several days because of damage to the main thoroughfares by floodwaters and landslides.

This report, prepared by the U.S. Geological Survey (USGS) in cooperation with the Municipality of Bayamón, documents the extent of the September 10 flood from the Río de Bayamón in the flooded areas of Bayamón. High-water marks and flood-discharge data obtained by personnel of the USGS immediately after the flood were the principal sources of data used to complete this report. Additional information was also obtained from interviews with residents who live or work in the study area. The information provided through this report can be of value and interest to engineers, developers, planners, and government officials.

RÍO DE BAYAMÓN DRAINAGE BASIN

The Río de Bayamón drainage basin includes the towns of Aguas Buenas, Bayamón, Cataño, Cidra, Guaynabo, San Juan, and Toa Baja (fig. 4). The Río de Bayamón originates in the northern slope of the Cordillera Central. Its headwaters are formed by the Río de Bayamón, the Río Sabana, the Quebrada Prieta, and other small tributaries which flow into the Lago de Cidra. Downstream from the Lago de Cidra, the Río de Bayamón flows in a northerly direction through a narrow valley with an average slope of approximately 16 m/km. The Río Guaynabo flows into the Río de Bayamón before reaching the coastal flood plain. The Río de Bayamón empties into the Atlantic Ocean at Toa Baja through the Río de Bayamón Express Channel. The Río de Bayamón Express Channel is a trapezoidal earth channel having a 7.0-kilometer length constructed in 1972 to convey and contain the 100-year flood.

The drainage area of the Río de Bayamón at Highway PR-2 bridge in Bayamón is 186.2 km². At the streamflow-gaging station near Bayamón (station 50047850), the drainage area is 108.3 km². The Río de Bayamón at Lago de Cidra Dam has a drainage area of 18.1 km². Although Lago de Cidra, with an original storage capacity of 6.41 hm³, is in the headwaters area, it has had a significant effect on reducing flood flows downstream from the dam. The Río Guaynabo, with a drainage area of 50.8 km², is the main tributary of the Río de Bayamón.

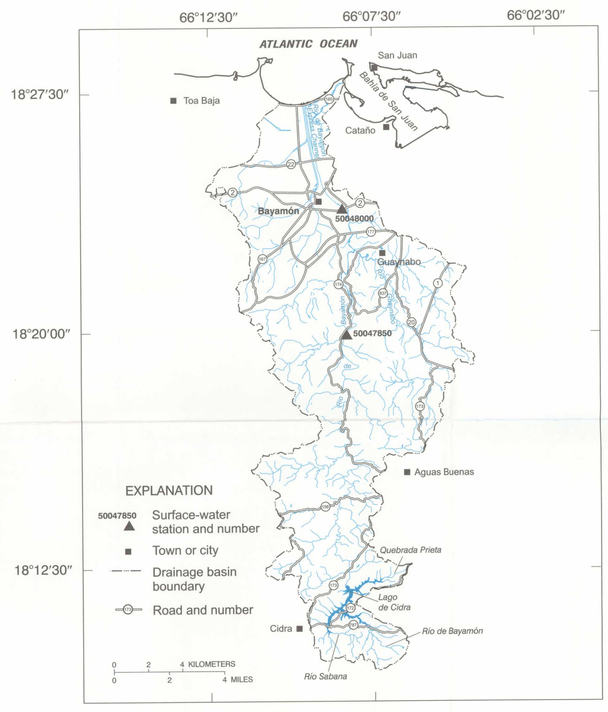

Figure 4. Río de Bayamón drainage basin.

FLOOD HISTORY

The Río de Bayamón has severely affected its flood-plain area at least ten times since 1899. Flood information has been obtained for floods of 1899, 1928, 1944, 1945, 1956, 1959, 1960, 1961, 1970, and 1996. However, no records exist to determine the magnitude of the floods for 1899, 1928, and 1944. The USGS documented the floods of August 4, 1945, and August 27, 1961 (López, 1962). The flood of September 10, 1996, was the first affecting Bayamón since the Río de Bayamón Express Channel was completed in 1972. Therefore, the extension of this flood downstream from Highway PR-2 bridge can not be compared with the floods prior to 1972. The flood conditions for the 1996 flood immediately upstream from the Highway PR-2 bridge can not be compared with flood conditions of previous floods since the bridge span was widened during early 1970's.

FLOOD DISCHARGE

Flood-discharge data for the September 10, 1996, flood in Bayamón were obtained through a number of indirect discharge measurements (slope-area and contracted opening measurements) conducted at selected sites in the Río de Bayamón and its tributary, the Río Guaynabo. In the Río de Bayamón, a four-section slope area measurement was conducted at the USGS streamflow-gaging station (Río de Bayamón near Bayamón; station 50047850). At this site the peak discharge was estimated in 1,840 m³/s. In the Río Guaynabo, a contracted-opening measurement was conducted at Highway PR-837 bridge in Guaynabo. The peak discharge at this site was determined to be 402 m³/s.

The computed peak discharges at the Río de Bayamón site and at the Río Guaynabo site were transferred downstream to the confluence of the Río de Bayamón and the Río Guaynabo. A procedure described by López and others (1979) was used to transfer the peak discharges to the confluence. The computation resulted in a peak discharge of 2,130 and 620 m³/s for the Río de Bayamón and the Río Guaynabo, respectively, or a combined peak discharge of 2,750 m³/s at the confluence. This combined peak discharge was then transferred to the Highway PR-2 bridge site resulting in an estimated peak discharge of 2,830 m³/s. This peak discharge exceeded the historical maximum discharge of 2,040 m³/s recorded at the streamflow-gaging station on the Highway PR-2 bridge during the August 4, 1945, flood. This gaging station (Río de Bayamón at Bayamón; station 50048000) was discontinued during 1976 and, therefore, no flood information has been recorded for floods after that date.

FLOOD PROFILES

The flood profile shows the water-surface elevation referenced to a datum (normally mean sea level) and distance along a base line. The base line, and therefore the profile, is not confined to the configuration of the channel, but follows a smoother path along the flood plain in the general direction of the flood flow. The 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.

Flood profiles for the September 10, 1996, and August 4, 1945, floods along the studied reach of the Río de Bayamón are shown in figure 5. The profiles are based on high-water marks identified and surveyed shortly after each flood. Information was also obtained from residents in the study area. During the 1996 flood, the water surface was below the low beam of the bridge on Highway PR-2 and at the elevation of the top of deck of the bridge on Highway PR-177, while during the 1945 flood, the water surface reached the low beam of the Highway PR-2 bridge. The bridge on Highway PR-177 was not in place during the 1945 flood. All elevations shown in the study area are referenced to mean sea level datum. Reference marks used in the study area were established by USGS personnel during the field survey or by private surveyors prior to this study (table 1).

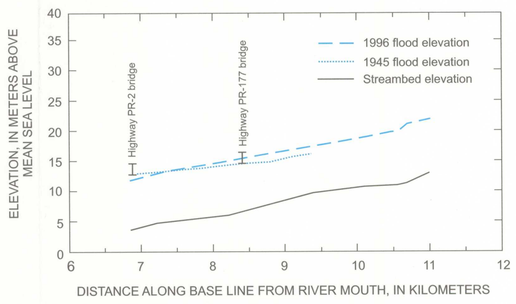

Figure 5. Flood profiles for the Río de Bayamón, Puerto Rico.

Table 1. Reference marks established by the U.S. Geological Survey and private surveyors in the Bayamón study area

Reference mark number	Elevation, in meters above mean sea level	Description
RM 1	10.68	5-centimeter disk stamped *Tren Urbano Station RT-117*, set flush at median between Highway PR-2 and access street to Santa Rosa Mall, about 20 meters from west end of median, in line with projection of the west wall of Denny's Restaurant, Santa Rosa, Bayamón.
RM 2	11.67	5-centimeter disk stamped *Tren Urbano Station RT-02*, set flush at center of triangular median which directs traffic from Aguas Buenas Avenue to the east or west on Highway PR-2, Santa Rosa, Bayamón.
RM 3	12.91	10-centimeter nail set in the middle of a large cross painted white on the southwest side of the asphalted surface of the Periférica Avenue near the intersection with Lcdo. Rafael Rivera Zayas street, 1 meter from curb, 6 meters southeast from the next to last concrete power pole, across house JJ-1, Jardines de Caparra, Bayamón. Established by Caribbean Aerial Survey and identified as point 149.
RM 4	16.42	Caribbean Aerial Survey GPS Station disk set on sidewalk at right downstream side of bridge over the Río de Bayamón on Highway PR-177, Bayamón.
RM 5	20.93	Caribbean Aerial Survey GPS Station disk set on sidewalk south of Highway PR-177, 2 meters east from the second concrete power pole from intersection of Highway PR-177 and entrance road to the 7Up Bottling Company, Bayamón.
RM 6	15.84	8-centimeter nail set in the middle of a small triangle painted red on the northeast corner of sidewalk which surround a monument with a Barrio Santa Rosa III sign in front of Mr. Esteban Cotto-Rivera's property at the access road to Barrios Frailes and Santa Rosa III from Highway PR-177, about 60 meters southwest from entrance to Plaza de Torrimar II apartment complex, 0.4 kilometer from intersection with Highway PR-177, Barrio Frailes, Guaynabo.
RM 7	25.25	Chiseled square, painted orange, set on top of a 1 meter height concrete base of a power pole at sidewalk east of Highway PR-174, kilometer 4.0, northeast from intersection of Highway PR-174 and south entrance to Versalles, Parcelas Juan Sánchez, Bayamón.

FLOOD FREQUENCY

The relation of the annual-maximum discharge to the probability of occurrence is referred to as a flood-frequency relation. The recurrence interval, as applied to flood events, is the long-term average interval of time within which a given flood level or magnitude will be exceeded once. For example, a 100-year flood can be expected to occur on the average of once in a 100-year period. This does not mean floods occur at uniformly distributed time intervals: a flood with a 100-year recurrence interval can be exceeded more than once in the same year or can occur in consecutive years.

The flood-frequency relations for the Río de Bayamón near Bayamón and the Río de Bayamón at Bayamón were determined from long-term records. At the Río de Bayamón near Bayamón gaging station, flood peak data have been collected by the USGS during the periods of 1965 to 1970, and 1989 to present. The flood-frequency relation for the Río de Bayamón at Bayamón gaging station was determined using historical data and systematic records. Historical data for the floods of 1945, 1959, 1960, and 1961 and flood-peak data collected from 1962 to 1970 and from 1974 to 1975 were considered in the analysis. These flood-frequency relations were derived using the log-Pearson Type III distribution method (Interagency Advisory Committee on Water Data, 1982).

The flood-frequency relation for the Río de Bayamón near Bayamón gaging station indicates that the discharge of 1,840 m³/s for the September 10, 1996 flood has a recurrence interval of 50 years. At the site of the discontinued gaging station in the Highway PR-2 bridge at Bayamón, the flood discharge, 2,830 m³/s, also has a recurrence interval of 50 years. Flood-frequency curves for both gaging stations are shown in figure 6.

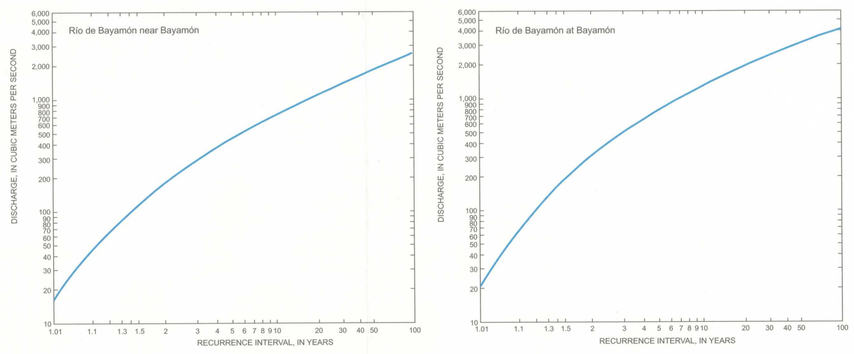

Figure 6. Flood-frequency curves for Río de Bayamón near Bayamón (50047850) and Río de Bayamón at Bayamón (50048000).

FLOODED AREAS

The September 10, 1996, flood was, with respect to area flooded, one of the largest ever recorded in the Bayamón area. Floodwaters of the Río de Bayamón inundated urban and rural areas. The areas affected in Bayamón were the urban subdivisions of Versalles, Santa Rosa, Jardines de Caparra, and Santa Cruz and the rural area of Parcelas Juan Sánchez sector of Barrio Minillas. More than 235 high-water marks were recovered and surveyed in these areas. The most affected areas were Parcelas Juan Sánchez and the urban subdivisions of Versalles and Santa Rosa, where the flood waters reached a maximum depth of about 2.7, 2.2, and 2.0 m, respectively. The Santa Rosa Mall and other businesses in the vicinity of Santa Rosa and Santa Cruz were seriously affected by the floodwaters of the Río de Bayamón. Downstream from the Highway PR-2 bridge the floodwaters were contained within the Río de Bayamón Express Channel.

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 are approximate and may not include areas where shallow flooding occurred. Some areas, outside the flood boundaries, were inundated by the backup of flood waters through the storm-water drains.

WATER-SURFACE CONTOURS

Water-surface contours are based on the elevation of high-water marks surveyed after the September 10, 1996, flood. These contours represent equal elevations of the water surface and are perpendicular to the direction of flow. Obstructions to the flow, such as very dense vegetation, manmade 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.

ADDITIONAL INFORMATION

Additional information related to this report can be obtained from the U.S. Geological Survey, Caribbean District, GSA Center, 651 Federal Drive, Suite 400-15, Guaynabo, Puerto Rico 00965-5703 and copies of this report can be purchased from the U.S. Geological Survey, Branch of Information Services, Box 25286, Federal Center, Denver, CO 80225-0286.

REFERENCES

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Hydrology Subcommittee Bulletin 17B, 183 p.

López, M.A., 1962, Floods at Bayamón and Cataño, Puerto Rico: U.S. Geological Survey Hydrologic Investigations Atlas HA-77, 1 pl.

López, M.A., Colón-Dieppa, Eloy, and Cobb, E.D., 1979, Floods in Puerto Rico, magnitude and frequency: U.S. Geological Survey Water-Resources Investigations Report 78-141, 68 p.

CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m³/s)	35.31	cubic foot per second
cubic hectometer (hm³)	810.7	acre-foot
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
centimeter (cm)	0.3937	inch
millimeter (mm)	0.03937	inch
square kilometer (km²)	0.3861	square mile
meter per kilometers (m/km)	5.280	foot per mile