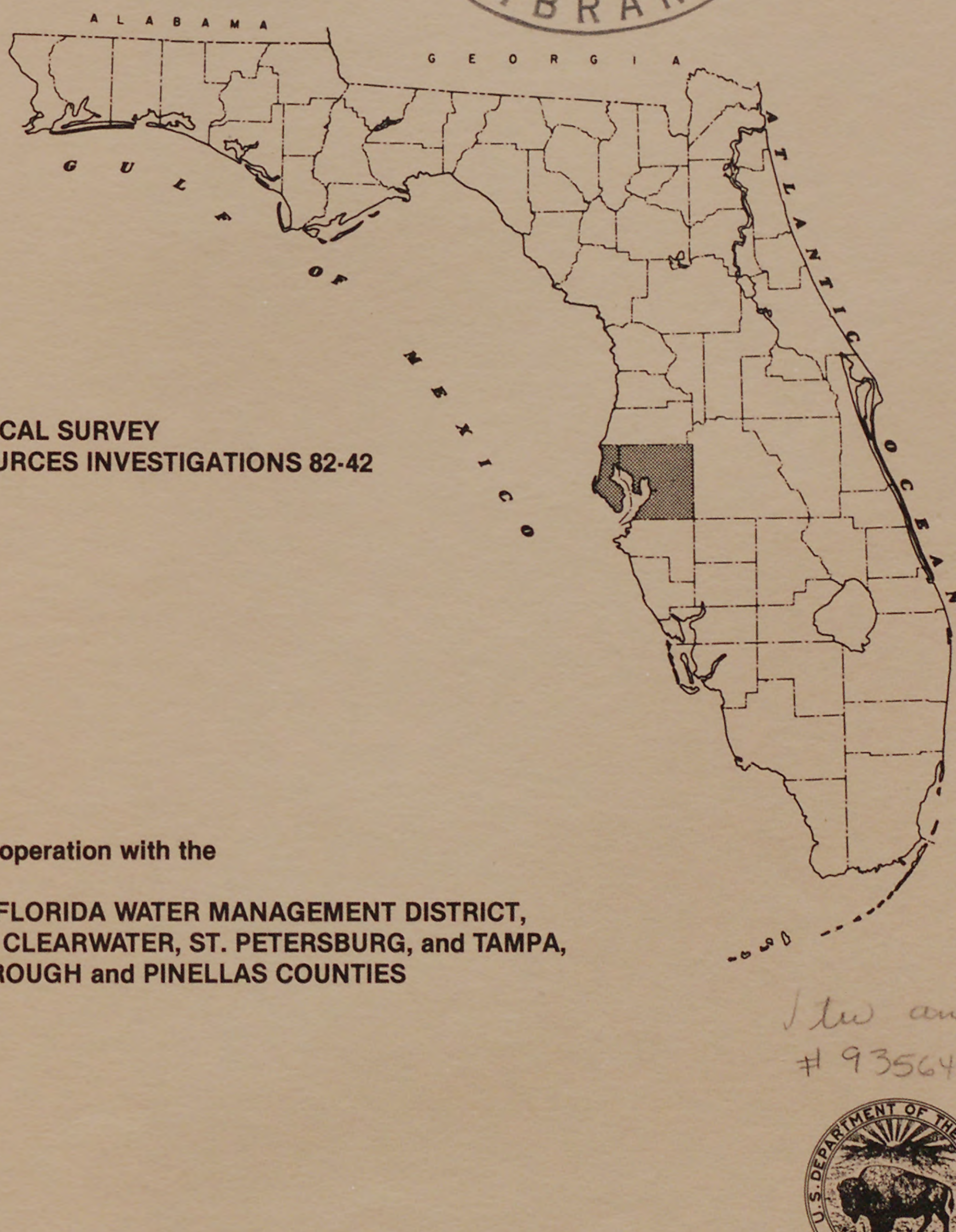
MAGNITUDE AND FREQUENCY OF FLOODING ON SMALL URBAN WATERSHEDS IN THE TAMPA BAY AREA, WEST-CENTRAL FLORIDA



U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 82-42

Prepared in cooperation with the

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT,
the CITIES OF CLEARWATER, ST. PETERSBURG, and TAMPA,
and HILLSBOROUGH and PINELLAS COUNTIES

82-42 MAGNITUDE AND FREQUENCY OF FLOODING ON SMALL URBAN WATERSHEDS IN THE TAMPA BAY AREA, WEST-CENTRAL FLORIDA 82-42

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Prepared in cooperation with the Southwest Florida Water Management District, the cities of Clearwater, St. Petersburg, and Tampa, and Hillsborough and Pinellas Counties.

16. Abstract (Limit: 200 words) This report describes hydrologic data collected on nine small urban watersheds in the Tampa Bay area of west-central Florida and develops a method for estimating peak discharges in the study area. The watersheds have mixed land use and range in size from 0.34 to 3.45 square miles. Watershed soils, land use, and storm-drainage system data are described. Urban development ranged from a sparsely populated area with open-ditch storm sewers and 19 percent impervious area to a completely sewered watershed with 61 percent impervious cover.

The U.S. Geological Survey natural-basin and urban-watershed models were calibrated for the nine watersheds using 5-minute interval rainfall and discharge data. The calibrated models were used with historical storm rainfall data from the Tampa, Florida, National Weather Service rain gage to simulate annual peak discharge for the period 1906-52.

A log-Pearson Type III frequency analysis of the simulated annual maximum discharge was used to determine the 2-, 5-, 10-, 25-, 50-, and 100-year flood discharges for each watershed. Flood discharges were related in a multiple-linear regression to drainage area, channel slope, detention storage area, and an urban-development factor determined by the extent of curb and gutter street drainage and storm-sewer system. The average standard error for the regional relations ranged from ±32 to ±42 percent.

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By M. A. Lopez and W. M. Woodham

U.S. GEOLOGICAL SURVEY

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Tallahassee, Florida

1983

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UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONTENTS

ILLUSTRATIONS

TABLES

ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of Units (SI) and abbreviation of units

Multiply	By	To obtain
acre	0.4047	hectometer^2 (hm^2)
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
degree Fahrenheit (°F)	$\frac{(^{\circ}F-32)5}{9}$	degree Celsius (°C)

* * * * * * * * * * * * * *

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level." In the text of this report, NGVD of 1929 is referred to as sea level.

GLOSSARY

Some of the technical terms used in this report are defined here for convenience. See Dalrymple (1960) and Langbein and Iseri (1960) for additional information regarding flood-frequency analyses and associated hydrologic terminology. Statistical terms are defined with respect to flood analysis applications described in this report.

Annual maximum discharge.--The highest instantaneous peak discharge for a water year that begins October 1 and ends September 30.

Correlation.--Linear dependence between two hydrologic variables.

Correlation coefficient.--The degree of linear dependence of two hydrologic variables. The correlation coefficient can range from plus one, perfect correlation, to minus one, perfect inverse correlation. A value of zero indicates no correlation.

Equivalent years of record.--Number of years of streamflow record that would be necessary to produce a frequency distribution with accuracy equal to that of the regression analysis.

Exceedance probability.--The probability that a flood will exceed a specified magnitude in any water year. Recurrence interval is computed as the inverse of exceedance probability.

Flood-frequency curve.--A graph showing flood magnitudes that will, on the average, be exceeded once within a specified number of years (Riggs, 1968).

Mean.--The sum of individual observations divided by the number of observations.

Multiple correlation coefficient.--A measure of the explanatory power of a regression involving three or more hydrologic variables.

Recurrence interval.--The average interval of time within which a specified flood magnitude will be exceeded once.

Residual.--The difference between an observed and a predicted value.

Significance (level of).--The specified probability level at which a statistical test is made to determine whether or not the explained variation in a dependent variable explained by an independent variable in a regression analysis could have occurred by chance alone.

Skew coefficient.--Relative measure of the deviation of the mean from the median value of a frequency distribution.

Soil-infiltration index.--The maximum infiltration, in inches, that can occur during an annual flood under average soil-moisture conditions.

Standard deviation.--A measure of the amount of variation in a sample of size n. The standard deviation is determined by taking the square root of the average squared deviations of the observations from the sample mean.

Standard error of estimate.--A measure of the uncertainty of a regression equation. In this report, the standard error of estimate is given as an average percentage value representing the average range about the regression equation that includes about 68 percent of all regression data points. More technically, the standard error of estimate is the standard deviation of the residuals about the regression equation.

T-year event.--Specified recurrence interval, in years.

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ABSTRACT

This report describes hydrologic data collected on nine small, urban watersheds in Hillsborough and Pinellas Counties in west-central Florida. The data network included 9 streamflow stations, 13 recording rain gages, including the Tampa, Florida, U.S. National Weather Service (Weather Bureau) rain gage, and 1 daily pan evaporation station. Five-minute storm rainfall and discharge data and daily rain and evaporation data are stored in the U.S. Geological Survey computer WATSTORE data files. U.S. Geological Survey natural-basin and urban-watershed models were calibrated with data from the nine watersheds. The watersheds have mixed land use and range in size from 0.34 to 3.45 square miles. Watershed soils, land use, and storm-drainage system data are described. Urban development ranged from a sparsely populated area, with open-ditch storm sewers and 19 percent impervious cover, to a completely sewered watershed with 61 percent impervious cover.

The calibrated models used the historical rainfall data from the Tampa, Florida, U.S. National Weather Service rain gage to simulate annual peak discharges for the period 1906-52. A log-Pearson Type III frequency analysis of the simulated annual maximum discharge was used to determine the 2-, 5-, 10-, 25-, 50-, and 100-year flood discharges for each watershed. These discharges were then related to watershed characteristics using regression analysis. Equations were developed whereby flood discharges were found to vary with drainage area, an urban development factor, main channel slope, and percentage of area in lakes and detention basins. The average standard error of estimate for these equations ranged from ±32 to ±42 percent, and the average multiple-correlation coefficient was 0.93. These equations apply to urban watersheds in the Tampa Bay area with drainage areas less than 10 square miles. The relations may not provide valid flood estimates for watersheds having soils index greater than 3.89 inches or that have more than 3.5 percent of the drainage area in detention basin or lake area. Estimates of flood magnitude on urban watersheds with land-use or drainage-system characteristics outside the range measured in the study will be improved by weighting with the estimate computed with the seven-variable relation developed in a nationwide urban flood study.

INTRODUCTION

The rapid increase in population in the Tampa Bay area of west-central Florida and accompanying urban development have created a large stress on the land and water resources. Of major concern is the impact of urban development on the water resources. Flood flows from urbanizing watersheds will increase with expansion of impervious cover into previously rural areas and with the modification of natural drainage systems. Flood damage will increase as urbanization encroaches further on flood plains.

Data describing flooding in most natural basins are available, but data for urbanizing basins are virtually nonexistent. Flood-frequency relations for the west-central Florida area are available in Barnes and Golden (1966) and Seijo and others (1979). These studies did not include rural or urban basins smaller than 10 mi^2 in size.

Because flood data for urban basins were lacking in the Tampa Bay area, the U.S. Geological Survey, in cooperation with the Southwest Florida Water Management District, Hillsborough County, Pinellas County, and the cities of Clearwater, St. Petersburg, and Tampa, initiated a study in 1974 to determine the effect of urban development on the quality and quantity of storm runoff. The objectives of the study were: (1) to assess the quantity and quality of stormwater; (2) to relate stormwater runoff and water quality to land use, including intensity and type of development; and (3) to develop planning and management information needed for design and management of storm-drainage systems to meet peak-flow and water-quality criteria imposed by regulatory agencies. To accomplish these objectives, a multiphase program was designed as follows:

1. Establish a hydrologic data base consisting of land use, storm-runoff quantity and quality, and rainfall;
2. Develop regional relations for estimating flood discharges in small watersheds under varying levels of urbanization;
3. Develop regional relations for estimating stormwater runoff loads of problem chemical and organic constituents.

The first phase, a description of the hydrologic data base and a tabulation of data processed through September 30, 1976, is completed and the data are available in a report by Lopez and Michaelis (1978). The hydrologic data base has already been utilized by local governments and their consultants in designs of a master storm-drainage plan for Pinellas County and to identify sources and magnitude of urban-runoff load as part of the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program (NURP) study for the city of Tampa. This report culminates phase 2; a third report culminating phase 3 is planned.

PURPOSE AND SCOPE

The purpose of this report is to provide results of runoff studies describing flood-frequency relations for small urban watersheds in the Tampa Bay area.

Data on rainfall, streamflow, land use, and watershed characteristics were obtained for nine watersheds for use in calibration of the U.S. Geological Survey natural-basin model described by Dawdy and others (1972) and urban-watershed model by Carrigan and others (1977). Calibrated models were used with historical rainfall at Tampa to simulate historical annual maximum discharges for each watershed. Flood-frequency relations for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year floods were developed in a regression analysis using various land use, basin development indices, and drainage-system characteristics.

This report presents a summary of observed flood data, land-use and physical characteristics, model calibration results, and analyses showing the relative effect of several physical watershed characteristics on flood peaks. Flood-frequency relations are presented in mathematical and graphical format that may be used to estimate the magnitude and frequency of floods for watersheds in the Tampa Bay area with various levels of development.

DESCRIPTION OF THE AREA

The study area is located in the Tampa Bay area of west-central Florida and includes the western part of Hillsborough County and all of Pinellas County (fig. 1). The area is about 1,000 mi^2 in size and includes watersheds of tributaries to the Hillsborough River estuary, Tampa Bay, and the Gulf of Mexico.

Topography and Drainage

The study area lies entirely in the Coastal Lowlands, one of the five natural topographic regions of Florida (Pride, 1958). Land-surface altitudes range from sea level to between 55 and 60 feet in St. Petersburg and Tampa and to 70 feet in Clearwater. Natural drainage patterns have been altered or modified to some extent in most of the study area. Shallow lakes and ponds in urban areas have been connected to storm-drainage systems and act as detention basins. Other areas are drained by ditches constructed for agricultural or urban development.

In Pinellas County there are scattered pockets of internally draining basins that are not connected to the storm-drainage system. In the north part of Tampa, a karst area has several internally drained areas. These basins retain storm runoff that gradually evaporates or seeps into the ground. Extensive low-lying areas of northwest Hillsborough and Pinellas Counties have little relief and natural drainage patterns are poorly defined.

Geology

Hillsborough and Pinellas Counties are underlain by Pleistocene to Holocene sands that comprise the surficial aquifer wherein the water table is 5 to 10 feet below land surface.

The structure and composition of the overlying soils vary and this variation influences the amount of runoff. The capacity of soil to receive, store, and transmit water can be expressed by a soil-infiltration index--the maximum infiltration, in inches, that can occur during an annual flood under average soil-moisture conditions. The index can be determined from runoff curve numbers as explained in the National Engineering Handbook, Hydrology, Section 4, page 10.6a (U.S. Department of Agriculture, Soil Conservation Service, 1972). A map showing soil-infiltration index values, modified from an unpublished map compiled by the Soil Conservation Service, is shown in figure 2.

The overlying soils in areas extending north and east of Tampa are generally fine grained and highly permeable (Florida Department of Administration, 1975). Much of the rainfall in these areas where the indexes are 3.89 and 5.38, respectively, infiltrates rapidly; a large part of surface runoff enters sinkholes or depression areas. In other parts of the study area where the index is 2.05, rocks and soils tend to be less pervious, and runoff response is faster.

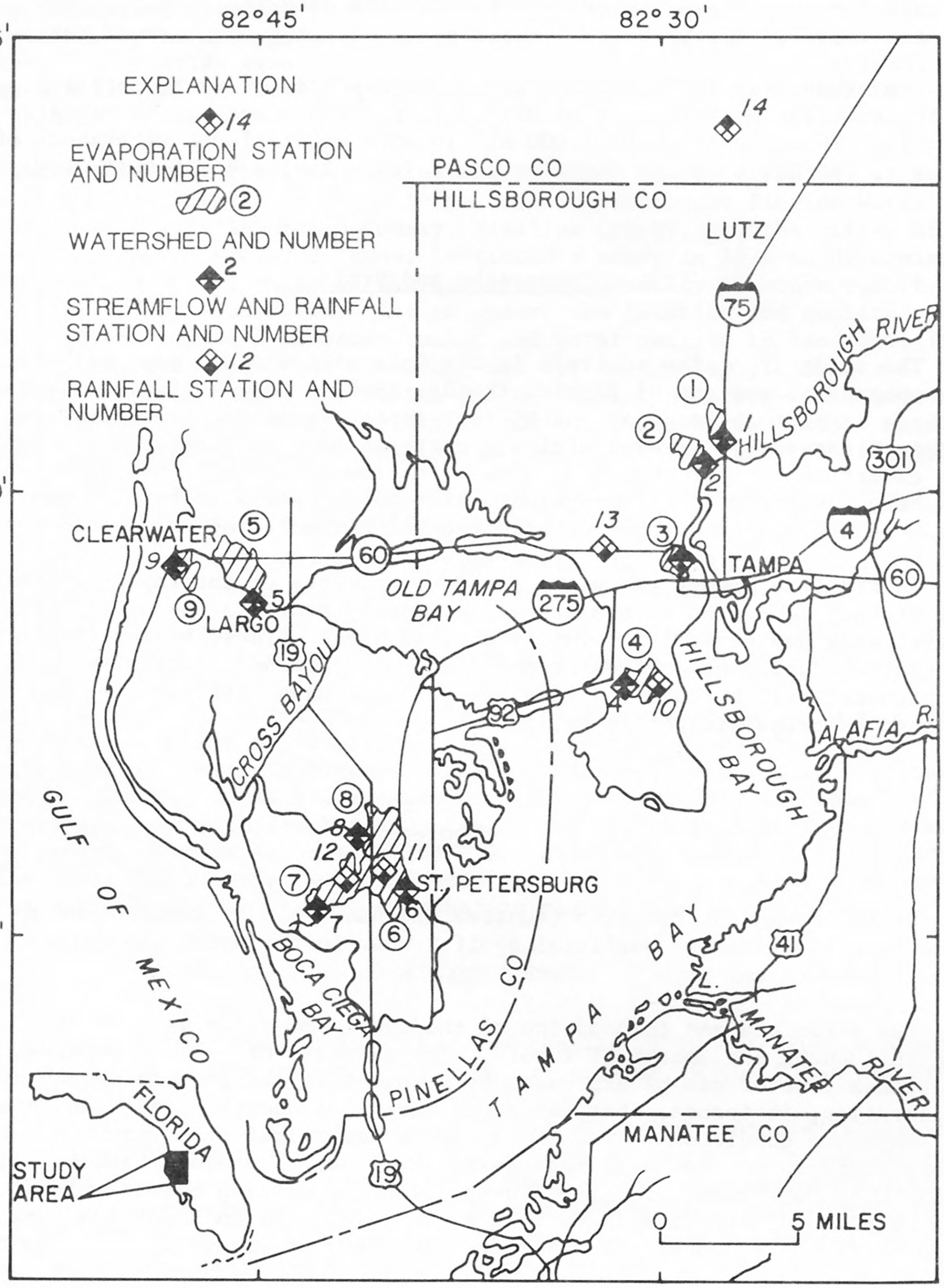

Figure 1.--Location of study area and data-collection sites.

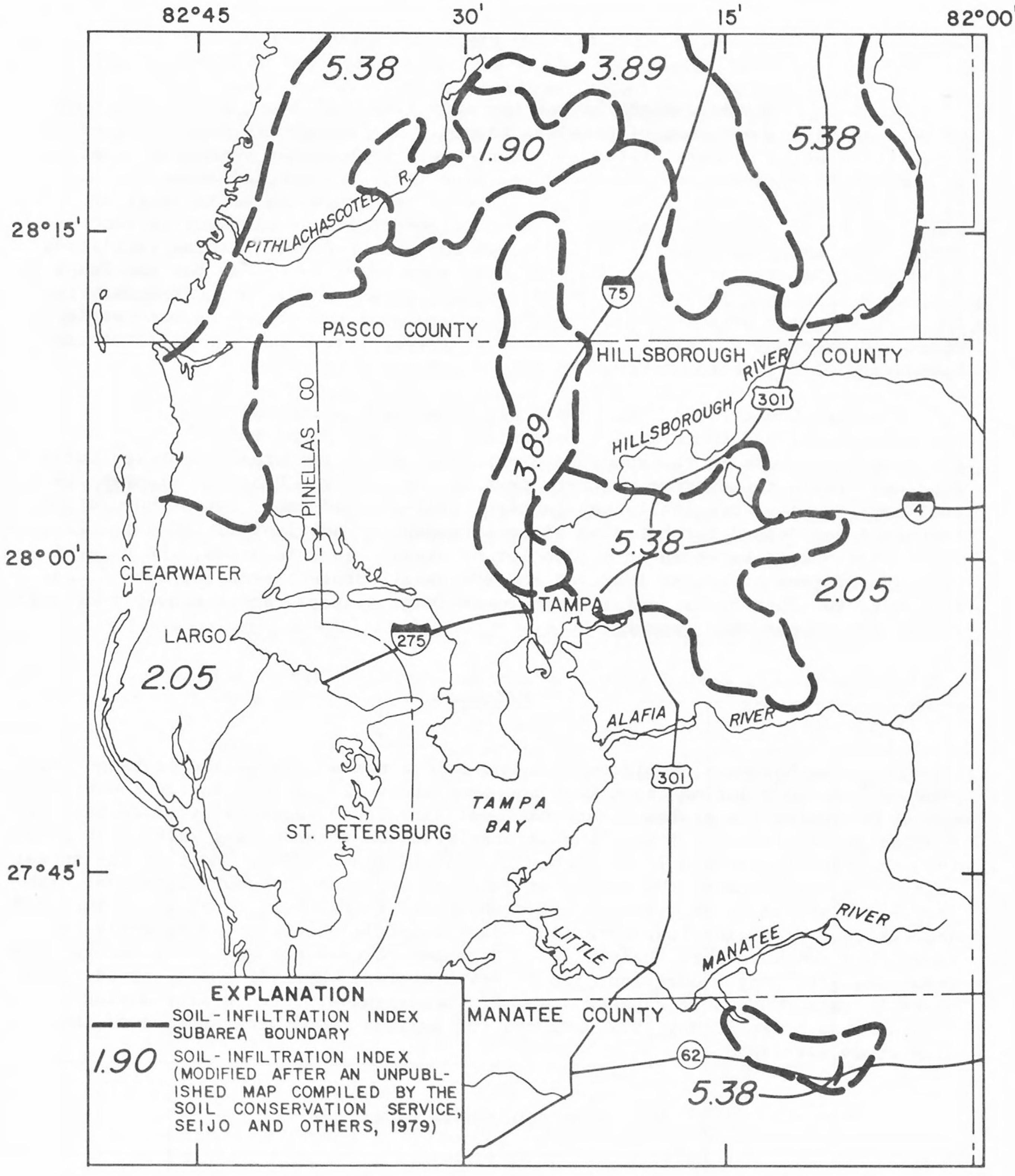

Figure 2.--Variation of soil-infiltration index values.

Land Use

Urban development extends beyond the city limits of Tampa in Hillsborough County and throughout most of Pinellas County. Development is characterized by paved residential streets drained by storm-sewer systems and commercial centers or industrial plants with large paved parking lots. Commercial areas in the city of Tampa are scattered along main streets and concentrated in large shopping centers in outlying residential areas. Industrial development is concentrated near shipping areas in Hillsborough Bay and phosphate loading facilities outside of the city of Tampa along the east side of Hillsborough Bay and Tampa Bay. The principal land use in unincorporated areas in Hillsborough County is for single-family or multifamily residences and agriculture. Phosphate strip mines and processing plants are located along the extreme eastern and southern boundaries of Hillsborough County.

Pinellas County is almost completely urbanized; principal land-use types are residential and commercial. Commercial areas are along main highways and at shopping centers in the suburban area. The only large areas of agricultural land use are in the extreme northern part of the county. Urban development in the Tampa Bay area originally was on high, well-drained land, but as population increased and demand for building sites exceeded the availability of suitable land, development extended into flood-prone areas. In some areas, the natural drainage systems have been improved and adequately protect property from flooding; but, in other areas, existing storm-drainage systems cannot convey increased runoff from urban developments.

Climate

The area has warm, humid summers and mild winters. Temperatures range from about 70° to 90°F during the summer and from about 32° to 70°F during the winter. Annual precipitation at Tampa International Airport averages about 51 inches, but fluctuates widely. The lowest annual precipitation recorded was 28.89 inches in 1956 and the highest was 76.67 inches in 1959 (Wright, 1974). Most of the annual rainfall occurs between the months of June and September as short duration, high intensity, afternoon or evening thundershowers. Hurricanes, tropical storms, and depressions, producing long duration, heavy rainfall occur most frequently between June and November. Rainfall for December through May generally occurs from less frequent, longer duration, frontal-type storms. Most of the observed flood peaks in this study were caused by summer thundershowers, but a slow-moving frontal-type storm in May 1979 produced the maximum flood peak at five of the nine study watersheds.

HYDROLOGIC DATA BASE

A rainfall, streamflow, and water-quality data-collection network was established in 1974 and 1975 and included 10 continuous-record streamflow stations and 13 recording rain gages. One streamflow station, Cass Street storm drain at Tampa, Fla., was discontinued in 1977 because of tide effects.

Data used in the study were systematically processed and stored using existing software on the Geological Survey computer system in Reston, Va., using programs described in the WATSTORE (National Water Data Storage and Retrieval System) Users Guide (Hutchinson, 1975). Selected WATSTORE programs used specifically to process data for use with the USGS rainfall-runoff models are described by Carrigan and others (1977).

Rainfall, Runoff, and Evaporation Data

Rainfall and runoff data recorded at 5-minute intervals for selected storms were stored in the WATSTORE unit-values file. The data were subsequently edited and only significant runoff events were kept in the file. Rainfall and runoff unit-value data at the 9 streamflow stations, 12 study rain gages, and the historical data from the U.S. National Weather Service gage in Tampa, available in the WATSTORE files, are summarized in table 1.

Daily rainfall data at the 12 study rain gages and the U.S. National Weather Service gage in Tampa and daily pan evaporation data at Lake Padgett near Lutz are stored in the WATSTORE daily-values file and are summarized in table 2. Locations of streamflow stations, rain gages, and evaporation pan are shown in figure 1.

Table 1.--Discharge and rainfall data in WATSTORE unit-values file

[Upper values in table refer to discharge, lower values are for rainfall]

Site No. (fig. 1)	Station No. and name	Period of record		Maximum	
		First-last date	Number of days	Discharge (ft^3/s)	Rainfall (in/5 min)
1	02306002 Artic Street storm drain at Tampa, Fla.	10/17/75-5/25/79	247	142	
		10/16/75-9/20/79	181		0.66
2	02306006 Kirby Street drainage ditch at Tampa, Fla.	6/05/75-9/30/79	497	192	
		6/05/75-9/30/79	467		.54
3	02306021 St. Louis Street drainage ditch at Tampa, Fla.	6/08/75-10/02/79	394	357	
		6/08/75-9/29/79	123		.50
4	02306071 Gandy Boulevard drainage ditch at Tampa, Fla.	5/28/75-5/24/79	220	692	
		5/28/75-5/24/79	95		.82

Table 1.--Discharge and rainfall data in WATSTORE unit-values file--Continued

Site No. (fig. 1)	Station No. and name	Period of record		Maximum	
		First-last date	Number of days	Discharge (ft^3/s)	Rainfall (in/5 min)
5	02307731 Allen Creek near Largo, Fla.	7/10/71-3/14/80	1,236	852	
		7/10/71-3/13/80	465		0.50
6	02308193 Booker Creek at St. Petersburg, Fla.	5/14/75-9/30/79	229	862	
		5/14/75-9/29/79	155		.68
7	02308773 Bear Creek at St. Petersburg, Fla.	5/15/75-9/30/79	347	922	
		5/15/75-9/30/79	168		.64
8	02308929 Saint Joes Creek at St. Petersburg, Fla.	3/10/75-9/30/79	277	350	
		11/30/74-3/21/80	480		.58
9	02309160 Turner Street storm drain at Clear-water, Fla.	6/08/75-9/30/79	277	350	
		6/08/75-9/29/79	190		.58
10	275336082300900 Himes Avenue rain gage at Tampa, Fla.	--			
		5/10/75-6/08/79	242		.58
11	274739083400400 Twenty-fifth Street rain gage at St. Peters-burg, Fla.	--			
		5/10/75-9/29/79	326		.68
12	27465082410800 Lafayette Street rain gage at St. Petersburg, Fla.	--			
		5/15/75-9/29/79	283		.69
13	27580008232001 Tampa, Fla. W12842 WBAP	--			
		6/20/05-11/16/51	190		.95

Table 2.--Rainfall and evaporation data in WATSTORE daily-values file

Site No. (fig. 1)	Station No. and name	Period of record	Daily maximum (in)
1	02306002 Artic Street storm drain at Tampa, Fla.	10/74-9/30/79	9.70
2	02306006 Kirby Street drainage ditch at Tampa, Fla.	10/1/74-9/30/79	8.28
3	02306021 St. Louis Street drainage ditch at Tampa, Fla.	10/1/74-9/30/79	5.76
4	02306071 Gandy Boulevard drainage ditch at Tampa, Fla.	10/1/74-6/30/79	12.30
5	02307731 Allen Creek near Largo, Fla.	10/1/70-9/30/79	5.20
6	02308193 Booker Creek at St. Petersburg, Fla.	8/1/74-9/30/79	6.25
7	02308773 Bear Creek at St. Petersburg, Fla.	10/1/74-9/30/79	5.14
8	02308929 Saint Joes Creek at St. Petersburg, Fla.	10/1/74-9/30/79	5.70
9	02309160 Turner Street storm drain at Clearwater, Fla.	10/1/74-9/30/79	6.09
10	275336082300900 Himes Avenue rain gage at St. Petersburg, Fla.	10/1/74-5/31/79	10.68
11	274739082400400 Twenty-fifth Street rain gage at St. Petersburg, Fla.	10/1/74-9/30/79	6.25
12	27465082410800 Lafayette Street rain gage at St. Petersburg, Fla.	8/1/74-9/30/79	9.02
13	27580008232001 Tampa, FL WBAP W12842	10/1/1897-9/30/72	9.88
14	023003440 Lake Padgett evaporation pan gage near Lutz, Fla.	10/1/72-9/30/79	.41

Water-Quality Data

The results of physical measurements and chemical analyses of water samples collected at all network stations are stored in the WATSTORE quality-of-water file. Water samples were collected during storm runoff and base flow. In addition, one series of benthic material (bottom samples) was collected at each of the seven open-channel sampling stations (sites 2, 3, 4, 5, 6, 7, and 8, fig. 1). Plans are for a summary of water-quality data collected at network stations to be provided in a separate report.

Data Availability

All data files of WATSTORE are maintained on the central computer facilities of the Geological Survey in Reston, Va. However, information about the availability of specific types of data, the acquisition of data or products, and user charges can be obtained locally from the U.S. Geological Survey, F-240, 325 John Knox Road, Tallahassee, FL 32303, telephone: 904/386-7145.

Evaluation of Hydrologic Data Base

The data available on rainfall intensity and discharge hydrographs for 20 to 50 storms at each site provide an adequate data base to characterize storm rainfall and runoff in the Tampa Bay area.

Generally, thundershower and frontal-type storm rainfall amounts and intensities were accurately recorded at all rain gages. However, the rainfall that occurred on May 8, 1979, was not accurately recorded as it exceeded the volume of all USGS rain gages in Pinellas County except the gage on Turner Street storm drain. The May 8 daily rainfall total was less than the daily maximum for the period of record at three study rain gages in Hillsborough County and the Turner Street storm drain in Pinellas County. For those sites that recorded the total for the May 8 storm, the 24-hour depth ranged from 5.14 to 12.30 inches, with recurrence intervals ranging from 2 to 100 years, respectively (U.S. Department of Commerce, 1961). The May 8, 1979, rainfall at the U.S. National Weather Service rain gages at Tampa and St. Petersburg were 11.45 inches and 7.65 inches, respectively.

Five-minute rainfall intensity data for the National Weather Service rain gage in Tampa were used to determine frequency distributions for 5-, 15-, 30-, 60-, 120-, and 180-minute maximum rainfall intensities. A comparison among these intensities, the data published in Technical Paper No. 40 (U.S. Department of Commerce, 1961) and the Pinellas County Storm Drainage Basin Study Rainfall Analysis (Ross, Saarinen, Bolton and Wilder, 1979), is shown in table 3. Generally, intensity data from the National Weather Service rain gage in Tampa used in the simulation study compared best with data shown in Technical Paper No. 40. Thirty-minute duration rainfall intensities were from 9 to 15 percent less than the data shown in Technical Paper No. 40, and those for 120-minute duration were 6 to 20 percent less. The best agreement was for the 60-minute duration, where the differences ranged from about 10 percent less to 7 percent greater.

The highest recorded 5-minute rainfall for basins used in the study ranged from 0.50 to 0.82 inch (table 1) and had recurrence intervals that ranged from 5 to 50 years based on Tampa National Weather Service 5-minute intensity data (table 3). Storm rainfall amounts and intensities were recorded and stored for 5 to 10 storms per year at each gage and were representative of typical storm rainfall for the study area.

Storm-runoff hydrographs were recorded for the maximum flood of record at all gages except possibly Artic Street storm drain (site no. 1) where the May 8, 1979, record was lost.

Table 3.--Comparison of Tampa Bay area rainfall-intensity data

Recurrence interval, years	Rainfall, in inches, for specific time, in minutes											
	5				15				30			
	Data used in this study 1/	Tampa Bay area average 2,3/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/	Data used in this study 1/	Tampa Bay area average 2,6/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/	Data used in this study 1/	Tampa Bay area average 2/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/
2	0.45	0.67	--	--	1.1	1.3	--	--	1.6	1.8	--	--
5	.55	.85	--	--	1.4	1.7	--	--	2.0	2.3	--	--
10	.63	.92	--	--	1.5	1.8	--	--	2.3	2.5	--	--
25	.72	1.1	--	--	1.7	2.1	--	--	2.6	2.9	--	--
50	.80	1.2	--	--	1.8	2.3	--	--	2.9	3.2	--	--
100	.90	1.3	--	--	1.9	2.5	--	--	3.1	3.5	--	--

1/ Frequency analysis based on Tampa, Fla., National Weather Service 5-minute intensity data, December 1905 to November 1951.

2/ Tampa Bay area average from isohyetal maps in Technical Paper No. 40 (U.S. Department of Commerce, 1961).

3/ 30-minute intensity multiplied by 0.37 to obtain 5-minute intensities (U.S. Department of Commerce, 1961).

4/ Frequency analysis based on Tampa National Weather Service 60-minute rainfall intensity data, June 1948 to August 1952 and July 1958 to December 1977 (Table IV-3, Ross, Saarinen, Bolton and Wilder, 1979).

5/ Frequency analysis based on St. Petersburg National Weather Service 60-minute rainfall intensity, February 1946 to December 1977 (Table IV-3, Ross, Saarinen, Bolton and Wilder, 1979).

6/ 30-minute intensity multiplied by 0.72 to obtain 15-minute intensities (U.S. Department of Commerce, 1961).

Table 3.--Comparison of Tampa Bay area rainfall-intensity data--Continued

Recurrence interval, years	Rainfall, in inches, for specified time, in minutes											
	60				120				180			
	Data used in this study 1/	Tampa Bay area average 2,3/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/	Data used in this study 1/	Tampa Bay area average 2,6/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/	Data used in this study 1/	Tampa Bay area average 2/	Pinellas County storm drainage basin study (Tampa) 4/	Pinellas County storm drainage basin study (St. Petersburg) 5/
2	2.1	2.3	--	--	2.4	2.9	--	--	2.5	3.3	--	--
5	2.7	3.0	2.18	2.51	3.1	3.6	2.68	2.85	3.3	4.0	2.80	3.24
10	3.1	3.3	2.50	2.83	3.7	4.1	3.05	3.21	3.9	4.6	3.13	3.68
25	3.7	3.6	2.91	3.20	4.4	4.7	3.46	3.62	4.6	5.5	3.50	4.22
50	4.1	4.0	3.21	3.48	5.0	5.3	3.73	3.92	5.3	6.0	3.74	4.62
100	4.6	4.3	3.52	3.74	5.6	5.8	3.97	4.21	6.0	6.5	3.97	5.01

1/ Frequency analysis based on Tampa, Fla., National Weather Service 5-minute intensity data, December 1905 to November 1951.

2/ Tampa Bay area average from isohyetal maps in Technical Paper No. 40 (U.S. Department of Commerce, 1961).

3/ 30-minute intensity multiplied by 0.37 to obtain 5-minute intensities (U.S. Department of Commerce, 1961).

4/ Frequency analysis based on Tampa National Weather Service 60-minute rainfall intensity data, June 1948 to August 1952 and July 1958 to December 1977 (Table IV-3, Ross, Saarinen, Bolton and Wilder, 1979).

5/ Frequency analysis based on St. Petersburg National Weather Service 60-minute rainfall intensity, February 1946 to December 1977 (Table IV-3, Ross, Saarinen, Bolton and Wilder, 1979).

6/ 30-minute intensity multiplied by 0.72 to obtain 15-minute intensities (U.S. Department of Commerce, 1961).

The highest peak discharges recorded and used in rainfall-runoff model calibration are listed in table 4. The highest recorded peaks were used in the model calibrations at watershed numbers 3, 4, and 9. The highest peak discharges recorded at watershed numbers 5, 6, 7, and 8 in Pinellas County occurred on May 8, 1979, but could not be used in the model because the rainfall record at these sites was not complete. At those sites where the highest peak was not used, the highest peak discharge used in the model calibration was from 0.59 to 0.95 of the highest peak discharge recorded.

Table 4.--Highest peak discharges recorded and used in rainfall-runoff model calibration

Watershed No. (fig. 1)	Highest peak discharge recorded		Highest peak discharge used in calibration	
	ft^3/s	Date	ft^3/s	Date
1	146	July 12, 1978	126	Jan. 12, 1979
2	193	Sept. 21, 1979	178	May 8, 1979
3	340	June 18, 1975	340	June 18, 1975
4	314	May 8, 1979	314	May 8, 1979
5	852	May 8, 1979	813	July 1, 1977
6	862	May 8, 1979	506	Sept. 25, 1979
7	922	May 8, 1979	705	July 1, 1977
8	413	May 8, 1979	295	July 13, 1975
9	350	July 19, 1978	350	July 19, 1978

WATERSHED DESCRIPTIONS

The following criteria were followed in selecting basins for the study:

1. Size of drainage area is within the range of typical drainage-system designs in the Tampa Bay area.
2. Land use in the watershed is typical of the types of development in the Tampa Bay area.
3. Land-use type and amount of development would remain stable during the investigation.
4. Stage-discharge relation at watershed outlet could be defined by current-meter measurements.
5. Water-quality samples of storm runoff could be collected throughout the range of discharge experienced.

Of the nine selected watersheds, four were in Hillsborough County, all within the Tampa city limits. The other five were located in Pinellas County, three in the city of St. Petersburg, one near the town of Largo, and one in the city of Clearwater (fig. 1).

Maps for each watershed are provided in a report by Lopez and Michaelis (1978). Aerial photographs and contour and storm-drainage system maps, from which land-use maps and watershed characteristics were determined, are on file in the U.S. Geological Survey office in Tampa.

Land Use

The selected watersheds had drainage areas that ranged in size from 0.34 to 3.45 mi^2. Each contained a variable mixture of residential, commercial, industrial, and undeveloped land use that is typical of urban development in the Tampa Bay area. Two of the watersheds in Tampa, Artic Street storm drain and Kirby Street drainage ditch, have a soil-infiltration index of 3.89 inches. All other watersheds have a soil-infiltration index of 2.05 inches. Land-use characteristics and values of soil-infiltration index for each watershed are listed in table 5.

Following are definitions of characteristics used to describe watersheds listed in table 5:

Drainage area.--Area, in square miles, planimetered from U.S. Geological Survey 7-1/2-minute series topographic maps. Watershed boundaries were delineated on topographic maps; natural divides were modified to include or exclude areas where storm sewers crossed the natural divides, based on information from city and county agencies.

Population density.--The number of persons per acre computed by dividing the population within the watershed boundary by the watershed area, in acres. Population was estimated from 1970 census data.

Land Use

Roads.--Percentage of watershed area covered by paved roads;

Single-family residential.--Percentage of watershed area covered by single-family homes;

Multifamily residential.--Percentage of the watershed area covered by multifamily homes or apartments;

Commercial.--Percentage of the watershed area covered by commercial buildings and associated parking lots;

Industrial.--Percentage of the watershed area covered by industrial buildings and associated parking lots;

Institutional.--Percentage of the watershed area covered by public institutions and surrounding grounds, such as schools, colleges, hospitals, and clinics;

Recreational.--Percentage of the watershed area covered by recreational facilities, such as ball fields, basketball courts, and tennis courts;

Open space.--Percentage of the watershed area covered by unused, undeveloped, or agricultural land.

Table 5.--Land-use characteristics

Site No. (fig. 1)	Watershed	Drainage area (square miles)	Population density (persons per acre)	Land use, percentage of watershed area								Soil-infiltration index (inches)
				Roads	Single-family residential	Multifamily residential	Commercial	Industrial	Institutional	Recreational	Open space	
1	Artic Street storm drain at Tampa	0.34	6.6	14.7	46.2	0	36.5	0	1.5	0	1.1	3.89
2	Kirby Street1/ drainage ditch at Tampa	1.40	6.8	4.4	69.0	3.3	4.5	0	2.2	1.0	15.6	3.89
3	St. Louis Street drainage ditch at Tampa	.51	8.2	11.8	68.1	0	3.3	0	6.5	2.3	8.0	2.05
4	Gandy Boulevard drainage ditch at Tampa	1.29	5.7	8.5	31.6	5.1	21.0	0	3.9	5.6	24.3	2.05
5	Allen Creek1/ near Largo	1.79	6.9	10.3	59.0	3.9	7.0	0	7.9	0.5	11.4	2.05
6	Booker Creek1/ at St. Petersburg	3.45	5.8	12.3	48.8	1.7	18.1	4.4	3.0	2.7	9.0	2.05
7	Bear Creek at St. Petersburg	1.89	6.9	12.8	66.1	4.3	5.8	0	5.5	1.0	4.5	2.05
8	Saint Joes Creek at St. Petersburg	1.72	5.3	12.0	47.7	.1	16.2	7.7	1.8	1.9	12.6	2.05
9	Turner Street1/ storm drain at Clearwater	.45	6.9	12.7	37.4	1.4	28.0	20.0	.4	0	.1	2.05

1/ Drainage area and land use revised in 1980.

Urban Development Characteristics

As land use in a watershed changes from natural or agricultural to urban, changes in the drainage system and in the imperviousness of the contributing drainage area also occur. Channels are altered by realinement or paving and ultimately may be fully enclosed. Realinement often shortens the channel length and increases the slope. Paved streets with curb and gutter replace dirt roads and roadside ditches. Depressions, ponds, and lakes are connected to the drainage system to accommodate storm runoff. Impervious areas, such as roads, parking lots, roofs, sidewalks, and driveways, increase as urban development continues.

The average and range in percentage of impervious area measured for various land-use types in the study area are as follows:

Land-use type	Percentage of watershed area as impervious cover	
	Average	Range
Single-family residential		
Low-density (1/2 to 2 acres per dwelling)	10	3-14
Medium-density (1/8 to 1/3 acres per dwelling)	20	15-22
Multifamily residential	41	30-68
Commercial	64	35-98
Industrial	50	30-65
Recreational	1	0-3.5
Open space	0	-

Urban development characteristics for each watershed studied are listed in table 6. The drainage-system characteristics, channel type, and street type, are tabulated for the upper, middle, and lower third of each watershed. The prevalent channel and street types are assigned an index number given in the footnote.

Basin development factor (BDF) is the sum of all street and channel index numbers. Values of BDF can vary from zero to 12. A value of zero does not necessarily mean the watershed is completely natural because watersheds that have all index numbers of zero may have housing, streets, and other developmental features that create impervious areas. The BDF was found to be highly significant in previous studies of urban flood-peak discharge (Sauer and others, 1981).

Main channel length, in miles, is measured from the streamflow station to the watershed boundary.

Channel slope, in feet per mile, is measured between points 10 and 85 percent of the distance from the streamflow station to the watershed boundary.

Detention storage area is the area of natural lakes or ponds, detention basins, and retention basins measured from aerial photographs or topographic maps and listed as a percentage of the watershed drainage area.

Table 6.--Urban development characteristics

Site No. (fig. 1)	Prevalent channel type[1/]			Prevalent street type[2/]			Basin development factor BDF[3/]	Main channel		Detention storage area (percent)	Impervious area (percent)	
	Upper 1/3	Middle 1/3	Lower 1/3	Upper 1/3	Middle 1/3	Lower 1/3		Length (mi)	Slope (ft/mi)		Total	Hydraulically connected
1	3	3	3	1	1	1	12	1.25	12.3	0	61	53
2	1	1	1	0	0	0	3	2.40	8.1	3.5	19	5.5
3	3	3	3	1	1	1	12	1.12	10.2	0	27	9.0
4	3	2	2	0	1	1	9	1.63	4.6	.9	38	28
5	3	1	1	1	1	1	8	1.40	23.4	.9	36	26
6	3	2	3	1	0	1	10	3.20	7.1	.9	41	26
7	3	3	2	1	1	1	11	3.79	12.1	2.6	32	25
8	3	3	2	1	1	0	10	1.48	5.5	.4	38	26
9	3	3	3	1	1	1	12	1.06	23.6	.4	48	33

1/ Channel type codes: 0=natural, 1=improved, 2=paved, 3=storm drains or sewers.

2/ Street type codes: 0=swale or ditch drainage, 1=curb and gutter drainage.

3/ Basin development factor, equal to sum of channel and street type codes.

Total impervious area is the total impervious area determined for each type of land use by area measurement of road, sidewalk, driveway, parking lots, and roof areas. Areas of residential developments having different densities or house and lot sizes were measured separately. All watersheds studied had at least two different patterns of residential density. The older homes were smaller and closer together, whereas, more recent developments had larger homes and lower percentages of impervious area. Apartment buildings had the highest percentage of impervious area for residential land use because paved parking lots were included.

Impervious areas for commercial, industrial, and institutional land uses were highly variable and were, therefore, computed separately. High schools had large parking lots and, therefore, larger impervious areas than elementary and junior high schools.

Hydraulically connected impervious area is the characteristic described by Miller (1979) as the hydraulically effective impervious area. The hydraulically connected impervious area was computed by adding only those roofs, streets, and paved areas that are directly connected to a storm drain or a street with curb and gutter drainage leading to a storm drain. The storm drain can be a sewer pipe or drainage ditch.

RAINFALL-RUNOFF MODEL

The U.S. Geological Survey rainfall-runoff model for natural watersheds is a parametric simulation model based on bulk-parameter approximations to the physical laws governing infiltration, soil-moisture accretion and depletion, and surface runoff. It was developed by Dawdy and others (1972) for use with point rainfall data and daily potential evapotranspiration data to predict flood volumes and peak rates of runoff for small drainage areas. The model simulates three components of the hydrologic cycle--antecedent moisture, infiltration, and surface-flow routing. Brief descriptions of the model parameters are listed in table 7.

A modified version of the runoff model for natural basins (RRURBAN1), described by Carrigan and others (1977) and referred to in this report as the urban model, was also calibrated for each watershed. The urban model is identical to the natural watershed model except for the following features:

1. Rainfall from up to five gages can be used as input;
2. The percentage of impervious area can be varied throughout the watershed;
3. The unit hydrograph is replaced by a time-area histogram and time to peak of triangular translation hydrograph (TP) is not optimized.

Calibration Procedure

Calibration of the model for a watershed involves selection of initial, maximum, and mimimum values for model parameters and trial and error adjustment of parameter values to minimize the difference between observed and simulated

Table 7.--Definitions of parameters for runoff model for natural basins

Parameter	Units	Definition and application
		Antecedent-moisture component
EVC	--	Coefficient to convert values of pan evaporation to potential evapotranspiration.
RR	--	Proportion of daily rainfall that infiltrates the soil.
BMSM	Inches	Soil-moisture storage volume at field capacity.
DRN	Inches per hour	A constant drainage rate for redistribution of soil moisture.
		Infiltration component
PSP	Inches	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
KSAT	Inches per hour	The minimum (saturated) hydraulic conductivity used to determine infiltration rates.
RGF	--	Ratio of the product of moisture deficit and suction at the wetted front for soil moisture at wilting point to that at field capacity.
		Surface-runoff component (routing)
KSW	Hours	Time characteristic for linear reservoir routing.
TC	Minutes	Length of the base of the triangular translation hydrograph.
TP	Minutes	Time-to-peak of triangular translation hydrograph.

values of flood discharge and volumes. The comparison is made by testing for the minimum value of a selected objective function; for example, the sum of squared deviations of the linear regression of the logarithms of simulated and observed peak flows and volumes. Observed streamflow, 5-minute rainfall, and daily evaporation data are input to the model.

The objective function is minimized in three separate phases of calibration. During phase one, antecedent-moisture and infiltration component model parameters are optimized using direct runoff volumes. In phase two, surface-runoff component model parameters for hydrograph shape are optimized using peak discharges. In phase three, parameters affecting the moisture-accounting and infiltration components are optimized using peak discharges.

The current (1980) version of the watershed model for rural basins has been adapted for use on urban watersheds. Percentage of the basin area as impervious cover is input to the model. Impervious area is assumed to be uniformly distributed over the watershed and capable of storing 0.05 inch of precipitation. All precipitation in excess of 0.05 inch on the impervious area is assumed to be direct runoff.

Assumptions of the calibration process are as follows:

1. Storm rainfall for a single rain gage in the natural watershed model or the weighted rainfall of two to five gages in the urban model is representative of rainfall throughout the basin;

2. Rainfall is uniformly distributed over the watershed;

3. Basin changes have not affected the homogeneity of flood records used for model calibration.

Selection of Data

Rainfall and discharge records for each watershed were reviewed for completeness and accuracy. Daily discharge for selected storm events was compared with daily rainfall measured in the study watersheds and at nearby sites to determine if the rainfall distribution was homogeneous, and selected storms were processed through the first calibration phase of the natural-basin model to optimize model parameters controlling runoff volumes. Simulated runoff volumes were compared to observed volumes and outliers were eliminated from the input data set. The number of storms retained for the next two phases of calibration ranged from 13 at sites 6 and 8 to 35 at site 9. The standard error of estimate of simulated runoff volume ranged from 10 to 32 percent.

Watershed Data

Watershed data input required for calibration of the natural-basin and urban models include drainage area and percentage of the watershed as impervious area. Time-area histograms are also required for the urban model. Previous studies indicated that total impervious area (TIA) caused models to overestimate runoff volumes from small storms and underestimate runoff volumes from large storms (Wibben, 1976). The hydraulically connected impervious area (HCIA) defined as the hydraulically effective impervious area (HEIA) by Miller (1979) is probably a better estimate of the impervious area contributing direct runoff to the drainage system.

George R. Dempster, Jr. (oral commun., 1980) suggested a method of determining effective impervious area (EIA) using the runoff-volume calibration phase. This technique was used by Laenen (1980) with data from urban watersheds in Portland, Ore. Effective impervious areas were determined by varying impervious area (percent) in the calibration of storm-runoff volumes. For example, variation of the standard error of simulated volumes with percent imperviousness for Gandy Boulevard drainage ditch and Booker Creek stations (sites 4 and 6, fig. 1) is shown in figure 3. The effective impervious area (EIA) corresponds to the minimum values of standard error on the curves. For example, the EIA for the Gandy Boulevard watershed is 20 percent and that for Booker Creek is 18 percent. Effective impervious areas for all watersheds are listed in table 8 along with total impervious and hydraulically connected impervious areas. Effective impervious area (EIA) was less than the field-determined hydraulically connected impervious area (HCIA) at five sites and the same at the other four sites. Effective impervious areas listed in table 8 were used for model calibration.

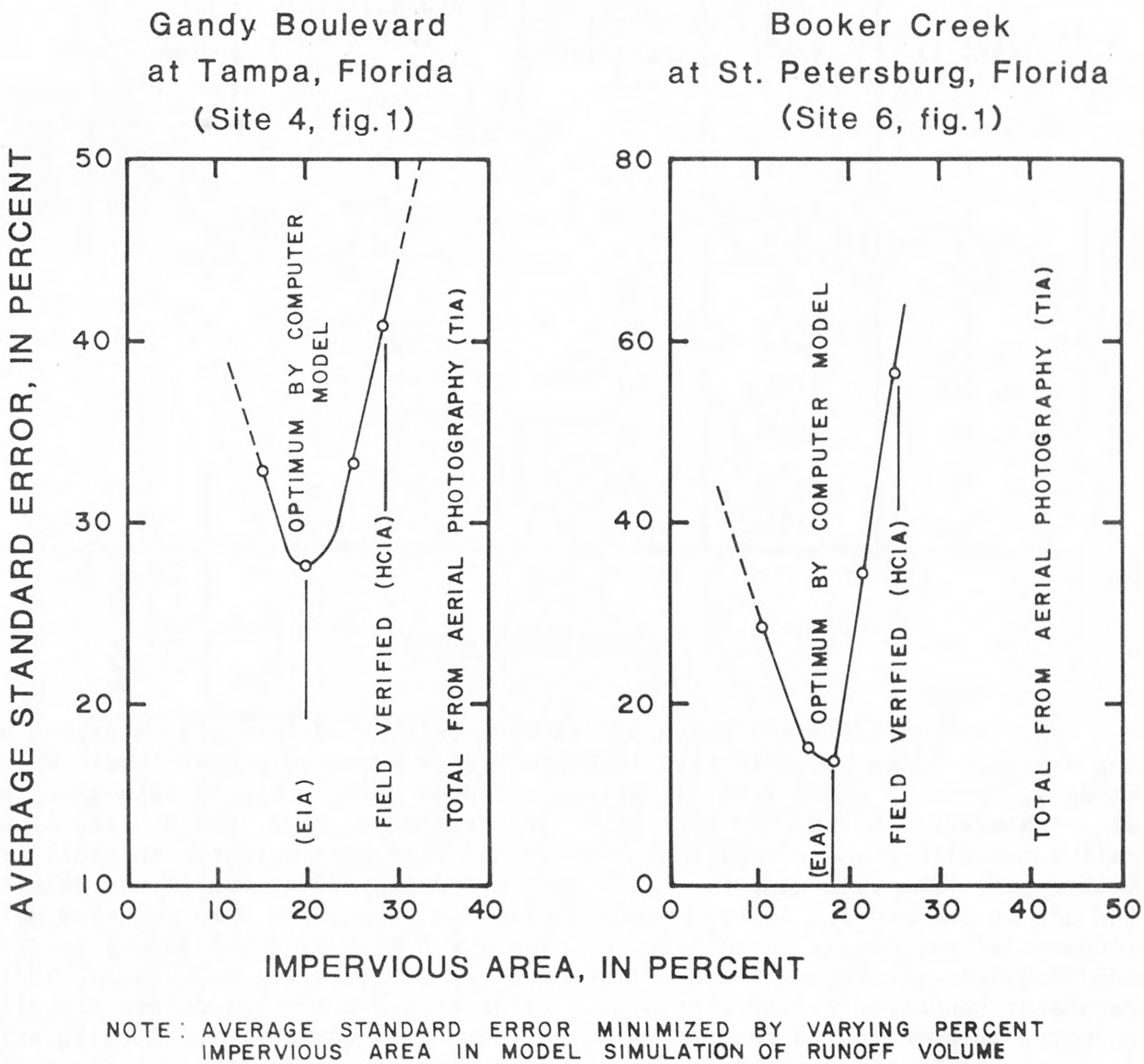

Figure 3.--Determination of effective impervious area.

Table 8.--Watershed drainage area, impervious area, hydraulically connected impervious area, and effective impervious area

Site No. (fig. 1)	Drainage area (mi^2)	Percentage of watershed area as		
		Total impervious area	Hydraulically connected impervious area	Effective impervious area
1	0.34	61	53	40
2	1.40	19	5.5	5.5
3	.51	27	9.0	9.0
4	1.29	38	28	20
5	1.79	36	26	20
6	3.45	41	26	18
7	1.89	32	25	25
8	1.72	38	26	26
9	.45	48	33	20

Model Calibration

The natural-basin and urban models were calibrated for each watershed using drainage areas and effective impervious area previously described. Watersheds 1, 2, 3, 5, and 9 (fig. 1) were calibrated using a single rain-gage record. Watersheds having two rain gages (watersheds 4, 6, 7, and 8, fig. 1) were calibrated with each rain gage separately and also with weighted rainfall from both gages. The rain gage that gave the best calibration results was selected for use in the model. Initial values for model parameters were selected using recommended guidelines in the User's Guide for U.S. Geological Survey Rainfall-Runoff Models--Revision of Open-File Report 74-33 (Carrigan and others, 1977). Parameter constraints that control the range within which parameters are allowed to vary, recommended in the User's Guide, were used during initial calibration. In final calibration trials, the constraints were relaxed until the slope of the plot of simulated and observed peak discharges and volumes (direct runoff) did not significantly differ from one and the correlation coefficient was significantly different from zero at the 5-percent level of significance. Model calibration results for the natural-basin and urban models are shown in table 9.

The factors used in selecting the best model were slope, correlation coefficient, and standard error from the regression of simulated and observed flood peaks and volumes (direct runoff) (table 9). Data having a perfect fit would have a slope equal to 1.0, a correlation coefficient of 1.0, and a standard error of zero. Using these criteria, the natural-basin model was selected for watersheds 4, 5, 6, and 9, and the urban model was selected for watersheds 1, 2, 3, 7, and 8.

Table 9.--Model calibration results

Site No. (fig. 1)	Watershed	Rain gage No. (fig. 1)	Model[1/]	Number of peaks	Period of record	EIA (percent)
1	Artic Street storm drain at Tampa, Fla.	1	N	18	1976-79	40
		1	U	18	1976-79	40
2	Kirby Street drainage ditch at Tampa, Fla.	2	N	20	1975-79	5.5
		2	U	16	1975-79	5.5
3	St. Louis Street drainage ditch at Tampa, Fla.	3	N	34	1975-79	9.0
		3	U	34	1975-79	9.0
4	Gandy Boulevard drainage ditch at Tampa, Fla.	10	N	28	1977-79	20
		10	U	28	1977-79	20
5	Allen Creek near Largo, Fla.	5	N	25	1975-79	20
		5	U	25	1975-79	20
6	Booker Creek at St. Petersburg, Fla.	6	N	13	1977-79	18
		6	U	15	1977-79	18
7	Bear Creek at St. Petersburg, Fla.	12	N	31	1975-79	25
		7	U	25	1975-79	25
8	Saint Joes Creek at St. Petersburg, Fla.	8	N	13	1975-78	26
		8	U	13	1975-78	26
9	Turner Street storm drain at Clearwater, Fla.	9	N	35	1976-79	20
		9	U	32	1976-79	20

Footnotes are at end of table.

Table 9.--Model calibration results--Continued

Site No. (fig. 1)	Optimized parameters 2/										Regression 3/		
	EVC	RR	BMSM	DRN	PSP	KSAT	RGF	KSW	TC	TP	Slope	R 4/	SE 5/
1	0.625	0.624	37.7	0.259	9.74	0.991	29.0	0.208	33.0	16.8	0.785	0.937	20
	.496	.346	28.9	.242	29.7	.996	49.3	.441	19.8	--	.818	.940	19
2	.628	.437	11.8	1.08	9.80	.165	16.5	2.93	100	42.1	.863	.925	23
	.630	.554	11.5	1.16	9.52	.177	15.9	4.95	165	--	1.07	.959	17
3	.759	.890	6.60	.988	3.94	.401	19.9	.218	26.1	13.2	.959	.914	33
	.684	.776	8.11	.845	3.29	.346	25.5	.240	22.7	--	1.00	.941	26
4	.707	.703	14.9	1.42	7.64	.531	17.5	1.33	90.5	44.1	.938	.941	22
	.648	.993	7.94	2.97	7.95	.567	19.4	2.09	92.9	--	.904	.931	23
5	.870	.914	4.25	1.68	3.33	.138	7.45	1.21	55.6	49.0	.981	.940	24
	.850	.934	4.34	1.09	2.46	.159	9.94	1.89	64.3	--	.958	.941	24
6	.797	.604	1.82	1.98	9.79	.998	19.8	.759	62.6	42.7	1.13	.974	19
	.781	.634	1.35	1.89	9.27	.497	29.9	.675	67.5	--	.920	.924	21
7	.775	.730	37.4	1.97	8.13	.123	9.14	.879	52.9	43.4	.944	.958	19
	.998	.857	2.21	.549	12.1	.196	3.21	.911	61.8	--	1.04	.970	14
8	.648	.516	1.10	2.21	14.4	2.98	59.9	2.00	113	71.2	.965	.970	20
	.618	.520	1.44	2.93	11.3	2.87	60.0	3.18	193	--	.974	.971	20
9	.664	.695	18.4	1.16	5.01	.380	8.35	.506	54.0	36.8	1.07	.936	31
	.602	.534	15.0	2.25	9.78	.741	14.0	.459	45.2	--	1.11	.889	34

1/ N = natural basin, U = urban.
2/ Parameters described in table 5.
3/ Linear regression of log observed peak discharge on log simulated peak discharge.
4/ Correlation coefficient.
5/ Standard error of estimate, average percent.

Evaluation of Rainfall-Runoff Model

The validity of model results depends on representative hydrologic input data, accurate watershed physical characteristics used for calibration, and the response of the model to storm rainfall expected beyond the range of calibration data. Three to 4 years of rainfall, runoff, and evaporation data were adequate to calibrate a model for each study site. Measurements of drainage area and hydraulically connected impervious area, based on detailed maps of the storm-drainage system and 1-foot contour maps of each watershed, are within the accuracy of the planimeter used (0.5 percent). The effective impervious area for each watershed was optimized in the first phase of calibration and is accurate to within 1.0 percent.

Storms that produced the highest peak discharge for the period of record were used in calibration of the models at three sites. The recurrence intervals of these peak discharges ranged from a little less than 5 years to slightly more than 5 years. Maximum peak discharge used in calibration of models at the other six sites had recurrence intervals that ranged from less than 2 years to more than 5 years.

Peak Discharge Simulation

The calibrated models were used with pan-evaporation data for Lake Padgett (site 14, fig. 1) and long-term rainfall records for the National Weather Service Tampa rainfall station (site 13, fig. 1) to simulate annual maximum discharges, 1906-52, for each watershed. A flood-frequency curve was determined for each watershed using the simulated annual maximum discharges in a log-Pearson frequency analysis. Flood discharges from these frequency curves were used in developing flood relations discussed in a following section of this report.

FLOOD-FREQUENCY ANALYSIS

A flood-frequency analysis was performed for each watershed using guidelines and procedures outlined by the Water Resources Council, Bulletin 17A (U.S. Water Resources Council, 1977). The analysis was done as follows:

1. A Pearson Type III distribution was developed for each watershed by determining the mean, standard deviation, and skew coefficient of the logarithms of the simulated annual maximum discharges, 1906-52;
2. Skew coefficients were generalized in linear-regression analysis relating station skew coefficients to watershed characteristics;
3. A weighted skew coefficient, based on the generalized and station skew coefficients and length of record, was used to compute the final flood-frequency curve for each site.

Pearson Type III Analysis

The Pearson Type III distribution with base 10 logarithmic transformation of annual maximum discharges was used to define station flood-frequency distributions.

U.S. Geological Survey computer program J407, used in making the statistical computations, includes many features described in Bulletin 17A, but requires judgment in analyzing historic floods, establishing screening levels for outliers, and interpreting the frequency curve.

Generalized Skew Coefficient

A flood-frequency curve based on generalized skew coefficients from records of nearby watersheds is considered more reliable than a station distribution based on actual records shorter than 25 years (U.S. Water Resources Council, 1977). When flood records of 25 to 100 years in length are available, a weighted skew should be used. For flood records over 100 years in length, the station skew should be used without weighting with a generalized skew.

Skew coefficients determined for each watershed were plotted on a map, but areal patterns were not discernible. Therefore, skew coefficients were regressed with base 10 logarithms of watershed characteristics resulting in the following relation:

$$\overline{G} = 0.604(DA)^{0.803} \tag{1}$$

where $\overline{G}$ = Generalized distribution skew coefficient;
DA = Watershed drainage area, in square miles;

The standard error of estimate is ±45 percent and the correlation coefficient is 0.83.

Weighted Skew Coefficient

Bulletin 17A of the U.S. Water Resources Council (WRC) recommends weighted station skew coefficients for flood-frequency analysis. The method recommended by the Council for calculation of the weighted station skew coefficient is as follows:

$$G_w = \frac{N-25}{75} \cdot G_s + \frac{100-N}{75} \cdot \overline{G} \tag{2}$$

where G_w = Weighted skew coefficient;
N = Number of simulated annual maximum discharges;
G_s = Estimate of station skew coefficient, based on observed records;
$\overline{G}$ = Generalized skew coefficient.

Flood-frequency curves were determined for each watershed using the weighted skew coefficient described above.

PEAK-FLOW REGIONALIZATION

Flood-frequency relations were determined for the study area by relating flood discharges of selected recurrence intervals to selected watershed characteristics. Regionalized relations provide a method for estimating flood-frequency data at ungaged sites and for improving estimates at gaged sites having short records.

Regression Analysis

The Statistical Analysis System (SAS), Barr and others (1976), was used in developing areal flood relations. The regression procedure used, MAXR, is a variation of the step-forward regression analysis method (Wesolowsky, 1976) for selecting independent variables. The procedure tests all combinations of independent variables and selects the best one, two, three, and so forth, parameter models. The final prediction equation for each recurrence interval depends on the significance of the independent parameters and the degree of improvement in the standard error of estimate.

Flood magnitudes for recurrence intervals of 2, 5, 10, 25, 50, and 100 years were regressed using the log transforms of land-use and urban development characteristics summarized in tables 5 and 6. Tampa Bay area flood-frequency relation coefficients are given in table 10 using the following equations:

$$Q_R = B_0 \cdot (DA)^{B_1} \cdot (BDF)^{B_2} \cdot (SLOPE)^{B_3} \cdot (DTENA + 0.01)^{B_4} \qquad (3)$$

for the 2-, 5-, and 10-year floods, and

$$Q_R = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3} \qquad (4)$$

for the 25-, 50-, and 100-year floods

where Q_R = Estimate of the T-year flood, in cubic feet per second:

B_0 = Regression constant that varies with T, recurrence interval (table 10);

DA = Drainage area, in square miles;

BDF = Basin development factor (dimensionless);

SLOPE = Channel slope, in feet per mile;

DTENA = Surface area of lakes, ponds, detention basins, and retention basins, as a percentage of drainage area;

B_1, B_2, B_3, and B_4 are exponents of the variables in the regression that vary with T, recurrence interval (table 10).

The measure of urban development (13-BDF) was found to be the most effective form of this variable in a nationwide urban flood-frequency study by Sauer and others (1981), and it was the form that gave the best results in the regressions for the 25-, 50-, and 100-year recurrence intervals in this study also.

Table 10.--Tampa Bay area urban watershed flood relations

Recurrence interval, T, in years	Annual exceedance probability	Regression constant B_0	Regression coefficients					Multiple correlation coefficient R	Standard error of estimate (percent)		
			(DA) B_1	(BDF) B_2	(13-BDF) B_2	(SLOPE) B_3	(DTENA + 0.01) B_4		Positive	Negative	Average
2	0.5	3.72	1.07	1.05	--	0.77	-0.11	0.96	38	28	33
5	0.2	7.94	1.03	0.87	--	0.81	-0.10	0.95	37	27	32
10	0.1	12.9	1.04	0.75	--	0.83	-0.10	0.94	41	29	35
25	0.04	214	1.13	--	-0.59	0.73	--	0.92	43	30	37
50	0.02	245	1.14	--	-0.55	0.74	--	0.91	47	32	39
100	0.01	282	1.16	--	-0.51	0.76	--	0.91	51	34	42

$$Q_R = B_0 \cdot (DA)^{B_1} \cdot (BDF)^{B_2} \cdot (SLOPE)^{B_3} \cdot (DTENA + 0.01)^{B_4} \quad \text{(equation 3)}$$

$$Q_R = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3} \quad \text{(equation 4)}$$

The multiple correlation coefficient and the standard error of estimate (table 10) indicate the goodness of fit of the estimate versus the observed value used in the regression. The plot of this comparison for the 25-year flood is shown in figure 4.

Accuracy of Flood Estimate

Accuracy of the flood estimate depends on time-sampling error and errors in the relation between flow and basin characteristics. The standard error of prediction of a flood estimate tends to vary widely from region to region and depends largely on the variability of annual flood events. Accuracy of estimates derived from regional flood relations can be expressed in terms of equivalent years of record (Hardison, 1971). However, in cases where prediction error is difficult to determine, the standard error of estimate of the regression can be used without affecting the validity of the weighting procedure (W. O. Thomas, Jr., written commun., 1980). In this study, the standard error of estimate of the regression was used to compute the equivalent years of record. Accuracy of the flood relation for estimating a flood discharge at an ungaged site, in terms of equivalent years of record, is as follows:

Recurrence interval, in years	Accuracy of estimate, in equivalent years
2	2
5	3
10	4
25	5
50	5
100	5

In a subsequent comparison of equivalent years of record of flood-frequency estimates based on rainfall-runoff modeling with estimates based on observed data, W. O. Thomas, Jr. (written commun., 1980) found that the equivalent years of record for simulated frequency curves were from 17.5 times larger at 2-year recurrence interval to 4.5 times larger at 100-year recurrence interval than the values using Hardison's (1971) equation for historical flood records. This comparison was made using data from Houston, Tex., but it may indicate that the equivalent years of record used in this report are conservative.

The accuracy appraisals shown determine the weight given the regression estimates when adjusting flood-frequency estimates at gaged sites and can be used to improve the estimate of flood magnitude based on the weighting of two independent estimates.

Evaluation of Tampa Bay Area Flood Relations

The multiple-correlation coefficient, R, is a measure of the closeness of association between the flood estimate and the watershed characteristics and varies from 0.96 for the 2-year flood to 0.91 for the 100-year flood (table 10).

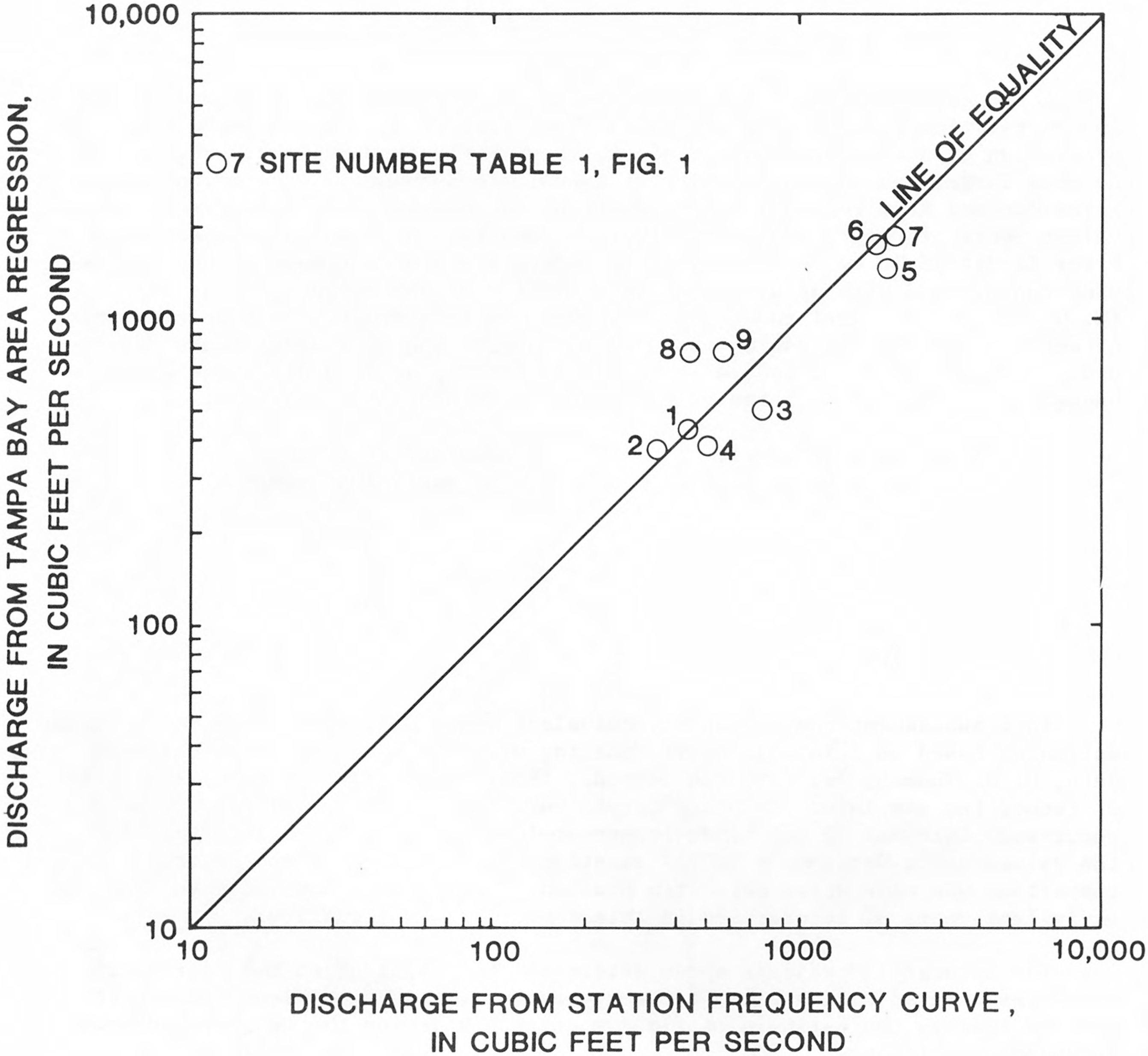

Figure 4.--Comparison of flood discharges from Tampa Bay area regression and station frequency curve, 25-year recurrence interval.

The square of the multiple-correlation coefficient, R^2, indicates the percentage of the variation in the dependent variable explained by the independent variables. This means that from 92 percent to 83 percent of the variation in the estimate of flood discharge is explained by the independent variables. Watershed drainage area (DA) and channel slope (SLOPE) are the most significant independent variables in both regression equations (equations 3 and 4). Basin development factor (BDF) in equation 3 and 13-BDF in equation 4 are the third significant independent variables. Area of lakes and retention or detention basins (DTENA + 0.01) was marginally significant in the estimate of 2-, 5-, and 10-year floods (equation 3) and was not used in the estimate of 25-, 50-, and 100-year floods (equation 4). The effect of storage on peak discharge would logically be less for the larger, high recurrence-interval floods.

The effect of measurement errors in watershed characteristics on flood estimates from the regionalized flood relation was evaluated by computing changes in flood estimates for 5 and 20 percent increases in the independent variables of the regression, changing one variable at a time while holding the remaining variables constant. Sensitivity of regression flood estimates to changes in each watershed characteristic is shown in table 11. As shown, a 5 or 20 percent increase in each variable results in the same change in the 10-year flood estimate, using equation 3, for Kirby Street drainage ditch and Booker Creek. The percentage change in the 25-year flood estimate using equation 4 is about the same as the change in the 10-year flood for each variable except DTENA, which was not used in equation 4, and for BDF. The change in the 25-year flood estimate with 5 and 20 percent increase in BDF is variable; relatively small when BDF is low and large when BDF is high. This is caused by the use of 13-BDF in the regression equation 4.

Limitations of Relations

Areal flood-frequency relations provided in this report should be considered as defining relations in the Tampa Bay area within the range of data used. Maximum and minimum values of watershed characteristics used in the estimating equation are summarized below. The ranges of watershed characteristics that determined the accuracy of the rainfall-runoff models and other characteristics that were not statistically significant in the regression, but affect hydrologic and hydraulic processes, are listed below:

Watershed characteristic	Range
Drainage area	0.34 to 3.45 mi^2
Noncontributing internal drainage	0 to 0.3 percent of watershed area
Soil-infiltration index	2.05 to 3.89 inches
Total impervious area	19 to 61 percent of watershed area
Hydraulically connected impervious area	5.5 to 53 percent of watershed area
Effective impervious area	5.5 to 40 percent of watershed area
Channel slope	4.6 to 23.6 ft/mi
Lake and detention basin area	0 to 3.5 percent of watershed area
Basin development factor	3 to 12 (dimensionless)

Table 11.--Effect of measurement errors in watershed characteristics on flood estimates

Watershed characteristic		Percent change in regionalized flood estimate for 5 and 20 percent increase in watershed parameter			
		10-year flood[1/]		25-year flood[2/]	
		5 percent	20 percent	5 percent	20 percent
Kirby Street drainage ditch					
Drainage area (DA)	1.40	5	21	6	23
Basin development factor (BDF)	3	4	15	1	4
Channel slope (SLOPE)	8.1	4	16	4	14
Lake and detention/retention basin area (DTENA)	3.5	0	-2	-	-
Booker Creek					
Drainage area (DA)	3.45	5	21	6	23
Basin development factor (BDF)	10	4	15	11	91
Channel slope (SLOPE)	7.1	4	16	4	14
Lake and detention/retention basin area (DTENA)	.9	0	-2	-	-

1/ Equation 3, $12.9 \cdot (DA)^{1.04} \cdot (BDF)^{0.75} \cdot (SLOPE)^{0.83} \cdot (DTENA + 0.01)^{-0.10}$

2/ Equation 4, $214 \cdot (DA)^{1.13} \cdot (13\text{-}BDF)^{-0.59} \cdot (SLOPE)^{0.73}$

In those areas where the watershed characteristics are outside the range used in this study, the flood estimate computed by the regressions may not be representative of the actual discharge.

In order to evaluate the use of the Tampa Bay area urban flood relations in areas where the watershed characteristics were outside the range used in the regression analysis, a comparison was made with estimates based on a nationwide study of urban flood frequency (Sauer and others, 1981).

The nationwide urban flood regression equations are based on multiple regression analyses of 199 gaged watersheds in urban areas throughout the conterminous United States with a wide range of watershed and climatic characteristics. Variables used in the equations and the range are as follows:

Variable	Range	
	Minimum	Maximum
CONTDA - The contributing drainage area, in square miles. In urban areas, drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing CONTDA.	0.2	100
SLOPE - The main channel slope, in feet per mile, measured between points that are 10 percent and 85 percent of the main channel length upstream from the study site. For sites where SLOPE is greater than 70 ft/mi, use 70 ft/mi in the equations.	3.0	500
I2H2Y - Rainfall intensity, in inches, for the 2-hour, 2-year occurrence. Determined from USWB Technical Paper 40.	0.2	2.8
STORAGE- The percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands. In-channel storage, of a temporary nature, is not included in the computation of STORAGE.	0	11
BDF - A basin development factor that is computed by subdividing the basin into thirds (upper, middle, and lower) and determining the prevalent drainage system characteristics as shown in table 5.	0	12
IMP_A - The percentage of the drainage basin occupied by impervious surfaces.	3	50

A seven-variable regression equation was developed that had the following form:

$$UQx = k \cdot (CONTDA)^{a} \cdot (SLOPE)^{b} \cdot (I2H2Y+3)^{c} \cdot (STORAGE+8)^{d} \cdot (13-BDF)^{e} \cdot (IMP\_A)^{f} \cdot (RQx)^{g} \qquad (5)$$

where UQx = Peak discharge for the urban watershed for recurrence interval, x. That is, UQ2 = 2-year urban peak discharge, UQ5 = 5-year, and so forth;

k = Regression constant that varies with x, recurrence interval (table 12);

RQx = Peak discharge for an equivalent rural drainage basin in the same hydrologic area as the urban basin. The equivalent rural discharge RQx should be for the same recurrence interval, x, as is desired for the urban discharge. That is, if the 100-year urban discharge, UQ100, is being computed, then the 100-year rural discharge, RQ100, should be used in the equation. For this study, equivalent rural discharges were computed from Seijo and others (1979);

a, b, c, d, e, f, g = Exponents of the variables in the regression that vary with x, recurrence interval (table 12).

The average multiple regression correlation coefficient is 0.962 and the average standard error of regression is ±40 percent.

A simplified version of the regression has three variables, as shown in table 13.

Table 12.--Nationwide urban flood estimates, seven-variable regression coefficients

Recurrence interval, x, in years	2	5	10	25	50	100
Regression constant, k	2.35	2.70	2.99	2.78	2.67	2.50
Exponents, a	.41	.35	.32	.31	.29	.29
b	.17	.16	.15	.15	.15	.15
c	2.04	1.86	1.75	1.76	1.74	1.76
d	-.65	-.59	-.57	-.55	-.53	-.52
e	-.32	-.31	-.30	-.29	-.28	-.28
f	.15	.11	.09	.07	.06	.06
g	.47	.54	.58	.60	.62	.63

$$UQx = k \cdot (CONTDA)^{a} \cdot (SLOPE)^{b} \cdot (I2H2Y + 3)^{c} \cdot (STORAGE + 8)^{d} \cdot (13\text{-}BDF)^{e} \cdot (IMP\_A)^{f} \cdot (RQx)^{g} \quad \text{(equation 5)}$$

Table 13.--Nationwide urban flood estimates, three-variable regression coefficients

Recurrence interval, x, in years	2	5	10	25	50	100
Regression constant, k	13.2	10.6	9.51	8.68	8.04	7.70
Exponents, a	.21	.17	.16	.15	.15	.15
b	-.43	-.39	-.36	-.34	-.32	-.32
c	.73	.78	.79	.80	.81	.82

$$UQx = k \cdot (CONTA)^{a} \cdot (13\text{-}BDF)^{b} \cdot (RQx)^{c} \quad \text{(equation 6)}$$

The average multiple regression correlation coefficient is 0.955 and the average standard error of regression is ±43 percent.

Comparisons of the 10- and 50-year flood estimates for the study sites using the Tampa Bay area regressions and the seven-variable and three-variable nationwide urban flood equations are shown in figures 5 and 6, respectively. The plots of the seven-variable nationwide urban flood estimates compare better with the Tampa Bay area flood estimates than the three-variable nationwide urban

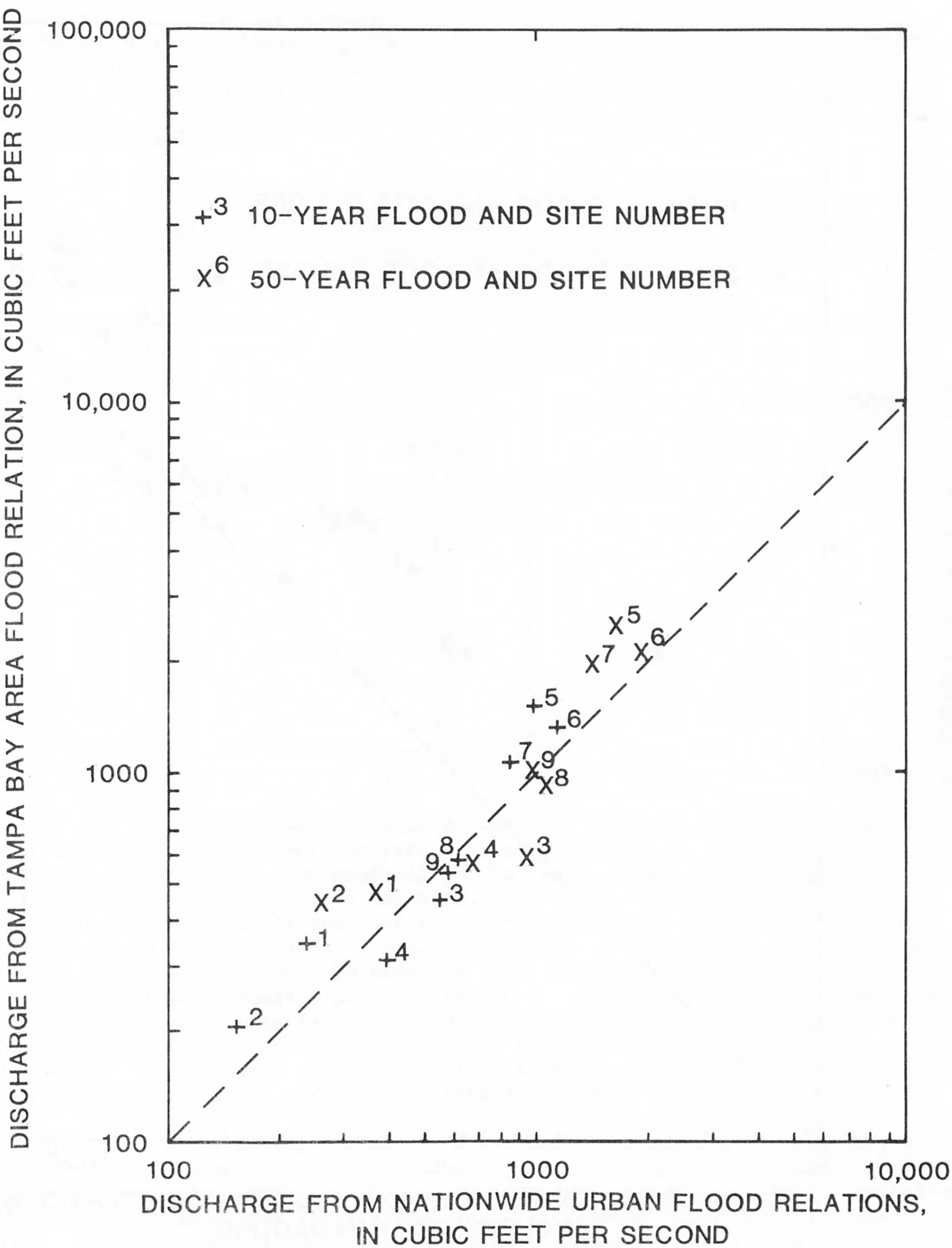

Figure 5.--Comparison of flood estimates using Tampa Bay area and seven-variable nationwide urban flood relations.

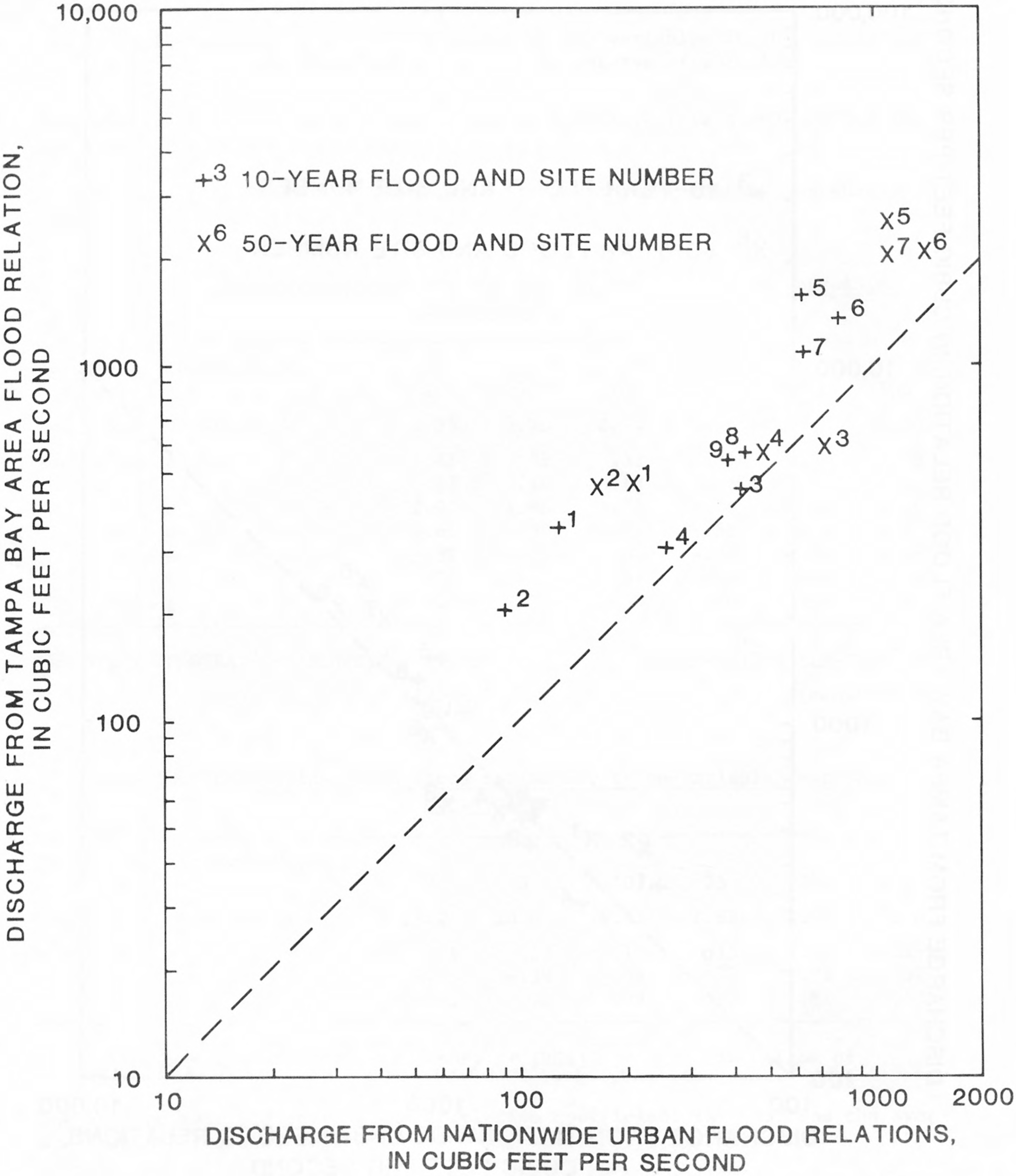

Figure 6.--Comparison of flood estimates using Tampa Bay area and three-variable nationwide urban flood relations.

flood estimates. The correlation coefficient and standard error of estimate of regression of the nationwide estimate against the Tampa Bay area estimate for all recurrence intervals are listed in table 14. In all cases, the regression of seven-variable nationwide urban against the Tampa Bay area flood estimate has a higher correlation coefficient and lower standard error of estimate than the three-variable model.

Table 14.--Correlation coefficient and standard error of estimate from nationwide urban flood estimates regressed against the Tampa Bay area flood estimate

Recurrence interval, in years	Nationwide urban flood regressions			
	Seven-variable model		Three-variable model	
	Correlation coefficient	Standard error (percent)	Correlation coefficient	Standard error (percent)
2	0.97	19	0.94	26
5	.95	23	.92	30
10	.93	26	.90	33
25	.89	33	.86	38
50	.87	35	.85	40
100	.85	38	.82	43

From this analysis, we can conclude that the flood estimate at an ungaged urban watershed in the Tampa Bay area with watershed characteristics outside the range used in the regression analysis can be improved by using the seven-variable nationwide urban flood relation (equation 5). Use of these relations on rural watersheds has not been tested, but a comparison was made with flood estimates computed at the study sites by the rural watershed regional regression developed by Seijo and others (1979). To simulate rural conditions for the 2-, 5-, and 10-year floods with equation 3, the value of BDF was set equal to one (BDF equal to zero could not be used to compute the flood estimate). The simulated rural flood estimate was computed using BDF equal to zero in equation 4 for the 25-, 50-, and 100-year floods. The flood estimates computed by the rural and urban equations are listed in table 15 and plotted in figure 7.

The Tampa Bay area regression flood estimates for the 2-, 5-, and 10-year floods for rural conditions using equation 3 are lower than the regional rural watershed regression estimate for site numbers 3-9, whereas the urban regression estimates are higher than the regional rural regression estimates for sites 1 and 2. The soil-infiltration index for sites 1 and 2 is 3.89 inches while all other sites are in the 2.05-inch soil-infiltration index area. This seems to indicate that equation 3 does not adequately compensate for different soil-infiltration rates in rural watersheds and, on the average, may underestimate the 2-, 5-, and 10-year floods.

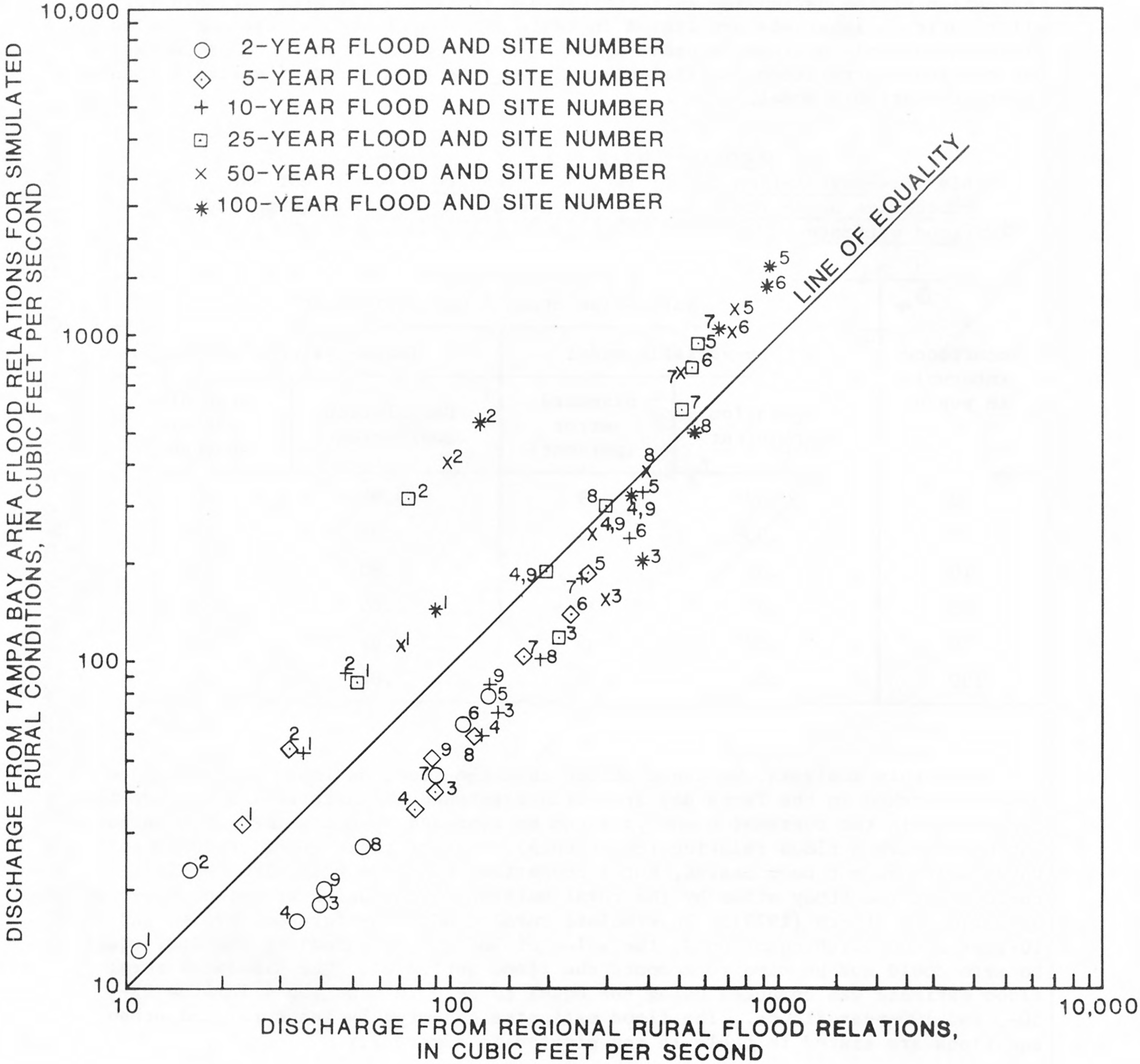

Figure 7.--Comparison of flood estimates using Tampa Bay area flood relations with simulated rural conditions and regional rural flood relations.

Urban regression estimates of the 25-, 50-, and 100-year floods for rural conditions using equation 4 are approximately equal to or higher than the rural regression estimate except for site number 3. Equation 4 seems to generally overestimate the 25-, 50-, and 100-year floods, especially at sites with a high percentage of the area in lakes or detention storage.

This comparison is not conclusive because the rural regional flood estimates are based on data from watersheds larger than 9 mi^2, whereas the urban regressions are based on data from watersheds that ranged in size from 0.34 to 3.45 mi^2.

The Tampa Bay area urban flood relations should be used with caution in rural areas, especially where the watershed characteristics are outside the limits of the data used in the regression analysis.

The increase in flood discharge expected as a rural watershed is developed is shown by the graphs of the 2-, 5-, 10-, 25-, 50-, and 100-year floods in figure 8. The change in peak discharge is expressed as a ratio of flood magnitudes equal to the discharge computed with an assumed BDF divided by the discharge computed for the same watershed with simulated rural conditions using equations 3 and 4 as listed in table 15. The ratio of flood magnitudes for the 2-, 5-, and 10-year floods computed using equation 3 is very sensitive to degree of urban development. The ratio increases approximately linearly to a maximum of 14.2, 8.7, and 6.4 at BDF equal to 12 for the 2-, 5-, and 10-year floods, respectively. These ratios are possibly exaggerated because equation 3 may underestimate floods under rural conditions (fig. 7).

The ratio of flood magnitudes for the 25-, 50-, and 100-year floods, computed using equation 4, is much lower and almost linear until BDF increases to about 9 or 10. For increase of BDF above 10, the ratio increases exponentionally. The ratio of flood magnitudes is approximately 2 at BDF equal to 9 and then rapidly increases to 4.5, 4.2, and 3.7 at BDF equal to 12 for the 25-, 50-, and 100-year floods, respectively. These ratios may be more representative of the effect of urban development on flood discharges in small watersheds in the Tampa Bay area.

DETERMINATION OF THE MAGNITUDE AND FREQUENCY OF FLOODS

Regionalized flood relations are used to estimate flood discharges for ungaged sites and to improve flood estimates for gaged sites. Flood discharges computed using station and weighted skew coefficients and the Tampa Bay area flood relations for various recurrence intervals are summarized in table 16. For gaged sites, the best estimate of the T-year flood discharge is the weighted estimate value shown in table 16. For ungaged sites on the same stream as a gaged site, the regionalized estimate can be improved by using the gaged-site data if drainage area of the ungaged site is greater than one-half or less than twice that of the gaged site. The regionalized estimate would be used for ungaged sites outside the drainage area criteria for adjustment with gaged-site data.

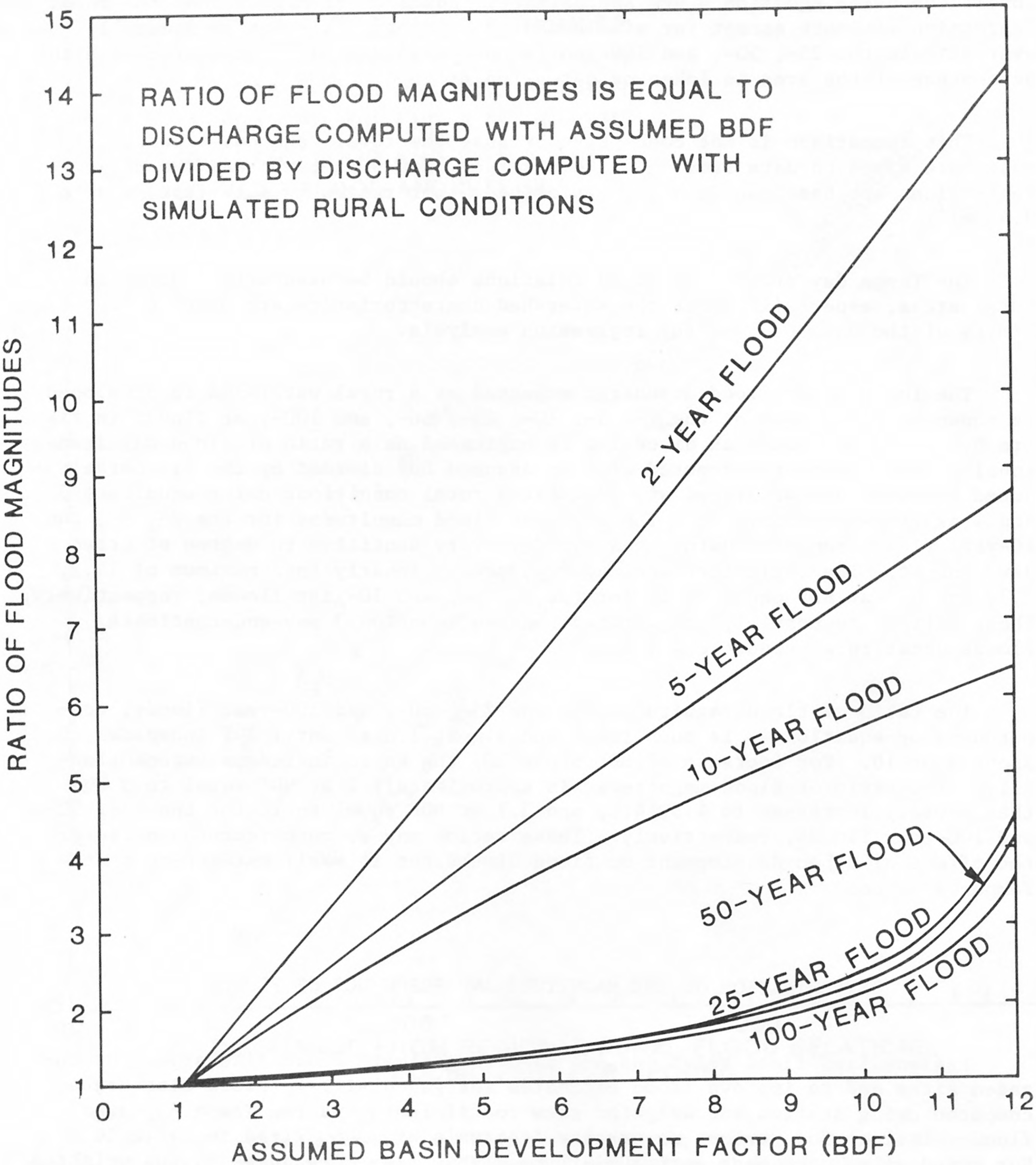

Figure 8.--Effect of urban development on Tampa Bay area flood estimates.

Table 15.--Comparison of flood estimates from Tampa Bay area flood relations with simulated rural conditions and regional rural flood relations

Site No. (fig. 1)	Watershed	Recurrence interval (years)	Flood estimate (ft^3/s)	
			Tampa Bay area flood relations 1/	Regional rural flood relations 2/
1	Artic Street storm drain at Tampa, Fla.	2	13	11
		5	32	23
		10	53	35
		25	87	52
		50	112	70
		100	145	90
2	Kirby Street drainage ditch at Tampa, Fla.	2	23	16
		5	54	32
		10	92	48
		25	316	74
		50	410	98
		100	546	124
3	St. Louis Street drainage ditch at Tampa, Fla.	2	18	40
		5	41	91
		10	70	140
		25	119	216
		50	155	293
		100	202	393
4	Gandy Boulevard drainage ditch at Tampa, Fla.	2	16	34
		5	36	78
		10	60	122
		25	190	198
		50	248	270
		100	323	360
5	Allen Creek near Largo, Fla.	2	79	131
		5	188	262
		10	327	380
		25	904	572
		50	1,190	738
		100	1,627	948
6	Booker Creek at St. Petersburg, Fla.	2	64	110
		5	140	233
		10	240	351
		25	795	543
		50	1,040	716
		100	1,407	930

Footnotes are at end of table.

Table 15.--Comparison of flood estimates from Tampa Bay area flood relations with simulated rural conditions and regional rural flood relations--Continued

Site No. (fig. 1)	Watershed	Recurrence interval (years)	Flood estimate (ft^3/s)	
			Tampa Bay area flood relations 1/	Regional rural flood relations 2/
7	Bear Creek at St. Petersburg, Fla.	2	45	90
		5	105	168
		10	180	250
		25	594	512
		50	782	512
		100	1,050	666
8	Saint Joes Creek at St. Petersburg, Fla.	2	27	54
		5	60	
		10	102	186
		25	300	295
		50	392	398
		100	517	526
9	Turner Street storm drain at Clearwater, Fla.	2	20	41
		5	49	88
		10	85	131
		25	191	203
		50	249	270
		100	330	356

1/ $Q_R = B_0 \cdot (DA)^{B_1} \cdot (BDF)^{B_2} \cdot (SLOPE)^{B_3} \cdot (DTENA)^{B_4}$ (equation 3)

BDF = 1: 2-, 5-, and 10-year floods.

$Q_R = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3}$ (equation 4)

BDF = 0: 25-, 50-, and 100-year floods.

2/ $Q_R = C_R\ C_G\ (DA)^{B_1}\ (SL)^{B_2}\ (LK)^{B_3}$ (Seijo and others, 1979, equation 5).

Note: 0.01 added to percent lakes (LK).

Table 16.--Comparison of station, regionalized, and weighted flood discharges

Site No. (fig. 1)	Station name	Method of discharge computation	Skew coefficient	Peak discharge, in cubic feet per second, for indicated recurrence interval, in years					
				2	5	10	25	50	100
1	Artic Street storm drain at Tampa, Fla.	Station skew	0.138	253	319	361	413	451	488
		Weighted skew[1]	.256	252	318	361	416	456	496
		Regionalized estimate[2]		183	275	344	395	459	543
		Weighted estimate[3]		249	316	360	415	456	498
2	Kirby Street drainage ditch at Tampa, Fla.	Station skew	1.098	73	139	210	348	500	710
		Weighted skew[1]	.976	74	141	210	336	468	642
		Regionalized estimate[2]		74	140	209	370	476	631
		Weighted estimate[3]		74	141	210	337	468	641
3	St. Louis Street drainage ditch at Tampa, Fla.	Station skew	.384	216	385	533	767	981	1,230
		Weighted skew[1]	.467	216	386	533	766	978	1,220
		Regionalized estimate[2]		244	358	450	545	634	754
		Weighted estimate[3]		217	385	529	756	961	1,200
4	Gandy Boulevard drainage ditch at Tampa, Fla.	Station skew	1.122	194	286	369	502	627	777
		Weighted skew[1]	1.082	197	290	368	489	596	721
		Regionalized estimate[2]		161	243	313	384	473	596
		Weighted estimate[3]		195	288	366	484	590	716
5	Allen Creek near Largo, Fla.	Station skew	.482	779	1,150	1,450	1,870	2,230	2,630
		Weighted skew[1]	.633	760	1,140	1,460	1,950	2,390	2,910
		Regionalized estimate[2]		705	1,150	1,550	1,600	2,020	2,680
		Weighted estimate[3]		758	1,140	1,460	1,930	2,370	2,900
6	Booker Creek at St. Petersburg, Fla.	Station skew	1.619	717	1,030	1,340	1,860	2,380	3,020
		Weighted skew[1]	1.516	719	1,030	1,340	1,860	2,380	3,020
		Regionalized estimate[2]		718	1,040	1,350	1,900	2,340	3,000
		Weighted estimate[3]		719	1,030	1,340	1,860	2,380	3,020

Footnotes are at end of table.

Table 16.--Comparison of station, regionalized, and weighted flood discharges--Continued

Site No. (fig. 1)	Station name	Method of discharge computation	Skew coefficient	Peak discharge, in cubic feet per second, for indicated recurrence interval, in years					
				2	5	10	25	50	100
7	Bear Creek at St. Petersburg, Fla.	Station skew	0.952	749	1,160	1,520	2,120	2,670	3,340
		Weighted skew 1/	.922	747	1,160	1,520	2,130	2,690	3,380
		Regionalized estimate 2/		559	843	1,090	1,800	2,190	2,760
		Weighted estimate 3/		738	1,140	1,500	2,120	2,670	3,350
8	Saint Joes Creek at St. Petersburg, Fla.	Station skew	.916	218	292	352	439	514	598
		Weighted skew 1/	1.071	219	293	352	438	511	593
		Regionalized estimate 2/		306	448	374	717	877	1,100
		Weighted estimate 3/		222	298	359	446	522	608
9	Turner Street storm drain at Clearwater, Fla.	Station skew	.547	212	335	439	597	737	898
		Weighted skew 1/	.307	214	338	436	582	707	847
		Regionalized estimate 2/		271	429	546	872	1,020	1,230
		Weighted estimate 3/		216	341	440	592	718	860

1/ Weighted skew coefficient, $G_W = \frac{N-25}{75} \cdot G_S + \frac{100-N}{75} \cdot \bar{G}$ (equation 2).

2/ Equation 3 for 2-, 5-, and 10-year floods. Equation 4 for 25-, 50-, and 100-year floods.

3/ Weighted estimate, $\text{Log } Q_W = \frac{N_1 (\text{Log } Q_G) + N_2 (\text{Log } Q_{RG})}{N_1 + N_2}$ (equation 7).

Gaged Sites

Flood estimates for gaged sites with 10 or more years of record can be determined from a method suggested by the U.S. Water Resources Council (1977) as follows:

$$\text{Log } Q_W = \frac{N_1 (\text{Log } Q_G) + N_2 (\text{Log } Q_{RG})}{N_1 + N_2} \qquad (7)$$

where Q_W = Weighted estimate of the T-year flood at a gaged site, in cubic feet per second;

Q_G = Estimate of the T-year flood at a gaged site from the adjusted station frequency distribution using the weighted generalized skew, in cubic feet per second;

N_1 = Number of annual floods for the gaged site, in years;

Q_{RG} = Regional flood estimate for the gaged site, computed from equation 3 or 4, or obtained from table 16, in cubic feet per second;

N_2 = Accuracy of the regional flood estimate, in equivalent years.

The accuracy of the weighted estimate, Q_W, in equivalent years of record, is equal to N_1 plus N_2 provided the estimate Q_{RG} and the estimate Q_G are independent. A flood discharge estimated by regional regression tends to be independent of the estimate obtained from the station frequency distribution. For situations where the estimates are not independent, accuracy is reduced in proportion to the degree of correlation of the estimates.

Ungaged Sites

Flood discharges for ungaged sites are determined by using the appropriate value of drainage area, basin development factor, and channel slope with areal flood relation coefficients given in table 10.

The regional estimate for an ungaged site can be improved if the site is located near a gaging station with at least 10 years of record. A coefficient obtained by using the ratio of Q_W to Q_{RG} (as defined for gaged sites) and drainage areas of the gaged and ungaged sites are used to adjust the regional estimates.

The adjusted estimate, Q_U, for an ungaged site can be determined from equation 8 or 9 as follows:

$$Q_U = Q_{RU} \left[\left(\frac{Q_W}{Q_{RG}} - 1\right) \cdot \left(\frac{2A_U - A_G}{A_U}\right) + 1 \right] \qquad (8)$$

For gaged sites downstream from ungaged sites

$$Q_U = Q_{RU} \left[\left(\frac{Q_W}{Q_{RG}} - 1\right) \cdot \left(\frac{2A_G - A_U}{A_U}\right) + 1 \right] \qquad (9)$$

For gaged sites upstream from ungaged sites where Q_{RU} = Regional estimate for the ungaged site from the regression equation, in cubic feet per second;

Q_W = Weighted estimate of the T-year flood at the gaged site, in cubic feet per second;

Q_{RG} = Regional flood estimate for the gaged site from the regression equation, in cubic feet per second;

A_U = Drainage area for the ungaged site, in square miles;

A_G = Drainage area for the gaged site, in square miles.

For ungaged sites, the accuracy of the adjusted estimate, Q_U, in equivalent years of record, N, is not the sum of the accuracy of each estimate, but some figure of accuracy greater than N_2 but less than $N_1 + N_2$. If the regional estimate is the only estimate available, then the accuracy of the estimate in equivalent years of record is equal to N_2.

Illustrated Examples

The procedure for estimating flood discharge for a desired recurrence interval is outlined below.

Category	Method used	Explanation	Accuracy, in equivalent years, N
Gaged sites; having 10 or more years of record.	Q_W; equation 7	Gaged site station data weighted with regional estimate.	$N = N_1 + N_2$
Gaged sites; having less than 10 years of record.	See ungaged sites.	--	--
Ungaged sites; located near a gaged site.	Q_U; equation 8 or 9	Regionalized estimate at ungaged site adjusted by ratio of weighted station data to regionalized estimate at gaged site.	$N_2 < N < (N_1 + N_2)$
Ungaged sites; not located near a gaged site and watershed characteristics within range of regression analysis.	Q_{RU}; equations 3 and 4	Regionalized estimate is the best estimate available.	$N = N_2$
Watershed characteristics outside range of regression analysis.	Q_{RU}; equations 3 and 4 UQx; equation 5	Regionalized estimate weighted with nationwide urban flood estimate.	

Following are four examples that illustrate methods described in this report.

Example 1: Assume a discharge is needed for the 25-year flood on Bear Creek at Gulfport Boulevard in Gulfport, Pinellas County.

(1) First, drainage area, basin development factor, and channel slope are determined from available maps.

Drainage area (DA) = 2.80 mi^2
Basin development factor (BDF) = 10
Channel slope (SLOPE) = 10.9 ft/mi

Calculate Q_{RU} by equation 4.

$$Q_{RU} = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3} \quad (4)$$

(B_0, B_1, B_2, B_3 from table 10)

$$= 214 \cdot (2.80)^{1.13} \cdot (3)^{-0.59} \cdot (10.9)^{0.73}$$

$$= 2{,}050\ ft^3/s.$$

(2) The Bear Creek gaging station (02308773, site 7, fig. 1) is located 1-1/2 miles upstream and has a drainage area of 1.89 mi^2.

(a) Compute drainage area ratio (r) to determine if site is within the limits for weighting the estimate with the gaging-station data.

$$r = A_G/A_U$$
$$= 1.89/2.80$$
$$= 0.68.$$

The ratio A_G/A_U is greater than one-half and less than two, therefore, station flood data can be used to adjust the flood estimate at the ungaged site.

(b) Adjust regression estimate by the gaged-site data from table 16 using equation 9 (gage site upstream from ungaged site).

$$Q_U = Q_{RU}\left[\left(\frac{Q_W}{Q_{RG}} - 1\right) \cdot \left(\frac{2A_G - A_U}{A_U}\right) + 1\right] \quad (9)$$

$$Q_U = 2{,}050\left[\left(\frac{2{,}120}{1{,}800} - 1\right) \cdot \left(\frac{2(1.89) - 2.8}{2.8}\right) + 1\right]$$

$$Q_U = 2{,}180\ ft^3/s.$$

Example 2: Determine the 50-year flood discharge for a proposed road crossing Rice Creek in Hillsborough County by an extension of Symmes Road eastward from U.S. 301. The watershed has a soil-infiltration index of 2.05 inches, and aerial photographs taken in 1979 indicated that urban development was insignificant, consisting of trailers on 1-acre lots in the area east of

Balm-Riverview Road. The rest of the area is in pasture and fish farms. Fish ponds and lakes have a total surface area of 39 acres or 2.6 percent of the watershed.

(1) Calculate Q_{RU} by equation 4.

Drainage area (DA) = 2.02 mi^2
Basin development factor (BDF) = 0
Channel slope (SLOPE) = 13.5 ft/mi

$$Q_{RU} = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3} \qquad (4)$$

$$Q_{RU} = 245 \cdot (2.02)^{1.14} \cdot (13)^{-0.55} \cdot (13.5)^{0.74}$$

$$Q_{RU} = 914 \text{ ft}^3/\text{s}.$$

This is the estimated 50-year flood discharge under present watershed development. Within the expected life of the proposed crossing structure, this watershed will probably be completely developed because of its proximity to Interstate-75 Bypass.

The next example is for this site with development projected in the year 2000.

Example 3: Determine the 50-year flood discharge for the above site assuming full development. The drainage area and the channel slope are assumed to remain the same. The basin development factor will increase from zero under present conditions (1981) to 9 in the year 2000, assuming all new development will be completely sewered and have curb and gutter streets and the main channel will be improved but not lined.

(1) Calculate Q_{RU} by equation 4.

Drainage area (DA) = 2.02 mi^2
Basin development factor (BDF) = 9
Channel slope (SLOPE) = 13.5 ft/mi

$$Q_{RU} = B_0 \cdot (DA)^{B_1} \cdot (13\text{-}BDF)^{B_2} \cdot (SLOPE)^{B_3} \qquad (4)$$

$$Q_{RU} = 245 \cdot (2.02)^{1.14} \cdot (4)^{-0.55} \cdot (13.5)^{0.74}$$

$$Q_{RU} = 1{,}750 \text{ ft}^3/\text{s}.$$

(2) If the new developments were designed with swale type road drainage as much as possible, the basin development factor could be reduced from 9 to 6. The peak discharge for the site would then be:

$$Q_{RU} = 245 \cdot (2.02)^{1.14} \cdot (7)^{-0.55} \cdot (13.5)^{0.74}$$

$$Q_{RU} = 1{,}280 \text{ ft}^3/\text{s}.$$

Example 4: The 100-year flood discharge is required for a flood insurance base flood elevation in northwest Hillsborough County. This area contains many lakes and swampy areas, and the percentage area of lakes, detention and retention basins is beyond the range used in the regression analysis in this study. The estimate of the flood discharge will be improved by the estimate computed by the seven-variable nationwide urban runoff regression.

The data required for the flood estimates are as follows:

Drainage area (DA), (CONTDA) -------------------------	2.65
Channel slope (SLOPE) --------------------------------	2.87
2-hour, 2-year rainfall (I2H2Y) ----------------------	2.9
Percentage area in lakes and swamps (STORAGE) --------	29.0
Percentage area in lakes, detention, and retention basins (DTENA) -------------------------------------	13.9
Basin development factor (BDF) -----------------------	2
Percentage impervious area (IMP_A) -------------------	5
Rural watershed regression flood estimate (RQ_{100}) ----	112

(a) Compute the 100-year estimate using the regionalized equation (table 10, equation 4).

$$Q_{100} = 282 \cdot (DA)^{1.16} \cdot (13\text{-}BDF)^{-0.51} \cdot (SLOPE)^{0.76}$$
$$= 282 \cdot (2.65)^{1.16} \cdot (11)^{-0.51} \cdot (2.87)^{0.76}$$
$$= 573 \text{ ft}^3/\text{s}.$$

(b) Compute the 100-year estimate using the seven-variable nationwide urban flood relation (table 12, equation 5).

$$UQ100 = 2.50 \cdot (CONTDA)^{0.29} \cdot (SLOPE)^{0.15} \cdot$$
$$(I2H2Y + 3)^{1.76} \cdot (STORAGE + 8)^{-0.52} \cdot$$
$$(13\text{-}BDF)^{-0.28} \cdot (IMP\_A)^{0.06} \cdot (RQ_{100})^{0.63}$$
$$= 2.50 \cdot (2.65)^{0.29} \cdot (2.87)^{0.15} \cdot (5.9)^{1.76} \cdot$$
$$(37.0)^{-0.52} \cdot (11)^{-0.28} \cdot (5)^{0.06} \cdot (112)^{0.63}$$
$$= 149 \text{ ft}^3/\text{s}.$$

At present, there are no guidelines available for determining the weight given to either estimate for computing the weighted average discharge. Judgment based on knowledge of the area and flood characteristics of similar watersheds will have to be used in making the weighted estimate.

In this example, the authors believe that the nationwide urban flood estimate should be given more weight than the Tampa Bay area urban regionalized estimate. The percentage of area in lakes and swamps is far beyond the data used in this study, and the nationwide urban flood relation does take into account local conditions by using the rural watershed regional estimate (RQx).

SUMMARY AND CONCLUSIONS

Rainfall, runoff, and water-quality data were collected between 1975 and 1980 on nine urban watersheds in the Tampa Bay area that range in size from 0.34 mi^2 to 3.45 mi^2. Rainfall and runoff recorded at 5-minute intervals during selected storms and daily rainfall for each watershed are stored in WATSTORE data files. In addition, selected storm and daily rainfall at the National Weather Service rain gage at Tampa, Fla., from 1906 to 1952 and daily pan-evaporation data at Lake Padgett near Lutz, Fla., from 1971 to 1979 are stored in WATSTORE.

The U.S. Geological Survey rural and urban watershed rainfall-runoff models were calibrated for each watershed, and the historical National Weather Service rainfall record at Tampa was used to simulate annual peak discharges for 1906 to 1952. A generalized skew coefficient was used in a log Pearson type III frequency analysis to compute the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The 2-, 5-, and 10-year flood discharges were related to drainage area, basin development factor, channel slope, and percentage of area in lakes, detention, and retention basins. The 25-, 50-, and 100-year flood discharges were related to drainage area, basin development factor, and channel slope. The average standard error of estimate ranges from 32 percent for the 5-year flood to 42 percent for the 100-year flood, and the average multiple correlation coefficient is 0.93. Error analysis indicates that the regression estimate for the 25-, 50-, and 100-year floods are more sensitive to changes in basin development factor when the basin development factor is high. This is due to the form used in the regression, (13-BDF).

In those urban areas where the watershed characteristics and basin development factors are outside the range used in this study, the flood estimate can be improved by comparison with the estimate computed by a seven-variable nationwide urban flood regression (Sauer and others, 1981).

The use of the urban flood relations on small rural watersheds has not been tested, and a comparison of flood estimates computed at the study sites with simulated rural conditions and the regional rural watershed relations given by Seijo and others (1979) was not conclusive. The urban flood relations may be used on small rural watersheds in the Tampa Bay area, but caution should be exercised, especially when watershed characteristics are outside the range used in the regression analysis.

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