Prepared in cooperation with the
Nebraska Department of Roads

Peak-Flow Frequency Relations and Evaluation of the Peak-Flow Gaging Network in Nebraska

Water-Resources Investigations Report 99–4032

U.S. Department of the Interior
U.S. Geological Survey

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By Philip J. Soenksen, Lisa D. Miller, Jennifer B. Sharpe, *and* Jason R. Watton

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U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	0.3048	meter per mile
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per hour (in/hr)	0.0254	meter per hour

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ABSTRACT

Estimates of peak-flow magnitude and frequency are required for the efficient design of structures that convey flood flows or occupy floodways, such as bridges, culverts, and roads. The U.S. Geological Survey, in cooperation with the Nebraska Department of Roads, conducted a study to update peak-flow frequency analyses for selected streamflow-gaging stations, develop a new set of peak-flow frequency relations for ungaged streams, and evaluate the peak-flow gaging-station network for Nebraska. Data from stations located in or within about 50 miles of Nebraska were analyzed using guidelines of the Interagency Advisory Committee on Water Data in Bulletin 17B. New generalized skew relations were developed for use in frequency analyses of unregulated streams. Thirty-three drainage-basin characteristics related to morphology, soils, and precipitation were quantified using a geographic information system, related computer programs, and digital spatial data.

For unregulated streams, eight sets of regional regression equations relating drainage-basin to peak-flow characteristics were developed for seven regions of the state using a generalized least squares procedure. Two sets of regional peak-flow frequency equations were developed for basins with average soil permeability greater than 4 inches per hour, and six sets of equations were developed for specific geographic areas, usually based on drainage-basin boundaries. Standard errors of estimate for the 100-year frequency equations (1percent probability) ranged from 12.1 to 63.8 percent. For regulated reaches of nine streams, graphs of peak flow for standard frequencies and distance upstream of the mouth were estimated.

The regional networks of streamflow-gaging stations on unregulated streams were analyzed to evaluate how additional data might affect the average sampling errors of the newly developed peak-flow equations for the 100-year frequency occurrence. Results indicated that data from new stations, rather than more data from existing stations, probably would produce the greatest reduction in average sampling errors of the equations.

INTRODUCTION

Estimates of peak-flow magnitude and frequency are required for the efficient design of structures that convey flood flows, such as bridges and culverts, or of structures that occupy floodways, such as roads. In the fall of 1994, a 4-year cooperative study was begun by the Nebraska Department of Roads and the U.S. Geological Survey (USGS) to update the methods for making these estimates. Objectives of the study included (1) updating of the peak-flow frequency analyses for selected streamflow-gaging stations, (2) development of a new set of regional peak-flow frequency relations for ungaged streams, and (3) evaluation of the peak-flow gaging-station network for Nebraska.

A number of new technologies had recently become available that made improvements in the peak-flow relations possible. New computer programs and procedures had been developed by the USGS for analyzing peak-flow frequency data for gaging stations. A geographic information system (GIS) and digital data could be used to compute drainage-basin characteristics that previously were undefined because they were too difficult or time-consuming to compute manually. For relating drainage-basin characteristics to peak-flow characteristics, a generalized least squares (GLS) regression program was available that could adjust for differences in record length and flow variance, and for cross-correlations among gaging stations. A companion network-analysis program (NET) also was available that could use the output from the GLS program to evaluate how the addition of new data from existing or new peak-flow gaging stations might reduce the average sampling errors of any newly developed peak-flow frequency equations. These two programs were available together as GLSNET from Gary Tasker (USGS, written commun., 1995).

Background

Several methods of computing peak flows for selected frequencies of occurrence had been developed previously by the USGS and others for Nebraska. Furness (1955) presented a method for computing peak flows up to the 50-year frequency (recurrence interval or probability) for two regions in Nebraska. The equations were considered applicable to sites with at least 100 mi^2 of drainage area. Beckman and Hutchison (1962) presented a method for computing peak flows up to the 100-year recurrence interval for sites with less than 300 mi^2 of drainage area. There are 10 hydrologic areas within two regions for this method. Patterson (1966) and Matthai (1968) developed methods for sections of Nebraska as part of regional studies on the Missouri River Basin. All of the above are index-flood methods; they use a dimensionless frequency curve and a relation for predicting the mean-annual flood from hydrologic characteristics to estimate a frequency curve for any location in a region. Beckman (1976) used multiple-regression techniques to develop regional equations for peak flows up to the 100–year recurrence interval. Basin characteristics were used as the explanatory variables in the five sets of regional equations.

Cordes (1993) updated Beckman's (1976) equations based on additional data and the new flood-flow frequency guidelines of Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). He developed a generalized skew coefficient map (of base-10 logarithms of annual maximum peak flows) for Nebraska and included several new explanatory variables in the regional regression analyses of peak-flow frequencies. However, no new hydrologic regions were developed, and no adjustments were made to the default frequency analyses for individual stations (Rollin Hotchkiss, University of Nebraska-Lincoln, oral commun., 1997). The mean-square errors (MSEs) for the updated equations, as reported by Cordes (1993, p. 70), apparently were based on natural logarithms (Rollin Hotchkiss, University of Nebraska-Lincoln, oral commun., 1998). The MSEs were converted to standard errors of estimate (SEEs), in natural logarithms, by taking the square root of the values; those values then were converted to SEEs, in percent, using tabled values from Tasker (1978, p. 87). A comparison of SEEs, in percent, for corresponding equations shows that SEEs are smaller, in all cases, for the Beckman (1976) equations than for the Cordes (1993) equations. Therefore, newly developed equations in this report are compared only to the Beckman (1976) equations.

Experience has shown that the Bulletin 17B default low-outlier tests are not well suited for detecting multiple low outliers and that the log-Pearson Type III (LP3) distribution recommended by Bulletin 17B is sensitive to high outliers. The treatment of outliers can have substantial effects on peak-flow analyses, including skew coefficients from which a generalized skew-coefficient map is developed.

As part of this study, annual peak-flow data for Nebraska were compiled, checked, and published by Boohar and Provaznik (1996). Provaznik also investigated L-moments and several frequency distributions as possible alternatives to the methods recommended in Bulletin 17B. Results of the L-moment investigation can be found in Provaznik (1997), and Provaznik and Hotchkiss (1998).

Purpose and Scope

The purposes of this report are to: (1) present updated peak-flow frequency analyses for selected streamflow-gaging stations in Nebraska; (2) present and describe the development of new methods to estimate peak flows for selected frequencies for ungaged streams in Nebraska; and (3) present an evaluation of the peak-flow gaging-station network in Nebraska. Peak-flow frequency analyses and the network analyses were done for streamflow-gaging stations in or within about 50 miles of Nebraska (fig. 1).

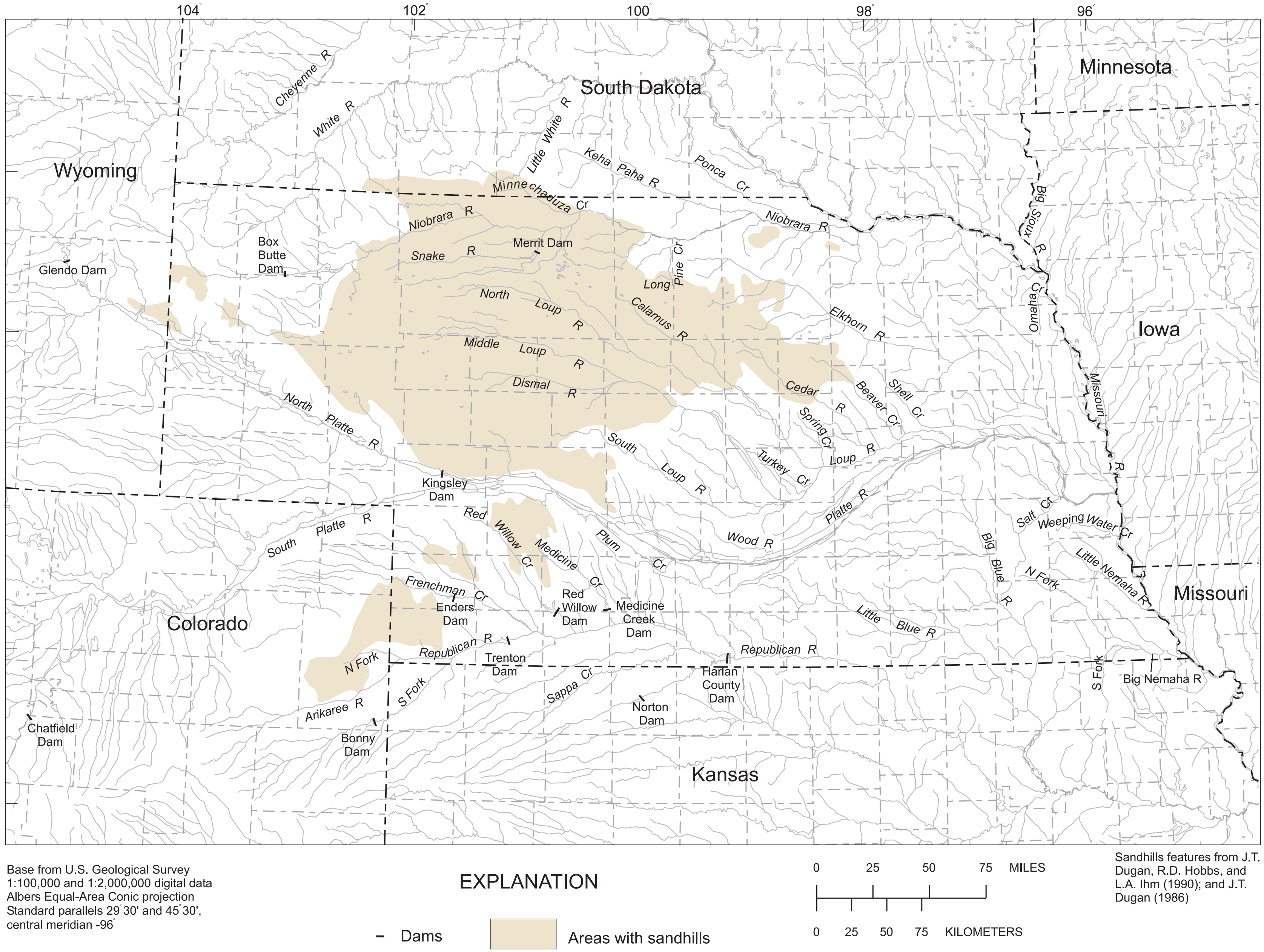


Figure 1. Selected streams and dams, and areas with sandhills in Nebraska and parts of adjacent states.

Acknowledgments

The authors acknowledge Milo Cress of the Federal Highway Administration for his support in initiating this study, and the dedicated USGS student employees who spent many hours digitizing drainage-basin data layers and computing basin characteristics with GIS programs: Christopher P. Stanton, David L. Rus, Cody L. Knutson, John T. Shulters, and Mary Kay Provaznik.

QUANTIFICATION OF DRAINAGE-BASIN CHARACTERISTICS

Morphometric, soil, and precipitation drainage-basin characteristics were determined for streamflow-gaging stations having 10 or more years of record in Nebraska and for selected stations outside of Nebraska. Most of the out-of-state stations had 25 years of record and had basin centroids within 50 miles of Nebraska; however, some stations had as few as 18 years of record or were as far away as about 80 miles. GIS-related programs and procedures were used or modified to quantify drainage-basin characteristics from digital data layers of basin boundaries, elevations, streams, soil, and precipitation.

Morphometric Characteristics

Twenty-seven drainage-basin characteristics were quantified using a modified version of Basinsoft (Harvey and Eash, 1996), a computer program developed by the USGS (Majure and Soenksen, 1991; and Eash, 1994). These morphometric characteristics generally describe the form and structure of a drainage basin and its drainage network, including measurements of area, length, relief, aspect, and stream order (appendix A and table B1). Four source-data layers, representing the surface-water drainage divide (basin boundary), hydrography (stream network), hypsography (elevation contours), and a lattice elevation model of the drainage basin, were required to run Basinsoft.

Existing data layers of drainage-basin boundaries for gaging stations were obtained from the Nebraska Natural Resources Commission and the Iowa City, Iowa, office of the USGS. Boundaries for Nebraska basins had been delineated using 1:24,000-scale USGS topographic maps; those for Iowa basins had been delineated using 1:250,000-scale USGS topographic maps. The remaining basin boundaries for Nebraska and surrounding states were delineated on 1:250,000-scale USGS maps and digitized manually to produce GIS digital data layers. Because of the difficulty in delineating noncontributing drainage area (*NCDA*) over the large sandhills areas of Nebraska (fig. 1), basin-characteristic measurements were made over the total drainage area (*TDA*) rather than over the contributing drainage area (*CDA*). Some basin characteristics were computed from other characteristics rather than being measured directly. Characteristics that required *CDA* in their computations were computed using published values of *CDA*.

Stream-network source-data layers were created by scanning mylar maps of 1:250,000-scale USGS hydrography data, which were converted to digital data layers using ARC/INFO version 7.0.4 (Environmental Systems Research Institute, 1996). Unfortunately, 1:250,000-scale hydrography data did not always extend to some small drainage-area basins. USGS 1:100,000 digital line graph (DLG) Quadrangle Series hydrography data were retrieved from the EROS Data Center of USGS, but these data were not used because of edge-matching problems.

Source-data layers of elevation contours and the lattice elevation model were created from 1:250,000-scale U.S. Defense Mapping Agency digital elevation model (DEM) data. GIS software was used to convert the DEM data into a lattice of point elevations and create elevation contours (Harvey and Eash, 1996). The elevation contour interval was selected to provide at least 10 contour lines per basin.

Manual topographic-map measurements of selected drainage-basin characteristics were made for 11 drainage basins in Iowa by Harvey and Eash (1996) to verify the accuracy of drainage-basin characteristics quantified using Basinsoft. Manual measurements and Basinsoft quantifications were made at identical scales. Comparison tests indicated that Basinsoft quantifications were not significantly different from manual measurements.

As an additional check of Basinsoft quantifications, manual topographic-map measurements of selected drainage-basin characteristics were made for five Nebraska drainage basins. Basinsoft quantifications did not appear to be significantly different than the corresponding manual measurements. Also, all *TDAs* determined using Basinsoft were compared with published values. Basinsoft was unable to compute basin characteristics for several stations; the reasons are not understood. These stations were not used in the development of peak-flow frequency relations for unregulated streams.

Soil Characteristics

Four drainage-basin characteristics (Dugan, 1984) that describe some aspect of the interaction of soil and water were computed from developed equations using ARC/INFO. Soil data for Nebraska and surrounding states were obtained from a digital data layer of the State Soil Geographic Data Base (STATSGO) (Natural Resources Conservation Service, 1994). The upper 60 inches of the soil profile were used to determine the majority of the soil characteristics, which include average permeability rate of the soil profiles (*P60*), average available water capacity of the soil profiles (*AWC*), average permeability of the least permeable layers of the soil profile (*PLP*), and the average maximum soil slope (*MSS*) (appendix A and table B1). Manual calculations were made to verify soil characteristics for selected drainage-basins.

Precipitation Characteristics

Two drainage-basin characteristics describing expected precipitation were quantified using ARC/INFO. The 2-year (recurrence interval), 24-hour (duration) precipitation (*TTP*) 1-inch contours were digitized manually from Weather Bureau Technical Paper 40 (Hershfield, 1961) into a GIS digital data layer. Additionally, 0.1-inch interval contours were interpolated and digitized (fig. A1). Mean annual precipitation (*MAP*) data compiled by the National Oceanic and Atmospheric Administration were retrieved for the period 1961–90 from the National Climatic Data Center Web site (URL *http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html*). These data were used to create a data layer of points from which Thiessen polygons were created (fig. A2). *TTP* and *MAP* values then were determined by taking the area-weighted average of precipitation polygons coincident to the total drainage area of each basin (table B1). Manual calculations were performed to verify precipitation values for selected drainage basins.

PEAK-FLOW FREQUENCY ANALYSES

Relations between peak flows and frequency of occurrence (recurrence interval or probability of occurrence) for individual drainage basins are basic to the development of peak-flow frequency relations for larger areas. Bulletin 17B of the IACWD (Interagency Advisory Committee on Water Data, 1982) contains guidelines for the development of these basic relations using the log-Pearson Type III (LP3) frequency distribution. Three parameters—the mean, the standard deviation, and the skew coefficient of the logarithms of the annual maximum peak flows—are used to fit the station data to the LP3 distribution. These parameters can be thought of as the middle point, average slope, and bend or shape of a computed peak-flow frequency curve. Increasing the standard deviation or range of the peak-flow data increases the slope or steepness of the frequency curve, and decreasing the standard deviation flattens the slope of the curve. Positive skew coefficients cause the frequency curve to bend upward, negative skews cause the curve to bend downward, and zero skews produce a straight line.

For stations with unregulated (natural) streamflow, station skew coefficients of peak flows should be weighted with generalized skew coefficients for that area or for basins with similar characteristics. The assumption is that skews will be similar for stations that have similar basin characteristics or are in close proximity, and that the accuracy of the applied skew can be improved by incorporating the influence of other stations. The national map of generalized skew coefficients in Bulletin 17B provides default values for areas where local values have not been determined independently. For stations with regulated streamflow, only the station skew coefficients were used in peak-flow frequency analyses because the flow characteristics are based on imposed criteria, not on the characteristics of the drainage basins. Bulletin 17B also provides guidelines for making adjustments for historic data and low outliers. It also provides guidelines for developing composite peak-flow frequency relations for stations with peak flows that are produced by different runoff-producing mechanisms, such as rainfall and snowmelt.

Standard Analyses

Annual peak flows for USGS gaging stations with at least 10 years of record through 1993 and located in or within about 50 miles of Nebraska were retrieved from the USGS's national streamflow data base (Dempster, 1983). Peak-flow data were loaded into a Watershed Data Management (WDM) file (Flynn and others, 1995) and then checked and updated as necessary. Stations in the study area, but with streams that do not flow into Nebraska and with drainage areas that are mostly outside of the study area, were not used. The program PEAKFQ—an updated version of program J407 (Kirby, 1981) that utilizes WDM files— follows the guidelines of Bulletin 17B and was used for the peak-flow frequency analyses for all the gaging stations. The program outputs computed peak flows for standard exceedance probabilities (frequencies) in a tabular form and as a peak-flow frequency curve in graphical form.

Peak flows that were known to have been or could possibly have been affected to some degree by regulation—such as flood control, irrigation diversions, power generation, storage detention, or other factors—were separated from unregulated peaks before further analysis. Determinations generally were based on information from the peak-flow data base, water-data and flood-frequency reports, USGS files, topographic maps, and a statewide data base for dams, which contains location, year of completion, and amount of storage. A rough criterion was developed for estimating possible effects of regulation on peaks using a comparison of the average flow to the amount of storage in the basin. It was developed from data for stations with significant changes in storage during their periods of record by comparing changes in peak-flow frequency relations to the changes in storage for both earlier and later periods of record. The criterion was developed primarily for estimating whether the cumulative storage of numerous small dams might be affecting peaks at downstream stations. Because of the limited data upon which it was based, the criterion was used only as a guideline.

Two sets of standard peak-flow frequency analyses were computed for stations on unregulated streams. The first set of standard analyses was used to determine skew coefficients from the peak-flow data for each station. Using these station skews, several generalized skew relations then were developed. The second set of standard analyses was done using the individual station skews weighted with the newly developed generalized skews. For stations on regulated streams, one set of standard analyses was made based on station skews only. Adjustments were made to individual peak-flow frequency analyses, as appropriate, for historic data, and for high and low outliers as described in the following sections. Results of frequency analyses for peak-flow gaging stations are listed in table B2.

Adjustments for Historic Data

The number of annual peak flows, during which data were collected systematically at a gaging station (systematic record), is used in the computation of the LP3 parameters and in the determination of the plotting positions of the peak flows for the frequency curve. If one or more of the peak flows within the systematic record are known to be the largest in a period longer than the systematic record, the frequency analysis can be adjusted to this historic period. This provides a means to correct, at least partially, for the adverse effects that a very large peak flow might otherwise have on the computed peak-flow frequency curve. Historic peak flows without an associated historic period cannot be added to the record being analyzed. Historic periods for peak-flow data were determined primarily from the peak-flow data base, but also from water-data and flood-frequency reports, USGS files, newspaper accounts of floods, and comparisons with records for other nearby stations.

Adjustments for High and Low Outliers

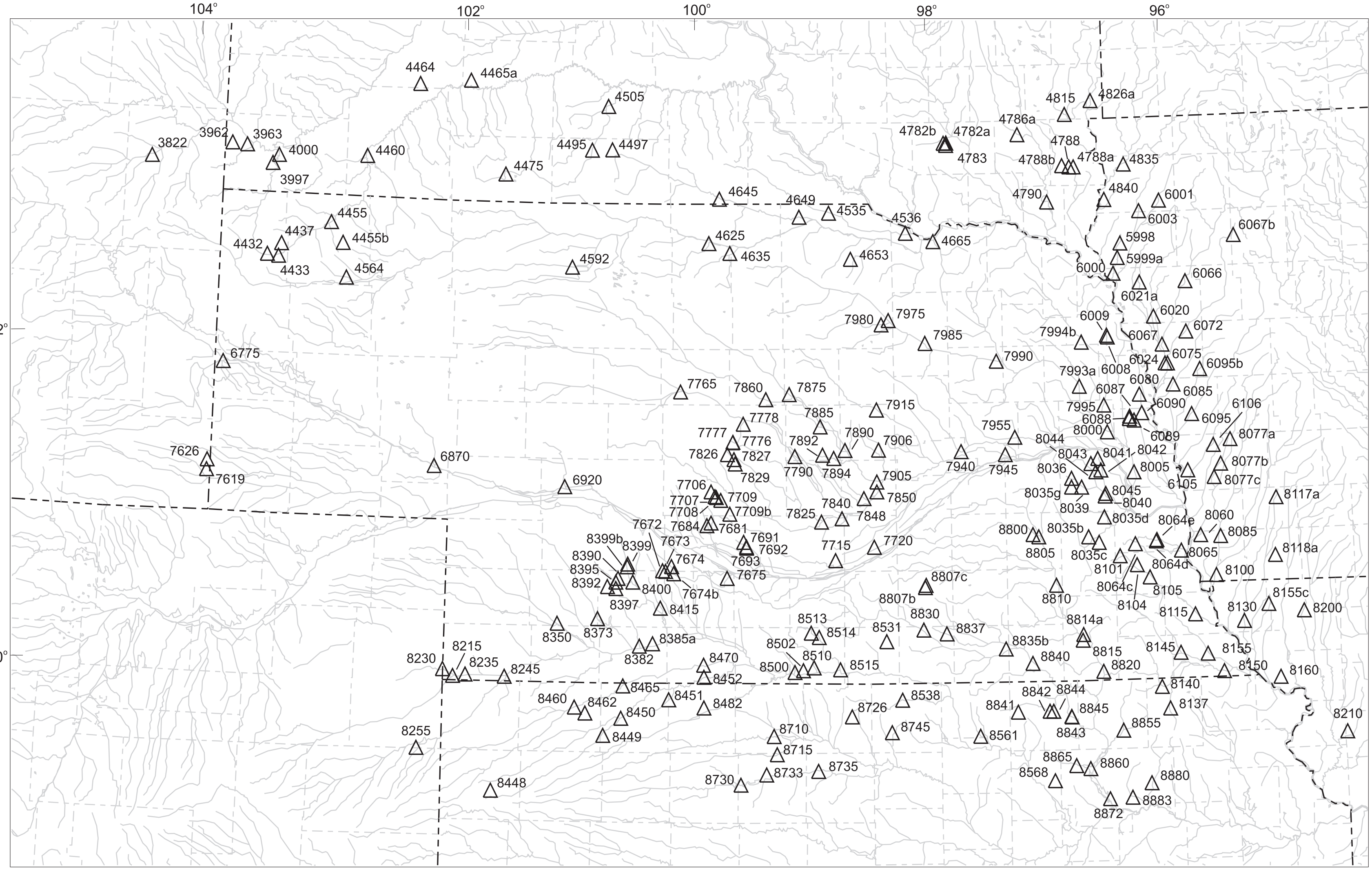
Extremely high or low annual peak flows that significantly depart from the trend of the rest of the data are outliers that can have a disproportionate effect on the LP3 parameters used to compute frequency curves. High outliers tend to increase both skew coefficients and standard deviations. Low outliers tend to decrease skew coefficients but increase the standard deviations. The outcome can be varied depending on the number of outliers and their values. Decreasing the skew bends the frequency curve downward and reduces expected high-end peak flows; increasing the standard deviation steepens the slope and increases expected high-end peak flows. Statistical tests done by the program PEAKFQ identify both high and low outliers, but adjustments cannot be made for high outliers unless historic data are available, as previously discussed. By default, any identified low outliers are eliminated (censored) by PEAKFQ and a conditional probability adjustment is made based on the assumption that the remaining values are representative of the entire period of record. Experience of the authors has shown that the statistical tests included in Bulletin 17B are not well suited for detecting multiple low outliers for many Nebraska stations. Therefore, adaptations of the existing procedure, other tests, and considerable judgment were used to identify and censor low outliers in those situations. If numerous enough, multiple low outliers can become a special case of mixed populations, as discussed later, requiring the development of composite frequency curves (see Composite Analyses).

The default PEAKFQ procedure for identifying low outliers was adapted to test other peak flows suspected of being low outliers based on a visual inspection of the default peak-flow frequency curve. The gage-base threshold can be set in PEAKFQ to isolate specific peak flows to be tested as low outliers. Peaks below the user-set gage base are not used in PEAKFQ computations, except for determining plotting positions, and a new low-outlier threshold is computed from the remaining data. This allowed the first peak above the gage base to be tested as a low outlier against the remainder of the data. This was done in two ways: (1) by raising sequentially the gage-base threshold from the lowest flows, and (2) by setting the gage-base threshold based on breaks in the data. Data breaks were identified visually on plots of the default peak-flow frequency curves. The sequential test was used when at least one low outlier had already been identified, either by the original outlier test or by a break test. The gage-base threshold was set to the value of the largest identified low outlier and the analysis was recomputed. If a new outlier was identified, the process was repeated until no more low outliers were identified. This worked well if the low-end values were well spaced. If peak flows were grouped together below a data break, then the gage-base threshold was set to the second largest peak flow of the group, to isolate the largest peak flow below the data break, and the analysis was recomputed. Judgment was used in both of the low-outlier identification procedures when the criterion was within at least 90 percent of the peak-flow value being tested.

Another low-outlier test used was to censor peak-flow values, either individually or in groups, and observe the effects on the high end of the peak-flow frequency curve. This was done by setting the low-outlier criterion to the value of interest. For stations with multiple low outliers, this procedure was usually not very effective until most or all of the low outliers were censored. Considerable judgment was used with this procedure, but usually at least a 10-percent change in the 100-year frequency peak flow was required before the censored value or values were considered low outliers. For many stations, although the lower peak-flow values did not appear to be representative, there was no clear-cut data break and the quantitative outlier tests were not definitive. In these cases, a visual evaluation of the fit, especially of the upper half of the peak-flow frequency curve, from which all of the peak-flow frequency values of interest were determined, was the final and overriding test of low outliers.

Generalized Skew Coefficients

Regional equations relating generalized skew coefficients (of base–10 logarithms ($\log_{10}$) of annual maximum peak flows) to basin characteristics were developed for most of the state, and a statewide map of generalized skew coefficients for basins with relatively low soil permeability also was developed. These relations were based on frequency analyses from 224 gaging stations (fig. 2 and table B2) and the procedures given in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). The national skew coefficient map included in Bulletin 17B was developed originally for Bulletin 17 (U.S. Water Resources Council, 1976), and was based on a relatively small number of stations with minimal evaluation of low outliers, no adjustments for historic data, no identification or treatment of high outliers, and no



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30',
central meridian -96°

EXPLANATION

△ 8735 Gaging station and map number (referenced in tables B1 and B2)

0 25 50 75 MILES
0 25 50 75 KILOMETERS

Figure 2. Location of streamflow-gaging stations in Nebraska and adjacent states used to develop generalized skew coefficient relations for log-Pearson Type III peak-flow-frequency analyses.

detailed evaluation of individual peak-flow frequency curves. In Nebraska, values shown by the national map were influenced by the high positive skews from a few stations with drainage areas mostly in the sandhills. Because the map is generalized, this influence went beyond the actual area of the sandhills.

Station skew coefficients were computed using PEAKFQ for stations in or within about 50 miles of Nebraska that, generally, had 25 years or more of unregulated peaks. Several stations with as few as 18 annual peaks were used where data were lacking. Adjustments for historic information and low outliers were made as previously described. Low outliers tend to make the station skew more negative and high outliers tend to make it more positive. Because procedures were applied to reduce the effects of low outliers in most cases, it also was considered necessary to limit the effects of high outliers, identified by PEAKFQ, to limit bias in any skew relations developed.

After other adjustments had been made to the peak-flow frequency analyses, stations with PEAKFQ high outliers were analyzed further to estimate how sensitive the station skew coefficients were to the high outliers. Using the historic adjustment procedure in PEAKFQ, high outliers for a station were assumed to be historic peaks and then the record length was doubled, tripled, and quadrupled arbitrarily. The new skew coefficients were noted and differences from the original values were computed. The skew was considered fairly stable if it did not change by more than 0.20, 0.30, or 0.40, respectively, for sandhills stations, and by more than 0.10, 0.15, or 0.20, respectively, for all other stations. Stations with skew changes greater than these were considered unstable because of the high outlier(s), and those stations were eliminated from further consideration in the skew relations.

Equations to predict skew coefficients were preferred to a skew map because equations eliminate the assumption that basins in close proximity have similar skew values. Rather, skews estimated using equations are based on measurable characteristics for each individual basin. It is more difficult to compute skews with equations compared to determining skews from maps because each of the explanatory variables in the equation must be measured or computed.

A skew equation first was developed for basins with average soil permeability (*P60*) greater than 2.5 in/hr (high-permeability regional skew equation); this eliminated the need to map the high positive skew areas of the sandhills as was done for the national map. A skew map then was developed for basins with *P60* less than 4 in/hr, and for the entire Elkhorn River Basin (see fig. 1 for location of specific streams), which includes basins with *P60* greater than 4 in/hr. This resulted in some overlap with the high-permeability equation. Regional equations, based mostly on geographic areas, also were developed; however, only those with mean-square errors (MSE*s*) less than those for the newly developed skew map were used, as recommended in Bulletin 17B. Because of the importance of *P60* in deciding which skew relation to use, a generalized map of *P60_SS* (appendix A) is presented (fig. A3). For actual measurements of *P60* for a drainage basin, values should be quantified using a GIS, as previously described. Using Statit statistical programs (Statware, Inc., 1990) standard multiple-regression techniques were used to develop skew estimation equations (table 1). Residuals were analyzed to define regions and to try and determine the best combination of explanatory variables. Equations were examined to ensure that they were hydrologically reasonable. The adjusted R-square, MSE, ratio of MSE to variance, and standard error of estimate (SEE) were computed from or taken from Statit output files for each equation (table 1). Regions and skew coefficients that have been defined geographically are shown in figure 3.

High-Permeability Regional Skew Equation

The high-permeability regional skew equation is based on 38 stations with at least 25 years of record and with *P60* greater than 2.5 in/hr, except those in the Elkhorn River Basin. The equation applies to high-permeability basins, not to a distinct geographic area. However, it is uncertain whether the equation is applicable to: right-bank tributaries of the Little White River and adjoining left-bank tributaries of the Niobrara River upstream of and including Minnechaduza Creek; and right-bank

Table 1. Generalized skew equations

[*BS*, basin slope, in feet per mile; *CR*, compactness ratio, dimensionless; *GSkew*, generalized skew coefficient of base–10 logarithms ($\log_{10}$) of annual maximum peak flows, dimensionless; MSE, mean square error; *MSS*, average maximum soil slope, in percent; *P60*, permeability of the 60-inch soil profile, in inches per hour; *PLP*, permeabilitiy of the least permeable layer, in inches per hour; SEE, standard error of estimate; *SR*, slope ratio of main-channel slope to basin slope, dimensionless; >, greater than]

Estimation equation	Adjusted R-square	MSE	Ratio of MSE to variance	SEE
	(based on $\log_{10}$ transforms of peak-flow data)			
High Permeability Skew Region				
(38 stations with 25 or more years of record)				
$GSkew = \frac{-1.261}{CR} + 1.169(\log_{10}P60) - 0.112$	0.74	0.055	0.23	0.234
Northern and Western Skew Region				
(31 stations with 20 or more years of record)				
$GSkew = 0.1716PLP + \frac{1.216}{MSS} - \frac{0.6688}{CR} + 0.109$	.84	.033	.16	.182
Northeastern Skew Region				
(30 stations with 20 or more years of record)				
$GSkew = 0.4811(\log_{10}SR) - \frac{0.4452}{P60} - 0.5595(\log_{10}MSS) + 1.129$	.63	.024	.35	.155
Southeastern Skew Region				
(28 stations with 25 or more years of record)				
$GSkew = -0.001853BS + 0.4928\ (\log_{10}P60) - 0.058$	.54	.018	.46	.134

NOTE: *CR*, *SR*, and *BS* are data-scale dependent.

tributaries of the Niobrara River that are adjacent to the Elkhorn River Basin (left and right banks are referenced to facing in the downstream direction). Stations from these areas were not used because of insufficient record length or problems in computing the basin characteristics. Three stations in the Little White River-Minnechaduza Creek divide area had negative skews, which were not consistent with the equation results of positive skews for stations with high permeabilities and low compactness ratios (*CR*). Therefore, station skews were used in the peak-flow frequency analyses for this area instead of skews estimated from the equations.

Northern and Western Regional Skew Equation

The northern and western regional skew equation is based on 31 stations with at least 20 years of record, from southeastern Wyoming, southern South Dakota, and northern and western Nebraska. Stations are in the following basins: right-bank Cheyenne River, upper White River, Little White River, Missouri River tributaries from the South Dakota-Nebraska state line to and including right-bank tributaries of the Big Sioux River, and the North and South Platte Rivers. This region (fig. 3) overlaps with the northeastern skew region and includes some stations used in the high-permeability regional skew equation.

Northeastern Regional Skew Equation

The northeastern regional skew equation is based on 30 stations with at least 20 years of record, from northeastern Nebraska, southeastern South Dakota, and northwestern Iowa.

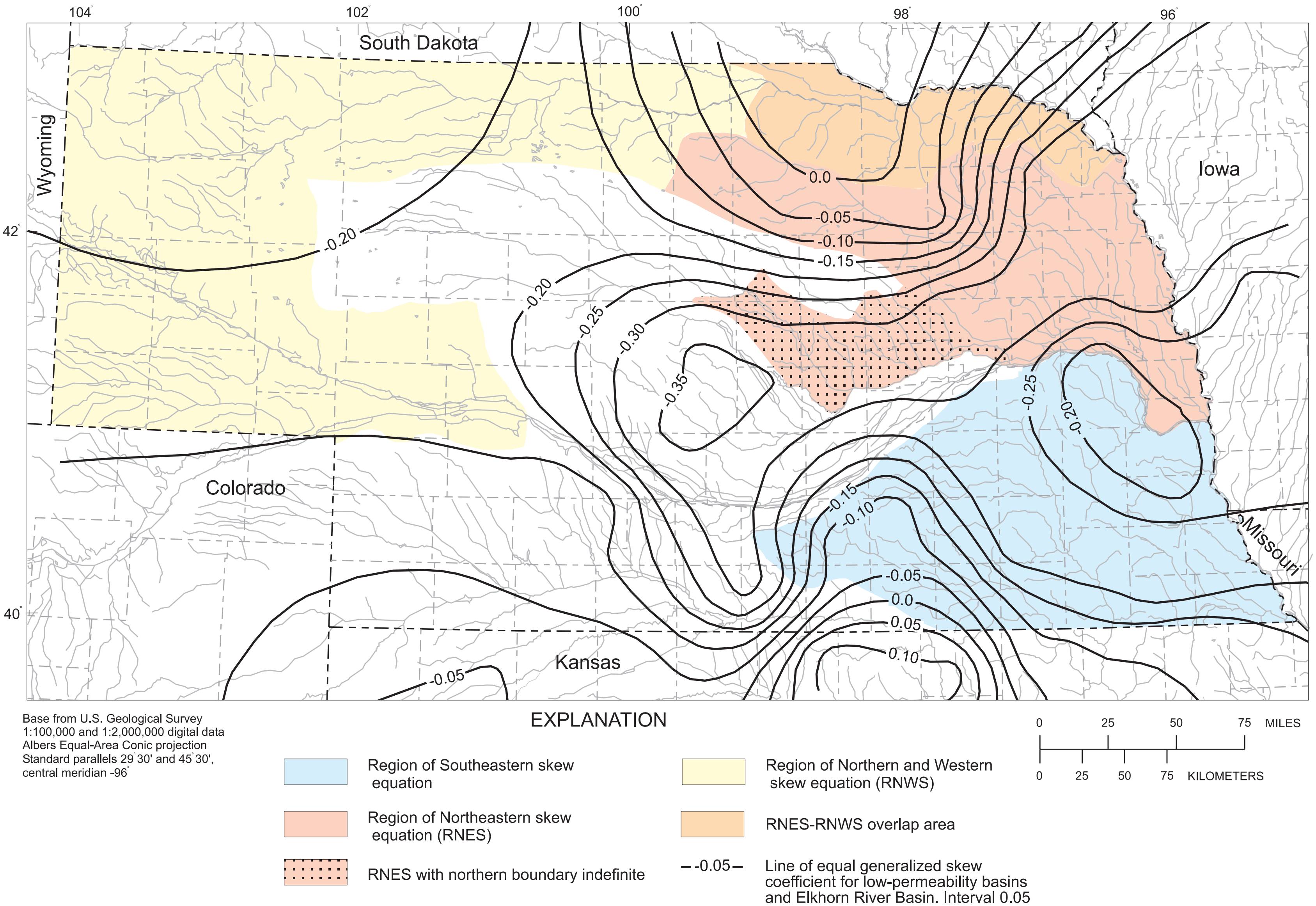


Figure 3. Regions of generalized skew-coefficient equations for Nebraska, and distribution of generalized skew-coefficients for basins with average permeability of the top 60 inches of soil (*P60*) of less than 4 inches per hour but including the entire Elkhorn River Basin. Coefficients are for log-Pearson Type III frequency analyses of unregulated annual peak flows.

Stations are in the following basins: Ponca Creek, lower Niobrara River (adjacent to the Elkhorn River Basin), Missouri River tributaries from the Niobrara River to the Platte River, Middle Loup and Loup River tributaries downstream of and including Turkey Creek, Shell Creek, and the Elkhorn River. The region also is considered to include other left-bank Platte River tributaries downstream of the Loup River. This region (fig. 3) overlaps with the northern and western skew region and includes some stations used in the high-permeability regional skew equation.

Southeastern Regional Skew Equation

The southeastern regional skew equation is based on 28 Nebraska stations with at least 25 years of record, from the Salt and Weeping Water Creek Basins, the Little and Big Nemaha River Basins, and the Little and Big Blue River Basins. The region also is considered to include other right-bank tributaries of the Platte River downstream of Hydrologic Unit 10200103 (U.S. Geological Survey, 1976) (which extends several miles below the mouth of the Loup River) and of the Missouri River between the Platte River and the Nebraska-Kansas state line. The region is shown in figure 3.

Low-Permeability Skew Map

A low-permeability skew map of Nebraska (lines of equal generalized skew coefficient, fig. 3) was developed for basins with *P60* less than 4 in/hr, and including the entire Elkhorn River Basin regardless of soil permeability. Skew values were plotted at the centroid of the drainage area for each station. The skew values were clustered geographically based on judgment with consideration given to such factors as basin similarity and apparent trends. An average skew value, weighted by the number of annual peak years for each station, was computed for each cluster. The weighted-average value then was assigned to every point in the cluster. Lines of equal skew coefficient initially were determined using a contouring program and were revised manually using judgement. Differences between the lines and the actual station skew values were determined and the MSE was computed by summing the squares of the differences and dividing by the total number of stations used. Several clustering schemes were used in an attempt to minimize the MSE while still keeping the lines general enough to represent broad trends. The map became more general as the number of clusters was reduced; a single cluster would result in an overall average skew for the state. The final map (fig. 3) is based on 189 stations and has an MSE of 0.052 and a SEE of 0.24. The skew map in Bulletin 17B has a standard deviation (computed the same as the SEE reported here) of 0.55, but this is not comparable because it is for the whole country. Cordes (1993, p. 59–60) reports that the standard deviation is 0.78 for the Nebraska part of the national map in Bulletin 17B. The skew map for Nebraska presented by Cordes, which includes the high-permeability sandhills areas, as was done for the national map, has a standard deviation of 0.59.

Composite Analyses

Using a conditional probability method suggested by William Kirby (USGS) (Wilbert Thomas, Jr., USGS, written commun., 1995), an alternative set of frequency analyses were computed for selected high-permeability stations that apparently have two different populations of annual peak flows in the data. A pattern that showed different flow characteristics for the largest peaks seemed apparent from the initial peak-flow frequency curves for most of the high-permeability stations. Because sandhills terrain typically includes large areas of noncontributing drainage and high permeability, it was theorized that most of the lower-flow peaks consisted primarily of interflow and baseflow and that the higher-flow peaks had a significantly greater proportion of surface runoff than the lower-flow peaks.

Unit-value flow data were not readily available for using a flow-hydrograph separation technique to test the theory. Therefore, plots of peak flow versus the lower of the 1- or 2-day lag of daily flow were made for several stations to determine if the theory was at least plausible. Three such plots, along with their respective peak-flow frequency plots, are shown in figure 4. The results are not definitive because daily value data are so generalized compared to unit value data (commonly 15-minute intervals) and true recessions are not always apparent, especially if secondary peaks are masked within the daily values. Even so, there is a general tendency for the higher flows to have a greater proportionate drop-off in flow than do the lower flows. This supports the theory because flows with proportionately more surface runoff than interflow or baseflow would have steeper recessions for a given station. Based on the

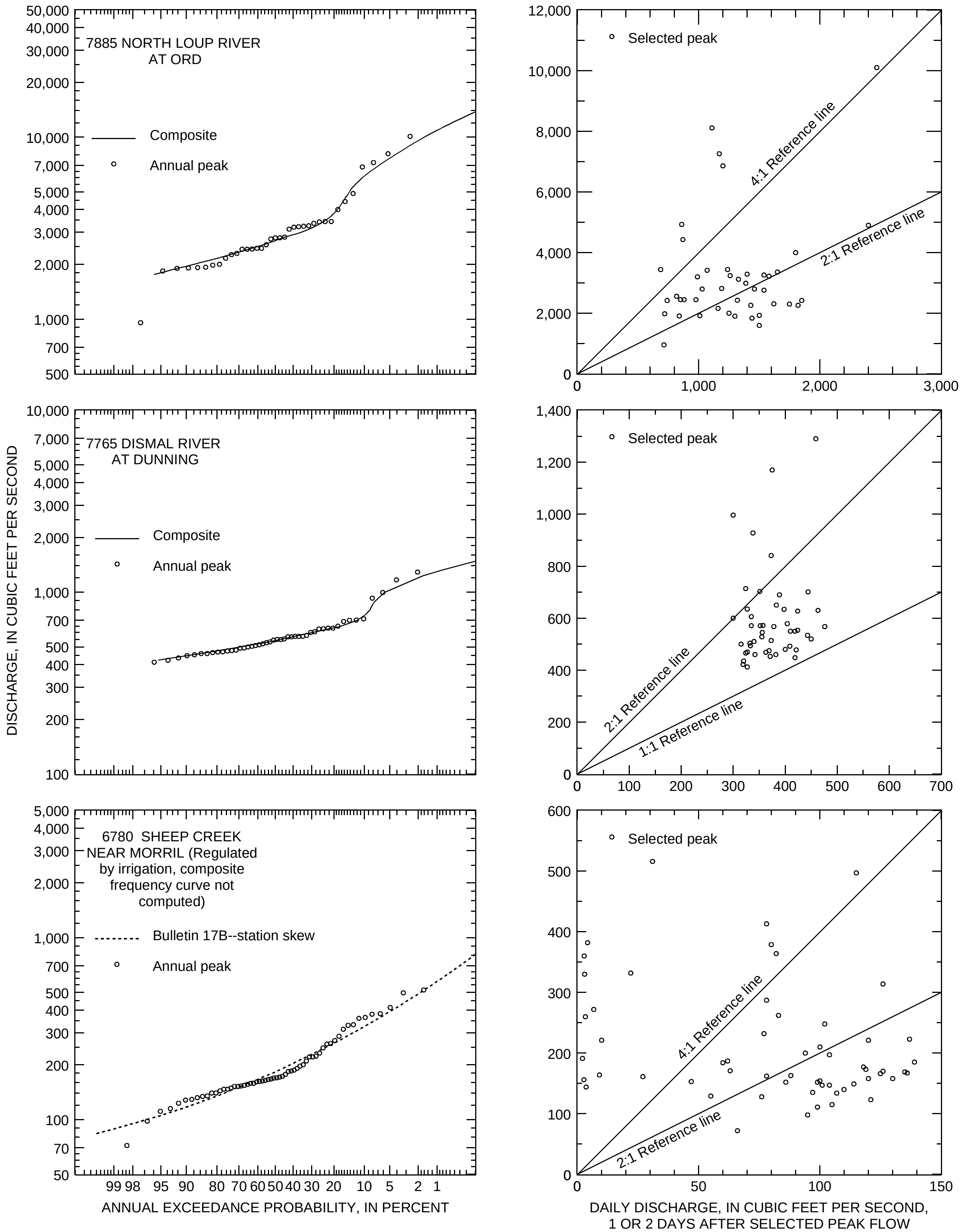


Figure 4. Peak-flow frequency curves and daily discharge lag plots for three Nebraska streamflow-gaging stations.

observed patterns in the peak-flow frequency plots and the lag plots, it was decided to treat the peak flows above and below the breaks on the peak-flow frequency plots as two different populations, or regimes, of flow for an alternative set of frequency analyses.

Kirby's method of developing a composite peak-flow frequency curve for a station requires that there be enough annual peaks of each flow regime to compute separate frequency curves. PEAKFQ requires at least three peaks to make a computation. Peak-flow values for the selected stations were separated into higher- and lower-flow regimes and loaded into special WDM files. Because there were no generalized skew relations established for these situations, analyses were computed with PEAKFQ using station skews only. The use of zero skews or weighted skews might have been preferable in some situations to limit the effects of outliers on curves with already limited data. The results from the individual analyses were combined using conditional probabilities as shown in Kirby's equation modified from Thomas (Wilbert Thomas, Jr., USGS, written commun., 1995):

$$P(F > x) = \begin{array}{l}[P(F > x \backslash F \in H) \times P(F \in H)] + \\ [P(F > x \backslash F \in L) \times P(F \in L)]\end{array} \quad (1)$$

where: P = probability that

F = annual maximum peak flow

x = given value of peak flow

\ = given that

$F \in H$ = annual maximum peak flow is a higher-regime flow

$F \in L$ = annual maximum peak flow is a lower-regime flow

Composite peak-flow frequency curves were plotted and peak flows for the standard exceedance probabilities were determined visually from the graphs. This was done for 22 high-permeability (*P60* greater than 4 in/hr) stations with unregulated flows (fig. 4 and figs. C1 to C4).

Other types of mixed populations in station data also were apparent, including stations with relatively low permeability and precipitation—especially in northwestern Nebraska—and stations on partially regulated streams. The thorough investigations required to split the data and to do the analyses of all of these other cases were beyond the scope of this study. Low-permeability stations with apparent mixed populations were dropped from the regional analyses of peak-flow frequency but are listed with appropriate notes in table B2. Preliminary composite analyses were done for several Platte River stations, including Platte River at Brady (7660) (fig. 5). However, most stations on partially regulated streams were simply computed with station skews and, where mixed populations appeared to be most apparent, notes were included in the appropriate figures and tables.

In the more arid areas of Nebraska, annual maximum peak flows can be very small or even zero. The lower-regime flows are essentially low outliers from the remaining peak-flow data. When these lower flows comprise a large proportion of the data, they cannot all be censored because Bulletin 17B analyses require that at least half of the data be used. If they are numerous enough and their range in flow is great enough, the computed peak-flow frequency curves are too steep and the indicated high-end peak flows can be unreasonable. Chadron Creek tributary at Chadron Creek State Park near Chadron (4455a) and Antelope Creek tributary near Gordon (4578) are two examples of this situation (fig. 5). For the Chadron Creek tributary station, 12 of the 26 peaks were zero and no more peaks could be cut off in the standard Bulletin 17B analyses or the calculations would abort. For this station the data were simply split into zero and non-zero flows, analyzed separately and then recombined with the conditional probability adjustment.

For the Antelope Creek tributary station (4578), less than half of the non-zero flows appear to be true indicators of flood flow and splitting the data into zero and non-zero flows does not produce a reasonable fit of the largest flows. The fairly obvious break used to split the non-zero flow data for this station is not always as apparent for other stations and is difficult to justify without more investigation. Another solution might be to use a different type of analysis that uses all of the peak flows above a selected base flow in the computations (partial-duration series) rather than just the annual maximum peak flows (annual maximum series). Some, if not all, of the lower peak flows from dry years potentially could be replaced in the analyses with larger peak flows from wetter years. Unfortunately, all of the stations

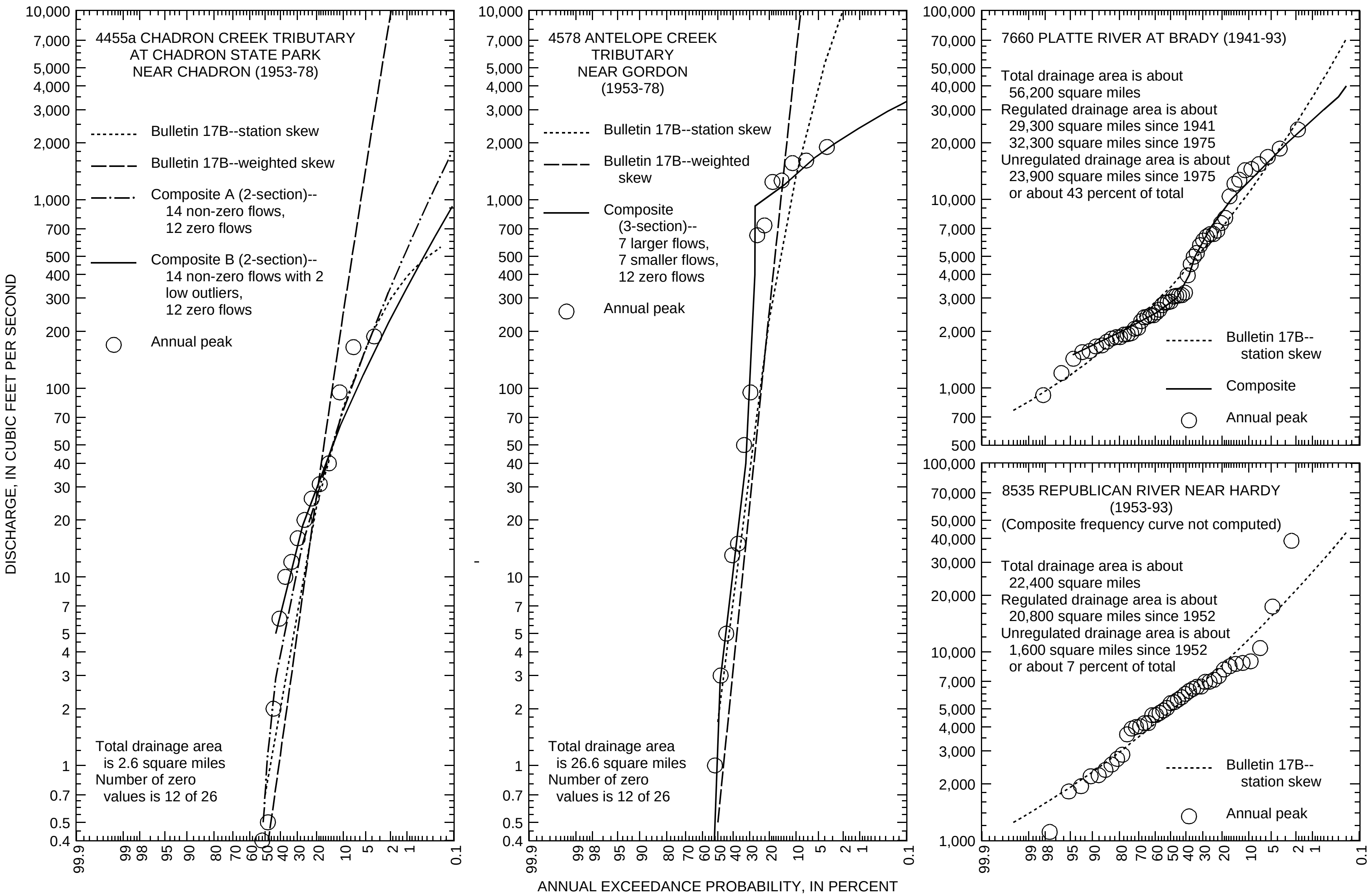


Figure 5. Four examples of Nebraska streamflow-gaging stations requiring composite frequency curves because of apparent mixed populations of data that are not caused by basins with large proportions of noncontributing drainage area or by average soil permeability of the top 60 inches of more than 4 inches per hour.

where this was observed were operated as peak-stage gages where only annual maximum peaks were reported. For both the Chadron Creek and Antelope Creek tributary stations, regional skews were used when analyzing the higher flows.

For regulated or partially regulated streams, the farther downstream from a control structure a station is located, the more likely it is that peaks will be produced from the unregulated drainage area between the structure and the station; even a small amount of drainage area can produce a large peak if a storm over the area is intense enough. The Republican River at Hardy (8535) is an example of a partially regulated station with an apparent mixed population (fig. 5). Based on a comparison with two other long-term stations between the Hardy station and the Harlan County Dam upstream, it is apparent that at least the two largest peaks at the Hardy station, which are distinctly different from the majority of the other peaks, were produced from the unregulated drainage area below the dam.

PEAK-FLOW FREQUENCY RELATIONS

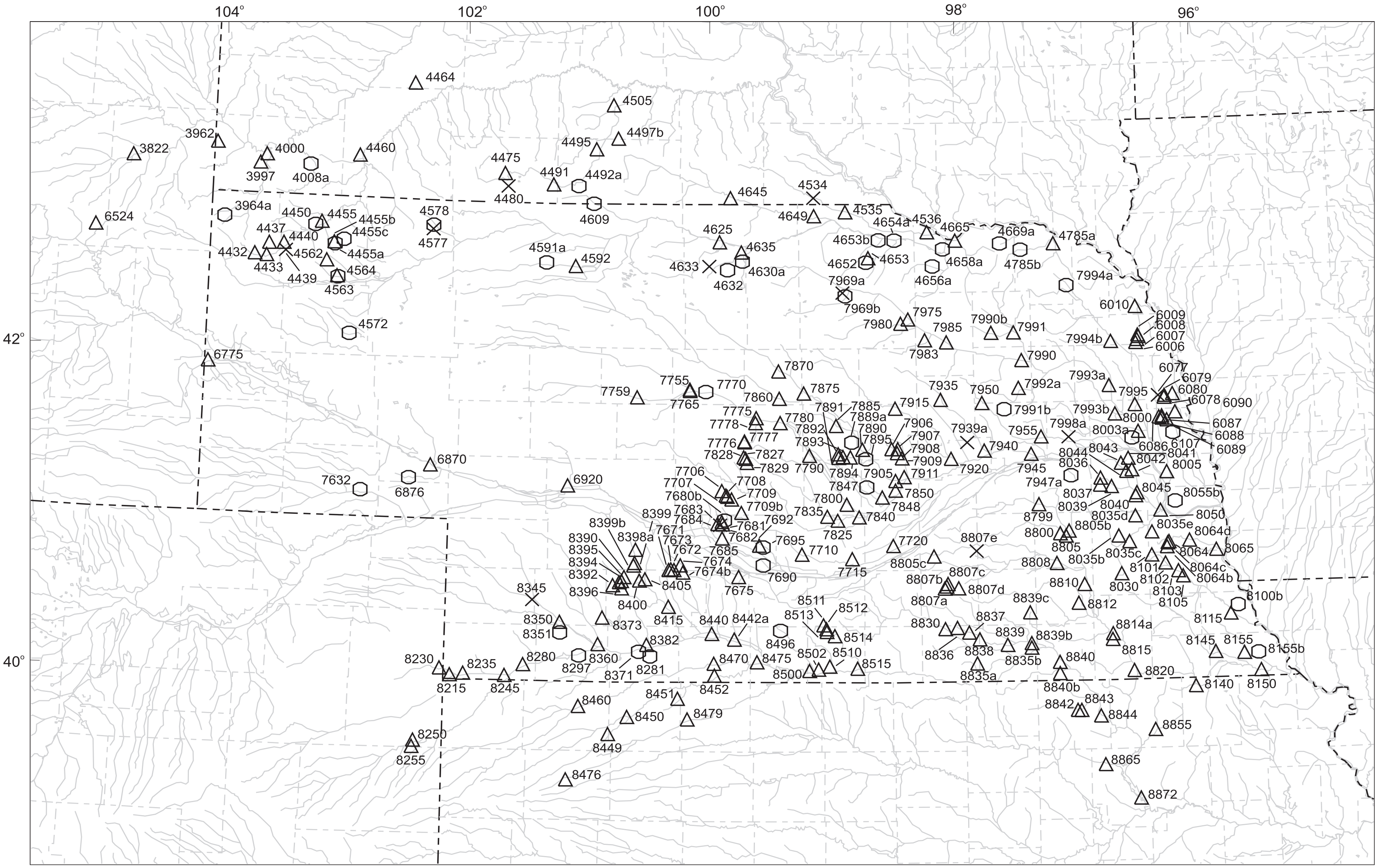
Peak-flow frequency relations were developed for standard exceedance probabilities of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent, or frequencies of occurrence (recurrence intervals) of 2, 5, 10, 25, 50, 100, 200, and 500 years, respectively. For unregulated streams, eight sets of regression equations relating drainage-basin characteristics to annual peak flows for selected frequencies of occurrence were developed for seven regions of the state. Two sets of regional peak-flow frequency equations were developed for a high-permeability region that includes basins with *P60* greater than 4 in/hr. Six sets of equations were developed for specific geographic areas, primarily on the basis of drainage-basin boundaries. One set of the high-permeability equations was developed using data from standard frequency analyses and the other was developed using data from composite frequency analyses. In general, the two sets of high-permeability equations were developed for basins with sandhills-type terrain. Statewide regression equations also were computed, but they are not presented because MSEs were larger than those for regional equations. Data from stations in Wyoming, South Dakota, Colorado, and Kansas were used along with data from stations in Nebraska in the development of unregulated peak-flow frequency relations (fig. 6).

Stations along streams with flows that are known to have been or possibly could have been affected to some degree by regulation (flood control, irrigation diversions, power generation, storage detention, or other factors) were excluded from regional analyses relating drainage-basin characteristics to peak-flow characteristics (fig. 7). Log-linear relations of peak-flow frequency and distance upstream from the mouth were developed for parts of nine streams.

Unregulated Streams

Using analyses for stations with at least 10 years of record, preliminary peak-flow frequency equations were developed and regions were defined using ordinary least squares (OLS) multiple-regression procedures. Final equations were developed using a generalized least squares (GLS) multiple-regression procedure. OLS regression procedures were used to identify the most likely combinations of drainage-basin characteristics for the development of peak-flow frequency equations and to define regions.

OLS regression analyses were done using Statit statistical programs (Statware, Inc., 1990). Peak-flow data were transformed to base-10 logarithms ($\log_{10}$). Several additional drainage-basin characteristics were computed using Statit from the existing characteristics before $\log_{10}$ and reciprocal transforms were computed. Correlation coefficients and plots of the data were used to screen out drainage-basin characteristics that were highly correlated with each other or were poorly distributed relative to the peak-flow data for statistical analyses. Multiple-regression programs ALLREG, GREGRES, and REGRES (Statware, Inc., 1990) were used to identify statistically significant combinations of explanatory variables (basin characteristics) for predicting peak flows for standard frequencies of occurrence. Initial selection of explanatory variables for OLS regression equations was based primarily on minimizing the Mallow's Cp statistic in ALLREG. Mallow’s Cp was used to achieve a balance between minimizing bias, by including all relevant variables, and minimizing the variance of the estimator, by keeping the number of variables small (E.J. Gilroy, D.R. Helsel, and T.A. Cohen, USGS, written commun., 1991).



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30',
central meridian -96°

EXPLANATION

△4455 Gaging station used in development of frequency relations, and map number

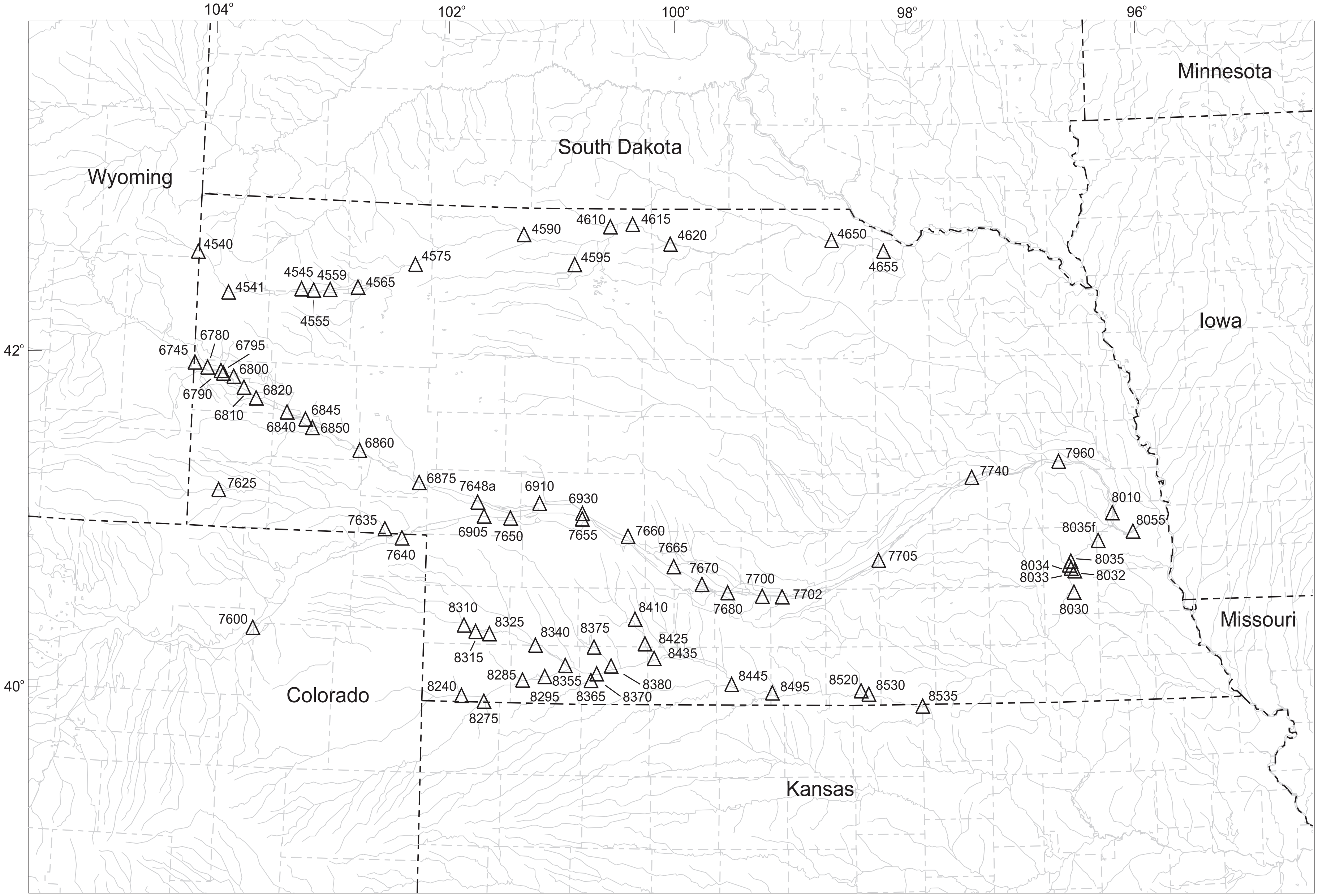
⬡8297 Gaging station used as new station in network analyses, and map number

✕8345 Gaging station not used for frequency relations or for network analyses, and map number

(Map numbers referenced in tables B1 and B2)

0 25 50 75 MILES

0 25 50 75 KILOMETERS



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30',
central meridian -96°

EXPLANATION

△ 8535 Gaging station and map number (referenced in tables B1 and B2)

This also usually resulted in minimizing the MSE and in keeping the absolute value of the t-ratios greater than 2. The t-ratio was computed for each explanatory variable as the fitted coefficient divided by its standard error; it was used to test whether or not the coefficient (slope) of each explanatory variable was significantly different than zero.

Regional Equations

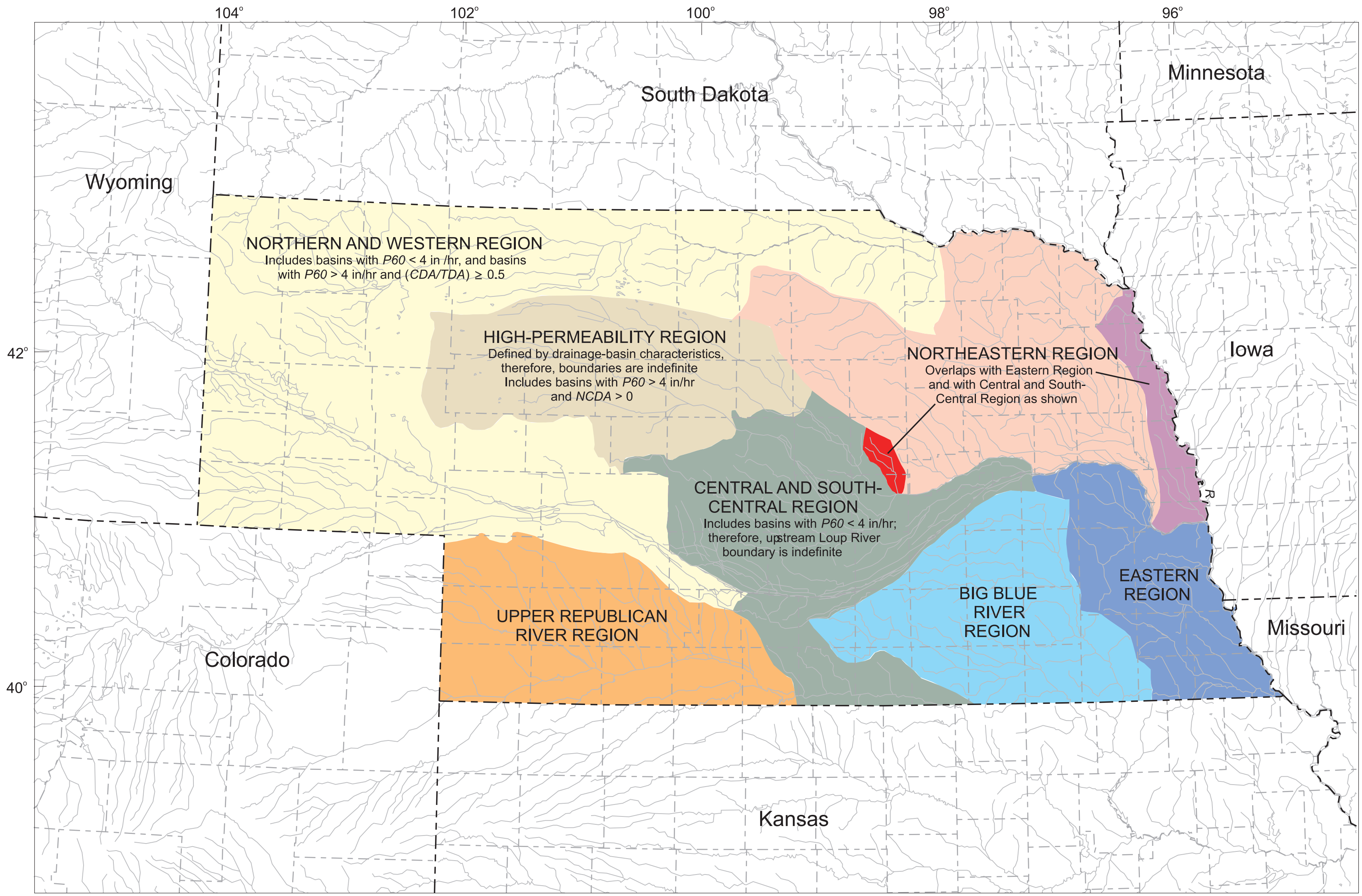
Residual values and plots from preliminary OLS regression analyses were used to delineate the six hydrologic regions (fig. 8) based on geography and outlier stations before final regression equations were developed using the GLS program in GLSNET (Gary Tasker, USGS, written commun., 1995). The GLS program adjusts for differences in record lengths, differences in peak-flow variances, and cross-correlations of concurrent peak-flows among stations used in the regression analysis (Tasker and Stedinger, 1989). Only $\log_{10}$ transforms of peak-flow and drainage-basin characteristic data were used for GLS regression analyses. This allowed for the simple transformation of the final equations to exponential form. Selection of drainage-basin characteristics as explanatory variables for GLS regression equations was based primarily on minimizing the GLS version of the prediction error sum of squares, or PRESS statistic, (Gilroy and Tasker, 1989; and E.J. Gilroy, D.R. Helsel, and T.A. Cohen, USGS, written commun., 1991) and, to a lesser extent, on minimizing the standard error of prediction (SEP).

The PRESS statistic is the sum of the squared prediction residuals. The prediction residuals are the differences between each observed value of the dependent variable and its predicted value that is determined from a regression equation computed with all data except that of the observed value for which the residual is being determined. The SEP was preferable to the standard error of estimate (SEE) for equation comparisons because the SEE is based only on the model error (error in the equation that will change only if the equation itself is changed, not by collecting more data) while the SEP also includes the sampling error (error in estimating the true equation parameters from limited data) (Gary Tasker, U.S. Geological Survey, written commun., 1995). The t-ratios for each of the explanatory variables also were examined; those with an absolute value of less than 2 were not used, in most cases. Also, explanatory variables that were not considered hydrologically valid were eliminated from the regression analyses on a case-by-case basis.

Short-record stations with less than 15 years of peak-flow record were not used, except for two regions in eastern and southeastern Nebraska. In general, use of short-record stations added considerable variability to peak-flow frequency relations; commonly, these stations had individual peak-flow frequency relations that did not fit the data well. Stations with an excessive number of low outliers that precluded development of reasonable peak-flow frequency curves, most typically in northern and western Nebraska, also were not used (see previous discussion “Composite Analyses”). In addition, stations with total drainage areas (*TDA*) of less than 1 mi^2 generally were not used. For most regions where a slope characteristic was identified as significant, stations with drainage areas of less than 5 mi^2 were not used. The 1:250,000-scale DEM data used to quantify basin characteristics resulted in some characteristics that were regarded as too low and unreliable for use in the regression analyses—this was particularly evident for basins with small drainage areas and low relief.

For both OLS and GLS regression analyses, allowances were made in the basic selection process to try to keep drainage-basin characteristics consistent for the various peak-flow frequency equations within a region. This was not always possible, however, and some equations for the same region have different sets of characteristics as explanatory variables. Judgement must to be used in the application of these equations in these situations.

For each region, equations were developed for the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year frequencies of occurrence (recurrence intervals), designated as Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{200}, and Q_{500} respectively. A table of equations for each region with summary statistics follows a discussion of each of the regions. There is overlap between several of the regions where more than one equation can be used to estimate peak flows.



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 digital data
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30',
central meridian -96°

0 25 50 75 MILES

0 25 50 75 KILOMETERS

EXPLANATION

CDA	Contributing drainage area	*TDA*	Total drainage area
NCDA	Noncontributing drainage area	>	Greater than
P60	Permeability of the 60-inch soil profile	<	Less than

Figure 8. Hydrologic regions in Nebraska for unregulated peak-flow frequency equations.

Tables of equations include: the average sampling error (ASE), average model error (AME), SEP, and SEE— all based on the $\log_{10}$ transforms of the data; SEE in percent of the untransformed data; and the average equivalent years of record (AEYR) for each equation. SEP was computed as the square root of the sum of ASE and AME. SEE was computed as the square root of AME (Gary Tasker, U.S. Geological Survey, written commun., 1995). For comparisons to equations developed by Beckman (1976), for which SEPs were not reported, SEEs in percent were computed from the SEEs in $\log_{10}$ units using tabled values from Tasker (1978, p. 87). The AEYR is an estimate of the number of years of at-site streamflow data that would be required to predict the streamflow characteristic with accuracy equivalent to that of the regression equation (Hardison, 1971, p. C232). The explanatory variables are listed in the equations in the order of decreasing t-ratios from the GLS output. This was done to illustrate the changing significance, if any, among the variables from one frequency of occurrence (recurrence interval) to another.

For unregulated stations, estimated peak flows were computed (table B2) from the applicable regional equations using basin-characteristic data (table B1). Code(s) designating the applicable set of regional equation(s) are also listed for each station.

High Permeability Region

This region generally includes drainage basins with sandhills terrain (figs. 1 and 8); it includes a large area of Nebraska, not all of it contiguous, and smaller areas in Colorado, South Dakota, and Wyoming. The region is nearly coincident with Beckman's Region 2 (1976, p. 10-11), which was defined geographically; in this report the region is defined by basin characteristics. Only basins with *P60* greater than 4 in/hr and with some noncontributing drainage area (*NCDA*) were used to develop the equations. These criteria eliminated the lower Niobrara River Basin stations downstream of Long Pine Creek (fig. 1). Although these basins have values of *P60* greater than 4 in/hr, they have little or no *NCDA* and the terrain is distinctly different from that of the nearby sandhills areas, as determined from visual inspection of topographic maps. Peak-flow frequency data from these basins also did not fit well with that from the sandhills-type basins. Consequently, the lower Niobrara River Basin is included within one of the six geographically based regions.

Equations for the High-Permeability Region and standard-frequency analyses (HPS) (table 2) are based on data from 49 stations with at least 15 years of record and *TDAs* of 94.8 to 15,200 mi^2. The explanatory variables for the HPS equations were not entirely consistent for all frequencies. Contributing drainage area (*CDA*) and mean annual precipitation (*MAP*) were the two most significant variables in all equations. Basin slope (*BS*) was significant at the smaller frequencies, and available water capacity (*AWC*) and main-channel slope (*MCS*) were significant at the middle and larger frequencies. Stations with *TDA*s less than 5 mi^2 were not considered because *BS* and *MCS* were in the equations (see previous discussion of Regional Equations).

Equations for the High-Permeability Region and composite-frequency analyses (*HPC*)(table 2) were based on data from 23 stations with at least 20 years of record and *TDA*s of 172 to 4,490 mi^2. The number of stations used to develop the regression equations was limited because of the amount of time required to compute the composite-frequency curves. Also, not every high-permeability station had enough peaks in the higher-flow regime to which a separate peak-flow frequency curve could be fitted. The explanatory variables for the composite-analysis equations are very similar to those for the standard-analysis equations except for the addition of drainage frequency (*DF*), which is significant for all frequencies.

SEEs for both sets of high-permeability equations are lower than are those corresponding to Beckman's Region 2 (1976, p. 60) equations. The SEEs for the standard equations generally are lower than are those for the composite equations; this could be because of the limited number of stations used to develop the composite equations. However, the peak-flow frequency curves that are the basis for the composite equations are considered to fit the peak-flow frequency data better at the high ends than do the standard peak-flow frequency curves. Judgment is required in determining which equations should be used in a particular instance.

Table 2. Peak-flow equations for the High-Permeability Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *AWC*, available water capacity of 60–inch soil profile, in inches per inch; *BS*, basin slope, in feet per mile; *CDA*, contributing drainage area, in square miles; *DF*, drainage frequency, in first-order streams per square mile; *MAP*, mean annual precipitation, in inches; *MCS*, main-channel slope, in feet per mile; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; SEE, standard error of estimate; SEP, standard error of prediction]

Estimation equation	ASE	AME	SEP	SEE	SEE (percent)	AEYR (years)
	(based on variables in $\log_{10}$ units)					
Standard analysis						
(49 stations with 25 or more years of record)						
$Q_2 = 0.0662CDA^{0.750}(MAP-15)^{0.548}BS^{0.933}$	0.003	0.030	0.183	0.174	41.8	3.6
$Q_5 = 0.408CDA^{0.777}(MAP-15)^{0.525}BS^{0.653}$	.004	.030	.182	.172	41.2	7.0
$Q_{10} = 8.76CDA^{0.736}(MAP-15)^{0.527}BS^{0.539}AWC^{0.835}$	.005	.031	.189	.176	42.2	9.7
$Q_{25} = 14.8CDA^{0.773}(MAP-15)^{0.695}AWC^{1.17}MCS^{0.546}BS^{0.318}$	.007	.033	.200	.181	43.5	13.2
$Q_{50} = 73.2CDA^{0.779}(MAP-15)^{0.756}AWC^{1.35}MCS^{0.766}$	.007	.036	.208	.189	45.8	15.9
$Q_{100} = 119CDA^{0.777}(MAP-15)^{0.787}AWC^{1.56}MCS^{0.860}$	.008	.038	.214	.195	47.2	18.7
$Q_{200} = 184CDA^{0.774}(MAP-15)^{0.816}AWC^{1.74}MCS^{0.942}$	.009	.041	.224	.203	49.3	20.8
$Q_{500} = 313CDA^{0.769}(MAP-15)^{0.850}AWC^{1.94}MCS^{1.04}$	.011	.047	.240	.217	53.1	22.7
Composite analysis						
(23 stations with 20 or more years of record)						
$Q_2 = 0.127CDA^{0.684}BS^{0.968}(MAP-15)^{0.715}DF^{0.456}$	.006	.022	.167	.149	35.4	3.3
$Q_5 = 1.09CDA^{0.774}(MAP-15)^{0.590}BS^{0.576}DF^{0.454}$	.008	.031	.196	.175	42.0	5.2
$Q_{10} = 21.8CDA^{0.744}(MAP-15)^{0.626}BS^{0.602}DF^{0.399}AWC^{1.17}$	.011	.033	.211	.182	43.9	7.1
$Q_{25} = 159CDA^{0.805}(MAP-15)^{0.718}DF^{0.637}AWC^{1.40}MCS^{0.773}$	.014	.038	.229	.195	47.2	9.2
$Q_{50} = 368CDA^{0.817}(MAP-15)^{0.730}DF^{0.637}AWC^{1.76}MCS^{0.864}$	.016	.040	.238	.201	48.8	11.3
$Q_{100} = 776CDA^{0.828}(MAP-15)^{0.741}AWC^{2.07}DF^{0.641}MCS^{0.941}$	.019	.044	.251	.210	51.4	13.0
$Q_{200} = 1,520CDA^{0.838}AWC^{2.35}(MAP-15)^{0.752}DF^{0.645}MCS^{1.01}$	.022	.050	.267	.223	55.0	14.1
$Q_{500} = 3,390CDA^{0.851}AWC^{2.67}(MAP-15)^{0.767}DF^{0.654}MCS^{1.09}$	.026	.060	.293	.244	61.0	15.0

APPLICABLE RANGES OF VARIABLES:
Standard-analysis equations—*CDA* 8.6–6,230; *MAP* 15.12–26.09; *AWC* 0.07–0.17; *MCS* 4.41–28.22; *BS* 41.0–286
Composite-analysis equations—*CDA* 8.6–1,310; *BS* 55.7–249; *MAP* 16.39–26.09; *DF* 0.05–0.60; *AWC* 0.08–0.15; *MCS* 5.6–19.4

NOTE: *BS*, *MCS*, and *DF* are data-scale dependent.

Northern and Western Region

This region was developed from stations in eastern Wyoming, southern South Dakota, and northern and western Nebraska and includes the Cheyenne, White, and Niobrara River Basins except as noted (figs. 1 and 8). The region is roughly coincident with Beckman's Region 1 (1976, p. 10-11), but excludes (1) the Niobrara River mainstem, (2) the Platte River Basin downstream of where the sandhills near the Platte River end along the left bank of the Platte and downstream of Plum Creek on the right bank, and (3 the Republican River Basin. There is some overlap with the High-Permeability Region, because stations with *P60* greater than 4 in/hr were used if the ratio of *CDA* to *TDA* was at least 50 percent.

Equations for the Northern and Western Region (table 3) are based on data from 34 stations with at least 15 years of record and *TDA*s of 0.6 to 2,160 mi^2. *CDA* and *MAP* are significant explanatory variables at all frequencies. Relative relief (*RR*) and average permeability of the least permeable layer (*PLP*) are significant for the Q_2 through Q_{50} equations, and *BS* is a significant explanatory variable for the Q_{100} through Q_{500} equations. SEEs for all equations, except for Q_2, are lower than Beckman's Region 1 equations (1976, p. 60), especially at the larger frequencies.

Table 3. Peak-flow equations for the Northern and Western Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *BS*, basin slope, in feet per mile; *CDA*, contributing drainage area, in square miles; *MAP*, mean annual precipitation, in inches; *PLP*, permeability of least permeable layer, in inches per hour; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; *RR*, relative relief, in feet per mile; SEE, standard error of estimate; SEP, standard error of prediction]

Estimation equation	ASE (based on variables in $\log_{10}$ units)	AME	SEP	SEE	SEE (percent)	AEYR (years)
(34 stations with 15 or more years of record)						
$Q_2 = 0.176 CDA^{0.762} RR^{0.878} (MAP - 12)^{0.929} PLP^{-0.357}$	0.032	0.180	0.460	0.424	126	1.7
$Q_5 = 0.686 CDA^{0.642} RR^{0.932} (MAP - 12)^{1.05} PLP^{-0.360}$	.014	.061	.275	.247	61.8	6.0
$Q_{10} = 1.69 CDA^{0.577} (MAP - 12)^{1.08} RR^{0.892} PLP^{-0.337}$	.014	.049	.251	.222	54.5	9.5
$Q_{25} = 5.06 CDA^{0.508} (MAP - 12)^{1.07} RR^{0.802} PLP^{-0.302}$	.016	.050	.257	.224	55.2	12.4
$Q_{50} = 10.7 CDA^{0.464} (MAP - 12)^{1.06} RR^{0.731} PLP^{-0.272}$	.018	.056	.271	.236	58.5	13.5
$Q_{100} = 35.2 CDA^{0.213} BS^{0.589} (MAP - 12)^{0.643}$	.018	.064	.288	.254	63.8	14.0
$Q_{200} = 37.4 CDA^{0.192} BS^{0.629} (MAP - 12)^{0.711}$	.020	.067	.295	.259	65.3	15.3
$Q_{500} = 41.6 CDA^{0.168} BS^{0.669} (MAP - 12)^{0.786}$	.023	.075	.313	.274	70.0	16.1

APPLICABLE RANGES OF VARIABLES: *CDA* 0.61–2,160; *RR* 4.2–48.3; *MAP* 14.19-24.69; *PLP* 0.10-5.00; *BS* 52.5–462

NOTE: *BS* and *RR* are data-scale dependent.

Northeastern Region

This region covers most of the northeastern part of Nebraska. It includes (1) the right bank Missouri River tributary basins downstream of the Niobrara River and upstream of the Platte River, (2) the left bank Platte River tributary basins downstream of the Loup River, and (3) the left bank Loup River tributary basins downstream of the North Loup River (figs. 1 and 8). It includes all of Beckman's Region 3 (1976, p. 10–11) north of the Platte River plus some other areas farther west. Unlike Beckman's Region 3, but similar to the Northern and Western Region, there is some overlap of the Northeastern Region with the High-Permeability Region (*P60* greater than 4 in/hr), most notably the entire basins of the Elkhorn and Cedar Rivers and Beaver Creek. The left bank Loup River tributary basins also overlap with the low-permeability Central and South-Central Region discussed next.

Equations for the Northeastern Region (table 4) are based on data from 40 stations with at least 15 years of record and *TDA*s of 1.5 to 6,950 mi^2. *TDA*, shape factor (*SF*), and *DF* are significant explanatory variables for all of the Northeastern Region equations. *PLP* is the second most significant variable for the Q_2 and Q_5 equations, but it becomes less significant at larger frequencies and is not significant for the Q_{200} and Q_{500} equations. SEEs for all equations are lower than Beckman's Region 3 equations (1976, p. 60).

Table 4. Peak-flow equations for the Northeastern Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *DF*, drainage frequency, in first-order streams per square mile; *PLP*, permeabilitiy of the least permeable layer, in inches per hour; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; SEE, standard error of estimate; SEP, standard error of prediction; *SF*, shape factor, dimensionless; *TDA*, total drainage area, in square miles]

Estimation equation	ASE	AME	SEP	SEE	SEE (percent)	AEYR (years)
	(based on variables in $\log_{10}$ units)					
(40 stations with 15 or more years of record)						
$Q_2 = 132TDA^{0.676}PLP^{-0.592}SF^{-0.335}DF^{0.295}$	0.007	0.037	0.209	0.191	46.2	4.4
$Q_5 = 395TDA^{0.652}PLP^{-0.514}SF^{-0.421}DF^{0.323}$	.006	.023	.170	.153	36.3	8.6
$Q_{10} = 715TDA^{0.633}SF^{-0.469}PLP^{-0.443}DF^{0.338}$	.006	.022	.167	.147	34.9	11.9
$Q_{25} = 1,360TDA^{0.612}SF^{-0.518}DF^{0.356}PLP^{-0.352}$	.007	.023	.173	.151	35.8	15.2
$Q_{50} = 2,070TDA^{0.597}SF^{-0.548}DF^{0.370}PLP^{-0.286}$	.008	.025	.182	.157	37.5	16.9
$Q_{100} = 3,000TDA^{0.583}SF^{-0.573}DF^{0.384}PLP^{-0.223}$	.010	.028	.192	.166	39.6	17.9
$Q_{200} = 5,240TDA^{0.562}SF^{-0.667}DF^{0.452}$	.009	.031	.201	.176	42.3	19.0
$Q_{500} = 7,030TDA^{0.551}SF^{-0.655}DF^{0.440}$	.011	.034	.213	.185	44.7	20.1
APPLICABLE RANGES OF VARIABLES: *TDA* 1.50–6,950; *PLP* 0.38–5.56; *SF* 0.49–56.4; *DF* 0.01–1.33						

NOTE: *DF* is data-scale dependent.

Central and South-Central Region

This region consists of low-permeability (*P60* less than 4 in/hr) basins, generally south and east of the central sandhills, that are tributaries within the middle Platte, Loup, and middle Republican River Basins (figs. 1 and 8). It includes (1) left bank Platte River tributary basins downstream of where the sandhills end along the left bank of the Platte River to just downstream of the Loup River but excluding the left-bank Loup River tributary basins downstream of Spring Creek (shortly below the confluences of the Middle and North Loup Rivers)—Beckman's Region 4 (1976, p. 10–11), and (2) Republican River tributary basins in Nebraska downstream of Harlan County Dam—part of Beckman's Region 1 (1976, p. 10–11). The Central and South-Central Region is presumed to include right bank Platte River tributary basins, for which there are no stations, downstream of Plum Creek, to the Loup River. Spring Creek, a left-bank Loup River tributary, overlaps with the Northeastern Region.

Equations for the Central and South-Central Region (table 5) are based on data from 37 stations with at least 15 years of record and with *TDAs* of 1.5 to 711 mi^2. Explanatory variables are the same for all equations, and include *TDA*, *RR*, 2–year, 24–hour precipitation (*TTP*), and *SF*. For the Q_2 and Q_5 equations, *TTP* is the second most significant variable, but for equations Q_{10} and larger, *RR* is more significant. SEEs are lower than Beckman's Region 1 equations (1976, p. 60), and lower than Beckman's Region 4 equations (1976, p. 60) for equations Q_{25} and larger.

Table 5. Peak-flow equations for the Central and South-Central Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; *RR*, relative relief, in feet per mile; SEE, standard error of estimate; SEP, standard error of prediction; *SF*, shape factor, dimensionless; *TDA*, total drainage area, in square miles; *TTP*, 2–year, 24–hour precipitation, in inches]

Estimation equation	ASE (based on variables in log_{10} units)	AME (based on variables in log_{10} units)	SEP (based on variables in log_{10} units)	SEE (based on variables in log_{10} units)	SEE (percent)	AEYR (years)
(37 stations with 15 or more years of record)						
$Q_2 = 54.8TDA^{0.994}(TTP-2)^{4.24}SF^{-0.738}RR^{1.00}$	0.016	0.072	0.297	0.269	68.3	4.1
$Q_5 = 73.4TDA^{0.942}(TTP-2)^{3.98}RR^{1.32}SF^{-0.647}$	.011	.038	.222	.196	47.4	8.2
$Q_{10} = 80.8TDA^{0.931}RR^{1.51}(TTP-2)^{3.92}(SF)^{-0.614}$	.012	.035	.216	.187	45.1	11.0
$Q_{25} = 89.4TDA^{0.923}RR^{1.71}(TTP-2)^{3.88}SF^{-0.587}$	.014	.039	.230	.198	47.9	13.0
$Q_{50} = 96.4TDA^{0.918}RR^{1.83}(TTP-2)^{3.84}SF^{-0.572}$	.016	.045	.247	.212	51.8	13.5
$Q_{100} = 104TDA^{0.914}RR^{1.93}(TTP-2)^{3.83}SF^{-0.560}$	.019	.052	.263	.228	56.4	13.6
$Q_{200} = 111TDA^{0.910}RR^{2.02}(TTP-2)^{3.81}SF^{-0.549}$	.021	.060	.285	.245	61.3	13.5
$Q_{500} = 121TDA^{0.906}RR^{2.12}(TTP-2)^{3.80}SF^{-0.538}$	.025	.072	.310	.268	68.0	13.2
APPLICABLE RANGES OF VARIABLES: *TDA* 1.50–711; *TTP* 2.35–2.55; *SF* 0.89–13.0; *RR* 2.72–21.4						

NOTE: *RR* is data-scale dependent.

Eastern Region

This region consists of Missouri River tributary basins from and including Omaha Creek (several miles below the mouth of the Big Sioux River) to the Nebraska-Kansas state line, but only includes Platte River tributary basins downstream of Hydrologic Unit 10200103 (U.S. Geological Survey, 1976)(which extends several miles below the mouth of the Loup River) along the right bank and downstream of the Elkhorn River along the left bank (figs. 1 and 8). It is a sub-area of Beckman's Region 3 (1976, p. 10-11). The Eastern Region north of the Platte River overlaps with the Northeastern Region.

Equations for the Eastern Region (table 6) are based on data from 42 stations with at least 10 years of record and *TDA*s of 1.6 to 1,640 mi^2. The explanatory variables of *CDA*, *BS* and, *PLP* are consistent for all equations. SEEs are lower than Beckman's Region 3 equations (1976, p. 60), especially at the larger frequencies. Five stations with *TDAs* less than 5 mi^2 were used to develop the equations even though *BS* was a significant explanatory variable; all values of *BS* for the five stations were relatively large (greater than 100 ft/mi) and appeared very reasonable compared to other stations in the region with larger *TDA*s.

Table 6. Peak-flow equations for the Eastern Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *BS*, basin slope, in feet per mile; *CDA*, contributing drainage area, in square miles; *PLP*, permeability of the least permeable layer, in inches per hour; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; SEE, standard error of estimate; SEP, standard error of prediction]

Estimation equation	ASE (based on variables in log_{10} units)	AME	SEP	SEE	SEE (percent)	AEYR (years)
(42 stations with 10 or more years of record)						
$Q_2 = 5.70 CDA^{0.558} BS^{0.655} PLP^{-0.470}$	0.006	0.036	0.206	0.191	46.1	4.4
$Q_5 = 21.1 CDA^{0.533} BS^{0.551} PLP^{-0.528}$	.004	.016	.141	.126	29.7	10.9
$Q_{10} = 42.1 CDA^{0.519} BS^{0.495} PLP^{-0.537}$	.004	.012	.125	.107	25.1	18.0
$Q_{25} = 90.2 CDA^{0.504} BS^{0.433} PLP^{-0.520}$	.005	.011	.124	.104	24.3	24.5
$Q_{50} = 151 CDA^{0.494} BS^{0.390} PLP^{-0.498}$	.005	.012	.131	.109	25.4	26.6
$Q_{100} = 242 CDA^{0.485} BS^{0.349} PLP^{-0.474}$	.006	.013	.140	.116	27.2	27.3
$Q_{200} = 377 CDA^{0.476} BS^{0.310} PLP^{-0.450}$	.007	.015	.150	.124	29.3	27.2
$Q_{500} = 650 CDA^{0.465} BS^{0.260} PLP^{-0.417}$	.008	.019	.163	.136	32.2	26.6
APPLICABLE RANGES OF VARIABLES: *CDA* 1.55–1,640; *BS* 12.8–315; *PLP* 0.13–0.60						

NOTE: *BS* is data-scale dependent.

Upper Republican River Region

This region was developed from stations in the Republican River Basin upstream of Harlan County Dam, and includes parts of southwestern Nebraska, northeastern Colorado, and northwestern Kansas (figs. 1 and 8). The South Fork of the Republican River (below Bonny Dam in Colorado) and the mainstem of the Republican River downstream of the South Fork are not included in this region because of regulation. Because the upper Republican River Region includes basins with *P60* greater than 4 in/hr, it overlaps with the High-Permeability Region and contains parts of Beckman's Regions 1 and 2 (1976, p.10–11).

Equations for the Upper Republican River Region (table 7) are based on data from 33 stations with at least 15 years of record and *TDAs* of 6.8 to 7,740 mi^2. The explanatory variables *CDA*, *MCS*, and compactness ratio (*CR*) are included in all of the equations, with *CR* and *MCS* varying in significance after *CDA*. SEEs are lower than Beckman's Region 1 and 2 equations (1976, p. 60), especially for Region 1. Stations with *TDAs* less than 5 mi^2 were not used to develop the equations because *MCS* is a significant explanatory variable (see previous discussion of "Regional Equations").

Table 7. Peak-flow equations for the Upper Republican River Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *CDA*, contributing drainage area, in square miles; *CR*, compactness ratio, dimensionless; *MCS*, main-channel slope, in feet per mile; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; SEE, standard error of estimate; SEP, standard error of prediction]

Estimation equation	ASE	AME	SEP	SEE	SEE (percent)	AEYR (years)
	(based on variables in $\log_{10}$ units)					
(33 stations with 15 or more years of record)						
$Q_2 = 1.97 CDA^{0.545} MCS^{1.19} CR^{-0.735}$	0.008	0.045	0.229	0.211	51.6	5.0
$Q_5 = 3.67 CDA^{0.570} CR^{-0.895} MCS^{1.32}$	.008	.037	.210	.192	46.3	8.1
$Q_{10} = 4.93 CDA^{0.583} CR^{-0.937} MCS^{1.39}$	.008	.038	.216	.196	47.5	10.3
$Q_{25} = 6.58 CDA^{0.597} MCS^{1.46} CR^{-0.946}$	.010	.044	.233	.211	51.5	12.3
$Q_{50} = 7.84 CDA^{0.606} MCS^{1.50} CR^{-0.931}$	.012	.050	.250	.224	55.3	13.3
$Q_{100} = 9.12 CDA^{0.613} MCS^{1.54} CR^{-0.905}$	.014	.057	.266	.239	59.6	13.9
$Q_{200} = 10.4 CDA^{0.619} MCS^{1.57} CR^{-0.868}$	.016	.065	.284	.255	64.2	14.2
$Q_{500} = 12.2 CDA^{0.626} MCS^{1.61} CR^{-0.809}$	.018	.076	.307	.276	70.5	14.5
APPLICABLE RANGES OF VARIABLES: *CDA* 6.78–4,450; *MCS* 7.1–46.3; *CR* 1.22–11.2						

NOTE: *MCS* and *CR* are data-scale dependent.

Big Blue River Region

This region was developed from stations in the Big Blue River Basin, which includes parts of southeastern Nebraska and northeastern Kansas (figs. 1 and 8). It is the same as Beckman's Region 5 (1976, p. 10–11).

Equations for the Big Blue River Region (table 8) are based on data from 32 stations with at least 10 years of record and *TDAs* of 2.0 to 4,450 mi^2. The explanatory variables, *TDA*, average maximum soil slope (*MSS*), and stream density (*SD*) are significant for all equations. *SF* is significant for all equations except Q_2, and *TTP* is significant only for Q_{10} and smaller. Except for the Q_2 equation, SEE*s* are lower than Beckman's Region 5 equations (1976, p. 60), especially for equations Q_{25} and larger.

Application of Equations

The applicability of each of the regional peak-flow frequency equations is limited to the range of values of the drainage-basin characteristics used to develop the equations. The minimum and maximum values of the characteristics used to develop the equations are listed in tables 2–8. For the best compatibility with the equations, drainage-basin characteristics should be determined using the same scale and type of data used in the development of the equations. The same method of quantification (GIS/Basinsoft) also should be used for the measurement of *MCS* and *BS*. For equations that have different explanatory variables for the various frequencies, judgment must be used, because predicted peak flows may not always increase for successively larger frequencies. One approach might be to compute estimated peak-flow values from the equations for each recurrence interval and then plot the results on probability paper. A smoothed curve then could be drawn through the points, perhaps giving more influence to points with lower SEEs.

Table 8. Peak-flow equations for the Big Blue River Region

[AEYR, average equivalent years of record; AME, average model error; ASE, average sampling error; *MSS*, average maximum soil slope, in percent; *Q*, peak discharge, in cubic feet per second, for a given recurrence interval, in years; SEE, standard error of estimate; SEP, standard error of prediction; *SD*, stream density, in miles per square mile; *SF*, shape factor, dimensionless; *TDA*, total drainage area, in square miles; *TTP*, 2–year, 24–hour precipitation, in inches]

Estimation equation	ASE (based on variables in $\log_{10}$ units)	AME	SEP	SEE	SEE (percent)	AEYR (years)
(32 stations with 10 or more years of record)						
$Q_2 = 54.0TDA^{0.627}TTP^{1.69}SD^{0.468}MSS^{0.425}$	0.007	0.027	0.185	0.164	39.1	4.9
$Q_5 = 160TDA^{0.580}MSS^{0.492}SD^{0.533}TTP^{1.05}SF^{-0.220}$	.004	.006	.103	.079	18.4	19.6
$Q_{10} = 267TDA^{0.546}MSS^{0.534}SF^{-0.264}SD^{0.511}TTP^{0.790}$	.004	.002	.075	.044	10.2	49.7
$Q_{25} = 463TDA^{0.500}MSS^{0.618}SF^{-0.360}SD^{0.631}$	.004	.002	.075	.041	9.5	69.2
$Q_{50} = 607TDA^{0.491}MSS^{0.638}SF^{-0.372}SD^{0.617}$	.005	.002	.081	.045	10.3	71.2
$Q_{100} = 764TDA^{0.483}MSS^{0.656}SF^{-0.382}SD^{0.601}$	.006	.003	.091	.052	12.1	67.2
$Q_{200} = 936TDA^{0.477}MSS^{0.672}SF^{-0.389}SD^{0.584}$	.006	.004	.101	.061	14.1	61.8
$Q_{500} = 1,190TDA^{0.469}MSS^{0.692}SF^{-0.396}SD^{0.557}$	.008	.005	.116	.074	17.2	55.0

APPLICABLE RANGES OF VARIABLES: *TDA* 2.03–4,450; *TTP* 2.62–3.35; *SD* 0.14–1.39; *MSS* 1.9–14.5; *SF* 0.13–7.60

NOTE: *SD* is data-scale dependent.

Regulated Streams

Peak-flow frequency analyses for stations on regulated streams in Nebraska with at least 10 years of regulated peak flows were done using program PEAKFQ based on Bulletin 17B guidelines and the log-Pearson Type III (LP3) distribution with skew coefficients derived only from each station's peak-flow data. All available peak-flow records within the period of current regulated condition were used for these analyses; they are identified as "REG" under the type of analysis in table B2. For reaches of streams that include more than one station with at least 25 years of regulated record, approximate graphical relations of peak-flow frequency and distance upstream of the mouth also were developed. These relations are very generalized.

Graphical peak-flow frequency relations were developed for the Niobrara, North Platte, South Platte, Platte, and Republican Rivers, and for Salt, Antelope (not shown), Frenchman, and Red Willow Creeks (fig. 1). Peak-flow frequency values for 58 stations were plotted against distance, in miles, as measured upstream from the mouth along their respective streams. Only the 49 stations with at least 25 years of regulated record were used to develop approximate log-linear relations. The remaining stations, with less than 25 years of record, were used only for reference. The periods of the current regulated condition for each of these streams were identified and used to determine the period for which the peak-flow frequency analyses would be computed for each station (table 9). Each of the nine regulated streams is discussed separately in the following sections, and the locations of selected dams are shown on figures 1 and 9.

Niobrara River

The Niobrara River originates in Wyoming, flows through northern Nebraska, and drains as a right-bank tributary into the Missouri River in northeastern Nebraska. Major tributaries to the Niobrara include, in downstream order: Snake River, Minnechaduza Creek, and Keya Paha River. Values of Q_5 through Q_{500} decrease measurably from the station at the Wyoming state line to the station at Agate and they increase from there to the station above Box Butte Reservoir (fig. 10) even for concurrent periods of record (data shown). Patterson (1966, p. 410) noted that the peak flows at Agate are materially affected by diversions for irrigation; however, the ratios of irrigated acres to drainage area are nearly identical (8.0 to 10.4) for all three stations, with Agate actually having the smallest ratio (Boohar and others, 1992, p. 55–57). It is possible that the flow records for one or more of the stations is not representative of their long-term peak-flow characteristics, but the differences are so large that some additional explanation seems warranted. One possible explanation, or contributing factor, could be that the drainage basin narrows and the channel gradient decreases from the state line to Agate; this could result in significant attenuation of flows. Because of the uncertainty, no estimated relations between peak-flow frequency and distance from the mouth were developed for this reach of the Niobrara River.

Two major dams are located in the Niobrara River Basin—Box Butte on the mainstem and Merritt on the Snake River (table 9). Except for Q_2, Box Butte Dam causes large reductions in the peak flows downstream, especially as frequencies increase (fig. 10). The effects of the dam appear to diminish within about 70 mi downstream of the dam. Merritt Dam appears to have little effect on the Niobrara River peak flows, especially considering its small reduction in peak flows for the Snake River itself (table B2).

North Platte River

The North Platte River originates in the mountains of northern Colorado and flows through the mountains and plains of Wyoming to its confluence with the South Platte River in western Nebraska. There are four major dams on the North Platte River—Seminoe, Pathfinder, and Glendo, in Wyoming, and Kingsley in Nebraska (table 9). Glendo was the last of these dams built on the North Platte River, and it is the most downstream of the three Wyoming dams; therefore, its operational date of October 1957 was used as the beginning date of the current regulated condition of the North Platte River between Glendo and Kingsley Dams. The operational date of Kingsley Dam, February 1941, was used as the beginning date for stations downstream of Kingsley Dam because the large storage capacity of Lake McConaughy would be

Table 9. Summary of regulation data for selected stream reaches

[Apr, April; Aug, August; Feb, February; Nov, November; Oct, October; Sept, September; POR, period of record]

Stream name	Stream reach	Period of current regulated condition	Remarks[1]
Niobrara River (fig. 10)	Wyoming state line to Box Butte Dam	Entire POR	Affected by irrigation during entire POR
	Box Butte Dam to Snake River	Oct 1945–	Box Butte Dam (1,460 mi^2, approximately; Oct 1945)
	Snake River to mouth	Feb 1964–	Merrit Dam (640 mi^2, approximately; Feb 1964)
North Platte River (fig. 11)	Wyoming state line to Kingsley Dam	Oct 1957–	Affected by Seminoe (7,230 mi^2, Apr 1939), Pathfinder (10,711 mi^2, Apr 1909), and Glendo (15,545 mi^2, Oct 1957) Dams in Wyoming
	Kingsley Dam to mouth	Feb 1941–	Kingsley Dam (29,300 mi^2, approximately; Feb 1941)
South Platte River (fig. 12)	South Platte River near Balzac, Colorado to mouth	Entire POR	Affected by transmountain and irrigation diversions, storage reservoirs, power generation, and irrigation return flows during entire POR; because of large amount of intervening drainage area, Chatfield Dam (3,018 mi^2, May 1975) assumed not to increase regulation significantly
Platte River (fig. 13)	Confluence of North and South Platte Rivers to mouth	Feb 1941–	Effects of regulation much less below Loup River
Salt Creek (fig. 14)	Hickman Branch to Cardwell Branch	1965–	Olive Creek Lake (8.2 mi^2, 1964), Bluestem Lake (16.6 mi^2, 1963), Wagon Train Lake (15.6 mi^2, 1963), and Stagecoach Lake (9.2 mi^2, 1964) Dams
	Cardwell Branch to Oak Creek	1966–	Yankee Hill Lake (8.4 mi^2, 1965), Conestoga Lake (15.1 mi^2, 1964), Pawnee Lake (35.9 mi^2, 1965), East and West Twin Lakes (11.0 mi^2, 1965), and Holmes Lake (5.4 mi^2, 1962) Dams
	Oak Creek to mouth	1968–	Branched Oak Lake Dam (88.7 mi^2, 1967)
Antelope Creek (fig. 14)	Holmes Lake Dam to mouth	1962–	Holmes Lake Dam (5.4 mi^2, 1962)
Republican River (fig. 15)	South Fork Republican River to Trenton Dam	July 1950–	Bonny Dam (1,820 mi^2, approximately; July 1950)
	Trenton Dam to Frenchman Creek	May 1953–	Trenton Dam (8,620 mi^2, approximately; May 1953)
	Frenchman Creek to Red Willow Creek	May 1953–	Enders Dam (950 mi^2, approximately; Oct 1950)
	Red Willow Creek to Medicine Creek	Sept 1961–	Red Willow Dam (730 mi^2, approximately; Sept 1961)
	Medicine Creek to Harlan County Dam	Sept 1961–	Medicine Creek Dam (880 mi^2, approximately; Aug 1949)
	Harlan County Dam to Kansas state line	Nov 1952–	Harlan County Dam (20,750 mi^2, approximately; Nov 1952)
Frenchman Creek (fig. 16)	Colorado state line to Enders Dam	Entire POR	Affected by irrigation during entire POR
	Enders Dam to mouth	Oct 1950–	Enders Dam (950 mi^2, approximately; Oct 1950)
Red Willow Creek (fig. 16)	Above Red Willow Dam	Entire POR	Peak flows do not appear to be affected substantially by irrigation development although natural streamflow is affected
	Red Willow Dam to mouth	Sept 1961–	Red Willow Dam (730 mi^2, approximately; Sept 1961)

[1]For dams, numbers in parentheses are drainage area and beginning date of operation.

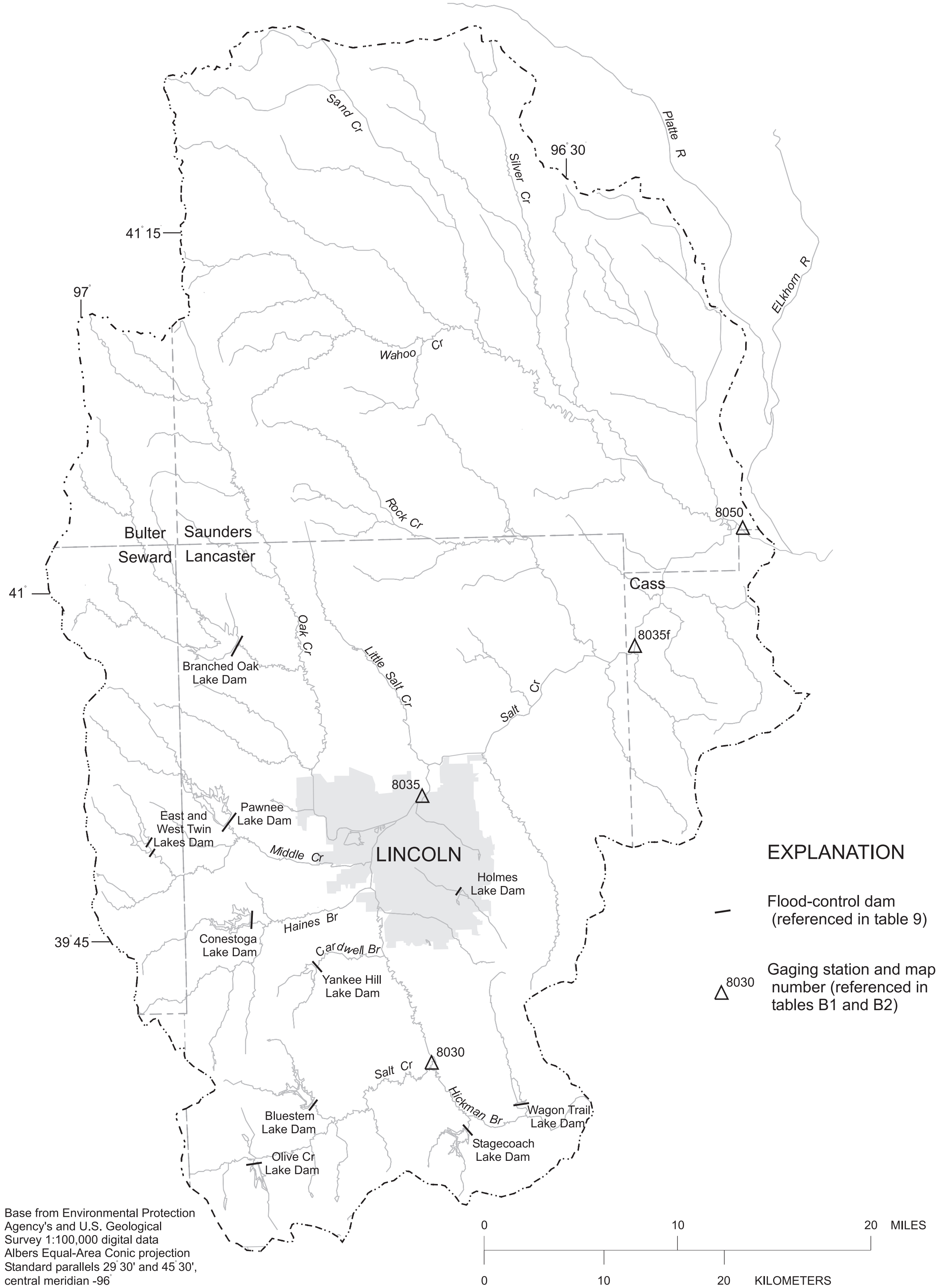


Figure 9. Location of flood-control dams in the Salt Creek drainage basin and of streamflow-gaging stations along the mainstem of Salt Creek.

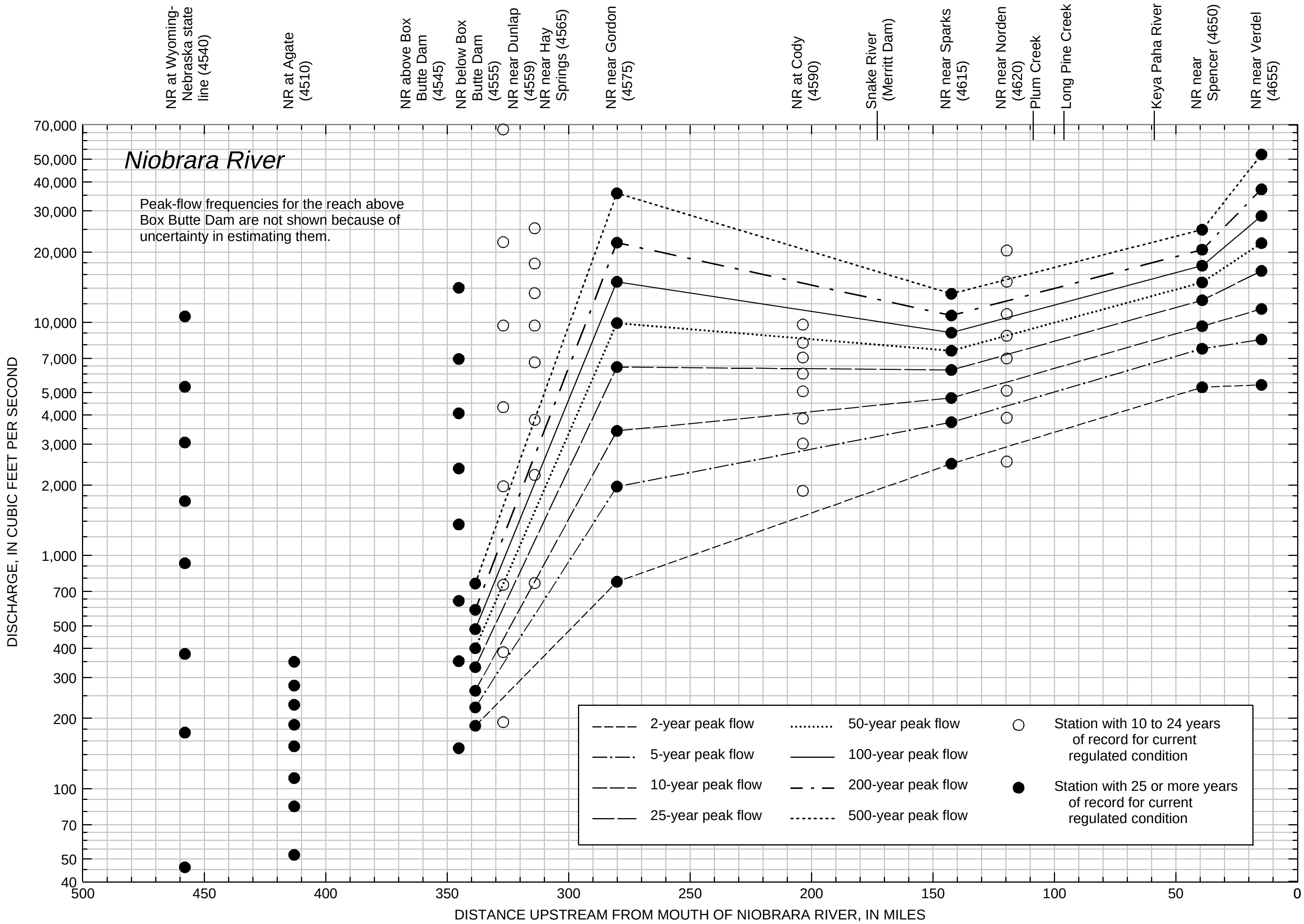


Figure 10. Peak-flow frequencies for the current regulated condition of the Niobrara River (NR) in Nebraska estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

expected to mask the effects of the operation of Glendo Dam that began in 1957. Peak-flow frequency relations for the North Platte River downstream of the Wyoming-Nebraska state line are fairly uniform, with a noticeable reduction in peak flows downstream of Kingsley Dam (fig. 11).

South Platte River

The South Platte River originates in the mountains of central Colorado and flows across the plains to its confluence with the North Platte River in western Nebraska. Regulation of the South Platte River began prior to collection of streamflow records. Reservoir storage created by dams in the South Platte River Basin is less than in the North Platte River Basin (Eschner and others, 1983, page A6). Chatfield, the largest dam in the South Platte River Basin, began operation in May 1975. Because Chatfield Dam is located near the upstream end of the basin and controls less than 13 percent of the drainage area upstream of Nebraska, it was assumed that its affect on peak flows in Nebraska was minimal. Therefore, the entire periods of record were used for South Platte River stations. Peak-flow frequency relations decrease in the downstream direction, generally with only small increases for several frequencies from South Platte River at Paxton (7650) to South Platte River at North Platte (7655) (fig. 12).

Platte River

The Platte River begins at the confluence of the North and South Platte Rivers in western Nebraska and drains into the Missouri River as a right-bank tributary in eastern Nebraska. In addition to the mainstem Platte River stations, peak-flow frequency values were computed for Wood River near Alda (7720), Loup River at Columbus (7945), Elkhorn River at Waterloo (8005), and Salt Creek at Ashland (8050) to estimate each tributary's effect on Platte River peak flows. Wood River peak flows were relatively small, but the peak flows for the Loup River were larger than those estimated graphically for the Platte River just upstream of the mouth of the Loup River. Therefore, the peak-flow values for the Loup River are used for the Platte River mainstem at their junction; this results in a discontinuity in the plots at that point (fig. 13). The peak-flow frequency values for the Platte River above and below the Elkhorn River (also a discontinuity on fig. 13) were extrapolated from the values for the Platte River at North Bend (7960) based on respective estimated drainage areas. The effect of Salt Creek could not be determined reliably. Although Kingsley Dam appears to have little effect on the peak-flow frequency values of the Platte River below the Loup River, for consistency, none of the Platte River stations were analyzed for periods prior to the Kingsley Dam operational date of February 1941.

Salt and Antelope Creeks

Salt Creek originates in southeastern Nebraska and flows north and northeast through Lincoln before draining into the Platte River in northwestern Cass County (fig. 9). The upper basin is fan shaped with a number of tributaries converging with the main stream in or near Lincoln, including Antelope Creek (not shown), which flows northwest through the middle of Lincoln. After two large floods in the early 1950s, a series of flood-control dams were constructed on several streams around Lincoln (table 9). Peak-flow frequency analyses for periods since regulation began were computed for three stations on Salt Creek and for three stations on Antelope Creek (fig. 14). Olive Creek, Bluestem Lake, Wagon Train Lake, and Stagecoach Lake Dams are located upstream of Salt Creek at Roca (8030). Yankee Hill Lake, Conestoga Lake, Pawnee Lake, East and West Twin Lakes, Holmes Lake, and Branched Oak Lake Dams are located downstream of Roca and upstream of Salt Creek at Lincoln (8035). Holmes Lake Dam is located upstream of the three Antelope Creek stations (not shown). The peak-flow frequency relations for both Salt and Antelope Creeks increase in the downstream direction with the exception of Q_{500} on the upper reach of Antelope Creek, which decreases slightly (fig. 14).

Republican River

The Republican River Basin is in parts of three states—Colorado, Nebraska, and Kansas. The Republican River begins at the confluence of the North Fork Republican and the Arikaree Rivers, both of which originate in Colorado. It then flows through southern Nebraska, and joins the Smoky

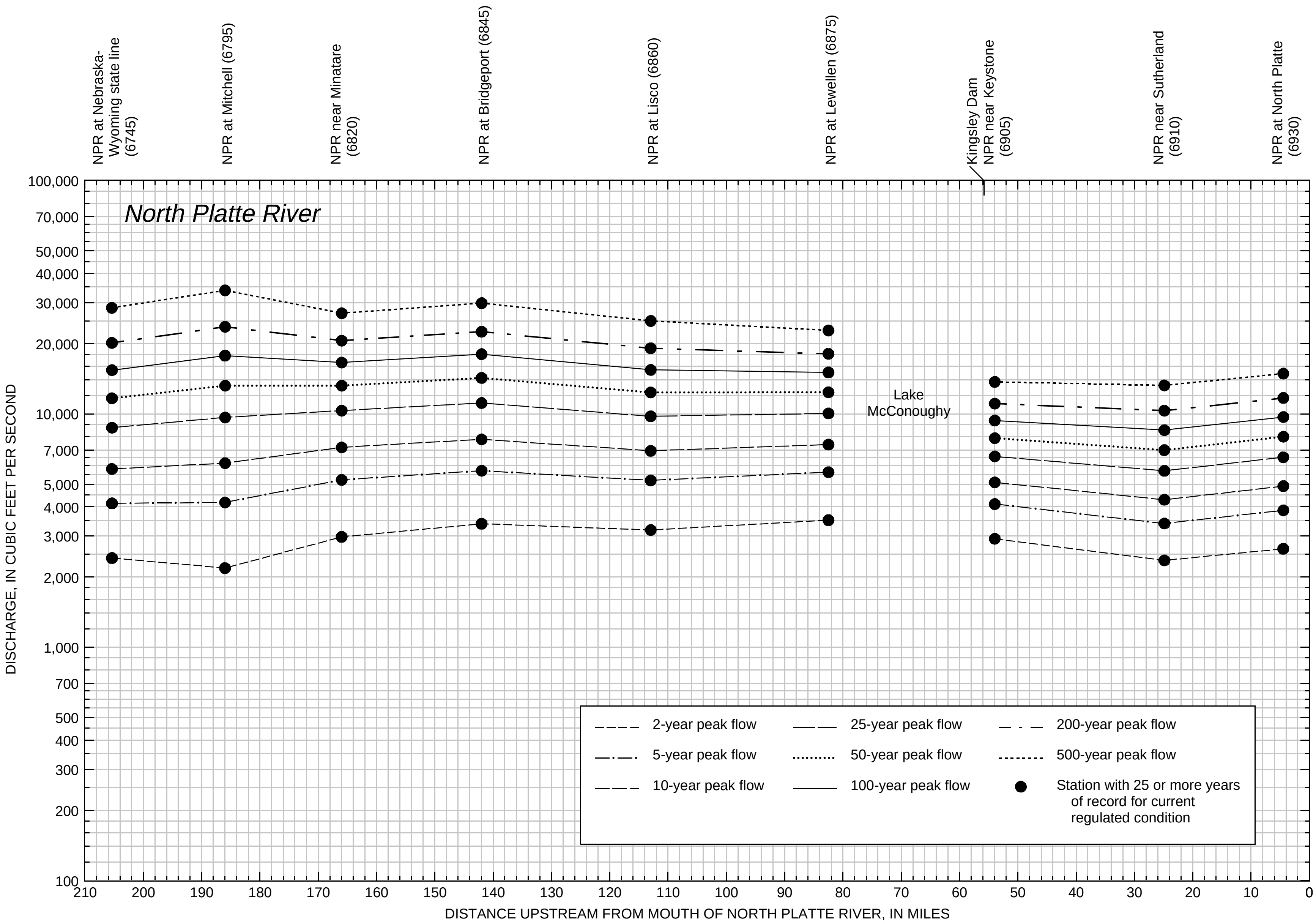


Figure 11. Peak-flow frequencies for the current regulated condition of the North Platte River (NPR) in Nebraska estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

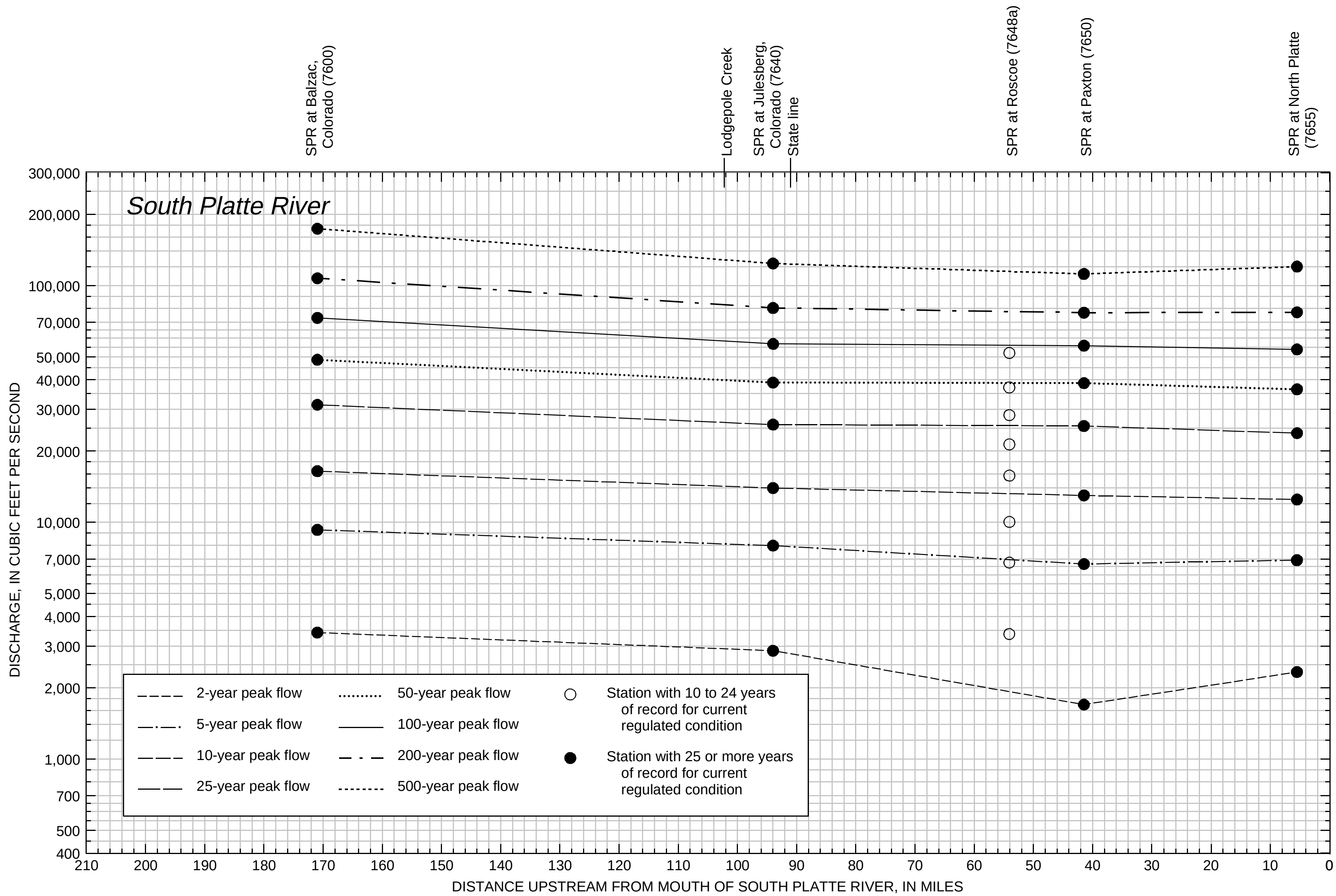


Figure 12. Peak-flow frequencies for the current regulated condition of the South Platte River (SPR) in Nebraska and part of Colorado estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

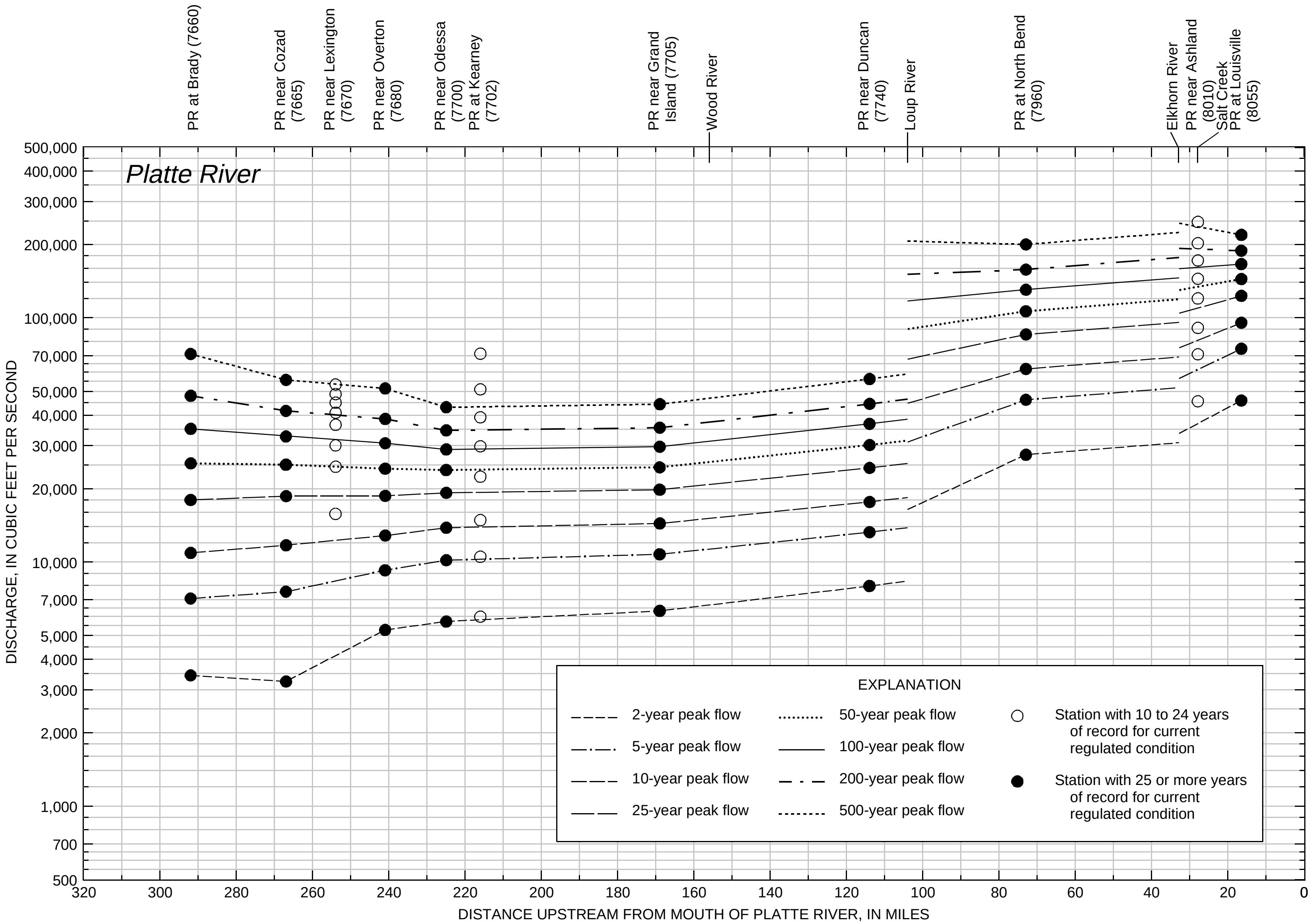


Figure 13. Peak-flow frequencies for the current regulated condition of the Platte River (PR) in Nebraska estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

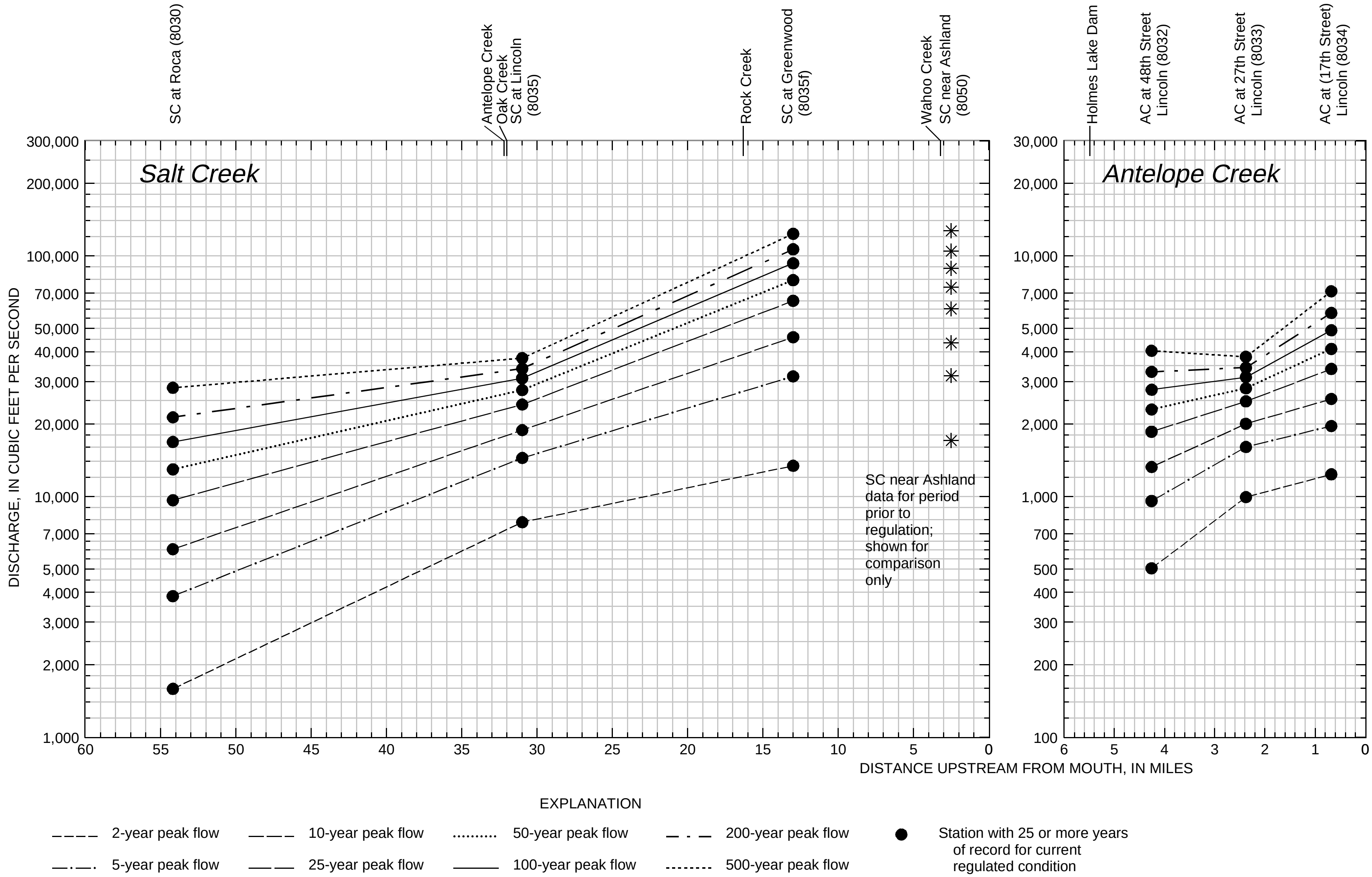


Figure 14. Peak-flow frequencies for the current regulated conditions of Salt (SC) and Antelope Creeks (AC) in Lancaster, Cass, and Saunders Counties of Nebraska estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

Hill River to form the Kansas River in north-central Kansas. Two mainstem dams and five tributary dams have been constructed in the Republican River Basin upstream of the Nebraska-Kansas state line. The operational dates for Bonny, Trenton, Enders, Red Willow, Medicine Creek, and Harlan County Dams and their effects on the period of current regulated condition were determined (table 9). Norton Dam is not listed because Prairie Dog Creek, on which it is located, flows directly into Harlan County Lake below which the effects of Norton Dam are masked because of Harlan County Lake's relatively large storage capacity. Analyses for eight mainstem stations were used in estimating peak-flow frequency relations for the Republican River (fig. 15).

The operational date of July 1950 for Bonny Dam on the South Fork of the Republican River in northeastern Colorado was used as the beginning date of the current regulated condition for the South Fork below Bonny Dam and for the Republican River mainstem between the mouth of the South Fork and Trenton Dam farther downstream. Considering the amount of intervening drainage area, the effect of Bonny Dam on most peak flows into Nebraska is probably not very significant. However, it could have had a significant effect, had it existed, on the very large flood of 1935 because much of the flow for that flood originated in the upper part of the basin. See the maximum peak flows for South Fork Republican River near Idalia, Colorado (8250) and Republican River at Max (8280) in table B2.

The peak-flow frequency values for the Republican River above Trenton Dam were extrapolated from those for Republican River at Stratton (8285) based on respective drainage areas. Peak-flow values for the Republican River below Sappa Creek were based on the larger of those computed for Sappa Creek near Stamford (8475) and those for Republican River near Orleans (8445) extrapolated for the increased drainage area from Sappa Creek. The peak-flow values for the Republican River above Harlan County Dam were extrapolated from the values below Sappa Creek, previously described, based on drainage areas.

Trenton and Harlan County Dams cause large reductions in Republican River peak flows, and Enders Dam on Frenchman Creek probably contributes to the decreases in Q_{200} and Q_{500} between the Republican River stations at Trenton (8295) and at McCook (8370) (fig. 15). There are discontinuous increases in peak flows at the junction with Sappa Creek, especially at the larger frequencies. Elsewhere, peak-flow frequency relations increase in the downstream direction with the exception of Q_{500} and Q_{200} between the stations at Guiderock (8530a) and near Hardy (8535), where they decrease slightly.

Frenchman Creek

Frenchman Creek originates in northeastern Colorado and drains as a left-bank tributary into the Republican River in southwestern Nebraska. Irrigation has affected flows in Frenchman Creek since before streamflow gaging began and the entire periods of record were used to compute peak-flow frequency analyses for stations above Enders Dam, the only major dam on Frenchman Creek. The operational date of October 1950 for Enders Dam was used for the beginning date of analyses for stations downstream of the dam. In addition to the Frenchman Creek stations (fig. 16), peak-flow frequency values were computed for Stinking Water Creek near Palisade (8350) to estimate its effect on Frenchman Creek values.

Enders Dam causes reductions in peak flows for Q_{10} through Q_{500}, with increasingly larger reductions for the larger frequencies (fig. 16). Peak flows increase in the downstream direction below the dam, except for Q_2 between the junction with Stinking Water Creek and Frenchman Creek at Culbertson (8355), which decreases slightly.

Red Willow Creek

Red Willow Creek originates in southwestern Nebraska and flows to the southeast before draining as a left-bank tributary into the Republican River. Red Willow Dam is the only major dam on the creek. Its operational date of September 1961 was used as the beginning date for peak-flow frequency analyses of the two stations located downstream of the dam (fig. 16). For comparison, the peak-flow frequency values for an unregulated station, Red Willow Creek above Hugh Butler Lake (8373) located upstream of the dam, also are included on figure 16.

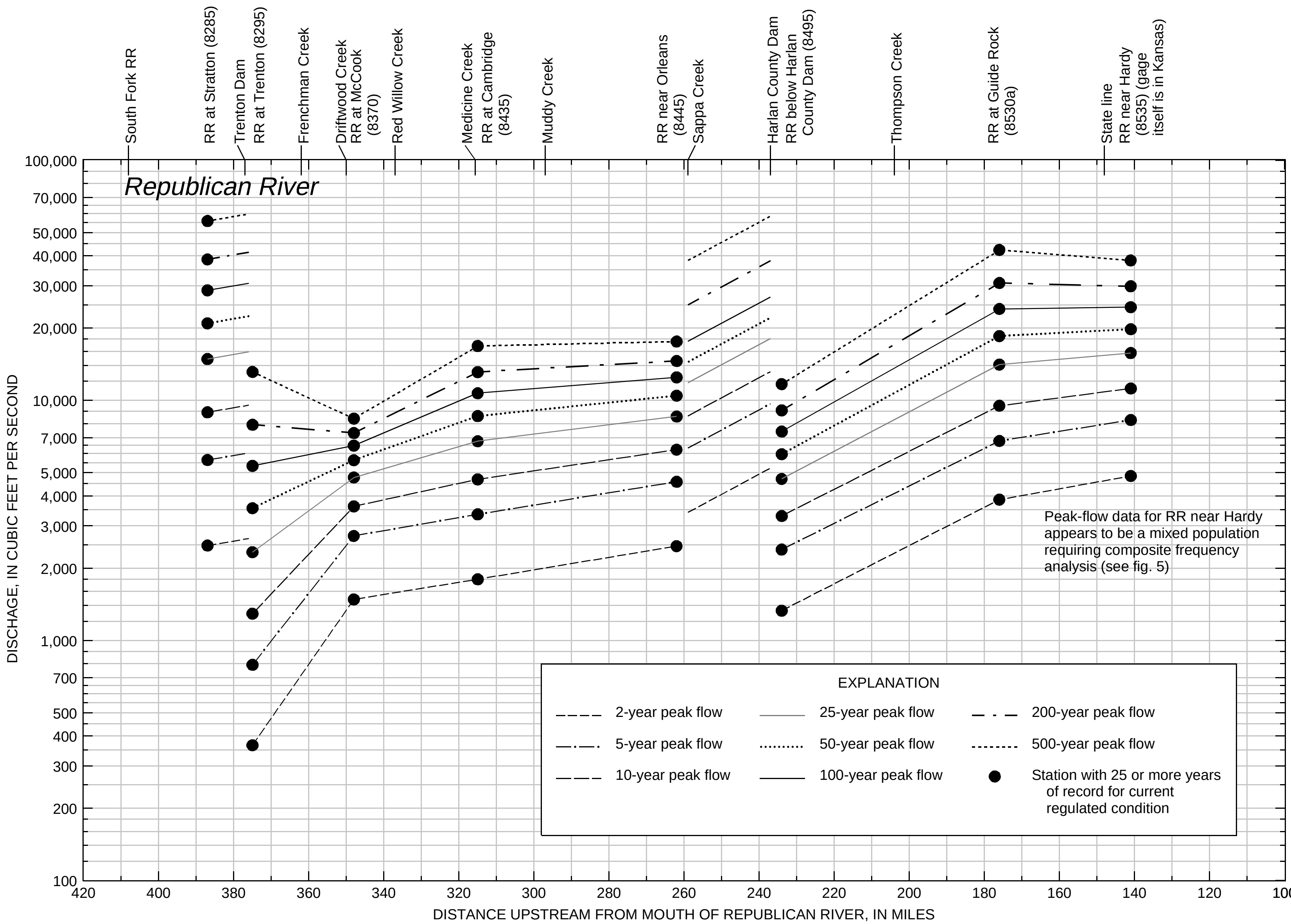


Figure 15. Peak-flow frequencies for the current regulated condition of the Republican River (RR) in Nebraska and part of Kansas estimated from streamflow-gaging data (number following station name is map number referred in tables B1 and B2).

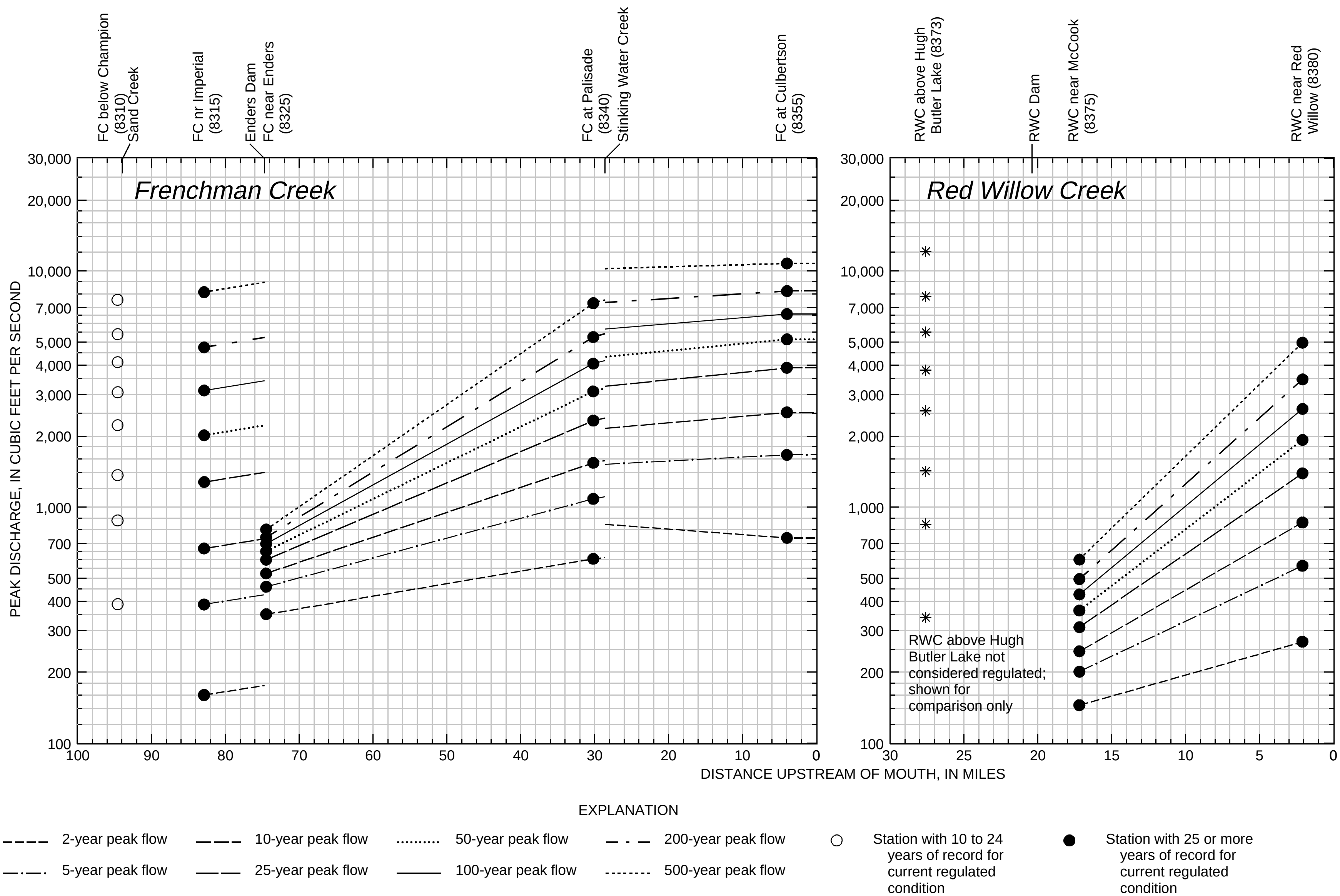


Figure 16. Peak-flow frequencies for the current regulated conditions of Frenchman (FC) and Red Willow (RWC) Creeks in Nebraska estimated from streamflow-gaging station data (number following station name is map number referred in tables B1 and B2).

Red Willow Dam causes large reductions in peak flows compared to the unregulated flows upstream. In the downstream direction below the dam, peak flows increase.

NETWORK EVALUATION

For each peak-flow frequency region, statistical analyses were done to estimate how additional years of peak-flow data might affect the average sampling errors (ASEs) of the newly developed 100-year frequency (recurrence interval) equations. Four different scenarios were evaluated—10- and 20-year periods of additional data collection (planning horizons) with "equation" stations (those stations used in the development of the equations) and 10- and 20-year planning horizons with "equation" stations plus with new stations. Output for the various scenarios for each region can be compared to determine where the largest reduction in ASE of the newly developed peak-flow frequency equations could be gained for the least amount of new data collection, and hence for the least cost.

Station Selection

Three types of stations were identified and used for the network analyses of a particular regional equation: active, inactive, and new. Active stations were "equation" stations that were still being operated as of 1994. For analytical purposes, it was assumed that they would continue to be operated for the planning horizons with existing base-network funds. Inactive stations were "equation" stations that had been discontinued by 1994; it was assumed that they would be operated for the planning horizons but only with new discretionary funds. "New" stations could be completely new stations with no peak-flow record available or they could be stations with some record but not enough to have been used in the development of the equations. In either case, it was assumed they would be operated for the planning horizons but only with new discretionary funds.

The future operation of "new" stations would not only provide additional peak-flow data for updating the regional equations, but potentially could increase the range of the explanatory variables in the regional equation, thereby broadening the applicability of the equations. Before the effects of any "new" stations could be analyzed, their latitude and longitude needed to be known or determined along with values of the explanatory variables that had been used in the development of the equation being evaluated. With the exception of the Eastern and Big Blue River Regions, stations with 10 to 14 years of record were not used in the development of regional peak-flow frequency equations (tables 2–8). However, because basin characteristics already had been determined for most stations with 10 to 14 years of record, they were used as the "new" stations for the network analyses. The special nature of the composite equations prevented their evaluation by the network analysis program for any of the "new" station scenarios.

Analyses and Output

To do the network analyses, output from the GLS (regression) part of the GLSNET program that had been used to compute a particular peak-flow frequency equation was input to the NET program of GLSNET. The stations used in the development of the equation were flagged as either active or inactive. The NET program then was run for each of the planning horizons being considered (10 and 20 years). For the other two scenarios, data for any "new" stations within the region were input, and the program was run again for the two planning horizons.

For each scenario, the expected ASE of the equation was computed first by NET assuming that all available stations had been operated for the given planning horizon. Then the discretionary station that would cause the ASE to increase the least if it were not operated for the planning horizon was identified and removed from the data set, and the ASE was recomputed. This process was repeated internally within NET until only the active stations remained. For each scenario, the output from the NET analysis was used to produce a plot of the number of stations in relation to the ASE (figs. 17 and 18). The analyses that include "new" stations are unique for those sets of stations; a different set of "new" stations would produce different results. Therefore, those analyses should be considered only examples of, not accurate determinations of, how "new" stations would affect the ASEs.

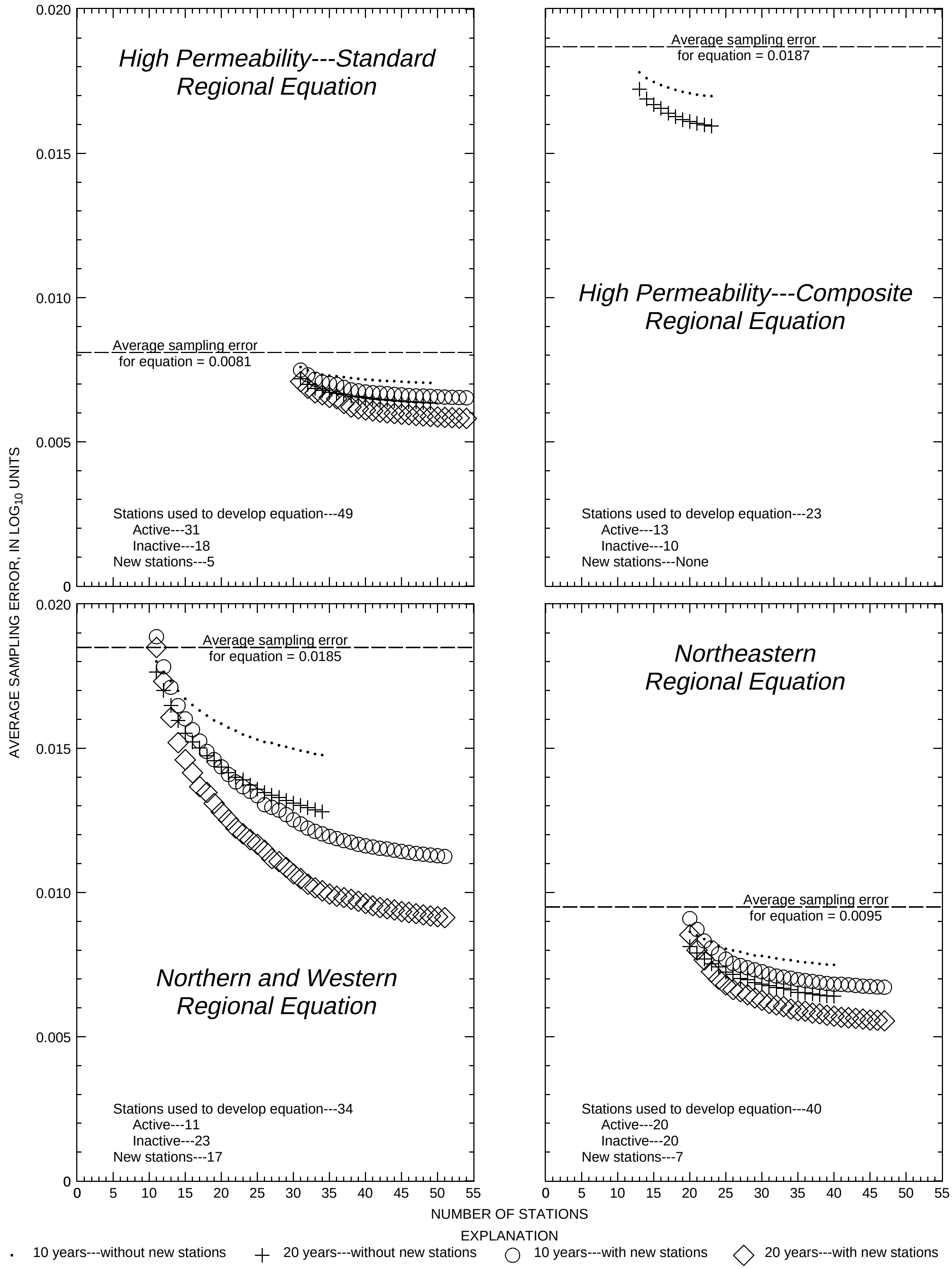


Figure 17. Results of network analyses for 10- and 20-year planning horizons for High-Permeability—Standard, High Permeability—Composite, Northern and Western, and Northeastern regional 100-year peak-flow-frequency equations.

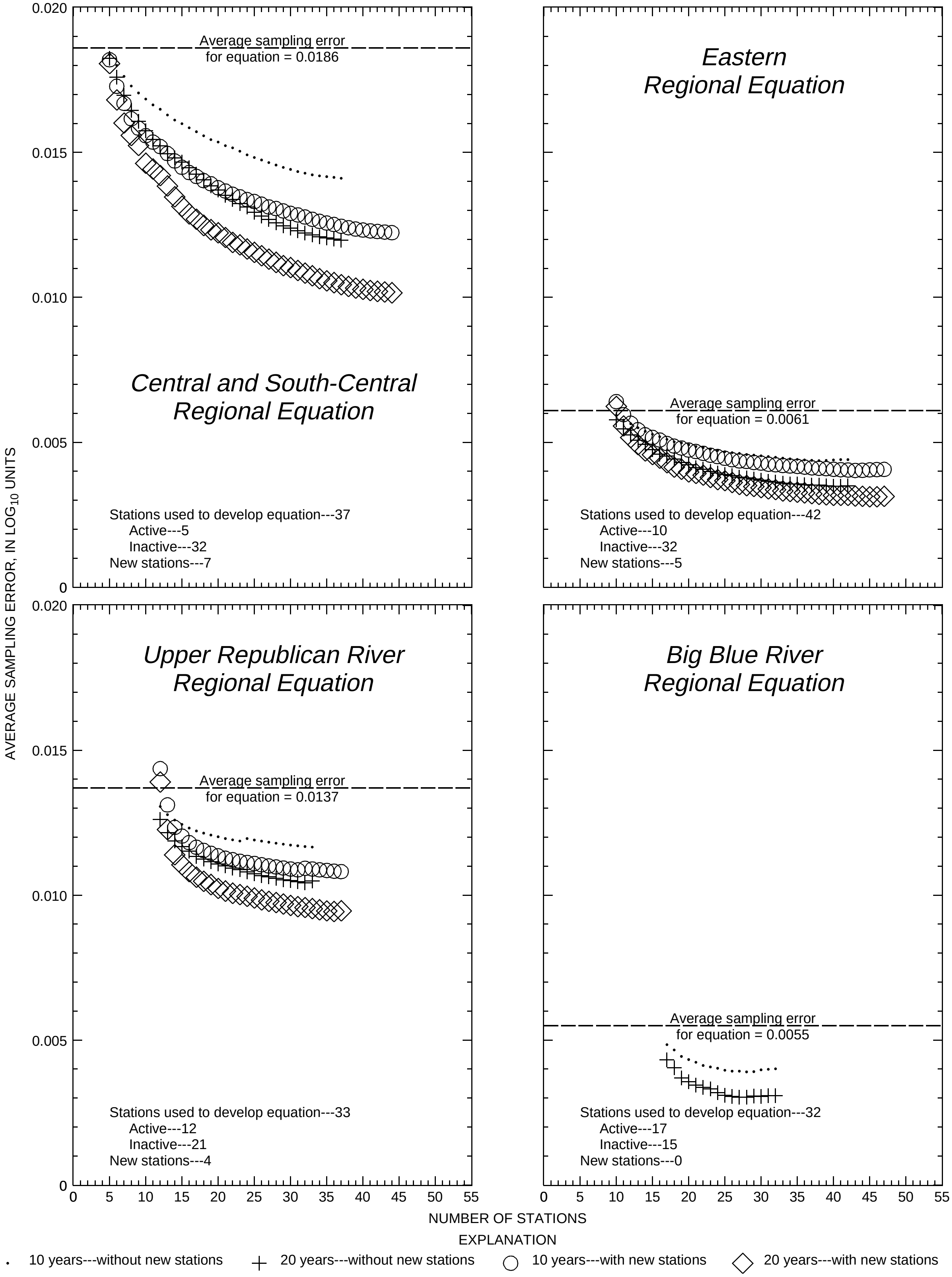


Figure 18. Results of network analyses for 10- and 20-year planning horizons for Central and South-Central, Eastern, Upper Republican River, and Big Blue River regional 100-year peak-flow-frequency equations.

Discussion of Results

For each of the plots (figs. 17 and 18), the point associated with the smallest number of stations represents the ASE with only the active or base-network stations being operated for the various scenarios. The second point represents the ASE with one discretionary station being operated, the one that most reduces the ASE for that scenario. The effect of that station is actually the difference in ASE of the two points. The points associated with the largest number of stations for each plot represent the ASEs with all discretionary stations being operated for the various scenarios. For scenarios with “new” stations, the first stations included after the base-network stations were, in all cases, the “new” stations.The results illustrate that collecting data at “new” stations in a region probably would reduce the ASE for that region’s peak-flow equations more than would collecting the same amount of data at stations that are inactive but that were used in the development of the regional equation.

Note that the ASEs for the active stations only are not the same for scenarios with and without “new” stations, even for the same planning horizon. In most cases, the ASEs actually are larger for the scenarios with “new” stations. This is because NET covers the entire range of basin characteristics, including those of the possible “new” stations, even before the assumed benefits of data from those “new” stations have been incorporated into the analysis. The updated equations would be applicable over a broader range of characteristics than the existing equations, but the ASE could be larger until data actually were available from those stations that had broadened the range of the characteristics.

Based on the plots, it appears that the Northern and Western, and Central and South-Central regional equations, which have the second and third largest ASEs, would benefit the most from additional discretionary peak-flow data, especially if collected at “new” stations. The High-Permeability—Standard, Eastern, and Big Blue River regional equations probably would benefit the least from additional discretionary peak-flow data. Although not directly apparent from the plots, "new" data that could be provided by additional composite analyses for existing stations probably would be of considerable benefit for the High-Permeability—Composite equation, which had the largest ASE and the smallest number of stations of all the regional equations.

Based on the results, data from new stations, rather than more data from stations used to develop the regional peak-flow frequency equations, probably would most reduce the ASE of the equations.

SUMMARY AND CONCLUSIONS

Estimates of peak-flow magnitude and frequency are required for the efficient design of structures that convey flood flows, such as bridges and culverts, or of structures that occupy floodways, such as roads. In the fall of 1994, a cooperative study was begun by the Nebraska Department of Roads and the U.S. Geological Survey (USGS) to update peak-flow frequency analyses for selected streamflow-gaging stations, develop a new set of peak-flow frequency relations for ungaged streams, and evaluate the peak-flow gaging-station network for Nebraska. Using a geographic information system (GIS) and digital spatial data, drainage-basin characteristics—many of which were previously undefined for Nebraska—were quantified. Regional equations relating drainage-basin characteristics to peak-flow frequency characteristics were developed using a generalized least-squares (GLS) regression program. An evaluation of each of the regional gaging-station networks also was made to estimate how additional peak-flow data might reduce average sampling errors (ASEs) of future equations.

Twenty-seven morphometric characteristics were quantified using Basinsoft, a computer program developed by the USGS. Four soil characteristics were quantified using ARC/INFO. Two precipitation characteristics were quantified using ARC/INFO. Manual measurements and calculations were made to verify computer-quantified values for selected drainage basins.

Peak-flow frequency analyses were done for unregulated streamflow-gaging stations with at least 10 years of annual peak-flow record through 1993 and located in or within about 50 miles of Nebraska using the log-Pearson Type III (LP3) frequency distribution and the guidelines in Bulletin 17B of the Interagency Advisory Committee on Water Data. Two sets of standard analyses were made. The first set of standard analyses for unregulated streams was done using skew coefficients derived only from each station’s peak-flow data. These station skews then were used to develop generalized skew relations. The second set of standard analyses was done using station skews weighted with generalized skews from the new skew relations. One set of standard analyses, using station skews only, was done for stations on regulated streams. Adjustments were made to peak-flow frequency analyses, as appropriate, for historic data and high and low outliers. Experience of the authors showed that the statistical tests for low outliers included in Bulletin 17B were not well suited for detecting multiple outliers. Therefore, adaptations of the existing procedure, other tests, and considerable judgment were used to identify and censor low outliers in these situations.

Regional equations relating generalized skew coefficients to basin characteristics were developed for most of the state, and a statewide map of generalized skew coefficients for basins with relatively low average permeability also was developed. Station skew coefficients were computed for stations in or within about 50 miles of Nebraska that, generally, had 25 years or more of unregulated peak flows. Several stations with as few as 18 peak flows were used where data were lacking. After other adjustments had been made, stations with identified high outliers were analyzed further to estimate how sensitive the station skew coefficients were to the high outliers. As a result, some stations were eliminated from further consideration in the development of skew relations.

An equation to estimate skew was developed first for basins with average permeability of the 60-inch soil profile (*P60*) of more than 2.5 inches per hour. A skew map of the state then was developed for basins with *P60* less than 4 inches per hour, except for the Elkhorn River Basin where all basins were included. Regional equations, based on geographic areas, also were developed; those with mean-square errors (MSEs) less than those for the new skew map were adopted. The standard error of estimate (SEE) of the statewide skew map is 0.24. This compares to 0.78 for the Nebraska part of the National skew map and to 0.59 for the map developed by Cordes (1993), both of which include the high-permeability sandhills areas. SEEs for the skew equations ranged from 0.13 to 0.23. The equations were developed using multiple-regression analyses; residuals from the analyses were used to define regions and to determine the best combination of explanatory variables that were reasonable hydrologically.

An alternative set of peak-flow frequency analyses were computed for selected stations using a conditional probability method suggested by William Kirby (USGS). Peak-flow frequency curves for most of the high-permeability stations appeared to indicate a pattern of different characteristics for the larger peak flows. Because of the relatively high permeabilities and large amounts of noncontributing drainage area in typical sandhills terrain, it was theorized that most of the smaller peak flows primarily were interflow and baseflow and that the larger peak-flows included a significantly greater proportion of surface runoff. Plots of peak flow compared to the 1- or 2-day lag of daily flow for several stations appeared to indicate that the theory was plausible.

Other types of mixed populations in peak-flow data also were apparent, including partially regulated stations and low-permeability stations that were usually from the more arid parts of the state. Composite analyses were done for several of these stations; however, the thorough investigations required to justify and split the data, and actually do composite analyses for all of these other stations were beyond the scope of this study. Instead, peak-flow frequencies for partially regulated sites were computed using only station skews, and low-permeability stations were excluded from the regional analyses of peak-flow frequency.

Peak-flow frequency relations were developed for standard probabilities of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent or for frequencies of 2, 5, 10, 25, 50, 100, 200, and 500 years, respectively. Streamflow-gaging stations with peak flows that are known to have been or that could have been affected to some degree by regulation (flood control, irrigation diversions, power generation, storage detention, or other factors) were excluded from regional peak-flow frequency analyses. Preliminary regional equations were developed and regions were defined using ordinary least squares (OLS) multiple-regression procedures. Final regression equations were developed using a GLS multiple-regression procedure. The GLS procedure adjusts for differences in record lengths, differences in peak-flow variances, and cross-correlations of concurrent peak flows among stations used in the regression analysis.

For unregulated streams, eight sets of regression equations relating drainage-basin characteristics to peak flows for selected frequencies of occurrence were developed for seven regions of the state. Two sets of regional peak-flow frequency equations were developed for a high-permeability region that includes basins with *P60* greater than 4 inches per hour. Six sets of equations were developed for specific geographic areas, usually based on drainage-basin boundaries. Of the two sets of high-permeability equations, one set was developed using data from standard frequency analyses and the other was developed using data from composite frequency analyses. In general, these two sets of equations are for drainage basins with sandhills-type terrain. The six hydrologic regions based on geography were delineated using residual values and plots from preliminary regression analyses. There is overlap between several of the regions where more than one equation can be used to estimate peak flows.

Tables for each region include the equations, the SEE in $\log_{10}$ units and in percent, the average standard error of prediction (SEP) in $\log_{10}$ units, the average equivalent years of record for each equation, and the applicable range of the explanatory variables used to develop the equations. SEEs for the 100-year recurrence interval equations ranged from 12.1 to 63.8 percent.

For streamflow-gaging stations on regulated streams in Nebraska with at least 10 years of regulated peak flows, peak-flow frequency analyses were done using the LP3 distribution and the guidelines in Bulletin 17B of the Interagency Advisory Committee on Water Data. Skew coefficients used were those derived only from each station's peak-flow data. Peak-flow records within the period of the current regulated condition were used for the station analyses. For nine streams that included more than one station with at least 25 years of regulated record, graphs of peak-flow frequency and distance upstream of the mouth were estimated. Log-linear graphs were developed for the Niobrara, North Platte, South Platte, Platte, and Republican Rivers, and for Salt, Antelope, Frenchman, and Red Willow Creeks.

For the regional peak-flow frequency equations for unregulated streams, statistical analyses were done to estimate how additional years of peak-flow data might affect the ASEs of the equations for the 100-year frequency of occurrence. For each regional equation, analyses were done for four different scenarios—10 and 20 years of additional record from the stations used to develop the equation; and 10 and 20 years of additional record from new stations as well as from the stations used to develop the equation.

Various scenarios and regions can be compared to determine where the greatest overall benefits might be gained for the least amount of new data and hence for the least cost. For each scenario, plots of ASE and number of stations in the network were presented. Based on the results, data from new stations, rather than more data from stations used to develop the regional peak-flow frequency equations, probably would most reduce the ASE of the equations.

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