Water Resources Division
U.S. Geological Survey

Caribbean District
Open-File Report

A PROPOSED STREAMFLOW-DATA PROGRAM FOR PUERTO RICO

UNITED STATES DEPARTMENT OF THE INTERIOR
in cooperation with the
COMMONWEALTH OF PUERTO RICO

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A PROPOSED STREAMFLOW-DATA PROGRAM

FOR PUERTO RICO

by
Miguel A. López and Fred K. Fields
U.S. Geological Survey

Prepared in cooperation with
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RESUME

1. The streamflow data-collection program in Puerto Rico was instituted in 1907 by the Puerto Rico Water Resources Authority. Except for long-term operating records, most of the records were short-term for immediate design purposes. The United States Geological Survey started an extensive network of gaging stations in 1958 to meet both short-term and long-term needs.

2. Maturing aspects of data collection dictated that an analysis be made of the records on a statistical basis, with the view of determining how the programs best could meet needs of the future. Data needs are classified in four types:

A. Current use
B. Planning and design
C. Long-term trends
D. Stream environment

3. Statistical methods used include frequency of occurrence and multiple regression, the latter involving the records for 70 gaging stations, 5 streamflow characteristics, and 32 drainage-basin parameters. Equations (models) are developed to enable streamflow characteristics to be estimated at ungaged sites in the volcanic upland area of Puerto Rico.

4. Accuracy goals are established, but were met or exceeded only for peak flows. Higher accuracy of other streamflow characteristics can be sought with more data collection, with due regard to diminishing returns.

5. Gaging station networks are proposed to meet the four types of data needs listed in (2) above. Present networks need revamping, which involves both eliminating some gaging stations and establishing others.

6. The streamflow data analysis will lead to the early preparation of five statistical summaries of data by selected characteristics. The accumulated data is closely related to numerous other projects and reports in the areas of areal water resources, flood mapping, and environmental studies.

RESUMEN

1. El programa de acumular datos del caudal de los ríos de Puerto Rico fué iniciado en el 1907 por la Autoridad de las Fuentes Fluviales de Puerto Rico. La mayor parte de la información acumulada era a corto plazo, para uso inmediato en diseños, exceptuando los datos de operaciones a largo plazo. El Servicio Geológico de los Estados Unidos inició una extensa red de estaciones de aforo en 1958 para recoger información para uso inmediato y a largo plazo.

2. Para determinar la manera más efectiva en que el programa puede llenar las necesidades futuras, se analizarán estadísticamente los datos acumulados. Los datos necesarios se clasificaron en cuatro tipos:

A. Uso presente
B. Planificación y diseño
C. Tendencias a largo plazo
D. Características ambientales del cauce y área de captación

3. Las estadísticas usadas incluyen análisis de frecuencia y regresión múltiple. Esta última incluye los datos de 70 estaciones de aforo, 5 características del caudal y 32 parámetros en la cuenca de desague. Se desarrollaron ecuaciones (modelos) para estimar las características de la corriente en la meseta volcánica de Puerto Rico.

4. Se establecieron metas de precisión, pero estas fueron alcanzadas o excedidas sólo para el flujo máximo. Se puede tratar de mejorar la precisión de otras características de las corrientes recogiendo más datos, pero teniendo en cuenta la proporción de rendimiento obtenible.

5. Se propuso establecer nuevas estaciones de aforo para recopilar los datos necesarios, mencionados anteriormente en el párrafo (2). La presente red de estaciones necesita ser reorganizada, lo que incluye la eliminación de algunas estaciones y el establecimiento de otras nuevas.

6. El análisis de los datos recopilados nos llevará a la pronta preparación de cinco resúmenes estadísticos, divididos en determinadas características. Los datos acumulados están estrechamente relacionados con otros proyectos e informes sobre recursos hidrológicos regionales, mapas de inundaciones, y estudios ambientales.

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A PROPOSED STREAMFLOW-DATA PROGRAM FOR PUERTO RICO

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PRESENT PROGRAM AND METHOD OF EVALUATION

The streamflow-data program of the U.S. Geological Survey (USGS) in Puerto Rico has been one of the principal parts of an overall appraisal of the water resources of the Island since the initiation of a cooperative agreement with agencies of the Commonwealth Government in 1957. The streamflow-station network has increased in direct response to the demand for data to support planning for the rapidly accelerated industrial and population growth that has occurred since.

The earliest systematic collection of streamflow data in Puerto Rico was begun by the Puerto Rico Water Resources Authority (PRWRA) in 1907. Their early records consisted of computed monthly inflow to irrigation and hydroelectric-power reservoirs. Over the years, PRWRA also collected daily discharge records at 158 proposed power and irrigation reservoir sites. Most of the records were short-term and were based on daily staff-gage readings and periodic streamflow measurements. Automatic stage recorders were operated, however, at 12 sites after 1946.

The Geological Survey's streamflow network has increased from 10 continuous-record streamflow stations in 1960 to 63 in early 1970. Many of the stations were established for specific areal studies undertaken to formulate water management decisions. The list of stations in operation and the purpose of the data collected at them appears later in this report.

A network of low-flow partial-record stations was established in 1959 to define low-flow characteristics.

A high-flow partial-record network was started in 1960. This project for determining flood-peak elevation and discharge was augmented after the disastrous floods of September 6, 1960, by the initiation of a flood plain mapping project in 1961. The highway bridge-site evaluation project started in 1962 further expanded the high-flow partial-record network, and early in 1970 there were 71 stations of this type in operation.

The increasing cost of operation, the constraints on funds and manpower, and the need for a greater variety of hydrologic information made it imperative that a systematic evaluation of the streamflow-data program be made. The question was how to apply the funds and manpower available in order to best serve Commonwealth and Federal interests. The purpose of this study is to evaluate the available streamflow data and to use this evaluation to design a program that will produce the types of information needed most efficiently.

The concepts and procedures used in this study have been presented in detail by Carter and Benson (1970), and are summarized only briefly in this report. The basic steps are: (1) definition of the long-term objectives of the streamflow-data program in quantitative form; (2) examination and analysis of all available data to determine which objectives already have been met; (3) consideration of alternate means of meeting the remaining objectives; and (4) preparation of a proposed program of data collection and analysis to meet the remaining objectives. Heavy reliance is placed on statistical analysis.

The water-resources investigation in Puerto Rico has been supported by both Commonwealth and Federal agencies in financial cooperation with the U.S. Geological Survey. The evaluation cuts across the programs with all agencies, so the proposed program is identified with no specific agency. This does not imply any change in existing cooperative relations.

ASPECTS OF HYDROLOGY OF PUERTO RICO

The geography and climate of Puerto Rico have been described by Picó (1950). His classification of the geographic regions spans the range from rain forest at the higher elevations in the interior to semiarid terrain in the southwest. Average annual rainfall ranges from about 210 inches in the Luquillo Mountains to about 25 inches at the southwest corner of the Island. The two principal influences on the weather and rainfall are the persistent tradewinds from the east northeast and the random pattern of hurricanes.

Daily streamflow in Puerto Rico varies widely as a result of hard and often short showers, and rugged terrain. It also shows wide seasonal and year-to-year variation. Peak discharge during great floods ranks with the highest known in the world on a unit-area basis, sometimes exceeding the 100-percent Myers rating (Barnes and Bogart, 1961). Mean annual flow from streams in the igneous and metamorphic rock areas ranges from about 85 percent of the average annual rainfall at the higher altitudes to about 15 percent along the south coast (Giusti and López, 1967). The annual rainfall-runoff relation is fairly well defined.

Streams draining the north coast limestone area generally are characterized by relatively high sustained base flow. Flood peaks probably are not as great on a unit basis as in the volcanic interior uplands, but extensive flooding of coastal lowlands does occur. There are not sufficient data for streams draining exclusively limestone terrane to determine the rainfall-runoff relation.

The lower reaches of many of the streams draining the south slope of the Island have no flow during much of the year owing to diversion for irrigation and recharge of ground water in the alluvial valleys. Discharge from ground-water storage, however, causes flow to reappear in the channels close to the coast.

CONCEPTS AND PROCEDURES USED IN THIS STUDY

The principal planning concept of this study is that streamflow information may be needed at any point on any stream in Puerto Rico and that the program must be designed to accomodate the need. This information can be provided by a combination of data collection and hydrologic studies that generalize the information obtained at gaging sites.

Another important concept is that the goals of the program, including accuracy goals, should be identified in quantitative form. This permits evaluation of existing data to determine which goals have been attained and how the program should be modified to reach the goals that have not been attained.

The procedures used in this study are presented with reference to the general framework shown by table 1. Streamflow data are classified into four types: (1) data for current use; (2) data for planning and design; (3) data to define long-term trends; and (4) data on the stream environment. For planning and design, streams are further classified as natural or regulated.

In the first step of the study, program goals were established for each type of data. All available data then were examined and analyzed. This led to a comparison of the information now available with the goals that had been set and to consideration of the elements that should be included in the future program.

Criteria for each of the four types of data and the methods employed in deriving information are discussed in the following sections.

Table 1.--Framework for design of data-collection program.

	Type of data				
		Planning and design			
	Current use	Natural flow	Regulated flow	Long-term trends	Stream environment
	To provide current data on streamflow needed for day-to-day decisions on water management as required.	To provide information on statistical characteristics of flow at any site on any stream in Puerto Rico to the specified accuracy.		To provide a long-term data base of homogeneous record on natural-flow streams.	To describe the hydrologic environment of stream channels and drainage basins.
Accuracy goal	As required.	Equivalent to 10 years of record.	Equivalent to 10 years of record.	Highest obtainable.	As required.
Approach	Operate gaging stations as required to provide specific information needed. Less than a complete record may be adequate for some purposes.	Gage at selected points. Transfer data to ungaged points by regression or interpolation.	Develop generalized relations that account for the effect of storage, diversion, or regulation on natural-flow characteristics. For larger streams, develop and apply an analytical model of the stream system.	Operate a few carefully selected gaging stations indefinitely.	Observe and publish information on stream environment.
Evaluate available data	Identify stations where data are used currently and code the specific use of data.	Develop relation for each flow characteristic and compare standard error with accuracy goal. Evaluate sample.	Appraise type of regulation, data available, and type of analysis needed.	Are existing stations, designated for this purpose, adequate?	Evaluate information available in relation to goals.
Design program	Identify goals that have not been attained. Consider alternate means of attaining goals. Identify elements of future program.				

CONCEPTS AND PROCEDURES USED IN THIS STUDY

Data for Current Use

Current information on streamflow is needed at many sites for day-to-day decisions on water management, for assessment of current water availability, for management of water quality, for forecast of water hazards, and for surveillance necessary to comply with legal requirements. Sites at which data are collected for these purposes are termed "current-purpose" streamflow stations.

Data for current use are obtained by operating gaging stations to obtain the data specifically required for water-management systems. Current-purpose data stations are identified separately from others in this study because: (1) justification can be related to specific needs; (2) the data may have little or no transfer value in a hydrologic sense; and (3) the location of the station, the accuracy requirements, and the period of operation are specified by the user of the data, who usually provides the financing.

This part of the program is not subject to design. It changes in response to needs for data in water management.

Data for Planning and Design

Streamflow records provide basic information for planning and designing water-related facilities. Past hydrological experience, however, never is duplicated precisely in the future; for example, a past sequence of wet and dry years probably will not occur again in exactly the same way. For this reason, planners and designers commonly utilize statistical characteristics of streamflow rather than the records of flow at specific times. It is assumed that the characteristics of future flow can be approximated from those which have occurred in the past. Typical statistical characteristics are the mean flow, the flood of 50-year recurrence interval, and the standard deviation of annual mean flows.

A long record of streamflow at a specific site is desirable for defining statistical characteristics of streamflow at that site. Although it is not feasible to collect a long continuous streamflow record at every site where it may be needed, a number of such records are required to provide information that can be transferred to ungaged sites or to sites where less information is available.

Different methods of defining and transferring streamflow characteristics are used for natural-flow and for regulated-flow streams, as described below.

Natural-Flow Streams

Transferring information obtained at gaging stations on natural-flow streams is done by relating flow characteristics to basin parameters such as drainage area, topography, and climate; by relating a short record to a longer one; or by interpolating between gaged points on a stream channel.

Regulated-Flow Streams

The natural flow regimen of many streams is altered by storage reservoirs and by diversion of water. These alterations increase the scope of both the data collection and the analysis that is required to provide information on flow characteristics.

To be useful in statistical prediction, streamflow data must be homogeneous in time. It frequently is not possible, however, to obtain a long record under a single condition of development because changes are made in the regulating system .

Definition of flow characteristics at an ungaged point on a stream also is much more difficult under conditions of regulation. The procedures used for natural streams--regression and interpolation--cannot be applied.

For regulated streams, a systems approach seems to be the most efficient way of providing meaningful information on the statistical characteristics of flow. This approach requires some sort of analytical model of the stream system. Such models are simple in concept and generally consist of water-budget equations and flow-storage equations. In many instances, however, a digital computer is required to handle complex equations or large volumes of data. A computer program tailored to the individual system must be prepared.

Development of an analytical model requires information on stage-capacity curves of reservoirs, stage-discharge curves at the outlets, operating-rule curves for the release of water, losses due to evaporation and seepage, the geometry of the stream channel, and records of diversion and return flow. Information on streamflow at some point or points also is needed as input to the model and to verify the output. Frequently, aquifer characteristics and groundwater pumpage should be considered.

The model and the associated data can be used to derive homogeneous data for both the natural and the regulated condition. All historical streamflow records for both natural and regulated flow can be used as input to the model. Furthermore, data also can be derived for ungaged sites in the regulated stream system.

Accuracy of Streamflow Characteristics

Some error must be tolerated in using hydrologic experience to appraise the probability of future occurrence. Natural streamflow, like other events related to climate, generally is random in occurrence and varies greatly in time and space. Statistical techniques used in analysing random events, therefore, are considered applicable when measures of the variability with time of annual mean flow and other streamflow characteristics are determined from historical streamflow data, the probable error involved in defining streamflow characteristics then can be appraised.

The principal measure of the accuracy with which a particular streamflow characteristic can be determined is the statistical measure of error, "standard error of estimate," which is expressed in this report as a percentage of the average value of the characteristic. The standard error is the estimated limit above and below the average within which about two-thirds of future values of the characteristic are expected to fall. Conversely, it indicates that there is only 1 chance in 3 that future values will differ from the average by more than one standard error.

The longer the record, in general, the more reliable are the estimates of probable future occurrence. Even with a long record, say 50 to 100 years or more, however, it is not possible to determine with great precision the probability of certain flow characteristics--for example, floods of a given magnitude. The standard error of various streamflow characteristics decreases with the years of available record, but at a decreasing rate. Diminishing return sets in, as illustrated in figure 1. The incremental economic value of additional years of record beyond a reasonable limit in planning and designing projects is under continuing study, but no usable guidelines are available at present.

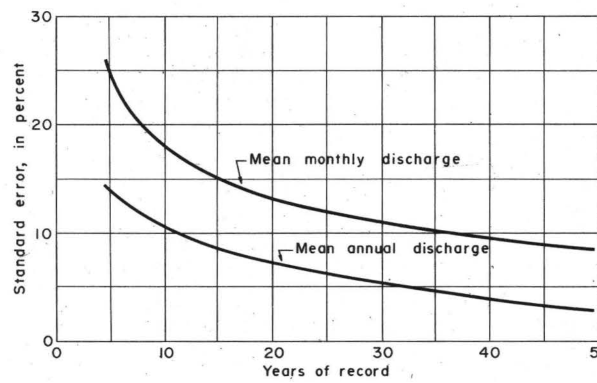

Figure 1.--Relation of standard error to length of record, based on selected goals of Puerto Rico program.

At sites on natural-flow streams where streamflow records are not available, desired streamflow characteristics may be defined by means of the relation between the streamflow characteristics and the measured parameters of the drainage basin. Definition is accomplished by multiple-regression analysis, a statistical method of handling sample data that can relate a streamflow characteristic to the topographic, geologic, and climatic parameters that affect streamflow.

This analysis produces a regression equation that can be used to compute flow properties at any point on natural streams in Puerto Rico. The standard error of a regression equation provides a measure of the accuracy of an estimate made at an ungaged site. That error may be compared with the error associated with the same characteristic at a gaged site, defined from a number of years of record to determine if the accuracy objective has been met.

CONCEPTS AND PROCEDURES USED IN THIS STUDY

Data to Define Long-Term Trends

Properties of streamflow defined from gaging-station records are used to estimate future flow characteristics, on the assumption that the observed record is a representative sample of the long-term flow of the stream. To affirm this assumption, or to define better the ways in which the properties of flow change with time, selected gaging stations on natural streams should be operated indefinitely. The accuracy of gaging at these sites should be the highest that the state of the art permits.

Data of Stream Environment

Environmental data describe the physical environment in which the water exists, especially those features that relate to the use of water for recreation, waste disposal, conjunctive surface water-ground water supply, and the preservation of the esthetic character of water features. The types of data required for this purpose are listed in the following chapter.

OBJECTIVE OF THE PUERTO RICO STREAMFLOW—DATA PROGRAM

The objective of the streamflow-data program is to provide information on flow at any point on any stream in Puerto Rico. Within this general objective, specific goals have been set for each of the four types of data that represent the particular information that is needed--refer to table 1.

Data for Current Use

The program goal of data for current use is to provide the particular information needed at specific sites for current use. Accuracy goals at a given site are specified by the data user. Unusually high accuracy can be obtained by intensive observation or by sophisticated instrumentation. No specific length of record can be set, for the length of record is the same as the length of the need for the data.

Data for Planning and Design

The goal of data for planning and design is to define flow properties at ungaged sites to an accuracy that is equivalent to 10 years of record. This accuracy goal applies not only to streams with natural flow but also to streams that are affected by diversion and regulation. Selection of the 10-year equivalent accuracy criterion, was based on two factors: (1) the rapid development of water-supply sources may not permit a lengthy investigation; and (2) economic and sociological considerations may outweigh hydrologic realities, therefore, accuracy that could be obtained from a longer record is not needed.

The standard error, in percent, corresponding to 10 years of record can be calculated from a theoretical relation of standard error to an index of variability. Standard errors are shown in table 2 for selected streamflow characteristics.

Table 2.--Accuracy goals.

Streamflow characteristic	Standard error for 10 years of record, percent
Mean annual discharge	9
Standard deviation of annual discharge	22
Mean monthly discharge (average)	18
Standard deviation of monthly discharges (average)	22
50-year flood	50
2-year 1-day low flow	12
10-year 1-day low flow	16
20-year 1-day low flow	17

OBJECTIVE OF THE PUERTO RICO STREAMFLOW-DATA PROGRAM

Data to Define Long-Term Trends

The goal of data to define long-term trends is to operate indefinitely a small network of gaging stations on streams that are expected to be relatively free from manmade change. Stations should be located in each major climatic region of Puerto Rico.

Data on Stream Environment

Environmental data describe the basin, the flow, and the stream channel in terms that will be valuable in planning the use of the stream for any purpose, such as combined surface water-ground water supply, waste disposal, and recreation; and in evaluating detrimental change caused by man's activities. The long-range goals of this type of data in Puerto Rico are given below.

1. Define the location, extent, and characteristics of aquifers that are hydrologically connected to stream channels.
2. Measure the time of travel of water and dissolved wastes in streams and lakes.
3. Define flood profiles along selected stream reaches.
4. Define the area subject to flooding along selected stream reaches.
5. Describe stream channel geometry and its relation to streamflow quality.
6. Determine the effect of sand and gravel extraction from streams and estuaries.
7. Determine watershed land use and its effect on streamflow quantity and quality.

EVALUATION OF EXISTING DATA

In this evaluation, all available data are considered and analyzed in relation to the program objectives. A separate evaluation is made of each of the four types of data.

Evaluation of Data for Current Use

Twelve streamflow records for current use in Puerto Rico are collected by Puerto Rico Water Resources Authority and one record is collected by Puerto Rico Aqueduct and Sewer Authority--see table 3. The records are for reservoirs operated by these agencies, and it is assumed that the need for this type of data is being met.

Evaluation of Data for Planning and Design

The statistical characteristics of streamflow needed for planning and design can be defined by sample gaging, analytical methods of regionalization, system studies, or any combination of the three. The following discussion of the evaluation of this type of data follows the framework shown in table 1.

Table 3.--Current-purpose streamflow stations.

Station number	Stream name and location
50-0107.5	Río Guajataca at Lago Guajataca
0201	Río Vacas at Lago Garzas
0271	Río Grande de Arecibo at Lago Dos Bocas
0323	Río Toro Negro at Lago El Guineo
0326	Río Matrullas at Lago de Matrullas
0400	Río de la Plata at Lago Carite
0441	Río de la Plata at Represa de Comerío
0590	Río Grande de Loíza at Lago Loíza
0930.5	Río Grande de Patillas at Lago Patillas
1068.5	Río Coamo at Lago Coamo
1113	Río Jacaguas at Lago Guayabal
1258	Río Yauco at Lago Lucchetti
1410	Río Yahuecas near Adjuntas

All are operated by PRWRA except 0590 which is operated by PRASA.

All except 1410 are at reservoirs.

Evaluation of Natural-Flow Systems

The purpose of the evaluation of natural-flow systems is to determine how accurately the statistical characteristics that are listed as goals can be defined by regionalization of the data now available. The most effective way known to define statistical streamflow characteristics on a broad scale is to relate them to basin parameters. Equations of relation are developed by means of multiple-regression techniques applied to the data.

Once the regression equations are defined, streamflow properties at ungaged sites can be computed by substituting the appropriate values of basin parameters in the equations.

Both PRWRA and USGS streamflow records were used to define streamflow characteristics. Because of the nature of individual records, not all flow properties could be defined reliably for each record. Records of monthly flow based on monthly change in reservoir contents, for example, are not detailed enough to define low-flow and peak-flow characteristics.

Likewise, the continuous USGS streamflow records, none of which exceeds 9 years in length, do not provide an adequate time sample for defining flow characteristics of large recurrence interval. By utilizing both long and short records from various sources and types, and historical data on floods and droughts, however, reliable estimates of flow have been defined at many sites.

Streamflow characteristics

The following streamflow characteristics were defined at many gaging stations. They include the full range of flow, as required for planning and design:

1. Flood-peak characteristics are represented by discharge from annual flood-frequency curves at recurrence intervals of 2, 5, 10, 25, and 50 years. In this report, these peak-flow rates are denoted as Q_2, Q_5, etc. The peak-discharge frequency curves were prepared by the graphical method because many of the data sets were incomplete (Dalrymple 1960) and mathematical curve fitting was not practical.

2. Low-flow characteristics are the annual minimum 1-day mean flow at 2-year, 10-year, and 20-year recurrence interval ($M_{1,2}$, $M_{1,10}$, and $M_{1,20}$). These were determined from low-flow frequency curves prepared by the graphical method.

3. Mean flow characteristics are described by the average of the annual means (Q_a) on a calendar-year basis, the average of records for each month (q_n), where the subscript refers to the numerical order of the month beginning with January as 1.

4. The variability of mean flow is represented by the standard deviation of the annual and monthly means. The symbols used are, respectively, SD_a and SD_n, where the subscript n refers to the numerical order of months with January as 1.

5. Flood-volume characteristics were not defined for this study because the short daily discharge records available may not be representative of long-term flood-volume frequency.

Table 8 (in Appendix) lists the gaging stations used and the type of record obtained at each.

Drainage-basin parameters

Drainage-basin parameters defined for this study are:

1. Drainage area (A), in square miles, as determined from USGS topographic maps, scale 1:30,000. Also computed in square kilometers.

2. Main-channel length (L), in kilometers, from streamflow site to drainage divide.

3. Basin width (W), in kilometers, computed by dividing drainage area in square kilometers by main-channel length in kilometers.

4. Forest cover (F), expressed as the proportional part of the drainage area covered by forest as shown on topographic maps, determined by the grid method.

5. Surface storage (St), expressed as the proportional part of the drainage area covered by lakes, reservoirs, or swamps as shown on topographic maps, determined by the grid method.

6. Main-channel slope (S), in meters per kilometer, computed from elevations at 10 percent and 85 percent of the distance along the channel.

7. SCS curve number (Curve), as determined from SCS "National Engineering Handbook," Section 4, using soil-index data provided by the San Juan office of the Soil Conservation Service.

8. Climatic index (Index), Thornthwaite's climatic index as determined from climatic index map for Puerto Rico minus a constant of 60 (Giusti and López 1967).

9. Mean basin elevation (E), in hundred meters above sea level.

10. Mean annual precipitation (P), in inches minus a constant of 50, as determined from USWB Climatography of the United States No. 86-45.

11. Mean monthly precipitation (Pn), in inches, for each month, where n is the numerical order with January as 1.

12. Maximum 24-hour precipitation having a recurrence interval of 2 years (P 24,2), in inches, from USWB Technical Paper No. 42.

In addition, 8 geologic indices, 5 rainfall-intensity indices, 5 indices of the interaction between rainfall intensity and drainage area, and 2 temperature indices were defined for the 70 gaging stations used in the analysis. Selected basin characteristics are listed in table 9 (in Appendix). The complete list is available at the USGS office in San Juan.

Regression analysis

The next step was to relate each of the streamflow characteristics to basin physical and climatic parameters by multiple regression. This defines streamflow in terms of the basin parameters that cause variation in streamflow from one place to another (Benson, 1962). The regression model (equation) used has the form

$$Y = a \cdot A^{b} S^{c} P^{d} \ldots$$

where Y is a streamflow characteristic; A, S, P, are basin or climatic parameters; and a, b, c are coefficients determined by regression.

The initial regression equation for each flow characteristic included all the basin parameters thought to be appropriate. Each basin parameter was tested for statistical significance. The least significant one was dropped, and the regression was recomputed. The process was repeated until only the most significant parameters remained. The entire computation process then was repeated using another streamflow characteristic.

Table 4 shows for each streamflow characteristic the significant basin parameters, the regression coefficients, the regression constant, and the standard error.

Although all basin parameters listed in table 4 are statistically significant, some have little practical significance; that is, the reduction in standard error because of their inclusion is negligible. For example, the equation for mean annual flow (first entry, table 3) is:

$$Q_a = 0.0305\ (A)^{0.79}\ (S)^{-0.26}\ (\text{Index}-60)^{1.02}\ (E)^{0.37}\ (\text{Temp }1-50°)^{0.55}$$

where drainage area, slope, climatic index, mean basin elevation, and average January minimum temperature are the independent variables. The standard error of this regression is 18 percent.

A simplified equation with only the slightly higher standard error of 20 percent is:

$$Q_a = 0.173\ (A)^{0.76}\ (S)^{-0.25}\ (\text{Index}-60)^{1.07}$$

This equation is more useful than the first one because fewer basin parameters have to be computed in order to apply it to an ungaged site.

The standard error achieved in the regressions is compared with the accuracy goal for each flow characteristic in table 5. The comparison shows that flood peaks at ungaged sites can be estimated within the specified accuracy. Some of the other regressions that did meet the goals, however, will be useful before they are improved in the future. For example, the estimate of the mean annual flow at an ungaged site, which has a two-thirds probability of being within 18 percent, may be adequate for a given purpose and is easily and quickly obtained.

The geographic distribution of the sites at which streamflow characteristics are defined for this study are shown in figures 2-4 (in Appendix). The coverage appears adequate except in the north-coast limestone area and in small stream basins at lower elevations. Otherwise, drainage areas from 1.3 to 200 square miles are adequately covered.

Table 4.--Summary of regression equations

$$Y = a\,(A)^{b1}\,(S)^{b2}\,(\text{Index }-60)^{b3}\,(E)^{b4}\,(\text{Temp }1\text{-}50°)^{b5}\,(St)^{b6}\,(F)^{b7}\,(\text{Precip }-50)^{b8}$$

Dependent variable Y	Regression constant a	Regression coefficients of independent variables b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	Standard error of estimate, percent
Q_a	3.05×10^{-2}	0.79	-0.26	1.02	0.37	0.55				18
* Q_a	1.73×10^{-1}	.76	- .25	1.07						20
SD_a	2.77×10^{-2}	.90		.96						33
q_1	5.08×10^{-3}	.93		1.51						39
SD_1	4.62×10^{-3}	.90	- .75	1.62	.82					44
q_2	2.34×10^{-5}	1.00		1.71	.99	1.12				40
SD_2	2.75×10^{-4}	.87		2.10						110
q_3	3.05×10^{-5}	.94		1.39	.92	1.54				40
SD_3	7.53×10^{-5}	.70			1.55	3.21				90
q_4	5.30×10^{-2}	.75	- .26	1.26						44
SD_4	1.64×10^{-1}	.61	- .53			1.07		0.59		45
q_5	2.34×10^{-2}	.73			1.01	1.80				63
SD_5	1.84	.82			.51					69
q_6	3.77×10^{-1}	.56				1.37				59
SD_6	1.15×10^{-1}	.74				1.34	.39			59
q_7	1.96×10^{-1}	.63				1.56				48
SD_7	3.16	.72								84
q_8	1.43	.71				.77				37
SD_8	3.11	.86								53
q_9	4.64×10^{-1}	.74		.75						34
SD_9	4.98	.75					.34			64
q_{10}	1.35×10^{-1}	.85		.86	.36					21
SD_{10}	1.49	.83			.52		.48			31
q_{11}	3.39	.73							0.25	29
SD_{11}	1.47	.75					.40		.27	36
q_{12}	2.20×10^{-2}	.97		1.23						35
SD_{12}	2.44	.90								69
$M_{1,2}$	6.05×10^{-4}	.93		1.13				.57		42
$M_{1,10}$	1.27×10^{-4}	.93		1.19				.77		50
$M_{1,20}$	2.94×10^{-3}	.90						.62	.67	53
Q_2	4.39×10^{2}	.49							.28	35
Q_5	1.78×10^{3}	.55								38
Q_{10}	2.23×10^{3}	.60								35
Q_{25}	2.84×10^{3}	.66								34
Q_{50}	3.23×10^{3}	.71								34

* Simplified equation.

Table 5.--Comparison of standard error of regression with standard error goal.

Streamflow characteristics	Standard error, percent	
	Goal, 10-year record equivalent	By regression
Mean annual flow	9	18
Standard deviation of annual flow	22	38
Mean monthly flow (average)	18	41
Standard deviation of monthly flow	22	63
2-year 1-day low flow	12	42
10-year 1-day low flow	16	50
20-year 1-day low flow	17	53
5-year peak flow	33	38
10-year peak flow	38	35
25-year peak flow	44	34
50-year peak flow	50	34

Table 6.--Stations for which annual and monthly reservoir inflow has been computed by PRWRA.

Station number	Stream name and reservoir	Record began
50-0107.5	Río Guajataca at Lago Guajataca	1917
0201	Río Vacas at Lago Garzas	1925
0271	Río Grande de Arecibo at Lago Dos Bocas	1929
0323	Río Toro Negro at Lago El Guineo	1928
0326	Río Matrullas at Lago de Matrullas	1928
0400	Río de la Plata at Lago Carite	1908
0441	Río de la Plata at Presa de Comerío	1928
0930.5	Río Grande de Patillas at Lago Patillas	1908
1068.5	Río Coamo at Lago Coamo	1908
1113	Río Jacaguas at Lago Guayabal	1909

Evaluation of Regulated-Flow Systems

Determination of streamflow characteristics of regulated streams ranges from simple adjustment of monthly flow for changes in storage and/or for diversions, to the development of a complex stream-system model. Because system studies are beyond the scope of this report, the evaluation of regulated-stream systems is limited to appraising the adequacy of available data for such studies.

Data are being collected on all major reservoirs and diversions by PRWRA and PRASA. Streamflow records are being collected by PRWRA and USGS at strategic sites on regulated streams (except on Río Grande de Loíza). The major diversions for water supply, irrigation, and hydroelectric power and the data-collection stations on regulated streams are shown in figure 5 (in Appendix). The regulated stream gaging stations are listed in table 10 (in Appendix).

Evaluation of Data to Define Long-Term Trends

Mean annual and monthly inflow has been computed by PRWRA for the reservoirs listed in table 6.

The inflow to the reservoirs is computed from irrigation or hydroelectric-power release, plus base-flow release and spillage, plus/minus change in contents. A preliminary evaluation of the records indicates that the first seven reservoirs can be used for defining long-term trends in annual and monthly flow. Silting of the reservoir and unmeasured imported water make the computed flow into the last two of doubtful value for defining long-term changes.

PRWRA has collected streamflow record 50-1410 on Río Yahuecas near Adjuntas since 1946. This record is suitable for defining long-term trends for minimum and peak flows, and annual and monthly flows.

More years of operation must be invested in the USGS streamflow network to bring it to a more useful stage for defining long-term trends.

Evaluation of Data on Stream Environment

The goals for collection of data on stream environment are being partially met, as follows:

1. The location, extent, and characteristics of aquifers that are hydrologically connected to stream channels have been investigated along the south coast of Puerto Rico from Río Loco to Río Guamaní. An analog model of the Guayama area has been constructed, and initial tests indicate that the aquifer-stream connection has been approximated fairly closely. Hydrologic data for construction of an analog model of the Yabucoa Valley are being collected currently (July 1970).

2. The time of travel of dissolved solids in Río Tanamá from gage 0280 (fig. 2) near Utuado to its mouth at Río Grande de Arecibo was determined in 1966 by means of a fluorescent dye tracer.

3. Profiles have been defined for historical floods in the lower reaches of most major rivers in Puerto Rico. Generally the flood profiles extend from the head of the alluvium to the sea. The only exception is the flood profiles of Río Grande de Loíza and Río Gurabo, which end at the dam that contains Lago Loíza.

4. The area subject to flooding has been defined in the same river valleys mentioned above.

5. The relation of stream channel geometry to peak flow has been determined for slope-area and contraction peak-flow computations at selected sites. The results of these relations have not been analyzed to regionalize the relation. Streamflow quality data also are available at some sites where channel geometry data are available.

6. No data have been collected to determine the effect of sand and gravel extraction from streams and estuaries, except that one long-term station was destroyed by such an operation.

7. Measures of land use have been determined for multiple regressions developed for streamflow characteristics. These measures are forest cover in percent of drainage area and the SCS curve number, which includes type of cover as well as soil type.

The information developed in different segments of this study has been merged and applied in planning a streamflow-information program. The purpose is to attain as many of the remaining goals as possible within the limits of available funds and manpower. For the optimum program, a balance must be maintained between data collection and data analysis, for continuous interaction between the two is needed. This interaction will lead to a better understanding of the hydrologic system and will guide future evaluation of the program in meeting everchanging needs and in adapting to changing technology. As these changes occur, the streamflow data program for Puerto Rico must be reevaluated and the necessary modifications in data collection and analysis must be made.

Data Collection

Data for Current Use

Computation of inflow to the 13 reservoirs identified as presently meeting the needs for current purpose data (table 3) should be continued by PRWRA and PRASA. The gaging-station record at Río Yahuecas near Adjuntas should be continued by PRWRA or USGS. Rehabilitation of the station should be undertaken to insure continued dependable record.

All the current-purpose gaging-station records are being used for operational data. But changing needs should be assessed periodically, and the network should be modified as needs change for current-purpose data. The need for current-purpose data should be examined for each site, and a determination also should be made as to whether a continuous record of daily discharge is required. Or will the measure of a specific flow characteristic, such as peak flow or minimum flow, suffice?--in which case other types of data collection will be needed.

Data for Planning and Design

Flood-frequency characteristics can be estimated at ungaged sites within the accuracy goals by regression except in the north coast limestone area, in small drainage basins at elevations lower than 500 meters, and in urban areas. Additional peak-flow partial-record stations should be established in these areas.

In urban areas, the hydrograph of storm runoff and a continuous record of the causative rainfall should be collected at selected partial-record stations. In the parts of Puerto Rico where peak-flow characteristics at ungaged sites can be estimated within the accuracy goals, some reduction in the number of peak flow partial-record stations can be made. It is anticipated, however, that there will be demand for the 100-year recurrence interval flood, so certain of these stations should be operated indefinitely.

Peak-flow partial-record stations at proposed bridge sites will be discontinued after design and construction of the bridge. Selected stations will be continued if needed, however, for better definition of regional flood frequency. Proposed peak-flow partial-record stations are listed in table 11 (in Appendix) and are shown in figure 6 (in Appendix) except for the stations to be installed in urban areas. The peak-flow partial-record stations for urban areas should be located in the San Juan metropolitan area and at Ponce or Mayaguez.

Regionalization by regression did not meet the accuracy goals for annual and monthly means, and for standard deviations, partly because some of the gaging-station records were too short to define these flow characteristics accurately enough. Within fiscal-year 1971 an attempt will be made to improve the regression model.

The existing stations for planning and design data will be correlated, with the view of continuing only the stations that are representative of a region; and whose record can be used to estimate annual and monthly means at the discontinued sites. This technique should prove to be successful where stations are grouped, such as on the north slope of Sierra de Luquillo and the mountain streams near Ponce.

Low-flow characteristics also were not successfully regionalized by regression. Except, the fairly dense network of PRWRA gaging stations in the upper Río Grande de Arecibo and Río Grande de Añasco basins give good areal coverage of the western interior region of the Island.

Elsewhere, accurate estimates of low-flow characteristics at a site will require correlation with concurrent flow at a continuous-record index station where similar hydrologic conditions prevail. A partial-record station should be adequate at such sites. They will be discontinued when a successful correlation with the index station is achieved, which usually requires several years. It will be desirable to operate them by groups in a planned sequence in order to obtain intensive-enough geographic coverage.

The number and location of gaging stations on regulated streams is adequate except that stations are needed on Río Piedras downstream from the Río Piedras treatment plant and Río Grande de Loíza below Lago Loíza.

The existing stations on regulated streams should be continued in operation. Collection of additional data on storage, diversion, relation between ground water and surface water, return flow, etc., is not recommended at this time. The needs for additional information of this type will not be known until planned system studies are partly completed.

Because of its rapid development and continuing change in water use, the south coast of Puerto Rico is planned as the area for a system study. The alluvial coastal plain and its contributing streams from Río Matilde to Río Grande de Patillas all are part of this system. In fact, the system also includes the present trans-mountain diversions from the basins of Río Grande de Arecibo, Río Grande de Manatí, and Río de la Plata. The effect of the proposed additional diversion from the Río Grande de Arecibo and Río Grande de Manatí basins on the system also will be studied.

Preliminary areal studies of most of the sub-basins on the south coast have been completed, and now the overall system will be considered. The products will be the basis for the hydrologic input to a planning and management model for the south coast of Puerto Rico.

Because analytical approaches and data requirements are not yet well defined, it is recommended that the USGS Systems Laboratory Group review the present data-collection network in the system as related to present and proposed water distribution schemes and to projections of water requirements. After this review has been made, additional data-collection sites can be proposed for inclusion in the network.

Data to Define Long-Term Trends

Nine stations in the present network are proposed to be operated indefinitely to meet the needs for long-term trend data. The stations selected to provide a long-term sample reflecting areal coverage of Puerto Rico are listed in table 7 and are shown in figure 7 (in Appendix).

Table 7.--Stations to be continued to define long-term trends.

Station number	Station name	Drainage area, square miles	Record started
50-0326 *	Río Matrullas at Lago de Matrullas	4.46	1928
0400 *	Río de la Plata at Lago Carite	8.18	1908
0457	Río Lajas at Toa Alta	8.65	1967
0550	Río Grande de Loíza at Caguas	89.8	1959
0710	Río Fajardo near Fajardo	14.9	1961
0920	Río Grande de Patillas near Patillas	17.8	1967
1240	Río Guayanilla near Guayanilla	18.5	1961
1410 *	Río Yahuecas near Adjuntas	15.4	1946
1478	Río Culebrinas at Hwy PR-404 near Moca	71.2	1967

* Being operated by PRWRA as of July 1970.

Recommendations for gaging station operation for each of the foregoing three data types (current use, planning and design, long-term trends) are combined in table 12 (in Appendix) where each station is classified as to purpose. Locations are shown in figure 8 (in Appendix).

Environmental Data

Work toward the goals for environmental data should be initiated as needs are anticipated and as funds and manpower become available. Mapping flood-prone areas is continuing as the only significant environmental type of project. It is planned that mapping all the major areas of flooding will be completed by 1972. In the interim, the possible need for mapping lesser areas will be evaluated.

Data Analysis and Reports

The streamflow-data network operated through the years provides the base for the analysis of stream hydrology in Puerto Rico. Coupled with ground-water and aquifer studies, and with determination of the quality of both streamflow and ground water, a broad spectrum of the analysis of terrestial hydrology is made possible.

A wide variety of reports thus also is made possible. Some of them are a direct result of this streamflow analysis and some are in progress or are planned in the continuing regular water-resources investigations.

Streamflow Characteristics Studies

Streamflow characteristics in Puerto Rico, to be released in parts during FY-1971; to be covered by a single comprehensive volume; to be updated when additional collected and analysed data would improve the result.

Part 1 - Flow duration and flow frequency (released in April 1970)
Part 2 - Annual and monthly mean flow variation
Part 3 - Floods, magnitude and frequency
Part 4 - Low flow, magnitude and frequency
Part 5 - Chemical quality

Areal Water-Resources Studies

Water resources studies of selected areas in Puerto Rico, a continuing series of projects.

In press July 1970 - Juana Díaz area
Tallaboa Valley
Guayanilla-Yauco area

In review July 1970 - Jobos area
Coamo area
Ponce area

Active July 1970 - North coast limestone area
Copper-mining area
Yabucoa area (including analog model)
Guayama area (including analog model)

Planned - Selected areas, Arecibo to Bayamón
San Juan area
Carolina-Río Grande area

Fajardo area
Caguas area
Cayey area

Arroyo area
Lajas Valley
Mayaguez area

Associated with the foregoing projects is the reconnaissance and monitoring of salinity in coastal areas, currently active along south coast.

Flood Mapping

Delineation of major areas subject to flooding, a continuing series of projects.

In press - Storm waves along north coast
Yabucoa area
Guayanilla-Yauco area
Añasco area

In review July 1970 - Caguas, Gurabo, Juncos, San Lorenzo area
Guanajibo Valley
Aguadilla-Aguada area

Active July 1970 - Patillas-Maunabo area
Guayama area
Salinas area
Santa Isabel area
Sabaneta-Pastillo area

Planned - San Juan area
Carolina-Río Grande area
Luquillo-Fajardo area

Upland valleys
Tallaboa Valley
Lajas Valley

Associated active project - definition of flood characteristics at proposed bridge sites.

Environmental Studies

Interpretive studies mostly of the environmental and one-of-a-kind type are in general planning. The implementation of some of them depends upon the revision and further development of the data-collection networks.

Development of better measures of basin characteristics and an improved regression model for regionalizing streamflow characteristics
Definition and regionalization of suspended sediments in streams
Effect of sand-and-gravel removal

Flood characteristics of streams in urban areas
Flow in river estuaries
Gain and loss of flow in streams

Lagoon system in San Juan area
Intensive study of Río Maunabo basin
Model of stream-aquifer system, south coast

System studies of regulated streams
Time of travel in selected streams
Tortuguero Lagoon (active July 1970)

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APPENDIX

Tables 8-12

Figures 2-8

Table 8.--Gaging station records used to define streamflow characteristics.

Station number		Stream and location	Period of record used in regressions			
USGS	PRWRA		Type of record 1/	Flood frequency	Low-flow frequency	Mean annual and monthly
50-0107.5		Río Guajataca at Lago Guajataca	d			1917-66
0201		Río Vacas at Lago Garzas	d			1925-66
0205	102, 102A	Río Grande de Arecibo near Adjuntas	b,a		1925-35	
0209	117	Río Pellejas near Adjuntas	b		1924-43	
0211	116	Río Pellejas near Barrio Pellejas	b		1930-44	
0216	101	Río Grande de Arecibo above Utuado	b		1925-35	
0229.5	115	Río Viví near Adjuntas	b		1924-43	
0231	114	Río Viví near Utuado	c		1929-43	
0251.3	126	Río Saliente at Coabey	b		1924-44	
0251.7	106	Río Grande de Jayuya at Jayuya	b		1929-44	
0255	122	Río Jauca near Coabey	c		1925-48	
0255.5	105	Río Jauca near La Pica	b		1925-48	
0261	103A	Río Caonillas near Utuado	a			1944-48
0271		Río Grande de Arecibo at Lago Dos Bocas	d,e	1899-1967		1929-66
0280	110	Río Tanamá near Utuado	b,a	1960-67	1945-67	1959-67
0323		Río Toro Negro at Lago El Guineo	d			1929-67
0326		Río Matrullas at Lago de Matrullas	d			1928-66
0335	404A	Río Bauta near Divisoria	a	1949-60		1949-58
0350	400A	Río Grande de Manatí at Ciales	a,e	1928-67	1946-53, 1961-68	1946-53, 1961-68
0381		Río Grande de Manatí at Barceloneta	e	1928-67		
0395		Río Cibuco at Vega Baja	e	1915-67		
0400		Río de la Plata at Lago Carite	d			1908-66
0430		Río de la Plata at Proyecto La Plata	a	1960-68	1959-69	1960-68
0441		Río de la Plata at Represa de Comerío	d	1927-66		1928-66
0460		Río de la Plata at Toa Alta	a,e	1899-1967		1960-68
0485		Río de Bayamón at Hwy 178 at Bayamón	e	1899-1967		
0550		Río Grande de Loíza at Caguas	a,e	1945-68	1960-68	1959-68
0570		Río Gurabo at Gurabo	a,e	1960-68	1960-68	1959-67
0590		Río Grande de Loíza at Lago Loíza	d,e	1958-67		
0617		Río Cubuy near Campo Rico	a	1946-52		~~1946-52~~ No
0632.5	564A	Río Espíritu Santo above El Verde	a			1945-52
0710		Río Fajardo near Fajardo	a	1960-68	1962-68	1961-68
0720		Río Fajardo at Fajardo	b			1960-66
0750	580A	Río Icaco near Naguabo	a	1947-62	1946-52	1945-53
0820		Río Humacao at Humacao	e	1960-67		
0930.5		Río Grande de Patillas at Lago Patillas	d	1944-61	1950-58	1908-66
1068.5		Río Coamo at Lago Coamo	d			1908-66
1113		Río Jacaguas at Lago Guayabal	d	1940-66		1909-29
1144		Río Bucaná near Ponce	e	1899-1967		
1159		Río Portugués at Hwy PR-14 at Ponce	e	1899-1967		
1170		Río Cañas at Ponce	e	1899-1967		
1185		Río Pastillo at Ponce	e	1899-1967		
1210	370	Río Tallaboa at Peñuelas	a,e	1928-67		
1220		Río Tallaboa at Tallaboa	a,e	1928-67		
1233	362	Río Guayanilla above Guayanilla	b		1932-44	
1240		Río Guayanilla near Guayanilla	a		1961-69	1961-67
1245	360	Río Guayanilla at Guayanilla	b,e	1899-1968	1936-53	~~1935-62~~ No
1254.5	355	Río Yauco above Río Naranjo at Lago Lucchetti	b		1932-44	
1255.5	350, 350A	Río Yauco above Q. Grande at Lago Lucchetti	b,a		1945-53	
1259.5	358, 358A	Río Duey near Lago Lucchetti	b,a	1952-68		~~1946-52~~ No
1281		Río Yauco at Central San Francisco	e	1899-1968		
1290	341	Río Loco near Yauco	b		1932-44	
1314.5	305	Río Guanajibo near Sabana Grande	b		1932-46	
1318	304	Río Cupeyes near San Germán	b		1932-49	
1338	308, 308A	Río Duey near Rosario	b,a	1960-64	1936-44	
1345.5	302	Río Hoconuco near Pico	b		1935-48	
1359	306	Río Rosario near Maricao	b	1926-48		
1360	300	Río Rosario near Rosario	b		1936-48, 1961-65	
1360	300A	Río Rosario near Rosario	a	1960-68		
1390		Río Yaguez at Mayaguez	e	1933-68		

Table 8.--Gaging station records used to define streamflow characteristics.--Continued

Station number		Stream and Location	Period of record used in regressions			
USGS	PRWRA		Type of record 1/	Flood frequency	Low-Flow frequency	Mean annual and monthly
50-1410	226A	Río Yahuecas near Adjuntas	a	1946-68	1946-66	1946-66
1416	223,223A	Río Guayo at mouth near Lares	b,a	1949-55	1924-47	
1427	207	Río Prieto near Lares	b		1924-45, 1950-55	
1430.6	204	Río Lajas near Maricao	b		1924-26, 1935-48	
1431.1	203	Río Guaba near Maricao	b		1924-48	
1433.5	206	Río Grande de Añasco near Hacienda Espino	b		1924-44	
1438.5	210	Río Grande de Añasco above Río Arenas near Las Marías	b		1924-46	
1439	201	Río Arenas at mouth near Las Marías	b		1924-45	
1440		Río Grande de Añasco near San Sebastián	a	1899-1968		1964-67
1450		Río Grande de Añasco at El Espino	b			1961-66

1/ a - Stage-graph recorder
b - Staff-gage readings
c - Periodic streamflow measurements only
d - Computed inflow into reservoir
e - Historical flood-peak survey

Table 9.--Selected basin parameters at gaging stations.

Station number		A	S	SCS Curve	Climatic	Basin elev	Temp 1	St	F	Precip.,
USGS	PRWRA	sq mi	meters/km	Number -60	Index -60	in 100 meters	°F -50	%+ 1	%+ 1	inches -50
50-0107.5		25.0	4.38	29	63	3.17	11.5	6.60	44	39.4
0201		6.03	39.6	23	65	8.41	8.0	3.80	94	42.2
0205	102, 102A	18.7	37.5	23	65	6.74	8.0	1.00	85	30.0
0209	117	2.34	107	30	65	6.84	8.0	1.00	67	30.0
0211	116	7.90	42.0	30	65	5.96	8.0	1.00	82	30.0
0216	101	35.2	28.8	22	61	5.94	8.0	1.00	74	30.0
0229.5	115	3.21	41.0	22	65	6.90	8.0	1.00	86	30.0
0231	114	6.04	30.8	20	65	6.33	8.0	1.00	86	30.0
0251.3	126	5.68	97.6	23	65	11.2	8.1	1.00	89	41.8
0251.7	106	17.9	44.9							
0255	122	1.83	60.0	23	65	9.20	8.0	1.00	59	30.0
0255.5	105	4.16	40.5	22	65	8.13	8.0	1.00	62	50.0
0261	103A	43.9	18.1	16	58	6.18	9.1	1.00	63	11.2
0271		169	15.3	18	51	4.71	9.7	1.60	65	30.0
0280	110	18.4	25.0	24	40	5.87	9.2	1.00	89	29.7
0323		1.64	52.4	25	65	10.3	7.4	6.10	99	62.6
0326		4.46	32.6	24	65	8.55	6.7	3.50	87	39.0
0335	404A	8.60	31.0	27	63	7.93	6.7	1.00	62	27.0
0350	400A	128	13.4	25	48	5.61	9.8	1.00	48	30.6
0381		203	7.95	25	42	4.59		20.0	56	29.3
0395		70.5	11.6	24	40	1.88		19.0	28	25.4
0400		8.18	19.9	24	72	6.20	11.1	7.40	95	31.1
0430		54.8	9.13	26	42	5.30	10.2	1.00	25	5.38
0441		135	7.56	29	34	5.11	10.6	1.00	23	14.8
0460		200	7.14	25	36	4.09	11.8	1.00	25	5.31
0485		73.2	12.1	26	38	2.36		1.59	36	25.2
0550		89.8	9.82	27	63	2.59	10.3	1.00	16	28.0
0570		60.2	14.1	25	52	1.71	11.0	1.00	13	22.0
0590		208	4.84	25	54	2.07		1.57	19	32.9
0617	575A	2.80	10.8	26	104	6.42		1.00	63	47.0
0632.5	564A	2.13	6.40	24	115	7.65	12.0	1.00	101	
0710		14.9	33.5	23	79	2.91	16.0	1.00	63	55.8
0720		21.6	21.7	22	66	2.33	16.5	1.00	41	44.7
0750	580A	1.26	26.6	27	115	6.83	12.0	1.00	101	107
0820		17.3	1.60	28	57	1.58		1.00	20	34.8
0930.5		25.6	43.5	27	65	3.84	14.1	2.90	60	42.0
1068.5										
1113		43.5	15.1	27	36	4.25	18.3	2.38	58	
1144		25.6	30.3	25	40	4.16		1.00	79	24.2
1159		18.6	29.0	26	37	3.84		1.00	70	17.1
1170		8.63	34.9	26	23	3.02		1.00	60	16.7
1185		10.7	19.5	25	26	1.78		1.00	55	15.7
1210	370	24.2	41.7	27	47	2.59		1.00	58	16.6
1220		31.5	27.0	15	33	2.20		1.00	57	20.9
1233	362	16.3	14.1	38	42	6.51	9.0	1.00	43	17.5
1240		18.5	31.9	28	36	3.81	9.2	1.00	54	18.4
1245	360	20.8	27.8	28	31	3.69		1.00	49	15.1
1254.5	355	9.05	34.9	26	46	5.30	8.0	1.00	58	16.7
1255.5	350, 350A	13.4	47.8	27	42	4.98	8.0	1.00	75	15.0
1259.5	358, 358A	3.40	105	28	47	7.29		1.00	77	28.5
1281		45.9	14.0	24	30	2.84		1.00	55	5.50
1290	341	8.50	27.5	29	20	2.77	8.4	1.00	34	3.80
1314.5	305	27.2	22.2	28	35	2.44	9.0	1.00	45	18.7
1318	304	4.24	35.7	30	44	2.82	10.0	1.00	46	32.5
1338	308, 308A	4.42	54.3	29	66	3.00	11.6	1.00	81	38.0
1345.5	302	4.44	35.8						77	35.0
1359	306	11.9	29.4	26	43	4.45	10.1	1.00	97	50.0
1360	300, 300A	17.6	25.6	26	77	3.88	10.6	1.00	89	
1390		13.2	19.0	24	64	1.87		1.00	84	32.5
1410	226A	15.4	42.5	26	64	7.02	8.0	1.00	78	80.1

Table 9.--Selected basin parameters at gaging stations.--Continued

Station number		A	S	SCS Curve		Basin elev	Temp 1	St	F	Precip.,
USGS	PRWRA	sq mi	meters/km	Number -60	Index -60	in 100 meters	°F -50	%+ 1	%+ 1	inches -50
50-1416	223, 223A	9.74	43.5	24	65	6.31	8.0	1.00	60	30.0
1427	207, 207A	14.2	35.7	24	65	7.31	8.0	1.00	90	82.3
1430.6	204	3.03	60.5	27	89	6.49	9.0	1.00	93	48.3
1431.1	203	11.2	38.1	26	85	6.27	9.0	1.00	96	45.4
1433.5	206	99.3	12.5	25	71	2.42	8.8	1.00	82	36.5
1438.5	210	118	12.6	25	63	5.15	9.1	1.00	81	39.6
1439	201	5.95	24.4	24	65	2.31	10.0	1.00	76	50.0
1440		130	9.95	25	72	4.73		1.44	78	42.5

Table 10.--Regulated-stream gaging stations.

Station number	Station name	Type of record 1/
50-0107.5	Río Guajataca at Lago Guajataca	a
0112	Río Guajataca below Lago Guajataca	b
0114	Río Guajataca above mouth near Quebradillas	b
0201	Río Vacas at Lago Garzas	a
0205	Río Grande de Arecibo near Adjuntas	b
0215	Río Pellejas near Utuado	b
0271	Río Grande de Arecibo at Lago Dos Bocas	a
0272	Río Grande de Arecibo below Lago Dos Bocas	b
0290	Río Grande de Arecibo at Central Cambalache	b
0293	Caño Suroeste near Central Cambalache	b
0295	Caño Tiburones Outlet near Arecibo	b
0297	Caño Noreste near Barceloneta	b
0323	Río Toro Negro at Lago El Guineo	a
0326	Río Matrullas at Lago de Matrullas	a
0331	Río Toro Negro at Cerro Gordo	c
0350	Río Grande de Manatí at Ciales	b
0381	Río Grande de Manatí at Hwy PR-2 near Manatí	b
0400	Río de la Plata at Lago Carite	a
0430	Río de la Plata at Proyecto La Plata	b
0441	Río de la Plata at Represa de Comerío	a
0460	Río de la Plata at Toa Alta	b
0478.5	Río de Bayamón near Bayamón	b
0590	Río Grande de Loíza at Lago Loíza	d
0930.5	Río Grande de Patillas at Lago Patillas	a
0952	Río Guamaní at Guayama	b
0955	Río Guamaní near Guayama	b
1068.5	Río Coamo at Lago Coamo	a
1102	Canal de Aceituna near Villalba	b
1113	Río Jacaguas at Lago Guayabal	a
1117	Río Jacaguas near Juana Díaz	b
1159	Río Portugués at Hwy PR-14 at Ponce	b
1210	Río Tallaboa at Peñuelas	b
1258	Río Yauco at Lago Lucchetti	a
1440	Río Grande de Añasco near San Sebastián	b

1/ a Inflow into reservoir computed by PRWRA.
b Gaging station operated by USGS.
c Gaging station operated by PRWRA.
d Inflow into reservoir computed by PRASA.

Table 11.--Proposed peak-flow partial-record station network.

Station number	Stream name	A sq mi	Purpose code	Discontinue code
50-0230	Río Viví near Central Pellejas	5.66	[1]	5
0250	Río Grande de Arecibo near Utuado	88.7	1	
0289	Río Grande de Arecibo near Arecibo		[2]	1,2
0381	Río Grande de Manatí near Manatí		[2]	1,2
0381.4	Río Grande de Manatí near Barceloneta		2	
0383	Río Corozal at Corozal	9.12	1	
0384.5	Río Cibuco below Vega Alta		2	
0387	Río Morovis at Morovis	25.8	1	
0389	Río Indio at Vega Baja		2	
0395	Río Cibuco at Vega Baja		1	
0432	Río Usabón near Barranquitas	9.15	1	
0434	Río Aibonito tributary near Aibonito	1.13	1	
0436	Río Hondo near Comerío	10.5	1	
0446.5	Quebrada del Toro near Naranjito	.54	1	
0448	Quebrada Anones near Naranjito	2.32	1	
0480 *	Río de Bayamón at Hwy 2 at Bayamón	71.9	1	
0526	Río Grande de Loíza tributary at San Lorenzo	.27	[1]	4
0540	Quebrada Quebradillas near Caguas	6.25	1	
0560	Río Valenciano near Las Piedras	6.85	1	
0562	Río Valenciano tributary near Las Piedras	.77	[1]	4
0583	Quebrada Arena near Caguas	3.77	1	
0617 *	Río Cubuy near Campo Rico	2.80	1	
0647	Quebrada Boneta at Río Grande	.77	1	
0680	Río Sabana at Luquillo	7.05	1	
0732	Río Daguao at Daguao	2.26	1,2	
0734	Quebrada Palma near Daguao	4.84	1,2	
0740	Río Santiago at Naguabo	4.99	1,2	
0750 *	Río Icacos near Naguabo	1.26	1	
0755	Río Blanco at Florida	11.0	[1]	5
0774	Río Blanco at Colonia La Fe	16.4	2	
0785	Río Antón Ruiz at Central Pasto Viejo	4.33	[1]	3,4
0810	Río Humacao at Las Piedras	6.54	1	
0818	Río Humacao at Humacao	10.0	[1]	4
0820	Río Humacao at Hwy 3 at Humacao	17.3	1	
0822	Río Humacao near La Suiza	19.9	[2]	5
0851	Río Guayanés at Central Roig	26.5	[2]	2
0861	Río del Ingenio at Comunas	5.50	[2]	2
0865	Río de Guayanés at Playa de Guayanés	39.3	[2]	2
0872	Caño Santiago near Central Roig	6.04	[2]	2
0910	Río Maunabo at Maunabo	12.4	2	
0912	Río Maunabo near Maunabo	12.7	[2]	5
0914	Río Jacaboa near Lamboglia	4.13	1,2	
0917	Río Chico at Patillas	6.32	1,2	
0918	Río Chico at Providencia	6.97	[2]	3,4
0942	Río Grande de Patillas at Patillas	27.9	2	
0943	Río Patillas at Providencia	29.0	2	
0944	Río Nigua at Pitahaya	5.86	2	
0944.5	Río Nigua at Central Lafayette	7.65	2	
0953	Río Guamaní at Lago Melanía	11.0	2	
0955	Río Guamaní near Guayama	12.4	[2]	5
0968	Río Seco at Hacienda Juana	7.06	2	
1007	Río Majada at Rabo del Buey	22.2	1	
1012	Río Majada at Sabana Llana	34.5	2	
1056	Río Cuyón near Coamo	16.5	1	
1065	Río Coamo near Coamo	46.0	[1]	5
1068	Río Coamo at Flores	57.0	2	
1080	Río Descalabrado near Los Llanos	12.9	1	
1082	Río Descalabrado near Las Ollas	13.9	2	
1116	Río Jacaguás at Poblado Jacaguas	52.1	2	
1126	Río Inabón at Coto Laurel	13.0	2	

Table 11.--Proposed peak-flow partial-record station network.--Continued

Station number	Stream name	A sq mi	Purpose code	Discontinue code
50-1131	Río Guayo near Coto Laurel	11.8	2	
1137	Quebrada Jamiel near Ponce	.54	[1]	4
1259.5 *	Río Duey near Lago Lucchetti	3.40	1	
1335	Río Guanajibo tributary near San Germán	-	[1]	3,4
1355	Quebrada Mendoza at Cabo Rojo	2.93	1	
1357	Río Maricao at Maricao	2.14	[1]	3
1390 *	Río Yaguez at Mayaguez	13.2	1	
1431	Río Lajas near Maricao	3.10	[1]	3
1431.5	Río Bucarabones near Las Marías	6.54	[1]	3
1432	Río Guaba near Las Marías	25.2	[1]	3
1470	Río Culebrinas at San Sebastián	-	1	
1472	Río Guatemala at San Sebastián	-	1	
1473	Río Soñador at Perchas	-	1	
1483	Río Cañas tributary near Aguada	-	1	

* New station.

Purpose code: 1, regional flood frequency; 2, bridge-site investigation; [ ], discontinue.

Discontinue code: 1, flood frequency defined; 2, bridge design completed; 3, basin characteristics sampled by other station; 4, variable or poor rating conditions; 5, replaced by gaging station.

Table 12.--Proposed streamflow data collection program.

Station number	Station name	Type of data a/	Recommendation b/
50-0070	Quebrada de los Cedros near Isabela	2	4
0105	Río Guajataca at Lares	2	4
0107.5	Río Guajataca at Lago Guajataca	1	4
0110	Canal Principal de Diversion at Lago Guajataca	2	4
0112	Río Guajataca below Lago Guajataca	2	4
0114	Río Guajataca above mouth near Quebradillas	2	4
0130	Río Camuy near Lares	2	4
0140	Río Criminales near Lares	2	4
0150	Río Camuy at La Cuesta	2	4
0160	Río Camuy near Camuy	2	4
0201	Río Vacas at Lago Garzas	1	4
0205	Río Grande de Arecibo near Adjuntas	2	4
0209.8	Río Pellejas above Central Pellejas	2	5
0210	Río Pellejas at Central Pellejas	2	4
0215	Río Pellejas near Utuado	2	4
0225	Río Viví above Central Pellejas	2	4
0230	Río Viví near Central Pellejas	2	4
0263	Río Yunes at Hacienda Marqués	2	4
0267	Río Limón near Hacienda Limón	2	4
0268	Río La Venta at Hacienda Piedra Gorda	2	4
0271	Río Grande de Arecibo at Lago Dos Bocas	1	4
0272	Río Grande de Arecibo below Lago Dos Bocas	2	4
0280	Río Tanamá near Utuado	2,3	4
0284	Río Tanamá at Charco Hondo	2	4
0290	Río Grande de Arecibo at Central Cambalache	2	4
0293	Caño Suroeste near Central Cambalache	2	4
0295	Caño Tiburones Outlet near Arecibo	2	4
0297	Caño Noreste near Barceloneta	2	4
0312	Río Grande de Manatí near Morovis	2	4
0315	Río Sana Muerto near Orocovis	2	4
0323	Río Toro Negro at Lago El Guineo	1	4
0326	Río Matrullas at Lago de Matrullas	1,3	4
0331	Río Toro Negro at Cerro Gordo	2	4
0340	Río Bauta near Orocovis	2	4
0341	Río Bauta at Cerro Mime near Orocovis	2	4
0350	Río Grande de Manatí at Ciales	2	4
0358	Río Cialitos at Hacienda Santa Elena	2	4
0359.5	Río Cialitos at Hwy PR-649 at Ciales	2	4
0381	Río Grande de Manatí at Hwy PR-2 near Manatí	2	4
0382	Laguna Tortuguero Outlet near Vega Baja	2	4
0383	Río Cibuco near Corozal	2	4
0383.6	Río Mavilla near Corozal	2	4
0386	Río Unibón near Morovis	2	4
0396	Río Cibuco at Central San Vicente	2	4
0400	Río de la Plata at Lago Carite	1,3	4
0430	Río de la Plata at Proyecto La Plata	2	4
0441	Río de la Plata at Represa de Comerío	1	4
0457	Río Lajas at Toa Alta	2	4
0460	Río de la Plata at Toa Alta	2	4
0475.5	Río de Bayamón at Lago Cidra	1	4
0478.5	Río de Bayamón near Bayamón	2	4
0480 *	Río de Bayamón at Hwy PR-2 at Bayamón	2	
0489 *	Río Piedras at Hwy PR-176 at Río Piedras	2	
0489.5 *	Río Piedras at Río Piedras	2	
0495 *	Quebrada Margarita at Hwy PR-19 near Guaynabo	2	
0550	Río Grande de Loíza at Caguas	2	4
0570	Río Gurabo at Gurabo	2	4
0590	Río Grande de Loíza at Lago Loíza	1	4
0610 *	Río Grande de Loíza at Carolina	2	
0613	Río Canovanillas near Loíza	2	4

Table 12.--Proposed streamflow data collection program.--Continued

Station number	Station name	Type of data a/	Recommendation b/
50-0618	Río Canóvanas near Campo Rico	2	4
0625	Río Herrera near Colonia Dolores	2	4
0633	Río Espíritu Santo near El Verde	2	4
0638	Río Espíritu Santo near Río Grande	2	4
0642	Río Grande near El Verde	2	4
0655	Río Mameyes near Sabana	2	4
0657	Río Mameyes at Hwy PR-191 at Mameyes	2	5
0710	Río Fajardo near Fajardo	2	4
0770 *	Río Blanco near Naguabo	2	
0822 *	Río Humacao near La Suiza	2	
0828	Río Guayanés near Colonia Laurel	2	4
0835	Río Guayanés near Yabucoa	2	4
0840	Río Limones near Yabucoa	2	4
0905 *	Río Maunabo above Maunabo	2	
0912 *	Río Maunabo near Maunabo	2	
0920	Río Grande de Patillas near Patillas	2	4
0930.5	Río Grande de Patillas at Lago Patillas	1	4
0942 *	Río Grande de Patillas at Patillas	2	
0945 *	Río Nigua at Arroyo	2	
0952	Río Guamaní at Guayama	2	4
0955	Río Guamaní near Guayama	2	4
1065	Río Coamo near Coamo	2	4
1068	Río Coamo at Lago Coamo	1	4
1102	Canal de Aceituna near Villalba	2	4
1112	Río Toa Vaca near Villalba	2	5
1113	Río Jacaguas at Lago Guayabal	1	4
1117	Río Jacaguas near Juana Díaz	2	4
1125	Río Inabón near Real Abajo	2	4
1140	Río Cerrillos near Ponce	2	4
1144	Río Bucaná near Ponce	2	4
1150	Río Portugués near Ponce	2	4
1159	Río Portugués at Hwy PR-14 at Ponce	2	4
1210	Río Tallaboa at Peñuelas	2	4
1240	Río Guayanilla near Guayanilla	2,3	4
1249.5	Río Yauco above Lago Lucchetti	1	4
1258	Río Yauco at Lago Lucchetti	1	4
1318	Río Cupeyes near San Germán	2	4
1338	Río Duey near Rosario	2	4
1345.5	Río Hoconuco near Pico	2	4
1360	Río Rosario near Rosario	2,3	4
1380 *	Río Guanajibo near Hormigueros	2	
1410	Río Yahuecas near Adjuntas	1,3	4
1440	Río Grande de Añasco near San Sebastián	2	4
1478	Río Culebrinas at Hwy PR-404 near Moca	2,3	4

* New station.

a/ 1 - Current purpose
2 - Planning and design
3 - Long-term trend

b/ 4 - Include in network
5 - Discontinue operation