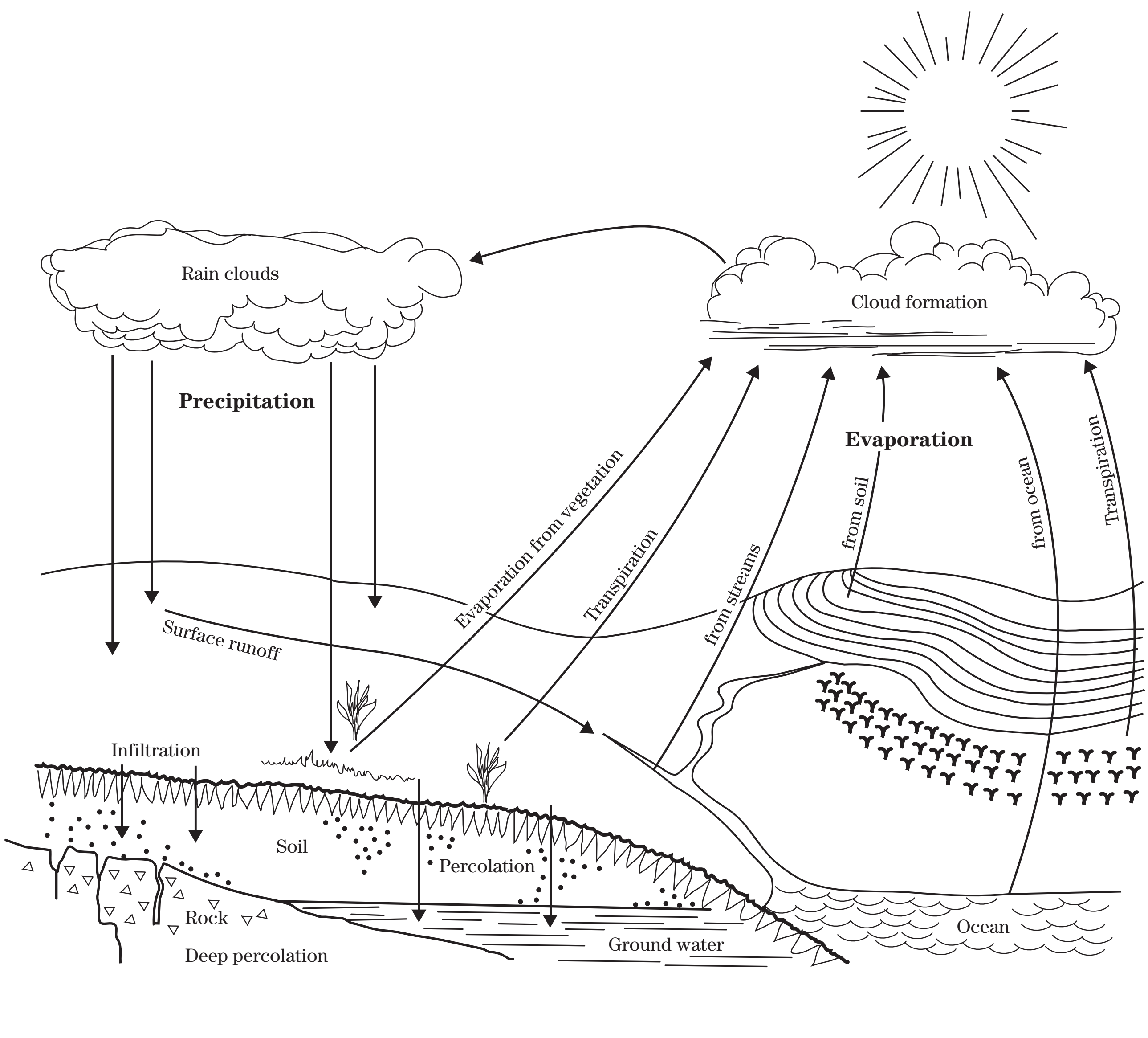
United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 630 Hydrology
National Engineering Handbook

Chapter 21 Design Hydrographs



Draft August 2006

Acknowledgments

Chapter 21, Design Hydrographs, was originally prepared by Victor Mockus (retired). A subsequent revision in 1965 was edited by Vincent McKeever (retired), William Owen (retired), and Robert Rallison, (retired) and was reprinted in 1972 with minor modifications. This version was prepared by Edward J. Schmit (retired) and Wiley Scott, hydraulic engineer, Natural Resources Conservation Service (NRCS), Nashville, TN, under the guidance of Donald E. Woodward (retired) and finalized under the guidance of Claudia C. Hoeft, national hydraulic engineer, Washington, D.C.

Chapter 21 Design Hydrographs

Contents

Tables

Figures

Chapter 21 Design Hydrographs

630.2100 Introduction

Chapter 21 presents a systematic aproach to the development of design hydrographs for use in proportioning earth dams and their spillways according to Natural Resources Conservation Service (NRCS) criteria. Sources of data for design rainfall amount, duration, and distribution are also included along with methods of modifying design runoff to include effects of baseflow, channel losses, quick return flow, or upstream release. The methodology presented in this chapter is intended for the design of earth dams that provide temporary storage for flood prevention along with permanent storage for other uses. Its chief purpose is to contribute to safe design. Although the methods are based on data of actual storms and floods, they are not intended for reproducing hydrographs of actual floods. The general methodology for development of flood hydrographs is in NEH 630.16. Version 2005.02 of the SITES computer program can be used to develop the design hydrographs for a particular project.

An earth dam generally has two spillways and perhaps a low flow outlet to meet downstream and instream needs. The design of a safe dam requires that these spillways be sized appropriately. This is done by routing several hydrographs through the spillways. Development of these design hydrographs take into account storm return period and duration which is dependent on purpose, size, location, and classification of the dam and type of spillways.

The principal spillway provides the outlet capacity and storage to meet the design objectives of the structure. The principal spillway is sized to limit the frequency of operation of the auxiliary spillway and to set the crest elevation of the auxiiary spillway so that it does not flow during the passage of the principal spillway storm. The capacity of the principal spillway for flood-retarding structures is determined using the 10-day hydrograph. The principal spillway for other structures is usually sized using a 1-day hydrograph.

The auxiliary spillway provides the necessary capacity to maintain the integrity of the earth dam when the capacity of the principal spillway is exceeded. A series of storm durations is needed to evaluate the auxiliary spillway system. The appropriate precipitation values are taken from the National Weather Service (NWS) Hydrometeorological report (HMR) for the area of interest. The duration that poduces the highest water surface must be used to set the height of dam and the freeboard requirements for the structure. The stability of the auxiliary spillway is determined using a Stability Design Hydrograph (SDH). The minimum freeboard and the integrity of the auxiliary spillway are determined using a Freeboard Hydrograph (FBH). Both hydrographs are constructed by the same procedure.

A hydrograph for low flow discharge may be routed through the structure to meet downstream channel stability, environmental requirements, and other downstream requirements. If a watershed consists of two or more hydrologic subareas, hydrographs should be developed for each subarea and combined before routing through the structure.

Technical Release 60 (TR–60) Earth Dams and Reservoirs (2005) describes design procedures and provides minimum requirements for planning and designing earth dams and associated spillways.

630.2101 Principal spillway

Any one of the following four methods to determine runoff volume is suitable for the design of principal spillway capacity, retarding storage, and the auxiliary spillway crest:

- runoff curve number procedure using rainfall data and the watershed's characteristics
- runoff volume maps covering specific areas of the United States
- regionalization and transposition of volume-duration-probability analyses
- local streamflow data

The last two methods are not discussed in this chapter. NEH 630, chapter 18 provides details for the use of these methods. Use of the last two methods must be approved by the Conservation Engineering Division (CED) in National Headquarters before their use.

(a) Runoff curve number procedure

The runoff curve number (CN) procedure uses certain climatic data and the characteristics of a watershed to convert rainfall data to runoff volume.

(1) Rainfall data sources

Rainfall data for durations up to 1 day and return periods up to 100 years and durations from 2 to 10 days and storm return periods to 100 years for the determination of direct runoff may be obtained from the published sources in table 21–1.

(2) Areal adjustment of rainfall amount

If the drainage area above a structure is 10 square miles or less, no areal adjustment is made. If it is more than 10 square miles, the area-point ratios in table 21–2 may be used to reduce the rainfall amount. The table applies to all geographical locations serviced by the NRCS. The ratios are based on the 1- and 10-day depth-area curves of figure 10 in U.S. Weather Bureau TP–49 (1965), but are modified to give a ratio of 1 at 10 square miles.

(3) Runoff CNs

The runoff CN for the drainage area above a structure is determined and runoff is estimated as described in NEH 630, chapters 7 through 10. The CN is for the average antecedent runoff condition II (ARC II) unless a special study shows that a different condition is justified. ARC II applies to the 1-day storm used to develop design hydrographs. If the 100-year frequency, 10-day duration point rainfall for the structure site is 6 or more inches, the CN for the 10-day storm is taken from table 21–3. If it is less than 6 inches, the CN for the 10-day storm is the same as that for the 1-day storm. The 10-day CN is used only with the total 10-day rainfall. In the Western States, CN can be reduced for durations between 24 hours and 10 days by linear interpolation.

(4) Baseflow

Baseflow is stream discharge derived from groundwater sources. It is sometimes considered to include flows from regulated lakes or reservoirs depending on the situation. Baseflow fluctuates much less than storm runoff.

When a principal spillway hydrograph is developed from rainfall, the baseflow is added to the base of the entire hydrograph. When the principal spillway hydrograph is developed from runoff, all hydrograph discharge values less than baseflow should be increased to the baseflow value. The recession or tail of the principal spillway hydrograph may be controlled by quick return flow if this is higher than the baseflow (fig. 21–1).

(5) Climatic index

The climatic index is used to estimate channel losses and quick return flow. The climatic index is:

$$\mathrm{Ci} = \frac{100\mathrm{Pa}}{(\mathrm{Ta})^2} \qquad \text{(eq. 21–1)}$$

where:
Ci = climatic index
Pa = average annual precipitation in inches
Ta = average annual temperature in °F

Precipitation and temperature data can be obtained from the NRCS National Water and Climate Center in Portland, Oregon. The Internet address is:

http://www.wcc.nrcs.usda.gov

Average annual precipitation and average annual temperature are available in TAPS and WETS tables.

Table 21–1 NWS references for precipitation data [1/]

Durations to 1 day and return periods to 100 years

Technical Memorandum HYDRO–35. Durations 5 to 60 minutes for the eastern and central states (1977)

Technical Paper 40. 48 contiguous states (1961) (Use for 37 contiguous states east of the 105th meridian)

Technical Paper 42. Puerto Rico and Virgin Islands (1961)

Technical Paper 47. Alaska (1963)

NOAA Atlas 2. Precipitation Frequency Atlas of the United States (1973)

Vol. I, Montana	Vol. II, Wyoming	Vol. III, Colorado
Vol. V, Idaho	Vol. VI, Utah	Vol. VII, Nevada
Vol. IX, Washington	Vol. X, Oregon	Vol. XI, California

NOAA Atlas 14. Precipitation Frequency Atlas for the United States
Vol. I (2003), Semiarid Southwest
Vol. II (2004), Ohio River Basin and surrounding states

Durations from 2 to 10 days and return periods to 100 years

Technical Paper 49. 48 contiguous states (1965)

Technical Paper 51. Hawaii (1965)

Technical Paper 52. Alaska (1965)

Technical Paper 53. Puerto Rico and Virgin Islands (1965)

Probable maximum precipitation (PMP)

Hydrometeorological Report 36. California Pacific Drainage (1961)

Hydrometeorological Report 39. Hawaii (1963)

Hydrometeorological Report 43. Northwest States Pacific Drainage (1981)

Hydrometeorological Report 49. Colorado River and Great Basin Drainage (1977)

Hydrometeorological Report 51. United States East of the 105th meridian (1978)

Hydrometeorological Report 52. Application of probable maximum precipitation estimates, states east of the 105th meridian (1980)

Hydrometeorological Report 53. Seasonal variation of 10 square-mile probable maximum precipitation estimates, states east of the 105th meridian (1980)

Hydrometeorological Report 54. Probable maximum precipitation and snowmelt criteria for southeast Alaska (1963)

Hydrometeorological Report 55A. United States between the Continental Divide and the 103rd meridian (1988)

Technical Report 42. Puerto Rico and Virgin Islands (1961)

Technical Report 43. Hawaii (1962)

Technical Report 47. Alaska (1963)

1/ National Weather Service, National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce

Table 21–2 Principal spillway volume adjustment: minum areal adjustment ratios for precipitation*

Area (mi²)	--Area/point ratio-- 1 day	10 days	Area (mi²)	--Area/point ratio-- 1 day	10 days
≤10	1.000	1.000	45	0.951	0.976
15	0.977	0.991	50	0.948	0.974
20	0.969	0.987	60	0.944	0.972
25	0.965	0.983	70	0.940	0.970
30	0.961	0.981	80	0.937	0.969
35	0.957	0.979	90	0.935	0.977
40	0.954	0.977	100	0.932	0.966

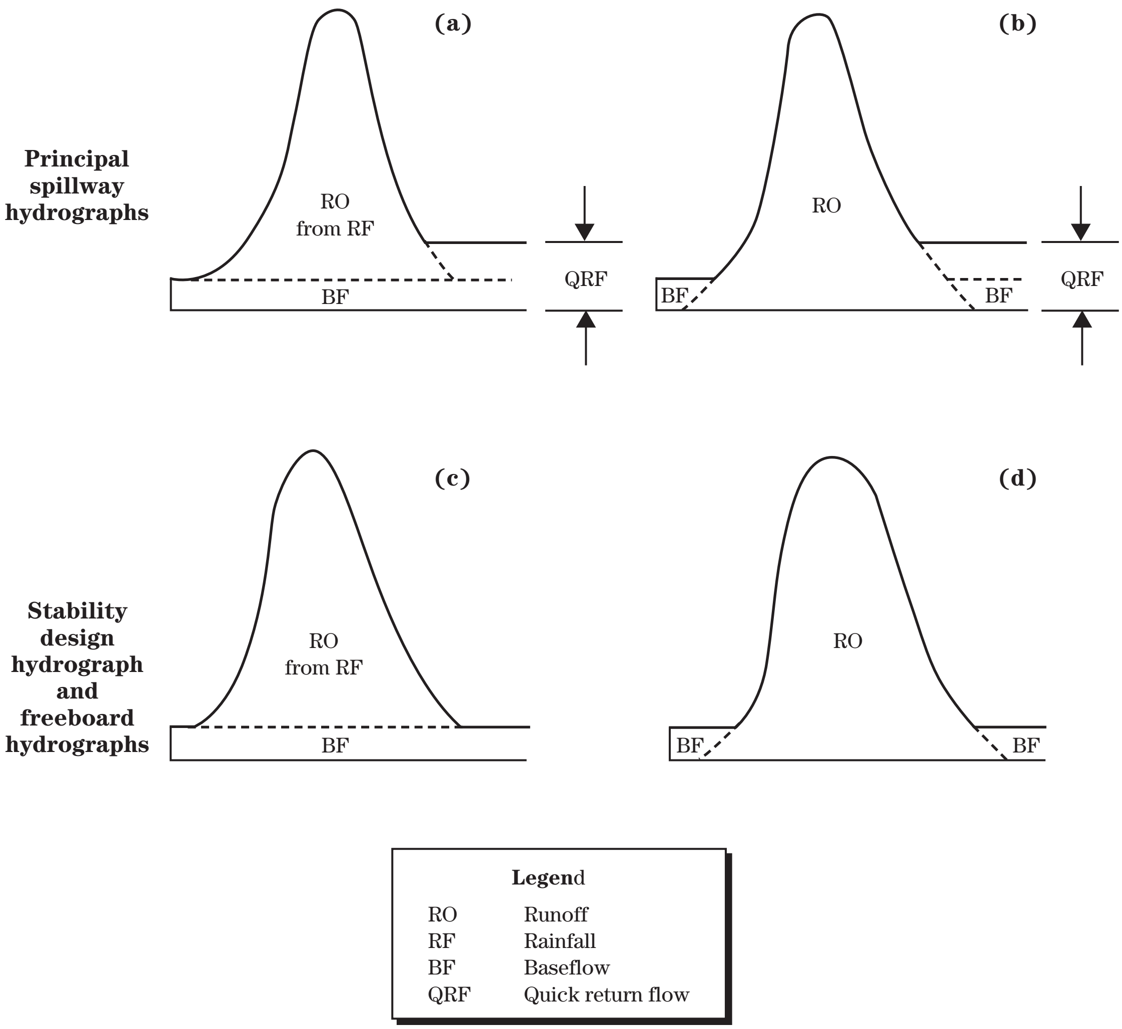
* If area is greater than 100 square miles, request PMP from Conservation Engineering Division (CED).

Table 21–3 Principal spillway volume adjustment: 10-day runoff CN adjustment*

Runoff curve numbers					
1 day	10 days	1 day	10 days	1 day	10 days
100	100	80	65	60	41
99	98	79	64	59	40
98	96	78	62	58	39
97	94	77	61	57	38
96	92	76	60	56	37
95	90	75	58	55	36
94	88	74	57	54	35
93	86	73	56	53	34
92	84	72	54	52	33
91	82	71	53	51	33
90	81	70	52	50	32
89	79	69	51	49	31
88	77	68	50	48	30
87	76	67	49	47	29
86	74	66	47	46	28
85	72	65	46	45	28
84	71	64	45	44	27
83	69	63	44	43	26
82	68	62	43	42	25
81	66	61	42	41	24

* This table is used only if the 100-year frequency 10-day point rainfall is 6 or more inches. If it is less, the 10-day CN is the same as that for the 1-day CN.

Figure 21–1 Inflow design hydrographs with baseflow and quick return flow (QRF)



- **Channel losses**—If the drainage area above a structure has a climatic index less than 1, then the direct runoff from a rainfall may be decreased to account for channel losses of influent streams. Channel losses can be determined from local data, but losses must not be more than that determined by using table 21–4. When adequate local data are not available, table 21–4 is to be used. A special study is required if channel losses appear to be significant even though the climatic index is 1 or more, such as in cavernous areas. The results of this study must be approved by the CED director before they are used in final design hydrology.

Table 21–4 Channel loss factors for reduction of direct runoff

Drainage area (mi²)	Climatic index (ci) 1.0	0.9	0.8	0.7	0.6	0.5	0.4 or less
1 or less	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	0.98	0.97	0.95	0.93	0.90	0.87
3	1.00	0.98	0.95	0.92	0.89	0.85	0.80
4	1.00	0.97	0.94	0.90	0.86	0.81	0.76
5	1.00	0.96	0.92	0.88	0.84	0.78	0.73
6	1.00	0.96	0.92	0.87	0.82	0.76	0.70
7	1.00	0.96	0.91	0.86	0.81	0.75	0.68
8	1.00	0.95	0.90	0.85	0.79	0.73	0.66
9	1.00	0.95	0.90	0.84	0.78	0.72	0.65
10	1.00	0.95	0.89	0.84	0.77	0.71	0.63
20	1.00	0.93	0.86	0.79	0.72	0.64	0.55
30	1.00	0.93	0.85	0.77	0.69	0.60	0.51
40	1.00	0.92	0.84	0.75	0.66	0.57	0.48
50	1.00	0.91	0.83	0.74	0.65	0.55	0.46
60	1.00	0.91	0.82	0.73	0.63	0.54	0.44
70	1.00	0.91	0.81	0.72	0.62	0.53	0.43
80	1.00	0.90	0.81	0.71	0.62	0.52	0.42
90	1.00	0.90	0.80	0.71	0.61	0.51	0.41
100	1.00	0.90	0.80	0.70	0.60	0.50	0.40
150	1.00	0.89	0.78	0.68	0.57	0.47	0.37
200	1.00	0.89	0.77	0.66	0.56	0.45	0.35
250	1.00	0.88	0.77	0.65	0.54	0.44	0.33
300	1.00	0.88	0.76	0.64	0.53	0.42	0.32
350	1.00	0.87	0.75	0.64	0.52	0.41	0.31
400	1.00	0.87	0.75	0.63	0.51	0.41	0.30

If the climatic index is less than 0.4, approval of the CED must be obtained to use a value less than information in table 21–4.

- **Quick return flow**—Quick return flow (QRF) is the rate of discharge that persists for some period beyond that for which the 10-day principal spillway hydrograph (PSH) is derived. It includes baseflow and other flows that become a part of the flood hydrograph such as:
  - rainfall that has infiltrated and reappeared soon afterwards as surface flow
  - drainage from marshes and potholes
  - snowmelt

  If the drainage area above a structure has a climatic index greater than one, then QRF is added to the hydrograph of direct runoff from rainfall. QRF can be determined from local data, but it must not be less than the steady rate determined using table 21–5. When adequate local data are not available, table 21–5 is to be used.

- **Combinations of channel loss, quick return flow**—For large watersheds, the topography may be such that two climatic indexes are needed, for example where mountains surround a semiarid plain. In such cases:
  - The design storm precipitation is determined for the watershed as a whole.
  - The direct runoff is estimated separately for the two parts by use of the appropriate CNs and then combined.
  - The channel loss reduction is based on the area of the semiarid plain and its climatic index.
  - The hydrograph or mass curve of direct runoff is constructed.
  - The QRF from the mountain area is added.

(6) Upstream releases

Releases from upstream structures must be accounted for in the runoff hydrograph, regardless of other additions or subtractions of flow. Upstream release rates are determined from routings of applicable hydrographs through the upstream structures and the reaches downstream from them.

Table 21–5 Minimum QRF for PSH derived from rainfall

Ci	------- QRF -------		Ci	------- QRF --------	
	in/d	csm		in/d	csm
1.00	0	0	1.50	0.233	6.28
1.02	0.011	0.30	1.52	0.239	6.42
1.04	0.022	0.60	1.54	0.244	6.56
1.06	0.033	0.90	1.56	0.249	6.70
1.08	0.045	1.20	1.58	0.254	6.83
1.10	0.056	1/50	1.60*	0.259	6.95
1.12	0.067	1.80	1.65	0.270	7.26
1.14	0.078	2.10	1.70	0.280	7.53
1.16	0.089	2.40	1.75	0.290	7.79
1.18	0.100	2.70	1.80	0.299	8.05
1.20	0.112	3.00	1.85	0.309	8.30
1.22	0.122	3.29	1.90	0.318	8.54
1.24	0.133	3.58	1.95	0.326	8.77
1.26	0.144	3.86	2.00	0.335	9.00
1.28	0.153	4.12	2.05	0.343	9.22
1.30	0.163	4.37	2.10*	0.351	9.44
1.32	0.171	4.61	2.20	0.367	9.86
1.34	0.180	4.83	2.30	0.382	10.26
1.36	0.188	5.05	2.40	0.396	10.65*
1.38	0.195	5.25	2.50	0.410	11.02
1.40	0.202	5.44	2.60	0.423	11.38
1.42	0.209	5.63	2.70	0.436	11.73
1.44	0.216	5.80	2.80	0.449	12.07
1.46	0.222	5.97	2.90	0.461	12.41
1.48	0.228	6.13	3.00**	0.473	12.73

* Change in tabulation interval
** For Ci greater than 3, use:

$$QRF\ (csm) = 9(Ci-1)^{0.5}$$

$$QRF\ (in/d) = 0.03719\ [QRF\ (csm)]$$

where:
QRF = quick return flow
csm = cubic feet per second per square mile
Ci = climatic index
in/d = inches per day

(b) Runoff volume maps procedure

The runoff volume and rate maps (figs. 21–2 through 21–6) are provided for areas of the United States where measured runoff volumes vary significantly from those obtained from the CN procedure for converting rainfall to runoff. The mapped areas are of two general types:

- areas where runoff from either snowmelt, dormant season rainfall, or a combination of the two produce greater runoff volumes than growing season rainfall
- deep snowpack areas of high mountain elevations

(1) Areas of mapped runoff volume

The 100-year, 10-day runoff volume maps (figs. 21–2 and 21–5) represent regionalized values derived from gaged streamflow data and supplemented with climatological data and local observations. These values should be used for estimating floodwater detention storage within the map area where local streamflow data are not adequate. Areal reduction should not be made on the 10-day runoff volumes shown in the maps. These amounts were derived from stream gage data, so baseflow and channel loss are automatically included in the map values.

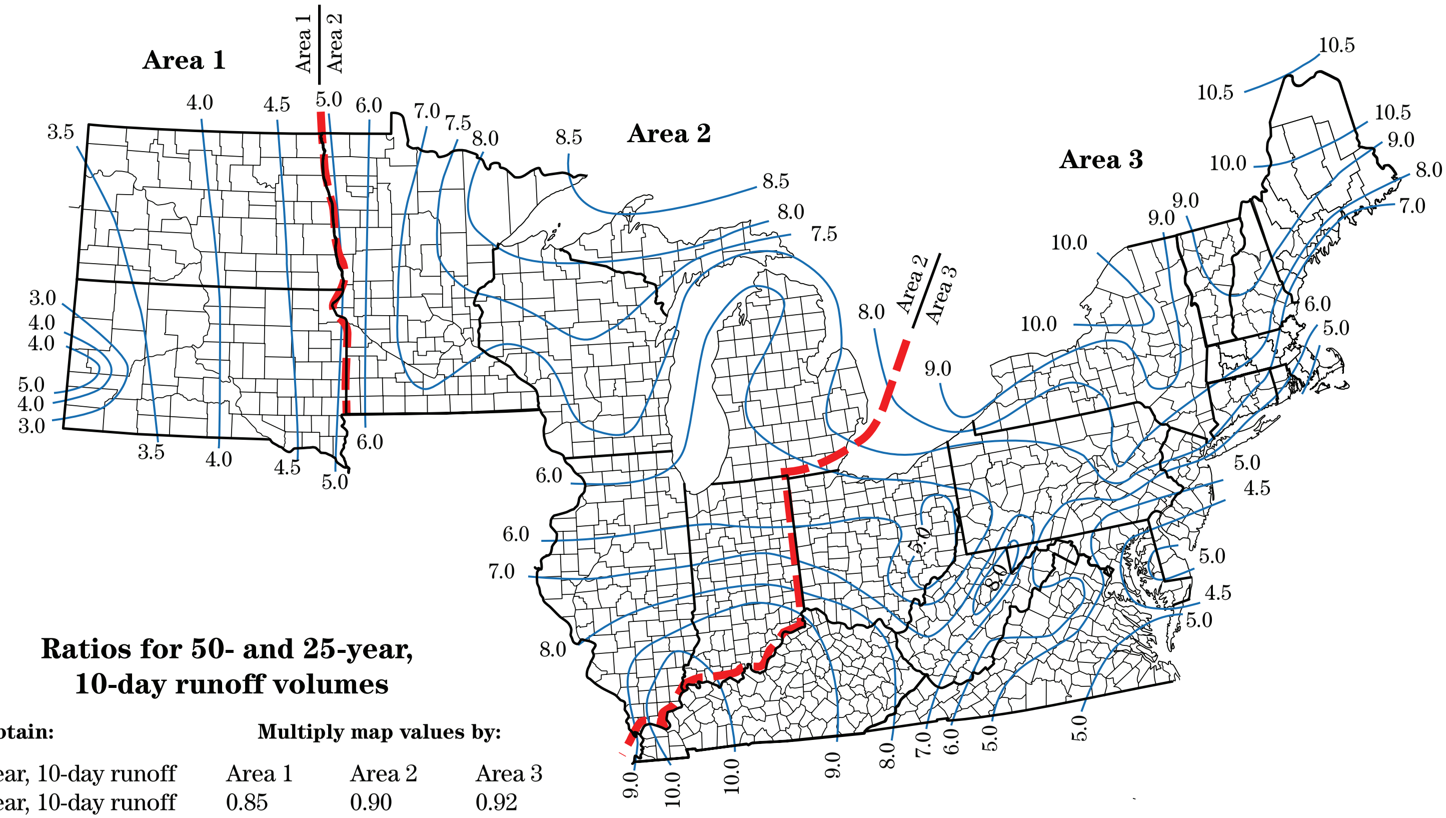
QRF in this procedure is used as the rate of discharge expected to persist beyond the flood period described under the 10-day PSH. When using the Runoff Volume Maps Procedure, the QRF rate (fig. 21–4) is an extension to the PSH before routing it through the reservoir (fig. 21–1). The rates of discharge given in figure 21–4 were derived by averaging the accumulated depths of runoff between the 15th and 30th day on volume duration probability (VDP) accumulation graphs. They were obtained from the same VDP station data from which the 100-year, 10-day runoff volumes in figure 21–2 were obtained.

(2) Deep snowpack areas

Flood volume estimates from the deep snowpack areas may be calculated from local streamflow data or by regionalization and transposition of streamflow data. A standard procedure for making a regional analysis of volumes of runoff for varying durations and frequencies has not been developed at this time. Experience indicates that acceptable estimates can be made using multiple regression techniques. If water-

Figure 21–2 100-year, 10-day runoff (inches) for developing the principal spillway hydrograph (Northeast States)

100-year, 10-day runoff volumes (in) for developing the principal spillway hydrograph



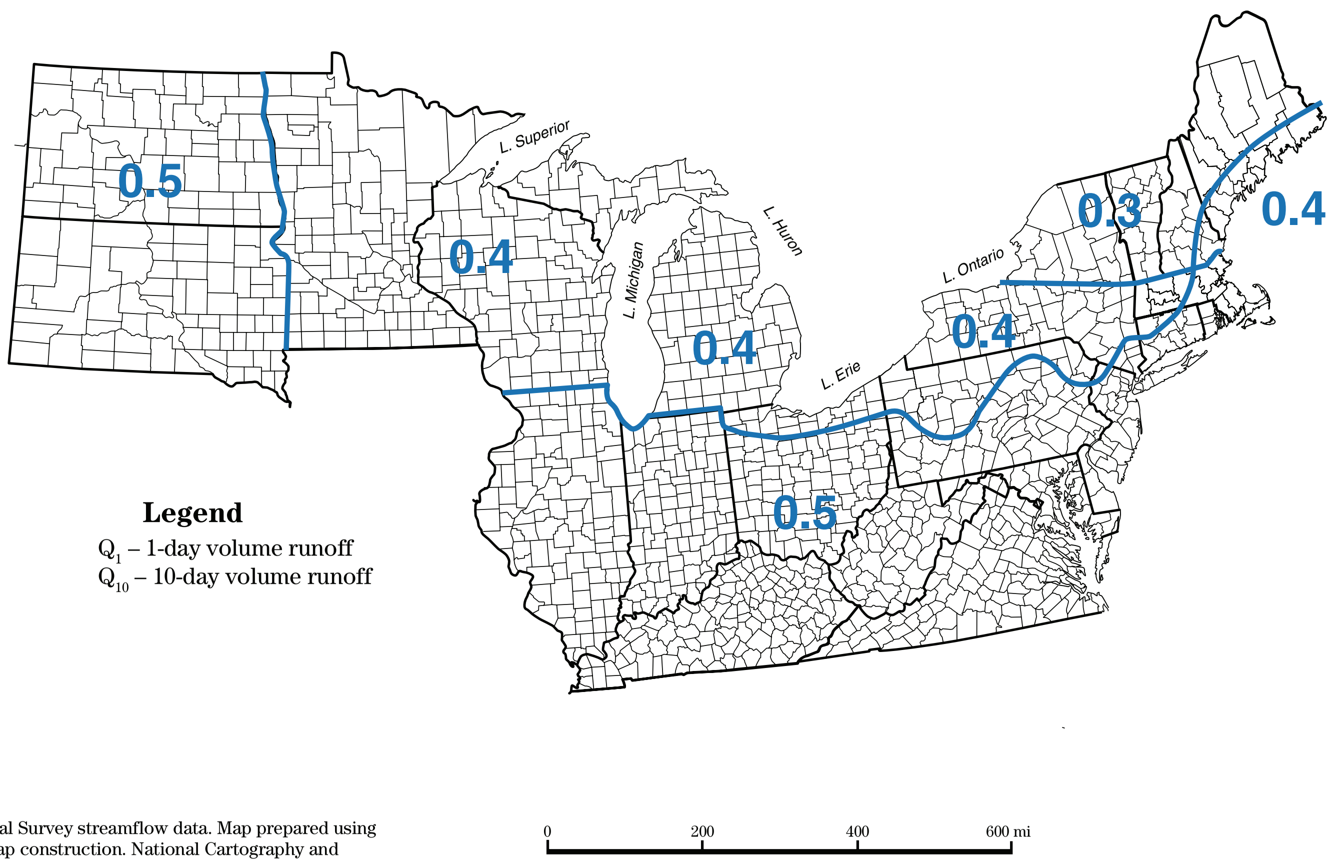
Ratios for 50- and 25-year, 10-day runoff volumes

To obtain:	Multiply map values by: Area 1	Area 2	Area 3
50-year, 10-day runoff	0.85	0.90	0.92
25-year, 10-day runoff	0.70	0.80	0.90

Source:
U.S. Geological Survey streamflow data. Map prepared using automated map construction. National Cartography and Center. Fort Worth, Texas. 1997

Figure 21–3 Ratios of volumes of runoff (Q_1/Q_{10}) for developing the principal spillway hydrograph (Northeast States)

Ratios of volumes of runoff (Q_1/Q_{10}) for developing the principal spillway hydrograph



Legend

Q_1 – 1-day volume runoff
Q_{10} – 10-day volume runoff

Source:
U.S. Geological Survey streamflow data. Map prepared using automated map construction. National Cartography and Center. Fort Worth, Texas. 1997

Figure 21–4 Quick return flow (csm) for developing the principal spillway hydrograph

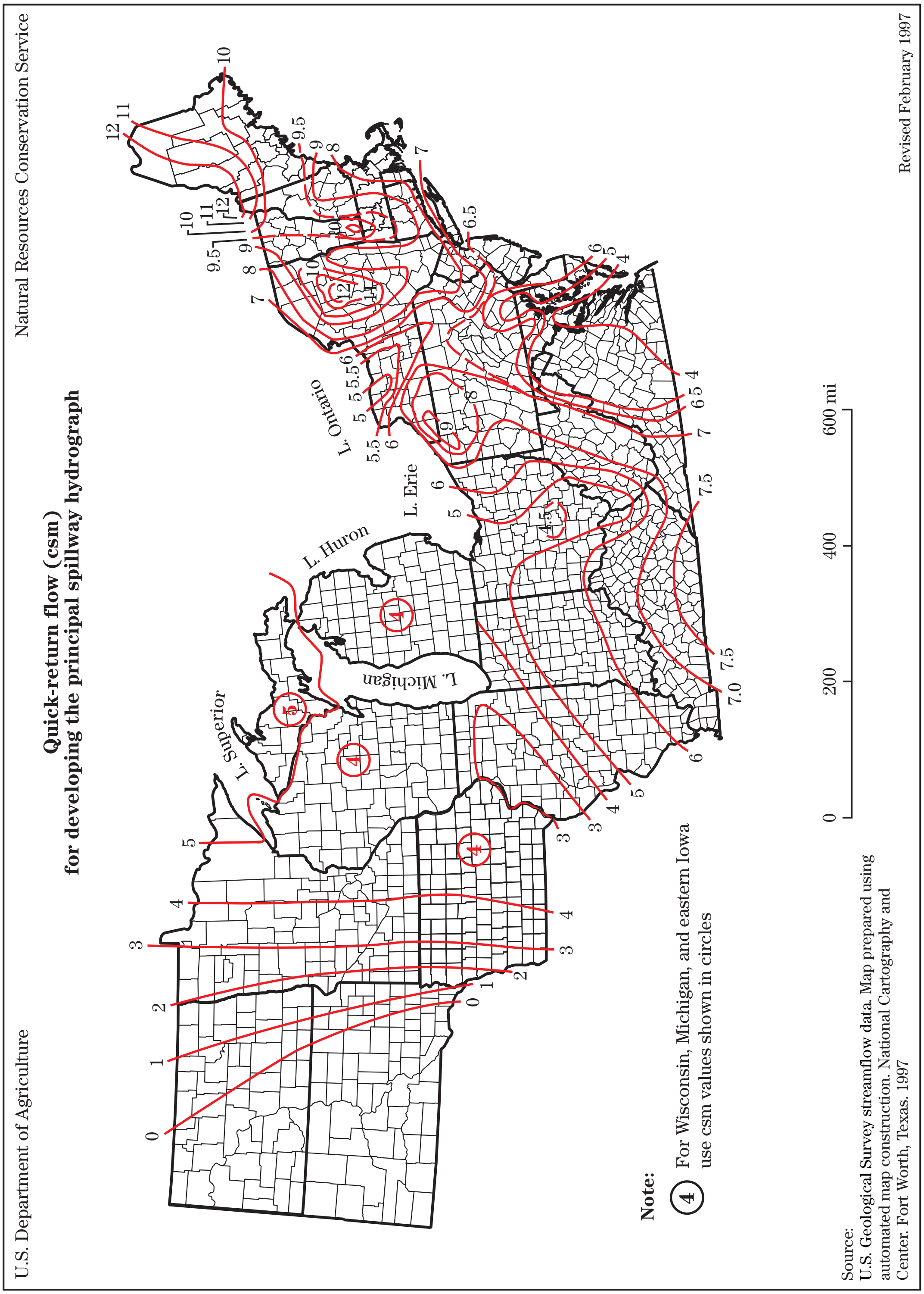


Figure 21–5 100-year, 10-day runoff (in) for developing the principal spillway hydrograph (Northwest States)

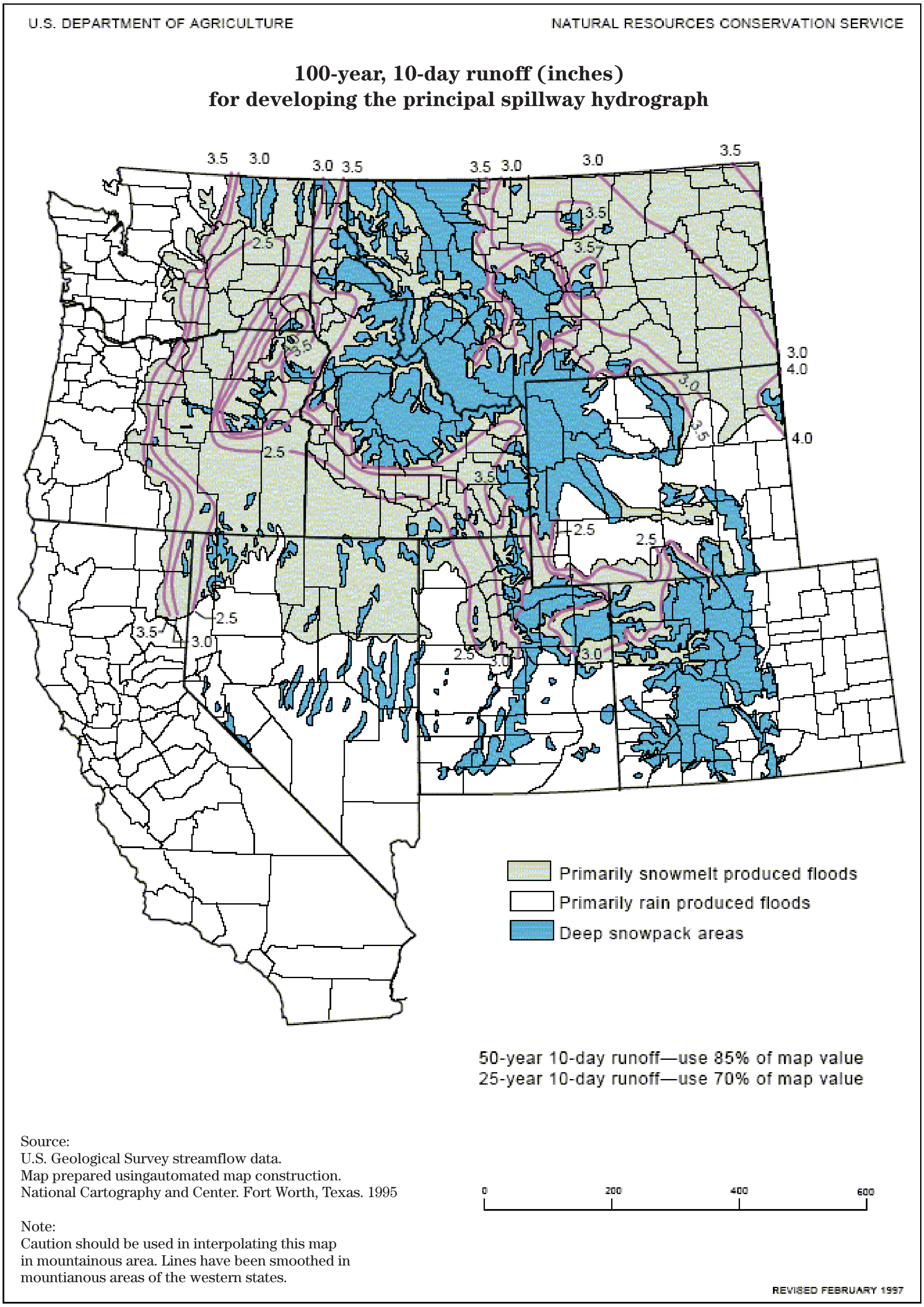


Figure 21–6 Ratios of volumes of runoff (Q_1/Q_{10}) for developing the principal hydrograph (Northwest States)

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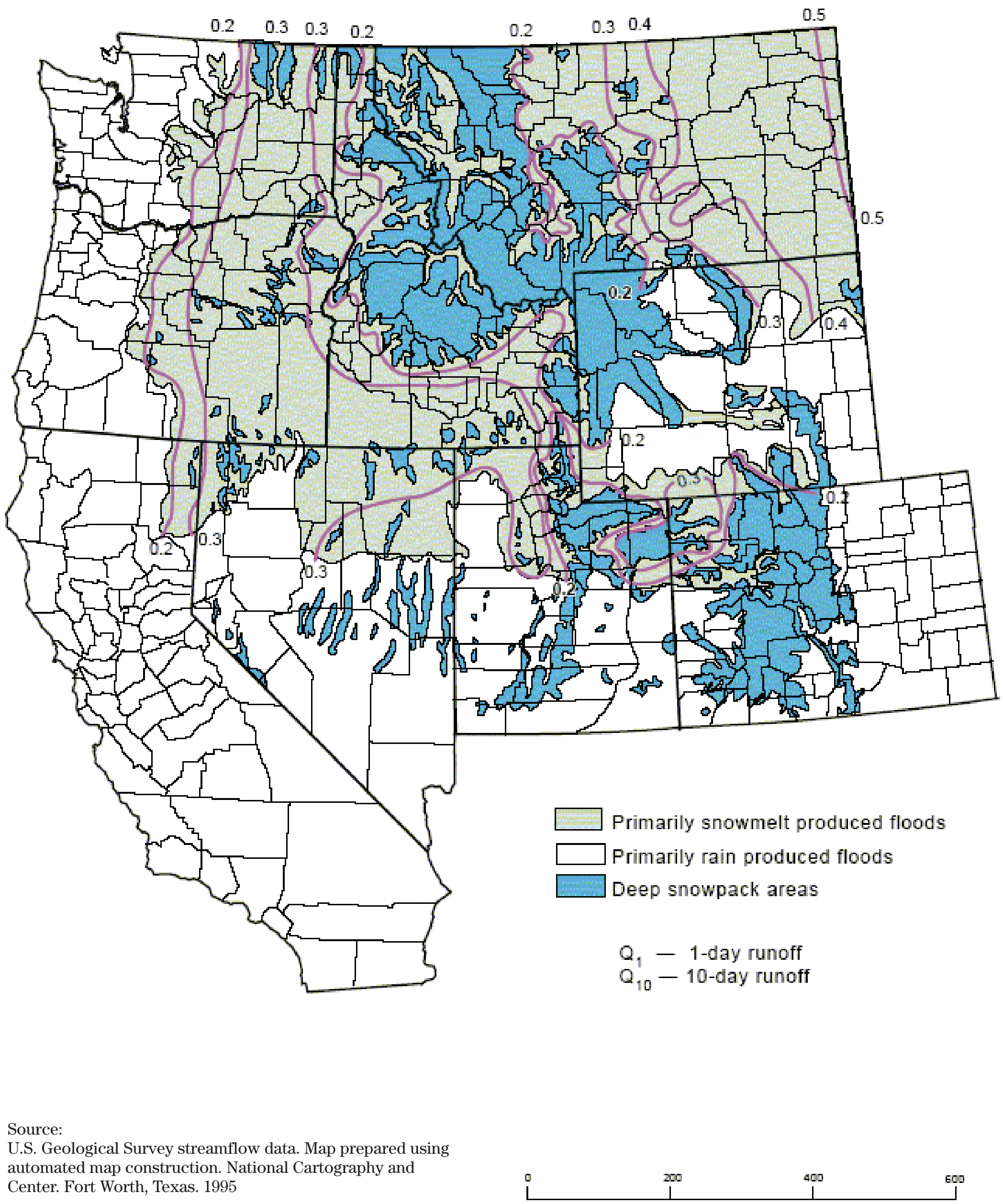
Ratios of volumes of runoff (Q_1/Q_{10}) for developing the principal spillway hydrograph



Source:
U.S. Geological Survey streamflow data. Map prepared using automated map construction. National Cartography and Center. Fort Worth, Texas. 1995

Note:
Caution should be used in interpolating this map in mountainous area. Lines have been smoothed in mountianous areas of the western states.

REVISED FEBRUARY 1997

sheds can be selected that are reasonably homogeneous with regard to seasonal precipitation, range of elevation, aspect, cover, geology, soils, and other characteristics, estimating equations can be developed with a minimum number of independent variables.

Until techniques are developed to properly analyze the effects of a number of variables, the selection of homogeneous-gaged watersheds with as much similarity to the ungaged watersheds as possible is recommended for estimating VDP data. Statistics from VDP studies of gaged watersheds can also be used to assist in developing estimating equations. NEH 630, chapter 18 details development of these studies.

(3) Development of the 1-day/10-day hydrograph

PSHs are developed from a continuous 10-day period of on site direct runoff, all of a given frequency. Choice of the 10-day period is based on NRCS experience using streamflow records. If the runoff in the 10-day period is arranged in order of decreasing rate of flow and then accumulated to form a mass curve, it has the appearance of curve in figure 21–7. Such a curve is a straight line on log paper with the equation:

$$Q_D = Q_{10}\left(\frac{D}{10}\right)^a \quad \text{(eq. 21–2)}$$

where:
Q_D = total runoff at time D in days
Q_{10} = total runoff at the end of 10 days
D = time in days
a = log (Q_{10}/Q_1)
where: Q_1 = total runoff at 1 day

Thus a continuous mass curve can be developed for the entire 10-day period, knowing only the 1- and 10-day runoff amounts.

Examination of such mass curves of runoff from streamflow stations in many locations of the United States showed that exponent a varies from 0.1 to 0.5.

The 10-day onsite runoff was rearranged as shown in table 21–6 to provide a moderately critical distribution of the 10-day runoff. This gives a distribution midway between the possible extremes. In figure 21–7, curves A and B show the extremes and curve C shows the rearranged distribution in table 21–6.

A step by step procedure for development of the PSMC is illustrated in appendix A. Development of the flood hydrograph using the PSMC follows procedures outlined in NEH 630, chapter 16. Routimg hydrograph through the structure is described in NEH 630, chapter 17.

Figure 21–7 Mass curves of principal spillway mass curve (PSMC) runoff in various arrangements

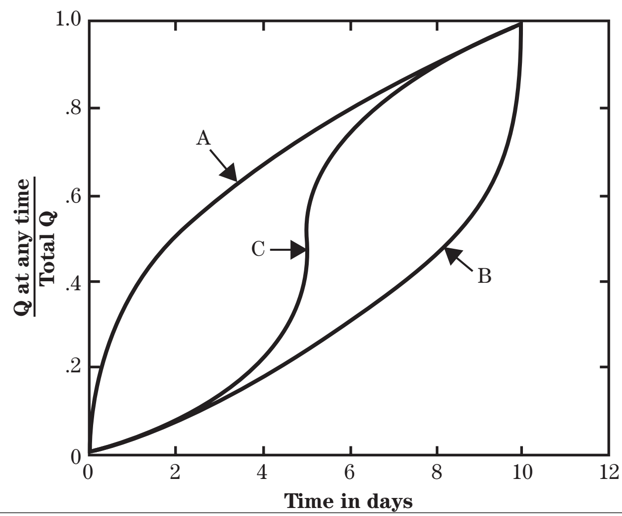


Table 21–6 Arrangement of increments of PSMC for curve C in figure 21–7

Time (days)	Increment
0.0 to 0.5	19th largest 1/2 day
0.5 to 1.0	17th largest 1/2 day
1.0 to 1.5	15th largest 1/2 day
1.5 to 2.0	13th largest 1/2 day
2.0 to 2.5	11th largest 1/2 day
2.5 to 3.0	9th largest 1/2 day
3.0 to 3.5	7th largest 1/2 day
3.5 to 4.0	5th largest 1/2 day
4.0 to 4.5	3rd largest 1/2 day
4.5 to 4.6	9th largest 1/10 day
4.6 to 4.7	7th largest 1/10 day
4.7 to 4.8	5th largest 1/10 day
4.8 to 4.9	3rd largest 1/10 day
4.9 to 5.0	Largest 1/10 day
5.0 to 5.1	2nd largest 1/10 day
5.1 to 5.2	4th largest 1/10 day
5.2 to 5.3	6th largest 1/10 day
5.3 to 5.4	8th largest 1/10 day
5.4 to 5.5	10th largest 1/10 day
5.5 to 6.0	4th largest 1/2 day
6.0 to 6.5	6th largest 1/2 day
6.5 to 7.0	8th largest 1/2 day
7.0 to 7.5	10th largest 1/2 day
7.5 to 8.0	12th largest 1/2 day
8.0 to 8.5	14th largest 1/2 day
8.5 to 9.0	16th largest 1/2 day
9.0 to 9.5	18th largest 1/2 day
9.6 to 10.0	20th largest 1/2 day

630.2102 Auxiliary spillway

Flows larger than those controlled by the principal spillway and retarding storage are safely conveyed past an earth dam by an auxiliary spillway designed using a stability design hydrograph (SDH). The auxiliary spillway's minimum freeboard and integrity are determined using a freeboard hydrograph (FBH). The SDH and FBH are constructed by the same procedures of hydrograph development shown in NEH 630, chapter 16 with the temporal distribution as described in this section.

Methods of routing the SDH and FBH through structures are given in NEH 630, chapter 17. Version 2005.0.2 of the SITES computer program can be used to do the actual hydrograph development and routings.

(a) Runoff curve number procedure

The runoff CN procedure uses climatic data and the characteristics of a watershed to convert rainfall data to runoff volume.

(1) Rainfall data sources

The precipitation values for the SDH and FBH are a function of the dam classification and the design storm. The various NWS HMRs used as references for the Probable Maximum Precipitation (PMP) and the appropriate storm frequencies are listed in table 21–1.

(2) Areal adjustment of rainfall amount

If the drainage area above a structure is 10 square miles or less, the areal rainfall is the rainfall taken from source data. If the area is more than 10 square miles, but not over 100 square miles, the area rainfall is obtained using an adjustment factor as described in the applicable hydrometerological source. In areas without applicable NWS references for spatial rainfall distribution, minimum areal adjustment ratios shown in figure 21–8 may used.

For watersheds greater than 100 square miles in area, the use of special studies is encouraged. Special studies may be used for watersheds of any size, but use of any special study must be coordinated through the Conservation Engineering Division (CED).

(3) Precipitation amounts for SDH and FBH

A storm duration greater than or equal to the time of concentration (T_c) should be used for the SDH and FBH. Values should be taken from the appropriate NWS publication (table 21–1).

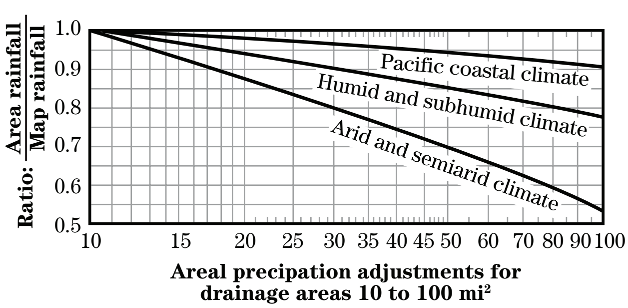
(4) Rainfall temporal distribution

In areas without applicable NWS reference for temporal distribution, the dimensionless auxiiliary and freeboard storm distribution shown in figure 21–9 may be used.

Alternately, the 24-hour storm distribution can be constructed by critically stacking incremental rainfall amounts of successive 6-, 12-, and 24-hour duration as described in Hydrometeorological Report 52 (HMR52) and outlined below.

1. From the appropriate HMR publications, obtain the 6-hour, 12-hour, and 24-hour PMP rainfall for the point location under consideration.
2. Distribute the rainfall into 4- to 6-hour increments.
3. With the largest 6-hour PMP in the second 6-hour block. (Editor's note: this is not complete; does this go with 2 above or 4 below?)
4. Subtract the 6-hour PMP rainfall from the 12-hour PMP rainfall, and distribute this in the third 6-hour block.
5. Subtract the 12-hour PMP rainfall from the 24-hour PMP rainfall.
6. Divide this remainder by 2, and distribute each half into the first and fourth 6-hour blocks.
7. Divide each of the rainfalls in the four blocks by the 24-hour PMP rainfall to obtain the fractions for the 5-point distribution.

Figure 21–8 Areal adjustment for SDH and FBH



Example:

6-hour PMP = 29.0 inches

12-hour PMP = 34.0 inches

24-hour PMP = 38.0 inches

For the 12-hour less the 6-hour 34–29 = 5
5/38 = 0.1316

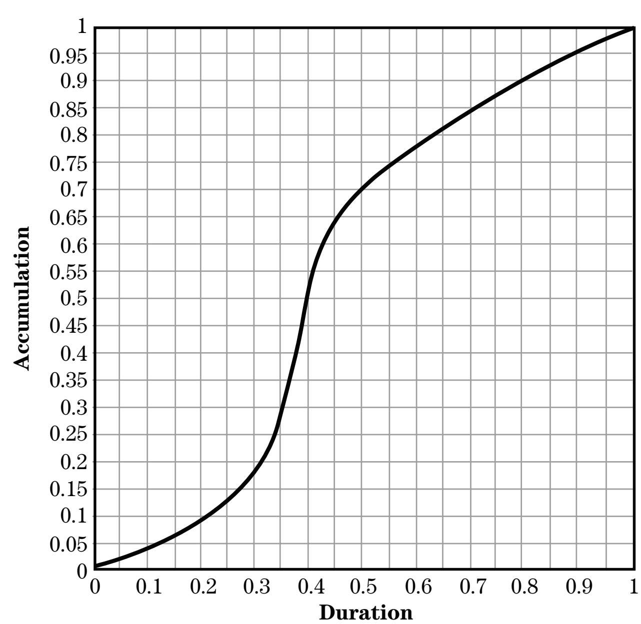
For the 24-hour less the 12-hour 38–34 = 4
4/38 = 0.1053
0.1053/2 = 0.0526

For the 6-hour 29
29/38 = 0.7632

The accumulated 5-point distribution is then:

0	6	12	18	24
0.00	.053	.816	.948	1.000

Figure 21–9 Dimensionless design storm distribution, SDH and FBH (Note: This is the same as figure 2–4 on page 2–12 of TR–60.)



(5) Runoff CNs

Runoff is determined from rainfall using the methods described in chapter 10. The runoff CN for the drainage area above a structure is determined by any of the methods in chapter 10. This CN must be for an average antecedent runoff condition II (ARC II), and it applies throughout the design storm, regardless of storm duration.

(6) Baseflow

Baseflow is stream discharge derived from groundwater sources. It is sometimes considered to include flows from regulated lakes or reservoirs. Baseflow fluctuates much less than storm runoff.

When a SDH or FBH is developed from rainfall, the baseflow is added to the base of the entire hydrograph (fig. 21–1c). When the SDH or FBH is developed from runoff, all hydrograph discharge values less than baseflow should be increased to the baseflow value (fig. 21–1d).

(7) Upstream releases

Releases from upstream structures must be accounted for in the runoff hydrograph, regardless of other additions or subtractions of flow. Upstream release rates are determined from routings of applicable hydrographs through the upstream structures and the reaches downstream from them.

630.2103 References

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Appendix A Example of PSH Development