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BASIC HYDROLOGIC PRINCIPLES

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BASIC HYDROLOGIC PRINCIPLES

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Introduction

The geography and geology of the Western Region presents diverse forecasting requirements. As a result, the forecasting techniques vary considerably, with many unusual problems that require special solutions.

Water-control structures such as dams, levees, etc., offer a positive method of reducing or eliminating the damages caused by flooding. In numerous situations, however, topographic (lack of potential dam sites) and/or economic factors make the control of floods impractical or unjustifiable. In these situations river forecasting provides a valuable alternative means of reducing flood damage and loss of life. Advance warning of an approaching flood permits evacuation of people, livestock, and equipment. The warning time available determines how much evacuation is possible. River forecasts are required for estimating inflow to reservoirs in order to permit the most efficient operation for flood control or other purposes. In addition, there is an increasing demand for day-to-day forecasts of river stages and discharges by those interested in navigation, water supply, stream pollution, and many other related disciplines.

Because of the importance of the time factor, great stress must be placed on the development of forecast procedures that will enable flood warnings to be issued at the earliest possible time. A warning received too late to permit evacuation of people and removal of property from the threatened area is of no value.

I. Basic River-Forecasting Procedures

Where adequate data are available and forecasts of the complete hydrograph are required, a reasonably standardized approach to river forecasting has been developed. Rainfall-runoff relations are used to estimate the amount of water expected to appear in the streams, while unit hydrographs and streamflow-routing procedures, in one form or another, are utilized to determine the time distribution of this water at a forecast point. Stage-discharge relations are then utilized to convert these flows to stages.

A. Rainfall-Runoff Relations

Rainfall-runoff relations are developed using data from one or more headwater areas in the basin for which forecasts are required.

Studies must be limited to areas for which the runoff can be evaluated (from the hydrograph) for each individual storm event.

The storm precipitation is the average over the basin. If a sufficient number of precipitation stations are available, an arithmetic mean is usually sufficient, although a weighting technique can be used, especially to take into account elevation.

The storm runoff in most river-forecasting relations is direct runoff. Direct runoff is assumed to be the water which reaches the stream by traveling over the soil surface and through the upper soil horizons and has a rapid time of concentration. It is composed of surface runoff, precipitation intercepted by the channel, and interflow.

B. Unit Hydrographs

The rainfall-runoff relation provides an estimate of the volume of water which will run off for a given storm situation. It is then necessary to determine the distribution of this water with respect to time at the forecast point by using a unit hydrograph. In order to deal effectively with uneven distribution of runoff in time, unit hydrographs for short periods are used, very often for 6- or 12-hour durations. The increment of runoff is estimated for each time period, with the contributions from each interval superimposed upon the previous contributions.

C. Streamflow Routing

The next basic problem is to predict the movement and change in shape of a flood wave as it moves downstream. Specifically, the river forecaster is interested in determining the shape of the flood wave from an upstream point to a downstream point after being modified by lag and storage in the reach.

D. Stage-Discharge Relations

One of the final products of the forecaster is the stage to which the river will rise. When the forecast point is a rated station and the stage-discharge relation is defined by a single curve there is no problem in converting discharge to stage. If the gage is not rated, then it is necessary to develop a synthetic rating using concurrent records at the unrated gage and the nearest rated station.

In many cases the relationship of discharge to stage is complicated by the effects of slope, backwater, and scour. Another problem is the extension of rating curves beyond the maximum observed discharge so that forecasts of record-breaking flows can be converted to stage.

E. Average Precipitation where Topography is a Factor

In mountainous areas where topographic features affect the precipitation, average basin-precipitation values determined by arithmetic means or Thiessen weights can be considered only as an index to the actual amounts. A solution is to use the percent normal method. 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, and these percentage values averaged for the basin. The basin normal annual precipitation multiplied by this storm percent value provides an average storm precipitation. Use of this percent normal method reduces the need for a consistent reporting network.

This technique also provides a method for estimating average precipitation when only a portion of the basin is contributing to runoff. From the normal annual isohyetal map, the normal annual precipitation below various elevations can be determined. The contributing area is related to elevation. The normal annual precipitation below the elevation would be multiplied by storm percent value to obtain the average precipitation over the contributing area.

F. Note on Conceptual Hydrologic Models

Rainfall-runoff relationships fall into the category of index methods in river forecasting. Gradually, index methods are being replaced where practicable by conceptual hydrologic models. These include: a soil moisture accounting model, snow accumulation and ablation model, and dynamic flood routing.

The soil moisture accounting model describes the movement of water within the mantle. It considers percolation down through the soil, soil moisture, drainage, and evapo-transpiration in representing the significant hydrologic processes in the soil.

The snow model describes the important physical processes taking place during the accumulation and ablation of a snow cover. Dynamic routing utilizes one-dimensional equations for unsteady flow to route water from upstream areas to downstream areas.

II. HYDROGRAPHS AND UNIT HYDROGRAPHS

A hydrograph is a graph of stage or discharge against time. The hydrograph of outflow from a small basin is the sum of the elemental hydrographs from all of the subareas of the basin, modified by the effect of transit time through the basin and storage in the stream channels.

It would be wrong to imply that one typical hydrograph would suffice for any basin. Although the physical characteristics of the basin remain relatively constant, the variable characteristics of storms cause variations in the shape of the resulting hydrographs. The storm characteristics include rainfall duration, time-intensity pattern, areal distribution of rainfall, and the amount of rainfall.

Duration - Since the unit hydrograph always contains 1 inch of runoff, increasing the duration of the rainfall, while keeping the total rainfall amount the same, lengthens the time base and lowers the unit hydrograph peak.

Time-intensity pattern - In practice, unit hydrographs can be based only on an assumption of uniform intensity of runoff. However, large variations in rain intensity (and hence runoff rate) during a storm are reflected in the shape of the resulting hydrograph.

Areal distribution of runoff - The areal pattern of runoff can cause variations in the hydrograph shape. If the area of high runoff is near the basin outlet, a rapid rise, sharp peak and rapid recession usually result. Higher runoff in the upstream portion of the basin produces a slow rise and recession and a lower, broader peak.

Amount of runoff - A basic part of the unit hydrograph idea is that the ordinates of flow are proportional to the volume of runoff for all storms of a given duration.

The duration assigned to a unit hydrograph should be the duration of rainfall producing significant runoff. This should be determined by inspection of hourly rainfall data. The unit hydrograph is best derived from the hydrograph of a storm of reasonably uniform intensity and duration of desired length.

The unit hydrograph can be used to derive the hydrograph of runoff due to any amount of effective rainfall.

Assumptions:

a) The effective rainfall is uniformly distributed within a specified period of time.

b) The effective rainfall is uniformly distributed throughout the whole area of the drainage basin.

c) The base or time duration of the hydrograph of direct runoff due to an effective rainfall of unit duration is constant.

d) The ordinates of the direct-runoff hydrographs of a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph.

e) For a given drainage basin, the hydrograph of runoff due to a given period of rainfall reflects all of the combined physical characteristics of the basin.

Under the natural condition of rainfall and drainage basins, the above assumptions cannot be satisfied perfectly. However, when the hydrologic data used for unit-hydrograph analysis are carefully selected so that they meet the above assumptions closely, the results obtained by the unit-hydrograph theory have been found acceptable for practical purposes.

Physical characteristics that may be expected to have some effect on the dimensions or shape of the unitgraph:

Area - The total volume in a unitgraph is proportional to the area of the drainage basin (always is equal to 1" of runoff).

Channel Slope - Other things being equal, the steeper the channel slope, the greater the velocity of flow and the more peaked the unitgraph.

Size of Channel - As between two channels of equal slope, the one with the larger cross-section has more storage capacity per mile and may therefore be expected to exert a greater regulatory or attenuating effect on the passage of a flood wave.

Condition of Channel - Affects the velocities and therefore the peaks.

Stream Pattern - A fan-shaped area with streams radiating more or less from a common point suggests the possibility of synchronized peaks from the constituent subareas, while an elongated area traversed by one major stream with more or less uniformly spaced tributaries suggests the possibility of a slower and less pronounced rise and recession.

Stream Density - Closely spaced tributaries suggest the possibility of more rapid runoff; however, it is easily possible to overestimate the importance of the characteristic.

III. STREAMFLOW ROUTING

A flood wave changes shape as it moves downstream. The rising side of the wave is steeper than the recession side, and hence moves faster. A rapid rise causes high velocities in the first stages of the flood, which in turn results in rapid dissipation of the first portion of the flood wave in valley, or channel, storage. As the channel cross-sectional area increases downstream, valley storage increases with a corresponding attenuation in the crest flows. At the same time steeper channel slopes result in higher velocities.

The shape of a flood wave is affected by several factors:

1) Rate of rise
2) Height of rise
3) Slope of channel
4) Stages downstream
5) Channel sections downstream
6) Length of reach.

The degree of flattening and the shape of the hydrograph are determined by relatively stable channel characteristics. Thus, the relationship of hydrograph shape at some point to hydrograph shape downstream from this point can be determined by analysis of past floods.

Also, there will be tributaries entering some, if not all, of the reaches into which the river must be divided for routing purposes. The flow of these tributaries may be sufficient to mask completely the attenuating effects of storage in the mainstream channel. Moreover, the flood hydrographs of the tributaries are not necessarily, or even likely to be, synchronous with the flood hydrograph at the upstream end of the reach. As a result the lag may also be masked--even to the extent that in extreme cases the peak discharge from a reach may precede the peak inflow to the reach.

Crest-Stage Relations

In routing water downstream gage relations are most effective when the local inflow is relatively small compared with the mainstream inflow. It is also necessary that the peak of the local inflow bear a fixed time relation to the peak of the mainstream inflow.

Simple Gage Relations. The simple stage relation is a plotting of *crest stage* at one station against the corresponding *crest stage* at a downstream station.

Complex Stage Relations. As conditions depart more and more from the ideal situation, the deviations from an average stage relation become larger and larger.

If the variations from the normal curve appear to be due to variations in local inflow, the obvious parameter is a factor which expresses the amount of tributary inflow. If a single large tributary enters the reach, stages on that tributary may serve as the necessary element.

Tributary stages are the most desirable parameter for stage relations, as they provide definite information as to magnitude and volume of tributary inflow.

The best data for development of simple gage relations are crest stages or discharges. If stages during the rise and fall are plotted, they will define a loop similar to that of storage vs. outflow. Moreover, local inflow during rising and falling stages is not necessarily in the same proportion as at crest. The most reliable crest data are obtained from charts of automatic water-stage recorders.

In constructing a complex gage relation, using tributary stage as a parameter, records from automatic gages are highly desirable. *It is important in all gage relations that the stages used for upstream points be those actually influencing the crest at the downstream station.* In other words, *the upstream and downstream stages must be separated by a time interval* equal *to the time of travel*.

Lag and *time of travel* are usually approximately equal since the center of mass of a hydrograph tends to bear the same time relation to the peak at both stations, but, in general, the lag is slightly longer than the time of travel.

Time of travel is not necessarily a constant for a particular reach. In those reaches where adequate data throughout the entire range of stage are available, time of travel will be found to be quite long at low stages, to decrease to a minimum at some moderate stage, and to increase slowly again as stages pass bankful and overbank storage takes place.

To estimate travel time a very simple formula, $^{D}/\sqrt{S'}$, can be used. D is the reach length, in miles. S'is the mean slope, in ft./mile. The result of $D/\sqrt{S'}$ is the approximate travel time in hours.

A. Factors Affecting Flood Flow

Levees. It is by no means easy to predict the effect of levees on the shape of the hydrograph or height of the flood crest. In the process of confining a flood, the levees deny to the river a considerable amount of storage formerly available to it in overbank areas. One effect of a levee system is to impede normal attenuation and thus tend to make flood peaks downstream from the system higher than they were before its construction.

Channel Improvements. By lowering the stage corresponding to a given flow, channel improvements tend to modify the storage relationship in the direction of reducing the amount of storage in the reach adjacent to, and upstream from, the improvements. This reduces the natural attenuation and thus tends to increase flood peaks downstream.

IV. STEPS TO DEVELOP PROCEDURES FOR LOCAL PROBLEM AREAS

1. Derive Area-Elevation Curve

The area-elevation curve is, in a sense, the basin profile, and its mean slope (in feet per square mile) is a useful statistic in comparing basins.

Area-elevation data (Figure 1) is usually produced by planimetering on topographic maps the area enclosed within each contour and the basin divide. Equally satisfactory results may be obtained by use of a transparent grid laid over a topographic map. The number of intersections falling within various elevation ranges can be counted, and the resulting tally (Figure 2) gives a frequency distribution of elevation of grid intersections which, if based on a significant number of points, is also a reasonably close approximation of the area-elevation distribution.

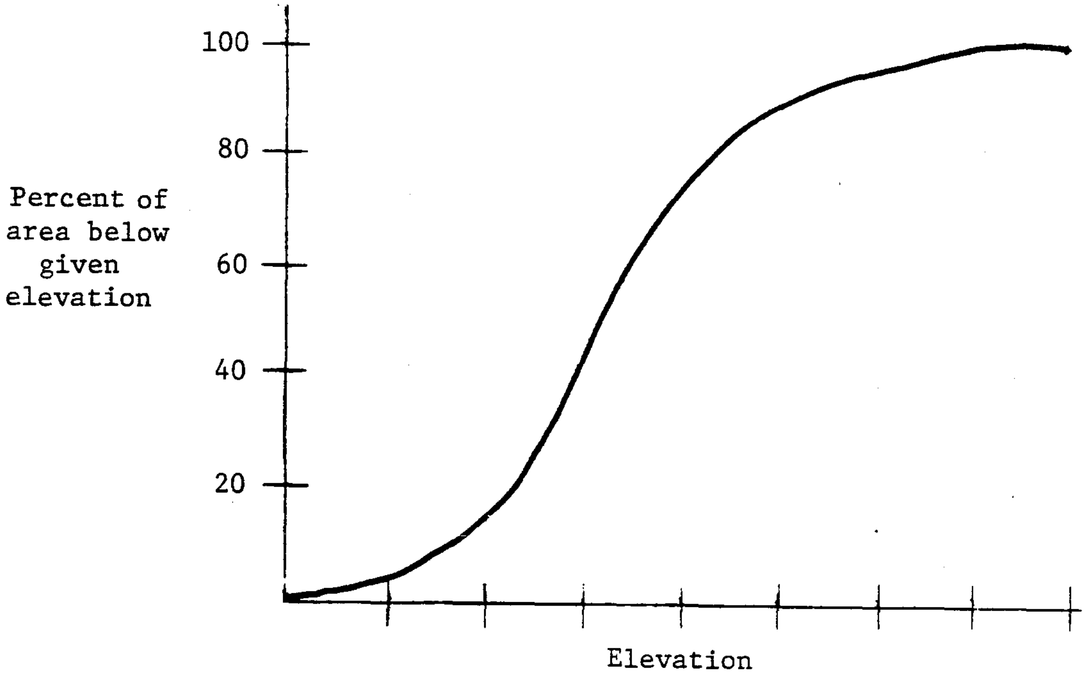


Figure 1. Area - Elevation Curve

AREA-ELEVATION COMPUTATION

Basin Big Cottonwood Creek above Cottonwood, Utah Drainage area 920 sq mi

Maps Salt Lake City Quadrangle, USGS Scale 1' 125,000 Grid 4 mi

Salt Lake City Aeronautical Chart Scale 1' 500,000 Grid 4 mi

Elev. 100 ft	Tally	Total Tally	Acc. Tally	% Area Below Elev.	Mean Zonal Elev.	Moment About MSL
				0.		
45						
	111	3	3	1.3	4,750	14,250
50						
	~~1111~~ 1	6	9	3.9	5,250	31,500
55						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ 11	22	31	13.4	5,750	126,500
60						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ 1111	44	75	32.4	6,250	275,000
65						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ 1111	39	114	49.4	6,750	263,250
70						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ 11	27	141	61.1	7,250	195,750
75						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~	25	166	72.0	7,750	193,750
80						
	~~1111~~ ~~1111~~ ~~1111~~ ~~1111~~ 1111	24	190	82.3	8,250	198,000
85						
	~~1111~~ ~~1111~~ ~~1111~~ 1111	19	209	90.5	8,750	166,250
90						
	~~1111~~ ~~1111~~ 11	12	221	95.7	9,250	111,000
95						
	~~1111~~ 1	6	227	98.4	9,750	58,500
100						
	1111	4	231	100.0	10,250	41,000
TOTAL		231	231	100.0	--	1,674,750

Maximum elev. 11,075' Minimum elev. 4,990' Mean elev. 7,250'

Table 1. Computation Form for Area-elevation Data

2. Derive Unit Hydrograph
(See detailed derivation in Section VIII)

   a. The unit hydrograph is best derived from the hydrograph of a storm of reasonably uniform intensity, duration of desired length, and a runoff volume near one inch.

   b. A unit hydrograph derived from a single storm may be in error. It is desirable to average the unit hydrographs from several storms of the same duration.

   c. The steps in the derivation of a unit hydrograph are as follows:

      1) Separate the groundwater flow, and measure the volume of direct runoff from the storm.

      2) Divide the ordinates of direct runoff by the runoff volume (expressed in inches over the drainage basin). The resulting hydrograph is a unit graph for the basin.

      3) Determine the effective duration, i.e., 2 hours, of runoff-producing rain for which the unit graph is applicable by studying the rainfall records.

3. Simple Rating Curves

The stage-discharge relation at a gaging station is usually determined experimentally by measurements of discharge and observations of stage. Generally, the resulting rating curve is a simple one, parabolic in shape, with slight "breaks" where one partial control is superseded by another.

Even with a well-defined rating curve and an apparently permanent control, periodic measurements are desirable, as "shifts" in the rating may occur whenever the channel scours or fills. During winter months there may be backwater from ice, and during the summer there may be weeds or aquatic growth on or above the control. Shifts in ratings may develop from scour or fill in the approach channel or downstream from the control, with no change in the control itself. One partial control may shift without affecting a control effective at other stages.

In developing a rating curve the mean or average stage during the time of measurement is plotted against the measured discharge for each measurement. If the rise or fall in gage height is slight, the average of the gage heights at the beginning and end of the measurement may be used. If the change in stage is large, a weighted mean gage height is computed by multiplying the discharge in each partial section or group of subsections by the average gage height which was observed during the measurement of the subsection, then the products for all of the subsections are added and are divided by the total discharge.

A <u>synthetic</u> rating curve can be generated using the Manning formula with cross-sectional information:

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

Q = discharge (cfs)

n = roughness coefficient (Table 1)

R = hydraulic radius = $\left(\frac{\text{cross-sectional area}}{\text{wetted perimeter}}\right)$

S = energy slope (channel slope can be substituted)

A = cross-sectional area

$$\text{hydraulic radius} = \frac{\text{cross-sectional area}}{\text{wetted perimeter}}$$

wetted perimeter = length ABCD

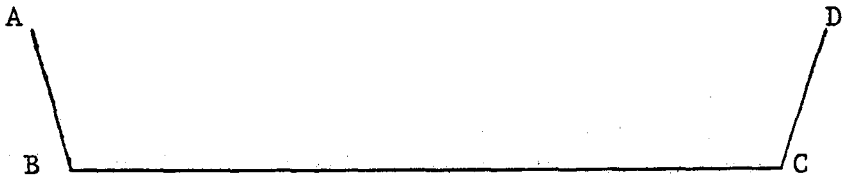


Figure 2. Hypothetical Stream Cross Section.

4. Obtain Rating Curve for the Forecast Point

   a. Simple rating curves

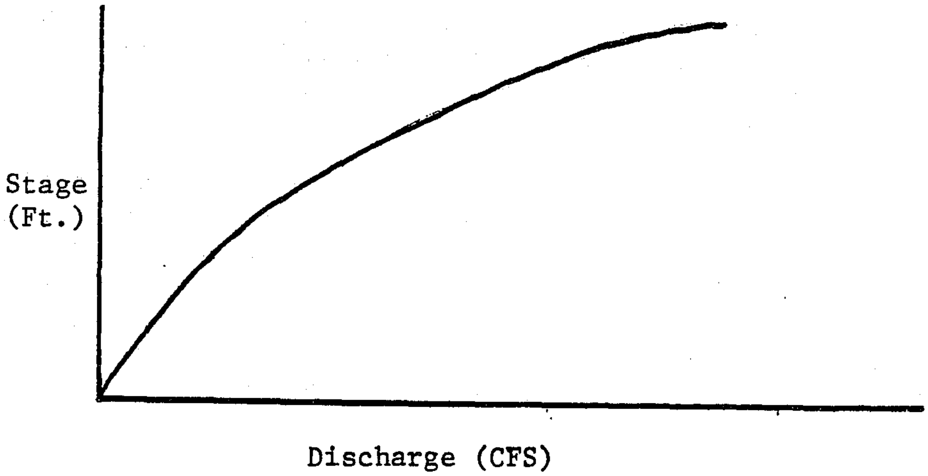


Figure 3. Hypothetical Rating Curve.

Table 2. Manning Roughness Coefficients for Various Boundaries

Boundary	Manning Roughness n
Very smooth surfaces such as glass, plastic, or brass	0.010
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition--some growth	0.025
Winding natural streams and canals in poor condition--considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	0.040-0.050
Alluvial channels, sand bed, no vegetation	
1. Lower regime	
Ripples	0.017-0.028
Dunes	0.018-0.035
2. Washed-out dunes or transition	0.014-0.024
3. Upper regime	
Plane bed	0.011-0.015
Standing waves	0.012-0.016
Antidues	0.012-0.020

V. HYDROGRAPHS FROM BASIN CHARACTERISTICS

A) $D/\sqrt{s'}$

$$t = D/\sqrt{s'}, \text{ where}$$

t = Travel time (hours)

D = Distance from divide to forecast point or length of the reach (miles)

s′ = Slope (feet/mile)

B) Determining t_c by Kirpich's Equation

$$t_c = 0.00013 \frac{L^{0.77}}{S^{0.385}}$$

L = Length of the basin in feet, measured along the watercourse from the divide nearest the upper end of the watercourse to the gaging station.

S = The ratio of the elevation change along L, to the length L.

t_c = Time of concentration (hours)

Sample "Travel time" (t) and "Time of Concentration" (t_c) calculations.

<u>Example #1</u>

West End Wash

Flows into Lake Mead northeast of Henderson, Nevada.

L = 8.47 miles

L_c = 4.44 miles

S = 0.05590

Elevation Range = 2050 feet.

a) Kirpich's Equation

$$t_c = 0.00013 \frac{L^{0.77}}{S^{0.385}}$$

$$= 0.00013 \frac{((8.47)\ (5280\ \text{ft/mi}))^{0.77}}{(0.05590)^{0.385}}$$

$$= 0.00013 \left(\frac{3809.8}{0.32942}\right)$$

$$= 1.5 \text{ hours.}$$

b) $D/\sqrt{s}$

$$t = 8.47/\sqrt{2050/8.47}$$

$$= 0.54 \text{ hours.}$$

Example #2

Lee Canyon near Charleston Park, Nevada.

$L = 4.03$ miles

$L_c = 1.81$ miles

$S = 0.14945$

Elevation Range = 3120 feet.

a) Kirpich's Equation

$$t_c = 0.00013 \frac{L^{0.77}}{S^{0.385}}$$

$$= 0.00013 \frac{((4.03)\ (5280))^{.77}}{(0.14945)^{.385}}$$

$$= \frac{0.27955}{0.48104}$$

$$= 0.58 \text{ hours.}$$

b) $D/\sqrt{s}$

$$t = 4.03/\sqrt{3120/4.03}$$

$$= 0.14 \text{ hours}$$

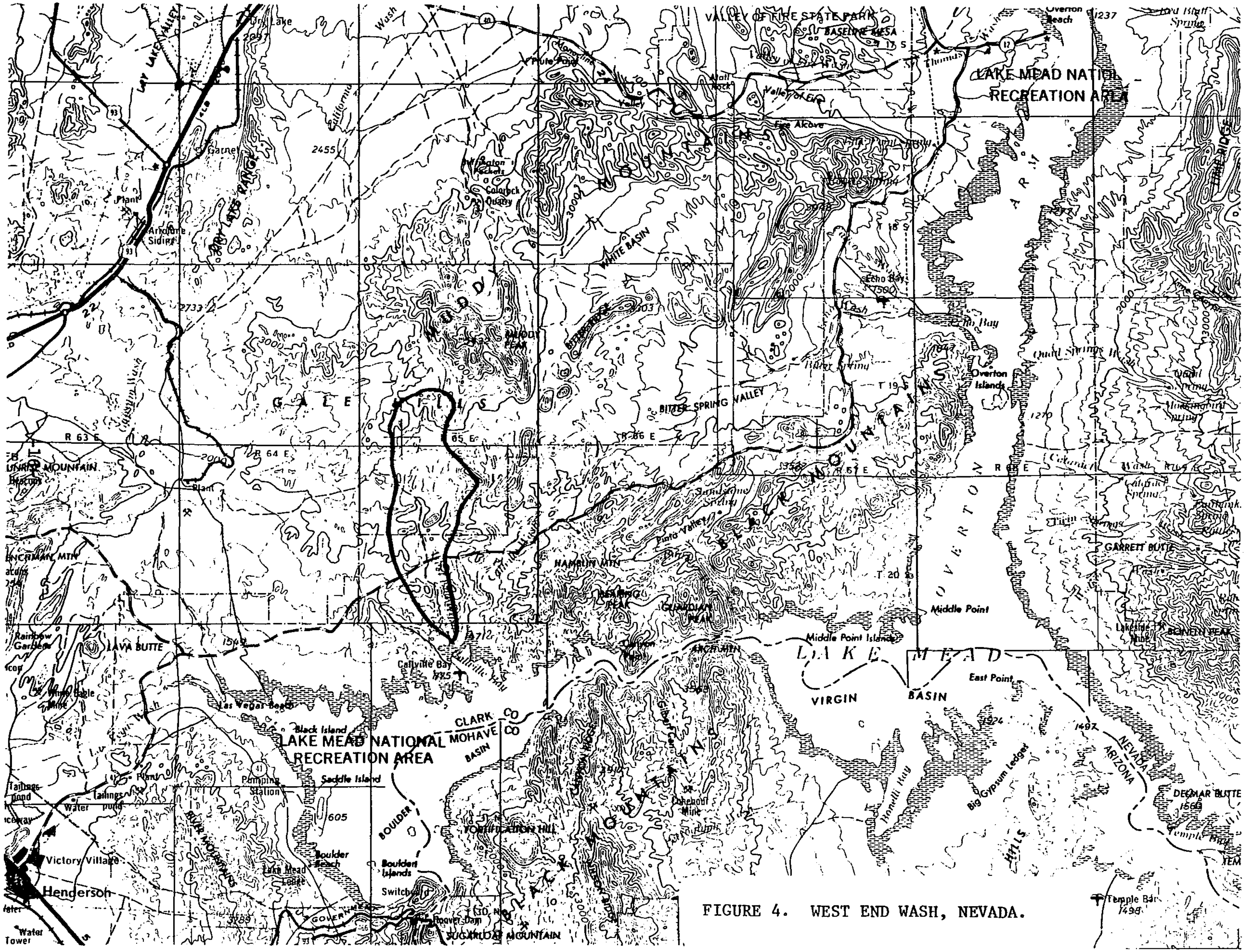


FIGURE 4. WEST END WASH, NEVADA.

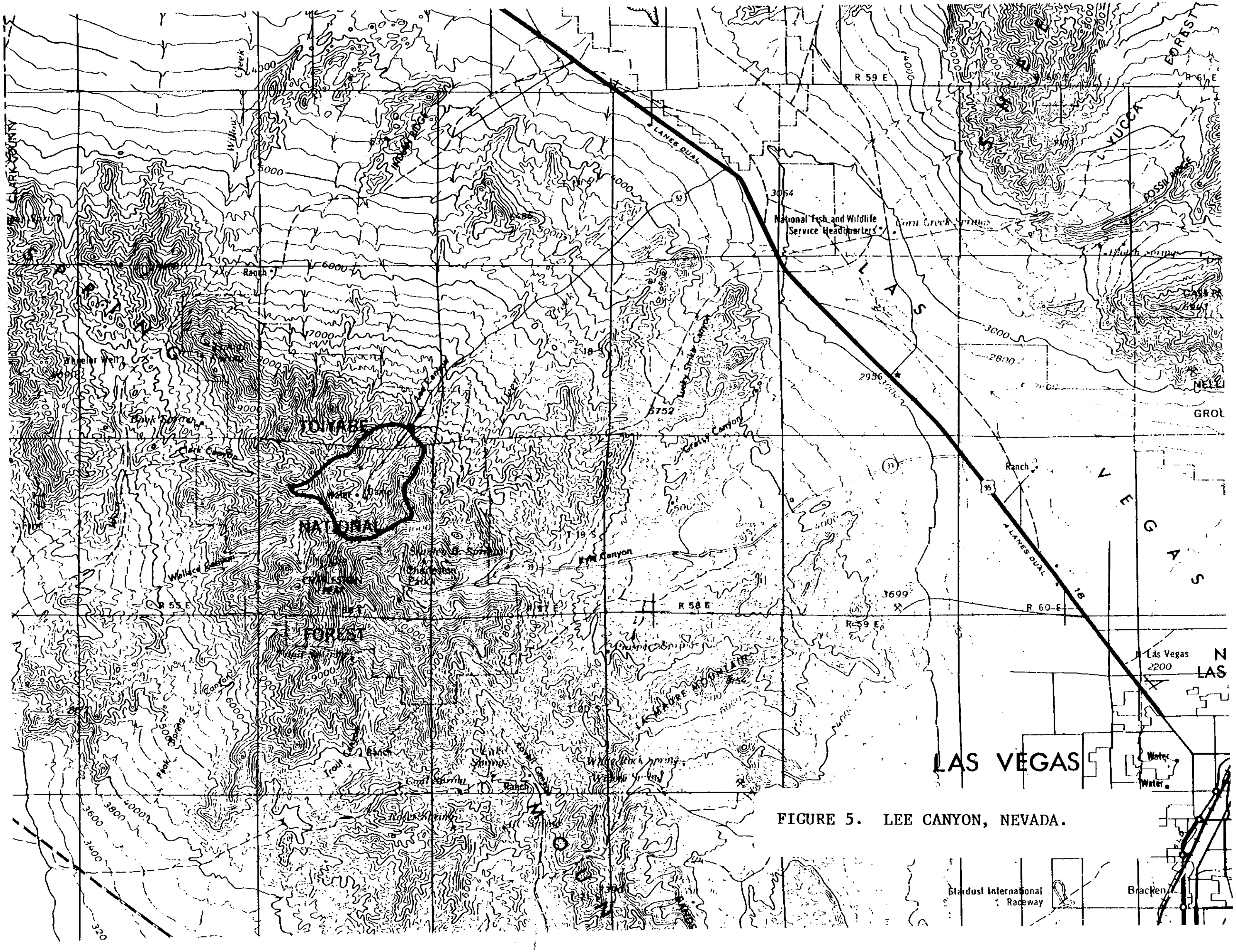


FIGURE 5. LEE CANYON, NEVADA.

VI. METEOROLOGICAL PARAMETERS COMMON TO FLASH FLOOD EVENTS

upper?

1. Storm area is very near the large-scale ridge pattern.

2. A weak mid-level short wave trough moving through or around the ridge helps to trigger and focus the storms.

3. In the western U.S., the storms usually occur during the afternoon hours.

4. The rain amounts tend to be lighter than those storms east of the Continental Divide.

   Examples:

   Pataha Creek nr. Pomeroy, WA
   September 15, 1966
   2" of rain in 45 minutes

   Whitman Co., WA
   July 1978
   1-1/2" in 20 minutes

   Spokane, WA
   July 1978
   0.78" in 15 minutes

   Grand Junction, CO
   September 1978
   3-4" in 1 hour.

5. Severe thunderstorm phenomena are often associated with the heavy rainstorms.

6. Surface dew-point temperatures are high.

7. High moisture contents are present through a deep tropospheric layer.

8. Vertical wind shear is weak through the cloud depth.

Small-scale terrain features, local heating anomalies, and thunderstorm scale motions interact to maximize rainfall in particular locations.

VII. DAM BREAKS

Outflow from dam breaks effected by:

(1) Size and shape of breach as a function of time

(2) Height of dam

(3) Storage volume of reservoir

(4) Inflow to reservoir

(5) Downstream channel conditions including channel size, roughness

Parameters needed to forecast outflow resulting from dam breaks:

(1) Contents or storage (acre-feet) at ΔT intervals

(2) Water surface elevation (feet) at ΔT intervals

(3) Breach description

(Shape vs. time)

VIII. TO DERIVE A UNIT HYDROGRAPH

1. FROM USGS WATER RESOURCES DATA PUBLICATIONS, PICK A STORM EVENT AND PLOT THE MEAN DAILY DISCHARGE VS. TIME. OFTENTIMES, THE USGS PUBLICATION WILL ALSO LIST THE PEAK STAGE, DISCHARGE AND CREST TIME. PLOT THIS, ALSO.

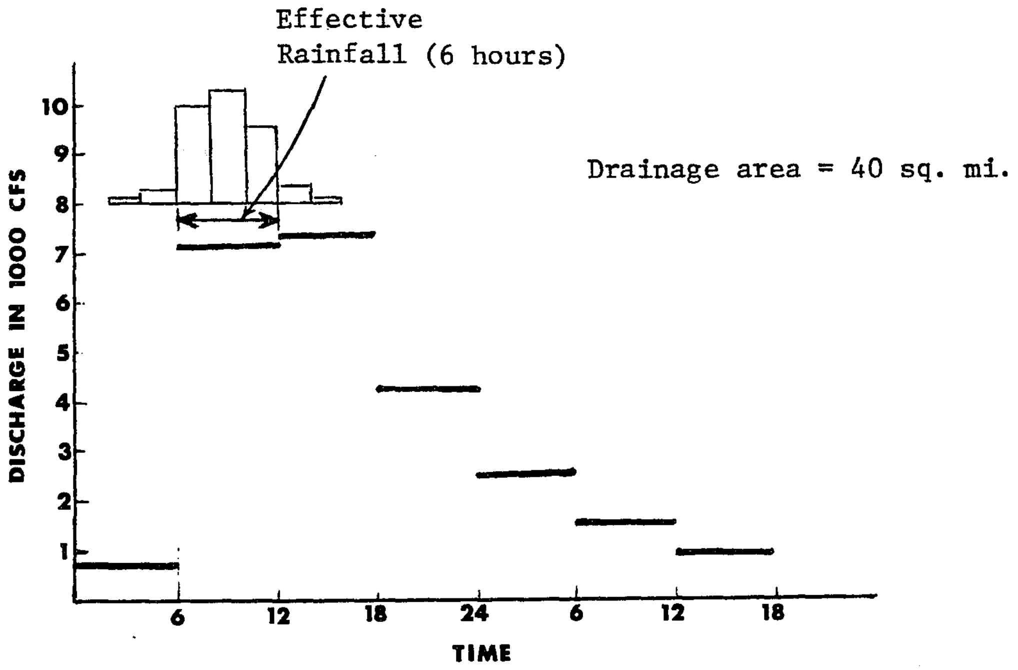


Figure 6. Mean Discharge Values for Each Time Period during Storm Event.

THE DURATION ASSIGNED TO A UNIT HYDROGRAPH SHOULD BE THE DURATION OF RAINFALL PRODUCING SIGNIFICANT RUNOFF. THIS SHOULD BE DETERMINED BY INSPECTION OF HOURLY RAINFALL DATA.

——→ LOOKING FOR A 6-HOUR UNIT GRAPH.

2. SKETCH A CURVE THROUGH THE MEAN DAILY DISCHARGE VALUES, KEEPING EQUAL AREAS ABOVE AND BELOW THE MEAN DAILY DISCHARGE VALUES FOR EACH TIME PERIOD.

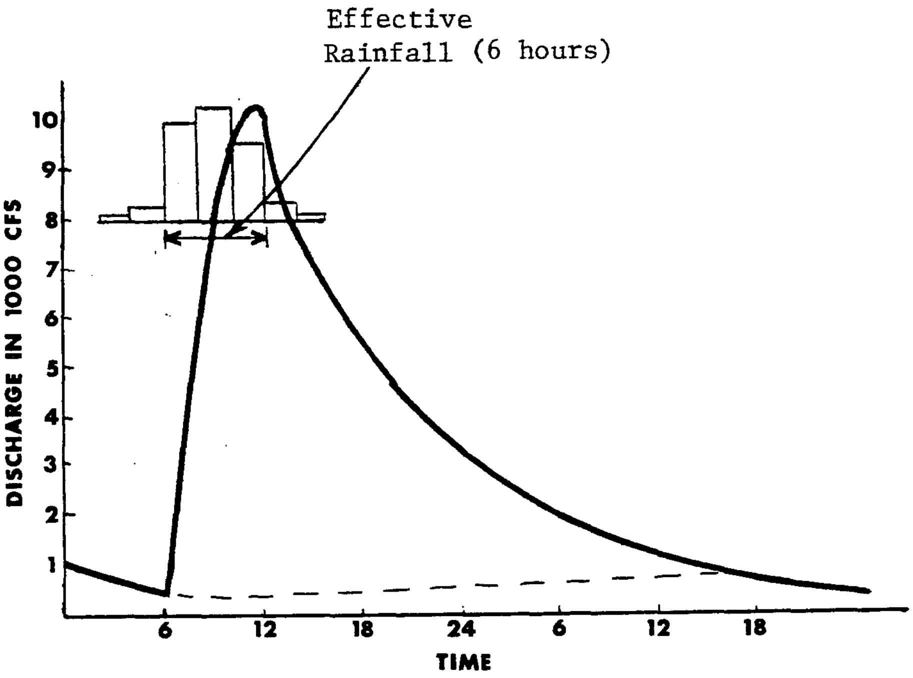


Figure 7. Hydrograph Sketched through Mean Discharge Values.

3. PICK OFF DISCHARGE VALUES FOR THE SKETCHED-IN HYDROGRAPH. THESE CAN BE EVERY 2 HOURS, 4 HOURS, 6 HOURS, ETC.; IN THIS CASE: EVERY 2 HOURS. WE WILL STILL HAVE A 6-HOUR UNIT GRAPH BECAUSE THE DURATION OF EFFECTIVE RAINFALL IS 6 HOURS.

Date	Hour	Total Flow
2/16	0600	500
	0800	5,600
	1000	9,200
	1200	10,100
	1400	7,800
	1600	6,600
	1800	5,550
	2000	4,700
	2200	4,000
	2400	3,300
2/17	0200	2,700
	0400	2,300
	0600	1,950
	0800	1,650
	1000	1,400
	1200	1,200
	1400	1,000
	1600	800

4. SUBTRACT OUT BASE FLOW TO ARRIVE AT DIRECT RUNOFF.

Date	Hour	Total Flow		Base Flow	Direct Runoff
2/16	0600	500	-	500	0
	0800	5600	-	450	5150
	1000	9200	-	400	8800
	1200	10100	-	400	9700
	1400	7800	-	450	7350
	1600	6600	-	450	6150
	1800	5550	-	500	5050
	2000	4700	-	550	4150
	2200	4000	-	600	3400
	2400	3300	-	600	2700
2/17	0200	2700	-	600	2100
	0400	2300	-	650	1650
	0600	1950	-	650	1300
	0800	1650	-	700	950
	1000	1400	-	700	700
	1200	1200	-	750	450
	1400	1000	-	750	250
	1600	800	-	800	0

5. SUM THE DIRECT RUNOFF ORDINATES (INSTANTANEOUS DISCHARGE READINGS)

Date	Hour	Total Flow		Base Flow	Direct Runoff
2/16	0600	500	-	500	0
	0800	5600	-	450	5150
	1000	9200	-	400	8800
	1200	10,100	-	400	9700
	1400	7800	-	450	7350
	1600	6600	-	450	6150
	1800	5550	-	500	5050
	2000	4700	-	550	4150
	2200	4000	-	600	3400
	2400	3300	-	600	2700
2/17	0200	2700	-	600	2100
	0400	2300	-	650	1650
	0600	1950	-	650	1300
	0800	1650	-	700	950
	1000	1400	-	700	700
	1200	1200	-	750	450
	1400	1000	-	750	250
	1600	800	-	800	0
					59,850

6. DIVIDE THE SUM OF THE INSTANTANEOUS READINGS (DIRECT RUNOFF) BY THE NUMBER OF READINGS IN 24 HOURS TO ARRIVE AT SECOND-FEET DAYS (SFD).

$$59{,}850 \div 12 = 4988 \text{ SFD}$$

7. DIVIDE SFD BY (26.9 * AREA (mi^2)) TO ARRIVE AT THE INCHES OF RUNOFF FROM THE BASIN.

$$\frac{4988}{(26.9)\ (40\ mi^2)} = 4.63 \text{ INCHES.}$$

8. DIVIDE THE DIRECT RUNOFF ORDINATES BY THE RUNOFF, IN INCHES, TO ARRIVE AT THE UNIT GRAPH ORDINATES.

Date	Hour	Total Flow		Base Flow	Direct Runoff	Unit Graph Ordinates
2/16	0600	500	-	500	0	0
	0800	5600	-	450	5150	1120
	1000	9200	-	400	8800	1915
	1200	10,100	-	400	9700	2110
	1400	7800	-	450	7350	1600
	1600	6600	-	450	6150	1340
	1800	5550	-	500	5050	1100
	2000	4700	-	550	4150	900
	2200	4000	-	600	3400	740
	2400	3300	-	600	2700	590
2/17	0200	2700	-	600	2100	460
	0400	2300	-	650	1650	360
	0600	1950	-	650	1300	280
	0800	1650	-	700	950	210
	1000	1400	-	700	700	150
	1200	1200	-	750	450	100
	1400	1000	-	750	250	50
	1600	800	-	800	0	0

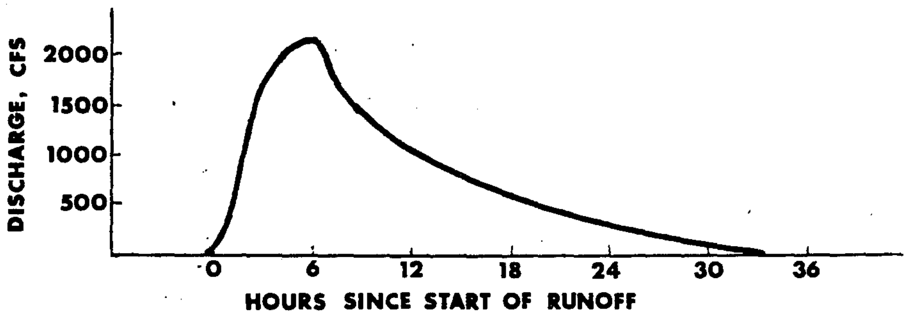


Figure 8. Six-hour Unit Hydrograph.

9. PLOT THE UNIT GRAPH.

IX. GENERATING A RIVER FORECAST

Basic to any river forecast is the need for rainfall reports. Utilizing the available rainfall reports the hydrologist determines the rainfall amount and distribution over the basin. This is important because variations in the spatial characteristics of the rainfall change the runoff timing and volume at the basin outflow point.

To determine how much of this rainfall will result in runoff it is necessary to know the soil moisture conditions of the basin. There are exceptions, such as flash flood situations where nearly the entire rainfall event comes out of the basin as runoff. Determining soil moisture, as such, is very subjective with every RFC handling the problem in a different manner. With a knowledge of the soil moisture conditions the hydrologist assumes that a certain percentage (i.e., 70%) of the rainfall will end up in the stream channel as runoff. The percentage changes depending on the amount of drying (or wetting) taking place.

Knowing the rainfall amount and distribution, and the percent expected to run off under the current soil moisture conditions, it is then fairly straightforward to determine the expected discharge at the basin outflow (forecast) point. The discharge is distributed in time by using a unit hydrograph. A unit hydrograph is a "standard hydrograph" for a particular headwater area normalized to 1" of <u>runoff</u> from the basin. It assumes an even rainfall distribution and pattern over the basin for a specified duration; e.g., 6 hours.

The unit hydrograph concept not only distributes the runoff in time but is used to convert runoff (in inches) to discharge (in cfs.) Since the unit hydrograph is proportional to 1" of runoff, to find the discharge for 0.5" of runoff each ordinate of the unit hydrograph (Fig. 9) is multiplied by 0.5. Likewise, to find the discharge for 1.5" of runoff, multiply the ordinates of the unit hydrograph by 1.5.

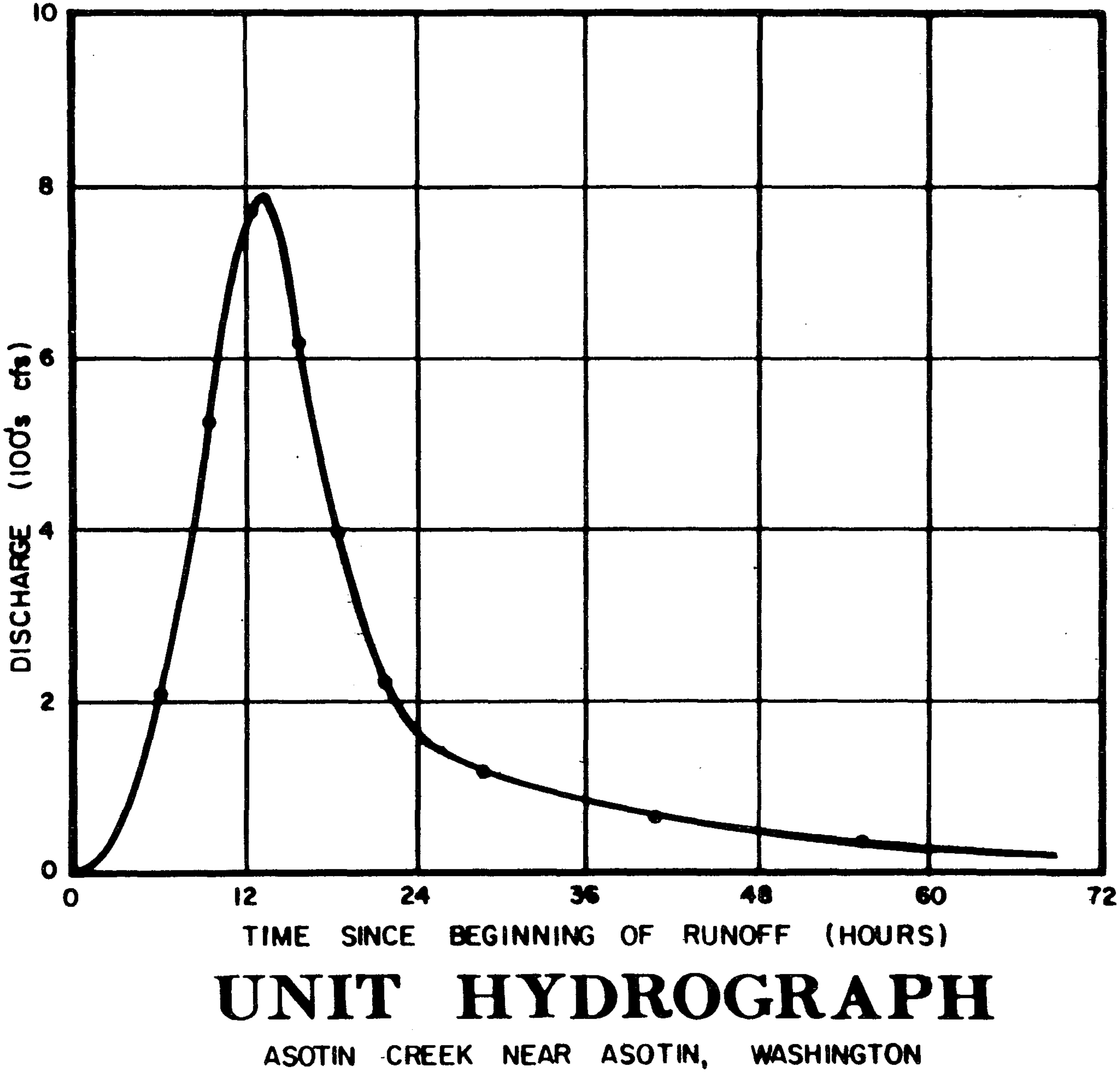
Referring to Figure 10, once the headwater discharge for the storm event has been determined for areas "A" and "B" the discharge values have to be blended with the current discharge data at "C" (Fig. 10).

With the discharge for each headwater area determined, the runoff from areas "A" and "B" (Fig. 10) is then added together to produce a forecast at "C" (Fig. 10). If the rainfall event is localized, then the forecast at "C" may just be the runoff from either Area "A" or "B".

Assuming only runoff from Areas "A" and "B", the discharge at "Qo" is a function of the discharge at "C". Routing is the term used to describe the procedure for determining downstream discharge (at "Qo") from upstream discharge (at "C"). With negligible runoff from the area between "C" and "Qo" the easiest solution is by using crest-stage relations (Fig. 11).

Crest-stage relations are usually derived by plotting, for a number of storm events, the peak upstream discharge versus the corresponding peak downstream discharge. However, any combination of peak upstream stage/discharge can be plotted against the corresponding peak downstream stage/discharge.

Figure 9. Unit Hydrograph for Asotin Creek Near Asotin, Washington.



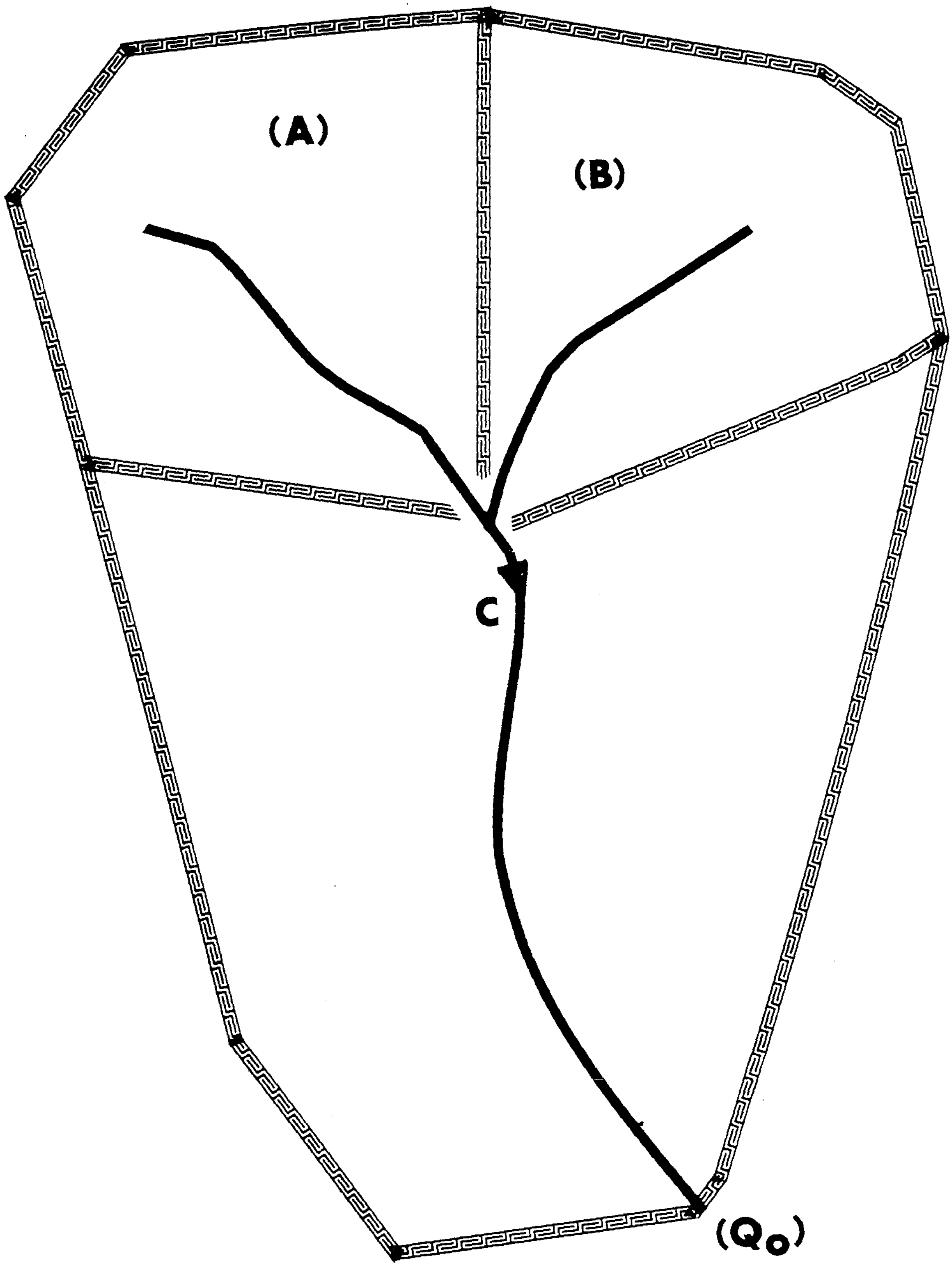


Figure 10. Muddy River Drainage.

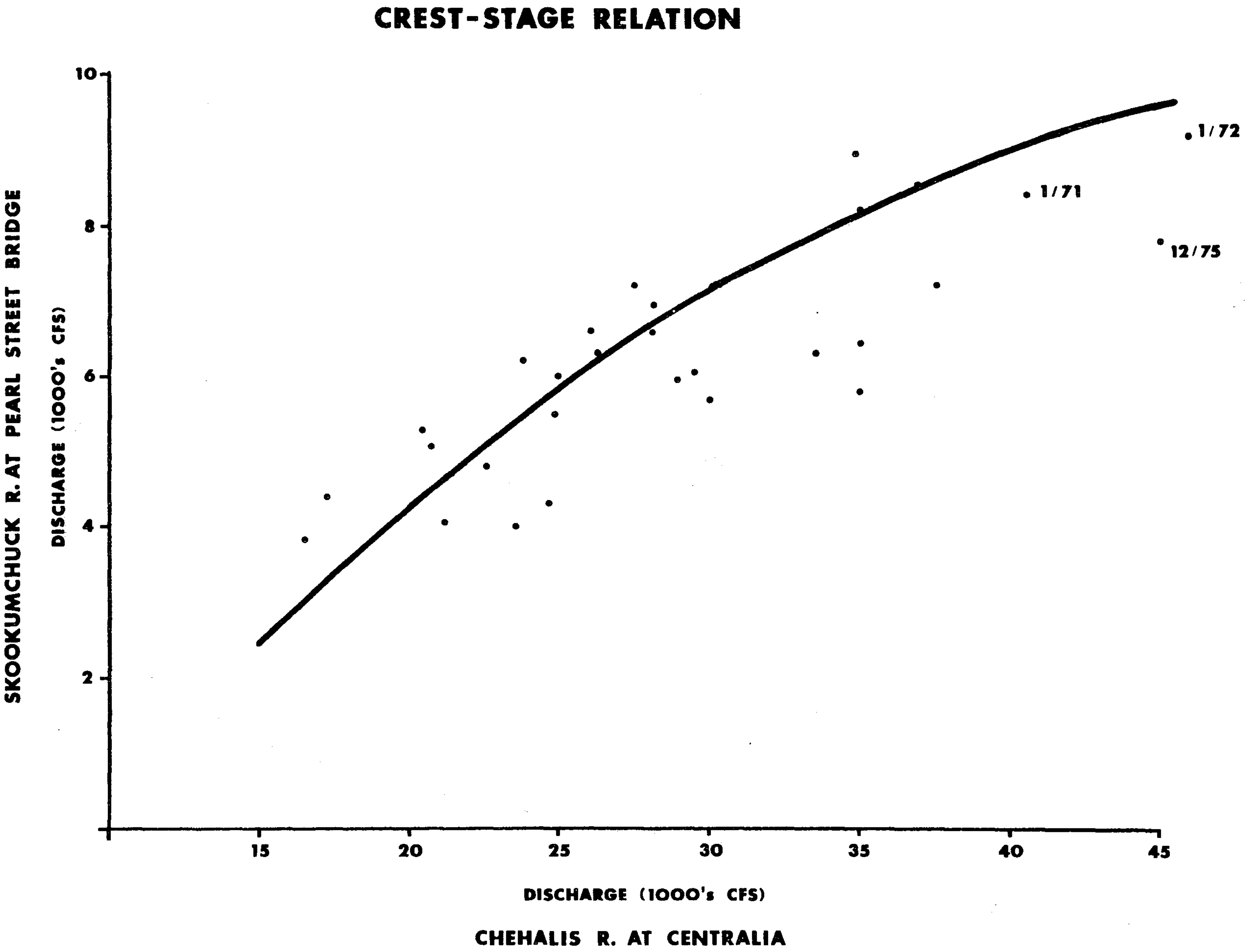


Figure 11. Crest-Stage Relation.

X. DEFINITIONS

Area-elevation Curve - A plot of elevation against area, or percentage of area, above or below a given elevation.

Backwater - The resulting high water surface in a given stream due to a downstream obstruction or high stages in an intersecting stream.

Crest-stage Relations - Graphs correlating an observed crest stage or discharge at an upstream station with the resulting crest stage or discharge at a downstream station.

Discharge - The rate of flow, or the volume of water that passes a particular reference section in a unit of time (e.g., CFS).

Flood Routing - The procedure whereby the time and magnitude of a flood wave at a point on a stream is determined from the known data at one or more points upstream.

Hydrograph - A graph of stage or discharge against time.

Lag - Ordinarily used to refer to the time difference between the occurrence of the center of mass of inflow and the center of mass of outflow.

Rainfall Excess - When the rainfall intensity at the soil surface exceeds the infiltration capacity, the rainfall excess begins to fill surface depressions. Almost immediately after the beginning of rainfall excess, the smallest depressions become filled and overland flow begins.

Time of Concentration (t_c) - The time required for water to travel from the most remote portion of the basin to the outlet.

Time of Travel - Refers to the elapsed time between the occurrence of a crest at one station and the corresponding crest at a downstream station.

Unit Hydrograph - The hydrograph of 1" of direct runoff from a storm of specified duration.

(From a storm of the same duration but with a different amount of runoff, the hydrograph of direct runoff can be expected to have the same time base as the unit hydrograph and ordinates of flow proportional to the runoff volume).

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