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Estimation of Magnitude and Frequency of Floods for Streams in Puerto Rico: New Empirical Models

By Orlando Ramos-Ginés

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CONVERSION FACTORS and ACRONYMS

Multiply	By	To obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
square mile (mi^2)	2.590	square kilometer

Acronyms used in this report:

CDA	Contributing drainage area
DR	Depth-to-rock
FEMA	Federal Emergency Management Agency
GEV/PWM	Generalized Extreme Value Distribution Probability-Weighted Moments
GIS	Geographic Information System
GLS	Generalized least-squares
MAR	Mean annual rainfall
PRWRA	Puerto Rico Water Resources Authority
USGS	United States Geological Survey
USNRCS	United States Natural Resources Conservation Service
WRC	U.S. Water Resources Council

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Abstract

Flood-peak discharges and frequencies are presented for 57 gaged sites in Puerto Rico for recurrence intervals ranging from 2 to 500 years. The log-Pearson Type III distribution, the methodology recommended by the United States Interagency Committee on Water Data, was used to determine the magnitude and frequency of floods at the gaged sites having 10 to 43 years of record. A technique is presented for estimating flood-peak discharges at recurrence intervals ranging from 2 to 500 years for unregulated streams in Puerto Rico with contributing drainage areas ranging from 0.83 to 208 square miles. Log-linear multiple regression analyses, using climatic and basin characteristics and peak-discharge data from the 57 gaged sites, were used to construct regression equations to transfer the magnitude and frequency information from gaged to ungaged sites. The equations have contributing drainage area, depth-to-rock, and mean annual rainfall as the basin and climatic characteristics in estimating flood peak discharges. Examples are given to show a step-by-step procedure in calculating a 100-year flood at a gaged site, an ungaged site, a site near a gaged location, and a site between two gaged sites.

INTRODUCTION

Available peak-discharge data are used in flood-frequency studies to estimate the magnitude and frequency of floods that can occur at gaged sites. Estimates of the magnitude and frequency of floods are used for planning and designing structures such as dams, bridges, culverts, highways, and buildings; establishment of actuarial flood-insurance rates; and for proper flood-plain management by Federal and State agencies. These estimates are also needed at ungaged sites, and may be computed using regression of flood magnitude and frequency information at gaged sites with particular climatic and basin characteristics.

Two previous reports published by the U.S. Geological Survey (USGS) presented techniques to estimate the magnitude and frequency of floods in Puerto Rico. López and Fields (1970) presented techniques for estimating the 5-, 10-, 25-, and 50-year floods using data collected through December 1969 at 35 gaged sites. López and others (1979) presented techniques for estimating the 2-, 10-, 25-, 50-, and 100-year floods using data collected through December 1975 at 50 gaged sites.

Segarra-García (1998) discussed the applicability of discriminant analysis to form statistically homogeneous clusters of basins having similar flood-response characteristics. Segarra-García found as statistically significant four cluster regions for Puerto Rico, although a map of the regions was not published. His analysis was based on the Generalized

Extreme Value Distribution Probability-Weighted Moments (GEV/PWM) technique developed by Hosking and others (1985). Segarra-García discussed the standard errors obtained by using the GEV/PWM technique for the 100-year flood, which ranged from 12.0 to 28.7 percent, and found they were lower than those previously published by López and others (1979). However, Segarra-García concluded the equations he developed underestimated the 100-year flood discharge when he compared the estimated value with that of the gaged site obtained by using the log-Pearson Type III relation. He also stated that the underestimated discharge value could be related to the estimation of the skew coefficient needed in the equation he developed, and that further study was needed to explain the observations. A comparison of the Segarra-García method with estimates of the 25-, 50-, and 100-year flood discharges estimated from gaged data is included in this report.

Because more years of record were available at gaged sites, in 1995 the USGS began a study in cooperation with the Commonwealth of Puerto Rico, to update the study by López and others (1979) or develop new regression equations for Puerto Rico by using data collected through September 1994. This report differs from previous USGS reports by López and Fields (1970), and López and others (1979), by taking into account additional available data, improved analysis techniques accepted by the U.S. Water Resources Council (WRC), separation of flood-response regions based on skew coefficients, and current national need for 500-year flood values that can be used in bridge-scour analysis and by the Federal Emergency Management Agency (FEMA) for defining flood plains in flood-insurance studies.

Acknowledgments

The author would like to thank the following USGS employees for their contributions to this report. John Parks, Computer Specialist, who determined the physical and climate basin characteristics reported herein; Gary D. Tasker, Research Hydrologist, who provided a thorough technical review of the generalized least-squares and who provided the FORTRAN program listed at the end of this report; and all co-workers involved in the preparation and production of this report, particularly Ruth Guzmán and Francisco Maldonado.

Purpose and Scope

This report presents, for unregulated streams[1] in Puerto Rico, estimates of the magnitude and frequency of floods at gaged sites having 10 or more years of record and presents a technique that can be used to estimate the magnitude and frequency of floods at ungaged sites. Flood-peak discharge and frequency data for 57 gaging stations in Puerto Rico for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years are presented. To transfer the magnitude and frequency information from gaged sites to ungaged sites, regression equations were developed using log-linear multiple-regression techniques. The equations incorporate contributing drainage area (CDA), depth-to-rock (DR), and mean-annual rainfall (MAR), as basin and climatic characteristics for estimating flood-peak discharges at ungaged sites in Puerto Rico, for recurrence intervals of 2 to 500 years and contributing drainage areas ranging from 0.83 to 208 square miles (mi^2). Techniques and examples are presented to estimate the discharge at an ungaged site located within 50 to 150 percent of the drainage area of a near gaged site upstream, downstream, or between two gaged sites.

Physiography and General Climatology

Puerto Rico is the smallest island of the Greater Antilles. It is bounded by the Atlantic Ocean to the north and the Caribbean Sea to the south. The major physiographic features are the Cordillera Central and the small coastal plains along the north and south coasts. The Cordillera Central is an east-west mountain range with peak elevations commonly ranging from 3,000 to 4,000 feet above sea level. The Cordillera Central divides the island into a northern two-thirds and a southern one-third, forming the principal drainage divide of the larger streams. River

[1] Some of the gaged sites were established downstream of dams, because of particular data needs. For other sites, where the regulation occurs only in a small segment of their drainage area, the peak flow record is not affected, whereas it has some effect in the low flows of the streams. Regulation occurs, however, in a large portion of the drainage area upstream of sites 50046000 and 50114000. For these stations, the data for the unregulated period were used.

valleys are deeply incised into the mountain and slopes, and the general characteristic is roughness. There are dense tropical rain forests in the Sierra Luquillo mountain-range in northeastern Puerto Rico, but semiarid conditions prevail in southern and southwestern parts of the island.

Nearly 70 non-navigable rivers and streams originate in the Cordillera Central. These rivers are narrow, shallow, and generally less than 20 miles (mi) long, making them susceptible to over-bank floods and flash floods. Flash floods typically result from rainfall that is intense in the upper basins but is sparse or nonexistent on the coast. Streams on the south coast are more susceptible to flash floods than those on the north coast because of their shorter length and steeper upper basin gradients. Average stream length and slope are 22 mi and 132 feet per miles (ft/mi), respectively, on the north side of the island and 14 mi and 237 ft/mi on the south coast (Puerto Rico Department of Natural Resources, 1980).

Puerto Rico has a tropical marine climate. Rain-producing weather systems generally move over the island from the east during June 1 to November 30 (hurricane season), and from the northwest during December to May. In the hurricane season, the weather systems are tropical waves that develop in the trade-wind current, and upper-atmospheric troughs or cyclones in the tropical belt. During December to May, the weather-producing systems are frontal systems and low-pressure troughs.

Mean annual rainfall (1931 to 1960 period) ranges from about 35 inches (in.) in the west to about 200 in. near the top of the Caribbean National Forest in northeastern Puerto Rico (fig. 1) (Calvesbert, 1970). The uneven rainfall distribution is due mainly to a combination of different topography and the prevailing easterly winds. The copious rainfall on the Sierra de Luquillo mountain-range in northeastern Puerto Rico results from the orographic effects of the easterly winds against the mountain slopes.

Tropical waves that bring moisture to Puerto Rico and its neighboring islands occur most frequently during the hurricane season. These waves sometimes develop into tropical storms and hurricanes, particularly during August and September. More than 100 major storms have affected the island since 1493 (Salivia, 1972).

Severe floods in Puerto Rico are generally associated with hurricanes or tropical storms and waves. Fourteen of the 17 severe floods in Puerto Rico, from 1988 to 1994, occurred during the hurricane season. Nine of these severe floods were produced by tropical storms and waves.

MAGNITUDE AND FREQUENCY OF FLOODS AT GAGING STATIONS

Most of the annual peak-flow data (the largest instantaneous discharge recorded each year at a gaged site) used in this report were collected and compiled by the USGS as part of the cooperative effort with Commonwealth of Puerto Rico and other Federal agencies. The former Puerto Rico Water Resources Authority (PRWRA) began the earliest systematic collection of stream-flow data in Puerto Rico in 1907. Systematic collection of streamflow records by the USGS began in Puerto Rico in 1958, when a cooperative Commonwealth-Federal streamflow-gaging program was initiated with 10 gaging stations. By 1994, the USGS maintained and operated 97 gaging stations in Puerto Rico in cooperation with Commonwealth agencies.

Discharge Data Available

Systematic record and historic data for existing and discontinued gaging sites on the island were obtained for this study from the USGS database WATSTORE (WATer STOrage and REtrieval) system and from published reports.

By 1994, there were 67 gaging stations in Puerto Rico with 10 or more years of record, of which 10 stations were not used in this study and are listed in table 1. The data of the remaining 57 stations (fig. 2 and table 2) were used in the flood frequency and magnitude analysis. The length of record ranged from 10 to 43 years, with a mean of 21 years. The data for the regulated period at station 50046000 (table 2) (since 1974) were discarded. Only 12 stations had record lengths equal to or longer than 20 years, of which 12 had record lengths equal to or longer than 30 years. A review of the 1,238 recorded annual maximum peak-discharges with known dates shows that about 67 percent of the peaks (829 peaks) occurred during the 6-month-long hurricane season, June 1 to November 30 each year (fig. 3).

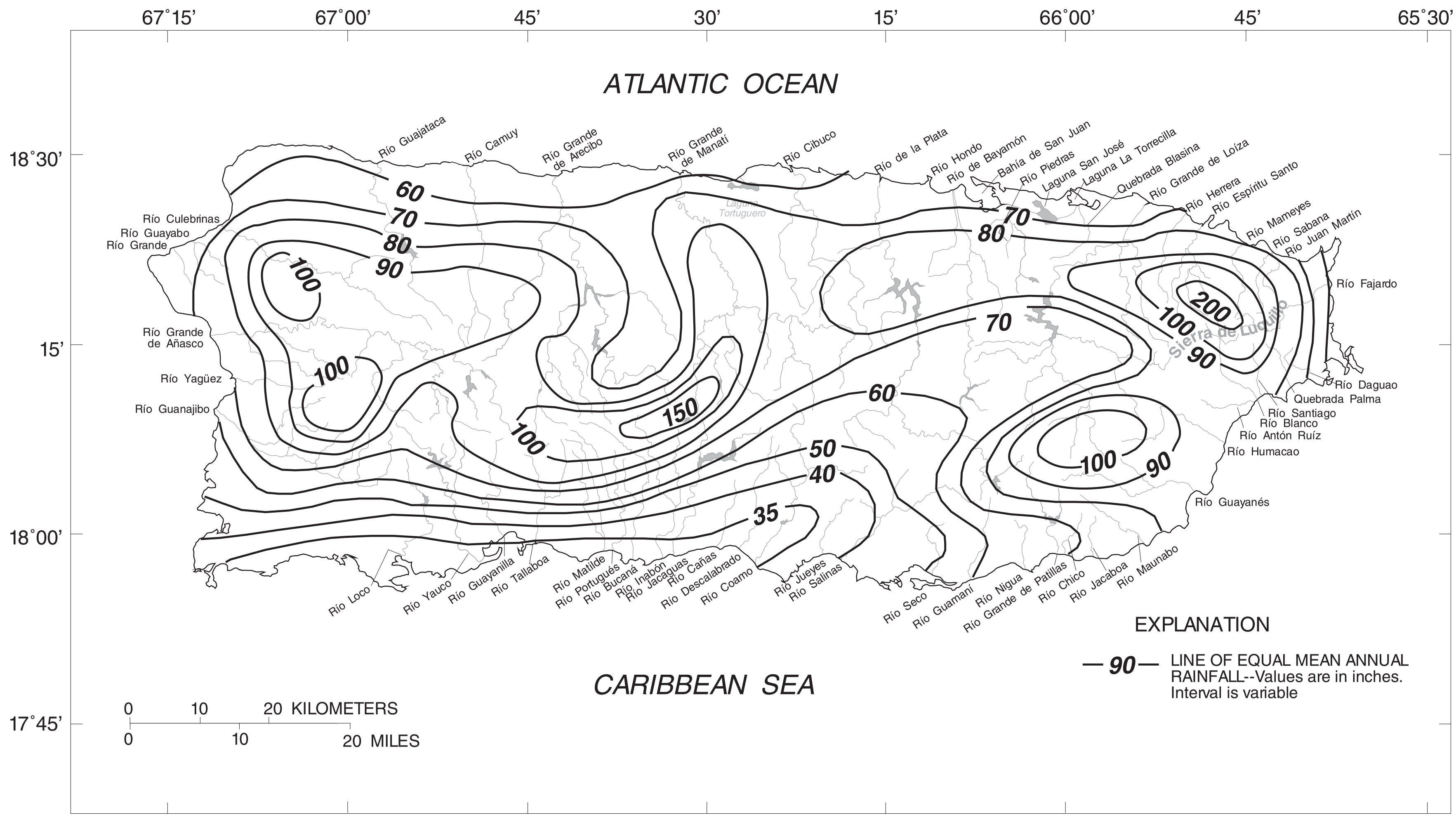

Figure 1. Mean annual rainfall in Puerto Rico, 1931-60 (from Calversbert, 1970).

Table 1. Stations with 10 or more years of peak-flow data which were not used in this report

USGS site identification	Site name	Latitude	Longitude	Years of record	Period of record	Reason(s)
50014800	Río Camuy near Bayaney	18°23'48"	66°49'03"	11	1984-94	Undetermined drainage area in karst area
50015700	Río Camuy near Hatillo	18°27'44"	66°49'56"	11	1984-94	Undetermined drainage area in karst area
50027750	Río Grande de Arecibo above Arecibo	18°25'29"	66°41'44"	13	1982-94	Upstream flow regulation
50029000	Río Grande de Arecibo at Central Cambalache	18°27'20"	66°42'10"	18	1899-1993	Upstream flow regulation
50049000	Río Piedras at Río Piedras	18°23'48"	66°03'24"	16	1973-93	Watershed more than 40 percent urbanized
50049100	Río Piedras at Hato Rey	18°24'34"	66°04'10"	17	1970-94	Watershed more than 40 percent urbanized
50051150	Quebrada Blanca at Jagual	18°09'40"	65°58'58"	10	1968-77	Ten peaks, one of which was an outlier
50063500	Quebrada Toronja at El Verde	18°19'43"	65°49'14"	12	1983-94	Small watershed and small variance in data
50073400	Quebrada Palma at Daguao	18°13'16"	65°41'30"	10	1968-77	Ten peaks, one of which was an outlier
50111500	Río Jacaguas at Juana Díaz	18°03'16"	66°30'40"	11	1984-94	Upstream flow regulation

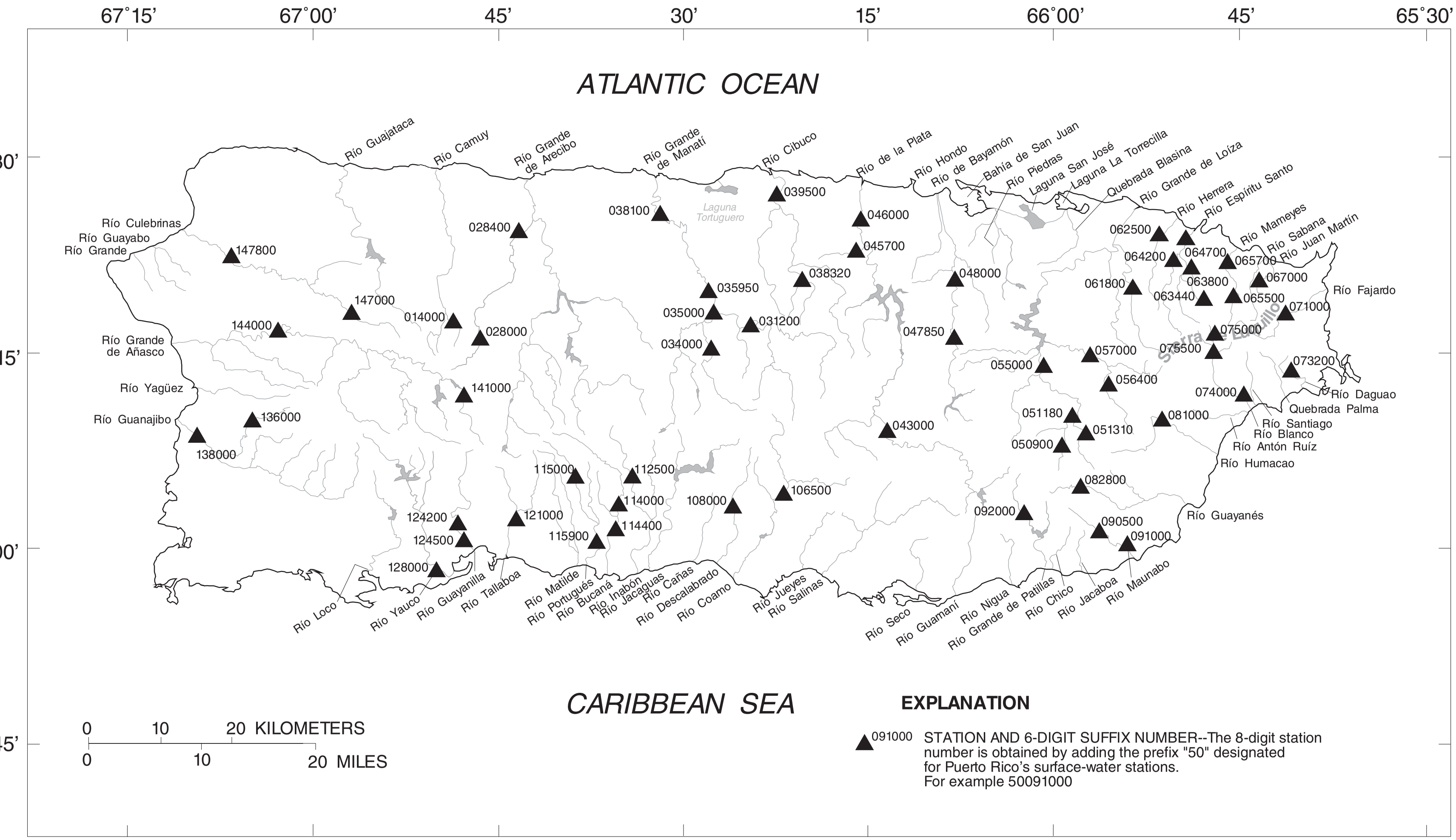

Figure 2. Location of gaging stations in Puerto Rico.

Table 2. Identification of stream-gaging stations having 10 or more years of record, up to water year 1994, and climatic and basin characteristics evaluated in this study

[CDA, contributing drainage area; DR, depth-to-rock; MAR, mean annual rainfall; SP, soil permeability; VC, vegetative cover; CS, channel slope; CL, channel length; GS, ground slope; RI-2, 2-year 24-hour rainfall intensity; RI-5, 5-year 24-hour rainfall intensity; RI-10, 10-year 24-hour rainfall intensity; RI-25, 25-year 24-hour rainfall intensity; RI-50, 50-year 24-hour rainfall intensity; RI-100, 100-year 24-hour rainfall intensity; mi^2, square miles; in., inch; in/hr, inch per hour; %, percent; ft/mi, feet per mile; mi, mile]

USGS site identification	Site name	Latitude	Longitude	Years of record	Period of record	CDA (mi^2)	DR (in.)	MAR (in.)	SP (in/hr)	VC (%)	CS (ft/mi)	CL (mi)	GS (%)	RI-2 (in.)	RI-5 (in.)	RI-10 (in.)	RI-25 (in.)	RI-50 (in.)	RI-100 (in.)
50014000	Río Criminales near Lares	18°17'57"	66°49'22"	13	1970-82	4.66	58.84	91.58	1.012	96.43	196.4	5.60	27.02	5.30	6.88	8.24	9.09	10.19	10.95
50028000	Río Tanamá near Utuado	18°18'02"	66°46'58"	35	1960-94	18.0	57.58	88.39	1.159	96.45	139.7	11.65	31.00	5.56	7.53	8.86	10.00	11.04	12.41
50028400	Río Tanamá at Charco Hondo	18°24'52"	66°42'52"	15	1969-94	22.2	53.04	87.64	1.137	96.09	102.4	24.63	34.54	5.39	7.25	8.52	9.57	10.52	11.76
50031200	Río Grande de Manatí near Morovis	18° 17'45"	66°24'47"	30	1965-94	55.2	51.19	74.83	1.265	93.51	86.25	25.24	32.51	5.26	7.18	8.84	10.58	12.02	13.55
50034000	Río Bauta near Orocovis[1]	18°14'10"	66°27'18"	19	1970-94	16.7	43.63	80.63	1.301	97.42	89.62	12.07	42.40	5.53	7.80	9.59	11.50	13.26	14.97
50035000	Río Grande de Manatí at Ciales	18°19'26"	66°27'36"	43	1899-1994	134.	48.68	83.04	1.225	95.13	76.76	32.06	37.83	5.39	7.41	9.08	10.81	12.34	13.89
50035950	Río Cialitos at Highway 649 at Ciales	18°20'18"	66°28'28"	13	1970-82	16.7	51.05	76.68	0.937	95.18	214.8	14.36	32.78	5.25	7.06	8.31	9.52	11.00	12.24
50038100	Río Grande de Manatí at Highway 2 near Manatí	18°25'52"	66°31'37"	37	1928-94	165.	48.07	82.25	1.190	94.43	54.57	47.79	36.02	5.33	7.31	8.92	10.55	12.08	13.58
50038320	Río Cibuco below Corozal	18°21'13"	66°20'07"	25	1970-94	15.2	47.95	80.31	1.250	86.68	198.0	6.30	22.35	4.99	6.82	7.89	9.61	10.58	11.60
50039500	Río Cibuco at Vega Baja	18°26'53"	66°22'29"	36	1959-94	81.6	45.85	78.10	0.944	87.44	73.60	19.39	22.47	4.94	6.73	7.87	9.45	10.63	11.66
50043000	Río de la Plata at Proyecto La Plata	18°09'37"	66°13'44"	33	1960-92	63.2	41.31	67.56	1.193	88.33	69.37	26.01	26.75	4.99	6.96	8.19	9.94	11.16	12.88
50045700	Río Lajas at Toa Alta	18°23'28"	66°15'28"	10	1966-75	8.28	41.31	79.41	0.909	91.93	69.92	5.37	19.00	4.90	6.49	7.53	8.90	9.97	11.02
50046000	Río de la Plata at Highway 2 near Toa Alta[2]	18°24'41"	66°15'39"	16	1928-73	208.	39.52	69.43	1.199	87.07	47.16	56.05	26.99	5.03	6.90	8.05	9.61	10.83	12.25
50047850	Río de Bayamón near Bayamón	18°20'08"	66°08'13"	15	1965-94	41.7	46.09	68.30	1.267	86.73	59.79	20.62	23.97	4.99	6.90	7.93	9.45	10.80	12.08
50048000	Río de Bayamón at Bayamón	18°23'53"	66°08'25"	15	1945-76	71.9	42.33	74.72	1.158	72.97	56.80	26.01	20.94	5.04	6.81	7.76	9.27	10.52	11.70
50050900	Río Grande de Loíza at Quebrada Arenas	18°07'10"	65°59'22"	17	1978-94	5.99	44.12	99.78	2.134	97.28	334.4	4.33	23.77	5.41	7.47	9.13	10.83	12.43	14.22
50051180	Quebrada Salvatierra near San Lorenzo[1]	18°10'24"	65°58'38"	11	1984-94	3.78	30.96	80.90	1.531	89.46	246.2	4.27	24.46	5.23	7.25	8.80	10.19	11.84	13.35
50051310	Río Cayaguas at Cerro Gordo	18°09'27"	65°57'29"	17	1978-94	10.2	39.91	100.00	2.787	97.61	55.37	9.78	18.89	5.60	7.79	9.30	11.08	12.66	14.44
50055000	Río Grande de Loíza at Caguas	18°14'33"	66°00'34"	36	1945-94	89.6	37.04	82.68	2.069	89.38	105.0	18.40	22.30	5.28	7.31	8.81	10.38	11.89	13.56
50056400	Río Valenciano near Juncos	18°12'58"	65°55'34"	24	1960-94	16.4	35.98	90.52	3.096	86.42	126.0	7.85	13.73	5.87	7.90	9.24	11.03	12.52	14.28
50057000	Río Gurabo at Gurabo	18°15'30"	65°58'05"	35	1960-94	60.1	36.70	80.81	2.671	88.87	171.3	16.28	17.35	5.76	7.77	9.16	10.84	12.27	13.73
50061800	Río Canóvanas near Campo Rico	18°19'08"	65°53'21"	27	1968-94	10.2	47.47	99.73	1.376	91.43	332.4	5.70	25.53	6.05	7.96	9.41	11.01	12.52	13.73
50062500	Río Herrera near Colonia Dolores	18°21'02"	65°52'00"	15	1968-82	2.75	52.23	142.34	1.241	82.97	376.1	3.63	21.49	6.12	7.99	9.43	10.90	12.43	13.73
50063440	Quebrada Sonadora near El Verde	18°19'24"	65°49'03"	12	1983-94	0.96	58.17	200.00	3.920	99.38	1,109.	1.55	28.76	6.79	8.63	10.00	11.96	13.00	14.71
50063800	Río Espíritu Santo near Río Grande	18°21'37"	65°48'49"	27	1967-94	8.64	54.25	184.61	1.734	95.39	364.5	7.41	24.56	6.61	8.41	10.06	11.71	12.98	14.52
50064200	Río Grande near El Verde	18°20'42"	65°50'30"	18	1968-94	7.34	53.43	172.74	3.541	95.00	449.6	6.37	26.01	6.37	8.19	9.86	11.43	12.87	14.28
50064700	Quebrada Boneta at Río Grande	18°22'42"	65°49'48"	13	1965-82	0.83	30.88	88.63	1.060	71.39	95.34	1.52	7.13	5.88	7.93	9.23	10.75	12.22	13.74
50065500	Río Mameyes near Sabana	18°19'46"	65°45'04"	17	1969-94	6.80	46.22	179.85	4.198	98.20	492.2	4.37	36.49	7.00	8.96	10.00	11.99	13.00	14.92
50065700	Río Mameyes at Highway 191 at Mameyes	18°22'03"	65°46'14"	18	1967-85	11.8	48.30	148.82	3.053	95.21	304.1	7.93	31.88	6.89	8.78	10.00	11.85	13.00	14.72
50067000	Río Sabana at Sabana	18°19'52"	65°43'52"	15	1980-94	3.91	59.15	105.25	1.320	95.11	406.1	3.55	29.84	6.76	8.55	10.00	11.72	12.97	14.37

Table 2. Identification of stream-gaging stations having 10 or more year of record, up to water year 1994, and climatic and basin characteristics evaluated in this study—Continued

USGS site identification	Site name	Latitude	Longitude	Years of record	Period of record	CDA (mi^2)	DR (in.)	MAR (in.)	SP (in/hr)	VC (%)	CS (ft/mi)	CL (mi)	GS (%)	RI-2 (in.)	RI-5 (in.)	RI-10 (in.)	RI-25 (in.)	RI-50 (in.)	RI-100 (in.)
50071000	Río Fajardo near Fajardo	18°17'56"	65°41'42"	34	1950-94	14.8	47.18	119.21	1.396	96.11	281.2	8.88	28.82	6.35	8.44	9.92	11.65	12.97	14.55
50073200	Río Daguao at Daguao	18°13'42"	65°40'39"	15	1966-82	2.25	31.34	83.83	0.993	91.31	154.8	4.11	23.33	5.64	8.05	9.77	11.52	13.00	15.00
50074000	Río Santiago at Naguabo	18°12'57"	65°43'51"	16	1966-82	4.99	34.77	127.27	4.675	93.70	196.7	3.69	27.81	6.31	8.37	10.00	11.98	13.00	15.00
50075000	Río Icacos near Naguabo	18°16'38"	65°47'09"	29	1946-94	1.26	56.76	199.94	1.300	98.70	100.6	1.30	22.18	6.93	8.99	10.00	12.00	13.00	15.00
50075500	Río Blanco at Florida	18°14'27"	65°47'06"	17	1962-82	10.8	38.34	160.13	5.988	96.85	673.1	4.23	32.26	6.60	8.62	10.00	11.94	13.00	14.94
50081000	Río Humacao at Las Piedras	18°10'27"	65°52'11"	15	1960-89	6.61	34.93	98.51	3.234	88.66	89.05	8.40	16.22	5.93	8.02	9.46	11.35	12.91	14.51
50082800	Río Guayanés near Colonia Laura	18°04'53"	65°57'33"	14	1969-82	4.83	38.12	95.41	2.654	93.37	170.8	5.17	20.32	5.46	7.54	9.20	10.99	12.54	14.32
50090500	Río Maunabo at Lizas	18°01'38"	65°56'24"	18	1972-94	5.29	28.60	80.64	3.975	97.40	225.9	5.03	28.80	5.50	7.60	9.27	11.11	12.61	14.32
50091000	Río Maunabo at Maunabo	18°00'24"	65°54'19"	16	1935-82	12.4	24.24	78.03	3.781	93.94	152.7	8.70	27.66	5.50	7.66	9.34	11.16	12.68	14.32
50092000	Río Grande de Patillas near Patillas	18°02'04"	66°01'58"	29	1966-94	18.4	34.72	87.56	2.263	98.14	227.0	8.46	36.06	5.22	7.15	8.79	10.25	11.96	13.42
50106500	Río Coamo near Coamo	18°03'52"	66°22'10"	19	1960-86	45.9	37.05	48.06	0.908	95.62	182.1	11.89	31.51	5.18	7.06	8.63	10.29	11.65	12.90
50108000	Río Descalabrado near Los Llanos	18°03'08"	66°25'34"	27	1966-94	12.9	41.08	46.61	0.476	95.29	187.8	8.00	26.59	4.98	6.95	8.31	9.84	11.33	12.54
50112500	Río Inabón at Real Abajo	18°05'10"	66°33'46"	31	1964-94	9.68	48.09	96.90	1.301	96.82	476.2	7.72	47.01	6.03	8.40	10.00	11.75	13.17	15.32
50114000	Río Cerrillos near Ponce[2]	18°04'15"	66°34'51"	18	1964-94	17.8	41.36	92.65	1.281	96.88	294.0	12.12	44.39	6.09	8.47	10.18	12.17	13.60	15.76
50114400	Río Bucaná at Highway 14 Bridge near Ponce	18°02'18"	66°35'12"	22	1899-1981	25.6	40.09	84.93	1.098	94.99	242.1	15.31	39.90	5.78	8.08	9.67	11.52	12.94	14.84
50115000	Río Portugués near Ponce	18°04'45"	66°38'01"	30	1965-94	8.80	40.07	94.59	1.292	95.71	280.0	8.54	43.10	6.08	8.59	10.32	12.53	13.98	15.99
50115900	Río Portugués at Highway 14 at Ponce	18°01'09"	66°36'26"	23	1899-1986	18.6	39.84	82.14	1.074	90.04	195.4	14.49	35.51	5.60	7.94	9.50	11.35	12.79	14.50
50121000	Río Tallaboa at Peñuelas	18°03'02"	66°43'19"	23	1928-82	22.0	39.59	85.72	1.283	95.40	257.7	10.28	37.27	5.76	8.41	10.07	12.29	13.82	15.89
50124200	Río Guayanilla near Guayanilla	18°02'40"	66°47'53"	14	1981-94	18.9	40.75	78.05	1.252	95.56	238.6	11.05	38.55	5.65	8.34	10.16	12.30	14.22	16.44
50124500	Río Guayanilla at Guayanilla	18°02'01"	66°47'57"	10	1899-1982	20.9	41.19	75.93	1.246	94.63	221.4	12.06	37.02	5.63	8.29	10.08	12.20	14.11	16.32
50128000	Río Yauco near Yauco	17°59'19"	66°49'55"	13	1899-1985	46.1	29.87	64.67	1.245	91.85	102.1	20.90	32.96	5.60	7.99	9.59	11.41	13.27	15.47
50136000	Río Rosario at Rosario	18°10'22"	67°04'31"	12	1975-86	17.6	43.72	99.54	1.185	96.45	146.6	12.83	34.07	5.46	7.58	9.38	11.18	13.02	14.76
50138000	Río Guanajibo near Hormiguero	18°08'36"	67°08'57"	19	1975-94	120.	35.55	70.83	1.158	91.31	75.35	27.72	24.02	5.59	7.46	9.09	10.67	12.16	13.78
50141000	Río Yahuecas near Adjuntas	18°12'19"	6648'01"	24	1947-85	15.2	54.79	86.83	1.300	97.67	239.2	7.03	35.43	6.18	8.94	10.87	13.45	15.18	17.48
50144000	Río Grande de Añasco near San Sebastián	18°17'05"	67°03'05"	32	1963-94	134	52.10	89.46	1.775	97.07	81.67	38.32	35.02	5.57	7.84	9.50	11.23	12.89	14.66
50147000	Río Culebrinas at San Sebastián	18°20'09"	66°59'46"	17	1960-82	16.7	54.49	91.55	1.163	92.71	107.2	11.36	22.05	4.70	6.23	7.29	8.14	9.20	9.89
50147800	Río Culebrinas at Highway 404 near Moca	18°21'42"	67°05'33"	26	1969-94	71.3	53.62	93.50	1.074	93.15	53.41	25.24	19.41	4.47	6.07	7.07	7.71	8.43	8.95

[1] Although at the 95-percent confidence level the data from these stations showed a significant trend, they were included in the analysis.
[2] Flow regulation occurs upstream of these sites. Only the data for the unregulated period were used. Regulation upstream of station 50046000 began in 1973, and upstream of station 50114000 in 1991.

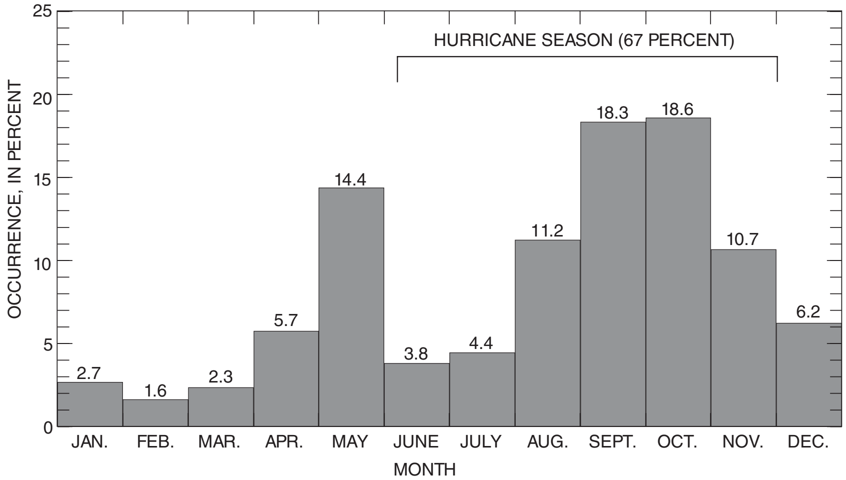

Figure 3. Monthly occurrence of 1,238 annual maximum peak discharges for 57 stream-gaged sites in Puerto Rico, 1899 to 1994.

Flood Frequency Analysis

Station flood-frequency relations were defined using the Bulletin 17B guidelines (Hydrology Subcommittee of Interagency Advisory Committee on Water Data, 1982). A flood-frequency relation is the relation of flood-peak magnitude to probability of exceedance or recurrence intervals. Probability of exceedance is the chance of a given flood magnitude being exceeded in any given year. A 25-year flood, for example, has the probability of 0.04 (4 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. We may expect a 25-year flood to be exceeded on average once in 25 years, or four times in 100 years. This does not mean floods occur at uniformly spaced intervals. In fact, a flood of this magnitude can be exceeded more than once in the same year, or it can occur in consecutive years.

Bulletin 17B guidelines recommend a minimum of 10 years of data for flood-frequency studies. The use of the 10-year data minimum still allows for a good representative sample of the type of flood data involved. Because of climatic changes, a smaller temporal sample may not represent all flow possibilities.

Bulletin 17B outlines procedures to fit the logarithms of observed annual peak discharges to the Pearson Type III frequency distribution, known as the log-Pearson Type III distribution. Three statistics characterize the log-Pearson Type III distribution: the mean, standard deviation, and skew coefficient. These statistics, computed from the base-10 logarithmic transformation of annual peak discharges, are presented in this report. The skew coefficient is the numerical measurement of the lack of symmetry. If the skew coefficient is zero, then the log-Pearson Type III distribution becomes identical to the log-normal distribution.

Bulletin 17B suggests the use of a generalized skew coefficient to improve the station skew coefficients, under the assumption that the generalized skew is unbiased and independent of station skew. The generalized skew is a numeric value derived by a procedure that integrates values obtained at many locations. Clark (1998) presented and discussed an isopleth map of skew coefficients for Puerto Rico. Clarks's report, however, did not present the skew statistic of flood data available for five additional gaged sites having more than 20 years of record. These sites were USGS site numbers 50075000 (Río Icacos near Naguabo), 50114400 (Río Bucaná at Highway 14 Bridge near Ponce), 50115900 (Río Portugués at Highway 14 at Ponce), 50121000 (Río Tallaboa at Peñuelas), and 50141000 (Río Yahuecas near Adjuntas), which had 29, 22, 23, 23, and 24 years of record, respectively, through September 1994. Clark appears to have also included data of the regulated period (after 1973) of USGS station 50046000 (Río de la Plata at Highway 2 near Toa Alta). A new map of skew coefficients for Puerto Rico was constructed by using average skew coefficients of stations with 20 or more years of record for different WRC regions (U.S. Water Resources Council, 1978) as presented in figure 4. It is this new map of average skew coefficients for the North Coast-East Coast (NC-EC) and the South Coast-West Coast (SC-WC) WRC regions that is used for the generalized skew coefficients in this report. Statistical tests indicate a significant difference between average skews for the regions shown in figure 4.

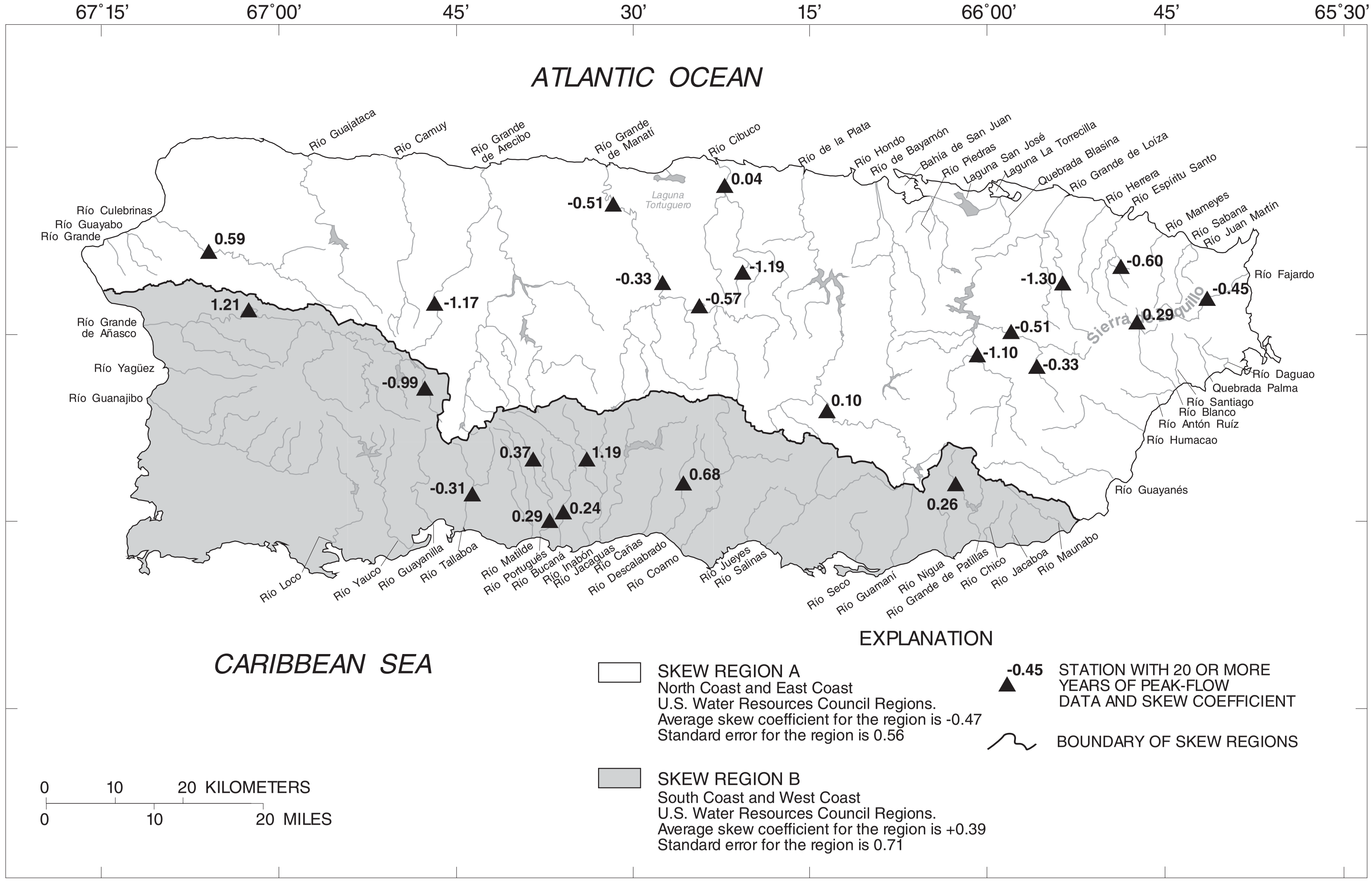

Figure 4. Skew regions in Puerto Rico, using stations having 20 or more years of record.

Annual peak-discharge data from gaging stations having a minimum of 10 years of record through September 1994 were used to define the flood-frequency relation at each gaged site. Following the Bulletin 17B guidelines, flood frequency relations were developed for each gaging station by using the log-Pearson Type III distribution. Peak-discharge statistics and T-year peak discharges at stream-gaging stations used in this report are presented in table 3. For stations where regulation began during the data collection period, peak-discharge statistics are only presented for the unregulated period.

REGIONAL MAGNITUDE AND FREQUENCY OF FLOODS AT UNGAGED SITES

Peak discharge of various recurrence intervals and physical and climatic basin characteristics for each gaging station were used in multiple-regression analyses to develop estimating equations for flood-peak discharges and frequencies on unregulated streams in Puerto Rico. Several physical and climatic basin characteristics were tested for significance in estimating flood peaks.

Basin Characteristics

Physical and climatic basin characteristics were computed by using the Caribbean District Geographic Information System (GIS) software. The characteristics were determined by using digitized 1:20,000-scale topographic maps and coverages or overlays containing the drainage-basin outlines, mean annual rainfall, 2-, 5-, 10-, 25-, 50-, and 100-year 24-hour rainfall intensity contours, streams, soil properties (permeability and depth-to-rock), and land use. The characteristics tested are below and a statistical summary of the climatic and physical basin characteristics tested is presented in table 4.

CDA: contributing drainage area computed up to the gaging site, in square miles. This characteristic differs from total drainage area in that all non-contributing areas such as sinkholes and drainage to caves were eliminated.

DR: depth-to-rock, in inches. The average of the maximum depth-to-rock values for the soils within the basins. Depth-to-rock values were obtained from the U.S. Natural Resources Conservation Services (USNRCS) data (Acevedo, 1982; Boccheciamp, 1977 and 1978; Carter, 1965; and Gierbolini, 1975 and 1979) in a GIS coverage.

MAR: weighted mean annual rainfall, in inches, on a basin computed by overlying a GIS coverage of lines of equal mean annual rainfall (1931-60 period, see fig. 1) (Calvesbert, 1970) on the drainage area basin coverage, and then computing the area-weighted average of rainfall in each basin.

SP: average permeability of soils within the basin, in inches per hour. Soil permeability data were obtained from the USNRCS (Acevedo, 1982; Boccheciamp, 1977 and 1978; Carter, 1965; and Gierbolini, 1975 and 1979) in a GIS coverage. The mid point of the range of soil permeability assigned to each soil type by the USNRCS was used to compute the average permeability of soils within the basin. For those soils assigned a permeability of greater than 20.0 in/hr, a value of 30.0 in/hr was used.

VC: vegetative cover of a drainage basin, in percent of the total drainage area. Computed from a GIS coverage of land use during 1977 (Puerto Rico Department of Natural and Environmental Resources, unpublished maps). The following land-use categories were included as vegetative cover: Ac (coffee), As (sugar cane), Ao (citric), Ag (coconuts), Ap (pineapple), Ab (plantain and bananas), At (tobacco), Af (floral culture), Am (mixed agriculture of minor fruits), Ay (specialized farming), AaB (dairy cattle), Aay-1 (horses), Ax (pastures), Ai (fallow lands), Ar (rice), Fd (large and high density of trees), Fb (high density of trees medium high, and short foliage), Fp (public forest), Ft (low density of trees), Fx (brush and bushes), OR-1 (golf fields), OR-5 (zoologic, aquarium), OR-6 (camping, field trip, and playgrounds), OR-3 (athletic fields).

CS: main-channel slope of a drainage basin, in feet per mile. This value is computed by dividing the altitude difference between points at the station and the upper end of the streamline.

CL: main-channel length, in miles. The distance along a stream from the gaging site to the drainage-basin divide, along the channel that drains the largest basin.

Table 3. Maximum annual peak-discharge statistics and t-year peak discharges at gaged sites in Puerto Rico having 10 or more years of record

[Std. dev., standard deviation; ft^3/s, cubic foot per second]

USGS site identification		Peak-discharge statistics from logarithms of maximum annual floods									
		Gaged record			t-year peak discharges, in ft^3/s						
		Mean	Std. dev.	Skew	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}
50014000	Gaged Record	3.45	0.24	-0.53	2,940	4,459	5,403	6,508	7,269	7,977	9,461
	Bulletin 17B weighted	3.45	0.24	-0.50	2,930	4,458	5,520	6,559	7,351	8,096	9,679
50028000	Gaged Record	3.72	0.22	-1.17	5,714	7,930	8,975	9,931	10,450	10,840	11,440
	Bulletin 17B weighted	3.72	0.20	-0.81	5,631	7,903	9,131	10,410	11,210	11,890	13,130
50028400	Gaged Record	3.53	0.36	0.24	3,301	6,831	10,180	15,830	21,220	27,770	48,690
	Bulletin 17B weighted	3.53	0.36	-0.13	3,477	6,943	9,867	14,250	17,980	22,120	33,360
50031200	Gaged Record	3.96	0.41	-0.57	9,884	20,330	28,260	38,810	46,790	54,720	72,760
	Bulletin 17B weighted	3.98	0.36	-0.11	9,700	19,230	27,280	39,360	49,700	61,170	92,510
50034000	Gaged Record	3.58	0.46	-1.25	4,699	9,222	11,800	14,360	15,790	16,900	18,570
	Bulletin 17B weighted	3.63	0.35	-0.33	4,414	8,451	11,580	15,910	19,350	22,920	31,730
50035000	Gaged Record	4.25	0.43	-0.33	18,730	41,610	61,320	90,740	115,500	142,400	213,000
	Bulletin 17B weighted	4.27	0.40	-0.08	18,650	40,100	59,410	89,870	117,100	148,300	237,800
50035950	Gaged Record	3.68	0.18	0.00	4,753	6,693	8,004	9,686	10,960	12,240	15,320
	Bulletin 17B weighted	3.68	0.18	-0.25	4,835	6,720	7,907	9,339	10,360	11,340	13,530
50038100	Gaged Record	4.28	0.48	-0.51	20,940	49,370	73,500	108,300	136,500	166,000	238,200
	Bulletin 17B weighted	4.28	0.48	-0.49	20,890	49,360	73,680	109,000	137,800	168,000	242,600
50038320	Gaged Record	3.85	0.26	-1.19	7,854	11,570	13,380	15,050	15,960	16,650	17,710
	Bulletin 17B weighted	3.86	0.22	-0.58	7,682	11,230	13,350	15,760	17,370	18,850	21,850
50039500	Gaged Record	3.81	0.42	0.04	6,456	14,620	22,500	35,710	48,190	63,170	109,600
	Bulletin 17B weighted	3.81	0.42	-0.12	6,623	14,720	22,120	33,850	44,360	56,410	90,960
50043000	Gaged Record	4.04	0.43	0.10	10,720	24,700	38,580	62,490	85,670	114,100	205,300
	Bulletin 17B weighted	4.04	0.43	-0.09	11,060	24,930	37,810	58,580	77,450	99,350	163,300
50045700	Gaged Record	3.27	0.49	-0.02	1,884	4,835	7,903	13,330	18,670	25,280	46,590
	Bulletin 17B weighted	3.27	0.49	-0.29	1,982	4,891	7,615	11,950	15,790	20,140	32,230
50046000	Gaged Record	4.20	0.50	0.32	15,070	40,870	71,290	132,600	200,900	295,000	661,500
	Bulletin 17B weighted	4.20	0.50	-0.11	16,340	42,000	68,000	112,700	155,400	206,900	365,900
50047850	Gaged Record	3.76	0.42	-0.61	6,354	13,220	18,410	25,240	30,350	35,380	46,610
	Bulletin 17B weighted	3.81	0.33	-0.11	6,492	12,270	16,980	23,880	29,680	36,010	52,930
50048000	Gaged Record	4.00	0.35	0.74	9,115	19,100	29,870	50,430	72,650	102,800	218,700
	Bulletin 17B weighted	4.00	0.35	0.05	10,000	19,950	28,730	42,510	54,840	69,030	110,300
50050900	Gaged Record	3.68	0.23	1.12	4,355	7,129	9,803	14,460	19,100	25,010	45,660
	Bulletin 17B weighted	3.68	0.23	0.19	4,723	7,474	9,591	12,600	15,100	17,800	25,060
50051180	Gaged Record	3.39	0.41	-0.50	2,666	5,575	7,857	10,990	13,420	15,900	21,760
	Bulletin 17B weighted	3.39	0.41	-0.48	2,659	5,574	7,877	11,060	13,550	16,100	22,180
50051310	Gaged Record	3.66	0.38	-1.18	5,470	9,707	12,040	14,350	15,660	16,690	18,290
	Bulletin 17B weighted	3.69	0.33	-0.69	5,389	9,430	12,080	15,230	17,390	19,400	23,510
50055000	Gaged Record	4.26	0.38	-1.10	21,300	38,210	47,950	57,990	63,940	68,760	76,760
	Bulletin 17B weighted	4.28	0.35	-0.76	20,860	37,750	48,800	61,820	70,660	78,730	94,850
50056400	Gaged Record	3.94	0.34	-0.33	9,053	17,050	23,170	31,580	38,210	45,070	61,870
	Bulletin 17B weighted	3.94	0.34	-0.39	9,125	17,060	23,010	31,010	37,190	43,480	58,460
50057000	Gaged Record	4.15	0.48	-0.51	15,670	36,830	54,760	80,620	101,500	123,400	176,900
	Bulletin 17B weighted	4.15	0.48	-0.49	15,630	36,820	54,890	81,100	102,400	124,800	180,100
50061800	Gaged Record	3.65	0.38	-1.30	5,401	9,337	11,370	13,250	14,250	15,000	16,070
	Bulletin 17B weighted	3.68	0.30	-0.37	5,036	8,765	11,440	14,930	17,570	20,220	26,420
50062500	Gaged Record	3.26	0.31	-2.01	2,272	3,185	3,465	3,628	3,681	3,708	3,728
	Bulletin 17B weighted	3.30	0.23	-0.83	2,144	3,116	3,650	4,212	4,559	4,856	5,400
50063440	Gaged Record	3.04	0.24	-0.18	1,123	1,755	2,196	2,771	3,208	3,652	4,713
	Bulletin 17B weighted	3.04	0.24	-0.34	1,141	1,760	2,170	2,680	3,051	3,414	4,232
50063800	Gaged Record	3.82	0.30	-0.60	7,127	12,010	15,210	19,070	21,780	24,320	29,690
	Bulletin 17B weighted	3.82	0.30	-0.54	7,083	12,010	15,300	19,360	22,250	25,010	30,990

Table 3. Maximum annual peak-discharge statistics and t-year peak discharges at gaged sites in Puerto Rico having 10 or more years of record--Continued

USGS site identification		Peak-discharge statistics from logarithms of maximum annual floods									
		Gaged record			t-year peak discharges, in ft³/s						
		Mean	Std. dev.	Skew	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}
50064200	Gaged Record	3.70	0.32	-0.20	5,174	9,430	12,730	17,370	21,110	25,070	35,140
	Bulletin 17B weighted	3.70	0.32	-0.33	5,258	9,456	12,570	16,760	20,010	23,340	31,340
50064700	Gaged Record	3.09	0.39	0.92	1,063	2,422	4,049	7,486	11,560	17,530	43,960
	Bulletin 17B weighted	3.09	0.39	0.07	1,206	2,583	3,868	5,974	7,930	10,250	17,290
50065500	Gaged Record	4.01	0.18	0.17	10,080	14,430	17,540	21,690	24,960	28,380	37,010
	Bulletin 17B weighted	4.01	0.18	-0.14	10,300	14,530	17,290	20,740	23,270	25,770	31,550
50065700	Gaged Record	4.03	0.30	-0.58	11,400	19,380	24,670	31,120	35,670	39,980	49,190
	Bulletin 17B weighted	4.03	0.30	-0.52	11,330	19,370	24,820	31,580	36,450	41,130	51,370
50067000	Gaged Record	3.62	0.24	-0.03	4,164	6,625	8,430	10,890	12,830	14,870	20,010
	Bulletin 17B weighted	3.62	0.24	-0.26	4,250	6,656	8,306	10,420	12,000	13,580	17,260
50071000	Gaged Record	3.89	0.28	-0.45	8,102	13,460	17,090	21,640	24,940	28,160	35,320
	Bulletin 17B weighted	3.89	0.28	-0.46	8,109	13,460	17,080	21,600	24,880	28,060	35,130
50073200	Gaged Record	3.27	0.52	-0.48	2,053	5,172	7,969	12,180	15,710	19,500	29,140
	Bulletin 17B weighted	3.27	0.52	-0.47	2,051	5,172	7,974	12,200	15,750	19,560	29,290
50074000	Gaged Record	3.43	0.42	0.13	2,659	6,147	9,645	15,740	21,710	29,090	53,160
	Bulletin 17B weighted	3.43	0.42	-0.18	2,797	6,235	9,331	14,170	18,440	23,270	36,810
50075000	Gaged Record	3.09	0.18	0.29	1,210	1,739	2,126	2,657	3,085	3,539	4,721
	Bulletin 17B weighted	3.09	0.18	0.00	1,235	1,751	2,102	2,553	2,894	3,240	4,072
50075500	Gaged Record	3.91	0.32	0.50	7,564	14,540	21,200	32,620	43,780	57,650	103,900
	Bulletin 17B weighted	3.91	0.32	0.00	8,041	14,900	20,570	29,010	36,230	44,250	66,330
50081000	Gaged Record	3.50	0.40	0.69	2,841	6,506	10,680	19,030	28,420	41,550	94,750
	Bulletin 17B weighted	3.50	0.40	0.00	3,155	6,815	10,190	15,650	22,650	26,500	43,890
50082800	Gaged Record	3.55	0.22	-0.46	3,719	5,492	6,598	7,905	8,814	9,670	11,500
	Bulletin 17B weighted	3.55	0.22	-0.46	3,721	5,493	6,594	7,892	8,793	9,641	11,450
50090500	Gaged Record	3.35	0.39	-0.50	2,389	4,823	6,687	9,201	11,130	13,080	17,640
	Bulletin 17B weighted	3.35	0.39	-0.15	2,269	4,787	6,981	10,340	13,250	16,510	25,510
50091000	Gaged Record	3.38	0.52	-0.10	2,425	6,539	10,870	18,530	26,040	35,260	64,600
	Bulletin 17B weighted	3.38	0.52	0.11	2,328	6,460	11,150	20,170	29,720	42,280	87,190
50092000	Gaged Record	3.67	0.34	0.26	4,535	8,878	12,860	19,380	25,470	32,750	55,370
	Bulletin 17B weighted	3.67	0.34	0.30	4,514	8,861	12,890	19,550	25,830	33,400	57,260
50106500	Gaged Record	3.90	0.34	0.51	7,429	15,050	22,650	36,110	49,650	66,900	126,600
	Bulletin 17B weighted	3.90	0.34	0.46	7,473	15,100	22,600	35,730	48,790	65,260	121,300
50108000	Gaged Record	3.49	0.40	0.68	2,760	6,394	10,570	18,970	28,460	41,790	96,190
	Bulletin 17B weighted	3.49	0.40	0.57	2,806	6,456	10,520	18,430	27,110	38,950	85,000
50112500	Gaged Record	3.22	0.34	1.19	1,406	2,936	4,752	8,586	13,150	19,890	50,290
	Bulletin 17B weighted	3.22	0.34	0.87	1,464	3,028	4,744	8,091	11,780	16,880	37,220
50114000	Gaged Record	3.59	0.37	0.34	3,747	7,853	11,880	18,880	25,760	34,340	62,920
	Bulletin 17B weighted	3.59	0.37	0.35	3,737	7,844	11,900	18,970	25,960	34,720	64,110
50114400	Gaged Record	3.76	0.25	0.24	5,677	9,438	12,480	16,990	20,860	25,190	37,320
	Bulletin 17B weighted	3.76	0.25	0.30	5,648	9,418	12,510	17,160	21,190	25,740	38,730
50115000	Gaged Record	3.34	0.37	0.83	1,966	4,301	6,951	12,260	18,270	26,710	61,450
	Bulletin 17B weighted	3.34	0.37	0.68	2,005	4,355	6,922	11,870	17,260	24,600	53,070
50115900	Gaged Record	3.53	0.35	0.37	3,253	6,674	10,010	15,780	21,440	28,500	52,010
	Bulletin 17B weighted	3.53	0.35	0.38	3,251	6,671	10,010	15,800	21,490	28,590	52,290
50121000	Gaged Record	3.74	0.43	-0.31	5,838	12,870	18,920	27,930	35,530	43,780	65,440
	Bulletin 17B weighted	3.74	0.43	-0.08	5,617	12,770	19,480	30,380	40,360	52,010	86,390
50124200	Gaged Record	3.38	0.41	0.89	2,076	4,983	8,577	16,380	25,850	40,000	104,600
	Bulletin 17B weighted	3.38	0.41	0.66	2,152	5,098	8,516	15,460	23,350	34,480	80,240
50124500	Gaged Record	3.82	0.34	0.51	6,231	12,640	19,020	30,340	41,720	56,220	106,400
	Bulletin 17B weighted	3.82	0.34	0.45	6,279	12,690	18,970	29,920	40,780	54,420	100,600

Table 3. Maximum annual peak-discharge statistics and t-year peak discharges at gaged sites in Puerto Rico having 10 or more years of record--Continued

USGS site identification		Peak-discharge statistics from logarithms of maximum annual floods									
		Gaged record			t-year peak discharges, in ft³/s						
		Mean	Std. dev.	Skew	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}
50128000	Gaged Record	3.38	0.50	-0.67	2,744	6,454	9,434	13,480	16,560	19,620	26,460
	Bulletin 17B weighted	3.44	0.38	0.49	2,580	5,649	8,870	14,830	21,040	29,180	58,690
50136000	Gaged Record	3.74	0.26	1.96	4,602	8,022	12,180	21,110	31,970	48,400	126,600
	Bulletin 17B weighted	3.74	0.26	0.90	5,053	8,802	12,420	18,740	25,040	33,050	60,920
50138000	Gaged Record	3.86	0.59	0.54	6,400	21,360	43,080	96,270	167,000	280,000	848,500
	Bulletin 17B weighted	3.86	0.59	0.49	6,480	21,500	42,890	94,170	160,900	265,600	774,100
50141000	Gaged Record	3.79	0.25	-0.99	6,802	10,050	11,770	13,490	14,500	15,330	16,740
	Bulletin 17B weighted	3.81	0.21	-0.06	6,509	9,652	11,820	14,650	16,810	19,000	24,310
50144000	Gaged Record	4.19	0.32	1.21	13,300	26,610	41,970	73,520	110,200	163,200	394,400
	Bulletin 17B weighted	4.19	0.32	0.88	13,820	27,420	41,910	69,460	99,160	139,400	295,000
50147000	Gaged Record	3.74	0.14	-0.42	5,582	7,155	8,050	9,048	9,712	10,320	11,570
	Bulletin 17B weighted	3.74	0.14	-0.10	5,489	7,134	8,157	9,389	10,270	11,120	13,040
50147800	Gaged Record	4.38	0.17	0.59	23,080	32,640	40,000	50,580	59,450	69,200	96,010
	Bulletin 17B weighted	4.38	0.17	0.53	23,180	32,710	39,950	50,210	58,720	67,990	93,090

Table 4. Statistical summary of climatic and basin characteristics for gaged sites in Puerto Rico having 10 or more years of record

[CDA, contributing drainage area; DR, depth-to-rock; MAR, mean annual rainfall; SP, soil permeability; VC, vegetative cover; CS, channel slope; CL, channel length; GS, ground slope; RI-2, 2-year 24-hour rainfall intensity; RI-5, 5-year 24-hour rainfall intensity; RI-10, 10-year 24-hour rainfall intensity; RI-25, 25-year 24-hour rainfall intensity; RI-50, 50-year 24-hour rainfall intensity; RI-100, 100-year 24-hour rainfall intensity; mi^2, square miles; in., inch; in/hr, inch per hour; %, percent; ft/mi, feet per mile; mi, mile]

Basin characteristic	Minimum	Maximum	Median	Mean	Standard deviation
CDA (mi^2)	0.83	208.	15.8	32.24	43.80
DR (in.)	24.24	59.15	41.85	43.63	8.46
MAR (in.)	46.61	200.	87.60	97.30	34.37
SP (in/hr)	0.476	5.988	1.271	1.784	1.139
VC (%)	71.39	99.38	95.00	92.93	5.47
CS (ft/mi)	47.16	1,109.	176.70	211.06	177.53
CL (mi)	1.30	56.05	8.79	12.98	11.14
GS (%)	7.13	47.01	27.74	28.53	8.14
RI-2 (in.)	4.47	7.00	5.60	5.68	0.59
RI-5 (in.)	6.07	8.99	7.80	7.73	0.71
RI-10 (in.)	7.07	10.87	9.32	9.20	0.84
RI-25 (in.)	7.71	13.45	11.06	10.88	1.13
RI-50 (in.)	8.43	15.18	12.58	12.28	1.26
RI-100 (in.)	8.95	17.48	14.30	13.87	1.62

GS: the average of the ground slope of all 30- by 30-meter cell in a GIS coverage, within a drainage basin. The value is expressed in percent and was computed using a GIS.

RI-*i*: the average *i*-year 24-hour rainfall intensity in a GIS coverage, within the drainage basin. The value "*i*" was equal to 1, 2, 5, 10, 25, 50, and 100 years (U.S. Department of Commerce, 1961).

Development of Regional Regression Equations

After the discharge-frequency relations were defined and physical and climatic basin characteristics determined for each gaged site, the flood discharges for seven different recurrence intervals (2, 5, 10, 25, 50, 100, and 500 years) were related to the significant physical and climatic basin characteristics by using log-linear multiple-regression techniques to develop estimating equations for flood-peak discharges and frequencies on unregulated streams in Puerto Rico. The generalized least-squares (GLS) method developed by Stedinger and Tasker (1985) was used in the analyses. This technique is an improvement over ordinary least squares regression, because the GLS method accounts for cross-correlation between sites and for unequal record length.

Initially, all basin characteristics were used in each regression. Not all variables were used for the final equations. Step-wise, ordinary least squares regression technique was used for initial screening and in selecting possible variables using the base-10 logarithmic values of the 50-year flood and the basin characteristic values. Variable selection for the final models was made by choosing from among all possible subsets of basin characteristics that had the small Mallow's *Cp* (Montgomery and Peck, 1982; Myers, 1986) and had physically logical mathematical signs for their coefficients. The USGS developed computer program GLSNET (Generalized Least Squares and NETwork analysis) was used to determine the final models, presented in this report.

In this study, different techniques and methods were used in an attempt to group basins having similar flood response characteristics into homogeneous regions. Homogeneity of regions' flood characteristics can reduce errors in estimates of peak discharge for gaged and ungaged sites. The simplest method of regionalization is to group basins geographically. However, continuous geographical regions are not a guarantee of homogeneity since adjacent basins can be very different in terms of rainfall-runoff flood response. The techniques and methods considered and evaluated in this study were (1) regionalization by using the method of residuals (Choquette, 1988; Bhaskar and O'Conner, 1989) and (2) cluster analysis by using the disjoint clustering procedure based on Euclidean distances. In addition, the geographically-defined surface-water regions outlined by the U.S. Water Resources Council (1978) were also considered and evaluated in determining their appropriateness as homogeneous flood-response regions.

The regionalization by the method of residuals involves classifying basins into regions using the sign and magnitude of the residuals (differences in predicted and observed peak discharges), basin and climatic conditions, and hydrologic judgement. The method assumes that the general trends in the residuals reflect inherent variations in the flood response of various regions. Thus, residuals with similar sign and magnitude are assumed to represent regions with similar flood-response characteristics and are grouped together.

The regionalization by the method of clusters was done by using the following as the clustering variables: LCV, the coefficient of variation of the log-transformed maximum-annual flood series and QSP, the mean annual flood divided by the contributing drainage area. The LCV variable reflects the slope or steepness of the underlying flood-frequency distribution in the log-domain. It measures the year-to-year variability of the flood series at a site (local variability of flood response). The QSP variable captures the spatial intensity of flood series and directly reflects the variation of flood potential of each gaged watershed per unit drainage area (spatial variability of flood response).

Each possible region was evaluated by using the Wilcoxon signed-rank test and by regression analysis. The Wilcoxon test was performed to compare residuals between regions to decide if the apparent grouping of the residuals represents consistent differences in the residuals between regions and flood response. The Wilcoxon signed-ranks test does not statistically verify the regions but provides a quantitative index as a guide for defining homogeneous regions (Tasker, 1982).

Final Region and Equations

Among all the regions and variable combinations tested, by using CDA, DR, and MAR as the explanatory variables and the whole island of Puerto Rico as a single region was judged to be the best for flood peaks of 5, 10, 25, 50, 100, and 500 years. For the 2-year flood peak, only variables CDA and MAR were significant. The use of the whole island as one region generally agrees with López and others (1979) and yields lower standard errors with the new data and explanatory variables used (table 5).

Table 5. Regression equations for estimating peak discharges for streams in Puerto Rico developed in this study and those developed by López and Fields (1970) and López and others (1979)

Determined by	Equations for estimating flood magnitude	Model standard error (in log units)	Sampling error (in log units)	Model standard error (percent)	Average standard error of prediction (percent)	Equivalent years of record
This study	$Q_2 = 19.9\ CDA^{0.603}\ MAR^{0.852}$	0.0272	0.0026	39.4 +46.2,-31.6	41.4 +48.8,-32.8	3
López and others (1979)	$= 0.033\ A^{0.776} MAR^{2.11}$	-----	-----	+51,-34	+48,-32	5
López and Fields (1970)	$= 43.9\ A^{0.49}\ (MAR\text{-}50)^{0.28}$	-----	-----	35	-----	-----
This study	$Q_5 = 515\ CDA^{0.660}\ DR^{-0.470}\ MAR^{0.645}$	0.0154	0.0028	29.2 +33.1,-24.9	31.8 +36.4,-26.7	8
López and others (1979)	not determined	-----	-----	-----	-----	-----
López and Fields (1970)	not determined	-----	-----	-----	-----	-----
This study	$Q_{10} = 3{,}880\ CDA^{0.697}\ DR^{-0.869}\ MAR^{0.584}$	0.0104	0.0027	23.8 +26.5,-20.9	26.8 +30.2,-23.2	15
López and others (1979)	$= 3.72\ A^{0.822}\ MAR^{1.29}$	-----	-----	+45,-31	+36,-27	15
López and Fields (1970)	$= 2{,}230\ A^{0.60}$	-----	-----	35	-----	-----
This study	$Q_{25} = 24{,}940\ CDA^{0.730}\ DR^{-1.25}\ MAR^{0.540}$	0.0080	0.0029	20.8 +22.9,-18.6	24.4 +27.2,-21.4	24
López and others (1979)	$= 25.7\ A^{0.826}\ MAR^{0.953}$	-----	-----	+50,-33	+38,-28	19
López and Fields (1970)	$= 2{,}840\ A^{0.66}$	-----	-----	34	-----	-----
This study	$Q_{50} = 72{,}220\ CDA^{0.747}\ DR^{-1.48}\ MAR^{0.525}$	0.0080	0.0032	20.8 +22.9,-18.6	24.7 +27.6,-21.6	29
López and others (1979)	$= 89.9\ A^{0.83}\ MAR^{0.734}$	-----	-----	+50,-33	+38,-28	19
López and Fields (1970)	$= 3{,}230\ A^{0.71}$	-----	-----	34	-----	-----
This study	$Q_{100} = 1.80 \times 10^5\ CDA^{0.760}\ DR^{-1.68}\ MAR^{0.518}$	0.0089	0.0037	22.0 +24.3,-19.5	26.3 +29.5,-22.8	31
López and others (1979)	$= 268\ A^{0.832}\ MAR^{0.531}$	-----	-----	+61,-38	+46,-29	20
López and Fields (1970)	not determined	-----	-----	-----	-----	-----
This study	$Q_{500} = 1.09 \times 10^6\ CDA^{0.781}\ DR^{-2.07}\ MAR^{0.509}$	0.0136	0.0050	27.3 +30.8,-23.5	32.2 +36.9,-27.0	29
López and others (1979)	not determined	-----	-----	-----	-----	-----
López and Fields (1970)	not determined	-----	-----	-----	-----	-----

Q is estimated discharge, in cubic feet per second, for the indicated recurrence interval in years
A is drainage area, in square miles
MAR is mean annual rainfall, in inches
CDA is contributing drainage area, in square miles
DR is depth-to-rock, in inches

Because variables DR and MAR may not be available at a given time for some users of the new regression equations defined, regression analyses were conducted using only the CDA variable and are presented in table 6. The one-variable models presented in table 6 have higher standard errors and are not considered as accurate as the models in table 5 using CDA, DR, and MAR as variables.

Accuracy of Estimating Equations

The GLS regression technique provides a means of estimating the uncertainty or error in a prediction at an ungaged site (MSE_{pred}) by partitioning the mean square error into the part due to having an imperfect model (MSE_{model}) and the part due to sampling error (MSE_{samp}). The values for the standard error of the model (SE_{model}) are the square root of MSE_{model} and are calculated in base-ten logarithmic units. These values can be converted to plus and minus percentages by the formulas:

$$\text{Plus } SE_{model} = 100[10^{(SE_{model})} - 1], \text{ and}$$

$$\text{Minus } SE_{model} = 100[10^{(-SE_{model})} - 1].$$

The values of SE_{model} in log units and plus and minus percentages are shown for each equation in tables 5 and 6. The mean square sampling error at an ungaged site (MSE_{samp}) with basin characteristics given by the row vector $\mathbf{x_0}$ = [1, log(CDA), log(DR), log(MAR)] is calculated as:

$$MSE_{samp} = \mathbf{x_0}\{\mathbf{X^T C^{-1} X}\}^{-1}\mathbf{x_0}^T$$

where

C is the (57 by 57) covariance matrix associated with the log transformed flood peaks,

X is the (57 by 4) matrix of basin characteristics at the gaged sites augmented by a column of ones, and

T indicates the transpose of the specified matrix.

The diagonal elements of **C** are MSE_{model} plus the time sampling error at each site in the regression data, which is estimated as a function of the record length at each site. The off-diagonal elements of **C** are estimated as a function of the cross correlation between pairs of observed annual-peaks data (Tasker and Stedinger, 1989). The matrices $\{\mathbf{X^T C^{-1} X}\}^{-1}$ for

Table 6. One-variable regression equations for estimating peak discharges for streams in Puerto Rico

Recurrence interval	One-variable model for estimating flood magnitude	Model standard error (in log units)	Sampling error (in log units)	Model standard error (percent)	Average standard error of prediction (percent)	Equivalent years of record
2	$Q_2 = 1{,}264\ CDA^{0.497}$	0.0356	0.0023	45.6 +54.4,-35.2	47.2 +56.6,-36.1	3
5	$Q_5 = 2{,}032\ CDA^{0.575}$	0.0203	0.0019	33.7 +38.8,-28.0	35.3 +40.9,-29.0	6
10	$Q_{10} = 2{,}487\ CDA^{0.620}$	0.0153	0.0019	29.1 +33.0,-24.8	30.9 +35.3,-26.1	10
25	$Q_{25} = 3{,}071\ CDA^{0.657}$	0.0149	0.0021	28.7 +32.5,-24.5	30.7 +35.0,-25.9	14
50	$Q_{50} = 3{,}540\ CDA^{0.675}$	0.0172	0.0024	30.9 +35.3,-26.1	33.1 +38.0,-27.6	15
100	$Q_{100} = 4{,}036\ CDA^{0.690}$	0.0210	0.0028	34.3 +39.6,-28.4	36.7 +42.7,-29.9	15
500	$Q_{500} = 5{,}272\ CDA^{0.718}$	0.0348	0.0039	45.0 +53.7,-34.7	47.7 +57.3,-36.4	13

Q is estimated discharge, in cubic feet per second, for the indicated recurrence interval in years
CDA is contributing drainage area, in square miles

each equation in tables 5 and 6 are given in table 7. The standard error of prediction in log units at a specific ungaged site can be estimated as:

$$SE_{pred} = (MSE_{model} + MSE_{samp})^{0.5}$$

This value may be converted to a plus and minus percent error as explained above.

Another measure of uncertainty is the prediction interval of an estimate at an ungaged site. A desired prediction interval for the true flood peak (Q_{true}) at an ungaged site can be computed by:

$$(1/V)Q_{pred} < Q_{true} < (V)Q_{pred}$$

where

Q_{pred} is the regression estimate, and

V is computed from the relation

$$\log(V) = t_{(\alpha/2,n-p)} \times (SE_{pred})$$

where

$t_{(\alpha/2,n-p)}$ is the critical value of the Student's t distribution for n-p degrees of freedom and is tabulated in many statistical texts such as Ott (1993),

α is the total chance of error and equals to 1.00 minus the desired confidence coefficient,

n is the number of observations used in the regression (57), and

p is the number of basin characteristics used in the regression plus one.

<u>Example</u>

The calculation of a standard error of prediction and 90 percent prediction interval are illustrated in the following example. To estimate the 50-year peak (Q_{50}) at a 10 square mile site with depth-to-rock of 43 inches and mean annual rainfall of 92 inches. The estimate of Q_{50} is obtained from the equation in table 5 as:

$$Q_5 = (72{,}220)\,(10^{0.747})\,(43^{-1.48})\,(92^{0.525})$$

= 16,562 or about 16, 600 cubic feet per mile (ft^3/s).

From table 5, MSE_{model} = 0.0080 and from table 7 the matrix $\mathbf{\{X^TC^{-1}X\}^{-1}}$ is

CONSTANT	CDA	DR	MAR
0.30644	-0.84864×10^{-02}	-0.12353	-0.42169×10^{-01}
-0.84864×10^{-02}	0.19041×10^{-02}	-0.91078×10^{-03}	0.39281×10^{-02}
-0.12353	-0.91078×10^{-03}	0.10438	-0.26280×10^{-01}
-0.42169×10^{-01}	0.39281×10^{-02}	-0.26280×10^{-01}	0.40764×10^{-01}

The vector

x_0 = [1, log(10), log(43), log(92)]=[1, 1, 1.63347, 1.9638] and

$$MSE_{samp} = \mathbf{x_0\{X^TC^{-1}X\}^{-1}x_0^T} = 0.00175.$$

From the relationship above:

$$SE_{pred} = (MSE_{model} + MSE_{samp})^{0.5}$$
$$= (0.0080 + 0.00175)^{0.5}$$
$$= 0.0988, \text{ and}$$

$$\text{Plus } SE_{pred} = 100(10^{0.0988}-1) = 25.5 \text{ percent, and}$$

$$\text{Minus } SE_{pred} = 100(10^{-0.0988}-1) = -20.3 \text{ percent.}$$

A 90 percent prediction interval (α = 10) can be computed by setting $t_{0.05,53}$ = 1.67 (from statistical texts) and V = $10^{1.67(0.0988)}$ = 1.462. The 90 percent prediction interval is {16,600/1.462, 16,600(1.462)} or (11350, 24270). Therefore, there is a 90 percent chance that the true 50-year peak at the example site falls between 11,400 and 24,300 ft^3/s.

The computations needed to calculate the standard error of prediction and prediction intervals are of sufficient complexity to make it desirable to use a computer program to carry out the task. Therefore, a FORTRAN program and related data files are given in the appendix of this report. In addition, an executable file suitable for a personal computer with at least a 386 processor is available upon request.

Comparison of Estimates Using Different Models

The equations developed in this study and by López and others (1979) and Segarra-García (1998) were evaluated by comparing the differences in predicted (using the respective equations) and the observed values of the 25-, 50-, and 100-year flood estimates in the log-Pearson Type III analysis (weighted values) (appendix). The root-mean-square errors (RMSE) in log units were computed for each method by using the formula:

$$RMSE_{log} = \{[(\Sigma (\log Q_{rec,i} - \log Q^*_{rec,i})^2)]/N_p\}^{0.5}$$

where

$Q_{rec,i}$ is the estimated 25-, 50-, or 100-year flood estimate at site i based on at-site streamflow record;

$Q^*_{rec,i}$ is the regional regression estimate of the 25-, 50-, or 100-year flood at site i; and

N_p is the number of sites in the prediction sets.

The RMSE can be expressed as a percentage error by using the equation:

$$RMSE_{percent} = 100\ (e^{(5.302)\ (RMSE_{log})} - 1)^{0.5}$$

where

$RMSE_{log}$ is the root-mean-square, in log units.

When compared to other studies, the results indicate that the equations developed in this study yield the smallest RMSE (fig. 5). The RMSE for the 100-year flood, for example, using the equations developed in this study is 43 percent (3-variable model), while using Segarra-García (1998) and López and others (1979) the RMSE are 51 and 56 percent, respectively.

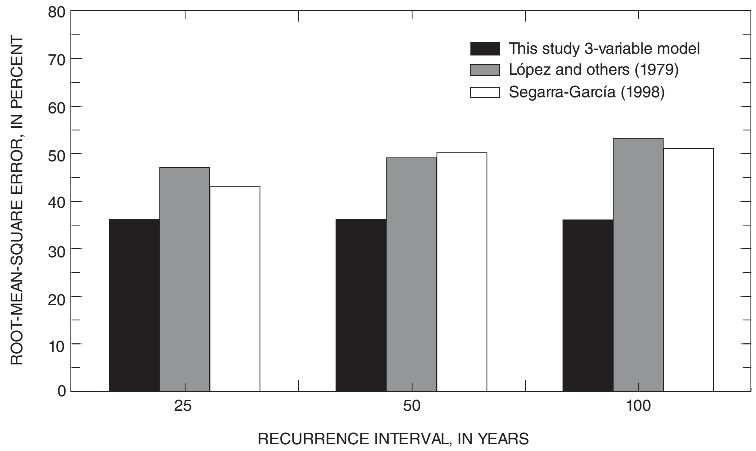

Figure 5. Comparison of the root-mean-square error, in percent, of the equations developed in this study, by López and others (1979), and Segarra-García (1998) models with estimates of the 25-, 50-, and 100-year flood discharge estimated from gaged data.

ESTIMATION OF PEAK DISCHARGE USING REGRESSION EQUATIONS

This section provides methods and examples for computing a peak discharge for a selected recurrence interval at a specific site. Two methods are provided for use, depending on if the site is gaged or ungaged. Both methods use the regression equations in table 5 for estimating peak discharges in Puerto Rico.

Gaged Sites

At gaged sites, two peak-discharge estimates are available, one from the frequency curves based on gaged record and the other computed from the regression equations. Another estimate would be to combine them. Combining the estimates provides a regional adjustment to the gaged record. To combine estimates, a weighted average of the peak discharges is used. The equation outlined in Choquette (1988) and described below weighs the two peak estimates by record length in years. By combining the regression and gaged record peak-discharge estimates and time-sampling, errors at sites with short record lengths are reduced, providing an improved estimate of peak discharge. The weighting equation for peak discharges at gaged stations is:

$$Q_{tw} = [Q_{tg}(N) + Q_{tr}(EQ)]/(N + EQ) \qquad (1)$$

where

Q_{tw} is the weighted average peak discharge, in cubic feet per second, for the t-year recurrence interval;

Q_{tg} is the t-year peak discharge, in cubic feet per second, computed from the gaged record;

Q_{tr} is the regional regression estimate, in cubic feet per second, from the equation in table 5 for the t-year peak discharge;

N is the number of years of gaged record at the station (table 2); and

EQ is the equivalent years of record associated with the regression equation (table 5) for the t-year peak discharge.

Ungaged Sites

The purpose of regional analysis is to transfer flood-frequency data spatially. This is done by using the derived regression equations for ungaged basins. Flood estimates for ungaged sites are determined from the regression equations in table 5. If an ungaged site is near a gaged site on the same stream, Thomas (1987) provides four equations that use both the regression equation estimate and the discharges from the flood-frequency analysis of the gaged site. A criterion for using these equations requires that the drainage area of the ungaged site be within 50 to 150 percent of the drainage area of the ungaged site. These equations were evaluated for applicability to streams in Puerto Rico by using six pairs of gaged sites that met the drainage-area size criterion. The equation providing the best results was that originally presented by Jordan (1984). This equation is:

$$Q_u = W_e(Q_{ru}) + W_g(Q_g) \quad (2)$$

where

Q_u is the final discharge (for a selected exceedance probability) estimate at the ungaged site,

W_e is equal to $0.5 - 0.5 \cos(4.53 \ln(A_u/A_g))$

Q_{ru} is the estimated discharge at the ungaged site using the regional regression equations,

W_g is equal to $1 - W_e$,

Q_g is the estimated discharge at the gaged site during the recorded period,

A_u is drainage area of the ungaged site, and

A_g is drainage area of the gaged site.

Sample Computations

The following examples illustrate the use of the methods described in this report for estimating peak discharges at gaged and ungaged sites.

Example 1

Gaged site: Estimate the 100-year peak discharge at Río Tanamá near Utuado (station 50028000).

First, determine if the station is on an unregulated stream. From table 5 the 100-year equation for Puerto Rico determined in this study is:

$$Q_{100r} = 1.80 \times 10^5 \, CDA^{0.760} \, DR^{-1.68} \, MAR^{0.518}. \quad (3)$$

The basin characteristics needed are contributing drainage area, depth-to-rock, and mean annual rainfall, which for station 50028000 are 18.0 mi^2, 57.58 in., and 88.39 in., respectively (table 2). These values fall within the ranges of values for each characteristic (table 4), so equation 3 is applicable for this site. Substituting the respective values in equation 3 gives the regression estimate:

$$Q_{100r} = 1.80 \times 10^5 \, (18.0)^{0.760}(57.58)^{-1.68}(88.39)^{0.518}$$
$$= 18{,}208 \text{ or about } 18{,}200 \text{ ft}^3\text{/s.}$$

From table 3, the 100-year peak discharge based on the gaged record (Q_{100g}) is 10,840 ft^3/s. The number of years of record (N) for the gaged record estimate is 35 years (from table 2). The weighted average estimate of the 100-year peak can now be determined from equation 1.

$$Q_{100w} = [10{,}840(35) + 18{,}200(31)]/(35 + 31)$$
$$= 14{,}297 \text{ or about } 14{,}300 \text{ ft}^3\text{/s.}$$

Therefore, the weighted average estimate of the 100-year peak discharge at station 50028000 is 14,300 ft^3/s. This is considered the best estimate for the 100-year peak discharge at the gaged site.

Example 2

Ungaged site near a gaged site on the same stream: Estimate the 100-year peak discharge at an ungaged site downstream of station 50028000 in the Río Tanamá. Contributing drainage area, depth to rock, and mean annual rainfall are 22.2 mi^2, 53.04 in., and 87.64 in., respectively.

Table 7. $(X^T C^{-1} X)^{-1}$ matrices for indicated equations

[----- means the equation does not include this variable]

Recurrence interval (years)	Base-ten logarithmic values for indicated variable:			
	Constant	Contributing drainage area	Depth-to-rock	Mean annual rainfall
Two- and three- variable models in table 5				
2	0.21951	-0.14310 X 10^{-01}	-----	-0.10113
	-0.14310 X 10^{-01}	0.27477 X 10^{-02}	-----	0.55743 X 10^{-02}
	-0.10113	0.55743 X 10^{-02}	-----	0.47514 X 10^{-01}
5	0.26035	-0.75859 X 10^{-02}	-0.96250 X 10^{-01}	-0.43934 X 10^{-01}
	-0.75859 X 10^{-02}	0.19947 X 10^{-02}	-0.21964 X 10^{-02}	0.44904 X 10^{-02}
	-0.96250 X 10^{-01}	-0.21964 X 10^{-02}	0.90860 X 10^{-01}	-0.27035 X 10^{-01}
	-0.43934 X 10^{-01}	0.44904 X 10^{-02}	-0.27035 X 10^{-01}	0.41955 X 10^{-01}
10	0.24655	-0.68152 X 10^{-02}	-0.95466 X 10^{-01}	-0.37558 X 10^{-01}
	-0.68152 X 10^{-02}	0.17017 X 10^{-02}	-0.14591 X 10^{-02}	0.36637 X 10^{-02}
	-0.95466 X 10^{-01}	-0.14591 X 10^{-02}	0.85270 X 10^{-01}	-0.23523 X 10^{-01}
	-0.37558 X 10^{-01}	0.36637 X 10^{-02}	-0.23523 X 10^{-01}	0.36297 X 10^{-01}
25	0.26943	-0.73763 X 10^{-02}	-0.73763 X 10^{-02}	-0.37829 X 10^{-01}
	-0.73763 X 10^{-02}	0.17125 X 10^{-02}	0.17125 X 10^{-02}	0.35611 X 10^{-02}
	-0.10778	-0.10049 X 10^{-02}	-0.10049 X 10^{-02}	-0.23741 X 10^{-01}
	-0.37829 X 10^{-01}	0.35611 X 10^{-02}	0.35611 X 10^{-02}	0.36680 X 10^{-01}
50	0.30644	-0.84864 X 10^{-02}	-0.12353	-0.42169 X 10^{-01}
	-0.84864 X 10^{-02}	0.19041 X 10^{-02}	-0.91078 X 10^{-03}	0.39281 X 10^{-02}
	-0.12353	-0.91078 X 10^{-03}	0.10438	-0.26280 X 10^{-01}
	-0.42169 X 10^{-01}	0.39281 X 10^{-02}	-0.26280 X 10^{-01}	0.40764 X 10^{-01}
100	0.35427	-0.99682 X 10^{-02}	-0.14276	-0.48817 X 10^{-01}
	-0.99682 X 10^{-02}	0.21960 X 10^{-02}	-0.95190 X 10^{-03}	0.45358 X 10^{-02}
	-0.14276	-0.95190 X 10^{-03}	0.12040	-0.30186 X 10^{-01}
	-0.48817 X 10^{-01}	0.45358 X 10^{-02}	-0.30186 X 10^{-01}	0.47003 X 10^{-01}
500	0.49671	-0.14520 X 10^{-01}	-0.19719	-0.71241 X 10^{-01}
	-0.14520 X 10^{-01}	0.31719 X 10^{-02}	-0.14581 X 10^{-02}	0.66746 X 10^{-02}
	-0.19719	-0.14581 X 10^{-02}	0.16870	-0.43307 X 10^{-01}
	-0.71241 X 10^{-01}	0.66746 X 10^{-02}	-0.43307 X 10^{-01}	0.67944 X 10^{-01}
One-variable model in table 6				
2	0.52177 X 10^{-02}	-0.30932 X 10^{-02}	-----	-----
	-0.30932 X 10^{-02}	0.26180 X 10^{-02}	-----	-----
5	0.37120 X 10^{-02}	-0.20624 X 10^{-02}	-----	-----
	-0.20624 X 10^{-02}	0.18042 X 10^{-02}	-----	-----
10	0.34762 X 10^{-02}	-0.18646 X 10^{-02}	-----	-----
	-0.18646 X 10^{-02}	0.16493 X 10^{-02}	-----	-----
25	0.39130 X 10^{-02}	-0.20945 X 10^{-02}	-----	-----
	-0.20945 X 10^{-02}	0.18524 X 10^{-02}	-----	-----
50	0.45759 X 10^{-02}	-0.24866 X 10^{-02}	-----	-----
	-0.24866 X 10^{-02}	0.21920 X 10^{-02}	-----	-----
100	0.54287 X 10^{-02}	-0.30054 X 10^{-02}	-----	-----
	-0.30054 X 10^{-02}	0.26413 X 10^{-02}	-----	-----
500	0.79931 X 10^{-02}	-0.46107 X 10^{-02}	-----	-----
	-0.46107 X 10^{-02}	0.40329 X 10^{-02}	-----	-----

First, determine if the station is on an unregulated stream. From table 5 the equation for estimating the 100-year flood for Puerto Rico is:

$$Q_{100r} = 1.80 \times 10^5\ CDA^{0.760}\ DR^{-1.68}\ MAR^{0.518}. \quad (3)$$

For this ungaged site the contributing drainage area is 22.2 mi^2, which falls within the range of drainage area values given in table 4, so that equation 3 can be used. To use equation 2, the contributing drainage area of the ungaged site must fall within the 50- and 150-percent limits of drainage area at the gaged site and be on the same stream. The contributing drainage area of station 50028000 is 18.0 mi^2 and the 50- to 150-percent lower and upper limits of drainage area are 9 to 27 mi^2. Because the drainage area of the ungaged site falls within these limits, equation 2 can be used. The regression estimate is:

$$Q_{100r} = 1.80 \times 10^5\ (22.2)^{0.760}\ (53.04)^{-1.68}\ (87.64)^{0.518}$$
$$= 24{,}405 \text{ or about } 24{,}400 \text{ ft}^3/\text{s}.$$

If the drainage area is less than 9 or greater than 27 mi^2, then the final estimate for this ungaged site would be 24,400 ft^3/s. The weighted estimate at the gaged site, station 50028000, is 14,300 ft^3/s, as computed previously. Applying equation 2 gives:

$$W_e = 0.5 - 0.5 \cos (4.53 \ln (A_u/A_g))$$
$$= 0.5 - 0.5 \cos (4.53 \ln (22.2/18.0))$$
$$= 6.87 \times 10^{-5}$$

$$W_g = 1 - W_e$$
$$= 1 - 6.87 \times 10^{-5}$$
$$= 0.999$$

Therefore, the final 100-year peak discharge for the ungaged site, Q_{100u}, is:

$$Q_u = W_e(Q_{ru}) + W_g(Q_g)$$
$$= (6.87\text{x}10^{-5})(24{,}400) + (0.9999)(10{,}840)$$
$$= 10{,}840 \text{ or about } 10{,}800 \text{ ft}^3/\text{s}.$$

This is considered the best estimate for the 100-year peak discharge at the ungaged site.

The site for which flood-frequency calculations are needed may sometimes be between two gaged sites on the same stream. The 50-, 150-percent rule should be first applied to determine which gage, if any, should be used to make the regional adjustment. If the ungaged site is within 50 percent of both gaged, correction factors should be computed using each gaged site. If both correction factors are greater than unity, the larger should be used (Hodge and Tasker, 1995). If both correction factors are less than unity, the smaller should be used. If one is greater than unity and one is less than unity, an average of both correction factors should be used. Correction factors are computed using the following equation:

$$R = Q_{tw}/Q_{tr} \quad (4)$$

where

Q_{tw} is the weighted discharge for recurrence interval t, and

Q_{tr} is the station discharge for recurrence interval t.

This ratio represents the correction needed to adjust the regression value, Q_{tr}, to the weighted value, Q_{tw}, at the gaged site. The equation for determining the correction factor for an ungaged site (R') that is near a gaged site on the same stream, is the following:

$$R' = R - [\Delta A(R - 1)]/[0.5CDA_g] \quad (5)$$

where

R' is the correction factor that is multiplied by the regression value, Q_{tr}, for the ungaged site;

R is the correction needed to adjust the regression value, Q_{tr}, to the weighted value, Q_{tw}, at the gaged site;

ΔA is the difference between the drainage areas of the gaged and ungaged sites; and

CDA_g is the contributing drainage area of the gaged site.

The best estimate for Q_{tu} is computed by the following equation:

$$Q_{tu} = Q_{tr}(R') \quad (6)$$

The following example illustrates the calculations for determining a 100-year flood for an ungaged site that is between two gaging sites on the same stream.

Example 3

Ungaged site between two gaged sites: Estimate the 100-year peak discharge at an ungaged site having a drainage area of 80 mi^2, and a Q_{100ru} of 65,000 ft^3/s, located upstream of station 50035000 and downstream of station 50031200.

First, determine if the station is on an unregulated stream. The drainage area of the ungaged site, 80 mi^2, is within 50 percent of the drainage areas at both gaged sites. Therefore, the station data for both gaged sites are used in the computations.

1) Gaged site 50031200, Río Grande de Manatí near Morovis

From table 1 the following data are obtained: N = 30 years, CDA = 55.2 mi^2, DR = 51.19 in., MAR = 74.83 in., and Q_{100g} = 54,720 ft^3/s. From table 5 the following data are obtained: $EQ_{100\text{-}y}$ = 31 years. These data are used to compute the Q_{100r} and Q_{100w} as follows:

$$Q_{100r} = 1.80 \times 10^5\ CDA^{0.760}\ DR^{-1.68}\ MAR^{0.518}$$
$$= 1.80 \times 10^5\ (55.2)^{0.760}\ (51.19)^{-1.68}\ (74.83)^{0.518}$$
$$= 47{,}700\ ft^3/s$$

$$Q_{100w} = [Q_{100g}(N) + Q_{100r}(EQ)]/(N + EQ)$$
$$= [(54{,}720)(30) + (47{,}700)(31)]/(30 + 31)$$
$$= 51{,}100\ ft^3/s.$$

Previous computed values of Q_{100w} and Q_{100r} and the data available from table 2 are used to compute the following:

$$R = Q_{100w}/Q_{100r}$$
$$= 51{,}100/47{,}700$$
$$= 1.07$$

2) Gaged site 50035000, Río Grande de Manatí at Ciales.

From table 2 the following data are obtained: N = 43 years, CDA = 134 mi^2, DR = 48.68 in., MAR = 83.04 in., and Q_{100g} = 142,400 ft^3/s. From table 5 the following data are obtained: $EQ_{100\text{-}y}$ = 31 years. These data are used to compute the Q_{100r} and Q_{100w} as follows:

$$Q_{100r} = 1.80 \times 10^5\ CDA^{0.760}\ DR^{-1.68}\ MAR^{0.518}$$
$$= 1.80 \times 10^5\ (134)^{0.760}\ (48.68)^{-1.68}\ (83.04)^{0.518}$$
$$= 107{,}500 \text{ or about } 108{,}000\ ft^3/s$$

$$Q_{100w} = [Q_{100g}(N) + Q_{100r}(EQ)]/(N + EQ)$$
$$= [(142{,}400)(43) + (107{,}500)(31)]/(43 + 31)$$
$$= 127{,}800 \text{ or about } 128{,}000\ ft^3/s.$$

Previous computed values of Q_{100w} and Q_{100r} and the data available from table 1 are used to compute the following:

$$R = Q_{100w}/Q_{100r}$$
$$= 108{,}000/128{,}000$$
$$= 0.84$$

The values for R' are computed now for the ungaged site using equation (5) as follows:

For the ungaged site using gaged site 50031200,

$$R' = R - [\Delta A(R - 1)]/[0.5(CDA_g)]$$
$$= 1.07 - [(70.0 - 55.2)(1.07 - 1)]/[(0.5)(55.2)]$$
$$= 1.03$$

For the ungaged site using gaged site 50035000,

$$R' = R - [\Delta A(R - 1)]/[0.5(CDA_g)]$$
$$= 0.84 - [(70.0 - 134)(0.84 - 1)]/[(0.5)(134)]$$
$$= 0.69$$

Because R' is neither greater nor lower for both gaged stations, the average of both correction factors should be used for computing the 100-year estimate discharge at the ungaged site as follows:

$$Q_{100u} = Q_{100ru}(R')$$
$$= 65{,}000((1.03+0.69)/2)$$
$$= 55{,}900\ ft^3/s.$$

This is considered the best estimate for the 100-year peak discharge at the ungaged site.

SUMMARY AND CONCLUSIONS

Methods are presented for estimating the magnitude and frequency of peak discharges in Puerto Rico for recurrence intervals 2, 5, 10, 25, 50, 100, and 500 years. Systematic record and historic data for a total of 57 gaged sites on the island were obtained through September 1994 to develop the station flood-frequency relations following the Bulletin 17B guidelines. Physical and climatic basin characteristics were computed by using a GIS. These characteristics were contributing drainage area, soil permeability, vegetative cover, channel slope, channel length, ground slope, depth-to-rock, 30-year mean annual rainfall (1931-60), and the 2-, 5-, 10-, 25-, 50-, and 50-year 24-hour rainfall intensities.

Different techniques and methods were used in an attempt to group basins having similar flood response characteristics into homogeneous regions. The techniques and methods used in this study were (1) regionalization by using the method of residuals and (2) cluster analysis by using the disjoint clustering procedure based on Euclidean distances. In addition, the geographically-defined surface-water regions outlined by the U.S. Water Resources Council were also considered and evaluated in determining their appropriateness as homogeneous flood-response regions.

A new map of skew coefficients for Puerto Rico was constructed by using average skew coefficients of stations with 20 or more years of record for different WRC regions. The two skew regions were North Coast-East Coast and South Coast-West Coast WRC areas, and they were used for the generalized skew coefficients in this study.

Among all the regions tested, the whole island of Puerto Rico is the region that best represents the general flood response of the basins in Puerto Rico included in the analyses. The use of the whole island as one flood region generally agrees with López and others (1979), and yields lower standard errors.

Station peak discharges for the seven different recurrence intervals were related to the physical and climatic basin characteristics by using log-linear multiple-regression techniques to develop estimating equations for flood-peak discharges and frequencies on unregulated streams in Puerto Rico. The independent variables contributing drainage area, depth-to-rock, and mean annual rainfall were the most significant variables to use in estimating flood-peak discharges for Puerto Rico sites. Regression equations were developed and standard errors of estimate and prediction, and equivalent years of record were obtained by using the USGS developed computer program GLSNET (Generalized Least-Square Methods and Network analysis). The equations presented in this report have lower standard errors than those previously developed by López and others (1979), and Segarra-García (1998).

Of the equations used by the U.S. Geological Survey to weight the discharge of the gaged to the ungaged site, whether upstream or downstream of the gaged site, the one providing the best results was that originally presented by Jordan (1984).

REFERENCES

Acevedo, Gilberto, 1982, Soil survey of the Arecibo area of northern Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 169 p.

Bhaskar, N.R., and O'Conner, C.A., 1989, Comparison of methods of residuals and cluster analysis for flood regionalization: Journal of Water Resources Planning and Management, American Society of Civil Engineers, v. 115, no. 6, p. 793-808.

Boccheciamp, R.A., 1977, Soil survey of the Humacao area of eastern Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 103 p.

Boccheciamp, R.A., 1978, Soil survey of the San Juan area of Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 141 p.

Carter, O.R., 1965, Soil survey of the Lajas valley area, Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 170 p.

Calvesbert, R.J., 1970, Climate of Puerto Rico and U.S. Virgin Islands, revised: U.S. Environmental Science Services Administration, Climatography of the United States 60-52, 29 p.

Choquette, A.F., 1988, Regionalization of peak discharges for streams in Kentucky: U.S. Geological Survey Water-Resources Investigations Report 87-4209, 105 p.

Clark, J.J., 1998, Determination of a regional skew coefficient for Puerto Rico: Proceedings of the Third International Symposium on Tropical Hydrology and Fifth Caribbean Islands Water Resources Congress, American Water Resources Association, p. 59-64.

Gierbolini, R.E., 1975, Soil survey of Mayagüez area of western Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 296 p.

Gierbolini, R.E., 1979, Soil survey of Ponce area of southern Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, 81 p.

Hodge, S.A. and Tasker, G.D., 1995, Magnitude and frequency of floods in Arkansas: U.S. Geological Survey Water-Resources Investigations Report 95-4224, 275 p.

Hosking, J.R., Wallis, J.R., and Woods, E.F., 1985, Estimation of the generalized extreme value distribution by the method of probability-weighted moments: Technometrics, v. 27, no. 3, p. 251-261.

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

Jordan, P.R., 1984, Magnitude and frequency of high flows of unregulated streams in Kansas: U.S. Geological Survey Open-File Report 84-453, 64p.

López, M.A., and Fields, F.K., 1970, A proposed streamflow-data program for Puerto Rico: U.S. Geological Survey unnumbered Open-File Report, 42 p.

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, 69 p.

Montgomery, D.C. and Peck, E.A., 1982, Introduction to linear regression analysis: New York, John Wiley and Sons, 504 p.

Myers, R.H., 1986, Classical and modern regression with applications: Boston, Duxbury Press, 359 p.

Ott, R.L., 1993, An introduction to statistical methods and data analysis: PWS-KENT Publishing Company, Belmont, California, 4th edition, 1184 p.

Puerto Rico Department of Natural Resources, 1980, Coastal flood hazards and responses in Puerto Rico, an overview: San Juan, Puerto Rico, Puerto Rico Department of Natural Resources, Planning Area, and Ralph M. Field and Associates, Consultant, 90 p.

Salivia, L.A., 1972, Historia de los temporales de Puerto Rico y las Antillas: San Juan, Puerto Rico, editorial Edil, Inc., 385 p.

Segarra-García, Rafael, 1998, Flood frequency estimation for ungaged catchments in Puerto Rico: Proceedings of the Third International Symposium on Tropical Hydrology and Fifth Caribbean Islands Water Resources Congress, American Water Resources Association, p. 65-70.

Stedinger, J.R., and Tasker, G.D., 1985, Regional hydrologic analysis 1: ordinary, weighted, and generalized least squares compared: Water Resources Research, v. 21, no. 9, p. 1421-1432.

Tasker, G.D., 1982, Simplified testing of hydrologic regression regions: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 108, no. HY10, p. 1218-1221.

Tasker, G.D., and Stedinger, J.R., 1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, p. 361-375.

Thomas, W.O., Jr., 1987, Techniques used by the U.S. Geological Survey in estimating the magnitude and frequency of floods, *in* Mayer, L., and Nash, D., eds., Catastrophic flooding: Boston, Allen and Unwin, p. 267-288.

U.S. Department of Commerce, 1961, Generalized estimates of probable maximum precipitation and rainfall, frequency data for Puerto Rico and U.S. Virgin Islands for areas to 400 square miles, durations to 24 hours and return periods from 1 to 100 years: Weather Bureau Technical Paper No. 42, 94 p.

U.S. Water Resources Council, 1978, The Nation's water resources, 1975-2000, Caribbean region: Washington, D.C., U.S. Government Printing Office, v. 1-4, 52 p.

APPENDIX

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models.

[First line, after column six, contains the log-Pearson Type III estimates for the gaged record (Bulletin 17B weighted); second line contains estimates based on this study models; third line are estimates using the single-variable model in this study; fourth line contains estimates using the models of López and others (1979); and fifth line are estimates using the models in Segarra-García (1998). CDA, contributing drainage area, in square miles; DR, depth-to-rock, in inches; MAR, mean annual rainfall, in inches; RI-5 and RI-25 are the 5-year and 25-year, respectively, 24-hour rainfall intensity, in inches per hour; -----, value not determined.]

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50014000	4.66	58.84	91.58	6.88	9.09	2,930	4,458	5,420	6,559	7,351	8,096	9,679
						2,362	3,860	4,598	5,396	5,872	6,403	7,848
						2,716	4,923	6,458	8,441	10,004	11,672	15,918
						1,502	-----	4,474	6,786	8,881	10,616	-----
						-----	-----	-----	-----	-----	-----	-----
50028000	18.00	57.58	88.39	7.53	10.00	5,631	7,903	9,131	10,410	11,210	11,890	13,130
						5,177	9,298	11,770	14,587	16,331	18,208	23,161
						5,316	10,708	14,926	20,511	24,906	29,654	42,001
						3,977	-----	12,979	20,031	26,564	32,067	-----
						8,349	13,567	15,654	20,873	25,047	29,222	-----
50028400	22.20	53.04	87.64	7.25	9.57	3,477	6,943	9,867	14,250	17,980	22,120	33,360
						5,833	11,038	14,558	18,752	21,473	24,405	32,198
						5,900	12,080	16,999	23,541	28,694	34,272	48,827
						4,596	-----	15,252	23,627	31,418	38,008	-----
						9,117	14,816	17,095	22,793	27,352	31,911	-----
50031200	55.20	51.19	74.83	7.18	10.58	9,700	19,230	27,280	39,360	49,700	61,170	92,510
						8,830	18,491	25,831	34,997	41,132	47,696	65,129
						9,279	20,396	29,900	42,829	53,065	64,252	93,905
						6,677	-----	26,301	43,129	59,586	74,570	-----
						11,064	22,128	31,611	47,417	58,481	71,126	-----
50034000	16.70	43.63	80.63	7.80	11.50	4,414	8,451	11,580	15,910	19,350	22,920	31,730
						4,576	9,501	13,474	18,589	22,185	26,137	37,019
						5,122	10,256	14,248	19,526	23,678	28,160	39,800
						3,091	-----	10,839	17,250	23,334	28,694	-----
						5,275	10,551	15,073	22,609	27,885	33,914	-----
50035000	134.00	48.68	83.04	7.41	10.81	18,650	40,100	59,410	89,870	117,100	148,300	237,800
						16,471	36,356	53,208	75,320	90,772	107,477	152,334
						14,418	33,963	51,818	76,699	96,560	118,482	177,516
						16,552	-----	62,360	99,084	134,281	164,827	-----
						23,918	47,836	68,338	102,506	126,425	153,760	-----
50035950	16.70	51.05	76.68	7.06	9.52	4,835	6,720	7,907	9,339	10,360	11,340	13,530
						4,384	8,544	11,415	14,867	17,126	19,560	26,069
						5,122	10,256	14,248	19,526	23,678	28,160	39,800
						2,780	-----	10,159	16,444	22,489	27,938	-----
						5,679	11,357	16,225	24,337	30,016	36,505	-----
50038100	165.00	48.07	82.25	7.31	10.55	20,890	49,360	73,680	109,000	137,800	168,000	242,600
						18,522	41,699	61,846	88,612	107,496	127,954	183,065
						15,990	38,280	58,954	87,936	111,123	136,778	206,124
						19,064	-----	73,087	116,600	158,482	194,993	-----
						28,230	56,461	80,658	120,987	149,217	181,481	-----
50038320	15.20	47.95	80.31	6.82	9.61	7,682	11,230	13,350	15,760	17,370	18,850	21,850
						4,309	8,520	11,597	15,390	17,945	20,721	28,232
						4,888	9,716	13,441	18,355	22,220	26,389	37,200
						2,849	-----	9,981	15,899	21,517	26,477	-----
						4,312	8,625	12,321	18,481	22,794	27,722	-----

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models—Continued.

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50039500	81.60	45.85	78.10	6.73	9.45	6,623	14,720	22,120	33,850	44,360	56,410	90,960
						11,592	25,909	38,272	54,675	66,306	78,977	113,460
						11,268	25,536	38,100	55,368	69,087	84,143	124,328
						9,896	-----	38,324	62,042	85,049	105,599	-----
						15,219	30,437	43,481	65,222	80,441	97,833	-----
50043000	63.20	41.31	67.56	6.96	9.94	11,060	24,930	37,810	58,580	77,450	99,350	163,300
						8,782	20,936	32,219	47,795	59,240	71,883	107,118
						9,924	22,046	32,518	46,811	58,142	70,542	103,488
						5,977	-----	25,765	43,754	61,851	79,049	-----
						10,916	23,652	32,749	58,220	90,969	118,260	-----
50045700	8.28	41.31	79.41	6.49	8.90	1,982	4,891	7,615	11,950	15,790	20,140	32,230
						2,959	6,075	8,588	11,828	14,129	16,678	23,780
						3,614	6,852	9,223	12,315	14,746	17,354	24,050
						1,736	-----	5,970	9,524	12,889	15,877	-----
						2,281	4,943	6,844	12,167	19,010	24,714	-----
50046000	208.00	39.52	69.43	6.90	9.61	16,340	42,000	68,000	112,700	155,400	206,900	365,900
						18,435	47,755	78,046	122,320	156,233	194,209	301,836
						17,940	43,733	68,057	102,388	129,926	160,478	243,414
						15,959	-----	71,054	120,129	169,609	216,085	-----
						28,624	62,019	85,872	152,661	238,533	310,093	-----
50047850	41.70	46.09	68.30	6.90	9.45	6,492	12,270	16,980	23,880	29,680	36,010	52,930
						6,898	15,220	22,064	30,951	37,139	43,848	62,059
						8,072	17,358	25,128	35,621	43,913	52,947	76,777
						4,430	-----	18,565	31,359	44,151	56,256	-----
						8,870	19,217	26,609	47,305	73,913	96,087	-----
50048000	71.90	42.33	74.72	6.81	9.27	10,000	19,950	28,730	42,510	54,840	69,030	110,300
						10,343	24,049	36,602	53,784	66,336	80,178	118,563
						10,581	23,743	35,225	50,951	63,430	77,107	113,529
						8,171	-----	32,622	53,577	74,122	92,839	-----
						13,286	28,786	39,858	70,859	110,717	143,932	-----
50050900	5.99	44.12	99.78	7.47	10.83	4,723	7,474	9,591	12,600	15,100	17,800	25,060
						2,957	5,512	7,395	9,730	11,346	13,141	18,101
						3,077	5,688	7,545	9,955	11,851	13,880	19,062
						2,187	-----	6,143	9,061	11,650	13,691	-----
						2,341	4,681	6,688	10,032	12,372	15,048	-----
50051180	3.78	30.96	80.90	7.25	10.19	2,659	5,574	7,877	11,060	13,550	16,100	22,180
						1,873	4,197	6,458	9,666	12,171	15,064	23,639
						2,448	4,365	5,672	7,357	8,686	10,102	13,697
						983	-----	3,210	5,072	6,816	8,351	-----
						1,713	3,427	4,895	7,343	9,056	11,014	-----
50051310	10.20	39.91	100.00	7.79	11.08	5,389	9,430	12,080	15,230	17,390	19,400	23,510
						4,084	8,222	11,708	16,286	19,610	23,334	33,799
						4,009	7,724	10,496	14,123	16,975	20,039	27,935
						3,320	-----	9,541	14,094	18,151	21,345	-----
						4,103	8,205	11,722	17,582	21,685	26,374	-----
50055000	89.60	37.04	82.68	7.31	10.38	20,860	37,750	48,800	61,820	70,660	78,730	94,850
						12,874	31,607	50,837	78,820	100,469	124,989	195,428
						11,804	26,946	40,374	58,877	73,589	89,752	132,964
						12,001	-----	44,544	70,766	95,840	117,651	-----
						18,713	37,425	53,464	80,196	98,909	120,295	-----

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models—Continued.

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50056400	16.40	35.98	90.52	7.90	11.03	9,125	17,060	23,010	31,010	37,190	43,480	58,460
						4,995	11,075	16,831	24,848	30,936	37,841	57,697
						5,076	10,150	14,089	19,294	23,390	27,810	39,286
						3,890	-----	12,398	18,975	25,022	30,055	-----
						7,405	12,959	14,810	20,364	23,140	27,769	-----
50057000	60.10	36.70	80.81	7.77	10.84	15,630	36,820	54,890	81,100	102,400	124,800	180,100
						9,924	24,032	38,280	58,840	74,678	92,607	144,135
						9,679	21,418	31,519	45,290	56,201	68,136	99,818
						8,388	-----	31,146	49,785	67,656	83,372	-----
						16,769	33,538	47,911	71,866	88,635	107,800	-----
50061800	10.20	47.47	99.73	7.96	11.01	5,036	8,765	11,440	14,930	17,570	20,220	26,420
						4,074	7,565	10,054	13,092	15,148	17,411	23,570
						4,009	7,724	10,496	14,123	16,975	20,039	27,935
						3,301	-----	9,508	14,058	18,115	21,314	-----
						5,427	9,497	10,854	14,924	16,959	20,351	-----
50062500	2.75	52.23	142.34	7.99	10.90	2,144	3,116	3,650	4,212	4,559	4,856	5,400
						2,503	3,830	4,568	5,408	5,954	6,584	8,327
						2,090	3,635	4,657	5,969	7,007	8,111	10,900
						2,529	-----	5,122	6,683	7,924	8,651	-----
						2,120	3,710	4,240	5,830	6,624	7,949	-----
50063440	0.96	58.17	200.00	8.63	11.96	1,141	1,760	2,170	2,680	3,051	3,414	4,232
						1,773	2,264	2,436	2,634	2,765	2,945	3,482
						1,239	1,985	2,425	2,990	3,444	3,924	5,120
						2,290	-----	3,344	3,874	4,246	4,317	-----
						1,095	1,916	2,190	3,011	3,421	4,106	-----
50063800	8.64	54.25	184.61	8.41	11.71	7,083	12,010	15,300	19,360	22,250	25,010	30,990
						6,229	9,473	11,426	13,688	15,174	16,871	21,486
						3,691	7,021	9,469	12,664	15,176	17,871	24,797
						10,643	-----	18,358	22,041	24,803	25,745	-----
						5,350	9,363	10,700	14,713	16,719	20,063	-----
50064200	7.34	53.43	172.74	8.19	11.43	5,258	9,456	12,570	16,760	20,010	23,340	31,340
						5,335	8,208	9,941	11,949	13,269	14,774	18,874
						3,404	6,393	8,559	11,377	13,594	15,969	22,057
						8,151	-----	14,736	18,081	20,632	21,699	-----
						4,389	7,681	8,778	12,070	13,716	16,460	-----
50064700	0.83	30.88	88.63	7.93	10.75	1,206	2,583	3,868	5,974	7,930	10,250	17,290
						812	1,638	2,373	3,368	4,130	5,011	7,619
						1,152	1,826	2,216	2,717	3,122	3,549	4,612
						367	-----	1,038	1,582	2,071	2,483	-----
						855	1,497	1,710	2,352	2,673	3,207	-----
50065500	6.80	46.22	179.85	8.96	11.99	10,300	14,530	17,290	20,740	23,270	25,770	31,550
						5,273	8,575	10,945	13,843	15,864	18,160	24,500
						3,277	6,118	8,163	10,820	12,911	15,149	20,879
						8,364	-----	14,578	17,641	19,946	20,804	-----
						6,115	10,702	12,231	16,817	19,111	22,933	-----
50065700	11.80	48.30	148.82	8.78	11.85	11,330	19,370	24,820	31,580	36,450	41,130	51,370
						6,256	10,695	13,849	17,688	20,312	23,244	31,238
						4,310	8,400	11,488	15,542	18,729	22,159	31,016
						8,602	-----	17,962	23,220	27,426	29,759	-----
						8,512	14,895	17,023	23,407	26,599	31,918	-----

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models—Continued.

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50067000	3.91	59.15	105.25	8.55	11.72	4,250	6,656	8,306	10,420	12,000	13,580	17,260
						2,393	3,751	4,393	5,084	5,498	5,970	7,266
						2,489	4,451	5,792	7,522	8,886	10,341	14,033
						1,758	-----	4,634	6,703	8,503	9,877	-----
						-----	-----	-----	-----	-----	-----	-----
50071000	14.80	47.18	119.21	8.44	11.65	8,109	13,460	17,080	21,600	24,880	28,060	35,130
						5,937	10,883	14,540	19,063	22,169	25,603	34,959
						4,824	9,568	13,220	18,036	21,824	25,908	36,494
						6,422	-----	16,253	22,662	28,125	31,939	-----
						8,388	14,679	16,776	23,067	26,213	31,455	-----
50073200	2.25	31.34	83.83	8.05	11.52	2,051	5,172	7,974	12,200	15,750	19,560	29,290
						1,412	3,032	4,544	6,645	8,266	10,135	15,652
						1,891	3,239	4,112	5,232	6,120	7,062	9,437
						708	-----	2,194	3,418	4,548	5,527	-----
						-----	-----	-----	-----	-----	-----	-----
50074000	4.99	34.77	127.27	8.37	11.98	2,797	6,235	9,331	14,170	18,440	23,270	36,810
						3,259	6,393	9,231	13,078	16,001	19,358	29,084
						2,810	5,121	6,737	8,829	10,477	12,236	16,719
						3,171	-----	7,236	9,826	11,969	13,383	-----
						-----	-----	-----	-----	-----	-----	-----
50075000	1.26	56.76	199.94	8.99	12.00	1,235	1,751	2,102	2,553	2,894	3,240	4,072
						2,088	2,740	3,008	3,312	3,513	3,772	4,530
						1,418	2,321	2,870	3,575	4,138	4,734	6,224
						2,827	-----	4,180	4,848	5,320	5,413	-----
						1,731	3,029	3,461	4,759	5,408	6,490	-----
50075500	10.80	38.34	160.13	8.62	11.94	8,041	14,900	20,570	29,010	36,230	44,250	66,330
						6,313	11,788	16,609	23,022	27,808	33,270	48,803
						4,124	7,983	10,874	14,664	17,643	20,846	29,105
						9,373	-----	18,356	23,142	26,890	28,742	-----
						-----	-----	-----	-----	-----	-----	-----
50081000	6.61	34.93	98.51	8.02	11.35	3,155	6,815	10,190	15,650	20,650	26,500	43,890
						3,104	6,511	9,631	13,904	17,139	20,829	31,497
						3,231	6,019	8,020	10,621	12,666	14,856	20,459
						2,297	-----	6,551	9,710	12,524	14,760	-----
						2,752	5,962	8,255	14,676	22,932	29,811	-----
50082800	4.83	38.12	95.41	7.54	10.99	3,721	5,493	6,594	7,892	8,793	9,641	11,450
						2,500	4,976	7,041	9,744	11,715	13,937	20,240
						2,765	5,026	6,603	8,642	10,249	11,964	16,332
						1,683	-----	4,858	7,268	9,429	11,177	-----
						-----	-----	-----	-----	-----	-----	-----
50090500	5.29	28.60	80.64	7.60	11.11	2,269	4,787	6,981	10,340	13,250	16,510	25,510
						2,288	5,427	8,728	13,618	17,563	22,182	36,158
						2,893	5,296	6,986	9,175	10,898	12,739	17,435
						1,267	-----	4,214	6,675	8,987	11,026	-----
						-----	-----	-----	-----	-----	-----	-----
50091000	12.40	24.24	78.03	7.66	11.16	2,328	6,460	11,150	20,170	29,720	42,280	87,190
						3,719	10,075	17,901	30,637	41,665	55,011	97,402
						4,418	8,643	11,847	16,057	19,367	22,930	32,140
						2,289	-----	8,135	13,074	17,792	22,012	-----
						-----	-----	-----	-----	-----	-----	-----

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models—Continued.

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50092000	18.40	34.72	87.56	7.15	10.25	4,514	8,861	12,890	19,550	25,830	33,400	57,260
						5,205	11,893	18,448	27,755	34,924	43,100	66,816
						5,375	10,844	15,131	20,810	25,279	30,108	42,669
						3,965	-----	13,056	20,216	26,866	32,496	-----
						5,947	9,664	11,151	14,868	17,841	20,815	-----
50106500	45.90	37.05	48.06	7.06	10.29	7,473	15,100	22,600	35,730	48,790	65,260	121,300
						5,418	14,323	23,227	36,074	45,831	56,735	87,890
						8,466	18,343	26,669	37,939	46,852	56,572	82,254
						2,273	-----	12,766	24,285	36,940	50,558	-----
						8,261	17,900	24,784	44,061	68,846	89,500	-----
50108000	12.90	41.08	46.61	6.95	9.84	2,806	6,456	10,520	18,430	27,110	38,950	85,000
						2,455	5,788	8,611	12,347	14,998	17,893	25,932
						4,505	8,841	12,141	16,479	19,891	23,564	33,066
						796	-----	4,323	8,267	12,595	17,302	-----
						-----	-----	-----	-----	-----	-----	-----
50112500	9.68	48.09	96.90	8.40	11.75	1,464	3,028	4,744	8,091	11,780	16,880	37,220
						3,852	7,130	9,425	12,208	14,076	16,129	21,706
						3,906	7,496	10,161	13,646	16,386	19,329	26,905
						2,983	-----	8,776	13,099	16,982	20,097	-----
						4,289	9,293	12,867	22,875	35,743	46,465	-----
50114000	17.80	41.36	92.65	8.47	12.17	3,737	7,844	11,900	18,970	25,960	34,720	64,110
						5,353	11,115	16,003	22,443	27,088	32,252	46,645
						5,287	10,639	14,823	20,361	24,719	29,427	41,666
						4,354	-----	13,665	20,758	27,244	32,575	-----
						6,295	13,639	18,884	33,572	52,456	68,193	-----
50114400	25.60	40.09	84.93	8.08	11.52	5,648	9,418	12,510	17,160	21,190	25,740	38,730
						6,188	13,554	20,133	29,027	35,553	42,824	63,222
						6,333	13,112	18,569	25,852	31,591	37,813	54,087
						4,804	-----	16,467	25,795	34,556	42,084	-----
						7,632	16,537	22,897	40,705	63,602	82,683	-----
50115000	8.80	40.07	94.59	8.59	12.53	2,005	4,355	6,922	11,870	17,260	24,600	53,070
						3,563	7,182	10,190	14,119	16,956	20,129	29,036
						3,725	7,096	9,578	12,818	15,365	18,099	25,125
						2,633	-----	7,866	11,832	15,415	18,328	-----
						3,598	7,795	10,793	19,188	29,981	38,975	-----
50115900	18.60	39.84	82.14	7.94	11.35	3,251	6,671	10,010	15,800	21,490	28,590	52,290
						4,961	10,775	15,889	22,756	27,775	33,366	49,064
						5,404	10,912	15,233	20,958	25,464	30,333	43,002
						3,494	-----	12,130	19,192	25,867	31,696	-----
						5,697	12,344	17,091	30,384	47,476	61,718	-----
50121000	22.00	39.59	85.72	8.41	12.29	5,617	12,770	19,480	30,380	40,360	52,010	86,390
						5,693	12,410	18,413	26,531	32,500	39,166	57,916
						5,874	12,018	16,904	23,402	28,519	34,058	48,510
						4,355	-----	14,713	22,962	30,680	37,282	-----
						7,954	15,907	22,725	34,087	42,041	51,131	-----
50124200	18.90	40.75	78.05	8.34	12.30	2,152	5,098	8,516	15,460	23,350	34,480	80,240
						4,796	10,425	15,292	21,774	26,466	31,668	46,195
						5,447	11,013	15,384	21,179	25,740	30,670	43,499
						3,177	-----	11,507	18,523	25,248	31,261	-----
						5,753	12,464	17,259	30,682	47,940	62,322	-----

Appendix 1. Comparison of log-Pearson Type III (Bulletin 17B weighted) estimates and estimates using empirical models—Continued.

Station	CDA	DR	MAR	RI-5	RI-25	Log-Pearson Type III (weighted estimates and estimates using empirical models, in cubic feet per second, for recurrence years						
						2	5	10	25	50	100	500
50124500	20.90	41.19	75.93	8.29	12.20	6,279	12,690	18,970	29,920	40,780	54,420	100,600
						4,978	10,890	15,991	22,779	27,678	33,097	48,192
						5,726	11,668	16,374	22,626	27,549	32,874	46,756
						3,241	-----	12,062	19,607	26,897	33,496	-----
						6,176	13,381	18,527	32,937	51,464	66,903	-----
50128000	46.10	29.87	64.67	7.99	11.41	2,580	5,649	8,870	14,830	21,040	29,180	58,690
						6,995	19,248	33,412	55,608	73,912	95,331	160,209
						8,484	18,389	26,741	38,048	46,990	56,742	82,511
						4,267	-----	18,789	32,341	46,099	59,404	-----
						-----	-----	-----	-----	-----	-----	-----
50136000	17.60	43.72	99.54	7.58	11.18	5,053	8,802	12,420	18,740	25,040	33,050	60,920
						5,652	11,257	15,777	21,587	25,692	30,233	42,751
						5,257	10,570	14,720	20,211	24,532	29,198	41,329
						5,021	-----	14,852	22,020	28,449	33,523	-----
						5,900	9,587	11,062	14,749	17,699	20,648	-----
50138000	120.00	35.55	70.83	7.46	10.67	6,480	21,500	42,890	94,170	160,900	265,600	774,100
						13,458	35,364	59,002	94,464	122,441	154,331	247,053
						13,649	31,875	48,391	71,335	89,629	109,796	163,994
						10,862	-----	46,388	77,731	109,028	138,191	-----
						-----	-----	-----	-----	-----	-----	-----
50141000	15.20	54.79	86.83	8.94	13.45	6,509	9,652	11,820	14,650	16,810	19,000	24,310
						4,605	8,415	10,810	13,588	15,347	17,246	22,290
						4,888	9,716	13,441	18,355	22,220	26,389	37,200
						3,359	-----	11,038	17,127	22,786	27,597	-----
						7,054	12,345	14,109	19,400	22,045	26,454	-----
50144000	134.00	52.10	89.46	7.84	11.23	13,820	27,420	41,910	69,460	99,160	139,400	295,000
						17,550	36,947	52,389	72,030	85,367	99,662	137,474
						14,418	33,963	51,818	76,699	96,560	118,482	177,516
						19,368	-----	68,647	106,371	141,825	171,475	-----
						24,650	53,409	73,951	131,468	205,419	267,044	-----
50147000	16.70	54.49	91.55	6.23	8.14	5,489	7,134	8,157	9,389	10,270	11,120	13,040
						5,099	9,290	11,962	15,079	17,067	19,216	24,927
						5,122	10,256	14,248	19,526	23,678	28,160	39,800
						4,041	-----	12,769	19,470	25,614	30,696	-----
						5,427	8,820	10,176	13,569	16,282	18,996	-----
50147800	71.30	53.62	93.50	6.07	7.71	23,180	32,710	39,950	50,210	58,720	67,990	93,090
						12,457	24,731	33,776	44,898	52,262	60,149	80,933
						10,537	23,629	35,042	50,671	63,072	76,662	112,848
						13,029	-----	43,264	65,882	86,776	103,850	-----
						16,628	27,021	31,178	41,571	49,885	58,199	-----

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report.

```
c
      CHARACTER*32 vout
      CHARACTER*1 Units
c
      PRINT *, ' '
      PRINT *, '  This program calculates estimates of 2-, 5-, 10,'
      PRINT *, '  25, 50-, 100-, and 500-year peak flows for '
      PRINT *, '  ungaged, unregulated rural streams in Puerto'
      PRINT *, '  Rico based on regression equations in the report '
      PRINT *, '  "Estimation of Magnitude and Frequency of Floods '
      PRINT *, '  for Streams in Puerto Rico: New Empirical Models'
      PRINT *, '  by Orlando Ramos-Gines, U.S. Geological'
      PRINT *, '  Survey Water Resources Investigations'
      PRINT *, '  Report 99-4142. The report contains limitations '
      PRINT *, '  of the regression equations and explains their '
      PRINT *, '  accuracy. The computations by this program are '
      PRINT *, '  more precise than by using the equations in the'
      PRINT *, '  report because the coefficients were rounded. '
      PRINT *, ' '
      PRINT *, ' ++++++++++++++++++++++++++++++++++++++++++++++++++ '
      PRINT *, '* NO WARRANTY, EXPRESSED OR IMPLIED,  IS MADE BY THE * '
      PRINT *, '*   USGS AS TO THE ACCURACY AND FUNCTIONING OF THE   * '
      PRINT *, '*         PROGRAM AND RELATED PROGRAM MATERIAL.      * '
      PRINT *, '*                       VERSION 02/10/99            * '
      PRINT *, ' ++++++++++++++++++++++++++++++++++++++++++++++++++ '
c
      PRINT *, ' '
      PRINT *, ' ENTER name of output file    '
      READ (*,9005) vout
 9005 FORMAT (a32)
      OPEN (16,file=vout)
      CALL RRE
      STOP
      END
c
c
      SUBROUTINE MLTPLY(PROD,X,Y,K1,K2,K3,N1,N2,N3)
c     IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER i, j, k, K1, K2, K3, N1, N2, N3
      REAL PROD(N1,K3), X(N2,K2), Y(N3,K3), sum
C ------------------------------------------------------------
C  X IS K1*K2 MATRIX
C  Y IS K2*K3 MATRIX
C  PROD = X*Y IS A K1*K3 MATRIX
C ------------------------------------------------------------
      DO 30 i = 1, K1
        DO 20 k = 1, K3
          sum = 0.
          DO 10 j = 1, K2
            sum = sum + X(i,j)*Y(j,k)
   10     CONTINUE
          PROD(i,k) = sum
   20   CONTINUE
   30 CONTINUE
      RETURN
      END
```

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report—Continued.

```
c
      SUBROUTINE RRE
      CHARACTER*32 Site
      COMMON /SS    / Site
      INTEGER model
      CHARACTER*1 xansw
c
   10 PRINT *, ' ENTER site id'
      READ (5,9005) Site
      PRINT *, ' '
      PRINT *, ' Do you want to use the multivariable (1) or'
      PRINT *, ' the simplified model (2)? ENTER 1 or 2'
      READ (*,*) model
      IF (model.eq.2)then
        CALL REG1
      ELSE
        CALL REG3
      END IF
      PRINT *, ' '
      PRINT *, ' Do you want to enter another site? (y or n)'
      READ (*,*) xansw
      IF (xansw.EQ.'N' .OR. xansw.EQ.'n') RETURN
      GOTO 10
 9005 FORMAT (a32)
      END
c
      SUBROUTINE ROUND(X)
      REAL div, test, X
      INTEGER i, ix
c
c Subroutine rounds peaks to three significant figures
c for writing in table.
c
      DO 10 i = 3, 8
        test = 10**i
        div = 10**(i-2)
        IF (X.GT.test) THEN
          X = X/div
          ix = int(X+.5)
          X  = div*ix
        ENDIF
   10 CONTINUE
      RETURN
      END
c
      BLOCK DATA
      INTEGER it
      COMMON /RI  / it(7)
c RECURRENCE INTERVALS FOLLOWS
      DATA it/2, 5, 10, 25, 50, 100, 500/
      END
c
```

```
      SUBROUTINE REG1
      REAL cda, dr, mar
      COMMON /CHAR   /cda, dr, mar
      INTEGER i, ip, j
      CHARACTER*32 Site
      COMMON /SS    / Site
      REAL yhat, sepl, sepu, cl, cu
      COMMON /QOUT  /cu(4,7), cl(4,7), yhat(7), sepl(7), sepu(7)
      REAL bs, v, vt, xtxi, temp, temp2, stut, vmodel,
     &     t, vpi, xt1, xt2
      DIMENSION bs(2,7), v(1,2), vt(2,1), xt1(2,2,7), xtxi(2,2),
     &          temp(1,2), temp2(1,1), vmodel(7),
     &          stut(4)
c
c PREDICTION INTERVALS
      DATA stut/.679,1.00,1.67,2.00/
c SINGLE VARIABLE MODEL COEFFICIENTS
      DATA bs/3.10182,0.49738,
     &        3.30782,0.57482,
     &        3.39567,0.62005,
     &        3.48725,0.65702,
     &        3.54906,0.67536,
     &        3.60600,0.69001,
     &        3.72197,0.71837/
c STANDARD ERRORS FOR THE SINGLE VARIABLE MODELS
      DATA vmodel/0.35575E-01,0.20286E-01,0.15341E-01,0.14909E-01,
     &     0.17202E-01,0.21009E-01,0.34797E-01/
c SINGLE VARIABLE MATRIX FOR ALL RECURRENCE INTERVALS
      DATA xt1/
     &  0.52177E-02,-0.30932E-02,
     & -0.30932E-02, 0.26180E-02,
     &  0.37120E-02,-0.20624E-02,
     & -0.20624E-02, 0.18042E-02,
     &  0.34762E-02,-0.18646E-02,
     & -0.18646E-02, 0.16493E-02,
     &  0.39130E-02,-0.20945E-02,
     & -0.20945E-02, 0.18524E-02,
     &  0.45759E-02,-0.24866E-02,
     & -0.24866E-02, 0.21920E-02,
     &  0.54287E-02,-0.30054E-02,
     & -0.30054E-02, 0.26413E-02,
     &  0.79931E-02,-0.46107E-02,
     & -0.46107E-02, 0.40329E-02/
c
      PRINT *, ' '
      PRINT *, ' ENTER contributing drainage area (sq.mi.)'
      read (*,*) cda
      WRITE (*,9010) Site, cda
      WRITE (16,9010) Site, cda
 9010 FORMAT (//,' Flood frequency estimates for',/,1x,a32,/,
     & ' Area (square miles)=',f10.2,//,
     & t2,'Return',t12,'Discharge',t25,'Standard Error of Prediction',
     & /,t2,'Period',t10,'(cubic feet',t25,'MINUS',t41,'PLUS',/,
     & t10,'per second)',t24,'(percent) ',t41,'(percent)',/)
c
      v(1,1) = 1.0
      v(1,2) = ALOG10(cda)
```

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report—Continued.

```
      vt(1,1) = 1.0
      vt(2,1) = v(1,2)
      DO 30 ip = 1, 7
        yhat(ip) = bs(1,ip) + bs(2,ip)*v(1,2)
        yhat(ip) = 10**yhat(ip)
c
c Compute CI
c
          DO 20 i = 1, 2
            DO 10 j = 1, 2
                xtxi(i,j) = xt1(i,j,ip)
   10       CONTINUE
   20     CONTINUE
          CALL MLTPLY(temp,v,xtxi,1,2,2,1,1,2)
          CALL MLTPLY(temp2,temp,vt,1,2,1,1,1,2)
        vpi = vmodel(ip) + temp2(1,1)
        asep=sqrt(vpi)
        sepl(ip) = 100.*(10**(-asep) -1.0)
        sepu(ip) = 100.*(10**(asep) -1.0)
        DO 21 is=1,4
          t = 10**(stut(is)*asep)
          cu(is,ip) = yhat(ip)*t
          cl(is,ip) = yhat(ip)/t
   21   CONTINUE
   30 CONTINUE
        call outeng(1)
      RETURN
      END
      SUBROUTINE REG3
      REAL cda, dr, mar
      COMMON /CHAR   /cda, dr, mar
      INTEGER i, ip, j
      CHARACTER*32 Site
      COMMON /SS    / Site
      REAL yhat, sepl, sepu, cl, cu
      COMMON /QOUT  /cu(4,7), cl(4,7), yhat(7), sepl(7), sepu(7)
      REAL bs, v, vt, xtxi, temp, temp2, stut, vmodel,
     &     t, vpi, xt1, xt2
      DIMENSION bs(4,7), v(1,4), vt(4,1), xt1(4,4,3), xtxi(4,4),
     &          temp(1,4), temp2(1,1), vmodel(7),emp(1,3),
     &          xt2(4,4,3),stut(4),xtx2(3,3),
     &          u(1,3), ut(3,1)
c
c
      DATA stut/.679,1.00,1.67,2.00/
c MULTIVARIABLE REGRESSION EQUATION COEFFICIENTS
      DATA bs/1.29966,0.60259,0.00000,0.85191,
     &        2.71160,0.65989,-0.46987,0.64522,
     &        3.58884,0.69677,-0.86931,0.58403,
     &        4.39693,0.73011,-1.24950,0.53968,
     &        4.85868,0.74704,-1.47605,0.52513,
     &        5.25481,0.75981,-1.67512,0.51825,
     &        6.03822,0.78133,-2.07196,0.50949/
c MULTIVARIATE MODEL STANDARD ERRORS
      DATA vmodel/0.27190E-01,0.15385E-01,0.10422E-01,0.80334E-02,
     &     0.80202E-02,0.89159E-02,0.13629E-01/
c MULTIVARIATE MODEL MATRIX FOR ALL RECURRENCE INTERVALS
```

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report—Continued.

```
      DATA xtx2/
     &  0.21951,    -0.14310E-01,-0.10113,
     & -0.14310E-01, 0.27477E-02, 0.55743E-02,
     & -0.10113,     0.55743E-02, 0.47514E-01/
c
      DATA xt1/
     &   0.26035,    -0.75859E-02,-0.96250E-01,-0.43934E-01,
     &  -0.75859E-02, 0.19947E-02,-0.21964E-02, 0.44904E-02,
     &  -0.96250E-01,-0.21964E-02, 0.90860E-01,-0.27035E-01,
     $  -0.43934E-01, 0.44904E-02,-0.27035E-01, 0.41955E-01,
     &   0.24655,    -0.68152E-02,-0.95466E-01,-0.37558E-01,
     &  -0.68152E-02, 0.17017E-02,-0.14591E-02, 0.36637E-02,
     &  -0.95466E-01,-0.14591E-02, 0.85270E-01,-0.23523E-01,
     &  -0.37558E-01, 0.36637E-02,-0.23523E-01, 0.36297E-01,
     &   0.26943,    -0.73763E-02,-0.10778,    -0.37829E-01,
     &  -0.73763E-02, 0.17125E-02,-0.10049E-02, 0.35611E-02,
     &  -0.10778,    -0.10049E-02, 0.92206E-01,-0.23741E-01,
     &  -0.37829E-01, 0.35611E-02,-0.23741E-01, 0.36680E-01/
c
      DATA xt2/
     &   0.30644,    -0.84864E-02,-0.12353,    -0.42169E-01,
     &  -0.84864E-02, 0.19041E-02,-0.91078E-03, 0.39281E-02,
     &  -0.12353,    -0.91078E-03, 0.10438,    -0.26280E-01,
     &  -0.42169E-01, 0.39281E-02,-0.26280E-01, 0.40764E-01,
     &   0.35427,    -0.99682E-02,-0.14276,    -0.48817E-01,
     &  -0.99682E-02, 0.21960E-02,-0.95190E-03, 0.45358E-02,
     &  -0.14276,    -0.95190E-03, 0.12040,    -0.30186E-01,
     &  -0.48817E-01, 0.45358E-02,-0.30186E-01, 0.47003E-01,
     &   0.49671,    -0.14520E-01,-0.19719,    -0.71241E-01,
     &  -0.14520E-01, 0.31719E-02,-0.14581E-02, 0.66746E-02,
     &  -0.19719,    -0.14581E-02, 0.16870,    -0.43307E-01,
     &  -0.71241E-01, 0.66746E-02,-0.43307E-01, 0.67944E-01/
c
      PRINT *, ' '
      PRINT *, ' ENTER Contributing Drainage Area (CDA, in sq.mi.)'
      read (*,*) cda
      PRINT *, ' '
      PRINT *, ' ENTER Depth to Rock (DR, in inches)'
      read (*,*) dr
      PRINT *, ' '
      PRINT *, ' ENTER Mean Annual Rainfall (MAR, in inches)'
      read (*,*) mar
      WRITE (*,9010) Site, cda, dr, mar
      WRITE (16,9010) Site, cda, dr, mar
 9010 FORMAT (//,' Flood frequency estimates for',/,1x,a32,/,
     & ' Area (square miles)=',f10.2,/,' Depth to rock (in.)=',f7.0,/,
     & ' Mean annual rainfall (in.)',f7.0,//,
     & t2,'Return',t12,'Discharge',t25,'Standard Error of Prediction',
     & /,t2,'Period',t10,'(cubic feet',t25,'MINUS',t41,'PLUS',/,
     & t10,'per second)',t24,'(percent) ',t41,'(percent)',/)
c
      v(1,1) = 1.0
      v(1,2) = ALOG10(cda)
      v(1,3) = ALOG10(dr)
      v(1,4) = ALOG10(mar)
      vt(1,1) = 1.0
      vt(2,1) = v(1,2)
```

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report—Continued.

```
      vt(3,1) = v(1,3)
      vt(4,1) = v(1,4)
      DO 30 ip = 1, 7
        yhat(ip) = bs(1,ip) + bs(2,ip)*v(1,2) + bs(3,ip)*v(1,3)
     &            + bs(4,ip)*v(1,4)
        yhat(ip) = 10**yhat(ip)
c
c Compute CI
c
        if (ip.eq.1)then
          u(1,1)=1.0
          u(1,2)=v(1,2)
          u(1,3)=v(1,4)
          ut(1,1)=1.0
          ut(2,1)=u(1,2)
          ut(3,1)=u(1,3)
          CALL MLTPLY(emp,u,xtx2,1,3,3,1,1,3)
          CALL MLTPLY(temp2,emp,ut,1,3,1,1,1,3)
        else
          DO 20 i = 1, 4
            DO 10 j = 1, 4
              IF (ip.LE.4) THEN
                xtxi(i,j) = xt1(i,j,ip)
              ELSE
                xtxi(i,j) = xt2(i,j,ip-4)
              ENDIF
   10       CONTINUE
   20     CONTINUE
          CALL MLTPLY(temp,v,xtxi,1,4,4,1,1,4)
          CALL MLTPLY(temp2,temp,vt,1,4,1,1,1,4)
        end if
        vpi = vmodel(ip) + temp2(1,1)
        asep=sqrt(vpi)
        sepl(ip) = 100.*(10**(-asep) -1.0)
        sepu(ip) = 100.*(10**(asep) -1.0)
        DO 21 is=1,4
          t = 10**(stut(is)*asep)
          cu(is,ip) = yhat(ip)*t
          cl(is,ip) = yhat(ip)/t
   21   CONTINUE
   30 CONTINUE
        call outeng(3)
      RETURN
      END
      SUBROUTINE OUTENG(model)
      INTEGER model
      REAL cda, dr, mar
      COMMON /CHAR   /cda, dr, mar
      REAL yhat, sepl, sepu, cl, cu
      COMMON /QOUT  /cu(4,7), cl(4,7), yhat(7), sepl(7), sepu(7)
      INTEGER it
      COMMON /RI  /it(7)
      DO 11 ip=1,7
       call round(yhat(ip))
       WRITE (16,9020) it(ip), yhat(ip), sepl(ip), sepu(ip)
       WRITE (*,9020) it(ip), yhat(ip), sepl(ip), sepu(ip)
   11 CONTINUE
```

Appendix 2. FORTRAN program to calculate the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for ungaged, unregulated rural streams in Puerto Rico based on new regression equations presented in this report—Continued.

```
       WRITE (16,9011)
       WRITE (*,9011)
      DO 14 is=1,4
        DO 14 ip=1,7
          call round(cu(is,ip))
          call round(cl(is,ip))
   14 CONTINUE
      DO 12 ip=1,7
       WRITE(16,9021)it(ip),(cl(is,ip),cu(is,ip),is=1,4)
       WRITE (*,9021)it(ip),(cl(is,ip),cu(is,ip),is=1,4)
   12 CONTINUE
      IF (cda.lt.0.83.or.cda.gt.208.0)THEN
        WRITE(*,9101)
        WRITE(16,9101)
      END IF
      if (model.eq.3)then
        IF (dr.lt.24.24.or.dr.gt.59.15)THEN
          WRITE(*,9102)
          WRITE(16,9102)
        END IF
        IF (mar.lt.46.61.or.mar.gt.200.)THEN
          WRITE(*,9103)
          WRITE(16,9103)
        END IF
      end if
      RETURN
 9011 FORMAT (/,'   PREDICTION INTERVALS, IN CUBIC FEET PER SECOND',/,
     & ' Return',t13,'50 PERCENT',t31,'67 PERCENT',t49,'90 PERCENT',
     & t67,'95 PERCENT',/,' Period',t10,'lower    upper',t28,
     & 'lower    upper',
     & t46,'lower    upper',t64,'lower    upper')
 9020 FORMAT (2x,i4,f12.0,f12.1,4x,f12.1)
 9021 FORMAT (2x,i4,4(f8.0,2x,f8.0))
 9101 FORMAT (' WARNING - Drainage area out of range
     & of observed data')
 9102 FORMAT (' WARNING - Depth to rock out of range
     & of observed data')
 9103 FORMAT (' WARNING - Mean annual rainfall out of range
     & of observed data')
      END
```