Procedures for Estimating Unit Hydrographs for Large Floods at Ungaged Sites in Montana

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Prepared in cooperation with the Montana Department of Natural Resources and Conservation

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Frontispiece. Flooding at Gibson Dam on the Sun River, Montana, June 1964. View is looking west. Photograph taken by George F. Roskie, Forest Supervisor, Lewis and Clark National Forest. Reprinted from USDA Forest Service, Lewis and Clark National Forest, and published with permission.

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By STEPHEN R. HOLNBECK and CHARLES PARRETT

Prepared in cooperation with the
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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
cubic foot per second-day (ft^3/s-d)	2,447	cubic meter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer
hour (h)	3,600	second
minute (min)	60	second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

SYMBOLS AND DEFINITIONS OF TERMS

The following definitions are for symbols and terms that appear in more than one location in the report or that are not explicitly defined in the text.

A	Drainage area (mi^2).
AF_i	Adjustment factor for 24 values of dimensionless time t used for adjusting the average dimensionless unit hydrograph to a form having a different magnitude and shape.
AF_t	Adjustment factor for any dimensionless time t used for adjusting the average dimensionless unit hydrograph to a form having a different magnitude and shape.
C_p	Dimensionless unit-hydrograph coefficient defined by Snyder (1938).
L	Main channel length (mi).
L_{ca}	Distance from basin centroid to mouth (mi).
$LL_{ca}/\sqrt{S}$	Basin factor, a unit-hydrograph variable originally defined and found significant by Snyder (1938) (mi^2).
PCT.PK	Percentage difference between the peak discharges of the calculated and derived unit hydrographs.
Q'	Discharge at the recession inflection point.
Q_s	Ordinate of discharge for a given time step on the derived or calculated unit hydrograph (ft^3/s).
q	Dimensionless discharge ordinate.
q_p	Peak of the dimensionless unit hydrograph.
$(q_p/13.6)$	The ratio of the peak of a dimensionless unit hydrograph (q_p) to the peak of the average dimensionless unit hydrograph (13.6) calculated in this study.
R	Clark basin-storage coefficient (h).
RMS.ER	Square root of the sum of the squares of the differences in discharge at each time step between the calculated and derived unit hydrographs.
S	Main channel slope (ft/mi).
T	Time on a hydrograph or hyetograph (h or min for either).
T_c	Time of concentration (h).
t	Dimensionless time expressed as a percent of ($t_p + 0.5t_r$).
t_p	Snyder standard lag (h).
t_{pR}	Lag time of a derived unit hydrograph (h).
t_R	Duration of the rainfall excess for a derived unit hydrograph (h).
t_r	Snyder standard duration obtained by dividing t_p by 5.5 (h).
V	Volume of direct runoff.
V'	Volume of 1 in. of runoff over the basin obtained by multiplying drainage area by the conversion factor 26.89 (ft^3/s-d).
Calculated hydrograph	Hydrograph of direct runoff plus base flow obtained from a derived or calculated unit hydrograph and recorded rainstorm data.
Calculated unit hydrograph	Unit hydrograph obtained by applying the estimation methods developed in this study.
Derived unit hydrograph	Unit hydrograph obtained from a recorded flood hydrograph by application of the automatic calibration and optimization routine in the HEC-1 rainfall-runoff simulation model.
Synthetic-flood hydrograph	Flood hydrograph of direct runoff plus base flow commonly used for design purposes and obtained from a rainfall-runoff simulation model that uses a calculated or derived unit hydrograph and a synthetic rainstorm.
Synthetic rainstorm	Estimated rainfall hyetograph based on a particular design criterion.

Procedures for Estimating Unit Hydrographs for Large Floods at Ungaged Sites in Montana

By Stephen R. Holnbeck *and* Charles Parrett

Abstract

Methods were developed for estimating unit hydrographs at ungaged sites in Montana using either the Clark or dimensionless unit-hydrograph method. Large rainfall-related flood events generally exceeding the 50-year recurrence interval were examined for drainage areas ranging from 6.31 to 1,548 square miles. Flood-hydrograph data for 26 U.S. Geological Survey streamflow-gaging stations and rainfall data were used together with a rainfall-runoff simulation model (HEC-1) to derive unit hydrographs and important unit-hydrograph variables.

A multiple-regression analysis relating four unit-hydrograph variables to basin characteristics showed a significant (95-percent confidence level) relation only with drainage area for time of concentration, basin-storage coefficient, and Snyder standard lag. In the regression relation for dimensionless peak discharge, the only significant basin characteristic was one originally defined by Snyder that is a function of channel length, distance from the basin centroid to mouth, and channel slope. An alternative equation based only on drainage area was almost as reliable. Regression equations for estimating basin-storage coefficient and dimensionless peak discharge had coefficients of determination ranging from 0.19 to 0.47. For the Clark method, equations for estimating time of concentration and basin-storage coefficient had standard errors of estimate equal to 0.160 and 0.390 log units, respectively. For the dimensionless unit-hydrograph method, an equation for estimating Snyder standard lag had a standard error of estimate of 0.168 log units, and two equations for estimating dimensionless peak discharge had standard errors of estimate of 0.153 and 0.164 log units. An average dimensionless unit hydrograph was determined for the 26 sites, and a method was developed for adjusting the magnitude and shape of the average dimensionless unit hydrograph to account for more site-specific information.

The 26 derived unit hydrographs were compared with those calculated by the Clark and dimensionless unit-hydrograph methods. Calculated unit hydrographs using each of the estimation methods matched derived unit-hydrograph peaks and shapes equally well. For the 26 comparisons, the median percent difference in calculated versus derived unit-hydrograph peak discharge was 9.2 for the Clark method and 1.7 for the dimensionless unit-hydrograph method. Shapes of derived and calculated unit hydrographs were compared using a dimensionless variable obtained by dividing the root mean square of the differences in discharge at each time step by the mean discharge of the derived unit hydrograph. The median value for the shape variable for the 26 comparisons was 4.2 for the Clark method and 5.2 for the dimensionless unit-hydrograph method. For both peak and shape variables, the interquartile range was slightly less for the Clark method than for the dimensionless unit-hydrograph method.

INTRODUCTION

Synthetic-flood hydrographs are commonly used to design spillways and other hydraulic structures and to analyze the safety of dams. Typically, a large synthetic rainstorm is applied to a calibrated rainfall-runoff model that uses unit-hydrograph methods to transform the rainfall into a synthetic-flood hydrograph. Two methods that have gained wide acceptance in spillway design and dam-safety analysis are the Clark unit-hydrograph method (Clark, 1945; U.S. Army Corps of Engineers, 1982) and the dimensionless unit-hydrograph method (Horner and Flynt, 1936; Barnes, 1965). For calibration to a specific basin, both methods require physiographic data from the basin and empirical coefficients that are determined from recorded rainfall-runoff data at the site or from regional relations based on recorded data.

In Montana, many small dams have been built or are proposed on streams for which no flood data have been collected. In addition, no systematic regional analysis of unit-hydrograph methods has previously been available for the State. As a result, calibration of unit-hydrograph methods has been subjective and the resultant synthetic-flood hydrographs can be controversial.

Because of its responsibility for managing the State dam-safety program, the Montana Department of Natural Resources and Conservation (DNRC) needs to estimate synthetic-flood hydrographs as objectively as possible for dam-safety analysis. Accordingly, the U.S. Geological Survey (USGS), in cooperation with the DNRC, conducted a regional analysis of the commonly used unit-hydrograph methods and variables.

This report describes methods for estimating unit hydrographs for large floods at ungaged sites in Montana. The theory of unit hydrographs is presented, and unit hydrographs are derived from recorded floods.

Recorded flood data are analyzed in two steps. First, a rainfall-runoff simulation model developed by the U.S. Army Corps of Engineers (HEC-1) is used to derive unit hydrographs and determine unit-hydrograph variables at selected gaged sites where rainfall and flood-hydrograph data from large floods (those generally having a 50-year or greater recurrence interval) are available. Second, the unit-hydrograph variables determined for the gaged sites are related to various measurable geomorphic and physiographic characteristics of the drainage basins using multiple-regression methods. Finally, methods for the estimation of unit hydrographs at ungaged sites are presented. The reliability, limitations and design considerations, and examples of the methods are described.

UNIT HYDROGRAPHS

Unit hydrographs are described in terms of theory, analysis of recorded floods, and estimation at ungaged sites. The data used in the analysis are from floods recorded at 26 sites in Montana.

Theory

The unit hydrograph, a concept first proposed by Sherman (1932), may be defined as the hydrograph of 1 in. of direct runoff resulting from a rainfall excess of some specified duration that is uniformly distributed, both temporally and areally, over a basin. The rainfall excess is the portion of total rainfall that is available for direct runoff after rainfall losses. For a given rainfall duration, the unit hydrograph is considered to be a function only of basin physiography. Thus, a rainfall excess with a duration of 1 hour will always result in the same unique unit hydrograph for a given basin. Unit-hydrograph theory presumes that runoff is linearly related to rainfall excess. Consequently, complex runoff hydrographs resulting from complex storms generally can be represented by superimposing and adding unit hydrographs. The linearity of unit-hydrograph theory is illustrated in figure 1.

For a site having gaged streamflow and rainfall records, a unit hydrograph can be derived from a trial-and-error analysis of recorded flood hydrographs (streamflow versus time) and hyetographs (quantity of rainfall versus time). First, base flows and rainfall losses need to be estimated and subtracted from recorded flood hydrographs and hyetographs to produce hydrographs of direct runoff and hyetographs of rainfall excess. Next, a unit-hydrograph procedure that relates unit-hydrograph shape and timing to the recorded hydrograph and hyetograph is used to derive a unit hydrograph. Then, the derived unit hydrograph is used to calculate a hydrograph of direct runoff using the linearity principle discussed above. If the calculated hydrograph of direct runoff plus base flow does not match the recorded hydrograph, the unit-hydrograph variables and rainfall losses are adjusted and the trial-and-error process is repeated. When the calculated hydrograph of direct runoff plus base flow closely matches the recorded hydrograph, the resultant unit hydrograph is considered to be appropriate for the basin.

For sites where rainfall and streamflow data are lacking, flood hydrographs to be used for design purposes are developed by using synthetic rainfall quantities, a unit hydrograph, and appropriate infiltration losses. In these instances, the unit-hydrograph variables are determined from a regional analysis of data from gaged sites.

Two unit hydrographs commonly used for design purposes are the Clark unit hydrograph (Clark, 1945) and the dimensionless unit hydrograph (Cudworth, 1989, p. 63-132). The dimensionless unit hydrograph is based on unit-hydrograph relations developed by Snyder (1938).

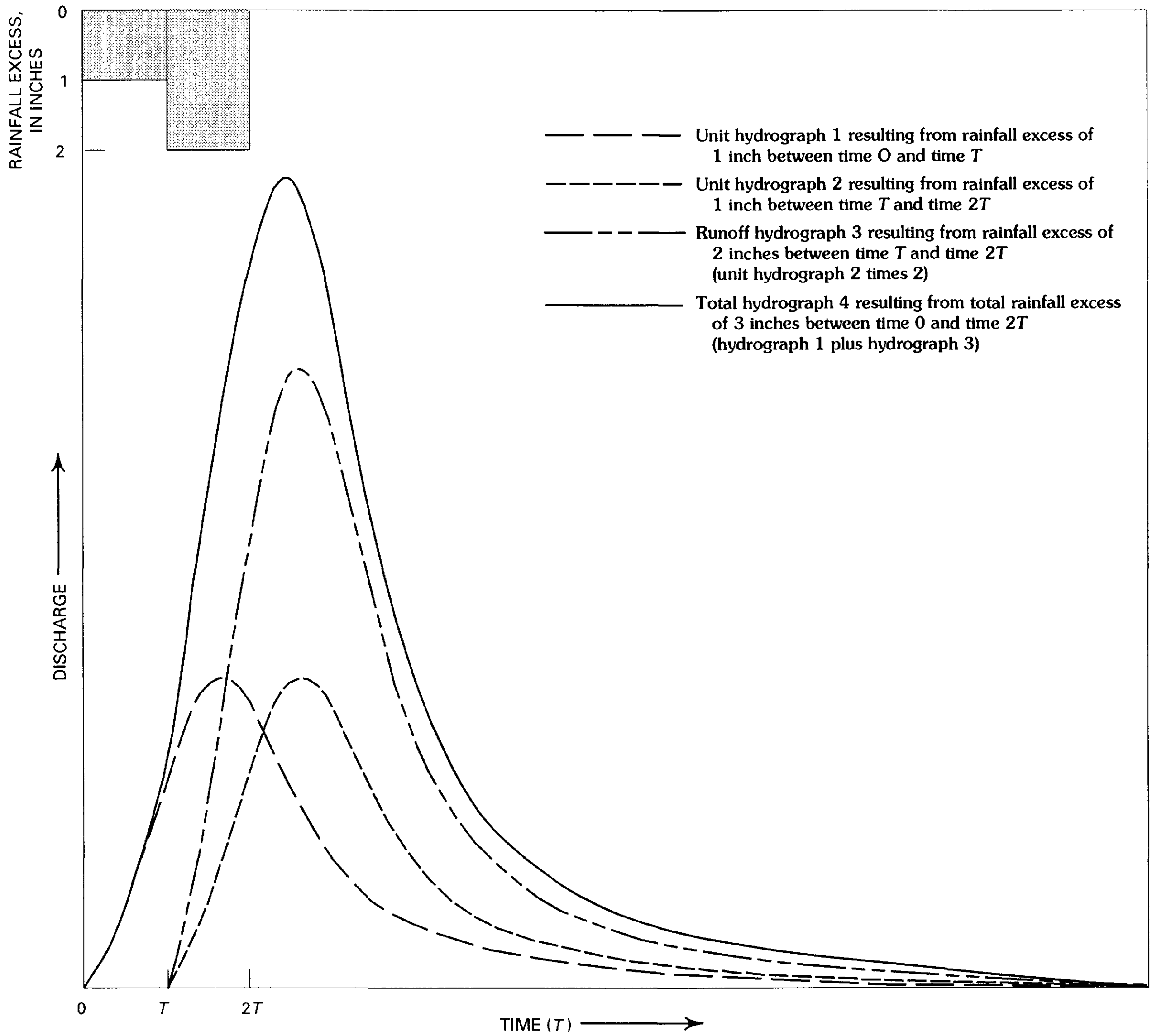


Figure 1. Linearity of unit hydrographs.

Clark Unit-Hydrograph Method

Three components are required to define the ordinates of a Clark unit hydrograph (Sabol, 1988, p. 105): the time of concentration (T_c); a basin-storage coefficient (R); and a time-area curve. If all three components are known, the ordinates of the Clark unit hydrograph can be calculated explicitly, and no trial-and-error shaping is required.

T_c is the time for a particle of water to travel from the most-upstream point in a basin to the basin outlet or point of interest. Clark (1945) assumed that T_c was the time from the end of rainfall excess to the inflection point on the recession limb of a hydrograph of direct runoff.

The variable R measures the effect of temporary basin storage or retention on the shape of the unit hydrograph. For T_c held constant, an increase in the value of R increases the temporary storage and decreases the flood peak. According to Sabol (1988), R has units of time and is equal to the discharge at the inflection point of the recession limb of the unit hydrograph divided by the slope of the recession limb at the inflection point. Alternatively, R can be defined as the volume of direct runoff (V) remaining after the inflection point divided by the discharge (Q') at the inflection point of the unit hydrograph. The value of R determined by either method is presumed to be the same. These definitions of T_c and R are illustrated in

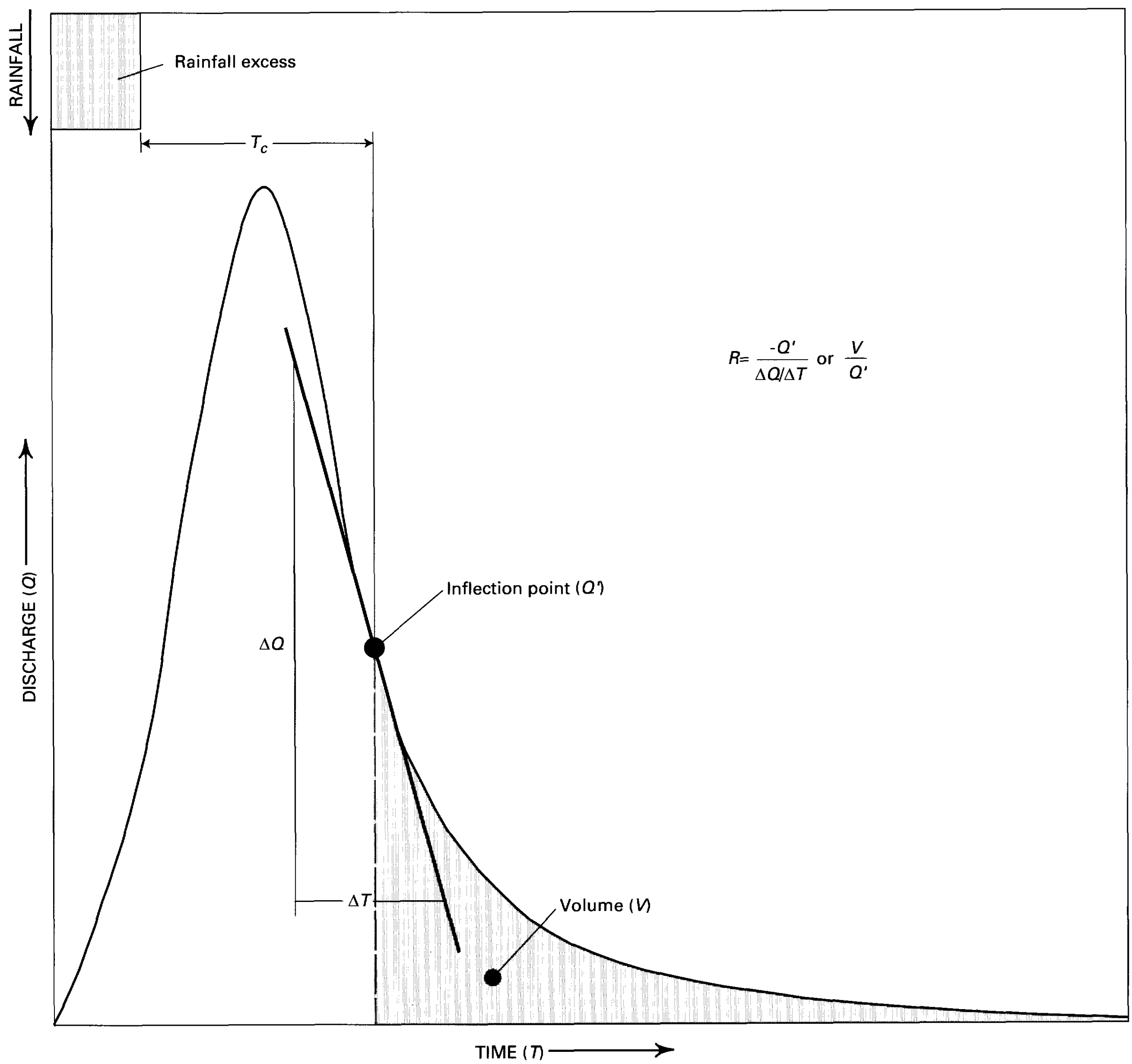


Figure 2. Time of concentration (T_c) and basin-storage coefficient (R) for the unit hydrograph.

figure 2. The Corps of Engineers (1982) and Sabol (1988) both indicate that R can be estimated by applying the definition to the hydrograph of direct runoff.

The time-area curve is a function of basin travel time (generally assumed to be equal to T_c) and shape; the curve indicates how much of the basin is contributing runoff at any time less than T_c. By definition, the entire basin is contributing runoff at all times equal to or greater than T_c. For most applications, a generalized time-area curve corresponding to a basin having a simple geometric shape is used (fig. 3). To calculate a unit hydrograph, the fraction of area contributing to runoff at each time step is converted to the fraction of unit-runoff volume occurring at each time step. In practice, T_c and R are adjusted, together with rainfall-loss coefficients, until the calculated hydrograph of direct runoff plus base flow is matched to the recorded hydrograph.

Dimensionless Unit-Hydrograph Method

Once a unit hydrograph has been derived from gaged streamflow and rainfall records, it can be made dimensionless by dividing discharge at each time step by some constant discharge and dividing each time step by some constant time measure. Making unit hydrographs dimensionless enables easier comparison

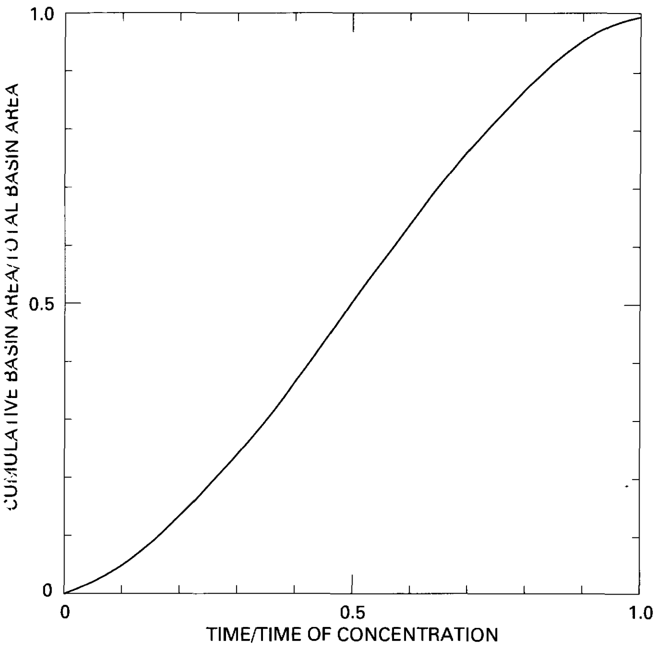


Figure 3. Time-area curve commonly used to determine the Clark unit hydrograph.

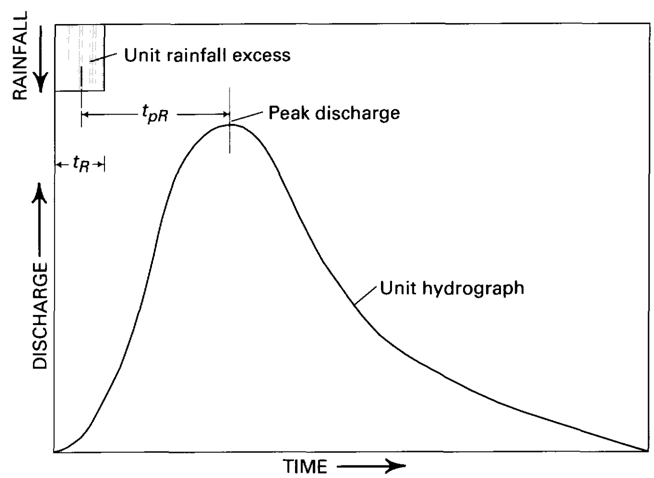


Figure 4. Lag time (t_{pR}) for a unit hydrograph of duration t_R.

among those representing widely varying drainage areas and widely varying time characteristics.

One time measure commonly used to make unit hydrographs dimensionless is termed lag time. As shown in figure 4, lag time for this study is defined as the time from the mid-point of unit rainfall excess to the unit-hydrograph peak, in hours. Lag time has also been defined as (1) the time from the centroid of rainfall excess to the time at which 50 percent of the unit runoff has passed the concentration point (Bureau of Reclamation, 1987, p. 31), (2) the elapsed time from centroid of rainfall excess to the centroid of the resultant runoff hydrograph (Stricker and Sauer, 1982; U.S. Army Corps of Engineers, 1987), and (3) the time from the centroid of rainfall excess to the peak of the resultant runoff hydrograph (U.S. Soil Conservation Service, 1975, p. 3-1). These different interpretations of lag time underscore the importance of (1) identifying which definition of lag time is used for a particular study, (2) correctly applying the definition to either the recorded flood hydrograph or the derived unit hydrograph, and (3) consistently using the definition when applying the resulting methods to the design of hydraulic structures.

The time measure used to make unit hydrographs dimensionless in this study is the "standard lag" defined by Snyder (1938). Snyder found that lag times for unit hydrographs derived in a given basin differed from one recorded flood to another and that lag time was dependent on the duration of unit rainfall excess as well as on the physiographic characteristics of the basin. The Snyder standard lag, a characteristic for a particular basin that is intended to overcome the observed differences from one flood to another, is related to lag time as follows:

$$t_p = (t_{pR} - 0.25\, t_R)/0.955 \qquad (1)$$

where

t_p is the Snyder standard lag, in h,
t_{pR} is lag time of the derived unit hydrograph, in h, and
t_R is the duration of the rainfall excess for the derived unit hydrograph, in h.

Snyder also defined a standard duration of rain (t_r) associated with the standard lag as $t_p/5.5$. This relation between lag and duration is commonly used to select appropriate unit-hydrograph durations when the dimensionless unit-hydrograph method is used with synthetic data for design. In this report, the standard unit hydrograph duration and the duration of a calculated unit hydrograph developed from the dimensionless unit-hydrograph method are the same (t_r).

The constant discharge used to make ordinates of the unit hydrograph dimensionless was defined by the Bureau of Reclamation (Cudworth, 1989) as the runoff volume divided by the Snyder standard lag plus one-half the unit-hydrograph duration expressed in cubic feet per second-day per hour. Thus, each ordinate of the dimensionless unit hydrograph can be expressed mathematically as:

$$q = Q_s\,(t_p + 0.5\, t_r)/V' \qquad (2)$$

where

q is the dimensionless discharge ordinate;

Q_s is the ordinate of discharge, in ft^3/s, for a given time step on the unit hydrograph; and

V' is the volume of 1 in. of runoff over the basin, in ft^3/s-d, obtained by multiplying drainage area in mi^2 by the conversion factor 26.89.

The other terms are as previously defined.

Dimensionless values of time on the abscissa are expressed as percentages of the Snyder standard lag plus one-half the duration of unit rainfall excess as follows:

$$t = 100T/(t_p + 0.5\, t_r) \quad (3)$$

where

t is the dimensionless value of time, and

T is the time, in h, on the unit hydrograph for which a dimensionless time is required.

The Snyder standard lag used in equations 2 and 3 tends to minimize differences from one flood to another and is a commonly used unit-hydrograph variable that is readily available from the HEC-1 model output. Because the Bureau of Reclamation commonly uses a different definition of lag time to develop dimensionless unit hydrographs (Cudworth, 1989), dimensionless unit hydrographs developed for this study are not directly comparable to those developed by that agency.

Analysis of Recorded Floods

The HEC-1 rainfall-runoff simulation model was used to derive Clark unit hydrographs and dimensionless unit hydrographs for large recorded floods in Montana. Factors considered important in deriving the unit hydrographs are rainfall losses, base flow, and effects of snowmelt.

Streamflow data for large recorded floods were obtained from records of the USGS. With few exceptions, rainfall data were obtained from precipitation gages of the National Weather Service and from published flood reports of the USGS. A regression analysis was performed on the unit-hydrograph variables to develop equations for estimating the variables at ungaged sites. An average dimensionless unit hydrograph was determined for the 26 sites, and a method is presented for adjusting the magnitude and shape of the average dimensionless unit hydrograph to allow more design flexibility based on site-specific information.

Use of HEC-1 Flood-Hydrograph Model

The HEC-1 model uses a Clark unit hydrograph; a generalized time-area curve (fig. 3); and an automatic calibration and optimization routine to adjust T_C, R, and rainfall-loss variables to provide an optimal match between calculated and recorded hydrographs. The model is a single-event rainfall-runoff model that does not account for changes in rainfall-loss variables between storms. The HEC-1 model calculates the Snyder standard lag, so the unit hydrograph derived from HEC-1 can be used with t_p and equation 2 to develop a dimensionless unit hydrograph. Input to the model includes starting flow, base flow, recorded flood hydrograph, basin area, total-basin rainfall, and temporal distribution pattern for total-basin rainfall. The total-basin rainfall is presumed to be uniformly distributed over the basin.

The calculated hydrograph of direct runoff plus base flow is considered to have an optimal match with the recorded hydrograph when an error function is minimized. The error function is calculated as follows:

$$STDER = \left[\sum_{i-1}^{n} (QREC_i - QCALC_i)^2 \cdot WT_i / n \right]^{0.5} \quad (4)$$

where

$STDER$ is the error function, in ft^3/s,

$QREC_i$ is the ordinate for the recorded hydrograph for time period i, in ft^3/s,

$QCALC_i$ is the ordinate for the calculated hydrograph for time period i, in ft^3/s,

WT_i is the weighting function for ordinate i, and

n is the total number of hydrograph ordinates.

The weighting function is calculated from the equation:

$$WT_i = (QREC_i + QAVE)/(22 \cdot QAVE) \quad (5)$$

where

WT_i is the weighting function, and

$QAVE$ is the average recorded discharge for n hydrograph ordinates, in ft^3/s.

The weighting function is biased toward the reproduction of peak flows rather than low flows, because errors for discharge ordinates exceeding the average discharge are weighted more heavily. The optimization technique for minimizing the error function used in the HEC-1 model is described in detail by

Ford and others (1980); the technique is summarized as follows:

1. Unit-hydrograph variables to be estimated (T_C, R, and rainfall loss) are given initial values either by the program user or by program-assigned default values. In this study, final values of the optimized unit-hydrograph variables were found to be insensitive to the initial values used.
2. Given initial variable estimates, a hydrograph of direct runoff plus base flow is calculated and compared to the recorded flood hydrograph to determine the value of the error function in accordance with equations 4 and 5.
3. Following the first calculation, each unit-hydrograph variable to be estimated is either decreased or increased, one at a time and in a prescribed order (U.S. Army Corps of Engineers, 1987, p. 47-48), by 1 percent and then 2 percent, and the error function is calculated each time. This procedure results in error functions for three equally spaced values of a given variable with all other variables held constant. The "best" value of the variable is then calculated using a numerical approximation method (Newton's method). The "best" value of the variable thus calculated can be either smaller or larger than the initial value. If the error function is not decreased for a change in a variable, the original value of the variable is used.
4. Step 3 is repeated using the "best" estimates of the variables.
5. Step 3 is repeated for the variable that most improved the value of the error function in its last change and is repeated for each successive variable with the next best improvement in error function until no single change in any variable results in a decrease of the error function of more than 1 percent.
6. Step 3 is repeated a final time.
7. A final adjustment to the rainfall loss variables is made, if necessary, to ensure that the volume of the calculated hydrograph of direct runoff plus base flow agrees within 1 percent with the volume of the recorded flood hydrograph.

To maintain consistency from one unit-hydrograph derivation to another, and to ensure that calculated peaks, volumes, and lag times of the hydrographs of direct runoff plus base flow were in close agreement with peaks, volumes, and lag times of recorded flood hydrographs, the following additional procedures were followed:

1. The optimization typically was started several time steps before the rising limb of the recorded flood hydrograph. The optimization region included the complete recorded flood hydrograph and terminated several time steps beyond the falling limb. In some instances, more time steps were included, before the rising and after the falling limbs, to account for the full duration of the hyetograph used in the derivation process.
2. In some instances, variables (T_C or R) automatically optimized using HEC-1 were further increased or decreased manually to ensure a better match of calculated and recorded hydrograph peaks. This manual adjustment, however, was limited to about 10 percent of the value of the unit-hydrograph variable automatically optimized.
3. In the HEC-1 modeling process, the duration of the rainfall excess associated with the resulting Clark unit hydrograph is set equal to the time step used for the unit-hydrograph derivation. As a practical matter, the time step is typically set equal to the time step of the recorded hyetograph and recorded flood-hydrograph data. If the time step is too large, unit-hydrograph ordinates at and near the peak may be underestimated. One criterion for selecting a proper time step (unit-hydrograph duration), developed by the U.S. Army Corps of Engineers (David Goldman, oral commun., 1992) and the Bureau of Reclamation (Cudworth, 1989), is that the duration of rainfall excess needs to be less than some measure of lag time or time of concentration divided by a number ranging from 3.0 to 5.5. In this study, an hourly time step was used for all hydrograph derivations but one, for which a 0.25-hour (15-minute) time step was used. In all instances, shorter time steps were tried but did not result in larger unit-hydrograph ordinates. The selected time steps also generally met the criteria developed by the U.S. Army Corps of Engineers and the Bureau of Reclamation and were thus considered to be appropriate.

Rainfall-Loss and Base-Flow Variables

In the HEC-1 model, all rainfall that does not contribute directly to streamflow is considered to be lost from the rainfall-runoff system. This rainfall loss includes all processes that prevent rainfall from producing direct runoff, such as depression storage, interception, and infiltration. The rainfall loss is considered to be uniform throughout the basin, except where the land surface is impervious and rainfall is not lost.

In this study, the exponential loss-rate method was used to calculate rainfall loss. With this method, the rate of rainfall loss is presumed to be a nonlinear function of rainfall intensity and accumulated rainfall loss. The rate of rainfall loss calculated by this method generally is greatest early in the storm (fig. 5).

Default values contained in the HEC-1 model for the rainfall-loss variables were initially used for each unit-hydrograph derivation. The final values for the rainfall-loss variables were automatically determined by optimization and calibration.

Streamflow hydrographs are commonly considered to have three components: direct runoff (surface or overland flow), delayed subsurface flow or interflow, and ground-water flow. Base flow generally is regarded to be the sustained or fair-weather streamflow, composed of delayed subsurface flow and ground-water flow (Chow, 1964, p. 14-2). In most instances, total streamflow is simply separated into direct runoff and base flow.

In the HEC-1 model, the effects of base flow on the streamflow hydrograph (fig. 6) are defined by three variables:

(1) *STRTQ*, the discharge at the start of the storm,
(2) *QRCSN*, the discharge below which base-flow recession occurs, and
(3) *RTIOR*, the ratio of recession discharge, *QRCSN*, to the discharge that occurs 1 hour later, Q_{T+1}.

Base-flow variables *STRTQ*, *QRCSN*, and *RTIOR* cannot be automatically estimated by optimization and calibration. Thus, they were estimated by inspection of each recorded hydrograph.

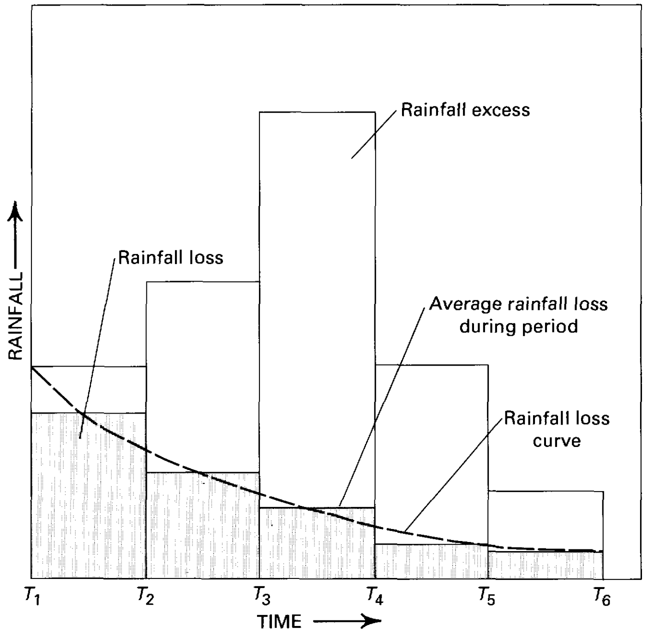


Figure 5. Exponential rainfall-loss rate.

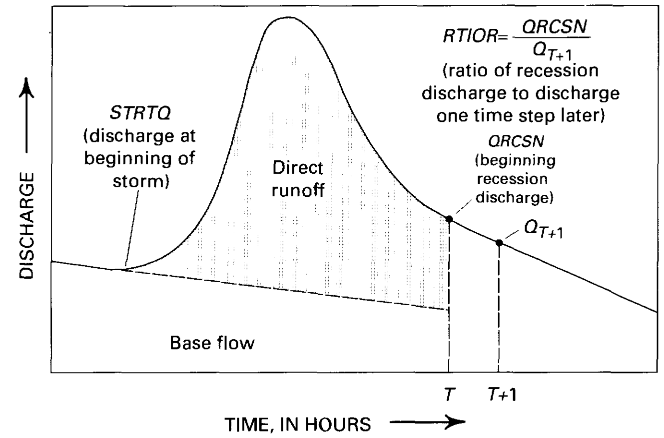


Figure 6. Effects of HEC-1 model base-flow variables on the streamflow hydrograph.

Effects of Snowmelt

Unit-hydrograph theory was developed for floods caused by rainfall only. In Montana, snowmelt often contributes to flood runoff, and snowmelt mixed with rain commonly produces the annual peak runoff in mountainous areas. Snowmelt mixed with rain complicates the runoff process, because the rain may be absorbed in the snowpack early in the storm only to be released later with the snowmelt. Thus, melting snowpack can alter both the timing of the peak and the volume of flood runoff (Bertle, 1966, p. 1).

For some hydrographs used in the study, snowmelt during a given rainstorm was a relatively small percentage of the total direct runoff. This condition was particularly evident in the floods of June 1964, when snowmelt contributed to the runoff, but only to a minor degree compared to the large quantity of rainfall. Nevertheless, rain is the predominant cause of most large floods in Montana, and the effects of snowmelt on the present study were minimized as follows:

1. Recorded flood hydrographs for winter were not considered for unit-hydrograph derivation.
2. Hydrographs were excluded from the study, regardless of season, if snowmelt was known to be a significant factor in the recorded flood-hydrograph peak.
3. Some recorded flood hydrographs could not be successfully matched by calculated hydrographs of direct runoff plus base flow, presumably because of snowmelt effects, and were eliminated from further analysis.

Streamflow and Rainfall Data Used

The HEC-1 model was used to derive unit-hydrograph variables for 27 recorded flood hydrographs at 26 gaged sites in Montana (fig. 7). Two different flood hydrographs were analyzed for site 5, and the resulting unit-hydrograph variables were averaged to provide a single set of variables for the site. Recorded flood hydrographs at 14 additional sites were initially included in the study, but later these were deleted because of a lack of rainfall data, because of problems related to the effects of snow, or because the flood was considered too small to be representative of the large floods generally used for design of major hydraulic structures. Data for small floods generally were not used in the analysis because unit-hydrograph peaks derived from small-storm hydrographs commonly are smaller than those derived from large-storm hydrographs. Unit-hydrograph peaks thus tend to be related to flood peaks in some generally undefined manner (Linsley and others, 1975, p. 237–238) as well as to duration of rainfall excess.

In general, a recorded flood hydrograph was considered to be usable for the determination of unit-hydrograph variables if the recurrence interval of the peak discharge was 50 years or greater. At four sites, the recurrence intervals of the recorded flood peaks were less than 50 years (table 1). These floods were used in the analysis because they occurred in eastern Montana, where flood-hydrograph data generally are lacking. In addition, two of the floods having the smallest recurrence intervals were in small basins (drainage areas less than 10 mi^2), where recorded flood-hydrograph data are almost totally lacking.

The recurrence interval of the peak discharge of each flood was determined from a log-Pearson type III flood-frequency analysis (Interagency Advisory Committee on Water Data, 1982). The streamflow-gaging stations and recorded flood-peak data used in the unit-hydrograph analysis are identified in table 1.

Most of the recorded flood hydrographs used in the analysis were caused by large, general storms rather than local storms. As defined by Hansen and others (1988, p. 5–6), a general storm commonly produces rainfall in an area of 500 mi^2 or more, has a duration greater than 6 hours, and is associated with a major weather pattern. In contrast, a local storm commonly covers areas smaller than 500 mi^2 and lasts less than 6 hours. The only recorded flood that was clearly the result of a local storm was the flood of July 24, 1982, on Prairie Dog Creek above Jack Creek, near Birney, Mont. (site 20).

The large, general storms commonly produced area-wide flooding that was documented in several reports. Floods and rainfalls that were analyzed include those in north-central Montana in 1953 (Wells, 1957), in northwestern Montana in 1964 (Boner and Stermitz, 1967), in southeastern Montana in 1978 (Parrett and others, 1979), in west-central Montana in 1981 (Parrett and others, 1982), and in north-central Montana in 1986 (Robert Sims, National Weather Service Forecasting Office, Great Falls, Mont., written commun., 1989). When available, unpublished data for storms from the 1950's to 1990 were also analyzed.

Total-basin rainfall data concurrent with each recorded flood hydrograph were obtained from isohyetal maps (showing lines of equal rainfall) contained in published flood reports where available. Total-basin rainfall for each of the 26 sites was determined from the isohyetal maps by using either the isohyetal method (Linsley and others, 1975, p. 82–84) or visual inspection. At two gaged sites (sites 20 and 21), isohyetal maps were not available, and total-basin rainfall was assumed equal to the recorded data at the nearest precipitation gages (fig. 7). Although data from individual precipitation gages represent point values only and generally need to be adjusted downward to represent an areal rainfall quantity, no adjustment was made for the two sites. For site 20, the drainage area was so small (6.57 mi^2) that no areal adjustment was considered necessary. For site 21, data from two rain gages were averaged and, on that basis, were considered to be representative of the area. With the exception of two precipitation gages (Altawan and Medicine Lodge) in Canada (Environment Canada, 1990) and one gage (Prairie Dog Project) in Montana (project files of the U.S. Geological Survey), the temporal rainfall data from continuous-recording precipitation gages were obtained from documented flood reports and by computer retrieval from records of the National Weather Service (James R. Stimson, Natural Resources Information System, Montana State Library, written commun., 1992).

Temporal distribution of total-basin rainfall was estimated on the basis of the temporal data. Cumulative-mass rainfall curves were generated from these data in some instances to help determine which precipitation-gage records were most representative of rainfall in the basin. Although the HEC-1 model has a provision for weighting several hyetographs to produce

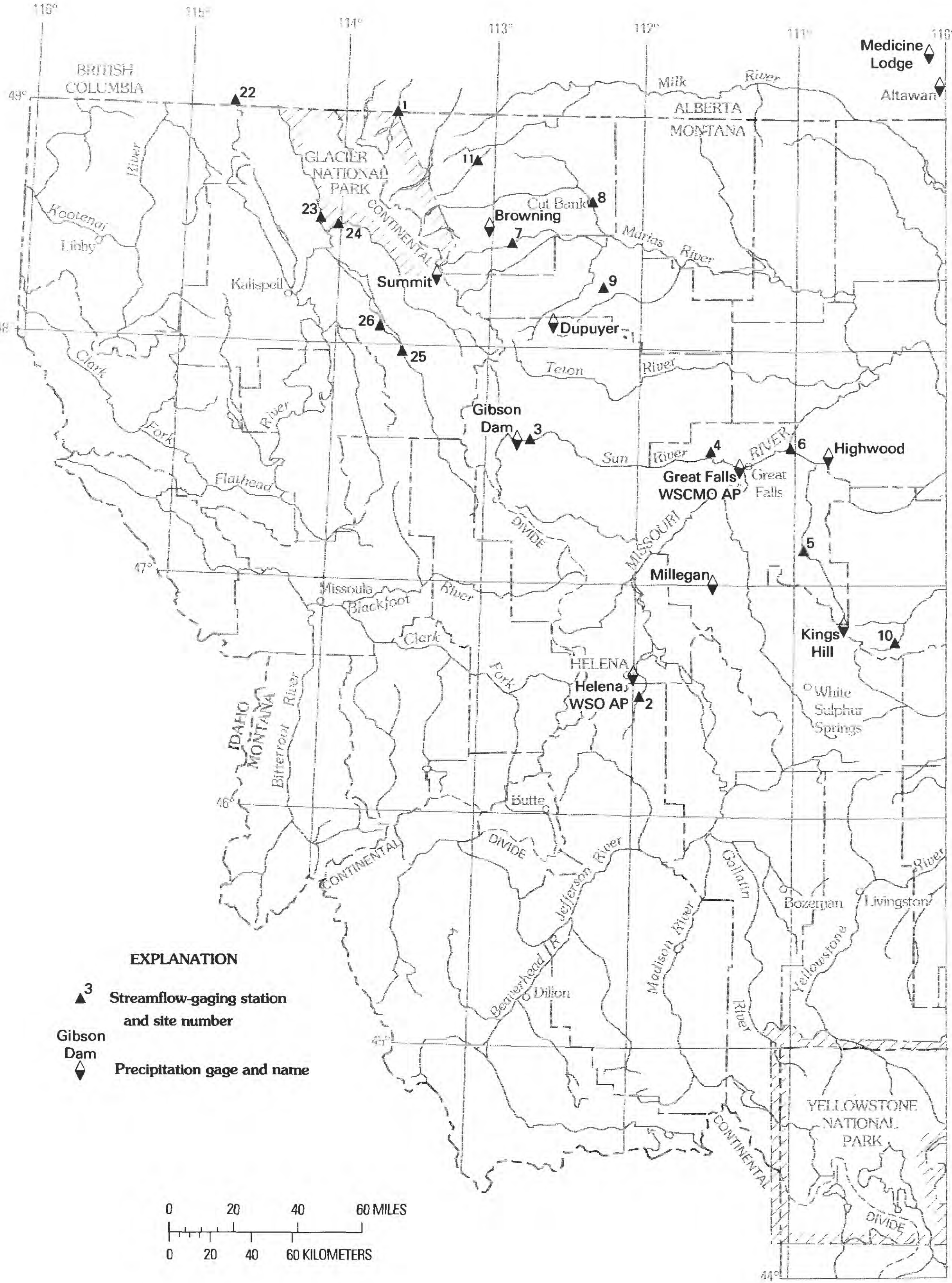
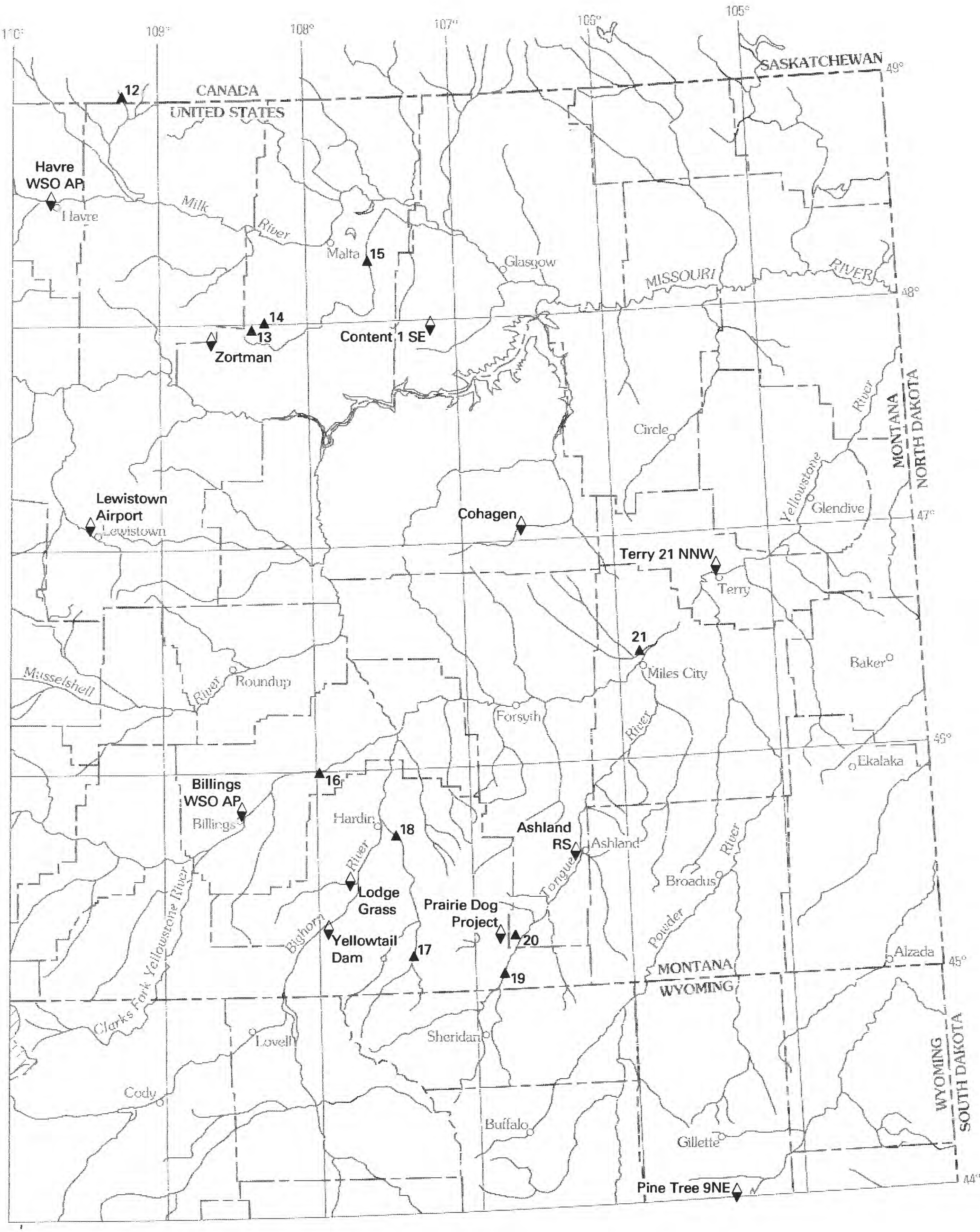


Figure 7. Location of study sites used for unit-hydrograph analysis.



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Baker
Musselshell River
Roundup
Forsyth
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Billings WSO AP
Billings
Hardin
18
Ekalaka
Ashland RS
Ashland
Tongue River
Bighorn River
Lodge Grass
Prairie Dog Project
20
Yellowtail Dam
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19
Broadus
Powder River
Alzada
MONTANA
WYOMING
Clarks Fork Yellowstone River
Lovell
Sheridan
Cody
Buffalo
Gillette
WYOMING
SOUTH DAKOTA
Pine Tree 9NE

Table 1. Streamflow-gaging stations and recorded flood data used in unit-hydrograph analysis for Montana

[Station number: Stations are listed in downstream order by standard drainage basin number. Each station number contains a 2-digit part number--Part 05 (Hudson Bay basin), Part 06 (Missouri River basin), Part 12 (upper Columbia River basin)--plus a 6-digit downstream order number. Symbols: --, not applicable; >, greater than]

Site no.	Station no.	Stream name	Drainage area, in square miles	Date of flood peak	Peak discharge, in cubic feet per second	Recurrence interval, in years
1	05010000	Belly River at international boundary	74.8	06-08-64	12,000	>100
2	06061500	Prickly Pear Creek near Clancy	192	05-22-81	2,300	>100
3	--	Sun River inflow to Gibson Reservoir[1]	575	06-08-64	60,000	>100
4	06088500	Muddy Creek at Vaughn	391	06-04-53	7,600	>100
5	06090500	Belt Creek near Monarch[2]	368	06-04-53	11,000	>100
	06090500	Belt Creek near Monarch[2]	368	05-22-81	8,270	100
6	06090610	Belt Creek near Portage[3]	799	05-22-81	14,300	>100
7	06092500	Badger Creek near Browning	133	06-08-64	49,700	>100
8	06099000	Cut Bank Creek at Cut Bank	1,065	06-09-64	16,600	>50
9	06100300	Lone Man Coulee near Valier	14.1	06-08-64	1,740	100
10	06109800	South Fork Judith River near Utica	58.7	06-08-64	1,290	100
11	06132200	South Fork Milk River near Babb	70.4	06-08-64	12,000	>100
12	06151000	Lyons Creek at international boundary[3]	66.7	09-25-86	1,400	25
13	06164615	Little Warm Creek at reservation boundary, near Zortman	6.31	09-25-86	300	5
14	06164630	Big Warm Creek near Zortman	8.58	09-25-86	630	10
15	06166000	Beaver Creek below Guston Coulee, near Saco	1,208	09-26-86	23,500	>100
16	06217750	Fly Creek at Pompeys Pillar	285	05-19-78	10,300	>100
17	06290500	Little Bighorn River below Pass Creek, near Wyola	428	05-19-78	8,010	>100
18	06294000	Little Bighorn River near Hardin[3]	1,294	05-19-78	22,600	>100
19	06306300	Tongue River at State line, near Decker	1,477	05-19-78	17,500	>100
20	06307525	Prairie Dog Creek above Jack Creek, near Birney	6.57	07-24-82	400	50
21	06309075	Sunday Creek near Miles City	714	05-07-75	6,760	10
22	12355000	Flathead River at Flathead, British Columbia	450	06-08-64	16,300	50
23	12355500	North Fork Flathead River near Columbia Falls	1,548	06-09-64	69,100	>100
24	12358500	Middle Fork Flathead River near West Glacier	1,128	06-09-64	140,000	>100
25	12359000	South Fork Flathead River at Spotted Bear Ranger Station, near Hungry Horse	958	06-08-64	36,700	50
26	12361000	Sullivan Creek near Hungry Horse	71.3	06-08-64	5,020	50

[1]Flood hydrograph computed from hourly record of change in contents and outflow from Gibson Reservoir.
[2]Two different recorded floods analyzed for the same site.
[3]Peak discharge shown is greater than maximum hourly value used in the HEC-1 analysis.

a temporal distribution, generally no more than two hyetographs were weighted because of the potential for loss of hyetograph detail for periods of intense rainfall. The streamflow hydrograph and the hyetographs used in each unit-hydrograph derivation are contained in the input data for the HEC-1 model provided in table 9 (at back of report). Also contained in the input data are the values of all input variables required in the automatic calibration and optimization routine. As allowed by the HEC-1 program, the input data for each derivation are in either a fixed, free, or mixed format (U.S. Army Corps of Engineers, 1987, p. 72). The choice of an input-data format was made at the discretion of the investigator and was largely based on the format of the input-data source.

The unit-hydrograph variables derived from the recorded-flood analyses at the 26 gaged sites are identified in table 2. Included are calculated values for T_C, R, various combinations of T_C and R found useful in previous regionalization studies by the U.S. Army Corps of Engineers (1982) [$T_C + R$ and $R/(T_C + R)$], the Snyder standard lag (tp) and regional coefficient (Cp), lag time as used by the Bureau of Reclamation (Lg), lag time as used by the U.S. Army Corps of

Table 2. Unit-hydrograph variables derived from recorded flood hydrographs at study sites in Montana

[Station number: Stations are listed in downstream order by standard drainage basin number. Each station number contains a 2-digit part number--Part 05 (Hudson Bay basin), Part 06 (Missouri River basin), Part 12 (upper Columbia River basin)--plus a 6-digit downstream order number. T_c, time of concentration, in hours; R, basin storage coefficient, in hours; t_p, Snyder standard lag, in hours; C_p, Snyder regional coefficient; L_g, lag time used by Bureau of Reclamation, in hours; L_{g2}, lag time used by U.S. Army Corps of Engineers, in hours; Q_p, peak discharge of derived unit hydrograph, in cubic feet per second; T_{PK}, time of peak of derived unit hydrograph, in hours; q_p, peak of dimensionless unit hydrograph. Symbol: --, not applicable]

Site no.	Station no.	Stream name	T_c	R	T_c+R	$R/(T_c+R)$	t_p	C_p	L_g	L_{g2}	Q_p	T_{PK}	q_p
1	05010000	Belly River at international boundary	10.1	23.8	33.9	0.70	10.1	0.33	21.2	28.2	1,640	10.0	8.6
2	06061500	Prickly Pear Creek near Clancy	9.00	35.0	44.0	.80	9.20	.22	28.3	37.2	3,080	10.0	5.7
3	--	Sun River inflow to Gibson Reservoir[1]	11.3	15.2	26.5	.57	10.7	.49	15.9	20.5	17,300	11.0	12.5
4	06088500	Muddy Creek at Vaughn	12.6	9.50	22.1	.43	11.2	.66	12.9	15.6	15,100	11.0	16.8
5	06090500	Belt Creek near Monarch[2]	16.2	29.4	45.6	.65	15.8	.40	28.2	36.2	6,280	16.0	10.4
6	06090610	Belt Creek near Portage	25.3	32.9	58.2	.56	24.6	.51	35.5	43.4	11,000	24.0	12.9
7	06092500	Badger Creek near Browning	6.00	2.20	8.20	.27	4.56	.80	4.37	5.14	14,800	5.0	21.0
8	06099000	Cut Bank Creek at Cut Bank	19.1	17.5	36.6	.48	17.6	.60	21.8	26.6	24,400	18.0	15.4
9	06100300	Lone Man Coulee near Valier	1.03	3.11	4.14	.75	1.49	.40	2.22	3.54	2,170	2.0	11.4
10	06109800	South Fork Judith River, near Utica	3.77	14.5	18.3	.79	4.00	.24	11.5	16.0	2,190	5.0	6.2
11	06132200	South Fork Milk River, near Babb	6.50	.65	7.15	.09	3.86	.81	3.39	3.89	9,330	4.0	21.5
12	06151000	Lyons Creek at international boundary	6.30	15.0	21.3	.70	6.19	.33	13.1	17.8	2,290	7.0	8.5
13	06164615	Little Warm Creek at reservation boundary, near Zortman	1.06	8.50	9.56	.89	1.72	.20	6.94	8.80	423	2.0	5.5
14	06164630	Big Warm Creek near Zortman	1.03	4.50	5.53	.81	1.61	.32	3.18	4.91	988	2.0	9.0
15	06166000	Beaver Creek below Guston Coulee, near Saco	23.0	11.0	34.0	.32	19.0	.76	19.9	22.2	32,100	19.0	19.2
16	06217750	Fly Creek at Pompeys Pillar	19.5	16.0	35.5	.45	17.7	.63	21.0	25.3	6,810	18.0	16.2
17	06290500	Little Bighorn River below Pass Creek, near Wyola	22.0	17.4	39.4	.44	19.9	.64	23.4	28.0	9,260	20.0	16.4
18	06294000	Little Bighorn River near Hardin	47.8	21.1	68.9	.31	39.2	.77	40.6	44.4	17,100	38.0	19.5
19	06306300	Tongue River at State line, near Decker	27.2	24.0	51.2	.47	25.0	.62	30.6	36.9	24,300	25.0	15.6
20	06307525	Prairie Dog Creek above Jack Creek, near Birney	.55	.27	.82	.33	.43	.67	.38	.54	6,010	.5	18.9
21	06309075	Sunday Creek near Miles City	27.2	8.80	36.0	.24	20.7	.80	20.7	22.2	18,600	20.0	20.5
22	12355000	Flathead River at Flathead, British Columbia	13.2	25.9	39.1	.66	13.0	.38	24.2	31.8	8,780	13.0	9.7
23	12355500	North Fork Flathead River, near Columbia Falls	33.0	19.0	52.0	.37	28.4	.72	30.8	35.0	26,400	28.0	18.3
24	12358500	Middle Fork Flathead River, near West Glacier	19.3	17.6	36.9	.48	17.7	.60	22.0	26.8	25,600	18.0	15.4
25	12359000	South Fork Flathead River at Spotted Bear Ranger Station, near Hungry Horse	13.8	25.6	39.4	.65	13.5	.39	24.4	31.9	18,600	14.0	10.1
26	12361000	Sullivan Creek near Hungry Horse	6.92	15.8	22.7	.70	6.93	.35	14.0	18.9	2,320	7.0	8.9

[1]Flood hydrograph computed from hourly record of change in contents and outflow from Gibson Reservoir.
[2]Values shown are averages of those derived from two recorded floods.

Engineers (Lg_2), the peak discharge of the derived unit hydrograph (Qp), time of peak of the derived unit hydrograph (Tp_K), and the peak of the dimensionless unit hydrograph (q_p). In addition to the unit-hydrograph variables given in table 2, the dimensionless unit hydrographs for each site are shown in figures

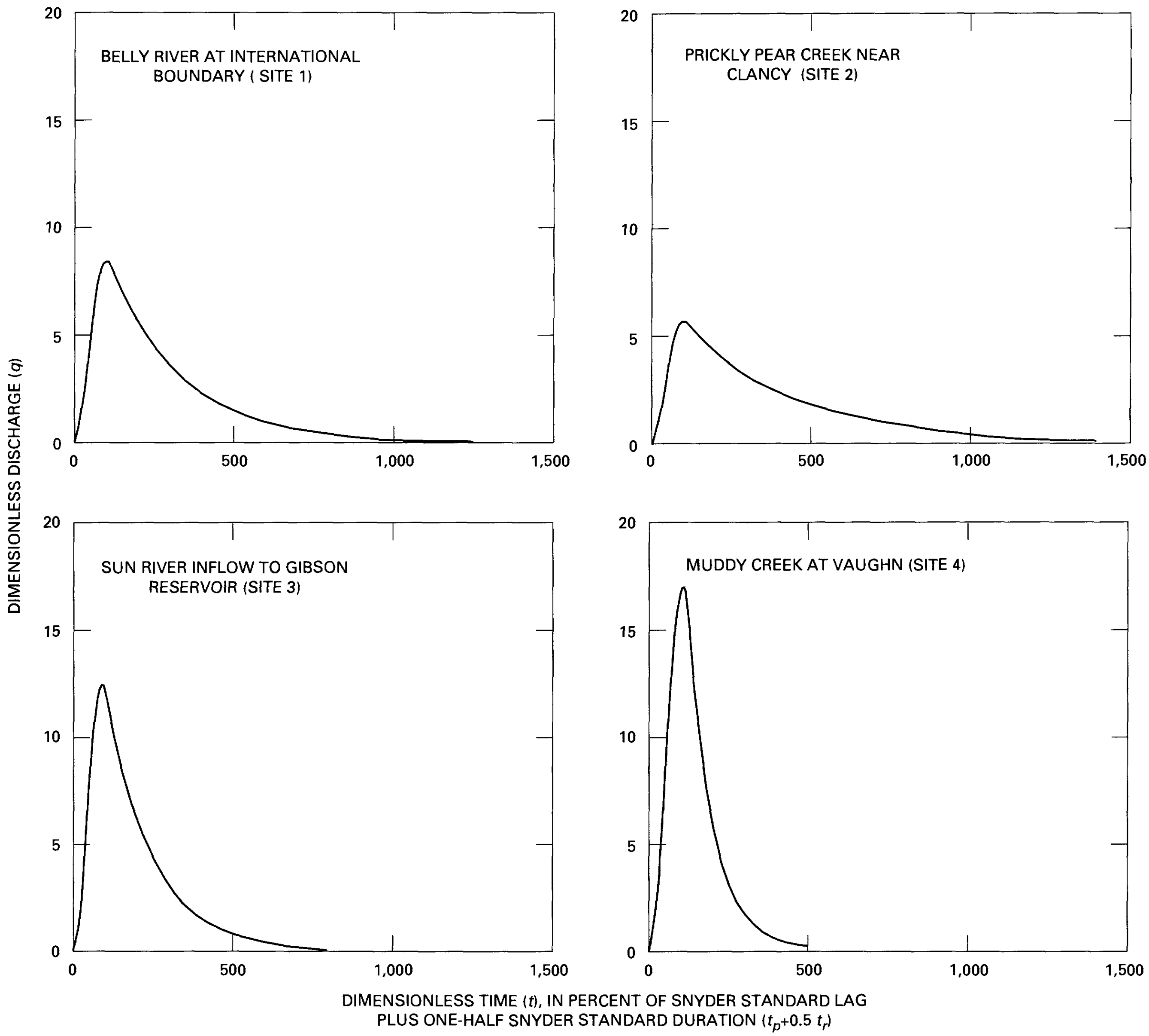

Figure 8. Dimensionless unit hydrographs in Montana for sites 1 through 4.

8 through 14. All values for Belt Creek near Monarch (site 5) in table 2 and in figure 9 are average results obtained from the analysis of two recorded floods.

Regression Analysis

Unit-hydrograph variables in table 2 were related to various basin physiographic characteristics using multiple-regression methods to define regional equations for estimating unit-hydrograph variables at ungaged sites. The four selected variables (Tc, R, t_p, and q_p) are those required to estimate unit hydrographs at ungaged sites using either the Clark or the dimensionless unit-hydrograph method.

Basin characteristics tested for inclusion as explanatory variables in the regression equations include:

A	drainage area, in mi^2;
S	main channel slope, in ft/mi;
L	main channel length, in mi;
L_{ca}	distance from basin centroid to mouth, in mi;

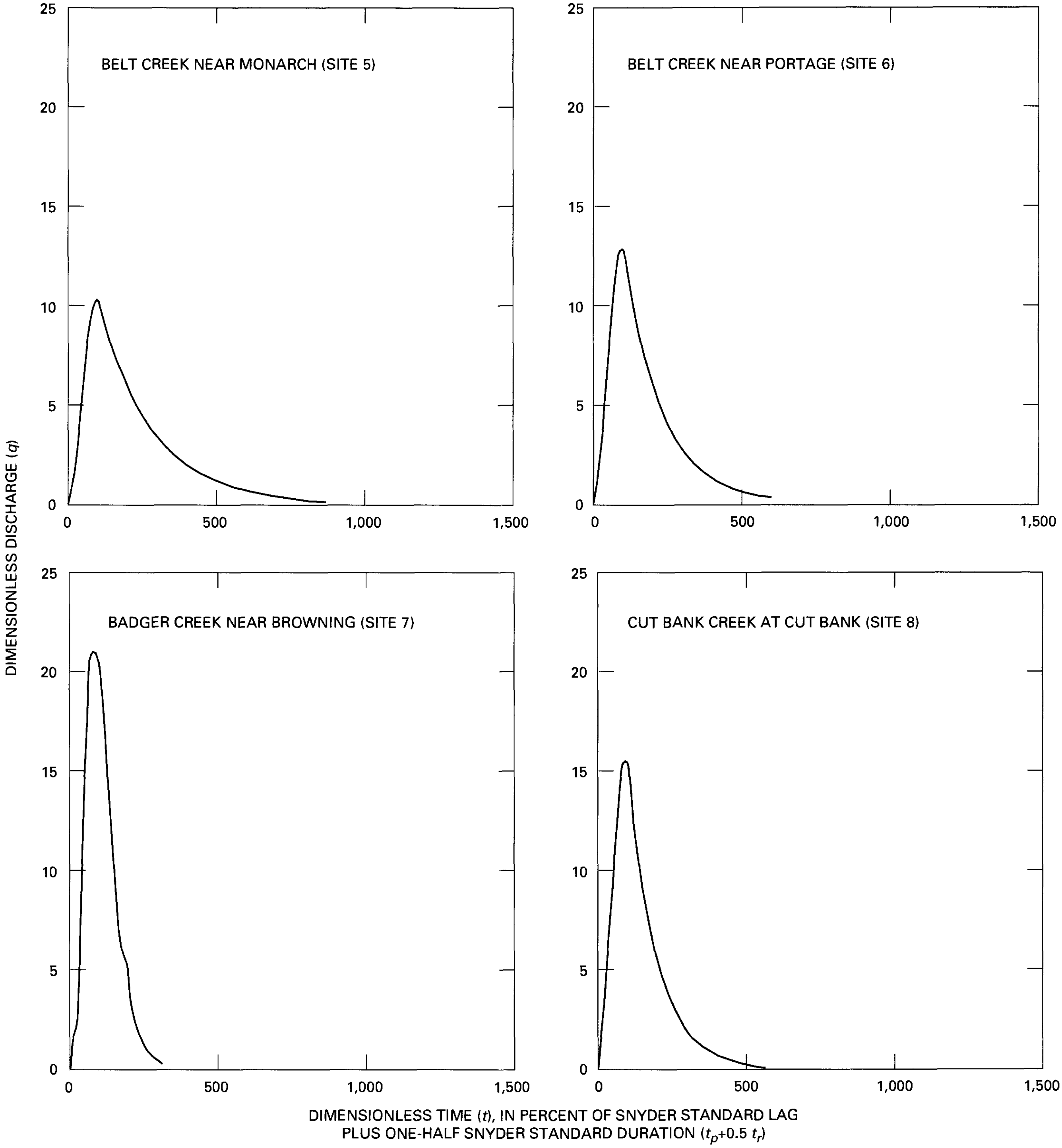

Figure 9. Dimensionless unit hydrographs in Montana for sites 5 through 8.

E mean basin elevation, in ft;

E_{6000} percentage of basin above 6,000 ft elevation, plus 10;

F percentage of basin covered by forest, plus 10;

$LL_{ca}/\sqrt{S}$ basin factor, a variable originally defined and found significant by Snyder (1938); and

TYPE an index variable set equal to 0 if the site is in a "mountains" basin (E_{6000}

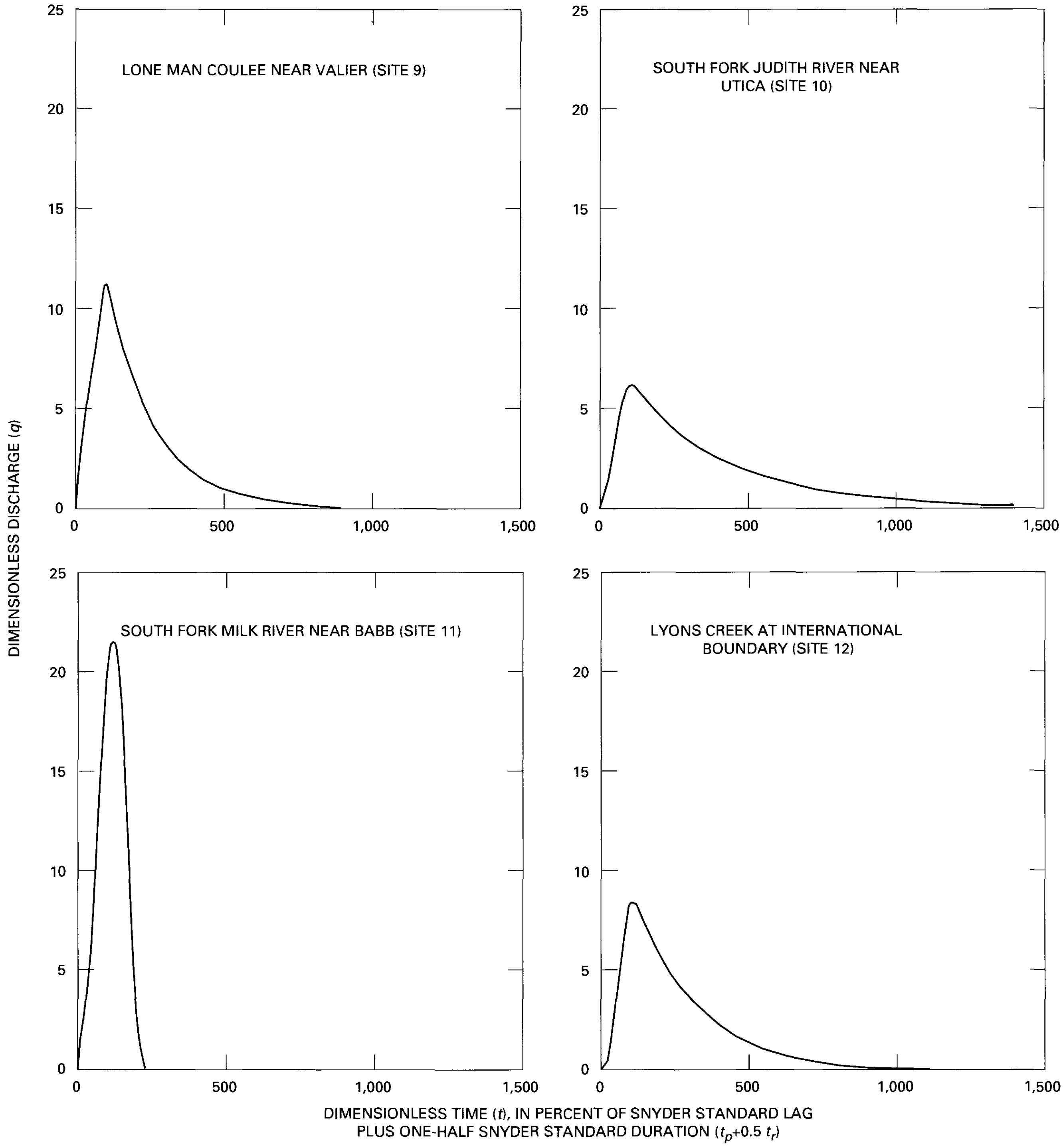

Figure 10. Dimensionless unit hydrographs in Montana for sites 9 through 12.

and F both equal to or greater than about 30) or 1 if the site is in a "plains" basin (either E_{6000} or F less than about 30).

The values of the basin characteristics measured at the 26 study sites are given in table 3.

The four selected unit-hydrograph variables and all basin characteristics except *TYPE* were converted to

Table 3. Basin characteristics at study sites in Montana

[Station number: Stations are listed in downstream order by standard drainage basin number. Each station number contains a 2-digit part number--Part 05 (Hudson Bay basin), Part 06 (Missouri River basin), Part 12 (upper Columbia River basin)--plus a 6-digit downstream order number. *A*, drainage area, in square miles; *S*, main channel slope, in feet per mile; *L*, main channel length, in miles; L_{ca}, distance from basin centroid to mouth, in miles; *E*, mean basin elevation, in feet above sea level; E_{6000}, percentage of basin above 6,000 feet elevation, plus 10; *F*, percentage of basin covered by forest, plus 10; $LL_{ca}/\sqrt{S}$, basin factor, a variable originally defined and found significant by Snyder (1938); *TYPE*, an index variable set equal to 0 if the site is in a "mountains" basin (E_{6000} and *F* both equal to or greater than about 30) or 1 if the site is in a "plains" basin (either E_{6000} or *F* less than about 30). Symbol: --, not applicable]

Site no.	Station no.	Stream name	A	S	L	L_{ca}	E	E_{6000}	F	$LL_{ca}/\sqrt{S}$	$TYPE$
1	05010000	Belly River at international boundary	74.8	42.1	15.3	8.38	6,180	68.0	61.3	19.8	0
2	06061500	Prickly Pear Creek near Clancy	192	157	18.9	8.66	5,660	44.0	93.5	13.1	0
3	--	Sun River inflow to Gibson Reservoir	575	52.2	34.2	8.42	6,350	78.0	95.7	39.9	0
4	06088500	Muddy Creek at Vaughn	391	10.6	31.0	17.7	3,840	10.0	13.9	169	1
5	06090500	Belt Creek near Monarch	368	60.2	35.0	17.5	6,190	66.0	98.3	78.9	0
6	06090610	Belt Creek near Portage	799	80.1	76.9	41.9	5,180	38.0	55.0	360	0
7	06092500	Badger Creek near Browning	133	66.0	28.4	16.4	6,020	61.0	69.3	57.3	0
8	06099000	Cut Bank Creek at Cut Bank	1,065	25.6	75.8	33.1	4,460	15.6	20.2	496	1
9	06100300	Lone Man Coulee near Valier	14.1	39.0	8.05	4.53	3,890	10.0	10.0	5.84	1
10	06109800	South Fork Judith River near Utica	58.7	126	12.5	4.90	6,640	104.0	103.4	5.46	0
11	06132200	South Fork Milk River near Babb	70.4	100	16.3	8.92	5,470	21.7	53.9	14.5	1
12	06151000	Lyons Creek at international boundary	66.7	26.3	19.2	9.97	3,000	10.0	10.0	37.3	1
13	06164615	Little Warm Creek at reservation boundary, near Zortman	6.31	108	5.68	2.90	3,850	10.0	47.0	1.59	1
14	06164630	Big Warm Creek near Zortman	8.58	119	4.61	2.85	3,730	10.0	30.0	1.20	1
15	06166000	Beaver Creek below Guston Coulee, near Saco	1,208	6.60	114	69.3	2,670	10.0	10.0	3,080	1
16	06217750	Fly Creek at Pompeys Pillar	285	10.7	43.6	22.1	3,470	10.0	15.5	295	1
17	06290500	Little Bighorn River below Pass Creek, near Wyola	428	135	37.9	19.0	6,140	57.0	55.9	62.0	0
18	06294000	Little Bighorn River near Hardin	1,294	23.7	101	62.7	4,770	29.8	31.6	1,300	0
19	06306300	Tongue River at State line, near Decker	1,477	76.2	72.6	35.0	5,800	47.0	47.0	291	0
20	06307525	Prairie Dog Creek above Jack Creek, near Birney	6.57	103	4.30	2.12	4,320	10.0	28.0	.90	1
21	06309075	Sunday Creek near Miles City	714	7.70	67.5	38.5	2,890	10.0	10.0	937	1
22	12355000	Flathead River at Flathead, British Columbia	450	31.7	46.7	21.7	6,010	57.0	107.7	180	0
23	12355500	North Fork Flathead River near Columbia Falls	1,548	8.09	95.7	42.3	5,120	39.0	97.3	1,420	0
24	12358500	Middle Fork Flathead River near West Glacier	1,128	11.7	84.7	30.3	5,800	54.0	94.7	750	0
25	12359000	South Fork Flathead River at Spotted Bear Ranger Station, near Hungry Horse	958	25.3	64.2	32.7	6,130	67.0	98.8	417	0
26	12361000	Sullivan Creek near Hungry Horse	71.3	124	13.0	3.24	5,510	48.0	90.0	3.78	0

base-10 logarithms and used in a computerized, linear multiple-regression analysis to derive equations of the form:

$$\log UHP = a + b_1 \cdot \log B + b_2 \cdot \log C + ... + b_n \cdot \log N, \quad (6)$$

where

UHP (response variable) is the unit-hydrograph variable,

a is a constant,

$b_1, b_2, ...b_n$ are the regression coefficients, and

$B, C, ...N$ are values of the significant basin characteristics (explanatory variables).

The use of the index variable *TYPE* determines whether different regression equations are applicable to

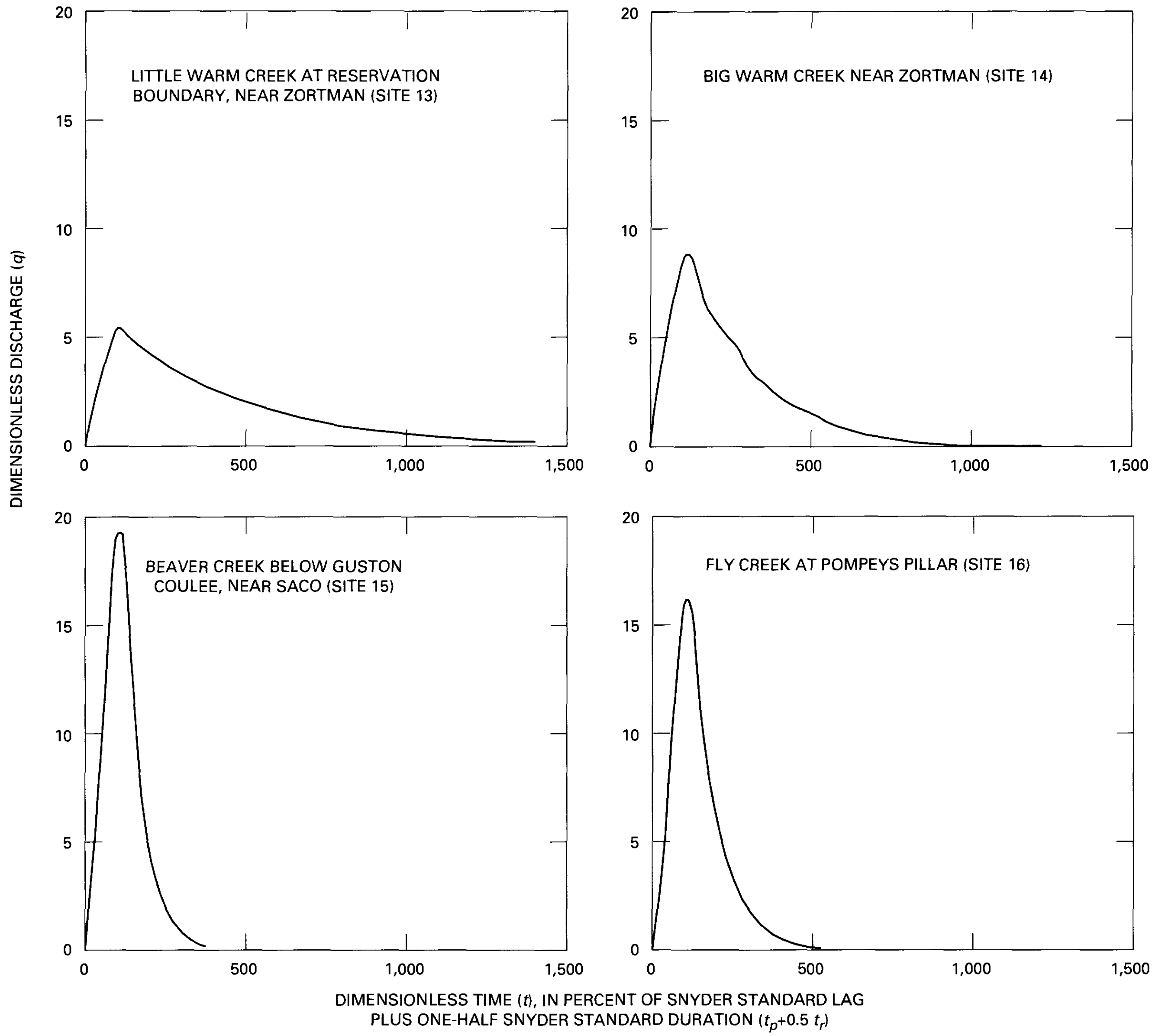

Figure 11. Dimensionless unit hydrographs in Montana for sites 13 through 16.

mountains and plains. If this variable is determined to be significant, the constant a can be expressed as

$$a = \log a' + b_{n+1} \cdot TYPE,$$

where a' is the regression constant. If $TYPE$ is not a significant variable, then the constant a is expressed as

$$a = \log a'.$$

Thus, if $TYPE$ is a significant variable, equations with different constants but the same regression coefficients will be derived for sites in mountains versus sites in plains.

The following nonlinear form of the regression equation results when antilogarithms of the terms are taken:

$$UHP = 10^{a} \cdot B \cdot b_1 \cdot C \cdot b_2 \cdot \ldots N \cdot b_n. \quad (7)$$

A step-wise regression procedure, which added explanatory variables to the equation one at a time until all significant variables were included, was used in this study. An explanatory variable was considered significant if the partial-F test statistic was equal to or greater than 4.0 (confidence level equal to or greater than about

Table 4. Results of regression analysis for selected unit-hydrograph variables for stream sites in Montana

[T_c, time of concentration, in hours; A, drainage area, in square miles; R, basin-storage coefficient, in hours; t_p, Snyder standard lag, in hours; q_p, peak of dimensionless unit hydrograph; L, main channel length, in miles; L_{ca}, distance from basin centroid to mouth, in miles; S, main channel slope, in feet per mile]

Equation			Coefficient of determination (r^2)	Standard error (logarithm, base 10)	Equation number
T_c	=	$0.298\,A^{0.65}$	0.91	0.160	8
R	=	$2.90\,A^{0.31}$ ("mountains" sites)	.47	.390	9
R	=	$1.30\,A^{0.31}$ ("plains" sites)	.47	.390	10
t_p	=	$0.393\,A^{0.58}$	.88	.168	11
q_p	=	$8.46\,(LL_{ca}/\sqrt{S}\,)^{0.10}$	.30	.153	12
q_p	=	$7.24\,A^{0.10}$	.19	.164	13

95 percent). The computerized regression procedure also provided standard errors of estimate and coefficients of determination as measures of the regression reliability. In general, the larger the coefficient of determination and the smaller the standard error of estimate, the more reliable is the estimating equation.

The results of the regression analysis (equations 8–13 in table 4) indicate that only one explanatory variable was significant in each equation, and that, in all instances but one, the significant variable was drainage area. The single exception was the equation for q_p where $LL_{ca}/\sqrt{S}$ was the only significant variable. Because this variable requires substantially more time to measure and calculate than does drainage area, a second equation for q_p was derived wherein all explanatory variables were considered for inclusion except $LL_{ca}/\sqrt{S}$. In this instance, drainage area was the most significant variable, and the coefficient of determination and the standard error for the equation using drainage area were not substantially worse than for the equation using $LL_{ca}/\sqrt{S}$.

On the basis of standard error and coefficient of determination, the equations for estimating T_c and t_p are the most reliable, and the equations for estimating R and q_p are the least reliable. The regression data and regression lines defined by the equations are plotted in figures 15 through 19. Visual inspection of the plotted data confirms that the equations for estimating Tc and t_p provide the best fit to the data, and that the equations for estimating R and q_p provide the worst fit.

As indicated by the large value of standard error shown for equations 9 and 10 in table 4 and the plot shown in figure 16, the values for R show a large scatter about the regression lines. One value of R for a mountains site and two values of R for plains sites plot well below the regression lines and may be anomalously small. Elimination of those values would result in very flat slopes for the regression lines for both mountains and plains indicating little or no relation between R and A and perhaps little or no distinction between mountains and plains. Users are thus cautioned that the equations for R, although statistically significant, may not always provide reliable results. The same is true for the equations for q_p (12 and 13), where the plots (fig. 18-19) show only a small amount of scatter but very flat slopes for the regression lines. The flat slopes indicate only weak relations between q_p and $LL_{ca}/\sqrt{S}$ and between q_p and A. Therefore, use of an average value for q_p may be just as reliable as the use of equations 12 or 13.

Average Dimensionless Unit Hydrograph

The ordinates of the 26 individual dimensionless unit hydrographs were averaged in the same manner that individual unit hydrographs are averaged at a single site (Linsley and others, 1975, p. 238) to produce the average dimensionless unit hydrograph shown in figure 20. Values of the abscissae and ordinates of the average dimensionless unit hydrograph are given in table 5.

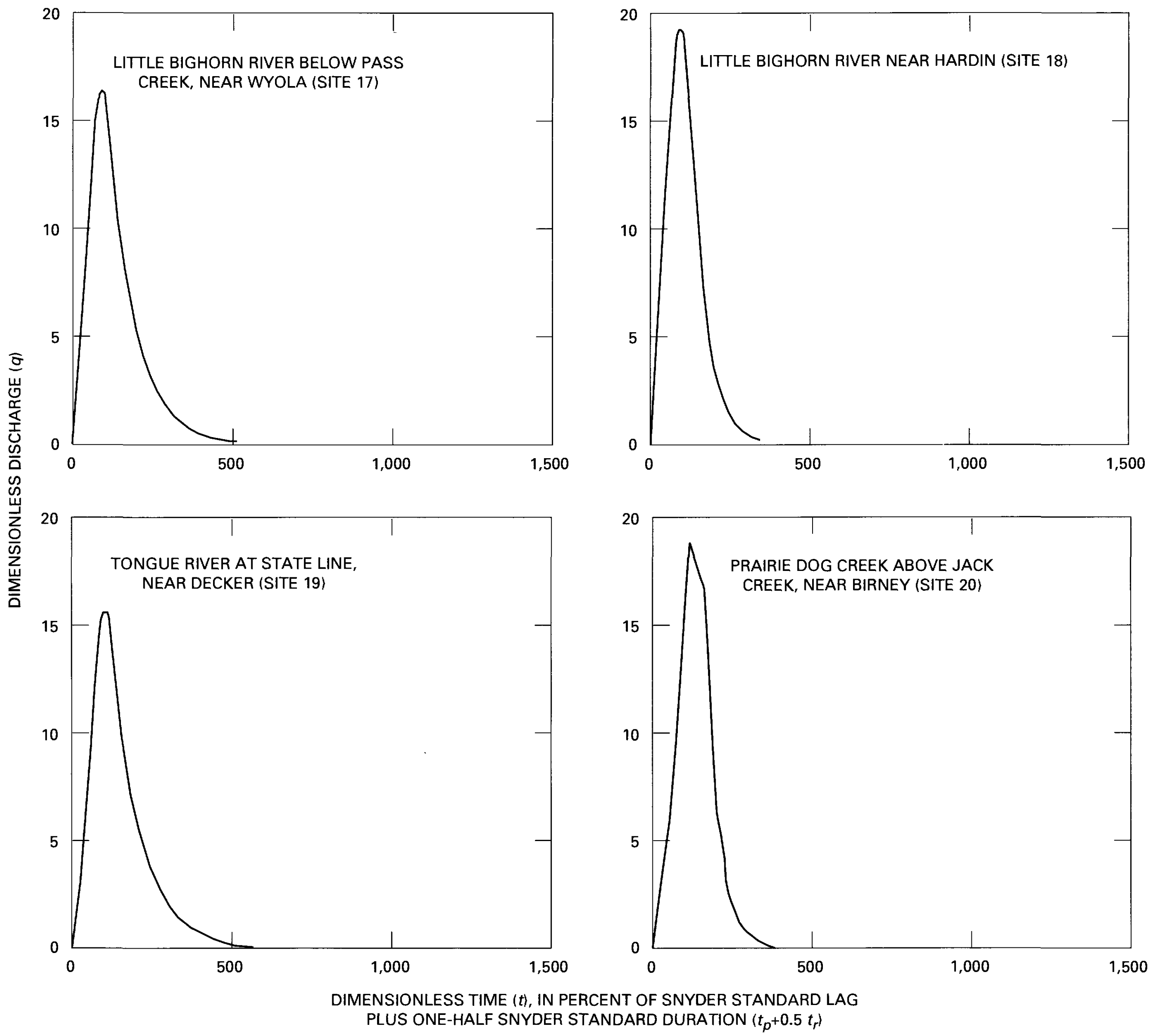

Figure 12. Dimensionless unit hydrographs in Montana for sites 17 through 20.

The peak dimensionless discharge (q_p) of the average dimensionless unit hydrograph shown in figure 20 is 13.6. As the regression equations for q_p indicate, the dimensionless peak discharge is weakly related to either basin factor or drainage area, and simply averaging all the dimensionless peaks may not result in the most accurate estimate for q_p. If either regression equation (12 or 13) is used to calculate q_p, and if the calculated value differs from 13.6, the ordinates of the average dimensionless unit hydrograph will need to be adjusted. The adjustment of ordinates needs to be done in such a way that the volume of the calculated unit hydrograph equals 1.0 in. of runoff. Similarly, the ordinates of the dimensionless unit hydrograph need to be adjusted if q_p was estimated on the basis of nearby gaged data.

To ensure that adjustment of ordinates of the average dimensionless unit hydrograph results in the

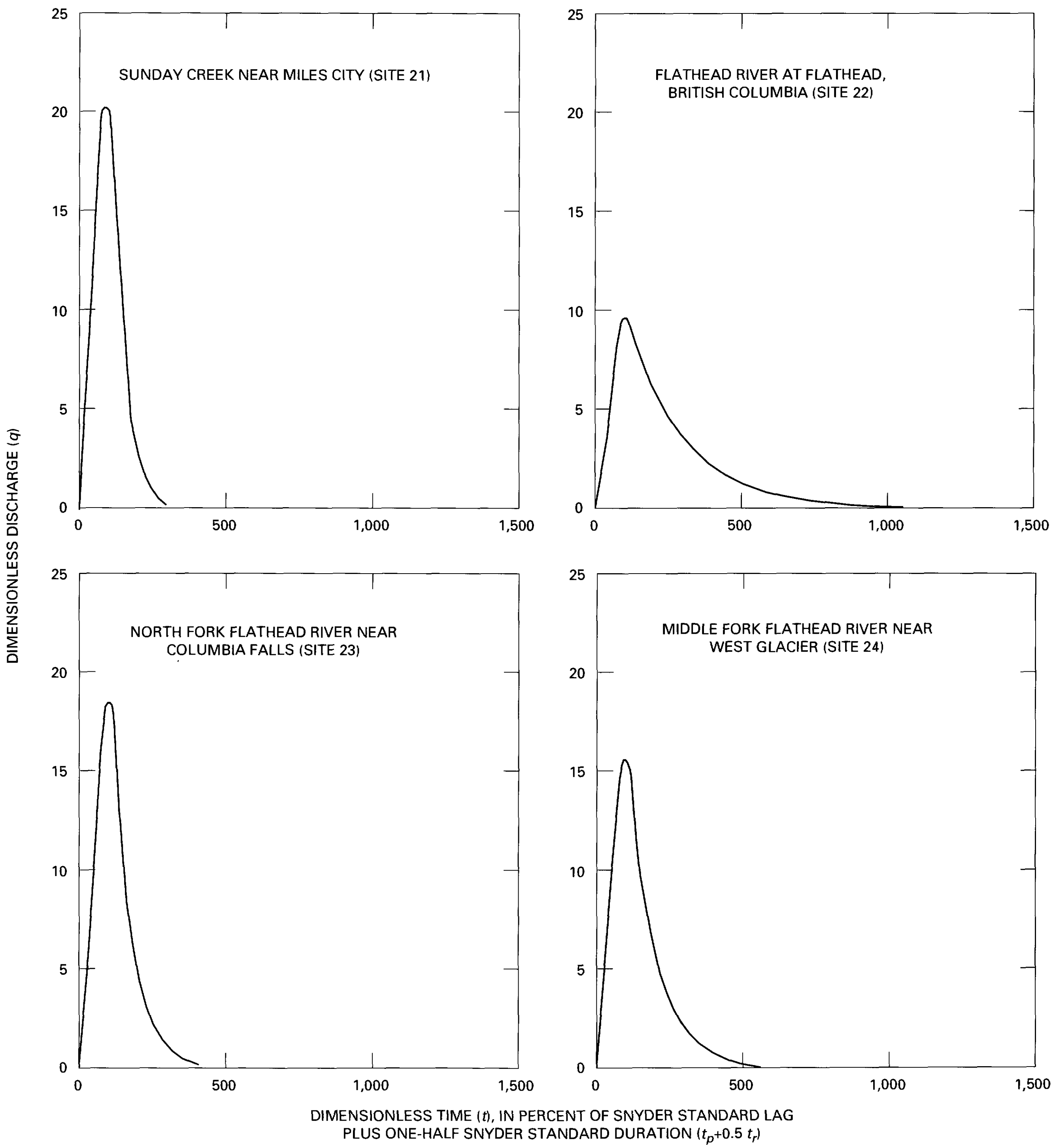

Figure 13. Dimensionless unit hydrographs in Montana for sites 21 through 24.

correct peak and volume, relations between the ordinates of the 26 dimensionless unit hydrographs and the ordinates of the average dimensionless unit hydrograph were developed for 24 selected values of dimensionless time using linear-regression analysis.

The linear-regression analysis provided 24 equations for calculating factors used to adjust the ordinates of the average dimensionless unit hydrograph. The equations are all based on the ratio of the calculated-dimensionless peak (q_p) to the peak of the average

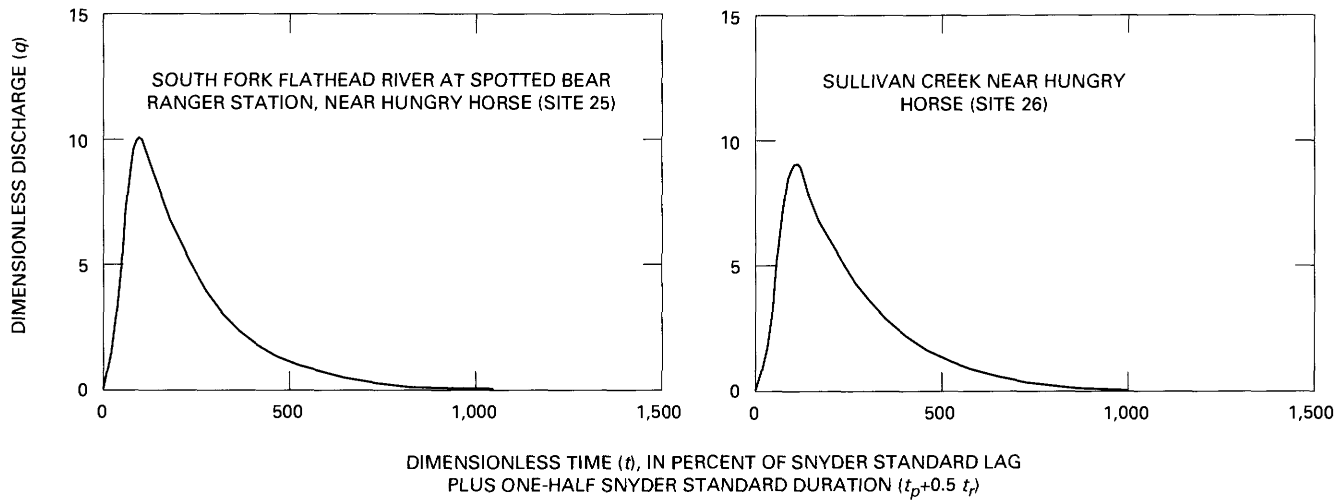

Figure 14. Dimensionless unit hydrographs in Montana for sites 25 and 26.

dimensionless unit hydrograph (13.6) for selected ordinates:

$$AF_i = a_i + b_i\ (q_p/13.6) \qquad (14)$$

where

- AF_i is the adjustment factor for the ordinate at selected time i, (i = 1 to 24),
- a_i is the regression constant for the equation at time i,
- b_i is the regression coefficient for the equation at time i, and
- q_p is the calculated dimensionless peak.

Because the adjustment factor has to equal 1.0 when q_p equals 13.6, equation 14 can be simplified:

$$1.0 = a_i + b_i\text{, or, in terms of } a_i$$
$$a_i = 1.0 - b_i \qquad (15)$$

Substituting this expression for a_i into equation 14 yields the following equation for AF_i in terms of the regression coefficient only:

$$AF_i = (1.0 - b_i) + b_i\ (q_p/13.6) \qquad (16)$$

The 24 selected times, the derived adjustment-factor regression constants and coefficients, the coefficients of determination, and the standard errors for the regressions are given in table 6. Although linear-regression equations were derived for all times for convenience and to ensure consistency among the 24 equations, examination of residual plots indicated that the relation between AF_i and $(q_p/13.6)$ was non-linear for values of q_p less than about 8.0, with values of dimensionless time greater than about 200. Consequently, for values of q_p less than about 8.0, calculated adjustment factors may not be reliable, and adjusted average dimensionless unit hydrographs may have appreciable error. In addition, equation 16 may yield estimates of AF_i that are negative for large values of q_p and dimensionless time. When that happens, the ordinate needs to be set to zero because negative discharge is not possible.

A plot of adjustment-factor regression coefficients versus dimensionless time (fig. 21) confirms that the relation between regression coefficients and the logarithms of dimensionless time (t) can be approximated by three separate linear relations applicable for $0 < t \leq 135$, $135 < t \leq 440$, and $440 < t \leq 1{,}000$. The relations between regression coefficients and dimensionless time were determined by another regression analysis, the results of which are given in table 7. The equations in table 7 were substituted into equation 16 to yield the following equations relating adjustment factor to dimensionless time and $(q_p/13.6)$:

$$AF_t = -0.42 + 0.22 \log t + (1.42 - 0.22 \log t)(q_p/13.6) \text{ for } 0 < t \leq 135, \qquad (17)$$

$$AF_t = -14.48 + 6.83 \log t + (15.48 - 6.83 \log t) \cdot (q_p/13.6) \text{ for } 135 < t \leq 440\text{, and} \qquad (18)$$

$$AF_t = -5.36 + 3.38 \log t + (6.36 - 3.38 \log t)(q_p/13.6) \text{ for } 440 < t \leq 1{,}000, \qquad (19)$$

where

- AF_t is the adjustment factor for any dimensionless time t, and
- q_p is the dimensionless peak discharge calculated from equation 12 or 13 (table 4).

Equations 17, 18, and 19 thus can be used to adjust the average dimensionless unit hydrograph for any calculated q_p ($q_p \geq 8.0$) for any point on the dimensionless time scale. For example, if q_p is calculated from equation 13 as 19.5, the adjustment factor for t = 125 would be calculated from equation 17 as follows:

$$AF_{125} = -0.42 + 0.22 \log 125 + (1.42 - 0.22 \log 125) \cdot (19.5/13.6)$$

$$AF_{125} = -0.42 + 0.22\,(2.097) + [1.42 - 0.22\,(2.097)] \cdot (19.5/13.6)$$

$$AF_{125} = -0.42 + 0.46 + [1.42 - 0.46]\,(1.43)$$

$$AF_{125} = 0.04 + 0.96\,(1.43)$$

$$AF_{125} = 1.41.$$

From table 5, the dimensionless discharge on the average dimensionless unit hydrograph for t = 125 is 11.8. The adjusted dimensionless discharge for this time thus would be 11.8 multiplied by 1.41 or 16.6.

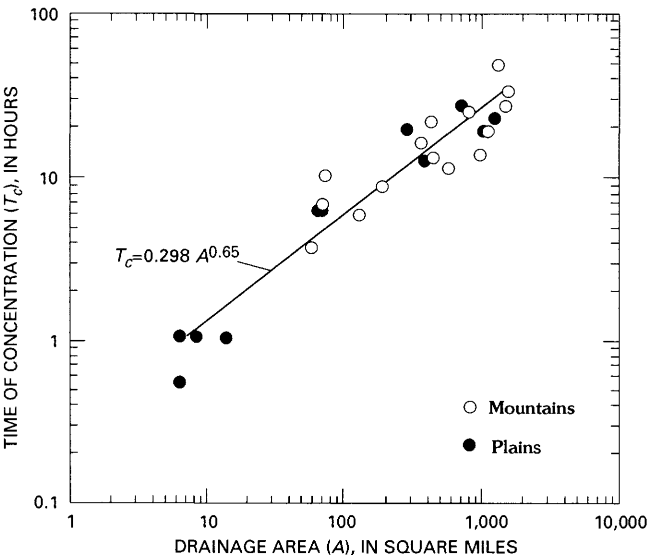

Figure 15. Regression relation for time of concentration (T_c) for stream sites in Montana.

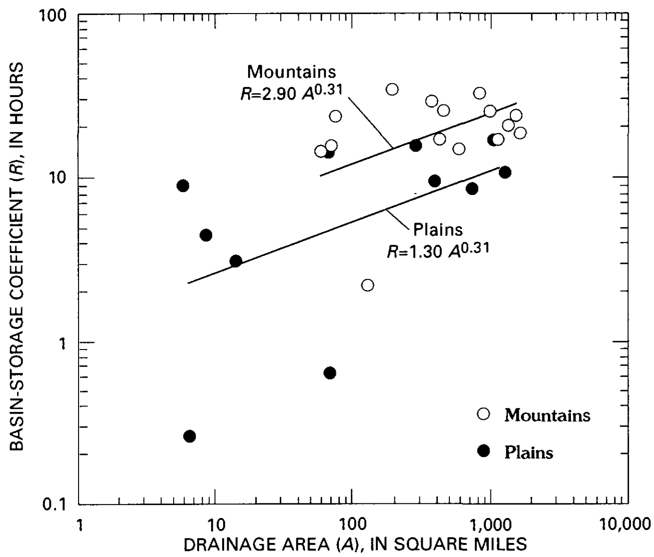

Figure 16. Regression relation for basin-storage coefficient (R) for stream sites in Montana.

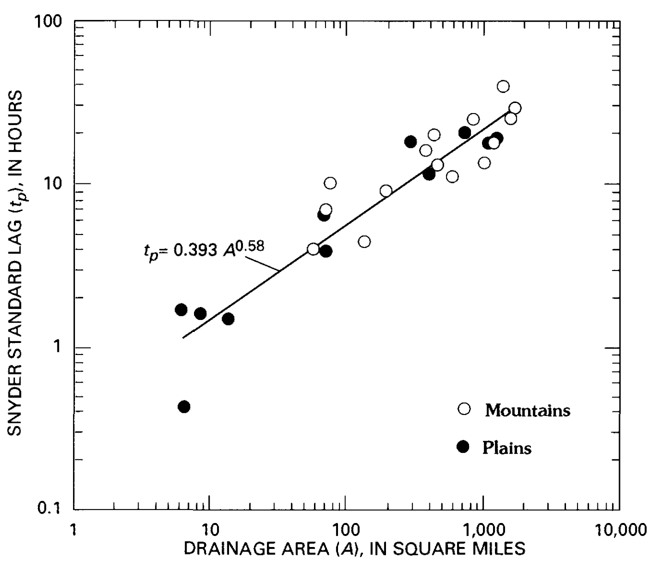

Figure 17. Regression relation for Snyder standard lag (t_p) for stream sites in Montana.

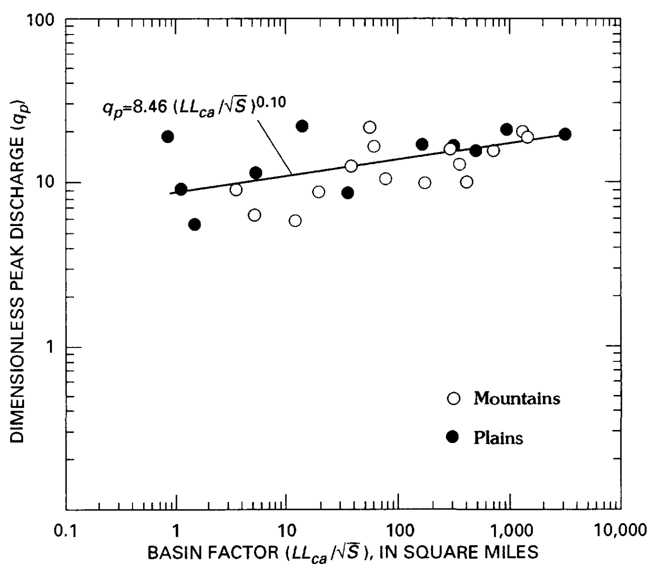

Figure 18. Regression relation for dimensionless peak discharge (q_p) versus basin factor for stream sites in Montana.

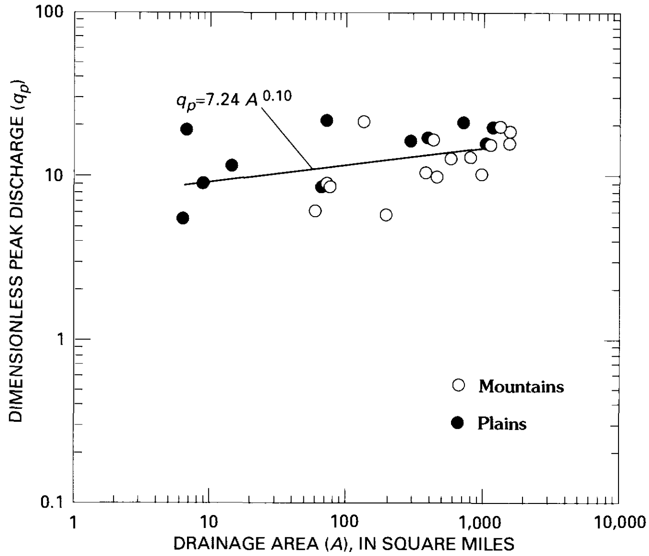

Figure 19. Regression relation for dimensionless peak discharge (q_p) versus drainage area for stream sites in Montana

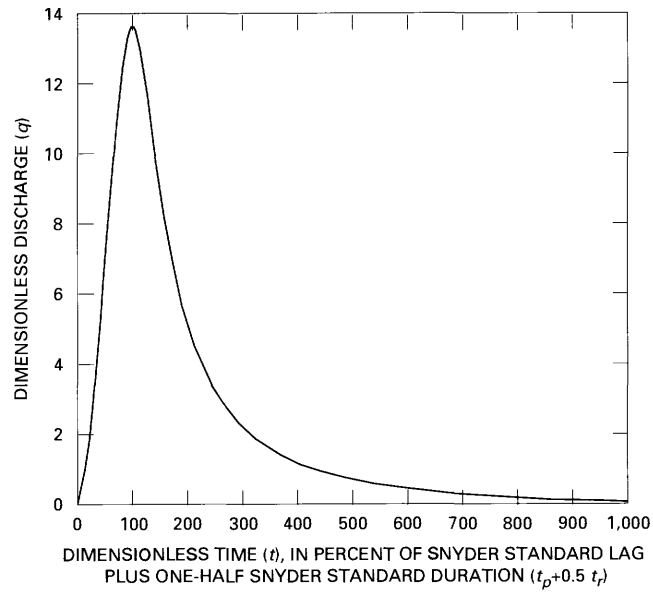

Figure 20. Average dimensionless unit hydrograph for stream sites in Montana.

Similarly, the adjustment factor for t = 800 would be calculated from equation 19 as follows:

AF_{800} = -5.36 + 3.38 log 800 + (6.36 - 3.38 log 800) · (19.5/13.6)

AF_{800} = -5.36 + 3.38 (2.903) + [6.36 - 3.38 (2.903)] · (19.5/13.6)

AF_{800} = -5.36 + 9.81 + [6.36 - 9.81] (1.43)

AF_{800} = 4.45 + (-3.45)(1.43)

AF_{800} = -0.48.

In this instance, the adjusted dimensionless discharge would be the discharge from the average dimensionless unit hydrograph for t = 800 multiplied by -0.48. Because a negative discharge is not possible, the adjusted discharge for t = 800 would be rounded to 0.0. Similar calculations for other times would provide a complete adjusted average dimensionless unit hydrograph as illustrated in figure 22.

As shown in figure 21, the values for adjustment-factor regression coefficients change rather abruptly when dimensionless time is at a value of about 135. Because of the abrupt change, the use of equations 17 and 18 for values of dimensionless time between about 110 and 150 may result in adjusted dimensionless unit hydrographs with two distinct peaks when q_p is less than about 11. To avoid this problem for small values of q_p, equations 17 and 18 are not used for values of dimensionless time between 110 and 150. Rather, values of the adjustment factor need to be interpolated between values calculated at dimensionless time 110 and 150 such that a smooth dimensionless unit hydrograph results. Likewise, the final calculated dimensionless unit hydrograph needs to be smoothed anywhere else the use of equations 17, 18, or 19 results in minor irregularities in hydrograph shape. All adjustments to the calculated dimensionless unit hydrograph need to be made such that the volume of the calculated unit hydrograph is equal to 1.0 in. of runoff.

Procedures for Estimating Unit Hydrographs at Ungaged Sites

The Clark or the dimensionless method can be used to estimate a unit hydrograph at any ungaged site in Montana once the appropriate unit-hydrograph variables have been determined. For the Clark method, the required unit-hydrograph variables are T_c and R. The regression equations in table 5 can be used to calculate T_c and R, but, as discussed previously, the equations for R may be unreliable. If the ungaged site is close to one of the gaged sites used in the analysis (table 2), or if a designer believes that the ungaged site is hydrologically similar to one of the gaged sites, the designer may choose to use the value of R at the gaged site. Likewise, if the dimensionless method is used, the required unit-hydrograph variables are t_p and q_p. For this

Table 5. Average dimensionless unit-hydrograph values for stream sites in Montana

[t_p, Snyder standard lag, in hours; t_r, Snyder standard duration, in hours; q, dimensionless discharge]

Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	q	Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	q	Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	q	Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	q	Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	q
5	0.28	205	4.85	405	1.16	605	0.41	805	0.18
10	.69	210	4.64	410	1.14	610	.40	810	.18
15	1.24	215	4.44	415	1.10	615	.40	815	.17
20	1.93	220	4.23	420	1.07	620	.39	820	.17
25	2.61	225	4.02	425	1.04	625	.38	825	.17
30	3.42	230	3.85	430	1.01	630	.37	830	.17
35	4.19	235	3.71	435	.99	635	.36	835	.16
40	5.15	240	3.54	440	.96	640	.35	840	.16
45	6.22	245	3.40	445	.94	645	.35	845	.16
50	7.29	250	3.28	450	.91	650	.34	850	.15
55	8.22	255	3.15	455	.89	655	.33	855	.15
60	9.23	260	3.03	460	.87	660	.33	860	.15
65	10.1	265	2.93	465	.85	665	.32	865	.14
70	11.1	270	2.81	470	.83	670	.31	870	.14
75	11.8	275	2.72	475	.80	675	.31	875	.13
80	12.4	280	2.62	480	.79	680	.30	880	.13
85	12.8	285	2.51	485	.77	685	.30	885	.13
90	13.3	290	2.42	490	.75	690	.29	890	.13
95	13.5	295	2.34	495	.73	695	.28	895	.12
100	13.6	300	2.24	500	.72	700	.28	900	.12
105	13.4	305	2.17	505	.70	705	.27	905	.12
110	13.2	310	2.11	510	.68	710	.27	910	.12
115	12.8	315	2.01	515	.66	715	.26	915	.11
120	12.3	320	1.96	520	.64	720	.26	920	.11
125	11.8	325	1.90	525	.62	725	.25	925	.11
130	11.3	330	1.83	530	.60	730	.25	930	.11
135	10.7	335	1.77	535	.59	735	.24	935	.11
140	10.0	340	1.73	540	.57	740	.24	940	.10
145	9.49	345	1.67	545	.56	745	.23	945	.10
150	8.98	350	1.62	550	.55	750	.23	950	.10
155	8.46	355	1.57	555	.54	755	.23	955	.10
160	7.95	360	1.52	560	.52	760	.22	960	.10
165	7.48	365	1.47	565	.51	765	.21	965	.10
170	7.09	370	1.44	570	.50	770	.21	970	.09
175	6.69	375	1.40	575	.48	775	.21	975	.09
180	6.28	380	1.34	580	.47	780	.20	980	.09
185	5.92	385	1.30	585	.46	785	.20	985	.09
190	5.66	390	1.27	590	.45	790	.19	990	.09
195	5.39	395	1.24	595	.44	795	.19	995	.09
200	5.07	400	1.20	600	.42	800	.18	1,000	.08

method, the regression equation for q_p may not provide reliable results, and a designer may choose to use the average value for q_p determined from the 26 gaged sites, an appropriate value from one of the gaged sites used in the analysis (table 2), or a value for q_p obtained from a nearby or hydrologically similar gaged site. The decision to use regression equations to estimate R or q_p needs to be based on the requirements of a particular design problem as well as sound hydrologic judgment. Particularly if the consequences of design failure

Table 6. Results of regression analysis relating adjustment factor (AF_i) to the ratio of dimensionless peak discharge to peak discharge of average dimensionless unit hydrograph ($q_p/13.6$) in Montana

[t_p, Snyder standard lag, in hours; t_r, Snyder standard duration, in hours]

Dimensionless time, in percent of $t_p + 0.5\ t_r$	Regression constant	Regression coefficient	Coefficient of determination (r^2)	Standard error, dimensionless
25	-0.125	1.12	0.75	0.243
50	-.044	1.04	.94	.097
75	-.024	1.02	.98	.050
85	-.021	1.02	.99	.042
100	-.001	1.00	1.00	.007
115	.006	.991	.99	.028
125	.058	.942	.97	.058
150	.354	.644	.85	.103
175	.832	.167	.22	.121
200	1.30	-.303	.25	.202
225	1.69	-.686	.57	.228
250	1.97	-.965	.75	.212
275	2.23	-1.23	.84	.201
300	2.49	-1.49	.92	.172
325	2.70	-1.70	.95	.155
350	2.87	-1.87	.97	.130
375	3.04	-2.04	.97	.133
400	3.19	-2.18	.98	.123
500	3.60	-2.59	.94	.243
600	4.10	-3.09	.84	.519
700	4.25	-3.24	.78	.653
800	4.43	-3.42	.70	.846
900	4.66	-3.65	.59	1.15
1,000	4.73	-3.72	.56	1.26

are large, a designer may choose to estimate R or q_p using the method that provides a conservative (larger peak discharge of the unit hydrograph) estimate.

However the unit-hydrograph variables are estimated, use of the Clark method requires that estimates of T_C and R be coupled with a time-area curve such as that in figure 3, and the HEC-1 model is typically used to calculate the unit hydrograph. The calculated unit hydrograph, an intermediate step in the HEC-1 modeling process, is finally used with a synthetic rainstorm to obtain the synthetic-flood hydrograph used for design. If the dimensionless unit-hydrograph method is used, estimates of t_p and q_p are used with the adjusted average dimensionless unit hydrograph to calculate the unit hydrograph. The unit hydrograph calculated by the dimensionless method is used as input to the HEC-1 model, along with a synthetic rainstorm, to obtain a synthetic-flood hydrograph used for design.

The reliability, limitations, and design considerations of the two methods are described in the fol-

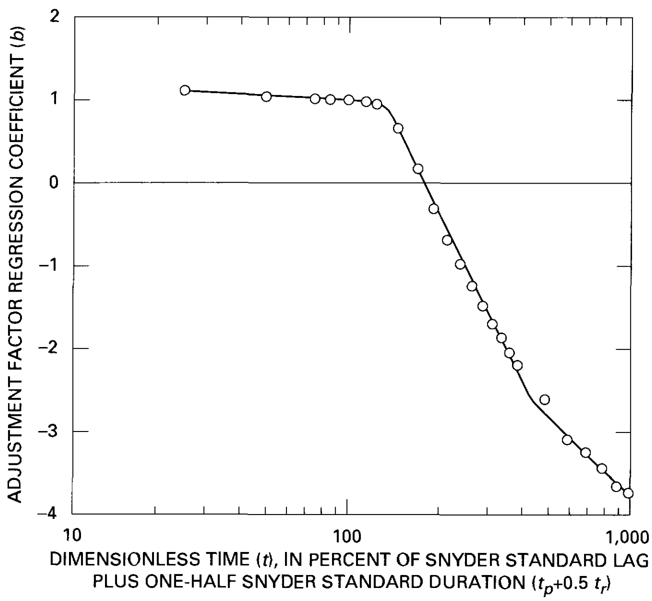

Figure 21. Adjustment-factor regression coefficient versus dimensionless time for stream sites in Montana.

Table 7. Equations relating adjustment-factor regression coefficient to dimensionless time in Montana

[t, dimensionless time expressed as a percentage of Snyder standard lag plus one-half duration of rainfall excess (t_p + 0.5 t_r); b_i, regression coefficient from equation relating adjustment factor (AF_i) to ratio of peak of dimensionless unit hydrograph to peak of average dimensionless unit hydrograph]

Equation	Applicable range of t	Coefficient of determination (r^2)	Standard error, in log units
b_i = 1.42 - 0.22 log t	0 < t ≤ 135	0.92	0.017
b_i = 15.48 - 6.83 log t	135 < t ≤ 440	.99	.064
b_i = 6.36 - 3.38 log t	440 < t ≤ 1,000	.95	.081

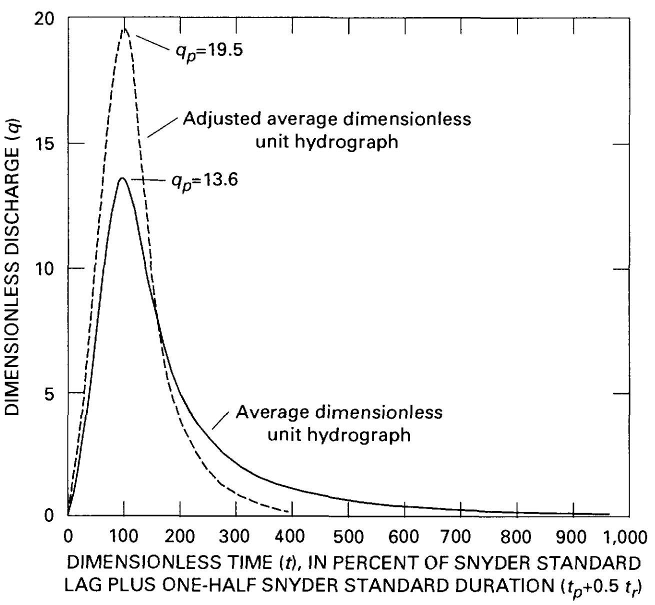

Figure 22. Adjusted average dimensionless unit hydrograph for stream sites in Montana.

lowing sections. Examples of the two methods also are presented.

Reliability

Although the coefficient of determination and the standard error are measures of the reliability of regression equations for calculating unit-hydrograph variables, they do not indicate how well a unit hydrograph calculated from either the Clark or dimensionless method would compare to a unit hydrograph derived from recorded rainstorm and runoff data. Ideally, such comparisons would be made at sites where the rainstorm and runoff data were not used to develop the equations for calculating unit-hydrograph variables. For this study, where all available data were used in the regression analysis, calculated and derived unit hydrographs can be compared only at the same sites used in the regression analysis.

To compare calculated unit hydrographs with unit hydrographs derived from recorded data, the regression equations were used to calculate unit-hydrograph variables (T_c, R, t_p, and q_p) at the 26 study sites. From the calculated values for T_c and R at each site, the HEC-1 model was used to calculate a unit hydrograph using the Clark method. For the dimensionless unit-hydrograph method, the 24 equations having regression constants and coefficients contained in table 6 and a calculated value of q_p (equation 12, table 4) were used to adjust the average dimensionless unit hydrograph. A calculated value of t_p was used to compute a suitable unit-hydrograph duration (duration, $t_r \leq t_p/5.5$) and the adjusted dimensionless unit hydrograph was converted to a unit hydrograph by multiplying each ordinate (q) by $V'/(t_p + 0.5\, t_r)$ (eq. 2) and each time step (t) by $(t_p + 0.5\, t_r)/100$ (eq. 3).

Two variables were used to compare the unit hydrographs calculated by the Clark and dimensionless methods and the unit hydrographs derived from recorded data. Because the peak discharge is the most important point on a flood hydrograph, one variable used for comparison was the percentage difference between the peak discharges of the calculated and derived unit hydrographs (*PCT.PK*). Another variable (*RMS.ER*), which was used to compare differences in hydrograph shapes, was the square root of the sum of the squares (root mean square or RMS) of the differences in discharge at each time step between the calculated and derived unit hydrographs divided by the mean discharge of the derived unit hydrograph. *RMS.ER* is dimensionless and expresses the total cumulative difference between a calculated and a derived unit hydrograph as a multiple of the mean discharge of the derived unit hydrograph. An *RMS.ER*

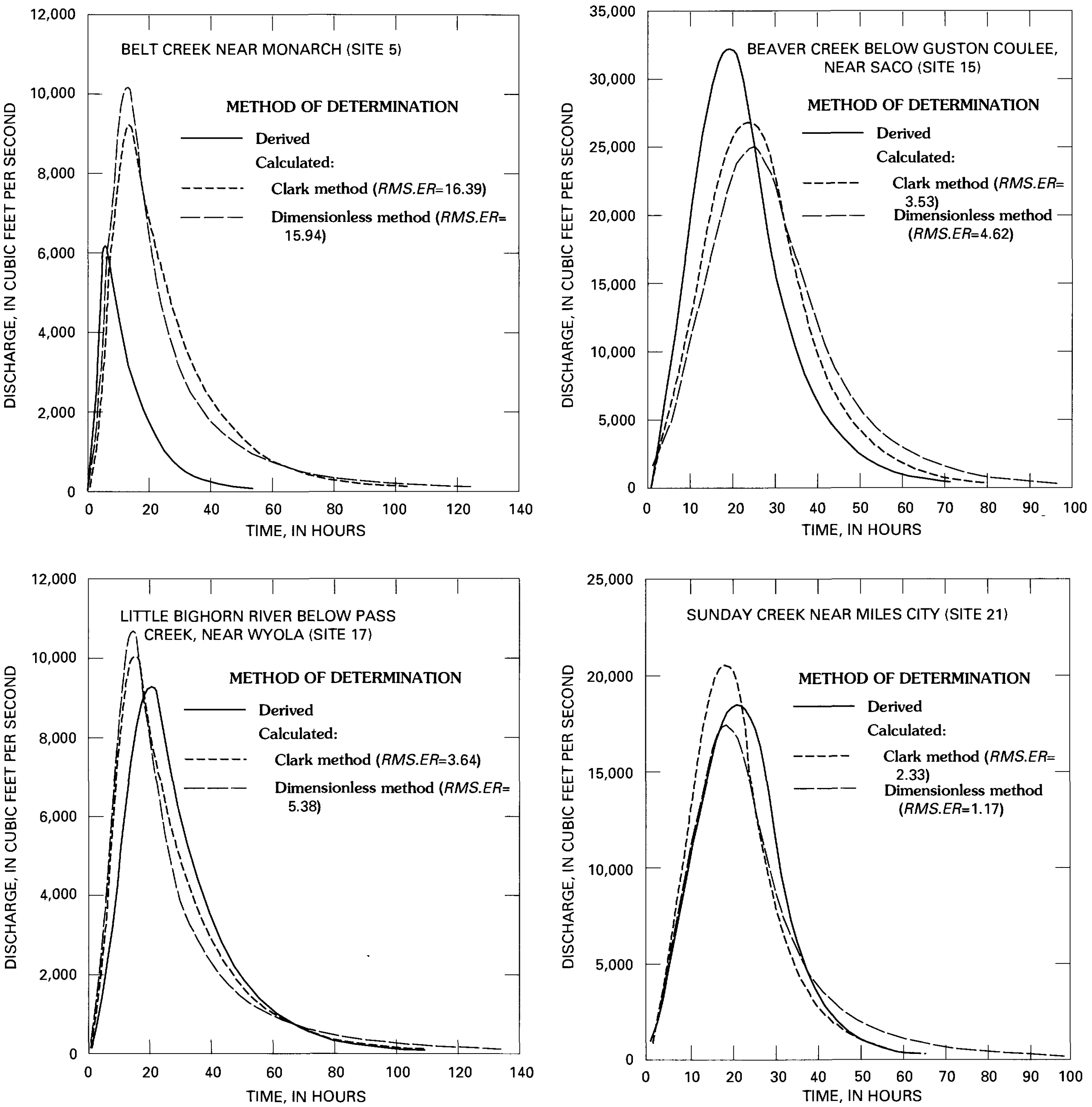

Figure 23. Root mean-square error (*RMS.ER*) for selected sites in Montana.

of 5.2, for example, means that the total cumulative difference between a calculated and derived unit hydrograph is 5.2 times the mean discharge of the derived unit hydrograph. To illustrate the difference in hydrograph shapes required to produce different values of *RMS.ER*, the calculated unit hydrographs from the two methods are plotted in figure 23 together with the derived unit hydrographs for recorded floods on Belt Creek (site 5), Beaver Creek (site 15), the Little Bighorn River (site 17), and Sunday Creek (site 21). These four examples are for one of the largest *RMS.ER* (site 5), the near-average *RMS.ER* (sites 15 and 17), and one of the smallest *RMS.ER* (site 21) of the 26 sites analyzed.

Table 8. Unit hydrographs calculated by the Clark and dimensionless methods and derived from recorded data for stream sites in Montana

[*PCT.PK*, percentage difference between calculated unit-hydrograph peak and derived unit-hydrograph peak; *RMS.ER*, root mean square of the differences in discharge at each time step between calculated and derived unit hydrograph divided by the mean discharge of the derived unit-hydrograph]

Site no.	*PCT.PK* for specified method		*RMS.ER* for specified method	
	Clark	Dimensionless	Clark	Dimensionless
1	108.24	157.96	15.67	20.27
2	102.44	106.99	12.00	11.93
3	-31.01	-32.57	6.10	8.29
4	.53	-24.50	.98	3.04
5	49.98	65.72	16.39	15.94
6	30.82	51.48	4.96	8.29
7	-66.75	-58.02	3.99	3.49
8	2.99	-19.32	3.51	4.42
9	-12.25	-28.23	1.10	1.67
10	33.70	50.37	3.42	4.91
11	-37.91	-56.69	1.59	2.08
12	143.18	90.73	15.01	9.75
13	182.51	96.45	12.36	7.79
14	49.70	4.76	3.21	.47
15	-16.91	-22.82	3.53	4.62
16	88.95	53.33	13.20	9.34
17	8.47	14.94	3.64	5.38
18	10.00	36.59	4.74	8.58
19	-16.80	-12.17	4.34	2.81
20	-76.42	-81.31	3.21	3.34
21	10.94	-5.48	2.33	1.71
22	17.87	38.74	3.23	6.07
23	-21.34	-2.97	4.01	.90
24	-31.81	-18.43	6.65	4.63
25	-14.21	-1.31	6.70	5.50
26	42.68	52.57	5.89	6.92

The results of the comparisons of calculated and derived unit hydrographs are given in table 8 and displayed graphically as boxplots in figures 24 and 25. Boxplots were used because they show the maximum, minimum, and spread of the values as well as the median. As indicated by the data in table 8 and the boxplots, the Clark and dimensionless unit-hydrograph methods performed about equally well in matching derived unit-hydrograph peaks and shapes. For the 26 comparisons, the median percent difference in unit-hydrograph peak discharge was 9.2 for the Clark method and 1.7 for the dimensionless method (fig. 24). The median percent difference provides a measure of the bias of the two estimation methods and not the absolute error. The small positive values for the median percent difference for the two methods indicate a small tendency for the methods to overestimate unit-hydrograph peak discharge; this tendency is to be expected, however, because the values of percent difference are bounded by -100.00 on the low end and are unbounded on the high end. Although the boxplot for *PCT.PK* indicates that both methods perform about equally well with a slight positive bias, results in table 8 show that the Clark method yields unit-hydrograph peak discharges that are consistently smaller than estimates from the dimensionless method for mountain sites. Conversely, the Clark method yields unit-hydrograph peak discharges that are consistently larger than estimates from the dimensionless method for plains sites. The median value for *RMS.ER* for the 26 comparisons was 4.2 for the Clark method and 5.2 for the dimensionless method (fig. 25). For both variables, the spread of the values, as measured by the difference between the 75th and 25th percentile values was slightly less for the Clark method than for the dimensionless method.

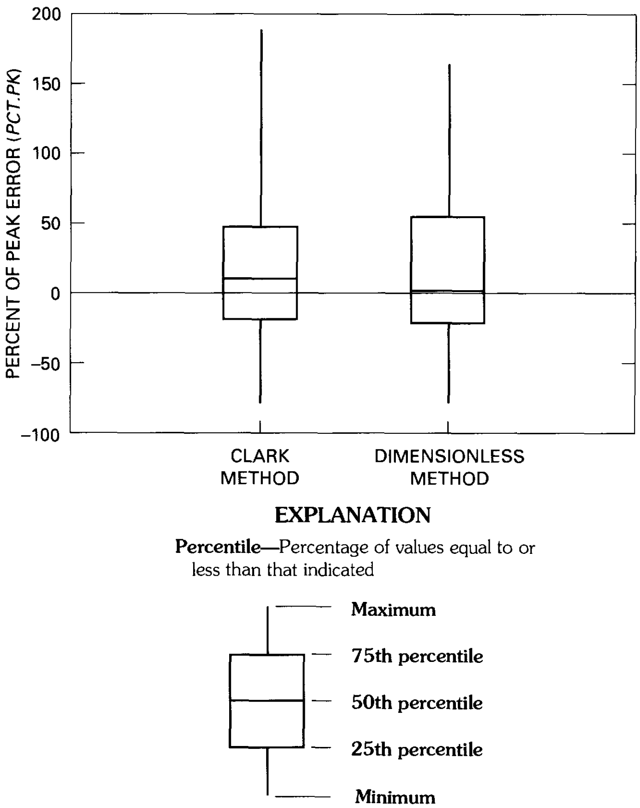

Figure 24. Boxplot showing percent-of-peak error (*PCT.PK*) for the Clark and dimensionless unit-hydrograph methods in Montana.

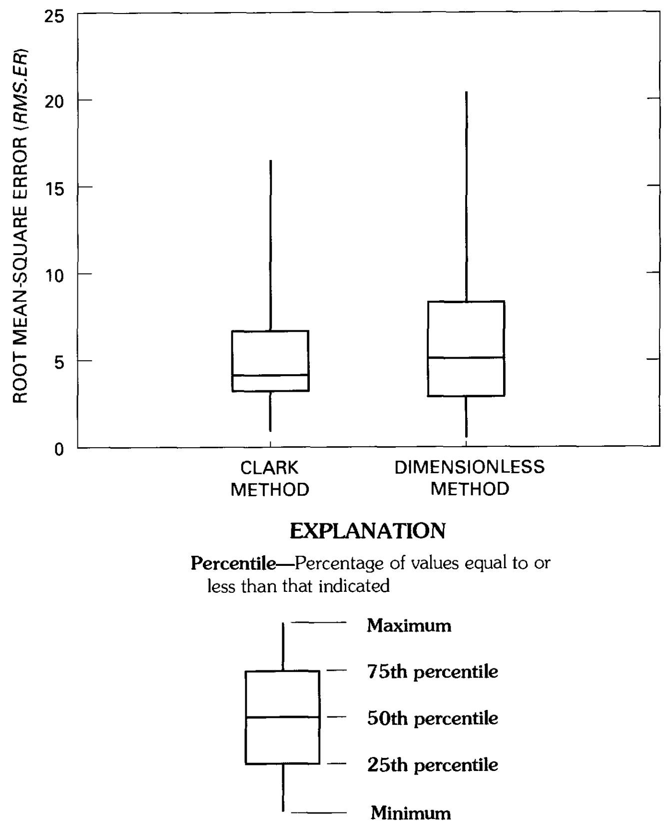

Figure 25. Boxplot showing root mean-square error (*RMS.ER*) for the Clark and dimensionless unit-hydrograph methods in Montana.

Limitations and Design Considerations

Recorded floods analyzed in this study were mainly the result of rainfall caused by general-storm activity; therefore, no conclusions can be made for unit-hydrograph characteristics resulting from local or thunderstorm events. With one exception (site 5), the derived unit hydrographs are based on a single recorded flood hydrograph for each study site. Although the use of several floods to derive an average unit hydrograph for a particular study site is desirable, the single events used in this study are some of the largest peak discharges and rainfall-runoff volumes recorded in Montana; thus, they probably reflect "worst-case" conditions.

Because lag times from the study were used to convert derived unit hydrographs to their dimensionless forms, lag-time relations given by other studies are not valid for use with any form of the dimensionless unit hydrograph contained in this report. Similarly, lag-time estimates determined in this report are not valid for use with other dimensionless unit hydrographs, such as those of the Bureau of Reclamation. Standard dimensionless unit hydrographs and relations developed by the Bureau of Reclamation (Cudworth, 1989, p. 71–97) for the western United States differ somewhat from dimensionless unit hydrographs and relations for the 26 study sites, as a result of differences in unit-hydrograph derivation methods, use of different lag times, and the large quantity of Montana data used in this study.

The unit duration of a calculated unit hydrograph needs to be small enough to prevent unit-hydrograph ordinates at and near the peak from being underestimated. When the calculated unit duration is less than 1 hour, it is commonly expressed in minutes and rounded down to the nearest 5, 10, 15, or 30 minutes. When the calculated unit duration is greater than 1 hour, it is commonly rounded down to the nearest 1, 2, 3, or 6 hours.

Although the unit-hydrograph method generally can be applied to basins having drainage areas as large as 2,000 mi^2, the method is applicable only to basins that are small enough that variations in areal runoff do not substantially change the hydrograph shape (Linsley and others, 1975, p. 237). Cudworth (1989, p. 66) proposed to subdivide basins exceeding 500 mi^2, use hydraulic principles to route resulting subbasin flood hydrographs to the points of interest, and combine routed hydrographs. Because the largest derived value of t_p in this study was 39.2 hours, a calculated unit duration greater than about 7 hours (t_p /5.5) may require that a basin be subdivided and separate unit hydrographs be calculated for each subbasin. Likewise, although the largest basin used to derive unit-hydrograph relations was 1,548 mi^2, development of a unit hydrograph for an ungaged basin larger than about 500 mi^2 may require subdivision of the basin to ensure that areal variation of runoff does not affect the hydrograph shape.

Equations developed for adjusting the peak and shape of the average dimensionless unit hydrograph are considered to be invalid where the desired dimensionless peak discharge is less than about 8.0. Because design criteria and assumptions about spillway and dam-related design need to be conservatively applied, an appropriate conservative constraint may be to adopt the average dimensionless peak value of 13.6 from the study as a lower design limit, particularly where no nearby gaged data are available.

Unit-hydrograph estimation methods in this report are known to apply only within the range of variables used and described by the tables, equations, and graphical plots and are subject to other constraints previously discussed. Use of the methods outside the range of variables used in the analysis may result in unreasonable or unreliable calculated unit hydrographs. Because some regression equations have considerable scatter, envelope curves bounding the graphical plots may assist in selecting unit-hydrograph variables with values different from values given by the equations.

Also, the methods presented in this report are intended for use at ungaged sites and may not be applicable when more site-specific information is available. Criteria and assumptions applied to spillway and dam-related design require a conservative approach; therefore, results obtained using the described methods need to be carefully evaluated on the basis of experience and professional judgment.

Examples of Estimated Unit Hydrographs

Unit hydrographs for ungaged sites are estimated in the following examples. The examples demonstrate the mechanics of the estimation methods and are not intended to suggest the particular method, equation, or degree of conservativeness to be used for an actual design situation. Because calculations for discharge are shown to a maximum of three significant figures, the results may not agree exactly with results calculated by computer.

Example 1. Use of the Clark method
Problem:

A unit hydrograph is needed as part of a spillway-design flood study for a proposed dam on an ungaged mountain site in western Montana. Use the Clark method to develop the unit hydrograph for the appropriate duration where the drainage area (A) is 22.2 mi^2.

Solution:

From equation 8 in table 4, the time of concentration (T_c) is

$$\begin{aligned} T_c &= 0.298\,A^{0.65} \\ &= 0.298\,(22.2)^{0.65} \\ &= 0.298\,(7.50) \\ &= 2.24\text{ h} \end{aligned}$$

Because of the wide latitude allowed in the determination of a suitable unit-hydrograph duration (lag time or T_c divided by a number ranging from 3.0 to 5.5), the duration (D) was selected to be T_c /4.0 as follows:

$$\begin{aligned} D &= T_c/4.0 \\ &= 2.24/4.0 \\ &= 0.56\text{ h (use 30 min)} \end{aligned}$$

An analysis of recorded flood hydrographs obtained from a nearby gaged site for several large floods indicates an average R value of 10 h. From equation 9 in table 4, R is

$$\begin{aligned} R &= 2.90\,A^{0.31} \\ &= 2.90\,(22.2)^{0.31} \\ &= 2.90\,(2.61) \\ &= 7.57 \\ &= 8\text{ h (in practice, } R \text{ is commonly rounded to the nearest whole number)} \end{aligned}$$

Because R calculated by equation 9 was found to be smaller and thus more conservative (leads to a larger

Time, *T*, in min	Unit-hydrograph discharge, in ft³/s	Time, *T*, in min	Unit-hydrograph discharge, in ft³/s	Time, *T*, in min	Unit-hydrograph discharge, in ft³/s
30	129	900	327	1,770	53
60	488	930	307	1,800	50
90	964	960	289	1,830	47
120	1,360	990	271	1,860	44
150	1,520	1,020	255	1,890	42
180	1,470	1,050	239	1,920	39
210	1,380	1,080	225	1,950	37
240	1,290	1,110	211	1,980	34
270	1,220	1,140	198	2,010	32
300	1,140	1,170	186	2,040	30
330	1,070	1,200	175	2,070	29
360	1,010	1,230	164	2,100	27
390	947	1,260	154	2,130	25
420	889	1,290	145	2,160	24
450	835	1,320	136	2,190	22
480	785	1,350	128	2,220	21
510	737	1,380	120	2,250	20
540	692	1,410	113	2,280	18
570	650	1,440	106	2,310	17
600	611	1,470	100	2,340	16
630	574	1,500	94	2,370	15
660	539	1,530	88	2,400	14
690	507	1,560	83	2,430	13
720	476	1,590	78	2,460	13
750	447	1,620	73	2,490	12
780	420	1,650	69	2,520	11
810	394	1,680	64	2,550	10
840	371	1,710	60	2,580	10
870	348	1,740	57	2,610	9

peak discharge) than the value for the nearby gaged site, the calculated value was chosen.

The calculated values for T_c and R, together with the drainage area of the basin, are input to the HEC-1 rainfall-runoff model to produce the unit hydrograph above having a duration equal to 30 minutes.

This unit hydrograph, coupled with a synthetic rainstorm for a particular design standard, would be used in the rainfall-runoff modeling procedures of HEC-1 to calculate a synthetic-flood hydrograph. The synthetic-flood hydrograph would then be used to conduct flood-routing studies through the reservoir and spillway system to determine a suitable spillway design.

Example 2. Use of the dimensionless method
Problem:

An existing emergency spillway for a dam on an ungaged basin is to be analyzed using the dimensionless unit-hydrograph method to determine if the spillway meets the current flood-hydrology standards for dam safety. No unit-hydrograph information is available from nearby gaged sites so the regression equations in table 4 are used to calculate t_p and q_p. Basin characteristics used in the regression equations are measured upstream from the dam as follows:

$$A = 228 \text{ mi}^2$$
$$L = 38.2 \text{ mi}$$
$$L_{ca} = 19.5 \text{ mi}$$
$$S = 18 \text{ ft/mi}$$

Solution:

(a) From equation 11 in table 4, the Snyder standard lag (t_p) for the site is

$$\begin{aligned} t_p &= 0.393\, A^{0.58} \\ &= 0.393\,(228)^{0.58} \\ &= 0.393\,(23.3) \\ &= 9.16 \text{ h} \end{aligned}$$

(b) From equation 12 in table 4, the peak of the dimensionless unit hydrograph (q_p) is

$$q_p = 8.46\,(^{LL_{ca}}/\sqrt{S})^{0.10}$$
$$= 8.46\,[(38.2 \times 19.5)/\sqrt{18}\,]^{0.10}$$
$$= 8.46\,(1.68)$$
$$= 14.2$$

Alternatively, equation 13 in table 4 expressing q_p as a function of drainage area could have been used as follows:

$$q_p = 7.24\,A^{0.10}$$
$$= 7.24\,(228)^{0.10}$$
$$= 7.24\,(1.72)$$
$$= 12.5$$

Because the consequences of failure were considered to be large, the more conservative value of 14.2 for q_p is chosen to complete the design example.

(c) The unit-hydrograph duration (t_r) is estimated to be

$$t_r = t_p/5.5$$
$$= 9.16/5.5$$
$$= 1.67 \text{ h (round down to the nearest hour; use 1.0)}$$

Although the unit-hydrograph duration is commonly rounded downward to the nearest 1 hour (or nearest 5, 10, 15, or 30 minutes if duration is less than 1.0 hour), $t_p + 0.5\,t_r$, by convention, is carried to the same number of significant digits as t_p.

The Snyder standard lag plus one-half the duration of the unit hydrograph is thus:

$$t_p + 0.5\,t_r = 9.16 + 0.5(1.0) = 9.66 \text{ h}$$

(d) The unit volume of runoff from the basin (V') is calculated by multiplying the drainage area by the conversion constant, 26.89:

$$V' = (26.89)\,(228)$$
$$= 6{,}130 \text{ ft}^3\text{/s-d}$$

(e) To determine an ordinate on the unit hydrograph for any time, T, the corresponding ordinate on the adjusted dimensionless unit hydrograph and dimensionless time, t, need to be calculated. For T = 10 h, for example, the corresponding dimensionless time is determined from equation 3 as follows:

$$t = 100\,T/(t_p + 0.5\,t_r)$$
$$= 100(10)/(9.66)$$
$$= 103.5$$

The adjustment factor for dimensionless time, t = 103.5, is calculated from equation 17 for q_p = 14.2 as follows:

$$AF_{103.5} = -0.42 + 0.22 \log 103.5 + (1.42 - 0.22 \log 103.5)\,(14.2/13.6)$$
$$= -0.42 + 0.22\,(2.015) + [1.42 - 0.22\,(2.015)](14.2/13.6)$$
$$= -0.42 + 0.44 + [1.42 - 0.44]\,1.04$$
$$= 0.02 + (0.98)(1.04)$$
$$= 1.04$$

From table 5, the average dimensionless discharge for dimensionless time, t = 103.5, is interpolated to be 13.5. Multiplying this value by $AF_{103.5}$ = 1.04 provides the adjusted dimensionless discharge (q) of 14.0 for t = 103.5. Finally, the ordinate on the unit hydrograph (Q_s) for time T = 10 h is computed by rearranging equation 2 as follows:

$$Q_s = q[V'/(t_p + 0.5\,t_r)]$$
$$= 14.0(6{,}130/9.66)$$
$$= 14.0\,(635)$$
$$= 8{,}890 \text{ ft}^3\text{/s}$$

(f) Information developed in parts (a) through (e) is summarized below; data are tabulated to illustrate the derivation of the full unit hydrograph:

Drainage area, A	= 228 mi^2
Snyder standard lag, t_p	= 9.16 h
Unit-hydrograph duration, t_r	= 1.0 h
Snyder standard lag plus one-half unit-hydrograph duration, $t_p + 0.5\,t_r$	= 9.66 h
Unit volume of runoff from basin, V'	= 6,130 ft^3/s-d

Similar to example 1, the calculated unit hydrograph developed here is then used with a specified synthetic rainstorm and a rainfall-runoff model like HEC-1 to transform the unit hydrograph into a synthetic flood hydrograph for investigating the required capacity of the spillway.

Time, T, in h	Dimensionless time, t, in percent of t_p + 0.5 t_r	Adjusted dimensionless unit-hydrograph ordinate, q	Calculated unit-hydrograph ordinate, Q_S, in ft^3/s
1	10.4	0.77	489
2	20.7	2.13	1,350
3	31.1	3.73	2,370
4	41.4	5.67	3,600
5	51.8	7.92	5,030
6	62.1	9.98	6,340
7	72.5	11.9	7,560
8	82.8	13.1	8,320
9	93.2	13.9	8,830
10	103.5	14.0	8,890
11	113.9	13.4	8,510
12	124.2	12.4	7,870
13	134.6	11.2	7,110
14	144.9	9.79	6,220
15	155.3	8.60	5,460
16	165.6	7.50	4,760
17	176.0	6.68	4,240
18	186.3	5.85	3,710
19	196.7	5.23	3,320
20	207.0	4.72	3,000
21	217.4	4.25	2,700
22	227.7	3.85	2,440
23	238.1	3.49	2,220
24	248.4	3.19	2,030
25	258.8	2.94	1,870
26	269.2	2.72	1,730
27	279.5	2.50	1,590
28	289.9	2.30	1,460
29	300.2	2.11	1,340
30	310.6	1.97	1,250
31	320.9	1.83	1,160
32	331.3	1.68	1,070
33	341.6	1.59	1,010
34	352.0	1.47	933
35	362.3	1.38	876
36	372.7	1.31	832
37	383.0	1.20	762
38	393.4	1.14	724
39	403.7	1.06	673
40	414.1	1.00	635
41	424.4	.94	597
42	434.8	.89	565
43	445.1	.85	540
44	455.5	.80	508
45	465.8	.75	476
46	476.2	.71	451
47	486.5	.68	432
48	496.9	.65	413
49	507.2	.61	387
50	517.6	.58	368

Time, T, in h	Dimensionless time, t, in percent of $t_p + 0.5\ t_r$	Adjusted dimensionless unit-hydrograph ordinate, q	Calculated unit-hydrograph ordinate, Q_S, in ft^3/s
51	528.0	.54	343
52	538.3	.52	330
53	548.7	.49	311
54	559.0	.46	292
55	569.4	.44	279
56	579.7	.42	267
57	590.1	.40	254
58	600.4	.37	235
59	610.8	.35	222
60	621.1	.34	216
61	631.5	.32	203
62	641.8	.30	191
63	652.2	.29	184
64	662.5	.28	178
65	672.9	.27	171
66	683.2	.26	165
67	693.6	.25	159
68	703.9	.24	152
69	714.3	.23	146
70	724.6	.22	140
71	735.0	.21	133
72	745.3	.20	127
73	755.7	.20	127
74	766.0	.18	114
75	776.4	.18	114
76	786.7	.17	108
77	797.1	.16	102
78	807.5	.16	102
79	817.8	.15	95
80	828.2	.15	95
81	838.5	.14	89
82	848.9	.13	83
83	859.2	.13	83
84	869.6	.12	76
85	879.9	.11	70
86	890.3	.11	70
87	900.6	.10	64
88	911.0	.10	64
89	921.3	.09	57
90	931.7	.09	57
91	942.0	.09	57
92	952.4	.09	57
93	962.7	.09	57
94	973.1	.08	51
95	983.4	.08	51
96	993.8	.08	51

SUMMARY AND CONCLUSIONS

Methods were developed for the estimation of unit hydrographs for large floods at ungaged sites in Montana using either the Clark method or the dimensionless unit-hydrograph method. The HEC-1 rainfall-runoff simulation model was used to derive unit hydrographs and important unit-hydrograph variables for recorded flood hydrographs at 26 U.S. Geological Survey streamflow-gaging stations where representative rainfall data were also available. In addition to recorded flood-hydrograph and rainfall data, factors considered in the analysis included estimation of rainfall losses, base flow, and the assessment of snowpack-related considerations.

Because of the conservative manner in which dam-related investigations must be performed, unit hydrographs and regional variables were derived from only large flood events that probably represented "worst-case" conditions. Equations and graphical relations for key variables were derived for recorded flood hydrographs with peak discharges that generally exceeded the 50-year recurrence interval for drainage areas ranging from 6.31 to 1,548 mi^2. With the exception of one site, the floods investigated were the result of general storms that produced area-wide flooding. Therefore, no comparisons could be made between general storm events and local thunderstorm events for unit-hydrograph variables.

Multiple-regression analysis was performed for unit-hydrograph variables derived from the 26 sites with a number of basin characteristics tested for inclusion as explanatory variables. The important unit-hydrograph variables investigated for the Clark method included time of concentration (T_c) and the Clark basin-storage coefficient (R). Variables analyzed for the dimensionless unit-hydrograph method included lag time expressed as the Snyder standard lag (t_p), and the peak dimensionless discharge ordinate (q_p). The results showed that only one variable was significant in each equation, and that, in all instances but one, the significant variable was drainage area. On the basis of the standard error and coefficient of determination, the equations for estimating T_c and t_p are the most reliable, and the equations for estimating R and q_p are the least reliable.

An average dimensionless unit hydrograph was developed from the 26 individual dimensionless unit hydrographs, and a technique was developed in which adjustment factors (AF_i) were applied to change the magnitude and shape of the average dimensionless unit hydrograph, thus allowing more design latitude for site-specific conditions. Values for AF_i are calculated based on a ratio of the calculated dimensionless peak (q_p) to the peak of the average dimensionless unit hydrograph (13.6). The relation between AF_i and (q_p/13.6) was nonlinear for values of q_p less than about 8.0 with values of dimensionless time greater than about 200. Consequently, for values of q_p less than about 8.0, calculated adjustment factors may not be reliable and adjusted average dimensionless unit hydrographs may have appreciable error.

Regression equations for calculating important unit-hydrograph variables can be used with a time-area curve or with the adjusted average dimensionless unit hydrograph to determine a unit hydrograph at any ungaged site in Montana. The reliability of the two methods was measured by comparing unit hydrographs calculated by the Clark and dimensionless unit-hydrograph methods to unit hydrographs derived from recorded data. The results of the comparisons indicate that the Clark and dimensionless unit-hydrograph methods performed about equally well in matching unit-hydrograph peaks and shapes derived from recorded flood hydrograph data.

The unit-hydrograph estimation methods are subject to several limitations and design considerations. For example, definitions of some unit-hydrograph variables used in the report are not compatible with definitions used in some other reports, and resultant unit hydrographs may be different. The methods described in this report are known to apply only within the range of variables used in the analysis, and use of the methods outside those ranges may result in unreliable unit hydrographs. Although the Clark and dimensionless unit-hydrograph methods from this report performed about equally well in matching derived unit-hydrograph peaks and shapes, both methods may underestimate actual unit-hydrograph peaks, and results need to be carefully evaluated based on experience and professional judgment.

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SUPPLEMENTAL DATA

HEC-1 MODEL INPUT DATA

The following data sets are the HEC-1 computer model input records for each of the 26 sites analyzed. The data sets include hourly recorded rainstorm data (PI records) and flood hydrograph data of direct runoff plus baseflow (QO records). Other records in each data set are information needed to perform the HEC-1 calibration and optimization routine for deriving a unit hydrograph and are described in the HEC-1 users manual (U.S. Army Corps of Engineers, 1987).

Table 9. Input data for HEC-1 flood-hydrograph model for sites in Montana

```
ID      SITE 1:  BELLY RIVER - FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 06JUN64    2400      97
IO     1        2
OU     1       97
PG   100     10.0
PG  1000
*     SUMMIT RAINFALL
IN    60 06JUN64    0100
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.02    0.01    0.07    0.07    0.05
PI  0.03     0.05    0.03    0.10    0.13    0.06    0.02    0.03    0.05    0.06
PI  0.06     0.10    0.22    0.19    0.32    0.29    0.29    0.16    0.27    0.33
PI  0.35     0.40    0.45    0.54    0.52    0.46    0.40    0.46    0.54    0.30
PI  0.44     0.15    0.07    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  BELLY RIVER AT INTERNATIONAL
*            BOUNDARY 05010000
IN    60 06JUN64    2400
QO 1380.    1380.   1380.   1370.   1370.   1370.   1370.   1370.   1380.   1390.
QO 1420.    1450.   1480.   1510.   1540.   1570.   1610.   1650.   1700.   1770.
QO 1850.    1920.   2000.   2070.   2140.   2360.   2570.   2980.   3390.   3940.
QO 4490.    5260.   6030.   6800.   7570.   8340.   9110.   9810.  10500.  11200.
QO11400.   11700.  11900.  12000.  12000.  11900.  11800.  11600.  11400.  11100.
QO10700.   10400.  10200.   9850.   9500.   9140.   8790.   8490.   8190.   7890.
QO 7590.    7340.   7090.   6840.   6590.   6360.   6130.   5890.   5660.   5480.
QO 5290.    5110.   4920.   4790.   4660.   4530.   4400.   4270.   4140.   4010.
QO 3880.    3750.   3620.   3490.   3360.   3280.   3190.   3110.   3030.   2940.
QO 2860.    2800.   2740.   2690.   2630.   2570.   2510.      0.      0.      0.
PT   100
PW   1.0
PR  1000
PW   1.0
BA  74.8
BF 1370.     -.25    1.00
UC 10.08    23.80
LE -0.05    -1.33    1.00    0.50     0.0
ZZ


ID      SITE 2:  PRICKLY PEAR CREEK - FLOOD OF MAY 1981
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 21MAY81    0100     150
IO     1        2
OU     1      150
PG   100      2.5
PG  1000
*        HELENA WSO AP RAINFALL
IN    60 19MAY81    0100
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.39    0.00    0.03    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.16     0.35    0.11    0.02    0.00    0.00    0.00    0.00    0.00    0.01
PI  0.01     0.00    0.01    0.06    0.06    0.11    0.13    0.02    0.03    0.03
PI  0.00     0.03    0.04    0.01    0.00    0.26    0.07    0.33    0.20    0.14
PI  0.12     0.26    0.12    0.02    0.00    0.06    0.09    0.18    0.02    0.00
PI  0.00     0.04    0.01    0.00    0.00    0.00    0.08    0.00    0.00    0.00
PI  0.06     0.11    0.05    0.02    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:   PRICKLY PEAR CREEK NR
*            CLANCY 06061500
IN    60 21MAY81    0100
QO  405.     418.    430.    435.    440.    440.    440.    440.    440.    440.
QO  440.     440.    460.    475.    500.    530.    570.    610.    660.    700.
QO  770.     830.    900.    960.    990.   1130.   1270.   1370.   1660.   2000.
QO 2280.    2180.   2130.   2000.   1960.   1950.   1960.   2180.   2200.   2300.
QO 2200.    2150.   2120.   2100.   2070.   2050.   1960.   1880.   1870.   1860.
QO 1810.    1770.   1740.   1700.   1680.   1660.   1630.   1600.   1565.   1530.
QO 1500.    1470.   1460.   1450.   1430.   1410.   1390.   1370.   1370.   1370.
QO 1365.    1360.   1340.   1320.   1310.   1300.   1280.   1260.   1240.   1220.
QO 1210.    1200.   1190.   1180.   1170.   1160.   1165.   1140.   1140.   1130.
QO 1130.    1130.   1140.   1150.   1150.   1150.   1135.   1120.   1105.   1090.
QO 1075.    1060.   1045.   1030.   1015.   1000.    985.    970.    955.    940.
QO  925.     910.    895.    900.    900.    895.    895.    895.    895.    892.
QO  892.     892.    892.    892.    892.    892.    892.    892.    892.    892.
QO  892.     892.    892.    892.    892.    892.    892.    892.    892.    892.
QO  892.     892.    892.    892.    779.    779.    779.    779.    779.    779.
PT  1000
PW   1.0
PR  1000
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PW  1.00
BA  192.
BF  600.     1.00      1.00
UC  9.00    35.00
LE -0.19    -1.63      1.00     0.50      0.0
ZZ


ID      SITE 3:  SUN RIVER - FLOOD OF JUNE 1964
ID      INFLOW TO GIBSON RES.
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 07JUN64     0500      140
IO      1        2
OU     15       85
PG  1000        10
*     GIBSON DAM RAINFALL
*     RAINFALL DATA AT GIBSON DAM LAGGED ADDITIONAL 5 HRS TO REFLECT
*     START OF STORM (Ts) - BASED ON AVERAGING OF TIME (Ts) AT GIBSON,
*     SUMMIT, AND BROWNING PRECIP GAGES.
IN     60 07JUN64     0500
*FREE
PI .02 .06 .13 .04 .05 .13 .07 .05 .08 .12 .15 .11 .16 .23 .18 .18 .22 .52 .56
PI .61 .48 .34 .35 .17 .19 .39 .41 .47 .27 .36 .30 .27 .20 .05 .04 .07 .04
*FIX
PG  2000        10
*         SUMMIT RAINFALL
IN     60 06JUN64     0100
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.02      0.01      0.07      0.07      0.05
PI  0.03     0.05      0.03     0.10      0.13      0.06      0.02      0.03      0.05      0.06
PI  0.06     0.10      0.22     0.19      0.32      0.29      0.29      0.16      0.27      0.33
PI  0.35     0.40      0.45     0.54      0.52      0.46      0.40      0.46      0.54      0.30
PI  0.44     0.15      0.07     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
KK    100       DATA FROM USGS WSP-1840-B; LAST 2 ROWS ESTIMATED; INFLOW TO
*               GIBSON RES.
IN     60 07JUN64     0400
QO 6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.
QO 6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.    6000.
QO 6300.    6700.    7100.    9800.   12500.   16000.   20000.   25500.   34000.   38300.
QO42700.   47000.   51300.   55700.   60000.   60000.   60000.   58900.   57700.   56600.
QO55300.   53800.   52200.   50400.   48400.   46100.   43500.   40000.   38000.   35800.
QO33900.   32200.   30600.   29100.   27800.   26550.   25300.   24420.   23530.   22650.
QO21770.   20880.   20000.   19480.   18970.   18450.   17930.   17420.   16900.   16530.
QO16170.   15800.   15430.   15070.   14700.   14415.   14130.   13850.   13570.   13285.
QO13000.   12830.   12670.   12500.   12330.   12170.   12000.   11830.   11670.   11500.
QO11330.   11170.   11000.   10880.   10770.   10650.   10530.   10420.   10300.   10200.
QO10100.   10000.    9900.    9800.    9700.    9620.    9530.    9450.    9370.    9280.
QO 9200.    9115.    9033.    8950.    8870.    8780.    8700.    8600.    8530.    8450.
QO 8360.    8280.    8200.    8115.    8030.    7950.    7860.    7780.    7700.    7615.
QO 7530.    7450.    7370.    7280.    7200.    7115.    7030.    6950.    6870.    6780.
PT  1000     2000
PW   1.0      0.0
PR  1000     2000
PW   1.0      0.0
BA  575.
BF 6000.     1.00      1.00
UC 11.29    15.20
LE -0.28    -3.23      1.00     0.50      0.0
ZZ


ID      SITE 4:  MUDDY CREEK - FLOOD OF MAY/JUNE 1953
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 02JUN53     1200
IO      1        2
OU     15       70
PG  1000       5.0
*       GREAT FALLS WSCMO AP RAINFALL
IN     60  1JUN53     0100
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.01      0.03      0.00
PI  0.00     0.00      0.00     0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.01     0.00      0.37     0.15      0.08      0.05      0.01      0.01      0.01      0.01
PI  0.00     0.26      0.09     0.04      0.01      0.00      0.02      0.01      0.02      0.06
PI  0.09     0.12      0.13     0.20      0.23      0.18      0.03      0.24      0.23      0.14
PI  0.08     0.05      0.05     0.02      0.06      0.05      0.03      0.01      0.02      0.02
PI  0.01     0.00      0.03     0.04      0.00      0.00      0.00      0.00      0.00      0.00
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI  0.00      0.00      0.00      0.00      0.01      0.01      0.01      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG  2000      5.0
*      KINGS HILL RAINFALL
IN    60   1JUN53     0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.01      0.01      0.01
PI  0.02      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.01      0.00      0.01      0.01      0.02
PI  0.04      0.10      0.14      0.08      0.13      0.13      0.07      0.04      0.01      0.01
PI  0.01      0.03      0.01      0.03      0.05      0.06      0.07      0.08      0.15      0.07
PI  0.11      0.12      0.25      0.10      0.15      0.05      0.05      0.05      0.05      0.01
PI  0.02      0.02      0.01      0.01      0.00      0.00      0.01      0.02      0.04      0.01
PI  0.00      0.00      0.01      0.01      0.07      0.01      0.03      0.01      0.01      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
KK   100      USGS RECORDED FLOOD HYDROGRAPH:    MUDDY CREEK AT VAUGHN   06088500
IN    60  01JUN53     2400
QO  752.      707.      661.      616.      570.      525.      480.      456.      431.      407.
QO  382.      382.      382.      403.      425.      446.      467.      489.      510.      549.
QO  588.      627.      667.      706.      745.      838.      930.     1020.     1120.     1210.
QO 1300.     1420.     1530.     1650.     1770.     1880.     2000.     2180.     2360.     2530.
QO 2710.     2890.     3070.     3410.     3750.     4210.     4660.     5290.     5910.     6760.
QO 7600.     6890.     6180.     5470.     4760.     4570.     4380.     3440.     3170.     2910.
QO 2640.     2520.     2390.     2270.     2150.     2020.     1900.     1830.     1750.     1680.
QO 1610.     1530.     1460.     1400.     1350.     1290.     1230.     1180.     1120.     1070.
QO 1020.      974.      925.      880.      828.      805.      782.      759.      736.      713.
QO  690.      678.      665.      653.      640.      628.      615.      610.      604.      598.
QO  593.      588.      580.      573.      567.      560.      553.      547.      540.      532.
QO  525.      517.      509.      502.      494.      485.      476.      468.      459.      450.
QO  441.      434.      426.      419.      411.      404.      396.      401.      407.      412.
QO  417.      423.      428.      435.      441.      448.      454.      461.      468.      474.
QO  481.      487.      494.      492.      490.
PT  1000      2000
PW  0.20      0.80
PR  1000      2000
PW  0.20      0.80
BA  391.
BF  400.      1.00      1.00
UC 12.61      9.50
LE -0.34     -3.11      1.00      0.50       0.0
ZZ


ID     SITE 5:  BELT CREEK NR MONARCH - FLOOD OF MAY-JUNE 1953
ID     DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60  01JUN53     2300      145
IO     1         2
OU     1       145
PG   100       6.0
PG  1000
*   KINGS HILL RAINFALL
IN    60  29MAY53     0100
PI  0.00      0.00      0.01      0.00      0.00      0.16      0.05      0.06      0.07      0.07
PI  0.08      0.04      0.01      0.07      0.08      0.04      0.11      0.05      0.04      0.03
PI  0.08      0.05      0.07      0.08      0.10      0.07      0.05      0.03      0.01      0.01
PI  0.01      0.04      0.08      0.02      0.00      0.01      0.00      0.01      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.01      0.01      0.01      0.02      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.01      0.00      0.01      0.01      0.02      0.04      0.10
PI  0.14      0.08      0.13      0.13      0.07      0.04      0.01      0.01      0.01      0.03
PI  0.01      0.03      0.05      0.06      0.07      0.08      0.15      0.07      0.11      0.12
PI  0.25      0.10      0.15      0.05      0.05      0.05      0.05      0.01      0.02      0.02
PI  0.01      0.01      0.00      0.00      0.01      0.02      0.04      0.01      0.00      0.00
PI  0.01      0.01      0.07      0.01      0.03      0.01      0.01      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.01      0.01      0.01      0.02      0.03      0.01      0.00      0.01      0.01
PI  0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.01      0.02      0.01      0.00      0.01      0.00
PI  0.01      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG  2000
*      GREAT FALLS WSCMO AP RAINFALL
IN    60  02JUN53     0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.01      0.00      0.37      0.15
PI  0.08      0.05      0.01      0.01      0.01      0.01      0.00      0.26      0.09      0.04
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI  0.01      0.00      0.02      0.01      0.02      0.06      0.09      0.12      0.13      0.20
PI  0.23      0.18      0.03      0.24      0.23      0.14      0.08      0.05      0.05      0.02
PI  0.06      0.05      0.03      0.01      0.02      0.02      0.01      0.00      0.03      0.04
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.01      0.01      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.02
PI  0.09      0.06      0.02      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG  3000
*      HIGHWOOD RAINFALL
IN     60  01JUN53     0100
PI  0.00      0.00      0.00      0.01      0.01      0.00      0.00      0.00      0.00      0.01
PI  0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.03      0.15
PI  0.00      0.00      0.01      0.02      0.06      0.01      0.10      0.01      0.00      0.00
PI  0.00      0.07      0.09      0.03      0.08      0.11      0.05      0.04      0.12      0.40
PI  0.35      0.38      0.22      0.25      0.18      0.27      0.13      0.15      0.15      0.30
PI  0.15      0.17      0.15      0.23      0.14      0.16      0.11      0.09      0.08      0.09
PI  0.02      0.01      0.05      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.03      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
KK    100      USGS RECORDED FLOOD HYDROGRAPH:  BELT CREEK NR MONARCH 06090500
IN     60  01JUN53     2300
QO 2130.     2140.     2150.     2150.     2150.     2140.     2140.     2130.     2130.     2120.
QO 2120.     2120.     2110.     2110.     2100.     2100.     2090.     2090.     2120.     2150.
QO 2180.     2210.     2290.     2380.     2460.     2570.     2680.     2800.     2910.     3020.
QO 3130.     3270.     3410.     3560.     3700.     3840.     4110.     4380.     4650.     4920.
QO 5240.     5560.     6200.     6840.     8220.     8950.     9670.    10400.    10400.    10500.
QO10600.    10700.    10700.    10800.    11000.    10800.    10700.    10500.    10400.    10200.
QO10100.     9900.     9750.     9590.     9780.     9640.     9360.     9220.     9090.     8950.
QO 8810.     8670.     8530.     8370.     8210.     8050.     7890.     7730.     7560.     7400.
QO 7240.     7080.     6920.     6760.     6600.     6510.     6410.     6320.     6220.     6130.
QO 6030.     5940.     5840.     5750.     5650.     5560.     5460.     5340.     5210.     5090.
QO 4960.     4840.     4710.     4590.     4460.     4340.     4210.     4090.     3960.     3940.
QO 3930.     3910.     3900.     3880.     3870.     3850.     3830.     3820.     3800.     3790.
QO 3770.     3750.     3740.     3720.     3700.     3690.     3670.     3650.     3640.     3620.
QO 3600.     3590.     3570.     3560.     3540.     3530.     3510.     3500.     3480.     3470.
QO 3450.     3440.     3420.     3410.     3390.        0.        0.        0.        0.        0.
PT    100
PW    1.0
PR   1000
PR   1000      2000      3000
PW   0.10      0.90      0.00
BA   368.
BF  2150.      1.00      1.00
UC  17.05     32.88
LE  -0.03     -5.06      1.00      0.50       0.0
ZZ


ID        SITE 5:  BELT CREEK NR MONARCH - FLOOD OF MAY 1981
ID        DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60  20MAY81     1700       125
IO      1         2
OU      1       125
PG    100       3.0
PG   1000
*      GREAT FALLS WSCMO AP RAINFALL
IN     60  20MAY81     0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.01      0.05      0.01      0.01
PI  0.01      0.00      0.00      0.00      0.00      0.04      0.05      0.02      0.03      0.09
PI  0.14      0.01      0.02      0.03      0.02      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.06      0.05      0.00      0.24      0.01      0.00      0.00
PI  0.00      0.00      0.02      0.23      0.07      0.02      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.04      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.03      0.04      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.14      0.00      0.00      0.00
PI  0.01      0.00      0.01      0.02      0.02      0.02      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG   2000
*      MILLEGAN RAINFALL
IN     60  20MAY81     0100
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.30    0.10    0.00    0.00
PI  0.00     0.10    0.10    0.10    0.10    0.00    0.10    0.00    0.00    0.10
PI  0.10     0.10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.10
PI  0.10     0.00    0.00    0.10    0.10    0.10    0.50    0.00    0.00    0.20
PI  0.50     0.20    0.00    0.00    0.00    0.20    0.00    0.00    0.00    0.00
PI  0.00     0.10    0.00    0.00    0.00    0.10    0.20    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.10     0.10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:    BELT CR NR MONARCH   06090500
IN    60 18MAY81    2200
QO 1370.    1390.   1410.   1430.   1460.   1480.   1500.   1510.   1520.   1540.
QO 1540.    1550.   1560.   1570.   1560.   1560.   1570.   1580.   1620.   1710.
QO 1730.    1740.   1790.   1840.   1870.   1900.   1900.   1910.   1880.   1880.
QO 1880.    1880.   1860.   1870.   1850.   1840.   1830.   1830.   1840.   1830.
QO 1830.    1840.   1830.   1850.   1890.   1920.   1960.   2000.   2030.   2070.
QO 2100.    2160.   2220.   2260.   2320.   2370.   2420.   2440.   2450.   2460.
QO 2490.    2490.   2560.   2600.   2600.   2600.   2600.   2620.   2990.   2790.
QO 2830.    2840.   2980.   3050.   3390.   4380.   4330.   4680.   4830.   5030.
QO 5530.    5730.   6100.   6550.   7010.   7310.   7720.   7880.   8050.   8130.
QO 8190.    8270.   8190.   8100.   8020.   7880.   7720.   7510.   7350.   7170.
QO 7060.    6730.   6640.   6430.   6360.   6230.   6120.   5880.   5830.   5750.
QO 5650.    5520.   5270.   5240.   5020.   4980.   4840.   4720.   4620.   4570.
QO 4400.    4300.   4200.   4210.   4170.   4090.   3890.   3920.   3840.   3760.
QO 3740.    3720.   3690.   3660.   3630.   3560.   3520.   3470.   3430.   3400.
QO 3390.    3320.   3260.   3210.   3170.   3140.   3080.   3070.   3030.   3000.
QO 2960.    2920.   2880.   2840.   2800.   2760.   2720.   2680.   2640.   2610.
QO 2580.    2550.   2520.   2490.   2460.   2440.   2420.   2400.   2380.   2370.
QO 2350.       0.      0.      0.      0.      0.      0.      0.      0.      0.
PT   100
PW   1.0
PR  1000     2000
PW  0.50     0.50
BA  368.
BF 1850.     1.00    1.00
UC 15.28    25.93
LE -0.18    -0.91    1.00    0.50    0.0
ZZ


ID       SITE 6:  BELT CREEK NR PORTAGE - FLOOD OF MAY 1981
ID       DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 19MAY81    2400     196
IO     1        2
OU     1      196
PG   100      3.1
PG  1000
*        GREAT FALLS WSCMO AP RAINFALL
IN    60 20MAY81    0100
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.01    0.05    0.01    0.01
PI  0.01     0.00    0.00    0.00    0.00    0.04    0.05    0.02    0.03    0.09
PI  0.14     0.01    0.02    0.03    0.02    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.06    0.05    0.00    0.24    0.01    0.00    0.00
PI  0.00     0.00    0.02    0.23    0.07    0.02    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.04    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.03    0.04    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.14    0.00    0.00    0.00
PI  0.01     0.00    0.01    0.02    0.02    0.02    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PG  2000
*        MILLEGAN RAINFALL
IN    60 20MAY81    0100
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI  0.00     0.00    0.00    0.00    0.00    0.00    0.30    0.10    0.00    0.00
PI  0.00     0.10    0.10    0.10    0.10    0.00    0.10    0.00    0.00    0.10
PI  0.10     0.10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.10
PI  0.10     0.00    0.00    0.10    0.10    0.10    0.50    0.00    0.00    0.20
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI  0.50     0.20     0.00     0.00     0.00     0.20     0.00     0.00     0.00     0.00
PI  0.00     0.10     0.00     0.00     0.00     0.10     0.20     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.10     0.10     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  BELT CR NR PORTAGE   06090610
IN    60 19MAY81     2400
QO 1890.    1950.    1980.    1980.    1980.    1970.    1990.    1990.    2050.    2080.
QO 2130.    2080.    2130.    2040.    2140.    2140.    2160.    2130.    2130.    2150.
QO 2190.    2150.    2140.    2130.    2160.    2450.    2250.    2350.    2510.    2450.
QO 2590.    2980.    3080.    3630.    3690.    4100.    4100.    4100.    4160.    4070.
QO 4220.    4100.    4310.    4310.    3980.    4280.    4040.    4100.    4250.    4390.
QO 5010.    4990.    5590.    5630.    5950.    6210.    6340.    7080.    7750.    9080.
QO 9600.    9720.    9510.    9370.    9370.   10700.   12700.   13800.   13760.   12800.
QO12300.   12300.   12100.   11600.   11500.   11600.   11600.   11600.   11900.   11800.
QO11600.   12000.   11500.   11400.   11200.   11200.   10800.   10700.   10300.    9800.
QO 9630.    9460.    9460.    9040.    9040.    8990.    8400.    8220.    8070.    8160.
QO 8240.    8110.    7900.    7790.    7640.    7140.    7080.    6770.    6960.    6860.
QO 6570.    6550.    6210.    6380.    5970.    6100.    5800.    5610.    5540.    5490.
QO 5430.    5420.    5140.    5260.    5160.    4930.    4960.    4940.    5010.    5040.
QO 4640.    4880.    4570.    4680.    4460.    4560.    4590.    4180.    4330.    4480.
QO 4100.    4610.    4220.    4160.    3860.    3910.    3930.    3930.    3860.    4010.
QO 4000.    3960.    3870.    3860.    3740.    3710.    3870.    3860.    3900.    3880.
QO 3810.    3810.    3740.    3700.    3700.    3670.    3600.    3590.    3480.    3440.
QO 3390.    3350.    3280.    3220.    3220.    3170.    3160.    3070.    2970.    3230.
QO 2990.    3210.    3140.    3040.    3050.    3030.    2980.    2940.    2820.    2850.
QO 2810.    2780.    2840.    2790.    2850.    2810.       0.       0.       0.       0.
PT   100
PW   1.0
PR  1000     2000
PW  1.00     0.00
BA  799.
BF 2130.     1.00     1.00
UC 25.35    32.89
LE -0.21    -0.54     1.00     0.50      0.0
ZZ


ID       SITE 7:  BADGER CREEK NR BROWNING - FLOOD OF JUNE 1964
ID       DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 07JUN64     2400       73
IO     1        2
OU     1       73
PG   100     12.0
PG  1000
*        GIBSON DAM RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.03     0.01     0.03     0.02     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.02
PI  0.06     0.08     0.04     0.04     0.08     0.02     0.03     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.02     0.06     0.13     0.04     0.05     0.13     0.07
PI  0.05     0.08     0.12     0.15     0.11     0.16     0.23     0.18     0.18     0.22
PI  0.52     0.56     0.61     0.48     0.34     0.35     0.17     0.19     0.39     0.41
PI  0.47     0.27     0.36     0.30     0.27     0.20     0.05     0.04     0.07     0.04
PI  0.00     0.00     0.01     0.01     0.01     0.00     0.01     0.00     0.01     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  2000
*        DUPUYER RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.04     0.01
PI  0.05     0.01     0.00     0.00     0.01     0.00     0.07     0.05     0.05     0.05
PI  0.13     0.15     0.24     0.19     0.27     0.05     0.11     0.19     0.31     0.12
PI  0.20     0.12     0.35     0.38     0.42     0.16     0.21     0.17     0.15     0.20
PI  0.35     0.15     0.71     0.29     0.14     0.03     0.02     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  3000
*       SUMMIT RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI  0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  BADGER CREEK NEAR
*            BROWNING  06092500
IN    60 07JUN64     2400
QO 1540.    1630.    1720.    2190.    2650.    3350.    4040.    5360.    6670.    8440.
QO10200.   18800.   27400.   35400.   43400.   46550.   49700.   29400.   24870.   20300.
QO15800.   13150.   10500.    9420.    8330.    7580.    6820.    6130.    5440.    4960.
QO 4480.    4320.    4150.    4040.    3930.    3820.    3710.    3600.    3500.    3400.
QO 3290.    3190.    3080.    3020.    2960.    2900.    2840.    2780.    2720.    2660.
QO 2600.    2540.    2770.    2410.    2350.    2310.    2260.    2220.    2170.    2130.
QO 2080.    2050.    2010.    1980.    1950.    1920.    1880.    1870.    1850.    1840.
QO 1830.    1810.    1800.       0.       0.       0.       0.       0.       0.       0.
PT   100
PW   1.0
PR  1000     2000     3000
PW  0.00     0.00     1.00
BA  133.
BF 1540.     1.00     1.00
UC  6.0       2.2
LE -0.00    -9.57     1.00     0.50      0.0
ZZ


ID       SITE 8:  CUT BANK CREEK AT CUT BANK - FLOOD OF JUNE 1964
ID       DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 07JUN64     0400      144
IO     1        2
OU     1      144
PG  1000     10.0
*        GIBSON DAM RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.03     0.01     0.03     0.02     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.02
PI  0.06     0.08     0.04     0.04     0.08     0.02     0.03     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.02     0.06     0.13     0.04     0.05     0.13     0.07
PI  0.05     0.08     0.12     0.15     0.11     0.16     0.23     0.18     0.18     0.22
PI  0.52     0.56     0.61     0.48     0.34     0.35     0.17     0.19     0.39     0.41
PI  0.47     0.27     0.36     0.30     0.27     0.20     0.05     0.04     0.07     0.04
PI  0.00     0.00     0.01     0.01     0.01     0.00     0.01     0.00     0.01     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  2000     10.0
*        SUMMIT RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI  0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  3000     10.0
*        DUPUYER RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.04     0.01
PI  0.05     0.01     0.00     0.00     0.01     0.00     0.07     0.05     0.05     0.05
PI  0.13     0.15     0.24     0.19     0.27     0.05     0.11     0.19     0.31     0.12
PI  0.20     0.12     0.35     0.38     0.42     0.16     0.21     0.17     0.15     0.20
PI  0.35     0.15     1.42     0.29     0.14     0.03     0.02     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  4000     10.0
*        BROWNING RAINFALL
IN    60 07JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.03     0.03     0.09     0.05     0.06
PI  0.09     0.01     0.01     0.03     0.03     0.10     0.14     0.14     0.13     0.14
PI  0.22     0.13     0.22     0.39     0.31     0.25     0.51     0.25     0.10     0.35
PI  0.38     0.34     0.43     0.54     0.48     0.56     0.56     0.41     0.13     0.05
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  CUT BANK CREEK AT CUT BANK 06099000
IN    60 07JUN64     0400
QO  575.     580.     590.     600.     620.     630.     640.     650.     660.     680.
QO  690.     710.     730.     750.     770.     790.     810.     830.     850.     870.
QO  890.     908.     926.     943.     961.     996.    1030.    1070.    1100.    1160.
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
QO 1220.    1270.    1330.    1440.    1550.    1630.    1720.    1800.    1880.    1970.
QO 2050.    3720.    4760.    4780.    4790.    6150.    8110.    8930.    9420.   16600.
QO16500.   16100.   15600.   14900.   14100.   13500.   12900.   12300.   11600.   11100.
QO10600.   10200.    9870.    9510.    9140.    8810.    8470.    8140.    7800.    7490.
QO 7170.    6860.    6540.    6310.    6070.    5840.    5600.    5410.    5220.    5020.
QO 4830.    4680.    4540.    4390.    4240.    4100.    3960.    3820.    3680.    3590.
QO 3500.    3410.    3320.    3240.    3170.    3090.    3010.    2940.    2860.    2780.
QO 2710.    2630.    2550.    2480.    2400.    2350.    2300.    2260.    2210.    2160.
QO 2110.    2070.    2030.    1990.    1940.    1900.    1860.    1820.    1780.    1740.
QO 1700.    1660.    1620.    1580.    1540.    1490.    1450.    1400.    1350.    1310.
QO 1270.    1230.    1190.    1150.    1100.    1060.    1020.    990.      950.     900.
QO  850.     800.     750.     700.
PT  1000     2000     3000     4000
PW  000.     000.      95.       5.
PR  1000     2000     3000     4000
PW  000.     000.      95.       5.
BA 1065.
BF  700.     1.00     1.00
UC 19.10    17.50
LE -0.69    -1.74     1.00     0.50     0.0
ZZ


ID      SITE 9:  LONE MAN COULEE NEAR VALIER - FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 07JUN64     1400       54
IO       1        2
OU       1       54
PG     100      8.0
PG    1000
*       GIBSON DAM RAINFALL
IN      60 06JUN64     0100
PI    0.00     0.00     0.00     0.00     0.00     0.03     0.01     0.03     0.02     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.02
PI    0.06     0.08     0.04     0.04     0.08     0.02     0.03     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.02     0.06     0.13     0.04     0.05     0.13     0.07
PI    0.05     0.08     0.12     0.15     0.11     0.16     0.23     0.18     0.18     0.22
PI    0.52     0.56     0.61     0.48     0.34     0.35     0.17     0.19     0.39     0.41
PI    0.47     0.27     0.36     0.30     0.27     0.20     0.05     0.04     0.07     0.04
PI    0.00     0.00     0.01     0.01     0.01     0.00     0.01     0.00     0.01     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG    2000
*       SUMMIT RAINFALL
IN      60 06JUN64     0100
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI    0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI    0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI    0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI    0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG    3000
*       DUPUYER RAINFALL
IN      60 06JUN64     0100
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.04     0.01
PI    0.05     0.01     0.00     0.00     0.01     0.00     0.07     0.05     0.05     0.05
PI    0.13     0.15     0.24     0.19     0.27     0.05     0.11     0.19     0.31     0.12
PI    0.20     0.12     0.35     0.38     0.42     0.16     0.21     0.17     0.15     0.20
PI    0.35     0.15     0.71     0.29     0.14     0.03     0.02     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG    4000
*       BROWNING RAINFALL
IN      60 07JUN64     0100
PI    0.00     0.00     0.00     0.00     0.00     0.03     0.03     0.09     0.05     0.06
PI    0.09     0.01     0.01     0.03     0.03     0.10     0.14     0.14     0.13     0.14
PI    0.22     0.13     0.22     0.39     0.31     0.25     0.51     0.25     0.10     0.35
PI    0.38     0.34     0.43     0.54     0.48     0.56     0.56     0.41     0.13     0.05
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK     100      USGS RECORDED FLOOD HYDROGRAPH:  LONE MAN COULEE NEAR VALIER 06100300
IN      60 06JUN64     2400
QO      0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
QO      0.       0.       0.       0.       0.       0.       0.       0.       0.       1.
QO      1.       2.       2.       2.       8.      14.      20.      26.      32.      35.
QO   310.     585.     860.     990.    1120.    1250.    1350.    1450.    1600.    1740.
QO 1420.    1100.     840.     580.     320.     220.     120.      19.      17.      15.
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
QO   12.        9.        6..       2.        2.        2.        2.        2.        2.        2.
QO    1.        1.        1.        1.        1.        1.        1.        1.        1.        1.
QO    1.        1.        0.        0.        0.        0.        0.        0.        0.        0.
PT   100
PW   1.0
PR  1000      2000      3000      4000
PW  0.00      0.00      0.00      1.00
BA  14.1
BF    2.      1.00      1.00
UC  1.03      3.11
LE -0.48     -2.71      1.00      0.50       0.0
ZZ


ID       SITE 10:  SOUTH FORK JUDITH RIVER NEAR UTICA - FLOOD OF JUNE 1964
ID       DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 06JUN64      2400        94
IO     1         2
OU     8        94
PG   100       3.0
PG  1000
*        GIBSON DAM RAINFALL
IN     60 06JUN64      0100
PI  0.00      0.00      0.00      0.00      0.00      0.03      0.01      0.03      0.02      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.02
PI  0.06      0.08      0.04      0.04      0.08      0.02      0.03      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.02      0.06      0.13      0.04      0.05      0.13      0.07
PI  0.05      0.08      0.12      0.15      0.11      0.16      0.23      0.18      0.18      0.22
PI  0.52      0.56      0.61      0.48      0.34      0.35      0.17      0.19      0.39      0.41
PI  0.47      0.27      0.36      0.30      0.27      0.20      0.05      0.04      0.07      0.04
PI  0.00      0.00      0.01      0.01      0.01      0.00      0.01      0.00      0.01      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG  2000
*      LEWISTOWN RAINFALL
IN     60 07JUN64      0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.04      0.12      0.10      0.10      0.06      0.05      0.02      0.00      0.00      0.00
PI  0.02      0.34      0.08      0.19      0.48      0.15      0.12      0.12      0.10      0.10
PI  0.05      0.07      0.11      0.11      0.04      0.02      0.05      0.04      0.01      0.02
PI  0.02      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.0        .00      0.00      0.00
PG  3000
*       DUPUYER RAINFALL
IN     60 06JUN64      0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.04      0.01
PI  0.05      0.01      0.00      0.00      0.01      0.00      0.07      0.05      0.05      0.05
PI  0.13      0.15      0.24      0.19      0.27      0.05      0.11      0.19      0.31      0.12
PI  0.20      0.12      0.35      0.38      0.42      0.16      0.21      0.17      0.15      0.20
PI  0.35      0.15      0.71      0.29      0.14      0.03      0.02      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PG  4000
*        KINGS HILL RAINFALL
IN     60 06JUN64      0100
PI  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.00      0.00      0.03      0.01      0.00      0.00      0.00      0.00      0.00      0.03
PI  0.06      0.06      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
PI  0.01      0.02      0.01      0.01      0.02      0.05      0.08      0.14      0.09      0.03
PI  0.01      0.03      0.02      0.02      0.08      0.12      0.03      0.00      0.00      0.00
PI  0.00      0.00      0.01      0.01      0.01      0.00      0.00      0.00      0.01      0.26
PI  0.24      0.16      0.14      0.16      0.07      0.04      0.05      0.06      0.06      0.06
PI  0.02      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
KK   100      USGS RECORDED FLOOD HYDROGRAPH:  SOUTH FORK JUDITH RIVER NR
*             UTICA 06109800
IN     60 06JUN64      2400
QO   76.       77.       79.       80.       80.       79.       79.       78.       78.       77.
QO   77.       80.       82.       84.       87.       97.      107.      117.      127.      139.
QO  185.      197.      204.      203.      196.      188.      181.      173.      170.      166.
QO  163.      159.      156.      162.      167.      196.      225.      347.      468.      590.
QO  760.      930.     1100.     1290.     1240.     1190.     1078.      966.      879.      791.
QO  758.      725.      691.      658.      631.      604.      577.      550.      534.      518.
QO  503.      487.      471.      455.      443.      431.      420.      408.      396.      384.
QO  381.      377.      374.      370.      367.      364.      360.      357.      351.      346.
QO  340.      335.      329.      323.      318.      312.      312.      312.      312.      307.
QO  301.      296.      290.      285.        0.        0.        0.        0.        0.        0.
PT   100
PW   1.0
PR  1000      2000      3000      4000
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PW  0.00     0.00     0.00     1.00
BA  58.7
BF   80.     -.25     1.00
UC  3.77    14.50
LE  0.30     0.76     1.00     0.50      0.0
ZZ


ID      SITE 11:  SOUTH FORK MILK RIVER NR BABB - FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 07JUN64     1000       95
IO     1        2
OU     1       55
PG   100     10.0
PG  1000
*       GIBSON DAM RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.03     0.01     0.03     0.02     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.02
PI  0.06     0.08     0.04     0.04     0.08     0.02     0.03     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.02     0.06     0.13     0.04     0.05     0.13     0.07
PI  0.05     0.08     0.12     0.15     0.11     0.16     0.23     0.18     0.18     0.22
PI  0.52     0.56     0.61     0.48     0.34     0.35     0.17     0.19     0.39     0.41
PI  0.47     0.27     0.36     0.30     0.27     0.20     0.05     0.04     0.07     0.04
PI  0.00     0.00     0.01     0.01     0.01     0.00     0.01     0.00     0.01     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  2000
*       SUMMIT RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI  0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PG  3000
*       DUPUYER RAINFALL
IN    60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.04     0.01
PI  0.05     0.01     0.00     0.00     0.01     0.00     0.07     0.05     0.05     0.05
PI  0.13     0.15     0.24     0.19     0.27     0.05     0.11     0.19     0.31     0.12
PI  0.20     0.12     0.35     0.38     0.42     0.16     0.21     0.17     0.15     0.20
PI  0.35     0.15     0.71     0.29     0.14     0.03     0.02     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100       USGS RECORDED FLOOD HYDROGRAPH:  SOUTH FORK MILK RIVER NR
*              BABB 06132200
IN    60 06JUN64     2400
QO   92.      92.      92.      92.      92.      92.      92.      95.      98.     101.
QO  104.     107.     110.     113.     117.     120.     130.     140.     151.     163.
QO  186.     220.     255.     290.     347.     404.     461.     518.     789.    1060.
QO 1810.    2560.    4190.    5820.    7910.   10000.   12000.   11600.   10900.   10200.
QO 8500.    6800.    5950.    5110.    4260.    3413.    2570.    1720.    1570.    1420.
QO 1280.    1130.     982.     834.     791.     749.     706.     663.     621.     578.
QO  558.     539.     519.     499.     480.     460.     452.     443.     435.     427.
QO  418.     410.     400.     390.     375.     360.     350.     340.     330.     315.
QO  300.     290.     280.     270.     260.     255.     240.     225.     210.     200.
QO  185.     170.     160.     150.     140.     130.     115.     100.      90.      85.
PT   100
PW   1.0
PR  1000     2000     3000
PW  0.00     0.70     0.30
BA  70.4
BF  100.     -.25     1.15
UC  6.50     0.65
LE -0.25    -4.77     1.00     0.50      0.0
ZZ


ID      SITE 12:  LYONS CREEK AT INTERNATIONAL BOUNDARY, SASKATCHEWAN -
*                 FLOOD OF SEPTEMBER 1986
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 23SEP86     2300       85
IO     1        2
OU    20       75
```

```
PG    10      5.30
PG    100
IN    60 25SEP86    0000
*    ALTAWAN RAINFALL
PI  0.00 .  0.24    0.28    0.31    0.28    0.24    0.28    0.35    0.35    0.35
PI  0.16    0.12    0.20    0.04    0.04    0.04    0.04    0.04    0.04    0.04
PI  0.00    0.04    0.00    0.04    0.00    0.00    0.00    0.04    0.00    0.00
PI  0.00    0.00    0.04    0.04    0.04    0.04    0.04    0.00    0.00    0.00
PG    200
IN    60 24SEP86    2100
*  MEDICINE LODGE RAINFALL
PI  0.16    0.35    0.28    0.24    0.24    0.24    0.35    0.31    0.16    0.24
PI  0.20    0.31    0.20    0.20    0.20    0.20    0.08    0.20    0.04    0.04
PI  0.04    0.04    0.12    0.12    0.08    0.12    0.08    0.04    0.08    0.04
PI  0.04    0.00    0.04    0.00    0.04    0.04    0.04    0.04    0.04    0.04
PI  0.00    0.04    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
*  HAVRE RAINFALL
*FREE
PG 300
IN 60 23SEP86 2300
PI .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .01 .03 .06 .1 .12 .14 .09
PI .08 .22 .18 .15 .15 .22 .2 .13 .14 .12 .12 .13 .01 .0 .0 .01 .0 .01 .02 .03
PI .01 .0 .0 .02 .03 .04 .04 .03 .01
*FIX
KK    100     USGS RECORDED FLOOD HYDROGRAPH:  LYONS CREEK AT INTERNATIONAL BOUNDARY,
*             SASKATCHEWAN 06151000
IN    60 23SEP86    2300
QO    0.        0.      0.      0.      0.      0.      0.      0.      0.      0.
QO    0.        0.      0.      0.      0.      0.      0.      0.      0.      0.
QO    0.        0.      0.      0.      0.      0.      0.      0.      0.    286.
QO  546.      599.    567.    536.    643.    759.   1050.   1380.   1250.   1130.
QO 1020.      911.    895.    880.    864.    849.    807.    763.    722.    664.
QO  616.      558.    539.    527.    527.    527.    521.    515.    503.    492.
QO  475.      458.    447.    425.    410.    394.    379.    364.    348.    333.
QO  325.      320.    319.    317.    314.    308.    303.    296.    290.    283.
QO  277.      270.    266.    263.    260.    256.    250.    248.    245.    243.
QO  240.      238.    236.    232.    230.    229.    228.    225.    221.    218.
QO  216.      215.    213.    211.    208.    208.    205.    201.    200.    198.
QO  194.      190.    186.    181.    178.    174.    172.    168.    165.    162.
QO  159.      156.    152.    148.    145.    144.    142.    140.    138.    134.
QO  133.      131.    129.    128.    128.    128.    126.    124.    123.    122.
QO  121.      121.    120.    118.    118.    117.    116.    116.    114.    114.
QO  113.      112.    111.    111.    111.    109.    108.    108.    107.    105.
QO  104.      104.    102.    100.     99.     99.     99.     97.   96.00     75.
*FREE
QO 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75 75
QO 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60
QO 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51
QO 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45
QO 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36
QO 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24
*FIX
PT    10
PR   100      200     300
PW  1.00     0.00    1.00
BA  66.7
BF   0.0     -.25    1.05
UC  6.30    15.00
LE -0.45    -.400      1.      .5
ZZ


ID      SITE 13:  LITTLE WARM CREEK AT RESERVATION BOUNDARY -
*                 FLOOD OF SEPTEMBER 1986
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT    60 24SEP86    1100     52
IO     1        2
OU     1       52
PG   100      5.3
*       ZORTMAN RAINFALL
IN    60 23SEP86    2200
PI  .000     .000    .000    .000    .000    .000    .000    .000    .000    .000
PI  .000     .000    .000    .000    .000    .000    .000    .000    .000    .000
PI  .000     .100    .400    .000    .300    .500    .100    .600    .300    .400
PI  .400     .300    .300    .400    .300    .300    .100    .200    .000    .200
PI  .200     .100    .000    .000    .000    .000    .000    .000    .000    .000
PG   200      5.3
*FREE
*       CONTENT RAINFALL
IN 60 24SEP86 1600
PI .01 .07 .48 .31 .08 .19 .53 .08 .16 .31 .62 .69 .30 .1 .22 .13 .14 .3 .19
PI .08 .06 0.0 .01 .02 .02 .02 0 0 0
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  LITTLE WARM CREEK AT RESERVATION
*            BOUNDARY 06164615
IN 60 24SEP86 1100
QO 7.9 8.9 12.6 17.4 24.3 32.2 39.8
QO 51.3 69.8 83.7 90.6 96.7 107 126 145 187 254 272 300 263 203 191 182 168 148
QO 132 121 112 103 94.8 88.3 82.3 71.5 60.7 50.0 41.9 35.8 28.8 24.3 19.7 16.9
QO 14.9 13.5 12.6 11.4 10.2 9.9 9.2 8.9 8.5 7.9 7.6
*FIX
PT   100      200
PW    20      100
PR   100      200
PW    20      100
BA  6.31
BF    8.     -.25     1.25
UC  1.06     8.50
LE -0.46    -0.02       1.       .5
ZZ


ID      SITE 14:  BIG WARM CREEK NEAR ZORTMAN - FLOOD OF SEPTEMBER 1986
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 24SEP86     1800       53
IO       1        2
OU       1       53
PG     100      5.5
*       ZORTMAN RAINFALL
IN      60 23SEP86     2300
PI  .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
PI  .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
PI  .000     .100     .400     .000     .300     .500     .100     .600     .300     .400
PI  .400     .300     .300     .400     .300     .300     .100     .200     .000     .200
PI  .200     .100     .000     .000     .000     .000     .000     .000     .000     .000
*FREE
PG 200 5.5
*       CONTENT RAINFALL
IN 60 24SEP86 1600
PI .01 .07 .48 .31 .08 .19 .53 .08 .16 .31 .62 .69 .30 .1 .22 .13 .14 .3 .19
PI .08 .06 0.0 .01 .02 .02 .02 0 0 0
*FIX
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  BIG WARM CR NR ZORTMAN 06164630
*FREE
IN 60 24SEP86 1800
QO 8.8 8.8
QO 8.8 10.7 20.1 30.0 56.5 131 317 513 582 630 585 538 516 500 460 425 416 395
QO 356 305 262 220 168 133 100 77.4 57.1 45.6 37.3 34.6 31.5 29.0 27.0 26.0
QO 24.6 24.1 23.2 22.2 21.8 21.8 21.3 21.3 21.3 20.9 20.9 20.1 20.1 20.1 20.1
QO 19.6 19.2 18.8 18.8
*FIX
PT   100      200
PW   100       50
PR   100      200
PW   100       50
BA  8.58
BF  15.0     1.00     1.00
UC  1.03     4.50
LE -0.43    -0.33     1.00     0.50     0.0
ZZ


ID      SITE 15:  BEAVER CREEK BL GUSTON COULEE NR SACO - FLOOD OF SEPTEMBER 1986
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 24SEP86     1600      212
IO       1        2
OU      25      110
PG     100     5.64
*       ZORTMAN RAINFALL
IN      60 23SEP86     2200
PI  .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
PI  .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
PI  .000     .100     .400     .000     .300     .500     .100     .600     .300     .400
PI  .400     .300     .300     .400     .300     .300     .100     .200     .000     .200
PI  .200     .100     .000     .000     .000     .000     .000     .000     .000     .000
PG     200     5.64
*       CONTENT RAINFALL
*FREE
IN 60 24SEP86 1600
PI .01 .07 .48 .31 .08 .19 .53 .08 .16 .31 .62 .69 .30 .1 .22 .13 .14 .3 .19
PI .08 .06 0.0 .01 .02 .02 .02 0 0 0
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
*FIX
PG   300     5.64
*      HAVRE RAINFALL
IN     60 23SEP88     2300
PI  .000     .000     .000     .000     .000     .000     .000     .000     .000     .000
PI  .000     .000     .000     .000     .000     .000     .000     .010     .030     .060
PI  .100     .120     .14      .090     .080     .220     .180     .150     .150     .220
PI  .200     .130     .140     .120     .120     .130     .010     .000     .000     .010
PI  .000     .010     .020     .030     .010     .000     .000     .020     .030     .040
PI  .040     .030     .010     .000     .000     .000     .000     .000     .000     .000
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  BEAVER CR BL GUSTON COULEE
*            NR SACO  06166000
*FREE
IT 60 24SEP86 2300
QO 700 700 700 700 700 700 700
QO 745 691 687 685 684 680 691 701 712 739 764 792 819 845 871 897 926 952 979
QO 1000 1030 1050 1080 1100 1030 1150 1170 1190 1210 1230 1250 1270 1280 1300
QO 1320 1340 1460 2200 4050 6650 11600 16000 20000 21700 23000 23500 22900
QO 22000 21500 20000 18200 17900 16100 16000 14500 14100 13700 13000 12300
QO 12070 11830 11600 11380 11080 10790 10510 10300 10030 9830 9570 9320 9070
QO 8890 8650 8480 8250 8020 7860 7700 7490 7280 7080 6940 6740 6600 6470 6370
QO 6280 6150 6060 5940 5850 5730 5650 5560 5480 5370 5290 5210 5100 5030 4950
QO 4880 4780 4710 4640 4530 4470 4400 4300 4240 4180 4120 4050 3960 3900 3850
QO 3790 3730 3670 3620 3560 3480 3460 3400 3350 3270 3220 3170 3130 3080 3030
QO 2980 2940 2890 2870 2820 2800 2760 2710 2690 2650 2630 2610 2590 2590 2560
QO 2520 2490 2460 2420 2390 2350 2320 2290 2250 2220 2190 2170 2140 2110 2090
QO 2060 2030 2010 1980 1950 1930 1900 1870 1840 1800 1770 1740 1700 1670 1640
QO 1590 1500 1510 1480 1450 1410 1380 1350 1310 1280 1250 1220 1180 1150 1110
QO 1080
*FIX
PT   100      200      300
PW     0        0      100
PR   100      200      300
PW     0        0      100
BA  1208
BF   700     1.00     1.00
UC 23.00    11.00
LE -.000    -7.18       1.       .5
ZZ


ID      SITE 16:  FLY CREEK AT POMPEYS PILLAR - FLOOD OF MAY 1978
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 16MAY78     1700      260
IO     1        2
OU    40      125
PG    10     3.30
PG   100
*      BILLINGS WSO AP RAINFALL
IN     60 16MAY78     1800
*FREE
PI .02 .00 .00 .06
PI      .14         .12         .14         .00         .01         .01         .00         .01
PI      .00         .04         .04         .04         .01         .05         .06         .06
PI      .04         .06         .04         .08         .08         .12         .10         .10
PI      .11         .06         .08         .14         .12         .12         .12         .08
PI      .14         .08         .10         .08         .15         .28         .08         .01
PI      .02         .05         .09         .09         .12         .08         .11         .08
PI      .06         .02         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00
PG   200
*  ASHLAND RAINFALL
IN     60 16MAY78     2100
PI .10 .10 .30 .20 .40 .10 .00 .10 .00 .00
PI .00 .00 .00 .00 .10 .00 .10 .00 .10 .00
PI .20 .20 .10 .20 .10 .00 .00 .00 .10 .00
PI      .00         .00         .10         .00         .10         .10         .00         .10
PI      .10         .00         .10         .10         .20         .00         .10         .00
PI      .30         .40         .00         .00         .10         .00         .10         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .10         .00         .10         .10         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .00         .00
PI      .00         .00         .00         .00         .00         .00         .10         .00
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PI     .00        .00        .00        .00        .00        .00        .00        .00
PI     .00        .00        .00        .00        .00        .00        .00        .00
PI     .00        .00        .00        .00        .00        .00        .00        .00
PI     .00        .00        .00        .00        .00        .00        .00        .00
PI     .00        .00        .00        .00        .00        .00        .00        .00
PI     .00
PG   300
*       YELLOWTAIL DAM RAINFALL
IN     60 16MAY78    1800
PI 0.0 0.0 .01 .14 .05 .07 .08 .05 .05 .01
PI .0 .04 .0 .05 .03 .0 .04 .1 .03 .1
PI .05 .02 .03 .06 .08 .04 .07 .1 .09 .06
PI .1 .1 .1 .1 .1 .11 .16 .11 .23 .24 .21 .26 .19 .22 .16 .12 .20 .13 .09 .12
PI .11 .06 .06 .05 .06 .06 .05 .01
KK   100      USGS RECORDED FLOOD HYDROGRAPH:  FLY CR AT POMPEYS PILLAR  06217750
IN     60 16MAY78    1700
QO   60.      60.      60.     60.      60.      60.      60.      60.      60.      60.
QO   60.      60.      60.     60.      60.      60.      60.      60.      60.      60.
QO   60.      60.      60.     60.      60.      60.      60.      60.      60.      60.
QO   64.      73.      82.     91.     100.     122.     144.     165.     187.     245.
QO  303.     387.     470.    576.     682.     921.    1160.    1890.    2610.    3440.
QO 4270.    5050.    5830.   6610.    7380.    7950.    8510.    9080.    9640.    9810.
QO 9970.   10140.   10300.   9980.    9660.    9340.    9020.    8490.    7960.    7430.
QO 6900.    6580.    6270.   5950.    5630.    5450.    5270.    5080.    4900.    4800.
QO 4690.    4590.    4480.   4380.    4270.    4180.    4080.    3990.    3900.    3800.
QO 3710.    3560.    3410.   3260.    3100.    2550.    2800.    2540.    2280.    2030.
QO 1760.    1510.    1250.   1160.    1070.     983.     894.     805.     716.     672.
QO  628.     584.     540.    517.     495.     472.     449.     418.     387.     655.
QO  324.     315.     306.    297.     288.     279.     268.     261.     254.     247.
QO  240.     233.     226.    221.     216.     211.     206.     201.     196.     193.
QO  189.     186.     182.    179.     175.     173.     170.     168.     165.     163.
QO  160.     157.     152.    148.     145.     142.     140.     135.     125.     121.
QO  118.     115.     135.    135.     135.     135.     135.     135.     135.     135.
QO  135.     135.     135.    135.     135.0    137.     139.     140.     142.     144.
QO  146.     150.     152.    154.     156.     156.     160.     163.     165.     168.
QO  170.     172.     174.    172.     170.     170.     168.     166.     165.0    160.
QO  158.     155.     150.    148.     145.     140.     140.     135.     130.     130.
QO  125.     130.     135.    135.     135.     130.     128.     125.     120.     115.
QO  110.     105.     100.0   98.      95.      92.       90.      88.      85.      85.
QO   85.      85.      85.     85.      85.      85.      85.      85.      85.      85.
QO   85.      85.      85.     82.      80.      77.      75.0     70.      67.      67.
QO   67.      67.      67.     67.      67.      67.      67.      67.      65.      65.
PT    10
PR   100       200      300
PW  0.00      0.00      1.0
BA 285.0
BF  65.0      1.00      1.00
UC 19.5     16.00
LE-0.07     -1.35       1.       .5
ZZ


ID      SITE 17:  LITTLE BIGHORN RIVER BL PASS CREEK, NEAR WYOLA 06290500 -
*                 FLOOD OF MAY 1978
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 16MAY78    1800      120
IO      1        2
OU      1      120
PG    100      2.5
*       BILLINGS WSO AP RAINFALL
IN     60 16MAY78    1800
*FREE
PI .02 .0 .0 .06 .14 .12 .14 .0 .01 .01 .0 .01 .0 .04 .04 .04 .01 .05 .06 .06
PI .04 .06 .04 .08 .08 .12 .10 .10 .11 .06 .08 .14 .12 .12 .12 .08 .14 .08 .10
PI .08 .15 .28 .08 .01 .02 .05 .09 .09 .12 .08 .11 .08 .02
PG    200      2.5
*       YELLOWTAIL DAM RAINFALL
IN     60 16MAY78    1800
PI .0 .0 .01 .14 .05 .07 .08 .05 .05 .01 .0 .04 .0 .05 .03 .0 .04 .1 .03 .1
PI .05 .02 .03 .06 .08 .04 .07 .1 .09 .06 .1 .1 .1 .1 .1 .11 .16 .11 .23 .24
PI .21 .26 .19 .22 .16 .12 .20 .13 .09 .12 .11 .06 .06 .05 .06 .06 .05 .01
PG    300      2.5
*       LODGE GRASS RAINFALL
IN     60 16MAY78    2000
PI .10 .20 .20 .10 .10 .00 .00 .00 .10 .00 .10 .00 .00 .00 .10 .10 .10
PI .10 .10 .30 .20 .00 .20 .00 .10 .00 .90 .10 .10 .10 .20 .10 .10 .10 .10
PI .10 .10 .10 .10 .60 .30 .50 .20 .00 .10 .20
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
KK    100    USGS RECORDED FLOOD HYDROGRAPH:  LITTLE BIGHORN RIVER BL PASS CREEK,
*                                             NR WYOLA 06290500
IN     60 16MAY78     1800
QO 1000 1000 1000 1000 1000
QO 1090 1100 1110 1110 1120 1130 1140 1150 1160 1160 1170 1180 1190 1210 1230
QO 1250 1270 1330 1380 1440 1490 1580 1680 1770 1860 1970 2080 2180 2290 2400
QO 2520 2630 2740 2880 3020 3160 3300 3510 3710 3920 4120 4700 5280 5660 6030
QO 6160 6290 6420 6550 7040 7520 8010 7740 7470 7200 7010 6820 6620 6430 6600
QO 6770 6390 6010 5630 5440 5240 5050 4830 4620 4400 4200 3990 3790 3630 3480
QO 3320 3160 3060 2950 2850 2740 2670 2600 2520 2450 2390 2330 2260 2200 2150
QO 2090 2040 1980 1950 1920 1890 1860 1830 1800 1750 1700 1660 1600 1560 1500
QO 1450 1400 1350 1300 1250 1200 1150 1100 1050 1000
PT    100       200       300
PW      0       100       100
PR    100       200       300
PW      0       100       100
BA    428
BF   1000      1.00      1.00
UC 22.01     17.44
LE   -.16      -.00        1.        .5
ZZ


ID      SITE 18:  LITTLE BIGHORN RIVER NEAR HARDIN - FLOOD OF MAY 1978
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 16MAY78     1800      158
IO      1         2
OU      1       158
PG    100       3.5
*      BILLINGS WSO AP RAINFALL
IN     60 16MAY78     1800
*FREE
PI .02 .0 .0 .06 .14 .12 .14 .0 .01 .01 .0 .01 .0 .04 .04 .04 .01 .05 .06 .06
PI .04 .06 .04 .08 .08 .12 .10 .10 .11 .06 .08 .14 .12 .12 .12 .08 .14 .08 .10
PI .08 .15 .28 .08 .01 .02 .05 .09 .09 .12 .08 .11 .08 .02
PG    200       3.5
*      YELLOWTAIL DAM RAINFALL
IN     60 16MAY78     1800
PI .0 .0 .01 .14 .05 .07 .08 .05 .05 .01 .0 .04 .0 .05 .03 .0 .04 .1 .03 .1
PI .05 .02 .03 .06 .08 .04 .07 .1 .09 .06 .1 .1 .1 .1 .1 .11 .16 .11 .23 .24
PI .21 .26 .19 .22 .16 .12 .20 .13 .09 .12 .11 .06 .06 .05 .06 .06 .05 .01
PG    300       3.5
*      LODGE GRASS RAINFALL
IN     60 16MAY78     2000
PI .10 .20 .20 .10 .10 .00 .00 .00 .10 .00 .10 .00 .00 .00 .10 .10 .10
PI .10 .10 .30 .20 .00 .20 .00 .10 .00 .90 .10 .10 .10 .20 .10 .10 .10 .10
PI .10 .10 .10 .10 .60 .30 .50 .20 .00 .10 .20
PG 400        3.50
*      ASHLAND RAINFALL
IN 60 16MAY78 2100
PI .10 .10 .30 .20 .40 .10 .00 .10 .00 .00 .00 .00 .00 .00 .10 .00
PI .10 .00 .10 .00 .20 .20 .10 .20 .10 .00 .00 .00 .10 .00 .10 .10 .00
PI .10 .10 .00 .10 .10 .20 .00 .10 .00 .30 .40 .00 .00 .10 .00 .10 .00
PI .00 .00 .00 .00 .00 .00 .00 .00 .10 .00 .10 .10
PG 500        3.50
*      PINE TREE 9NE RAINFALL
IN 60 16MAY78 1700
PI .33 .33 .33 .33 .33 .33 .04 .04 .04 .04 .04 .04 .04 .04 .04 .04 .04
PI .04 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125
PI .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125
KK    100   USGS RECORDED FLOOD HYDROGRAPH:  LITTLE BIGHORN RIVER NR HARDIN 06294000
IN     60 16MAY78     1800
QO 1400 1400 1400 1400 1400
QO 1440 1450 1470 1480 1490 1510 1520 1530 1530 1540 1550 1550 1560 1570 1580
QO 1590 1590 1600 1610 1640 1670 1690 1720 1750 1780 1930 2080 2230 2390 2540
QO 2690 2900 3120 3330 3540 3760 3970 4140 4320 4490 4660 4840 5010 5120 5230
QO 5340 5460 5570 5680 5760 5840 5910 5990 6070 6150 6380 6600 6830 7050 7280
QO 7500 7900 8290 10000 11700 15400 19000 19800 20500 20800 21000 22500 20900
QO 20700 20400 20000 19600 19100 18600 18100 17500 17100 16600 16100 15500
QO 15100 14700 14300 13800 13400 13000 12600 12200 11900 11500 11100 10700
QO 10400 10200 9860 9570 9290 9010 8820 8630 8440 8250 8060 7870 7710 7560 7400
QO 7240 7090 6930 6810 6680 6560 6440 6310 6190 6030 5880 5720 5560 5410 5250
QO 5150 5050 4950 4840 4740 4640 4530 4410 4300 4180 4070 3960 3880 3810 3730
QO 3650 3570 3500 3000 2500 2000 1500
PT    100       200       300       400       500
PW      0         0         0       100         0
PR    100       200       300       400       500
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
PW     0        0        0      100       0
BA  1294
BF  1400     1.00     1.00
UC 47.77    21.07
LE  -.16    -3.72       1.       .5
ZZ


ID      SITE 19:  TONGUE RIVER AT STATE LINE NEAR DECKER - FLOOD OF MAY 1978
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 16MAY78    1700     152
IO      1       2
OU      1     152
PG   100     3.25
*      BILLINGS WSO AP RAINFALL
IN     60 16MAY78    1800
*FREE
PI .02 .0 .0 .06 .14 .12 .14 .0 .01 .01 .0 .01 .0 .04 .04 .04 .01 .05 .06 .06
PI .04 .06 .04 .08 .08 .12 .10 .10 .11 .06 .08 .14 .12 .12 .12 .08 .14 .08 .10
PI .08 .15 .28 .08 .01 .02 .05 .09 .09 .12 .08 .11 .08 .02
PG   200     3.25
*      YELLOWTAIL DAM RAINFALL
IN     60 16MAY78    1800
PI .0 .0 .01 .14 .05 .07 .08 .05 .05 .01 .0 .04 .0 .05 .03 .0 .04 .1 .03 .1
PI .05 .02 .03 .06 .08 .04 .07 .1 .09 .06 .1 .1 .1 .1 .1 .11 .16 .11 .23 .24
PI .21 .26 .19 .22 .16 .12 .20 .13 .09 .12 .11 .06 .06 .05 .06 .06 .05 .01
PG   300     3.25
*      LODGE GRASS RAINFALL
IN     60 16MAY78    2000
PI .10 .20 .20 .10 .10 .00 .00 .00 .10 .00 .10 .00 .00 .00 .10 .10 .10
PI .10 .10 .30 .20 .00 .20 .00 .10 .00 .90 .10 .10 .10 .20 .10 .10 .10 .10
PI .10 .10 .10 .10 .60 .30 .50 .20 .00 .10 .20
PG 400       3.25
*      ASHLAND RAINFALL
IN 60 16MAY78 2100
PI .10 .10 .30 .20 .40 .10 .00 .10 .00 .00 .00 .00 .00 .00 .10 .00
PI .10 .00 .10 .00 .20 .20 .10 .20 .10 .00 .00 .00 .10 .00 .10 .10 .00
PI .10 .10 .00 .10 .10 .20 .00 .10 .00 .30 .40 .00 .00 .10 .00 .10 .00
PI .00 .00 .00 .00 .00 .00 .00 .00 .10 .00 .10 .10
PG 500       3.25
*      PINE TREE 9NE RAINFALL
IN 60 16MAY78 1700
PI .33 .33 .33 .33 .33 .33 .04 .04 .04 .04 .04 .04 .04 .04 .04 .04 .04
PI .04 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125
PI .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125 .125
KK    100  USGS RECORDED FLOOD HYDROGRAPH:  TONGUE RIVER AT STATE LINE NR
*                                           DECKER 06306300
IN     60 15MAY78    1800
QO 1600 1600 1600 1600 1600
QO 1640 1640 1650 1680 1690 1700 1790 1920 2000 1950 2100 2120 2180 2260 2320
QO 2370 2400 2410 2420 2450 2450 2440 2450 2480 2490 2520 2540 2560 2570 2590
QO 2590 2600 2610 2630 2680 2720 2780 2830 2890 2920 2990 3060 3140 3210 3280
QO 3370 3430 3500 3610 3730 3830 4010 4170 4310 4480 4690 4910 5170 5460 5810
QO 6180 6500 6860 7220 7570 8060 8520 9050 9660 10250 10730 11100 11260 11870
QO 12660 13070 13770 14620 15460 16090 16550 16900 17220 17360 17440 17500
QO 17390 17220 17010 16600 16150 15590 14970 14390 13870 13260 12660 12100
QO 11590 11110 10730 10370 10050 9700 9390 9040 8710 8410 8110 7840 7570 7330
QO 7100 6880 6670 6500 6310 6170 6040 5900 5760 5620 5500 5360 5230 5140 5040
QO 4950 4880 4800 4750 4700 4650 4600 4560 4520 4460 4420 4380 4320 4270 4230
QO 4160 4110 4070 4010 3960 3910 3860 3820 3790 3780 3770 3770 3780 3800 3820
QO 3840 3860 3870 3880 3880 3870 3840 3830 3800 3790 3750 3710 3690
PT    100      200      300      400      500
PW      0      100        0        0        5
PR    100      200      300      400      500
PW      0      100        0        0        5
BA   1477
BF   2420     1.00     1.00
UC 27.16    24.00
LE  -.22     -.00       1.       .5
ZZ
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
ID      SITE 20:  PRAIRIE DOG CREEK AB JACK CREEK NR BIRNEY
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     15 23JUN82     1500       75
IO      1        2
OU     23       37
PG    100      2.5
PG   1000
*       USGS PROJECT ON PRAIRIE DOG CREEK: 1982 RAINFALL
IN     30 22JUN82     1900
PI  0.00     0.00     0.00     0.00     0.55     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.50     0.00     0.00     0.00     0.00     0.03
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     2.04     0.22     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.13     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK    100    USGS RECORDED FLOOD HYDROGRAPH:  PRAIRIE DOG CREEK AB JACK
*            CREEK NR BIRNEY  06307525
IN     30 22JUN82     2400
QO  0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01
QO  0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01     0.01
QO  0.01     0.01     0.01     0.01       1.       2.       1.       1.       1.       1.
QO    1.       1.       1.       1.       1.       1.       1.       1.       1.       1.
QO    1.       1.       1.     400.      70.      50.      33.       9.       6.       5.
QO    5.       4.       3.       3.       3.       3.       2.       2.       2.       2.
QO    2.       2.       2.       2.       2.       1.       1.       1.       1.       1.
QO    1.       1.       1.       1.       1.       1.       1.       1.       1.       1.
QO    1.       1.       1.       1.       1.       1.       1.       1.       1.       1.
QO    1.       1.       1.       1.       1.       1.       1.       1.     0.01     0.01
PT    100
PW    1.0
PR   1000
PW   1.00
BA   6.57
BF     1.     1.00     1.00
UC  0.55     0.27
LE -0.69    -6.37     1.00     0.50      0.0
ZZ
```

```
ID     SITE 21:  SUNDAY CREEK NR MILES CITY - FLOOD OF MAY 1975
ID     DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 05MAY75     1500      122
IO      1        2
OU      1       90
PG    100
*      TERRY 21NNW RAINFALL
IN     60 05MAY75     1500
*FREE
PI .0 .0
PI .0 .0 .04 .04 .13 .30 .11 .04 .05 .2 .07 .0 .02 .0 .0 .02 .0 .0
PI .01 .24 .15 .12 .39 .11 .04
PG    200
*      COHAGEN RAINFALL
IN     60 05MAY75     1500
PI .0 .06 .2 .27 .3 .19 .2 .08 .0 .0 .01 .02 .1 .02 .15 .08 .1 .0 .09 .04 .09
PI .2 .13 .0 .0 .1 .0 .0 .0 .0 .0 .0 .0 .0 .0 .03 .02 .0 .0 .0 .0 .0 .0
PI .0 .0 .0 .05 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
PI .0 .0 .0 .04 .01
KK   100  USGS RECORDED FLOOD HYDROGRAPH:  SUNDAY CR NR MILES CITY  06309075
*   FLOWS ON RECESSION LIMB OF HYDROGRAPH BEYOND MAY 7TH ARE ADJUSTED
*   TO REMOVE INFLUENCE OF RAINFALL BEYOND STORM OF MAY 5TH AND 6TH.
IN     60 05MAY75     1600
QO 33 33 34 46 145 208 270 248 240 890 1640 2380 2580 2780 2980 2920 3170
QO 3410 3660 3900 4260 4610 4820 5040 5250 5460 5680 5890 6100 6310
QO 6530 6740 6760 6480 6200 6110 6020 5930 5840 5750 5550 5350 5150 4950
QO 4680 4410 4140 3870 3730 3600 3460 3320 3040 2750 2470 2180 2040
QO 1900 1750 1610 1520 1450 1370 1300 1230 1163 1096 1029 962
QO 895 828 799 769 740 710 707 665 636 607 578 549 520 491 477 462 448
QO 433 419 404 392 380 368 356 344 332 321 311 300 289 279 268 255 245
QO 235 225 215 200 190 180 170 155 146 130 115 100 90 75 60 50 40 33
*FIX
PT    100      200
PW    100      100
PR    100      200
PW    100      100
BA    714
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
BF    33     1.00     1.00
UC 27.20      8.8
LE  -.27    -0.03       1.       .5
ZZ


ID      SITE 22:  FLATHEAD RIVER AT FLATHEAD, BRITISH COLUMBIA - FLOOD OF JUNE 1964   ID
   DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 06JUN64     2400       85
IO      1        2
OU      1       85
PG   100      4.0
PG  1000
*    SUMMIT RAINFALL
IN     60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI  0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100      USGS RECORDED FLOOD HYDROGRAPH:  FLATHEAD RIVER AT FLATHEAD,
*             BRITISH COLUMBIA 12355000
IN     60 06JUN64     2400
QO 6310.    6250.    6190.    6120.    6060.    6000.    6050.    6100.    6150.    6210.
QO 6260.    6310.    6360.    6400.    6450.    6490.    6530.    6580.    6620.    6730.
QO 6830.    6940.    7050.    7150.    7260.    7490.    7710.    7940.    8160.    8370.
QO 8590.    9050.    9500.    9960.   10600.   11400.   12100.   12700.   13400.   14000.
QO14300.   14600.   15600.   15700.   15900.   15700.   15600.   16300.   15900.   15800.
QO15800.   15700.   14900.   14300.   14600.   14900.   15300.   15000.   14800.   14500.
QO14300.   13900.   13400.   13000.   12600.   12200.   11800.   11500.   11300.   11000.
QO10700.   10300.   10000.    9700.    9400.    9100.    8800.    8500.    8200.    7900.
QO 7700.    7400.    7000.    6700.    6300.
PT   100
PW   1.0
PR  1000
PW   1.0
BA  450.
BF 6300.     1.00     1.00
UC 13.16    25.86
LE -0.23    -0.31     1.00     0.50      0.0
ZZ


ID      SITE 23:  NORTH FORK FLATHEAD RIVER NR COLUMBIA FALLS -
*                 FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT     60 06JUN64     2400      145
IO      1        2
OU      1      145
PG   100      6.0
PG  1000
*    SUMMIT RAINFALL
IN     60 06JUN64     0100
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03     0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06     0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI  0.35     0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44     0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100      USGS RECORDED FLOOD HYDROGRAPH:  NORTH FORK FLATHEAD RIVER
*             NR COLUMBIA FALLS  12355500
IN     60 06JUN64     2400
QO16400.   16500.   16500.   16600.   16700.   16700.   16800.   16900.   16900.   17000.
QO17100.   17100.   17200.   17300.   17300.   17400.   17500.   17500.   17600.   17700.
QO17800.   17900.   18000.   18100.   18200.   18400.   18700.   18900.   19100.   19400.
QO19700.   20200.   20700.   21300.   21900.   22800.   23700.   25200.   26700.   28100.
QO29600.   31300.   32900.   34600.   36200.   37500.   38900.   40200.   41500.   44600.
QO47800.   51000.   54500.   58000.   60800.   63600.   66300.   69100.   68700.   68400.
QO68000.   65500.   62900.   61200.   59400.   57700.   55900.   54900.   54000.   53000.
QO51700.   50400.   49100.   47600.   46100.   44700.   43200.   41700.   40200.   39700.
QO39200.   38700.   38200.   37700.   37200.   36400.   35500.   34700.   33900.   33000.
QO32200.   31600.   31100.   30500.   29900.   29400.   28800.   28400.   28000.   27600.
QO27200.   26800.   26400.   26000.   25600.   25200.   24800.   24400.   24000.   23900.
QO23900.   23800.   23700.   23700.   23600.   23300.   23100.   22800.   22500.   22300.
QO22000.   21900.   21800.   21700.   21600.   21500.   21400.   21200.   21100.   21000.
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
QO20900.  20800.  20700.  20700.  20700.  20700.  20700.  20700.  20700.  20700.
QO20700.  20700.  20700.  20700.  20700.      0.      0.      0.      0.      0.
PT   100
PW   1.0
PR  1000
PW   1.0
BA 1548.
BF16500.    1.00    1.00
UC 33.00    19.0
LE-0.29    -2.24    1.00     0.50     0.0
ZZ


ID      SITE 24:  MIDDLE FORK FLATHEAD RIVER NR WEST GLACIER - FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 06JUN64    2400      149
IO       1       2
OU      10     100
PG     100    11.0
PG    1000
*     SUMMIT RAINFALL
IN      60 06JUN64    0100
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.02    0.01    0.07    0.07    0.05
PI    0.03    0.05    0.03    0.10    0.13    0.06    0.02    0.03    0.05    0.06
PI    0.06    0.10    0.22    0.19    0.32    0.29    0.29    0.16    0.27    0.33
PI    0.35    0.40    0.45    0.54    0.52    0.46    0.40    0.46    0.54    0.30
PI    0.44    0.15    0.07    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
KK     100    USGS RECORDED FLOOD HYDROGRAPH:  MIDDLE FORK FLATHEAD RIVER NR WEST
*                                          GLACIER  12358500
IN      60 06JUN64    2400
QO17400.  17400.  17400.  17400.  17400.  17400.  17400.  17400.  17400.  17400.
QO17500.  17500.  17500.  17500.  17500.  17500.  17500.  17500.  17500.  17600.
QO17700.  17800.  17900.  18000.  18000.  18500.  19000.  19400.  19900.  20400.
QO20900.  22400.  23800.  25300.  26700.  29600.  32400.  36400.  40400.  44400.
QO54300.  64200.  74100.  85300.  96500. 107800. 119000. 129000. 139000. 140000.
QO138000 136000. 128000. 120000. 112000. 107900. 103800.  99700.  95600.  91500.
QO87400.  84500.  81600.  78700.  75800.  72900.  70000.  67800.  65700.  63500.
QO61300.  59200.  57000.  55400.  53700.  52100.  50500.  48800.  47200.  46100.
QO44900.  43800.  42700.  46100.  44900.  43800.  42700.  41500.  40400.  39500.
QO38500.  37600.  36700.  35700.  34800.  34100.  33500.  32800.  32100.  31500.
QO30800.  30400.  30000.  29600.  29200.  28800.  29400.  28000.  27600.  27200.
QO26800.  26400.  26000.  25800.  25500.  25300.  25000.  24800.  24500.  24300.
QO24000.  23800.  23500.  23300.  23000.  22900.  22700.  22600.  22400.  22300.
QO22100.  22000.  21800.  21700.  21500.  21400.  21200.  21000.  20800.  20600.
QO20400.  20160.  20000.  19700.  19500.  19300.  19100.  18900.  18700.      0.
PT   100
PW   1.0
PR  1000
PW   1.0
BA 1128.
BF17400.     -.25    1.00
UC 19.30    17.60
LE -0.23    -6.76    1.00     0.50     0.0
ZZ


ID      SITE 25:  SOUTH FORK FLATHEAD RIVER AT SPOTTED BEAR RANGER STATION,
*                 NR HUNGRY HORSE - FLOOD OF JUNE 1964
ID      DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 06JUN64    2400      116
IO       1       2
OU       1     116
PG     100     4.5
PG    1000
*     SUMMIT RAINFALL
IN      60 06JUN64    0100
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.02    0.01    0.07    0.07    0.05
PI    0.03    0.05    0.03    0.10    0.13    0.06    0.02    0.03    0.05    0.06
PI    0.06    0.10    0.22    0.19    0.32    0.29    0.29    0.16    0.27    0.33
PI    0.35    0.40    0.45    0.54    0.52    0.46    0.40    0.46    0.54    0.30
PI    0.44    0.15    0.07    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
PI    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
```

Table 9.--Input data for HEC-1 flood-hydrograph model for sites in Montana--Continued

```
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  SOUTH FORK FLATHEAD RIVER AT
*            SPOTTED BEAR RANGER STATION, NR HUNGRY HORSE  12359000
IN    60 06JUN64     2400
QO11500.  11500.  11500.  11500.  11600.  11600.  11600.  11600.  11600.  11700.
QO11700.  11700.  11700.  11700.  11800.  11800.  11900.  11900.  12000.  12000.
QO12000.  12100.  12100.  12200.  12200.  12500.  12800.  13100.  13400.  14200.
QO15000.  15800.  16600.  18800.  20900.  23100.  25200.  27400.  29700.  31900.
QO33000.  34200.  35300.  35900.  36500.  36600.  36700.  36600.  36500.  35100.
QO35400.  34800.  34300.  33700.  33200.  32600.  32100.  31500.  30900.  30300.
QO29700.  29000.  28300.  27600.  26900.  26300.  25600.  25000.  24300.  23900.
QO23500.  23100.  22700.  22300.  21900.  21600.  21200.  20800.  20400.  20000.
QO19700.  19300.  18900.  18600.  18200.  17900.  17500.  17200.  16900.  16500.
QO16200.  15900.  15700.  15400.  15100.  14900.  14600.  14400.  14200.  14000.
QO13900.  13700.  13500.  13400.  13300.  13300.  13100.  13000.  12800.  12600.
QO12400.  12200.  12000.  11800.  11600.  11400.  11200.  11000.  10800.  10600.
QO10600.  10600.  10700.  10700.  10700.  10700.  10800.  10800.  10800.  10900.
QO10900.  10900.  10900.  10900.  10900.  10900.  10900.  10900.  10800.  10800.
QO10800.  10800.  10800.  10800.      0.      0.      0.      0.      0.      0.
PT   100
PW   1.0
PR  1000
PW   1.0
BA  958.
BF11500.     -.25     1.00
UC 13.84    25.63
LE -0.26    -0.50     1.00     0.50      0.0
ZZ


ID       SITE 26:  SULLIVAN CREEK NR HUNGRY HORSE - FLOOD OF JUNE 1964
ID       DERIVATION OF UNIT HYDROGRAPH AND RELATED VARIABLES
IT      60 06JUN64     2400      105
IO       1        2
OU       1      105
PG     100      6.0
PG    1000
*      SUMMIT RAINFALL
IN      60 06JUN64     0100
PI  0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00      0.00     0.00     0.00     0.00     0.02     0.01     0.07     0.07     0.05
PI  0.03      0.05     0.03     0.10     0.13     0.06     0.02     0.03     0.05     0.06
PI  0.06      0.10     0.22     0.19     0.32     0.29     0.29     0.16     0.27     0.33
PI  0.35      0.40     0.45     0.54     0.52     0.46     0.40     0.46     0.54     0.30
PI  0.44      0.15     0.07     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
PI  0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
KK   100     USGS RECORDED FLOOD HYDROGRAPH:  SULLIVAN CREEK NR
*            HUNGRY HORSE   12361000
IN    60 06JUN64     2400
QO 1250.     1240.    1240.    1230.    1230.    1220.    1210.    1210.    1200.    1200.
QO 1190.     1180.    1180.    1190.    1200.    1210.    1220.    1230.    1250.    1260.
QO 1270.     1280.    1290.    1300.    1310.    1360.    1420.    1470.    1520.    1580.
QO 1630.     1980.    2340.    2690.    3010.    3320.    3640.    3900.    4160.    4380.
QO 4600.     4810.    5020.    4840.    4650.    4520.    4390.    4250.    4120.    3960.
QO 3800.     3650.    3490.    3330.    3170.    3070.    2960.    2860.    2760.    2650.
QO 2550.     2510.    2470.    2430.    2390.    2350.    2310.    2260.    2220.    2170.
QO 2120.     2080.    2030.    1980.    1940.    1890.    1840.    1800.    1750.    1700.
QO 1660.     1610.    1560.    1520.    1470.    1460.    1450.    1440.    1430.    1420.
QO 1410.     1400.    1390.    1380.    1370.    1360.    1350.    1340.    1320.    1310.
QO 1300.     1280.    1270.    1260.    1240.    1230.    1220.    1200.    1190.    1180.
QO 1170.     1160.    1150.    1140.    1130.    1120.    1120.    1110.    1100.    1090.
QO 1080.        0.       0.       0.       0.       0.       0.       0.       0.       0.
PT   100
PW   1.0
PR  1000
PW   1.0
BA  71.3
BF 1240.     -.25     1.00
UC  6.92    15.80
LE -0.27    -2.63     1.00     0.50      0.0
ZZ
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