RAINFALL – RUNOFF SIMULATION IN THE RIO GRANDE DE LOIZA AT QUEBRADA ARENAS WATERSHED, PUERTO RICO

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CONVERSION TABLE

The following factors may be used to convert the inch-pound units published herein to the International System of Units (SI). This report contains both the inch-pound and SI unit equivalents in the station manuscript descriptions.

Multiply inch-pound units	By	To obtain SI units
	Length	
inches (in)	2.54×10^{1}	millimeters (mm)
	2.54×10^{-2}	meters (m)
feet (ft)	3.048×10^{-1}	meters (m)
	Area	
square miles (mi^2)	2.590×10^{0}	square kilometers (km^2)
	Flow	
cubic feet per second (ft^3/s	2.832×10^{1}	liters per second (L/s)
	2.832×10^{1}	cubic decimeters per second (dm^3/s)
	2.832×10^{-2}	cubic meters per second (m^3/s)
gallons per minute (gal/min)	6.309×10^{-2}	liters per second (L/s)
	6.309×10^{-2}	cubic decimeters per second (dm^3/s)
	6.309×10^{-5}	cubic meters per second (m^3/s)

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ABSTRACT

The Hydrological Simulation Program Fortran Model was applied to simulate rainfall-runoff in the Río Grande de Loíza at Quebrada Arenas Watershed in east-central Puerto Rico. The concepts, structure, development, application, and data requirements of the rainfall-runoff model are described.

The performance of the model was evaluated using several graphical and statistical tests. The result of the calibration and verification showed that Hydrological Simulation Program Fortran Model fairly simulates runoff on an annual, monthly, and daily basis during both the 2-year calibration interval and the 3-year verification interval. The results were affected by the quality of the runoff records and the location of the recording rain gage. The model can be used to simulate runoff from known amounts of rainfall in other small basins throughout Puerto Rico.

INTRODUCTION

Central Puerto Rico and coastal areas are characterized by small basins (less than 10 mi^2 dranaige area). Information about runoff data in small basins throughout Puerto Rico is scarce. Estimates of basin yield, peak runoff, and other flow statistics are based on drainage area comparisons, unit hydrograph models, and statistical estimates. In tropical areas like Puerto Rico, these estimates can depart significantly from actual values. This results in under or over-design of water works, with severe penalties in terms of cost or production capacity.

In 1983, the U. S. Geological Survey, Water Resources Division in cooperation with the Water Resources Research Institute of the University of Puerto Rico, Mayaguez Campus, initiated an investigation designed to calibrate a rainfall-runoff model at selected small basins in Puerto Rico. The model could then be utilized by the water planners, engineers, and scientists to estimate runoff in small basins where only continuous rainfall records are available.

Scope of Report

This preliminary report describes the characteristics and calibration of the Hydrological Simulation Program Fortran (HSPF) model as it was applied to the watershed. The performance of the model is evaluated in several graphical and statistical tests.

Description of the Study Area

Located near the headwaters of one of the major basins in Puerto Rico (fig. 1), the Río Grande de Loíza at Quebrada Arenas is not susceptible to industrial or urban expansion. The small dranaige are (6.0 mi^2) is typical of many small basins throughout Puerto Rico. Land is used mainly for pastures, dairy farming, and limited agriculture.

The basin lies within the mountainous area of the Cordillera Central. The main escarpment ranges between 650 feet and 2,500 feet above mean sea level. Channel slopes (about 18 percent) are very steep and stream velocities are extremely high in the upper reaches. The channel slope becomes less steep from the foothills to the gage site (about 2 percent).

Geologically, the watershed is comprised of plutonic rocks. Largely granodiorite and quartz diorite, some diorite, minor quartz porphyry, gabbro, and amphibolite, believed to have been emplaced during the late Tertiary and late Cretaceous period (Briggs, 1965). Hydrothermally altered

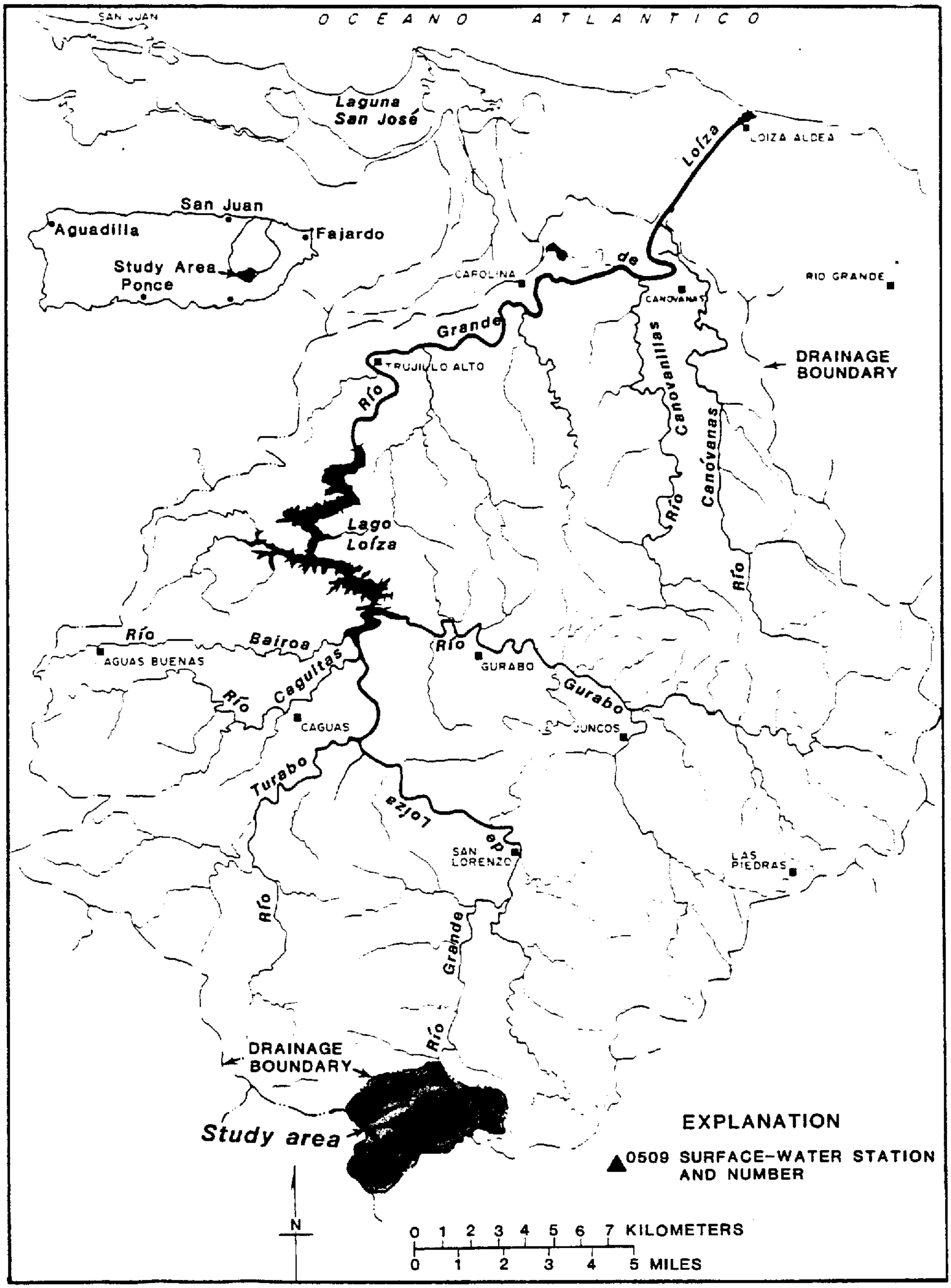

Figure 1.-- Location of the Río Grande de Loíza at Quebrada Arenas watershed.

rocks and some areas of complexly and intimately associated plutonic and volcanic rock are also present. These are locally deeply wethered.

Yield to wells are low, generally less than 10 gal/min, important only for small domestic supplies (Briggs, 1965).

The soils in the watershed are of the Panduras-Lirios Association (Soil Conservation Service, 1978 and 1984). This association is mostly well drained. These soils are difficult to work and limited for most urban use because it is moderately steep (12 to 20 percent slopes) to very steep (40 to 60 percent slopes).

The surface layer of the Panduras Member is a sandy loam about 7 inches thick while the Lirios Member, a silty clay loam, is 4 inches thick. This soil has a moderate permeable subsoil of sandy loam or silty-clay loam 5 to 20 inches thick. The substratum beginning at a depth 12-24 inches is a sandy loam saprolite or silty-clay loam saprolite. The solum is 6-14 to 20-24 inches thick.

The available water capacity ranges from low to moderate. Runoff is rapid and erosion is a hazard. Slippage is common in roadbanks, ditches, and drainage ways. The root zone is shallow to deep. Natural fertility is medium.

The soils have been in brush and brushy pasture, suited to grow pangola and Merker grass.

The drainage system (fig. 2) is composed of several tributaries, all of which drain to Río Grande de Loíza at Quebrada Arenas in the northern tip of the basin. These tributaries include Quebrada Lajas, Quebrada Arenas, and Quebrada Verraco. The long term average discharge of Río Grande de Loíza at Quebrada Arenas (at the U. S. Geological Survey gaging station 50050900) is 31.4 ft^3/s. On an annual basis, this is about 71 inches of runoff (overland flow, interflow, and baseflow) per year.

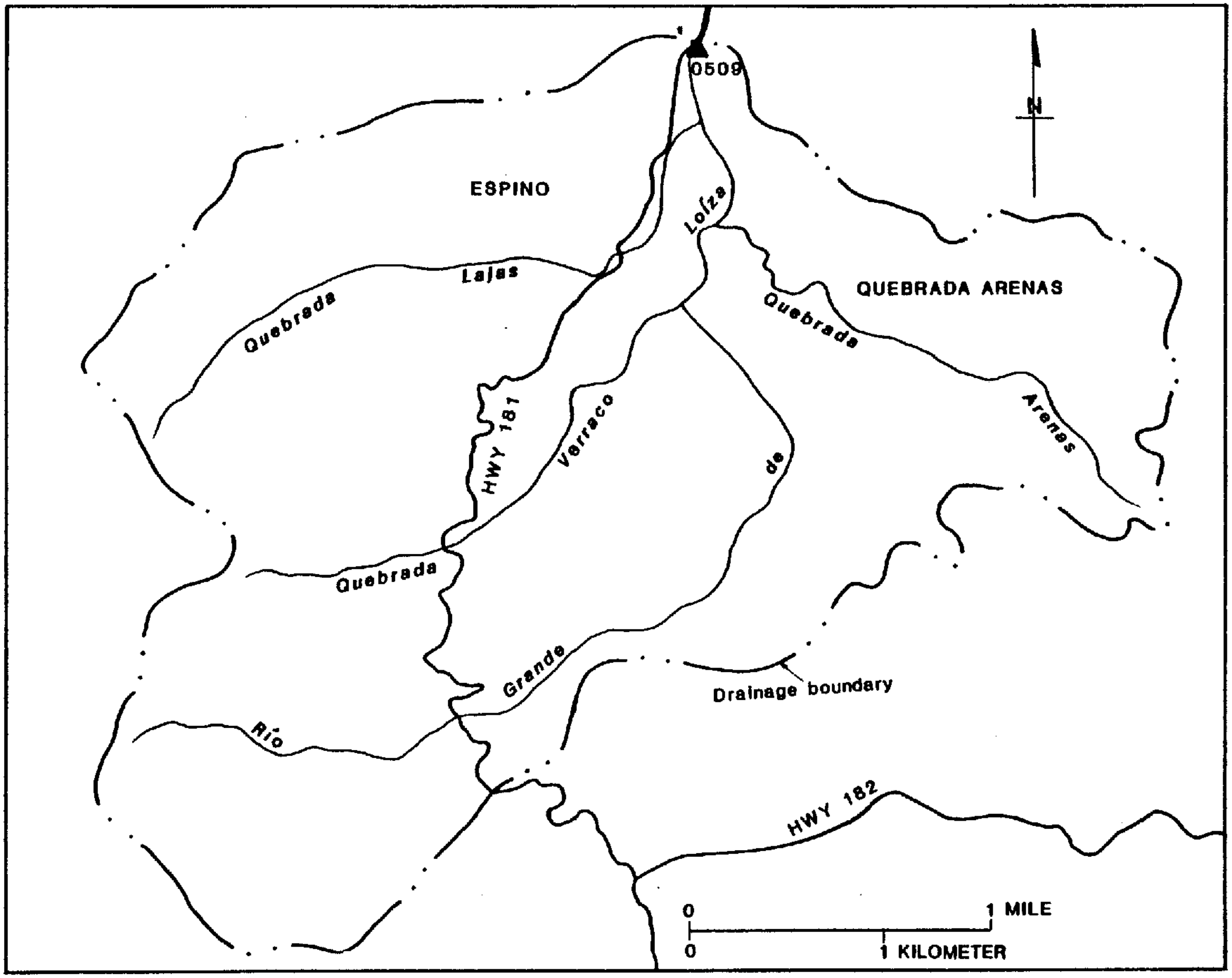

Figure 2.-- Drainage system of the Río Grande de Loíza at Quebrada Arenas watershed.

DEVELOPMENT OF THE RIO GRANDE DE LOIZA AT QUEBRADA ARENAS WATERSHED MODEL

The Hydrological Simulation Program - Fortran (HSPF) Model (Hydrocomp, 1980) was selected for simulation of rainfall-runoff in the study basin since it represented the most comprehensive hydrology model available when the investigation was initiated. HSPF is a continuous watershed and receiving water model which incorporates major elements of EPA's Nonpoint Source model (Donigian and Crawford, 1976) and the Agricultural Runoff Model (Donigian and Davis, 1978). In brief, the model accomplishes soil moisture accounting, runoff production, sediment and nonpoint source pollution generation, and the routing of water and pollutant loads through a channel system. In this investigation, only runoff production from rainfall was simulated.

This section highlights the following features of the development of the Río Grande de Loíza at Quebrada Arenas Watershed Model:

- The structure and capabilities of the HSPF model.
- Major characteristics of the application of the model to the Río Grande de Loíza at Quebrada Arenas Watershed.
- The calibration process
- Presentation of simulation results

Structure of the HSPF Model

A simplified representation of the basic operation of the HSPF model is shown in figure 3. Land uses within the watershed are divided into two distinct categories --pervious and impervious land surfaces. Runoff and nonpoint loads generated from pervious and impervious lands within each subwatershed are delivered to the appropriate stream channel reach. Each channel reach possesses its own distinctive hydraulic and geometric properties.

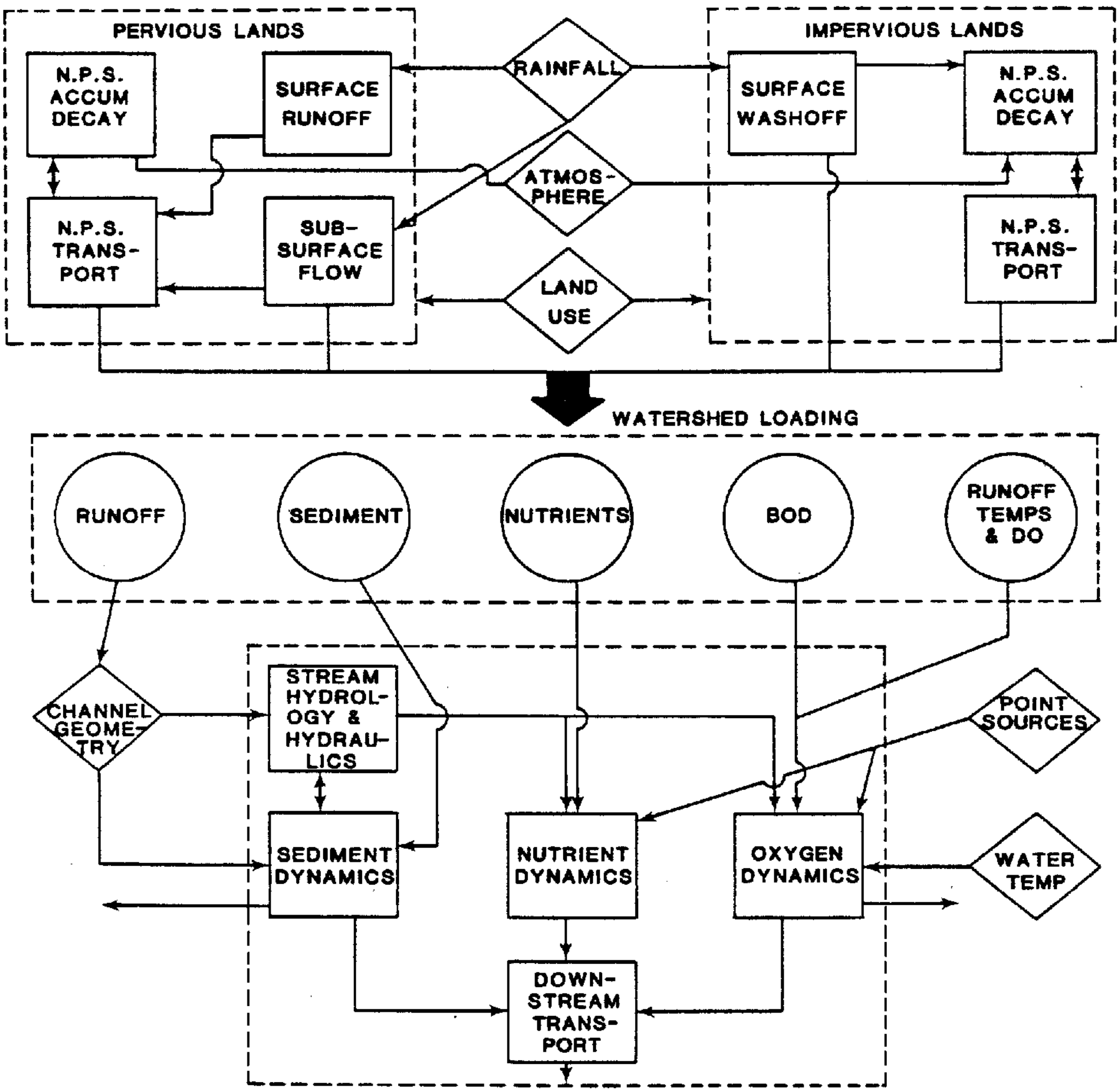

Figure 3.—Basic operation of the HSPF model.
(Modified from Schueler, Thomas R., 1983.)

Table 1.—Key processes simulated by HSPF.

PERVIOUS LANDS	CHANNEL REACHES
Surface and subsurface runoff	Stream hydrology/hydraulics
Soil erosion	Transport of water quality constituents
Generation/transport of N.P.S. pollutants	Point source loadings
IMPERVIOUS LANDS	Streambank erosion/sediment deposition
Surface runoff and solids washoff	Dissolved oxygen budget and nutrient transformations
Accumulation/washoff of N.P.S. pollutants	

The channel reaches are connected to each other so as to portray the general features of the drainage network of the watershed. Water quality loads can be sequentially transported along the reach network, after adjustments have been made to account for changes in loads due to physical and biological processes. Concentration of water quality constituents can be determined by averaging the load over the entire runoff volume contained in the reach during the hourly simulation interval.

Various physical, chemical and biological processes which can be simulated in the context of the HSPF model are presented in table 1. A general description of how each key process is simulated by HSPF follows. Only those applicable in the Río Grande de Loíza at Quebrada Arenas Watershed Model are mentioned.

Pervious Lands: Surface and Subsurface Runoff

The flux of water in a pervious area represents a rough balance between the supply of water via precipitation, and losses of water through evapotranspiration, surface/subsurface outflows, and subsurface storage. The HSPF relies on conventional soil moisture accounting technique to represent the flux of water between various storage components. These include interception storage, surface detention, upper and lower soil water storages and the active ground-water pool. The relative size of each of these storage components is a function of the physical characteristics of the specific land use and soil type. Outflows from storage components are governed by moisture availability, the rates of transmission between storages and their relative water holding capacity.

Outflow to strems are allocated in the following manner. Incoming precipitation falls on the land surface where it may infiltrate into the upper soil layer at a rate determined by the texture of the soil. If the rainfall intensity is greater than the infiltration capacity, the excess water is routed as surface runoff, subject to surface detention, and regulated by the characteristics of the overland plane. The water which infiltrates into the upper soil layer may travel laterally and emerge as interflow, or can percolate to the lower soil zone or ground-water pool, where it will eventually become baseflow.

APPLICATION OF HSPF TO THE RIO GRANDE DE LOIZA AT QUEBRADA ARENAS WATERSHED

Input Data Requirements

The application of a continuous simulation model on a watershed-wide scale requires the preparation of a large variety input data. The input requirements for the Río Grande de Loíza at Quebrada Arenas Watershed include:

Meteorological inputs -- Fifteen minutes rainfall and montly evapotranspiration values were supplied to dirve the soil moisture and water balance calculations.

Soil data -------------- Aggregated soil data was supplied to determine soil moisture storage.

Observed runoff -------- Data was supplied so they could be directly compared with simulated values.

General Availability of Data

There are 5 weather stations operated by the National Weather Service in or near the 6.0 mi^2 comprising the Río Grande de Loíza at Quebrada Arenas Basin above San Lorenzo. The location of each station in relation to the watershed boundary is shown in figure 4.

Continuous recording rainfall at 15 minute interval were collected at station 8816. Daily values are reported at two stations within boundaries of the Río Grande de Loíza Basin, stations 8815 and 8822. Outside the basin

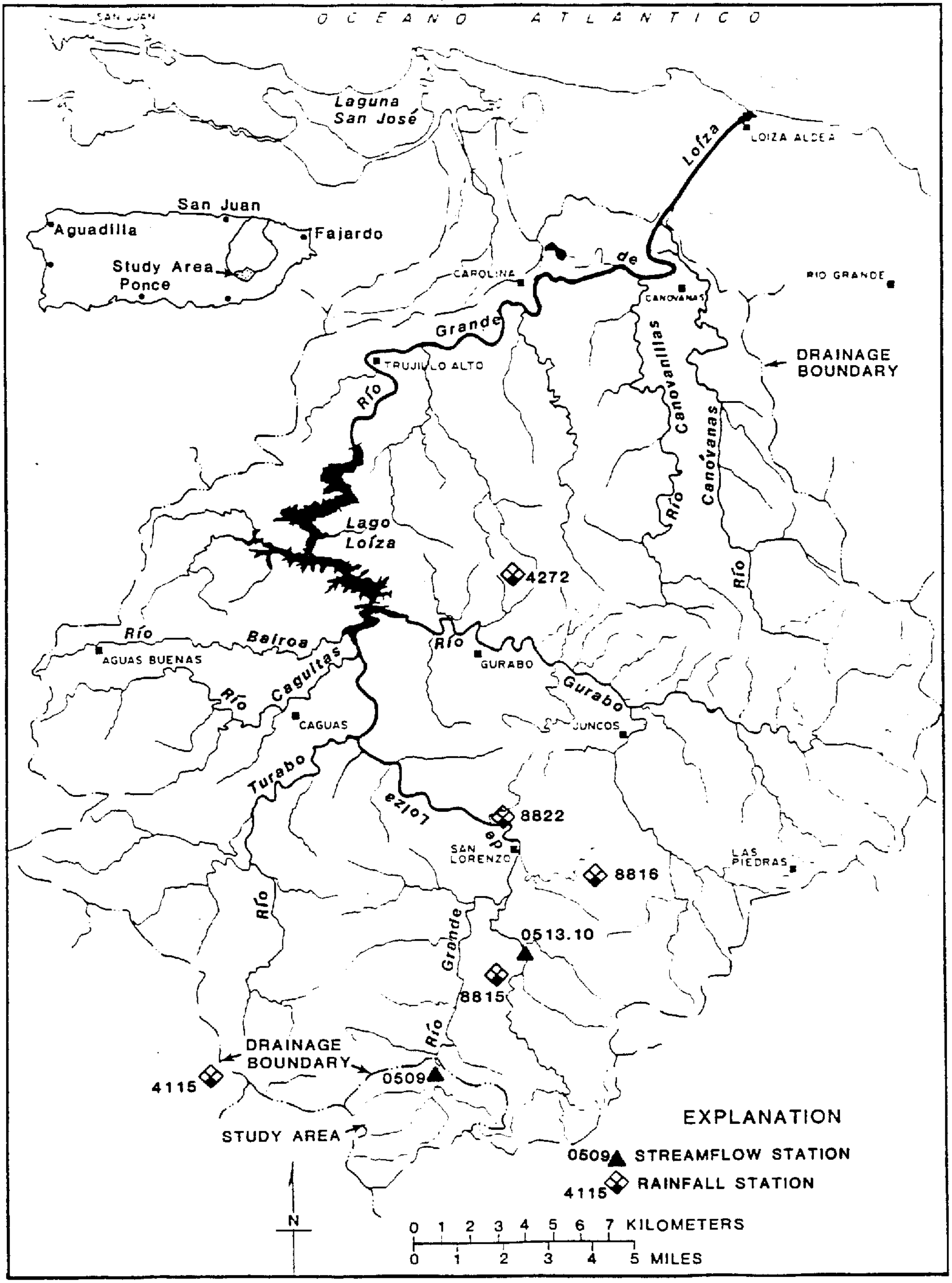

Figure 4.--Location of rainfall and streamflow stations.

boundaries information was also available. Daily values are reported at station 4115 located at headwaters on Río de la Plata Basin. Evaporation data was collected at station 4272 on the Río Gurabo watershed.

Precipitation

Mean-annual precipitation for the basin is about 100 inches. Since precipitation data is the most important parameter in the simulation, four records were used. Records for the simulated period (1978-1982) suggests that the precipitation at the recording gage 8816 is constantly about 60 to 70 percent of the recorded value at station 8815, which is closer and more representative, of the Río Grande de Loíza at Quebrada Arenas Watershed.

The record was generally good. Records were missing for 40 days and were filled by comparing streamflow rise to rainfall distribution pattern in all sour sites.

Potential Evapotranspiration (PET)

Mean annual PET for the Río Grande de Loíza at Quebrada Arenas was estimated at 60 inches. The record used for simulation was the Gurabo station 4272. Monthly totals were distributed to daily values for use by HSPF.

THE CALIBRATION PROCESS

Hydrologic calibration involves iterative adjustments of selected parameter values based on comparisons of observed and simulated runoff volumes and storm hydrograhs. The model representation and calibrated parameters are then verified by performing the same comparisions on an independent data set, i.e., runoff volumes and hydrographs that were not used in the calibration. The specific steps and calibration tests for each stage are outlined below.

Hydrology Calibration

1. Watershed data, obtained from published reports, was compiled and evaluated.

2. Initial parameter sets were constructed, based on watershed characteritics identified in step 1.

3. The streamflow record at the USGS gage was partioned into two periods: 1978 to 1979 and 1980 through 1982. The first interval was used as the calibration period; the latter interval was used for verification purposes.

4. The model was run for the calibration interval using the parameter set constructed in step 2. Observed and simulated streamflow were analyzed to be used in the final verification process.

5. The initial parameter set was incrementally adjusted (calibrated) in an iterative manner to minimize the difference between the observed and simulated discharge.

6. Calibration of the model proceeded along the following hierarchial sequence of increasing temporal resolution: annual-water yields, monthly-water yields, and daily flows.

7. The HSPF model was considered to be "calibrated" once it had achieved a reasonably good correspondence with the observed data for all levels of calibration indicated in step 6.

8. The final parameter set of the "calibrated" model was then run unchanged over the 5-year simulation period.

9. Flow duration analysis was performed on both observed and simulated data sets. This comparison assessed the model's capability to simulate the entire distribution of flow events that can be expected in the watershed.

PERFORMANCE OF THE MODEL

Simulation of Basin Hydrology

Several of the comparative graphics used to evaluate the adequacy of the calibration/verificaction of the runoff component of the Río Grande de loíza at Quebrada Arenas Watershed Model are presented in figures 5 through 8.

The first test of the model involved a two year comparison of observed and simulated runoff volumes recorded at Río Grande de Loíza at Quebrada Arenas, P. R. (fig. 5). This plot shows that the model is capable of adequately simulating annual runoff volumes. The mean error in projecting annual runoff volumes over the calibration and verification intervals was less than 3 percent.

A second comparative measure used to assess the model's ability to project runoff is shown in figure 6. This graph, termed a one-to-one plot, compares observed and simulated runoff volumes at montly intervals. Each point on the graph represents a pair of observed and simulated runoff volumes, and the proximity of the data points to the line of equal value serves as an indication of the accuracy of the simulation effort (the line of equal values is where observed monthly runoff volumes are equal to simulated runoff values). The scattering of points around this line shows that the modeled monthly runoff volumes are simulated lower than actual values.

A third test of the model (fig.7), is a comparison of observed and simulated mean daily discharge values during 1980. The top panel in figure 7 shows the observed discharge record projected by the model over the same interval. There is generally a fair correlation between both panels during most times of the year. High peaks are not properly simulated.

An additional method for assessing the success of the hydrology calibration/verification is flow duration analysis. Discharge values are plotted

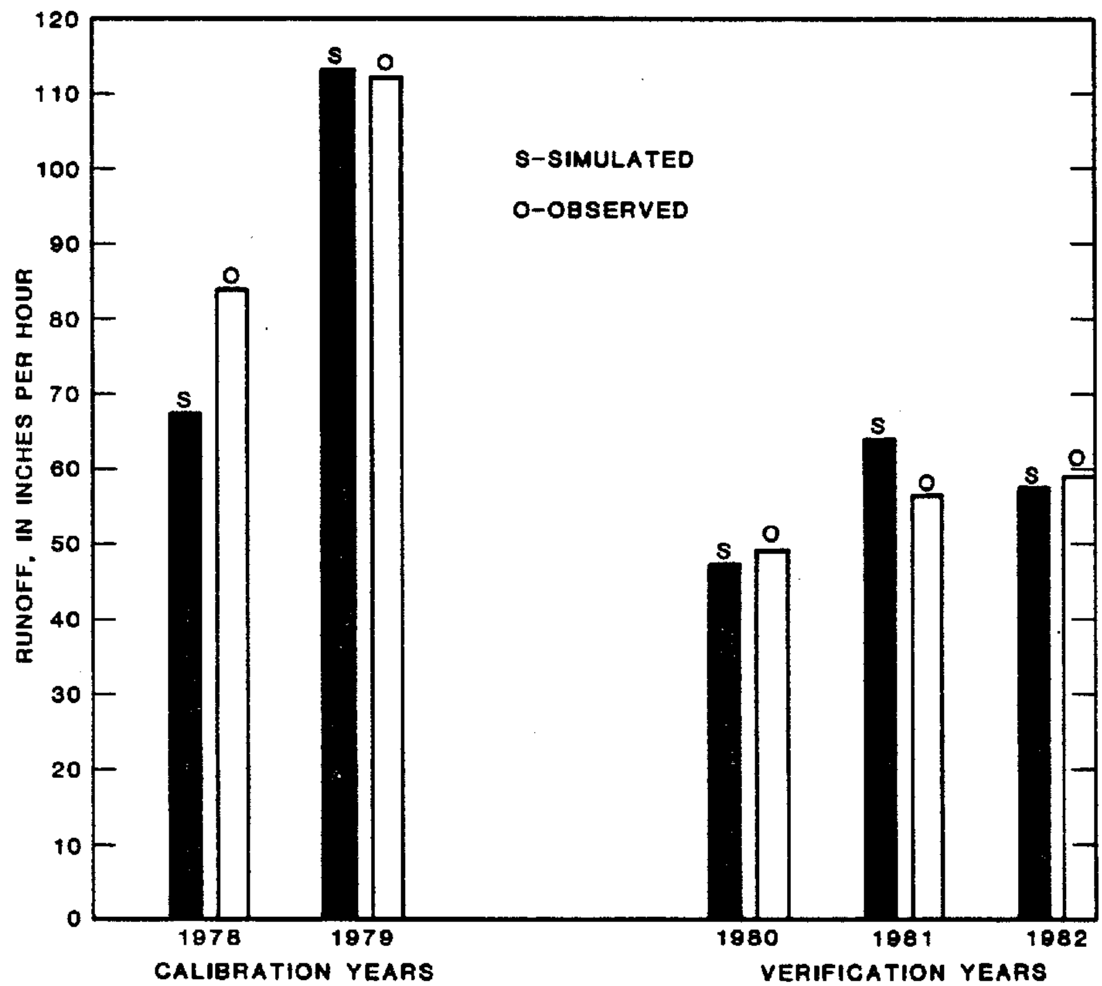

Figure 5.--Comparison of observed and simulated annual runoff volumes recorded at Río Grande de Loíza at Quebrada Arenas, 1978-1982.

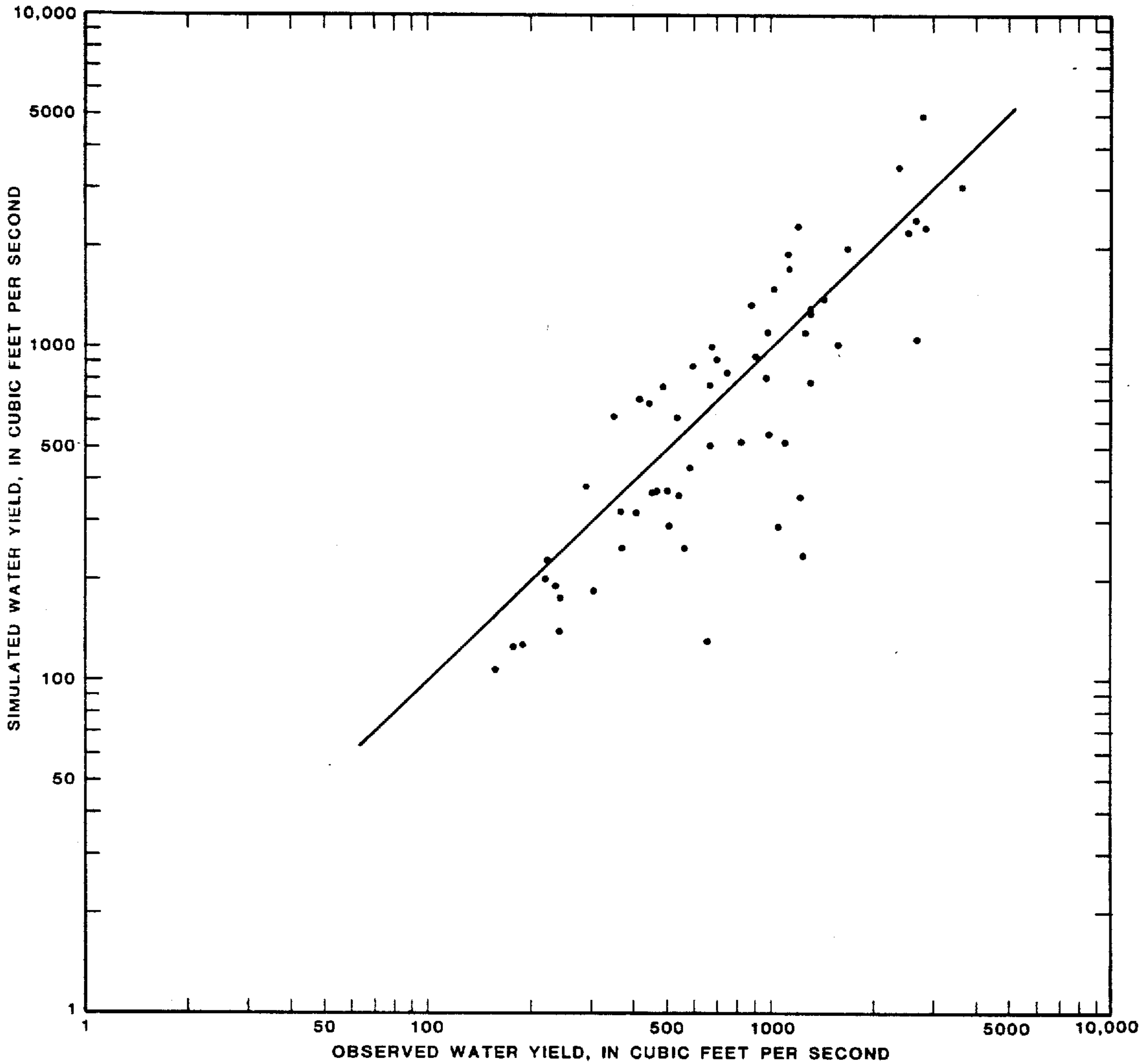

Figure 6.--A comparison of observed and simulated monthly water yields at Río Grande de Loíza at Quebrada Arenas, 1978-1982.

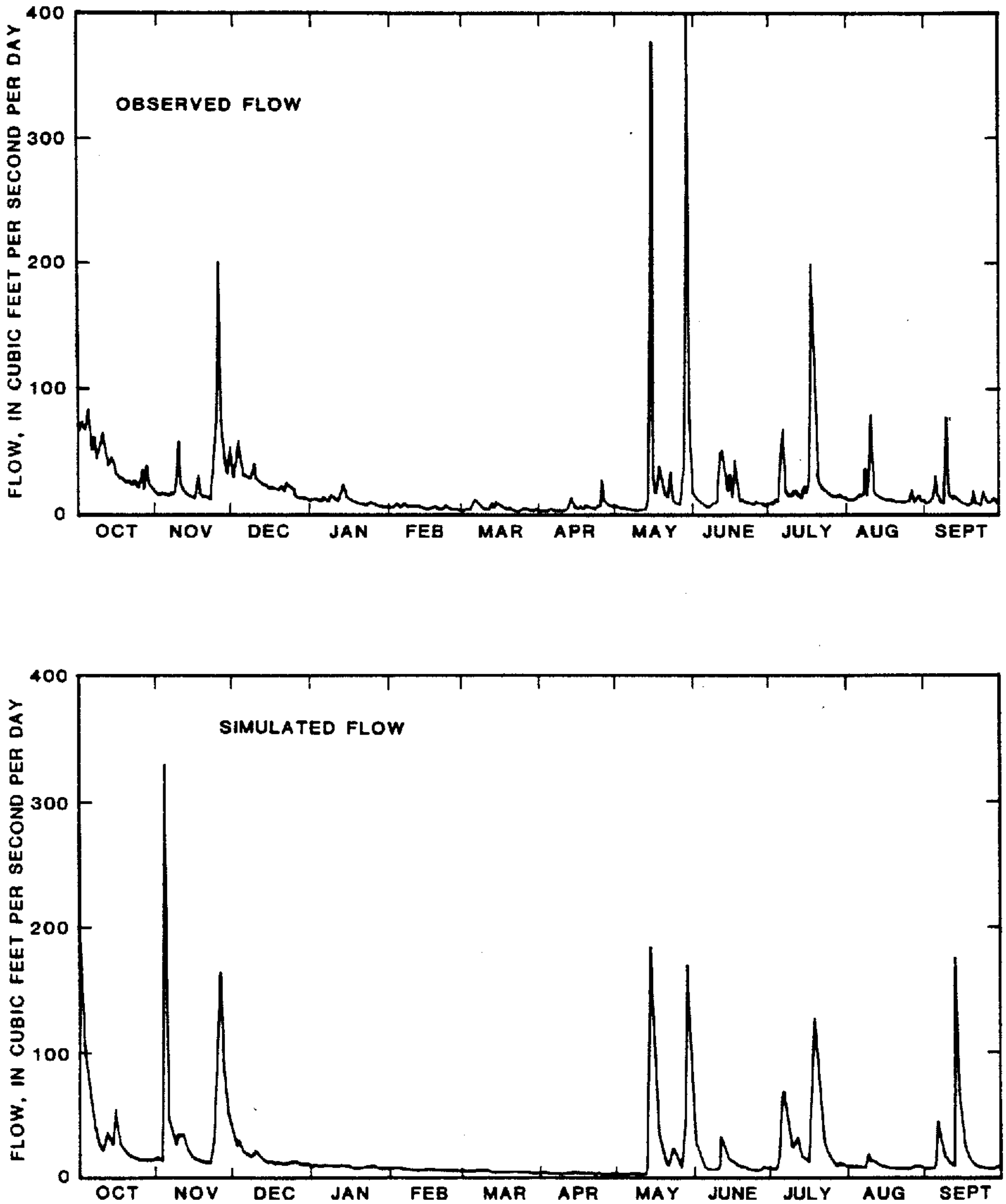

Figure 7.--Comparison of observed and simulated mean daily discharge at Río Grande de Loíza at Quebrada Arenas, 1980.

on the y-axis, and the cumulative frequency with which a given discharge level is exceeded is plotted as percentage on the x-axis. The procedure enables one to measure how well the model simulates runoff over the entire spectrum of flow conditions, relative to existing conditions. Figure 8 shows the results of comparative flow durations during the five-year simulation period. Each curve was constructed using over 1,000 different daily flow values. The simulated flow duration curve plots below the observed flow duration curve, except for the range between 60 ft^3/s through 150 ft^3/s where the curves virtually overplot. The simulated flow-duration curve underestimates peak values at the high end of the curve by 25 percent and underestimates low values at the low end of the curve by 40 percent.

Analysis of Results

The runoff difference between observed and simulated values in the graps presented are due mainly to two factors. First, the records collected at the continuous recording streamflow site during the entire period of simulation are fair to poor (higher than 10 percent departure from actual values). Second, the continuous recording-rain gage location, not properly within the basin, may not represent average meteorological conditions for the entire watershed.

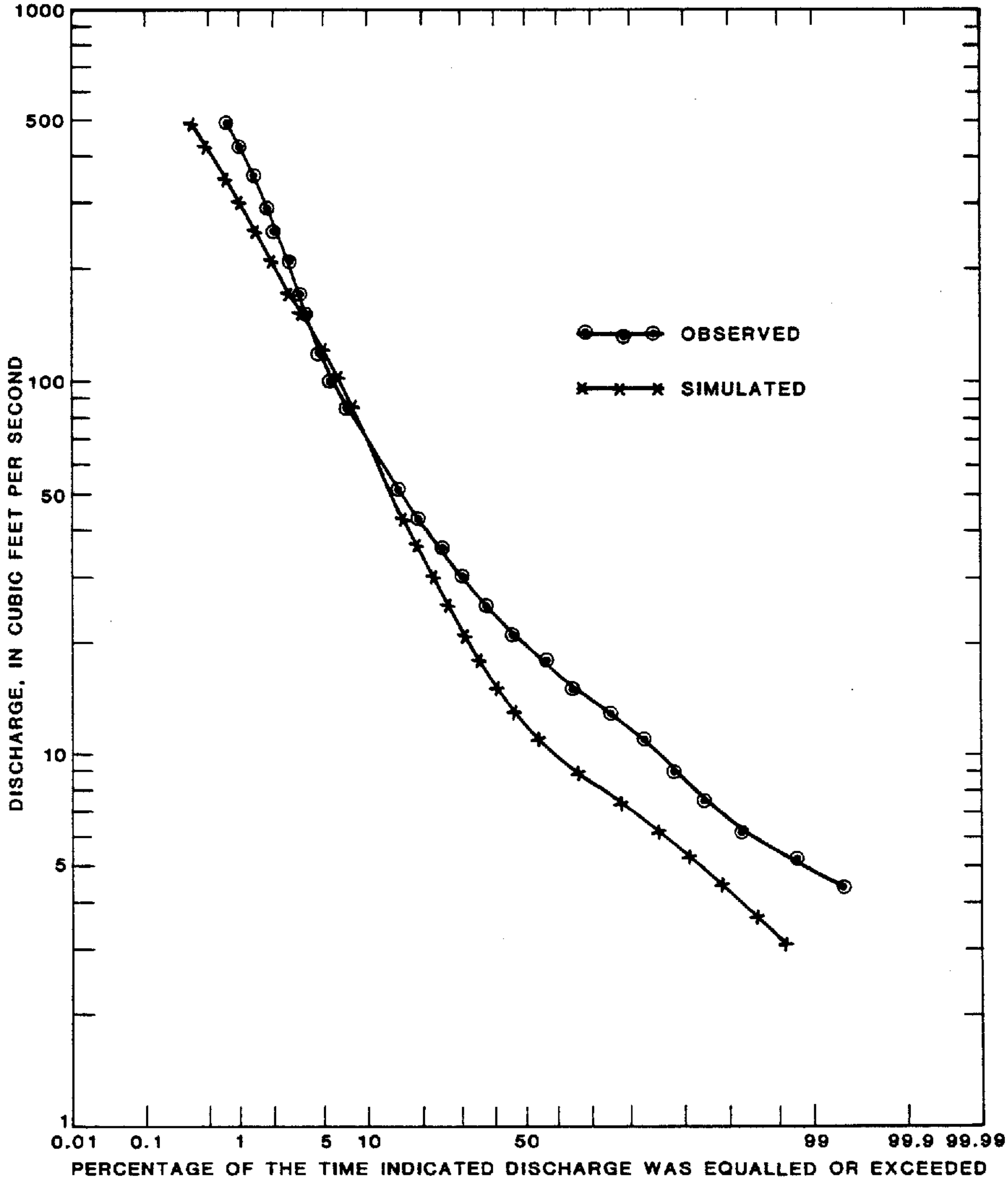

Figure 8.--Río Grande de Loíza at Quebrada Arenas flow duration analysis, 1978-1982.

SUMMARY

The runoff component of the Río Grande de Loíza at Quebrada Arenas Model was subjected to a series of tests. The result of the calibration and verification showed that the HSPF Model fairly simulates runoff on an annual, monthly, and daily basis during both the 2-year calibration interval and the 3-year verification interval. The results were affected by the quality of the runoff records and the location of the recording rain gage. In general, the rainfall-runoff component of the model was considered to be fairly calibrated and verified.

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