SO-260

Southern Forest Experiment Station

Research Note

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Rainfall Data Simulation

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SUMMARY

A simple simulation model to predict rainfall for individual storms in central Arkansas is described. Output includes frequency distribution tables for days between storms and for storm size classes; a storm summary by day number (January 1 = 1 and December 31 = 365) and rainfall amount; and an annual storm summary that includes monthly values for rainfall and number of storms. The model should be adaptable to other areas where 10 or more years of rainfall records are available.

Additional keywords: Computer models, model studies, simulation analysis.

INTRODUCTION

In the past few years hydrologic models have been developed to simulate various components of the water balance system. Some have simulated rainfall, but most have used actual rainfall as input to their hydrologic models. A few have simulated the complete water balance system. The objectives of this study were to (1) develop a model to simulate rainfall for individual storms, (2) develop the model so that it could be used as a submodel in a water balance system, and (3) compare the model output with actual rainfall records.

The model developed herein uses rainfall probabilities and parametric functions to simulate rainfall. It was classified as stochastic-empirical according to Clarke's (1973) definitions: it is stochastic in that the rainfall variable is random and has distributions in probability, and it is empirical in that it is based on observed data. It should be useful as a submodel for systems (such as soil water, runoff, tree growth, sediment and water balance) that need rainfall as input, and should be adaptable to any area where 10 or more years of rainfall records are available.

MODEL DEVELOPMENT

The model was written in GPSS, an IBM discrete simulation language (IBM 1971, IBM 1973) available on IBM and Univac computers. The language offers great flexibility and allows model modification without extensive reprograming. The model was programed and used on the IBM 370-155 computer at the University of Arkansas.

Rainfall models can be developed for individual storms, daily amounts or amounts over some other selected time interval. The model reported here was developed from individual storms. An individual storm was defined as a period of rain followed by at least 12 hours without rain. The time unit selected for this

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simulation was 1 day, so only one storm per day could occur. For this model, it was assumed that whatever happens one day (storm or no storm) was independent of the previous day. The model was developed from 13 years of rainfall data from the Alum Creek Experimental Forest in central Arkansas. Because the model only allows one storm per day, if two observed storms occurred on the same day the storm nearest to another day was said to occur on that day. Likewise, an observed storm that occurred on two or more days was said to occur on the day on which most of the rain occurred. The model relies mainly on four functions that determine (1) days to next storm and (2) amount of rainfall. The model can be run for 1 year or as many years as desired. A program listing of the model is given in the Appendix.

On the *first day of simulation* the model *calculates days to the first storm* (fig. 1). The number of days to the first storm is the integer of the equation: DBSD x ADBSM + 0.5 where days between storms (DBSD) and average number of days between storms by months (ADBSM) are continuous and discrete functions[1] respectively. The DBSD function was developed from a cumulative frequency distribution for days to next storm (fig. 2). During the 1961-1973 period, days between storms averaged 4.8203 days and ranged from 1 to 30 days. The monthly means for number of days to next storm varied by such a degree (fig. 3) that the DBSD function alone could not adequately define days between storms throughout the year. Therefore, to obtain monthly distributions of days to next storm, I developed the ADBSM function from day number at the end of each month (January = 31 and December = 365) and average number of days between storms for that month (fig. 3). Then I adjusted the DBSD function by dividing the upper limit of each days to next storm class by the average days between storms for the 13 years of data: for example, for day one, 1.499/4.8203 = 0.3110. The lower limit of the DBSD function was set

[1] With a continuous function, when an argument value lies between two successive X_i points the program interpolates linearly to obtain a dependent funciton value between the two associated Y_i points. With a discrete function, all argument values between X_i and X_i-1 have the same function value.

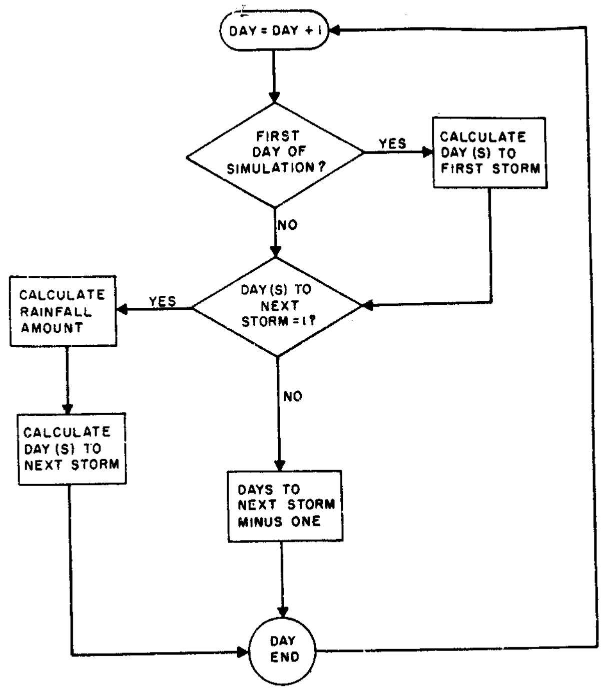

Figure 1.—*Rainfall simulation flow chart.*

so the month with the fewest average days between storms (April) could produce a storm on the following day. In determining days to next storm, the program generates a uniformly distributed six-digit fractional random number between 0 and 1. This number determines the value from the DBSD function. The day number determines the value from the ADBSM function. Days to next storm, which is distributed about the monthly mean, is the integer of the product of these two values and a rounding factor of 0.5.

Then, if *days to next storm = 1?* is not one, it is *reduced by one* (fig. 1). The simulation then proceeds to *day end, day + 1*, and *days to next storm = 1?*. When the number of *days to next storm = 1?* equals one, the rainfall amount is calculated from the equation: RAIN x ASSM where storm size (RAIN) and average storm size by months (ASSM) are continuous and discrete functions respectively. The RAIN function was developed from a cumulative frequency distribution of 0.10-inch storm size classes (fig. 4). Rainfall ranged from 0.01 to 8.30 inches and averaged 0.726 inches during the 1961-1973 period. Because of the large variance in mean monthly storm size (fig. 5)

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the RAIN function could not adequately define storm size in months that were much different than the mean storm size of 0.726 inches. Therefore, to obtain monthly distributions of storm size, I developed the ASSM function from day number at the end of each month and average storm size for that month (fig. 5). Then I adjusted the RAIN function by dividing the upper limit of each storm size class by the average storm size for the 13 years of data: for example, for the 0.10 size class, 0.10/0.726 = 0.1377. The lower limit of the RAIN function was set so the month with the lowest average storm size (February) would produce a storm of at least 0.01 inch. In determining rainfall amount, the program generates a uniformly distributed random number between 0 and 1, which determines the value from the RAIN function. The day number determines the value from the ASSM function. The product of these two values is rainfall amount which is distributed about the monthly mean.

The simulation then calculates a new value for *days to next storm*. Then proceeds to *day end, day + 1*, and *days to next storm = 1?*. The simulation continues in this way for the run time selected.

Output from this rainfall simulation model consists of (1) annual frequency distribution table for days between storms, (2) annual frequency distribution table for storm size classes, (3) storm summary by day number and rainfall amount (table 1), and (4) annual storm summary that includes monthly and annual values for rainfall and number of storms (table 2).

Table 1.—*Example of individual storm summary*

Storm Summary/For Year 5	
Day number	Rainfall (inches)
6	0.47
8	0.42
9	0.05
13	0.81
15	1.13
21	0.02
''	''
''	''
''	''
350	0.04
351	0.38
352	0.11
361	2.04
363	0.56

Table 2.—*Example of annual storm summary*

	Storm Summary	
	Rainfall (inches)	No. of storms
January	2.91	6
February	1.11	4
March	3.81	7
April	7.72	10
May	.66	9
June	7.46	9
July	2.68	6
August	2.41	6
September	1.39	3
October	0.91	3
November	8.74	9
December	3.14	5
Annual	46.93	77

The model can be easily altered to provide different tables, graphs, and forms of output. Any variable in the simulation can be in the statistical output on an annual basis. A TABULATE statement allows a user to produce frequency distribution tables with the following output: sum of the variable, number of table entries, mean variable value, standard deviation, and the number of times the variable fell within each frequency class. Graphs can be plotted from any of the variables in the simulation. Additional output can be obtained by access to user-written FORTRAN subroutines with the HELPA statement.

To use the model in areas other than central Arkansas, users must develop the DBSD, ADBSM, RAIN, and ASSM functions from at least 10 years of local rainfall data.

MODEL ACCURACY

I compared simulated rainfall for 20 years with the 13 years of record used to develop the model. Comparing simulated data against the data used to develop the model is not comprehensive validation; however, in this case I chose to use all the data available to develop the model. Chi-square tests were conducted on actual and simulated data for days to next storm, storm size classes, storms per month, and rainfall per month. The tests showed no differences between actual and simulated data. The simulated data had one less storm per year, and

Table 3.—*Comparison of 20 years of simulated rainfall data and actual rainfall data for 1961-1973*

	Number of storms annually		Average days between wet days	Annual precipitation (inches)		Average storm size (inches)
	Average	Range		Average	Range	
Actual	75.77	57-94	4.82	54.98	39.93-82.79	0.726
Simulated	74.75	61-89	4.89	53.82	37.51-74.45	0.720

simulated annual rainfall was an inch less than actual (table 3). The range of simulated storms per year was less than recorded during the study period. The range of simulated annual rainfall was somewhat smaller than that of actual, but the actual rainfall of 82.79 inches in 1973 was nearly 30 inches greater than normal and would probably only occur once in every 100 years.

To determine if the model was simulating the extreme values, I compared largest simulated rainfall to largest actual and largest calculated for a 100-year return period for storm, month, and annual values. The simulated storm and month values compared very favorably with the actual and 100-year return period values (table 4). The simulated annual value of 74.45 inches was lower than both the actual and 100-year return period values, but the actual value of 82.79 inches, as mentioned above, is probably the maximum that occurs once in every 100 years.

From these comparisons it can be said that the model accurately simulated rainfall events with the frequency and size as occurred between 1961-1973. This does not mean the model will accurately simulate rainfall events as they occur in the future as rainfall patterns may change. The model should be useful as a submodel for soil water, runoff, tree growth, sediment, water balance, and other systems needing rainfall as input.

Table 4—*Largest Rainfall values*

	Storm	Month	Annual
	Inches		
Actual	8.25	14.22	82.79
Simulated	8.89	19.49	74.45
100-year[1]	12.19	20.12	111.83

[1]Calculated from 13 years of actual data.

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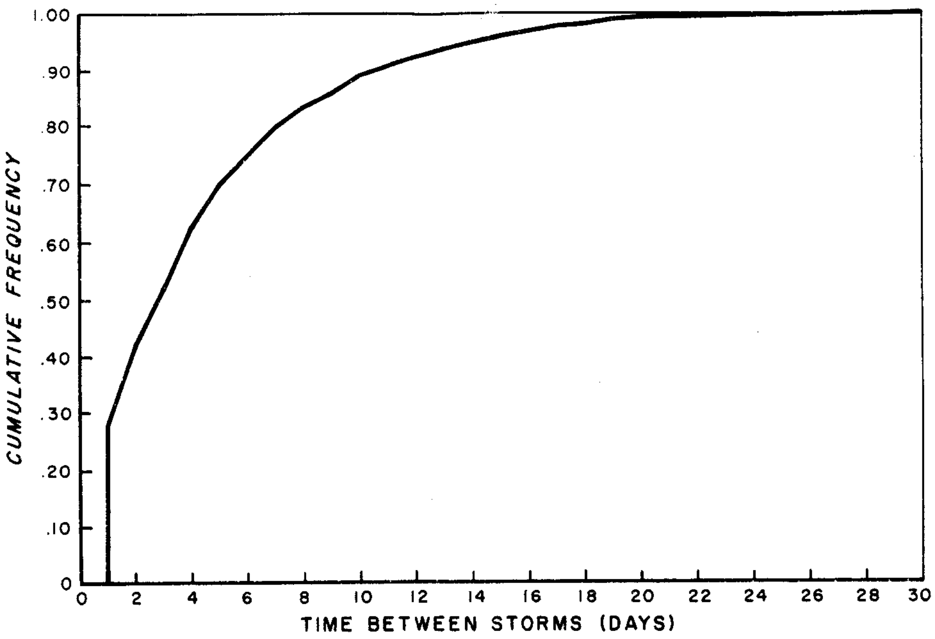

Figure 2.—*Cumulative frequency distribution of days between storms.*

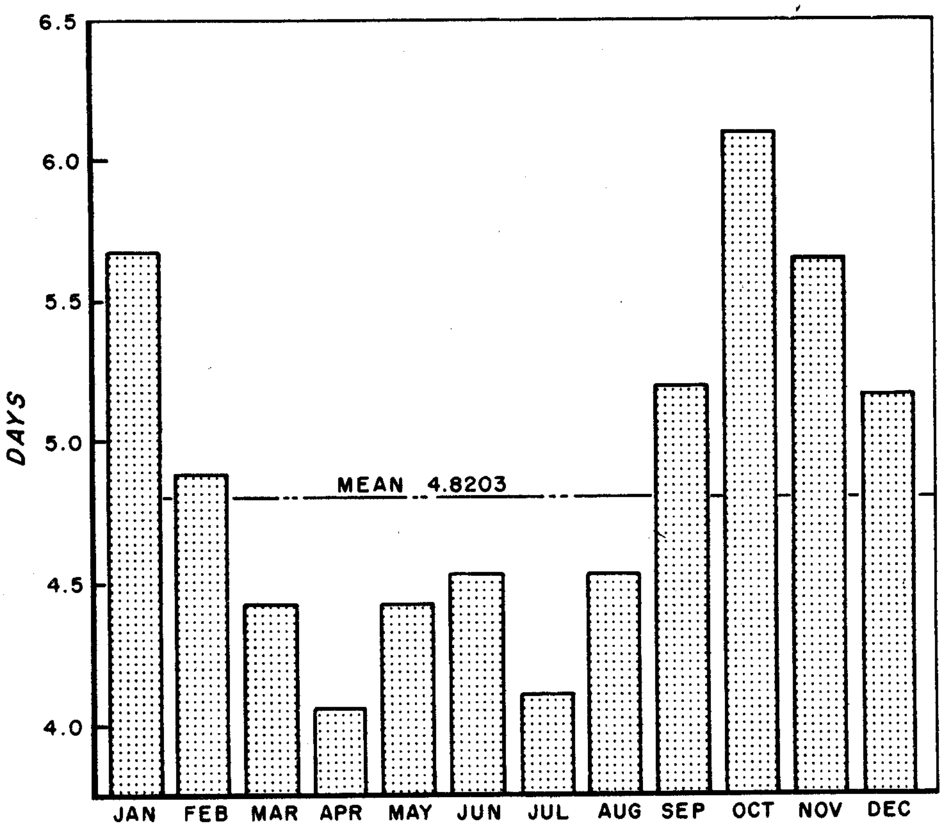

Figure 3.—*Mean number of days between storms by months.*

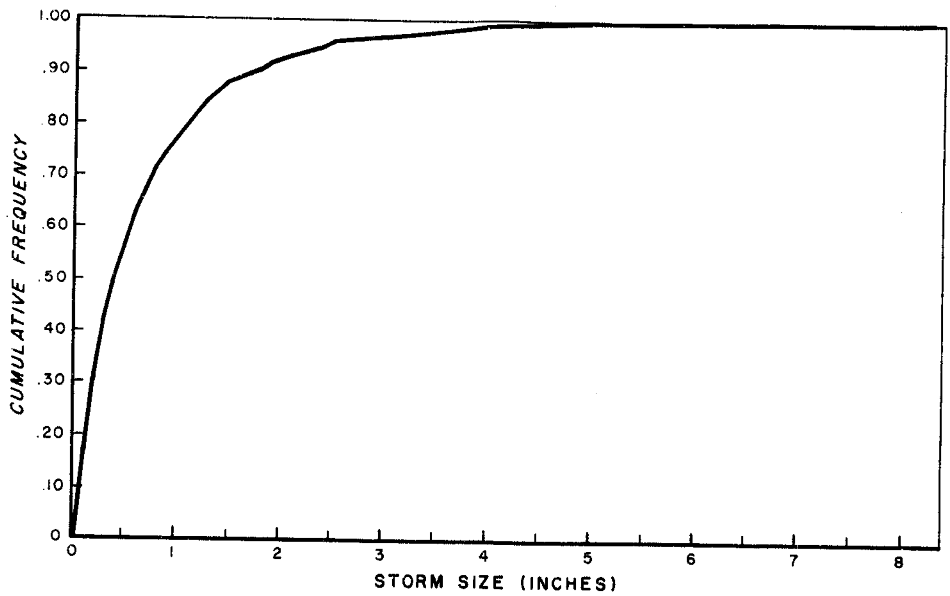

Figure 4.—*Cumulative frequency distribution of storm size.*

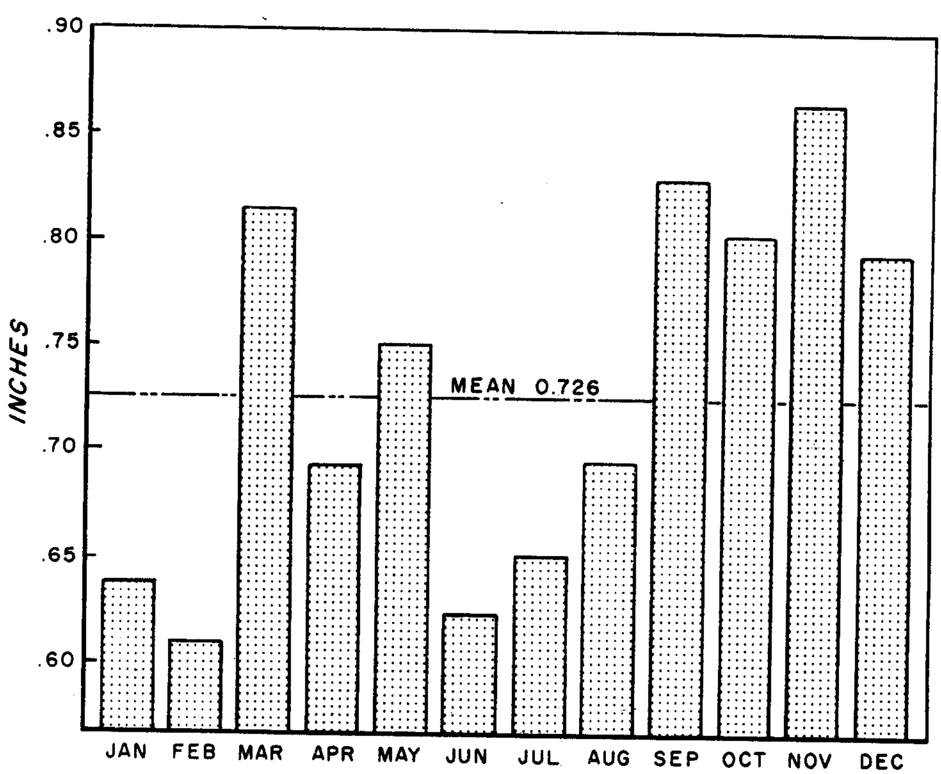

Figure 5.—*Mean storm size by months.*

APPENDIX

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BLOCK
NUMBER  *LOC      OPERATION   A,B,C,D,E,F,G,H,I           COMMENTS
        *
                  SIMULATE
        *****************************************************
        *                     PRESIM  MODEL                  *
        *    RAINFALL SIMULATION FOR ALUM CREEK EXPT FOREST  *
        *            BASED ON DATA FROM 1961-1973            *
        *****************************************************
        *
        *  AVERAGE NUMBER OF DAYS BETWEEN STORMS BY MONTHS FUNCTION
          ADBSM FUNCTION   C1,D12
        31,5.676/59,4.893/90,4.429/120,4.062/151,4.429/181,4.535/212,4.112
        243,4.528/273,5.200/304,6.106/334,5.652/365,5.167
        *
        * DAYS BETWEEN STORMS DISTRIBUTION FUNCTION
          DBSD FUNCTION    RN2,C31
        0,.1232/.2802,.3110/.4213,.5184/.5188,.7259/.6234,.9333/.6995,1.1408
        .7492,1.3482/.7970,1.5557/.8345,1.7632/.8579,1.9706/.8893,2.1781
        .9036,2.3855/.9228,2.5930/.9360,2.8004/.9452,3.0079/.9543,3.2154
        .9665,3.4228/.9746,3.6303/.9807,3.8377/.9858,4.0452/.9888,4.2526
        .9909,4.4601/.9919,4.6676/.9929,4.8750/.9939,5.0825/.9949,5.2899
        .9960,5.4974/.9970,5.7048/.9980,5.9123/.9990,6.1197/1.00,6.3272
        *
        * AVERAGE STORM SIZE BY MONTHS FUNCTION
          ASSM FUNCTION    C1,D12
        31,639/59,610/90,814/120,692/151,749/181,623/212,650/243,694/273,829
        304,802/334,865/365,795
        *
        * PRECIPITATION EVENT SIZE CLASS DISTRIBUTION
          RAIN FUNCTION RN3,C48
        0,.0164/.1706,.1377/.3036,.2755/.4142,.4132/.4964,.5510/.5685,.6887
        .6284,.8264/.6711,.9642/.7107,1.102/.7421,1.240/.7695,1.377/.7970,1.515
        .8213,1.653/.8447,1.791/.8619,1.928/.8792,2.066/.8843,2.204/.8964,2.342
        .9015,2.479/.9147,2.617/.9228,2.755/.9299,2.893/.9350,3.030/.9421,3.168
        .9482,3.306/.9553,3.444/.9584,3.581/.9624,3.719/.9645,3.857/.9665,3.994
        .9685,4.132/.9736,4.270/.9787,4.821/.9807,5.096/.9817,5.234/.9838,5.372
        .9888,5.510/.9898,5.647/.9909,6.061/.9929,6.336/.9939,6.612/.9949,6.887
        .9959,7.025/.9970,8.540/.9980,8.815/.9990,9.901/.9998,11.433/1.0,13.499
        *
          MOED FUNCTION    XH3,D11
        31,59/59,90/90,120/120,151/151,181/181,212/212,243
        243,273/273,304/304,334/334,365
        *
         STINT FVARIABLE  FN$ADBSM*FN$DBSD+.5
         PRCIP FVARIABLE  FN$ASSM*FN$RAIN
               RMULT      ,743,451
               INITIAL    XH1,0
               INITIAL    XH3,31
          STOM MATRIX     MX,12,2
        *
        *       FULLWORD SAVEVALUES                 HALFWORD SAVEVALUES
        *     X1 DAYS TO NEXT STORM            XH1 TEST VALUE FOR FIRST STORM EVENT
        *     X2 DAILY PRECIP                  XH2 HEADING TEST VALUE
        *     X3 MONTHLY PRECIP                XH3 MONTH END DATE
        *     X4 ANNUAL PRECIP
        *     X5 MONTHLY PRECIP
        *     X6 MONTHLY NO. OF STORMS
```

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*      X7 NO. OF STORM EVENTS
*      X8 MATRIX INPUT COUNTER
*      X9 STORMS ANNUALLY
*     X10 MATRIX OUTPUT COUNTER
*                           *
****   THE MODEL   *****
*                           *
1              GENERATE     1,,,365             SIMULATE DAY
2              TEST E       XH1,0,NOT1          TEST FOR INITIAL DAY OF SIM
3              SAVEVALUE    1,K1,XH             TEST VALUE
4              SAVEVALUE    1,V$STINT           DETERMINE INITIAL STORM DATE
5         NOT1 TEST E       X1,1,CONT           STORM EVENT TODAY
6              SAVEVALUE    2,V$PRCIP           SIZE OF STORM
7              TABULATE     2                   TABULATE STORM SIZE
8              SAVEVALUE    1,V$STINT           DETERMINE DAYS TO NEXT STORM
         ** OUTPUT **
9              TABULATE     1                   TABULATE DAYS BETWEEN STORMS
10             SAVEVALUE    3+,X2               MONTHLY PRECIP
11             SAVEVALUE    4+,X2               ANNUAL PRECIP
12             SAVEVALUE    7+,K1               STORM EVENT COUNTER
13             SAVEVALUE    2+,K1,XH            HEADING COUNTER
14             HELPA        PREOUT,C1,X2,XH2    PRINTOUT DAY AND PRECIP AMOUNT
15             TRANSFER     ,MONT               TRANSFER TO MONTH END TEST
16        CONT SAVEVALUE    1-,K1               REDUCE DAYS TO NEXT STORM BY 1
17        MONT TEST E       C1,XH3,NXDAY        TEST FOR DAY MONTH ENDS
18             SAVEVALUE    8+,K1               COUNTER FOR STORAGE VALUES
19             MSAVEVALUE   STOM,X8,1,X3        STORAGE OF PRECIP / MONTH
20             MSAVEVALUE   STOM,X8,2,X7        STORAGE OF STORMS / MONTH
21             SAVEVALUE    3,0                 INITIAL MONTHLY PRECIP TO 0
22             SAVEVALUE    9+,X7               STORMS ANNUALLY
23             SAVEVALUE    7,0                 INITIAL STORMS TO 0
24             SAVEVALUE    3,FN$MOED,XH        NEW MONTH END DATE
25             TEST E       C1,365,NXDAY        TEST FOR END OF YEAR
26             ASSIGN       10,12               MONTHLY PRINTOUT LOOP
27        REPT SAVEVALUE    10+K1               COUNTER
28             SAVEVALUE    5,MX$STOM(X10,1)    RECALL MONTHLY PRECIP
29             SAVEVALUE    6,MX$STOM(X10,2)    RECALL MONTHLY NO. OF STORMS
30             HELPA        PRESUM,X5,X6,X10    MONTHLY PRECIP & NO. OF STORMS
31             LOOP         10,REPT             MONTHLY PRINTOUT LOOP
32             HELPA        ANLPRE,X4,X9        ANNUAL PRECIP AND NO. OF STORMS
33       NXDAY TERMINATE    1
*
* TABLE DEFINITION CARDS
     1 TABLE                1A,0,1,35
     2 TABLE                X2,0,100
*
* CONTROL CARDS
               LOAD         PREOUT,PRESUM,ANLPRE
               START        365
               CLEAR        X1,XH1
               INITIAL      XH3,31
               START        365
               CLEAR        X1,XH1
               INITIAL      XH3,31
               START        365
               CLEAR        X1,XH1
```