Adjusting Stream Gage Data for Urbanization Effects

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ABSTRACT

A hydrologic method is developed to provide for the adjustment of stream gage data for the effects of urbanization. Use of the method provides a general adjustment of a series of annual peak flow rates which is impacted by the effects of continuing urbanization during the gage period. After adjustment, the resulting adjusted annual series represents an equivalent annual series of peak flow rates from a homogeneous record (i.e., of a constant level of development). The provided FORTRAN computer program implements the new hydrologic adjustment procedure.

INTRODUCTION

A statistical flood frequency analysis is based on the assumption of a homogeneous annual flood record. Significant changes in land use is a source of nonhomogeneity of flood characteristics. A flood frequency analysis based on a nonhomogeneous record will result in inaccurate estimates of flood estimates for any return period. Therefore, the effect of nonhomogeneity must be estimated prior to making a frequency analysis so the flood record can be adjusted.

Urbanization is a primary cause of nonhomogeneity of flood records. While this problem has been recognized for decades, there have been few attempts at developing a systematic procedure for making the necessary adjustment of flood records. Multi-parameter watershed models have been used for this purpose; however, a single model or procedure for adjustment has not been widely accepted by the professional community. Comparisons of methods for adjusting records have not been made.

A number of hydrologic methods and specific models have been proposed and are used to represent the effect of urbanization on peak discharges. In some cases, methods provide a basis for accounting for urbanization, but it is difficult to develop a general statement of the effect of urbanization. For example, with the Rational method, urban development would have an effect on both the runoff coefficient and the time of concentration. Thus, it is not possible to make a general statement that a 5 percent increase in imperviousness will cause an x percent increase in the peak discharge for a specific return period. Other models are not so constrained.

REGRESSION EQUATIONS

A number of regression equations are available that include percent imperviousness as a predictor variable. With such models, it is possible to develop a general statement on the effect of urbanization. Sarma and others (1969) provided one such example:

$$Q_p = 484.1\, A^{0.723}\, (1+U)^{1.516}\, P_E^{1.112}\, T_R^{-0.403} \qquad (1)$$

in which A is the drainage area in (square miles), U is the impervious area (in percent), P_E is the volume of excess rainfall (in inches), T_R is the duration of rainfall excess (in hours), and Q_p is the peak discharge (in cubic feet per second). Since the model has the power model form, the specific effect of urbanization depends on the values of the other predictor variables (A, P_E, and T_R). However, the relative sensitivity of Equation 1 can be used as a measure of the effect of urbanization. The relative sensitivity is given by:

$$S_R = \left(\frac{\partial Q_p}{\partial U}\right)\left(\frac{U}{Q_p}\right) \qquad (2)$$

Evaluation of Equation 2 yields a relative sensitivity of 1.415. Thus, a one percent change in U will cause a change of 1.516 percent in the peak discharge. This estimate is an average effect since it is independent of both the value of U and the return period.

Based on the work of Carter (1961) and Anderson (1970), Dunne and Leopold (1978) provided the following equation for estimating the effect of urbanization:

$$f = 1 + 0.015\, U \qquad (3)$$

in which f is a factor that gives the relative increase in peak discharge for a percent imperviousness of U. The following is a summary of the effect of urbanization based on the model of Equation 3:

U	0	10	20	30	40	50	100
f	1	1.15	1.3	1.45	1.6	1.75	2.5

Thus, a one percent increase in U will increase the peak discharge by 1.5 percent, which is the same effect shown by the model of Equation 2.

The Soil Conservation Service (SCS) provided an adjustment for urbanization for the TR-55 (U. S. Soil Conservation Service, 1975) Chart method. The adjustment depends on the percentages of imperviousness and the hydraulic length modified (Figures 1 and 2) as well as the runoff curve number (CN). Although the adjustment does not specifically include the return period as a factor, the Chart method incorporates the return period through the rainfall input. Table 1 provides the adjustment factors for imperviousness and the hydraulic length modified. Assuming that these changes occur in the same direct proportion, the effect of urbanization on peak discharges would be the square of the factor. Approximate measures of the effect of changes in f^2 from change in U are also shown in Table 1 (R_S). These values of R_S represent the change in peak discharge due to the peak factors provided in TR-55. Additional effects of urban development on the peak discharge would be reflected in change in the CN. However, the relative sensitivities of

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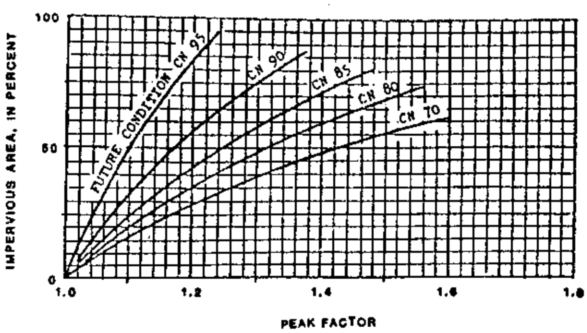

Fig. 1. Factors for adjusting peak discharges as a function of runoff curve-number and impervious area in the drainage basin.

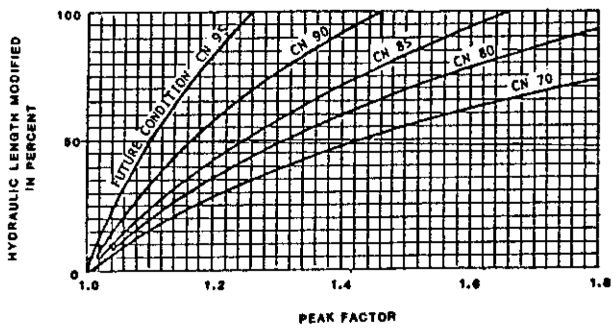

Fig. 2. Factors for adjusting peak discharges as a function of runoff curve-number and hydraulic length modified.

SCS Chart Method					USGS Urban			
CN	U	f	f^2	R_S	T	U	f_1	R_S
70	20	1.13	1.28	0.018	2 yrs	20	1.70	0.016
	25	1.17	1.37	0.019		25	1.78	0.016
	30	1.21	1.46	0.025		30	1.86	0.018
	35	1.26	1.49	0.026		35	1.95	0.020
	40	1.31	1.72	-.--		40	2.05	-.--
80	20	1.10	1.21	0.013	100 yrs	20	1.23	0.010
	25	1.13	1.28	0.014		25	1.28	0.008
	30	1.16	1.35	0.019		30	1.32	0.008
	35	1.20	1.44	0.015		35	1.36	0.010
	40	1.23	1.51	- --		40	1.41	-.--

Table 1. Adjustment factors for urbanization.

the SCS Chart method suggest a change in peak discharge of 2.3 to 2.6 percent for a 1 percent change in urbanization, which here is the combined effects of changes in imperviousness and modification of the hydraulic length.

The U. S. Geological Survey (USGS) urban peak discharge equations provide another alternative for assessing the effects of urbanization. The equations are given in Table 2. Figures 3 and 4 show the ratio of the urban to rural peak discharge as a function of the percentage of imperviousness and a basin-development factor. For the 2-year event (Fig. 3), the ratio ranges from 1 to 4.5, with the latter value for complete development. For the 100-year event (Fig. 4), the ratio has a maximum value of 2.2. The purposes of illustration and assuming that basin development occurs in direct proportion to changes in imperviousness, the values of Table 1 (R_S) show the effect of urbanization on peak discharge. The average change in peak discharge due to a one percent change in urbanization is 1.75 and 0.9 percent for the 2-year and 100-year events,

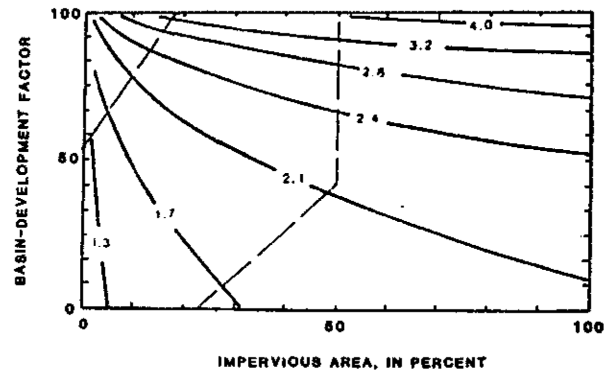

Fig. 3. Ratio of the urban to rural 2-year peak discharge as a function of basin development factor and impervious area.

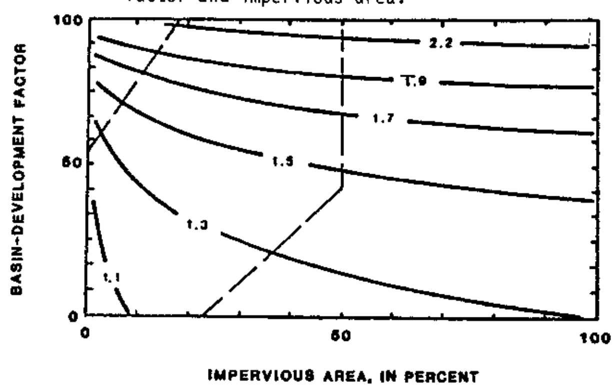

Fig. 4. Ratio of the urban to rural 100-year peak discharge as a function of basin development factor and impervious area.

Regression equations	R^2	Standard error of regression: Log units	Standard error of regression: Average percent
Seven-parameter equations			
$UQ2 = 2.35A^{0.41}SL^{0.17}(RI2+3)^{2.04}(ST+8)^{-0.65}(13\text{-}BDF)^{-0.32}IA^{0.15}RQ2^{0.47}$	0.93	0.1630	±38
$UQ5 = 2.70A^{0.35}SL^{0.16}(RI2+3)^{1.86}(ST+8)^{-0.31}IA^{0.11}(RQ5^{0.54}$	0.93	0.1584	37
$UQ10 = 2.99A^{0.32}SL^{0.15}(RI2+3)^{1.75}(ST+8)^{-0.57}(13\text{-}BDF)^{0.30}IA.^{0.09}RQ10^{0.58}$	0.93	0.1618	38
$UQ25 = 2.78A^{0.31}SL^{0.15}(RI2+3)^{1.76}(ST+8)^{-0.55}(13\text{-}BDF)^{-0.29}IA^{0.07}RQ25^{0.60}$	0.93	0.1705	40
$UQ50 = 2.67A^{0.29}SL^{0.15}(RI2+3)^{1.74}(ST+8)^{-0.53}(13-BDF)^{-0.28}IA^{0.06}RQ50^{0.62}$	0.92	0.1774	42
$UQ100 = 2.50A^{0.29}DL^{0.15}(RI2+3)^{1.76}(ST+8)^{-0.52}(13\text{-}DBF)^{-0.28}IA^{0.06}RQ100^{0.63}$	0.92	0.1860	44
$UQ500 = 2.27A^{0.29}SL^{0.16}(RI2+3)^{1.86}(ST+8)^{-0.54}(13\text{-}BDF)^{-0.27}IA^{0.05}RQ500^{0.63}$	0.90	0.2071	40
Three-parameter equations			
$UQ2 = 13.2A^{0.21}(13\text{-}BDF)^{-0.43}RQ^{2.73}$	0.91	0.1797	±43
$UQ5 = 10.6A^{0.17}(13\text{-}BDF)^{-0.39}RQ5^{0.78}$	0.92	0.1705	40
$UQ10\text{-}9.51A^{0.16}(13\text{-}BDF)^{-0.36}RQ10^{0.79}$	0.92	0.1720	41
$UQ25 = 8.68A^{0.15}(13\text{-}BDF)^{-0.34}RQ25^{0.80}$	0.92	0.1802	43
$UQ50 = 8.04A^{0.15}(13\text{-}BDF)^{-0.32}RQ50^{0.81}$	0.91	0.1865	44
$UQ500 = 7.70A^{0.15}(13\text{-}BDF)^{-0.32}RQ100^{0.82}$	0.91	0.1949	46
$UQ500 = 7.47A^{0.16}(13 = BDF)^{-0.30}RQ500^{0.82}$	0.89	0.2170	52

Table 2. Nationwide urban flood-frequency regression equations.

respectively. While the methods discussed previously provided an effect of about 1.5 percent, the USGS equations suggest that the effect is slightly higher for the more frequent storm events and slightly lower for the less frequent storm events.

Rantz (1971) provided a method for assessing the effect of urbanization on peak discharges using simulated data of James (1965) for the San Francisco Bay area. Urbanization is characterized by two variables, the percentages of channels sewered and basin developed. The percentage of basin developed is approximately twice the percentage of imperviousness. The peak factors are shown in Fig. 5. The data of Table 3 show the relative sensitivity of the peak discharge to (a) the percent imperviousness and (b) the combined effect of the two variables (percentages of channels sewered and basin developed). For urbanization as measured by the percentage change in imperviousness, the mean relative sensitivities are 2.6, 1.7, and 1.2 percent for the 2-year, 10-year, and 100-year events, respectively. These values are slightly larger (30 to 50 percent) than the values computed from the USGS urban equations. When both the percentages of channel sewered and basin developed are used as indices of development, the relative sensitivities are considerably higher. The mean relative sensitivities are 7.1, 5.1, and 3.5 percent for the 2-year, 10-year, and 100-year events, respectively. These values are much larger than the values suggested by the other methods discussed in the preceeding paragraphs.

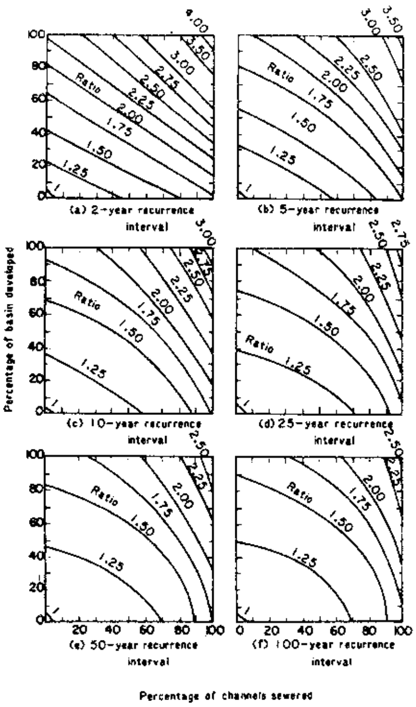

Fig. 5. Peak discharge adjustment factors as a function of basins developed and channels sewered (after Rantz, 1971).

ADJUSTMENT TECHNIQUE

The literature does not identify a single method that is considered to be the best method. Each method depends on the data used to calibrate the prediction process and the data basis used to calibrate the methods are very sparse. However, the sensitivities suggest that a 1 percent increase in urbanization causes an increase in peak discharge of about 1 to 2.5 percent, with the former value for the 100-year event and the latter for the 2-year event. However, there was considerable variation at any return period.

	T = 2 yrs		T = 10 yrs		T = 100 yrs	
U (%)	f	R_S	f	R_S	f	R_S
10	1.22	0.025	1.13	0.015	1.08	0.011
20	1.47	0.025	1.28	0.017	1.19	0.012
30	1.72	0.026	1.45	0.018	1.31	0.013
40	1.98	0.029	1.63	0.018	1.44	0.012
50	2.27		1.81		1.56	
D (%)						
10	1.35	0.040	1.18	0.022	1.15	0.010
20	1.75	0.060	1.40	0.040	1.25	0.025
30	2.35	0.085	1.80	0.050	1.50	0.050
40	3.20	0.100	2.30	0.092	2.00	0.055
50	4.20		3.22		2.55	

Table 3. Effect on peak discharges due to the percentage of imperviousness (U) and the combined effect of urban development (D).

Based on the general trends on the data, a method of adjusting a flood record was developed. Figure 6 shows the peak adjustment factor as a function of the exceedence probability for percentages of urbanization up to 70 percent. The greatest effect is for the more frequent events and the highest percentage of urbanization. Given the return period of a flood peak for a non-urbanized watershed, the effect of an increase in urbanization can be assessed by multiplying the discharge by the peak adjustment factor for the return period and percentage of urbanization. Where it is necessary to adjust a discharge from a practically urbanized watershed to a discharge for another watershed condition, the discharge can be divided by the peak adjustment factor for the existing condition and then multiply the resulting "rural" discharge can be divided by the peak adjustment factor for the existing condition and then multiply the resulting "rural" discharge by the peak adjustment factor for the second watershed condition. The first operation (division) adjusts the discharge to a magnitude representative of nonurbanized condition. The second operation (multiplication) adjusts the discharge of a magnitude that is representative of the watershed for the second watershed condition.

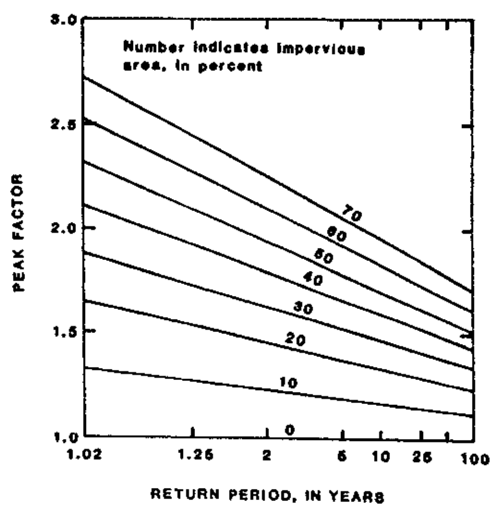

Fig. 6. Peak adjustment factors for urbanizing watersheds.

PROCEDURE

The adjustment method of Fig. 6 requires an exceedence probability. For a flood record, the best estimate of the probability is obtained from a plotting position formula. The following procedure can be used to adjust a flood record for which the individual flood events have occurred on a watershed that is undergoing a continuous change of the level of urbanization.

1. Identify both the percentage of urbanization for each event in the flood record and the percentage of urbanization for which an adjusted flood record is needed.
2. Compute the rank (i) and exceedence probability (p) for each event in the flood record (the Weibull plotting position formula can be used to compute the probability).
3. Using the exceedence probability and the actual percentage of urbanization find from Figure 6 the peak adjustment factor (f_1) to transform the measured peak from the actual level of urbanization to a nonurbanized condition.
4. Using the exceedence probability and the percentage of urbanization for which a flood series is needed find from Figure 6 the peak adjustment factor (f_2) that is necessary to transform the non-urbanized peak to a discharge for the desired level of urbanization.
5. Compute the adjusted discharge (Q_a) by

$$Q_a = (f_2/f_1)\,Q$$

in which Q is the measured discharge.

6. Repeat steps 3, 4, and 5 for each event in the flood record and rank the adjusted series.
7. If there are significant changes in the ranks of the measured (Q) and adjusted (Q_a) flood series, then repeat steps 2 through 6 until the changes are not significant.

COMPUTER PROGRAM

A FORTRAN computer program (Appendix A) was prepared to perform the operations listed in the PROCEDURE section of this paper. The user enters the stream gage recorded peak flow rate for each year and the corresponding percent impervious. Based on the desired percent impervious, the annual series is adjusted by use of Figure 6. The cycle is repeated until the ranking of the adjusted peak flow rates show a negligible change by another cycle of adjustments.

DATA ENTRY SEQUENCE

LINE NUMBER	VARIABLE	DESCRIPTION
1	NN	TOTAL NUMBER OF ANNUAL RECORDS
2	Q(1),URBOLD(1), URBNEW(1)	Q = ANNUAL PEAK DISCHARGE (CFS)
.	.	URBOLD = PERCENT OF IMPERVIOUS AREA WHEN ANNUAL PEAK DISCHARGE OCCURRED
.	.	
.	.	
NN+1	Q(NN),URBOLD(NN), URBNEW(NN)	URBNEW = PERCENT OF IMPERVIOUS AREA AT PRESENT OR DESIGN CONDITION

REFERENCES

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[5] Rantz, S. E., 1971, Suggested criteria for hydrologic design of storm-drainage facilities in the San Francisco Bay region, California, U.S. Geological Survey open-file report, 89 p.

[6] Sarma, P. G. S., Delleur, J. W., and Rav, A. R., 1969. A program in urban hydrology: Purdue University, Water Resources Center, Technical Report No. 9.

[7] U.S. Soil Conservation Service, 1975, Urban hydrology for small watersheds: Technical Release No. 55.

APPENDIX A:

ANNUAL PEAK FLOW SERIES ADJUSTMENT PROGRAM

```
C
C  THIS PROGRAM DETERMINES THE EFFECT OF URBANIZATION
C  ON PEAK Q
C
      DIMENSION Q(100),T(100),QADJ(100),URBOLD(100),URBNEW(100)
      DIMENSION F(251),Q1(100)
C. INPUT/OUTPUT UNITS
      IR=1
      NR=2
      IW=3
C..OPEN FILES
      OPEN(UNIT=IR,FILE='PAF.DAT',STATUS='OLD')
      OPEN(UNIT=NR,FILE='NORMAL.DAT',STATUS='OLD')
      OPEN(UNIT=IW,FILE='PAF.ANS',STATUS='UNKNOWN')
C  INPUT DATA
      READ(IR,*)NN
      DO 900 I=1,NN
      READ(IR,*)Q(I),URBOLD(I),URBNEW(I)
 900  CONTINUE
      READ(NR,*)(F(I),I=1,251)
C..OUTPUT FORMATS
 501  FORMAT(/,10X,'*** EFFECT OF URBANIZATION ON PEAK DISCHARGE',
     C ' ***',//,2X,13('-'),'HISTORICAL',14('-'),3X,14('-'),
     C 'ADJUSTED',15('-'),/,2(2X,'RETURN PERIOD',3X,'PEAK Q',3X,
     C 'URBANIZATION '))
 502  FORMAT(2(5X,F5.2,6X,F9.0,6X,F4.1,5X))
 503  FORMAT(//)
 504  FORMAT(/,'  *** FINAL RESULTS ***',/)
 506  FORMAT(' *** ITERATION NUMBER ',I2,' ***',/)
C
C  SORTING THE INITIAL ARRAY
C
      DO 100 I=2,NN
      DO 200 J=1,I-1
      IF(Q(I).LE.Q(J))GO TO 200
      QTEMP=Q(J)
      Q(J)=Q(I)
      Q(I)=QTEMP
      X1=URBOLD(J)
      X2=URBNEW(J)
      URBOLD(J)=URBOLD(I)
      URBNEW(J)=URBNEW(I)
      URBOLD(I)=X1
      URBNEW(I)=X2
 200  CONTINUE
 100  CONTINUE
```

```
C
C   INITIALIZE ARRAY
C
      NNN=0.
      DO 110 I=1,NN
      RET=(REAL(NN)+1.)/REAL(I)
      T(I)=RET
 110  CONTINUE
 600  DO 800 I=1,NN
      Q1(I)=Q(I)
      QADJ(I)=0.
 800  CONTINUE
     .KK=0
C
C   PEAK ADJUSTMENT FACTORS

C
C.. ADJUSTED FACTOR FOR OLD WATERSHED CONDITION
      DO 300 I=1,NN
      XF1=1
      XF2=1.
      IF(URBOLD(I).EQ.URBNEW(I))GO TO 310
      RET=(REAL(NN)+1.)/REAL(I)
      PROB=URBOLD(I)/10
      I1=IFIX(PROB)
      IF(I1.EQ.0)GO TO 320
      PROB=REAL(I1)*10.
      CALL FIG34(RET,PROB,XF11,F)
      GO TO 330
 320  XF11=0.
 330  PROB=PROB+10.
      CALL FIG34(RET,PROB,XF12,F)
      XF1=XF12-(PROB-URBOLD(I))*(XF12-XF11)/10
C   ADJUSTED FACTOR FOR NEW WATERSHED CONDITION
      PROB=URBNEW(I)/10
      I1=IFIX(PROB)
      IF(I1.EQ.0)GO TO 340
      PROB=REAL(I1)*10.
      CALL FIG34(RET,PROB,XF11,F)
      GO TO 350
 340  XF11=0.
 350  PROB=PROB+10
      CALL FIG34(RET,PROB,XF12,F)
      XF2=XF12-(PROB-URBNEW(I))*(XF12-XF11)/10.
 310  QADJ(I)=Q(I)*XF2/XF1
 300  CONTINUE
      WRITE(IW,501)
      DO 710 I=1,NN
      TX=(REAL(NN)+1.)/REAL(I)
      WRITE(IW,502)T(I),Q1(I),URBOLD(I),TX,QADJ(I),URBNEW(I)
 710  CONTINUE
      WRITE(IW,503)
C
C   SORTING ADJUSTED PEAK Q
C
      NNN=NNN+1
      WRITE(IW,506)NNN
      DO 400 I=2,NN
      DO 500 J=1,I-1
      IF(QADJ(I).LE.QADJ(J))GO TO 500
      QTEMP=QADJ(J)
      QADJ(J)=QADJ(I)
      QADJ(I)=QTEMP
      X1=URBOLD(J)
      X2=URBNEW(J)
      X3=T(J)
      URBOLD(J)=URBOLD(I)
      URBNEW(J)=URBNEW(I)
      T(J)=T(I)
      URBOLD(I)=X1
      URBNEW(I)=X2
      T(I)=X3
      XQTEMP=Q(J)
      Q(J)=Q(I)
      Q(I)=XQTEMP
      KK=1
 500  CONTINUE
 400  CONTINUE
C.. CHECK NUMBER OF ITERATION AND CONVERGENCE
      IF(NNN.EQ.10)GO TO 650
      IF(KK.EQ.1)GO TO 600
C.. OUTPUT RESULTS
       WRITE(IW,504)
      WRITE(IW,501)
       DO 700 I=1,NN
       TX=(REAL(NN)+1.)/REAL(I)
       WRITE(IW,502)T(I),Q1(I),URBOLD(I),TX,QADJ(I),URBNEW(I)
 700  CONTINUE
C
 650  STOP
      END
```

```
C-----------------------------------------------------------------
C-----------------------------------------------------------------
      SUBROUTINE FIG34(RET,PROB,XPF1,F)
C
C   THIS PROGRAM DETERMINES THE PEAK ADJUSTMENT FACTORS FOR
C   URBANIZING WATERSHEDS (FIGURE 43)
C
      DIMENSION F(251)
C
C   INITIALIZE PERAMETERS
C
      PRO=1.-1./RET
      DEL=.01
      SIGN=1.
C
      IF(PRO.GE.0.5)GO TO 120
      PRO=1.-PRO
      SIGN=-1
 120  DO 100 I=1,251
      X1=REAL(I-1)*DEL
      X2=X1+DEL
      F1=F(I)
      F2=F(I+1)
      IF(PRO.GE.F(I).AND.PRO.LT.F(I+1))GO TO 110
 100  CONTINUE
 110  PRO1=.01*(PRO-F1)/(F2-F1)+X1
      PRO1=PRO1*SIGN
      IF(PROB.EQ.10.)PFL=1.333
      IF(PROB.EQ.10.)PFR=1.127
      IF(PROB.EQ.20.)PFL=1.654
      IF(PROB.EQ.20.)PFR=1.245
      IF(PROB.EQ.30.)PFL=1.882
      IF(PROB.EQ.30.)PFR=1.345
      IF(PROB.EQ.40.)PFL=2.118
      IF(PROB.EQ.40.)PFR=1.436
      IF(PROB.EQ.50.)PFL=2.318
      IF(PROB.EQ.50.)PFR=1.509
      IF(PROB.EQ.60.)PFL=2.536
      IF(PROB.EQ.60.)PFR=1.618
      IF(PROB.EQ.70.)PFL=2.736
      IF(PROB.EQ.70.)PFR=1.718
C
      XPF1=PFR+(PFL-PFR)/4.38851*(2.326667-PRO1)
C
      RETURN
      END
C
```

NORMAL.DATA

```
.5000 .5040 .5080 .5120 .5160 .5199 .5239 .5279 .5319 .5359
.5398 .5438 .5478 .5517 .5557 .5596 .5636 .5675 .5714 .5753
.5793 .5832 .5871 .5910 .5948 .5987 .6026 .6064 .6103 .6141
.6179 .6217 .6255 .6293 .6331 .6368 .6406 .6443 .6480 .6517
.6554 .6591 .6628 .6664 .6700 .6736 .6772 .6808 .6844 .6879
.6915 .6950 .6985 .7019 .7054 .7088 .7123 .7157 .7190 .7224
.7257 .7291 .7324 .7357 .7389 .7422 .7454 .7486 .7517 .7549
.7580 .7611 .7642 .7673 .7704 .7734 .7764 .7794 .7823 .7852
.7881 .7910 .7939 .7967 .7995 .8023 .8051 .8079 .8106 .8133
.8159 .8186 .8212 .8238 .8264 .8289 .8315 .8340 .8365 .8389
.8413 .8438 .8461 .8485 .8505 .8531 .8554 .8577 .8599 .8621
.8643 .8665 .8686 .8708 .8729 .8749 .8770 .8790 .8810 .8830
.8849 .8869 .8888 .8907 .8925 .8944 .8962 .8980 .8997 .9015
.9032 .9049 .7066 .9082 .9099 .9115 .9131 .9147 .9162 .9177
.9192 .9207 .9222 .9236 .9251 .9265 .9279 .9292 .9306 .9319
.9332 .9345 .9357 .9370 .9382 .9394 .9406 .9418 .9429 .9441
.9452 .9463 .9474 .9484 .9495 .9505 .9515 .9525 .9535 .9545
.9554 .9564 .9573 .9582 .9591 .9599 .9608 .9616 .9625 .9633
.9641 .9649 .9656 .9664 .7671 .9678 .9686 .9693 .9699 .9706
.9713 .9719 .9726 .9732 .9738 .9744 .9750 .9756 .9761 .9767
.9773 .9778 .9783 .9788 .9793 .9798 .9803 .9808 .9812 .9817
.9821 .9826 .9830 .9834 .9838 .9842 .9846 .9850 .9854 .9857
.9861 .9864 .9868 .9871 .9875 .9878 .9881 .9884 .9887 .9890
.9893 .9896 .9898 .9901 .9904 .9906 .9909 .9911 .9913 .9916
.9918 .9920 .9922 .9925 .9927 .9929 .9931 .9932 .9934 .9936
.9938
```

EXAMPLE PROBLEM

As an application, the Alhambra Wash watershed in Los Angeles County, California is considered. The catchment shows a change in impervious cover versus time as shown in Figure 7. Based on the annual (unadjusted) series of peak flow rates and Figure 7, the program data entry sequence and computed results are as follows:

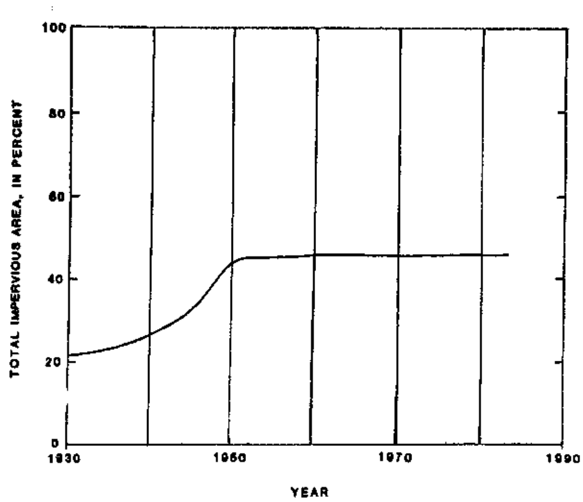

Fig. 7. Changes in impervious area for Alhambra Wash drainage basin.

INPUT DATA

54

1870.	22.0	46.
1530.	22.0	46.
1120.	22.0	46.
1850.	22.5	46.
4890.	23.0	46.
2280.	23.0	46.
1700.	24.0	46.
2470.	24.5	46.
5010.	25.0	46
2480.	26.0	46.
1280.	27.0	46.
2080.	28.0	46.
2320.	29.0	46.
4480.	30.0	46.
1860.	31.0	46.
2220.	33.0	46
1600.	35.0	46.
3810.	38.0	46
2670.	40.0	46.
758.	43.0	46
1630.	44.5	46.
1620.	45.5	46.
3810	46.0	46
3140.	46.0	46.
2410.	46.0	46
1890	46.0	46.
4550.	46.0	46.
3090.	46.0	46
4830.	46.0	46.
3170	46.0	46
1710	46.0	46.
1480.	46.0	46
2560.	46.0	46.
2210.	46.0	46
2210.	46.0	46.
3730.	46.0	46
3520	46.0	46.
3550	46.0	46
3480.	46.0	46.
3980.	46.0	46.
3430.	46.0	46.
4040.	46.0	46
2000	46.0	46.
4450.	46.0	46.
4330.	46.0	46.
6000.	46.0	46.
1820.	46.0	46.
1770	46.0	46.
5950.	46.0	46
4484.	46.0	46
6660.	46.0	46.
2750.	46.0	46
2410.	46.0	46.
7010.	46.0	46

RESULTS

*** ITERATION NUMBER 2 ***

*** FINAL RESULTS ***

HISTORICAL			ADJUSTED		
RETURN PERIOD	PEAK Q	URBANIZATION	RETURN PERIOD	PEAK Q	URBANIZATION
55.00	7010.	46.0	55.00	7010.	46.0
27.50	6660.	46.0	27.50	6660.	46.0
18.33	6000.	46.0	18.33	6000.	46.0
13.75	5950.	46.0	13.75	5950.	46.0
11.00	5010.	25.0	11.00	5901.	46.0
9.17	4890.	23.0	9.17	5886.	46.0
5.50	4480.	30.0	7.86	5065.	46.0
7.86	4830.	46.0	6.88	4830.	46.0
6.88	4550.	46.0	6.11	4550.	46.0
6.11	4484.	46.0	5.50	4484.	46.0
5.00	4450.	46.0	5.00	4450.	46.0
4.58	4330.	46.0	4.58	4330.	46.0
3.44	3810.	38.0	4.23	4041.	46.0
4.23	4040.	46.0	3.93	4040.	46.0
3.93	3980.	46.0	3.67	3980.	46.0
3.67	3810	46.0	3.44	3810.	46.0
3.24	3730.	46.0	3.24	3730.	46.0
3.06	3550.	46.0	3.06	3550.	46.0
2.89	3520	46.0	2.89	3520.	46.0
2.75	3480.	46.0	2.75	3480.	46.0
2.62	3430.	46.0	2.62	3430.	46.0
2.50	3170.	46.0	2.50	3170.	46.0
2.39	3140.	46.0	2.39	3140.	46.0
2.29	3090.	46.0	2.29	3090.	46.0
1.90	2470.	24.5	2.20	3015.	46.0
1.96	2480.	26.0	2.12	2982.	46.0
1.67	2280.	23.0	2.04	2836.	46.0
2.12	2670	40.0	1.76	2795.	46.0
2.20	2750	46.0	1.90	2750	46.0
1.72	2320.	29.0	1.83	2712.	46.0
2.04	2560	46.0	1.77	2560.	46.0
1.62	2220.	33.0	1.72	2493.	46.0
1.49	2080	28.0	1.67	2464.	46.0
1.83	2410.	46.0	1.62	2410.	46.0
1.77	2410.	46.0	1.57	2410.	46.0
1.38	1870.	22.0	1.53	2376.	46.0
1.31	1850.	22.5	1.49	2340.	46.0
1.53	2210.	46.0	1.45	2210.	46.0
1.57	2210.	46.0	1.41	2210.	46.0
1.34	1860.	31.0	1.38	2145.	46.0
1.20	1700.	24.0	1.34	2123.	46.0
1.45	2000.	46.0	1.31	2000.	46.0
1.10	1530.	22.0	1.28	1962.	46.0
1.41	1890.	46.0	1.25	1890.	46.0
1.28	1820.	46.0	1.22	1820.	46.0
1.12	1600.	35.0	1.20	1774.	46.0
1.25	1770.	46.0	1.17	1770.	46.0
1.22	1710.	46.0	1.15	1710.	46.0
1.17	1630.	44.5	1.12	1651.	46.0
1.15	1620.	45.5	1.10	1627.	46.0
1.06	1280.	27.0	1.08	1565.	46.0
1.08	1480.	46.0	1.06	1480.	46.0
1.04	1120.	22.0	1.04	1467.	46.0
1.02	758	43.0	1.02	779.	46.0