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BASIC HYDROLOGY

A PRIMER FOR METEOROLOGISTS

David B. Reed
Hydrologic Services Division
Fort Worth, TX

Scientific Services Division
Southern Region
Fort Worth, TX

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UNITED STATES
DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

National Oceanic and Atmospheric Administration
Diana H. Josephson
Acting Under Secretary

National Weather Service
Elbert W. Friday
Assistant Administrator

Acknowledgements and Foreword

The NWS is in an unprecedented era of modernization of technology available for use in field offices. This technology will make many basic and advanced hydrometeorologic techniques and data sets available to WFO hydrologists and meteorologists to assist in the dissemination of hydrologic forecasts and warnings to save lives and property. For effective use, some of this technology will draw upon one's hydrologic expertise. As a result, a massive training effort in the basics of hydrology is required to support this modernization effort.

In an attempt to begin supplying training material to meteorologists at WFOs, *Basic Hydrology—A Primer For Meteorologists* has been developed. It contains a brief discussion on the basics of hydrology needed by a meteorologist to provide hydrologic services to the public. This Primer is not intended to be an in-depth study of hydrology, but simply a concise text of information needed by meteorologists to issue better hydrologic products. Hopefully, it fulfills this need.

A large measure of credit goes to Southern Region's Regional Hydrologist David T. Smith for encouraging the authorship of this memorandum. He has critically reviewed the draft. Many of his suggestions for improving the readability and information presentation of this memorandum were incorporated into this finished publication. Thanks is also due to all other hydrologists and meteorologists that have reviewed this document.

Finally, thanks are due Marsha Spencer and Judy Magee, secretaries to SRH's Scientific Services Division/Hydrologic Services Division, for skillfully turning the draft into the highly readable document you have here.

August 1993
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1. Introduction

River forecast models attempt to simulate various components of the hydrologic cycle. Each component of the hydrologic cycle is very complex containing many variables. Simulations usually only model the most significant variables and may range from a simple rainfall/runoff relationship with one or two variables to a finite difference technique to estimate streamflow requiring large amounts of data and extensive CPU time.

Following are the basic concepts of parts of the hydrologic cycle that are needed to issue hydrologic products presented in a succinct manner with the meteorologist in mind. To assist in the learning process, simple mathematical models, sample problems, and study questions are included with each section. Finally, all components are put together into a simplified forecast technique to give a non-hydrologist a basic understanding of hydrologic modeling.

The workbook was not designed or developed to be a rigorous study of any components of the hydrologic cycle, but rather a succinct discussion of these components. Readers interested in a more rigorous approach to these subjects should consult additional references.

2. Surface Runoff

Surface runoff is that part of the rainfall which travels overland to the stream channel. Surface runoff occurs when the rainfall rate exceeds the rate that water can infiltrate into, or enter, the soil. Surface runoff combined with precipitation on the stream channel reaches the stream quickly, accounting for most flood-producing flow.

When rainfall begins, part of the rain is caught by plants as interception storage, never reaching the ground. Some rainfall reaches the ground and is stored in surface puddles as depression storage. Interception storage, depression storage, and evaporation during a storm make up surface retention. After meeting surface retention requirements, rainfall either infiltrates into the soil or flows overland by gravity to the stream channel. The water traveling overland to the stream channel, called surface runoff, plus rain that falls on the stream, reaches the stream relatively quickly and makes up the majority of the flow during a flood. Water that enters the soil may either percolate down to the groundwater or move laterally to the stream channel, reaching the stream channel much later.

Measurement of Surface Runoff

Runoff is generally measured as a given depth over a specified drainage area. Since the runoff depth occurs over an area, it represents a volume of water. For example, one inch of runoff for a one-square-mile basin represents:

$$1\ in \times (1\ mi^2) \times \frac{1\ ft}{12\ in} \times \frac{(5280\ ft)^2}{(1\ mi)^2} = 2{,}232{,}200\ ft^3$$

Factors Affecting Runoff

The amount of surface runoff from a storm will depend on soil moisture content, physical characteristics of the basin, and storm characteristics. These following factors will affect the amount of surface runoff generated from a rain event:

- **Soil Moisture** — As soil moisture increases, the amount of surface runoff will increase. Flash Flood Guidance (FFG) is an indicator of the amount of rainfall required to produce flooding and varies inversely with soil moisture. FFG values decrease with increasing soil moisture.

  During a rainstorm, the amount of moisture in the soil will increase. As the ground becomes wetter, a greater percentage of rainfall will be converted into surface runoff.

- **Soil type** — Soils made up of fine material, such as clay, have lower porosity and a lower infiltration capacity than sandy soils. More surface runoff will be generated from clay soils than from sandy soils. Rocky, impervious areas, or areas with shallow soils into which only a small amount of water can infiltrate, will generate more surface runoff than deep soils with no rocks.

Infiltration capacity is also related to soil moisture content as well as soil type. As soils become wetter, the pores in the soil become filled, and infiltration capacity decreases. Infiltration rates in fine soils range from 0.2 to 2 inches per hour and in coarse, sandy soils range from 0.5 to 3 inches per hour.

- **Slope** — Watersheds with steep slopes will produce more surface runoff than watersheds that are flat. The velocity of water moving overland is dependent on the ground slope. With higher water velocities, there is less time for the water to infiltrate into the soil as it travels to the stream channel. Surface runoff from a watershed with steep slopes will reach the stream channel quicker than basins with little or no slope.

- **Vegetation** — Dense low-lying vegetation in watersheds will retard overland flow, allow more time for the water to infiltrate into the soil, and result in less surface runoff than from areas with little or no vegetation. Vegetation will vary based on the time of year.

- **Rainfall intensity** — The amount of surface runoff is dependent on rainfall intensity. If rainfall intensity exceeds infiltration capacity, surface runoff will occur. For 2 inches of rainfall in 30 minutes (4 inches/hour) from a convective event, significant surface runoff will result. For an otherwise similar situation, 2 inches of rain in four hours (0.5 inches/hour) from a stagnant or slow moving overrunning situation will result in significantly less runoff.

- **Time of year** — For storms of similar intensity, duration, and amount, more surface runoff will be generated in the winter than in the summer. In winter, temperatures are lower. Evaporation and evapotranspiration will be less, and the soil will remain wetter longer.

- **Amount of rainfall** — As the storm total precipitation increases, the amount of surface runoff increases. When rainfall begins, infiltration rates are high; and the soil is relatively dry. As rainfall continues, the soil becomes wetter, and the infiltration capacity decreases. If 2 inches of rain fell in two hours at a constant intensity, more surface runoff would be generated from the inch of rainfall during the second hour than from the inch of rainfall in the first hour.

Most of the factors which affect the amount of surface runoff are interrelated. Because of this complex interrelationship, the generation of surface runoff is not a linear process. Doubling the rainfall amount or rainfall intensity will generally more than double surface runoff.

Procedures to Estimate Surface Runoff

In the NWS, the two primary methods of estimating surface runoff from a rainfall event are: (1) conceptual models to simulate the movement and occurrence of water on the soil surface and in the soil (Sacramento Soil Moisture Accounting Model); and (2) statistical methods based on time of year, storm duration and intensity, and initial soil moisture content (API Method). Both methods may be expressed as computer algorithms.

Sacramento Soil Moisture Accounting Model — SACSMA — The SACSMA, a conceptual model, estimates surface runoff amounts using a water balance to simulate the movement and occurrence of water on the soil surface and in two layers in the soil mantle. The model is a lumped parameter model with 17 variables that must be calibrated. Calibration is normally done using four years of historical data. Inputs include mean areal precipitation and evaporation (optional) for a basin. The SACSMA also estimates the runoff from water that infiltrates into the soil and percolates to the stream channel through the soil mantle.

SACSMA is used by RFCs Tulsa, Slidell, and Atlanta in the NWS Southern Region to estimate surface runoff, and by some local flood warning systems for small stream forecasting.

Antecedent Precipitation Index — API Method — The API method, a statistical model, uses an index (API value), usually ranging from 0 (driest) to 6 (wettest), to represent soil moisture. The API value changes daily; it increases by the amount of rainfall received in the previous day and is reduced by a recession constant to approximate the drying of the soil by evaporation. The API value, time of year, rainfall amount, and rainfall duration are used in a coaxial relationship to estimate surface runoff. A sample coaxial relationship is shown in Fig. 1. Each basin will have its own coaxial relationship, and development of a coaxial relationship requires rainfall and surface runoff data from several storms.

The API method of estimating surface runoff can be programmed into a computer and is used by RFC Fort Worth in the Southern Region to estimate runoff in river forecast models. It is also used in some local flood warning systems.

The API and SACSMA are lumped parameter models, using hydrologic parameters and data averaged over a basin. The more homogeneous the basin characteristics and rainfall patterns, the better the estimates of surface runoff volumes will be.

Sample Problem

1. Using Fig. 1, determine the surface runoff that will result from a storm that occurred during the 52nd week of the year with a 24-hour duration, 5.5 inch basin average rainfall, and API at the beginning of the storm of 0.8.

    From the coaxial relationship, the surface runoff is 3.8 inches. (Follow the "darkly arrowed" path through the coaxial quadrants.)

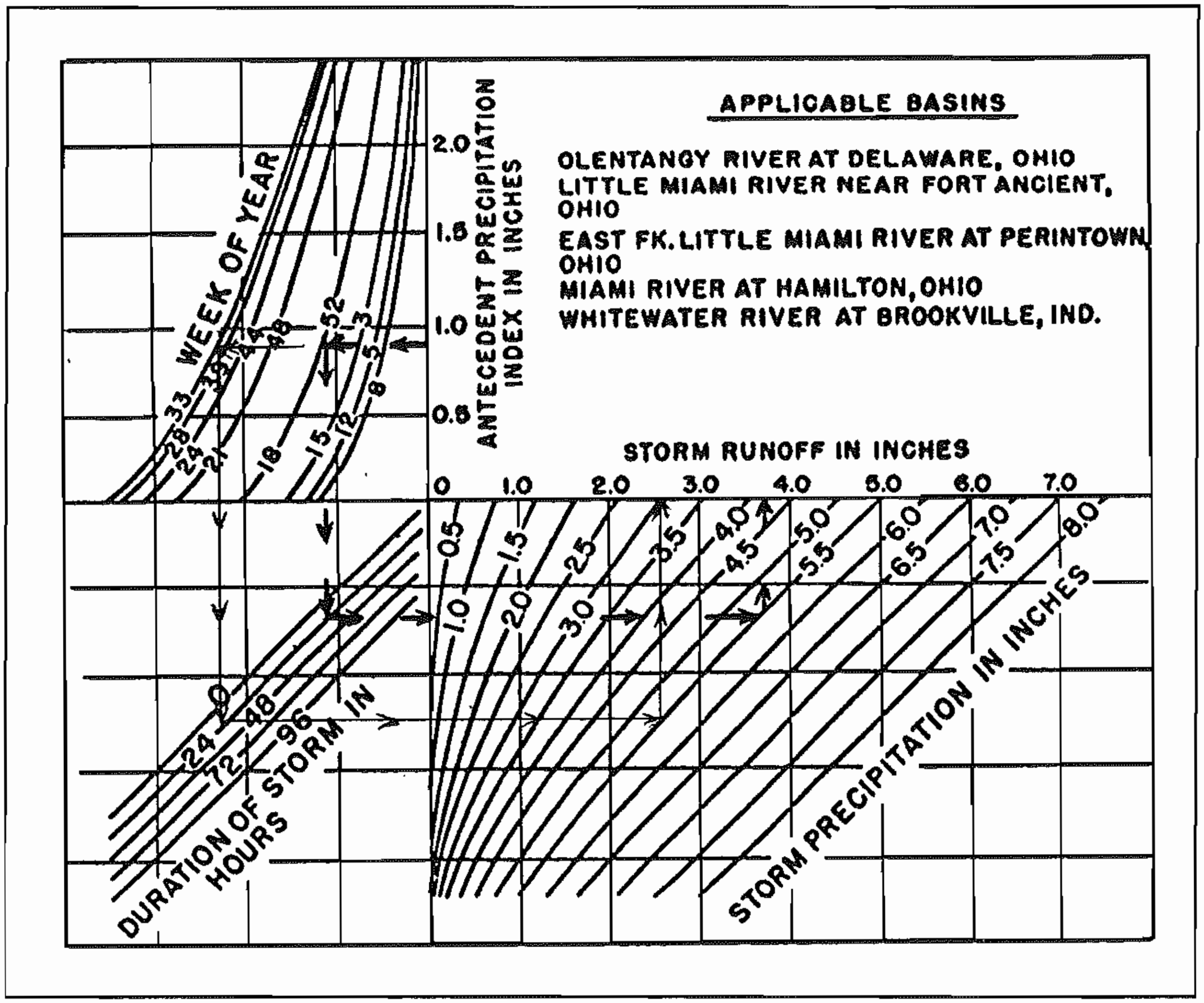


Figure 1. Sample API Coaxial Rainfall/Runoff Relationship (Linsley, et al., 1949).

2. Using Fig. 1, compute the surface runoff expected from the same storm in Problem 1 that occurred during week 33.

   From the coaxial relationship, the surface runoff is 2.6 inches. (Follow the "lightly arrowed" path through the coaxial quadrants.)

3. Relate week 52 in late December runoff to the runoff during week 33 in mid-August.

   The runoff during week 52 is much higher and is consistent with the fact that more runoff occurs during the winter than the summer.

Study Questions

1. Using the coaxial rainfall-runoff relationship in Fig. 1, determine the surface runoff expected from a 4-inch rainfall event of 24-hour duration the last week in December (week number 52). The soil moisture condition is very wet with an API of 2.0.

   Expected Runoff = _______ inches

2. Using the information from problem 1, how much runoff would be expected when extremely dry conditions (API of 0.5) existed?

   Expected runoff = _______ inches

3. At a particular gaging site, 1 inch of runoff will produce minor flooding, and some secondary roads must be closed. After a prolonged dry period (API of 0.3) in August (week number 33), a tropical storm is expected. How much rainfall in a 12-hour period will it take to cause flood problems?

   Rainfall for 1 inch of runoff = _______ inches.

4. At the site in question 3, how much rainfall would it take to cause flood problems if it is wet (API 2) in the last week in February (week 8)?

   Rainfall for 1 inch of runoff = _______ inches.

5. For a 24-hour rainfall event during week 5 or week 12 and an API of 0.5, 2 inches of rainfall produces about 1.1 inches of runoff. Four (4) inches of rainfall produces about 2.8 inches of runoff. The rain has been doubled, but the runoff for 4 inches of rain is over 2½ times the 2-inch rainfall amount. Why?

3. Unit Hydrographs

A storm hydrograph is a graph of stage or discharge at a gaging site versus time. A storm hydrograph is made up of two components — base flow and surface runoff. Base flow is that rainfall which infiltrates into the soil and moves laterally to the stream channel, reaching the stream channel after several days or more. Surface runoff, also referred to as direct runoff, is composed of the rainfall which travels overland by gravity to the stream channel plus rainfall directly on the channel. Surface runoff reaches the stream channel quickly and will continue for only a few days. During a flood, base flow is usually only a small percentage of the total flow. Fig. 2 shows a storm hydrograph and its surface runoff and base flow components.

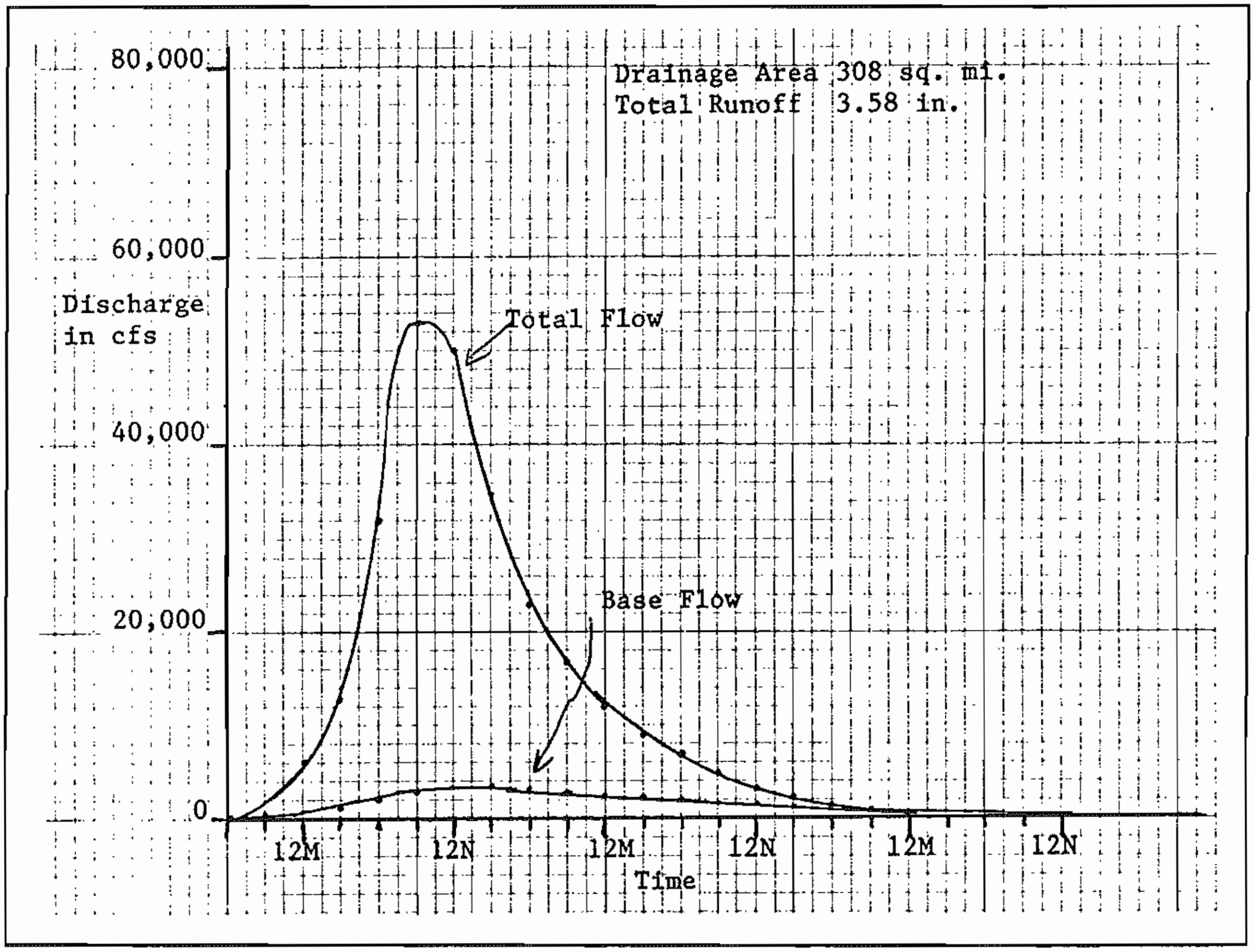


Figure 2. The separation of a storm hydrograph into base flow and surface or direct runoff components (Linsley, et al., 1949).

Unit Hydrograph Theory

By definition, a unit hydrograph (UHG) is the hydrograph of 1.00 inch of surface runoff generated uniformly over the entire basin during a unit duration. Unit hydrograph theory states surface runoff hydrographs for storm events of the same unit duration will have the same shape, and the discharge ordinates of the hydrograph will be proportional to discharge ordinates of a unit hydrograph. For example, the hydrograph ordinates from one-half of an inch of surface runoff will be half of the ordinates of the unit hydrograph.

In unit hydrograph theory, the following assumptions are made:

- Runoff is evenly distributed over the entire basin.
- Runoff is uniformly distributed over the time period.
- The basin characteristics are homogeneous.

UHGs are developed for a specified duration of runoff. Theoretically, a different unit hydrograph is needed for each duration of runoff event. However, small differences in durations of unit hydrographs only slightly affect the unit hydrograph. Because of data availability and model simulation time steps, the most common unit hydrographs developed and used in the NWS are of 3- or 6- hour duration. As more hourly stage and discharge data become available and the NWS begins to issue crest stage forecasts for smaller basins, one-hour unit hydrographs may be more widely used.

The unit hydrograph derived from the storm hydrograph in Fig. 2 is given in Table 1 and displayed in Fig. 3. The first abscissa, time 0, is at the time the runoff-producing rainfall begins. The UHG peaks 12 hours after the rainfall begins at 14,000 cfs.

Table I. Unit Hydrograph ordinates shown in Figure 3.

Time Since Rain Began (Hours)	Discharge (CFS)
0	0
3	1500
6	3300
9	8400
12	14000
15	12900
18	8700
21	5500
24	4000
27	2700
30	1900
33	1400
36	800
39	500
42	300
45	150
48	0
Total	66,050

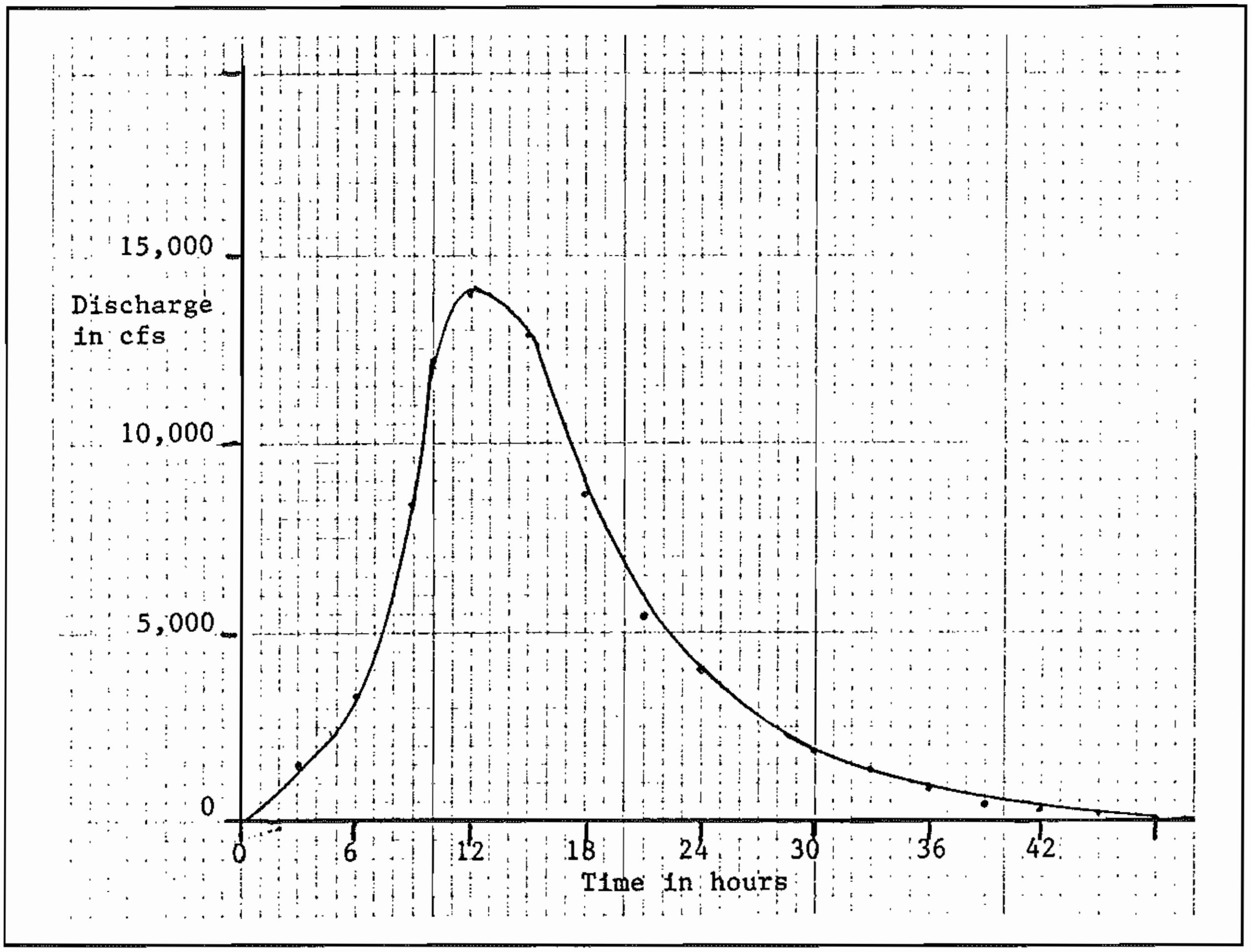
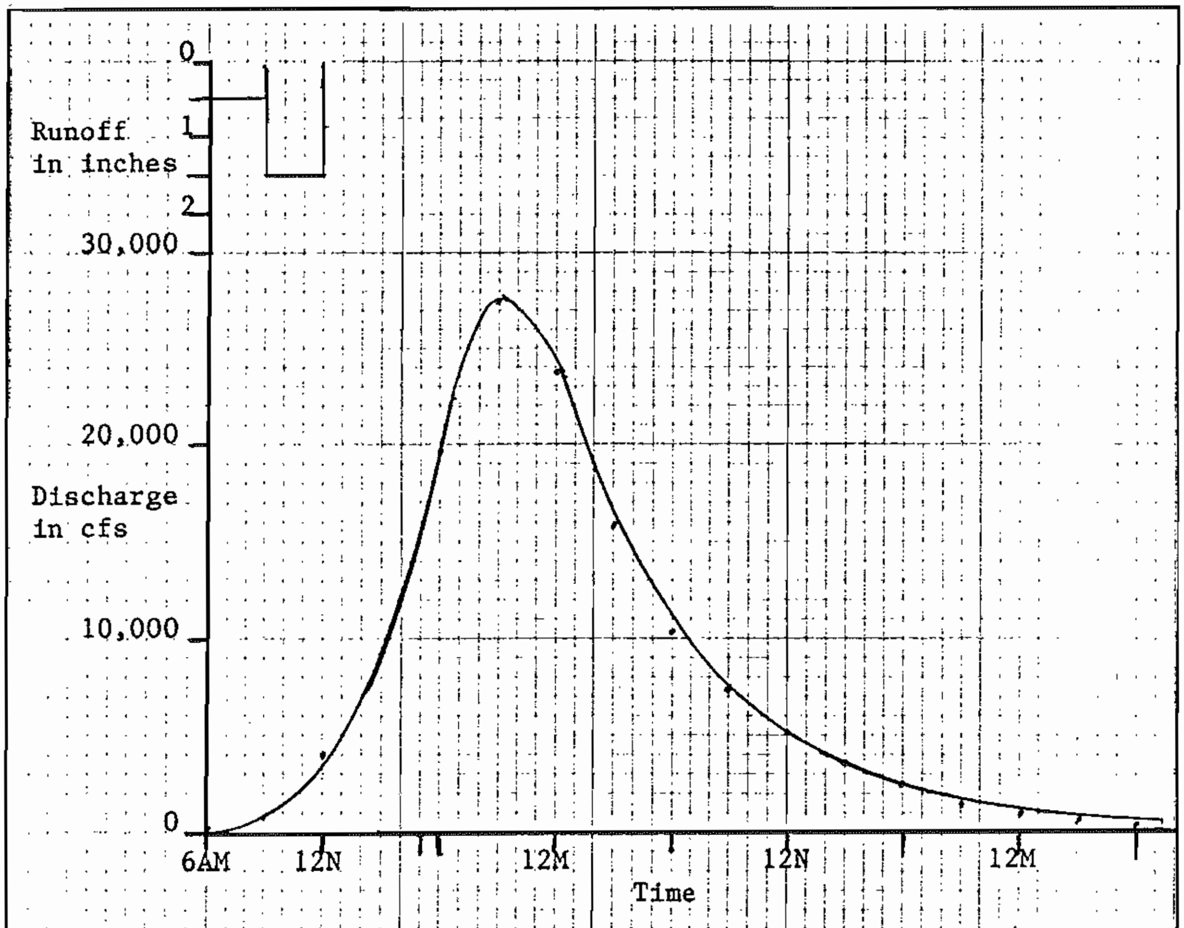


Figure 3. The unit hydrograph for data in Table 1.

Computing Storm Hydrographs

Since base flow usually comprises a small percentage of flood flows and it occurs very slowly, the accurate prediction of the amount and time distribution of surface runoff should yield an acceptably accurate prediction of flood peak flows. Using the Antecedent Precipitation Index (API) method or Sacramento Soil Moisture Accounting Model (SACSMA), surface runoff may be estimated; and using unit hydrograph theory, the hydrograph at a gaging point resulting from the surface runoff can be computed. The flow from surface runoff is added to the estimate of base flow to determine the total flow, or storm hydrograph, at the gaging site.

RFCs must use unit hydrographs to compute or predict the storm hydrograph for a gaging site. RFCs generally develop a unit hydrograph for each basin in their area and enter these into the RFC models when the models are set up. During each subsequent model run, the unit hydrograph is used to convert surface runoff computed using either the SACSMA model or an API model to streamflow. The flow from surface runoff is combined with an estimate of base flow to compute a storm hydrograph. For successive unit time periods, the flow computed from



	6AM	9AM	12N	3PM	6PM	9PM	12M	3AM	6AM
Base Flow	100	100	100	100	100	100	100	100	100
0.5"RO (6-9A)	0	750	1650	4200	7000	6450	4350	2750	2000
1.5"RO (9-12)	XXX	0	2250	4950	12600	21000	19350	13050	8250
Total Flow	100	850	4000	9250	19700	27550	23800	15900	10350

	9AM	12N	3PM	6PM	9PM	12N	3PM	6PM	9PM
Base Flow	100	100	100	100	100	100	100	100	100
0.5"RO (6-9A)	1350	950	700	400	250	250	150	75	0
1.5"RO (9-12)	6000	4040	2850	2100	1200	750	450	225	0

Figure 4. Solution to Sample Problem.

surface runoff is added to base flow and the flow which will result from surface runoff in previous time periods.

Sample Problem

1. A forecast model run at 12 noon estimated runoff from 6 a.m. to 9 a.m. to be 0.5 inches and 1.5 inches from 9 a.m. to noon. The base flow for the basin is assumed to be a constant 100 cfs. Forecast the magnitude and time of the peak flow using unit hydrograph theory and the unit hydrograph listed in Table 1 and displayed in Fig. 3.

   To compute the storm hydrograph, the components of base flow, flow from surface runoff from 6-9 a.m., and the flow from surface runoff from 9 a.m. to noon must be computed and then added together. These results are shown at the bottom of Fig. 4. The first row is the base flow estimated to be 100 cfs. The second row is the flow as a result of 0.5 inches of runoff from 6-9 a.m. Each ordinate is half of the corresponding UHG ordinate as specified by unit hydrograph theory. The first ordinate at the beginning of the rainfall at 6 a.m. is 0. The third row is the flow from 1.5 inches of runoff from 9 a.m. to noon and is 1.5 times the ordinates of the UHG. The storm hydrograph is the total of the first 3 rows. The results are plotted above the tabulations. The peak flow should occur about 9 p.m. on the day the rain occurs and should be about 28,000 cfs.

Unit Hydrograph Development

Unit hydrographs may be developed empirically from streamflow records or by synthetic methods. Synthetic methods are used to develop unit hydrographs for small basins, many with no historical data and recording river gage. These synthetic unit hydrographs are normally based on topography and basin size and shape. For gaging locations with historical data, a runoff event that closely follows the assumptions of UHG theory is divided into base flow and surface runoff components. The surface runoff depth is computed by integrating the area between the storm hydrograph and the base flow component. The ordinates of the unit hydrograph are derived by dividing the discharge from surface runoff by the amount of surface runoff in inches. Where several runoff events occur from a similar unit duration, the representative unit hydrographs may be averaged to obtain "a best UHG" for that unit duration. The unit hydrograph in Table 1 and Fig. 3 are derived from the storm hydrograph in Fig. 2 and the 3.58 inches of surface runoff that the hydrograph represents. The total volume of water represented by a unit hydrograph must total one inch of runoff. The total amount of runoff under a hydrograph, either a storm hydrograph or unit hydrograph, is represented by the following equation:

$$\text{Runoff} = \text{SDF} / (\text{DA} \times \text{N} \times 26.9)$$

where Runoff = amount of runoff in inches over area,
SDF = summation of second foot days under the hydrograph. If ordinates at other than 24 hour ordinates are summed, adjust by SDF/(24/N) where N is the time interval of the ordinates summed,
DA = drainage area in square miles, and
26.9 = units conversion factor.

For the ordinates in Table 1, the summation of all ordinates is 66,050 cfs. The unit hydrograph is for a drainage area of 308 square miles. The amount of surface runoff represented by the hydrograph is 1.00 inches.

Hydrographs When UHG Assumptions Are Not Met

During many flood events, the assumptions of Unit Hydrograph Theory will not be met. When these assumptions are not met, the observed flood hydrograph will be different from the forecasted flood hydrograph computed using Unit Hydrograph Theory. These differences will result from:

- **Duration of rain is different** — If the rainfall occurs in a significantly shorter time period than the duration of the unit hydrograph, the peak flow will be higher and sooner than forecasted by unit hydrograph theory as shown in Fig. 5a. This may occur when a convective storm produces one inch of runoff in one hour, but the NWS models use unit hydrographs with a duration of 6 hours. The converse is also true. That is, when rainfall occurs in a longer time period than the unit duration of the unit hydrograph used, the peak flow will be less and later than predicted.

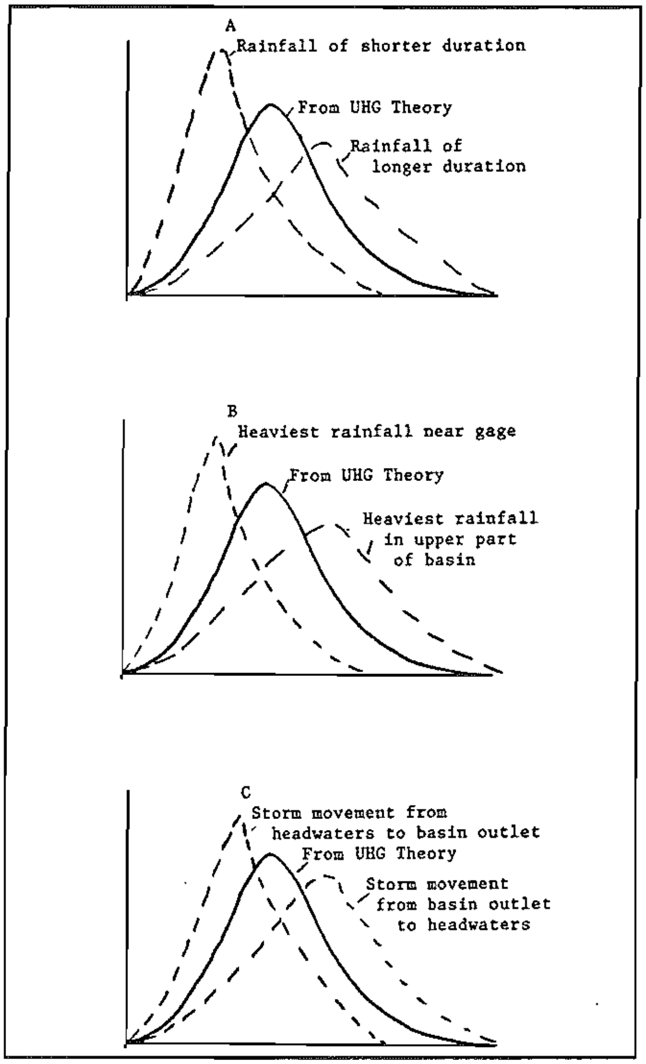


Figure 5. Differences in observed storm hydrographs from forecasted hydrograph using unit hydrograph theory when assumptions are not met.

- **Areal Distribution of Rainfall and Runoff** — If the heaviest rainfall and runoff occurs near the basin outlet, the resulting hydrograph will peak higher and sooner and rise faster than the forecasted hydrograph from Unit Hydrograph Theory as shown in Fig. 5b. If the heaviest rainfall occurred at the upper end of the basin, the storm hydrograph would peak lower and later; and the rise would be less sharp than the forecasted hydrograph.

- **Rainfall intensity** — Periods of short, intense rainfall imbedded in a general rainstorm may generate spikes in a hydrograph.

- **Storm movement** — If a storm moves from the headwaters of the basin to the basin outlet, the resulting hydrograph will peak higher and sooner than the forecasted hydrograph as shown in Fig. 5c. If the storm movement is from the basin outlet to the headwaters, the peak will be lower and later than the forecasted hydrograph.

Study Questions

1. Using the unit hydrograph in Fig. 3, how long after the runoff producing rainfall begins will the gaging site reach its peak flow?

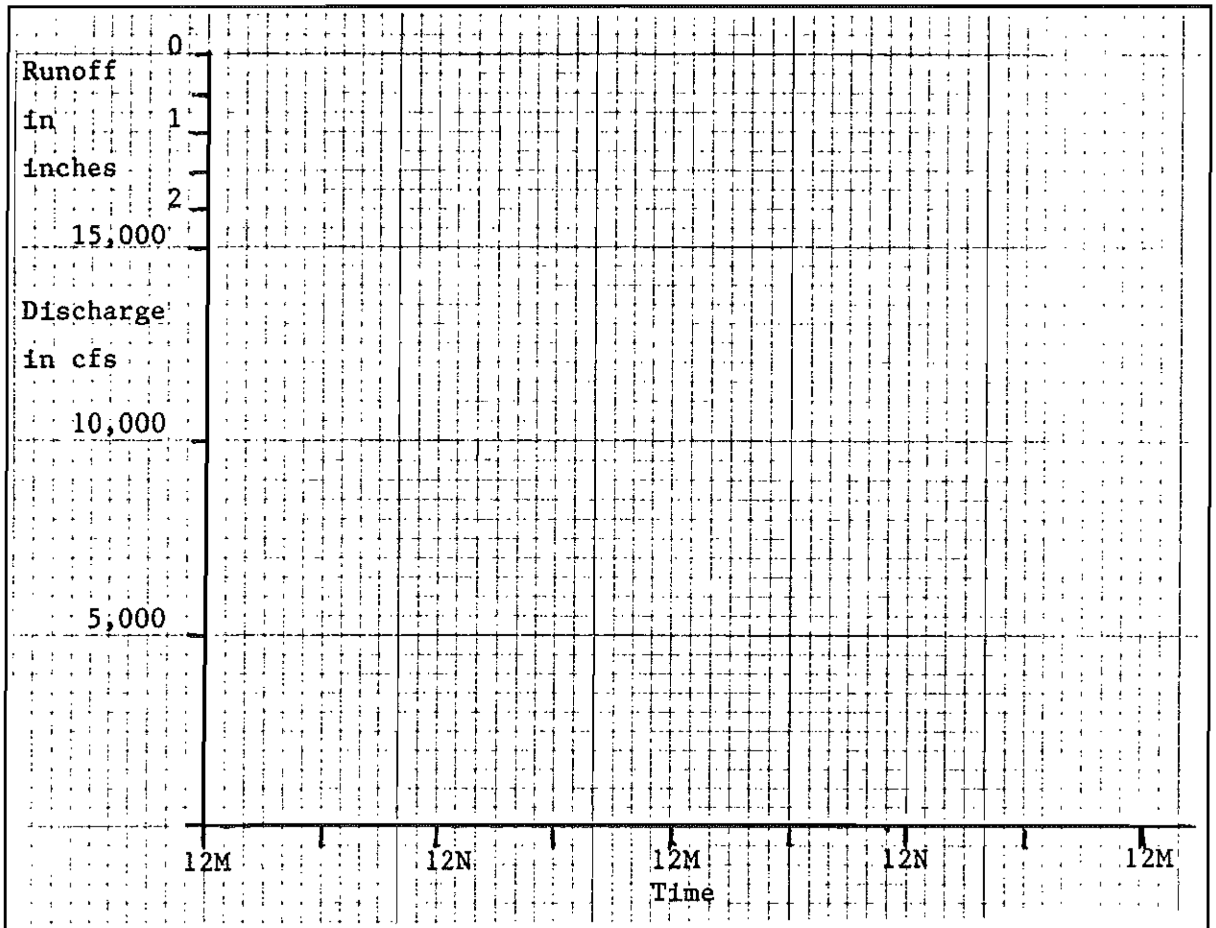
   Time to peak = __________ hours

2. How much runoff in a 3-hour period is necessary to produce a flow of 21,000 cfs using the unit hydrograph in Fig. 3. Assume base flow is 0.

   Surface runoff required = ________ inches

3. The river forecast model run at 6 a.m. estimated 1 inch of surface runoff from midnight to 3 a.m. of 1.00 inches and 0.25 inches of surface runoff from 3 a.m. - 6 a.m. Using the unit hydrograph in Fig. 3, estimate the magnitude and time of flood crest. Assume base flow is 150 cfs. (Helpful Hint: use Fig. 6.)

   Crest Time = _________
   Crest Discharge = _________ cfs



	12M	3AM	6AM	9AM	12N	3PM	6PM	9PM	12M
Base Flow									
1.0"RO(12-3)									
0.2"RO(3-6)									
Total Flow									

	3AM	6AM	9AM	12N	3PM	6PM	9PM	12M	3AM
Base Flow									
1.0"RO(12-3)									
0.2"RO(3-6)									
Total Flow									

Figure 6. Worksheet for sample problem.

4. Streamflow and Measurement

Streamflow is the flow of water past a point per unit time and is usually expressed in cubic feet per second (ft^3/sec) or cfs. Streamflow and discharge are used interchangeably. Streamflow is an important part of the hydrologic cycle and is the only part of the hydrologic cycle where accurate measurements of water can be made.

Measurement

To measure streamflow, water velocities are measured at several locations in the stream using a current meter. The cross sectional area and the average velocity are determined, and the discharge is computed by multiplying the cross sectional area of the stream channel by the average water velocity.

Direct measurement of streamflow is time consuming, tedious and labor intensive and does not lend itself to continuous recording. Instead of measuring streamflow directly, it is usually determined by measuring the stage or the height of the water surface above an arbitrary datum and relating the stage to discharge using a rating curve. The arbitrary datum which all stages are measured from is the gage datum or gage zero. The stage can be easily measured and recorded and later converted to discharge using the rating curve yielding a continuous discharge record.

Rating Curves

Stage-discharge relationships are generally developed from a series of stage-discharge measurements made by field personnel. The points are plotted on graph paper with stage on the y-axis and discharge on the x-axis, and a best estimate line is drawn through the points to yield a rating curve. The points from the curve are put in a tabular form called a rating table. The rating curve and rating table for the Salt Fork Arkansas River at Tonkawa, Oklahoma, are shown in Figs. 7 and 8, respectively. The rating curve is parabolic in shape and will usually plot as a nearly straight line on log-log graph paper, as shown in Fig. 9.

Stream Gaging

The U. S. Geological Survey (USGS) has the responsibility for measuring streamflow throughout the U.S. and operates stream gages at about 5000 sites to support this mission. These gages use paper tapes that periodically (as frequently as every 15 minutes) record the river stage. Monthly, the USGS retrieves the paper tapes and determines streamflow. The data are published annually. In support of these operations, the USGS makes discharge measurements and develops rating curves for their gaging sites. The rating curves or tables are made available to the NWS. When significant rises occur, the USGS may make discharge measurements and give the measurements to the NWS. These measurements are used to update rating curves as needed.

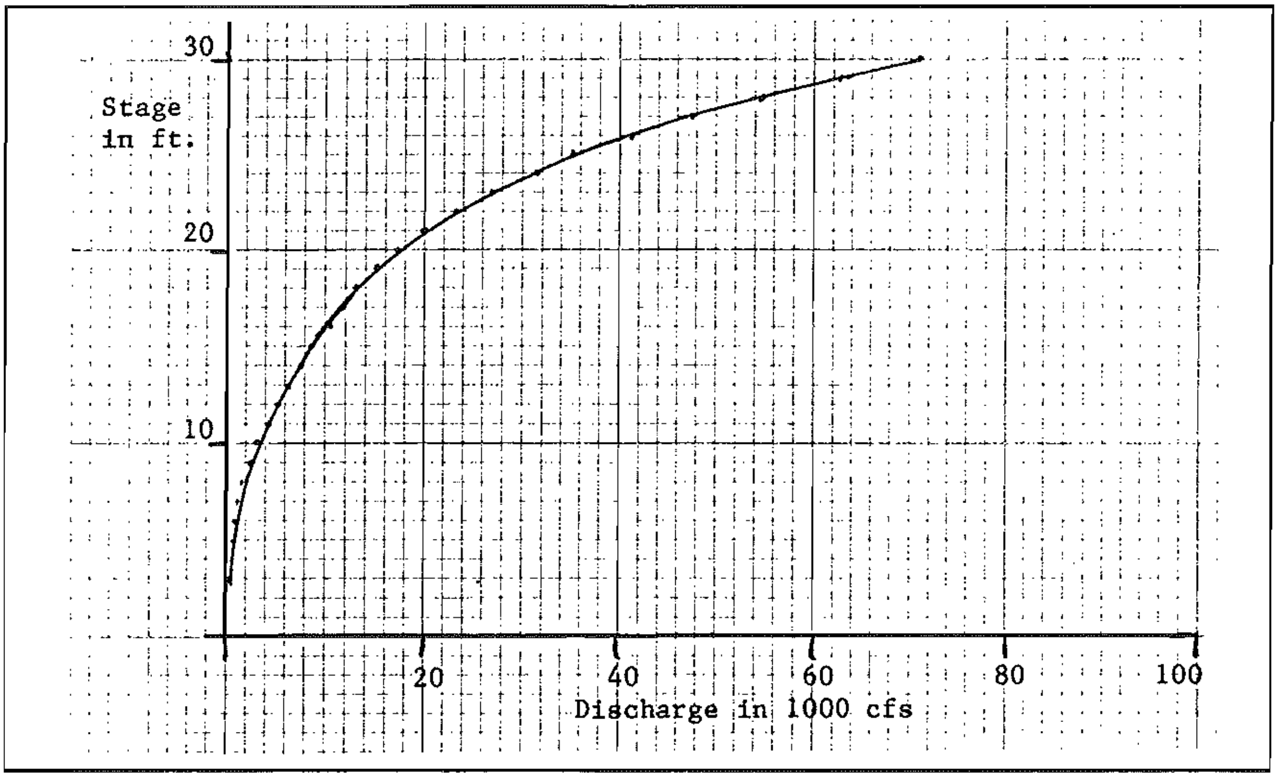


Figure 7. Rating curve for the Salt Fork Arkansas River at Tonkawa, OK.

Stage Data Collection

Stage data reach the NWS through various methods. Some gaging sites have a Data Collection Platform (DCP) connected to the USGS stream gaging equipment. The DCP stores the data from the USGS gage at frequent time intervals (as often as every 15 minutes) and transmits the data through a geostationary satellite (GOES) to a ground receive site in Wallops Island, Virginia. From there, the data are immediately transmitted to the NOAA Central Computer Facility (NCCF). At the NCCF, the GOES Data Distribution System (GDDS) or the Hydrometeorological Automated Data System (HADS) puts the data into a database as they are received and generates an AFOS product for transmission on the AFOS RDC every six hours. Data are transmitted in NMCRRA products and are used by NWS field offices to support the hydrologic program.

Additional river gages have a Limited Automatic Report Collector (LARC) or Digital Automated Remote Data Collector (DARDC) which connects the river gage to a telephone. A personal computer with a modem can be used to retrieve data from these sites, and NWS field offices often call these sites during flood events. The Centralized Automated Data Acquisition System (CADAS) polls all LARCs and DARDCs in the country and supplies these data to NWS offices through GDDS and HADS with GOES DCP data every six hours.

STAGE FEET	DISCHARGE IN 1000 CFS 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.011	0.022	0.033	0.044
4.0	0.055	0.071	0.087	0.103	0.119	0.135	0.154	0.173	0.192	0.211
5.0	0.230	0.250	0.286	0.314	0.342	0.370	0.404	0.438	0.472	0.506
6.0	0.540	0.584	0.628	0.672	0.716	0.760	0.816	0.872	0.928	0.964
7.0	1.040	1.114	1.168	1.262	1.336	1.410	1.468	1.526	1.584	1.642
8.0	1.700	1.775	1.850	1.925	2.000	2.075	2.150	2.225	2.300	2.375
9.0	2.450	2.535	2.620	2.705	2.790	2.875	2.960	3.045	3.130	3.215
10.0	3.300	3.390	3.480	3.570	3.660	3.750	3.840	3.930	4.020	4.110
11.0	4.200	4.300	4.400	4.500	4.600	4.700	4.800	4.900	5.000	5.100
12.0	5.200	5.315	5.430	5.545	5.660	5.775	5.890	6.005	6.120	6.235
13.0	6.350	6.465	6.580	6.695	6.810	6.925	7.040	7.155	7.270	7.385
14.0	7.500	7.635	7.770	7.905	8.040	8.175	8.310	8.445	8.580	8.715
15.0	8.85	8.98	9.12	9.25	9.39	9.52	9.66	9.79	9.93	10.06
16.0	10.20	10.34	10.49	10.63	10.78	10.92	11.07	11.21	11.36	11.50
17.0	11.65	11.80	11.96	12.11	12.27	12.42	12.58	12.73	12.89	13.04
18.0	13.20	13.38	13.57	13.75	13.94	14.12	14.31	14.49	14.68	14.86
19.0	15.05	15.26	15.48	15.69	15.91	16.12	16.34	16.55	16.77	16.98
20.0	17.20	17.48	17.76	18.04	18.32	18.60	18.88	19.16	19.44	19.72
21.0	20.00	20.32	20.64	20.96	21.28	21.60	21.92	22.24	22.56	22.88
22.0	23.20	23.56	23.92	24.28	24.64	25.00	25.36	25.72	26.08	26.44
23.0	26.80	27.23	27.67	28.10	28.54	28.97	29.41	29.84	30.28	30.71
24.0	31.15	31.58	32.02	32.45	32.89	33.32	33.76	34.19	34.63	35.06
25.0	35.50	36.04	36.59	37.14	37.69	38.24	38.79	39.34	39.89	40.44
26.0	40.99	41.68	42.37	43.06	43.75	44.44	45.13	45.82	46.51	47.20
27.0	47.89	48.58	49.27	49.96	50.65	51.34	52.03	52.72	53.41	54.10
28.0	54.79	55.60	56.41	57.22	58.03	58.84	59.65	60.46	61.27	62.08
29.0	62.89	63.70	64.51	65.32	66.13	66.94	67.75	68.56	69.37	70.18
30.0	70.99	71.94	72.89	73.84	74.79	75.74	76.69	77.64	78.59	79.54

Figure 8. Rating table for the Salt Fork Arkansas River at Tonkawa, OK.

Some ALERT local flood warning systems have river gages which supply real-time data to a base station. These river gages will transmit a radio signal of a stage value to the base station when the stage changes by a pre-set amount, usually 0.04 ft. NWS offices may use a personal computer to interrogate these base stations to retrieve the data and use it for river forecasting. Some NWS offices have a base station which receives the data in real-time from the radio signals.

The NWS issues forecasts for some gage sites where the USGS does not support streamflow measurements. At these sites, the NWS will install a staff gage or wire weight gage that a cooperative observer will read. The observer will telephone the responsible NWS office with an Automated Tone Dial Data Collection System (ATDTDCS) or the Remote Observation System Automation (ROSA). These systems will send this data on AFOS to NWS offices that need the data.

Study Questions

1. Using Fig. 7, determine the discharge when the river is at flood stage assuming flood stage is 15 feet.

   Discharge at Flood Stage = __________ cfs

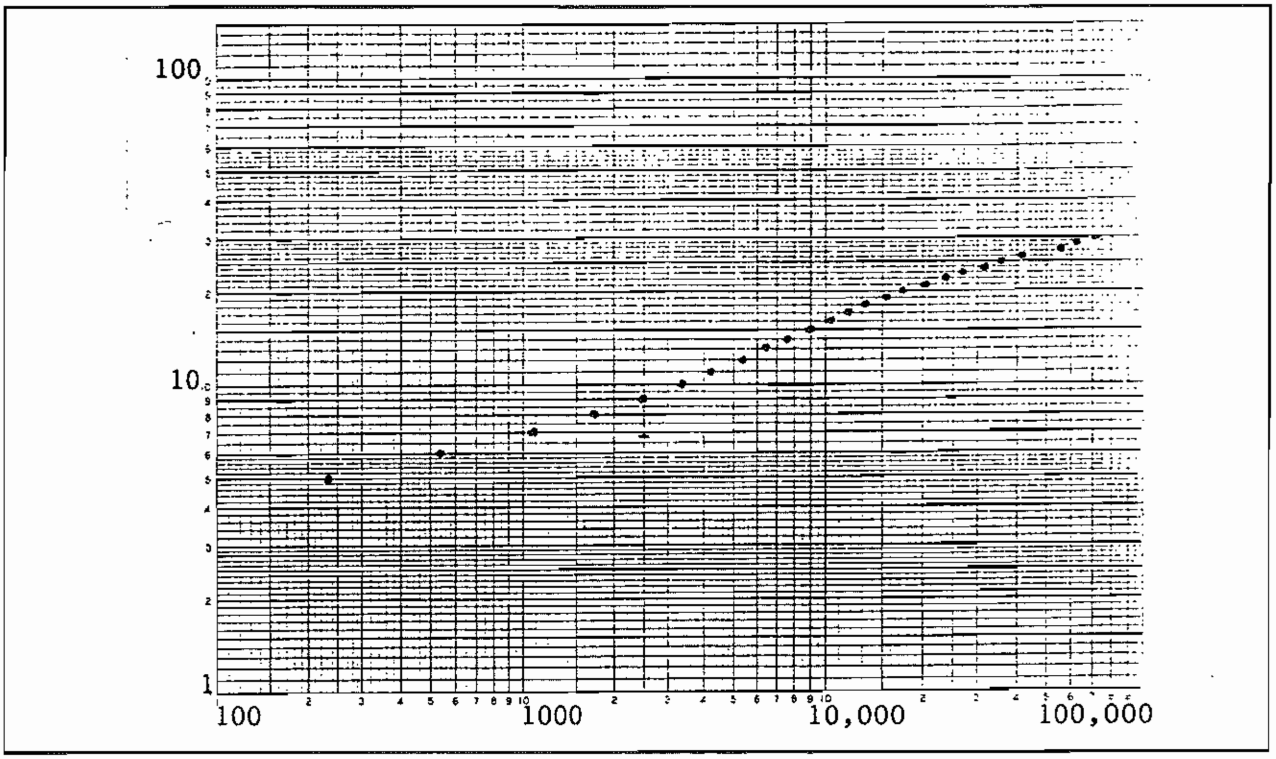


Figure 9. Log-log plot of rating curve for Salt Fork Arkansas River at Tonkawa, OK.

2. What is the ratio of the discharge at 10 feet stage versus that of discharge at a stage of 20 feet for the rating curve in Fig. 7?

   Discharge at 20 ft stage = ___________ cfs

   Discharge at 10 ft stage = ___________ cfs

$$Ratio = \frac{Discharge\ at\ 20\ ft}{Discharge\ at\ 10\ ft} = \frac{\_\_\_\_\ cfs}{\_\_\_\_\ cfs} = \_\_\_\_\_$$

3. Why is the discharge at 20 feet not twice the discharge at 10 feet?

4. The discharge at Tonkawa, Oklahoma, is 20,000 cfs. What is the stage?

   Stage = _____ ft

5. Streamflow Routing

As a flood wave travels down a river reach which has no intervening tributary flow, the peak flow will be delayed and attenuated. The delay or lag occurs because a finite amount of time is required for the flood wave to move downstream. The attenuation or reduction of peak flow occurs because as stage and discharge in the reach increase, the amount of water in temporary storage in the reach increases as shown in Fig. 10. Later, as the stage and discharge fall, water is released from temporary storage; and the time required for flood waters to pass a point increases.

An example of how a flood wave is lagged and attenuated as it moves down the Rio Grande from Eagle Pass to Laredo, Texas, is shown in Fig. 11.

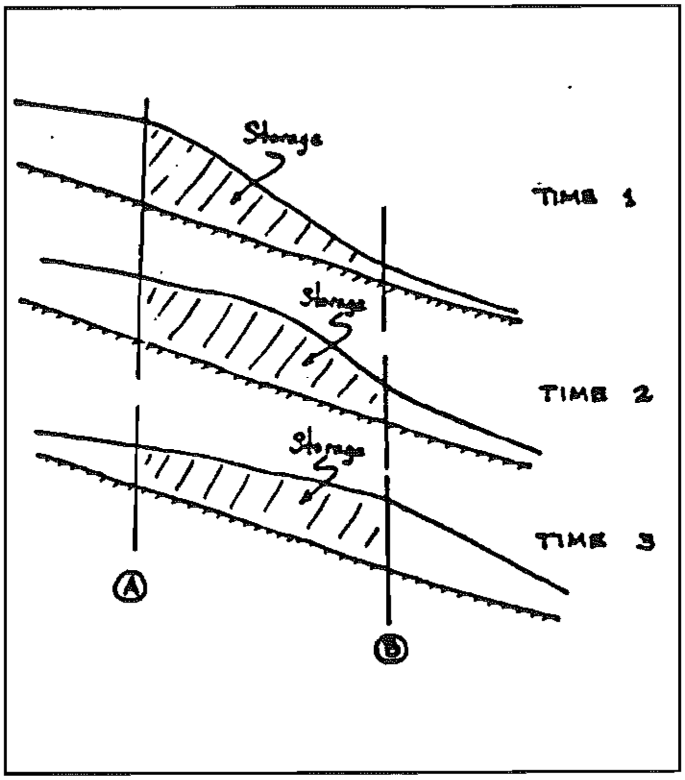


Figure 10. Diagram of channel storage in a river reach as a flood wave moves downstream.

Factors Affecting a Flood Wave

The changes in the shape of a flood wave, or its delay and attenuation, as it moves downstream depend on many factors:

- **Rate of Rise** — When flows rise rapidly, high velocities occur, and the flood will attenuate very rapidly. In general, the lag time will decrease as the rate of rise increases.

- **Height of Rise** — For high flows, more water is temporarily stored in a reach of a channel, and peaks are attenuated more than for low flows. While a river is within its banks, the lag time will normally decrease with increasing stage and flows. When the river goes out of banks and into the flood plain, the trees and vegetation in the flood plain will retard flow, and the lag time will normally increase.

- **Slope of channel** — Steeper channels will have less reduction in peak flows than flatter channels, and the lag time will normally decrease with increasing steepness of the channel.

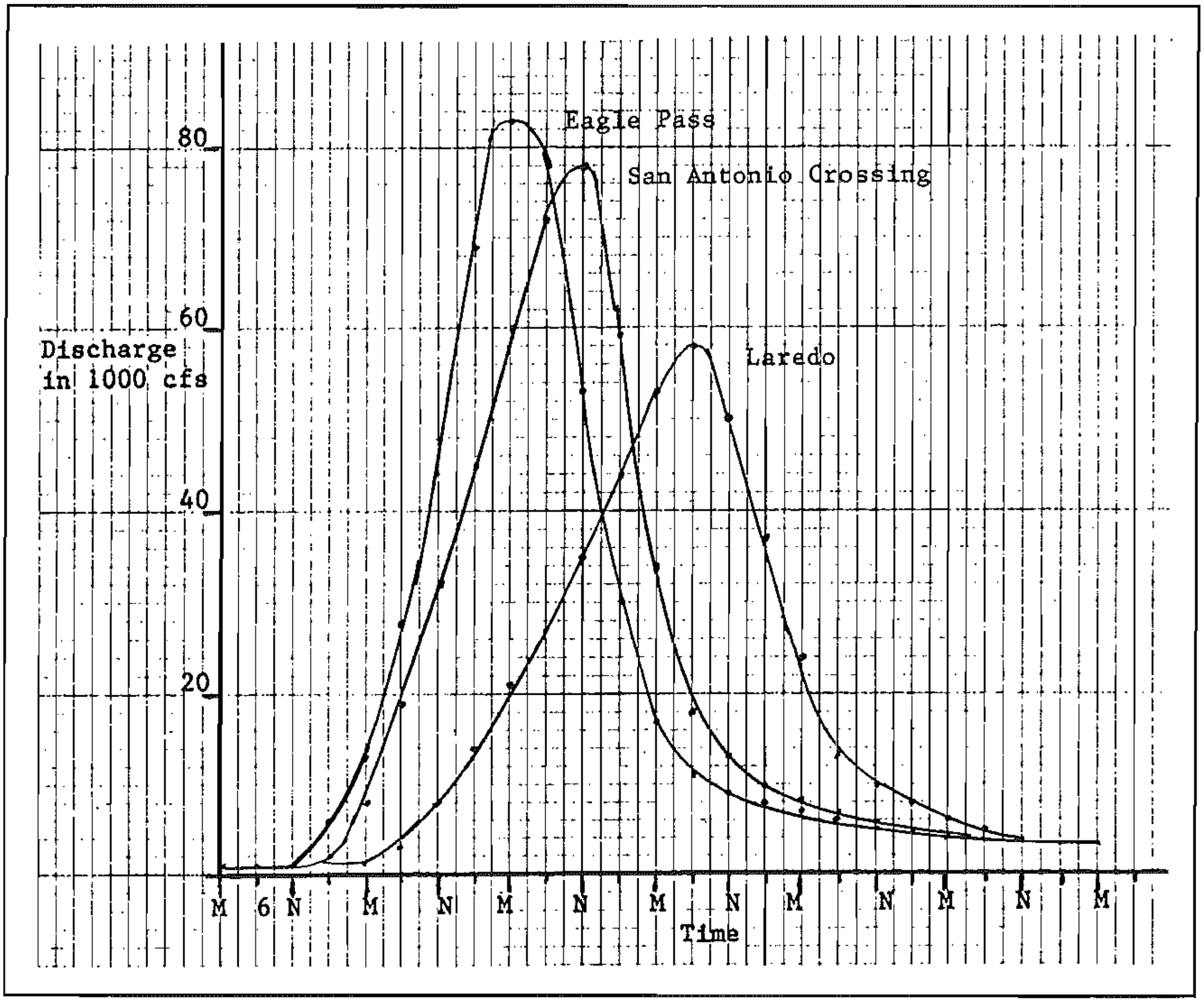


Figure 11. Hydrographs of the Rio Grande at Eagle Pass, San Antonio Crossing, and Laredo, Texas, showing the lag and attenuation of a flood wave as it moves downstream.

- **Stages downstream** — If stages downstream are falling, the flood wave will be attenuated more than if downstream stages are rising. Lag times will also increase.

- **Channel geometry** — The more the channel cross section size increases as you proceed downstream, the more the flood wave will be attenuated and retarded, and lag times will increase.

- **Length of reach** — The longer a river reach, the more water will be in channel storage, and the more the flood will be attenuated.

- **Crest shape** — Comparing two flood waves in the same river reach, the flatter flood crest of the two will be attenuated less. In general, lag times will increase with flatter crests.

In addition to being lagged and attenuated, some water in the flood wave will be lost as the flood wave moves downstream. These losses occur because of the following reasons:

- **Wetting the channel** — As a river rises, some of the flow is required to wet the river banks. It may percolate downward to the groundwater or evaporate into the atmosphere when the water level drops.

- **Overbank storage** — When a river goes out of banks, water flows in the flood plain. When the river returns to within banks, some of the water in the flood plain cannot flow back into the channel and is lost.

- **Seepage** — Because of the porous channel bottoms in some reaches, as much as 50% of the flow may be lost to groundwater.

Hydrologic Routing Techniques

Computer programs of mathematical models that simulate the energy and momentum equations have been developed to predict the movement of water in a river channel. These hydraulic models require a significant amount of information about the river channel and are CPU intensive. These models are in use in some RFCs that must forecast for large rivers such as the Mississippi. Hydraulic models are beyond this presentation.

In an attempt to simplify the simulation of water moving downstream, empirical solutions have been developed. These methods are referred to as hydrologic routing procedures. One of the earliest hydrologic routing methods, the Muskingum method, assumes that the outflow is proportional to the temporary channel storage; the temporary storage is proportional to the inflow and outflow at the beginning of the computational time period and inflow at the end of the computational time period. The computational time period is selected to be less than the shortest lag time between two points so that the hydrograph can be defined adequately. Since most NWS routing models work on a six-hour time step, six hours is normally used as the computational time. Mathematically, the Muskingum method is:

$$O_2 = (C_0 \times I_2) + (C_1 \times I_1) + (C_2 \times O_1)$$

where O_2 = the outflow at the end of the time interval,
I_2 = the inflow at the end of the time interval,
I_1 = the inflow at the beginning of the time interval,
O_1 = the outflow at the beginning of the time interval,
C_0, C_1, and C_2 are routing constants determined from previous streamflow records.

Streamflow data from previous floods are used to determine the storage function from which routing coefficients can be determined.

Sample Problem

1. Fig. 12 shows a hydrograph at the Rio Grande River at Eagle Pass, Texas. The flow at San Antonio Crossing is assumed to be 1000 cfs on 6 a.m. and noon. The Muskingum coefficients are: $C_0=0.02$, $C_1=0.80$, and $C_2=0.18$. Use the Muskingum Method to route this flow downstream to San Antonio Crossing, Texas. A six-hour time step will be used.

   Discharge values for Eagle Pass will be used as inputs (I values) for the Muskingum Method. The discharges at San Antonio are the outflow (0) time series.

   To compute the routed discharge at San Antonio at 6 p.m.,

   $I_1=1000$ (flow at Eagle Pass at 12 noon),
   $I_2=5000$ (flow at Eagle Pass at 6 p.m.), and
   $O_1=1000$ (flow at San Antonio at 12 noon).

   The routed discharge at San Antonio Crossing at 6 p.m. will be:

   $$O_2= (0.02)(5000) + (0.80)(1000) + (0.18)(1000) = 1080$$

   The discharge at San Antonio Crossing at 6 p.m. is known now. To compute the routed discharge at San Antonio Crossing at midnight:

   $I_1=5000$ (flow at Eagle Pass at 6 p.m.),
   $I_2=13000$ (flow at Eagle Pass at midnight), and
   $O_1=1080$ (flow at San Antonio Crossing at 6 p.m. — from above).

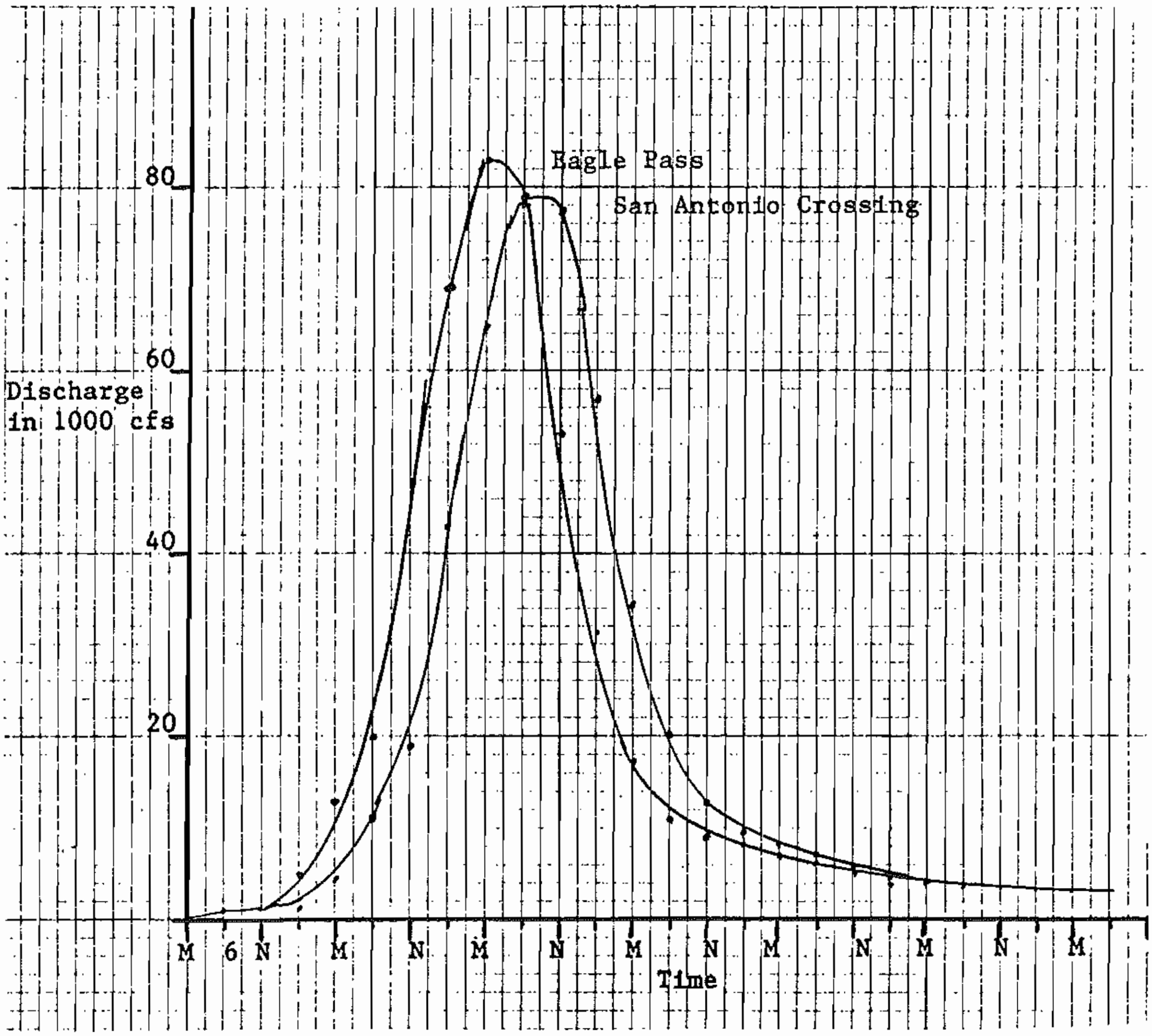
   The routed discharge at San Antonio Crossing at 12 midnight on day 1 will be:

   $$O_2= (0.02)(13000) + (0.80)(5000) + (0.18)(1080) = 4454$$

   This process must be continued until all ordinates of the outflow hydrograph are computed.

Study Questions

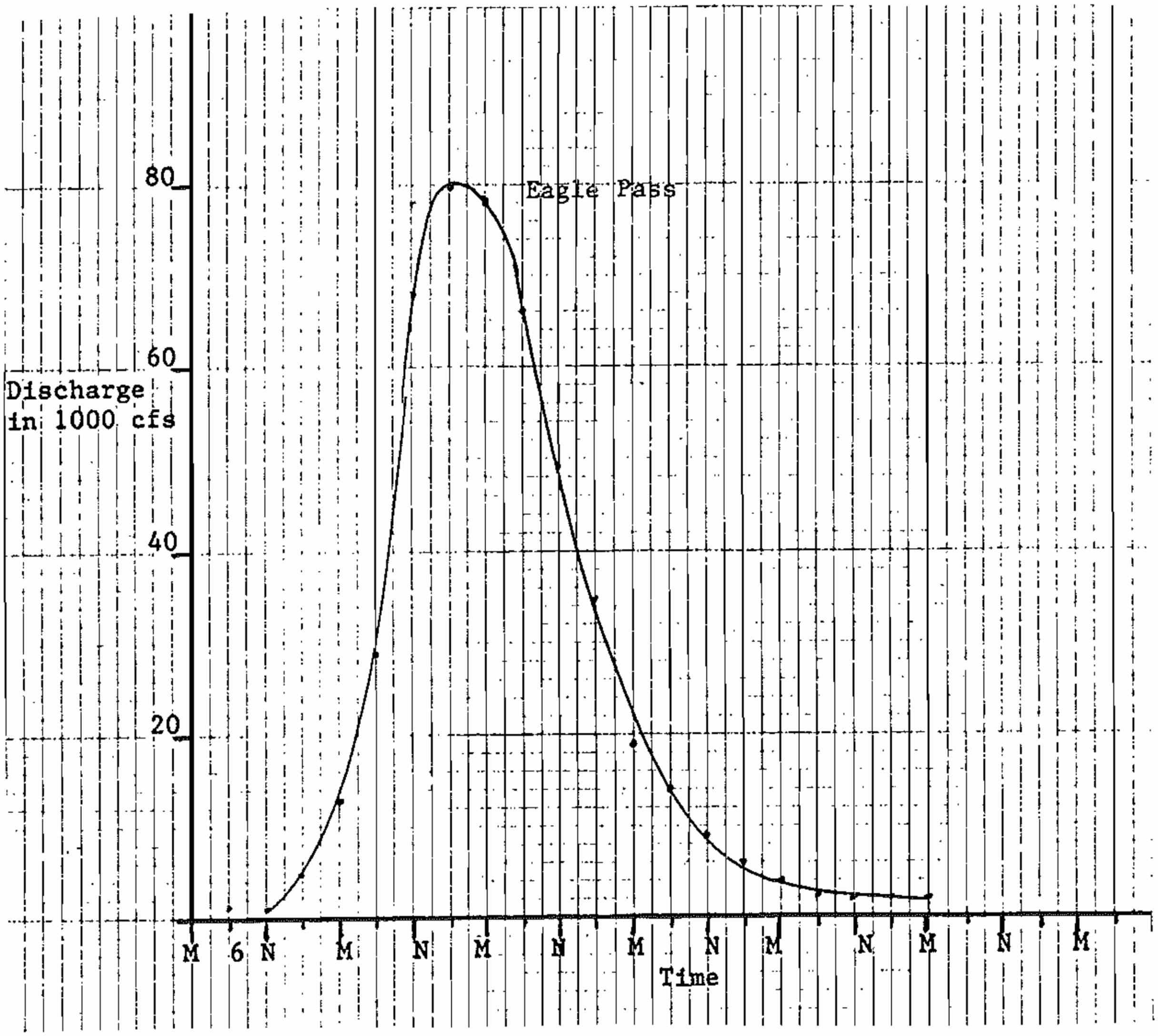
1. Using the routing constants in Sample Problem 1, route the flow in Fig. 13 from Eagle Pass to San Antonio Crossing.



	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM
Inflow	1000	1000	5000	13000	20000	48000	69000	83000	78000	53000	30000	17000	11000
Outflows	1000	1000	1080	4454	11602	19048	43209	64638	79595	77787	57002	34600	20048

	12N	6PM	12M	6AM	12N	6PM	12M	6AM	12N	6PM	12M
Inflow	9000	8000	7000	6000	5000	4500	4000	3800	3600	3500	3400
Outflows	12589	9626	8273	7209	6198	5206	4617	4107	3851	3643	3524

Figure 12. Sample problem on routing flow on the Rio Grande at Eagle Pass to San Antonio Crossing using the Muskingum method.



	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM	12N	6PM	12M
Inflow	1000	1000	5000	13000	30000	68000	80000	78000	66000	50000	35000	19000
Outflow	1000	______	______	______	______	______	______	______	______	______	______	______

	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM
Inflow	14000	9000	6000	4000	2000	2000	2000	2000	2000
Outflow	______	______	______	______	______	______	______	______	______

Figure 13. Worksheet for sample problem.

6. River Forecasting Operations

River forecasting models simulate the movement of water after it has reached the ground. Each RFC has its forecast models set up to specifically simulate the hydrology in its area utilizing the most appropriate hydrologic techniques.

River Forecast Components

The model that simulates the hydrology of an RFC is only a small part of the entire forecast system that must be in place to make forecasts. The main components of the forecast system are:

- **Data Entry** — Data required to run the forecast models must be input into the system before it can be used. Data entry includes decoding SHEF-coded data and putting the data into a database for use by other programs.

- **Data Pre-Processing** — Data in the system must put into a form for use by hydrologic models. For example, the SACSMA or the API model require average rainfall over a basin, and this average is generated in the Pre-Processor step. Forecast models simulate conditions at specific times, and data frequently are not available at those times. The pre-processor may estimate data at these times where appropriate.

- **Forecast model** — The forecast model simulates the hydrology for a particular river basin. It uses data from the pre-processor step and parametric data defining the hydrology for an area in this modeling process. Parametric data includes unit hydrographs, API coaxial relationships and/or SACSMA water balance parameters, channel routing constants, and other hydrologic information.

- **Parametric Database Management System** — A database management system manages the large volume of information and parametric data required in a forecast system.

Most RFCs use the National Weather Service River Forecast System Version 5.0 (NWSRFS) as their forecast system. NWSRFS includes all data entry, data pre-processing, parametric database management, and hydrologic techniques to make river forecast runs. RFCs are only required to decide which techniques are the most appropriate to model their area and determine the hydrologic parameters needed in the techniques.

NWSRFS Version 5.0 runs on a mainframe computer in Suitland, Maryland, and RFCs execute forecast runs on this computer through remote job entry. Because of data availability and RFC hours of operations, RFC models are normally executed once a day after all 7 a.m. precipitation and stage data have been received. The model simulates hydrologic conditions generally every six hours at synoptic times. NWSRFS has sufficient flexibility that as finer resolution precipitation and stage data become available, hydrologic models can simulate flows as often as every hour with forecast runs made every six hours.

In the MAR NWS, RFC AWIPS will have sufficient computing power to execute NWSRFS and all components locally. NWSRFS has been modified to run in an interactive mode allowing RFC hydrologists to easily change inputs into its hydrologic models and make river and flood forecasts in a more timely manner. In addition to the interactive capabilities of NWSRFS run locally, the link to the mainframe computers will be retained for backup operations.

Steps in Forecast Preparation

Forecast models simulate the hydrology for a river basin or reach. Consider a drainage area shown in Fig. 13 for the Alphabet River. The objective of a forecast model is to make a forecast for the forecast point at headwater Gage A and the downstream forecast point at Gage B. The hydrologic computations to make a forecast include:

(1) Estimate or predict flow at Gage A.
(2) Route that water downstream to Gage B.
(3) Compute the flow from the local area for Gage B.
(4) Add the flow from the local area for gage B to the routed flow to compute a storm hydrograph.

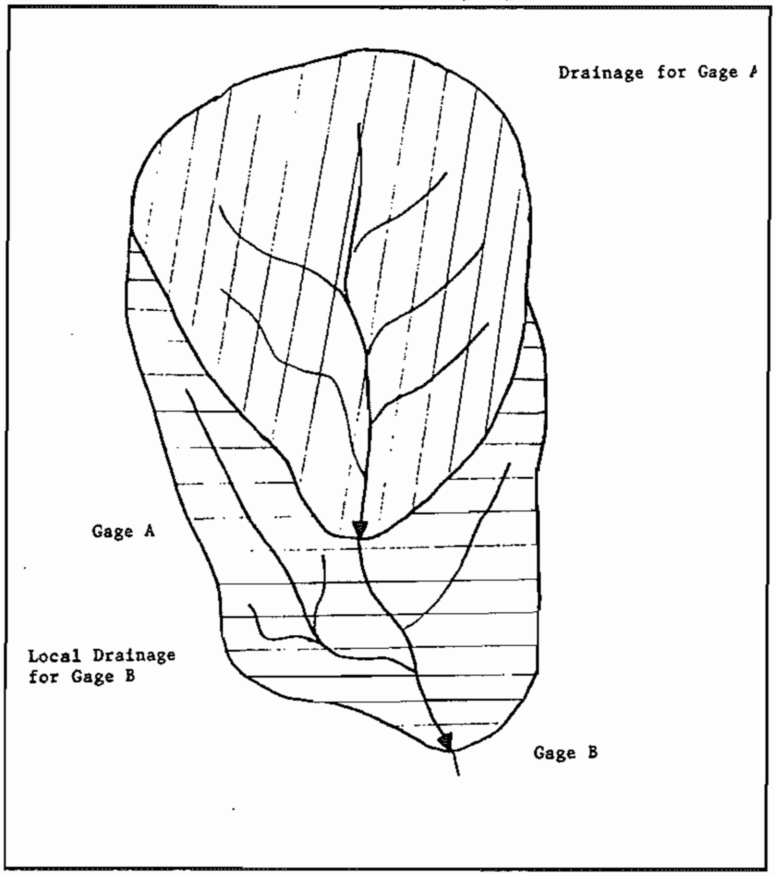


Figure 14. Diagram of the headwater basin for gage site A and local drainage for gage B on the Alphabet River.

The local drainage for Gage B is that area below Gage A that drains to Gage B. Local drainage may be considerable if it includes any major tributaries.

Forecast Needs

Before the forecast can be made, the following information defining the hydrology of the area must be known:

1. The API coaxial relationship for Headwater Basin A.
2. The UHG for Headwater Basin A.
3. The Stage-discharge relationship or rating for Gage A.
4. The routing coefficients to route the water from Gage A to Gage B.

5. The API coaxial relationship for the Local drainage for Gage B.
6. The UHG for the Local drainage for Gage B.
7. The Stage-discharge relationship or rating for Gage B.
8. The Base Flow in the river at both gages A and B.

Steps in Computing Forecasts

To make a forecast at Gages A and B, the following steps must be completed:

1. **API Model** — Based on rainfall, either from ground truth, radar, or both, estimate the amount of runoff for the headwater basin above Gage A for a particular time period or periods.

2. **Unit Hydrograph** — Based on runoff from the API model (step 1), determine the total surface runoff hydrograph from the surface runoff for each time period.

3. **Total Discharge Hydrograph** — Compute the ordinates of the storm hydrograph by adding the base flow to the ordinates from the UHG operation (step 2).

4. **Discharge/Stage Conversion** — Convert discharge (step 3) to stage to develop a stage hydrograph for Gage A.

Note: All of the computations for a single headwater point are complete, and a forecast for Gage A can be made.

5. **Routing** — Route the storm hydrograph from Gage A (step 3) to Gage B.

6. **API Model** — Based on rainfall, either from ground truth or from radar, estimate the surface runoff for the local drainage for Gage B for the particular time periods.

7. **Unit Hydrograph** — Based on the runoff from the API model (step 6), determine the total surface runoff hydrograph from the surface runoff from the local drainage for Gage B.

8. **Storm Hydrograph** — Compute the ordinates of the storm hydrograph by adding the base flow for the local drainage for Gage B, the ordinates of the UHG operation for the local drainage for Gage B (step 7), and the routed flows (step 5).

9. **Discharge/Stage Conversion** — Convert discharge (step 8) to stage to develop a stage hydrograph for Gage B.

Forecasted hydrographs of discharge and stage at Gage A and Gage B are produced. The RFC hydrologists will use their knowledge of hydrologic models, hydrologic conditions, and rainfall patterns to adjust forecast hydrographs for Gages A and B and arrive at a forecast for the sites.

This process is similar to the process meteorologists use when adjusting MOS guidance to make a weather forecast.

River forecast models used by RFCs employ the above computational techniques. When the hydrology warrants, RFCs will replace these simple techniques with more complicated ones performing the same task. However, the general forecast procedure remains the same.

There are some local applications programs available on personal computers to model parts of the hydrologic cycle. These applications usually employ manual data input and run very quickly at a WSFO to support flash flood and flood forecast operations. One such program is ADVIS, a program which models flows and stages in a single headwater basin for flash flood and small stream forecasting. It uses either a one- or three-hour time interval to do simulations. ADVIS or some other simplified headwater forecast technique will be included in AWIPS.

Sample Problem

1. It is 1200 UTC on March 1, and the Alphabet River basin (Fig. 14) has received heavy rainfall over the previous 24 hours. The average rainfall in inches for the basin is:

	1200-1800 UTC	1800-0000 UTC	0000-0600 UTC	0600-1200 UTC
Headwater Drainage for A	1.00	0.50	2.00	2.50
Local Drainage	0.50	1.00	2.00	2.00

Assume the API coaxial rainfall/runoff relationship in Fig. 1 is good for Basin A and B in the Alphabet River. It is assumed that the soil is moderately moist with an API value of 1.5 for both the headwater drainage A and local drainage for B.

Based on previous work by a hydrologist, the ordinates in cfs of the six-hour unit hydrograph for each basin are:

UHG for A	200	2000	1000	400	200	100	0
UHG for B Local	600	1900	700	400	200	100	0

The following Muskingum routing coefficients have been developed for the reach of the river from A to B.

$C_0 = 0.02$ $C_1 = 0.80$ $C_2 = 0.18$

Assume that baseflow for the A basin is 50 cfs and is 75 cfs for the local B drainage.

Rating curves for Gages A and B are shown in Fig. 15.

Determine the forecasted stage and discharge hydrograph at Gages A and B. When is each of the gages forecasted to crest?

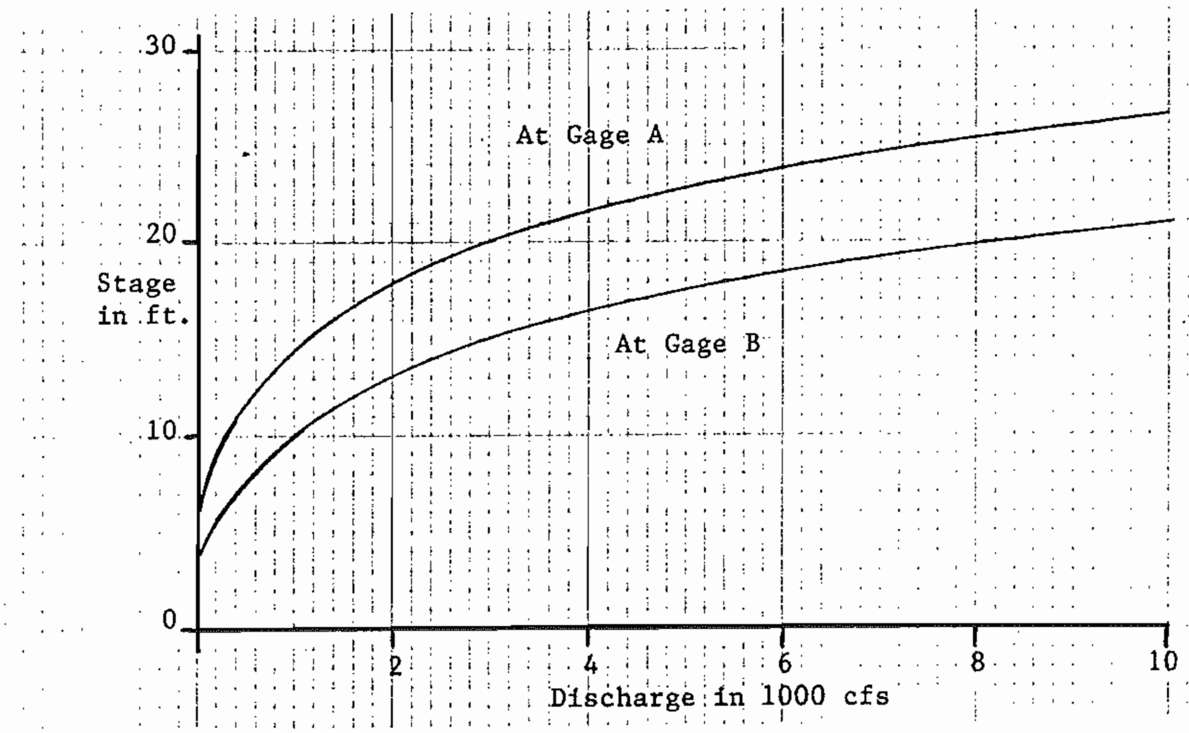


Figure 15. Rating curves for gages A and B on the Alphabet River.

Assume that the API value for computing runoff does not change during the storm. The calculations for each step as described above are shown in Fig. 16. The resulting forecasted discharge and stage hydrographs are plotted in Fig. 17 and 18, respectively. By inspection, the forecasted crest at Gage A would be about 13 feet occurring between 1200 UTC and 1800 UTC on March 1, or the morning of March 1. The forecasted crest at Gage B would be about 25 feet and occur between 1800 UTC on March 1 and 0000 UTC March 2, or the afternoon of March 1.

Study Questions

1. Following are the six-hour average basin rainfall totals for Headwater Drainage for Gage A and the Local Drainage for Gage B.

	February 28		March 1	
	1200-1800UTC	1800-0000UTC	0000-0006UTC	0600-1200UTC
Headwater Drainage for A	2.00	2.50	0.50	0.00
Local Drainage B	2.50	2.50	2.00	1.00

Basin A

		Feb 28 12-18Z	18-00Z	Mar 1 00-06Z	06-12Z
	6 hr Rain (in)	1.00	0.50	2.00	2.50
Step 1	6 hr Runoff (in)	0.60	0.20	1.30	1.80

Computations for Discharge at Gage A

Step 2 Discharge from Surface Runoff

	Feb 28 12Z	18Z	Mar 1 00Z	06Z	12Z	18Z	Mar 2 00Z	06Z	12Z	18Z	Mar 3 00Z	06Z	12Z	18Z	Mar 4 00Z
From RO from 12-18Z (cfs)	0	120	1200	600	240	120	60	0							
From RO from 18-00Z (cfs)		0	40	400	200	80	40	20	0						
From RO from 00-06Z (cfs)			0	260	2600	1300	520	260	130	0					
From RO from 06-12Z (cfs)				0	360	3600	1800	720	360	180	0				
Base Flow (cfs)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Step 3 Total Flow - A (cfs)	50	170	1290	1310	3450	5150	2470	1050	540	230	50	50	50	50	50
Step 4 Stage at Gage A (ft)	7.5	8.0	15.8	16.0	21.0	23.0	19.0	15.5	12.0	9.5	7.5	7.5	7.5	7.5	7.5
Step 5 Flow Routed to Gage B	50	52	171	1089	1313	3099	4727	2848	1363	682	308	96	58	51	50

Local Basin B

		Feb 28 12-18Z	18-00Z	Mar 1 00-06Z	06-12Z
	6 hr Rain (in)	0.50	1.00	2.00	2.00
Step 6	6 hr Runoff (in)	0.20	0.60	1.30	1.30

Computations for Discharge at Gage B

Step 7	Feb 28 12Z	18Z	Mar 1 00Z	06Z	12Z	18Z	Mar 2 00Z	06Z	12Z	18Z	Mar 3 00Z	06Z	12Z	18Z	Mar 4 00Z
From RO from 12-18Z (cfs)	0	120	380	140	80	40	20	0							
From RO from 18-00Z (cfs)		0	360	1140	420	240	120	60	0						
From RO from 00-06Z (cfs)			0	780	2470	910	520	260	130	0					
From RO from 06-12Z (cfs)				0	780	2470	910	520	260	130	0				
Base Flow (cfs)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Step 8 Total Flow at B (cfs)	125	247	986	3224	5138	6834	6372	3763	1828	887	383	171	133	126	125
Step 9 Stage at Gage B (ft)	5.0	6.5	10.0	14.5	17.9	19.0	18.8	16.0	12.8	9.8	7.0	5.8	5.2	5.0	5.0

Figure 16. Calculations for Sample Problem.

Using the hydrologic parameters in Sample Problem 1 in this chapter, determine the time of crest and crest stage and flow for Gages A and B. Use Fig. 19, 20, and 21 for your calculations.

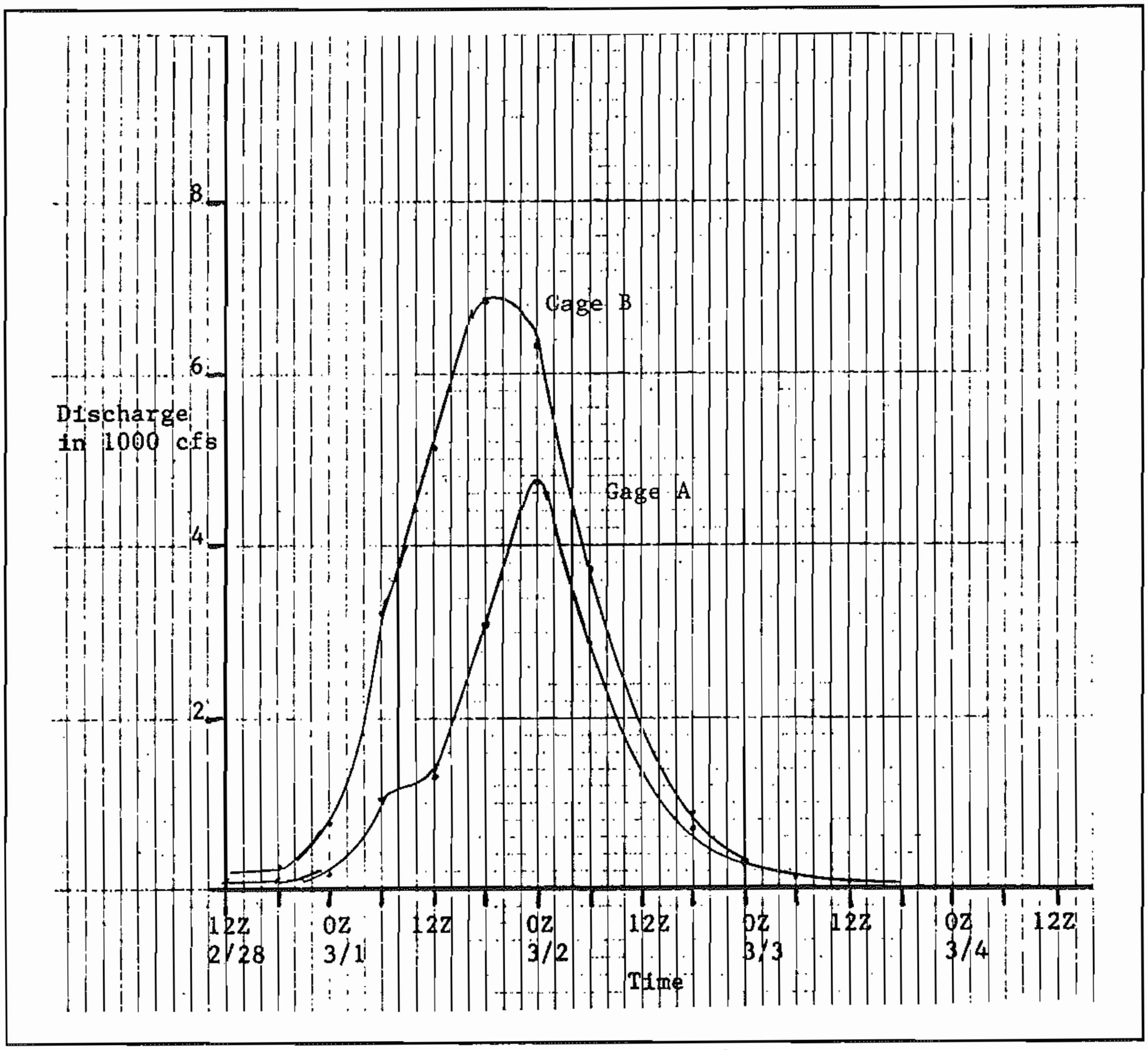


Figure 17. Forecast discharge hydrographs for Gage A and Gage B.

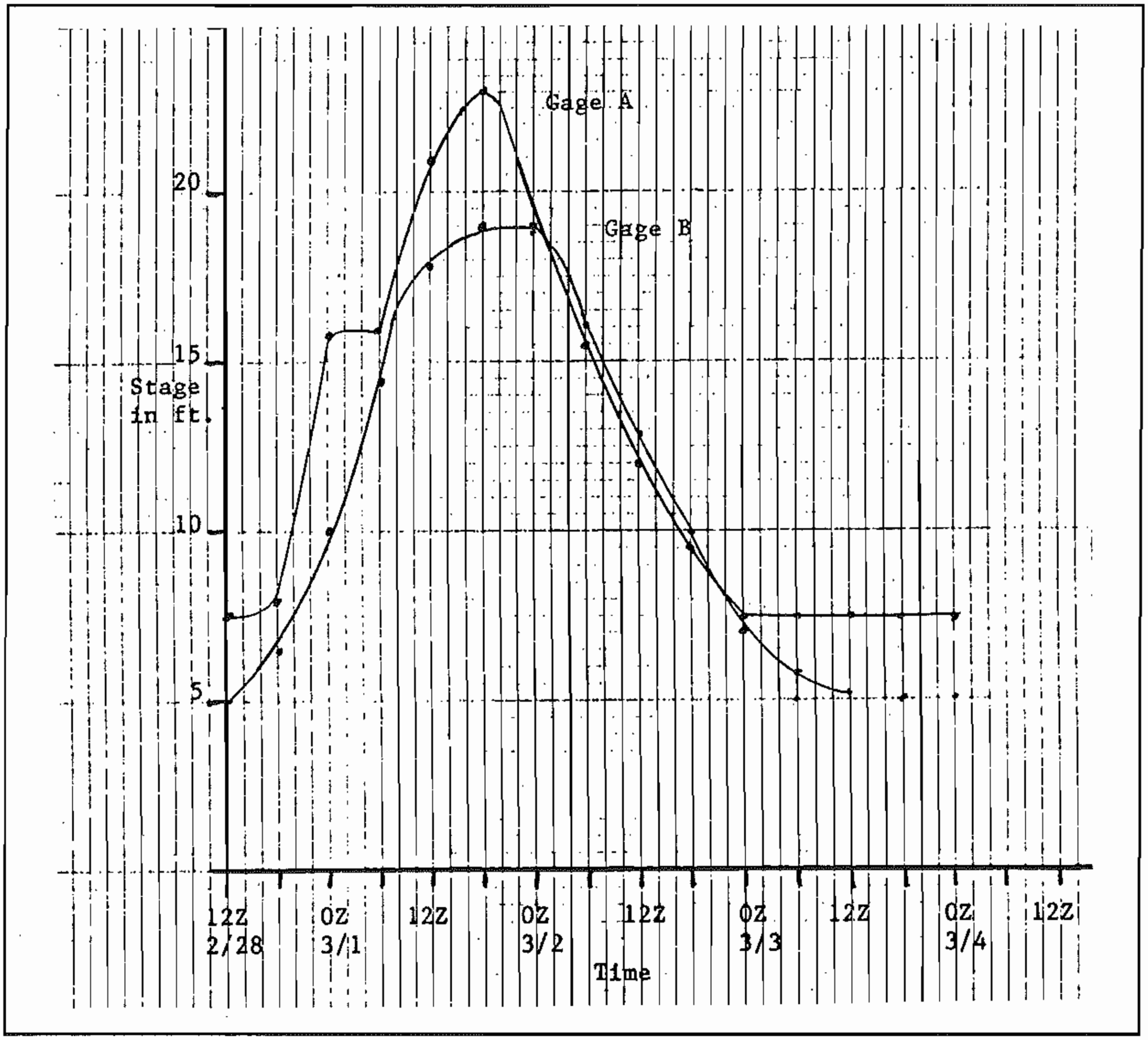


Figure 18. Forecast stage hydrograph at Gage A and Gage B.

Basin A

		Feb 28 12-18Z	18-00Z	Mar 1 00-06Z	06-12Z
	6 hr Rain (in)	2.00	2.50	0.50	0.00
Step 1	6 hr Runoff (in)	___	___	___	___

Computations for Discharge at Gage A

Step 2 Discharge from Surface Runoff

	Feb 28 12Z	18Z	Mar 1 00Z	06Z	12Z	18Z	Mar 2 00Z	06Z	12Z	18Z	Mar 3 00Z	06Z	12Z	18Z	Mar 4 00Z
From RO from 12-18Z (cfs)	___	___	___	___	___	___	___	___							
From RO from 18-00Z (cfs)		___	___	___	___	___	___	___	___						
From RO from 00-06Z (cfs)			___	___	___	___	___	___	___	___					
From RO from 06-12Z (cfs)				___	___	___	___	___	___	___	___				
Base Flow (cfs)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
Step 3 Total Flow - A (cfs)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
Step 4 Stage at Gage A (ft)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
Step 5 Flow Routed to Gage B	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___

Local Basin B

		Feb 28 12-18Z	18-00Z	Mar 1 00-06Z	06-12Z
	6 hr Rain (in)	2.50	2.50	2.00	1.00
Step 6	6 hr Runoff (in)	___	___	___	___

Computations for Discharge at Gage B

Step 7	Feb 28 12Z	18Z	Mar 1 00Z	06Z	12Z	18Z	Mar 2 00Z	06Z	12Z	18Z	Mar 3 00Z	06Z	12Z	18Z	Mar 4 00Z
From RO from 12-18Z (cfs)	___	___	___	___	___	___	___	___							
From RO from 18-00Z (cfs)		___	___	___	___	___	___	___	___						
From RO from 00-06Z (cfs)			___	___	___	___	___	___	___	___					
From RO from 06-12Z (cfs)				___	___	___	___	___	___	___	___				
Base Flow (cfs)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
Step 8 Total Flow at B (cfs)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
Step 9 Stage at Gage B (ft)	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___

Figure 19. Worksheet for Study Questions 1 in Chapter 6.

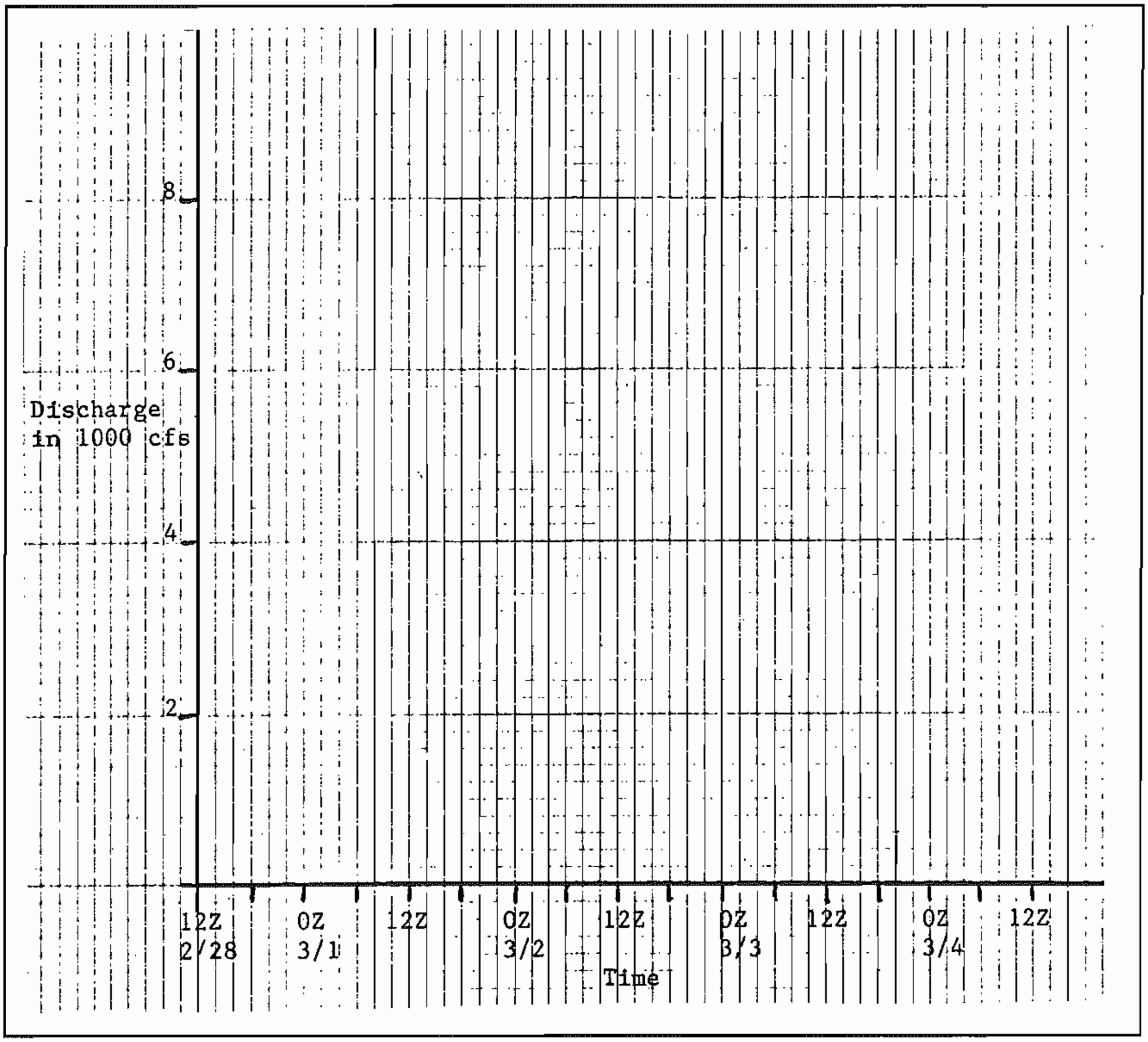


Figure 20. Worksheet to plot forecasted discharges for Study Question 1 in Chapter 6.

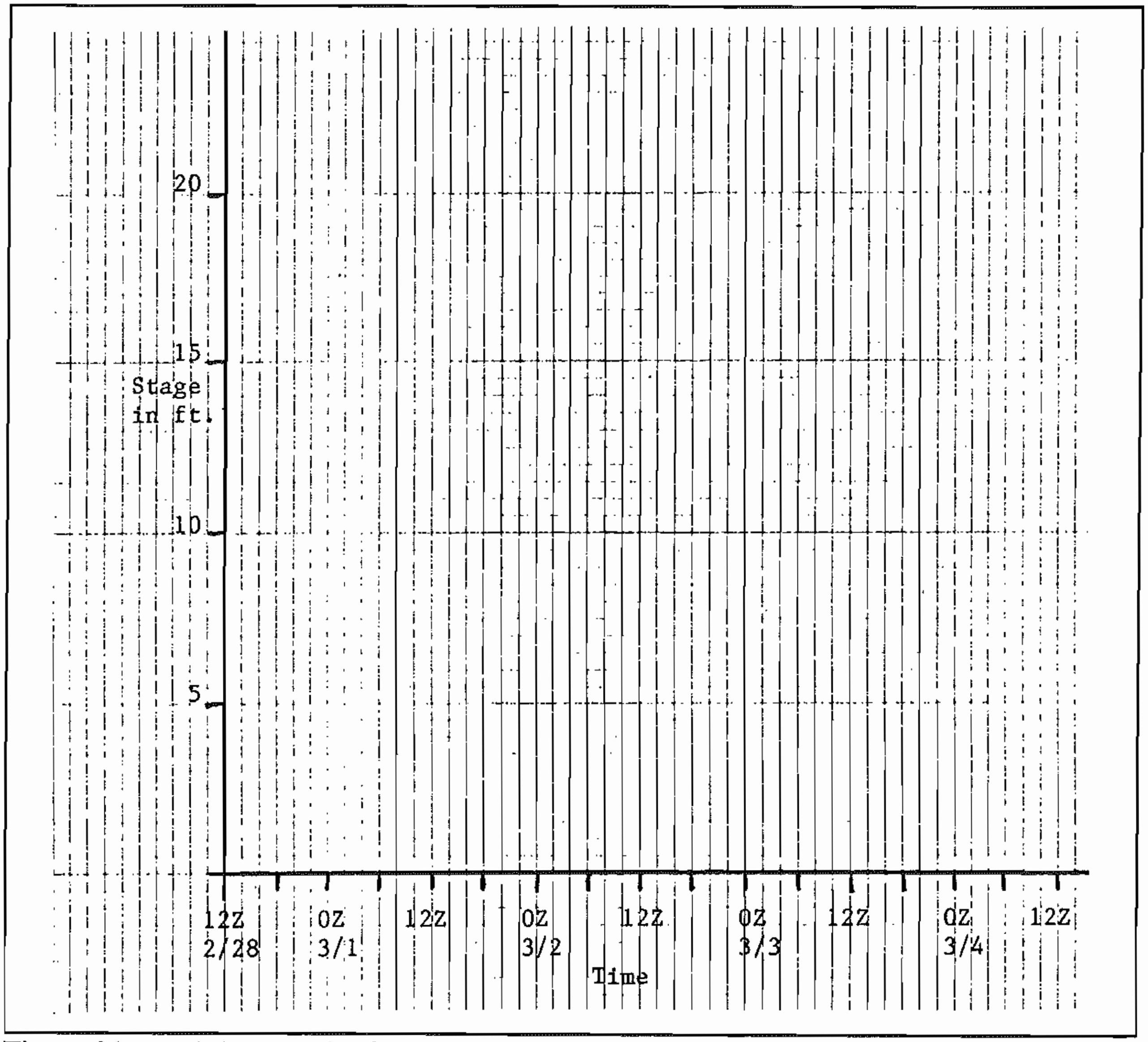


Figure 21. Worksheet to plot forecasted stage hydrograph for Study Question 1 in Chapter 6.

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Glossary of Terms

ADVIS — A program which combines the Antecedent Precipitation Index (API) method of estimating runoff with unit hydrograph theory to estimate streamflow for a headwater basin.

Antecedent Precipitation Index (API) — An index to soil moisture in a drainage.

Antecedent Precipitation Index (API) Method — A statistical method to estimate the amount of surface runoff which will occur from a basin from a given rainstorm based on the antecedent precipitation index, physical characteristics of the basin, time of year, storm duration, rainfall amount, and rainfall intensity.

Automated Tone Dial Telephone Data Collection System (ATDTDCS) — Data collection system where cooperative observers collect precipitation, stage, and temperature data from transmit the data to the NWS ATDTDCS computer through the telephone lines. The ATDTDCS computer transmits the data to AFOS.

Attenuation — The process where the flood crest is reduced as it progresses downstream.

Automated Local Evaluation in Real Time (ALERT) — A local flood warning system where river and rainfall data are collected via radio signals in real-time at an ALERT base station.

Bankfull stage/Elevation — An established river stage/water surface elevation at a given location along a river which is intended to represent the maximum water level that will not overflow the river banks or cause any significant damages from flooding.

Base Station — A computer which accepts radio signals from ALERT gaging sites, decodes the data, places the data in a database, and makes the data available to other users.

Baseflow — Streamflow which results from precipitation that infiltrates into the soil and eventually moves through the soil to the stream channel.

Basin — The area which contributes flow past a specified point.

Centralized Automated Data Acquisition System (CADAS) — A system of two mini-computers in NWSH that interrogates LARCs and DARDCs by telephone every 6 hours and transmits the data to AFOS.

Calibration — The process of using historical data to estimate parameters in a hydrologic forecast technique such as SACSMA, routings, and unit hydrographs.

Crest — The highest stage or water level of a flood wave as it passes a point.

Cross-sectional area — Area perpendicular to the direction of flow.

Cubic Feet per Second (CFS) — The flow rate or discharge equal to one cubic foot (of water, usually) per second.

Current meter — Device used to measure the water velocity or current in a river.

Day-Second Feet — Often abbreviated as DSF. Same as Second-Day Feet.

Digital Automated Recording Data Collector (DARDC) — A device that interfaces a sensor (river gage, temperature gage) to a telephone making it possible for a computer to interrogate the gage from a remote site.

Data Collection Platform (DCP) — An electronic device that connects to a river or rainfall gage that records data from the gage and at pre-determined times transmits that data through a satellite to a remote computer.

Discharge — The rate at which water passes a given point. Discharge is expressed in a volume per time with units of L3/T.

Evaporation — Process by which liquid water is converted into water vapor.

Evapotranspiration — Combination of evaporation from free water surfaces and transpiration of water from plant surfaces to the atmosphere.

Flash Flood — A flood which follows within a few hours (usually 6 hours) of heavy or excessive rainfall, dam or levee failure, or the sudden release of water impounded by an ice jam.

Flood — Any high flow, overflow, or inundation by water which causes or threatens damage.

Flood Routing — Process of determining progressively the timing, shape, and amplitude of a flood wave as it moves downstream to successive points along the river.

Flood Stage — An established gage height within a given river reach above which a rise in water surface level is defined as a flood.

Gage Datum — The arbitrary datum which all stage measurements are made from.

Gage Zero — The elevation of zero stage. (Same as gage datum.)

Geostationary Orbiting Environmental Satellite (GOES) — Satellite orbiting at 22,000 miles above the earth surface that remains above the same location on the earth. DCPs transmit river and rainfall data to the GOES for relay to a ground-receive site in Wallops Island, VA.

GOES Data Distribution System (GDDS) — The series of software program running on the mainframe computers in NWSH that process the GOES DCP data and LARC and DARDC data from CADAS and transmits it to NWS field offices through AFOS.

Ground receive site — A satellite dish and associated computer which receives signals from the GOES satellite, decodes the information, and transmits it to a another site for further processing. The GOES satellite ground-receive site is located at Wallops Island, VA; and the information is relayed to a mainframe computer at NWSH for processing.

Headwaters — Streams at the source of a river.

Headwater basin — A basin at the headwaters of a river. All discharge of the river at this point is developed within the basin.

Hydrograph — A graph showing the water level (stage), discharge, or other property of a river with respect to time.

Hydrograph Separation — The process where the storm hydrograph is separated into baseflow components and surface runoff components.

Hydrometeorological Automated Data System (HADS) — Software that will eventually replace the GDDS to process and distribute the GOES DCP data and CADAS data collected from DARDCs and LARCs.

Inches of Runoff — The volume of water from runoff of a given depth over the entire drainage.

Impervious — The ability to repel water or not let water enter.

Infiltration — Movement of water through the soil surface into the soil.

Infiltration capacity — The maximum rate at which water can enter the soil at a particular point under a given set of conditions.

Interception Storage Requirements — Water caught by plants at the onset of a rainstorm. This must be met before rainfall reaches the ground.

Lag — The time it takes a flood wave to move downstream.

Limited Automatic Report Collector (LARC) — An electronic device that interfaces a river or precipitation gage with a telephone line making it possible for remote computers to call a gaging site and retrieve data.

Main Stem — The reach of a river/stream formed by the tributaries that flow into it.

Mean Areal Precipitation (MAP) — The average rainfall over a given area, generally expressed as an average depth over the area.

National Weather Service River Forecast Model Version 5 (NWSRFS V5.0) — The system of data entry, data preprocessing, and forecast programs which are used by RFCs. To make river forecasts, RFCs run NWSRFS V5.0 on a mainframe computer in NWSH through Remote Job Entry.

Parametric Data — Data such as rating curves, unit hydrographs, and rainfall/runoff curves which define hydrologic variables in models.

Percolation — The movement of water within the soil.

Porosity — The ratio of pore volume to total volume of the soil. Sandy soils have large pores and a higher porosity than clays and other fine-grained soils.

Rating Curve — A graph showing the relationship between the stage, usually plotted vertically (Y-axis) and the discharge, usually plotted horizontally (X-axis).

Rating Table — A table of stage values and the corresponding discharge for a river gaging site.

Reach — The distance in the direction of flow between two specific points along a river, stream, or channel.

Recession Constant — Constant used to reduce the API value daily in the API method of estimating runoff.

Remote Job Entry (RJE) — Communications software and dedicated telephone lines which allow RFCs to do batch processing of jobs on a mainframe in NWSH.

Runoff — That part of precipitation that flows toward the streams on the surface of the ground or within the ground. Runoff is composed of base flow and surface runoff.

Sacramento Soil Moisture Accounting Model (SACSMA) — A model which simulates the movement and occurrence of water in and on top of the ground.

Second-Day Feet — The volume of water represented by a flow of one cubic foot per second for 24 hours; equal to 86,400 cubic feet. This is used extensively as a unit of runoff volume. Often abbreviated as SDF.

Staff gage — A vertical staff graduated in appropriate units which is placed so that a portion of the gage is in the water at all times. Observers read the river stage off the staff gage.

Stage — The level of the water surface above a given datum at a given location.

Streamflow — Water flowing in the stream channel. It is often used interchangeably with discharge.

Storm Hydrograph — A hydrograph representing the total flow or discharge past a point.

Surface Runoff — That runoff that travels overland to the stream channel. Rain that falls on the stream channel is often lumped with this quantity.

Transpiration — Water discharged into the atmosphere from plant surfaces.

Travel Time — The time required for a flood wave to travel from one location to a subsequent location downstream.

Unit Hydrograph — The discharge hydrograph from one inch of surface runoff distributed uniformly over the entire basin for a given time period.

Unit Hydrograph Duration — The time over which one inch of surface runoff is distributed for unit hydrograph theory.

Unit Hydrograph Theory — Unit Hydrograph Theory states that surface runoff hydrographs for storm events of the same duration will have the same shape, and the ordinates of the hydrograph will be proportional to the ordinates of the unit hydrograph. For example, the hydrograph from one-half inch of runoff will be half of that from the unit hydrograph.

Wire Weight Gage — A river gage which is a weight which is lowered to the water level. The weight is attached to a cable; and as the weight is lowered, a counter indicates the length of cable released. The stage is determined from the length of cable required to reach the water level.

Answers to Study Questions

Chapter 2

1. 2.8 inches

2. 2.0 inches

3. 4.0 inches

4. 1.5 inches

5. As the rainfall intensity increases, a higher percentage of rainfall will become surface runoff.

Chapter 3

1. 12 hours

2. 1.5 inches

3. Crest Time = Between 12 Noon and 3 p.m.

   Crest Discharge = 15850 cfs

   The discharge hydrograph is displayed in Fig. 22.

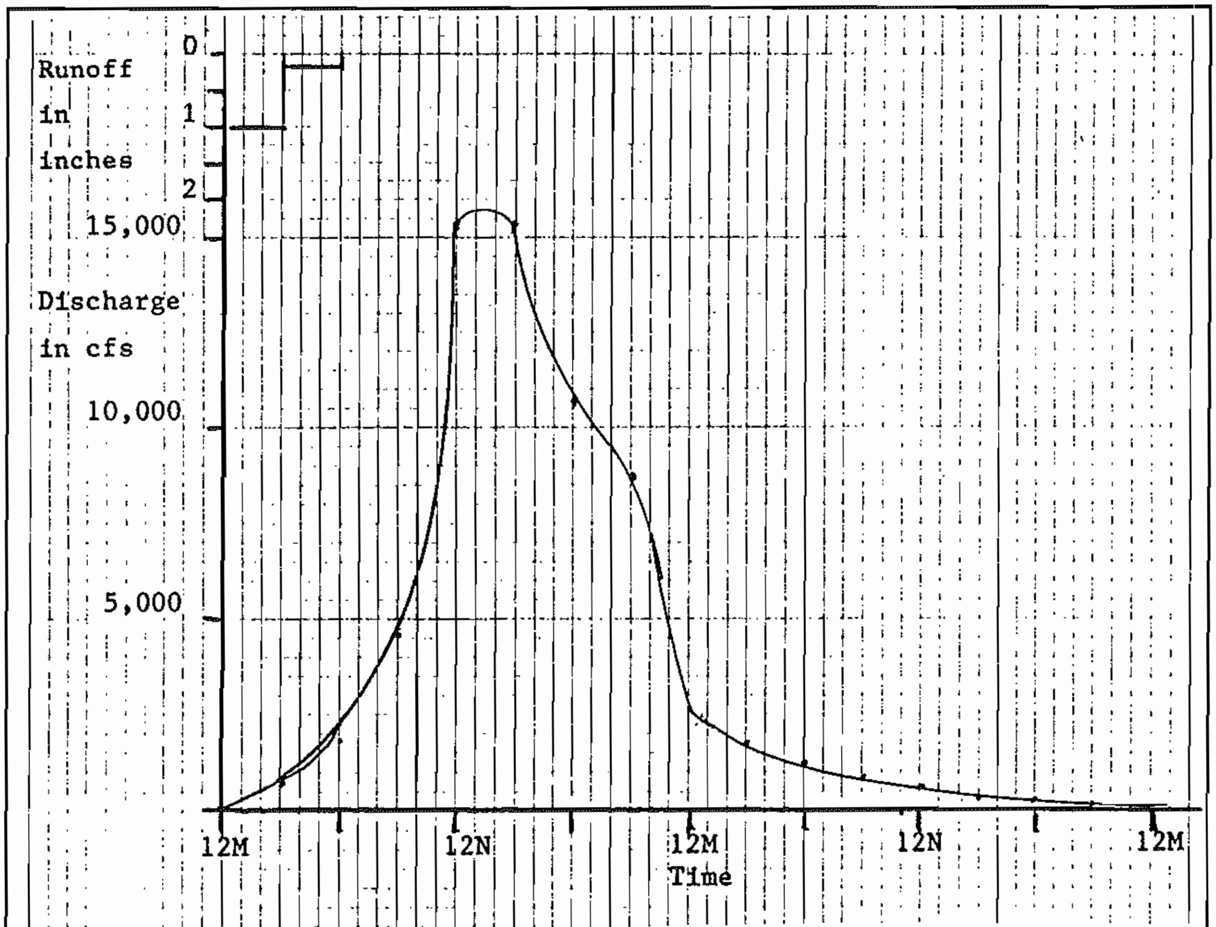
Chapter 4

1. 8800 cfs

2. Discharge at 20 ft stage = 17200 cfs

   Discharge at 20 ft stage = 3300 cfs

$$Ratio = \frac{Discharge\ at\ 20\ ft}{Discharge\ at\ 10\ ft} = \frac{17200\ cfs}{3300\ cfs} = \underline{5.2}$$



	12M	3AM	6AM	9AM	12N	3PM	6PM	9PM	12M
Base Flow	150	150	150	150	150	150	150	150	150
1.0"RO(12-3)	0	1500	3300	8400	14000	12900	8700	5500	4000
0.2"RO(3-6)	XXXXX	0	300	660	1680	2800	2580	1740	1100
Total Flow	150	1650	3750	9210	15830	15850	11430	7390	5250

	3AM	6AM	9AM	12N	3PM	6PM	9PM	12M	3AM
Base Flow	150	150	150	150	150	150	150	150	150
1.0"RO(12-3)	2700	1900	1400	800	500	300	150	0	XXXXX
0.2"RO(3-6)	800	540	380	280	160	100	60	30	0
Total Flow	3650	2590	1930	1230	810	550	360	180	150

Figure 22. Worksheet for sample problem.

3. As the stage increases, the cross sectional area of the flow increases at a much faster rate.

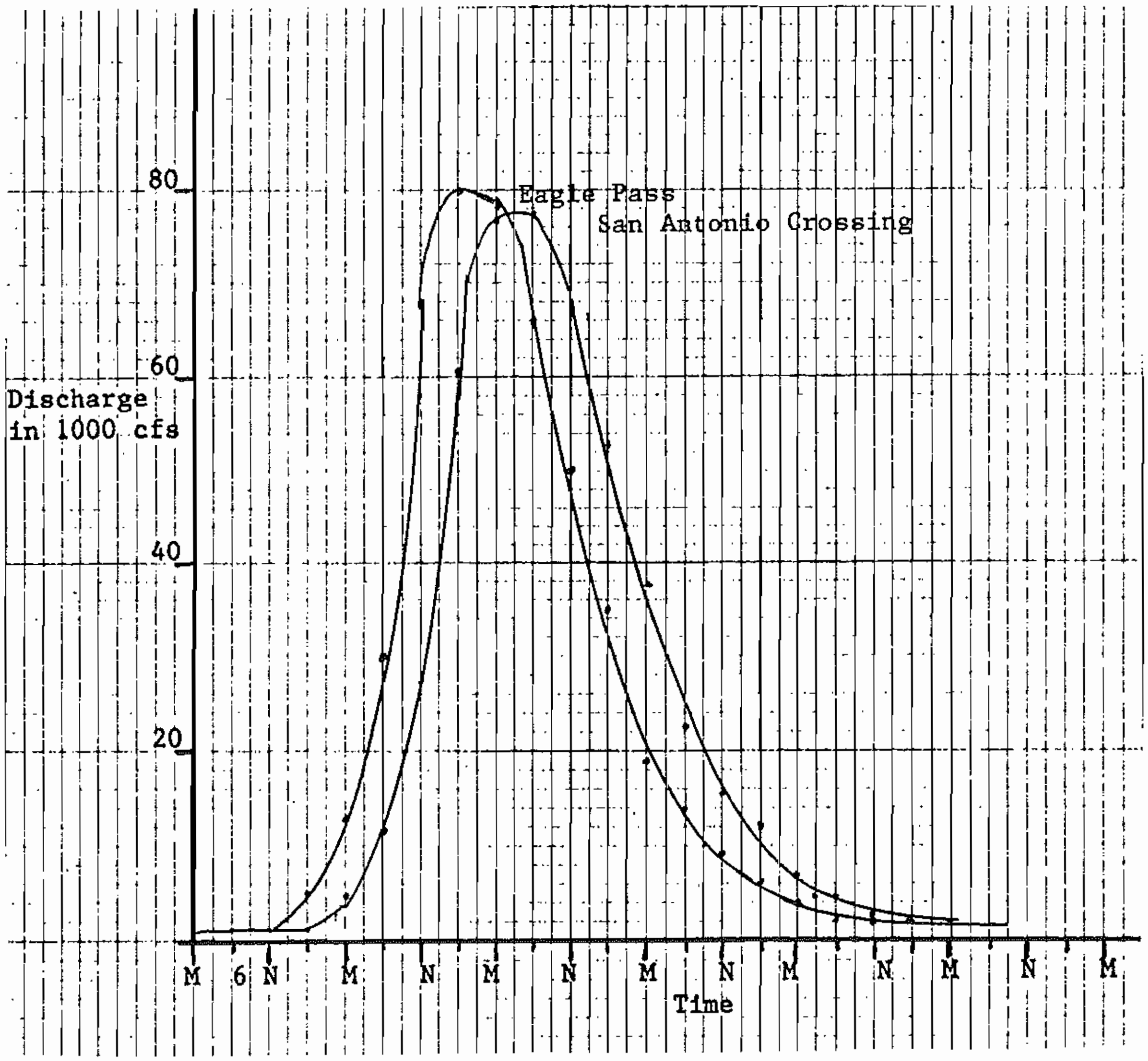
4. 21 ft.

Chapter 5

1. The hydrograph of routed flow from Eagle Pass to San Antonio Crossing is shown in Fig. 23.

Chapter 6

1. The computations, discharge hydrograph, and stage hydrograph are shown in Fig. 24, 25, and 26, respectively.



	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM	12N	6PM	12M
Inflow	1000	1000	5000	13000	30000	68000	80000	78000	66000	50000	35000	19000
Outflow	1000	1000	1080	4454	11802	27484	60947	76530	77495	67749	52895	37901

	6AM	12N	6PM	12M	6AM	12N	6PM	12M	6AM
Inflow	14000	9000	6000	4000	2000	2000	2000	2000	2000
Outflow	22302	15394	10091	6696	4445	2440	2079	2014	2003

Figure 23. Solution for sample problem in Chapter 5.

Basin A

		Feb 28		Mar 1	
		12-18Z	18-00Z	00-06Z	06-12Z
	6 hr Rain (in)	2.00	2.50	0.50	0.00
Step 1	6 hr Runoff (in)	1.30	1.80	0.20	0.00

Computations for Discharge at Gage A

Step 2 Discharge from Surface Runoff

	Feb 28		Mar 1				Mar 2				Mar 3				Mar 4
	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z
From RO from 12-18Z (cfs)	0	260	2600	1300	520	260	130	0							
From RO from 18-00Z (cfs)		0	360	3600	1800	720	360	180	0						
From RO from 00-06Z (cfs)			0	40	400	200	80	40	20	0					
From RO from 06-12Z (cfs)				0	0	0	0	0	0	0	0				
Base Flow (cfs)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Step 3 Total Flow - A (cfs)	50	310	3010	4990	2770	1230	620	270	70	50	50	50	50	50	50
Step 4 Stage at Gage A (ft)	7.5	10.0	20.1	22.8	19.6	15.8	12.5	9.8	8.0	7.5	7.5	7.5	7.5	7.5	7.5
Step 5 Flow Routed to Gage B	50	55	318	2565	4509	3052	1546	780	358	121	63	52	50	50	50

Local Basin B

		Feb 28		Mar 1	
		12-18Z	18-00Z	00-06Z	06-12Z
	6 hr Rain (in)	2.50	2.50	2.00	1.00
Step 6	6 hr Runoff (in)	1.80	1.80	1.30	0.60

Computations for Discharge at Gage B

	Feb 28		Mar 1				Mar 2				Mar 3				Mar 4
Step 7	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z
From RO from 12-18Z (cfs)	0	1080	3420	1260	720	360	180	0							
From RO from 18-00Z (cfs)		0	1080	3420	1260	720	360	180	0						
From RO from 00-06Z (cfs)			0	780	2470	910	520	260	130	0					
From RO from 06-12Z (cfs)				0	360	1140	420	240	120	60	0				
Base Flow (cfs)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Step 8 Total Flow at B (cfs)	125	1210	4893	8100	9394	6257	3101	1535	683	256	138	127	125	125	125
Step 9 Stage at Gage B (ft)	5.0	10.9	17.4	20.0	20.7	18.8	15.3	12.0	8.8	6.0	5.2	5.0	5.0	5.0	5.0

Figure 24: Computations for Study Questions 1 in Chapter 6.

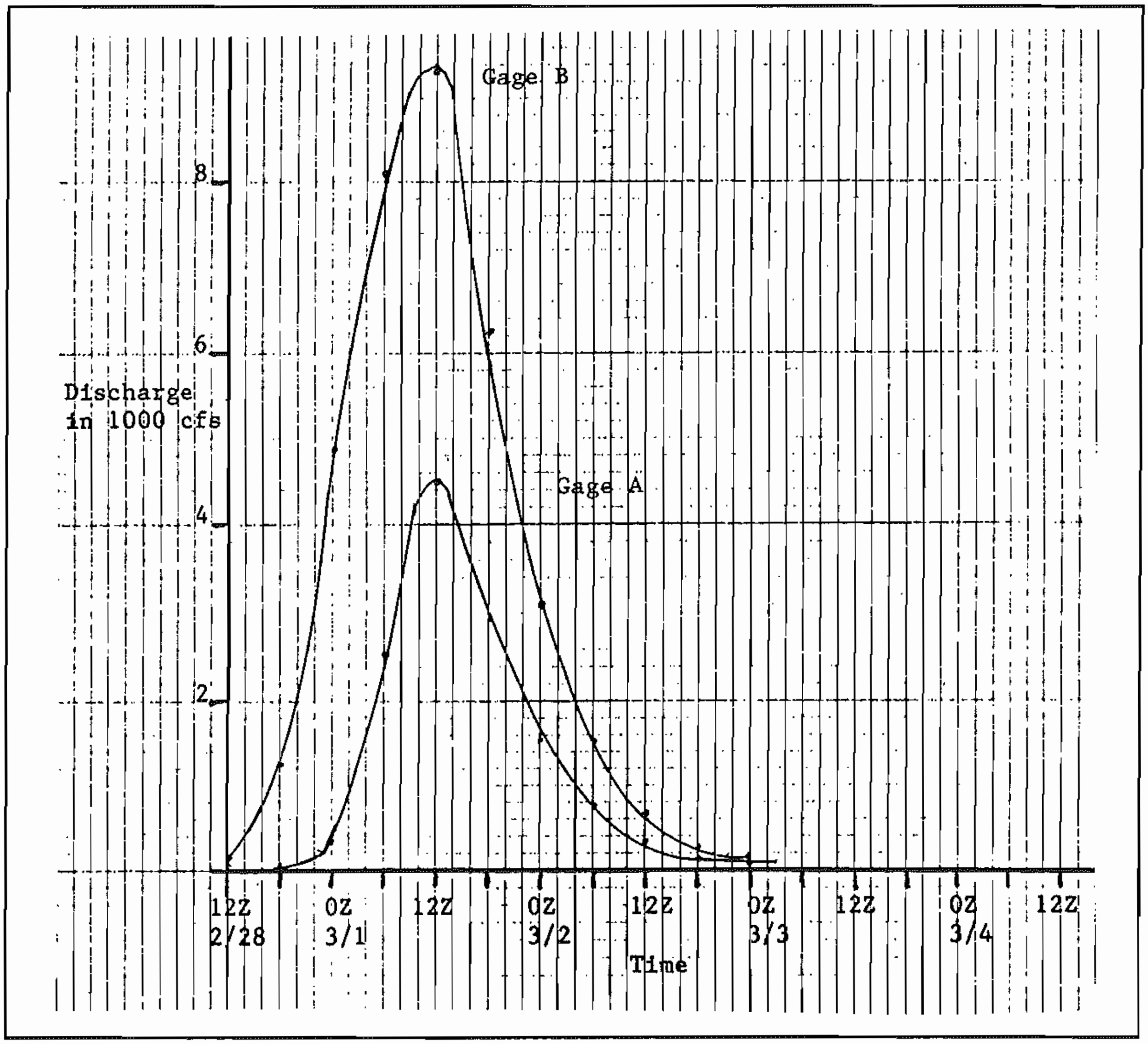


Figure 25. Plot of forecasted discharges for Study Question 1 in Chapter 6.

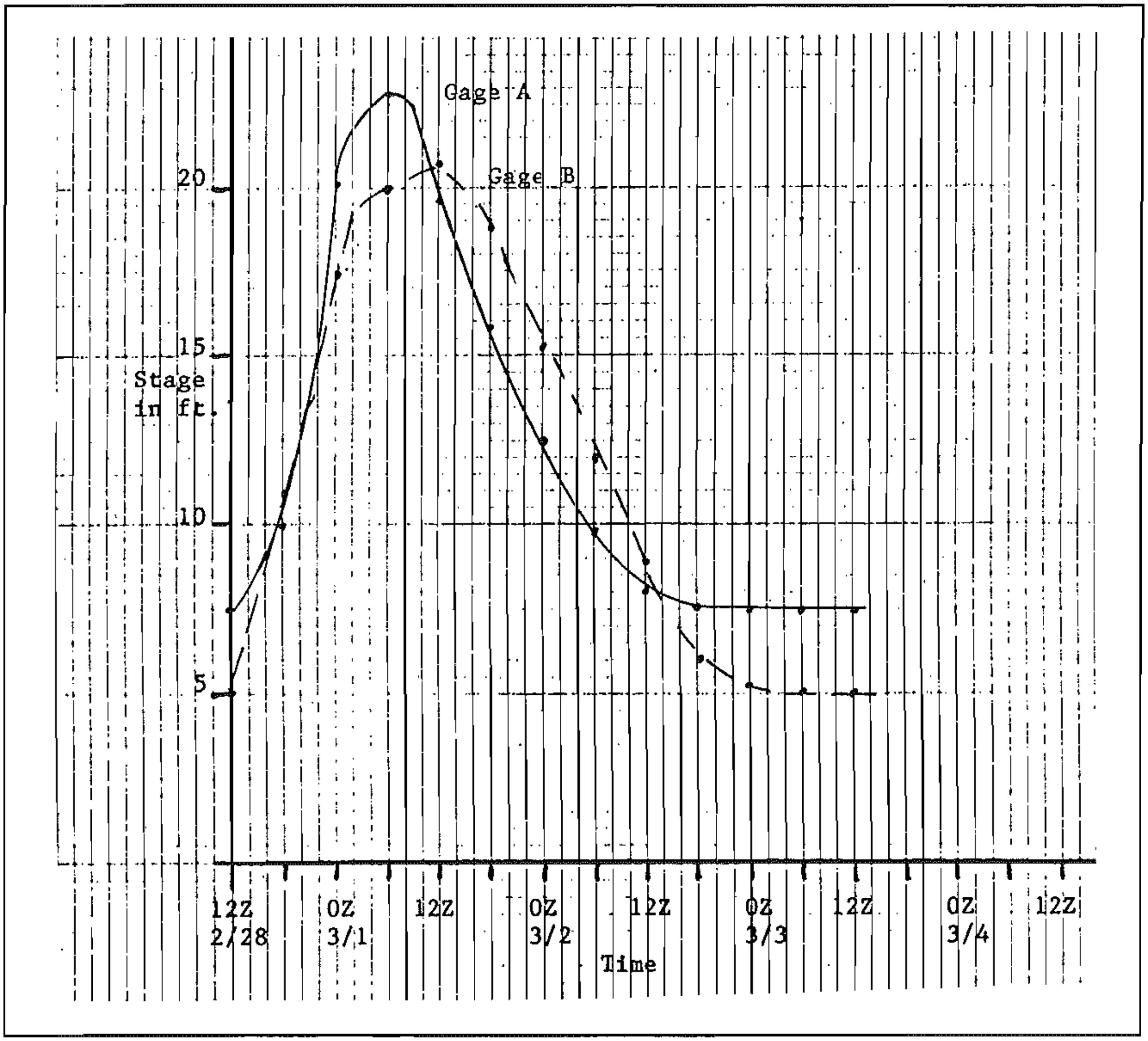


Figure 26. Plot of forecasted stage hydrograph for Study Question 1 in Chapter 6.