US Army Corps
of Engineers
Hydrologic Engineering Center

Streamflow Synthesis for Ungaged Rivers

October 1967

Approved for Public Release. Distribution Unlimited.

TP-5

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)* October 1967	**2. REPORT TYPE** Technical Paper	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Streamflow Synthesis for Ungaged Rivers	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Leo R. Beard	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5F. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	**8. PERFORMING ORGANIZATION REPORT NUMBER** TP-5
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/ MONITOR'S ACRONYM(S)** **11. SPONSOR/ MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the XIV General Assembly of the International Union of Geodesy and Geophysics, Bern, Switzerland

14. ABSTRACT

The Hydrologic engineering Center of the Corps of Engineers has developed a mathematical model for simulating monthly streamflow. This model has been tested extensively to assure that all characteristics of monthly average streamflow pertinent to water resources development are adequately described in the model.

Model coefficients consist of frequency and correlation coefficients for each of the twelve calendar months and number forty-eight for a single location. These are far more numerous where more than one location must be considered simultaneously. For the purpose of deriving a monthly streamflow model for ungaged locations, these coefficients must be combined into a small number of generalized coefficients, which can feasibly be related to drainage basin characteristics.

Generalized coefficients for simulating monthly streamflows have been developed with the requirement that important characteristics of flows generated using the generalized coefficients compare reasonably with those characteristics of recorded data at long-record stations through the United States.

Means of establishing generalized model coefficients and generating hypothetical streamflows ungaged locations are described. Such streamflows would form the basis for water resources studies in regions of little or no streamflow data.

15. SUBJECT TERMS
streamflow forecasting, synthesis, regression analysis, statistical methods, model studies, correlation analysis, statistical models, routing ,flood routing, stream gages, stochastic processes

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	30	**19b. TELEPHONE NUMBER**

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

Streamflow Synthesis for Ungaged Rivers

October 1967

US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

TP-5

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution with the Corps of Engineers.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

ABSTRACT

STREAMFLOW SYNTHESIS FOR UNGAGED RIVERS

by

Leo R. Beard

The Hydrologic Engineering Center of the Corps of Engineers has developed a mathematical model for simulating monthly streamflow. This model has been tested extensively to assure that all characteristics of monthly average streamflow pertinent to water resources development are adequately described in the model.

Model coefficients consist of frequency and correlation coefficients for each of the 12 calendar months and number 48 for a single location. These are far more numerous where more than one location must be considered simultaneously. For the purpose of deriving a monthly streamflow model for ungaged locations, these coefficients must be combined into a small number of generalized coefficients, which can feasibly be related to drainage basin characteristics.

Generalized coefficients for simulating monthly streamflows have been developed with the requirement that important characteristics of flows generated using the generalized coefficients compare reasonably with those characteristics of recorded data at long-record stations throughout the United States.

Means of establishing generalized model coefficients and generating hypothetical streamflows for ungaged locations are described. Such streamflows would form the basis for water resources studies in regions of little or no streamflow data.

STREAMFLOW SYNTHESIS FOR UNGAGED RIVERS(1)

by

Leo R. Beard(2)

INTRODUCTION

It is usual practice in designing water resources projects for water supply and other conservation purposes to base the design on assumed repetition of recorded historical streamflows, modified for changes in the stream system that have taken place and that are expected to take place during the life of the proposed project. Inasmuch as historical streamflows will not be repeated exactly in the future, and since they are not exactly representative of future expectation, this practice leads to considerable uncertainty in design. Much effort has been expended in recent years to develop procedures by which hypothetical streamflows can be generated, which can just as likely occur in the future as can repetition of historical streamflows. This would permit the consideration in design of many sequences of simulated streamflows, thus giving a more dependable design as well as some indication of the potential variation or uncertainty in project performance. Some success has attended these efforts.(1)(2)(3)

---

(1) For presentation at the XIV General Assembly of the International Union of Geodesy and Geophysics, Bern, Switzerland, September - October 1967.

(2) Chief, Hydrologic Engineering Center, U. S. Army Corps of Engineers, Sacramento, California.

This paper describes results of initial studies made in the Hydrologic Engineering Center of the Corps of Engineers, U. S. Army, to devise procedures for generating monthly streamflows for ungaged rivers, based on data from other rivers. These initial studies consist of reducing the very large set of parameters required for simulation to a manageable set of generalized parameters that will adequately describe the pertinent characteristics of monthly streamflows. These generalized parameters can be used in regional studies to generate streamflows for ungaged areas.

MONTHLY STREAMFLOW GENERATION MODEL

The general equation used for generation of a flow for month i at station j of n interrelated stations is as follows:

$$K'_{i,j} = \beta_1 K'_{i,1} + \beta_2 K'_{i,2} + \cdots + \beta_{j-1} K'_{i,j-1} + \beta_j K'_{i-1,j} + \beta_{j+1} K'_{i-1,j+1} + \cdots + \beta_n K'_{i-1,n} + \sqrt{1-R^2_{i,j}} \quad Z_{i,j} \qquad (1)$$

in which:

K' = Monthly flow logarithm, expressed as a normal standard deviate
β = Beta coefficient
i = Month number
j = Station number
n = Number of interrelated stations
R = Multiple correlation coefficient
Z = Random number from normal standard population

For the case of a single station, this resolves to:

$$K'_i = R_i K'_{i-1} + \sqrt{1-R_i^2} \quad Z_i \tag{2}$$

The normal standard deviate K' in Equations 1 and 2 is related to streamflow as follows:

$$X_{i,m} = \log (Q_{i,m}+q_i) \tag{3}$$

$$\bar{X}_i = \sum_{m=1}^{N} X_{i,m} /N \tag{4}$$

$$S_i = \sqrt{\sum_{m=1}^{N} (X_{i,m}-\bar{X}_i)^2/(N-1)} \tag{5}$$

$$g_i = N \sum_{m=1}^{N} (X_{i,m}-\bar{X}_i)^3/((N-1)(N-2)S_i^3) \tag{6}$$

$$t_{i,m} = (X_{i,m}-\bar{X}_i)/S_i \tag{7}$$

$$K_{i,m} = 6/g_i \left[((g_i t_{i,m}/2)+1)^{1/3} - 1 \right] + g_i/6 \tag{8}$$

in which:

X = Logarithm of incremented monthly flow
Q = Monthly recorded streamflow
q = Small increment of flow used to prevent infinite logarithms for months of zero flow
$\bar{X}$ = Mean logarithm of incremented monthly flows
N = Total years of record
S = Unbiased estimate of population standard deviation
g = Unbiased estimate of population skew coefficient
t = Pearson Type III standard deviate
i = Month number
m = Year number

In order to generate flows at a single station where records exist, it is necessary to compute values of $\overline{X}$, S and g for each of the 12 calendar months from recorded data using Equations 3 to 8. The unbiased estimate of the serial correlation coefficient R, also required for each month, is obtained from recorded streamflow data as follows:

$$R_i = \left\{1 - \left[1 - \left(\sum_{m=1}^{N} X_{i,m} X_{i-1,m}\right)^2 / \left(\sum_{m=1}^{N} X^2_{i,m} \sum_{m=1}^{N} X^2_{i-1,m}\right)\right] (N-1)/(N-2)\right\}^{\frac{1}{2}} \qquad (9)$$

These values are then used to generate normal standard deviates by means of Equation 2. In order to obtain flows Q from the deviates K' the transformation process of Equations 3 to 7 is reversed as follows:

$$t_{i,m} = \left\{\left[(g_i/6)(K'_{i,m} - g_i/6)+1\right]^3 - 1\right\} 2/g_i \qquad (10)$$

$$X_{i,m} = \overline{X}_i + t_{i,m} S_i \qquad (11)$$

$$Q_{i,m} = \text{Antilog } X_{i,m} - q_i \qquad (12)$$

imposing the constraint:

$$Q_{i,m} \geq 0 \qquad (13)$$

The procedure for generating flows for a number of stream locations simultaneously is similar, but involves the computation of a multiple regression equation from the inter-station and serial correlation coefficients. Flows are generated for each station in turn for one month before proceeding with generation for the subsequent month. In order to preserve pertinent gross and partial correlation when generating a flow for a station, it is necessary to consider flows already generated for that month at other stations and flows generated for the preceding month at the remaining stations. Where records are available, the correlation coefficients relating all pertinent pairs of variables are computed at the same time that frequency statistics (from Equations 4 to 6) are computed. These are then derived by standard multiple regression techniques and then used in Equation 1.

COORDINATION STUDIES OF MONTHLY STATISTICS

Frequency and correlation coefficients for each of the 42 long-record unregulated streams throughout the United States were published in 1964.(2) These consist of 48 statistics for each station. Devising such a set of interrelated statistics for an ungaged stream would be a complicated and arduous task, unless the set could be coordinated and expressed adequately in terms of a few generalized coefficients. Accordingly, much effort has been expended in devising means of coordinating the monthly statistics.

It appears that there is no simple model for accurately expressing all of the statistics for a single station in terms of a few generalized statistics. Yet a simple model is necessary for transposition to ungaged streams. Hence, the problem is to devise a model that sacrifices accuracy the least.

Expression of seasonal variation in terms of a sine function has not been practical for several reasons. Many regions have two distinct wet seasons. Dry seasons are generally not separated from wet seasons by 6 months (symmetrically); in fact the lag between wet and dry seasons varies greatly and is of great importance in water resources studies. Neither in the wet or dry season are average runoff quantities symmetrical in relation to time.

In view of these findings, it is considered that a generalized model for a single station must include consideration of the following:

a. Season of maximum runoff
b. Lag to season of minimum runoff
c. Average runoff
d. Variation between maximum and minimum runoff
e. Standard deviation of flows
f. Serial correlation of flows

In studying variations in the above quantities and their interrelationships, using data for stations listed in Table 1, the following significant negative indications were obtained:

a. Variation of flows from month to month within each season is not related to the difference between wet-season and dry-season flows.

b. Variation of flows from month to month occurring between wet and dry seasons is not related to the difference between wet-season and dry-season flows.

c. There is no consistent correlation between standard deviation of flows and the difference between wet-season and dry-season flows.

d. There is no consistent relation from month to month between standard deviation and average flow for the corresponding calendar month.

e. There is no consistent relation between serial correlation coefficient and difference between wet-season and dry-season flows or rate of change of flow.

f. There is no consistent relation between serial correlation coefficient and average standard deviation.

The following significant positive indications were found:

a. The carry-over effect from one year to the next is trivial, even where extensive lake areas prevail (This is obviously not true in the special case of St. Lawrence River draining from the Great Lakes, where high persistence exists from year to year).

b. Serial correlation is higher during the low-flow season than during the high-flow season.

c. Patterns of logarithmic means, serial correlation, and standard deviations are irregularly and characteristically different for different streams, but it is believed that generalized approximations are possible that permit adequate reconstitutions of critical streamflow features.

d. Patterns of skew coefficient are also significantly different for different streams, and the national average coefficient is zero. It is believed, however, that use of zero skew for the logarithms of all months at all streams would not greatly affect generated flows, since the influence of skew on generated flows is secondary.

Summaries of pertinent variation of means, standard deviations and correlation coefficients are given in Tables 2 to 4 for stations used in this analysis.

THE GENERALIZED MODEL

On the basis of the above observations and data shown in Tables 2 to 4, the following generalized model was devised:

Selection of seasons

From recorded data in the region or general knowledge of climate, determine the 3 consecutive months that best constitute the wet season and the 3 that best constitute the dry season.

Selection of mean logarithms

Two generalized statistics are required for each station and must be obtained from correlation studies relating these to drainage basin characteristics. These are the average values of $\bar{X}$ (mean logarithm) for the wet-season and for the dry-season. Mean logarithms for each month are obtained directly from these as follows:

a. Add .2 to the wet-season average to obtain $\bar{X}$ for the middle month and subtract .1 from the wet-season average to obtain $\bar{X}$ values for the other 2 months.

b. Use the average dry-season mean for each of the 3 dry-season months.

c. Interpolate linearly to obtain means for the 6 remaining months.

Selection of standard deviations

One generalized statistic is required for each station and must be obtained from correlation studies relating these to drainage basin characteristics. This is the average value of S (standard deviation) for all 12 months. This value is used for each of the 12 months.

Selection of skew coefficients

No generalized statistic is required. A value of zero is used for each of the 12 months.

Serial correlation coefficients

One generalized statistic is required for each station and must be obtained from correlation studies. This is the average value of R for all 12 months. Add .15 to this value for each of the 3 dry-season months and subtract .15 for each of the 3 wet-season months. The average value is applied to each of the remaining 6 months.

Inter-station correlation

One generalized statistic is required for each pair of stations for which flows are interrelated. This is the average value of correlation coefficient for simultaneous flows during each of the 12 months at a given pair of stations. These must be obtained for all pairs of stations from regional correlation studies. The average value is applied to each of the 12 months. Correlation coefficients relating flows for one month at one station to flows for the preceding month at another station are specified as zero, but are raised in the computer to minimum values consistent with other correlation coefficients.

Table 5 illustrates the relation of generalized statistics to recorded statistics and of model statistics to the generalized statistics.

TEST OF THE MODEL

In developing a generalized model for streamflow generation for ungaged rivers, it is recognized that uncertainties involved in calibrating the model to a particular river will be large. It certainly is not expected that generated flows for ungaged rivers will be as reliable as those for gaged rivers. Nevertheless, it is desirable that errors in generalizing the model are minimal - at least small in comparison with calibration errors. Table 6, which shows results of a test based on data for several stations, demonstrates that errors incurred in generalizing are relatively small.

This test is based on the consideration that the primary influence of generated flows on design is a function of the maximum or minimum quantities for specified durations. Consequently, comparison of the maximum and minimum quantities for specified durations occurring within a given length of record with corresponding quantities occurring in an equal length of generated values should be a good test. In order to provide a measure of expected differences in random samples, corresponding quantities for each half of the record are also shown in Table 6. Differences between recorded and generated quantities are considered to be generally within acceptable limits.

CALIBRATION OF THE MODEL

While very little work has been done in calibrating a streamflow generation model to ungaged rivers, it is expected that best results will be obtained through multiple correlation of each of the generalized statistics with pertinent drainage basin characteristics. Some work of this nature was done for single stations by Garcia(4) while temporarily working with the Hydrologic Engineering Center. In that study concerned with ungaged rivers in Guatemala, mean logarithms were related to drainage basin size and normal precipitation. However, very little improvement of estimates occurred when considering other basin characteristics. Division of large regions into a few principal zones did help, and some relatively satisfactory results were obtained. Standard deviations and correlation coefficients were only generally related to mean logarithms.

When multi-station generation is required, inter-station correlation coefficients must be correlated with factors such as distance between rivers, ratio of drainage basin sizes, etc.

The degree of success obtainable in application of the model will depend on the nature of stream flows. In humid regions where flows are rather stable, results should be good. In arid regions where flows are erratic, it will be extremely difficult to obtain highly representative generated streamflow patterns.

CONCLUSIONS

The generalized model described herein for generating monthly streamflows requires only 4 statistics for use at a single station. These are indexes of wet-season average flow, dry-season average flow, flow variation from year to year, and flow persistence from month to month. The statistics represent the important characteristics of streamflow and are designed so that any amount and type of information can be used in their estimation. When generating simultaneous flows at interrelated stations, an intercorrelation index between each pair of stations is also required.

Streamflows generated using these generalized statistics compare reasonably with recorded streamflows where these are available.

ACKNOWLEDGMENT

The generalized model described herein and computer programs required for its use were developed in the Hydrologic Engineering Center of the Corps of Engineers, U. S. Army, Sacramento, California, USA. Principal contributors include Harold Keith, Denver Mills and Edward Jones.

References

1. Maass, Arthur, et.al., Design of Water Resource Systems, Harvard University Press, 1962
2. Hydrologic Engineering Center Technical Bulletin No. 1, Simulation of Monthly Runoff, November 1964
3. Beard, Leo R., Use of Interrelated Records to Simulate Streamflow, Journal of the Hydraulics Division, ASCE, September 1965
4. Garcia, Luis, Estimation of Monthly Streamflow in Regions with Limited Data, Water for Peace Conference, Washington, D.C. May 1967

TABLE 1

STREAMGAGING STATION DATA

Station Number	Name	Drainage Area sq. mi.	Years of Record
102	Mattawamkeag R. at Mattawamkeag, Maine	1,400	58
105	Pemigewasset R. at Plymouth, N.H.	622	57
113	E. Br. Delaware R. nr. Fish's Eddy, N.Y.	783	41
121	Rappahannock R. at Fredericksburg, Va.	1,599	52
301	Allegheny R. at Red House, N.Y.	1,690	56
311	Hocking R. at Athens, Ohio	944	44
323	Embarrass R. at Ste. Marie, Ill.	1,540	45
335	Tuckasegee R. at Bryson City, N.C.	655	63
404	Wolf R. at New London, Wis.	2,240	64
501	Red R. of the North at Grand Forks, N. Dak.	30,100	77
523	Sugar R. at Brodhead, Wis.	529	45
534	Big Muddy R. at Plumfield, Ill.	753	45
806	Brazos R. at Waco, Texas	23,260	61
901	Blue R. at Dillon, Colo.	129	50
1002	Weber R. at Oakley, Utah	163	56
1108	Kern R. at Bakersfield, Calif.	2,420	67
1111	Kings R. at Piedra, Calif.	1,690	66
1119	Mdl. Fk. Feather R. at Bidwell Bar, Calif.	1,353	48
1124	San Antonio Cr. & Canals nr. Claremont, Calif.	17	54
1303	Boise R. at Twin Springs, Ida.	830	48
1404	Willamette R. at Albany, Ore.	4,840	64

TABLE 2

SEASONAL VARIATION OF MEAN LOGARITHMS

Station Number	3-month Range (1)	6-month Departure (2)	Season Lag (3)	Maximum 1-month (4)	Minimum 1-month (5)
102	.83	-.13	1	.25	.09
105	.65	-.06	0	.25	.06
113	.65	-.04	1	.12	.06
121	.50	0	3	.04	.07
301	.88	.03	2	.09	.09
311	.89	.03	3	.09	.09
323	.88	.09	2	.44	.07
335	.74	.01	4	.05	.02
404	.46	-.07	5	.13	.07
501	.83	-.13	5	.18	.07
523	.26	-.08	2	.15	.01
534	1.07	.02	3	.07	.13
806	.59	-.14	4	.18	.04
901	1.06	-.20	5	.18	.03
1002	.94	-.29	4	.20	.03
1108	.82	-.09	2	.08	.03
1111	1.19	-.12	2	.13	.03
1119	1.14	.03	2	.07	.07
1124	.48	-.04	3	.01	.02
1303	.87	.27	2	.13	.05
1404	.77	-.09	4	.04	.05
Avg	.787	-.048	2.8	.138	.056

(1) Difference between average mean logarithms for maximum and minimum 3 consecutive months of flow.

(2) Difference between average mean logarithms for remaining 6 months and 6 months of note 1.

(3) Number of months between maximum and following minimum 3 months of flow.

(4) Difference between mean logarithm for maximum month and average for maximum 3 months of flow.

(5) Difference between average mean logarithms for minimum 3 months and minimum month of flow.

TABLE 3

SEASONAL VARIATION OF STANDARD DEVIATIONS

Station Number	12-month Average	Max 3-mo Average(1)	Min 3-mo Average(2)	Remaining 6-mo avg
102	.29	.19	.38	.30
105	.25	.18	.26	.28
113	.29	.20	.35	.31
121	.32	.22	.46	.30
301	.30	.22	.35	.31
311	.35	.29	.35	.39
323	.51	.43	.46	.57
335	.18	.16	.20	.17
404	.17	.17	.16	.18
501	.40	.37	.38	.43
523	.20	.24	.18	.18
534	.65	.53	.66	.71
806	.54	.50	.58	.55
901	.13	.17	.11	.12
1002	.15	.23	.08	.14
1108	.24	.27	.19	.26
1111	.27	.21	.24	.32
1119	.26	.27	.13	.34
1124	.27	.35	.17	.28
1303	.14	.18	.10	.15
1404	.18	.20	.14	.20
Avg	.30	.266	.288	.310

(1) Average standard deviation for 3 consecutive months of maximum flow.

(2) Average standard deviation for 3 consecutive months of minimum flow.

TABLE 4

SEASONAL VARIATION OF SERIAL CORRELATION COEFFICIENTS

Station Number	12-month Average	Max 3-mo Average(1)	Min 3-mo Average(2)	Remaining 6-mo avg
102	.48	.14	.81	.58
105	.36	.25	.34	.43
113	.36	.05	.57	.42
121	.50	.36	.56	.54
301	.35	.03	.57	.39
311	.49	.41	.57	.49
323	.63	.54	.54	.72
335	.55	.44	.69	.54
404	.61	.36	.79	.65
501	.84	.62	.98	.87
523	.46	.29	.50	.53
534	.47	.55	.26	.54
806	.55	.43	.70	.54
901	.69	.50	.85	.70
1002	.72	.44	.84	.78
1108	.81	.88	.81	.78
1111	.70	.71	.67	.72
1119	.70	.70	.74	.68
1124	.85	.86	.94	.80
1303	.70	.61	.77	.72
1404	.54	.26	.72	.59
Avg	.59	.45	.68	.62

(1) Average correlation coefficient for 3 consecutive months of maximum flow.

(2) Average correlation coefficient for consecutive 3 months of minimum flow.

TABLE 5

ILLUSTRATION OF GENERALIZED MODEL COEFFICIENTS

MONTH	MEAN		STANDARD DEVIATION		SKEW		SERIAL CORRELATION		INTERCORRELATION	
	REC.	GEN.	REC.	GEN.	REC.	GEN.	REC.	GEN.	REC.	GEN.
STATION 1108										
10	1.189	1.20	.192	.25	.434	0	.910	.98	.867	.92
11	1.239	1.20	.180	.25	1.172	0	.656	.98	.814	.92
12	1.329	1.34	.204	.25	1.009	0	.604	.83	.887	.92
1	1.431	1.48	.262	.25	.971	0	.698	.83	.917	.92
2	1.514	1.62	.242	.25	.528	0	.740	.83	.920	.92
3	1.704	1.77	.262	.25	.647	0	.861	.83	.935	.92
4	1.917	1.92	.256	.25	.250	0	.879	.68	.920	.92
5	2.106	2.22	.262	.25	.185	0	.896	.68	.935	.92
6	2.048	1.92	.288	.25	-.532	0	.866	.68	.965	.92
7	1.715	1.68	.330	.25	-.038	0	.954	.83	.982	.92
8	1.358	1.44	.289	.25	.145	0	.950	.83	.959	.92
9	1.158	1.20	.217	.25	.311	0	.955	.98	.920	.92
STATION 1110										
10	.560	.58	.292	.31	.828	0	.731	.90	.867	.92
11	.733	.77	.301	.31	1.305	0	.465	.75	.814	.92
12	.970	.96	.386	.31	1.052	0	.498	.75	.887	.92
1	1.143	1.16	.386	.31	.645	0	.605	.75	.917	.92
2	1.320	1.36	.320	.31	.186	0	.691	.75	.920	.92
3	1.541	1.56	.266	.31	.276	0	.784	.75	.935	.92
4	1.782	1.76	.186	.31	-.232	0	.810	.60	.920	.92
5	1.980	2.06	.204	.31	-.549	0	.790	.60	.935	.92
6	1.812	1.76	.326	.31	-.761	0	.836	.60	.965	.92
7	1.257	1.17	.411	.31	-.092	0	.961	.75	.982	.92
8	.711	.58	.331	.31	.329	0	.961	.90	.959	.92
9	.467	.58	.258	.31	-.025	0	.920	.90	.920	.92

GENERALIZED STATISTICS	STATION 1108	STATION 1110
WET-SEASON MEAN	2.02	1.86
DRY-SEASON MEAN	1.20	.58
STANDARD DEVIATION	.25	.31
SERIAL CORRELATION	.83	.75
INTERCORRELATION	.92	.92

TABLE 6

COMPARISON OF RECORDED AND GENERATED STREAMFLOWS

Percentage of Recorded Mean Annual Volume

	MAXIMUM ANNUAL	MINIMUM ANNUAL	MEAN ANNUAL	MAXIMUM 6-MONTH	MINIMUM 6-MONTH	MAXIMUM 54-MONTH	MINIMUM 54-MONTH
STATION 102							
RECORDED	149	50	100	114	5	612	344
1st HALF	149	50	101	114	7	612	344
2nd HALF	144	56	98	112	5	583	349
GENERATED	217	59	110	197	9	683	290
STATION 113							
RECORDED	162	65	100	97	9	515	356
1st HALF	162	71	100	97	9	515	378
2nd HALF	127	65	99	93	10	509	356
GENERATED	218	43	99	190	9	677	295
STATION 301							
RECORDED	150	64	100	120	5	547	316
1st HALF	150	64	101	120	5	543	336
2nd HALF	148	67	99	109	6	547	336
GENERATED	203	39	95	186	5	602	300
STATION 323							
RECORDED	221	3	100	170	1	721	160
1st HALF	221	15	101	170	2	721	284
2nd HALF	216	3	100	168	1	663	160
GENERATED	182	14	89	171	1	623	151
STATION 404							
RECORDED	167	51	100	105	16	600	291
1st HALF	167	60	104	105	18	596	334
2nd HALF	165	51	96	102	16	600	291
GENERATED	164	68	100	118	15	572	329
STATION 523							
RECORDED	156	52	100	112	19	581	291
1st HALF	156	52	96	112	21	581	365
2nd HALF	151	54	94	98	21	553	320
GENERATED	164	60	102	121	16	555	392
STATION 806							
RECORDED	302	23	100	198	1	810	131
1st HALF	302	23	107	185	1	810	147
2nd HALF	270	23	95	198	2	780	131
GENERATED	415	19	116	407	2	868	247
STATION 1002							
RECORDED	187	35	100	171	9	675	292
1st HALF	187	48	112	171	10	675	359
2nd HALF	135	35	122	120	9	539	302
GENERATED	199	64	108	178	10	649	371
STATION 1111							
RECORDED	239	24	100	219	4	735	205
1st HALF	239	24	106	219	5	735	277
2nd HALF	200	29	94	175	4	654	270
GENERATED	224	51	109	207	3	837	256
STATION 1124							
RECORDED	314	20	100	252	8	791	146
1st HALF	314	32	106	252	12	717	224
2nd HALF	258	20	94	228	8	791	146
GENERATED	228	33	82	170	8	782	237
STATIONS 1107, 1108, 1109 AND 1110 TOTAL SIMULTANEOUS RUNOFF							
RECORDED	260	24	100	231	6	809	186
1st HALF	260	24	98	231	5	809	240
2nd HALF	209	34	102	180	6	733	254
GENERATED	343	30	110	311	3	1164	245

Technical Paper Series

TP-1 Use of Interrelated Records to Simulate Streamflow
TP-2 Optimization Techniques for Hydrologic Engineering
TP-3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4 Functional Evaluation of a Water Resources System
TP-5 Streamflow Synthesis for Ungaged Rivers
TP-6 Simulation of Daily Streamflow
TP-7 Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8 Worth of Streamflow Data for Project Design - A Pilot Study
TP-9 Economic Evaluation of Reservoir System Accomplishments
TP-10 Hydrologic Simulation in Water-Yield Analysis
TP-11 Survey of Programs for Water Surface Profiles
TP-12 Hypothetical Flood Computation for a Stream System
TP-13 Maximum Utilization of Scarce Data in Hydrologic Design
TP-14 Techniques for Evaluating Long-Tem Reservoir Yields
TP-15 Hydrostatistics - Principles of Application
TP-16 A Hydrologic Water Resource System Modeling Techniques
TP-17 Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18 Estimating Monthly Streamflows Within a Region
TP-19 Suspended Sediment Discharge in Streams
TP-20 Computer Determination of Flow Through Bridges
TP-21 An Approach to Reservoir Temperature Analysis
TP-22 A Finite Difference Methods of Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23 Uses of Simulation in River Basin Planning
TP-24 Hydroelectric Power Analysis in Reservoir Systems
TP-25 Status of Water Resource System Analysis
TP-26 System Relationships for Panama Canal Water Supply
TP-27 System Analysis of the Panama Canal Water Supply
TP-28 Digital Simulation of an Existing Water Resources System
TP-29 Computer Application in Continuing Education
TP-30 Drought Severity and Water Supply Dependability
TP-31 Development of System Operation Rules for an Existing System by Simulation
TP-32 Alternative Approaches to Water Resources System Simulation
TP-33 System Simulation of Integrated Use of Hydroelectric and Thermal Power Generation
TP-34 Optimizing flood Control Allocation for a Multipurpose Reservoir
TP-35 Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36 Evaluation of Drought Effects at Lake Atitlan
TP-37 Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38 Water Quality Evaluation of Aquatic Systems
TP-39 A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40 Storm Drainage and Urban Region Flood Control Planning
TP-41 HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42 Optimal Sizing of Urban Flood Control Systems
TP-43 Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44 Sizing Flood Control Reservoir Systems by System Analysis
TP-45 Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46 Spatial Data Analysis of Nonstructural Measures
TP-47 Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48 Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49 Experience of HEC in Disseminating Information on Hydrological Models
TP-50 Effects of Dam Removal: An Approach to Sedimentation
TP-51 Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52 Potential Use of Digital Computer Ground Water Models
TP-53 Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54 Adjustment of Peak Discharge Rates for Urbanization
TP-55 The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56 Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57 Flood Damage Assessments Using Spatial Data Management Techniques
TP-58 A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59 Testing of Several Runoff Models on an Urban Watershed
TP-60 Operational Simulation of a Reservoir System with Pumped Storage
TP-61 Technical Factors in Small Hydropower Planning
TP-62 Flood Hydrograph and Peak Flow Frequency Analysis
TP-63 HEC Contribution to Reservoir System Operation
TP-64 Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65 Feasibility Analysis in Small Hydropower Planning
TP-66 Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67 Hydrologic Land Use Classification Using LANDSAT
TP-68 Interactive Nonstructural Flood-Control Planning
TP-69 Critical Water Surface by Minimum Specific Energy Using the Parabolic Method

TP-70	Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
TP-71	Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72	Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
TP-73	Flood Mitigation Planning Using HEC-SAM
TP-74	Hydrographs by Single Linear Reservoir Model
TP-75	HEC Activities in Reservoir Analysis
TP-76	Institutional Support of Water Resource Models
TP-77	Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78	Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79	Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U.S. Hydropower Reservoirs
TP-80	Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81	Data Management Systems of Water Resources Planning
TP-82	The New HEC-1 Flood Hydrograph Package
TP-83	River and Reservoir Systems Water Quality Modeling Capability
TP-84	Generalized Real-Time Flood Control System Model
TP-85	Operation Policy Analysis: Sam Rayburn Reservoir
TP-86	Training the Practitioner: The Hydrologic Engineering Center Program
TP-87	Documentation Needs for Water Resources Models
TP-88	Reservoir System Regulation for Water Quality Control
TP-89	A Software System to Aid in Making Real-Time Water Control Decisions
TP-90	Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91	HEC Software Development and Support
TP-92	Hydrologic Engineering Center Planning Models
TP-93	Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94	Dredged-Material Disposal Management Model
TP-95	Infiltration and Soil Moisture Redistribution in HEC-1
TP-96	The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97	Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98	Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99	Reservoir System Analysis for Water Quality
TP-100	Probable Maximum Flood Estimation - Eastern United States
TP-101	Use of Computer Program HEC-5 for Water Supply Analysis
TP-102	Role of Calibration in the Application of HEC-6
TP-103	Engineering and Economic Considerations in Formulating
TP-104	Modeling Water Resources Systems for Water Quality
TP-105	Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106	Flood-Runoff Forecasting with HEC-1F
TP-107	Dredged-Material Disposal System Capacity Expansion
TP-108	Role of Small Computers in Two-Dimensional Flow Modeling
TP-109	One-Dimensional Model for Mud Flows
TP-110	Subdivision Froude Number
TP-111	HEC-5Q: System Water Quality Modeling
TP-112	New Developments in HEC Programs for Flood Control
TP-113	Modeling and Managing Water Resource Systems for Water Quality
TP-114	Accuracy of Computer Water Surface Profiles - Executive Summary
TP-115	Application of Spatial-Data Management Techniques in Corps Planning
TP-116	The HEC's Activities in Watershed Modeling
TP-117	HEC-1 and HEC-2 Applications on the Microcomputer
TP-118	Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119	Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120	Technology Transfer of Corps' Hydrologic Models
TP-121	Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122	The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123	Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124	Review of U.S. Army corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125	An Integrated Software Package for Flood Damage Analysis
TP-126	The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127	Floodplain-Management Plan Enumeration
TP-128	Two-Dimensional Floodplain Modeling
TP-129	Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130	Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131	Hydrologic Aspects of Flood Warning - Preparedness Programs
TP-132	Twenty-five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs
TP-133	Predicting Deposition Patterns in Small Basins
TP-134	Annual Extreme Lake Elevations by Total Probability Theorem
TP-135	A Muskingum-Cunge Channel Flow Routing Method for Drainage Networks
TP-136	Prescriptive Reservoir System Analysis Model - Missouri River System Application
TP-137	A Generalized Simulation Model for Reservoir System Analysis
TP-138	The HEC NexGen Software Development Project
TP-139	Issues for Applications Developers
TP-140	HEC-2 Water Surface Profiles Program
TP-141	HEC Models for Urban Hydrologic Analysis

TP-142	Systems Analysis Applications at the Hydrologic Engineering Center
TP-143	Runoff Prediction Uncertainty for Ungauged Agricultural Watersheds
TP-144	Review of GIS Applications in Hydrologic Modeling
TP-145	Application of Rainfall-Runoff Simulation for Flood Forecasting
TP-146	Application of the HEC Prescriptive Reservoir Model in the Columbia River Systems
TP-147	HEC River Analysis System (HEC-RAS)
TP-148	HEC-6: Reservoir Sediment Control Applications
TP-149	The Hydrologic Modeling System (HEC-HMS): Design and Development Issues
TP-150	The HEC Hydrologic Modeling System
TP-151	Bridge Hydraulic Analysis with HEC-RAS
TP-152	Use of Land Surface Erosion Techniques with Stream Channel Sediment Models
TP-153	Risk-Based Analysis for Corps Flood Project Studies - A Status Report
TP-154	Modeling Water-Resource Systems for Water Quality Management
TP-155	Runoff simulation Using Radar Rainfall Data
TP-156	Status of HEC Next Generation Software Development
TP-157	Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers
TP-158	Corps Water Management System (CWMS)
TP-159	Some History and Hydrology of the Panama Canal
TP-160	Application of Risk-Based Analysis to Planning Reservoir and Levee Flood Damage Reduction Systems
TP-161	Corps Water Management System - Capabilities and Implementation Status