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EVALUATION OF THE ADEQUACY OF STREAMFLOW OPERATIONAL HYDROLOGY IN DUPLICATING EXTENDED PERIODS OF HIGH AND LOW FLOWS

Roland W. Jeppson
and
Calvin G. Clyde

The work reported herein is based on partial findings of work conducted for the Office of Saline Water, Department of the Interior, under Contract No. 14-01-0001-1711, "Optimum Operation of Desalting Plants as a Supplemental Source of Safe Yield." The material contained in this report is also contained as Appendixes A and B of the final report under the same contract. The material under this cover has been separated from the main report because the reported information has applications of its own.

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INTRODUCTION

In recent years the generation of synthetic hydrologic records, particularly streamflow data, has been common in hydrologic studies which use a simulation approach. *Operational hydrology* is the term used to denote the generation of synthetic data. One of the most active groups promoting simulation techniques and operational hydrology was founded by Professor Harold A. Thomas, Jr. at Harvard, and from this group a number of publications originated (see Hufschmidt and Fiering, 1966; and Fiering, 1967). The operational hydrology computer program by the U. S. Corps of Engineers (Beard, 1965, and Hydrologic Engineering Center, 1967) has been used in research at USU supported by the Office of Saline Water, U. S. Dept. of the Interior.

Much thought and many analyses have contributed to present techniques of operational hydrology. It has long been recognized that monthly and seasonal flows demonstrate a high order of persistence, reflected by large correlation coefficients between flows in successive time periods. Although this is true to a lesser extent for annual values, examination of many flow records using spectral density methods, correlograms and other techniques discloses cycles that range over periods of several years. The fact that a long period of low or high flow can sometimes be extremely long has been called by Mandelbrot and Wallis (1968) the "Joseph Effect." Some have questioned the significance of these results, but analysis of precipitation records has demonstrated that it is possible to create such cyclic effects by a purely random variable as shown by Crippen (1965). Just the same persistently high flow and drought sequences are present in some historic streamflow data. Furthermore, the watershed can accentuate precipitation cycles so that the streamflow cycles become even more extreme. There might well be some as yet unknown meteorologic cause for such extended cycles. Several hypotheses have been suggested including the influence of solar spots, cosmic dust, and radiation belts. Whatever the cause, natural streamflow in certain regions exhibits a persistence even on an annual event basis that is difficult to attribute to a random variable, and evidently is also difficult to duplicate with operational hydrology.

While considerable disappointment with specific hydrologic models has been expressed by hydrologists (see Yevdjevich, 1968), verbal communication with Warren Hall at the University of California at Riverside, and Leo R. Beard and Harold Kubik of the Hydrologic Engineering Center at Sacramento, indicated that operational hydrology programs adequately retain critically low and high sequences for streams in more humid regions, but fail to adequately duplicate the "Joseph Effect" for streams in arid regions. These comments lead to careful examination of the generated streamflow obtained from the operational hydrology computer program. It is clear that such an evaluation is needed because the approach used in the OSW sponsored study for evaluating the incremental increases in safe yield obtainable from standby desalted water sources depends directly upon the simulated streamflow data for its results. The study of the adequacy of the generated streamflow data has not been exhaustive. Rather, a computer program applicable to any stream has been developed to aid in evaluating the adequacy of the generated streamflow. (The input data called for by this program is described in Appendix B along with a listing of the FORTRAN source statements.) Other methods than those used in the program might well have been selected for this evaluation. The urgency of examining the generated streamflow before proceeding further into the major work of the OSW contract necessitated that the evaluation be made without delay. Because the computer program thusly developed might be of aid to others in evaluating operational hydrologies, it seemed desirable to document the approach used and to list and explain the computer program in a separate report speciafically directed to the evaluation of generated streamflow data.

METHOD OF APPROACH

A preliminary analysis comparing the monthly means, monthly standard deviations, annual means and annual standard deviations of generated data and historic data from several streams indicated that these statistical parameters of the generated data were close to the same historic parameters. In essence this comparison simply verified the proper operation of the operational hydrology program, since these parameters are maintained in the generation process.

The deficiency in generated streamflow data, as others have pointed out, is that in consecutive annual events the historic data tend to be either consistently higher or lower than the generated data for some streams. To examine this characteristic of the generated streamflow data all possible running averages (averages of consecutive monthly flows) within the streamflow record are computed for several different length of periods. The computer program developed to accomplish this computation, has been designed to permit the analyses of the running average data for several specified periods of consecutive months during the same execution of the program. For the analyses already performed at USU, periods starting with 24 consecutive months and going through 192 consecutive months in increments of 24 months have been used. The computed running averages represent an additional data set covering flows of extended periods of time. The number of individual running averages computed in this manner are given by,

$$N_r = 12\, N_y - K + 1 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

in which N_y is the number of years of streamflow data, and K is the length of the period of consecutive months. While these individual averages are not independent, a frequency distribution of the resulting data indicates persistency trends of the data. To obtain this frequency distribution running averages are ranked in order of magnitude by the program from high to low. In addition, the mean, variance, standard deviation and skewness coefficient of the running averages of each period are computed, so that one might obtain the frequency distribution under the assumption that the data fit a normal distribution. The ranked running averages are then plotted as the ordinate against the probability computed by,

$$p = \frac{n}{N_r + 1} \quad . \; . \quad (2)$$

as the abscissa. In Eq. 2 n refers to the rank number.

By comparing the distribution of running averages obtained from the historic data with those resulting from the data obtained from the operational hydrology program, it is possible to determine whether extended periods of droughts and high flows are duplicated. If the running averages associated with small probabilities (i.e. the high flows) obtained from the generated streamflow data are smaller than the corresponding averages from the historic data, then the generated data does not maintain the needed dependence between annual events. Likewise if the running averages associated with large probabilities (i.e. the low flows) from the generated data are not as small as those from the historic data, persistence of droughts are not duplicated. In fact since the generated data cover a much longer time period than the historic data, its record should actually contain both larger and smaller running averages than the historic data.

An index to how well the generated data maintains critical periods is the difference between generated and historic standard deviations of the running averages. Since the standard deviation is a measure of the spread about the mean, the standard deviations of the running averages from the generated data should not be consistently smaller than those resulting from the historic data. The computer program contains instructions which compare the two standard deviations for each specified period of consecutive months by printing the difference between the two values. In addition the mean and standard deviation of these differences among the specified periods of consecutive months is computed and a value of t computed by

$$t = \frac{X_d N_p}{\sigma_p} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

in which X_d is the average difference between the two standard deviations, N is the number of separate periods used in the analyses and σ_p is the standard deviation of this same difference. While the value of t computed by Eq. 3 does not represent a true distribution of difference in mean values, an idea of the likelihood that the generated data is from the same population as the historic data can be acquired by comparing its value with the tabulated t-distribution.

RESULTS FROM ANALYSES OF THREE STREAMS

The streamflow at each gaging station is influenced by unique and complex interrelated phenomena. These phenomena are the result of the meteorology, geology and hydrology of that particular area. Completely meaningful generalizations cannot be made about watershed types, areal location or climate and their effects on streamflow. Often adjacent watersheds with similar topographical characteristics may have streamflows differing considerably both in total magnitude and seasonal distribution. It is necessary, therefore, to analyze streamflow data for each watershed separately to ascertain the adequacy of a particular operational hydrology for that stream gaging site. Three separate stream gaging sites have been selected for analysis of their streamflow in this report.

These three sites are all in different parts of the United States and their geologic histories are quite different. The first site, Cottonwood Creek near Orangeville, Utah, is in the Colorado River Basin in Central Utah, a relatively arid part of the United States. A significant portion of the streamflow results from groundwater storage, because flow continues through periods of neither snowmelt nor rainfall. The second selection is at the Cachuma project site in California. The streamflow at this site varies drastically when contrasted with Cottonwood Creek, and within a period of a month a difference of several thousand cubic feet per second of flow are commonly observed. Even though this area is not as arid as the Cottonwood Creek region, zero flow has occurred for many separate periods several months in length. The third selection is on the East Coast of the United States, Schoharie Creek at Prattsville, New York, a stream in a region of higher annual precipitation and exhibiting less erratic flow fluctuations than the Cachuma data.

The selection of these three stream gaging sites was not based on an attempt to find streams with peculiar behavior. Rather their selection resulted because they represent differing conditions and the latter two are to be used as bench marks on which the operating rule program resulting from the OSW contract is to be tested. The selection of Cottonwood Creek resulted because of the availability of good streamflow records and because it lies in a region similar to those in which other investigators have noted that operational hydrology programs do not adequately reproduce the "Joseph Effect" in historic data.

Partial results from the analyses provided by the computer program are given below for each of the three selected sites. These results are presented not only to document the findings regarding the adequacy or inadequacy of the operational hydrology program for each stream but also to illustrate how judgment might be used in interpreting the results from similar analyses of other streams. For each of these streams 500 years of data were obtained from the operational hydrology program using the available historic data as input. For each stream the generated data were obtained as 10 groups of 50 years each.

Cottonwood Creek near Orangeville, Utah

Historic streamflow data are available for Cottonwood Creek near Orangeville, Utah, from 1910 through 1965. The watershed area contributing to the flow at the gaging station is 205 square miles. For the entire 56 year period of record the streamflow data represents the natural flow of the stream with the exception of small diversions for irrigation above the gaging station, which are not measured. Diversions from the headwaters of Cottonwood Creek through Ephraim and Spring City tunnels, constructed by the Bureau of Reclamation in 1936 and 1938 respectively to the San-Pitch River Basin within the Great Basin, have been added to the measured flow at the station site near Orangeville, in order for the historic data to represent natural conditions.

For both the historic and the generated streamflow data, the cumulative frequency distributions of periods starting with all possible averages from 24 consecutive months through 192 consecutive months in increments of 24 months were obtained. On Fig. 1 are graphs on which the results of the frequency analyses are displayed. In comparing the curves on the graphs resulting from the generated data with those from the historic data a smoothing effect can be detected. A certain amount of this effect would be expected because the sample of data from the generated streamflow is larger. One might also note that the flows which are exceeded for small probabilities of occurrence (high flows), particularly for the longer periods of consecutive months as given by the analysis of the historic data, are larger than the corresponding flows as given by the analysis of the generated data. Furthermore, for larger probabilities of occurrence the average flow rates resulting from the analyses of the generated data are larger. Table 1 has been prepared to illustrate these differences.

If the generated data maintained the "Joseph Effect" which the historic data exhibits, this difference should not have occurred. In fact because of the larger number of generated data, one might expect the opposite tendency.

A further indication of the inadequacy of the generated data in duplicating extended critical periods is given in Table 2 in which the standard deviations of the running averages from both the historic and generated data are given. The fact that, for all periods of consecutive months, the standard deviations from the historic data are larger than those from the generated data indicates that the generated data do not contain as many persistently high-flow or drought sequences as do the historic data.

The conclusion, therefore, is that the operational hydrology program does not adequately reproduce the "Joseph Effect" for Cottonwood Creek near Orangeville.

Table 1. Average flowrate (ac-ft/month) over the given period of consecutive months that will be exceeded for several probabilities of occurrence. The flowrates are for both the historic and generated streamflow of Cottonwood Creek near Orangeville, Utah.

Period (Consecutive Months)	Probability of occurrence							
	2%		10%		90%		98%	
	Historic	Generated	Historic	Generated	Historic	Generated	Historic	Generated
24	9786	10,010	9210	8400	4068	4170	2797	3480
48	8769	8,960	8119	7670	4533	4660	3663	4110
72	8220	8,550	7930	7450	4838	4900	3557	4370
96	8095	7,930	7680	7320	5058	5180	4760	4510
120	8115	7,810	7564	7200	5060	5280	4719	4710
144	8164	7,550	7467	7080	5226	5370	4768	4890
168	7878	7,370	7122	6960	5365	5430	5165	5090
192	7437	7,200	7097	6900	5416	5490	5182	5170

Table 2. Comparison of standard deviations of running average data of streamflow at Cottonwood Creek near Orangeville, Utah. (Units are in ac-ft/month.)

No. of Consecutive Months	Standard deviations			
	Historic	Generated	Difference	Percent Difference
24	1810	1680	+ 130	7.25
48	1350	1180	+ 170	12.71
72	1090	970	+ 120	11.15
96	934	835	+ 99	11.47
120	895	728	+ 167	18.70
144	822	641	+ 181	23.30
168	695	570	+ 125	17.96
192	590	517	+ 73	12.25

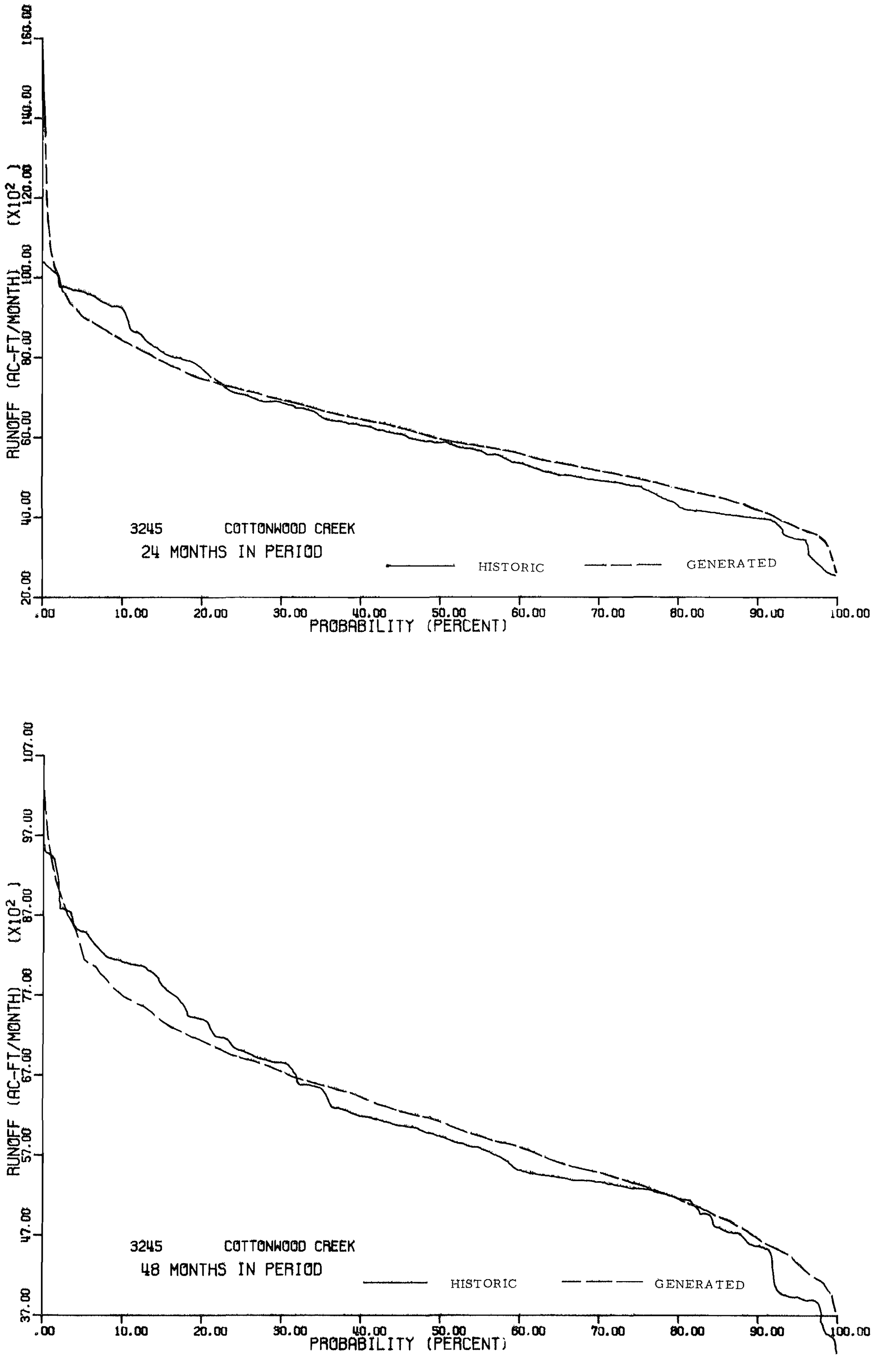


FIG I. RELATIONSHIPS BETWEEN AVERAGE QUANTITIES OF RUNOFF OVER EXTENDED PERIODS OF TIME AND PROBABILITY OF OCCURRENCE FOR COTTONWOOD CREEK NEAR ORANGEVILLE, UTAH.

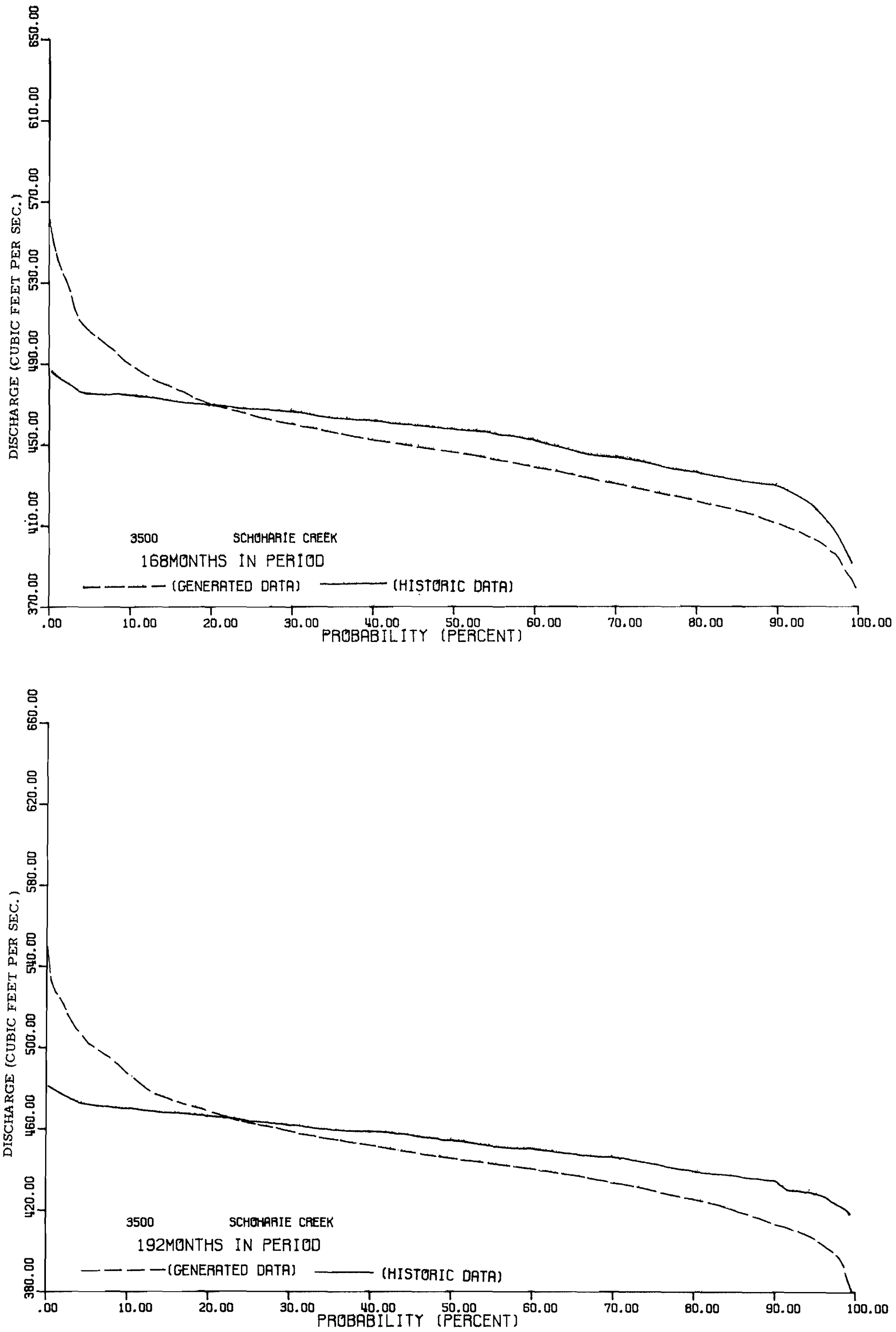

DISCHARGE (CUBIC FEET PER SEC.)
370.00
410.00
450.00
490.00
530.00
570.00
610.00
650.00
3500 SCHOHARIE CREEK
168MONTHS IN PERIOD
(GENERATED DATA)
(HISTORIC DATA)
.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
PROBABILITY (PERCENT)
DISCHARGE (CUBIC FEET PER SEC.)
380.00
420.00
460.00
500.00
540.00
580.00
620.00
660.00
3500 SCHOHARIE CREEK
192MONTHS IN PERIOD
(GENERATED DATA)
(HISTORIC DATA)
.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
PROBABILITY (PERCENT)

FIG 3. CON'T.

APPENDIX A

REFERENCE

1. Crippen, J. R., 1965, "Cycles in hydrologic data," *Civil Engineering,* ASCE, January.

2. Beard, Leo R., 1965, "Use of interrelated records to simulate streamflow," *Journal of the Hydraulics Division,* ASCE, Vol. 91, No. HY5, Proc. Paper 4463, September pp. 13-22.

3. Fiering, M. B., 1967, *Streamflow synthesis,* Harvard University Press, Cambridge, Massachusetts.

4. Hufschmidt, M. M. and M. B. Fiering, 1966, *Simulation techniques for design of water resource systems,* Harvard University Press, Cambridge, Massachusetts.

5. Hydrologic Engineering Center, 1967, "Generalized computer program— monthly streamflow simulation," *U. S. Army Corps of Engineers,* 650 Capitol Mall, Sacramento, California, July.

6. Mandelbrot, B. B., and J. R. Wallis, 1968, *Water Resources Research,* Vol. 4, No. 5, October pp. 909-918.

7. Yevdjevich, V. M., 1968, "Misconceptions in hydrology and their consequences," *Water Resources Research,* Vol. 4, pp. 225-232.

APPENDIX B
USE,DESCRIPTION AND LISTING OF FORTRAN PROGRAM

Data input required by program

The data cards read by the program consist of several control cards. Data containing the monthly values of streamflow are subsequently input. The program has been written for a system on which the FORTRAN logical unit 5 is the card reader and the control input parameters is through punched cards. The proper order of these control cards, containing the parameters which were used to evaluate the adequacy of the generated streamflow for Schoharie Creek at Prattsville, New York, is shown in Fig. B-1. These control cards are as follows (unless stated otherwise all numbers are punched in the designated columns right-justified):

Card 1. The first control card contains the format of the monthly streamflow data in columns 1 through 72 left-justified. The FORTRAN logical unit containing the input monthly streamflow data is in columns 73 through 76, and the FORTRAN logical unit on which the output is to be written is in columns 77 through 80.

Card 2. The second control card specifies the number of periods of consecutive months that are to be analyzed and the length of each of these periods in months. The number of periods is contained in columns 1 through 5, and with the present dimensions of the program must be equal to or less than 10. The lengths of each of these periods (given as number of consecutive months), are contained in the following columns of this card. Five columns are allocated for each number.

Card 3. The third card contains the name of the stream being investigated, and any other identification information desired in columns 1 through 72, left-justified.

Card 4. The fourth card contains several parameters which control the nature and amount of output as well as supply needed information about the data being analyzed. The name of each of these parameters as used in the FORTRAN program as well as its effect on the program are given in Table B-1.

Streamflow data. The streamflow data to be analyzed is required next by the program. This data may be punched on data cards. If so these cards follow the above control cards. The card reader must then be specified as the FORTRAN logical unit for data input. By specifying a tape unit, disk, drum or other input device, the streamflow data can be read from whatever input device this data is available on. The program contains a test to insure that the data for each year is for the specified station. This test requires that the station number precede the monthly data for that year. Should the station number be incorrect, execution is terminated. This portion of the program can readily be modified by deleting a few FORTRAN statements.

Any number of streamflow data can be analyzed by a single access to the computer. For each subsequent station's data (historic or generated) control cards 3 and 4 must be repeated. Should the format of the input data, its logical unit devices, or the number or lengths of consecutive months change for any subsequent stations data, then a card with any information followed by a card with 89 in columns 4 and 5 must precede the control cards beginning again with card 1 for that station. Execution is terminated by a card with any information followed by a card containing 99 punched in columns 4 and 5.

Table B-1. Control parameters on input data card no. 4.

Variable Name	Col's Containing Information	Information Contained in Parameter or Effect of parameter
NBASIN	1-5	is the river basin number of the streamflow data.
NSTA	6-10	is the number assigned to the streamflow data.
NYRB	11-15	is the beginning year of the streamflow data.
NYRE	16-20	is the final year of the streamflow data.
MISSING	21-25	is the number of missing years of data in the stream- flow data.

FIG. B-1. EXAMPLE INPUT FOR EXECUTION OF PROGRAM.

```
  99
TERMINATION OF THIS ACESS TO THE COMPUTER
```

CARDS CONTAINING GENERATED DATA (MAY BE ON ANY OTHER SPECIFIED INPUT UNIT)

```
1 3500    1  500    0    1   10    0    1 236.0         2    1
```

NBASIN NYRB MISSNG NPRIT IPLOT NGEN
NSTA NYRE NPRT NRIT AREA NCOMPR

```
SCHOHARIE CREEK -- GENERATED DATA
```

CARDS CONTAINING HISTORIC DATA (MAY BE ON ANY OTHER SPECIFIED INPUT UNIT)

```
1 3500    4   67    0    1   10    0    1 236.0         1    1
```

NBASIN NYRB MISSNG NPRIT IPLOT NGEN
NSTA NYRE KPRT NRIT AREA NCOMPR

```
SCHOHARIE CREEK AT PRATTSVILLE,N.Y.
```

NAME OF STREAM

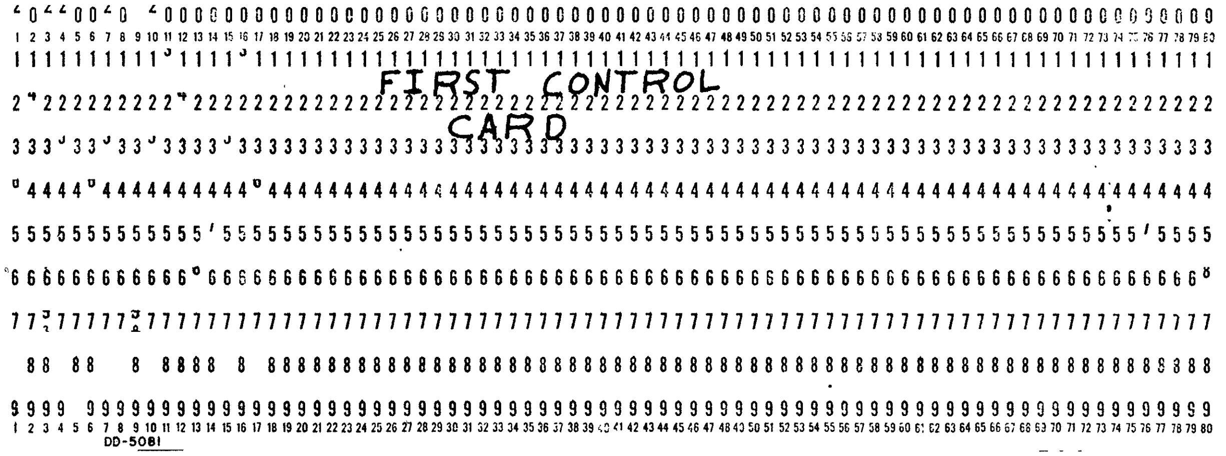
```
 8   24   48   72   96  120  144  168  192
```

NO. OF PERIODS
LENGTH OF EACH PERIOD IN MONTHS

```
(2X,I4,8X,12F5.1)                                        5    6
```

FORMAT OF INPUT DATA

INPUT UNIT
OUT-PUT UNIT



KPRT	26-30	is a parameter, which if assigned a value greater than 0 suppresses the writing of all the running average data which are computed for all possible consecutive months. The ranked running averages, their probabilities and ranked number are also printed.
NPRIT	31-35	determines how many of the running average data are written. For example if NPRIT equals 10 every tenth value is printed along with its probability of occurrence. If KPRT equals zero this data is not written separate from the data already written.
NRIT	36-40	determines whether the input streamflow data is to be written or not. If NRIT equals 0 the input streamflow data is written.
IPLOT	41-45	if IPLOT is greater than zero the subroutine PLTTR is called which writes a plot tape for plotting the results from the frequency distribution of the running averages, in order of high to lower values of stream- flow. The subroutine PLTTR must be altered as necessary to call plot subroutines implemented on the particular system being used.
AREA	46-55	is the area of the watershed contributing to the streamflow in square miles.
NGEN	56-60	is a parameter which determines whether the streamflow data is the historic data or the data obtained from an operational hydrology program. NGEN must equal 1 if historic data is input and must equal 2 if operational hydrology data is input.
NCOMPR	61-65	if a table comparing the historic and generated data is to be written NCOMPR should be greater than zero. Otherwise NCOMPR should be assigned zero. IF NCOMPR is greater than zero, it is necessary to follow the historic data by operational hydrology data in the same access to the program.

<u>Other variables used in computer program</u>

FSUM	double precision value used to temporarily store running average values.
S	used to obtain sums of the running averages
S2	used to obtain sum of differences squared between average and individual running averages
S3	used to obtain sum of difference cubed
FNID	double precision value of the number of years of data
DIF	difference
FNIDM	FNID - 1.0
DIF2	difference squared
RM	two dimensional array used to store monthly streamflow data, and annual values
NAME	array for storing the name of stream gaging station
FMT	array for storing format of streamflow data
SUMA	array for storing individual running averages which are computed from the streamflow data
SUMA1	array for storing ranked values of SUMA
SUMA2	array for storing a selected number of SUMA1
PRBOL	array for storing probabilities corresponding to values in SUMA2
STAD	two dimensional array for storing standard deviations
MEANR	two dimensional array for storing means
NPER	array for storing length of periods of consecutive months which are to be analyzed
NPERID	number of periods NPER
NI & NYRS	number of years of streamflow data. NI latter in the program also represents the number of computed running averages
RMM	used to compute annual streamflow
NYREM	NYRE - 1
FAC	factor to convert ac-ft to equivalent inches of depth over the watershed
NCOUNT	index to accumulate number of running averages
SUM	variable used to obtain running averages
FNI	floated value of NI
TP	recurrence interval
VAR	variance
STD	standard deviation
SKEW	skewness coefficient
AUM	average standard deviation
T	value to compare with statical t-distribution

LISTING OF FORTRAN PROGRAM

```
'I  FOR STRENF,STRENF
      DOUBLE PRECISION   FSUM,S,S2,S3,FNID,DIF,FNIDM ,DIF2
      DATA DASH/6H------/
      REAL RM(500,13),NAME(12),FMT(12),SUMA(6000),SUMA1(6000),SUMA2(793)
     $,PRBOL(793),STAD(10,2),MEANR(10,2),SUMAN(80,10),PRBON(80,10),ORID(
     $4)
      INTEGER NPER(10),IIIN(10)
   98 READ(5,143) (FMT(I),I=1,12),NREAD,NWRITE
  143 FORMAT(12A6,2I4)
      READ(5,102) NPERID,(NPER(I),I=1,NPERID)
  102 FORMAT(11I5)
   10 READ(5,143)(NAME(I),I=1,12)
      READ(5,100) NBASIN,NSTA,NYRB,NYRE,MISSNG,KPRT,NPRIT,NRIT,IPLOT,
     $AREA,NGEN,NCOMPR
  100 FORMAT(9I5, F10.5,3I5)
      IF(IPLOT .GT. 0) READ(5,133) ORID
  133 FORMAT(4A6)
C  NGEN=1 IF HISTORIC DATA8 = 2 IF GENERATED DATA
C   NCOMPR   IF COMPARISON BETWEEN HISTORIC AND GENERATED DATA IS TO BE MADE THE
C VALUE OF NCOMPR SHOULD NOT BE EQUAL TO 0, HISTORIC DATA SHOULD BE FIRST
      IF(NBASIN .EQ. 99) GO TO 99
      IF(NBASIN .EQ. 89) GO TO 98
      NI=NYRE-NYRB+1-MISSNG
      NYRS=NI
      DO 1 I=1,NI
      READ(NREAD,FMT) NUB,(RM(I,J),J=1,12)
      IF(NUB .EQ. NSTA) GO TO 1
      II=I
      GO TO 998
    1 CONTINUE
 2588 DO 63 I=1,NI
      RMM=0.0
      DO 64 J=1,12
   64 RMM=RMM+RM(I,J)
   63 RM(I,13)=RMM
      IF(NRIT .GT. 0) GO TO 62
      NYREM=NYRB-1
      DO 1582 I=1,NI
      II=NYREM+I
 1582 WRITE(NWRITE,1583) II,(RM(I,J),J=1,13)
 1583 FORMAT(1H ,I4,4F9.1,9F10.1)
   62 FAC=0.01875/AREA
   44 DO 2 IK=1,NPERID
      I1=1
      J1=1
      NP=NPER(IK)
      NP1=NP-1
      FNP=NP
      NIE=12*NYRS-NP1
      SUM=0.0
      NCOUNT=1
      IE=NP1/12
      IE1=IE+1
      JE=MOD(NP1,12)+1
      IF(IE .EQ. 0) GO TO 4
      DO 3 I=1,IE
      DO 3 J=1,12
    3 SUM=SUM+RM(I,J)
    4 DO 8 J=1,JE
    8 SUM=SUM+RM(IE1,J)
      SUM=SUM/FNP
      SUMA(NCOUNT)=SUM
      SUMA1(NCOUNT)=SUM
    5 JE=JE+1
      IF(JE-12) 9,9,20
   20 IE1=IE1+1
      JE=1
    9 SUM=SUM+(RM(IE1,JE)-RM(I1,J1))/FNP
      NCOUNT=NCOUNT+1
      SUMA(NCOUNT)=SUM
      SUMA1(NCOUNT)=SUM
      J1=J1+1
      IF(J1-12) 11,11,12
   12 I1=I1+1
      J1=1
   11 IF(NCOUNT .LT. NIE) GO TO 5
      NI=NCOUNT
      FNI=NI
      FNIM=FNI-1.0
      FNID=FNI
      FNIDM=FNID-1.0D00
      FNI1=100./(FNI+1.0)
      M=NI
  314 M=M/2
      IF(M) 322,322,316
  316 K=NI-M
      JJ=1
  317 I=JJ
  318 L=I+M
      IF(SUMA1(L)-SUMA1(I)) 321,321,320
  320 B=SUMA1(I)
      SUMA1(I)=SUMA1(L)
      SUMA1(L)=B
      I=I-M
      IF(I-1) 321,318,318
  321 JJ=JJ+1
      IF(JJ-K) 317,317,314
  322 CONTINUE
      WRITE(NWRITE,101) NBASIN,NSTA,NP,(NAME(I),I=1,11)
  101 FORMAT(1H0,//31H FREQUENCY ANALYSIS FOR STATION,I3,1H-,I4,17H FOR
     $A PERIOD OF ,I3,7H MONTHS,11A6)
      IF(KPRT .GT. 0) GO TO 73
      WRITE(NWRITE,112)
  112 FORMAT(1H0,64H       AV. RUNOFF         RANKED RUNOFF         RECUR.
     $     PROB.  )
      WRITE(NWRITE,103)
 103  FORMAT(1H ,66H     AC-FT/MO  INCHES  AC-FT/MO INCHES        INTER.
     $     LEVEL     )
   73 S=0.0
      S2=0.0
      S3=0.0
      PRB1=0.0
      FSUMF=0.0
      IP=1
      III1=0
      DO 56 I=1,NI
      FSUM=SUMA1(I)
   56 S=S+FSUM
      AS=S/FNID
      DO 55 I=1,NI
      FI=I
      TP=FNI/FI
      PRB=FNI1*FI
      PRB1=PRB
      IF(MOD(I-1,NPRIT) .NE. 0) GO TO 1754
      III1=III1+1
      IF(NGEN .EQ. 2) GO TO 1821
      PRBON(IIII,IK)=PRB
```

```
      SUMAN(III1,IK)=SUMA1(I)
 1821 PRBOL(III1)=PRB
      SUMA2(III1)=SUMA1(I)
 1754 FSUM=SUMA1(I)
      DIF=FSUM-AS
      DIF2=DIF*DIF
      S2=S2+DIF2
      S3=S3+DIF2*DIF
      IF(KPRT .GT. 0) GO TO 55
      FSUM1=FAC*SUMA(I)
      FSUM2=FAC*SUMA1(I)
      WRITE(NWRITE,110) I,SUMA(I) ,FSUM1,SUMA1(I),FSUM2,TP,PRB
   55 CONTINUE
      IF(NGEN .EQ. 1) IIIN(IK)=III1
  110 FORMAT(1H ,I3,2(F10.2,F 7.4),5X,2F10.2)
 1571 FNIM=FNI-1.0
      VAR=S2/FNIDM
      STD=SQRT(VAR)
      SKEW=FNID*S3/(FNIDM*S2)
      SKEW=SKEW/(STD*(FNI-2.))
      WRITE(NWRITE,121) AS,VAR,STD,SKEW
  121 FORMAT(4H AV=,F12.2,5H VAR=,F12.2,5H STD=,F12.2,6H SKEW=,2E14.5)
      IF(KPRT .EQ. 0) GO TO 2021
      WRITE(NWRITE,1679)
 1679 FORMAT(1H0, /,' PROBABALITY AND MAGNITUDES OF RUNOFF' )
      NM1=1
      NM2=13
 1676 IF(NM2 .GT. III1) NM2=III1
      WRITE(NWRITE,1674) (PRBOL(I),I=NM1,NM2)
      WRITE(NWRITE,1675) (SUMA2(I),I=NM1,NM2)
 1674 FORMAT(1H0,13F10.3)
 1675 FORMAT(1H ,13F10.1)
      IF(NM2 .EQ. III1) GO TO 2021
      NM1=NM1+13
      NM2=NM2+13
      GO TO 1676
 2021 STAD(IK,NGEN)=STD
      MEANR(IK,NGEN)=AS
      IF(IPLOT.GT.0 .AND. NGEN.EQ.2) CALL PLTTR(SUMA2,PRPOL,SUMAN,PRBON,
     $ORID,III1,IIIN,NSTA,NAME,NP,IK)
    2 CONTINUE
      IF(NCOMPR .EQ. 0 .OR. NGEN .EQ. 1) GO TO 10
      WRITE(NWRITE,1687)
      WRITE(NWRITE,1688)
      SUM=0.0
      SUM2=0.0
 1687 FORMAT('1PERIOD          STANDARD DEVIATIONS ')
 1688 FORMAT(' MONTHS     HISTORIC     GENERATED  DIFF. PERCENT DIFF.')
      WRITE(NWRITE,1690) (DASH,J=1,9)
 1690 FORMAT(1H ,9A6)
      DO 1686 IK=1,NPERID
      DFF=STAD(IK,1)-STAD(IK,2)
      PDFF=100.*DFF/STAD(IK,1)
      WRITE(NWRITE,1689) NPER(IK),STAD(IK,1),STAD(IK,2),DFF,PDFF
 1689 FORMAT(1H ,I5,4F12.2)
      SUM=SUM+DFF
 1686 SUM2=SUM2+DFF*DFF
      WRITE(NWRITE,1690) (DASH,J=1,9)
      PERID=NPERID
      AUM=SUM/PERID
      VAR=(SUM2-AUM*SUM)/(PERID-1.0)
      STD=SQRT(VAR)
      T=AUM*SQRT(PERID)/STD
      WRITE(NWRITE,1691) AUM,STD
 1691 FORMAT(16X,'AVERAGE DIFF. =',F12.2, / 16X,'STANDARD DEV.=',F12.2)
      WRITE(NWRITE,1692) T
 1692 FORMAT( ' STATISTICAL  T-VALUE EQUALS ,' F12.2)
      WRITE(NWRITE,1787)
      WRITE(NWRITE,1688)
 1787 FORMAT(/,/,'0PERIOD  MEANS OF RUNNING AVFRAGES')
      WRITE(NWRITE,1690) (DASH,J=1,9)
```

```
      DO 1786 IK=1,NPERID
      DFF=MEANR(IK,1)-MEANR(IK,2)
      PDFF=100.*DFF/MEANR(IK,1)
      WRITE(NWRITE,1689) NPER(IK),MEANR(IK,1),MEANR(IK,2),DFF,PDFF
 1786 CONTINUE
      WRITE(NWRITE,1690) (DASH,J=1,9)
      GO TO 10
  998 WRITE(6,999) NSTA,NUB,(RM(II,J),J=1,12)
  999 FORMAT(' INCORRECT DATA FOR STA.',I5,I5,12F8.3)
   99 STOP
      END
'I  FOR PLTTRF,PLTTRF
      SUBROUTINE PLTTR(Y,P,Y1,P1,ORID,NI,NN,NSTA,NAME,LP,KK)
      REAL Y(793),P(793),NAME(12),Y1(80,10),P1(80,10),ORID(4),YS1(80),
     $PS1(80)
      INTEGER NN(10)
      KKP=NN(KK)
      DO 3 I=1,KKP
      YS1(I)=Y1(I,KK)
    3 PS1(I)=P1(I,KK)
      ALX=10.0
      ALY=7.0
      CALL IDPLOT(ALX+1.5,ALY+1.5)
      IF(LP.EQ.24) CALL SYMBL4(.2,0.0,.10,58HMAIL TO R.W.JEPPSON,UWRL,UT
     $AH STATE UNIV.,LOGAN,UTAH,84321,90.0,58)
      CALL SCALE(P,NI,ALX,XMIN,DVX,1)
      CALL SCALE(Y,NI,ALY,YMIN,DVY,1)
      CALL PLOT(1.0,1.0,-3)
      CALL AXIS(0.0,0.0,22H PROBABILITY (PERCENT),-22,ALX,0.0,0.0,DVX)
      CALL AXIS(0.0,0.0,ORID,24,ALY,90.0,YMIN,DVY)
      CALL LINE(P,Y,NI,1)
      CALL LINE(PS1,YS1,KKP,1)
      CALL NUMBRI(0.5,0.8,.12,NSTA,0.0)
      CALL SYMBL4(2.2,.8,.12,NAME,0.0,30)
   11 CALL NUMBRI(0.3,0.5,.14,LP,0.0)
      CALL SYMBL4(1.5,0.5,.14,17H MONTHS IN PERIOD,0.0,17)
      CALL PLOT(-1.0,-1.0,-3)
      CALL FINI
      RETURN
      END
'N XQT STRENF
(2X,I4,8X,12F5.0)
    8   24   48   72   96  120  144  168  192
 COTTONWOOD CREEK
    9 3245   10   65    0    1   10    1    0 205.            1    1
 93245       1910 2790 2300 2220 1840 1670 559017000373001950O 5600 2900 4870103580
 93245       1911 1540 1900 1840 1840 2170 5920 49003020027100 5120 2470 2460 87460
 93245       1912 1730 1570 1540  861  667 1530 2490154005240013500 3690 2270 97648
 93245       1913 2030 1790 1230 1540 1390 1840 75604370023900 6820 3110 6190101100
 93245       1914 1780 1570 1750 1650 1560 2230 5870446004130012900 3920 2610121740
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