EVALUATION OF RAINFALL-RUNOFF DATA NETWORK, ROCKLAND COUNTY, NEW YORK

By Richard Lumia

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound units	By	To obtain SI units
	Length	
inch (in.)	25.4	millimeter (mm)
	0.0254	meter (m)
foot (ft)	0.0305	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4047	square meter (m^2)
	.0040	square kilometer (km^3)
	Volume	
acre-foot (acre-ft)	1233	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	.0283	cubic meter per second (m^3/s)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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ABSTRACT

Data from 12 rainfall-runoff gaging stations on 10 streams in Rockland County were collected during 1975-79; data from 10 of the sites were judged acceptable for input to watershed models. The HEC-1 Flood Hydrograph Package was used to develop a rainfall-runoff model for each site. Initial results of model analysis indicated a bias for peak discharges during the growing season; adjustment of input parameters to reflect antecedent soil-moisture conditions gave more accurate results. The average difference between observed and simulated peak-discharge magnitudes for all sites and events decreased from 41.7 percent to 25.0 percent after seasonal parameter adjustments. The results of the model analyses indicate that updated flood-frequency estimates for each site may be sufficiently reliable to aid in managing flood plains and drainage systems and in designing drainage structures.

INTRODUCTION

A significant increase in both population and development in Rockland County during the past few decades, and the likelihood of continued growth, have prompted the county to evaluate current design of drainage facilities and management of flood plains.

During 1975-77, the U.S. Geological Survey, in cooperation with the Rockland County Drainage Agency, installed a network of gaging stations and precipitation collectors on 10 designated streams to collect concurrent streamflow and rainfall data. Twelve rainfall-runoff gaging stations were installed, and the data were periodically provided to Rockland County for analysis. In 1979, the county requested the Survey to evaluate the established data network. Data collection was discontinued at all but three sites in 1979 pending the results of this study. Rainfall-runoff models for each site were developed from the HEC-1 Flood Hydrograph Package to aid in evaluating the network.

Purpose and Scope

This report evaluates the rainfall-runoff data collected at 12 sites on 10 streams in Rockland County during 1975-79 and examines the adequacy of the rainfall-runoff models developed for 10 of the sites. The predictive capability of the models will dictate their use in eventual determinations of flood-frequency relationships at each gaged site.

Description of Area

Rockland County, a 180-mi^2 area in southeastern New York State, is bounded on the east by the Hudson River and Westchester County, on the north and northwest by Orange County, and on the south and southwest by New Jersey (fig. 1).

The county's population in 1970 was 229,903 (Rockland County Planning Board, 1974) and had increased to 259,551 by 1980 (U.S. Bureau of Census, oral commun., 1981). The population is dispersed among 5 towns and 13 villages. Principal physiographic features are the Hudson River, numerous lakes, and the Palisade and Ramapo mountain ranges.

The climate of the area is the humid continental type. Average annual precipitation is 48 inches with fairly uniform distribution throughout the year. Coastal storms occur throughout the year, and severe thunderstorms are common during summer.

Approximately one-third of Rockland County is drained by eastward-flowing streams tributary to the Hudson River; the remainder is drained by southward-flowing streams entering the Hackensack and Passaic River systems of New Jersey. The streams studied and the associated gaging sites are listed in table 1; their locations are shown in figure 2. The gaged drainage basins range in size from 0.90 to 60.1 mi^2.

Most of Rockland County consists of crystalline bedrock mantled by unconsolidated materials. The soil cover includes three types of deposits: local stream and lake deposits of sand, gravel, silt, and clay; stratified deposits of sand and gravel, distributed primarily along the major stream valleys of the county; and an unstratifed and poorly sorted mixture ranging from clay particles to large boulders. The unstratified and poorly sorted material forms the soil cover in most of the county.

Selected physical and climatic characteristics of each drainage basin under study were computed to aid in the analysis of streamflow characteristics; these are listed in table 2.

DATA COLLECTION AND PROCESSING

Data-collection sites were established during 1975-77 at the 12 locations shown in figure 2. Rainfall and stream stage were recorded at each site on automatic-digital recorder (ADR) punched tapes at 15-minute intervals. The rainfall and stage recorders were connected to a single timer to obtain concurrent readings and were operated throughout the year. Snowmelt was not a significant factor.

Flood hydrographs were plotted and rainfall totals computed for all storms at each site. The hydrographs indicated that data recorded at 30-minute time intervals would be adequate as model input for all sites but one, Ramapo River at Sloatsburg, which represents the largest basin studied (drainage area 60.1 mi^2). For this site, a 60-minute interval was sufficient. Rainfall and discharge data from each site are stored at the U.S. Geological Survey office in Albany, N.Y. and are available for public inspection.

Difficulties during the data-collection period included instability of stage-discharge relationships because of channel modifications, equipment malfunctions (primarily because of freezing), and vandalism. The effect of these difficulties at the various sites is detailed in the following section.

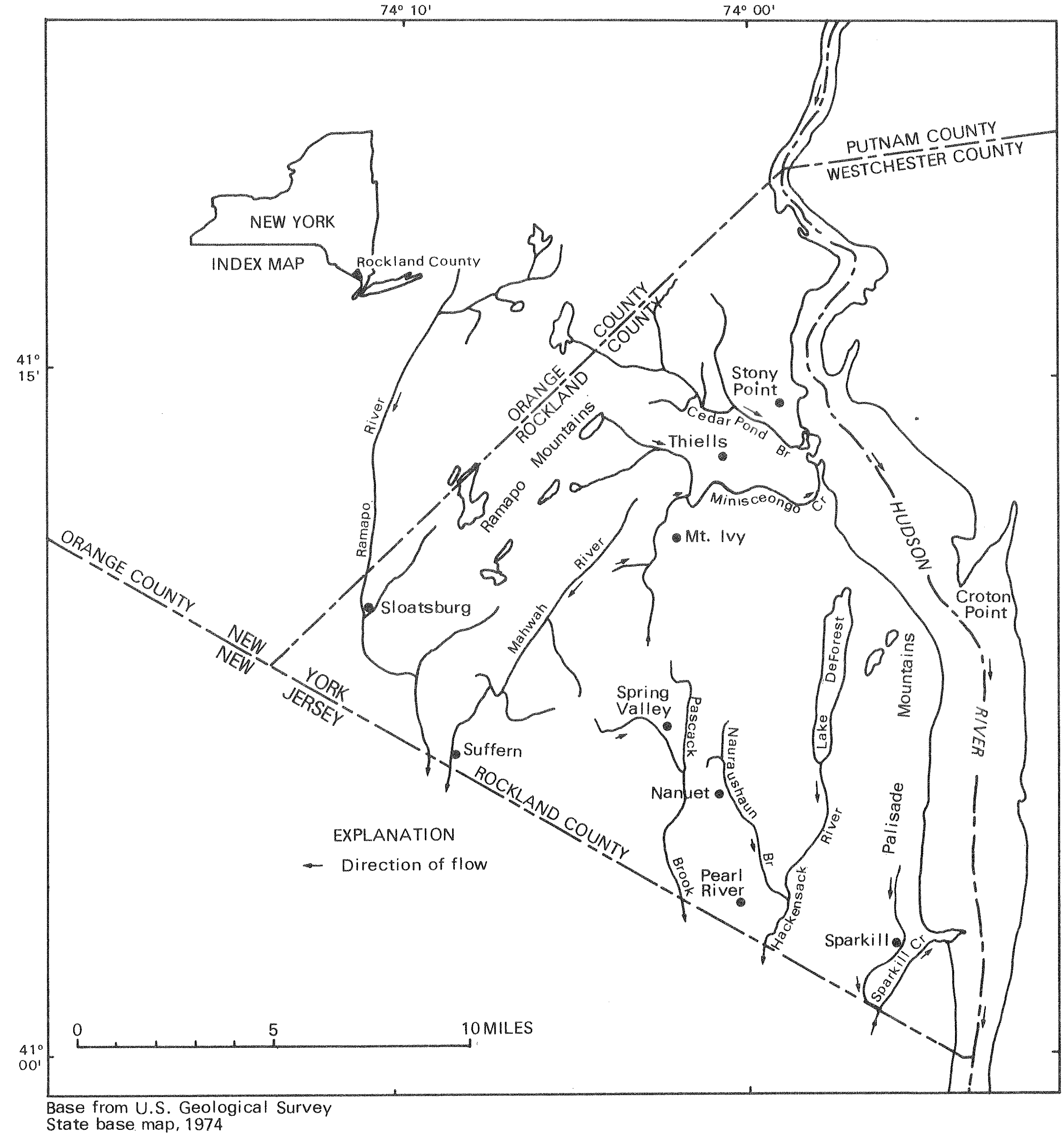


Figure 1.--Major physiographic features of Rockland County.

Table 1.--Rainfall-runoff sites in Rockland County, New York.

[Site locations are given in fig. 2]

Site number*	Site name	Drainage area (mi^2)	Date of installation
01374440	Cedar Pond Brook at Stony Point	17.3	1-75
01374454	South Branch Minisceongo Creek near Mt. Ivy	1.84	6-76
01374456	South Branch Minisceongo Creek Tributary near Mt. Ivy	0.90	6-76
01374458	South Branch Minisceongo Creek at Mt. Ivy	5.19	6-76
**01374480	Minisceongo Creek at Thiells	15.1	4-77
01376280	Sparkill Creek at Sparkill	10.7	12-74
01376842	Nauraushaun Brook at Nanuet	2.12	1-75
01376855	Nauraushaun Brook at Pearl River	6.00	1-75
01377196	Pascack Brook Tributary at Spring Valley	3.89	7-76
01377260	Pascack Brook near Pearl River	8.39	1-75
01387250	Ramapo River at Sloatsburg	60.1	12-74
01387450	Mahwah River near Suffern	12.3	6-75

*Site numbers represent U.S. Geological Survey gaging stations.
**Originally installed at West Haverstraw (station 01374485) June 1975.

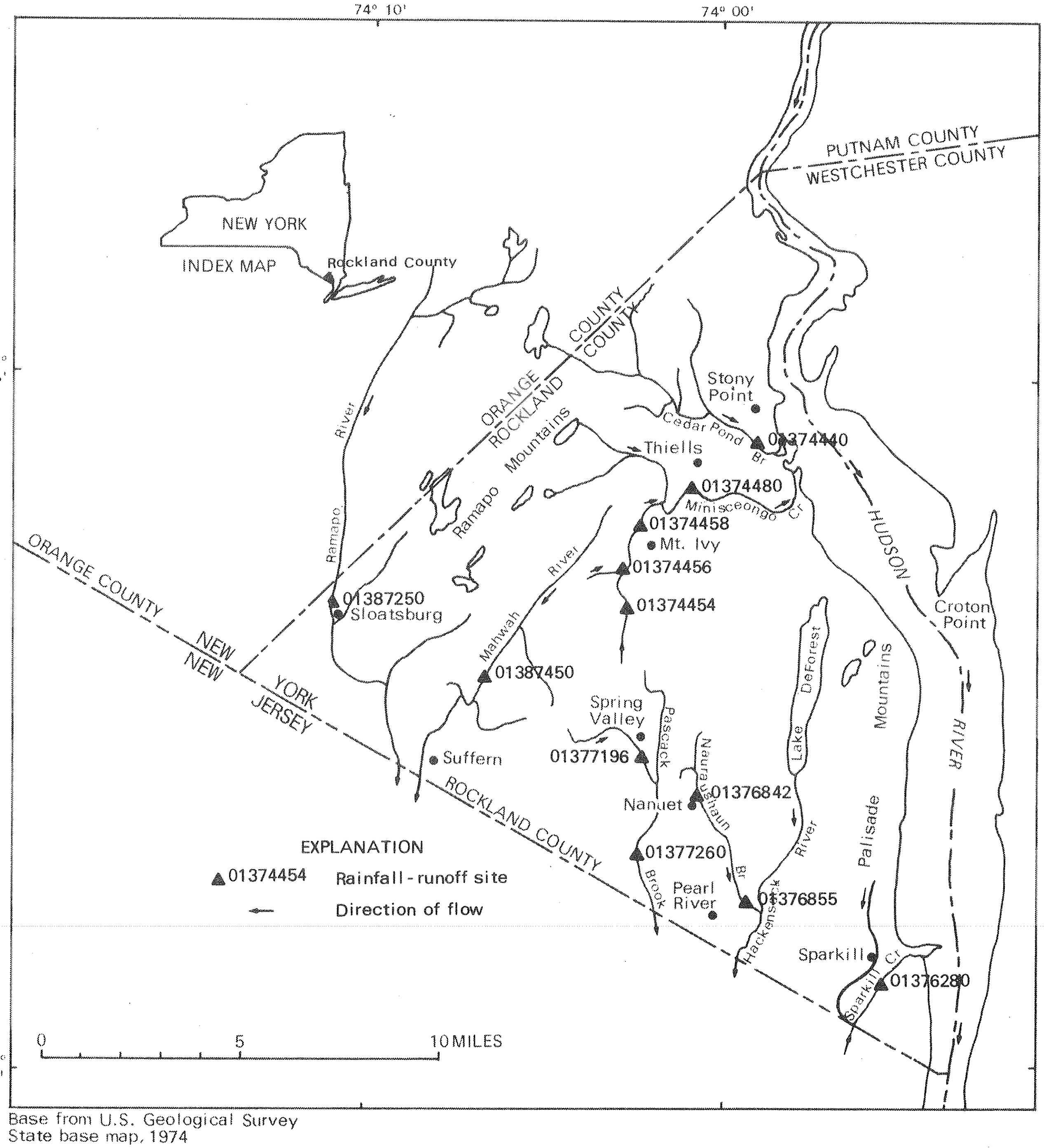


Figure 2.--Location of rainfall-runoff measurement sites.

Table 2.--Data on selected basin characteristics, Rockland County, New York.
[Site locations are given in fig. 2 and table 1]

	Basin Characteristics*					
Site number	A	P	L	S	St	I
01374440	17.3	47.5	7.9	162	6.1	6.6
01374454	1.84	48.0	2.6	66.0	1.1	14.5
01374456	0.90	48.0	1.4	116	11	8.4
01374458	5.19	48.0	4.5	31.9	12	5.8
01374480	15.1	48.0	8.6	115	11	4.7
01376280	10.7	48.0	6.7	32.2	3.7	13.2
01376842	2.12	48.0	3.0	74.8	4.3	22.6
01376855	6.00	48.0	6.4	42.1	3.8	24.9
01377196	3.89	48.0	3.8	66.5	5.7	29.6
01377260	8.39	48.0	6.5	39.8	2.9	20.6
01387250	60.1	46.0	16.1	17.3	10	5.0
01387450	12.3	47.0	6.6	30.1	5.7	6.2

*

A = Drainage area, in mi^2.--Area of a basin (watershed) upstream from the site of interest, delineated on 7.5-minute U.S. Geological Survey topographic maps and determined by planimetering the basin outline.

P = Mean annual precipitation, in in.--Mean annual precipitation determined from a rainfall map (Zembrzuski and Dunn, 1979) based on New York precipitation data from 1931-60.

L = Stream length, in mi.--Distance up the channel from site of interest to basin divide, determined from 7.5- or 15-minute maps.

S = Main channel slope, in ft/mi.--Difference in elevation (ft) between points 10 percent and 85 percent of distance up channel from site of interest to the basin divide, divided by distance (mi) between the two points, determined from 7.5- or 15-minute maps.

St= Storage, in percent.--Percentage of total drainage area shown as lakes, ponds, and swamps, determined from 7.5- or 15-minute topographic maps by grid sampling or planimetering.

I = Approximate impervious area, in percent.--Percentage of basin covered by buildings, streets, and paved parking lots. This value was approximated through use of topographic maps, county highway maps, and 1970 land-use maps. More accurate determinations could be made from aerial photographs, but this was beyond scope of study.

DATA EVALUATION

The data collected at each site were examined to determine acceptability for model input. The data set for a site was not used in model analysis if (1) the stage-discharge relationship was inadequately defined, (2) equipment performance was unreliable, or (3) fewer than six storm events were recorded.

Stage-discharge ratings for acceptable sites ranged from fairly well defined to well defined. Peak flows were considered fairly well defined if the maximum flow used in the analysis was no greater than twice the highest discharge measured by current meter. The high end of many of the rating curves are defined by measurements computed by indirect methods.

Floods to be simulated in model calibration and(or) verification (see section "Model Description") were selected to provide a broad range of storm types, antecedent soil-moisture conditions, and peak-discharge magnitudes. Storms producing peak discharges that were low in relation to base flow were excluded from the analyses, and storms with rainfall totaling less than 1 inch were generally eliminated. It was assumed that rainfall recorded at a single gage was representative of rainfall throughout the basin. Rainfall distribution over each basin was checked for uniformity by comparison with total rainfall recorded at adjacent sites.

Data from most stations were found acceptable for model input. The main exceptions were:

(1) Cedar Pond Brook at Stony Point (01374440)--An adequate stage-discharge relationship was defined, but flood data were not recorded until a medium stage was attained. (Complete flood hydrograph definition is required for model input). The gaging station was relocated to the Spring Valley Water Company reservoir in May 1979. A stage-discharge relationship was not adequately defined at this new site, nor was a sufficient number of storms recorded. This site was excluded from model analysis.

(2) South Branch Minisceongo Creek near Mt. Ivy (01374454)--The controlling structure (culvert) for the gage was damaged and became unstable so that a stage-discharge relationship could not be adequately defined. The gage was subsequently relocated in June 1977. However, road construction in 1978 altered streambed conditions so that, again, a reliable stage-discharge relationship could not be determined. This site was also eliminated from model analysis.

(3) Minisceongo Creek at West Haverstraw (01374485)--Shortly after installation in 1975, the recorded stage data became unusable because of channel dredging and streambank stabilization. The gage was relocated in April 1977 to an abandoned mill dam near Thiells (01374480). Although the shortened period of data collection limited the number of recorded floods, data from the Thiells site were used in the analysis.

(4) Nauraushaun Brook at Nanuet (01376842)--This gage was removed in August 1977 while channel work was being done and was reinstalled in August 1978 in a hydraulically more appropriate location. Although an adequate stage-discharge relationship was not defined for the new site, data from the original site were acceptable and used in the analysis.

(5) Pascack Brook near Pearl River (01377260)--Interference from overhanging trees prevented use of the rainfall data for modeling, but rainfall data from adjacent sites were substituted as model input and used in the analysis.

(6) Ramapo River at Sloatsburg (01387250)--Because of this basin's large size, 60.1 mi^2, it is unlikely that the rainfall recorded at the gage is representative of the entire basin, especially during high-intensity, short-duration thunderstorms. Additional rain gages upstream from the streamflow gage would have been desirable, but none in the immediate area were available to determine validity of the rain record at the streamflow gage. Data were used as recorded.

DESCRIPTION OF MODEL

The rainfall-runoff models developed in this study were derived from the HEC-1 Flood Hydrograph Package published by the U.S. Army Corps of Engineers Hydrologic Engineering Center (1973). The HEC-1 program does most ordinary rainfall-runoff computations for complex river basins or small watersheds. An important limitation is that HEC-1 is applicable only to single storm analyses; no accounting of soil-moisture conditions is made during periods of no precipitation. HEC-1 achieves "lumped" parameter modeling of the rainfall-runoff process, which means that the input or computed parameters are considered to represent the average for the entire basin. Because parameters are "lumped" temporally as well as spatially, the time interval selected for model input should be small enough that average over-the-period computations are applicable.

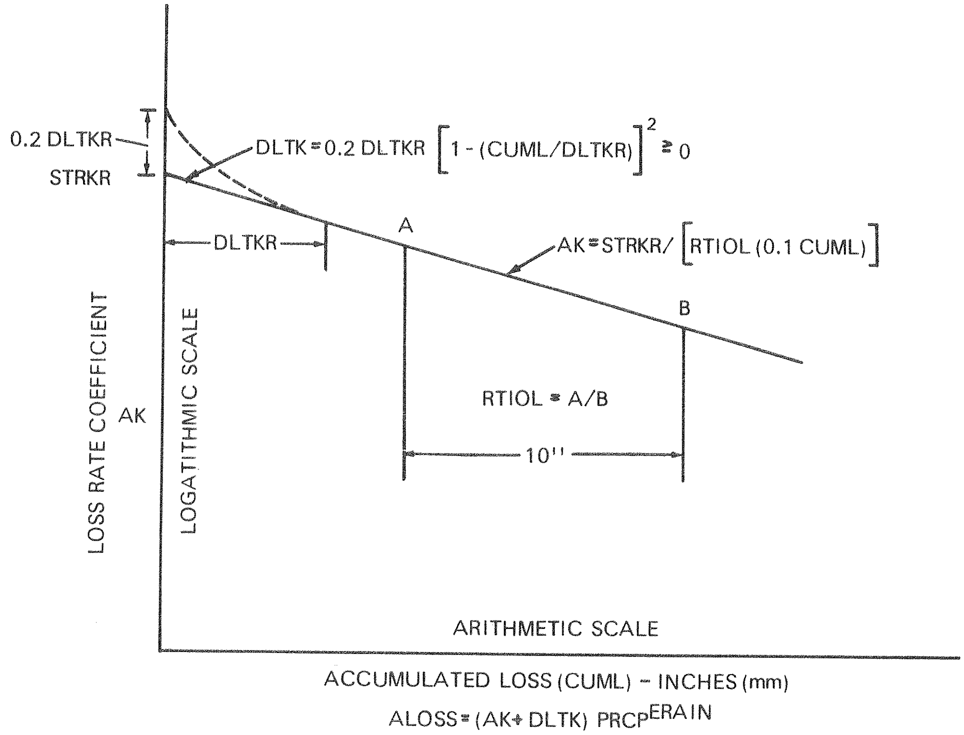
For each basin modeled, HEC-1 required complete definition of unit hydrograph and precipitation loss-rate criteria. The unit hydrograph for a site is defined as the discharge hydrograph, excluding base flow, that results from 1 inch of excess rainfall (runoff), uniformly distributed over the basin and generated uniformly within a time period defined as the unit time, or duration.

A generalized unit hydrograph for each basin was derived by the Clark (1945) method, whereby excess rainfall is converted into a translation hydrograph that represents the effect of varying traveltimes in each basin. The translation hydrograph is then routed through a linear reservoir to account for storage effects. An instantaneous unit hydrograph is developed from instantaneous excess rainfall of 1 inch. A unit hydrograph of specified duration can then be defined from the instantaneous unit hydrograph.

The variables and parameters necessary for HEC-1 rainfall-runoff analysis are explained in figure 3, which also illustrates the application of the loss-rate parameter to the general loss-rate function. Figure 4 depicts the process of determining a value for each hydrograph variable.

As shown in figure 3, the precipitation loss-rate (ALOSS) is computed for each time interval from initial (antecedent) conditions (STRKR and DLTKR), rainfall intensity (PRCP), and accumulated losses (ground wetness).

Initial values of the runoff hydrograph variables shown and explained in figure 4 were determined from observed flood hydrographs. Slight adjustments to these values were made to better simulate observed floods. The time of



EXPLANATION

DLTKR - Amount of initial accumulated rain loss during which loss-rate coefficient is increased (primarily a function of antecedent soil-moisture deficiency)

STRKR - Starting value of loss coefficient on exponential recession curve for rain losses (function of infiltration capacity)

RTIOL - Ratio of rain-loss coefficient on exponential loss curve to that corresponding to 10 inches more of accumulated loss (function of ability of surface of a basin to absorb precipitation)

ERAIN - Exponent of precipitation for rain-loss function

$$ALOSS = (AK + DLTK)\ PRCP^{ERAIN}$$

that reflects the influence of precipitation rate on basin-average loss characteristics, where:

ALOSS = loss rate, in inches per hour

AK = loss-rate coefficient at beginning of time interval, value on STRKR exponential loss curve

PRCP = rainfall intensity, in inches per hour

DLTK = incremental increase in loss-rate coefficient

Figure 3.--General loss-rate function used in HEC-1 program (Modified from U.S. Army Corps of Engineers, 1973)

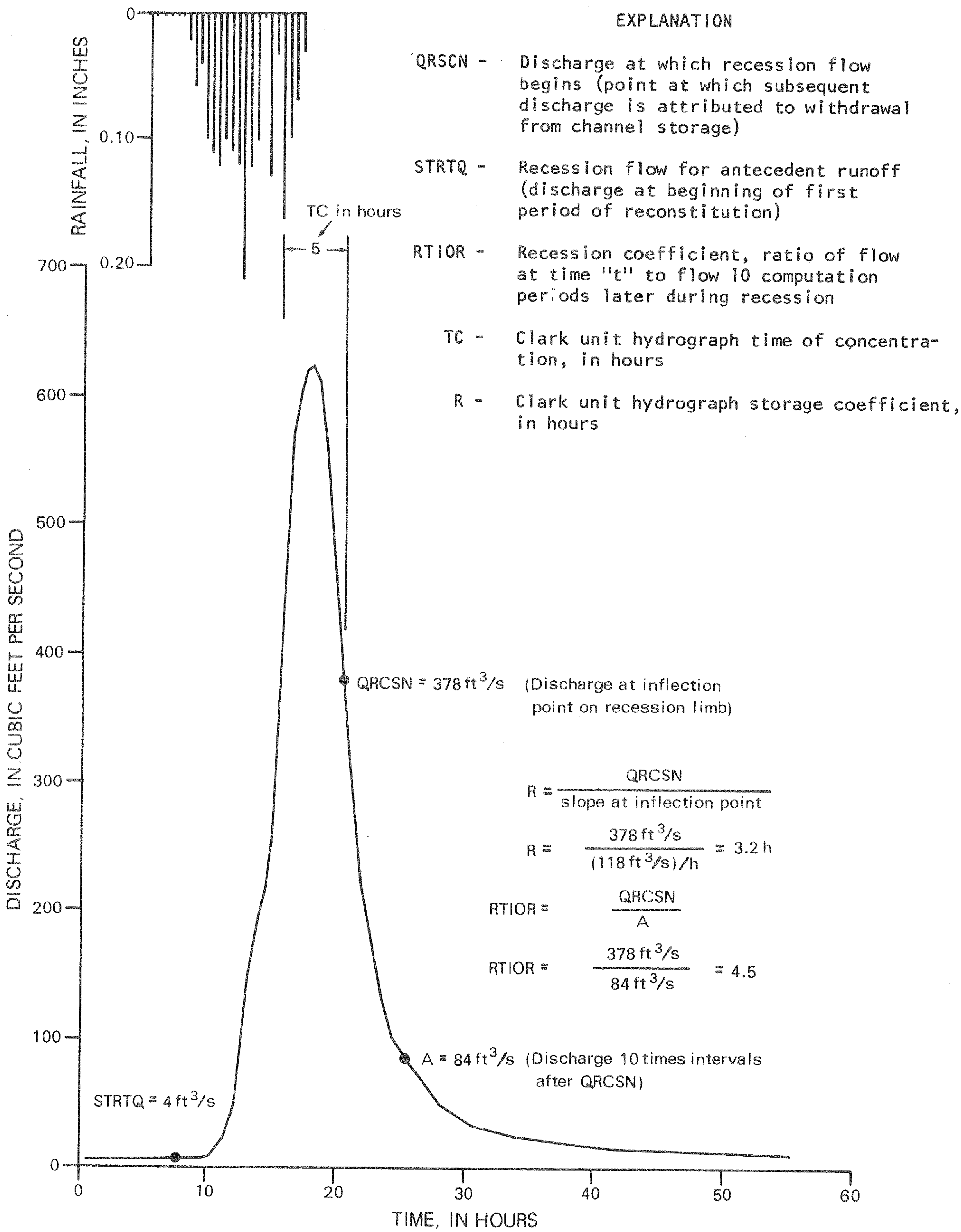


Figure 4.--Determination of HEC-1 runoff hydrograph variables.

concentration (TC) is estimated as the time from the end of effective rainfall (heavy rainfall excess) to the inflection point on the recession limb of the runoff hydrograph. QRCSN is the discharge at this point. The attenuation constant (storage coefficient R) is estimated at the point of inflection of the recession limb as:

$$R = \frac{QRCSN}{dQ/dt}$$

where dQ/dt is the rate of change of discharge (slope) at the inflection point.

From these runoff hydrograph values, an instantaneous unit hydrograph is determined and converted to a unit hydrograph of unit duration through the Clark (1945) method.

From unit rainfall, drainage area, and the runoff hydrograph values listed in figure 4, the HEC-1 program automatically determines a set of unit hydrograph and loss-rate values that best reconstitute an observed runoff event.

Model Calibration

Calibration of a model to a specific site requires trial-and error-adjustments of the parameter values to improve the comparison between observed and simulated flood hydrographs. An optimization procedure is used to adjust model parameters until a minimum value of an objective function (in this case the weighted root-mean-square errors between the observed and reconstituted hydrograph flows) is attained. During optimization, more weight is applied to higher flows to improve reproduction of peaks. Total flow volumes are checked to ensure close correspondence between observed and simulated hydrographs.

Data from all storms at each of the acceptable sites were screened for conformance to the modeling criteria, and questionable data resulting from equipment failure or insufficient runoff were excluded. Approximately half the storms having acceptable data at each site were used for model calibration. They were selected to represent a wide range of storm types, antecedent soil-moisture conditions, and peak-discharge magnitudes; the remainder were reserved for model verification. (See section "Model Verification.")

During the initial optimization process, values for all runoff hydrograph variables were estimated from observed flood hydrographs and held constant. The HEC-1 program was allowed to automatically derive values for the precipitation loss-rate parameters. The shape and magnitude of computed and observed hydrographs were compared, and recomputed parameter values were examined to ensure that they were comparable with those derived for hydrologically similar basins. Hydrographs of all selected storms were reconstituted with acceptable accuracy, and average precipitation loss-rate parameter values were computed. Each unit hydrograph derived from model calibration was plotted, and from these plots an average unit hydrograph for each basin was determined on the basis of peak discharge and time to peak. Optimized model parameters for each storm are presented in table 3.

Table 3.--Results of optimization phase of rainfall-runoff models
[Site locations are given in fig. 2; parameters and variables are defined in fig. 3.]

Site number	Drainage area (mi^2)	Storm date	Precipitation (inches)		Loss-rate parameters				Runoff hydrograph variables		Peak discharge (cubic feet per second)
			Total	Excess	STRKR	DLTKR	RTIOL	ERAIN	TC	R	Observed
01374456	0.90	*06-30-76	2.18	0.74	0.53	1.08	1.46	1.69	5.0	10.0	30
		*10-21-76	2.01	0.60	0.30	0.19	1.02	0.50	7.5	11.0	21
		12-07-76	1.71	0.59	0.30	0.67	1.00	0.50	6.0	10.0	23
		11-08-77	7.27	3.86	0.30	0.13	1.00	0.64	4.5	18.0	66
		03-27-78	4.02	1.50	0.32	0.52	1.35	0.51	4.5	16.0	33
01374458**	5.19	*06-10-77	3.19	1.00	0.30	0.33	1.87	0.50	16.4	55.2	44
		11-08-77	6.95	4.31	0.20	0.07	1.00	0.51	8.7	64.5	173
		03-27-78	2.12	1.49	0.10	0.04	1.03	0.51	13.7	55.4	78
01374480	15.1	*06-10-77	2.82	0.28	0.47	1.87	5.87	0.53	5.0	16.0	107
		01-25-79	3.32	1.69	0.19	0.09	1.00	0.51	3.0	15.0	731
		03-06-79	2.61	0.98	0.29	0.09	1.00	0.50	10.0	18.0	343
01376280	10.7	12-17-74	1.37	0.58	0.20	0.68	4.28	0.50	4.8	21.2	141
		12-26-75	1.62	0.92	0.16	0.25	1.00	0.51	10.2	17.8	252
		04-01-76	2.39	1.13	0.26	0.16	1.00	0.52	9.1	14.6	384
		05-02-76	1.75	0.61	0.29	0.89	2.40	0.51	1.7	19.4	173
		02-25-77	2.57	1.86	0.18	0.13	1.00	0.57	9.8	13.9	616
		*09-21-79	2.82	0.56	0.42	1.27	2.22	0.50	3.2	16.9	179
01376842	2.12	04-03-75	1.51	0.60	0.38	0.42	1.00	0.65	11.5	4.1	72
		11-21-75	1.74	1.07	0.15	0.32	1.42	0.47	11.5	3.7	138
		05-02-76	1.87	0.48	0.43	0.08	1.00	0.64	10.5	2.6	61
		*08-09-76	2.80	0.67	0.45	0.35	1.00	0.51	8.5	6.0	75
		*10-21-76	1.49	0.43	0.26	0.33	1.12	0.50	12.5	8.1	40
		03-22-77	2.41	1.57	0.16	0.07	1.00	0.51	9.5	4.4	179
01376855	6.00	05-02-76	1.69	0.24	0.46	0.49	1.00	0.58	1.0	2.4	224
		*08-09-76	3.00	0.68	0.48	0.84	1.00	0.53	1.0	2.2	565
		04-05-77	1.52	0.40	0.35	0.61	1.00	0.60	1.5	3.1	293
		*06-10-77	2.43	0.75	0.32	1.96	7.99	0.69	1.0	1.9	374
		11-08-77	5.97	2.47	0.39	0.33	3.37	0.47	1.0	2.0	1120
		*10-05-79	2.21	0.95	0.50	1.20	1.00	0.55	1.0	1.5	1150
01377196	3.89	11-26-77	1.25	0.35	0.37	0.40	1.00	0.60	0.5	2.6	167
		*08-04-78	2.08	0.53	0.60	1.26	1.32	0.87	1.2	2.4	255
		01-21-79	3.75	2.13	0.22	1.72	2.10	0.64	6.0	2.5	436
		05-24-79	4.26	1.98	0.25	1.15	2.39	0.55	0.5	4.0	376
01377260	8.39	11-21-75	1.73	0.94	0.17	0.89	1.90	0.47	5.0	3.0	623
		04-01-76	2.81	1.27	0.30	1.00	3.10	0.49	6.0	4.5	763
		*06-30-76	2.95	2.14	0.24	0.57	1.70	0.34	3.5	3.5	1890
		*10-21-76	1.50	0.36	0.29	0.33	1.00	0.50	3.5	5.5	211
		02-24-77	2.19	1.68	0.14	0.06	1.00	0.55	3.0	4.5	1150
		01-08-78	1.93	1.06	0.15	0.48	2.27	0.48	3.5	5.5	474
01387250***	60.1	05-12-75	1.28	0.99	0.01	0.65	1.80	0.50	35.0	18.0	827
		*10-19-75	3.30	1.43	0.21	0.69	1.98	0.51	39.2	30.9	816
		01-26-76	2.40	2.00	0.05	0.12	1.15	0.50	19.4	27.3	1480
		*08-09-76	3.10	0.63	0.44	1.07	1.83	0.50	23.9	20.0	699
		03-23-77	3.29	2.90	0.05	0.26	1.00	0.52	13.6	35.2	2380
		11-08-77	5.83	3.71	0.17	1.07	3.45	0.48	11.0	28.2	3630
		05-24-79	3.96	1.83	0.18	0.63	1.38	0.49	35.2	18.8	1300
01387450	12.3	04-01-76	2.41	0.58	0.43	1.23	2.34	0.51	6.0	9.3	357
		05-02-76	2.17	0.43	0.44	0.74	1.63	0.54	6.0	10.5	235
		*06-30-76	3.23	0.40	1.03	2.57	2.09	0.50	6.5	5.0	423
		*10-21-76	2.20	0.38	0.44	0.74	1.75	0.51	6.0	13.0	181
		02-25-77	2.69	1.04	0.37	0.96	2.32	0.50	5.5	8.0	720
		03-22-77	3.24	1.34	0.28	0.79	2.33	0.50	6.0	11.0	656

* Storm during growing season.
** Much of this basin is generally swampy as reflected in R (storage) values.
*** Included in this basin are 106 lakes and ponds as reflected in R (storage) values. Range of TC (time of concentration) values indicates rainfall variability over the basin.

These results indicate a seasonal pattern in some loss-rate parameters, as indicated by the scatter of data in figures 5A-5C. The yearly average parameter and variable values computed for each site (table 4) were used to recompute peak discharges for all events used for calibration of the models. Results are depicted in figure 6A.

As seen in figure 6, a bias is evident for peak discharges during the growing season (June 1 to October 20), wherein the computed peak discharge values are consistently larger than the observed values. An attempt was made to eliminate this seasonal bias by adjusting values of parameters STRKR and DLTKR (fig. 3), which reflect antecedent soil-moisture conditions. Seasonal average values of these parameters, based on optimization results for all sites and events, are as follows:

	STRKR	DLTKR
Growing season	0.45	1.10
Nongrowing season	0.25	0.50

Peak discharges computed from these modified values resulted in some improvement, but a significant bias was still evident for peaks during the growing season.

Table 4.--Yearly average parameter and variable values from optimization results. [Site locations are given in fig. 2; parameters and variables are explained in fig. 3.]

Site number	Precipitation loss-rate parameter				Hydrograph variable	
	STRKR	DLTKR	RTIOL	ERAIN	TC	R
01374456	0.35	0.52	1.17	0.50	5.5	13.0
01374458	0.20	0.15	1.30	0.51	13.0	58.5
01374480	0.32	0.68	2.62	0.51	6.0	16.5
01376280	0.25	0.56	1.98	0.52	6.5	17.5
01376842	0.28	0.29	1.10	0.53	10.0	4.5
01376855	0.42	0.90	2.56	0.57	1.0	2.0
01377196	0.36	1.13	1.70	0.66	2.0	3.0
01377260	0.22	0.56	1.68	0.47	4.0	4.5
01387250	0.18	0.64	1.80	0.50	23.5	26.5
01387450	0.39	0.89	2.07	0.51	6.0	9.5

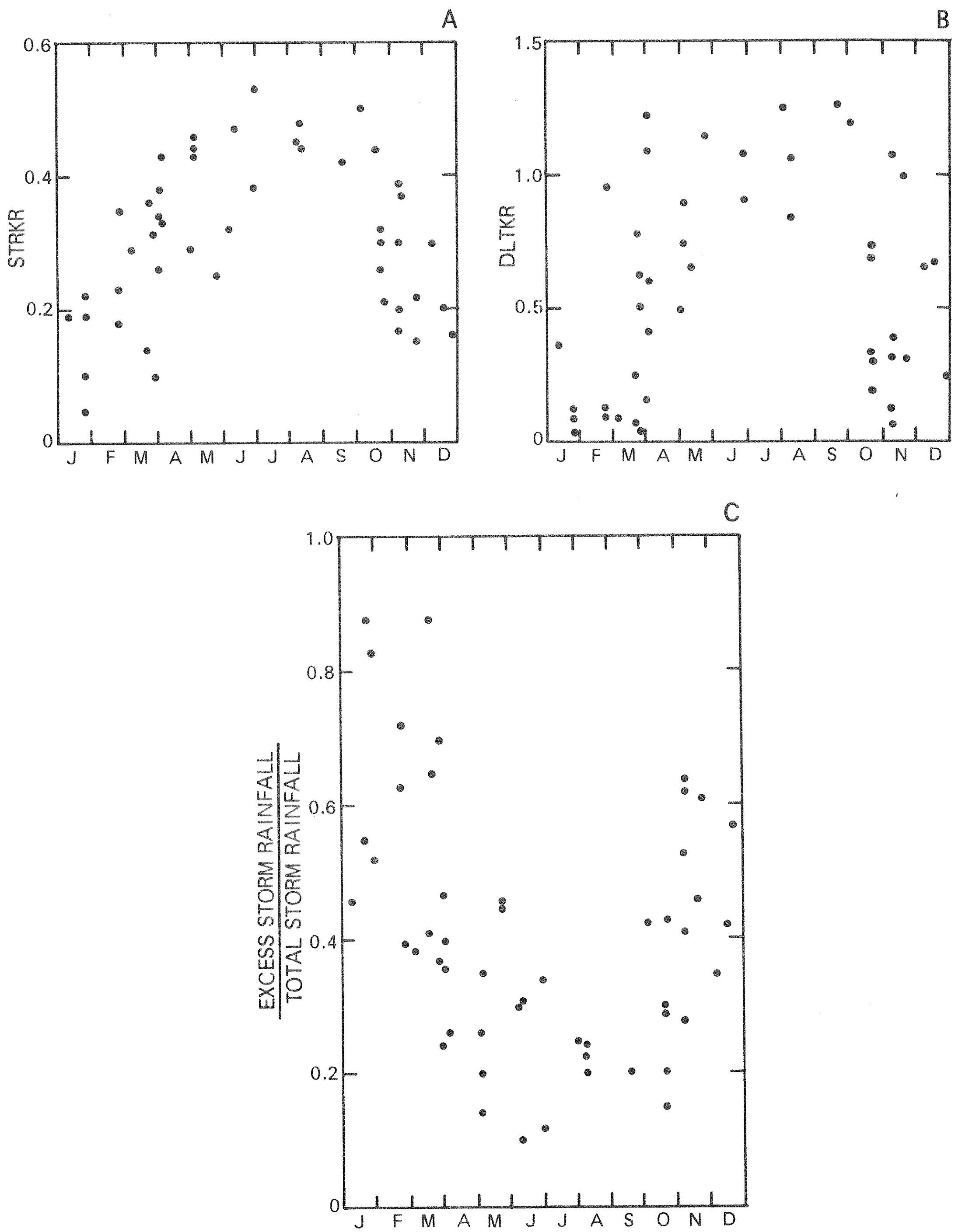


Figure 5.--Seasonal fluctuation of loss-rate parameters, based on optimization results for all sites. A, loss-rate parameter STRKR; B, loss-rate parameter DLTKR; C, excess storm rainfall.

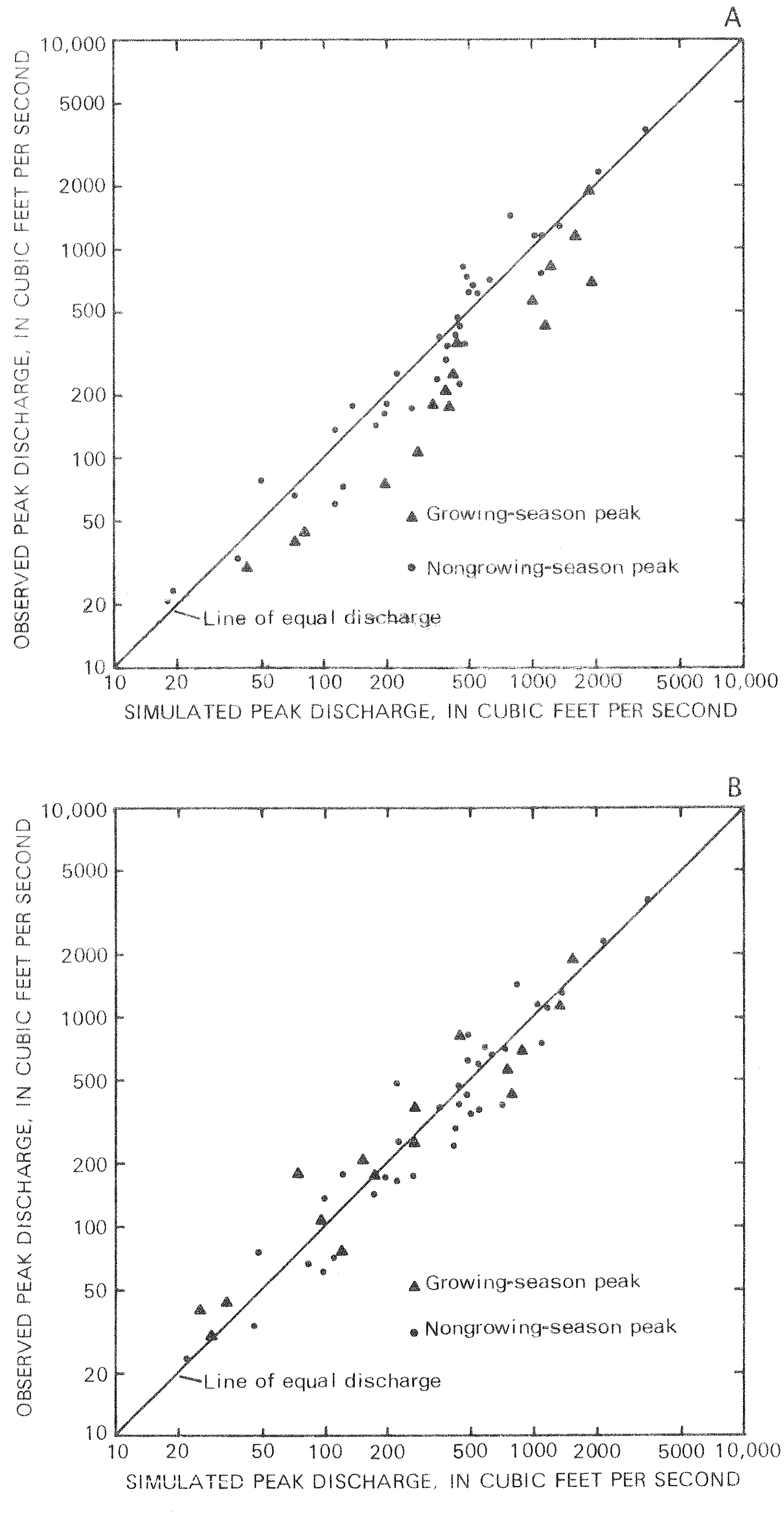


Figure 6.--Relationship between observed and computed peak discharges at all sites (calibration results): A, based on yearly average parameter values; B, with seasonal adjustments of STRKR and DLTKR.

An additional adjustment was made by averaging the overall seasonal values of STRKR and DLTKR with seasonal values of each parameter obtained at individual sites. The resulting computation of peak discharges indicated a substantial improvement in seasonal bias, as indicated in figure 6B. Final seasonal values of STRKR and DLTKR used in the model for each site are listed in table 5.

Table 5.--Final seasonal values of STRKR and DLTKR used in model for each rainfall-runoff site.
[Site locations are given in fig. 2.; STRKR and DLTKR are explained in fig. 3.]

Site Number	Growing Season		Nongrowing Season	
	STRKR	DLTKR	STRKR	DLTKR
01374456	0.49	1.09	0.28	0.44
01374458	0.37	0.71	0.20	0.28
01374480	0.46	1.49	0.24	0.29
01376280	0.43	1.19	0.23	0.46
01376842	0.40	0.72	0.27	0.36
01376855	0.47	1.22	0.33	0.50
01377196	0.53	1.18	0.27	0.80
01377260	0.36	0.78	0.22	0.55
01387250	0.39	0.99	0.17	0.53
01387450	0.59	1.38	0.32	0.72

Model Verification

Accuracy of rainfall-runoff models is measured in terms of prediction rather than fitting because fitting indicates only how well the model reproduces a set of data after adjusting model parameters, whereas accuracy of prediction indicates how well the model can reproduce a set of data that were not used to derive the parameter values. Errors in prediction are a major consideration if the models are to be used to extend a record in time.

To verify the model developed for each site, hydrographs for storms not used for calibration were simulated. Model data included unit rainfall from each storm, average loss-rate parameter values, the average unit hydrograph, starting discharge (baseflow) for each event, and drainage area above gage. The observed flood hydrograph was input for comparison.

Results of the flood simulations based on *yearly average* parameter and hydrograph variable values for each site are presented in table 6 and depicted in figures 7A and 7B. As in the calibration results, a bias is evident--most simulated peak discharges and flood volumes during the growing season were much larger in magnitude than the observed discharges. The average difference (absolute values) between observed and simulated peak discharges during the nongrowing season at all sites was 18.2 percent and increased to 41.7 percent when floods during the growing season were included. Corresponding flood-volume differences were 19.9 and 44.2 percent, respectively.

To reduce this bias, the seasonal values of loss-rate parameters STRKR and DLTKR (table 5), which implicitly account for antecedent soil-moisture conditions, were substituted into each model, and flood hydrographs were recomputed. Results were significantly improved, as indicated by a more balanced scatter of data in figures 8A and 8B. Model-verification results based on the *seasonally adjusted* parameter values are presented in table 7.

The average difference between observed and simulated peak discharges during the nongrowing season for all sites based on seasonally adjusted parameter values was 18.2 percent and increased to 25.0 percent when floods during the growing season were included. Corresponding flood-volume differences were 20.3 and 26.2 percent, respectively. The average percentage differences between observed and simulated peak discharges for individual sites, based on the seasonally adjusted parameter values, are listed below:

Site number*	Average difference (in percent) Nongrowing-season events	Average difference (in percent) All events
01374456	10.0	24.8
01374458	31.0	31.2
01374480	10.1	10.1
01376280	19.6	26.6
01376842	11.9	12.6
01376855	10.5	27.0
01377196	29.3	30.6
01377260	16.9	33.7
01387250	16.3	21.5
01387450	23.3	25.9
Mean	18.2	25.0

*Site locations are given in figure 2.

A statistical correlation between observed and computed peak discharge for all sites and events resulted in r^2 (coefficient of determination) values (SAS Institute, 1979) increasing from 0.76 to 0.92 after seasonal adjustment of parameters STRKR and DLTKR.

Table 6.--Results of model verifications based on yearly average parameter values determined for each site
[Site locations are given in fig. 2]

Site number	Drainage area (mi^2)	Storm date	Total storm rainfall (in.)	Peak discharge (cubic feet per second) Observed	Simulated	Flood volume (acre-ft.) Observed	Simulated
01374456	0.90	*08-09-76	3.33	24	33	33.4	49.0
		01-08-78	3.01	35	30	62.6	46.3
		*09-06-79	2.08	24	30	35.0	40.1
		*10-05-79	1.62	30	31	41.3	40.8
01374458	5.19	*08-09-76	3.13	72	96	213	236
		12-21-77	1.00	40	28	186	124
		05-15-78	3.90	70	98	332	378
		01-25-79	2.42	107	85	425	353
01374480	15.1	11-08-77	6.94	1640	1340	3180	3070
		05-15-78	3.49	572	494	1620	1040
		05-25-79	4.91	513	497	1300	1540
01376280	10.7	03-20-75	1.91	176	235	477	457
		*07-25-75	2.94	141	452	345	999
		03-23-77	2.62	536	321	931	737
		04-05-77	1.60	266	234	546	406
		*06-10-77	2.14	92	182	177	387
		*10-09-77	2.09	132	260	279	486
		11-08-77	5.65	1040	954	1920	1710
		05-25-79	3.08	302	244	970	760
01376842	2.12	01-18-75	1.04	38	40	41.9	37.5
		03-20-75	2.08	75	92	123	112
		*07-14-75	1.75	86	125	88.0	137
		*10-18-75	3.94	124	119	212	255
		04-01-76	2.80	172	205	167	205
01376855	6.00	*06-30-76	2.91	1550	1360	665	747
		03-22-77	2.36	443	433	439	326
		01-09-78	2.06	355	413	295	244
		02-26-79	2.23	305	271	377	220
		05-24-79	4.51	1140	1052	731	839
		*09-06-79	1.38	132	429	78.5	203
01377196	3.89	04-05-77	1.60	163	188	117	118
		*10-09-77	1.78	105	124	106	134
		05-14-78	2.55	260	252	241	259
		01-25-79	2.00	450	194	359	164
01377260	8.39	03-19-75	2.09	446	449	599	433
		*08-09-76	2.81	332	1050	229	752
		03-22-77	2.41	828	610	698	565
		11-08-77	6.07	1450	1510	1540	1750
		03-26-78	1.49	463	311	393	231
01387250	60.1	03-25-75	3.23	1350	1758	6440	6780
		*07-12-75	4.69	1000	2446	5500	10400
		*09-23-75	7.33	1290	1790	8600	12500
		01-27-78	1.88	889	753	4360	2950
		05-14-78	3.96	2070	2093	10100	8500
01387450	12.3	*07-12-75	4.97	475	890	648	1940
		*07-24-75	1.52	99	226	151	356
		11-21-75	1.62	206	257	365	396
		03-13-77	2.31	271	315	689	650
		11-08-77	6.77	1930	1423	2480	2020
		01-08-78	2.39	452	323	685	503
		05-14-78	3.93	719	565	1420	1020
		*09-06-79	3.02	356	762	385	1140

* Storm during growing season

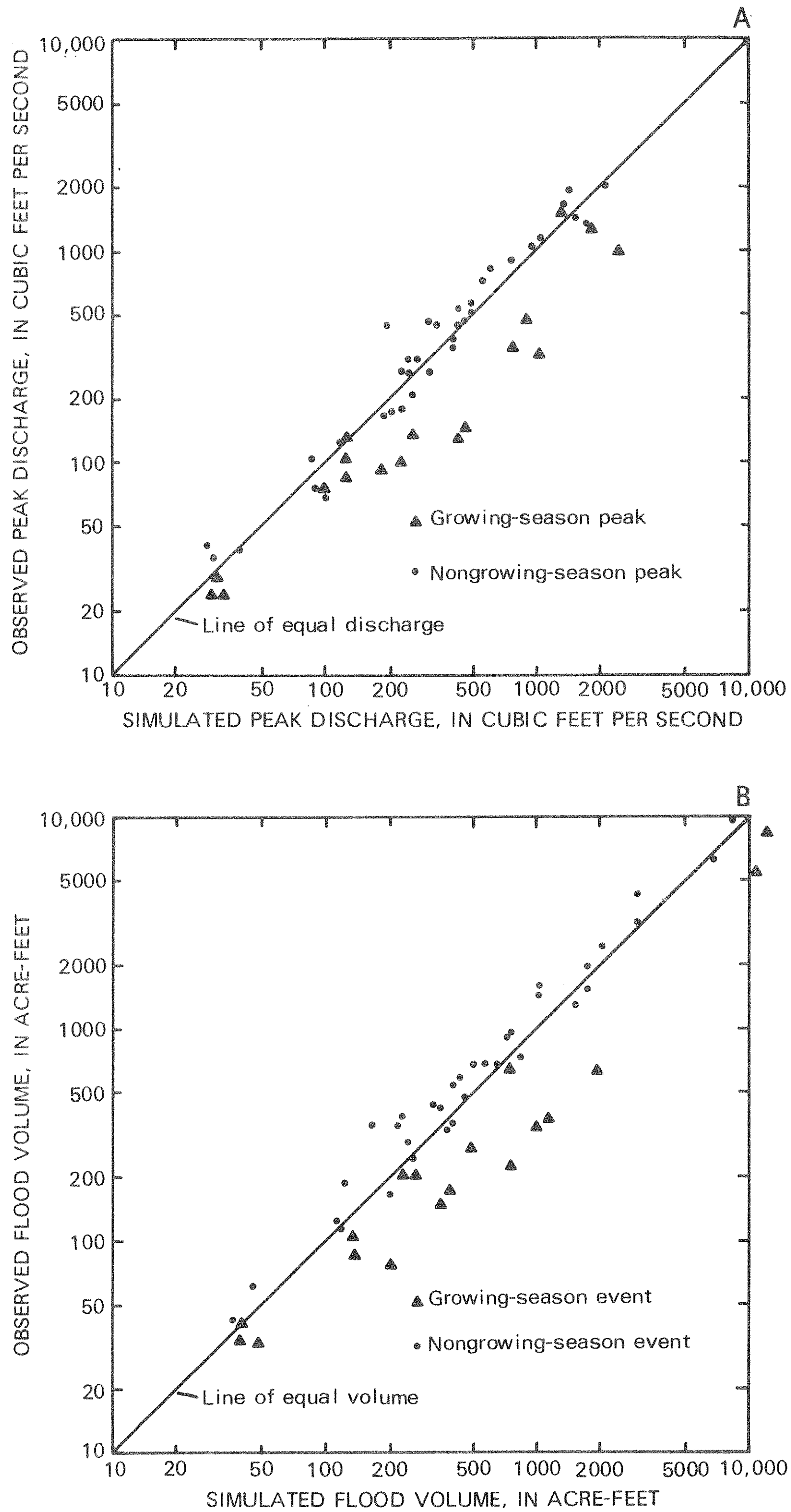


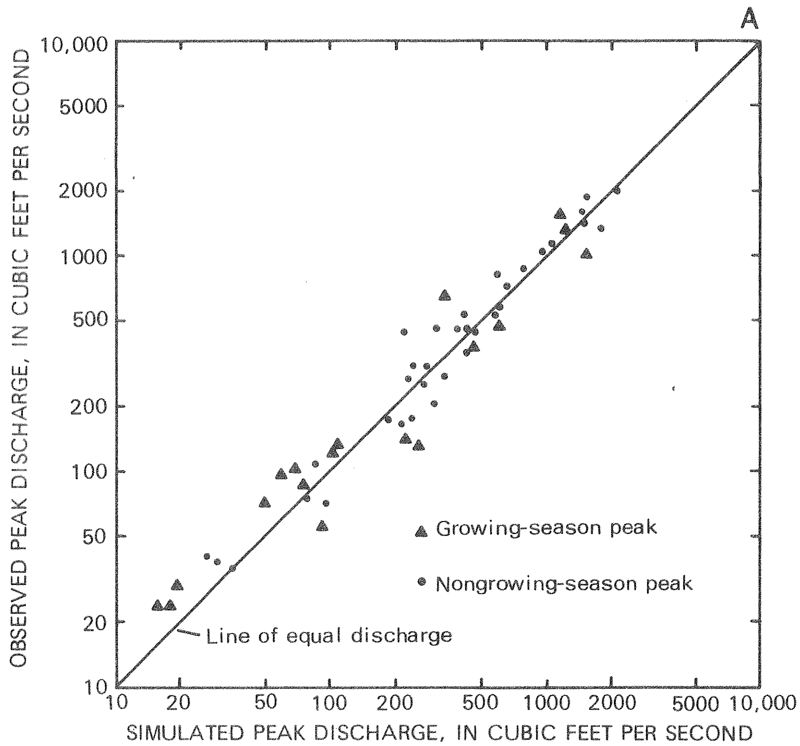
Figure 7.--Relationship between observed and simulated events at all sites based on yearly average parameter values (verification results): A, peak discharge; B, flood volume.

Table 7.--Results of model verifications based on seasonally adjusted values of STRKR and DLTKR

[Site locations are given in fig. 2]

Site number	Drainage area (mi^2)	Storm date	Total storm rainfall (in.)	Peak discharge (cubic feet per second) Observed	Peak discharge (cubic feet per second) Simulated	Flood volume (acre-ft.) Observed	Flood volume (acre-ft.) Simulated
01374456	0.90	*08-09-76	3.33	24	16	33.4	27.1
		01-08-78	3.01	35	35	62.6	59.1
		*09-06-79	2.08	24	17	35.0	26.7
		*10-05-79	1.62	30	19	41.3	28.2
01374458	5.19	*08-09-76	3.13	72	49	213	130
		12-21-77	1.00	40	26	186	115
		05-15-78	3.90	70	95	332	365
		01-25-79	2.42	107	83	425	341
01374480	15.1	11-08-77	6.94	1640	1492	3180	3540
		05-15-78	3.49	572	615	1620	1320
		05-25-79	4.91	513	584	1300	1900
01376280	10.7	03-20-75	1.91	176	238	477	486
		*07-25-75	2.94	141	222	345	581
		03-23-77	2.62	536	420	931	780
		04-05-77	1.60	266	234	546	401
		*06-10-77	2.14	92	55	177	117
		*10-09-77	2.09	132	109	279	205
		11-08-77	5.65	1040	949	1920	1860
		05-25-79	3.08	302	240	970	781
01376842	2.12	01-18-75	1.04	38	29	41.9	27.8
		03-20-75	2.08	75	78	123	92.2
		*07-14-75	1.75	86	75	88.0	102
		*10-18-75	3.94	124	106	212	221
		04-01-76	2.80	172	186	167	182
01376855	6.00	*06-30-76	2.91	1550	1153	665	573
		03-22-77	2.36	443	474	439	348
		01-09-78	2.06	355	430	295	238
		02-26-79	2.23	305	281	377	223
		05-24-79	4.51	1140	1071	731	878
		*09-06-79	1.38	132	257	78.5	105
01377196	3.89	04-05-77	1.60	163	212	117	131
		*10-09-77	1.78	105	69	106	78.9
		05-14-78	2.55	260	277	241	284
		01-25-79	2.00	450	219	359	202
01377260	8.39	03-19-75	2.09	446	438	599	405
		*08-09-76	2.81	332	669	229	458
		03-22-77	2.41	828	600	698	541
		11-08-77	6.07	1450	1499	1540	1740
		03-26-78	1.49	463	302	393	201
01387250	60.1	03-25-75	3.23	1350	1799	6440	6960
		*07-12-75	4.69	1000	1547	5500	6250
		*09-23-75	7.33	1290	1280	8600	5830
		01-27-78	1.88	889	780	4360	3070
		05-14-78	3.96	2070	2136	10100	8700
01387450	12.3	*07-12-75	4.97	475	606	648	1130
		*07-24-75	1.52	99	58	151	98.8
		11-21-75	1.62	206	306	365	477
		03-13-77	2.31	271	337	689	795
		11-08-77	6.77	1930	1535	2480	2290
		01-08-78	2.39	452	381	685	706
		05-14-78	3.93	719	665	1420	1330
		*09-06-79	3.02	356	435	385	700

* Storm during growing season



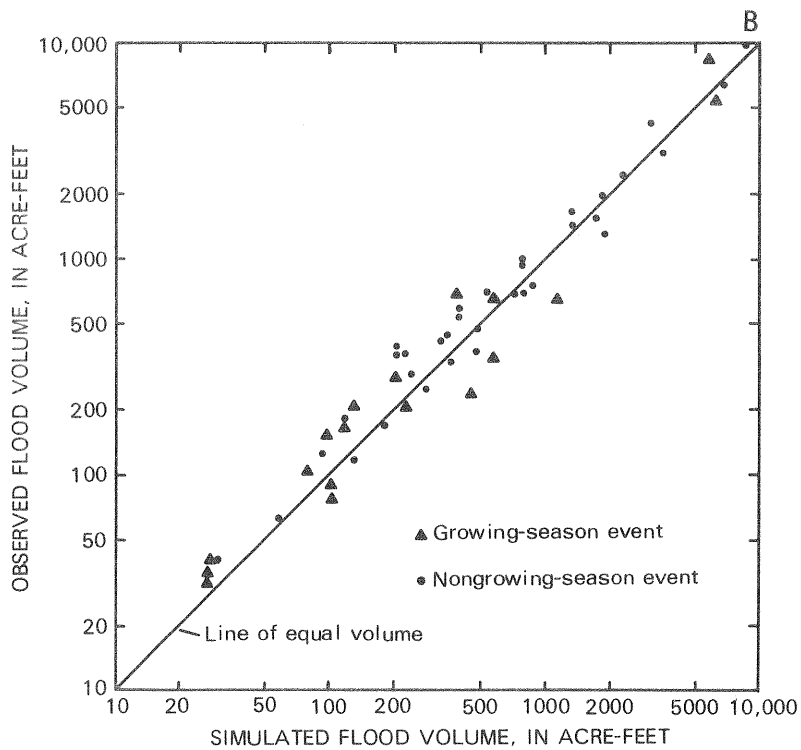


Figure 8.--Relationship between observed and simulated events at all sites based on seasonal adjustments of parameters STRKR and DLTKR (verification results): A, peak discharge; B, flood volume.

SUMMARY AND CONCLUSIONS

Twelve rainfall-runoff data collection sites were established during 1975-77 on selected streams in Rockland County. Rainfall-runoff relationships at 10 of these sites were modeled with the HEC-1 Flood Hydrograph Package; the other two sites were excluded from the analysis because of inadequate data.

HEC-1 is a lumped parameter model; thus, model parameter values are indices of average conditions for an entire basin and only approximate the "actual" values. It is expected that during the fitting process the precipitation loss-rate parameter values will deviate from their "true" values to minimize the deviations between the computed and observed flows as specified in the objective function.

Approximately half the floods at each site were selected for model calibration; most were reconstituted successfully. The major model constraint was the assumption that a single rain gage represents average rainfall over the entire basin being modeled. Optimization results indicated that the starting loss coefficient (STRKR) and the initial accumulated rain loss (DLTKR) for summer (growing-season) storms were significantly higher than those for the rest of the year, primarily because of drier antecedent soil-moisture conditions. A general seasonal pattern is apparent for both parameters.

Initial model results based on yearly average precipitation loss-rate parameters and unit hydrograph ordinate values gave a reasonably close match between observed and computed peak discharges. The only exceptions were for peak flows recorded during the growing season, which were generally much lower than the computed peak discharges. Although areal variability of rainfall during summer storms may contribute to this bias, a more probable explanation is the use of yearly average precipitation loss-rate parameter values in the computations. Parameter values reflecting the growing season (with drier antecedent soil-moisture conditions) differ noticeably from those of the nongrowing season, and, because more floods were recorded during the nongrowing season, a bias was developed. To correctly simulate summer (growing-season) storms, values of precipitation loss-rate parameters STRKR and DLTKR were adjusted to reflect the drier antecedent soil-moisture conditions. This adjustment was based on the seasonal relationships developed for all sites through optimizations.

The predictive capability of each model was substantially improved after seasonal adjustment of parameters STRKR and DLTKR, as indicated through verification of each model. The average difference between observed and simulated nongrowing-season peak discharge magnitudes based on yearly average parameter values for all sites was 18.2 percent, but, with growing-season events included, the average difference increased to 41.7 percent. After adjusting parameters STRKR and DLTKR for seasonal effects, the average differences were 18.2 percent for nongrowing-season peaks and 25.0 percent for all events.

The final version of the models developed for each site seem to adequately represent the rainfall-runoff processes under conditions at the time of data collection. More accurate determinations of impervious areas within each basin during the calibration period may increase the adequacy of the models, but significant improvement is unlikely. Although the final results reflect a combination of modeling, measurement, and sampling errors, it is doubtful that continued data collection would result in significant improvement of the models' predictive capability.

The analyses suggest that the models may be used for updating flood-frequency estimates for each site and can thereby aid in managing flood plains and drainage systems and in designing drainage structures for streams within the county.

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