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Study of flood hydrographs for small drainage basins in Wyoming--Progress report

by

G.S. Craig, Jr., D.L. Collins, and J.F. Wilson, Jr.

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Contents

	Page
Abstract	7
Introduction	9
Progress toward objectives	10
Parameters	14
Parameter delineation	14
Physical parameters	15
Runoff parameters	22
Hydrograph analysis	26
Discharge hydrographs	26
Comparison with Commons dimensionless hydrograph	30
Development of mean dimensionless hydrograph	41
Hydrologic analysis	48
Peak discharge, runoff volume, and precipitation	48
Peak discharge and runoff volume	49
Precipitation and peak discharge	54
Precipitation and runoff volume	59
Synthetic frequency of runoff events	59
Summary	66
References	67
Appendix	68

Illustrations

Page

Figure 1. Flow diagram showing progress of program as of April 1968-- 11

2. Index map of Wyoming showing the locations of 49 small basins studied-- 12

3. Graph showing comparison of computed basin-slope indexes-- 17

4. Graph showing correlation of basin-slope index and maximum basin relief---------------------------------- 19

5. Graph showing variation of channel-shape factors------- 21

6. Contrasts in observed hydrographs--------------------- 27

7. Simplification of a complex hydrograph----------------- 29

8. Original and modified Commons dimensionless hydrograph- 31

9-16. Comparison of synthetic and observed hydrographs.

9. McKenzie Draw tributary near Casper, Wyo., for peak of August 20, 1965----------------------- 33

10. McKenzie Draw tributary near Casper, Wyo., for peak of June 15, 1967------------------------- 34

11. Lance Creek tributary near Lance Creek, Wyo., for peak of July 2, 1966-------------------------- 35

12. Lance Creek tributary near Lance Creek, Wyo., for peak of June 10, 1965------------------------- 36

13. Seven L Creek near Edgerton, Wyo., for peak of June 10, 1965--------------------------------- 37

14. Seven L Creek near Edgerton, Wyo., for peak of July 5, 1965---------------------------------- 38

Page

Figure 15. Third Sand Creek near Medicine Bow, Wyo., for peak of September 9, 1967---------------------- 39

16. Third Sand Creek near Medicine Bow, Wyo., for peak of August 7, 1967------------------------- 40

17. Actual runoff hydrograph, Dugout Creek, May 23, 1965---- 43

18. Conversion table and resulting dimensionless hydrograph, Dugout Creek, May 23, 1965--------------- 44

19. Dimensionless hydrographs for North Prong East Fork Nowater Creek near Worland, Wyo.--------------------- 45

20. Dimensionless hydrographs for Pritchard Draw near Lance Creek, Wyo.------------------------------------ 46

21. Comparison of mean dimensionless hydrographs------------ 47

22-25. Graphs showing relation of peak discharge to volume.

22. McKenzie Draw tributary near Casper, Wyo.-------- 50

23. Nowood River tributary No. 2 near Basin, Wyo.---- 51

24. Pritchard Draw near Lance Creek, Wyo.------------ 52

25. Medicine Bow River tributary near Hanna, Wyo.---- 53

26-29. Graphs showing relation of precipitation to volume and to peak discharge.

26. McKenzie Draw tributary near Casper, Wyo.-------- 55

27. Nowood River tributary No. 2 near Basin, Wyo.---- 56

28. Medicine Bow River tributary near Hanna, Wyo.---- 57

29. Pritchard Draw near Lance Creek, Wyo.------------ 58

30. Frequency curves of rainfall depth and duration--------- 61

31. Graph showing relation of precipitation to peak discharge--- 62

32. Synthetic flood-frequency curve------------------------- 63

Tables

Page

Table 1. Rainfall, runoff, and lag times for selected storms on North Prong East Fork Nowater Creek near Worland--- 23

2. Point precipitation, in inches, near middle of Washakie County (near North Prong East Fork Nowater Creek), from USWB Technical Paper 40------------------------- 64

3. Rainfall and runoff data for synthetic flood-frequency relation for North Prong East Fork Nowater Creek near Worland-- 64

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Abstract

A continuing study of drainage basins smaller than 11 square miles in Wyoming is directed toward defining the characteristic shape of flood hydrographs in relation to physical characteristics of the basins and toward defining the magnitude and frequency of flood volumes. All streams in this study are normally dry and summer runoff is a direct result of rainfall. Rainfall-runoff data have been collected seasonally (May-October) for 3 years (1965-67) in 49 basins. The primary instrument on each basin simultaneously records the stage hydrograph of runoff and the rainfall associated with it.

Studies of physical parameters--drainage area, channel-slope index, basin-slope index, basin length, average width, and channel-shape factor--did not develop meaningful relationships among them. An interesting result of these studies was that basin-slope index could be computed using contour lines of large interval with little loss in accuracy and with a great saving in time. A comparison of 18 basins showed that measuring 100-foot contour lines rather than 20-foot contour lines gave results within 20 percent of an equal-slope line and 15 of these basins gave results within 10 percent of the line.

Studies of runoff parameters such as hydrograph rise time and hydrograph shape are more encouraging than those of physical parameters. Hydrograph shape was studied using Commons dimensionless hydrograph and a modified version of the Commons hydrograph. Synthetic hydrographs produced using these methods compare well with actual hydrographs. Mean dimensionless hydrographs were developed for several individual basins based on Commons' procedure. Actual discharge hydrographs for a basin were converted to dimensionless form and a mean dimensionless hydrograph was obtained by averaging individual points.

A synthetic flood-frequency curve for one drainage basin was developed from the U.S. Weather Bureau (1961) atlas of rainfall depths, durations, and frequencies and the relation of peak discharge to rainfall for the station.

Introduction

The inflow-hydrograph research project, a study of 49 small drainage basins in Wyoming, was begun in April 1964. This project is financed by the Wyoming State Highway Commission. The area of this investigation (excluding mountainous areas) is semiarid, and runoff events are infrequent. Floods on these small drainage areas (less than 11 square miles) are generally the result of thunderstorms during the summer months. A gaging station on each basin is equipped with an instrument to record both stream stage and rainfall (referred to as an S-R gage). A similar instrument to record rainfall only (an R gage) is located near the drainage divide at the upper end of most of the basins. One or two non-recording storage-type rain gages are located at other points near the divide on each basin to supplement the rainfall data. The instruments were received and installed early in 1965, and data have been collected for the summer seasons of 1965, 1966, and 1967. The project has reached the point where an assessment is required to determine whether results are leading toward success in meeting the project objectives.

The objectives of the study are to:

(1) Define the magnitude and frequency of flood volumes to be expected from small drainage areas in Wyoming.

(2) Define the characteristic shape of flood hydrographs in relation to the physical characteristics of the basin.

(3) Develop a rational method of accounting for the effect of embankment storage (ponding behind highway embankments) which will be useful in culvert design.

This report describes the progress of the study to April 1968 in light of the stated objectives. Parameters investigated are described, analyses of data are explained, and methods of analysis and their relation to objectives are discussed.

The flow diagram shown in figure 1 is intended to illustrate how the elements of the investigation are related. The diagram also serves as an outline of the topics discussed in this report.

Progress toward objectives

An index map of Wyoming (fig. 2) shows the location of the drainage basins being studied for this project.

There is no attempt to report conclusions in this report. The progress of the study is limited by the data available on each drainage basin. Stage-discharge relations have been developed for approximately one-third of the basins. Selected physical characteristics have been determined only for those basins covered by detailed topographic maps. Hydrograph analysis and runoff-parameter studies have been made for the basins, but are restricted by the number of medium-to-high runoff events.

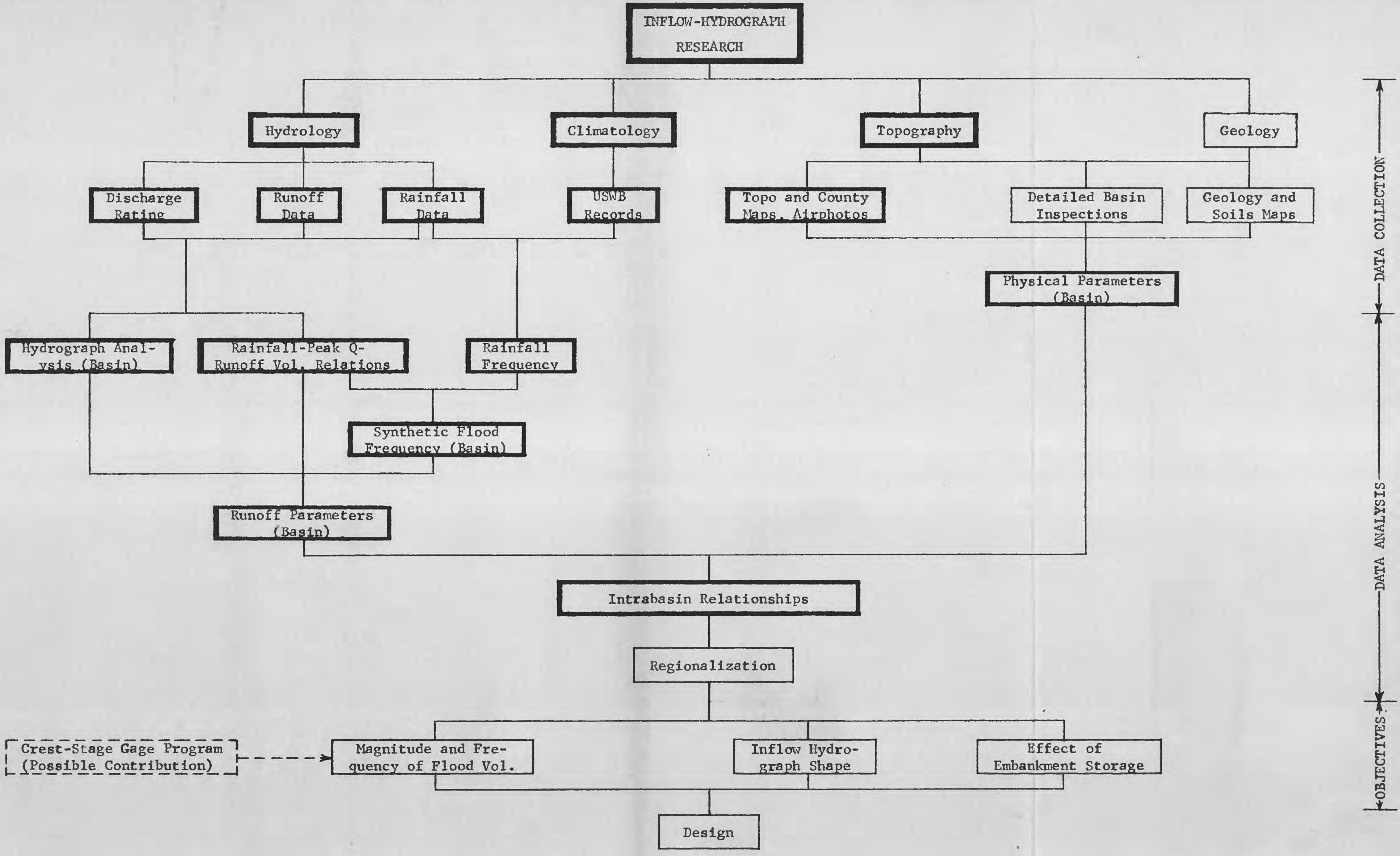

Figure 1.--Diagram showing progress of program as of April 1968. Heavy lines indicate subjects investigated (in varying degrees) to date and discussed in this report.

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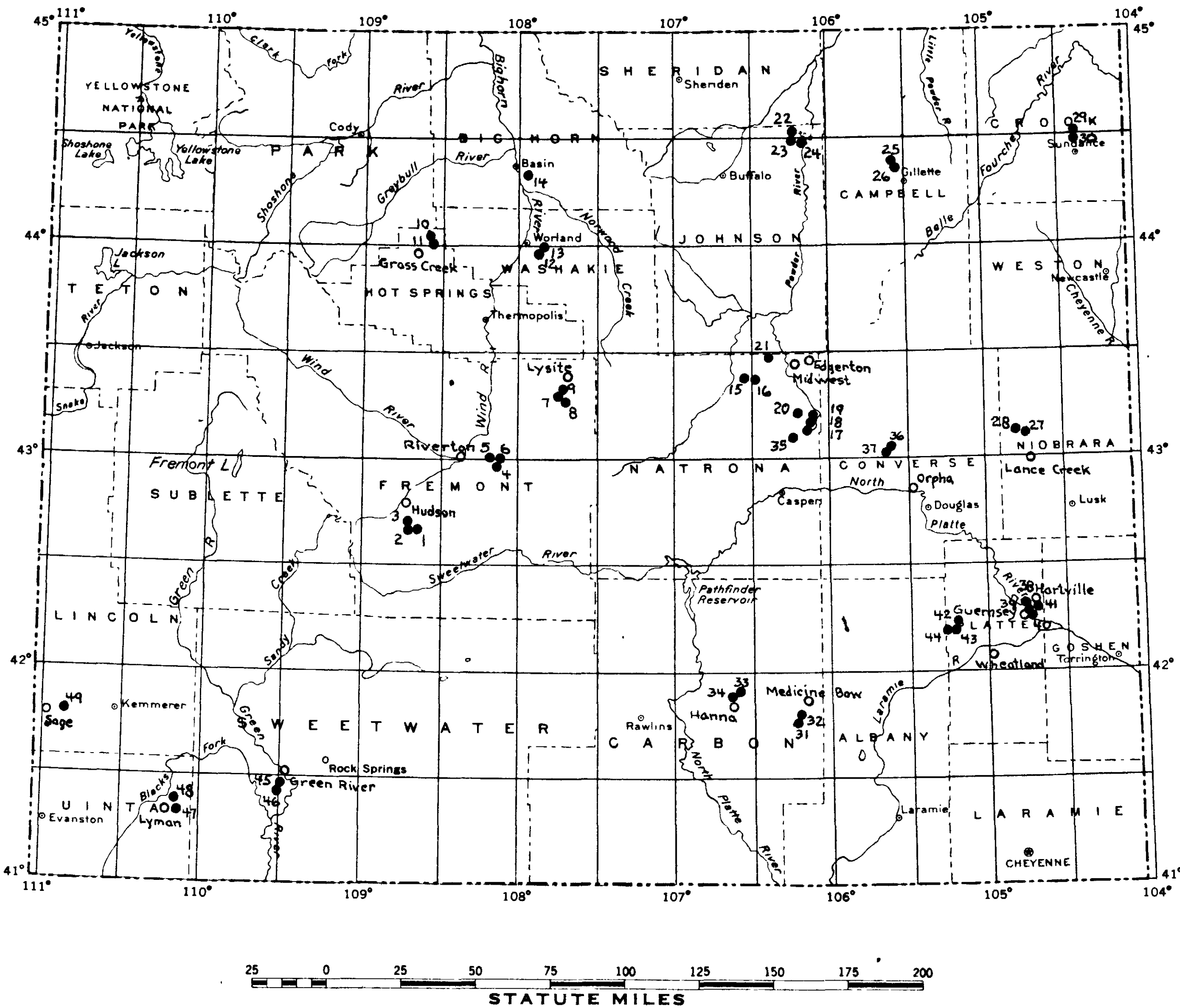

EXPLANATION

27
Basin

Numeral is basin number

Figure 2.--Index map of Wyoming showing the locations of 49 small basins studied.

Progress toward objective No. 1, defining the magnitude and frequency of flood volumes, is so dependent on time (several years of record) that it has not been attempted. Recorded runoff events during even a 10-year period may not be sufficient to yield meaningful results on magnitude and frequency of flood volumes. A synthetic method has been used in analyzing the data from one basin. The method utilizes the long-term rainfall records of the Environmental Science Services Administration (Weather Bureau) and requires that rainfall-runoff relations be determined on each basin. Definitions of peak-discharge to runoff-volume relations are progressing satisfactorily, but relations of rainfall to peak discharge and to runoff volume are not definable as yet.

Progress toward objective No. 2 in defining the characteristic shape of flood hydrographs is very encouraging. Synthetic methods, such as the Commons dimensionless hydrograph (Commons, 1942), were used to determine a general shape of flood hydrographs. Development of a mean dimensionless hydrograph from recorded runoff hydrographs for individual basins might prove to be the most practical approach for this study. A relationship probably exists between hydrograph characteristics and physical characteristics of the basin. However, no attempt has been made to develop such a relationship. Some physical parameters have been investigated and are described in this report. These parameters are listed in the appendix.

Objective No. 3, to develop a rational method of accounting for the effect of embankment storage, has received very little attention. However, Mr. A.M. Wacker of the Wyoming Highway Department has made a study of embankment storage for culvert design on one small drainage basin, Willow Springs Draw tributary near Hanna, Wyoming (basin No. 34 in figure 2). An inflow-storage-outflow study using discharge hydrographs and the stage-discharge relation developed for the inflow-hydrograph study showed a substantial economic savings by reducing the culvert size and utilizing embankment storage. Previous design methods have utilized only the peak discharge because the inflow hydrographs were either not available or could not be predicted accurately.

Parameters

Parameter delineation

A parameter is defined as an arbitrary constant each of whose values characterizes a member of a system. In a drainage basin numerous parameters control the conveyance of excess precipitation (runoff) from any part of the basin to an outlet site of interest. Certain parameters have a large effect on the runoff process, and among different sections of the country variations in these effects are to be expected because of topography, geology, and climate. The problem is to determine the variations, if any, within a region. This study is directed toward the idea that within a region certain dominant measurable parameters are consistent and can be related to runoff discharge and volume for all basins in a given geographic area.

Current investigations have been limited to physical and runoff parameters of individual basins. Physical parameters are measured values which describe the geomorphology of a basin, such as drainage area, main channel slope, and some index of geologic formation or soils. Runoff parameters are characteristics of runoff at a given point in a basin and include basin lag time, hydrograph rise time, hydrograph shape (perhaps), and the T-year [1/] flood.

A number of physical parameters have been determined from existing topographic maps. The only parameter determined for all the basins is drainage area which is one of the most important in any comparative study. Parameters determined for some of the basins are basin length, basin width, main channel length, maximum and minimum basin elevations, channel slope, and average basin slope. Runoff parameters are determined subsequent to the collection, listing, selection, and interpretation of field data. A limited number of runoff parameters have been investigated. The ironic fact that more peak flows have occurred in areas where there are no topographic maps, and consequently no physical parameter delineation, has restricted comparative studies relating basins by means of basin characteristics. As more data are collected in mapped areas and conversely as more maps become available in the study areas, investigations of interbasin relationships will be started.

Physical parameters

Drainage area.--This parameter has been determined for all basins in the study. Although county maps (scale 1:125,000) were used in some areas, the results are considered reasonably accurate.

1/ Also referred to as the N-year flood.

Channel-slope index.--This parameter has been determined for 21 basins. The method used is the one described by Benson (1962) and is the slope between two points located at 10 percent and 85 percent of the total length of the main channel from the recording gage to the edge of the drainage divide. A good estimate of slope is obtained by this method because it reduces or eliminates the effect of a cliff or sharp rise in the vicinity of the drainage divide.

Basin-slope index.--This parameter has been determined for 18 basins. It depicts the overland slope of the drainage basin. It is the product of the contour interval of the topographic map and the total length of all contour lines mapped of that interval in the basin divided by the drainage area of the basin. The best topographic maps for Wyoming covering the 18 drainage basins provide 20-foot contour intervals. The time consumed in computing basin-slope index is governed largely by the number of contour lines that must be measured. The question arises as to the error introduced by selecting a larger contour interval to measure than the basic 20-foot contour interval on most of the available maps.

A study was made of basin-slope index results comparing 20-foot contour intervals with 40-foot, 60-foot, 80-foot, and 100-foot contour intervals. A graphic comparison of results from using 20-foot and 100-foot contour intervals is shown in figure 3. Fifteen of 18 basins were within 10 percent of the equal slope line and all were within 20 percent. The greater deviations from the common slope line were results from basins of low relief. It would appear that the accuracy of basin-slope index computations would not be greatly affected by measuring only 100-foot contour lines. If basin slope is important and must be measured, considerable time could be saved by measuring fewer contour lines such as those for 100-foot contours.

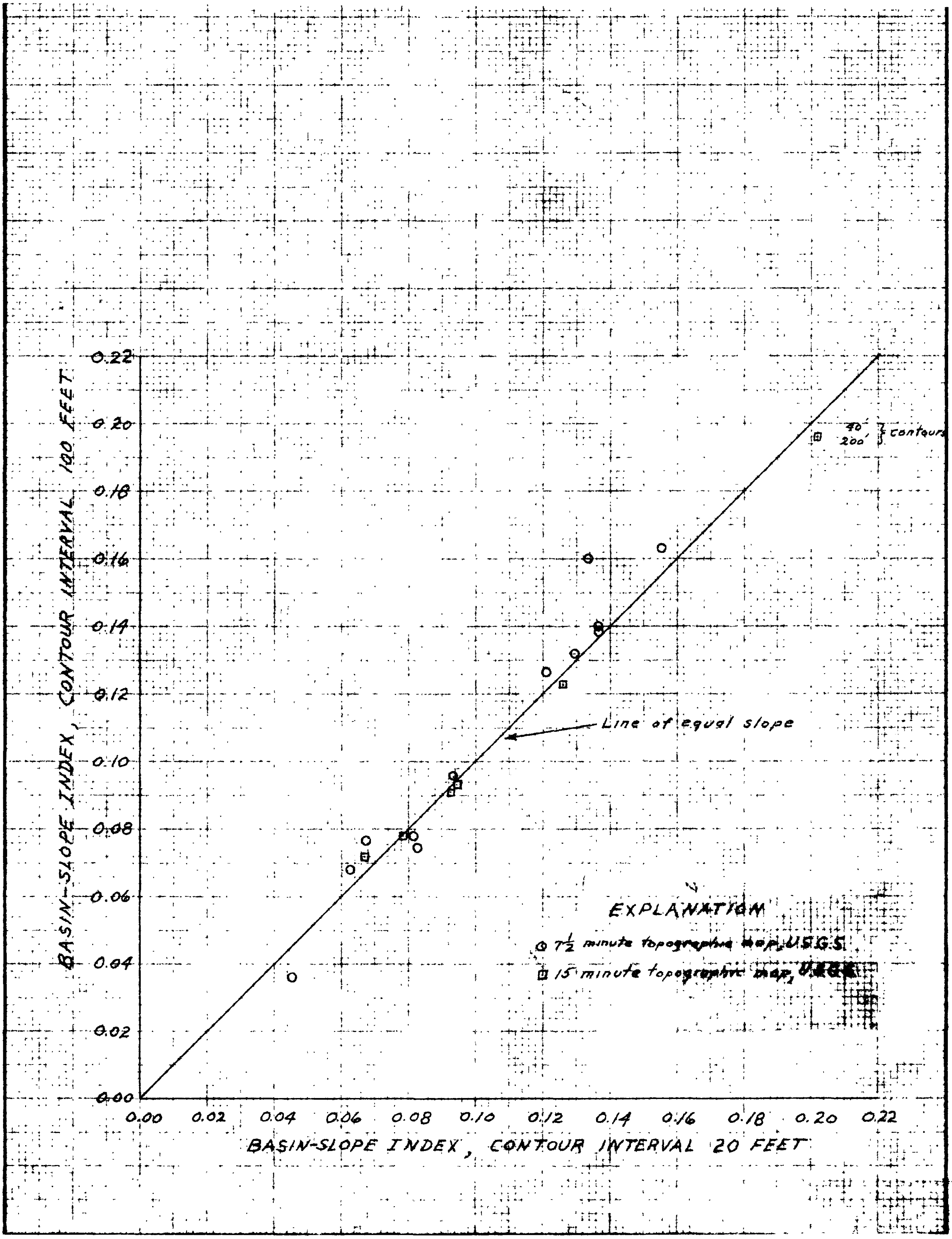

Figure 3.--Comparison of computed basin-slope indexes.

Because basin slope is difficult and time consuming to measure, it would be advantageous to find a related parameter that is easier to measure than basin slope. With this in mind, a comparative study was made between basin slope and main channel slope using graphical correlation. Other parameters introduced were maximum basin relief, main channel length, basin perimeter, and drainage area. There seemed to be a correlation between basin slope and main channel slope, but it was not conclusive enough to confirm the desired relationship. Also, a slight correlation is apparent between basin slope and maximum basin relief (fig. 4). There was no apparent relationship between basin slope and other parameters.

Basin length and average width.--These two dimensions have been determined for 27 basins. The length is the straight-line distance from the gage site to the most remote point in the basin, and the average width is obtained by dividing the drainage area by the length. Individually, there is no apparent relationship to other parameters. A ratio of the length to the width has not shown a relationship with other parameters.

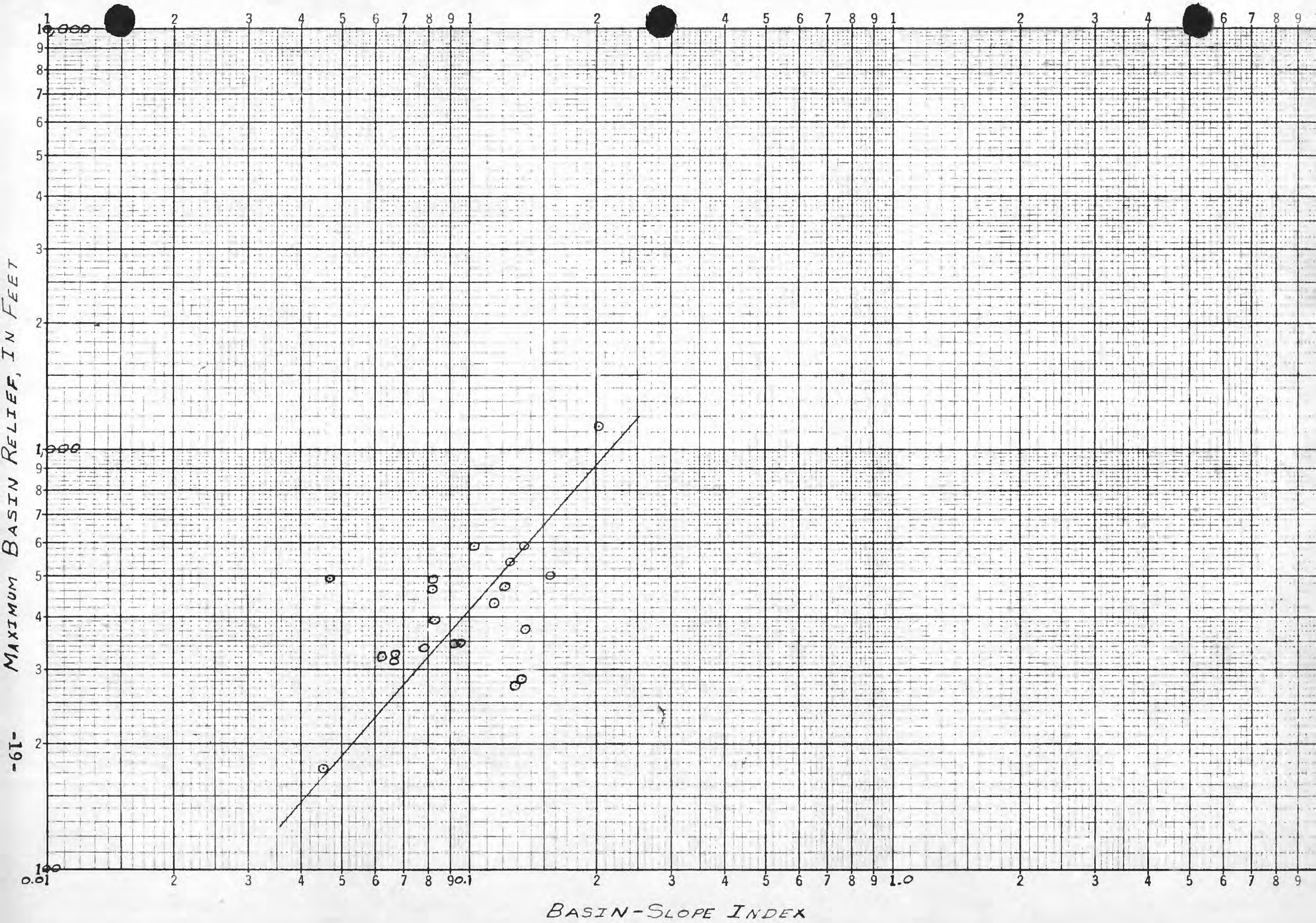

Figure 4.--Correlation of basin-slope index and maximum basin relief.

Channel-shape factor.--The possibility that stream channels could be compared using geometrical shapes was presented by Fahnestock (1963). The ratio of maximum depth to mean depth is Fahnestock's definition of a shape factor. Since shape factor would be an easy parameter to measure, it could be meaningful if it were related to the T-year flood or some other runoff parameter. A study was made of 5 streams where 13 indirect measurements provided both cross sections and discharge. One stream had as many as five measurements and two had only one. The results (fig. 5), while not conclusive, indicate no definite relationship between streams, although a slight relationship might be observed in the same stream at different discharges. It would appear at this time that channel-shape factor is not an important characteristic because it probably is dependent on other topographic and geologic features. If these features cannot be defined and evaluated, then further study of shape factor would be warranted.

Other parameters.--Several other parameters have been measured and used in the correlation studies mentioned previously. There are no significant results to report. These parameters are listed below:

Main channel length

Basin perimeter length

Maximum basin relief

Additional parameters that might prove important but that have yet to be investigated include:

Soils index

Infiltration index

Surface geology

Geological structure

Land use

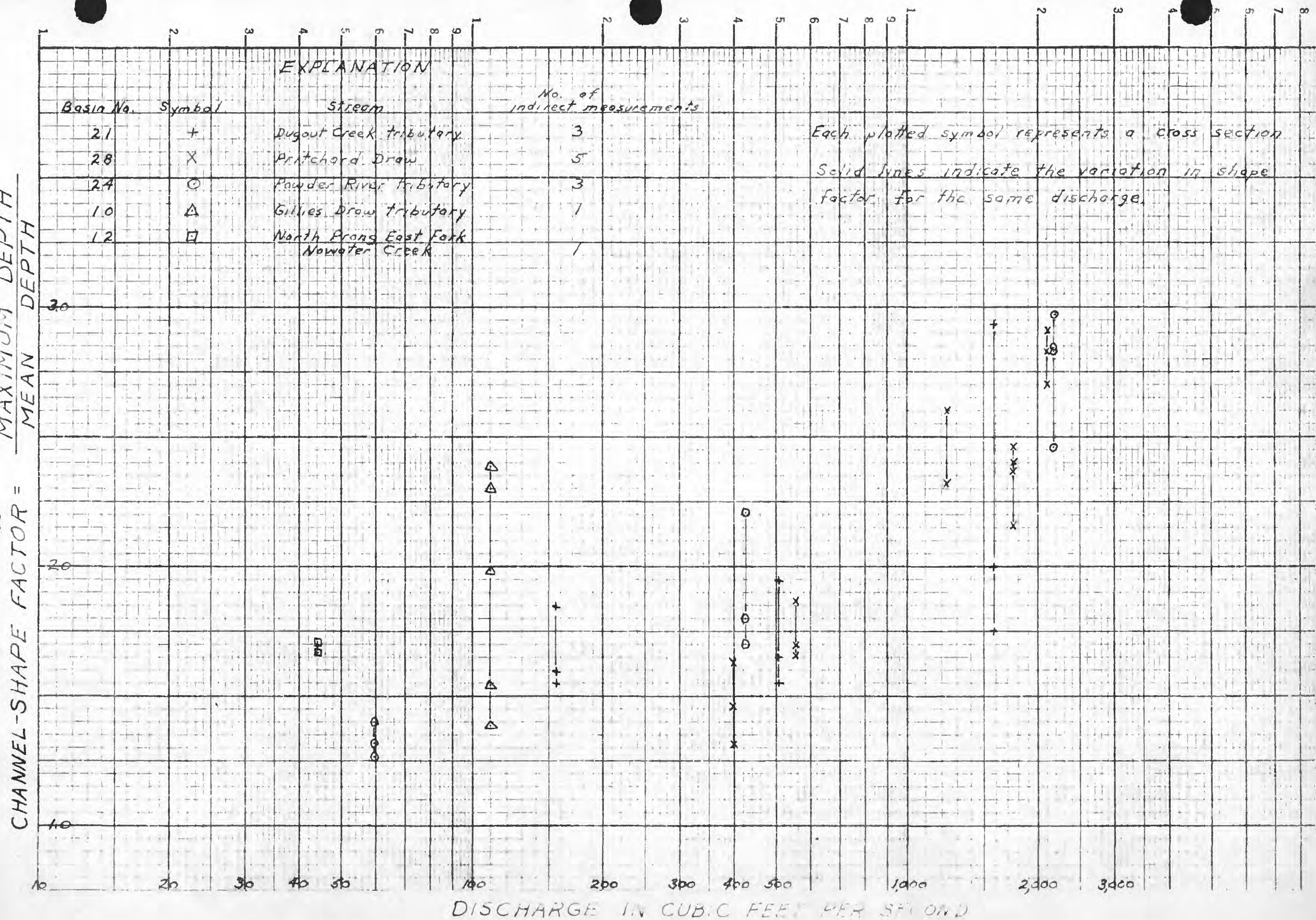

Figure 5.--Variation of channel-shape factors.

Runoff parameters

Lag time.--One of the potentially most useful runoff parameters is lag time, "variously defined as time from center of mass (or beginning) of excess rainfall to peak (or center of mass) of runoff," (Am. Soc. Civil Engineers, 1949, p. 106). The most consistent and technically rigorous definition is time from center of mass of rainfall excess to center of mass of runoff, which can be applied to simple and complex runoff events alike. Another definition, applicable only to simple events, is time from center of mass of rainfall excess to the peak discharge. Rainfall excess is defined as that part of total rainfall on the basin that appears as direct surface runoff at the gage.

Variations in storm direction and rainfall intensity will cause variations in lag time. However, an average lag time determined from a large number of storms may be considered as constant for a basin.

Only a few basins have produced enough data to attempt an estimate of lag time. Of these, North Prong East Fork Nowater Creek near Worland (basin No. 12), was selected for the first analysis; other basins will be analyzed in the future. The last definition of lag time, time from center of mass of rainfall excess to the peak discharge was used. For a given storm, the average lag time was determined using recorded rainfall at three sites: the main channel S-R gage, the tributary S-R gage, and a supplementary recording rain gage near the upper end of the basin. Data for 6 hydrographs with peak discharge ranging from 15 to 394 cfs (cubic feet per second) were used; the results are shown in table 1.

Table 1.--Rainfall, runoff, and lag times for selected storms on North Prong East Fork Nowater Creek near Worland.

Date	Average total rainfall (inches)	Approximate duration of rainfall excess (minutes)	Total runoff (inches)	Peak discharge (cfs)	Lag time, S-R gage only (minutes)	Average lag time, all gages (minutes)
9-18-67	1.32	180	0.440	394	136	134
6-23-67	.62	150	.138	169	111	131
6- 6-67	.26	10	.038	60	124	150
6- 5-67	.18	10	.011	31	(a)	212
8-21-65	.14	10	.004	15	150	213
6-11-67	.11	10	.006	15	160	(b)
				Mean	136	168
				Value used in computations	150	

a Duration of rainfall not recorded.

b Rainfall for auxillary gages indeterminate.

All the streams in this study are normally dry, and summer runoff is a direct result of rainfall. There is no base flow and runoff volume was computed from the entire observed hydrograph. The computed runoff volume in inches was determined from the upper parts of a rainfall hyetograph as rainfall excess. The lower part or remainder indicated infiltration and other losses. Centroid time and duration of rainfall excess were determined from the hyetograph. This method is only approximate because it does not consider the time variation of the losses, but the limited data restricted the use of more sophisticated methods.

There is some evidence that lag time estimated by using only the rainfall recorded at the S-R gage site in basin No. 12 is a fair approximation of lag time for that basin. In the above example a problem arose when several of the hydrographs used were recorded on the same chart within a 7-day period, making it difficult to match the storms with the hydrograph. Because of this and the limited data, it was decided to use data from supplementary recording rain gages to eliminate variations caused by direction of storm movement.

The effect of storm duration on lag time appears to be minor, at least in the above example, and was not considered in this analysis.

Hydrograph rise time.--Renard and Keppel (1966) used rise time as a runoff parameter instead of lag time. They felt it was a more accurate reflection of the many factors affecting runoff patterns in their study areas. Rise time may or may not be a constant. Seven hydrographs on North Prong East Fork Nowater Creek near Worland showed rise time varying from 1/2 to 2 hours. There was no apparent consistency in rise time for 5 storms of short duration (about 10 minutes), although for the 2 long-duration storms (2 to 3 hours) it was 2 hours, approximately equal to lag time. Because of the apparent variability of rise time, lag time appears to be a better parameter for our use. However, rise time of the mean dimensionless hydrographs discussed later may be a useful parameter in comparing basins.

T-year runoff event.--The T-year event is one that can be expected to be equalled or exceeded at intervals averaging T years in length. The T-year event provides a convenient means of relating discharge or runoff volume to basin parameters for interbasin comparisons and regionalization. Benson (1962), for example, developed multiple-regression equations for relating the T-year flood to significant basin characteristics. It has been suggested that a similar approach might be tried in the inflow-hydrograph study. The problem of defining flood frequency for a short-term record and one possible method of synthesizing frequencies are discussed in a subsequent section.

Hydrograph shape.--It is believed that the average shape of hydrographs of simple runoff events may be a unique characteristic of a given basin. If this is so, hydrograph shape may be a parameter that can be related to some physical parameters and thereby be predicted for ungaged sites. Considerable effort has been put into studying hydrograph shape for the inflow-hydrograph project because it is one of the few areas of analysis for which meaningful results might be obtained with limited data.

Hydrograph analysis

Discharge hydrographs

Discharge hydrographs have been plotted for most of the rated streams where simple runoff events have occurred. These hydrographs, although generally similar in shape, often vary in the rising limb or the recession. The variations range from nearly instantaneous rises caused by rapid runoff, to gradual rises from a general runoff which become more vertical just prior to the peak. The recessions from peak flow are fairly uniform and rapid, with variations at the tail portion from abrupt termination of flow to a more gradual termination. Some of these intermittent streams produce long shallow recession tails of very minor runoff. Most peaks have a fairly consistent appearance, being narrow and rounded or pointed on top. A few are quite different in that the peak is gradually rounded and sustained for a longer period of time while the rising and falling limbs are quite steep. These hydrographs might be referred to as "fat" hydrographs. The "fat" hydrograph seems to be typical of one station, North Prong East Fork of Nowater Creek, although it has occurred at other stations. Figure 6 illustrates normal hydrographs to show the more commonly observed shape and a "fat" hydrograph to indicate the contrast.

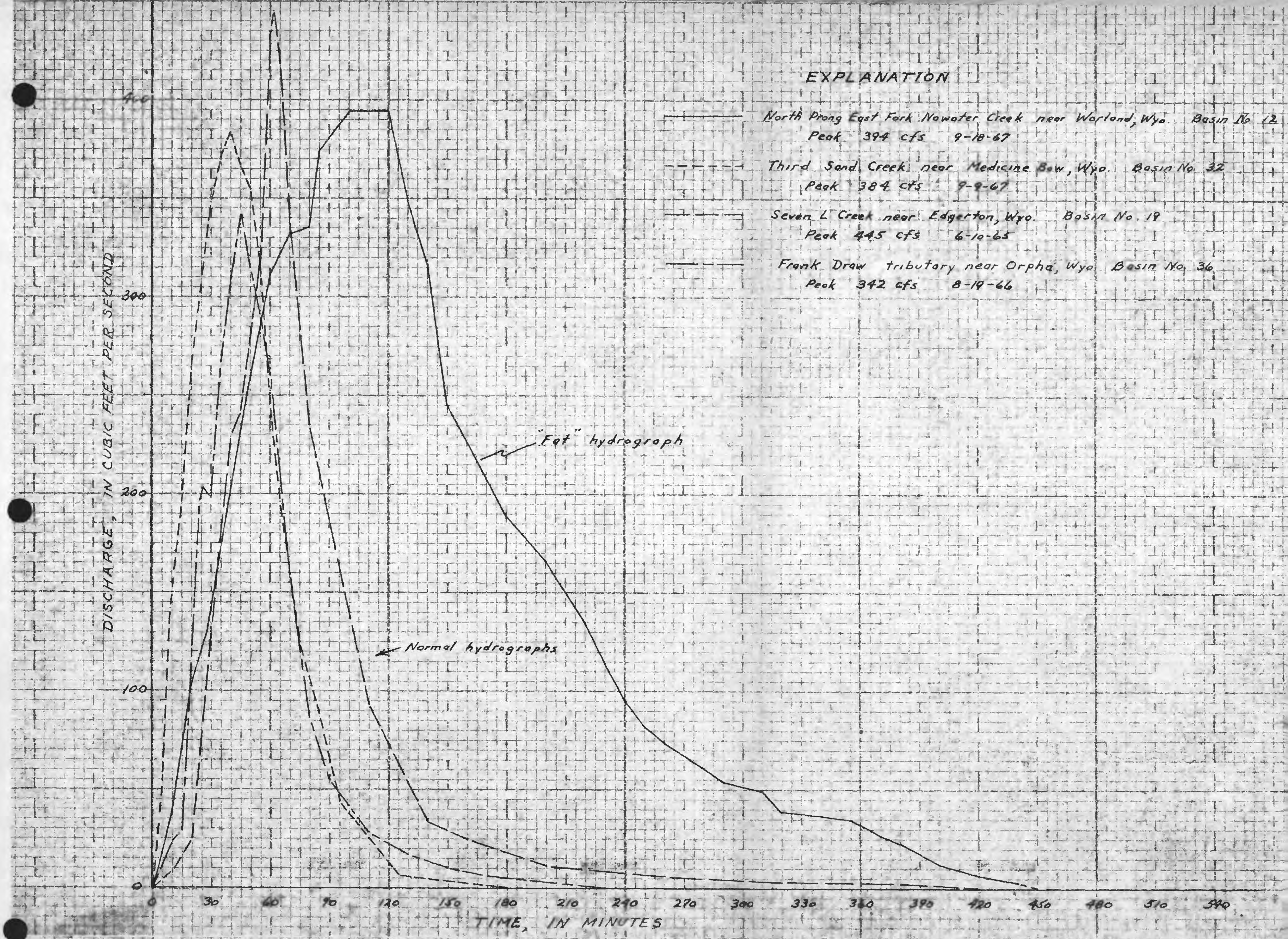

Figure 6.--Contrasts in observed hydrographs.

Although the hydrograph analysis has been mainly concerned with single-peak hydrographs (simple hydrographs) in determining a relation between peak discharge and runoff volume, multipeak hydrographs (complex hydrographs) have been recorded. There are methods that can be used to resolve complex peaks into a comparable number of simple peaks. The separation of complex peaks into their component simple peaks allows additional plotting points for analyses of simple events. Generally, the complex peaks associate low-peak discharge with high-volume runoff. Simplifying complex peaks on streams where many simple peaks are available would not provide information useful enough to warrant the effort. However, on streams where only a few simple peaks are available, a complex peak can be simplified and used to check a relation of peak discharge to volume that has been defined from only one or two higher peaks. Such an example is illustrated in figure 7 for Nowood River tributary No. 2 near Basin, Wyoming (basin No. 14). The weak relationship was defined by one high peak and several small ones. A double-peak event had been recorded and considered as a complex peak of high volume. The peaks were separated quite easily into two events which reduced the original volume to about half. The first peak was not used as it seems to have another complex portion associated with it. The peak discharge of the second peak (the higher of the two) was not affected and when plotted with its newly determined volume helped to verify the preliminary relationship. Use of simplified complex peaks to check preliminary relationships will be investigated more thoroughly in the future.

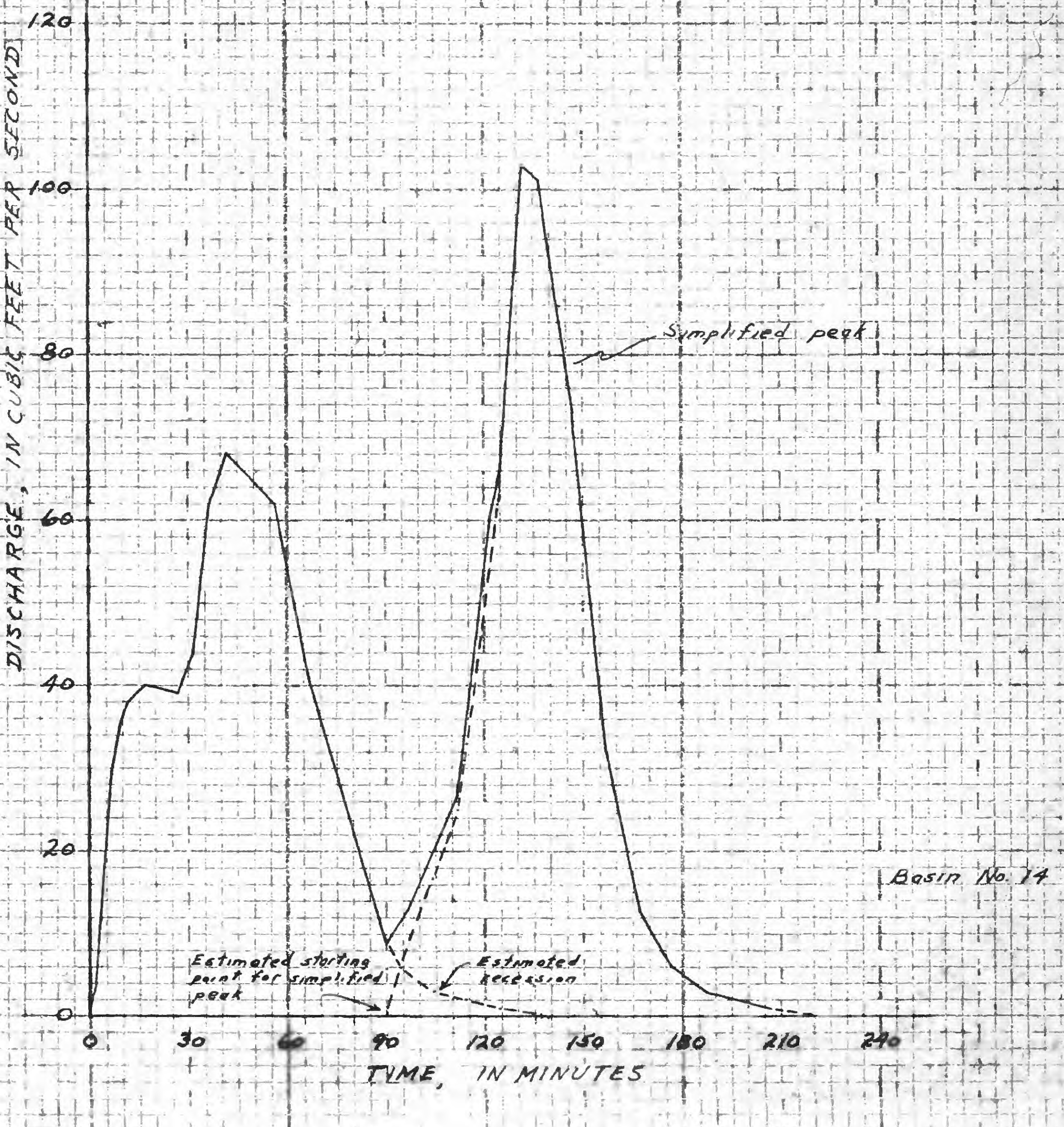

Figure 7.--Simplification of a complex hydrograph on Nowood River tributary No. 2 near Basin, Wyo. Peak of June 22, 1967.

Comparison with Commons dimensionless hydrograph

There appears to be a similarity in the shape of the many hydrographs plotted, indicating a regular pattern in the distribution of flow. This would mean that if information about the runoff volume were known, the main problem would be how to distribute it. A method being investigated provides the distribution in a standard shape hydrograph based on peak discharge and volume of a runoff event. G.G. Commons (1942) developed a dimensionless hydrograph (fig. 8) based on floods in Texas, and this hydrograph was compared with floods in New York, Connecticut, Pennsylvania, and other areas with great success. The Commons hydrograph has a fixed relative shape, with the peak discharge equal to 60 ordinate units, the time base equal to 100 abscissa units, and an area of 1,196.5 square units. One aspect of the Commons hydrograph that does not agree too well with hydrographs in this area is its long recession period. Because the dimensionless hydrograph was developed for large floods on perennial streams, it is possible that water coming out of storage would sustain the recession. For small ephemeral streams in Wyoming, the recession is of relatively short duration, at least down to an insignificant rate of flow.

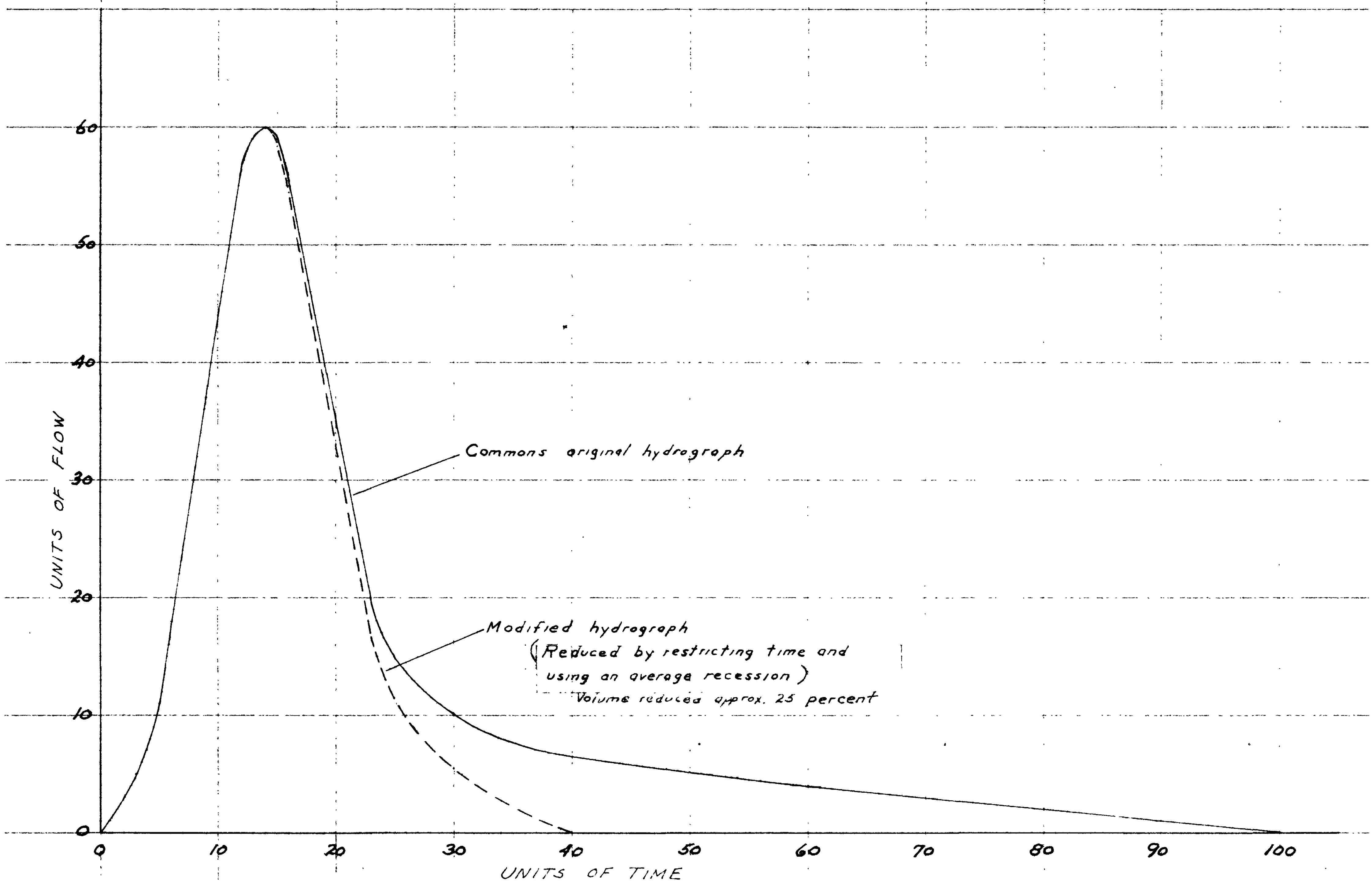

Figure 8.--Original and modified Commons dimensionless hydrograph.

A modified version (reduced recession) of the Commons hydrograph is also shown in figure 8. Comparisons of the original and (or) modified Commons hydrographs with observed hydrographs are shown in figures 9-16. The synthetic hydrographs are fairly representative of the observed hydrographs through the main part while the rise and recession parts vary. In general, the actual Commons hydrograph has a longer recession while the modified version has a shorter recession than the observed hydrographs. It would be possible to develop other modified versions of the Commons hydrograph that would be more representative; however, a more practical approach has been attempted. That is the development of a dimensionless hydrograph for each basin using the Commons method as a guide. The procedure used to develop a mean dimensionless hydrograph is described in the following section.

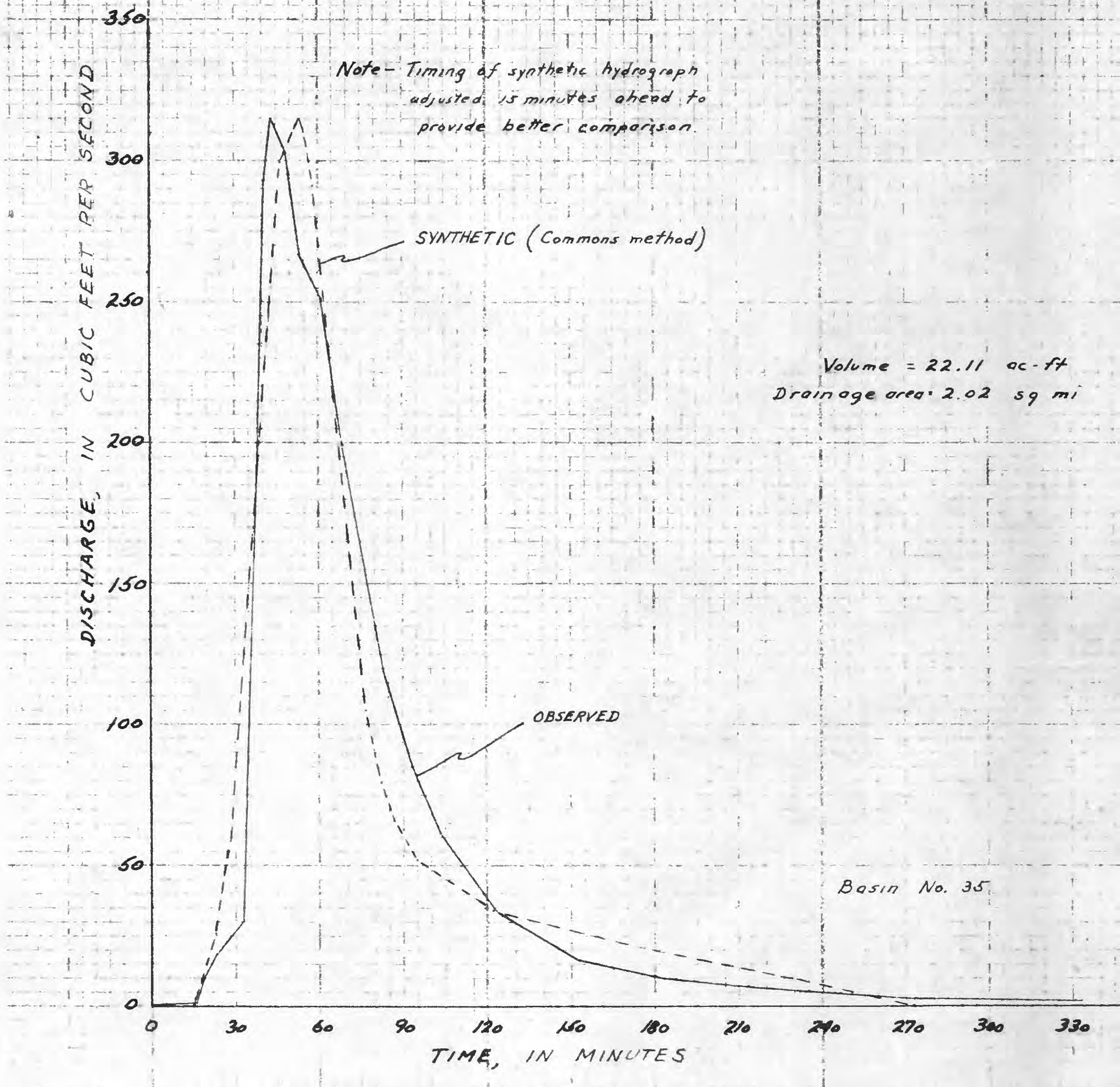

Figure 9.--Comparison of synthetic and observed hydrographs on McKenzie Draw tributary near Casper, Wyo., for peak of August 20, 1965.

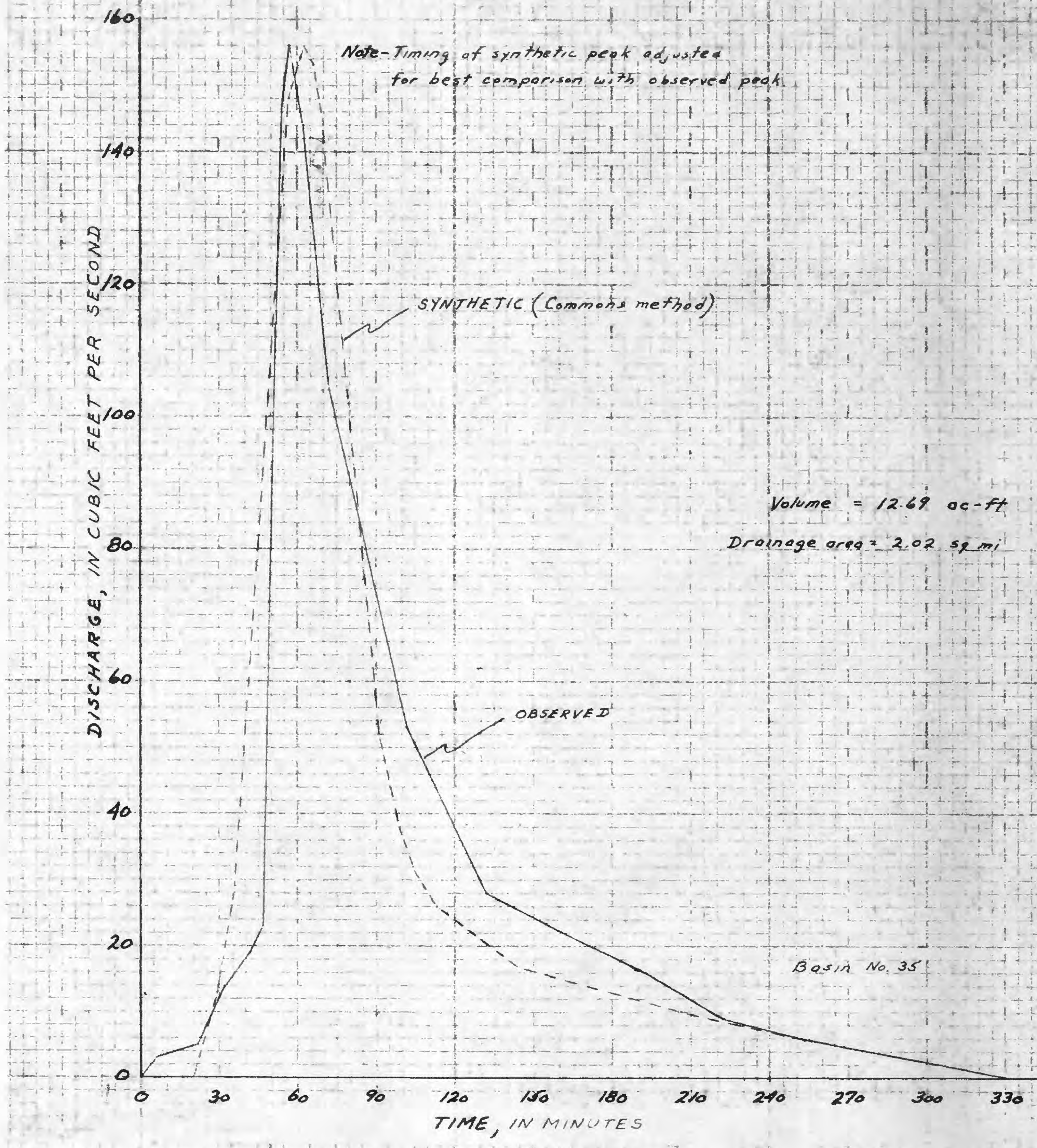

Figure 10.--Comparison of synthetic and observed hydrographs on McKenzie Draw tributary near Casper, Wyo., for peak of June 15, 1967.

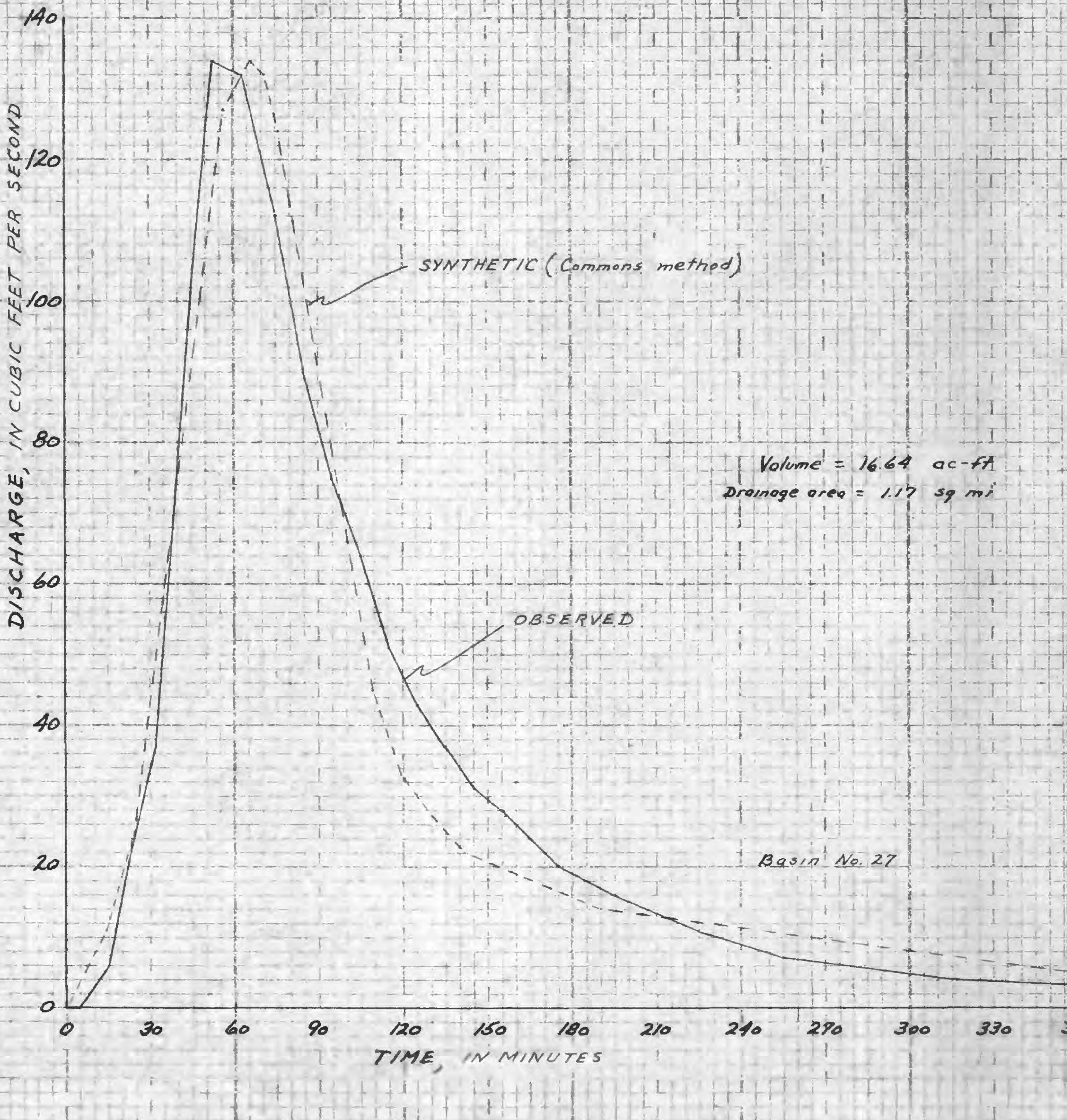

Figure 11.--Comparison of synthetic and observed hydrographs on Lance Creek tributary near Lance Creek, Wyo., for peak of July 2, 1966.

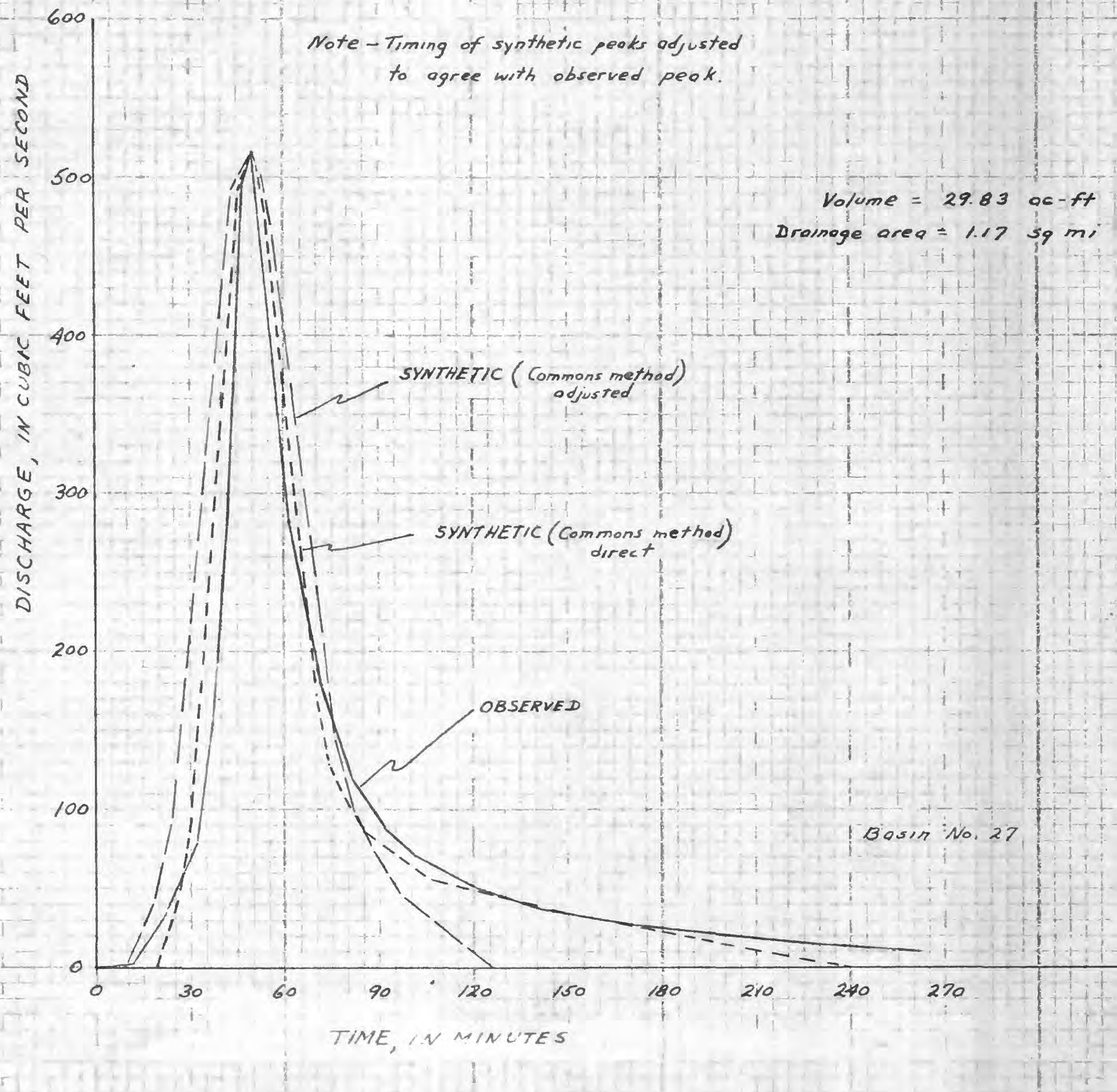

Figure 12.--Comparison of synthetic and observed hydrographs on Lance Creek tributary near Lance Creek, Wyo., for peak of June 10, 1965.

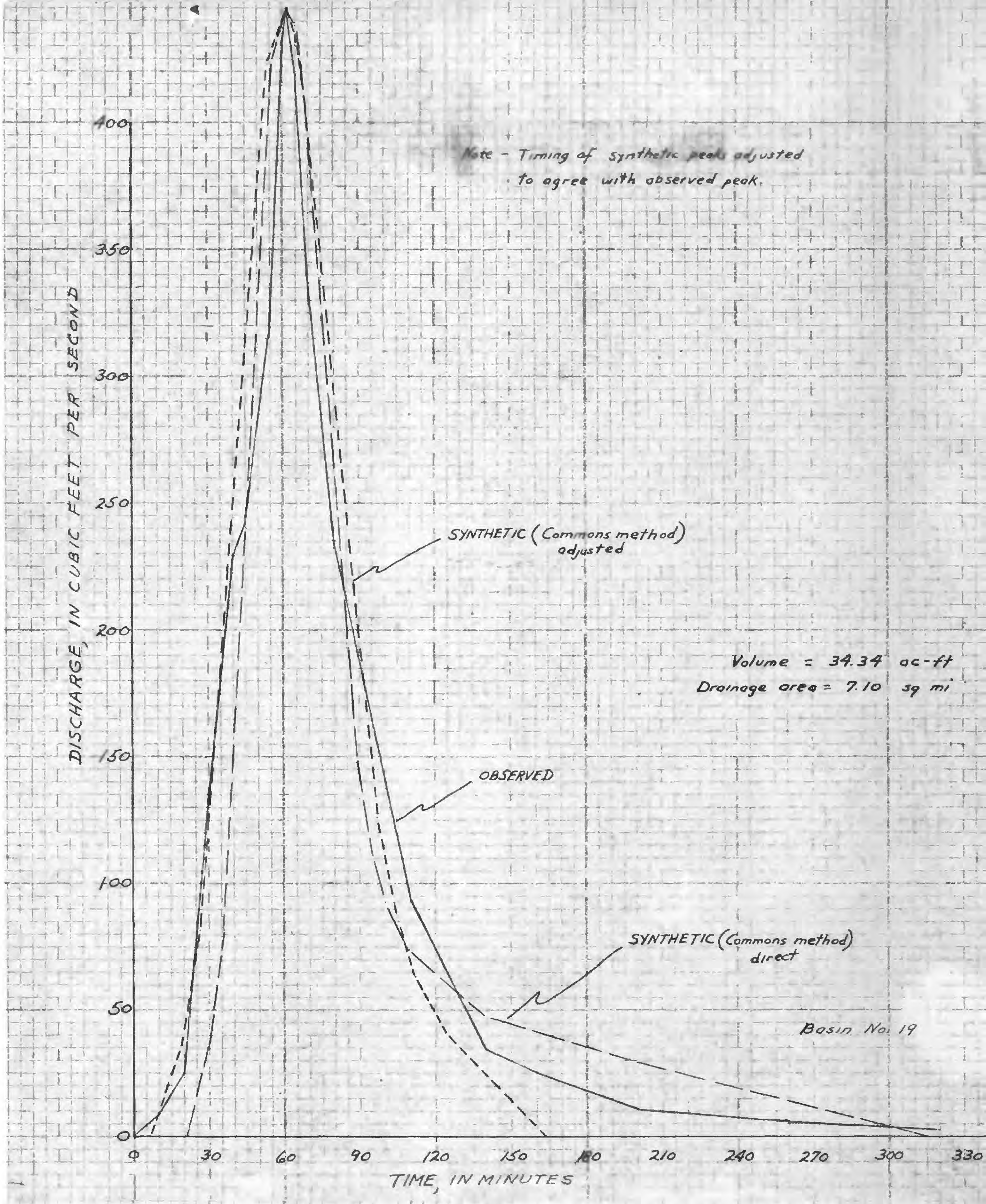

Figure 13.--Comparison of synthetic and observed hydrographs on Seven L Creek near Edgerton, Wyo., for peak of June 10, 1965.

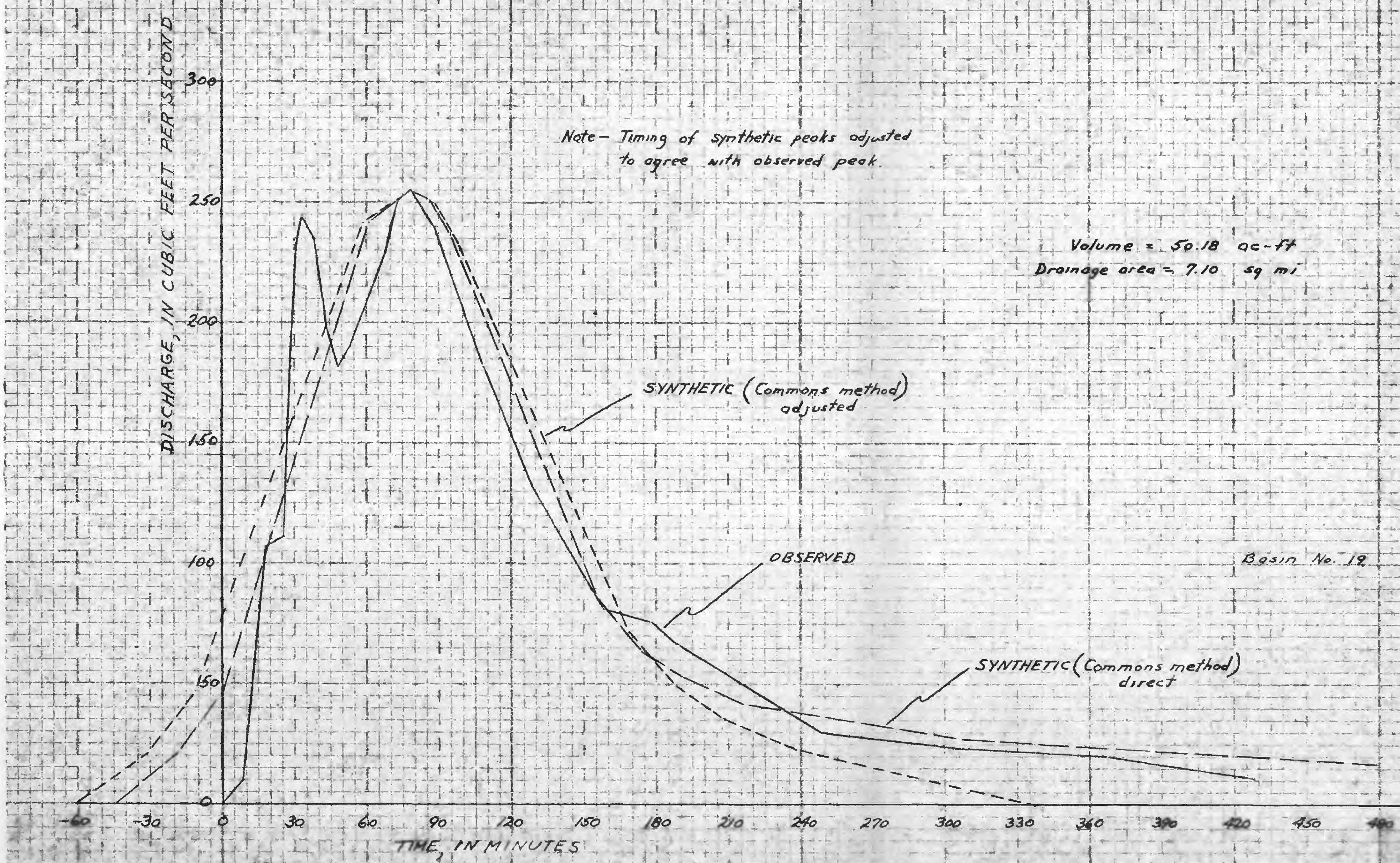

Figure 14.--Comparison of synthetic and observed hydrographs on Seven L Creek near Edgerton, Wyo., for peak of July 5, 1965.

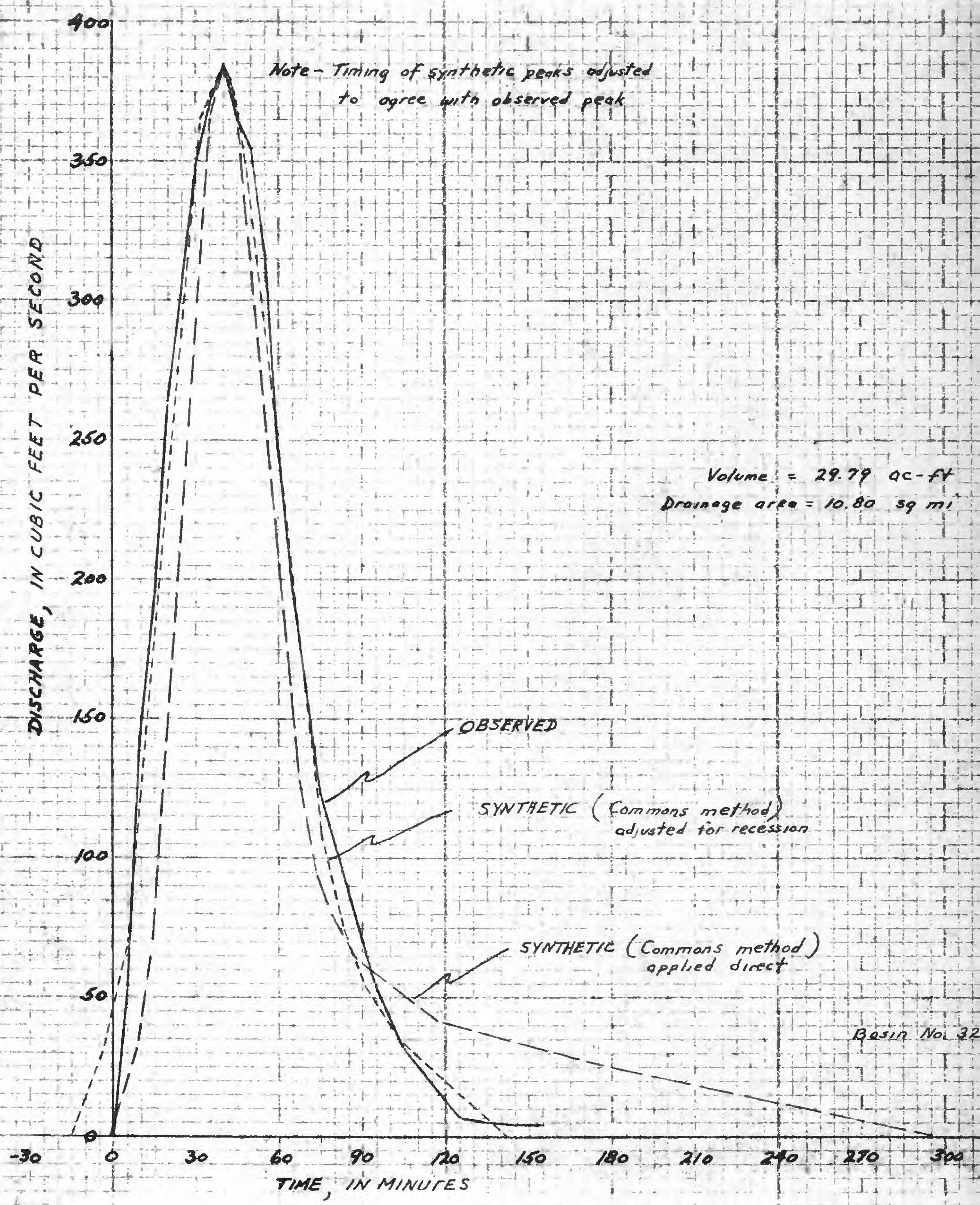

Figure 15.--Comparison of synthetic and observed hydrographs on Third Sand Creek near Medicine Bow, Wyo., for peak of September 9, 1967.

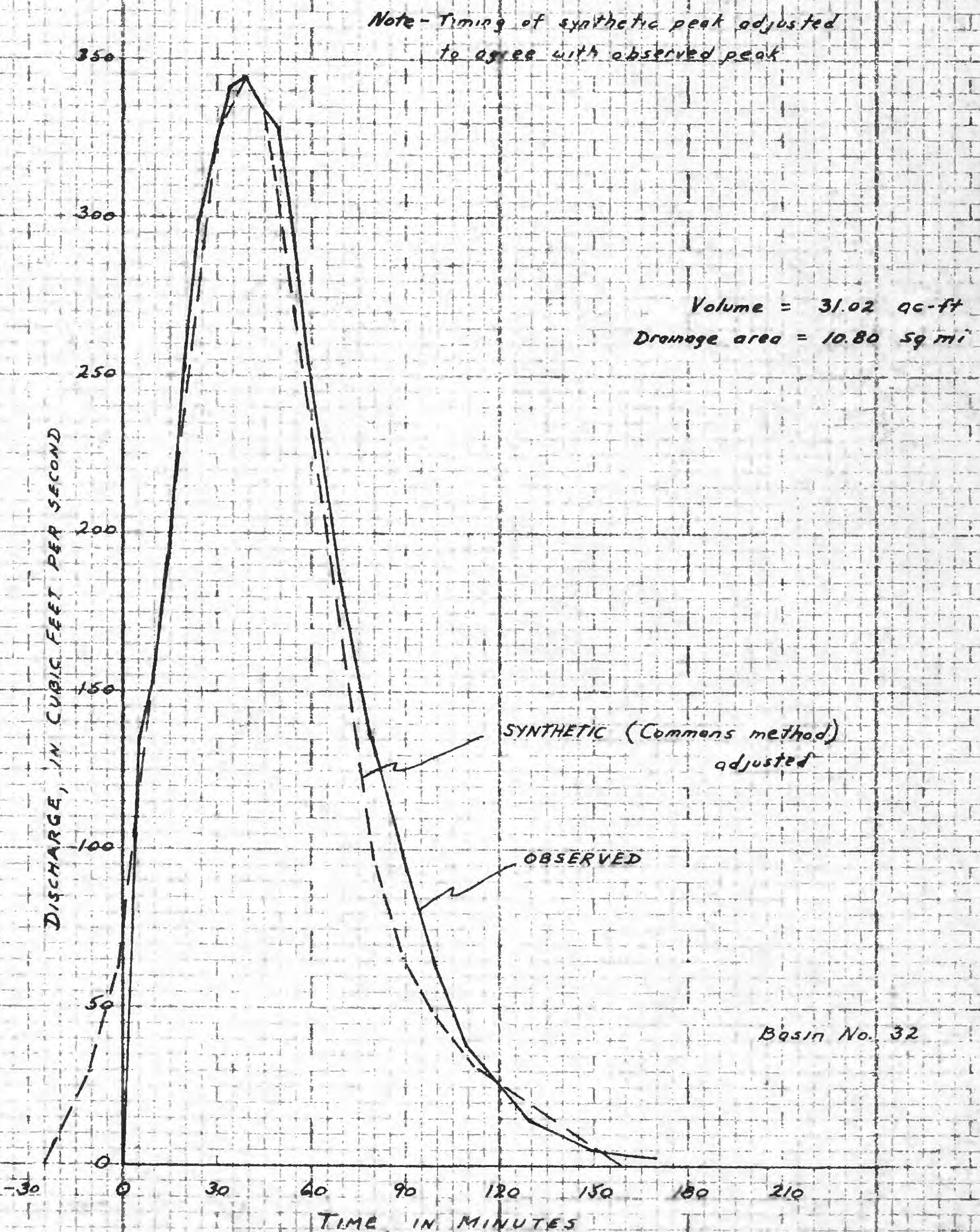

Figure 16.--Comparison of synthetic and observed hydrographs on Third Sand Creek near Medicine Bow, Wyo., for peak of August 7, 1967.

Development of mean dimensionless hydrograph

Mean dimensionless hydrographs were developed for 10 of the rated stations. These hydrographs were developed using a method similar to the Commons method but not using the typical Commons shape. The constants used in developing the dimensionless hydrographs were based on those for the Commons hydrograph. The peak discharge is the same, 60 ordinate units, while the area under the hydrograph was arbitrarily rounded to 1,000 square units. The time base, unlike that of Commons, is variable, to allow a more accurate definition of hydrograph shape for each station. Below is a general outline of the procedure followed.

1. Only stations with four or more simple hydrographs (single peaks) were used.
2. Each hydrograph was converted to dimensionless form as follows:
   a. Discharge factor = $\frac{60}{\text{peak discharge}}$
   b. Volume factor = Total volume/1,000
   c. Time factor = $\frac{\text{Peak discharge/60}}{\text{Volume factor x (constant)}}$

   Constant = 726 when volume is in acre-feet and time is in minutes.

   d. Discharge units (ordinate of plot) = discharge factor times discharge in cfs.
   e. Time units (abscissa of plot) = time factor times time in minutes.
   f. The plotted points were connected by straight lines to form a dimensionless hydrograph.

Steps 2a-f are illustrated in figures 17 and 18, starting with a simple hydrograph in figure 17. Numerous coordinate points from this hydrograph are listed in the table in figure 18. The coordinates were converted to dimensionless form using the three factors (discharge, volume, and time) and listed in columns 4 and 6 of the table. These dimensionless coordinates were then plotted in figure 18 to arrive at the dimensionless form of the hydrograph.

3. The dimensionless hydrographs for a given station were all plotted on a sheet of rectilinear paper using a common origin.

4. A composite or mean dimensionless hydrograph was developed by averaging the time units at each of several values of the discharge units on both the rising and recession limbs. A smooth curve was drawn through the average points. Figures 19 and 20 illustrate steps 3 and 4.

5. Discharge units were determined and recorded for comparison purposes at preselected time-unit intervals for the ten mean dimensionless hydrographs developed. The comparisons were made to determine any similarity of hydrographs for regionalizing hydrograph shape. There appears to be some similarity between hydrographs for some basins (fig. 21).

Discussion of results.--The purpose of this short study was not to develop a method that would predict the hydrograph shape for all runoff events (complex events, long-duration events) in a basin, but to develop some way of predicting the hydrograph shape that would be the most common shape for any simple-runoff event in the basin.

As mentioned above, a comparison was made between the mean dimensionless hydrographs for different basins with some of these showing similar shapes. It is hoped that this similarity of shape can be correlated with some physical parameter in order to regionalize hydrograph shape.

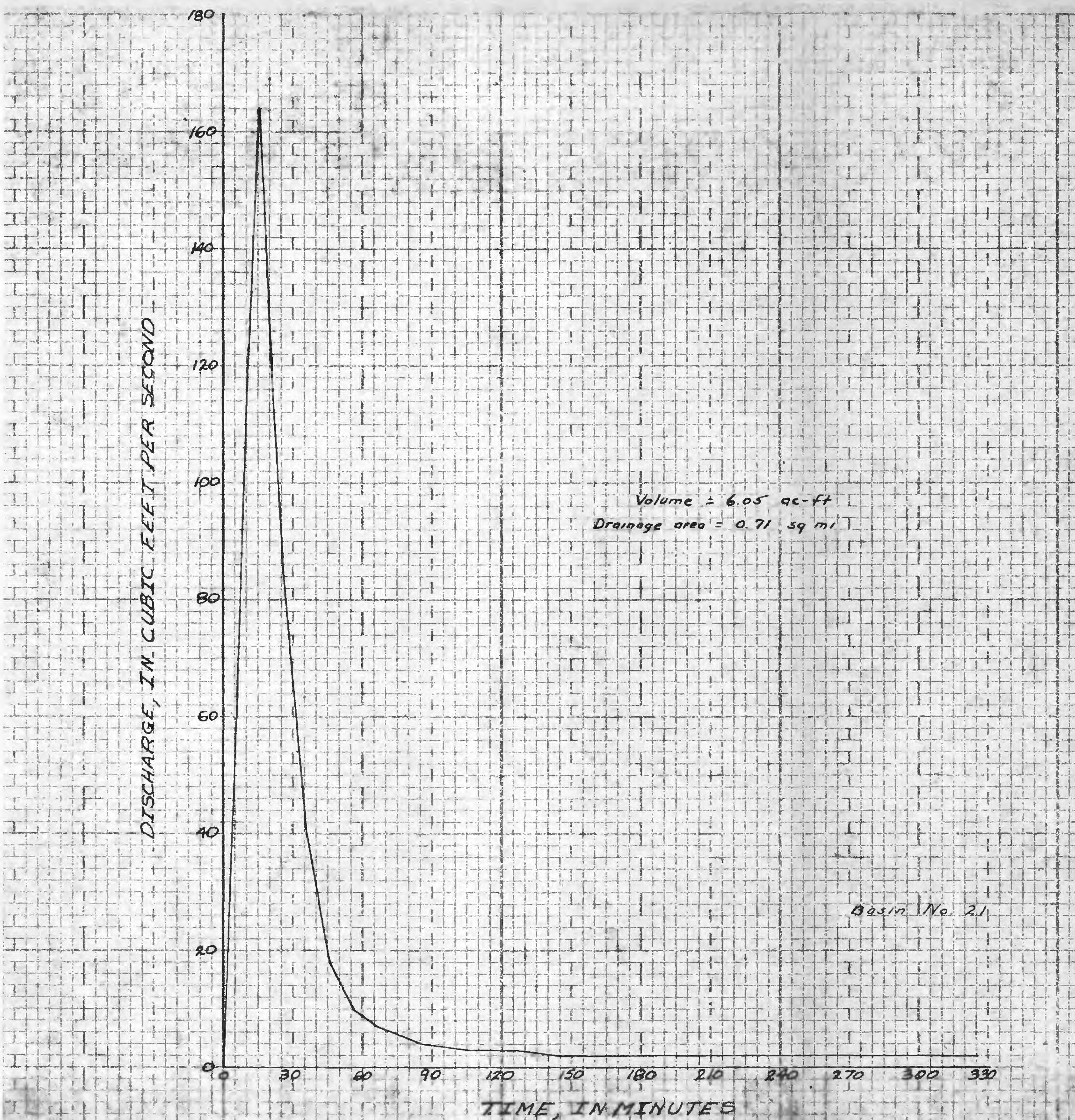

Figure 17.--Actual runoff hydrograph for Dugout Creek tributary near Midwest, Wyo., for peak of May 23, 1965.

EXPLANATION

$$\text{Discharge Factor} = \frac{60}{164} = 0.366$$

$$\text{Volume Factor} = \frac{6.05}{1000} = 0.00605$$

$$\text{Time Factor} = \frac{\frac{164}{60}}{(0.00605)(726)} = 0.622$$

1 Time (min)	2 Discharge (cfs)	3 Time Factor	4 Time Units	5 Discharge Factor	6 Discharge Units
0	0	0.622	0	0.366	0
6	63		3.7		23
11	123		6.8		45
16	164		10		60
21	120		13		44
26	85		16		31
36	41		22		15
46	18		29		6.6
56	10		35		3.7
66	7		41		2.6
86	4		53		1.5
106	3		66		1.1
126	3		78		1.1
146	2		91		0.73
206	2		128		0.73
326	2	0.622	203	0.366	0.73

Column 4 = Column 1 X Column 3

Column 6 = Column 2 X Column 5

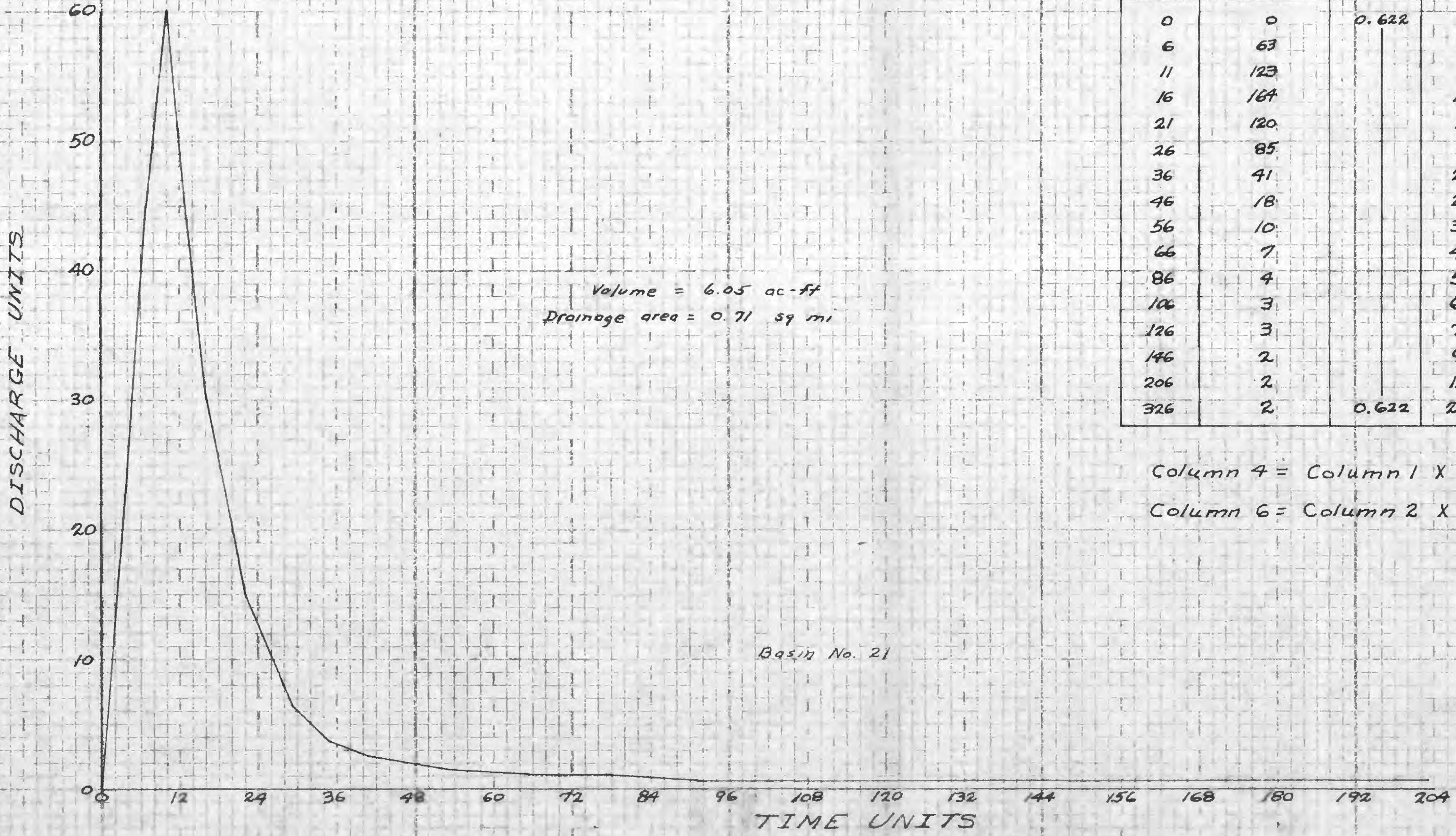

Figure 18.--Conversion table and resulting dimensionless hydrograph for Dugout Creek tributary near Midwest, Wyo., for peak of May 23, 1965.

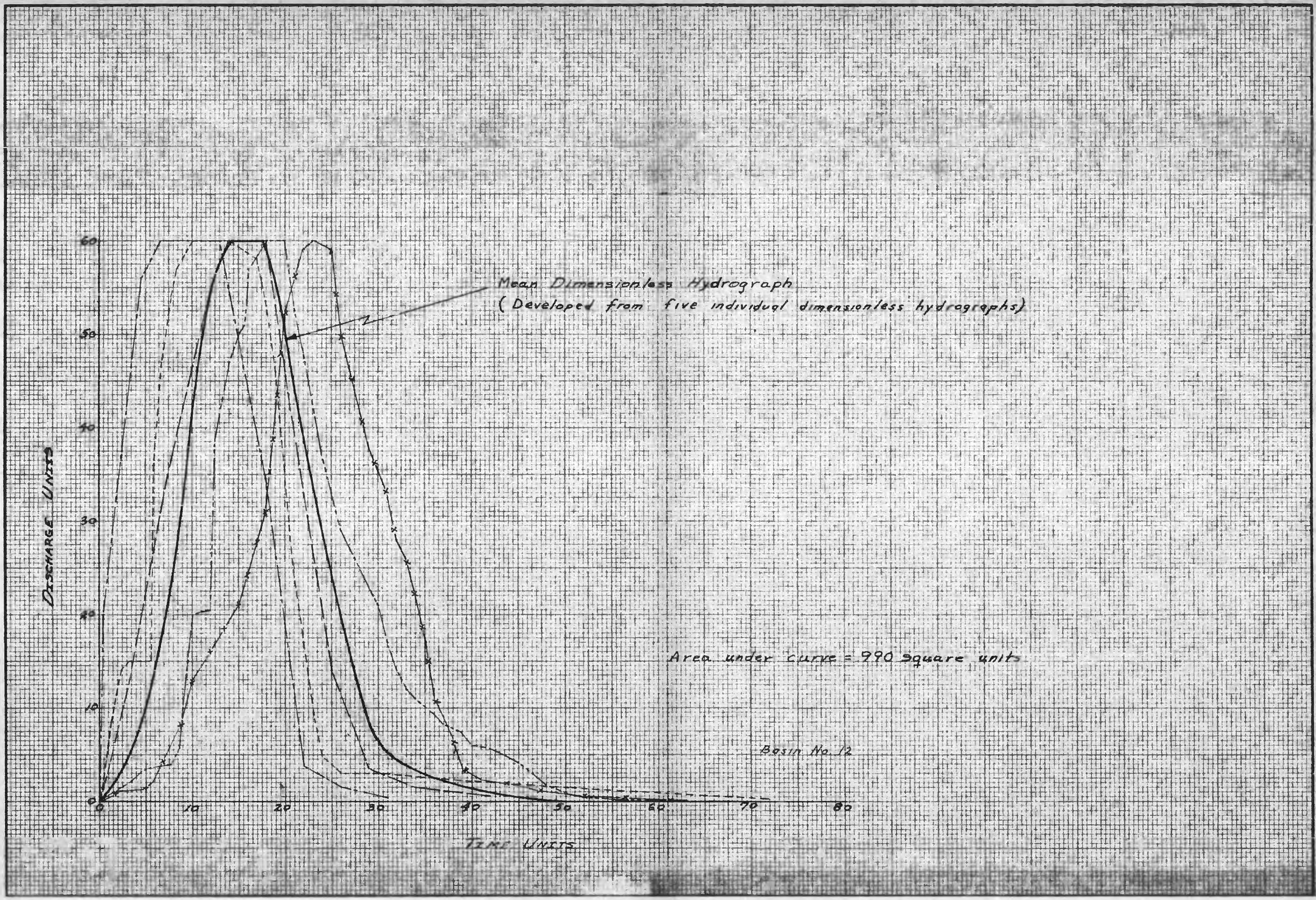

Figure 19.--Dimensionless hydrographs for North Prong East Fork Nowater Creek near Worland, Wyo.

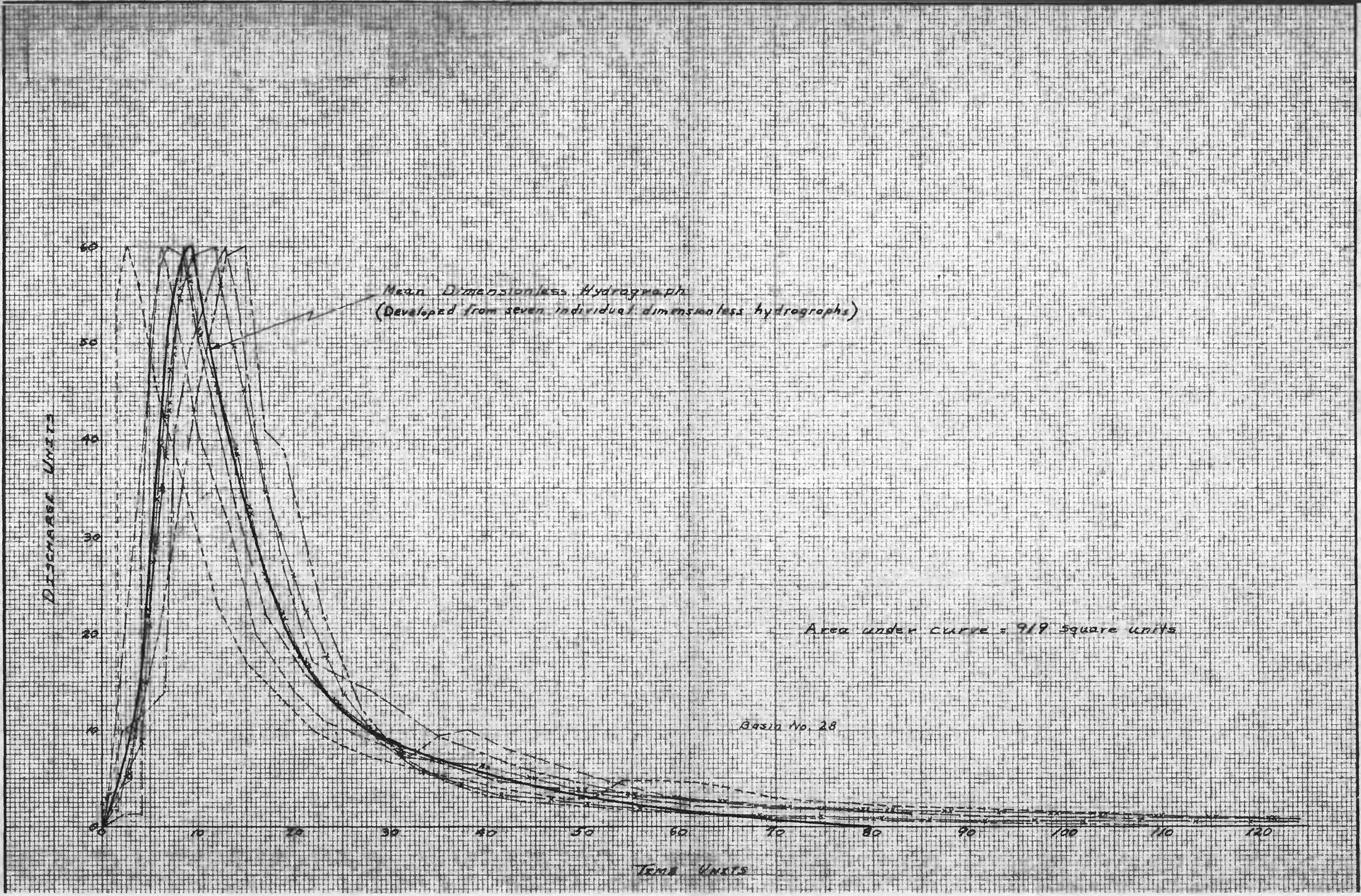

Figure 20.--Dimensionless hydrographs for Pritchard Draw near Lance Creek, Wyo.

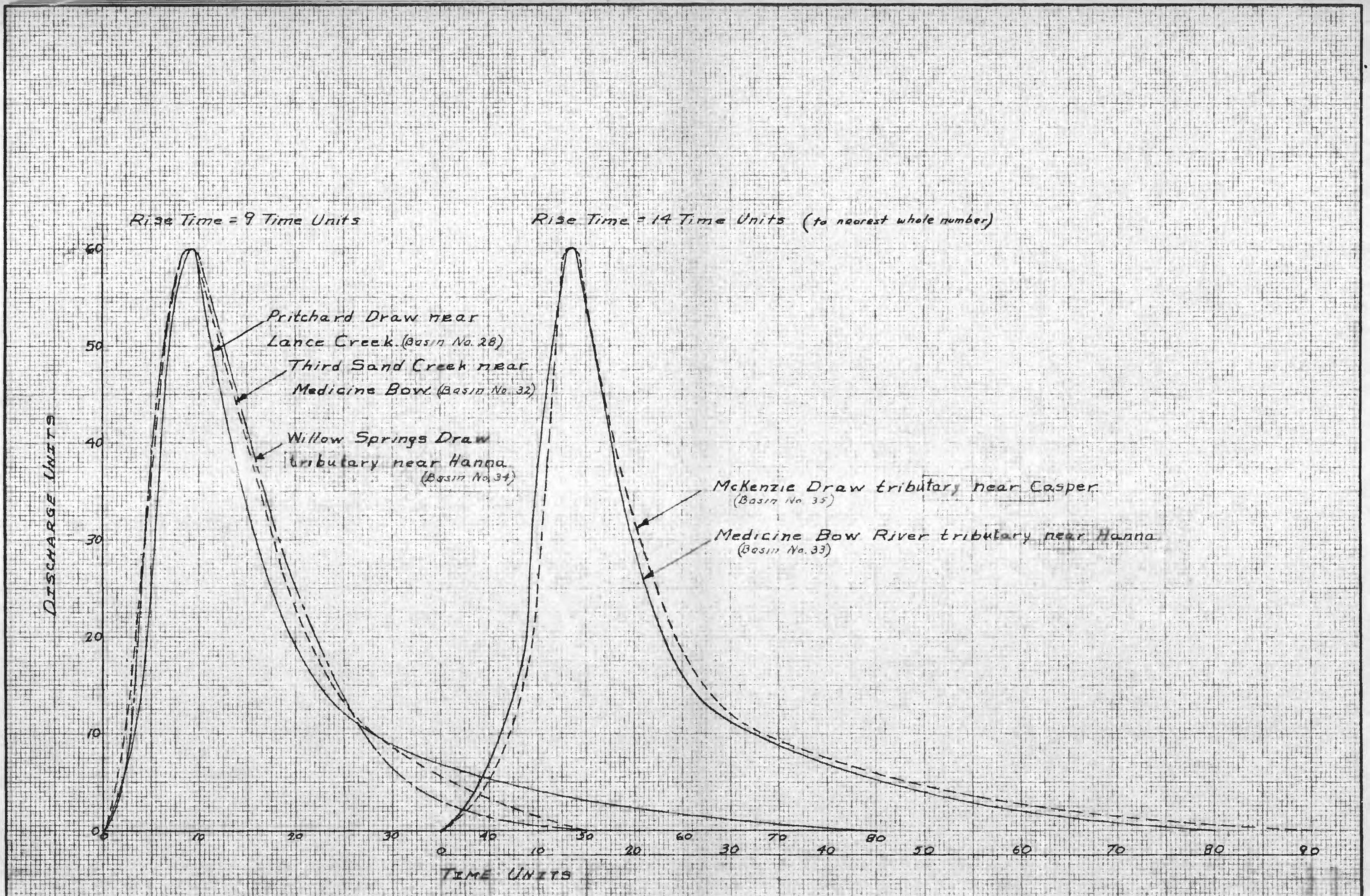

Figure 21.--Comparison of mean dimensionless hydrographs.

The dimensionless hydrographs for a basin (step 3) have variable rise times as a function of runoff volume and peak discharge. However, the rise time of the mean dimensionless hydrograph for a basin is constant, a factor that may also be useful in later regionalizing studies.

Very little has been done thus far in comparing the actual hydrograph for a storm with a predicted hydrograph using this method because all available simple runoff events at a station were used to develop the mean dimensionless hydrograph; independent events occurring in the future will be used for comparisons or checks.

Hydrologic analysis

Peak discharge, runoff volume, and precipitation

The following paragraphs describe the progress in defining relationships between peak discharge, runoff volume, and precipitation. Prerequisite to this type of study is the development of a station rating (a stage-discharge relation at the gaging station) for converting stage (depth of flow) to discharge and for computing the volume associated with each runoff hydrograph. Interpretation of recorded precipitation is also necessary for association with its resulting runoff event.

Some limitations should also be mentioned. Storms combining rainfall with snowmelt, and storms that are not basinwide must be omitted from the analysis. These events tend to have minimal overall effect on the analyses because of the small size of the drainage basins and the seasonal aspect of the data collected. Two other important factors are storm duration and antecedent moisture. Until more data are available to determine correction factors, these effects are assumed to be averaged out in the following relationships.

The relationships obtained between combinations of peak discharge, runoff volume, and precipitation are preliminary in nature and reflect the limited data available. Additional data will allow more sophisticated analyses (statistical) which should provide useable results.

Peak discharge and runoff volume

Graphs of peak discharge and runoff volume were developed for 15 of the 18 rated stations. The three stations omitted did not have a sufficient number of peaks to be considered at the present time. The number of individual peaks per station analyzed in each plot ranged from 5 to 19. The runoff hydrographs and the storms that caused them were investigated prior to drawing each best fit line to represent the peak-discharge to volume relationship for simple storms. Little attempt was made to simplify complex storms, and they were not considered in drawing the line. Curved lines passing through the origin were considered in the initial analysis because they seemed to fit better with the data. However, it appears likely that a straight-line approximation with one slope for the low events and a different slope for the higher events may be more practical. Because the low events probably will not prove significant in the final analysis, more importance was given to the higher events in determining the best fit line. Figures 22-25 are examples of these relationships. The relationships are not final because of the limited data, especially for higher flows.

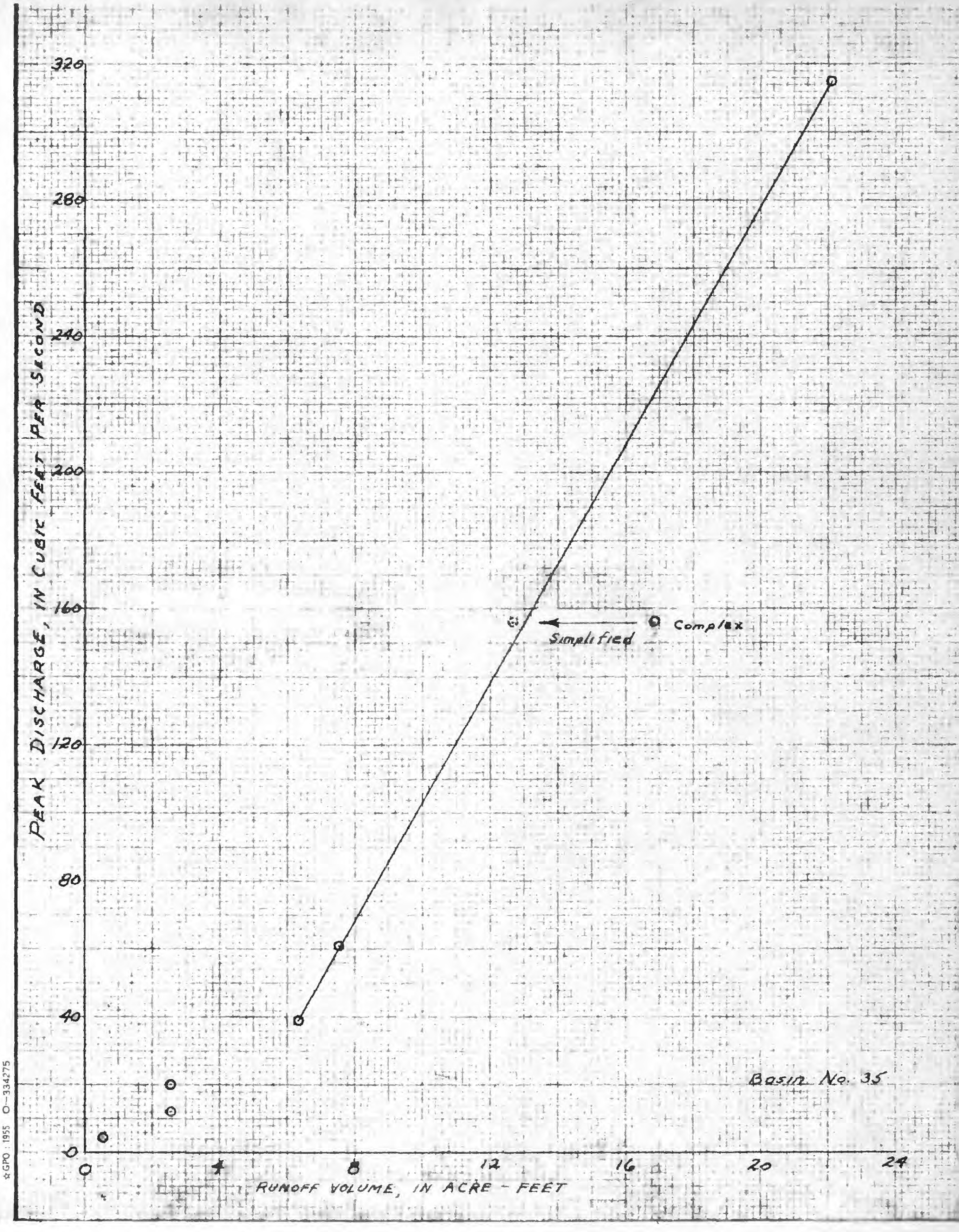

Figure 22.--Relation of peak discharge to volume for McKenzie Draw tributary near Casper, Wyo.

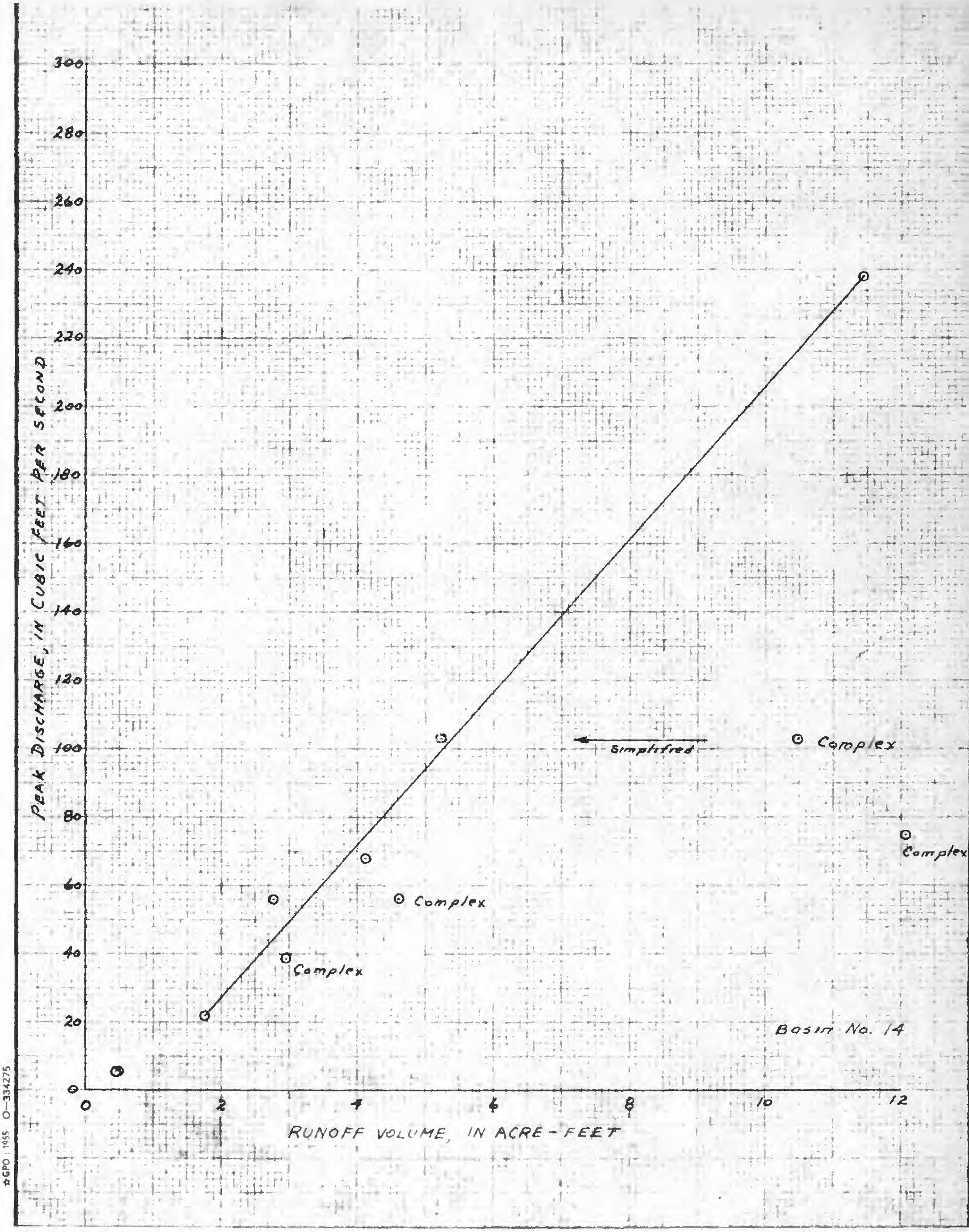

Figure 23.--Relation of peak discharge to volume for Nowood River tributary No. 2 near Basin, Wyo.

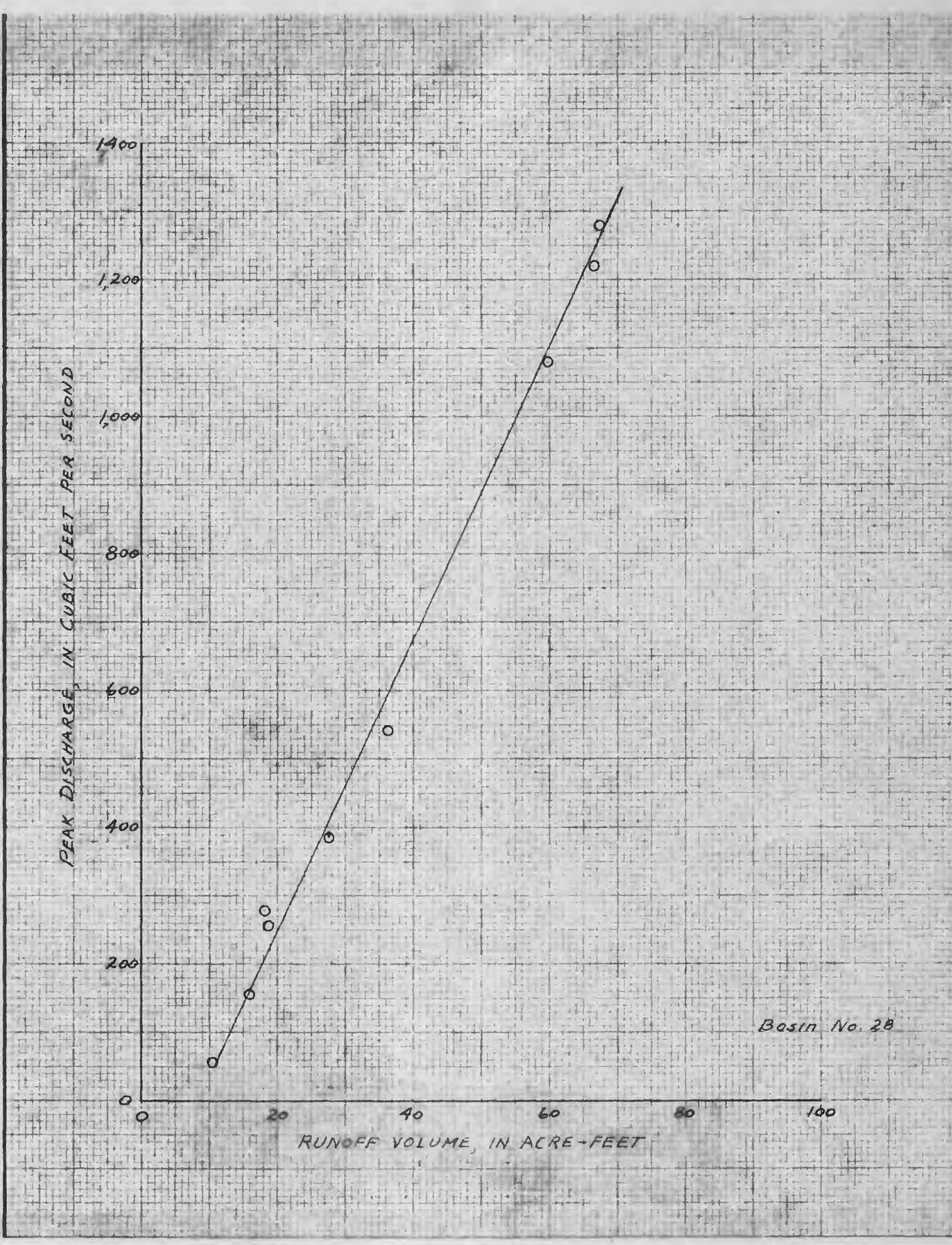

Figure 24.--Relation of peak discharge to volume for Pritchard Draw near Lance Creek, Wyo.

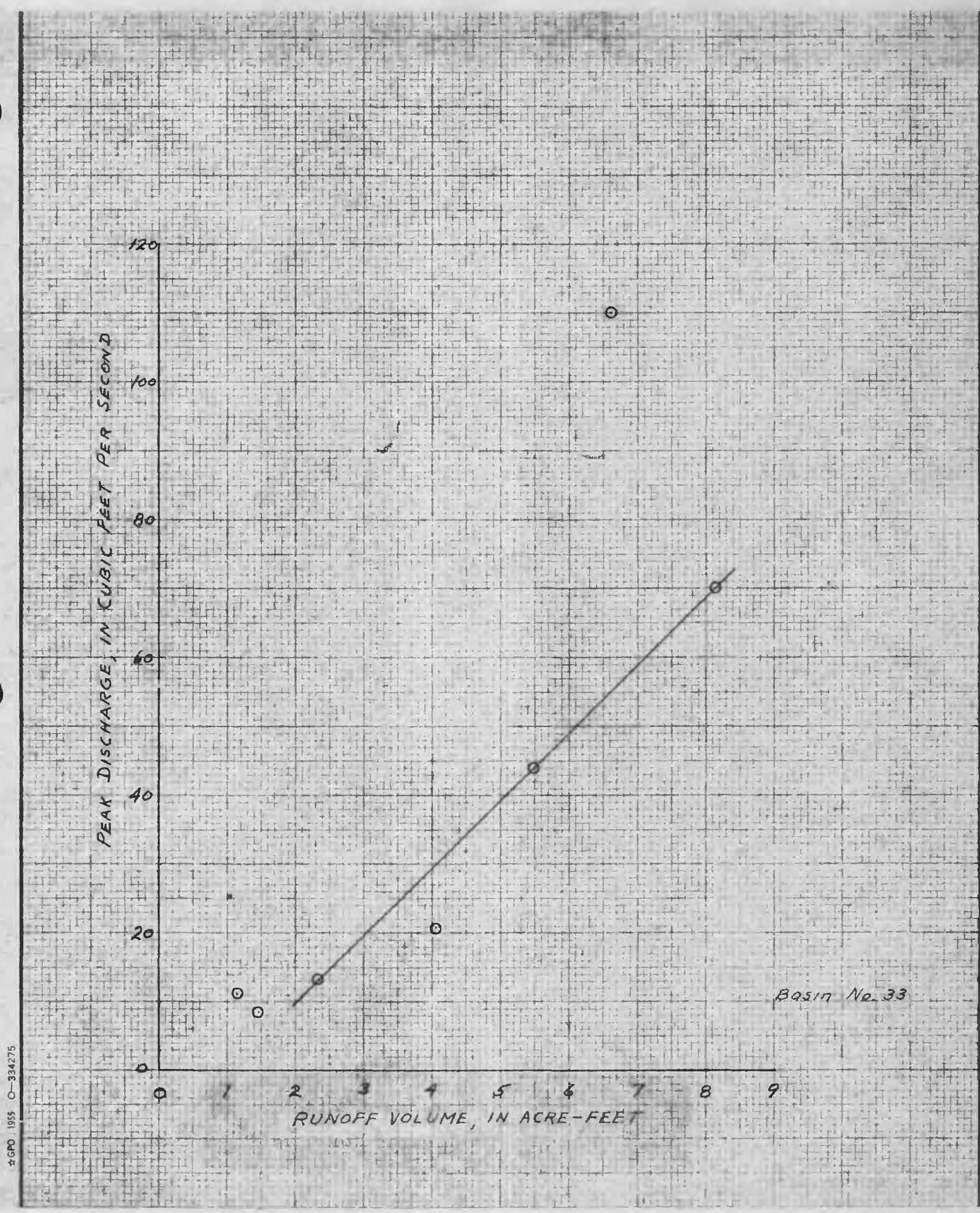

Figure 25.--Relation of peak discharge to volume for Medicine Bow River tributary near Hanna, Wyo.

Subsequent to developing relationships from single-peak events, a complex peak on McKenzie Draw tributary near Casper (basin No. 35) was simplified by elimination of a small secondary peak. The result closely checked the previously drawn relationship (fig. 22). A complex peak on Nowood River tributary No. 2 near Basin (basin No. 14) was simplified (fig. 7) and this simplified peak also closely checked the plot (fig. 23). A more comprehensive study of complex peaks is planned for the future.

Precipitation and peak discharge

Graphs of average basin precipitation and peak discharge were prepared for 15 of the 18 rated stations. The average precipitation was determined for the larger basins (over 5 square miles) using the Thiessen method while an arithmetic average of the recorded amounts was used for the smaller basins. This study considered all significant peaks, including complex peaks.

Linear plots (not illustrated) all show considerable scatter with no apparent relationship. Some logarithmic plots show a straight-line relation (figs. 26-28). Other logarithmic plots, especially for the larger (over 5 square miles) drainage basins, do not indicate a relationship (fig. 29).

Graphical correlation considering antecedent moisture, storm duration, and time of the year was attempted on the largest basin (Third Sand Creek near Medicine Bow, Wyoming), but it did not reduce the scatter significantly.

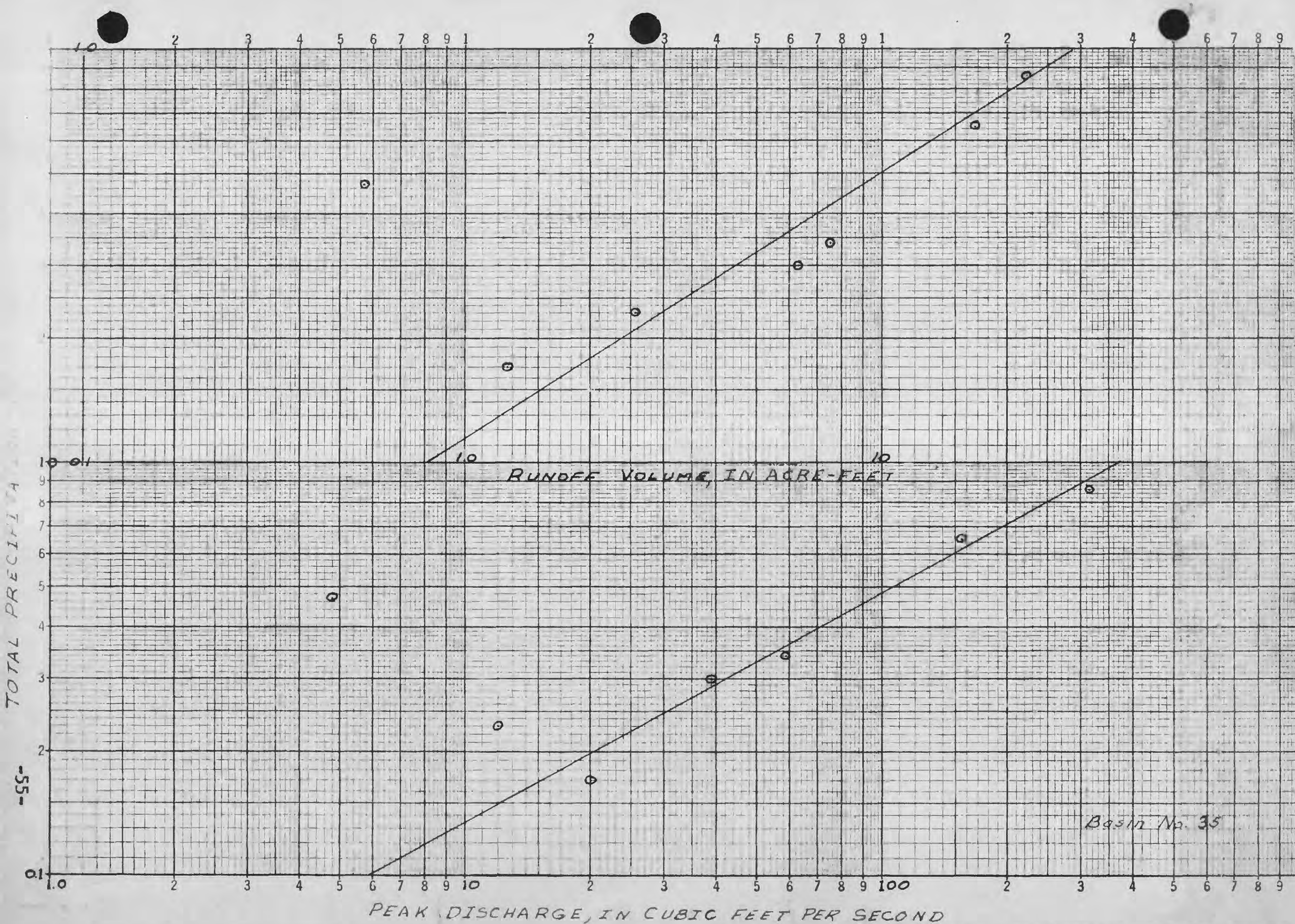

Figure 26.--Relation of precipitation to volume and to peak discharge for McKenzie Draw tributary near Casper, Wyo

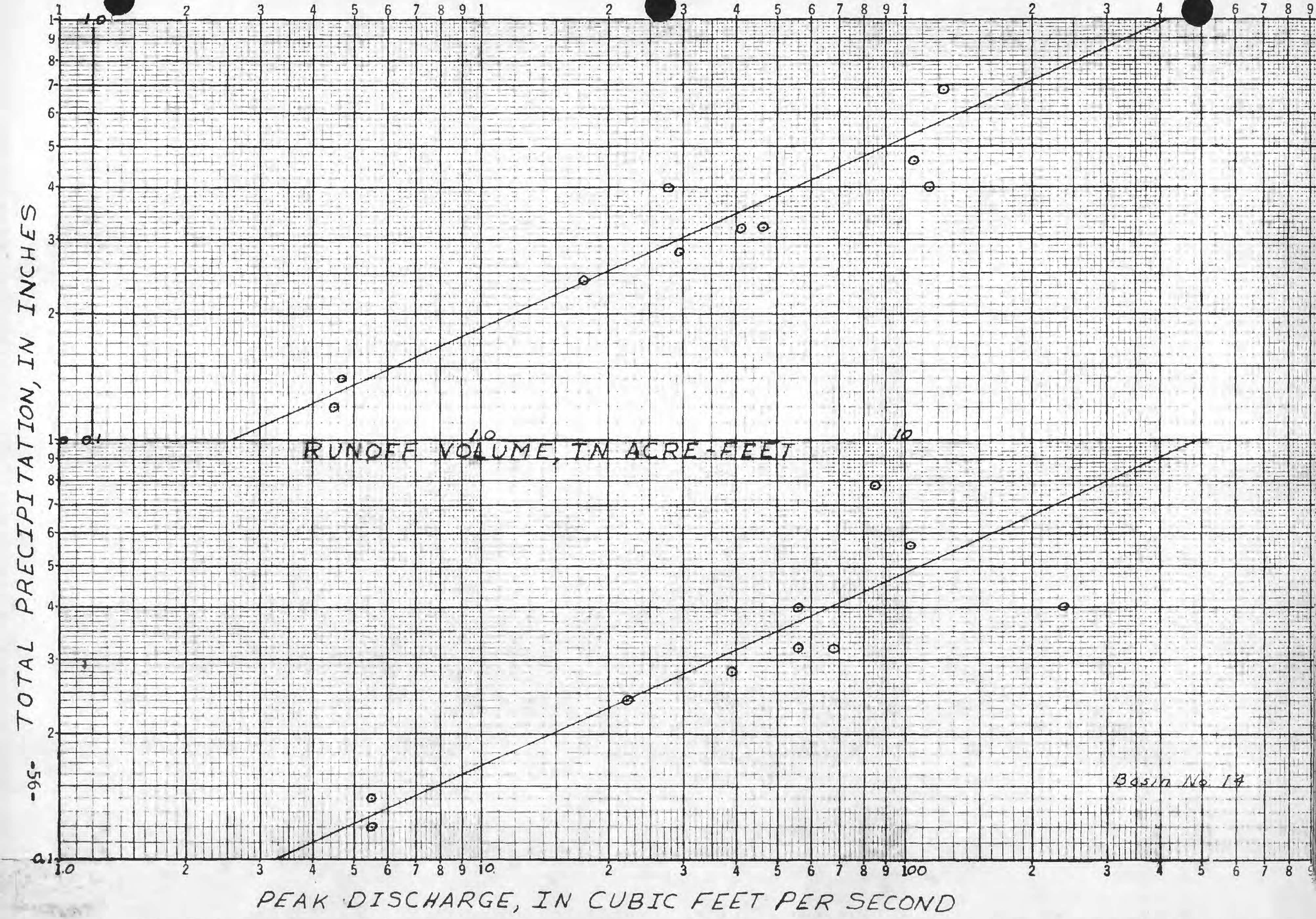

Figure 27.--Relation of precipitation to volume and to peak discharge for Nowood River tributary No. 2 near Basin, Wyo

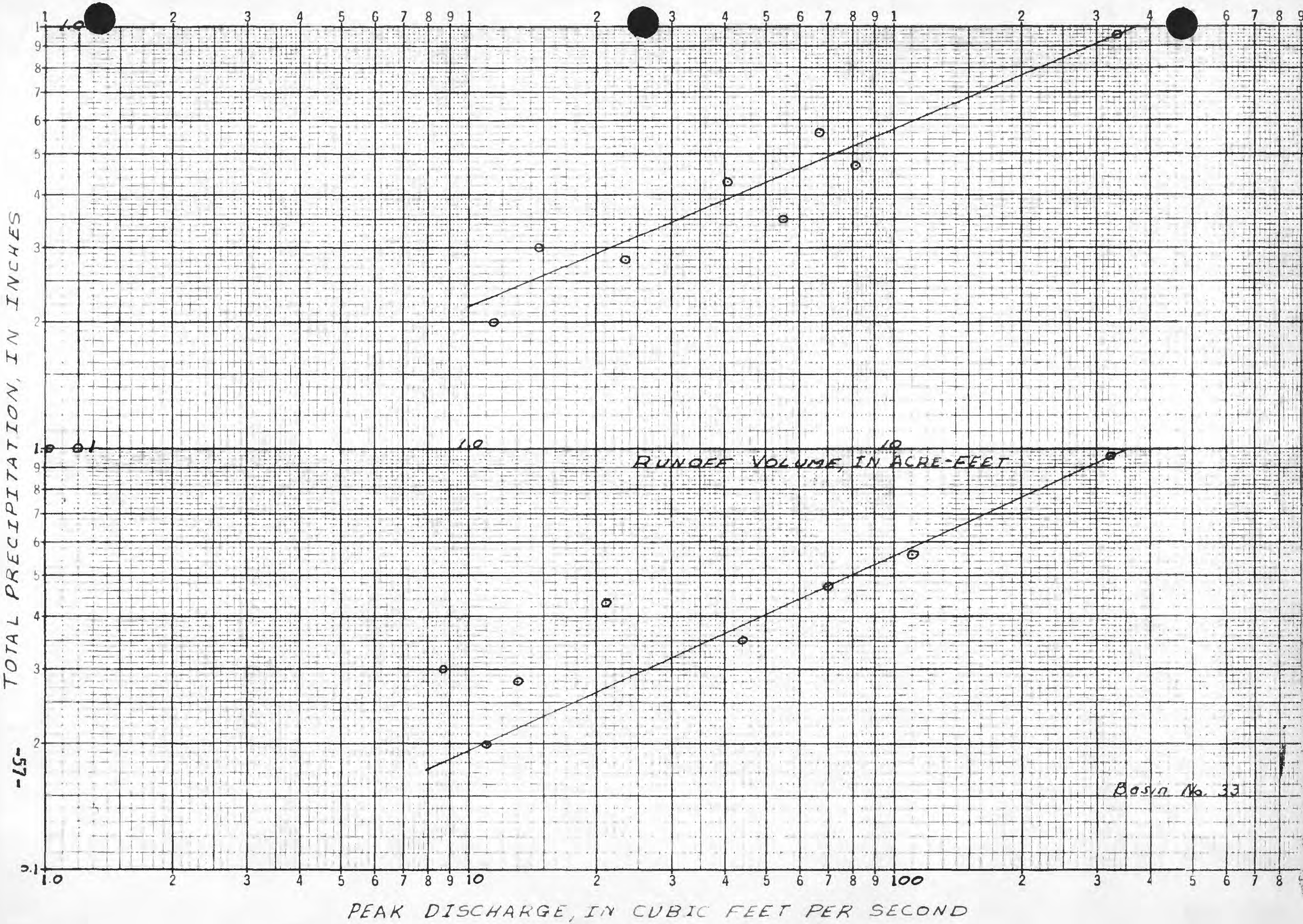

Figure 28.--Relation of precipitation to volume and to peak discharge for Medicine Bow River tributary near Hanna, Wyo.

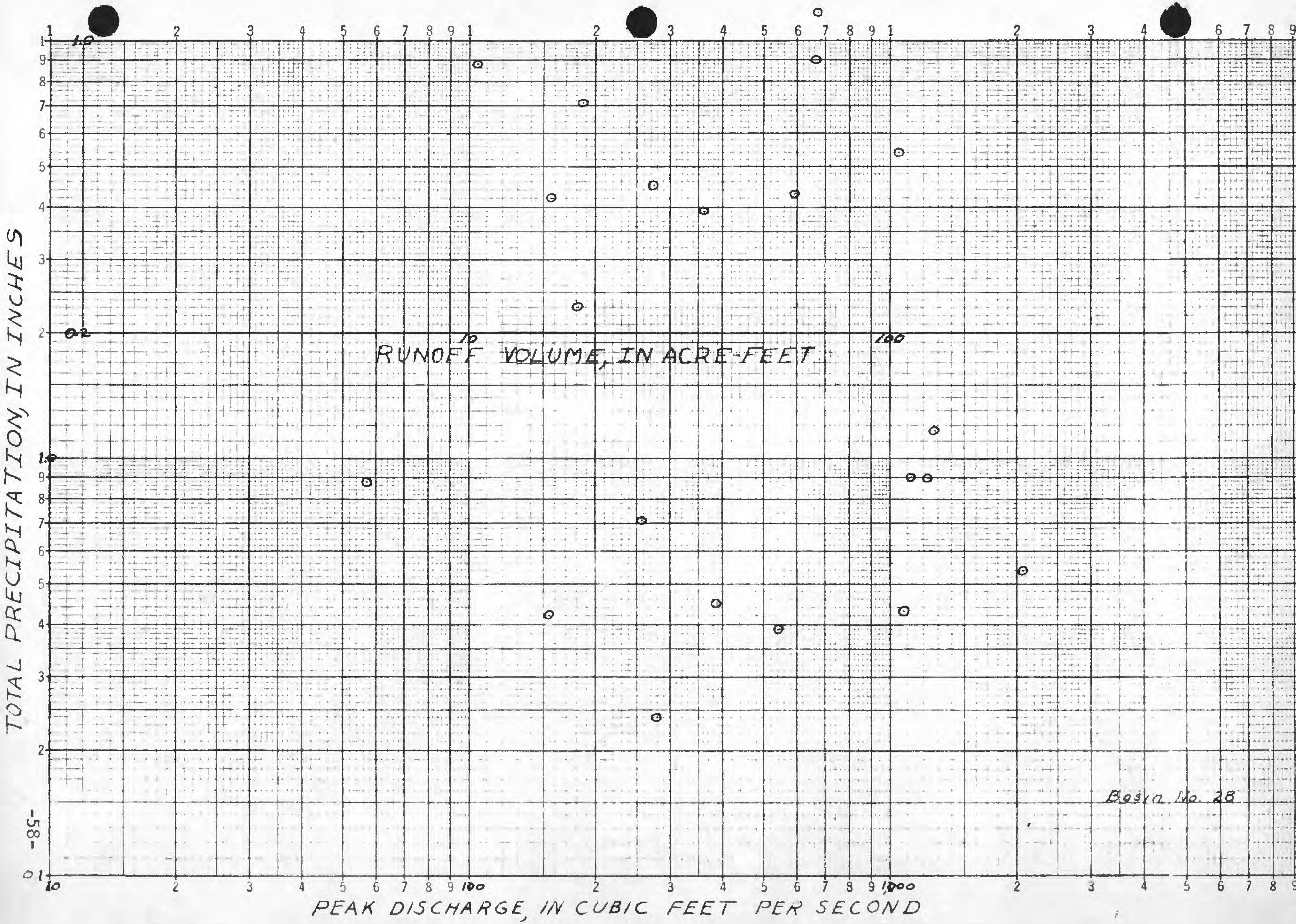

Figure 29.--Relation of precipitation to volume and to peak discharge for Pritchard Draw near Lance Creek, Wyo.

Precipitation and runoff volume

Graphs of average basin precipitation and runoff volume were also developed on the 15 stations with about the same results as mentioned in the preceding study (figs. 26-28). The larger basins in both cases appear to have the greatest variations (fig. 29).

Synthetic frequency of runoff events

One of the handicaps in working with short-term records is the lack of information on the frequency of runoff events. It is likely that frequency information will be needed in developing interbasin and regional relationships; that is, relating the T-year event for various basins to basin parameters. This 10-year project will not provide sufficient records for determining the magnitude of the less frequent runoff events (25-year, 50-year). However, the collection of both runoff and rainfall records on the drainage basins provides a possible means of utilizing Weather Bureau precipitation records to synthesize frequency curves (Snyder, 1958).

One approach is to correlate precipitation records at the study basins with long-term records for a nearby Weather Bureau station. The rainfall for a given frequency is determined for the gaged basin; then the graphs of rainfall to runoff volume or rainfall to peak discharge entered to determine the flood volumes or peaks resulting from this rainfall. There have been no attempts to correlate rainfall as yet because of the short period of record, but an attempt was made to use nearby Weather Bureau records to reconstruct missing records at several of the S-R gages. This effort was not successful, although a correlation such as mentioned above may eventually be possible.

The disadvantage in the above approach is that considerable effort would be needed just to obtain and list the Weather Bureau records for computer analyses of frequency. A different approach was attempted by utilizing Technical Paper 40, the Weather Bureau (1961) atlas of rainfall depth, duration, and frequency, for point precipitation, using the partial-duration series. The S-R site at North Prong East Fork Nowater Creek near Worland (basin No. 12) was selected for the first try.

The first step was to tabulate the precipitation depth (table 2) obtained from each of 49 maps (7 durations and 7 return periods). Depths were obtained by locating the gage site on each map (about 1:10,000,000 scale) and interpolating between the isopluvial lines. Frequency curves of rainfall depth and duration were than plotted (fig. 30). The next problem was to determine the critical duration, the storm duration which would produce the maximum peak discharge for a given precipitation depth. There is some indication that a runoff time parameter may be related to the critical duration (Wisler and Brater, 1949; Snyder, 1958; Fletcher and Davis, 1966; S. Rantz, USGS, written communication, 1967). Eventually, data from the present project may help answer the question; in the meantime, the lag time (discussed previously) was used as the critical duration. The lag time for North Prong East Fork Nowater Creek was fairly well defined by five hydrographs of varying magnitude.

Precipitation depths for the various recurrence intervals for a duration of 2.5 hours (the lag time) were then obtained from the frequency curves. The values were adjusted from the partial-duration series to the annual series by factors given in the Weather Bureau Technical Paper 40. These adjusted values of rainfall were used to obtain the corresponding peak discharge from the relationship developed for the S-R gage (fig. 31). The data used are shown in table 3. The synthetic flood-frequency curve was then plotted (fig. 32).

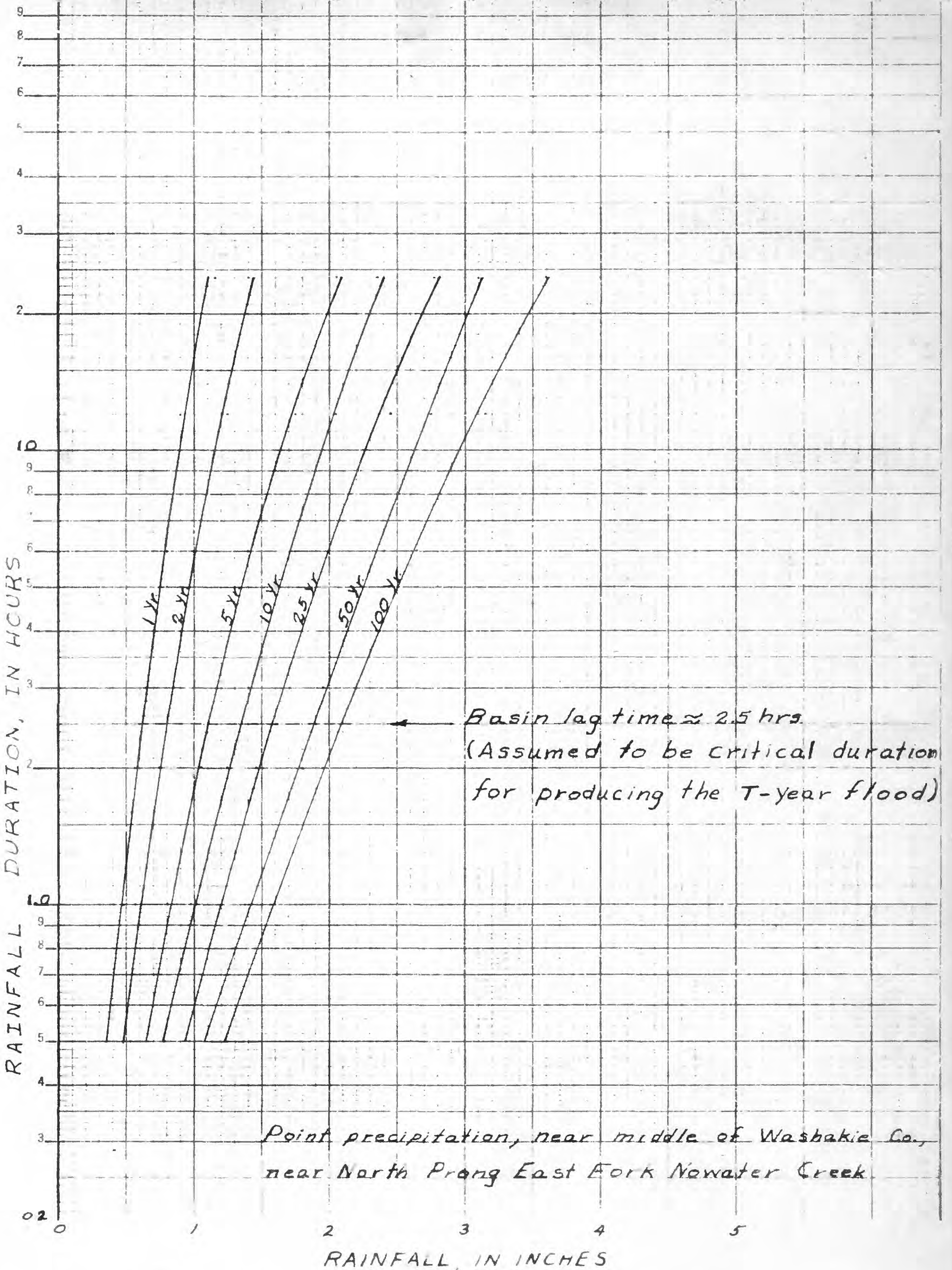

Figure 30.--Frequency curves of rainfall depth and duration (constructed from USWB Technical Paper 40, partial duration series, point precipitation).

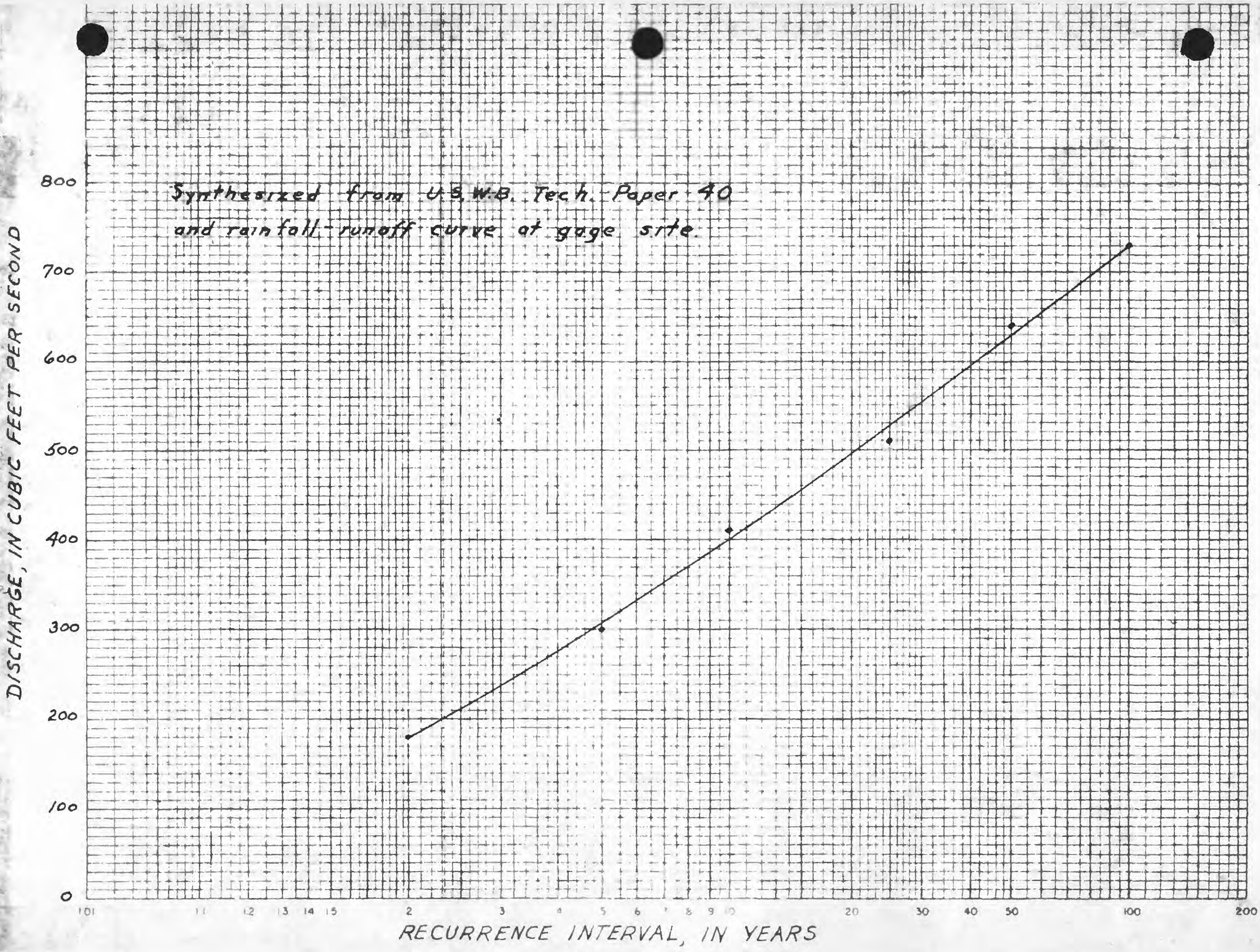

Figure 32.--Synthetic flood-frequency curve for North Prong East Fork Nowater Creek near Worland, Wyo.

Table 2.--Point precipitation, in inches, near middle of Washakie County (near North Prong East Fork Nowater Creek), from USWB Technical Paper 40.

Return period (years)	Rainfall duration (hours)						
	1/2	1	2	3	6	12	24
1	0.35	0.48	0.57	0.64	0.80	0.90	1.15
2	.52	.56	.75	.85	1.00	1.25	1.40
5	.70	.80	1.05	1.30	1.40	1.75	2.05
10	.78	.98	1.24	1.40	1.75	2.05	2.35
25	.97	1.20	1.47	1.70	2.00	2.45	2.78
50	1.12	1.38	1.80	1.95	2.40	2.75	3.10
100	1.24	1.56	1.95	2.20	2.65	3.14	3.60

Probable maximum 6-hour precipitation for 10 square miles = 15.5 inches, approximately equals 5.9 x 100-year 6-hour rainfall.

Table 3.--Rainfall and runoff data for synthetic flood-frequency relation for North Prong East Fork Nowater Creek near Worland.

Recurrence interval (years)	2.5-hr rainfall, partial-duration series (inches)	Conversion factor	2.5-hr rainfall, annual series (inches)	Peak discharge (cfs)
2	0.80	0.88	0.70	180
5	1.10	.96	1.06	300
10	1.35	.99	1.34	410
25	1.57	1.00	1.57	510
50	1.88	1.00	1.88	640
100	2.08	1.00	2.08	730

From the flood-frequency curve it was determined that the two highest peaks recorded to date, 394 cfs and 169 cfs, had recurrence intervals of 9.5 and 1.8 years, respectively.

The relations of rainfall to peak discharge and runoff for this site were developed by ignoring the storms which either were not basinwide or which obviously included snowmelt. Data were not sufficient to correct for storm duration or antecedent moisture, so an average curve was drawn. It is not possible to predict whether data for at least some sites eventually will allow consideration of these two variables.

The simplicity of this approach is attractive. It does not, however, recognize all of the complications of the runoff process, and thus must be used with extreme caution. The assumption of a unique relation between rainfall and peak flow is not reasonable in view of the large effect that antecedent conditions and distribution of rainfall may have on both volume of runoff and peak discharge. There is no basis in fact for the assumption that a T-year rainfall event produces a T-year flood peak. Furthermore, the use of a "critical duration" equal to the lag time may be questioned, and there is no way to evaluate the accuracy of the approach.

Further investigation, however, of the use of long-term records of rainfall to extend records of peak flow appears to be warranted. The use of the general purpose digital model of rainfall-runoff process which was developed by D. R. Dawdy will be explored. The data requirements for the model are a short-term record of storm rainfall and runoff at the gaged sites, and the availability of long-term rainfall records in the region. The use of the model approach avoids the assumptions described above and is an efficient way of utilizing both data and hydrologic knowledge in the study of flood frequency.

Summary

The study of flood hydrographs for small drainage basins in Wyoming is progressing satisfactorily. Analysis of 3 years of data collected to date (April 1968), although limited, indicates a good possibility of realizing the objectives of this planned 10-year program. The encouraging features include: 1) the successful instrumentation of the 49 basins; 2) the favorable correlation of runoff volume to rainfall and peak discharge; 3) the favorable results in synthesizing hydrograph shape, with indications that regionalization may be possible; and 4) the use of synthetic frequency as a potential means of extending the frequency distribution of runoff events. A more extensive study of basin parameters is necessary before they can be critically evaluated. These parameters are expected to be the key factors in relating drainage basins.

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APPENDIX.--List of 49 drainage basins involved in research project and the selected physical basin parameters determined to date. Numbers in left column are those placed on index map (fig. 2) for site location and identification.

No.	Station Name	Drainage Area (sq mi)	Main Channel Slope Index	Basin Slope Index (20' contour)	Basin Length (ft)	Average Basin Width (ft)	Main Channel Length (ft)	Basin Perimeter (ft)	Maximum Basin Reli[ef] (ft)
1	Monument Draw at upper station, near Hudson	5.50	0.0130	0.1208	21,400	7,160	27,450	60,780	478
2	Monument Draw at lower station, near Hudson	8.23	.0112	.1361	29,700	7,730	42,100	80,400	594
3	Coal Mine Draw tributary near Hudson	0.63	.0291	.1299	7,250	2,420	8,150	20,470	274
4	West Fork Dry Cheyenne Creek at upper station, near Riverton	0.69	.0145	.0455	9,600	2,000	10,200	24,890	173
5	West Fork Dry Cheyenne Creek tributary near Riverton	1.85	.0167	.0675	11,600	4,450	12,600	31,750	314
6	West Fork Dry Cheyenne Creek near Riverton	3.52	.0117	.0627	15,100	6,500	16,350	48,220	321
7	Dead Man Gulch tributary near Lysite	0.54	.0270	.1335	6,450	2,330	7,450	17,480	285
8	Dead Man Gulch near Lysite	4.11	.0168	.1554	16,550	6,920	18,700	47,840	500
9	Badwater Creek tributary near Lysite	5.86	-	-	19,850	8,230	25,600	-	-
10	Gillies Draw tributary near Grass Creek	1.30	.0386	.1364	7,450	4,860	7,150	28,180	375
11	Murphy Draw near Grass Creek	2.32	.0201	.0816	16,900	3,830	16,900	41,280	463
12	North Prong East Fork Nowater Creek near Worland	3.77	-	-	-	-	-	-	-
13	North Prong East Fork Nowater Creek tributary near Worland	2.11	-	-	-	-	-	-	-
14	Nowood River tributary No. 2 near Basin	1.51	.0265	.0828	13,450	3,130	14,400	33,440	397
15	Dead Horse Creek tributary near Midwest	1.53	-	-	-	-	-	-	-
16	Dead Horse Creek tributary No. 2 near Midwest	1.34	-	-	-	-	-	-	-
17	Bobcat Creek near Edgerton	8.29	-	*.0826	23,900	9,670	29,400	63,950	490
18	Coopers Draw near Edgerton	1.11	.0206	.0925	11,000	2,810	11,400	26,350	345
19	Seven L Creek near Edgerton	7.10	-	*.1034	21,200	9,340	24,400	59,700	585
20	East Teapot Creek Near Edgerton	5.44	-	*.1160	12,600	12,000	14,400	54,150	430
21	Dugout Creek tributary near Midwest	0.71	-	-	-	-	-	-	-
22	Headgate Draw at upper station, near Buffalo	1.13	-	-	-	-	-	-	-
23	Headgate Draw at lower station, near Buffalo	2.64	-	-	-	-	-	-	-
24	Powder River tributary near Buffalo	1.53	-	-	-	-	-	-	-
25	Box Draw tributary near Gillette	0.53	-	-	-	-	-	-	-
26	Rawhide Creek tributary near Gillette	2.65	-	-	-	-	-	-	-

APPENDIX.--List of 49 drainage basins involved in research project and the selected physical basin parameters determined to date. Numbers in left column are those placed on index map (fig. 2) for site location and identification.--Continued

No.	Station Name	Drainage Area (sq mi)	Main Channel Slope Index	Basin Slope Index (20' contour)	Basin Length (ft)	Average Basin Width (ft)	Main Channel Length (ft)	Basin Perimeter (ft)	Maximum Basin Relief (ft)
27	Lance Creek tributary near Lance Creek	1.17	-	-	-	-	-	-	-
28	Pritchard Draw near Lance Creek	5.12	-	-	-	-	-	-	-
29	Ogden Creek near Sundance	8.42	-	-	-	-	-	-	-
30	Sundance Creek tributary at Sundance	0.76	-	-	-	-	-	-	-
31	Third Sand Creek tributary near Medicine Bow	0.78	-	-	-	-	-	-	-
32	Third Sand Creek near Medicine Bow	10.80	-	-	-	-	-	-	-
33	Medicine Bow River tributary near Hanna	3.01	-	0.0936	-	-	-	-	495
34	Willow Springs Draw tributary near Hanna	1.98	-	.1226	14,000	3,940	12,600	40,230	540
35	McKenzie Draw tributary near Casper	2.02	0.0190	.0943	10,800	5,210	11,550	30,800	346
36	Frank Draw tributary near Orpha	0.79	.0230	.0785	9,700	2,270	10,600	23,250	337
37	Sage Creek tributary near Orpha	1.38	.0178	.0673	14,200	2,710	15,400	33,950	318
38	Deadmans Gulch near Guernsey	0.34	-	-	4,200	2,260	4,690	-	-
39	Fish Canyon near Guernsey	1.06	-	-	7,700	3,840	8,000	-	-
40	Black Canyon near Guernsey	0.22	-	-	3,600	1,700	3,770	-	-
41	Sparks Canyon near Hartville	0.74	-	-	6,600	3,130	7,400	-	-
42	Piney Creek tributary at upper station, near Wheatland	0.18	-	-	4,850	1,030	5,600	-	-
43	Piney Creek tributary at lower station, near Wheatland	0.58	-	-	7,300	2,210	8,050	-	-
44	Rabbit Creek near Wheatland	1.30	-	-	-	-	-	-	-
45	Telephone Canyon near Green River	6.98	-	-	-	-	-	-	-
46	Telephone Canyon tributary near Green River	3.44	-	-	-	-	11,550	-	-
47	Mud Springs Hollow tributary near Lyman	0.97	-	-	-	-	-	-	-
48	Mud Springs Hollow near Church Butte, near Lyman	8.83	-	-	-	-	-	-	-
49	Twin Creek tributary near Sage	2.91	.0414	**.2019	14,400	5,630	14,600	41,200	1,130

* Used 100 ft contours.--Not plotted on Figure 3.
** Used 40 ft contours.