NOAA Technical Memorandum NWS WR-158

HYDROLOGY PRACTICUM

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I. INTRODUCTION

In September 1970 one of the most disastrous flash floods ever to occur in Arizona killed 23 people and devastated thousands of dollars of personal property in the Tonto Creek watershed.

Across the United States, this type of scene is repeated all too often: Big Thompson, Rapid City, Johnstown. And with each disaster comes the realization that the hydrologist and meteorologist need to work closely together.

Each needs to know more about each other's discipline. Hydrologists need to understand mesoscale meteorology, while the meteorologist needs to have a knowledge of basic hydrology.

Although meteorologists and meteorological technicians are responsible for issuing the flash-flood watches and warnings, it would be to their benefit if they also understood some basic hydrology.

As an example, let's take a look at Tonto Creek. How high will Tonto Creek rise with 4 inches of precipitation in 2 hours over the headwaters? How long will it take for Tonto Creek above Gun Creek to crest? If Tonto Creek above Gun Creek crests at 43,000 cfs., what stage (or water surface elevation) does this correspond to?

These questions, especially "How long will it take for Tonto Creek above Gun Creek to crest?", are vitally important in flash-flood forecasting.

To this end, I have prepared a short, but challenging practice set to help the meteorologist and meteorological technician better understand basic hydrology. The practice set is based on NOAA Technical Memorandum NWS WR-136.

II. UNIT HYDROGRAPH DERIVATION

1. Using the mean daily discharge data for February 8-13 for Tonto Creek above Gun Creek (Table 1) and the hourly precipitation data for Payson in Table 2:

   a. Determine the duration of effective rainfall using the hourly precipitation data for Payson. For the purpose of this exercise, rounding the effective duration to the nearest 6 hours is sufficient. The computed unit hydrograph will then be a unit hydrograph for the specified storm duration. For example, a 6-hour effective rainfall duration will result in a 6-hour unit hydrograph.

   b. Sketch in the storm hydrograph using the information provided on Figure 1. Using the mean daily discharge data the concept of equal areas above and below the mean daily discharge applies for a given day.

   c. Derive the unit hydrograph. Table 3 is provided for computations. Figure 2 is provided for graphic display.

   d. Assuming a storm where the mean basin precipitation is 6.4" and the duration of effective rainfall is approximately equal to the duration of effective rainfall for the unit hydrograph, in how many hours would you expect Tonto Creek above Gun Creek to crest?

   e. Assuming a storm where the mean basin precipitation is 6.4" and the effective duration is significantly shorter than the duration of the unit hydrograph, what will be the effect on the timing of the flood crest?

09499000. TONTO CREEK ABOVE GUN CREEK, NEAR ROOSEVELT, ARIZ.

LOCATION.--Lat 33°58'48", long 111°18'10", in SW¼NE¼ sec.2, T.7 N., R.10 E., Gila County, in Tonto National Forest, on left bank 600 ft (183 m) upstream from Gun Creek, 17 mi (27 km) upstream from high-water line of Roosevelt Lake, and 24 mi (39 km) northwest of Roosevelt.

DRAINAGE AREA.--675 mi^2 (1,750 km^2).

PERIOD OF RECORD.--December 1940 to current year.

GAGE.--Water-stage recorder. Datum of gage is 2,523.14 ft (769.053 m) above mean sea level.

AVERAGE DISCHARGE.--35 years (1941-76), 115 ft^3/s (3.257 m^3/s), 83,320 acre-ft/yr (103 hm^3/yr); median of yearly mean discharges, 83 ft^3/s (2.35 m^3/s), 60,100 acre-ft/yr (74 hm^3/yr).

EXTREMES.--Current year: Maximum discharge, 34,900 ft^3/s (988 m^3/s) Feb 9 (gage height, 15.10 ft or 4.602 m); minimum daily, 3.6 ft^3/s (0.10 m^3/s) July 9, 10.
Period of record: Maximum discharge, 53,000 ft^3/s (1,500 m^3/s) Sept. 5, 1970 (gage height, 18.2 ft or 5.55 m), from rating curve extended above 27,000 ft^3/s (765 m^3/s) on basis of slope-area measurement of peak flow; no flow at times.

REMARKS.--Records good. Small diversions above station for irrigation.

REVISIONS.--WSP 1283: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	6.2	9.7	30	26	17	91	60	73	16	7.2	37	10
2	6.2	8.7	25	22	18	96	63	65	15	7.2	21	9.3
3	5.4	9.7	26	22	18	97	63	60	14	7.2	15	8.5
4	5.4	9.2	28	23	36	124	65	97	14	6.0	12	8.5
5	5.4	8.2	24	23	2500	104	70	124	13	6.0	7.2	23
6	5.8	7.8	22	23	2630	104	68	97	13	5.4	6.6	58
7	7.0	8.7	18	23	955	110	53	88	13	4.8	6.0	28
8	5.4	11	21	21	385	118	53	85	13	4.0	6.0	24
9	5.8	13	20	20	11000	110	51	73	12	3.6	6.0	16
10	6.2	13	20	21	3740	110	53	63	12	3.6	6.0	16
11	7.8	12	19	20	1380	110	51	46	12	4.4	6.0	17
12	7.4	10	19	19	693	114	48	42	12	10	6.0	18
13	6.6	13	21	18	467	104	48	41	12	7.2	5.4	15
14	7.4	13	37	17	437	85	60	35	12	6.0	5.4	12
15	7.0	14	51	17	379	82	85	32	12	4.0	4.8	11
16	7.8	14	35	14	361	79	401	28	12	5.4	4.4	11
17	8.7	12	30	14	286	82	373	30	12	6.6	4.0	9.3
18	7.8	12	27	16	230	88	303	32	11	11	4.0	7.8
19	8.2	13	26	16	184	97	492	32	11	8.5	4.4	7.2
20	10	14	24	16	159	114	550	73	11	18	4.4	6.6
21	12	14	141	16	135	104	520	53	11	17	4.8	7.8
22	13	14	211	17	110	85	471	44	10	14	5.4	8.5
23	12	14	108	18	97	82	379	33	10	15	6.0	10
24	11	15	70	19	85	88	276	30	9.3	89	12	56
25	11	14	53	22	73	104	211	27	8.5	32	12	155
26	10	13	42	22	70	107	167	24	7.8	41	9.3	495
27	10	12	37	20	70	97	143	24	7.2	26	9.3	276
28	9.2	32	33	21	70	88	118	22	7.2	24	9.3	107
29	9.7	70	30	21	73	85	104	20	7.8	71	9.3	58
30	10	42	27	20	---	76	85	17	7.2	128	9.3	41
31	10	---	27	18	---	65	---	16	---	39	10	---
TOTAL	255.4	466.0	1302	605	26658	3000	5484	1526	338.0	632.1	268.3	1530.5
MEAN	8.24	15.5	42.0	19.5	919	96.8	183	49.2	11.3	20.4	8.65	51.0
MAX	13	70	211	26	11000	124	550	124	16	128	37	495
MIN	5.4	7.8	18	14	17	65	48	16	7.2	3.6	4.0	6.6
AC-FT	507	924	2580	1200	52880	5950	10880	3030	670	1250	532	3040

CAL YR 1975 TOTAL 27280.4 MEAN 74.7 MAX 1180 MIN 2.9 AC-FT 54110
WTR YR 1976 TOTAL 42065.3 MEAN 115 MAX 11000 MIN 3.6 AC-FT 83440

PEAK DISCHARGE (BASE, 1,700 CFS)

DATE	TIME	G. H.	DISCHARGE	DATE	TIME	G. H.	DISCHARGE
2-5	1445	9.03	5,120	2- 9	1600	15.10	34,900 – *Peak Discharge
2-6	1830	8.48	3,440	9-26	0630	6.30	1,940

Table 1. Discharge Data for Tonto Creek above Gun Creek near Roosevelt, Arizona

Table 2. Rainfall - February 1976

Daily Reports

	8th	9th	10th	Time of Observation
Gisela		2.00		6 p.m.
Payson 12 NNE	.10	2.38	.37	SS
Payson RS 2	.06	2.15	.07	5 p.m.
Payson	.05	1.85	.10	5 p.m.
Pleasant Valley RS		1.62		5 p.m.
Tonto Creek FH		1.13	1.55	7 a.m.

Hourly Precipitation

		1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
FLG	a.m.	.06	.09	.08	.15	.17	.25	.21	.17	.15	.19	.20	.16	
(9th)	p.m.	.01			.03									2.07
Payson	a.m.	.1			.1		.2	.2	.2	.2	.2	.1	.2	
	p.m.	.2	.1											1.80
Workman Creek 1	a.m.		.1				.1		.1	.1	.1	.2	.2	
(9th)	p.m.	.4	.2	.1	.3	.2	.1							2.20

Table 3. Unit Hydrograph Computations

for Tonto Creek above Gun Creek

Local Time	Date	Q (CFS)	Base Flow	Direct Runoff	Unit Hydrograph Ordinates	= Direct Runoff/ Runoff (Inches)
03	2/9/76					
06						
09						
12						
15						
18						
21						
24						
03	2/10/76					
06						
09						
12						
15						
18						
21						
24						
03						
06						
09						
12						
15						
18						
21						
24						
03	2/12/76					
			$\Sigma =$			

$$\frac{\Sigma \text{ Direct Runoff}}{8} = \text{"A"}$$

$$\text{Runoff (Inches)} = \frac{\text{"A"}}{(695)(26.9)} =$$

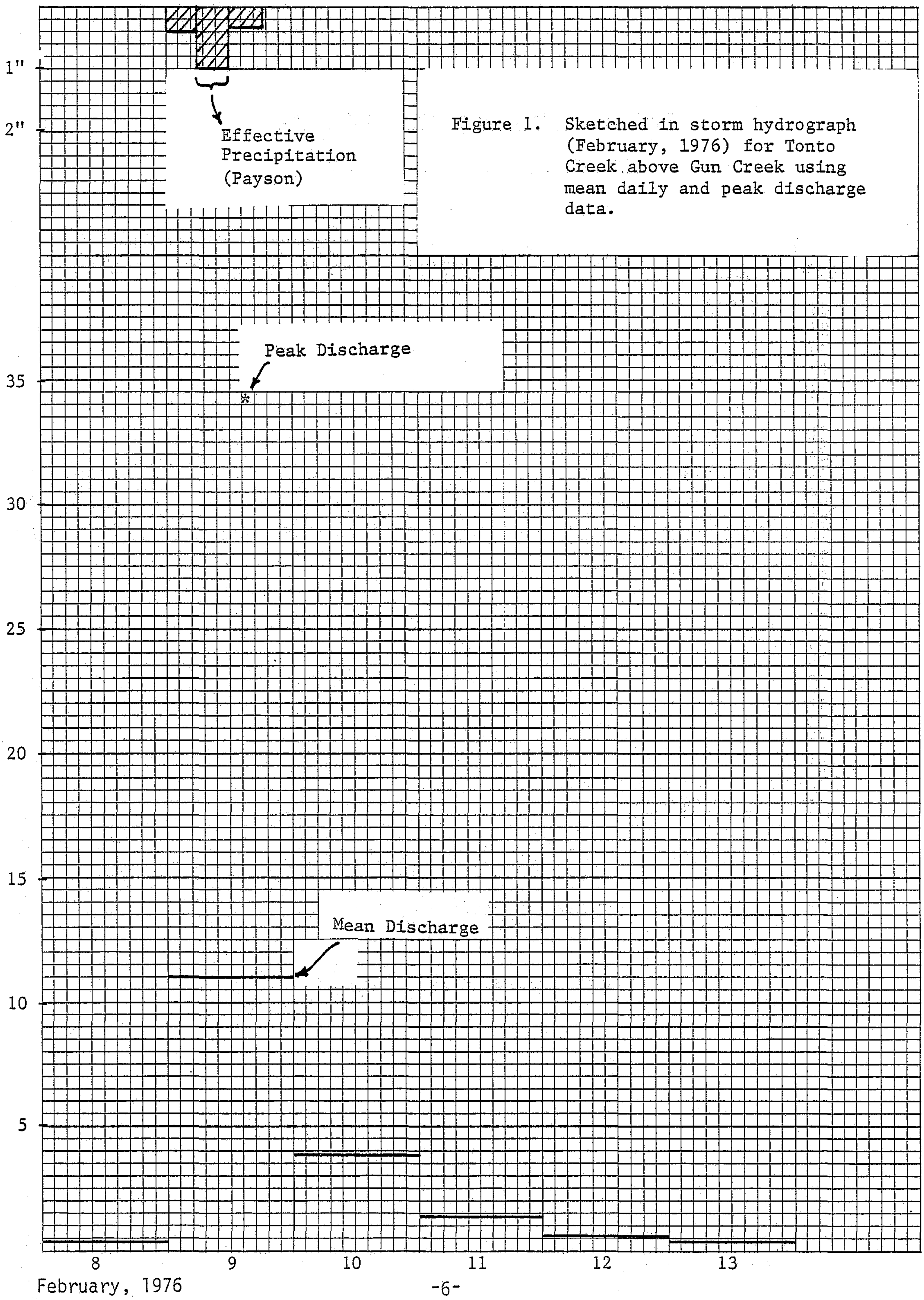


Figure 1. Sketched in storm hydrograph (February, 1976) for Tonto Creek above Gun Creek using mean daily and peak discharge data.

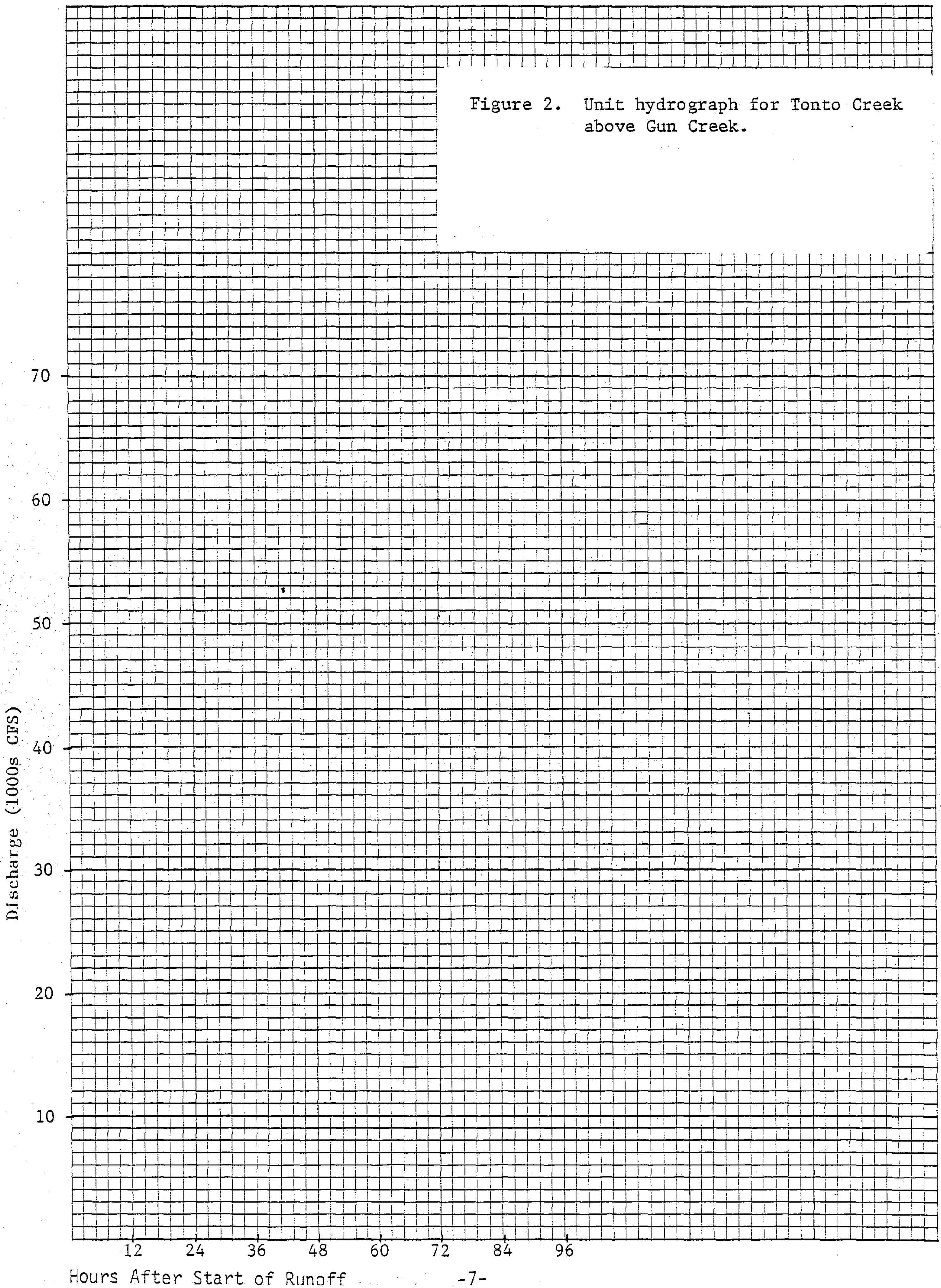


Figure 2. Unit hydrograph for Tonto Creek above Gun Creek.

III. DERIVATION AND APPLICATION OF AREA-ELEVATION CURVE

1. Using the USGS topographic map (Figure 3):

   a. Derive the area-elevation curve for Tonto Creek above Gun Creek (Ref. Section IV.1, Basic Hydrologic Principles, 1979).

   b. Plot on Figure 4.

2. From the area-elevation curve, the percent contributing area can be determined by knowing the melting level. Generally, the melting level is assumed to be 1,000 feet lower than the freezing level.

   Assuming a freezing level of 6,500', what is:

   a. The melting level?

   b. Percent contributing area?

IV. DERIVATION OF A RATING CURVE

1. Using gage height and discharge data (Table 1 and Table 4):

   a. Develop a rating curve by plotting the stage and discharge data on Figure 5.

   Source of data: USGS. "Water Resources Data for Arizona."
   A rating curve can also be obtained from the local USGS office.

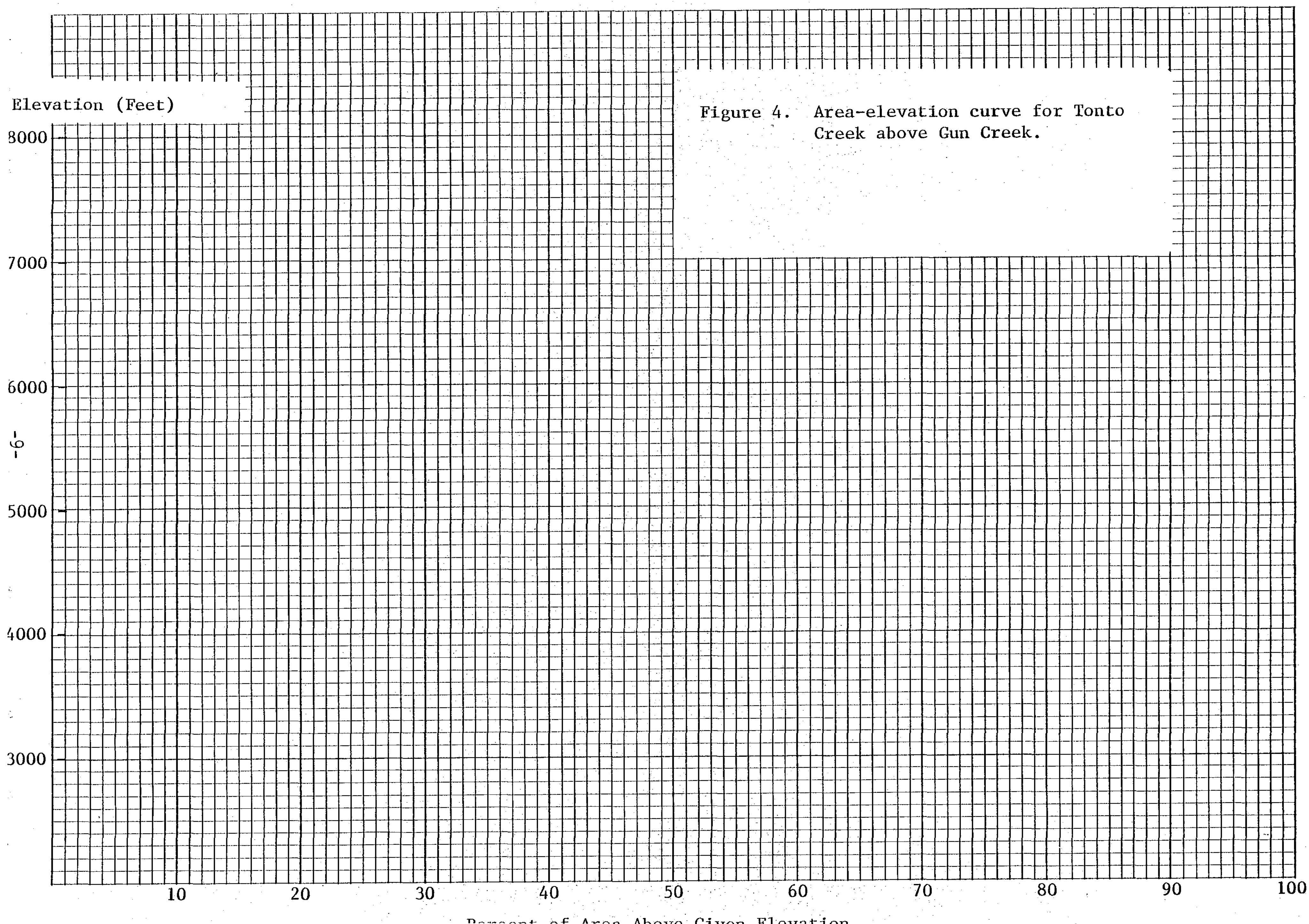


Figure 4. Area-elevation curve for Tonto Creek above Gun Creek.

Table 4. Discharge and Gage Height Data for Tonto Creek Above Gun Creek

Date	Time	Gage Ht.	Dischg.	Date	Time	Gage Ht.	Dischg.
1/ 6/65	2200	9.70	12,200	6/22/72	1300	6.14	2,020
1/ 7/65	1830	9.91	12,900	9/ 2/72	1900	6.20	2,100
3/13/65	2100	6.98	2,670	10/ 7/72	0200	8.88	8,580
4/10/65	1900	7.85	3,980	10/19/72	1230	16.00	39,800
8/17/65	0500	6.43	1,720	11/16/72	1030	8.08	6,390
9/ 2/65	1000	6.21	2,060	12/28/72	1400	11.00	16,800
11/25/65	2100	7.35	4,060	2/12/73	0800	7.69	4,680
12/10/65	0600	11.20	18,200	2/22/73	0700	8.50	6,300
12/22/65	2100	16.70	44,700	3/16/73	2130	8.75	5,800
12/30/65	1100	12.40	22,100	3/30/73	2030	9.45	7,270
				5/ 5/73	1800	8.60	5,400
7/25/70	0030	7.35	2,990				
9/ 5/70	2100	18.20	53,000	1/21/74	1130	7.98	2,940
				8/ 6/74	2400	8.20	3,800
8/ 9/71	1800	7.65	5,280				
10/17/71	1200	6.03	2,070	2/ 5/76	1445	9.03	5,120
10/25/71	2000	6.36	2,440	2/ 6/76	1830	8.48	3,440
12/26/61	2330	6.44	2,600	2/ 9/76	1600	15.10	34,900
				9/26/76	0630	6.30	1,940

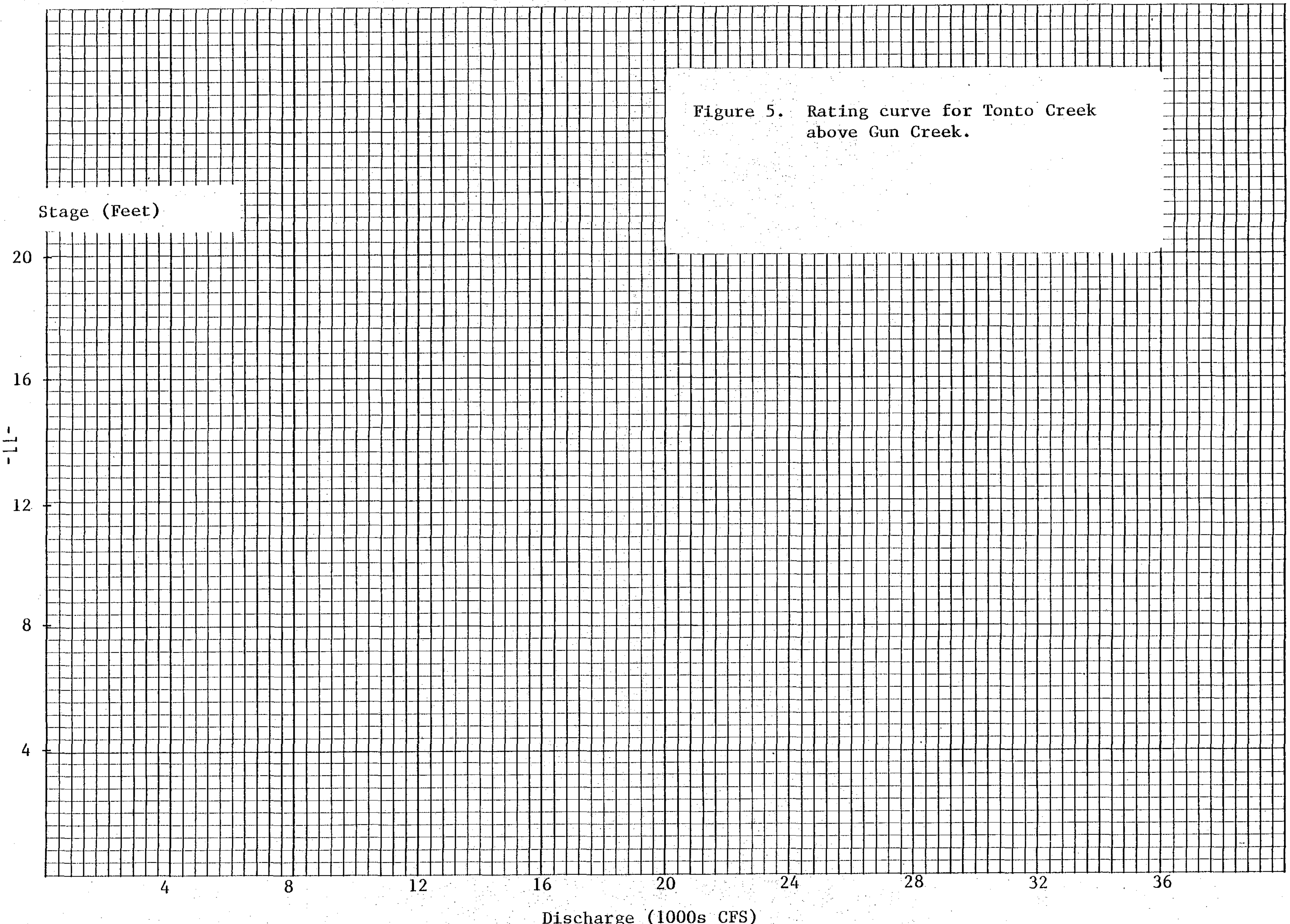


Figure 5. Rating curve for Tonto Creek above Gun Creek.

V. PRECIPITATION AND RUNOFF ANALYSES OF SEPTEMBER 1970 STORM

1. Using the Arizona normal annual precipitation map (Figure 6):

   a. Determine the basin normal annual precipitation (BNAP) for the Tonto Creek watershed above Gun Creek.

   Storm precipitation in mountainous areas tends to conform to the normal annual isohyetal pattern. Storm precipitation values at each station can be expressed in percent of its annual normal (% NAP) and the station percentage values averaged for the basin (B% NAP). The basin normal annual precipitation (BNAP) multiplied by the storm percent value (B% NAP) provides a basin average storm precipitation (BASP).

   b. Using the hourly precipitation data for the September 1970 storm (Table 5) determine for each station the percent of its annual normal precipitation (% NAP). Do this for each 6-hour period and the 24-hour total. Enter calculations on Table 6.

   c. Determine the 6-hour (6 $\overline{AVG}_{1-n}$) averages and the storm total (B% NAP) average for the station percent normal values (% NAP). Table 6 is provided for calculations. Also enter values for 6 $\overline{AVG}_{1-n}$ on line 5, Table 7 and B% NAP on line 4, Table 7.

   d. Calculate the 6 hourly precipitation (inches) by multiplying the 6 hourly percent normal averages (6 $\overline{AVG}_{1-n}$) by the basin normal annual precipitation (BNAP). Enter calculations on line 6, Table 7.

   e. Determine the 6 hourly runoff amounts (inches) by multiplying the percent rainfall expected to run off (% RO) by the 6 hourly precipitation. For this example, the % RO is supplied on line 3, Table 7. Enter on line 7, Table 7.

   f. Determine the runoff adjusted for contributing area (ADJRO) by multiplying the 6 hourly runoff determined in (e) by the % contributing area. Enter on line 8, Table 7.

   g. If necessary, add in a little runoff to take care of snowmelt and any forecast runoff. If the storm happens to be a rain-on-snow event some additional runoff will have to be added to take care of the melting snow. At the same time it might be felt that additional runoff is going to occur in a future period. If this is the case, a small amount of runoff can be added to the forecast. Enter on line 9, Table 7.

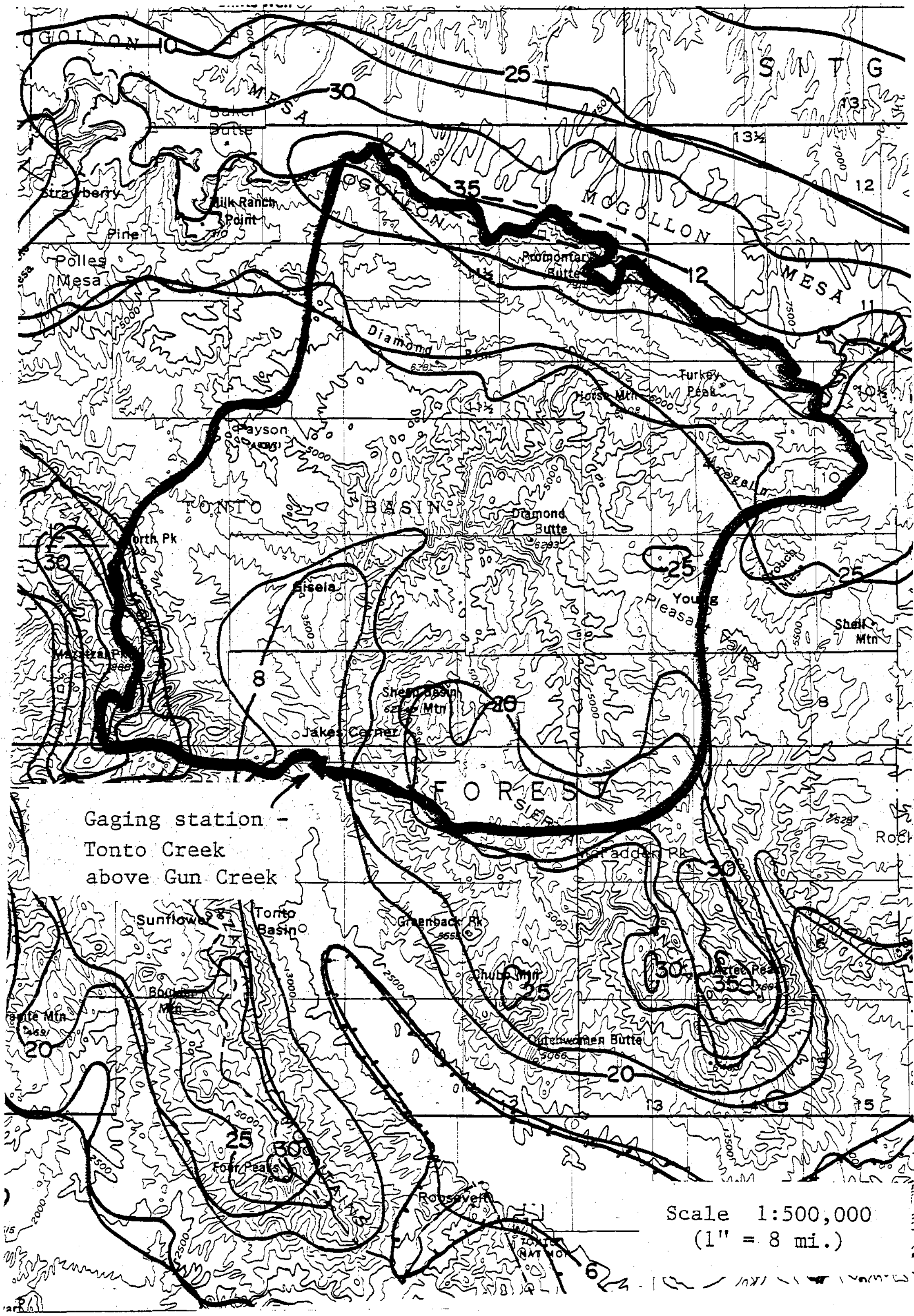


Figure 6. Normal annual precipitation -
Tonto Creek above Gun Creek basin.

Table 5. Rainfall Data - September 1970, Tonto Creek Flood

Hourly Precipitation (February 5, 1976)

		1	2	3	4	5	6	7	8	9	10	11	12
FLG	a.m.	.02	.01	.06	.10	.11	.15	.02	.20	.62	.30	.25	.12
(5th)	p.m.	.53	.28	.05		.02							
Payson	a.m.		.4	.4	.3	.1		.1		.1	.2	.2	.2
(5th)	p.m.	.2	.1	.2	.8	1.7	.6	.4	.1	.1			
Workman Creek 1	a.m.	.18	.31	.05	.35	.43	.39	.16	.22	1.05	1.20	.82	.51
(5th)	p.m.	.42	.95	.17	.46	.63	.42	.79	.71	.55	.17	.03	.02

Table 6. Precipitation Analysis
(Tonto Creek Above Gun Creek)

Station	Avg. Annual Ppt.	Storm Precipitation 5/06	/12	/18	/24	Total	Percent of Normal Annual Precipitation (% NAP) 5/06	/12	/18	/24	Total
Flagstaff	19.3										
Payson	20.7										
Workman Creek 1	22.5										

$6\overline{AVG}_1 =$

$6\overline{AVG}_2 =$

$6\overline{AVG}_3 =$

$6\overline{AVG}_4 =$

$\Sigma =$

$\Sigma/3 = B\%\ NAP =$

Basin Normal Annual Precipitation (BNAP) = ______

Basin Avg. Storm Precipitation (BASP) = BNAP X B% NAP

= ____ X ____

= ____

h. Determine the actual runoff (TOTRO) by summing lines 8 and 9, Table 7.

NOTE: Determining the percent runoff (% RO) is the most difficult part of making a headwater forecast. This is because runoff is a function of the soil moisture conditions as well as the rainfall amount, duration, intensity and distribution.

During a prolonged storm event of several days the amount of precipitation that will occur as runoff will increase with time as the soil moisture increases.

Table 7. Runoff Computations (Tonto Creek Above Gun Creek)

	6-Hour Periods	Date: Sept. 5, 1970 5/06	/12	/18	/24	
1)	Melting Level					
2)	Contributing Area (%)					
3)	Total RO (%) - Subjective	8	41	34	1	
4)	24-hour Precipitation (% Normal)					
5)	6-hourly Precipitation (% Normal) (BNAP = ___)					Sum should equal 24-hour Precipitation (Line 4)
6)	Period Precipitation (Inches)					
7)	Period Runoff (L3 X L6)					
8)	RO Adj. for contributing area (L2 X L7)					
9)	RO Including Snowmelt and Forecast					
10)	Actual RO (TOTRO)					
11)	Base Flow (1000 CFS)					
12)	Unit					
13)	Graph (1000 CFS)					
14)	Ordinates					

Peak Discharge = ________

Crest Stage = ________ (From Rating Curve)

Note: Unit graph ordinates are calculated by mulitplying the unit graph values by the actual runoff (TOTRO) for each 6-hourly period.

VI. UNIT HYDROGRAPH AND RATING CURVE APPLICATIONS

1. a. Convert 6 hourly runoff (inches) to discharge (CFS) by using the unit hydrograph. Since the unit hydrograph, as derived, is normalized to 1" of runoff, multiply the ordinates of the unit hydrograph by the total runoff in each period, then sum to arrive at the forecast hydrograph. Enter calculations on Table 7. (Make sure that the runoff, derived by applying the unit graph, begins in the period when the rainfall excess occurs. See examples, Table 8). Make some estimate of the base flow and enter on line 11. See example, Table 8.

   b. Plot the forecast and observed hydrograph on Figure 7.

   You will notice a considerable difference between the forecast and observed hydrographs. There are reasons for this: 1) We are using only a 6-hour unit hydrograph and 6 hourly rainfall which produce a "smoothed" forecast. If, by converting to a 3-hour unit hydrograph and using 3 hourly rainfall, we could have generated a better forecast. 2) Also, in generating the forecast hydrograph we used mean basin precipitation which disregards, for the most part, variations in intensity and distribution. These variations can have a significant influence on the hydrograph, especially during short-duration, high-intensity storms.

2. Convert the peak discharge to the crest stage by entering the rating curve with the peak discharge.

Table 8. Runoff Calculations, Skookumchuck River Near Centralia, WA

6-Hour Periods Date ( )	06	12	18	24	06	12	18	24
1) Melting Level	5000							
2) Contributing Area (%)	100	100	100					
3) Total RO (%) - RFC	55	70	60					
4) 24-Hour Precipitation (% N)				4				
5) Period Precipitation (% N) (N = 70)	1	2	1					
6) Period Precipitation (Inches)	.70	1.40	.70					
7) Period Runoff (L3 X L6)	.38	.77	.39					
8) RO Adj. for CA (L2 X L7)	.38	.77	.39					
9) RO Incl. Snowmelt								
10) Actual RO	.38	.77	.39					
11) Base Flow	.10	.10	.10	.10	.10	.10	.10	.10
12) Unit Graph)	.06	.36	.77	1.00	1.00	.88	.72	.57
13) Ordinates)		.12	.80	1.78	2.30	2.23	1.84	1.41
Runoff (1000's CFS)			.06	.36	.77	1.00	1.00	.88
	.16	.58	1.73	3.24	4.17	4.21	3.66	2.96

Corresponding Stage

For Peak Discharge (4210 CFS)

= 81.8'

VII. ADDITIONAL QUESTIONS AND PROBLEMS

1. In general, what effect do levees have on flood waves as they pass through a levee system? Why?

2. Derive a crest-stage relation for the Verde River near Clarkdale vs. Verde River below Tangle Creek, using the data in Table 9. Plot on Figure 7. Why is there so much scatter?

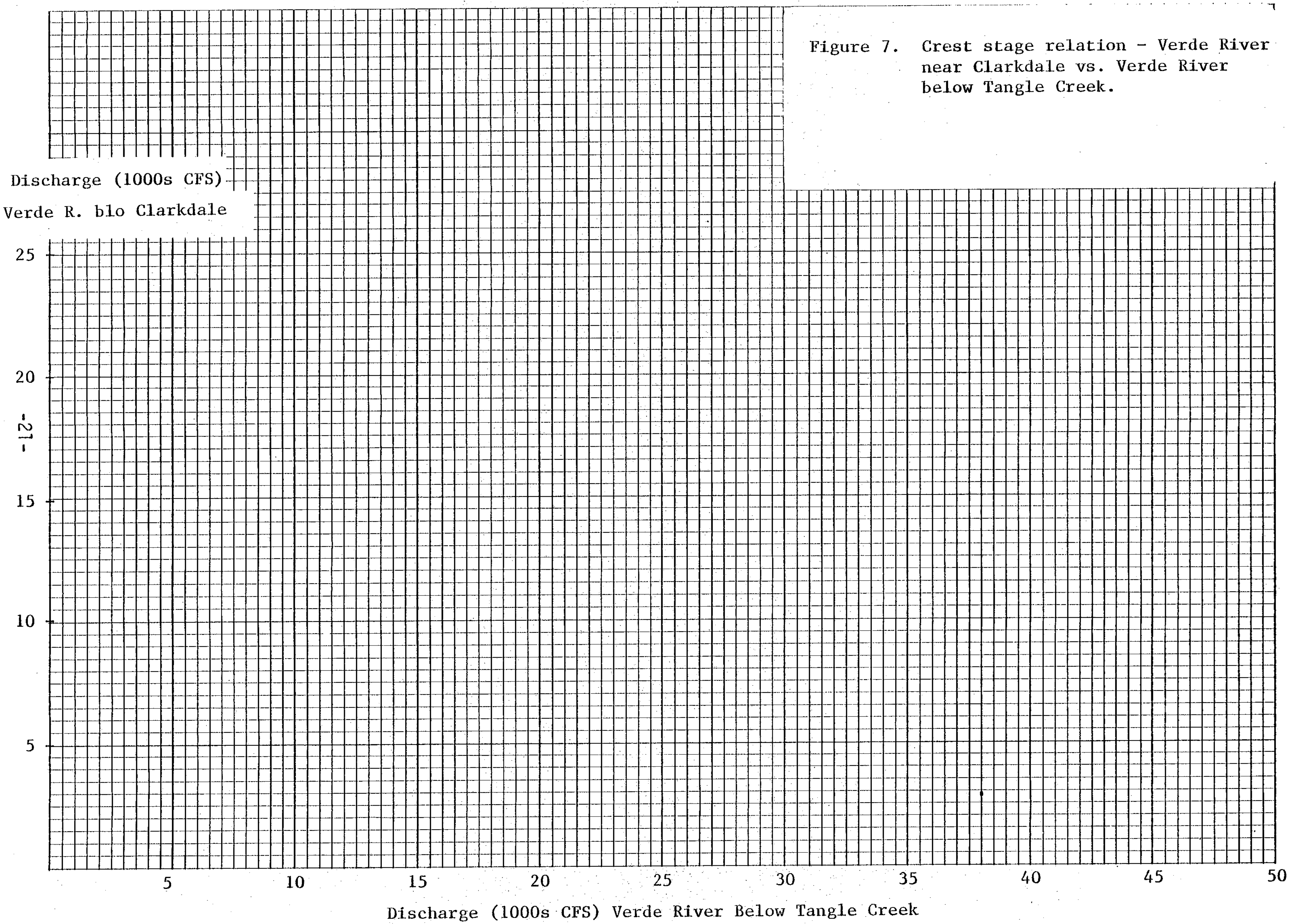
3. Derive travel time and the time of concentration as described in Section V, Basic Hydrologic Principles (NOAA TM NWS WR-136), for the East Verde River above the confluence with the Verde River. Although travel time and time of concentration are not the same, how do the results compare?

4. Although Section 6, Basic Hydrologic Principles (NOAA TM NWS WR-136) lists some meteorological parameters found by Maddox and Chappel to be common to flash flood events, what do you, as a forecaster, look for?

Table 9. Peak Discharge Data
(Verde River Near Clarkdale and Verde River Below Tangle Creek)

Clarkdale				Below Tangle Creek			
Date	Time	Gage Ht.	Peak Dischg.	Date	Time	Gage Ht.	Peak Dischg.
4/17/65	2330	8.70	7,040				
11/25/65	1530	11.50	11,200	11/26/65	0700	15.94	31,400
12/10/65	0700	12.39	12,900	12/11/65	0300	15.00	25,600
12/23/65	1400	6.90	3,810				
12/30/65	1100	11.70	11,600	12/31/65	0530	15.58	31,600
3/15/66	0130	5.26	2,070	3/15/66	1900	9.57	5,870
7/29/71	2000	5.65	2,300				
7/31/71	2045	6.99	3,930				
8/13/71	0730	5.56	2,240				
8/25/71	1845	6.48	3,280				
12/26/71	1030	9.17	7,540	12/27/71	0130	14.20	21,100
8/13/72	0145	8.36	6,260				
10/ 7/72	1130	5.89	14,000	10/ 7/72	0900	13.50	16,700
10/19/72	1030	12.50	14,000	10/20/72	0600	19.00	63,400
12/28/72	1815	5.25	2,320	12/28/72	2000	15.05	27,100
3/29/73	2315	4.99	2,050	4/ 1/73	0700	11.00	8,250
7/ 7/74	2115	6.10	3,160				
7/19/74	2045	5.98	3,020				
9/26/74	Unk.	6.70	3,960				
2/ 9/76	1500	14.10	18,000	2/10/76	0600	17.00	39,900
4/21/76	0115	5.34	2,310	4/21/76	1030	10.52	6,520

Figure 7. Crest stage relation - Verde River near Clarkdale vs. Verde River below Tangle Creek.



102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, October 1975. (PB-246-902/AS)
103 Application of the National Weather Service Flash-Flood Program in the Western Region. Gerald Williams, January 1976. (PB-253-053/AS)
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