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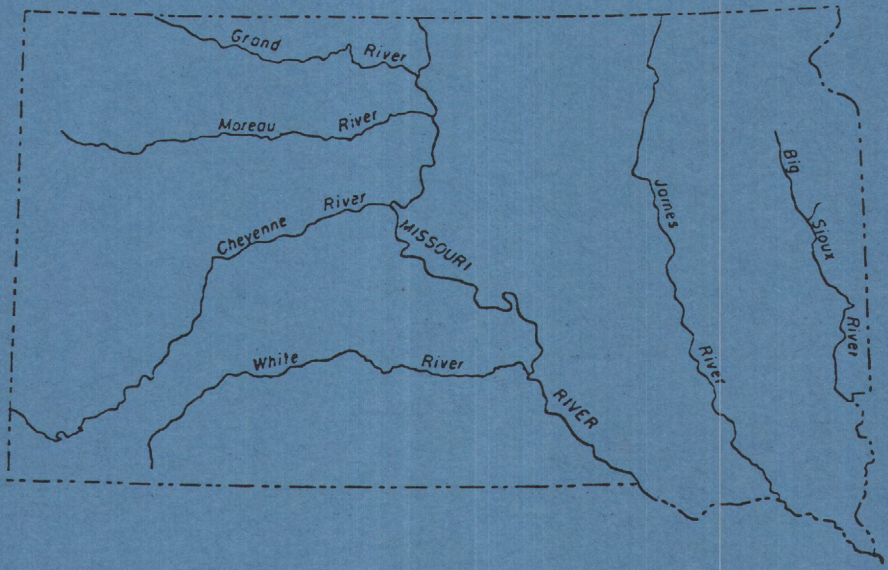
TECHNIQUES FOR ESTIMATING FLOOD PEAKS, VOLUMES, AND HYDROGRAPHS ON SMALL STREAMS IN SOUTH DAKOTA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-80

Prepared in cooperation with the
South Dakota Department of Transportation
and the U.S. Department of Transportation,
Federal Highway Administration



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16. Abstract (Limit: 200 words) Procedures are defined for estimating magnitude and frequency of future flood peaks and flood volumes and for estimating hydrograph shape of rainfall-induced runoff of small streams in South Dakota where flood flows are not significantly affected by artificial storage or other manmade activities. For 115 gaged sites, the estimates are from frequency curves defined from the gaging records. Estimates are made for ungaged sites using regression relations based on drainage basin size, main channel slope, and a soil-infiltration index. Estimating relations are applicable for flood peaks on watersheds draining 0.05 to 100 square miles and for flood volumes on watersheds draining from 0.05 to 15 square miles. Limitations on use of the regression relations and the reliability of estimates are discussed. A method is indicated for using the estimating procedures and embankment ponding to design smaller highway culverts.

The procedures were developed from analysis of flood records of 123 gaged sites. For 66 sites, short-term records were extended using long-term climatic records and a rainfall-runoff model. Flood magnitudes as dependent variables were related by regression analyses to indexes describing the drainage basins as independent variables. A dimensionless hydrograph shape was found appropriate for rainfall-runoff hydrographs.

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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METRIC CONVERSIONS

The analyses and compilations used in this report are based on inch-pound units of measurements. Conversion factors for inch-pound units and metric units are listed below. Multiply inch-pound units by the conversion factor to obtain metric units.

Inch-pound units	Conversion factor	Metric units
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
acre-foot (acre-ft)	1233.	cubic meter (m^3)

TECHNIQUES FOR ESTIMATING

FLOOD PEAKS, VOLUMES, AND HYDROGRAPHS

ON SMALL STREAMS IN SOUTH DAKOTA

by Lawrence D. Becker

ABSTRACT

Procedures are defined for estimating the magnitude and frequency of future flood peaks and flood volumes and for estimating the expected hydrograph shape of rainfall-induced runoff of small streams in South Dakota. The procedures are applicable to flood flows that are not significantly affected by artificial storage or other manmade activities. For 115 gaged sites within the State, the estimates are from the frequency curves defined from the gaging records. Flood-frequency estimates are made for ungaged sites by using regression relations that require evaluation of the size, main channel slope, and a soil-infiltration index for the drainage basin. Regression relations are considered applicable for estimating flood peaks at sites on basins draining 0.05 to 100 square miles and for estimating flood volumes at sites on basins draining from 0.05 to 15 square miles.

Limitations on use of the regression relations and the reliability of regression estimates are discussed. A method is indicated for using the estimating procedure and embankment ponding to design smaller highway culverts.

The procedures were developed from analysis of flood records of 123 gaged sites in South Dakota and adjacent States. For 66 sites, short-term records were extended on the basis of long-term climatic records and a rainfall-runoff model. Linear least-squares regression analyses were used with logarithmic transformation of variables to relate flood magnitudes as dependent variables to indexes describing the drainage basins as independent variables. A dimensionless hydrograph shape was found appropriate for rainfall-runoff hydrographs in South Dakota.

INTRODUCTION

The magnitude and frequency of flood flows need to be considered in the design of highway structures such as bridges and culverts, in land-use planning, in establishing rates for flood insurance, or in formulating emergency evacuation plans for flood-prone areas. A regional flood-frequency analysis, which provides techniques for estimating peaks with recurrence intervals of as much as 100 years at most ungaged sites located in unregulated drainage basins, has been made for South Dakota

(Becker, 1974). However, the magnitude of flood volumes and the characteristic shape of flood hydrographs to be expected must also be known if embankment ponding is to be considered as a design factor and used to reduce required culvert size. In order to determine flood-flow characteristics in unregulated drainage basins with areas less than 10 mi^2, the U.S. Geological Survey, in cooperation with the South Dakota Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration, conducted an investigation to: (1) Determine the magnitude and frequency of flood peaks and volumes in small, unregulated drainage basins, (2) define the characteristic shape of flood hydrographs, and (3) develop a method for using embankment ponding in culvert design.

This is the final report resulting from the investigation and supplements earlier reports by Becker (1973, 1974). The report presents flood frequency information at gaged sites; a simple, practical method for estimating flood peaks and volumes at ungaged sites; a method for estimating flood volumes based on known flood peaks; a method for determining the shape of flood hydrographs; and a method for using embankment ponding in reducing culvert size. The opinions, findings, and conclusions presented in this report are those of the U.S. Geological Survey and are not necessarily those of the cooperating agencies.

The report is organized so that the estimating relations, their accuracy and limitations, and examples of their use; and a method regarding use of embankment ponding are presented first. These items are followed by a documentation of the data available and of the procedures used in the data analysis including aspects of rainfall-runoff modeling, flood-frequency analysis, regression analysis, and determination of hydrograph shape.

Approach

The approach to this research has been to collect and analyze data on flood peaks and flood volumes on a sample of streams draining basins with areas generally less than 10 mi^2. These data were augmented by peak-flow data from a crest-stage gaging program that were collected on basins of between 10 and 150 mi^2 in area.

Analysis included defining relationships between magnitude and frequency of flood peaks and flood volumes for gaged sites. Because reliability of that frequency relationship increases with record length, a rainfall-runoff model was used to synthesize long-term flood records from available long-term climatological records. Multiple-regression analysis defined relations for estimating the magnitude-frequency relation for both flood peaks and flood volumes at ungaged sites. The average time-distribution (hydrograph) of observed rainstorm floods also was defined.

Acknowledgments

Long-term daily precipitation records and 5-minute incremental storm-rainfall data were obtained from the National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, at Asheville, N.C.

D. M. Thomas and G. R. Dempster, Jr., of the U.S. Geological Survey, provided technical advice and assistance needed to apply the rainfall-runoff model to hydrologic conditions in South Dakota and to refine the model to meet specific project objectives.

ESTIMATING RELATIONS

The most reliable estimators of future floods generally are the frequency analyses of gaging-station records. Streamflow characteristics listed in tables 4 and 5 at the back of the report under the heading "Supplemental Information" may provide satisfactory estimates for planning and design of bridges and culverts at or near gaged sites, particularly where long-term records are available. Therefore, the estimating technique includes a search for available flood-frequency data for the desired site.

Estimating peak discharges and runoff volumes at ungaged sites or at gaged sites with short-term records where floodflow is virtually natural involves solving mathematical equations relating flow magnitude to basin characteristics. The equations are:

$$Q_t = aA^bS^cSi^d \text{ (peak discharge)}, \tag{1}$$

$$V_t = aA^bSi^c \text{ (runoff volume)}, \tag{2}$$

where

Q = peak discharge, in cubic feet per second;

V = runoff volume, in acre-feet;

t = flood recurrence interval, in years;

a = regression constant;

b, c, and d = regression coefficients;

A = contributing drainage area upstream from site, in square miles;

S = main channel slope, in feet per mile; and

Si = soil-infiltration index, in inches.

Flood-frequency Equations

Estimates of peak discharges and runoff volumes for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval floods can be computed for natural-flow sites in South Dakota by using the following relations. The applicability and limitations of these equations are discussed in a following section.

Equations for peak discharges are:

$$Q_2 = 21.2\ A^{0.48}\ S^{0.44}\ Si^{-1.16} \tag{3}$$

$$Q_5 = 41.2\ A^{0.53}\ S^{0.42}\ Si^{-0.91} \tag{4}$$

$$Q_{10} = 57.7\ A^{0.56}\ S^{0.43}\ Si^{-0.80} \tag{5}$$

$$Q_{25} = 83.4\ A^{0.60}\ S^{0.44}\ Si^{-0.72} \tag{6}$$

$$Q_{50} = 106\ A^{0.63}\ S^{0.45}\ Si^{-0.69} \tag{7}$$

$$Q_{100} = 132\ A^{0.65}\ S^{0.46}\ Si^{-0.67} \tag{8}$$

Equations for runoff volumes are:

$$V_2 = 129\ A^{0.72}\ Si^{-1.74} \tag{9}$$

$$V_5 = 222\ A^{0.72}\ Si^{-1.69} \tag{10}$$

$$V_{10} = 296\ A^{0.73}\ Si^{-1.65} \tag{11}$$

$$V_{25} = 403\ A^{0.75}\ Si^{-1.59} \tag{12}$$

$$V_{50} = 491\ A^{0.76}\ Si^{-1.54} \tag{13}$$

$$V_{100} = 589\ A^{0.77}\ Si^{-1.49} \tag{14}$$

The above equations are based on inch-pound units of measurement. Substitution of metric values for A, S, and Si will not provide correct answers.

Values for A, S, and Si in equations 3 through 14 may be determined as follows:

(1) The contributing drainage area (A), in square miles, for a gaged site may be obtained from the latest annual U.S. Geological Survey streamflow data publications. The contributing drainage area for any ungaged site may be determined by outlining the drainage basin on the best available topographic maps and planimetering the area within the outline or by laying a transparent grid, having squares of known area, over a map and counting the number of squares within the basin outline.

(2) The main channel slope (S), in feet per mile, is the average slope between points 10 and 85 percent of the distance along the main-stream channel from the site to the basin divide. Appropriate measurement on the best available map usually will require that the channel length be extended from the indicated ending to the basin divide. The main channel upstream from stream junctions is defined as the one draining the largest area. Distance may be measured by setting draftsman's dividers at a 0.1-mile increment and then following the channel with the dividers or by using a wheel-map measure. Elevation differences between the 10- and 85-percent points are divided by the distance between the points to determine the slope.

(3) The soil-infiltration index (Si), in inches, is an indication of the capacity of the soil to absorb moisture. The soil-infiltration index for a basin may be determined using a map presented in the section "Estimating Procedure and Examples." If the basin of interest occurs in more than one index area, the index needs to be weighted based on the percentage of the basin occurring in each index area in order to obtain an accurate value for the basin.

Estimates of peak discharge or runoff volume for recurrence intervals, between 2 and 100 years, other than those for which equations are given may be obtained by interpolation from a frequency curve, which is a plot of discharge or volume versus recurrence interval. Discharges or volumes for the frequency curve are computed using equations 3 through 8 or 9 through 14, as applicable.

Relations also were defined for estimating a flood peak from a known flood volume and for estimating a flood volume from a known flood peak. Equations are:

$$Q = 10.6\ V^{0.64}, \qquad (15)$$

$$V = 0.17\ Q^{1.10}, \qquad (16)$$

where

Q = peak discharge, in cubic feet per second; and

V = runoff volume, in acre-feet.

See "Limitations of Estimating Relations" for restrictions placed on use of the above equations. Although based only on short-term records, about 70 percent of the total variation is accounted for by the direct relations. These direct relationships of peak discharge and runoff volume are presented because of the many sites in South Dakota where flood peak information, but not flood volume information, is available.

Estimation of Flood Hydrograph

The average distribution of rainfall runoff in time--the average hydrograph--has been defined from a study of recorded flood hydrographs on small streams in South Dakota. The average shape can be considered as the expected or most likely shape of any future rainfall-runoff hydrographs and is presented, therefore, as a possible design tool in using embankment ponding to reduce culvert size. This average hydrograph shape (fig. 14, see "Estimating Procedure and Examples") is defined by the dimensionless set of time and discharge values tabled below:

i	t'_i (time units)	q'_i (discharge units)	i	t'_i (time units)	q'_i (discharge units)
1	0	0	9	14	55
2	3	5.6	10	18	38
3	5	13	11	23	23
4	7	25	12	30	12
5	10	49	13	40	5.2
6	11	57	14	50	2.0
7	12	60	15	60	0.5
8	13	59	16	70	0

The average hydrograph, as indicated, is presented in dimensionless units. Determining the likely hydrograph at any particular site requires modifying the time scale, t' and discharge scale, q' of the average hydrograph. Equations (adapted from Craig and Rankl, 1978) used to modify these scales are:

$$t_i = 44.91 \frac{V}{Q} t'_i \qquad (17)$$

$$q_i = \frac{Q}{60} q'_i \qquad (18)$$

where

t_i = time to instant i from start of runoff, in minutes;

q_i = discharge rate at instant i, in cubic feet per second;

t'_i = dimensionless time value at instant i;

q'_i = dimensionless discharge rate at instant i;

Q = peak discharge, in cubic feet per second; and

V = runoff volume, in acre-feet.

A complete hydrograph for rain-induced floods of any desired recurrence interval may be defined using estimates of Q and V for the desired recurrence interval to compute all values of t_i and q_i.

Accuracy of Estimates

The realiability of flood estimates at ungaged sites is indirectly indicated by the standard errors of estimate of the regression equations. A large part of this error is the result of time-sampling errors in the actual records and model error in the synthetic records used in the regression analysis. The standard error, given in percent, is the range of error to be expected about two-thirds of the time. That is, the difference between the estimated and the actual peak discharge or runoff volume for two-thirds of the estimates will be within plus or minus one standard error of estimate. Because logarithms of variables were used in the analyses, the positive standard errors will be the larger errors.

Approximate standard errors of estimate for defined relations (equations 3-14) are:

Peak-discharge relation	Standard error of estimate (percent) Average	Range	Runoff-volume relation	Standard error of estimate (percent) Average	Range
Q_2	106	(+152,-60)	V_2	96	(+136,-58)
Q_5	92	(+129,-56)	V_5	94	(+131,-57)
Q_{10}	90	(+124,-55)	V_{10}	92	(+128,-56)
Q_{25}	90	(+125,-56)	V_{25}	90	(+125,-56)
Q_{50}	93	(+130,-56)	V_{50}	89	(+123,-55)
Q_{100}	98	(+139,-58)	V_{100}	89	(+123,-55)

At or near gaged sites, a designer may use flood magnitudes based on estimating relations or streamflow characteristics based on actual records collected at that site. An assessment of the relative accuracy of the estimates needs to be made in such situations. The weighted average of the two estimates may provide the most accurate result.

There is always a chance that a rare flood will occur during any specified period on any small stream. The probability of one or more floods exceeding a flood of given return interval (the t-year flood) within a given period of years can be estimated. Procedures for making these risk estimates are given by the U.S. Water Resources Council (1977).

Estimating relations presented in this report are considered more reliable for small streams (less than 100 mi^2), than relations given in earlier reports, because they are based on (1) 6 years more of actual record at the crest-stage gages considered, (2) long-term synthetic data generated at 66 small-streams sites not previously available, and (3) currently recommended methods for computation of station frequency curves.

Limitations of Estimating Relations

Limitations of estimating relations are based on a requirement for equivalence of the ungaged site and the data sample used in regression analysis. The following limitations are applicable to the estimating relations (equations 3 through 16):

(1) The relations are applicable only to sites where floodflows are virtually natural. Therefore, they are not applicable where peak discharge and runoff volume are significantly affected by manmade works such as major dams, reservoirs, diversions, or urbanization. Many of the records collected in much of the State reflect minor effects from stock ponds or "dugouts." Therefore, the estimating relations are applicable to drainage basins containing stock ponds or "dugouts" providing these are not of major significance and are not located on the main channel so near the site in question as to have an appreciable effect. The estimating relations have a wider, more practical scope of application because of this consideration; however, applicability must be judged by the possible effect expected on hydrograph magnitude and shape.

(2) Estimating relations for peak discharge are considered applicable to contributing drainage areas ranging from 0.05 to about 100 mi^2. Drainage areas considered in the analysis of peak discharges ranged from 0.04 to 148 mi^2. Equations given in Becker (1974) may be used for estimating peak discharges for drainage basins larger than 100 mi^2. For drainage areas of about 100 mi^2, the designer may wish to compute estimates using both the methods given in Becker (1974) and those given herein. If significantly different, an average may be the most accurate result obtainable.

Estimating relations for runoff volume are considered applicable to contributing drainage areas ranging from about 0.05 to 15 mi^2. Drainage areas for modeled sites ranged from 0.09 to 15.6 mi^2.

(3) Main channel slopes of the gaged basins used in defining the estimating relations ranged from 4.86 to 408 ft/mi. Using estimating relations given herein for basins having

slopes smaller or larger than this range may or may not provide reliable estimates.

(4) Observed peak data have been collected throughout the year at all sites, including modeled sites, and were used with the synthetic peak data in the peaks analysis. Consequently, estimating relations for peak discharge are applicable to all seasons.

Generally, it is likely that the larger peak discharges will result from rainfall. However, it is possible for the largest instantaneous peak during any given year to result from either snowmelt or a combination of snowmelt and rainfall.

Estimating relations for runoff volume are not applicable to floods resulting from snowmelt runoff nor to floods where ice effects occur because only floods resulting from rainfall were considered in the modeling. Concurrent rainfall-runoff data were collected on a seasonal basis only, approximately April 15 to October 15. Data are not available to assess the effect of snowmelt on runoff volumes from small drainage basins in South Dakota.

(5) Equations 15 and 16 directly relating peak discharge and runoff volume are considered applicable only to floods resulting from rainfall and to sites where flow is virtually natural; to single-peak floods; and to basins with areas of less than 15 mi^2.

(6) The use of the mean dimensionless hydrograph requires obtaining estimates of a runoff volume and a peak flow of desired recurrence interval. In this study, relations for estimating volume are limited to basins with areas of less than 15 mi^2 and are applicable only to floods resulting from rainfall. The shape of flood-hydrographs associated with peak discharges resulting from snowmelt or affected by ice from small basins is unknown and hydrograph shapes for peaks resulting from snowmelt and rainfall may not be similar to those resulting only from rainfall.

ESTIMATING PROCEDURE AND EXAMPLES

The procedure for making flood estimates includes: (1) A search for flood data in appropriate tables for gaged sites, (2) computation of required variables and use of regression relations to estimate needed flood information for ungaged sites, and (3) estimation of flood hydrograph, if needed.

Because future flood magnitude and frequency can be estimated most reliably from gaged flood records, the planner, designer, or other user of flood-frequency estimates is provided with the flood characteristics of gaged records as an initial basis for estimating future flood characteristics. The U.S. Water Resources Council (1977) has provided guidelines for defining flood magnitude and frequency relations from gaged records. For sites where gaged records are unavailable, relations described in this report can be used to estimate flood peak and frequency, flood volume and frequency, and hydrograph shape.

The illustrations that need to be referred to most often in making flood estimates are grouped, for convenience, in this section of the report. Graphical solutions for the estimating relations (equations 3 through 14) are given in figures 1 through 12; figures 1 through 6 are for the peak-discharge relations and figures 7 through 12 are for the runoff-volume relations. Soil-infiltration indexes are shown on figure 13 and the mean dimensionless hydrograph needed to estimate shape of the design hydrograph is shown in figure 14.

Related illustrations and flood data useful in planning and design, are presented on figures 16 and 17 and in tables 4 and 5 at the back of the report under "Supplemental Information." Location of gaged sites is shown on figures 16 and 17. Tables 4 and 5 provide flood-frequency and magnitude information defined in accordance with U.S. Water Resources Council (1977) guidelines for sites in South Dakota that were gaged as part of this cooperative research project or as part of other U.S. Geological Survey work. Also presented in table 4 are basin characteristics of gaged sites.

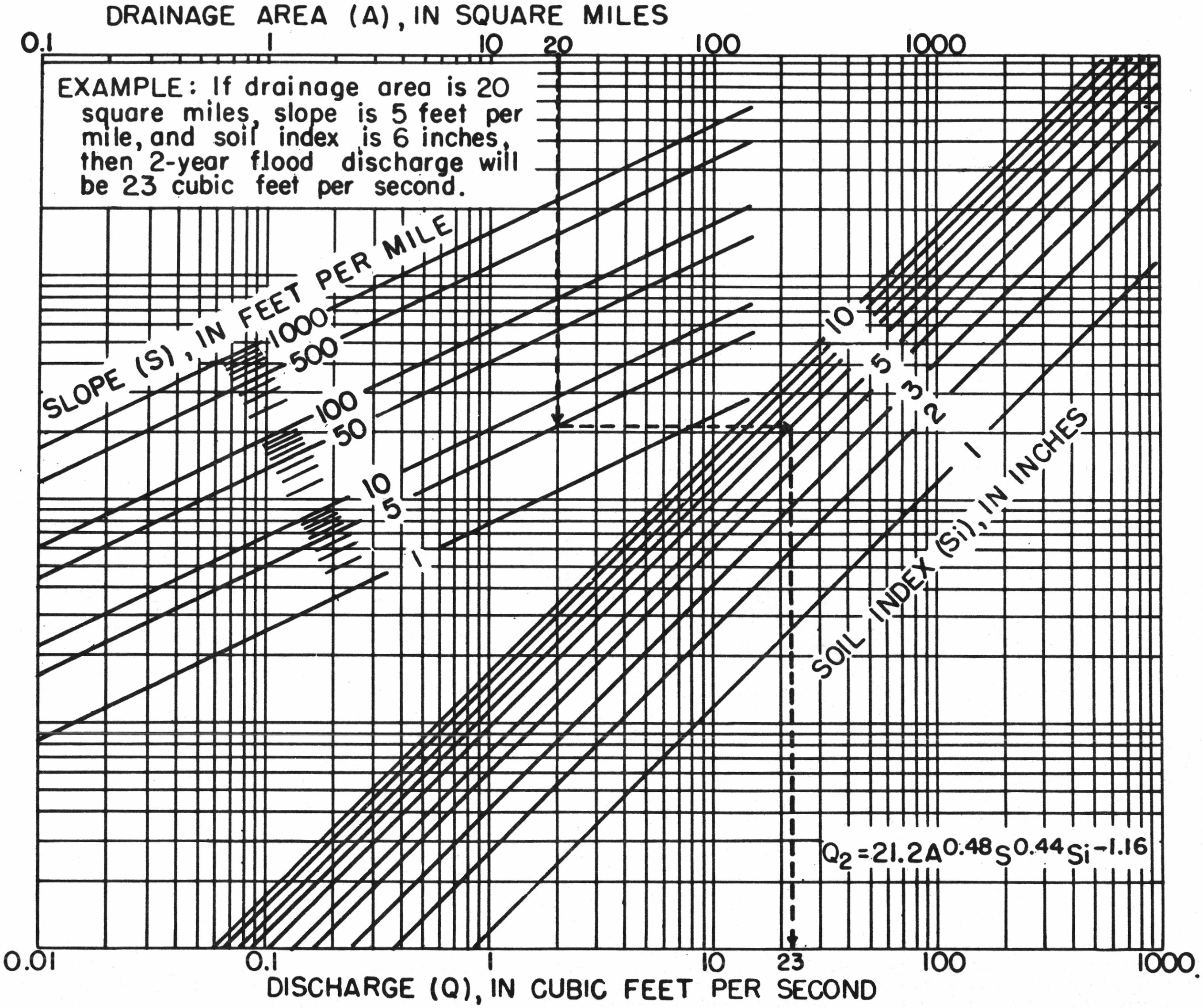


Figure 1.--Relation of 2-year flood peak to basin characteristics.

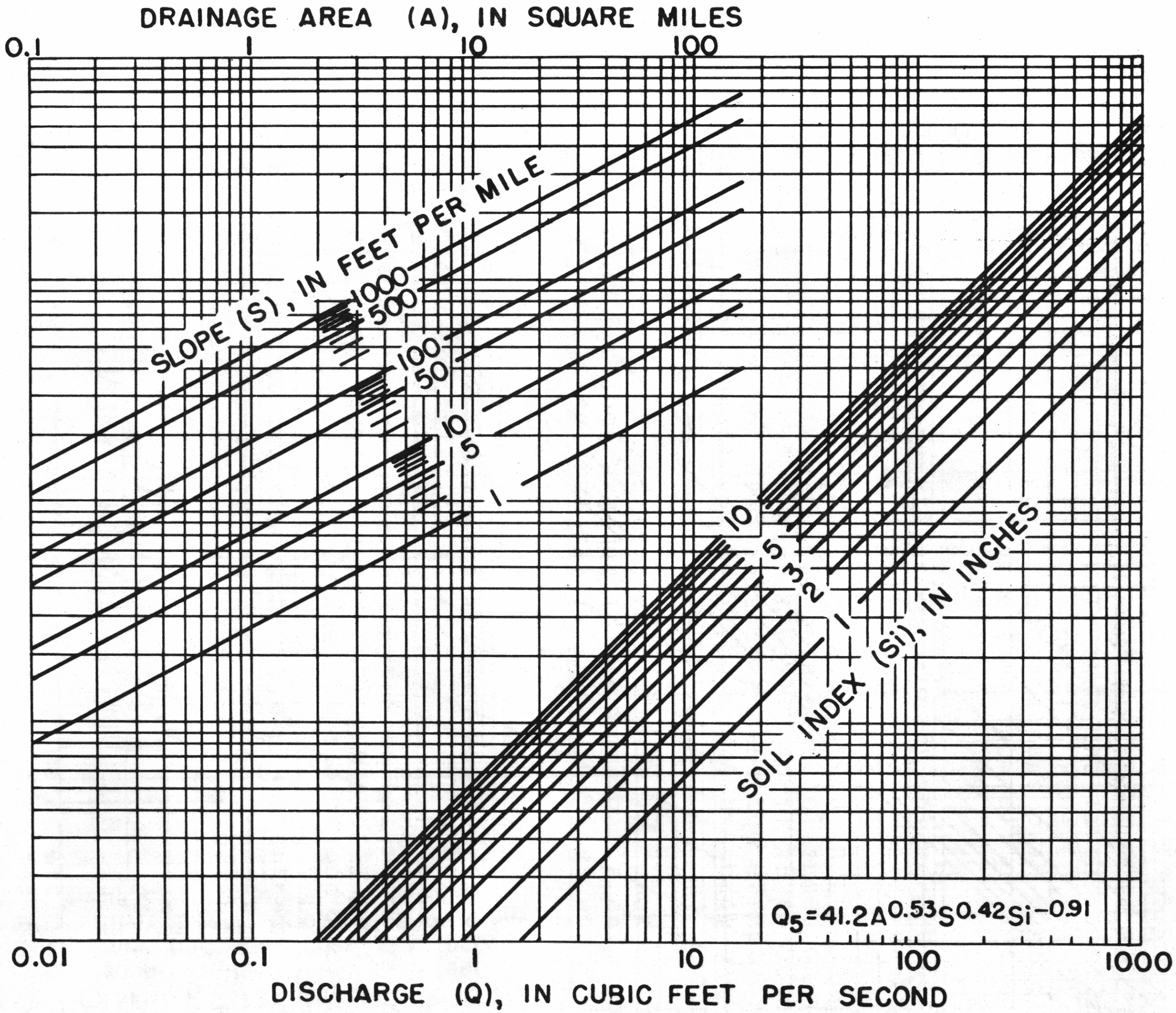


Figure 2.--Relation of 5-year flood peak to basin characteristics.

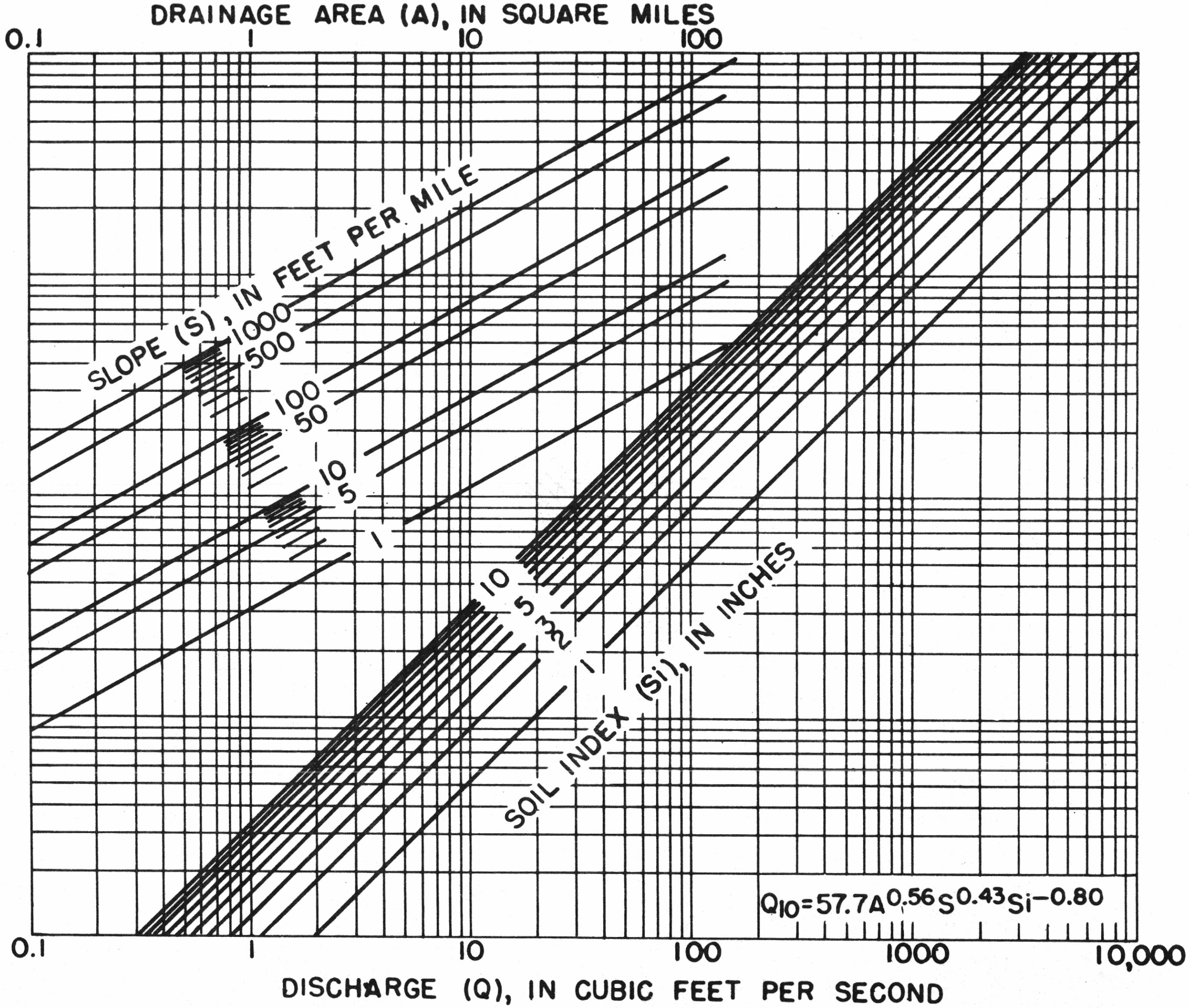


Figure 3.--Relation of 10-year flood peak to basin characteristics.

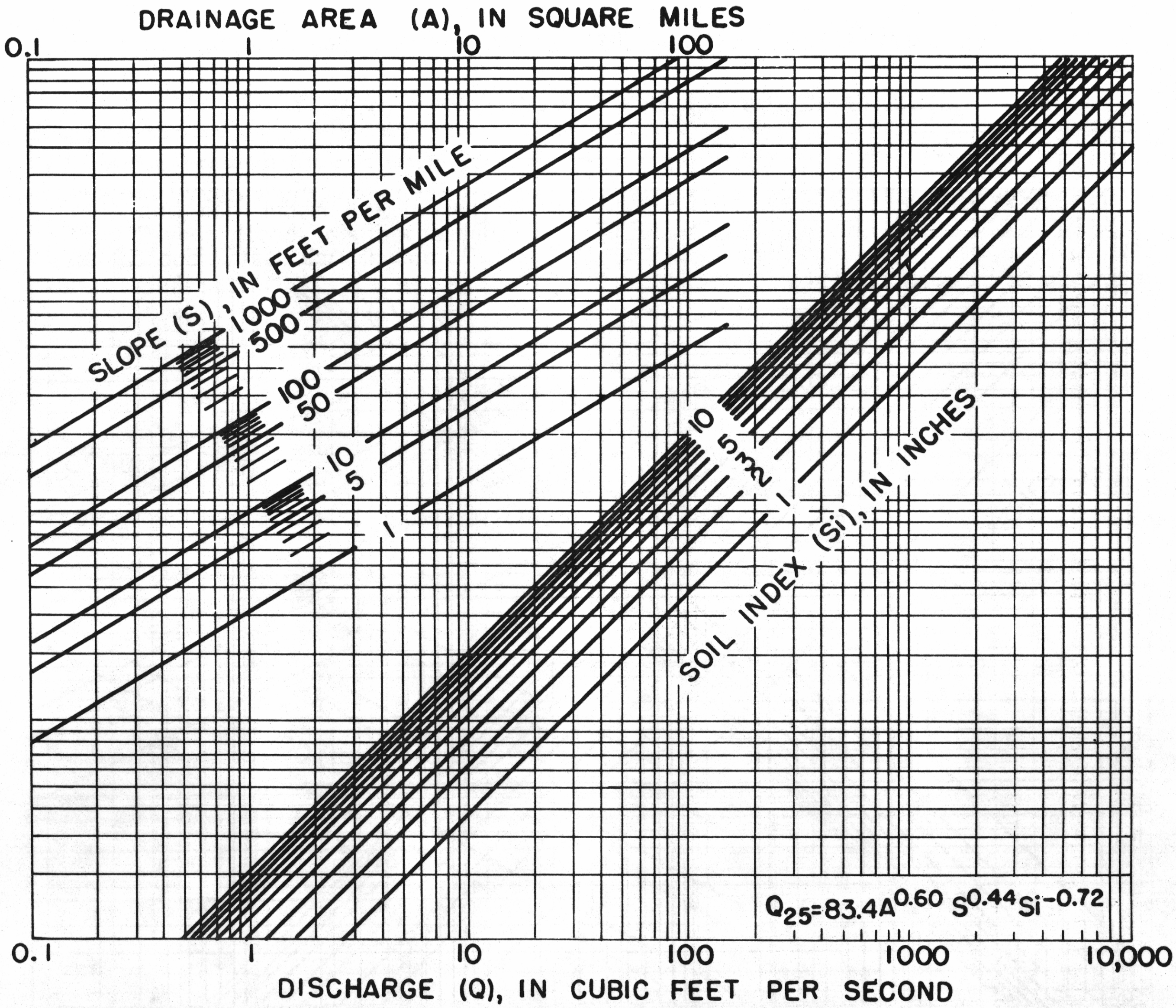


Figure 4.--Relation of 25-year flood peak to basin characteristics.

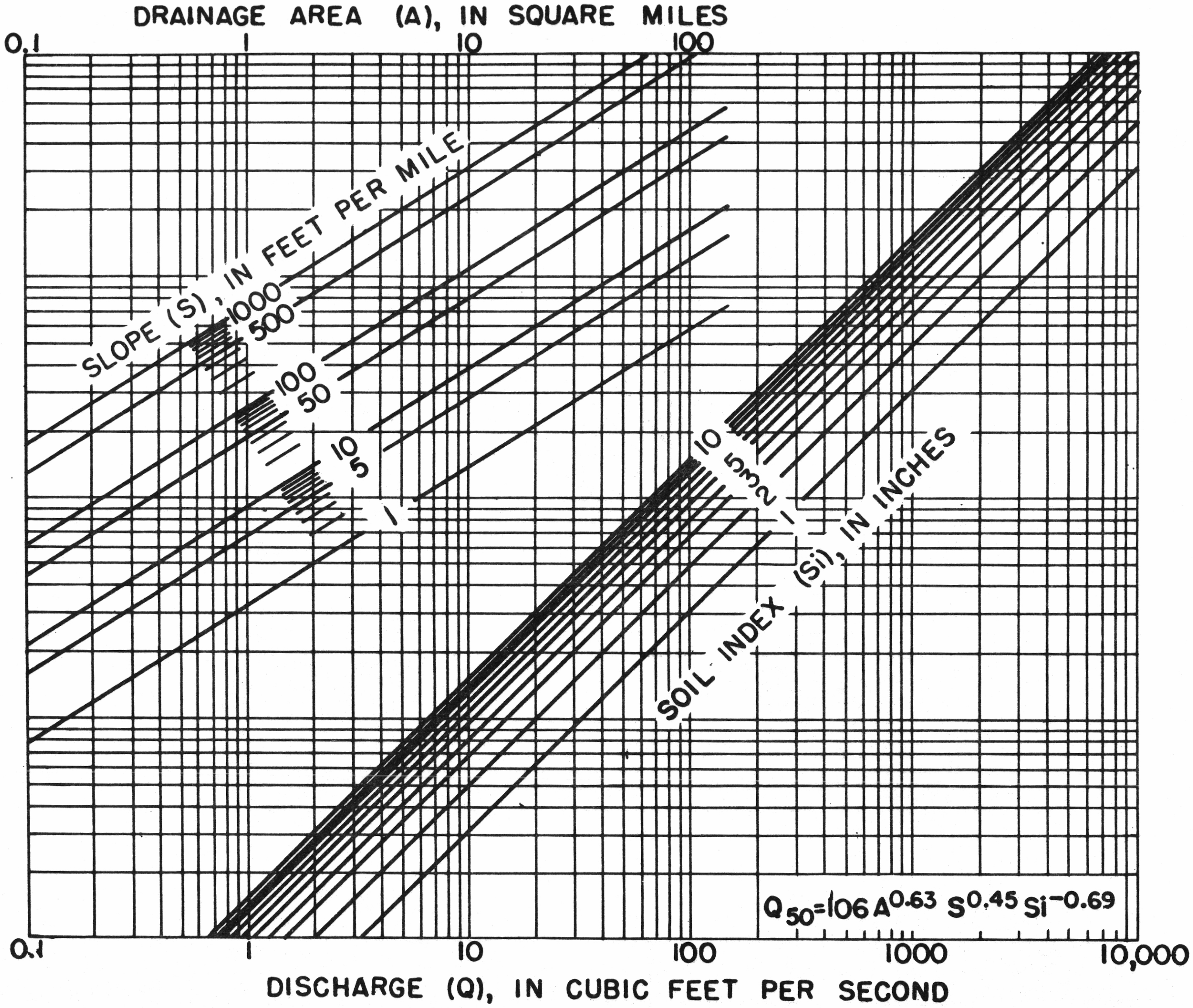


Figure 5.--Relation of 50-year flood peak to basin characteristics.

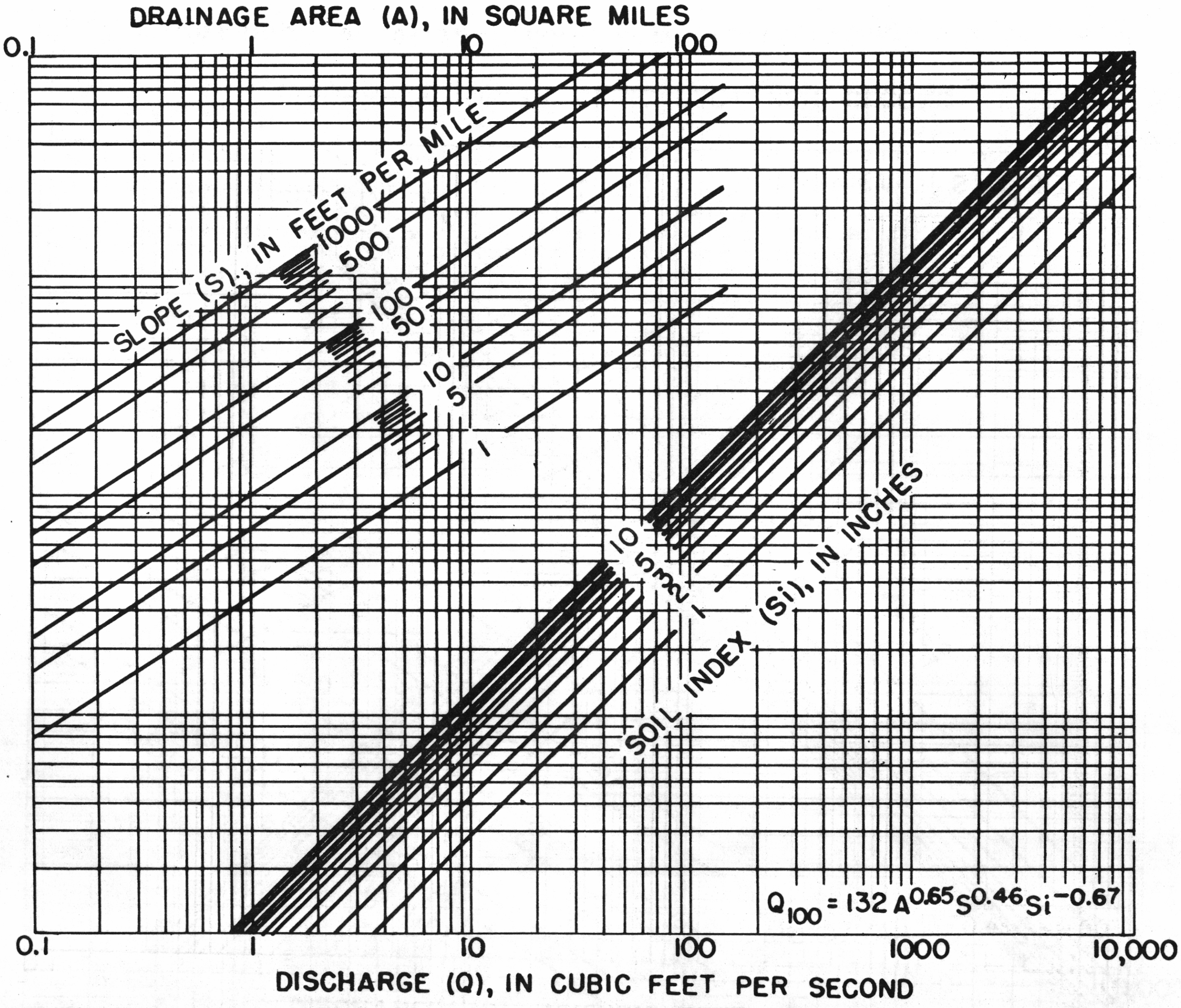


Figure 6.--Relation of 100-year flood peak to basin characteristics.

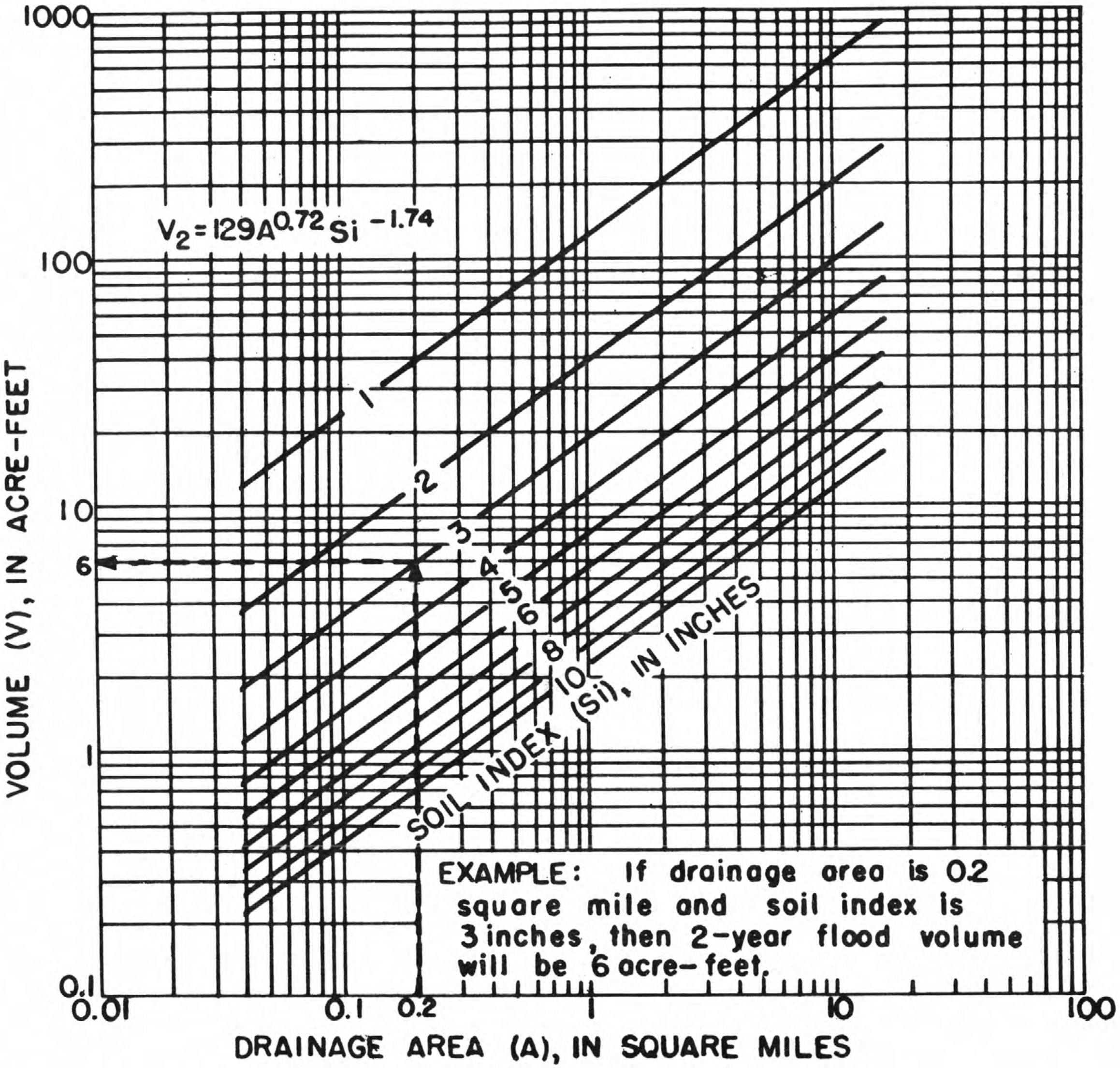


Figure 7.--Relation of 2-year flood volume to basin characteristics.

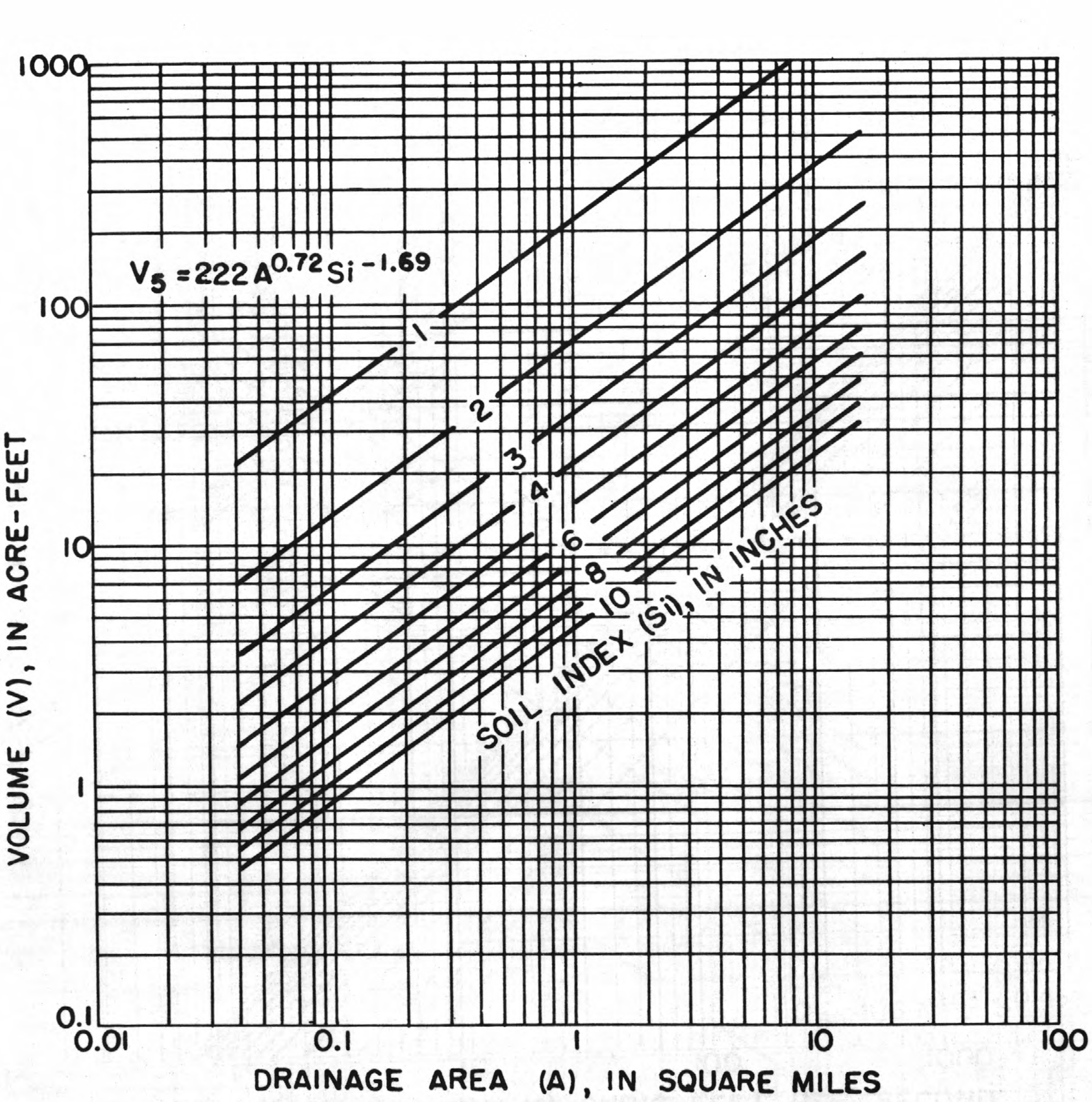


Figure 8.--Relation of 5-year flood volume to basin characteristics.

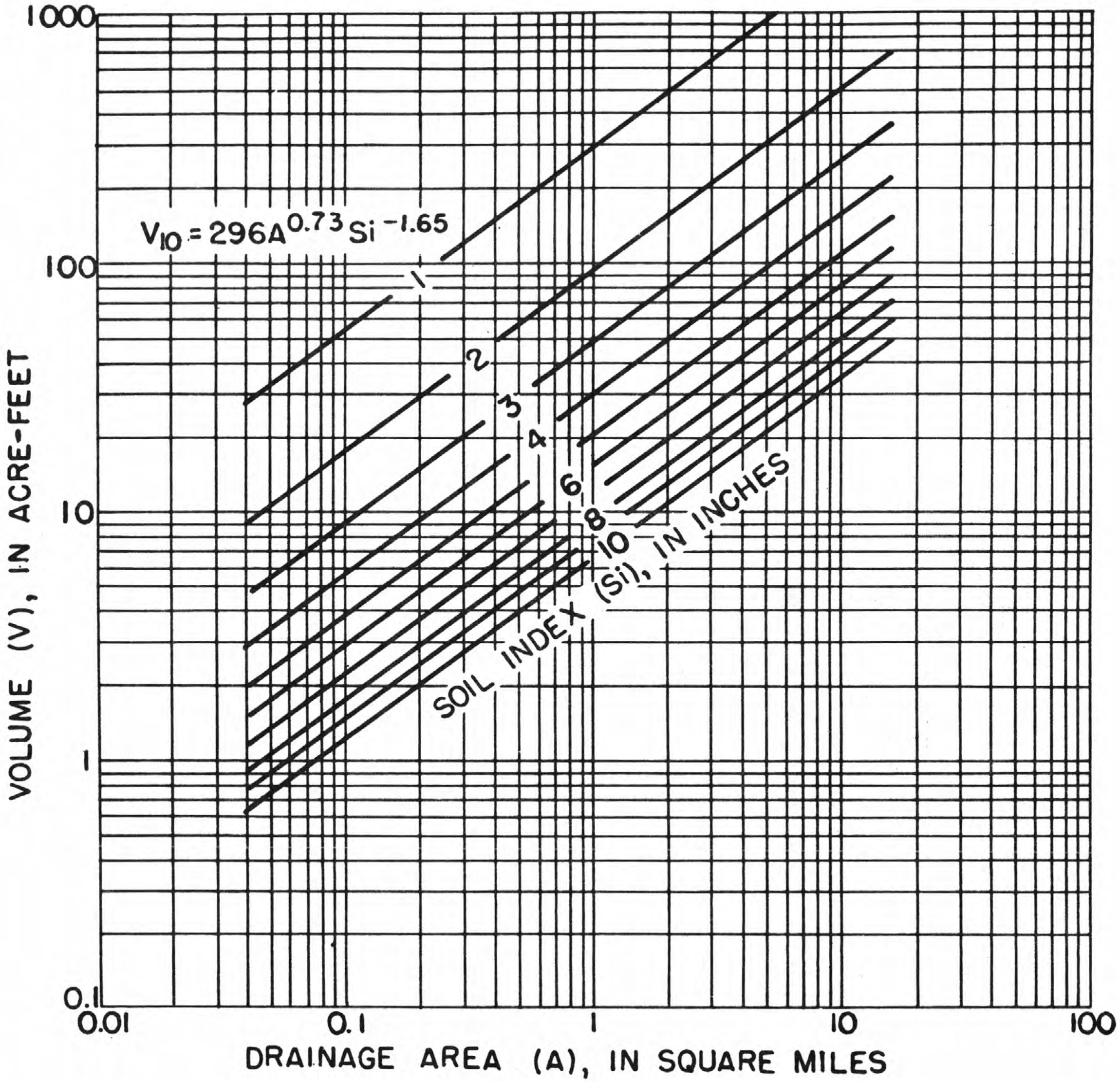


Figure 9.--Relation of 10-year flood volume to basin characteristics.

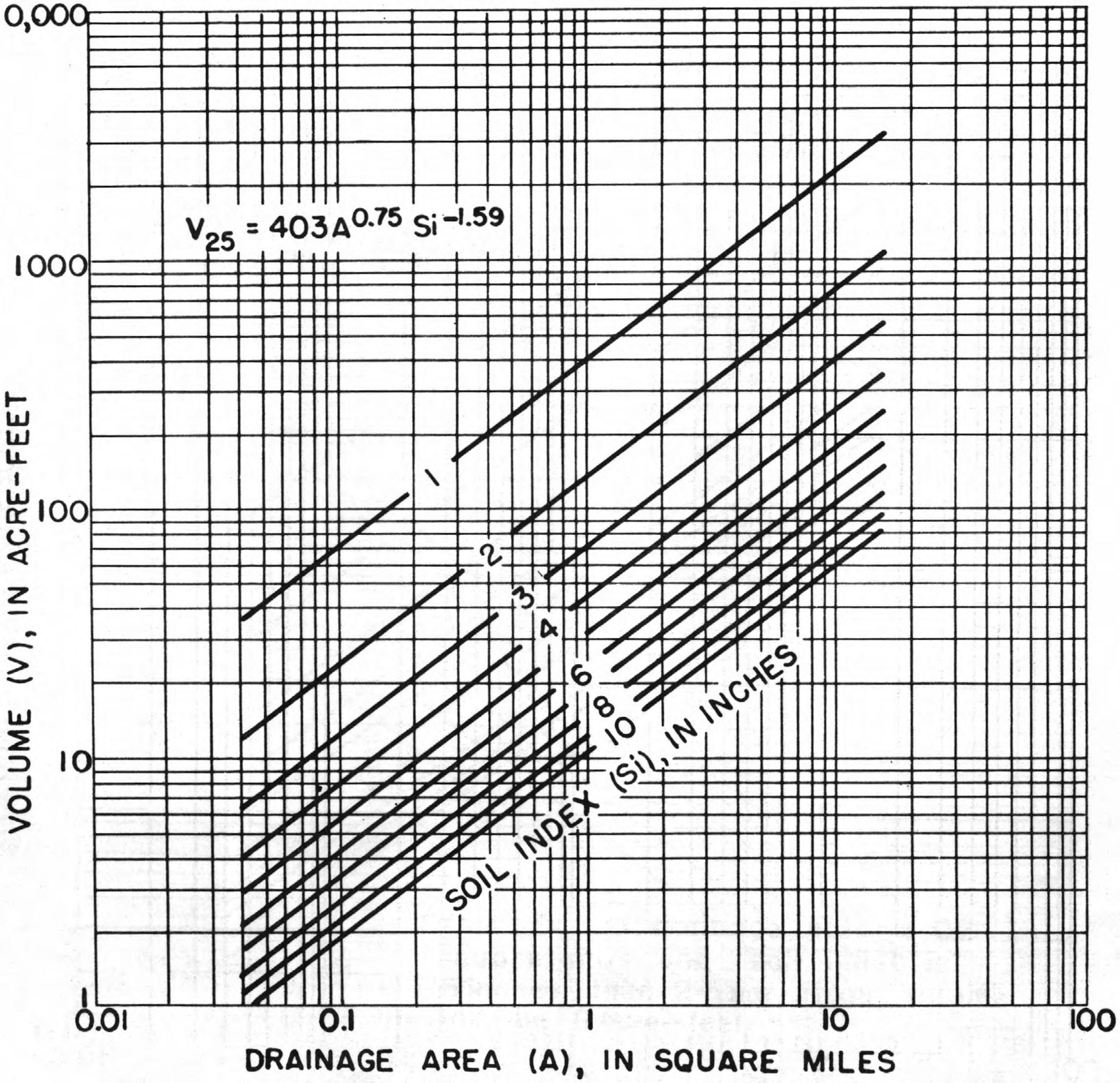


Figure 10.--Relation of 25-year flood volume to basin characteristics.

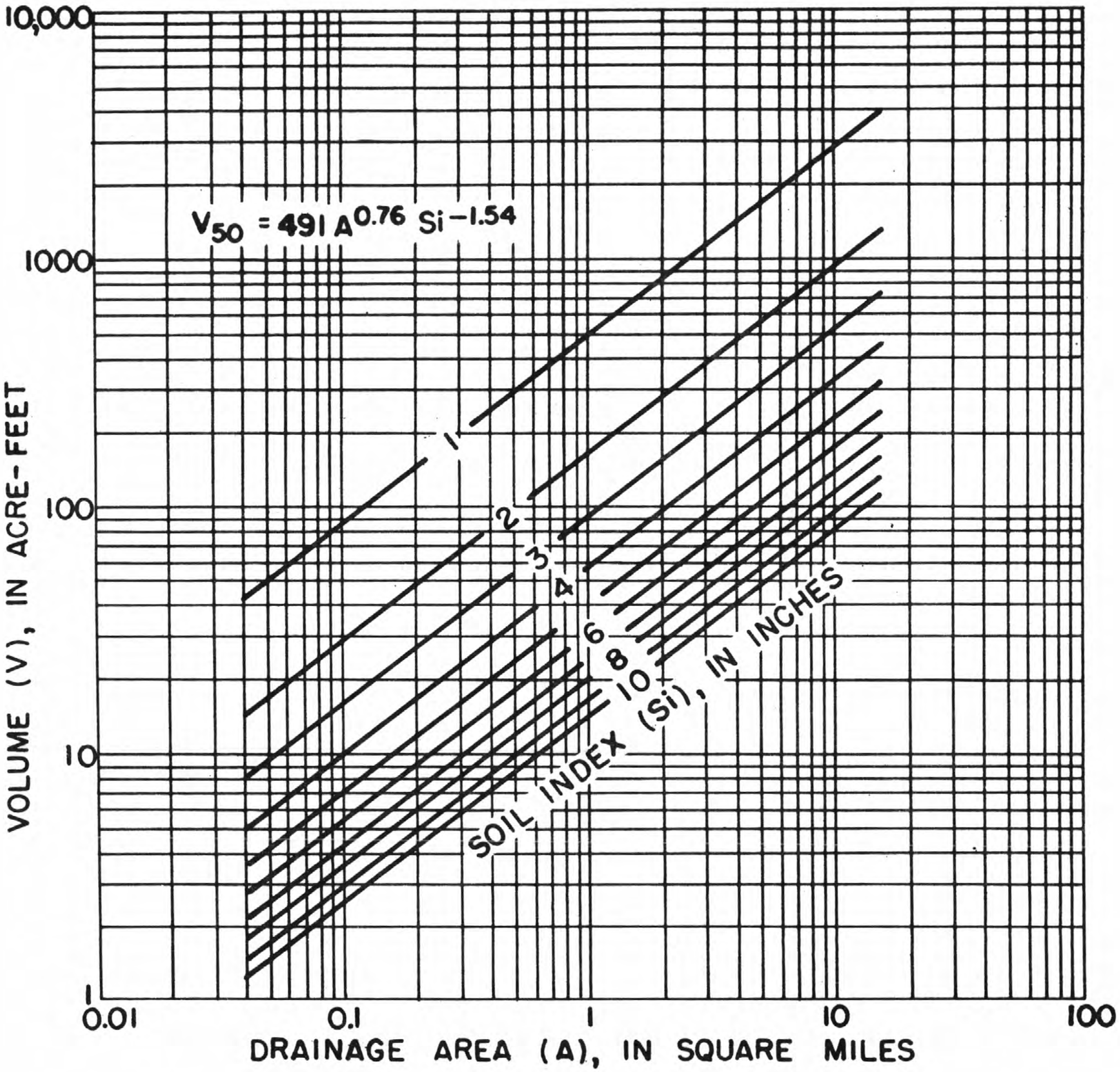


Figure 11.-- Relation of 50-year flood volume to basin characteristics.

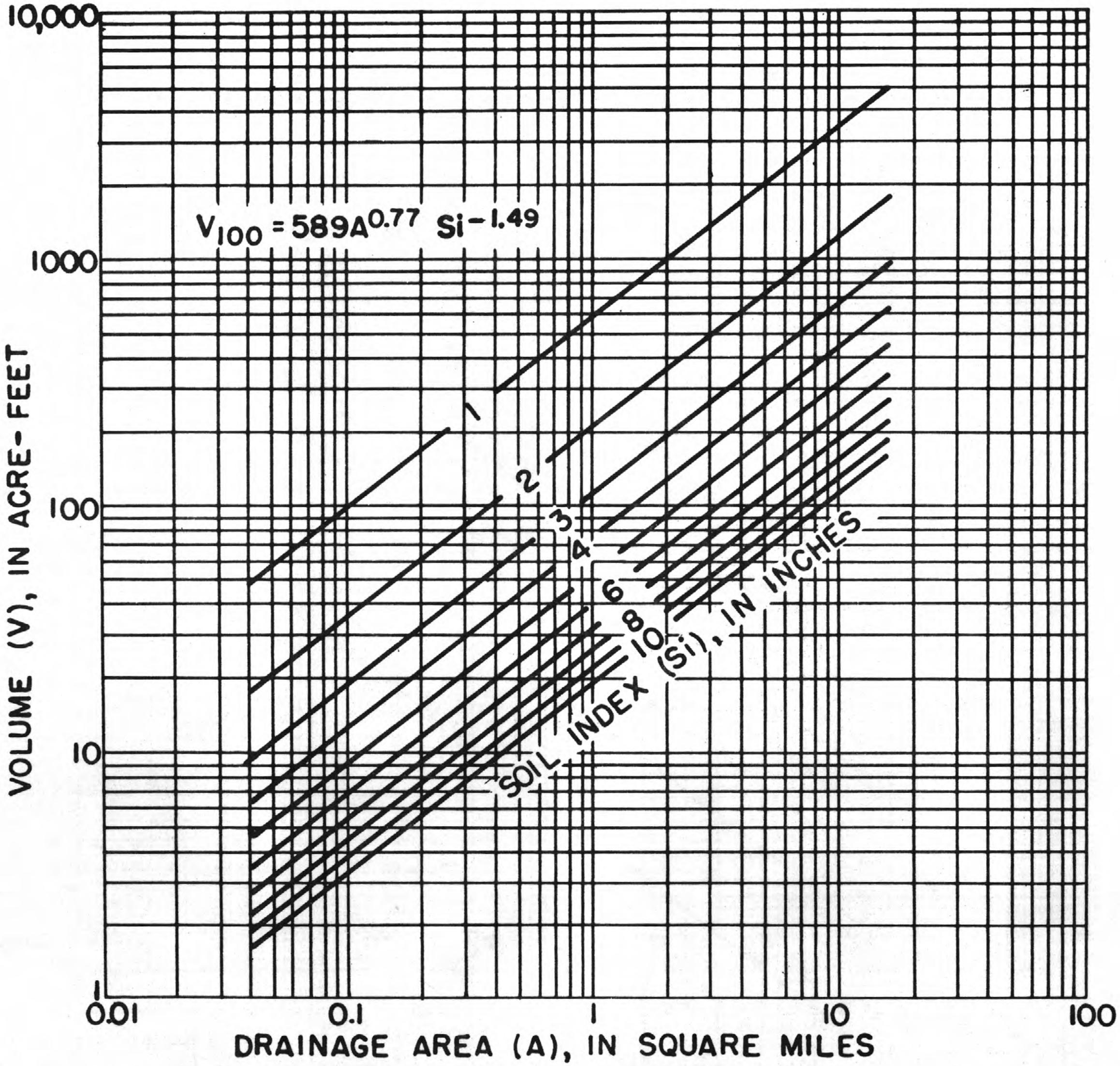
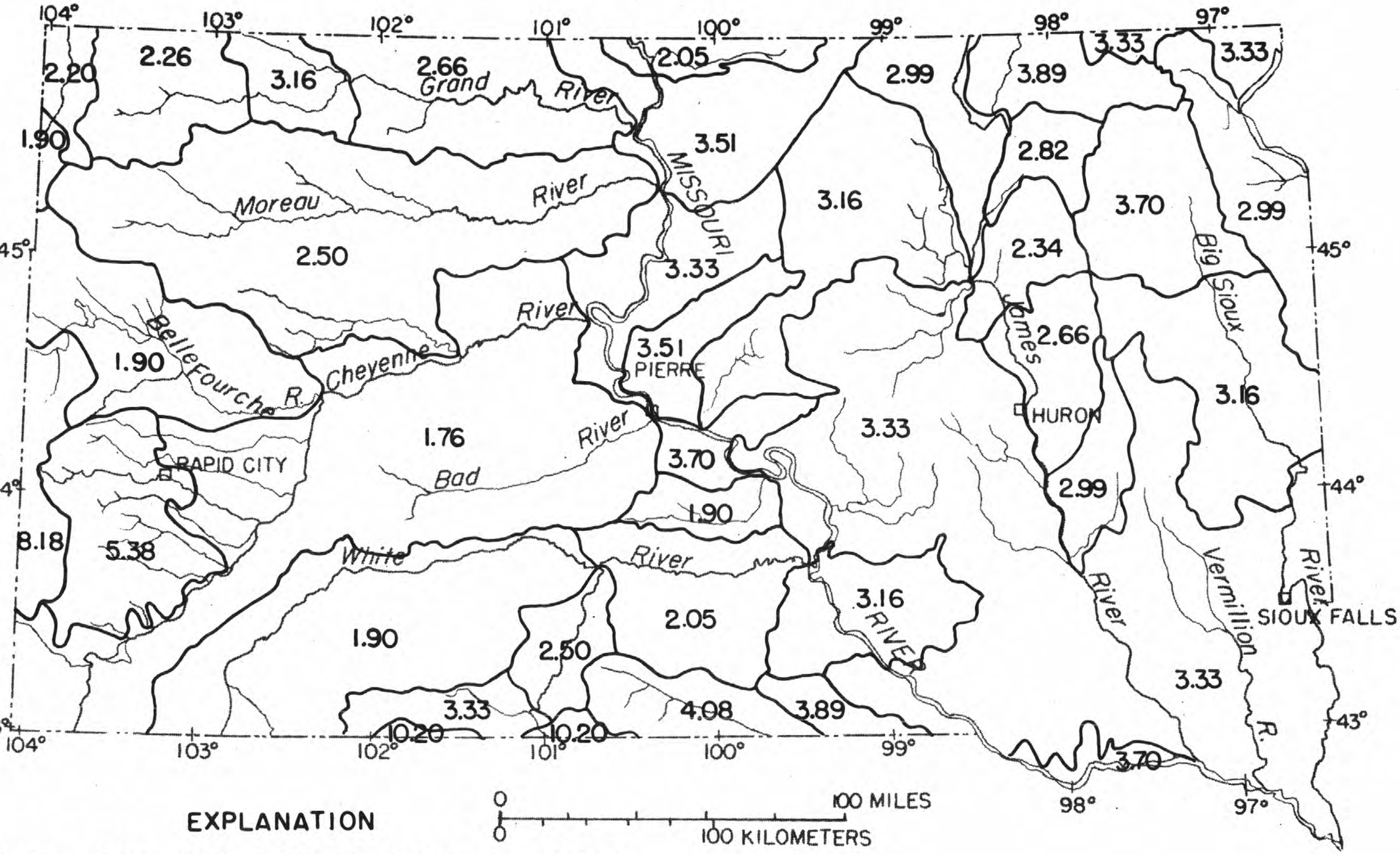


Figure 12.-- Relation of 100-year flood volume to basin characteristics.



EXPLANATION

1.90 SOIL-INFILTRATION INDEX, IN INCHES

INDEX BOUNDARY

Figure 13.--Map showing soil-infiltration indexes in South Dakota.
(Data furnished by the U. S. Soil Conservation Service)

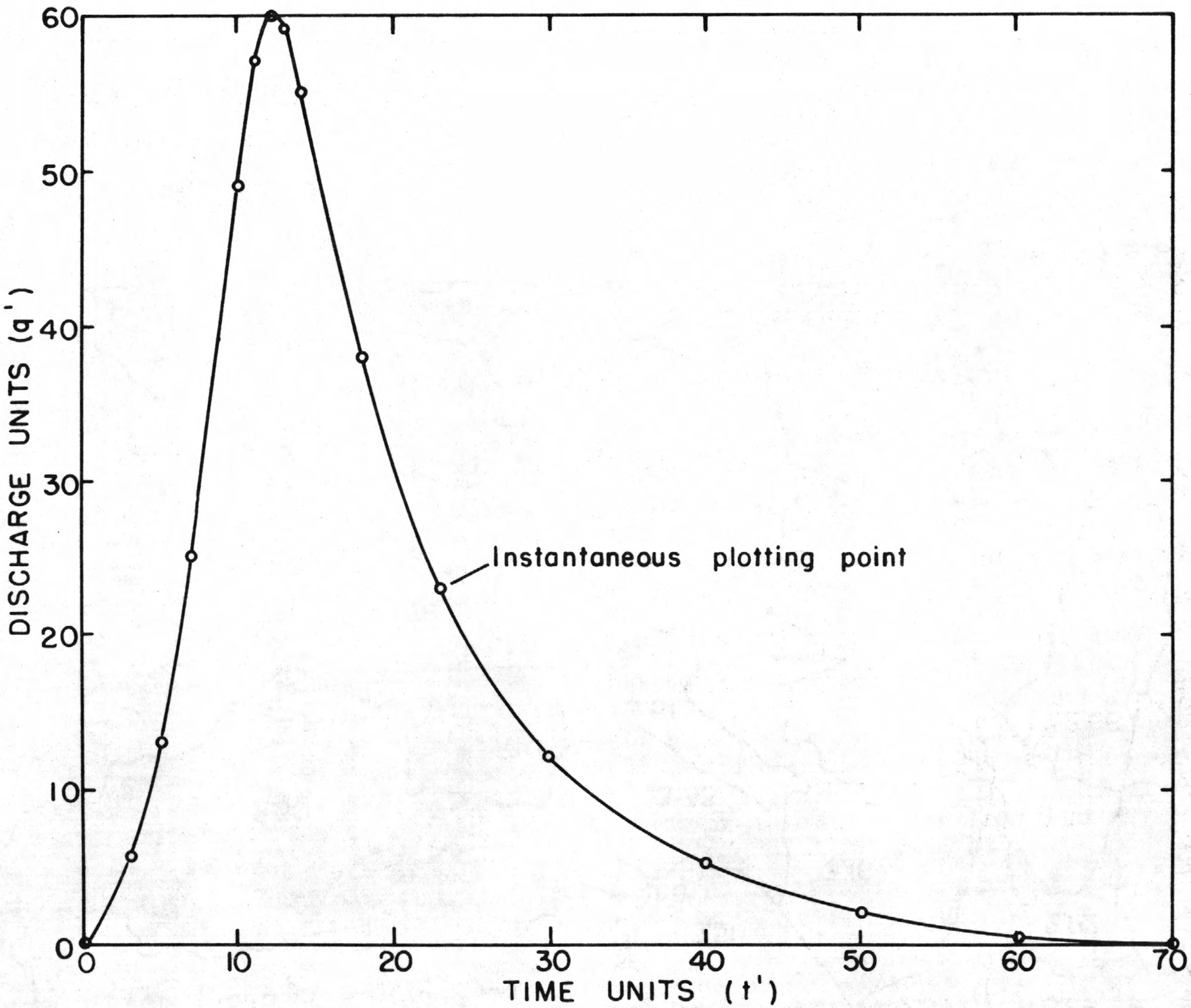


Figure 14.--Mean dimensionless hydrograph applicable to South Dakota small basins.

To illustrate use of estimating relations the following examples are given.

Example 1.--Estimate peak discharges and runoff volumes for 25-year and 100-year floods on a small basin tributary to the Moreau River. Assume contributing drainage area is 5.00 mi^2 and channel slope is 150 ft/mi.

Solution:

(1) Search for gaging station records (figures 16 and 17 and tables 4 and 5). If an ungaged site or if all flood characteristics not found for desired site, use estimating relations.

(2) Relations for peak discharge are given by equations 3 through 8 while relations for runoff volume are given by equations 9 through 14.

(3) From figure 13, applicable soil index is 2.50 inches for drainage basin located in Moreau River basin.

(4) For this example, use A=5.00, S=150, and Si=2.50 in applicable equations.

(5) Compute Q_{25} and Q_{100} by substitution in equations 6 and 8.

$$Q_{25} = 83.4(5.00)^{0.60}(150)^{0.44}(2.50)^{-0.72} = 1{,}030 \text{ ft}^3/\text{s}$$

$$Q_{100} = 132(5.00)^{0.65}(150)^{0.46}(2.50)^{-0.67} = 2{,}040 \text{ ft}^3/\text{s}$$

(6) Compute V_{25} and V_{100} by substitution in equations 12 and 14.

$$V_{25} = 403(5.00)^{0.75}(2.50)^{-1.59} = 314 \text{ acre-ft}$$

$$V_{100} = 589(5.00)^{0.77}(2.50)^{-1.49} = 519 \text{ acre-ft}$$

(7) Above results may be quickly verified from curves given in figures 4, 6, 10, and 12.

Example 2.--Determine probable runoff volume associated with the peak discharge of record of 548 ft^3/s which occurred at a crest-stage gage (West Branch Horse Creek near Mission, S. Dak.) in June 1968.

Solution:

(1) Assumption is made that a single-peak flood occurred.

(2) Use Q=548; frequency of flood not determined.

(3) Compute runoff volume (V) by substitution in equation 16.

$$V = 0.17Q^{1.10} = 0.17(548)^{1.10} = 175 \text{ acre-ft}$$

Example 3.--Determine a synthetic hydrograph for the 25-year flood for the small drainage basin given in example 1.

Solution:

(1) From example 1, Q_{25}=1,030 ft^3/s and V_{25}=314 acre-ft.

(2) Use equations 17 and 18 to compute instantaneous time (t_i) and discharge (q_i) values needed to define the synthetic hydrograph. See "Estimation of Flood Hydrograph."

$$t_i = 44.91\frac{V}{Q}t'_i = 44.91\frac{(314)}{(1{,}030)}t'_i = 13.69\ t'_i \text{ minutes}$$

$$q_i = \frac{Q}{60}q'_i = \frac{1{,}030}{60}q'_i = 17.17\ q'_i \text{ ft}^3/\text{s}$$

(3) For i = 3; t'_3= 5 and q'_3= 13:

$$t_3 = 13.69\ t'_3 = (13.69)(5) = 68.5 \text{ minutes}$$

$$q_3 = 17.17\ q'_3 = (17.17)(13) = 223 \text{ ft}^3/\text{s}$$

Required instantaneous data are computed and tabulated as follows:

(i)	TIME UNITS (t'_i)	TIME CONSTANT (44.91 V/Q)	MINUTES (t_i)	DISCHARGE UNITS (q'_i)	DISCHARGE CONSTANT (Q/60)	CUBIC FEET PER SECOND (q_i)
1	0	13.69	0	0	17.17	0
2	3	13.69	41	5.6	17.17	96
3	5	13.69	68	13	17.17	223
4	7	13.69	96	25	17.17	429
5	10	13.69	137	49	17.17	841
6	11	13.69	151	57	17.17	979
7	12	13.69	164	60	17.17	1,030
8	13	13.69	178	59	17.17	1,010
9	14	13.69	192	55	17.17	944
10	18	13.69	246	38	17.17	652
11	23	13.69	315	23	17.17	395
12	30	13.69	411	12	17.17	206
13	40	13.69	548	5.2	17.17	89
14	50	13.69	685	2.0	17.17	34
15	60	13.69	821	0.5	17.17	8.6
16	70	13.69	958	0	17.17	0

(4) Plot time (t_i) and discharge (q_i) from previous tabulation to obtain synthetic hydrograph (fig. 15, see "Supplemental Information").

USE OF EMBANKMENT PONDING

The potential exists in South Dakota for using a highway embankment to create a temporary storage for flood flows and, thereby, to reduce flood peak magnitudes which, in turn, may reduce culvert size requirements at highway-stream crossings. The strategy is to store flows by ponding during the times of high rates of runoff and subsequently to release the stored water at lesser flow rates. The design problem becomes one of selecting a culvert of appropriate flow characteristics that effectively uses the storage capacity existing behind the highway embankment.

The analytical approach--known as flow routing--starts with a known or assumed inflow to the site including peak flow rate, total flow volume, and hydrograph shape. Each of these needed characteristics can be estimated from information provided in this report. Also needed are a storage-elevation relation, which can be defined from a contour map of the ponded area, and outflow rate-elevation characteristics of the culverts that may be considered for use. Flow routing techniques then can be used to compute the inflow volume, outflow volume, change in storage volume, and water-surface elevation for sequential, discrete time increments during the runoff.

A computer program has been developed within the U.S. Geological Survey (Jennings, 1977) that can be used to route incremental discharge of a known inflow downstream through an uncontrolled reservoir to provide data needed to plot the outflow hydrograph. Conversely, incremental discharges of a known outflow may be routed upstream to provide data for plotting the inflow hydrograph. A modified Puls Method (U.S. Soil Conservation Service, 1972) is used for the routing computations. Plots of inflow, outflow, storage, and water-surface elevations versus time are provided as computer output.

Example problems are given by Jennings (1977) that illustrate the routing of flows in both the upstream and downstream directions through culverts. This approach or some simpler, approximate routing approach may be used in planning outflow structures (culverts) which best utilize embankment ponding.

Craig and Rankl (1978) studied ponding behind highway embankments; results of their tests are applicable to small streams in other, nearby States. The response of pond elevation and culvert outflow to varied inflow, storage capacity, and culvert size was tested. By comparing results of routing multiple-peak and single-peak floods they showed that, in general, the single-peak flood was more significant in culvert design. That finding supports the use of synthetic inflow hydrographs based on the single-peak mean dimensionless hydrograph.

ANALYTICAL PROCEDURES

This section of the report documents the data available for small streams in South Dakota and the procedures used in analyzing these data. Data collection, rainfall-runoff modeling, flood-frequency analysis, regionalization by regression analysis, and analysis of hydrograph shape are discussed.

Data Collection

A statewide data-collection network was designed, instrumented, and operated (Becker, 1973) to collect an adequate amount of data to be used with a rainfall-runoff model developed by the U.S. Geological Survey to simulate a long record of annual floods at each gaged site. About 80 gages were operated on basins with drainage areas generally less than 10 mi^2. Gaged sites were distributed geographically to include all significant hydrologic areas in the State and to include a wide range of basin characteristics. Concurrent streamflow and precipitation were recorded at 5- or 15-minute intervals, dependent upon basin response time, by continuous digital recorders (Isherwood, 1963) operated on a seasonal basis. Gaging stations generally were located upstream from culverts, which were used as flow measuring devices when storage from ponding was not significant. Discharge ratings were computed using flow-through-culvert methods (Bodhaine, 1968) with verification by current-meter measurements when possible.

A major problem during the investigation was obtaining sufficient data for use in the rainfall-runoff model. This lack of data (recorded rainfall and resultant runoff) was due to the semiarid climate that required a relatively long period of data collection to obtain a representative sample and the drought (Matthai, 1979, p. 23, 33-36), which necessitated an extension of the data-collection period. Sufficient data were collected to allow modeling of 66 gaged sites and to meet other major research objectives. Much of the new and additional hydrologic data collected in connection with this project have become a part of the computer files of streamflow data maintained by the U.S. Geological Survey.

Rainfall-runoff Modeling

Two distinct procedures are required in using rainfall-runoff modeling to expand the hydrologic knowledge for a given site. First, the model must be calibrated for a given site using relatively short-term rainfall and runoff data for the site. Then the calibrated model is used with available long-term climatological records to simulate long-term flood records at that site.

Model Description

The parametric rainfall-runoff model described by Dawdy, Lichty, and Bergmann (1972) was used with point rainfall data and data on potential evapotranspiration to simulate flood hydrographs from small drainage basins. The model consists of a series of mathematical equations presented in the form of computer programs (Carrigan, 1973) that describe antecedent moisture, infiltration, and surface runoff. The model uses 10 parameters (table 1, see "Supplemental Information") in making approximations to the physical laws governing infiltration, soil-moisture accretion and depletion, and surface streamflow. Values for these parameters, applicable to modeling streamflow at a particular site, are determined by a process of calibration using the concurrent rainfall and runoff data that have been collected at the site. Initial parameter values are assumed for the calibration process and from these the model determines optimum values based on an iterative comparison of predicted and observed runoff. Final parameter values determined for a particular site serve as the basis for the model with which flood peaks and runoff volumes may be simulated from long-term rainfall records. These simulated flood peaks and volumes may be used to extend the length of streamflow records at given sites which, in turn, are used in the analysis of flood magnitude and frequency.

Model Calibration

The model has been used as a tool in the study of peak discharge in several States. However, this study and a similar study in Wyoming (Craig and Rankl, 1978) also included runoff volumes. The added requirement of runoff volume as a primary model output considerably broadened the scope of the modeling effort.

In normal calibration of the model, the 10 parameters are evaluated by the iterative optimization routine. Usually about 15-20 significant storms covering a wide range of possible antecedent and rainfall conditions are desired for each site. Because of the difficulties in obtaining the desired number of storms in South Dakota, the calibration operation was modified somewhat. Comparison of results of model calibration in other areas (Hauth, 1974, Lichty and Liscum, 1978) with calibrations of those South Dakota sites having the most recorded storms indicated that a more meager calibration procedure was feasible.

In this study, values for certain model parameters were not varied after being either assumed, based on results from prior use of the model (Hauth, 1974), or measured from hydrographs. In this manner, 6 parameters (EVC, RR, DRN, KSW, TC, and TP/TC) of the 10 model parameters were arrived at directly, thereby leaving only 4 parameters (BMSM, PSP, KSAT, and RGF) to be determined by optimization. The practical advantage gained was that significantly fewer storms were required at a particular site for the number of storms to exceed the number of parameters being optimized.

Considering the paucity of data that could be collected for small basins in South Dakota, this approach proved especially significant as 66 sites (table 2, see "Supplemental Information") were successfully modeled. It allowed 53 modeled sites, each having 6 or more storms, to be used as control basins in the calibration process as opposed to approximately 20 sites which would have met previous requirements regarding numbers of storms. Additionally, those sites having only two or three storms or even a single storm could realistically be calibrated. The validity of parameter values obtained for such sites was judged by comparing these values with parameter values determined for control basins located near the basin being calibrated. A greater leeway in screening the data was available because fewer storms were needed for calibration. Consequently, more of the atypical or otherwise questionable storms were "screened out." More reliable calibrations resulted despite fewer storms being considered in final calibrations.

Initial calibrations indicated that the model was not satisfactorily accounting for actual hydrologic conditions. Constraints placed on model parameters may have prevented proper fitting of flood data and this lack of fit may have reflected the use of seasonal rainfall data for calibration. Markedly improved calibrations resulted when additional considerations were applied to the modeling process. Standard errors were greatly reduced and bias was removed by: (1) Subtraction of appropriate base flows from recorded hydrographs so as to obtain the best estimate of direct runoff, (2) extensive screening of data, and (3) introduction of a small percentage of impervious areas in the basins into the calibrations.

A small percentage of impervious area in each basin was used for most calibrations to achieve a reasonable match between actual and simulated flood data. The need for considering a percentage of the drainage basin as impervious was evident for certain basins based on known conditions. For example, some basins are underlain by relatively impermeable materials such as shales and have sparse vegative cover. These basins were calibrated by determining optimum percentages of imperviousness through repetitive calibrations using varying percentages of impervious area. Optimum percentages determined for three of the most distinctive of these basins were 15, 20, and 33 percent. The inclusion of relatively small percentages of impervious area in nearly all calibrations is perhaps reasonable because ponds, roadways, or other undefined physical features produce the effect of impervious areas within the basins. Percentages of impervious areas used in the individual calibrations are shown in table 2 and averaged about 2.0 percent excluding the three largest.

Transfer of evaporation data from the single evaporation station used (Redfield) to modeled sites was accomplished by varying the EVC parameter used in model calibration. The ratio of average-annual lake evaporation to average-annual pan evaporation at Redfield was determined using maps by Spuhler, Lytle, and Moe (1971). This ratio of lake evaporation to pan evaporation was used to vary the EVC parameter throughout the State.

Comparison of storm rainfall with resultant storm runoff provided an adequate estimate of the RR parameter for each modeled site. The DRN parameter was held constant at 1.00 and the TP/TC parameter was held constant at 0.50 in final calibrations as indicated by Carrigan, Dempster, and Bower (1977). Little improvement in calibrations resulted when other values for these parameters were used. The TC and KSW parameters describing the surface-runoff component were measured from hydrographs plotted during initial calibration runs. Typical values of the KSW and TC parameters for each modeled site were then used with refinement in final calibrations.

Best-fit values for the BMSM, PSP, KSAT, and RGF parameters were determined by optimization during the calibration process.

Final sets of parameter values were determined using screened storm data and were based on phase 3 model computations (Hauth, 1974). Checks were made to assure a rational consistency of parameter values from basin to basin throughout the State. The average standard deviation of differences between recorded and simulated flood peaks was about 46 percent for the 53 sites included in the control group. The final parameter values, which were later used in synthesis of flood records, are listed, in downstream order, in table 3 at the back of the report under "Supplemental Information."

Synthesis of Flood Records

Long-term records of rainfall and evaporation in South Dakota were used to generate the long series of synthetic floods required to improve the flood-frequency curves at short-term gaging sites. Long-term daily and unit-precipitation (5-minute incremental rainfall for storm periods) data for Huron and Rapid City were obtained from the National Climatic Data Center, Asheville, N.C. These records provided the basic rainfall data for model input. Rainfall records for Rapid City and Huron were shown to be significantly different, statistically (P. H. Carrigan, Jr., U.S. Geological Survey, written commun., 1974), based on results using the Cramer-von Mises Two-Sample Test described by Conover (1971). Therefore, it was judged necessary to use both rainfall records in flood synthesis.

To provide a realistic basis for synthesizing an annual series flood record, unit-precipitation data were needed for all storms that might have conceivably produced the largest peak flood during any water year (October 1 to September 30) during the long-term period considered. However, the number of storms selected was generally limited to no more than four or five per year. Initial selections of storms were made by a computer routine based on daily precipitation amounts as described by Hauth (1974). Final selections of storms and dates were made manually based on antecedent rainfalls, rainfall intensities, temperature trends, and other climatological data during each year. Selected storms believed to represent snowfall were excluded and a storm from the non-snowfall period was substituted. This assured that the single storm most likely to have caused the maximum flood peak was included. Storms were usually 1 or 2 days in length although longer storms occurred. The number of storms in each record for which 5-minute unit-rainfall data were provided are shown below:

National Weather Service station number	Station name	Period of continuous record used	Number of storms used
W14936	Huron WSO	1898-1973	369
W24090	Rapid City WSO	1907-74	312

Approximately 700 days of unit-rainfall data for both Huron and Rapid City (76 and 68 years of record, respectively) were used in flood simulations to compute peak discharges and flood volumes.

The two long-term daily precipitation records were adjusted in the modeling process to better define antecedent-moisture conditions during the period for which flood data were synthesized. The amount of runoff resulting from a storm in South Dakota is quite dependent upon these antecedent conditions because of the semiarid environment. The purpose in using this adjustment was to, in effect, transfer the long-term daily precipitation records collected at Huron and Rapid City to the 66 modeled sites, thereby taking into account the areal and seasonal variation in rainfall throughout the State.

Daily rainfall at Huron and at Rapid City was compared to that at 20 other National Weather Service stations, each with an average of about 60 years of record, situated uniformly throughout the State. Annual totals for May through September were used in determining adjustment factors applicable to the Huron and Rapid City records for each of the 20 stations. Approximately 67 percent of the annual precipitation occurs during May through

September. Ratios to the Huron record ranged from 0.76 at Camp Crook to 1.33 at Sioux Falls and Vermillion while ratios to the Rapid City record ranged from 0.81 at Camp Crook to 1.42 at Sioux Falls and Vermillion. Average seasonal rainfall at Huron is 7 percent greater than at Rapid City. Maps showing these ratios were prepared and lines of equal ratio were drawn. The adjustment factors applicable to each of the two long-term daily records were then determined from these maps for each modeled site.

A similar approach, based on ratios determined for daily data, was attempted to adjust the unit-rainfall data. However, such a simple approach to transferring unit-rainfall data proved grossly inadequate and had to be discarded because disproportionate changes to rainfall intensities resulted. As no satisfactory answer to the problem of change in intensity was discerned, adjustment of unit-rainfall data was deemed unwarranted.

The most suitable long-term evaporation record available in South Dakota is for the Redfield 6E pan-evaporation gage, located in the east-central part of the State, at which operation began in June 1949. Evaporation data have been collected only on a seasonal basis, generally during April through October, at this site. The months of missing record were estimated from precipitation and temperature trends to provide a continuous evaporation record for 29 years. A computer program (Carrigan and others, 1977) was used to fit a harmonic (sine-cosine) function to this 29-year evaporation record and to then generate a synthetic daily evaporation record for 1898 through 1948. The single, partly synthesized, evaporation record for Redfield 6E was considered adequate for flood synthesis at all 66 modeled sites based on the experience of Hauth (1974).

Optimum parameter values determined during the calibration process were used in the model along with long-term daily rainfall, daily evaporation, and unit rainfall to produce two long-term series of floods at each of the 66 modeled sites. Frequency curves from both synthetic flood records, based on Huron and Rapid City rainfall records, were combined where appropriate. Otherwise, the flood record most applicable to the site was used. A simple averaging of frequency data from both synthesized flood records was judged inadequate.

A weighting scheme based on the inverse ratios of distances from Huron and Rapid City to the modeled site was used to combine the synthetic frequency curves (both for volumes and for peaks) applicable to the modeled site. A line was drawn on a map between Huron and Rapid City and distances to the various gaged sites were determined along this line of reference. In weighting the synthesized flood data, equal weight was given to both records for a site located midway while inverse proportional weight was given to sites elsewhere along the reference line. Only the Rapid City rainfall record was used in modeling sites located west of Rapid City and only the Huron rainfall record was used in modeling sites located east of Huron.

Flood-frequency Analysis

Analysis of station data was based on use of the log-Pearson Type III method for fitting flood-frequency curves. Details of the log-Pearson Type III method and calculations are given by the U.S. Water Resources Council (1977). Generalized skew coefficients, determined from the map given therein, were used in analysis of recorded peak data. Use of generalized skew coefficients was not considered appropriate in analysis of the synthetic flood records. Frequency analyses, in general, are the most reliable estimators of future floods and form the basis for regression relations that transfer information to ungaged sites.

Frequency curves of runoff volumes were defined using weighted synthetic records ranging in length from 68 to 76 years resulting from the modeling of the 66 small basins.

Frequency curves for peak discharges at the 66 modeled sites were defined by averaging frequency curves obtained using the synthetic records resulting from modeling and using records of annual-maximum discharges ranging in length from 8 to 11 years. Also, peak discharge frequencies were determined, based on actual records, at 57 additional crest-stage or continuous-record gaging stations. Average record length was 22 to 23 years for most of these additional stations.

The 66 modeled sites for which both peak-discharge and runoff-volume data are available are shown on figure 16. Stations for which only peak-discharge data are available are shown on figure 17. Flood characteristics derived from these data are listed for 115 selected stations in table 4 (peak discharge) and for 66 stations in table 5 (runoff volume). See "Supplemental Information." Some station data from adjacent States were used, but these stations and their flood characteristics are not included on figure 16 and 17 or in tables 4 and 5.

Regionalization by Regression Analysis

The regional analyses of observed and synthesized flood records by regression techniques provides the means of transferring the hydrologic information available at individual gaged sites to most ungaged sites within the State where estimates may be required.

Regionalization of the flood-frequency data was based on multiple-regression techniques as described by Benson (1962). These techniques have been previously used by Larimer (1970) and by Becker (1974) in analyses of South Dakota streamflow data. The relations of flood peaks and flood volumes to drainage basin and climatic characteristics were determined from a regression model of the assumed form Q or $V = aA^bB^cC^d...$, where the dependent variable (Q or V) is the peak discharge or the runoff volume and the independent variables (A, B, and C) are basin or climatic characteristics. In the equation, the constant and coefficients of regression are indicated respectively by "a" and by "b, c, and d." The regression constant and regression coefficients are defined, the statistical significance of each basin or climatic characteristic is evaluated, and a standard error of estimate is determined using regression analysis techniques.

Regression analyses for runoff volumes were based on the weighted synthetic frequency data for the 66 modeled sites. Regression analyses for peak discharges were based on a combination of the averaged synthetic and actual data for the 66 modeled sites and of the actual data for 57 other stations (crest-stage and regular gaging stations).

Frequencies of peak discharge were analyzed in several ways and results compared. Regressions were made using: (1) Synthetic data, only, for modeled sites, (2) combined actual and synthetic data for modeled sites, and (3) combined actual and synthetic data for the 66 modeled sites and actual data for the 57 sites not modeled. Regressions based only on synthetic data had significantly smaller standard errors of estimate, but estimates based on these regressions lacked the large variability normally associated with streamflow records in South Dakota. Combining the actual peak-frequency data with the synthetic data for the modeled sites introduced variability into the frequency data lacking in the synthetic data due to using the same long-term rainfall data at all sites in the modeling. Inclusion of the 57 other sites (actual data, only) gave broader areal coverage with respect to sampling drainage basins with areas less than 10 mi^2. More importantly, addition of these station data in the regressions extended the sample of data in the estimating relations to drainage basins with areas as much as 100 mi^2. In so doing, the coefficients of the drainage-area variable determined for estimating relations were better defined because a greater range in this variable was considered and because some weight was given to the larger drainage basins (as much as 150 mi^2). Final estimating relations for peak discharge were based on regression analyses using data from 123 gaged sites.

Residuals (differences between actual flood characteristics and estimates obtained from the initial regression equations) were plotted for both peak discharges and runoff volumes. No distinct geographic bias was discerned for estimating relations for either peak discharge or runoff volume although residuals varied widely between some stations. A single flood-frequency region (applicable statewide) was used and so a single set of equations applies for peak discharges and a single set of equations applies for runoff volumes. No satisfactory division of the State into subregions was found which materially improved accuracy of estimates as judged by the standard estimates of error.

Numerous basin and climatic characteristics were considered in the regression models; however, only those of both statistical and hydrologic significance were retained in the estimating relations. Several variables, although statistically significant at the 95-percent level for some relations, were omitted because they did not sufficiently improve accuracy of the estimating relations. To further simplify estimating relations, maintain consistency between estimating relations, and facilitate their use; uniform sets of variables were used for all flood equations defined. Variables based on drainage area, main channel slope, and soil-infiltration index proved most significant and useful in estimation of floods at ungaged sites in South Dakota. Other independent variables considered were stream length, mean-basin elevation, area of lakes and ponds, forested area, mean-annual precipitation, precipitation intensity (2-year, 24-hour), mean-minimum January temperature, snowfall index, and gaging station latitude and longitude. Area and soil index are significant in all relations for runoff volume while area, slope, and soil index are of hydrologic significance for peak discharge. Basin characteristics of contributing drainage area, main channel slope, and soil-infiltration index are listed for selected stations in table 4 under "Supplemental Information."

Comparisons of estimates based on relations given herein and of estimates based on relations given previously by Becker (1974) with actual flood-frequency data for all 123 stations were made using a computer routine. Significantly smaller aggregate differences between estimates and actual data were obtained using relations herein as compared to using previous relations (5- and 50-year floods were tested). These comparisons indicated that improved estimates of peak discharge are obtained for basins with drainage areas less than 100 mi^2 using the relations given herein.

Direct relationships between recorded runoff volumes and recorded peak discharges were also investigated. Such direct relationships are possibly useful as an alternative to estimating relations based on basin characteristics where reliable flood information is already available. For example, estimation of the runoff volume corresponding to a known peak discharge may be desirable because of the many sites in South Dakota for which peak discharges have previously been determined. Several assumptions were necessary to directly relate peak discharge and runoff volume. The most important of these assumptions was hydrograph shape.

A single-peak hydrograph needs to be used when estimating runoff volume from peak discharge or when estimating peak discharge from runoff volume. Obviously, this is often not the situation.

A study was made of 300 of the largest floods recorded at the 66 modeled sites. A relationship whereby the runoff volume can be estimated from the known peak discharge was defined. Likewise, peak discharge has been related to runoff volume so that peak discharge can be estimated if the runoff volume is known. See "Estimating Relations," equations 15 and 16. These relations are based on linear regression generally using the three largest floods recorded at each modeled site (190 floods).

Analysis of Hydrograph Shape

The average time distribution (hydrograph) of rainstorm floods is defined as a possible aid to planning and designing for future floods.

Flood hydrographs from the 66 modeled sites in South Dakota have a marked similarity in shape. Further, this similarity of hydrograph shape is evident from basin to basin and from region to region in the State. However, a method of reducing these hydrographs of varied flow magnitude and time duration to some standard flow magnitude and time duration was required in order to systematically analyze hydrograph shape.

A method developed and used by Craig and Rankl (1978), based on earlier work by Craig (1970) and Commons (1942), was found to adequately describe hydrograph shapes in South Dakota. Comparisons made by Craig and Rankl indicated that the standard mean dimensionless hydrograph developed for small streams in Wyoming also was applicable to similar areas outside of Wyoming based on tests using data from New Mexico and Arizona. Investigations of floods resulting from rainfall on small drainage basins in South Dakota indicate that this mean dimensionless hydrograph can be used to produce synthetic hydrographs that compare well with single-peak floods that occur in South Dakota.

A computer routine was developed to reduce actual flood hydrographs from small streams in South Dakota to dimensionless form and subsequently plot these dimensionless hydrographs to test the applicability and goodness of fit of the mean dimensionless hydrograph developed for Wyoming. Selected hydrographs from a representative sample consisting of 16 of the 66 model basins were used to test, in detail, the applicability of the mean dimensionless hydrograph.

Reducing hydrographs to the dimensionless form not only allowed comparisons of hydrographs of varied flood magnitude at a given site, but also allowed comparisons of hydrographs from basin to basin. Comparisons of the mean dimensionless hydrograph with four actual flood hydrographs, reduced to dimensionless form, from four different regions of the State are shown in figure 18 (see "Supplemental Information"). These actual hydrographs are typical of selected hydrographs used in verifying the applicability of the mean dimensionless hydrograph to small streams in South Dakota. The consistent agreement of these and many other comparisons was expected based on experience of Craig and Rankl. The use of this standard hydrograph shape is judged to be adequate for design purposes on small, ephemeral streams in South Dakota.

SUMMARY

This research has been directed toward definition of flood characteristics of small streams in South Dakota. This knowledge of flood characteristics is needed for planning and designing drainage structures, for establishing equitable land-use regulations, and for many other uses.

Much new and additional peak flow and rainfall-runoff data have been collected and placed in the public domain for alternate and future analyses. Sufficient data were collected to allow reliable modeling of the rainfall-runoff process at 66 gaged sites.

Analyses of data from this research project and of additional data from other studies have provided simple, accurate, and practical relations for estimating flood characteristics at gaged and ungaged sites located in small drainage basins. These analyses have provided: (1) Flood peak-frequency relations for 115 gaged sites where flood flows are virtually natural, (2) flood volume-frequency relations for 66 gaged sites, (3) regression relations for estimating flood peak-frequency relations at ungaged sites, (4) regression relations for estimating flood volume-frequency relations at ungaged sites, and (5) relations for estimating the most likely flood hydrograph for future floods of given magnitude.

In addition, this project has provided the hydrologic information required for using temporary storage at highway embankments to reduce the size of culverts at highway-stream crossings.

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SUPPLEMENTAL INFORMATION

Figures 15 to 18; Tables 1 to 5.

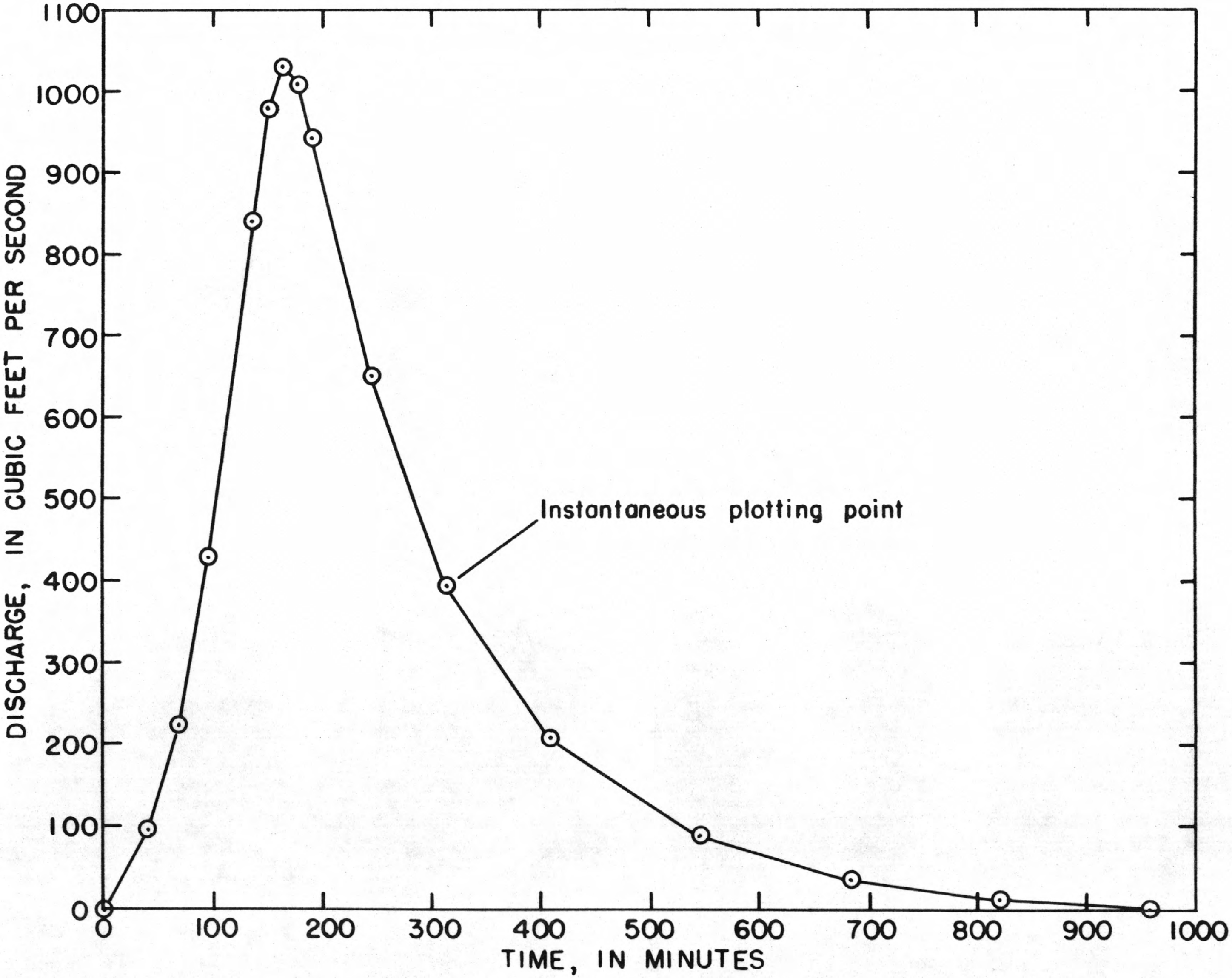
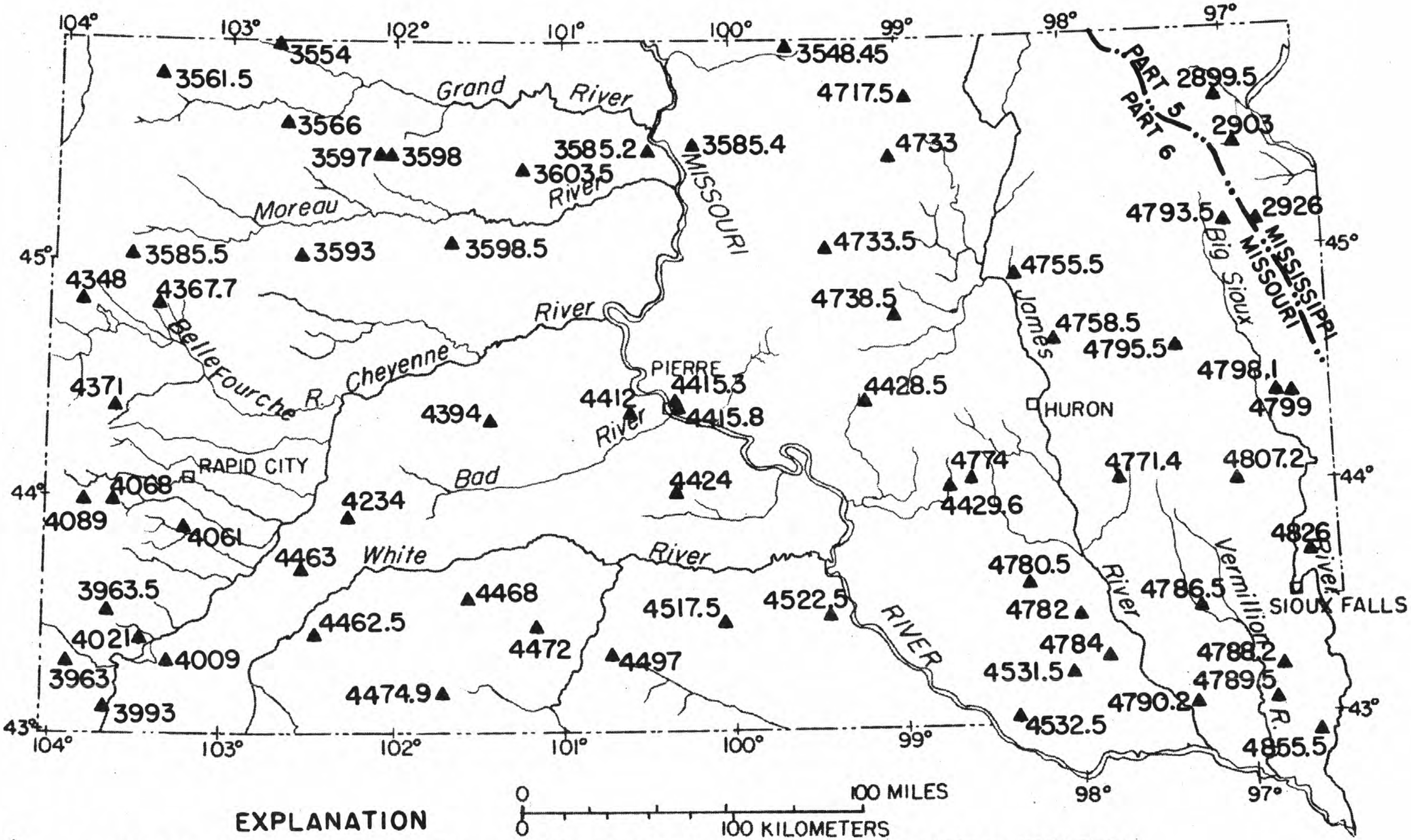


Figure 15.--Synthetic hydrograph based on mean dimensionless hydrograph method.

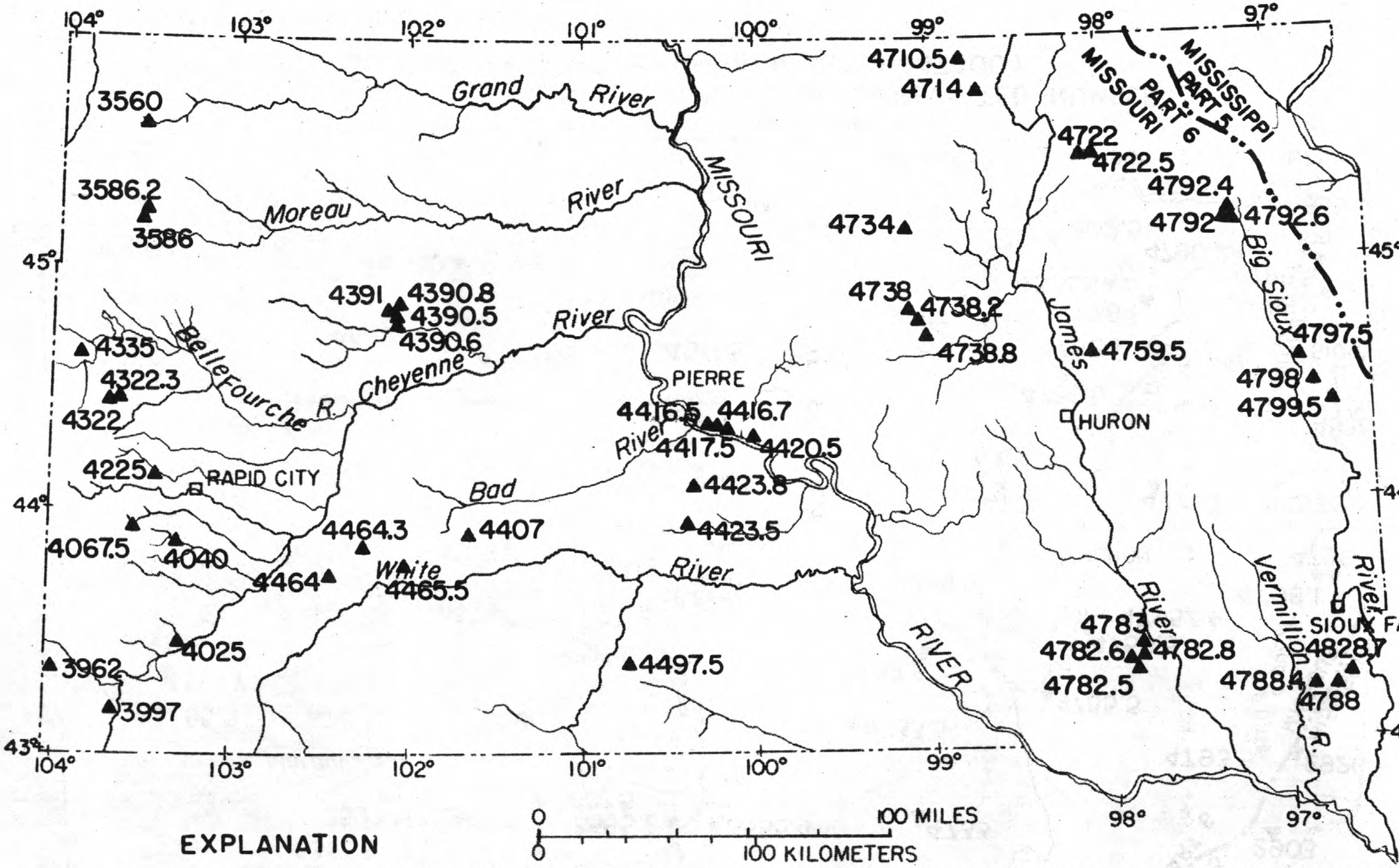


EXPLANATION

4472 GAGING STATION, RAINFALL-RUNOFF, 4472 IS AN ABBREVIATED NUMBER (U.S. GEOLOGICAL SURVEY STATION NUMBER IS 06447200)

RIVER BASIN BOUNDARY

Figure 16.--Location and distribution of rainfall-runoff stations where small basins were modeled.



EXPLANATION

▲ 4322 GAGING STATION, CONTINUOUS-RECORD OR CREST-STAGE, 4322 IS AN ABBREVIATED NUMBER (U.S. GEOLOGICAL SURVEY STATION NUMBER IS 06432200)

—··— RIVER BASIN BOUNDARY

Figure 17.--Location of additional gaging stations used in peak regression analyses.

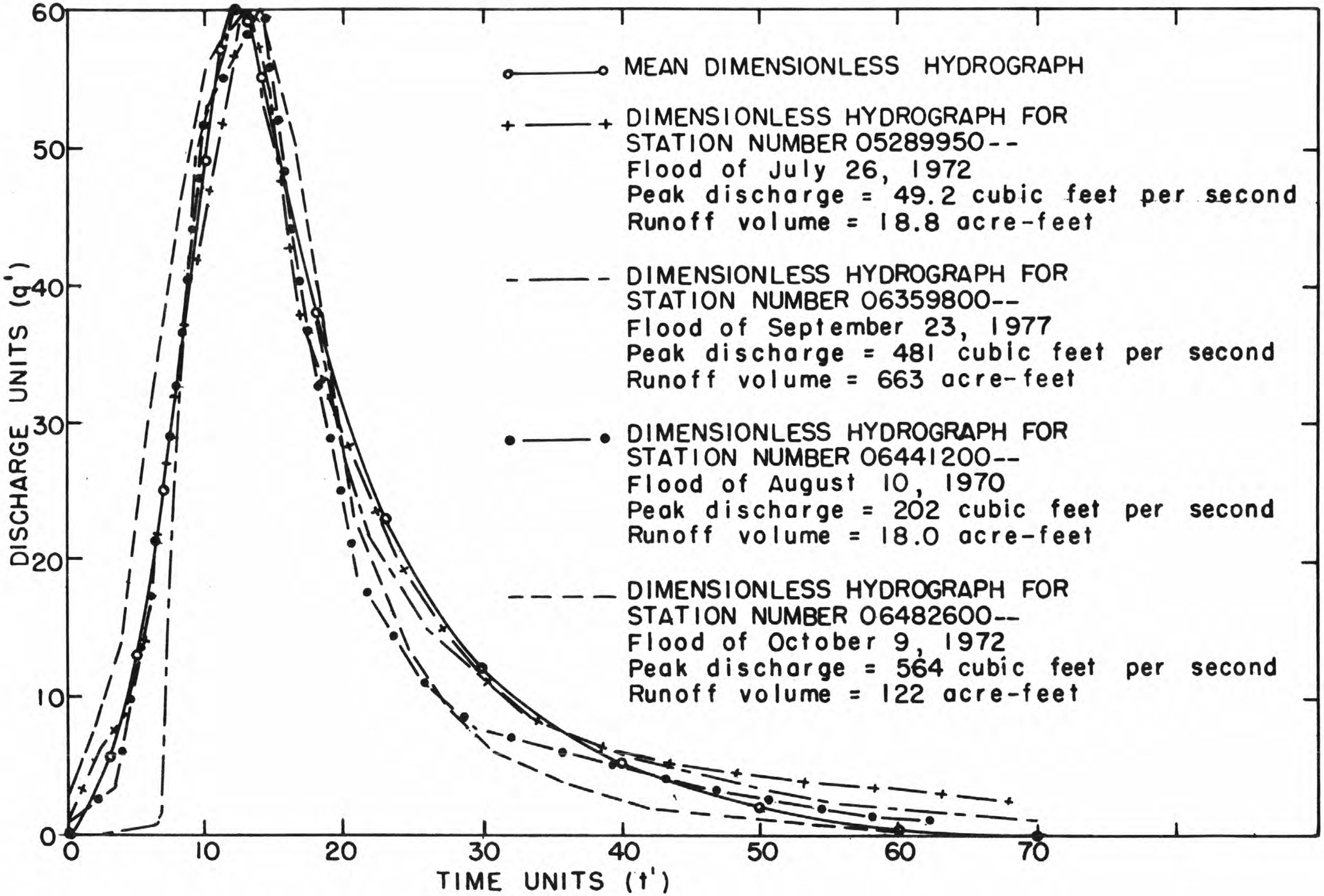


Figure 18.--Comparison of selected flood hydrographs, reduced to dimensionless form, with mean dimensionless hydrograph.

Table 1.--The 10 model parameters and their applications in the modeling process.

Parameter	Units	Definition and application
		Antecedent-moisture component
EVC---	----------------	Coefficient to convert pan evaporation to potential evapotranspiration.
RR----	----------------	Proportion of daily rainfall that infiltrates the soil.
BMSM--	Inches----------	Soil-moisture storage volume at field capacity.
DRN---	----------------	Drainage parameter for redistribution of soil moisture.
		Infiltration component
PSP---	Inches----------	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
KSAT--	Inches per hour-	The minimum (saturated) hydraulic conductivity used to determine infiltration rates.
RGF---	----------------	Ratio of the product of moisture deficit and suction at the wetted front for soil moisture at wilting point to that at field capacity.
		Surface-runoff component (routing)
KSW---	Hours-----------	Time characteristic for linear reservoir routing.
TC----	Minutes---------	Length of the base of the triangular translation hydrograph.
TP/TC-	----------------	Ratio of time to peak to base length of the triangular translation hydrograph.

Table 2.--Small basins for which the model was calibrated.

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
05289950	L Minnesota R trib at Sisseton, SD	4.21	0.5	18	13	71.0	C
05290300	N Fk Whetstone R trib nr Wilmot, SD	.96	5.0	25	16	41.1	C
05292600	N Fk Yellow Bank R trib nr Stockholm, SD	8.15	2.0	18	12	36.9	C
06354845	Spring Cr trib nr Greenway, SD	.99	1.0	5	3	--	--
06355400	N Fk Grand R trib nr Lodgepole, SD	3.07	3.0	12	9	38.1	C
06356150	N Jack Cr nr Ludlow, SD	1.69	3.0	14	12	52.1	C
06356600	S Fk Grand R trib nr Bison, SD	1.00	4.0	13	11	52.9	C
06358520	Deadman Cr trib nr Mobridge, SD	.30	9.0	14	10	38.0	C
06358540	Blue Blanket Cr trib nr Glenham, SD	.62	1.5	8	7	30.7	C

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06358550	Battle Cr trib nr Castle Rock, SD	1.57	4.0	23	15	39.4	C
06359300	Deep Cr trib nr Maurine, SD	1.26	.5	5	5	77.4	C
06359700	Thunder Butte Cr trib nr Meadow, SD	3.00	2.0	11	8	38.7	C
06359800	Thunder Butte Cr trib nr Glad Valley, SD	8.00	1.0	14	11	43.2	C
06359850	Elm Cr trib nr Dupree, SD	4.16	7.0	9	6	44.9	C
06360350	Little Moreau R trib nr Firesteel, SD	2.09	.0	8	3	--	--
06396300	Cottonwood Cr trib nr Edgemont, SD	.09	5.0	18	12	31.3	C
06396350	Red Canyon Cr trib nr Pringle, SD	.20	.0	1	1	--	--
06399300	Hat Cr trib nr Ardmore, SD	3.74	15.0	6	5	25.3	C
06400900	Horsehead Cr trib nr Smithwick, SD	1.52	4.0	7	5	45.7	C

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06402100	Fall R trib at Hot Springs, SD	3.81	2.5	22	16	42.7	C
06406100	Battle Cr trib nr Hermosa, SD	3.49	.0	1	1	--	--
06406800	Newton Fork nr Hill City, SD	8.17	.5	9	8	55.2	C
06408900	Heeley Cr nr Hill City, SD	4.88	.0	7	5	38.3	C
06423400	Bull Cr trib nr Wall, SD	.39	.0	4	3	--	--
06434800	Owl Cr trib nr Belle Fourche, SD	3.06	1.0	11	9	45.6	C
06436770	Dry Cr trib nr Newell, SD	.20	1.5	6	4	--	--
06437100	Boulder Cr nr Deadwood, SD	1.32	5.0	14	12	25.5	C
06439400	Plum Cr trib nr Milesville, SD	.50	.5	8	4	--	--
06441200	Powell Cr trib nr Fort Pierre, SD	.40	5.0	13	9	43.9	C

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06441530	Hilgers Gulch trib nr Pierre, SD	1.33	5.0	16	9	45.0	C
06441580	Hilgers Gulch at Pierre, SD	6.49	2.0	12	10	47.0	C
06442400	Medicine Cr trib No. 2 nr Vivian, SD	9.21	5.0	8	5	59.1	C
06442850	Elm Cr trib nr Ree Heights, SD	.70	.5	5	5	18.2	C
06442960	Smith Cr trib nr Gann Valley, SD	5.85	2.0	7	6	41.2	C
06446250	Porcupine Cr trib nr Rockyford, SD	1.65	20.0	21	15	42.5	C
06446300	Big Hollow Cr trib nr Scenic, SD	2.71	33.0	39	39	68.0	C
06446800	Cottonwood Cr nr Wanblee, SD	1.70	.5	4	1	--	--
06447200	Black Pipe Cr trib nr Norris, SD	4.19	4.0	25	20	38.6	C
06447490	Little White R trib nr Martin, SD	8.90	.0	1	1	--	--

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06449700	Little Oak Cr nr Mission, SD	2.58	0.5	8	5	22.4	C
06451750	Cottonwood Cr trib nr Winner, SD	4.00	5.0	12	7	55.7	C
06452250	Fivemile Cr trib nr Iona, SD	2.35	7.0	12	7	32.2	C
06453150	Choteau Cr trib nr Tripp, SD	.54	2.0	17	10	51.3	C
06453250	Choteau Cr trib nr Wagner, SD	15.6	.0	12	9	57.7	C
06471750	Snake Cr trib nr Leola, SD	4.49	.0	3	3	--	--
06473300	Preachers Run trib at Ipswich, SD	7.88	.0	3	2	--	--
06473350	S Fk Snake Cr trib nr Seneca, SD	4.54	1.0	3	3	--	--
06473850	Shaefer Cr trib nr Orient, SD	5.17	.0	5	4	--	--
06475550	Dry Run trib nr Frankfort, SD	4.19	.5	17	13	46.4	C

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06475850	Foster Cr trib nr Carpenter, SD	4.93	1.0	7	6	67.4	C
06477140	Rock Cr trib nr Roswell, SD	5.67	.0	5	5	84.2	C
06477400	Firesteel Cr trib nr Wessington Springs, SD	.22	2.0	15	12	55.4	C
06478050	Enemy Cr trib nr Mount Vernon, SD	3.38	1.0	10	7	28.2	C
06478200	Coffee Cr trib nr Parkston, SD	.81	.0	14	12	48.7	C
06478400	Lonetree Cr trib nr Kaylor, SD	3.65	2.0	6	6	33.5	C
06478650	W Fk Vermillion R nr Monroe, SD	2.74	5.0	17	13	27.5	C
06478820	Saddlerock Cr trib nr Beresford, SD	2.22	4.5	12	10	28.3	C
06478950	Ash Cr nr Beresford, SD	5.00	1.0	21	15	47.2	C
06479020	Smoky Run nr Irene, SD	4.96	1.5	13	9	44.4	C

Table 2.--Small basins for which the model was calibrated.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Impervious area (percent)	Number of storms considered	Number of storms used in final calibration	Standard error of estimate (percent)	Control basin
06479350	Soo Cr trib nr South Shore, SD	1.56	1.5	20	13	52.2	C
06479550	Dolph Cr trib nr Lake Norden, SD	5.91	1.0	8	7	41.2	C
06479810	North Deer Cr trib nr Brookings, SD	.33	1.0	19	14	52.3	C
06479900	Sixmile Cr trib nr Brookings, SD	9.78	.5	7	6	68.1	C
06480720	Bachelor Cr trib nr Wentworth, SD	1.03	2.0	7	5	37.4	C
06482600	West Pipestone Cr trib nr Garretson, SD	2.16	.0	14	10	86.5	C
06485550	West Union Cr nr Alcester, SD	3.48	.0	16	9	41.0	C

Table 3.--Rainfall-runoff model parameters determined for small basins.

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
05289950	L Minnesota R trib at Sisseton, SD	1.028	0.061	1.00	22.86	4.125	0.67	0.90	5.500	300.0	0.50
05290300	N Fk Whetstone R trib nr Wilmot, SD	1.557	.064	1.00	18.82	1.111	.68	.84	7.000	360.0	.50
05292600	N Fk Yellow Bank R trib nr Stockholm, SD	2.005	.003	1.00	38.88	1.403	.69	.88	8.500	240.0	.50
06354845	Spring Cr trib nr Greenway, SD	3.292	.144	1.00	14.16	2.410	.73	.91	.800	100.0	.50
06355400	N Fk Grand R trib nr Lodgepole, SD	.842	.060	1.00	8.089	3.132	.79	.88	3.500	165.0	.50
06356150	N Jack Cr nr Ludlow, SD	2.332	.051	1.00	7.742	10.21	.80	.88	7.000	300.0	.50
06356600	S Fk Grand R trib nr Bison, SD	5.952	.158	1.00	26.05	2.081	.80	.93	1.250	45.00	.50
06358520	Deadman Cr trib nr Mobridge, SD	1.062	.032	1.00	32.75	2.408	.75	.82	.405	47.25	.50
06358540	Blue Blanket Cr trib nr Glenham, SD	5.424	.441	1.00	30.03	2.621	.75	.98	.900	75.00	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06358550	Battle Cr trib nr Castle Rock, SD	3.970	0.033	1.00	17.60	1.000	0.83	0.87	0.750	65.00	0.50
06359300	Deep Cr trib nr Maurine, SD	3.502	.243	1.00	12.10	1.175	.81	.93	1.000	90.00	.50
06359700	Thunder Butte Cr trib nr Meadow, SD	5.297	.209	1.00	25.61	13.04	.79	.96	4.000	130.0	.50
06359800	Thunder Butte Cr trib nr Glad Valley, SD	.439	.021	1.00	1.345	1.678	.79	.60	9.000	510.0	.50
06359850	Elm Cr trib nr Dupree, SD	.773	.191	1.00	4.423	2.571	.79	.84	3.500	240.0	.50
06360350	Little Moreau R trib nr Fire-steel, SD	1.140	.069	1.00	6.022	1.441	.77	.86	3.500	210.0	.50
06396300	Cottonwood Cr trib nr Edgemont, SD	1.876	.064	1.00	7.053	1.496	.93	.83	.280	30.00	.50
06396350	Red Canyon Cr trib nr Pringle, SD	2.047	.091	1.00	9.287	5.901	.93	.86	.170	20.00	.50
06399300	Hat Cr trib nr Ardmore, SD	.644	.026	1.00	3.720	3.000	.93	.56	7.000	600.0	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06400900	Horsehead Cr trib nr Smithwick, SD	2.356	0.229	1.00	23.92	1.440	0.90	0.96	2.500	120.0	0.50
06402100	Fall R trib at Hot Springs, SD	3.993	.487	1.00	39.74	1.125	.90	.98	1.000	90.00	.50
06406100	Battle Cr trib nr Hermosa, SD	6.653	.164	1.00	15.89	6.760	.86	.97	1.250	60.00	.50
06406800	Newton Fork nr Hill City, SD	9.969	.954	1.00	39.38	6.075	.87	.99	.451	55.58	.50
06408900	Heeley Cr nr Hill City, SD	8.623	.260	1.00	33.02	4.105	.87	.99	1.150	70.00	.50
06423400	Bull Cr trib nr Wall, SD	.933	.037	1.00	3.884	5.289	.84	.90	3.250	100.0	.50
06434800	Owl Cr trib nr Belle Fourche, SD	1.420	.020	1.00	4.432	1.523	.84	.67	7.000	560.0	.50
06436770	Dry Cr trib nr Newell, SD	5.847	.033	1.00	37.74	2.951	.83	.96	.350	45.00	.50
06437100	Boulder Cr nr Deadwood, SD	2.862	.063	1.00	12.00	10.60	.85	.77	3.000	255.0	.50
06439400	Plum Cr trib nr Milesville, SD	2.523	.244	1.00	1.101	1.020	.83	.95	.750	80.00	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06441200	Powell Cr trib nr Fort Pierre, SD	0.996	0.074	1.00	13.92	3.174	0.80	0.85	1.000	55.00	0.50
06441530	Hilgers Gulch trib nr Pierre, SD	3.051	.101	1.00	12.44	7.187	.79	.85	2.500	240.0	.50
06441580	Hilgers Gulch at Pierre, SD	2.530	.293	1.00	16.53	2.937	.79	.95	.608	81.00	.50
06442400	Medicine Cr trib No. 2 nr Vivian, SD	2.408	.071	1.00	14.69	1.493	.80	.88	5.000	300.0	.50
06442850	Elm Cr trib nr Ree Heights, SD	9.946	.497	1.00	39.80	19.86	.76	.99	.250	30.00	.50
06442960	Smith Cr trib nr Gann Valley, SD	9.910	.491	1.00	39.06	5.471	.77	.98	1.250	60.00	.50
06446250	Porcupine Cr trib nr Rockyford, SD	1.321	.123	1.00	10.58	15.57	.86	.79	.550	70.00	.50
06446300	Big Hollow Cr trib nr Scenic, SD	1.500	.050	1.00	5.500	2.300	.75	.90	.600	90.00	.50
06446800	Cottonwood Cr nr Wanblee, SD	1.350	.043	1.00	4.878	14.46	.84	.93	.700	60.00	.50
06447200	Black Pipe Cr trib nr Norris, SD	3.753	.080	1.00	21.08	1.015	.84	.92	6.500	380.0	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06447490	Little White R trib nr Martin, SD	8.130	0.264	1.00	21.59	11.14	0.86	0.98	0.850	120.0	0.50
06449700	Little Oak Cr nr Mission, SD	3.935	.136	1.00	18.90	3.048	.84	.94	1.750	105.0	.50
06451750	Cottonwood Cr trib nr Winner, SD	2.651	.125	1.00	6.789	13.97	.82	.90	3.000	290.0	.50
06452250	Fivemile Cr trib nr Iona, SD	1.401	.158	1.00	21.67	1.085	.81	.89	4.000	240.0	.50
06453150	Choteau Cr trib nr Tripp, SD	3.513	.083	1.00	11.93	9.777	.80	.85	.500	40.00	.50
06453250	Choteau Cr trib nr Wagner, SD	8.221	.491	1.00	31.88	3.735	.81	.98	1.422	72.91	.50
06471750	Snake Cr trib nr Leola, SD	2.794	.100	1.00	11.38	2.616	.72	.95	3.000	210.0	.50
06473300	Preachers Run trib at Ipswich, SD	6.972	.152	1.00	29.05	2.211	.73	.99	4.250	105.0	.50
06473350	S Fk Snake Cr trib nr Seneca, SD	9.705	.430	1.00	38.82	13.72	.74	.98	1.500	120.0	.50
06473850	Shaefer Cr trib nr Orient, SD	2.406	.077	1.00	5.003	7.651	.75	.90	10.00	480.0	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06475550	Dry Run trib nr Frankfort, SD	4.427	0.495	1.00	30.89	8.345	0.73	0.99	0.900	120.0	0.50
06475850	Foster Cr trib nr Carpenter, SD	1.082	.081	1.00	29.53	3.600	.74	.93	7.500	540.0	.50
06477140	Rock Cr trib nr Roswell, SD	4.046	.160	1.00	19.76	1.579	.75	.95	5.000	540.0	.50
06477400	Firesteel Cr trib nr Wessington Springs, SD	3.489	.062	1.00	29.66	3.142	.77	.88	1.250	75.00	.50
06478050	Enemy Cr trib nr Mount Vernon, SD	5.099	.259	1.00	17.48	6.602	.78	.94	3.000	120.0	.50
06478200	Coffee Cr trib nr Parkston, SD	1.648	.100	1.00	12.10	1.503	.79	.88	3.500	210.0	.50
06478400	Lonetree Cr trib nr Kaylor, SD	7.594	.476	1.00	33.75	2.303	.78	.95	1.100	100.0	.50
06478650	W Fk Vermillion R nr Monroe, SD	4.804	.209	1.00	18.51	4.078	.78	.94	7.000	180.0	.50
06478820	Saddlerock Cr trib nr Beresford, SD	6.718	.118	1.00	7.996	2.559	.78	.91	2.750	135.0	.50
06478950	Ash Cr nr Beresford, SD	4.680	.096	1.00	16.82	1.781	.79	.84	2.400	195.0	.50

Table 3.--Rainfall-runoff model parameters determined for small basins.--Continued

U.S. Geological Survey station number	Station name	Parameters (See table 1)									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
06479020	Smoky Run nr Irene, SD	11.71	0.853	1.00	36.43	12.85	0.80	0.98	3.000	120.0	0.50
06479350	Soo Cr trib nr South Shore, SD	9.838	.022	1.00	22.50	2.912	.68	.88	1.800	165.0	.50
06479550	Dolph Cr trib nr Lake Norden, SD	6.202	.213	1.00	7.835	3.150	.73	.96	9.500	480.0	.50
06479810	North Deer Cr trib nr Brookings, SD	2.619	.078	1.00	12.49	1.325	.74	.80	.600	50.00	.50
06479900	Sixmile Cr trib nr Brookings, SD	.735	.068	1.00	29.48	3.553	.73	.85	.600	600.0	.50
06480720	Bachelor Cr trib nr Wentworth, SD	4.471	.245	1.00	15.51	3.261	.75	.85	3.000	240.0	.50
06482600	West Pipestone Cr trib nr Garretson, SD	3.966	.058	1.00	10.75	4.251	.75	.86	1.750	180.0	.50
06485550	West Union Cr nr Alcester, SD	2.297	.137	1.00	11.56	7.716	.80	.85	.750	70.00	.50

Table 4.--Peak-frequency data and basin characteristics for selected small basins.

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
05289950	L Minnesota R trib at Sisseton, SD	4.21	167.8	2.99	104	226	333	497	639	800
05290300	N Fk Whetstone R trib nr Wilmot, SD	.96	69.80	2.99	25	46	63	89	112	137
05292600	N Fk Yellow Bank R trib nr Stockholm, SD	8.15	53.00	2.99	278	504	695	984	1,230	1,500
06354845	Spring Cr trib nr Greenway, SD	.99	101.0	3.51	37	108	194	365	546	785
06355400	N Fk Grand R trib nr Lodgepole, SD	3.07	69.20	3.16	151	296	414	596	762	955
06356000	S Fk Grand River at Buffalo, SD	148	17.80	2.66	641	1,460	2,230	3,480	4,610	5,930
06356150	N Jack Cr nr Ludlow, SD	1.69	77.20	2.66	32	62	85	119	147	178
06356600	S Fk Grand R trib nr Bison, SD	1.00	--	3.16	29	62	92	144	193	251
06358520	Deadman Cr trib nr Mobridge, SD	.30	157.7	3.51	53	103	146	209	263	325

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06358540	Blue Blanket Cr trib nr Glenham, SD	0.62	46.70	3.51	6.5	13	20	32	45	65
06358550	Battle Cr trib nr Castle Rock, SD	1.57	93.30	2.50	154	326	474	701	902	1,120
06358600	S Fk Moreau R trib nr Redig, SD	2.33	48.00	2.50	52	123	192	306	414	540
06358620	Sand Cr trib nr Redig, SD	.04	100.0	2.50	21	36	46	61	73	85
06359300	Deep Cr trib nr Maurine, SD	1.26	85.00	2.50	13	40	81	190	344	600
06359700	Thunder Butte Cr trib nr Meadow, SD	3.00	--	2.50	22	54	88	148	207	281
06359800	Thunder Butte Cr trib nr Glad Valley, SD	8.00	--	2.50	351	901	1,680	3,510	5,790	9,140
06359850	Elm Cr trib nr Dupree, SD	4.16	30.60	2.50	209	393	531	720	869	1,020
06360350	Little Moreau R trib nr Firesteel, SD	2.09	31.40	2.50	107	198	270	381	484	608

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06396200	Fiddle Cr nr Edgemont, SD	0.64	68.97	1.76	12	36	68	142	233	370
06396300	Cottonwood Cr trib nr Edgemont, SD	.09	282.0	1.76	24	46	64	92	116	145
06396350	Red Canyon Cr trib nr Pringle, SD	.20	171.0	5.38	26	61	92	141	185	235
06399300	Hat Cr trib nr Ardmore, SD	3.74	28.74	1.76	137	257	408	794	1,360	2,350
06399700	Pine Cr nr Ardmore, SD	7.36	56.70	1.76	709	1,060	1,340	1,760	2,130	2,540
06400900	Horsehead Cr trib nr Smithwick, SD	1.52	59.20	1.76	15	34	56	102	159	250
06402100	Fall R trib at Hot Springs, SD	3.81	167.5	5.38	29	49	63	83	100	119
06402500	Beaver Cr nr Buffalo Gap, SD	130	58.86	5.38	120	556	1,340	3,640	7,190	13,600
06404000	Battle Cr nr Keystone, SD	66.00	79.57	5.38	312	720	1,120	1,800	2,460	3,250
06406100	Battle Cr trib nr Hermosa, SD	3.49	59.90	5.38	27	53	79	126	175	239

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06406750	Sunday Gulch nr Hill City, SD	6.56	237.4	5.38	10	38	81	186	322	536
06406800	Newton Fork nr Hill City, SD	8.17	177.3	5.38	24	45	62	90	114	143
06408900	Heeley Cr nr Hill City, SD	4.88	145.8	5.38	8.0	18	28	44	61	80
06422500	Boxelder Cr nr Nemo, SD	96.00	60.71	5.38	201	655	1,240	2,500	3,960	6,040
06423400	Bull Cr trib nr Wall, SD	.39	62.00	1.76	31	46	54	65	73	81
06432200	Polo Cr nr Whitewood, SD	10.30	173.3	8.18	189	515	868	1,510	2,160	2,980
06432230	Miller Cr nr Whitewood, SD	5.23	233.1	8.18	13	79	201	541	1,020	1,810
06433500	Hay Cr at Belle Fourche, SD	121	29.63	8.18	61	205	385	753	1,160	1,710
06434800	Owl Cr trib nr Belle Fourche, SD	3.06	55.70	1.90	105	174	225	296	356	422
06436770	Dry Cr trib nr Newell, SD	.20	129.3	1.90	7.0	15	23	35	47	61

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06437100	Boulder Cr nr Deadwood, SD	1.32	218.3	1.90	44	92	136	210	281	366
06439050	Cherry Cr trib nr Avance, SD	.60	80.00	2.50	22	68	123	228	338	482
06439060	Cherry Creek trib No. 2 nr Avance, SD	.11	80.00	2.50	6.4	24	47	98	155	235
06439080	Cherry Cr trib No. 3 nr Avance, SD	4.58	23.33	2.50	69	326	728	1,700	2,940	4,800
06439100	Beaver Cr nr Faith, SD	37.1	225.8	2.50	215	1,040	2,350	5,580	9,740	16,000
06439400	Plum Cr trib nr Milesville, SD	.50	--	1.76	48	106	160	259	367	517
06440700	Brady Cr trib nr Philip, SD	4.84	47.40	1.76	100	392	847	2,020	3,630	6,260
06441200	Powell Cr trib nr Fort Pierre, SD	.40	88.90	1.76	50	111	171	273	373	496
06441530	Hilgers Gulch trib nr Pierre, SD	1.33	83.60	3.51	34	88	148	265	388	550

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06441580	Hilgers Gulch at Pierre, SD	6.49	81.40	3.51	149	567	1,280	3,210	5,960	10,500
06441650	Mush Cr nr Pierre, SD	14.2	41.27	3.51	626	1,630	2,690	4,580	6,460	8,800
06441670	Missouri R trib nr Pierre, SD	.42	272.7	3.51	58	177	318	593	886	1,270
06441750	Missouri R trib nr Canning, SD	.19	408.3	3.51	77	134	178	241	293	349
06442050	Missouri R trib nr DeGrey, SD	1.73	97.78	3.51	153	442	768	1,380	2,020	3,860
06442350	N Fk Medicine Cr nr Vivian, SD	47.0	24.40	1.90	69	221	419	846	1,350	2,070
06442380	Medicine Cr trib nr Vivian, SD	.29	50.00	1.76	31	97	179	348	539	802
06442400	Medicine Cr trib No. 2 nr Vivian, SD	9.21	28.23	1.90	152	320	475	729	966	1,250
06442850	Elm Cr trib nr Ree Heights, SD	.70	61.70	3.33	7.3	17	27	45	65	88

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06442960	Smith Cr trib nr Gann Valley, SD	5.85	35.90	3.33	37	71	102	156	207	270
06446250	Porcupine Cr trib nr Rockyford, SD	1.65	74.10	1.90	280	426	533	676	789	904
06446300	Big Hollow Cr trib nr Scenic, SD	2.71	41.60	1.90	623	941	1,140	1,380	1,540	1,720
06446400	Cain Cr trib at Imlay, SD	15.8	17.01	1.90	612	1,270	1,930	3,110	4,310	5,840
06446430	White River trib nr Conata, SD	.17	168.8	1.76	109	197	275	401	518	658
06446550	White R trib nr Interior, SD	.32	309.7	1.90	188	302	396	539	664	807
06446800	Cottonwood Cr nr Wanblee, SD	1.70	75.00	1.90	278	477	642	974	1,400	2,120
06447200	Black Pipe Cr trib nr Norris, SD	4.19	32.00	1.90	53	110	170	279	394	545
06447490	Little White R trib nr Martin, SD	8.90	35.00	3.33	24	54	86	149	218	314

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06449700	Little Oak Cr nr Mission, SD	2.58	23.67	2.50	33	112	241	601	1,150	2,140
06449750	West Branch Horse Cr nr Mission, SD	6.31	50.14	2.50	29	111	245	610	1,140	2,060
06451750	Cottonwood Cr trib nr Winner, SD	4.00	--	2.05	98	193	278	413	536	680
06452250	Fivemile Cr trib nr Iona, SD	2.35	159.6	3.16	51	89	125	188	250	329
06453150	Choteau Cr trib nr Tripp, SD	.54	95.20	3.33	55	131	211	355	499	681
06453250	Choteau Cr trib nr Wagner, SD	15.6	45.00	3.33	29	84	155	316	519	835
06471050	Elm R trib nr Leola, SD	18.0	32.27	2.99	56	172	296	505	700	926
06471400	Willow Cr trib nr Leola, SD	6.69	10.00	2.99	16	47	77	127	171	222
06471750	Snake Cr trib nr Leola, SD	4.49	41.10	2.99	71	175	284	476	668	906
06472200	Mud Cr trib nr Groton, SD	56.7	20.45	2.82	31	125	244	475	714	1,100

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06472250	Mud Cr trib No. 2 nr Groton, SD	75.8	19.44	2.82	39	137	249	450	645	879
06473300	Preachers Run trib at Ipswich, SD	7.88	24.90	3.16	23	58	101	199	326	527
06473350	S Fk Snake Cr trib nr Seneca, SD	4.54	11.50	3.16	24	37	48	65	81	100
06473400	N Fk Snake Cr trib nr Wecota, SD	2.69	19.60	3.16	15	44	76	129	180	241
06473800	Matter Cr trib nr Orient, SD	7.63	19.90	3.33	15	91	223	564	1,010	1,670
06473820	Shaefer Cr nr Orient, SD	51.3	23.12	3.33	69	288	588	1,220	1,930	2,890
06473850	Shaefer Cr trib nr Orient, SD	5.17	20.00	3.33	76	163	241	366	479	608
06473880	Shaefer Cr trib nr Miller, SD	5.95	16.52	3.33	16	62	120	236	362	525
06475550	Dry Run trib nr Frankfort, SD	4.19	4.86	2.34	21	51	83	140	198	274
06475850	Foster Cr trib nr Carpenter, SD	4.93	11.30	2.66	47	109	169	273	371	492

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics			Flood characteristics					
		Drainage area (square miles)	Channel slope (feet per mile)	Soil infiltration index (inches)	Peak discharge, in cubic feet per second, for indicated recurrence interval, in years					
					2	5	10	25	50	100
06475950	Shue Cr trib nr Yale, SD	6.90	6.91	2.66	14	42	71	119	165	218
06477140	Rock Cr trib nr Roswell, SD	5.67	12.40	2.99	32	108	204	402	624	930
06477400	Firesteel Cr trib nr Wessington Springs, SD	.22	92.90	3.33	14	30	45	71	98	133
06478050	Enemy Cr trib nr Mount Vernon, SD	3.38	30.00	3.33	24	52	80	132	186	257
06478200	Coffee Cr trib nr Parkston, SD	.81	15.40	3.33	25	54	79	121	158	201
06478250	N Branch Dry Cr trib nr Parkston, SD	3.19	7.64	3.33	21	110	257	629	1,110	1,850
06478260	N Branch Dry Cr nr Parkston, SD	54.1	12.06	3.33	86	420	948	2,230	3,840	6,240
06478280	S Branch Dry Cr nr Parkston, SD	25.8	14.60	3.33	56	215	429	885	1,410	2,120
06478300	Dry Cr nr Parkston, SD	99.2	6.73	3.33	151	540	1,040	2,060	3,180	4,690

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06478400	Lonetree Cr trib nr Kaylor, SD	3.65	22.60	3.33	35	64	93	147	206	288
06478650	W Fk Vermillion R nr Monroe, SD	2.74	17.60	3.33	30	61	91	139	186	243
06478800	Saddlerock Cr nr Canton, SD	13.0	22.62	3.33	88	274	475	832	1,180	1,590
06478820	Saddlerock Cr trib nr Beresford, SD	2.22	41.30	3.33	39	91	149	258	372	522
06478840	Saddlerock Cr nr Beresford, SD	23.1	15.85	3.33	67	255	490	949	1,430	2,040
06478950	Ash Cr nr Beresford, SD	5.00	54.50	3.33	158	371	581	945	1,310	1,770
06479020	Smoky Run nr Irene, SD	4.96	6.98	3.33	22	37	50	70	88	107
06479200	Big Sioux R nr Ortley, SD	53.8	9.62	3.70	146	396	638	1,030	1,370	1,760
06479240	Big Sioux R trib No. 2 nr Summit, SD	.26	53.16	3.70	8.5	26	44	75	103	135

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06479260	Big Sioux R trib No. 3 nr Summit, SD	6.61	26.65	3.70	90	330	614	1,140	1,650	2,280
06479350	Soo Cr trib nr South Shore, SD	1.56	55.60	3.70	51	139	235	407	582	804
06479550	Dolph Cr trib nr Lake Norden, SD	5.91	18.20	3.16	24	54	86	146	212	300
06479750	Peg Munky Run nr Estelline, SD	25.2	24.81	3.16	226	705	1,210	2,080	2,890	3,840
06479800	North Deer Cr nr Estelline, SD	48.3	18.11	3.16	178	700	1,350	2,580	3,830	5,380
06479810	North Deer Cr trib nr Brookings, SD	.33	54.20	3.16	35	101	175	311	447	615
06479900	Sixmile Cr trib nr Brookings, SD	9.78	23.41	3.16	278	700	1,140	1,900	2,640	3,520
06479950	Deer Cr nr Brookings, SD	4.04	47.43	3.16	47	215	443	911	1,410	2,060
06480720	Bachelor Cr trib nr Wentworth, SD	1.03	31.60	3.16	11	28	47	81	117	163

Table 4.--Peak-frequency data and basin characteristics for selected small basins.--Continued

U.S. Geological Survey station number	Station name	Basin characteristics: Drainage area (square miles)	Basin characteristics: Channel slope (feet per mile)	Basin characteristics: Soil infiltration index (inches)	Flood characteristics: Peak discharge, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	25	50	100
06482600	West Pipestone Cr trib nr Garretson, SD	2.16	49.50	3.33	116	339	582	1,010	1,430	1,940
06482870	Little Beaver Cr trib nr Canton, SD	.31	122.2	3.33	26	44	57	74	86	99
06485550	West Union Cr nr Alcester, SD	3.48	37.50	3.33	337	807	1,260	2,000	2,680	3,490

Table 5.--Volume-frequency data for modeled basins.

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
05289950	L Minnesota R trib at Sisseton, SD	4.21	125	243	348	517	671	851
05290300	N Fk Whetstone R trib nr Wilmot, SD	.96	34	63	88	129	167	212
05292600	N Fk Yellow Bank R trib nr Stockholm, SD	8.15	551	902	1,180	1,580	1,920	2,290
06354845	Spring Cr trib nr Greenway, SD	.99	25	43	61	90	119	156
06355400	N Fk Grand R trib nr Lodgepole, SD	3.07	120	215	288	388	468	551
06356150	N Jack Cr nr Ludlow, SD	1.69	56	96	130	179	222	270
06356600	S Fk Grand R trib nr Bison, SD	1.00	29	46	59	78	94	112
06358520	Deadman Cr trib nr Mobridge, SD	.30	17	29	38	52	64	78
06358540	Blue Blanket Cr trib nr Glenham, SD	.62	3.3	5.7	8.1	12	17	22
06358550	Battle Cr trib nr Castle Rock, SD	1.57	49	90	125	179	228	283

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06359300	Deep Cr trib nr Maurine, SD	1.26	15	25	34	47	59	73
06359700	Thunder Butte Cr trib nr Meadow, SD	3.00	19	31	40	53	64	77
06359800	Thunder Butte Cr trib nr Glad Valley, SD	8.00	703	1,110	1,400	1,780	2,080	2,400
06359850	Elm Cr trib nr Dupree, SD	4.16	161	295	401	550	671	801
06360350	Little Moreau R trib nr Firesteel, SD	2.09	114	204	275	378	462	553
06396300	Cottonwood Cr trib nr Edgemont, SD	.09	2.9	5.5	7.4	9.9	12	14
06396350	Red Canyon Cr trib nr Pringle, SD	.20	2.9	6.5	9.8	15	20	25
06399300	Hat Cr trib nr Ardmore, SD	3.74	344	541	686	883	1,040	1,210
06400900	Horsehead Cr trib nr Smithwick, SD	1.52	10	20	29	44	57	73
06402100	Fall R trib at Hot Springs, SD	3.81	12	21	28	38	46	55

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06406100	Battle Cr trib nr Hermosa, SD	3.49	60	93	117	152	180	210
06406800	Newton Fork nr Hill City, SD	8.17	15	24	30	38	45	53
06408900	Heeley Cr nr Hill City, SD	4.88	4.2	7.6	11	17	24	32
06423400	Bull Cr trib nr Wall, SD	.39	30	47	61	80	96	112
06434800	Owl Cr trib nr Belle Fourche, SD	3.06	242	392	507	669	802	946
06436770	Dry Cr trib nr Newell, SD	.20	3.8	6.6	9.1	13	17	22
06437100	Boulder Cr nr Deadwood, SD	1.32	57	89	115	151	181	214
06439400	Plum Cr trib nr Milesville, SD	.50	13	25	34	44	51	59
06441200	Powell Cr trib nr Fort Pierre, SD	.40	26	41	53	70	85	101
06441530	Hilgers Gulch trib nr Pierre, SD	1.33	27	47	65	94	120	151

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06441580	Hilgers Gulch at Pierre, SD	6.49	50	96	143	229	320	442
06442400	Medicine Cr trib No. 2 nr Vivian, SD	9.21	180	372	553	856	1,150	1,500
06442850	Elm Cr trib nr Ree Heights, SD	.70	1.2	1.9	2.4	3.1	3.7	4.4
06442960	Smith Cr trib nr Gann Valley, SD	5.85	19	32	43	61	79	99
06446250	Porcupine Cr trib nr Rockyford, SD	1.65	57	97	129	175	214	256
06446300	Big Hollow Cr trib nr Scenic, SD	2.71	141	246	327	443	537	639
06446800	Cottonwood Cr nr Wanblee, SD	1.70	105	172	225	300	363	433
06447200	Black Pipe Cr trib nr Norris, SD	4.19	66	123	176	264	349	453
06447490	Little White R trib nr Martin, SD	8.90	40	62	80	105	126	150
06449700	Little Oak Cr nr Mission, SD	2.58	22	43	64	103	143	198

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06451750	Cottonwood Cr trib nr Winner, SD	4.00	67	138	202	307	403	516
06452250	Fivemile Cr trib nr Iona, SD	2.35	66	115	159	229	293	368
06453150	Choteau Cr trib nr Tripp, SD	.54	21	34	43	57	69	82
06453250	Choteau Cr trib nr Wagner, SD	15.6	14	30	50	92	143	220
06471750	Snake Cr trib nr Leola, SD	4.49	81	168	255	411	570	772
06473300	Preachers Run trib at Ipswich, SD	7.88	27	60	100	186	290	443
06473350	S Fk Snake Cr trib nr Seneca, SD	4.54	22	33	41	54	65	77
06473850	Shaefer Cr trib nr Orient, SD	5.17	166	315	440	627	790	971
06475550	Dry Run trib nr Frankfort, SD	4.19	8.9	15	22	33	43	57
06475850	Foster Cr trib nr Carpenter, SD	4.93	94	196	301	489	680	927

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06477140	Rock Cr trib nr Roswell, SD	5.67	29	78	139	273	434	673
06477400	Firesteel Cr trib nr Wessington Springs, SD	.22	6.5	11	16	23	30	38
06478050	Enemy Cr trib nr Mount Vernon, SD	3.38	14	26	39	62	87	120
06478200	Coffee Cr trib nr Parkston, SD	.81	14	35	55	89	121	160
06478400	Lonetree Cr trib nr Kaylor, SD	3.65	19	32	45	65	84	108
06478650	W Fk Vermillion R nr Monroe, SD	2.74	33	57	81	122	165	219
06478820	Saddlerock Cr trib nr Beresford, SD	2.22	39	73	107	165	224	299
06478950	Ash Cr nr Beresford, SD	5.00	63	128	197	327	466	653
06479020	Smoky Run nr Irene, SD	4.96	36	54	69	90	110	131
06479350	Soo Cr trib nr South Shore, SD	1.56	21	49	79	139	204	293

Table 5.--Volume-frequency data for modeled basins.--Continued

U.S. Geological Survey station number	Station name	Drainage area (square miles)	Runoff volume, in acre-feet, for indicated recurrence interval, in years					
			2	5	10	25	50	100
06479550	Dolph Cr trib nr Lake Norden, SD	5.91	67	125	184	292	402	547
06479810	North Deer Cr trib nr Brookings, SD	.33	12	22	30	43	55	70
06479900	Sixmile Cr trib nr Brookings, SD	9.78	262	530	774	1,170	1,530	1,970
06480720	Bachelor Cr trib nr Wentworth, SD	1.03	4.3	11	18	34	54	82
06482600	West Pipestone Cr trib nr Garretson, SD	2.16	44	91	137	216	294	391
06485550	West Union Cr nr Alcester, SD	3.48	53	106	158	248	338	450

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