REPORT

on

International Workshop in Hydrologic Engineering

Sponsored by

Hydrologic Engineering Center
Corps of Engineers
Davis, California

by

Yao-Huang Wu

September 1974

CER74-75YHW46

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September 1974

TO: Mr. E.F. Schulz, Associate Professor

FROM: Yao-Huang Wu

SUBJECT: Report of Training on International Workshop in Hydrologic Engineering Sponsored by Hydrologic Engineering Center, Corps of Engineers at Davis, California.

Upon the recommendation made by you on the memo date July 17, 1974 the subject training course was attended by the writer from August 5 to August 30, 1974.

According to the above memo, the expections in attending the training are as follows:

1. Gain a working knowledge of HEC-1 and HEC-2 computer programs.
2. Study carefully that part of the computer program containing the subroutine for deriving the unit hydrograph from an observed rainfall-runoff event.
3. Attempt to derive a unit hydrograph from the two rainfall-runoff events taken from the ARS Data Book. The two rainfall-runoff events are:
    a. Safford Watershed, Arizona, catchment area 1.13 mile^2, flood event on July 22, 1955.
    b. Oxford Watershed, Mississippi, catchment area 35.6 mile^2, flood event on May 31, 1967.

Course Content:

The purpose of the training was intended to provide participants with the knowledge of hydrologic engineering techniques and provide the participants with some experience in making hydrologic analyses with computer programs developed by the Hydrologic Engineering Center.

The major emphasis of the workshop are on 1) rainfall-runoff analysis of single events (rain storms), 2) river hydraulics, 3) statistical methods in hydrology, and 4) simulation of reservoir systems.

The four week classes (20 days) were arranged as shown in the following tabulation:

1st-4th day	1.	Unit hydrograph concepts and derivation including rainfall-runoff analysis, rainfall-loss analysis, estimating stream flow for ungaged watershed and Clark method and Snyder method for deriving unit hydrograph.
	2.	Application of HEC-1 program to determine unit hydrograph and loss rate parameters.
5th day	1.	Hydrologic techniques for flood routing.
	2.	Basin modeling with HEC-1.
6th-8th day	1.	Steady flow water surface profile.
	2.	Application of HEC-2 program for computation of back water curve.
9th day	1.	Concepts and principles of fluvial hydraulics.
10th-12th day	1.	Hydrologic statistics.
	2.	Frequency analysis including graphical and analytical methods.

3. Linear regression analysis and regional correlation analysis.

13th day
1. Introduction and application of stochastic hydrology.
2. Application of computer program HEC-4, "Monthly Streamflow Simulation."

14th-16th day
1. Systematic analysis of multipurpose water resource system.
2. Simulation of reservoir system with computer program HEC-3.

17th day
1. Simulation to estimate power potential.
2. Application of HEC-3 for evaluation of hydro-electric generation in a reservoir system.

18th day
1. Flood regulation with reservoir systems.
2. Introduction to computer program HEC-5, "Reservoir System Analysis for Flood Control."

19th-20th day
1. Introduction to analysis of complex water resources systems.
2. Plan of study for hydrologic analysis of water resources system.

I. Content of HEC Program:

The programs currently in the program series are:

HEC-1	Flood hydrograph package
HEC-2	Water surface profile
HEC-3	Reservoir system analysis (for conservation)
HEC-4	Monthly streamflow simulation
HEC-5	Reservoir system operation for flood control

Each program is written in Fortran IV and is designed to be contained in 32,000 words of core, insofar as possible. Up-to-date information and copies of source statement cards for the programs are available from the Hydrologic Engineering Center.

HEC-1 Flood Hydrograph Package

This package represents a combination of several smaller programs which had previously been operated independently. These computer programs are still available at HEC as separate programs. The program numbers and names are:

L 2230	Unit Hydrograph and Loss Rate Optimization
L 2260	Basin Rainfall and Snowmelt Computation
L 2280	Unit Graph and Hydrograph Computation
L 2310	Streamflow Routing Optimization
L 2320	Hydrograph Combining and Routing
L 2370	Balanced Hydrograph

All ordinary flood hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with this package. Routines include rainfall-snowfall-snowpack-snowmelt determinations, computation of basin precipitation, unit hydrographs, and of hydrographs, routing by reservoir, storage-lag, multiple-storage, straddle stagger, Tatum and Muskingum methods, and complete stream system hydrograph combining and routing. Best-fit unit hydrograph, loss-rate, snowmelt, base freezing temperatures and routing coefficients can be derived automatically. Automatic routines are also provided. Input may be in either English or Metric units.

HEC-2 Water Surface Profile

The program computes water surface profiles for steady, gradually varied flow in rivers of any cross section. Flow may be subcritical or supercritical. Various routines are available for modifying input cross section data, for example, for locating encroachments or inserting a trapezoidal excavation on cross sections. The water surface profile through structures such as bridges, culverts and weirs can be modeled. Variable channel roughness and variable reach length between adjacent cross sections can be accommodated. Printer plots can be made of the river cross sections and computed profiles. Input may be in either English or Metric units.

HEC-3 Reservoir System Analysis

Program will perform a multipurpose, multireservoir simulation of a reservoir system. All requirements are supplied from reservoirs so as to maintain a specified balance of storage in all reservoirs, insofar as possible.

HEC-4 Monthly Streamflow Simulation

This program will analyze monthly streamflows at a number of interrelated stations to determine their statistical characteristics and will generate a sequence of hypothetical streamflows of any desired length having those characteristics. It will reconstitute missing streamflows on the basis of concurrent flows observed at other locations. It will also use the generalized simulation model for generating monthly streamflows at ungaged locations based on regional studies.

HEC-5 Reservoir System Operation for Flood Control

The program is intended to simulate the sequential operation of a system of reservoirs of any configuration for controlling historical or synthetic floods. The program may be used to determine:

1. Flood control storage requirements of reservoirs.
2. The influence of a system of flood control reservoirs on the spatial and temporal distribution of runoff in a basin.
3. Operation criteria for minimizing flooding.

Because of the tight arrangement of courses during the four-week training, the writer had no opportunity of going into detail in every part of HEC program. However, the backwater curve computation in HEC-2 and unit hydrograph derivation in HEC-1 have been more carefully studied. For the derivation of unit hydrograph, the writer studied in more detail, discussed with the staff of HEC several times and practised the program with the sample data from the ARS Data Book.

II. Deriving the Unit Hydrograph from an Observed Rainfall-Runoff Event

Unit hydrograph is done by Clark method which uses the concept of the instantaneous unit hydrograph (IUH).

Clark Method: The Clark method translates incremental runoff from subareas within a basin to the basin outflow location according to travel times and then routes this runoff through a linear reservoir in order to account for the storage effects of the basin and channels. The time of concentration (tc) is defined as the travel time of water particles from the most upstream point in the basin to the outflow location. This lag time may be estimated by measuring the time between the end of effective rainfall and the inflection point on the recession limb of the observed hydrograph. When the time of concentration has been determined, the basin is divided into incremental runoff-producing areas that have equal travel times to the outflow location. Isochromes representing equal travel time to the outflow location are laid out using the distance traveled per unit time to establish the location of the lines. The areas between the isochromes are then measured and tabulated with the corresponding travel time (from 0 to tc) for each incremental area. The time period selected as the computation interval should be approximately equal to the unit duration of excess (Fig. 1).

The runoff from the contributing areas (between the isochromes) which has been translated to the outflow location is in units of volumes (in-mi^2 or mm-km^2) and these must be converted to the proper units of discharge (c.f.s. or m^3/s).

The routing of the translated runoff through storage at the outflow location is accomplished as follows:

$$O_i = CI_i + (1 - C)O_{i-1}$$

where O_i = outflow from the basin at end of period

I_i = inflow or runoff from each area at end of period i

C = dimensionless routing constant

The above routing results from setting the Muskingum "x" equal to zero in the coefficient method of routing.

$$C = \frac{2\Delta t}{2R + \Delta t}$$

Δt = time period of computation interval

R = attenuation constant

The Clark Conceptual Model of the IUH

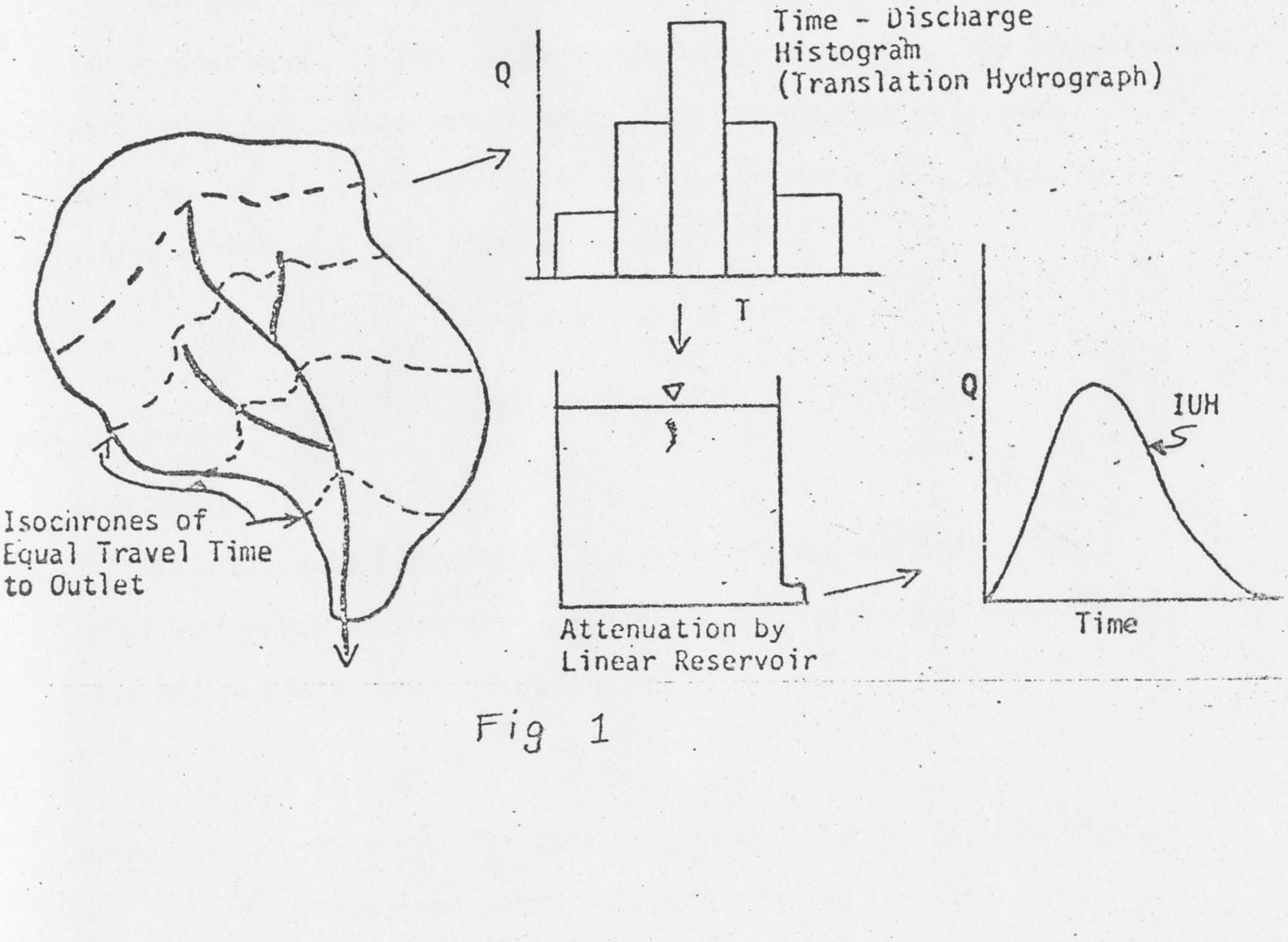


Fig 1

It can be shown that when inflow into the principal storage reach has ceased (Muskingum "x" = 0),

$$R = -\frac{Q}{dQ/dt}$$

The magnitude of R can be approximately evaluated at the point of inflection of the recession limb of the observed surface runoff hydrograph.

The hydrograph that results from routing these flows from the incremental areas is the instantaneous unit hydrograph. The instantaneous unit hydrograph can be converted to a unit hydrograph of a unit duration Δt by simply averaging two instantaneous unit hydrographs spaced at interval Δt apart as follows:

$$O_i = O_i \qquad \text{for } i - 1$$

$$O_i = 0.5(O_i + O_{i-1}) \text{ for } i \geq 2$$

Loss Rate:

Rainfall excess generating runoff is the rainfall minus loss. HEC-1 loss model assumes the loss rate is the function of accumulated loss and rainfall intensity as: (Fig. 2)

$$L = (K + \Delta K)P^E$$

where L = loss rate for particular time interval in inches/hr.

K = loss rate coefficient at beginning of time interval

P = rainfall intensity in in/hr

ΔK = incremental increase in loss rate coefficient

E = exponent of precipitation for rain loss function.

Again, $K = Ks/Ra^{.1\ Lc}$

$$\Delta K = 0.2\, \ell s\, [1 - (Lc/\ell s)]^2$$

where K_s = starting value of loss coefficient on exponential recession curve

R_a = ratio of rain loss coefficient on exponential loss curve to that corresponding to 10 inches more of accumulated loss

L_c = accumulated loss

ΔK = incremental increase in loss coefficient. ΔK is assumed to be a parabolic function of the accumulated loss for ℓs amount of accumulated loss. ΔK is a maximum of .2 ℓs initially and reducing to zero when the accumulated loss equals ℓs

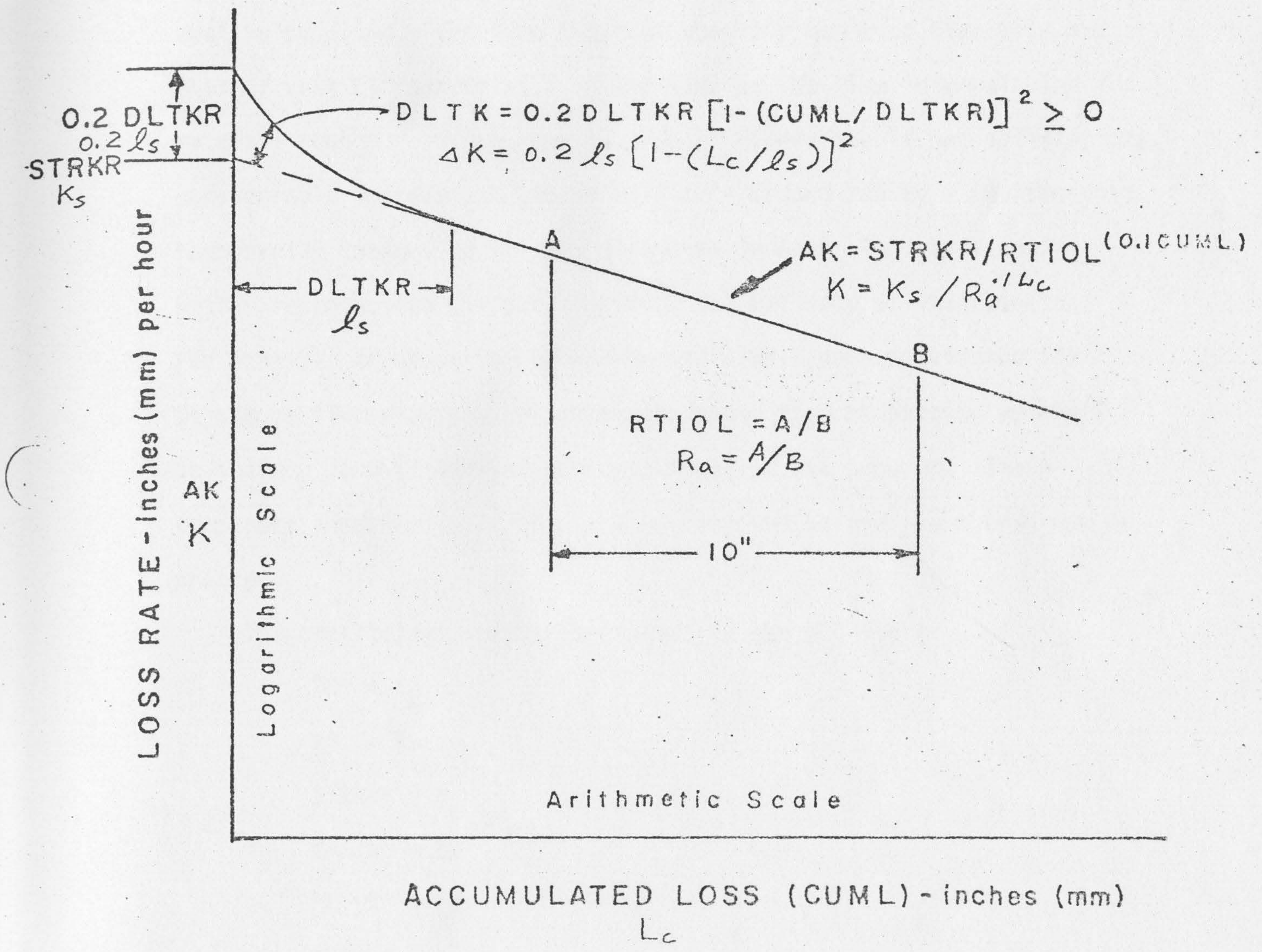
ℓs = amount of initial accumulated rain losses during which the loss rate coefficient is increased.

Unit Hydrograph and Loss Rate Optimization:

HEC-1 has the capability to automatically determine a set of unit hydrograph and loss rate parameters that "best" reconstitutes an observed runoff event for a basin given the average rainfall for the basin, the drainage area and a few runoff hydrograph parameter values for starting flow and base flow recession computations.

The best reconstitution is considered to be that which minimizes the weighted squared deviation between the observed hydrograph and a reconstituted hydrograph. The optimization procedure used to derive values for the variables is the univariate gradient search procedure. In order to improve the reproduction of peak flows, errors associated with high flows are weighted heavier than those associated with low

HEC-1 LOSS FUNCTION



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

$$L = (K + \Delta K)\, P^{E}$$

Fig. 2

flows. Each error square is multiplied by $(Q + \overline{Q})/2\overline{Q}$ where $\overline{Q}$ is the average flow. A volume check is included in the hydrograph reconstruction that assures approximate correspondence in volume between the observed and computed hydrographs.

In order to optimize coefficients, a hydrograph of observed runoff must be supplied. The time interval used for observed flow data and that of unit hydrograph will be the same as the time interval used in rainfall record. If the reproduction of hydrograph is not satisfactory, considerable improvement can be made in a second run by a routine that temporarily changes up to five flow data in each flood to force a better reproduction without impairing the validity of the results. For example, if a portion of a reconstituted hydrograph is too low it can be fitted better by increasing a key flow by putting weight 2 to the key flow (double of observed flow) in the program. These temporary adjustments to the flow are removed before the hydrograph is printed.

The coefficients can be optimized in the HEC-1 are:

TC* = t_c
R* = R
STRKR* = K_s
ERAIN* = E
DLTKR* = ℓs
RTIOL* = R_a

*Variable symbols in computer program

These variables can be in the manner that part of variables are fixed and the remaining are to be optimized. For example, T_c and R coefficient in Clark method can be given values obtained from the observed hydrograph.

Following data will also be given in the program:

NHR = number of whole hrs in tabulation interval

NMIN = number of minutes in tabulation interval in addition to NHR above

STRTQ = flow at start of storm. The base flow below STRTQ will be receded in same manner as QRCSN below.

QRCSN = flow below which base flow recession occurs in accordance with the recession constant RTIOR

RTIOR = ratio of recession flow, QRCSN to that flow occurring 10 tabulation intervals later

Minimizing the weighted squared deviation between the observed hydrograph and a reconstituted hydrograph will be conducted for the hydrograph between the time of STRTQ and QRCSN.

Symthetic Time-area Curve:

As stated above, in the application of Clark's unit hydrograph procedure, it is necessary to utilize a time-area curve for the basin under study. Those data will be given in computer program as follows:

TAREA = catchment area

NTA = number of Clark time-area ordinates to be read

QCLK(1) = area at time 0

ACLK(2) = area contributes runoff during first NTA equal interval

QCLK(3) = area contributes runoff during second NTA equal interval

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It has been found that it is not necessary to use the actual distance-area curve in the analysis. Instead, a distance-area curve of general shape is used to represent the time-area curve of the basin. This generalized distance-area curve is referred to as a synthetic time-area curve. It is convenient to use a function of the form

$$\text{Accumulated Area} = CT^n \qquad \text{for } 0 < T < \frac{Tc}{2}$$

$$1 - \text{Acc. Area} = C(1 - T)^n \qquad \text{for } 0 < \frac{Tc}{2} < Tc$$

Such a function, with $n = 1$, represents a rectangular watershed and $n = 2$, represents a diamond shaped area. In HEC-1, the exponent "n" has been set to 1.5, which was found to yield a shape representative of a common watershed configuration (Fig. 3).

The symthetic time-area curve in HEC-1 may be used for most watersheds. However, for basins that deviate substantially from the generalized shape, a real time-area curve should be used.

III. Deriving Unit Hydrographs from the Two Rainfall-runoff Events Taken from the ARS Data Book by HEC-1

Attempt to drive unit hydrograph was made for the two watershed (1) Safford, Arizona, catchment area = 1.13 mi^2, and (2) Oxford, Mississippi, catchment area = 35.6, which represent one big watershed and one small watershed respectively. The rainfall and runoff records are shown in Attachment 1.

Since time interval for computation in hyetograph, observed hydrograph as well as unit hydrograph should be the same in HEC-1, the rainfall and runoff records have been rearranged to the equal interval records.

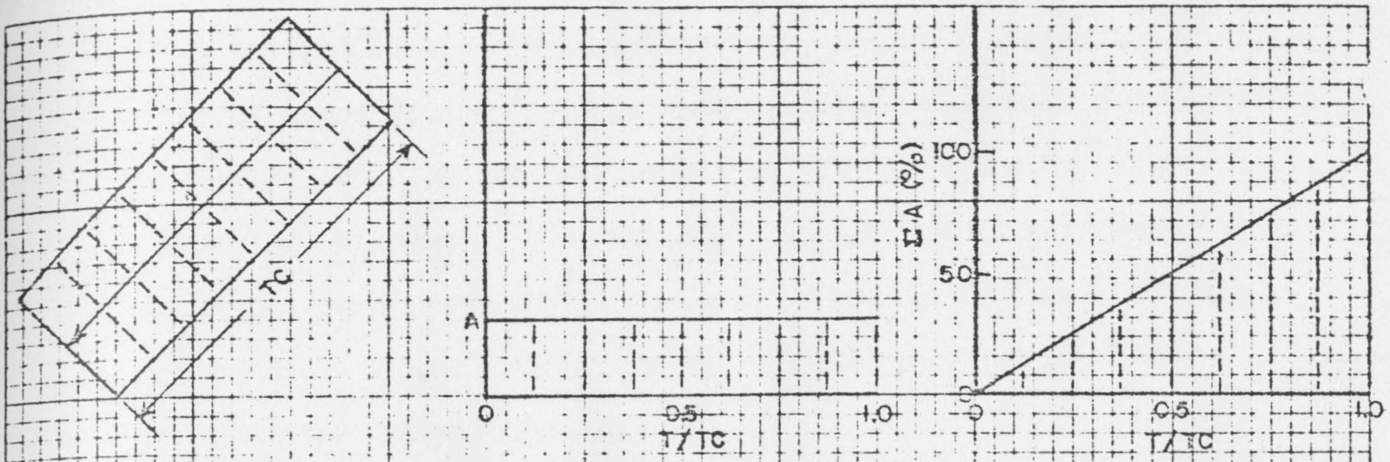


Fig. 3 Rectangular Shape Watershed, n=1

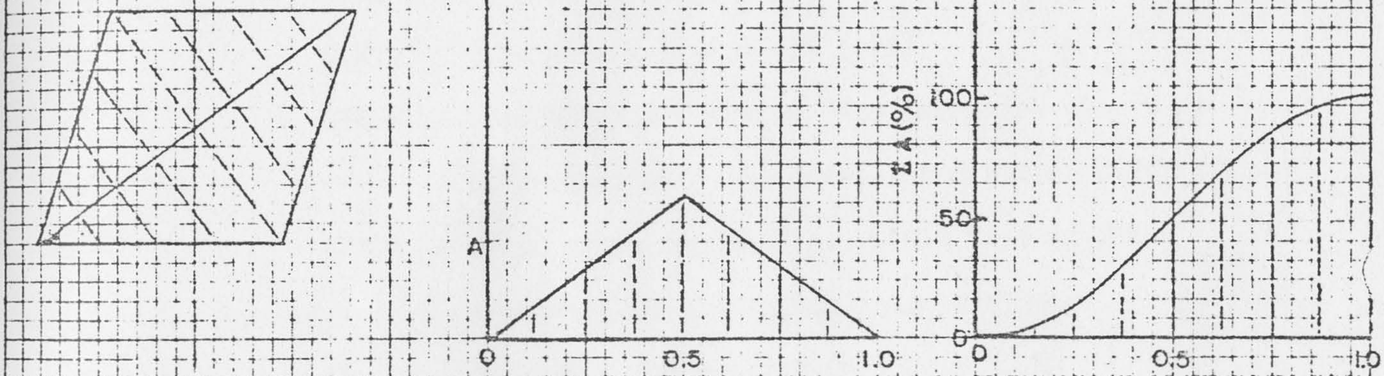


Fig. 4 Diamond Shape Watershed, n=2

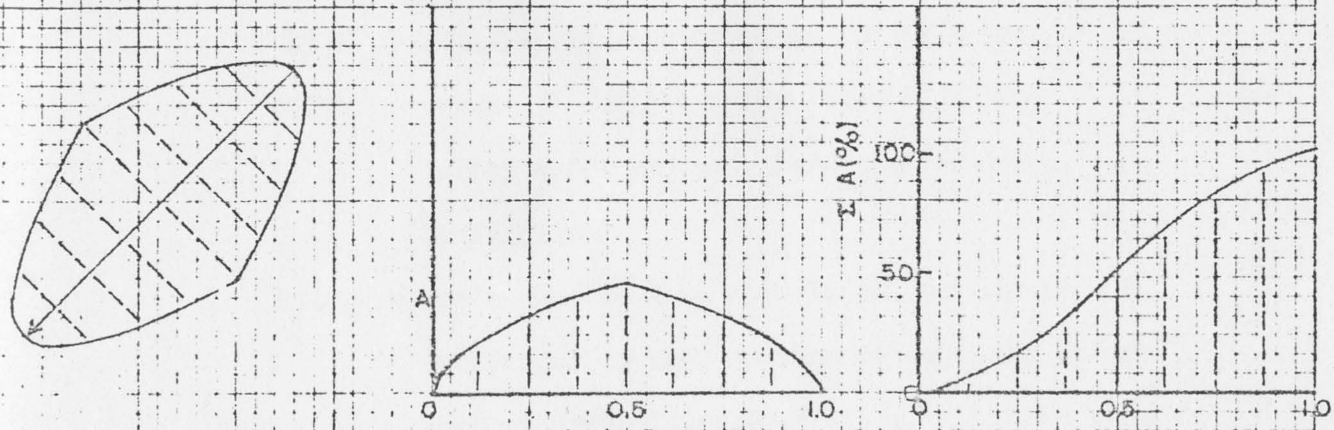


Fig 3 Generalized Shape Watershed, n=1.5

Besides, both of the watersheds are very small with very short time of concentration, the time interval should be small. For Safford watershed, the time interval was set at 10 minutes and for Oxford Watershed, 30 minutes. Consequently, the output unit hydrographs represent the hydrographs of 1 inch of direct runoff from a rainfall excess of 10 minute duration for Safford Watershed and 30 minute duration for Oxford Watershed.

The input data are as follows:

NMIN = number of minutes in tabulation interval (min)
TAREA = total catchment area (mi^2)
STRTQ = flow at start of storm (cfs)
QRCSN = flow below which base flow recession occurs in accordance with the recession constant RTIOR (cfs)
RTIOR = ratio of recession flow, QRCSN to that flow occurring 10 tabulation intervals later
TC = time of concentration (hr)
R = attenuation constant (hr)
STRKR = starting value of loss coefficient
ERAIN = exponent of precipitation for rain loss
DLTKR = amount of initial accumulated rain loss during which the loss rate coefficient is increased
RTIOL = ratio of rain loss coefficient on exponential loss curve to that corresponding to 10 inches more of accumulated loss
NWT = number of pairs of weighting factors for runoff data
IQ(n) = sequence number of flow value selected to be adjusted
RQ(n) = ratio by which selected flow is temporarily multiplied to aid in reconstruction

For the time-area curve in the Clark method, HEC-1 representative watershed with the exponent "n" equal to 1.5 has been used

A. Safford Watershed, Arizona: (1.13 mi^2)

a. Input rainfall and runoff data: (July 22, 1955) - rearranged to a constant time interval record

Time	No. of Time Interval	Rainfall (in)	Runoff (cfs)
1550	0	0	0
1600	1	.01	0
1610	2	.23	0
1620	3	.73	69.3
1630	4	.33	387.9
1640	5	.06	623.5
1650	6	.04	334.0
1700	7	.02	111.6
1710	8		54.7
1720	9		28.4
1730	10		14.6
1740	11		8.0
1750	12		3.6
1800	13		1.5
1810	14		.7
1820	15		0

b. Fixed variables in several runs

NMIN = 0

TAREA = 1.13

STRTQ = 0

c. Variables which have been changed in several runs in order to get best fit unit hydrograph

QRCSN

RTIOR

NWT

IQ(n)

RQ(n)

TC, R, STRKR, ERAIN, DLTKR, RTIOL to be optimized by Program HEC-1

* Output of the program:

. Output of the program includes:

1. Optimization results of variables.
2. Coordinate of unit hydrograph.
3. Coordinate of observed hydrograph and reconstituted hydrograph computed by using newly established unit hydrograph.
4. Comparison graph of observed and reconstituted hydrograph with hyetograph showing rainfall excess and loss.
5. Data showing the differences between observed and reconstituted hydrograph.

   The comparison is made for the hydrograph of a time base which is equal to 3 times the lag (from the centroid of rainfall excess to the observed peak) or which is equal to a period from the centroid of the rainfall excess to a recession Q equal to one half the peak Q, whichever gives the largest time base.

d. Comparison of observed and reconstituted hydrograph:

	Input Variables					Comparison of Observed and Reconstituted Hydrograph				
Runs	QRCSN	RTIOR	NWT	IQ(n)	RQ(n)	Peak Difference %	Time Dif. of Peak %	Standard Error cfs	Standard Error as a % of Mean	Volume Dif. %
1	50.00	1.90	0	-	-	-25.45	0	66.06	28.73	-11.99
2	0	-	0	-	-	- 9.87	0	41.99	18.26	1.81
3	0	-	1	5	1.10	- 8.75	0	43.13	18.76	1.76
4	0	-	1	5	1.30	- 6.97	0	47.35	17.97	3.77
5	0	-	1	5	1.80	- 6.53	0	52.29	22.74	1.80
6	110	20.00	1	5	1.50	-23.72	0	65.37	28.43	-6.72

e. Discussion on the results

1. The watershed has the catchment area of only 1.13 mile^2. Because of the small watershed, the observed hydrograph has a very sharp peak. HEC-1 program uses Clark method and HEC-1 loss model for deriving the unit hydrograph. The results of reconstituted hydrograph is very difficult to agree with the peak of observed hydrograph.

2. Run 1 and 6 assumed a flow QRCSN below which the flow recession occurs in accordance with the recession constant RTIOR. RTIOR is the ratio of recession flow at the beginning of recession to that at the 10 intervals later. This means the hydrograph below QRCSN is fixed. Because of the steep drawn down of the observed hydrograph, the reconstituted hydrograph is always higher than the observed hydrograph on recession part. Through the optimization of variables basing on the smallest volume difference between the observed and reconstituted hydrograph, the reconstituted peak is always much lower than the observed peak. Perhaps, increase of RTIOR will help decrease of difference in peak,

3, Runs 2 through 5 assumed QRCSN as zero. That means that all hydrograph coordinates are flexible in the process of reconstitution during optimization. The difference of peak as well as that of total volume are much smaller than those in run 1 and 6.

4. Since the peak difference in run 2 was considered too big and the reconstituted peak is too low, the observed peak has been temporarily increased during optimization by putting weight on it. In run 5, the observed peak was temporarily increased to 1.8 times the original peak. As the result, the peak difference has been reduced to the least but the standard error as % of mean has been increased.

5. If the peak of event is considered more important than the coordinates of hydrograph in the study, the weight of observed peak can be increased some extent to meet the requirement. Besides, flow at the end of other intervals can also be temporarily adjusted by weight during optimization for the purpose of getting better fit reconstituted hydrograph.

6. Among the 6 runs which have been done, run 5 is considered as the best one. The comparison of observed and reconstituted hydrographs is shown in Fig. 4 and the unit hydrograph performed in run 5 is shown in Fig. 5. The outputs are shown in Attachment 2.

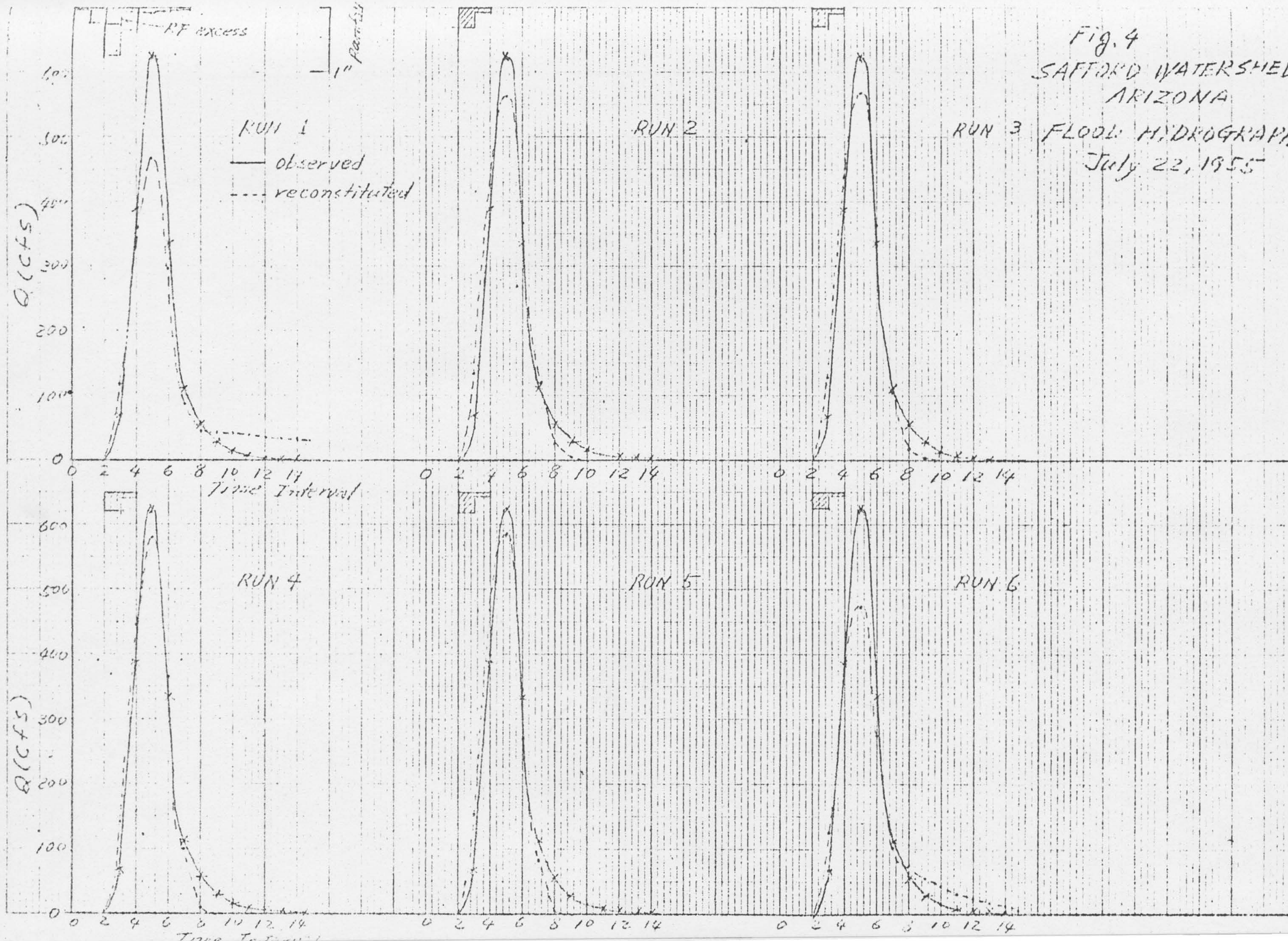


Fig. 4
SAFFORD WATERSHED,
ARIZONA
FLOOD HYDROGRAPH
July 22, 1955

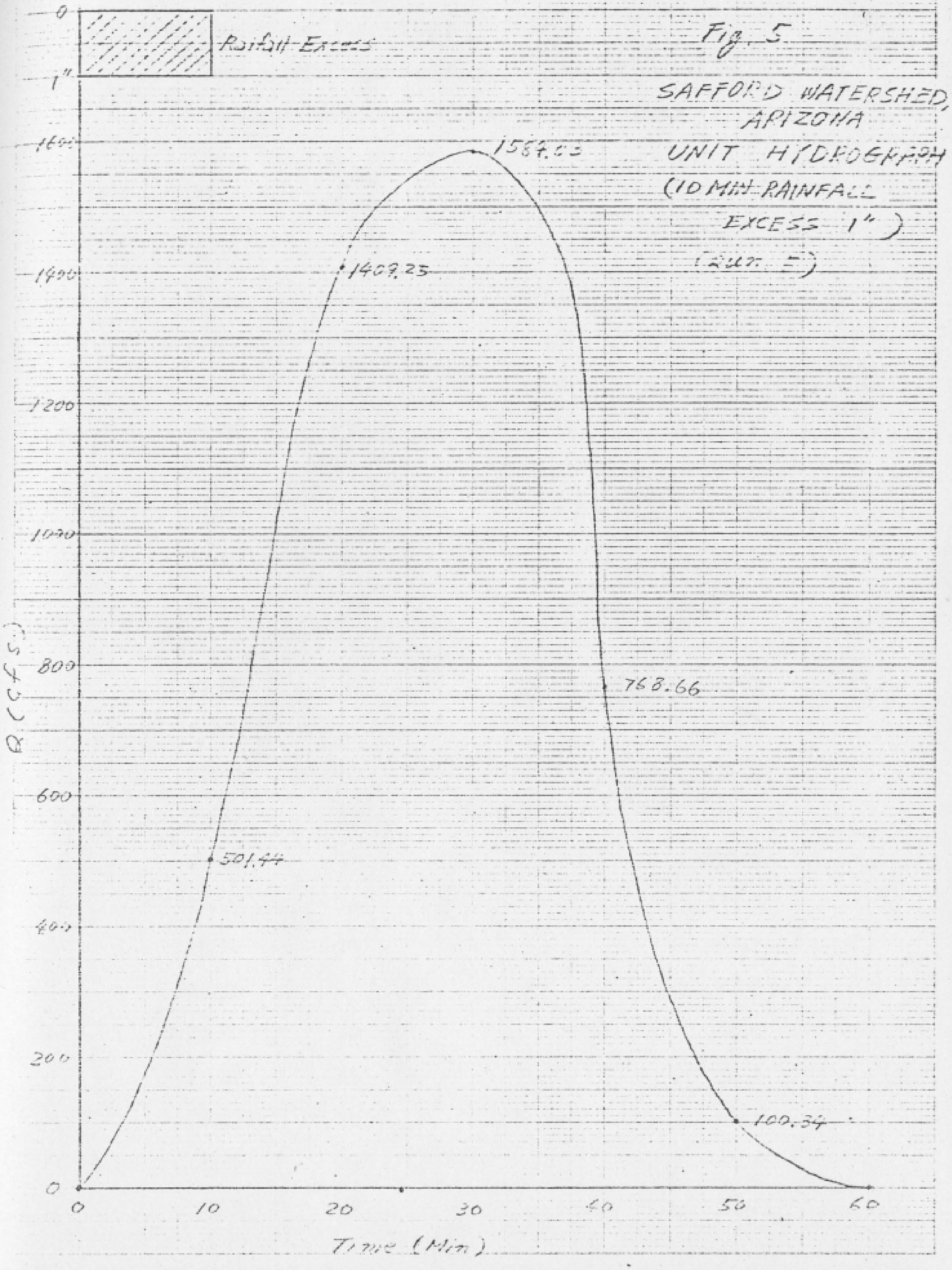


Fig. 5

SAFFORD WATERSHED, ARIZONA

UNIT HYDROGRAPH

(10 MIN RAINFALL EXCESS 1")

(Run 5)

B. Oxford Watershed, Mississippi (35.6 mi^2)

a. Input rainfall-and runoff data: (May 31, 1967) - rearranged to a constant time interval record

Date	Time	No. of Time Interval	Rainfall (in)	Runoff (cfs)
5-31	14:00	0	.00	0
	14:30	1	.04	.5
	15:00	2	.28	1.4
	15:30	3	.88	11.1
	16:00	4	.11	133.2
	16;30	5	.01	992.4
	17:00	6		1702.0
	17;30	7		1403.3
	18;00	8		918.8
	18;30	9		564.7
	19;00	10		367.7
	19;30	11		264.9
	20;00	12		208.0
	20:30	13		186.9
	21;00	14		153.4
	21;30	15		130.0
	22;00	16		106.5
	22;30	17		87.6
	23;00	18		70.8
	23;30	19		58,3
	24;00	20		47,6
6-1	0;30	21		41.3
	1;00	22		35,1

1:30	23	28.8
2:00	24	25.4
2:30	25	21.9
3:00	26	18.4
3:30	27	16.7
4:00	28	15.2
4:30	29	14.0
5:00	30	12.4
5;30	31	10.9
6;00	32	9.5
6;30	33	9.1
7;00	34	8.7

b, Fixed variables in several runs

NMIN = 30

TAREA = 35.6

STRTQ = 0

c, Variables which have been changed in several runs in order to get best fit unit hydrograph

QRCSN

RTIOR

NWT

IQ(n)

RQ(n)

TC,R,STRKR,ERAIN,DLTKR,RTIOL to be optimized by Program HEC-1

d. Comparison of observed and reconstituted hydrograph:

	Input Variables					Comparison of Observed and Reconstituted Hydrograph				
Runs	QRCSN	RTIOR	NWT	IQ(n) no. of time interval	RQ(N) weight	Peak Difference %	Time Difference %	Standard Error cfs	Standard Error as a % of Mean	Volume Difference %
1	100.00	1.20	0	-	-	-33.51	0	255.77	38.95	-11.64
2	0	-	0	0	0	-18.55	0	197.25	33.04	8.91
3	0	-	1	6	1.20	- 6.10	0	222.26	37.23	14.36
4	300.00	8.00	1	6	1.30	-11.36	0	247.06	37.63	5.30
5	300.00	7.00	1	6	1.50	-11.48	0	256.44	39.05	4.40
6	400.00	6.00	1	6	1.80	-16.29	0	255.41	36.15	-.96
7	400.00	6.00	2	6	1.80	-21.98	0	227.76	34.69	-.90
				7	2.10					

e. Discussion on the results

1. From the original flood event data, the total rainfall was 1.32 inches, but the total runoff was only .17 inches. This means that the rainfall excess occurred only in one time interval of peak rainfall, i.e. No. 3 interval, which has the interval time rainfall of .88 inches. Therefore, the shape of reconstituted hydrograph should be the same with the unit hydrograph optimized through the computation.

2. In runs 1, 4, 5, 6 & 7, the parameter of recession curve (QRCSN, RTIOR) has been fixed during the computation. RTIOR in run 1 is too small and the reconstituted recession curve is much higher than the original. However, through the adjustment the recession limbs of reconstituted hydrographs fit the observed hydrograph very well in runs 6 and 7.

3. Since the reconstituted peaks in runs 1 and 2 were much less than the observed peak, more weight on peak was put for the computation in runs 3 to 7. As the result, the run 3 had the least peak difference. Among the 7 runs which have been done, run 3 is considered as the best one.

4. In comparing runs 4, 5, 6 and 7 with run 3, more weight on peak was put in runs 4, 5, 6 and7. But the reconstituted peaks in those runs were lower than that in run 3. The reason is that the parameters of recession curve were fixed for better fit with the original recession limb in

runs 4, 5, 6 and 7. In comparison with run 3, the run-off volume on the tail part of hydrograph in runs 4, 5, 6 and 7 has been much increased. In order to fit the observed total run-off volume of hydrograph, the peaks were decreased.

5. From the result of 7 runs, the increasing parts of reconstituted hydrographs were always much higher than that of observed hydrograph. In order to have better fit hydrograph, it seems that the lower weight of less than 1 should be put on the coordinate of observed discharge occurred prior to the peak.

6. The comparison of observed and reconstituted hydrograph is shown in Fig, 6 and the unit hydrograph performed in run 3 is shown in Fig. 7. The outputs are shown in Attachment 2.

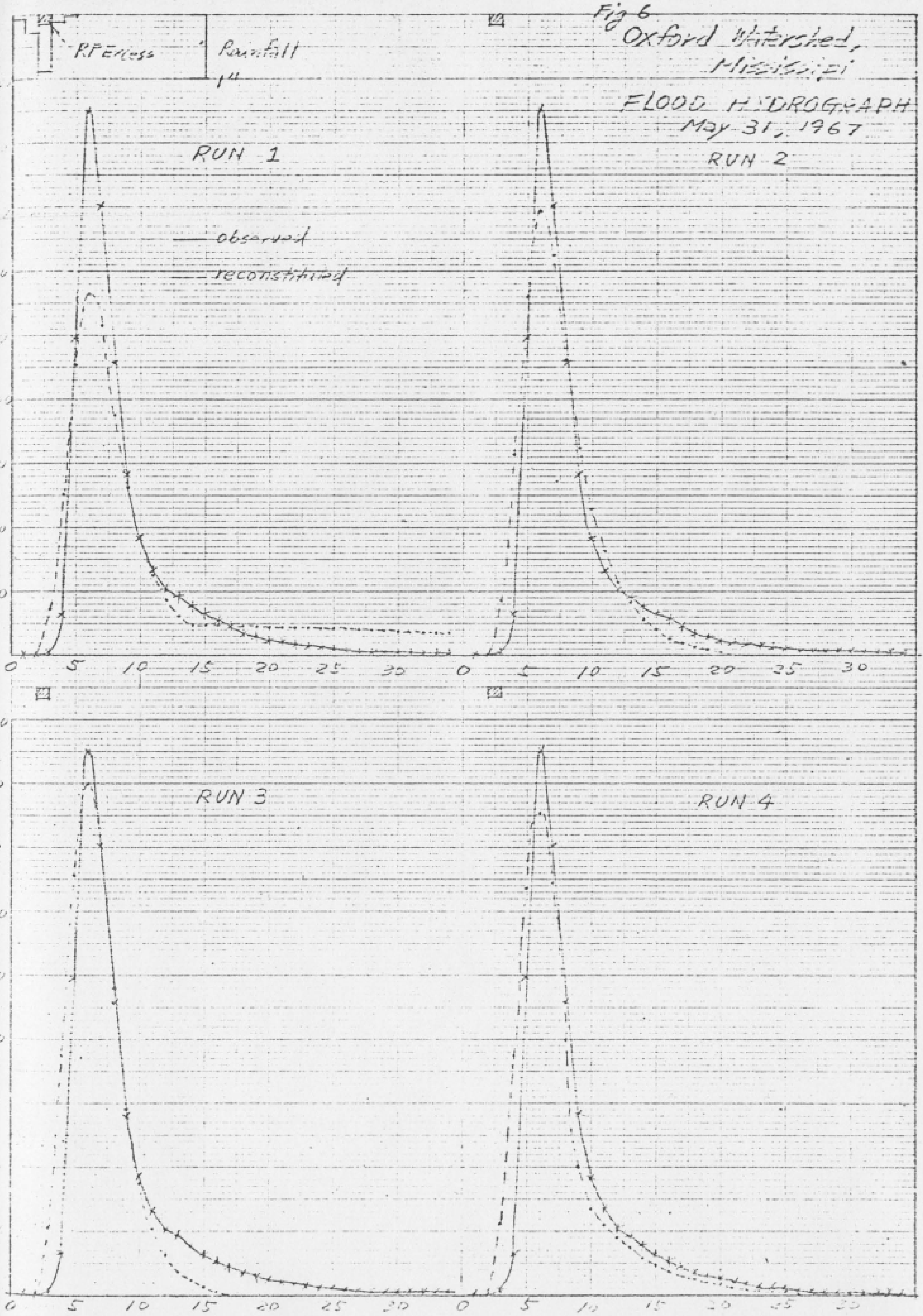


Fig 6

Oxford Watershed, Mississippi

FLOOD HYDROGRAPH May 31, 1967

Fig 6

RUN 5
RUN 6
RUN 7
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30

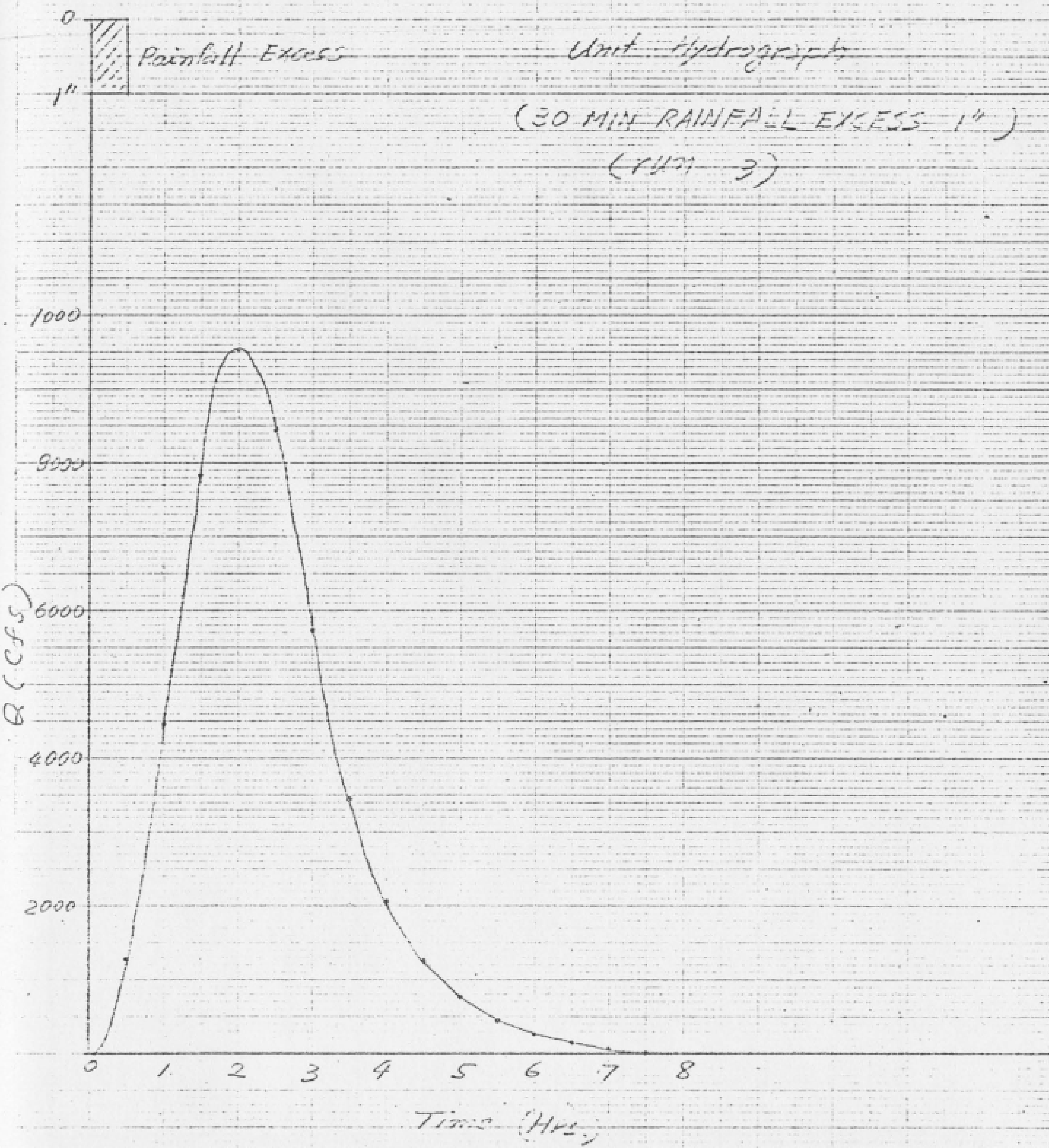


Fig 7

Oxford Watershed, Mississipi

Unit Hydrograph

(30 MIN RAINFALL EXCESS 1")

(RUN 3)

ATTACHMENT 1

Hydrologic Data for Experimental Agricultural Watershed in the United States 211 1967 ARS, USDA

MONTHLY PRECIPITATION AND RUNOFF (inches) 1/						SAFFORD, ARIZONA WATERSHED 45.005 AREA—723 ACRES (1.13 SQ. MILES)				W 5			45.04
MONTH / YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
P													
Q													
STA AVG P													
Q													
MEAN 69 YR P 2/	.65	.66	.62	.29	.14	.27	1.82	1.74	1.04	.63	.57	.77	9.20

ANNUAL MAXIMUM DISCHARGES (inches per hour) AND ANNUAL MAXIMUM VOLUMES OF RUNOFF (inches) FOR SELECTED TIME INTERVALS

YEAR	MAXIMUM DISCHARGE		MAXIMUM VOLUME FOR SELECTED TIME INTERVAL													
			1 HOUR		2 HOURS		6 HOURS		12 HOURS		1 DAY		2 DAYS		8 DAYS	
	DATE	RATE	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME
1967	9-25	.007	9-25	.003	9-25	.003	9-25	.003	9-25	.003	9-25	.003	9-25	.003	9-25	.003
MAXIMUMS FOR PERIOD OF RECORD 1/																
19 TO 19																

NOTES: 1/ Not calculated. Data are being reevaluated. As soon as retabulation is completed, revised data will be reported for these two sections. 2/ Mean P based on 69-yr (1899-67) U.S. Weather Bureau record period at Safford, Ariz.

1955 SELECTED RUNOFF EVENT

SAFFORD, ARIZONA WATERSHED 45.005

Event of July 22, 1955

ANTECEDENT CONDITIONS			RAINFALL				RUNOFF			
DATE MO-DAY	RAINFALL (inches)	RUNOFF (inches)	DATE MO-DAY	TIME OF DAY	INTENSITY (in/hr)	ACC. (inches)	DATE MO-DAY	TIME OF DAY	RATE (in/hr)	ACC. (inches)
	RG R-12		7-22	RG	R-12		7-22			
7-10	.31	.00		1543	.00	.00		1612	.000	.0000
7-13	.05	.00		1607	.08	.03		1613	.001	.0000
7-17	.15	.00		1610	4.20	.24		1614	.022	.0002
7-21	.05	.00		1615	5.16	.67		1617	.025	.0014
7-22	.02	.00		1620	3.60	.97		1618	.066	.0021
				1630	1.98	1.30		1619	.082	.0034
				1650	.30	1.40		1620	.095	.0048
				1800	.02	1.42		1621	.119	.0066
								1622	.167	.0090
								1623	.193	.0120
								1624	.255	.0157
								1625	.299	.0204
								1626	.342	.0257
								1627	.392	.0318
								1628	.451	.0383
								1629	.495	.0467
								1630	.532	.0553
								1631	.564	.0644
								1632	.613	.0742
								1633	.656	.0848
								1634	.700	.0961
								1635	.724	.1080
								1637	.780	.1330
								1639	.841	.1601
								1641	.868	.1886
								1642	.926	.2035
								1643	.830	.2181
								1644	.790	.2316
								1645	.761	.2446
								1646	.728	.2570
								1647	.660	.2685
								1648	.595	.2790
								1649	.540	.2885
								1650	.458	.2968
								1651	.444	.3043
								1652	.378	.3112
								1653	.336	.3171
								1654	.288	.3223
								1655	.266	.3269

Watershed conditions: About 80% of area is bare. Vegetation consists mostly of short grasses (black grama, sideoats grama, and tobosa), with some shrubs and forbs.

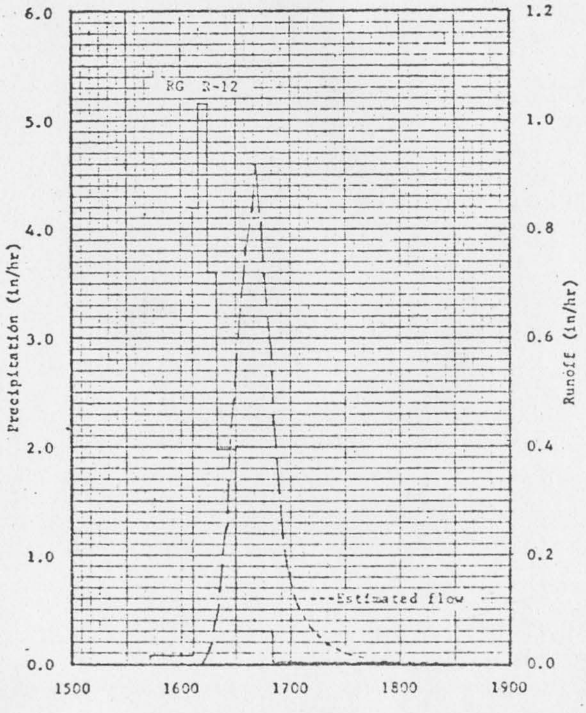
Continued on next page

NOTES: TO CONVERT RUNOFF IN IN/HR TO CFS, MULTIPLY BY 729.02. FOR TOPOGRAPHIC MAP OF WATERSHED SEE HYDROLOGIC DATA FOR EXPERIMENTAL AGRICULTURAL WATERSHEDS IN THE UNITED STATES, 1956-59, USDA, MISC. PUB. 945, P. 45.4-4. SELECTED EVENT IS FROM RE-EVALUATED DATA.

1955 SELECTED RUNOFF EVENT | SAFFORD, ARIZONA WATERSHED 45.005 W-5

ANTECEDENT CONDITIONS			RAINFALL				RUNOFF			
DATE MO-DAY	RAINFALL (inches)	RUNOFF (inches)	DATE MO-DAY	TIME OF DAY	INTENSITY (in/hr)	ACC. (inches)	DATE MO-DAY	TIME OF DAY	RATE (in/hr)	ACC. (inches)
			Event of July 22, 1955 continued							
							7-22	1656	.232	.3311
								1657	.189	.3346
								1659	.165	.3405
								1701	.141	.3456
								1703	.120	.3500
								1705	.100E	.3536E
								1710	.075E	.3609E
								1715	.056E	.3664E
								1716	.054E	.3673E
								1718	.044E	.3689E
								1721	.036E	.3710E
								1724	.030E	.3726E
								1727	.024E	.3740E
								1731	.018E	.3753E
								1734	.014E	.3762E
								1739	.010E	.3772E
								1744	.007E	.3779E
								1750	.005E	.3785E
								1756	.003E	.3789E
								1804	.002E	.3792E
								1812	.001E	.3794E
								1822	.000E	.3795E
								1829	.000E	.3796E
								2001	.000E	.3796E

NOTES: TO CONVERT RUNOFF IN IN/HR TO CFS, MULTIPLY BY 729.02.



July 22, 1955 10366 [illegible]

SAFFORD, ARIZONA WATERSHED 45.005

MONTHLY PRECIPITATION AND RUNOFF *(inches)*

OXFORD, MISSISSIPPI WATERSHED W-12 1/ 62.04
AREA—22,800 ACRES (35.6 SQ. MILES)

YEAR \ MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1967 P 2/	1.57	2.99	4.52	4.45	7.83	2.38	7.19	7.09	1.14	2.12	1.95	7.73	50.96
Q	.04	.13	1.00	.17	1.42	.03	1.24	1.44	.04	.03	.03	.74	6.31
STA AV 3/ P	3.57	4.97	4.81	4.50	4.16	3.10	4.28	3.74	4.28	2.07	4.07	5.05	48.60
(57-67) Q	.68	1.09	1.15	.62	.51	.18	.27	.25	.24	.06	.31	.73	6.09
MEAN P 4/ 48 YR	5.67	5.27	5.93	5.06	4.65	3.76	4.40	3.27	3.45	2.83	4.51	5.13	53.99

ANNUAL MAXIMUM DISCHARGES *(inches per hour)* **AND ANNUAL MAXIMUM VOLUMES OF RUNOFF** *(inches)* **FOR SELECTED TIME INTERVALS**

YEAR	MAXIMUM DISCHARGE		MAXIMUM VOLUME FOR SELECTED TIME INTERVAL													
			1 HOUR		2 HOURS		6 HOURS		12 HOURS		1 DAY		2 DAYS		8 DAYS	
	DATE	RATE	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME
1967	7-9	.30	7-9	.29	7-9	.56	7-9	.99	7-9	1.06	7-9	1.09	8-2	1.29	8-2	1.37
MAXIMUMS FOR PERIOD OF RECORD																
1957 TO 1967	2-23 1962	.35	2-23 1962	.35	2-23 1962	.68	2-23 1962	1.38	2-23 1962	1.62	2-23 1962	1.84	1-30 1957	2.28	3-24 1965	4.36

NOTES: Watershed conditions: About 18% in cultivation (cotton, corn and soybeans), fair cover November to March, poor cover April and May improving to good by mid-July; 44% in pasture and idle land, good cover April to October with fair cover remainder of year; 33% in woods, good cover; 1% in bare gullies; 4% urban. Percentages of total area in various land use categories are based on the latest survey completed in 1963. 1/ About 23% of drainage area above small desilting and retention dams. 2/ Monthly precipitation Thiessen weighted from 16 rain gages. 3/ Precipitation and runoff records began Jan. 1957. 4/ Mean P based on 48-yr (1920-67) U. S. Weather Bureau record period at Holly Springs 2N, Miss.

1967 DAILY PRECIPITATION *(inches)*

OXFORD, MISSISSIPPI WATERSHED W-12 62.04

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	.00	.00	.00	.00	1.54	.00	.15	.23	.00	.00	.23	.00
2	.00	.42	.00	.00	.03	.00	.68	3.53	.00	.00	.00	1.50
3	.00	.00	.00	.00	.00	.00	.00	.65	.00	.00	.18	.00
4	.00	.00	.00	.00	.00	.00	.00	.56	.00	.00	.00	.00
5	.00	.00	.57	.00	.00	.00	1.35	.00	.00	.00	.00	.00
6	.00	.00	2.51	.00	2.68	.00	.00	.00	.00	.00	.00	.14
7	.04	.00	.00	.00	.00	.00	.00	.16	.21	.00	.00	.00
8	.00	.00	.00	.00	.00	.00	.00	.00	.50	.06	.00	.00
9	.00	.00	.00	.00	.00	.01	3.03	.01	.00	.00	.00	1.25
10	.00	.00	.00	.08	.00	.00	.00	.00	.00	.00	.00	.15
11	.00	.00	.00	.00	.00	.00	.09	.00	.05	.00	.34	.42
12	.00	.00	.00	.00	.00	.00	.07	.00	.00	.00	.00	.00
13	.54	.00	.00	.50	.00	.00	.44	.00	.00	.00	.00	.00
14	.07	.00	.00	.76	.32	.00	.00	.00	.00	.00	.00	.46
15	.00	.01	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22
16	.00	.13	.00	.00	.00	.00	.00	.00	.00	1.54	.00	.00
17	.00	.29	.00	.00	.00	.00	.00	.08	.00	.11	.00	.80
18	.00	.01	.00	.00	.00	.15	.00	.38	.00	.00	.00	.00
19	.00	.36	.05	.00	.00	.00	.00	.00	.00	.00	.00	.00
20	.00	.71	.19	.00	.35	.05	.08	.00	.00	.00	.05	1.39
21	.00	.00	.00	.07	.87	.56	.01	.00	.11	.00	.21	.80
22	.00	.00	.00	.10	.00	.35	.20	.00	.00	.00	.13	.00
23	.00	.00	.00	1.35	.00	.35	.00	.00	.00	.00	.03	.00
24	.00	.00	.00	.00	.00	.00	.00	.27	.00	.08	.00	.00
25	.00	.00	.00	.70	.00	.00	.13	.00	.00	.00	.03	.00
26	.92	.00	.97	.52	.00	.02	.21	1.16	.00	.00	.00	.00
27	.00	1.06	.23	.00	.00	.00	.00	.06	.27	.00	.00	.055
28	.00	.00	.00	.00	.00	.50	.43	.00	.00	.00	.00	.00
29	.00	--------	.00	.00	.00	.07	.32	.00	.00	.00	.55	.00
30	.00	--------	.00	.37	.35	.82	.00	.00	.00	.25	.23	.11
31	.00	--------	.00	--------	1.47	--------	.00	.00	--------	.06	--------	.44
TOTAL	1.57	2.99	4.52	4.45	7.83	2.38	7.19	7.09	1.14	2.12	1.95	7.73
STA AV	3.57	4.97	4.81	4.50	4.16	3.10	4.28	3.74	4.28	2.07	4.07	5.05

NOTES: FOR DAILY AIR TEMPERATURES IN THE VICINITY, SEE TABLE FOR WATERSHED W-4A, P. 62.1-1. DAILY PRECIPITATION VALUES THIESSEN WEIGHTED FROM RAIN GAGES 4-9, 13, 15, 18-20, 25, 29-31, AND 33. STATION AVERAGE IS FOR 11-YR (1957-67) RECORD PERIOD

1967 MEAN DAILY DISCHARGE (cfs) | OXFORD, MISSISSIPPI | WATERSHED W-12 62.

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	.82	.31	2.68	.38	308.59	9.07	3.83	.24	2.29	1.00	1.35	1.
2	.82	10.75	2.28	.71	26.56	1.75	12.44	830.50	2.29	[illegible]	1.26	62.1
3	.82	1.68	2.11	.71	4.64	1.00	1.99	29.84	2.21	.82	1.06	2.2
4	.87	1.00	2.02	.71	3.45	.87	.39	444.49	1.78	.76	1.00	1.1
5	.76	1.00	2.51	.71	3.09	.82	64.60	3.85	1.48	.76	1.00	1.
6	.71	.88	847.90	.65	599.20	.61	6.82	1.35	1.26	.82	1.00	1.
7	.71	.82	35.06	.60	246.39	.51	3.83	.88	1.26	.82	1.00	[illegible]
8	.69	.93	12.53	.51	10.72	.43	3.09	.71	1.71	.88	1.00	[illegible]
9	.60	1.00	7.36	.56	1.35	.28	1028.43	.60	1.12	.93	1.00	31.4
10	.65	1.00	4.80	.62	.93	.22	19.92	.51	1.00	.93	.93	27.4
11	.56	.82	3.56	.82	.82	.18	3.68	.42	.87	.93	.87	4.15
12	.47	.52	2.98	.65	.61	.23	4.19	.42	.87	.93	.93	1.4
13	.56	.38	2.66	.69	.39	.31	24.38	.47	.93	1.13	1.00	1.
14	.65	.35	2.29	2.04	.49	.28	1.84	.42	.93	1.26	1.00	1.45
15	.65	.25	1.71	.56	1.37	.28	.56	.35	.87	1.26	1.06	2.2
16	.60	.20	1.26	.51	.27	.25	.00	.31	.87	1.40	1.00	1.96
17	.56	.18	.89	.42	.14	.25	.38	.25	.87	1.15	.93	51.05
18	.51	.16	.71	.42	.14	.31	.82	.96	.87	.76	1.06	25.44
19	.51	.22	.82	.47	.13	.31	.76	.35	.87	.74	1.06	3.17
20	.56	17.36	.76	.51	.18	.35	1.63	.35	.87	.82	1.00	277.65
21	.56	4.43	.71	.60	1.84	.46	1.47	.32	.87	.82	1.06	159.61
22	.56	2.98	.66	.61	1.15	.73	.76	.28	.87	.82	1.06	20.82
23	.56	2.77	.84	80.50	.23	.82	.71	.28	.87	.93	1.00	1.04
24	.56	2.77	1.19	3.22	.14	.35	.71	.36	.87	.93	1.00	.60
25	.51	2.66	1.26	1.65	.13	.39	.71	1.03	.87	.87	1.00	.56
26	18.49	2.66	1.85	50.35	.19	.33	.86	45.29	.87	1.00	.88	.60
27	3.52	56.18	9.62	3.93	.20	.25	.61	4.69	.87	1.06	.76	.71
28	.42	12.04	2.23	2.56	.13	.25	.59	3.09	.87	.93	.76	.66
29	.38	-------	1.14	2.66	.15	.40	1.10	2.87	.93	1.00	.88	.43
30	.35	-------	.87	2.26	.22	6.20	1.05	2.66	.93	1.19	1.00	.35
31	.31	-------	.76	-------	150.65	-------	.36	2.56	-------	1.26	-------	1.34
MEAN	1.26	4.50	30.90	5.39	44.01	.94	36.46	44.53	1.13	.96	.99	22.77
INCHES	.04	.13	1.00	.17	1.42	.03	1.24	1.44	.04	.03	.03	.74

NOTES: TO CONVERT DISCHARGE IN CFS TO IN/DAY, MULTIPLY BY 0.0010439. QUALITY OF RECORDS: GOOD, ESTIMATED TO BE WITHIN 10% OF ACTUAL.

1967 SELECTED RUNOFF EVENT | OXFORD, MISSISSIPPI | WATERSHED W-12 62.04

Event of May 31 - June 3, 1967 1/

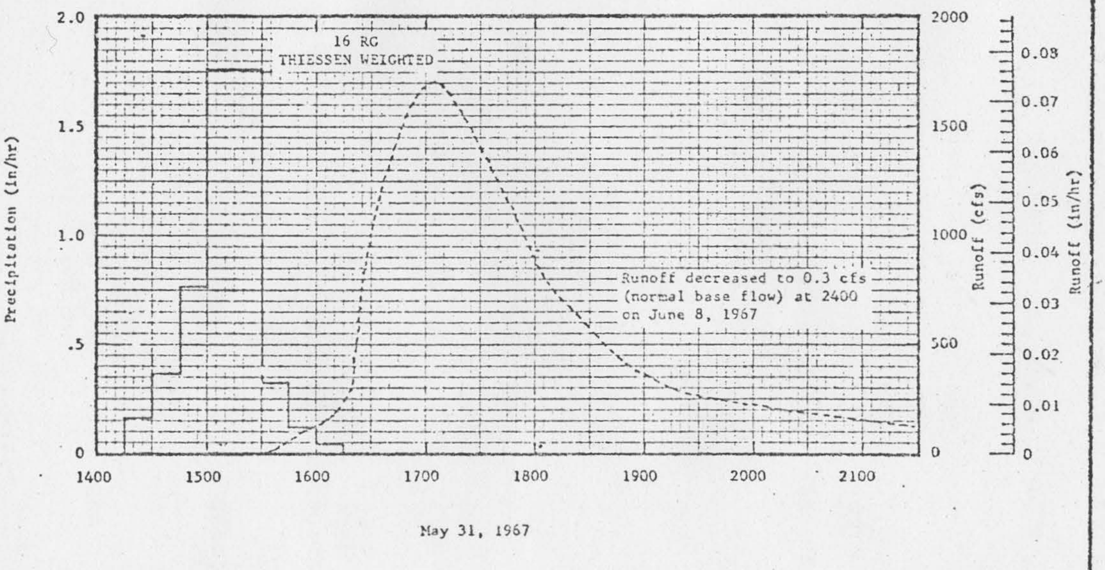
ANTECEDENT CONDITIONS			RAINFALL				RUNOFF			
DATE MO-DAY	RAINFALL (inches)	RUNOFF (inches)	DATE MO-DAY	TIME OF DAY	INTENSITY (in/hr)	ACC. (inches)	DATE MO-DAY	TIME OF DAY	RATE (cfs)	ACC. (inches)
5-31	2/.14	3/.0002	5-31	16 RG	AVG4/		5-31	1420	.20	.0000
				1415	.00	.00		1438	.76	.0001
				1430	.16	.04		1454	.87	.0001
				1445	.35	.13		1517	2.56	.0001
				1500	.76	.32		1536	13.99	.0002
				1515	1.76	.76		1554	101.81	.0010
				1530	1.76	1.20		1612	196.10	.0029
				1545	.32	1.28		1620	321.89	.0044
				1600	.12	1.31		1624	699.52	.0059
				1615	.04	1.32		1632	1090.00	.0111
								1646	1477.28	.0241
								1704	1732.00	.0449
								1726	1470.26	.0702
								1748	1192.00	.0907
								1812	735.59	.1067
								1828	580.00	.1143
								1850	412.19	.1222
								1920	278.73	.1297
								2010	209.70	.1366
								2058	155.00	.1449
								2206	101.81	.1513
								2254	73.35	.1543
								2325	59.00	.1559
								2400	47.58	.1572
							6-1	0130	28.41	.1597

Watershed conditions: 18% of area in cultivation, chiefly cotton, corn and soybeans, generally poor cover; 16% in pasture and 28% idle, fair to good cover; 33% in woods, good cover; 1% in bare gullies; 4% urban.

NOTES: TO CONVERT RUNOFF IN CFS TO IN/HR, MULTIPLY BY 0.0000435. FOR MAP OF WATERSHED, SEE HYDROLOGIC DATA FOR EXPERIMENTAL AGRICULTURAL WATERSHEDS IN THE UNITED STATES, 1956-59, USDA MISC. PUB. 945, P. 62.4-6. 1/ ISOHYETAL MAP ON P. 62.11-4. 2/ RAINFALL PRIOR TO 1415 ON 5-31-67. 3/ RUNOFF PRIOR TO 1420 ON 5-31-67. FOR 30-DAY ANTECEDENT P AND Q, SEE TABLES ON THIS AND PREVIOUS PAGE. 4/ THIESSEN WEIGHTED STORM RAINFALL, RAIN GAGES 4-9, 13, 15, 18-20, 25, 29-31 AND 33. DAILY TOTALS FOR INDIVIDUAL GAGES LISTED ON PP. 62.11-2 AND 62.11-3.

1967	SELECTED RUNOFF EVENT				OXFORD, MISSISSIPPI			WATERSHED W-12		62.4-3
ANTECEDENT CONDITIONS			RAINFALL				RUNOFF			
DATE MO-DAY	RAINFALL (inches)	RUNOFF (inches)	DATE MO-DAY	TIME OF DAY	INTENSITY (in/hr)	ACC. (inches)	DATE MO-DAY	TIME OF DAY	RATE (cfs)	ACC. (inches)
			Event of May 31 - June 3, 1967 - Continued							
							6-1	0302	14.19	.1612
								0602	9.51	.1630
								1200	4.46	.1646
								2400	2.37	.1656
							6-2	2400	1.17	.1685
							6-3	2400	1/.47	.1695

NOTES: TO CONVERT RUNOFF IN CFS TO IN/HR, MULTIPLY BY 0000435, 1/ RUNOFF DECREASED TO 0.3 CFS (NORMAL BASE FLOW) AT 2400 ON JUNE 8, 1967.



OXFORD, MISSISSIPPI WATERSHED W-12

ATTACHMENT 2

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*******************************
HEC-1 VERSION DATED JAN 1973
UPDATED AUG 74

*******************************
                                      CLARK METHOD FOR DERIVING UNIT HYDROGRAPH, BY HEC-1
                                      SAFFORD WATERSHED,ARIZONA,DATA FROM HYDRO DATA FOR EXPER AGR WATERSHED
                                        YAOHUANG WU

                                                                 JOB SPECIFICATION
                                             NQ     NHR   NMIN    IDAY   IHR   IMIN METRC   IPLT   IPRT NSTAN
                                             15       0     10  0 022     15     50     0      2      1     0
                                                                  JOPER        NWT
                                                                      2          1

                TEMPORARY ADJUSTMENT TO OBSERVED FLOWS QO       5  1.80


                                               HYDROGRAPH AND LOSS RATE OPTIMIZATION COMPUTATIONS
                                       ISTAQ    ISNOW    TAREA     SNAP     STRTQ     QRCSN    RTIOR     NCLRK
                                           1        0     1.13      .00       .00       .00     1.00         0

                                                                     INPUT DATA
                           TC            R        COEF     STRKR    STRKS    RTIOK     ERAIN     FRZTP     DLTKR     RTIOL
                         -.52         -.13         .00     -1.00      .00      .00     -1.00       .00     -1.00     -1.00
                                                                INITIAL ESTIMATES
                         TC+R     R/(TC+R)        COEF     STRKR    STRKS    RTIOK     ERAIN     FRZTP     DLTKR     RTIOL
                         3.90          .20         .00       .20      .00      .00       .50       .00       .50      2.00

                                                                    PRECIP DATA
                                                              NP   STORM       DAJ       DAK
                                                               7     .00       .00       .00
                                                                    PRECIP PATTERN
                          .01          .23         .73         .33        .06        .04        .02

      STANDARD ERROR FOR VARIABLE 1    347.9594      345.9357      344.1542
      VAR  1 ADJ FROM    3.90 TO    3.55

      STANDARD ERROR FOR VARIABLE 2    340.5421      340.0093      339.4773
      VAR  2 ADJ FROM     .20 TO     .15

      STANDARD ERROR FOR VARIABLE 4    327.5316      323.2249      318.9548
      VAR  4 ADJ FROM     .90 TO     .60

      STANDARD ERROR FOR VARIABLE 7    221.3879      220.6419      219.9536
      VAR  7 ADJ FROM     .50 TO     .43

      STANDARD ERROR FOR VARIABLE 9    216.0131      216.1055      216.2376
      VAR  9 ADJ FROM    2.24 TO    2.28

      STANDARD ERROR FOR VARIABLE10    215.9469      215.9645      215.9823
      VAR 10 ADJ FROM    2.00 TO    3.00

      STANDARD ERROR FOR VARIABLE 1    215.2995      217.6248      220.6181
      VAR  1 ADJ FROM    3.55 TO    3.66

      STANDARD ERROR FOR VARIABLE 2    211.1257      211.1844      211.2519
      VAR  2 ADJ FROM     .15 TO     .16
```

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STANDARD ERROR FOR VARIABLE 4     210.9600     210.8682     210.8456
VAR  4 ADJ FROM     .60 TO     .59

STANDARD ERROR FOR VARIABLE 7     210.8445     210.7485     210.6888
VAR  7 ADJ FROM     .43 TO     .42

STANDARD ERROR FOR VARIABLE 9     210.6645     210.8035     210.9827
VAR  9 ADJ FROM    2.28 TO    2.35

STANDARD ERROR FOR VARIABLE10     210.4893     210.5022     210.5154
VAR 10 ADJ FROM    3.00 TO    4.50

STANDARD ERROR FOR VARIABLE 1     210.0182     211.1573     212.7371
VAR  1 ADJ FROM    3.66 TO    3.74

STANDARD ERROR FOR VARIABLE 2     208.8912     208.9012     208.9194
VAR  2 ADJ FROM     .16 TO     .16

STANDARD ERROR FOR VARIABLE 4     208.8890     208.8679     208.9099
VAR  4 ADJ FROM     .59 TO     .58

STANDARD ERROR FOR VARIABLE 7     208.8671     208.7703     208.7063
VAR  7 ADJ FROM     .42 TO     .40

STANDARD ERROR FOR VARIABLE 9     208.6711     208.8130     208.9961
VAR  9 ADJ FROM    2.35 TO    2.42

STANDARD ERROR FOR VARIABLE10     208.4925     208.5028     208.5132
VAR 10 ADJ FROM    4.50 TO    6.75

STANDARD ERROR FOR VARIABLE 1     208.1241     208.5574     209.3749
VAR  1 ADJ FROM    3.74 TO    3.76

STANDARD ERROR FOR VARIABLE 2     208.0387     208.0492     208.0673
VAR  2 ADJ FROM     .16 TO     .16

STANDARD ERROR FOR VARIABLE 4     208.0358     208.0960     208.2146
VAR  4 ADJ FROM     .58 TO     .59

STANDARD ERROR FOR VARIABLE 7     208.0275     207.9312     207.8648
VAR  7 ADJ FROM     .40 TO     .39

STANDARD ERROR FOR VARIABLE 9     207.8197     207.9636     208.1495
VAR  9 ADJ FROM    2.42 TO    2.49

STANDARD ERROR FOR VARIABLE10     207.6404     207.6497     207.6592
VAR 10 ADJ FROM    6.75 TO   10.12

STANDARD ERROR FOR VARIABLE 1     207.3071     207.5105     208.0917
VAR  1 ADJ FROM    3.76 TO    3.76

                               INFILTRATION INDEX =2.100 IN/HR ( 53 MM/HR)

                                    STRKR FOR RTIOL OF 3. =  .79

                                         OPTIMIZATION RESULTS
                  TC      R     COEF    STRKR    STRKS    RTIOK    ERAIN    FRZTP    DLTKR    RTIOL
                 .53    .10     .00      .85      .00      .00      .39      .00     3.60    10.12
```

```
          UNIT HYDROGRAPH   5 END-OF-PERIOD ORDINATES, LAG=     .32 HOURS, CP=  .76  VOL= 1.00
501.44    1409.25    1584.03      768.66      100.34

                                          END-OF-PERIOD FLOW
                  PERIOD        TIME    RAIN     EXCS     COMP Q       OBS Q
                     1       22 15 60    .01      .00        .00         .00
                     2       22 16 10    .23      .00        .00         .00
                     3       22 16 20    .73      .31     154.08       69.30
                     4       22 16 30    .33      .07     467.20      387.90
                     5       22 16 40    .06      .00     582.79      623.50
                     6       22 16 50    .04      .00     344.16      334.00
                     7       22 16 60    .02      .00      83.23      111.60
                     8       22 17 10    .00      .00       6.84       54.70
                     9       22 17 20    .00      .00        .00       28.40
                    10       22 17 30    .00      .00        .00       14.60
                    11       22 17 40    .00      .00        .00        8.00
                    12       22 17 50    .00      .00        .00        3.60
                    13       22 17 60    .00      .00        .00        1.50
                    14       22 18 10    .00      .00        .00         .70
                    15       22 18 20    .00      .00        .00         .00

                                   SUM  1.42      .38    1638.00     1637.80


            THE FOLLOWING INFORMATION IS FOR A TIME BASE
            WHICH IS EQUAL TO 3 TIMES THE LAG FROM THE CENTROID
            OF RF EXCESS TO THE OBSERVED PEAK
                                     -OR-
            WHICH IS EQUAL TO 4 PERIOD FROM THE CENTROID OF THE
            RF EXCESS TO A RECESSION Q EQUAL TO ONE-HALF THE PEAK Q
                       -WHICHEVER GIVES THE LARGEST TIME BASE


            TIME BASE STARTS AT PERIOD  3, ENDS AT PERIOD   9



        COMPUTED PEAK=     582.79
        OBSERVED PEAK=     623.50     PEAK DIFF. (PERCENT)= -6.53

        COMPUTED PEAK LAG=   .30  HOURS
        OBSERVED PEAK LAG=   .30  HOURS    TIME DIFFERENCE    .0 HOURS

        STANDARD ERROR=  52.289
        MEAN FLOW=   229.9
        STANDARD ERROR AS A PERCENT OF MEAN=   22.74

        AVERAGE ERROR (PERCENT)=   52.18

        COMPUTED VOLUME=       1638.
        OBSERVED VOLUME=       1609.           VOLUME DIFF. (PERCENT)=  1.80
```

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             STATION     1               YAOHUANG WU

                          INFLOW(I), OUTFLOW(O) AND OBSERVED FLOW(*)
     0.      100.      200.      300.      400.      500.      600.      700.         0.        0.        0.       0.         0.
                                                                                                      PRECIP(L) AND EXCESS(X)
     .0        .0.       .0.       .0.       .0.       .0.       .0.       .0.        .8.       .6.       .4.       .2.       .0
22 15 60*         .         .         .         .         .         .         .         .         .         .         .        LX
22 16 10*         .         .         .         .         .         .         .         .         .         .      LLLLLLLLLLLLLX
22 16 20.      *  .    I    .         .         .         .         .         .         . LLLLLLLLLLLLLLLLLLLLLLLXXXXXXXXXXXXXXXX
22 16 30.         .         .         .        *.      I  .         .         .         .         .  LLLLLLLLLLLLLLXXXX
22 16 40.         .         .         .         .         .       I . *       .         .         .         .      LLLX
22 16 50.         .         .         .  *I     .         .         .         .         .         .         .       LLX
22 16 60.      I  .*        .         .         .         .         .         .         .         .         .        LX
22 17 10.I   *    .         .         .         .         .         .         .         .         .         .         L
22 17 20I  *      .         .         .         .         .         .         .         .         .         .         L
22 17 30I*        .         .         .         .         .         .         .         .         .         .         L
22 17 40I*        .         .         .         .         .         .         .         .         .         .         L
22 17 50*         .         .         .         .         .         .         .         .         .         .         L
22 17 60*         .         .         .         .         .         .         .         .         .         .         L
22 18 10*         .         .         .         .         .         .         .         .         .         .         L
22 18 20*         .         .         .         .         .         .         .         .         .         .         L
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*****************************
HEC-1 VERSION DATED JAN 1973
UPDATED AUG 74

*****************************
                           CLARK METHOD FOR DERIVING UNIT HYDROGRAPH, BY HEC-1
                           OXFORD WATERSHED,MISSISSIP,DATA FROM HYDRO DATA FOR EXPER AGR WATERSHED
                             YAOHUANG WU

                                                  JOB SPECIFICATION
                                  NO   NHR  NMIN  IDAY   IHR  IMIN METRC  IPLT  IPRT NSTAN
                                  34     0    30 0 031    16     0     0     2     1     0
                                                    JOPER   NWT
                                                        2     1

        TEMPORARY ADJUSTMENT TO OBSERVED FLOWS QO      6  1.20



                                           HYDROGRAPH AND LOSS RATE OPTIMIZATION COMPUTATIONS
                              ISTAQ   ISNOW   TAREA    SNAP   STRTQ   QRCSN   RTIOR   NCLRK
                                  1       0   35.60     .00     .00     .00    1.00       0

                                                          INPUT DATA
                     TC          R     COEF   STRKR   STRKS   RTIOK   ERAIN   FRZTP   DLTKR   RTIOL
                  -2.17      -1.46      .00   -1.00     .00     .00   -1.00     .00   -1.00   -1.00
                                                     INITIAL ESTIMATES
                   TC+R   R/(TC+R)     COEF   STRKR   STRKS   RTIOK   ERAIN   FRZTP   DLTKR   RTIOL
                   7.26        .40      .00     .20     .00     .00     .50     .00     .50    2.00

                                                         PRECIP DATA
                                                NP   STORM     DAJ     DAK
                                                 5     .00     .00     .00
                                                        PRECIP PATTERN
                    .04        .28        .88        .11        .01

STANDARD ERROR FOR VARIABLE 1    277.0616     272.7606     268.8878
VAR  1 ADJ FROM   7.26 TO   6.49

STANDARD ERROR FOR VARIABLE 2    263.4466     260.4277     257.4161
VAR  2 ADJ FROM    .40 TO    .27

STANDARD ERROR FOR VARIABLE 4    218.4573     215.7486     217.0561
VAR  4 ADJ FROM    .81 TO    .80

STANDARD ERROR FOR VARIABLE 7    215.6866     215.9786     216.8511
VAR  7 ADJ FROM    .50 TO    .50

STANDARD ERROR FOR VARIABLE 9    215.6866     216.1852     217.6771

STANDARD ERROR FOR VARIABLE10    215.6866     215.6888     215.6952
VAR 10 ADJ FROM   2.00 TO   2.00

STANDARD ERROR FOR VARIABLE 1    215.6866     216.8968     218.9740
VAR  1 ADJ FROM   6.49 TO   6.55

STANDARD ERROR FOR VARIABLE 2    215.3195     215.6391     215.9966
VAR  2 ADJ FROM    .27 TO    .29
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   STANDARD ERROR FOR VARIABLE 4    213.8114     213.2518     216.5104
   VAR  4 ADJ FROM     .80 TO    .79

   STANDARD ERROR FOR VARIABLE 7    213.0105     213.2949     214.1404
   VAR  7 ADJ FROM     .50 TO    .50

   STANDARD ERROR FOR VARIABLE 9    213.0105     213.4990     214.9568
   VAR  9 ADJ FROM    2.02 TO   2.02

   STANDARD ERROR FOR VARIABLE10    213.0105     213.0125     213.0186
   VAR 10 ADJ FROM    2.00 TO   2.00

   STANDARD ERROR FOR VARIABLE 1    213.0105     214.0394     215.9268
   VAR  1 ADJ FROM    6.55 TO   6.60

   STANDARD ERROR FOR VARIABLE 2    212.7882     212.9980     213.2512
   VAR  2 ADJ FROM     .29 TO    .30

   STANDARD ERROR FOR VARIABLE 4    212.2116     212.5042     216.4771
   VAR  4 ADJ FROM     .79 TO    .79

   STANDARD ERROR FOR VARIABLE 7    211.8809     212.1560     212.9786
   VAR  7 ADJ FROM     .50 TO    .50

   STANDARD ERROR FOR VARIABLE 9    211.8809     212.3583     213.7872
   VAR  9 ADJ FROM    2.02 TO   2.02

   STANDARD ERROR FOR VARIABLE10    211.8809     211.8830     211.8889
   VAR 10 ADJ FROM    2.00 TO   2.00

   STANDARD ERROR FOR VARIABLE 1    211.8809     212.8845     214.5722
   VAR  1 ADJ FROM    6.60 TO   6.66

   STANDARD ERROR FOR VARIABLE 2    211.8483     212.0075     212.3774
   VAR  2 ADJ FROM     .30 TO    .30

   STANDARD ERROR FOR VARIABLE 4    211.8153     212.8768     217.5215
   VAR  4 ADJ FROM     .79 TO    .79

   STANDARD ERROR FOR VARIABLE 7    211.7356     212.0009     212.8061
   VAR  7 ADJ FROM     .50 TO    .50

   STANDARD ERROR FOR VARIABLE 9    211.7356     212.2065     213.6184

   STANDARD ERROR FOR VARIABLE10    211.7356     211.7377     211.7436
   VAR 10 ADJ FROM    2.00 TO   2.00

   STANDARD ERROR FOR VARIABLE 1    211.7356     211.9457     213.1621
   VAR  1 ADJ FROM    6.66 TO   6.64

                              INFILTRATION INDEX =1.420 IN/HR ( 36 MM/HR)

                                 STRKR FOR RTIOL OF 3. =  .82

                                      OPTIMIZATION RESULTS
                 TC        R     COEF    STRKR    STRKS    RTIOK    ERAIN    FRZTP    DLTKR    RTIOL
                2.32     1.01     .00      .80      .00      .00      .50      .00     2.05     2.00

                UNIT HYDROGRAPH 14 END-OF-PERIOD ORDINATES, LAG=   1.80 HOURS, CP=  .76   VOL= 1.00
       1297.32    4450.04    7820.71    9529.78    8439.00    5729.78    3447.86    2074.72    1248.45    751.25
```

```
       452.06     272.02     163.69      98.50

                                              END-OF-PERIOD FLOW
                PERIOD          TIME    RAIN       EXCS        CUMP Q         OBS Q
                   1         31 16 30    .04        .00           .00           .50
                   2         31 16 60    .28        .00           .00          1.40
                   3         31 17 30    .88        .17        217.56         11.10
                   4         31 17 60    .11        .00        746.25        133.20
                   5         31 18 30    .01        .00       1311.50        992.40
                   6         31 18 60    .00        .00       1598.10       1702.00
                   7         31 19 30    .00        .00       1415.18       1403.30
                   8         31 19 60    .00        .00        960.86        918.80
                   9         31 20 30    .00        .00        578.19        564.70
                  10         31 20 60    .00        .00        347.92        367.70
                  11         31 21 30    .00        .00        209.36        264.90
                  12         31 21 60    .00        .00        125.98        208.00
                  13         31 22 30    .00        .00         75.81        186.90
                  14         31 22 60    .00        .00         45.62        153.40
                  15         31 23 30    .00        .00         27.45        130.00
                  16         31 23 60    .00        .00         16.52        106.50
                  17         32  0 30    .00        .00           .00         87.60
                  18         32  0 60    .00        .00           .00         70.80
                  19         32  1 30    .00        .00           .00         58.30
                  20         32  1 60    .00        .00           .00         47.60
                  21         32  2 30    .00        .00           .00         41.30
                  22         32  2 60    .00        .00           .00         35.10
                  23         32  3 30    .00        .00           .00         28.80
                  24         32  3 60    .00        .00           .00         25.40
                  25         32  4 30    .00        .00           .00         21.90
                  26         32  4 60    .00        .00           .00         18.40
                  27         32  5 30    .00        .00           .00         16.70
                  28         32  5 60    .00        .00           .00         15.20
                  29         32  6 30    .00        .00           .00         14.00
                  30         32  6 60    .00        .00           .00         12.40
                  31         32  7 30    .00        .00           .00         10.90
                  32         32  7 60    .00        .00           .00          9.50
                  33         32  8 30    .00        .00           .00          9.10
                  34         32  8 60    .00        .00           .00          8.70

                                  SUM   1.32        .17       7676.00       7676.50


               THE FOLLOWING INFORMATION IS FOR A TIME BASE
               WHICH IS EQUAL TO 3 TIMES THE LAG FROM THE CENTROID
               OF RF EXCESS TO THE OBSERVED PEAK
                                    -OR-
               WHICH IS EQUAL TO A PERIOD FROM THE CENTROID OF THE
               RF EXCESS TO A RECESSION Q EQUAL TO ONE-HALF THE PEAK Q
                         -WHICHEVER GIVES THE LARGEST TIME BASE


               TIME BASE STARTS AT PERIOD  2, ENDS AT PERIOD  12



            COMPUTED PEAK=   1598.10
            OBSERVED PEAK=   1702.00      PEAK DIFF. (PERCENT)= -6.10

            COMPUTED PEAK LAG=  1.50  HOURS
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OBSERVED PEAK LAG=  1.50  HOURS       TIME DIFFERENCE     .0 HOURS

STANDARD ERROR= 222.255
MEAN FLOW=   597.0
STANDARD ERROR AS A PERCENT OF MEAN=   37.23

AVERAGE ERROR (PERCENT)=  230.19

COMPUTED VOLUME=      7511.
OBSERVED VOLUME=      6567.             VOLUME DIFF. (PERCENT)= 14.36
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             STATION      1             YAOHUANG WU

                           INFLOW(I), OUTFLOW(O) AND OBSERVED FLOW(*)
      0.     200.       400.      600.      800.     1000.     1200.     1400.     1600.     1800.        0.        0.        0.
                                                                                                     PRECIP(L) AND EXCESS(X)
      .0        .0.       .0.       .0.       .0.       .0.       .0.       .0.       .0.      1.2.       .8.       .4.       .0
31 16 30*         .         .         .         .         .         .         .         .         .         .         .        LX
31 16 60*         .         .         .         .         .         .         .         .         .         .         .  LLLLLLLX
31 17 30.*        .I        .         .         .         .         .         .         .         .       LLLLLLLLLLLLLLLLLLXXXXX
31 17 60.      *  .         .         .      I  .         .         .         .         .         .         .         .      LLLX
31 18 30.         .         .         .         .         *         .     I   .         .         .         .         .        L
31 18 60.         .         .         .         .         .         .         .         I    *    .         .         .        L
31 19 30.         .         .         .         .         .         .         *I        .         .         .         .        L
31 19 60.         .         .         .         .     * I .         .         .         .         .         .         .        L
31 20 30.         .         .       *I.         .         .         .         .         .         .         .         .        L
31 20 60.         .      I* .         .         .         .         .         .         .         .         .         .        L
31 21 30.         I  *      .         .         .         .         .         .         .         .         .         .        L
31 21 60.     I   *         .         .         .         .         .         .         .         .         .         .        L
31 22 30.   I    *.         .         .         .         .         .         .         .         .         .         .        L
31 22 60. I     * .         .         .         .         .         .         .         .         .         .         .        L
31 23 30.I     *  .         .         .         .         .         .         .         .         .         .         .        L
31 23 60.I   *    .         .         .         .         .         .         .         .         .         .         .        L
32  0 30I   *     .         .         .         .         .         .         .         .         .         .         .        L
32  0 60I   *     .         .         .         .         .         .         .         .         .         .         .        L
32  1 30I  *      .         .         .         .         .         .         .         .         .         .         .        L
32  1 60I *       .         .         .         .         .         .         .         .         .         .         .        L
32  2 30I *       .         .         .         .         .         .         .         .         .         .         .        L
32  2 60I *       .         .         .         .         .         .         .         .         .         .         .        L
32  3 30I*        .         .         .         .         .         .         .         .         .         .         .        L
32  3 60I*        .         .         .         .         .         .         .         .         .         .         .        L
32  4 30I*        .         .         .         .         .         .         .         .         .         .         .        L
32  4 60I*        .         .         .         .         .         .         .         .         .         .         .        L
32  5 30I*        .         .         .         .         .         .         .         .         .         .         .        L
32  5 60I*        .         .         .         .         .         .         .         .         .         .         .        L
32  6 30I*        .         .         .         .         .         .         .         .         .         .         .        L
32  6 60I*        .         .         .         .         .         .         .         .         .         .         .        L
32  7 30I*        .         .         .         .         .         .         .         .         .         .         .        L
32  7 60*         .         .         .         .         .         .         .         .         .         .         .        L
32  8 30*         .         .         .         .         .         .         .         .         .         .         .        L
32  8 60*         .         .         .         .         .         .         .         .         .         .         .        L
```