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By W. R. OSTERKAMP *and* E. R. HEDMAN

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

The International System (SI) of Units is used in this report, although approximate conversions to inch-pound units are provided where practical. The coefficients of all power-function equations provided here are calculated from data expressed in SI units; conversions using inch-pound units are given in table 10. SI units used in this report may be expressed as inch-pound units by use of the following conversion factors:

To convert SI units	*Multiply by*	*To obtain inch-pound units*
millimeter (mm)	0.0394	inch (in)
meter (m)	3.28	foot (ft)
kilometer (km)	0.622	mile (mi)
cubic meter per second (m^3/s)	35.3	cubic foot per second (ft^3/s)

PERENNIAL-STREAMFLOW CHARACTERISTICS RELATED TO CHANNEL GEOMETRY AND SEDIMENT IN MISSOURI RIVER BASIN

By W. R. Osterkamp and E. R. Hedman

ABSTRACT

Geometry, channel-sediment, and discharge data were collected and compiled from 252 streamflow-gaging stations in the Missouri River basin. The stations, with several exceptions, have at least 20 years of streamflow records and represent the complete ranges of hydrologic and geologic conditions found in the basin. The data were analyzed by computer to yield simple and multiple power-function equations relating various discharge characteristics to variables of channel geometry and bed and bank material. The equations provide discharge as the dependent variable for the purpose of making estimates of discharge characteristics at ungaged sites.

Results show that channel width is best related to variables of discharge, but that significant improvement, or reduction of the standard errors of estimate, can be achieved by considering channel-sediment properties, channel gradient, and discharge variability. The channel-material variables do not have uniform effects on width-discharge relations and, therefore, are considered as sediment-data groups, or stream types, rather than as terms in multiple power-function equations.

Relative to streamflow, narrowest channels occur when streams of steady discharge transport sufficient silt and clay to form stable, cohesive banks but have a small bed-material load of sand and coarser sizes. Stable channels also are associated with relatively large channel gradients, relatively large channel roughness, and armoring of bed and bank by coarse particle sizes. The widest, most unstable channels are ones that apparently transport a large bed-material load of sand sizes. The downstream rates of change of width with discharge reflect these trends, indicating that a given bed-material load necessitates a minimum width for movement of tractive material.

Comparisons of standard errors of estimate given here with similar results from regional studies are variable. It is assumed, however, that a benefit of this study is that the use of the equations is not limited to the Missouri River basin. Besides the principal utility of estimating discharge characteristics of ungaged streams, the equations given here can be used for the design of artificial channels and can be used as a basis of predicting channel changes resulting from upstream alterations of the basin or channel.

INTRODUCTION

Numerous studies have related the geometry of alluvial stream channels to the amount and variation of discharge, sediment characteristics, climate and vegetation, and various basin characteristics. In recent years, a practical result of these studies has been the use of channel-geometry measurements to estimate the discharge characteristics of ungaged streams. By correlating variables of channel size and shape to specified flows at gaged sites, the relations, generally expressed as power-function equations, can provide estimates of discharge for the same recurrence frequencies at ungaged sites. Because a value of streamflow is determined, discharge is treated as the dependent variable. Therefore, the channel-geometry technique is the use of channel measurements as an indirect means of evaluating streamflow characteristics at a site.

The channel-geometry technique differs from that of hydraulic geometry by relying on measurements taken from an identifiable geomorphic reference point or level in the channel section rather than from the water surface. The size and shape of the channel cross section are assumed to be the integrated resultant of all discharges, water and sediment, conveyed by that channel (Pickup and Rieger, 1979, p. 41; Osterkamp, 1979a, p. 2). Because it is based on channel rather than basin characteristics, the technique provides discharge estimates more closely related to the measured variables than do many of the older indirect techniques of estimating discharge. Most of these older methods use either drainage area, precipitation, and other basin characteristics as a means of evaluating discharge, or they rely on correlation methods of transferring data from gaged sites to ungaged sites in contiguous or nearby basins.

PURPOSE AND SCOPE

Most published channel-geometry equations relate discharge to width or to width and depth. This study was initiated with the recognition that width-discharge relations vary significantly with channel-sediment properties (that is, the size characteristics of material forming the channel perimeter). Thus, numerical consideration of the sediment characteristics offers a means of refining the channel-geometry technique, as well as contributing to the understanding of fluvial processes. The purposes of the study were to: (1) evaluate which, if any, characteristics of channel sediment significantly affect channel morphology, (2) describe these effects quantitatively, thereby providing equations useful for discharge estimates, (3) gain further understanding of the processes that form and continually alter the shape of perennial stream channels, and (4) provide a basis for anticipating the results of natural or imposed upstream changes in the variables that determine channel size and shape.

The hydrologic, geometry, and sediment data (see "Supplemental Information," tables 8, 9) on which this paper is based were collected at or near 252 streamflow-gaging stations in the Missouri River basin. The various gaging sites and drainage basins are representative of the wide range of hydrologic, geologic, topographic, and climatic conditions found in the Missouri River basin. The data were collected primarily at perennial streams, but several of the small channels have intermittent streamflow. Most of the streams have unregulated discharge; many of the relatively large streams, however, are partly regulated by one or more upstream reservoirs.

PREVIOUS INVESTIGATIONS

Relative to the numerous alluvial stream channels of the United States and elsewhere, streamflow-gaging stations provide current and historical discharge information on a small part of those channels from which such information is desirable. The increasing demand for current, inexpensive hydrologic information led to the development of the various indirect methods for estimating discharge characteristics from ungaged basins. The earlier methods relied on precipitation records and comparisons of streamflow and basin-characteristic data from nearby basins and generally were applied to relatively humid regions. In those areas, variations in precipitation and runoff are less significant than in arid areas (Riggs, 1978). Because the channel-geometry method relies only on channel properties, its use is less restricted by climate and other basin variables than the earlier indirect methods.

Among the early papers dealing with the effect of discharge on channel shape were articles on regime theory (no net erosion or deposition) by Kennedy (1895) and Lacey (1930). Though not the first to apply the dynamic-equilibrium concept to rivers, Leopold and Maddock (1953) published the first widely accepted benchmark paper of the relations between perennial discharge and channel properties. They established power-function equations between mean discharge and stream width, mean water depth, and mean velocity. For practical purposes, a shortcoming of the study by Leopold and Maddock (1953), and of several subsequent papers, was that a relatively permanent, observable datum from which channel width and depth could be measured was not used. Instead, measurements were related to the level of the water surface at mean discharge. Hence, the technique was termed hydraulic geometry. A study of the Brandywine Creek drainage by Wolman (1955) reduced the problem by the use of measurements determined for bankfull stage (fig. 1), a readily observable feature in that drainage basin. Other hydrologists in England and Wales (Nixon, 1959), central Pennsylvania (Brush, 1961), Illinois (Stall and Fok, 1968), Alaska (Emmett, 1972), and elsewhere made similar measurements at bankfull stage. Other workers have used reference levels for channel measurements taken at the top of the "main channel" (Riggs, 1974; Lowham, 1976) or "whole channel" (Riggs and Harenberg, 1976); these levels were defined similarly to and are virtually coincident with the bankfull stage.

From 1953 to recent years, a variety of hydraulic-geometry studies resulted in numerous power functions relating width with variables of discharge for the "downstream" case (Leopold and Maddock, 1953). In 1966, at the suggestion of W. B. Langbein, attention within the U.S. Geological Survey was turned to in-

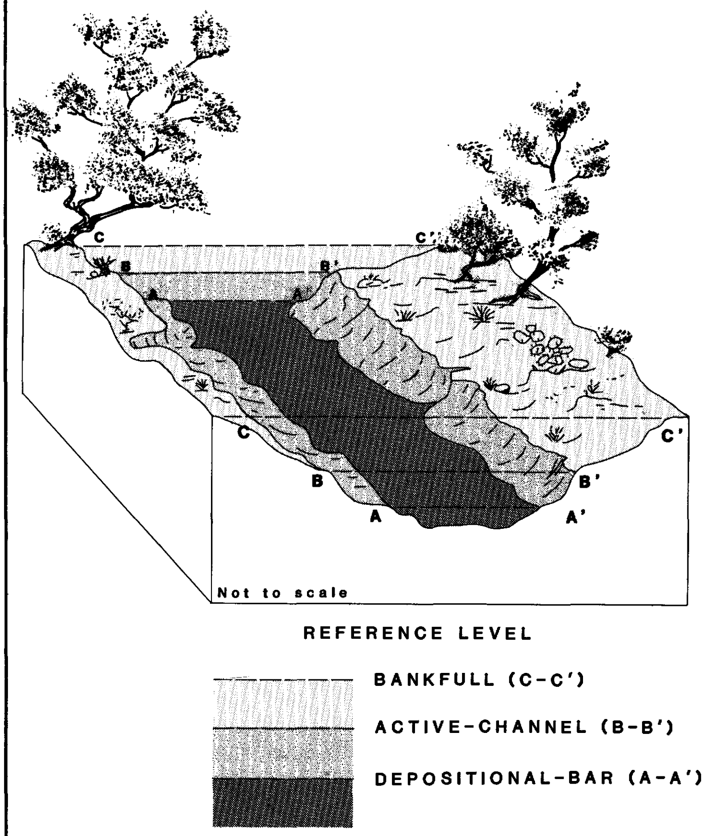


FIGURE 1.—Commonly used reference levels.

channel reference levels for discharge-geometry correlations. Langbein recognized that active, short-term geomorphic features might be identifiable in all alluvial stream channels and that they are indicative of recent (decades or less) rather than historic stream dynamics. The suggestion was advanced as a possible means of estimating flow characteristics of ungaged basins; the intent was to determine discharge from channel characteristics. The first paper using this suggestion was by Moore (1968), who estimated mean runoff from Nevada basins on the basis of channel width and mean depth measured from the top edge of in-channel, or depositional, bars (fig. 1, A–A'). The bars were regarded as the highest channel features shaped by annual bed-material movement and the lowest prominent bed forms. The same technique was used in California by Hedman (1970); in western Georgia, U.S.S.R., by Kopaliani and Romashein (1970); in Kansas by Hedman and Kastner (1972); in Colorado by Hedman, Moore, and Livingston (1972); in New England by DeWalle and Rango (1972); and throughout the Missouri River basin by Hedman and Kastner (1977).

Experience has shown, however, that measurements based on bar geometry are subject to the same problem as is the bankfull stage method of Wolman (1955) the lack of a universally recognizable datum. Many slow-moving streams, for example, that have a well-defined bankfull stage (flood plain) do not exhibit bar geometry. In addition, deposition of material forming in-channel bars occurs principally during recession of relatively large discharges. Thus, a spurious relation is possible between bar geometry and all discharge rates exceeding that required for movement of point-bar material. An alternative in-channel reference level, therefore, was proposed by Hedman, Kastner, and Hejl (1974), the active channel. This feature (fig. 1, B–B') is described by Osterkamp and Hedman (1977, p. 256) as

> ***a short-term geomorphic feature subject to change by prevailing discharges. The upper limit is defined by a break in the relatively steep bank slope of the active channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with the lower limit of permanent vegetation so that the two features, individually or in combination, define the active channel reference level. The section beneath the reference level is that portion of the stream entrenchment in which the channel is actively, if not totally, sculptured by the normal process of water and sediment discharge.

Recent studies that used the active-channel reference level, or a similarly defined level, include those of Scott and Kunkler (1976), Hedman and Kastner (1977), and Osterkamp (1977, 1979a).

Except for a large number of papers concerning the hydraulics of sediment transport and the behavior of various sediment types in laboratory flumes, literature relating sediment characteristics to properties of channel morphology is much less extensive than for that of streamflow characteristics. Among the papers that have considered the effect of sediment on channel morphology are those of Schumm (1960a, b, 1963, 1968). These papers related a weighted mean percentage of bed and bank silt-clay to width-depth ratios of alluvial channels, but the papers did not consider discharge directly. The final study of this sequence (Schumm, 1968) provided a basis of prediction of the changes in morphology that might occur as a result of a significant change in the regimen of sediment transport of a stream, whether natural or induced. Combining the channel-geometry techniques of Hedman, Kastner, and Hejl (1974) with the use of channel silt-clay content (Schumm, 1960b), Osterkamp (1977) developed simple and multiple power-function equations relating mean discharge to channel width and sediment characteristics of Kansas streams. The equations assumed that mean discharge exerts a fixed effect on channel width that is modified by other variables, particularly the particle sizes of channel material. The relations described herein evolved from techniques developed during the study of perennial stream of Kansas.

DATA COLLECTION AND ANALYSIS

Sites at or near streamflow-gaging stations where channel-geometry and channel-sediment data were collected for this study are shown in figure 2. The site numbers in figure 2 refer to lists of the discharge (table 8) and channel-properties (table 9) data from which the power-function equations were developed.

ONSITE PROCEDURES

Measurement and sampling procedures at channel-geometry sites were developed using several basic assumptions. Among these are that: (1) A channel section generally is narrowing toward a minimum width corresponding to the recent discharge characteristics of the stream; (2) a section below the active-channel reference level can be recognized at all sites and is indicative of those discharge characteristics; (3) the sediment load of a stream, both suspended and bed material, has a quantitative effect on geometry-discharge relations; and (4) the particle sizes of bank material are indicative of the suspended sediment, whereas the bed material is indicative of the traction-force load. Thus, the principal data collected at each gage were those of geometry and of the variables inferred to be most closely related to the geometry—characteristics of

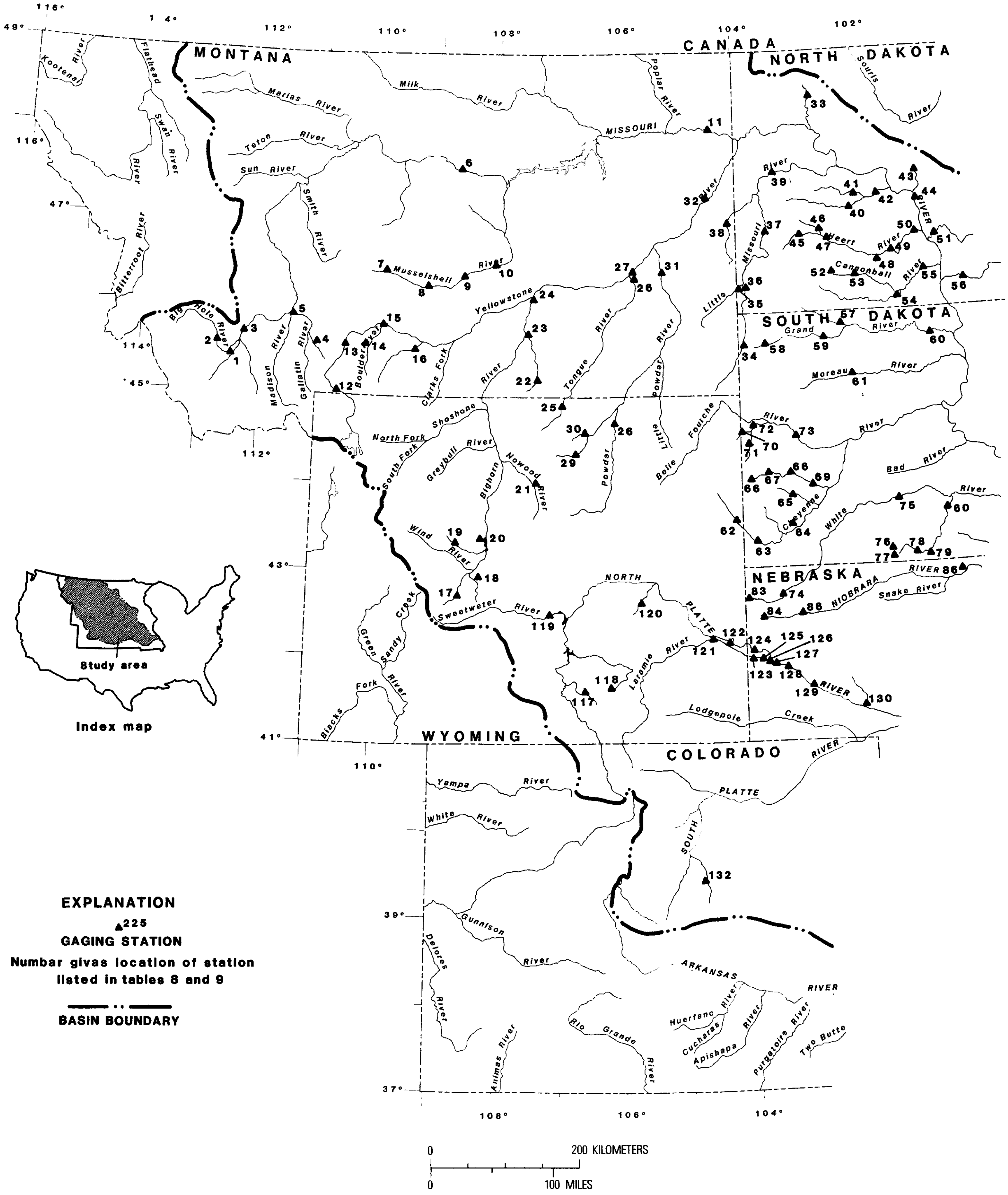
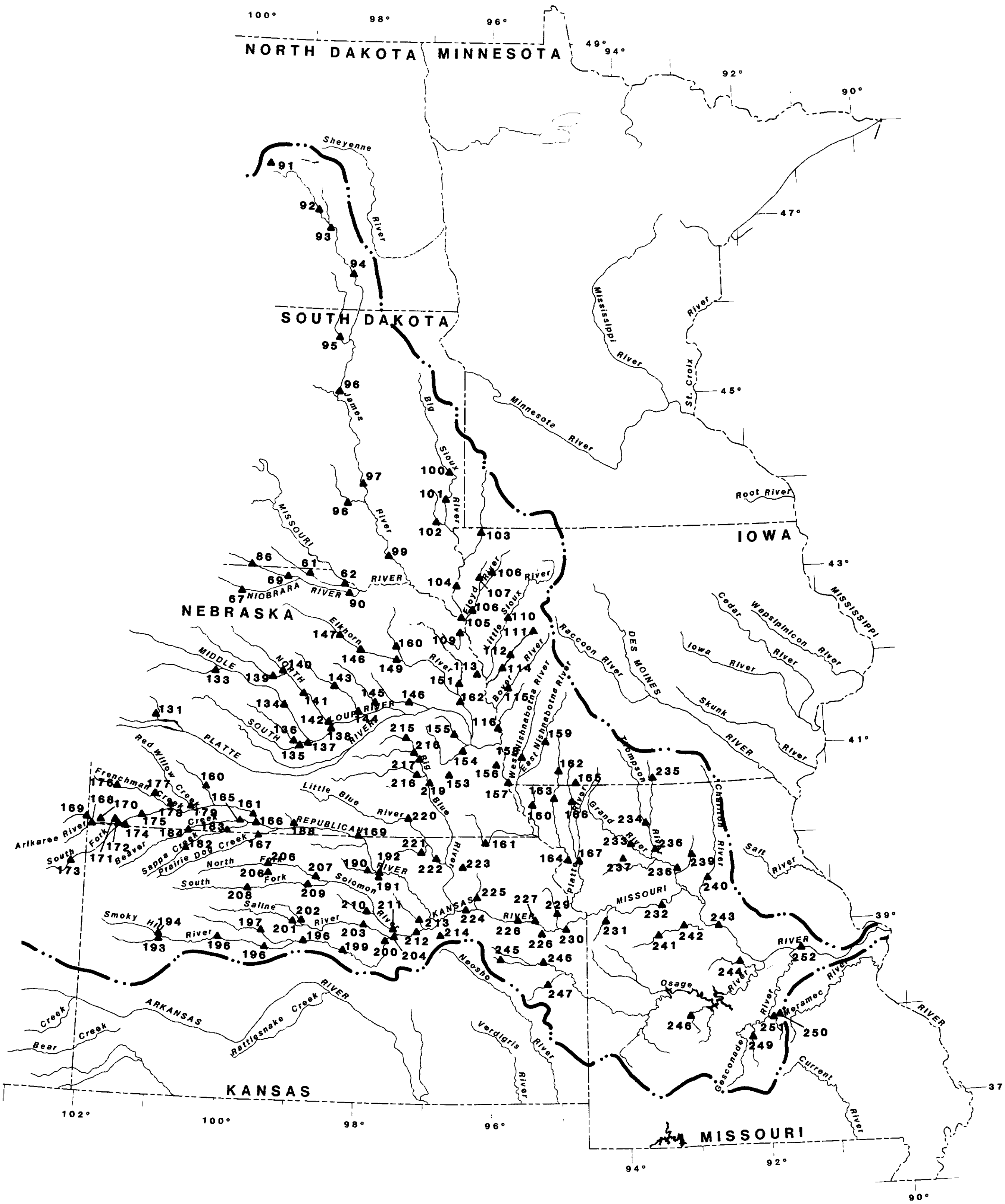


FIGURE 2 (above and facing pages).— Location of measurement and sampling sites.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Big Sioux River
Minnesota River
Mississippi River
St. Croix River
Root River
MISSOURI RIVER
NIOBRARA RIVER
Elkhorn River
Floyd River
Little Sioux River
Boyer River
West Nishnabotna River
East Nishnabotna River
Raccoon River
DES MOINES RIVER
Cedar River
Wapsipinicon River
Iowa River
Skunk River
MISSISSIPPI RIVER
MIDDLE LOUP
NORTH LOUP
SOUTH LOUP
LOUP RIVER
PLATTE
Red Willow Creek
Frenchman Creek
Arikaree River
South Fork
Beaver Creek
Sappa Creek
Prairie Dog Creek
REPUBLICAN RIVER
Little Blue River
Big Blue River
North Fork
South Fork
Solomon River
Saline River
Smoky Hill River
KANSAS RIVER
Neosho River
Verdigris River
ARKANSAS RIVER
Rattlesnake Creek
Creek
Bear Creek
Thompson River
Grand River
Chariton River
Platte River
Salt River
Osage River
Gasconade River
Meramec River
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water and sediment discharge. Other variables affecting the width-discharge relations that were not directly considered in this study include discharge variability (including the effects of streamflow regulation), climate and riparian vegetation, and other upstream channel or basin changes resulting from water-use and land-use activities.

In all instances, geometry and bed-and-bank data were collected at or near gage sites where discharge data were available. To the extent practical, measurements were made in a generally straight reach where flow velocities were relatively uniform across the channel width. If a stream had pool-riffle sequences, a site normally was selected a short distance upstream or downstream from a riffle. Sites were avoided if bedrock was apparent in the channel bed, if bank instability occurred in or directly above the active-channel section, or if there was local evidence of recent scour or deposition. Channel reaches altered by riprap or other types of natural or unnatural linings or obstructions were avoided, as were reaches where bank surfaces were erosional rather than depositional.

At each site, width and mean-depth measurements were made from the active-channel reference level (fig. 1, B–B'). Integrated or composite sediment samples were obtained by collecting sediment at equally spaced intervals across the channel bed and up each bank. Thus, three separate composite samples, representing the bed and each bank, were collected at each measurement site. If the channel material was mostly gravel or coarser sizes, in situ pebble-count techniques or other suitable methods were used to describe the bed-and-bank material (Wolman, 1954). For all sites, care was taken not to sample those parts of the channel transitional between bed and banks; thereby, contamination of samples by material from other parts of the channel section largely was avoided. In general, sites were selected to insure that the bed samples were typical of bed-material movement during periods of normal discharge rates and that the bank samples were representative of material taken from suspension. Specific procedures for channel measurement and sampling are given by Osterkamp (1979b).

LABORATORY TECHNIQUES AND DATA ANALYSIS

Discharge data (table 8) were compiled from the records of the various gage sites. All discharge data were computed using established techniques of the U.S. Geological Survey. Values for the discharge characteristics (table 8) are based on a minimum of 20 years of continuous steamflow records, although several exceptions were made in order to expand the ranges of stream size and geographic coverage.

A standard particle-size analysis (dry sieve, VA tube, and wet sieve) was made of each of the three sediment samples from each site (Guy, 1969). Summary results of the analyses are listed in table 9 as the median particle sizes and the silt-clay percentages of the bed-material samples and as the values of the silt-clay percentages for the two bank-material samples. Channel gradients (table 9) were computed from 7½-minute topographic maps. Except where significant tributary inflow or diversion was apparent near a gage, the gradient measurements were centered at or near the gaging stations. For large streams, the calculated gradient represents a reach of as much as 20 km (12 mi) in length, whereas reaches as short as 1.0 km (0.62 mi) were used to calculate the gradient of small streams.

Most equations given in this report are simple or multiple power functions of the form:

$$Q_v = aW^b, \tag{1}$$

or

$$Q_v = aW^bG^c, \tag{2}$$

where Q_v is a discharge characteristic (such as a flood discharge with a 2-year recurrence interval); a is a coefficient; W and G, respectively, are channel width and gradient; and b and c are exponents. The equations were developed by use of a stepwise regression program (BMD02R) from the Biomedical Computer Programs of the School of Medicine, University of California (Dixon, 1965). The program forms a sequence of linear regression equations in a stepwise manner. In the first step, a simple relation is defined with the independent variable that most effectively explains the site-to-site variation of a selected flow characteristic. In each subsequent step, one variable is added to the equation.

For those computer analyses yielding simple-regression (power-function) equations (one independent variable), the program was modified to convert the result to a structural analysis (Mark and Church, 1977; Osterkamp, McNellis, and Jordan, 1978). This statistical technique distributes error to both the dependent and independent variables. The closely related technique of least-squares regression differs by ascribing all error to the independent variable. Because errors must be assumed for all the variables considered in this study, structural analysis is considered the better method of developing simple power-function equations. The two techniques, however, when applied to groups of data presented here, provide results that do not differ markedly.

The standard errors of estimate (SE), the correlation coefficient (R), and the *F*-ratios are provided as output of program BMD02R. The standard error of estimate of a regression or structural analysis is a measure of the deviation or scatter of the dependent variable about the linear relation; the correlation coefficient is an indicator of data scatter relative to the range of the data. The *F*-ratio is the ratio of the explained to unexplained variance in the dependent variable. The level of significance can be determined from the *F*-ratio and the numbers of cases and variables. The levels of significance provided in tables of this report are given as decimal fractions, expressing the likelihood that the observed *F*-ratio has occurred by chance. Thus, a significance level of 0.01 indicates that the probability of the observed relation occurring randomly is no greater than 1 percent.

RESULTS

Previous studies (Schumm, 1960a, b, 1968; Hedman and Kastner, 1977; Osterkamp and Hedman, 1977; Osterkamp, 1977, 1979a) provided evidence that channel-sediment characteristics have a measureable effect on geometry-discharge relations. The initial computer analyses of this study, therefore, were designed to identify geometry and sediment variables that effectively provide a basis for defining stream-channel types from the entire data set (tables 8, 9). These preliminary analyses produced the following deductions:

1. Except for some braided streams, the size distribution of fluvial sediment generally has a greater effect on channel morphology than does sediment discharge.
2. Multiple power-function equations need to be used cautiously because the effects of complicating variables on width-discharge relations generally are not linear.
3. Because channel shape is partly the result of the sediment sizes transported by a stream, indiscriminate use of geometry and channel-material variables in multiple power-function equations results in redundency.
4. Variables other than channel sediment, such as discharge variability and riparian vegetation, have significant effects on geometry-discharge relations and, therefore, account for part of the observed standard errors of estimate.

The principal purpose of the relations given in this paper is to provide rapidly calculated estimates of discharge characteristics. Therefore, the stream classes or groups used here were defined to include the range of sediment conditions normally found in natural alluvial channels, and the equations developed for the groups require only data that are quickly and easily measured or estimated.

COMPUTER ANALYSES

The 252 sites in the Missouri River basin at which data were collected (fig. 2; tables 8, 9) were selected using criteria previously discussed. Criteria for site selection were not imposed rigidly, however, but were relaxed in some cases to extend the range of data. Accordingly, the data used for this paper include very small channels with less than 20 years of streamflow records and some large streams (particularly the Missouri River), which are partly regulated and may be affected by nearby channel modifications or stabilization structures. It is assumed that the use of these data, however, increases the confidence that can be placed in the resulting power functions, although they increase the standard errors of estimate.

Mean discharges (table 8) of the data used in the computer analyses range from 0.00402 to 2,260 m^3/s (0.142–79,800 ft^3/s), and measured active-channel widths range from 0.762 to 430 m (2.50–1,410 ft). These ranges comprise about 5.75 log cycles for mean discharges and 2.75 log cycles for active-channel widths. Similarly, the channel-material characteristics of streams sampled in the Missouri River basin range from those having as much as 92 percent silt and clay in the bed material to alpine streams with median particle sizes as great as 250 mm (9.8 in.). Measured gradients range from 0.000060 to 0.028 (nondimensional), or about 2.7 log cycles.

No attempt was made to quantify and consider the effects of riparian and channel vegetation as independent variables, although qualitative evidence indicates that changes in riparian vegetation, in particular, can have a pronounced effect on width-discharge relations. Discharge variability also is known to have substantial effects on channel morphology (Schumm and Lichty, 1963; Burkham, 1972; Osterkamp, 1978, p. 1267). Limited attention is given to discharge variability here, however, because normally it is a variable that cannot be measured or estimated well at ungaged sites.

Previous investigations and the preliminary computer analyses led to the classification of channels into seven groups according to channel-sediment properties for further analysis. The sediment properties on which the groups are based (silt-clay content and median particle size of the bed material, and silt-clay content of the bank material) led to simple power-function equa-

TABLE 1.—*Descriptions of data groups based on channel material*

[Channel types used for identification purposes are not intended to be descriptive of the stream types. SC_{bd} is silt-clay content of bed material in percent, SC_{bk} is the higher silt-clay content, in percent, of the two bank-material samples; and d_{50} is the diameter size of particles, in millimeters, for which equal parts of the sample are of greater or smaller weight]

Channel types	No. of sampling sites	Channel-sediment characteristics		
High silt-clay bed . . .	15	$SC_{bd}=61-100$		$d_{50}<2.0$
Medium silt-clay bed	17	$SC_{bd}=31-60$		$d_{50}<2.0$
Low silt-clay bed . . .	30	$SC_{bd}=11-30$		$d_{50}<2.0$
Sand bed, silt banks	33	$SC_{bd}=1-10$	$SC_{bk}=70-100$	$d_{50}<2.0$
Sand bed, sand banks	96	$SC_{bd}=1-10$	$SC_{bk}=1-69$	$d_{50}<2.0$
Gravel bed	42			$d_{50}=2.0\text{-}64$
Cobble bed	19			$d_{50}>64$

tions relating width to discharge for the entire ranges of each group. The sediment properties are not expressed as independent variables of a multiple power-function equation because such a relation would necessarily be either too complex for general use or would be oversimplified and inaccurate.

Specifically, none of the three channel-sediment properties on which the channel types are defined (table 1) have a linear or even consistent effect on width-discharge relations. Relative to discharge, active-channel width increases with increasing sandiness (decreasing silt-clay content) because the cohesiveness afforded by the silt and clay produces relatively stable banks not easily eroded by floods. If a significant amount of fine material is present in the bed material, cohesive banks are virtually assured. If, however, the bed material is largely sand, the silt and clay (taken from suspension) in the banks can be correlated with width-discharge relations.

For streams of similar discharge characteristics, minimum channel widths generally occur if the median particle size of the bed material is very small (high silt-clay content). Width tends to increase with increasing median particle size, reaching a maximum when the bed material is well-sorted, medium- to coarse-grained sand (Osterkamp, 1977). For median particle sizes increasingly greater than about 2 mm (0.08 in.), the course fraction of the bed material provides an armoring or stabilizing effect similar to that provided by the cohesiveness of silt and clay. The result is narrower, more stable channels than those that have sand beds. The effects of particle-size ranges are considered indirectly because the channel types (table 1) are defined in terms of both silt-clay content and median particle size.

Equations relating discharge characteristics to active-channel width for the seven channel types (table 1) are listed in table 2. Casual inspection of the equations for mean discharge shows that, for channels of similar width, the greatest mean discharges occur in channels of fine-grained bed-and-bank material. As the sandiness of the channel material increases, the mean discharges decrease to the extent that the predicted mean discharge of a sand-bed, sand-banks channel 20 m (66 ft) in width is only 21 percent of the predicted discharge for a high silt-clay bed channel of similar width. As median particle sizes, and the resulting armored effect, increase from about 2 mm (0.08 in.), the trend is

TABLE 2.—*Width-discharge relations for channels of specified sediment properties*

[SC_{bd} is silt-clay percentage of bed material; SC_{bk} is silt-clay percentage of bank material; and d_{50} is median particle size of bed material, in millimeters. $\bar{Q}$ is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; and W is active-channel width, in meters]

Channel type (table 1)	Equation	Standard error of estimate, SE (percent)	Coefficient of correlation, R	Level of significance (from *F*-ratio for width)
High silt-clay bed (SC_{bd}= 61. 100; d_{50}<2.0)	$\bar{Q}=0.031W^{2.12}$	35	0.98	0.001
	$Q_2=2.0W^{1.86}$	52	.94	.001
	$Q_5=5.3W^{1.77}$	54	.93	.001
	$Q_{10}=8.1W^{1.74}$	57	.92	.001
	$Q_{25}=13W^{1.71}$	62	.90	.001
	$Q_{50}=16W^{1.71}$	65	.89	.001
	$Q_{100}=19W^{1.74}$	69	.88	.001

TABLE 2.—*Width-discharge relations for channels of specified sediment properties*—Continued

Channel type (table 1)	Equation	Standard error of estimate, SE (percent)	Coefficient of correlation, R	Level of significance (from *F*-ratio for width)
Med. silt-clay bed (SC_{bd}= 31.60; d_{50}<2.0)	$\overline{Q}=0.033W^{1.76}$	56	0.92	0.001
	$Q_2=2.6W^{1.27}$	118	.63	.01
	$Q_5=7.2W^{1.16}$	105	.63	.01
	$Q_{10}=18W^{1.08}$	103	.61	.01
	$Q_{25}=22W^{1.05}$	100	.58	.025
	$Q_{50}=31W^{0.99}$	99	.56	.025
	$Q_{100}=36W^{1.02}$	98	.54	.025
Low silt-clay bed (SC_{bd}= 11.30; d_{50}<2.0)	$\overline{Q}=0.031W^{1.73}$	83	0.91	0.001
	$Q_2=2.8W^{1.25}$	107	.77	.001
	$Q_5=9.0W^{1.11}$	102	.74	.001
	$Q_{10}=16W^{1.05}$	99	.73	.001
	$Q_{25}=30W^{0.97}$	98	.71	.001
	$Q_{50}=43W^{0.93}$	97	.69	.001
	$Q_{100}=55W^{0.93}$	97	.67	.001
Sand bed, silt	$\overline{Q}=0.027W^{1.69}$	57	0.95	0.001
banks, ($SC_{bd}\leqslant$	$Q_2=3.3W^{1.16}$	47	.93	.001
10; SC_{bk}=	$Q_5=9.3W^{1.07}$	46	.92	.001
70.100;	$Q_{10}=16W^{1.02}$	45	.91	.001
d_{50}<2.0)	$Q_{25}=29W^{0.96}$	46	.90	.001
	$Q_{50}=40W^{0.93}$	49	.87	.001
	$Q_{100}=51W^{0.92}$	53	.85	.001
Sand bed sand	$\overline{Q}=0.029W^{1.62}$	73	0.94	0.001
banks, ($SC_{bd}\leqslant$	$Q_2=0.96W^{1.32}$	107	.85	.001
10; SC_{bk}<	$Q_5=2.4W^{1.26}$	124	.80	.001
70;	$Q_{10}=4.1W^{1.21}$	132	.78	.001
d_{50}<2.0)	$Q_{25}=7.5W^{1.15}$	140	.74	.001
	$Q_{50}=11W^{1.12}$	146	.72	.001
	$Q_{100}=14W^{1.12}$	152	.70	.001
Gravel bed (d_{50}= 2.0.64)	$\overline{Q}=0.023W^{1.81}$	54	0.96	0.001
	$Q_2=1.9W^{1.15}$	80	.82	.001
	$Q_5=6.6W^{0.95}$	81	.75	.001
	$Q_{10}=12W^{0.84}$	86	.69	.001
	$Q_{25}=25W^{0.70}$	93	.60	.001
	$Q_{50}=32W^{0.67}$	99	.54	.001
	$Q_{100}=54W^{0.60}$	106	.47	.005
Cobble bed (d_{50}>64)	$\overline{Q}=0.024W^{1.84}$	24	0.99	0.001
	$Q_2=0.82W^{1.43}$	80	.90	.001
	$Q_5=3.1W^{1.16}$	74	.87	.001
	$Q_{10}=6.0W^{1.03}$	72	.85	.001
	$Q_{25}=12W^{0.89}$	74	.80	.001
	$Q_{50}=20W^{0.80}$	81	.74	.001
	$Q_{100}=28W^{0.75}$	91	.66	.005

reversed, and predicted mean discharges increase for channels of similar width. The predicted mean discharge of a 20-m (66-ft) wide channel armored with cobbles and boulders is 60 percent greater than that of the sand-bed, sand-banks channel.

In general, the results in table 2 for a given channel type show increasing coefficients and decreasing exponents as magnitudes and recurrence intervals of the floods increase. The causes of the decreasing exponents are (1) the tendency for increased attenuation of flood discharges in the downstream direction with increase in recurrence interval and (2) the tendency for decreased peak rates of precipitation and runoff, per unit area of a drainage basin, with increasing basin size. In other words, for most alluvial streams, the ratio of the 10-year flood to mean discharge ($Q_{10}/\overline{Q}$) decreases as mean discharge, drainage area, and flood-plain size increase in the downstream direction. For example, a greater rate of decrease generally occurs for the ratio $Q_{50}/\overline{Q}$ than for $Q_{10}/\overline{Q}$. The result is a smaller exponent associated with Q_{50} than with Q_{10}. The relations for each stream type of table 2 are based on differing discharges (mean discharge or flood discharges of specified recurrence interval) but on the same active-channel widths. Thus, the relatively large exponents associated with mean discharges indicate that mean discharge commonly increases at a greater rate in the downstream direction than do, for example, the 50-year floods, which have relatively small associated exponents.

As comparisons to the various channel-type relations of table 2, structural analyses of the discharge characteristics with active-channel width were made for the entire file of 252 data sets (tables 8, 9). The results (table 3) demonstrate the differences that occur when the data are not separated into the sediment-characteristics groups (table 1). The standard errors of estimate for these relations indicate considerable data scatter, particularly for the large flood discharges, and the possibility of large errors if the equations were to be used for predictive purposes. As examples, if very silty bed channels and cobble-bed channels of 20-m (66-ft) width are considered, the discharges predicted by the equation for mean discharge of table 3 are 74 percent (silty bed) and 24 percent (cobble bed) less than those given by the corresponding equations in table 2.

As median particle sizes of bed material decrease from very course to very fine, associated channel gradients also decrease (Lane, 1957; Osterkamp, 1978). The relation is not uniform, however, particularly for sand channels. Therefore, gradient cannot be incorpo-

TABLE 3.—*Width-discharge relations resulting from analysis of all data*

[$\bar{Q}$ is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; and W is active-channel width, in meters.]

Equation	Standard error of estimate, SE (percent)	Coefficient of correlation, R	Level of significance (from *F*-ratio for width)
$\bar{Q}=0.027W^{1.71}$	79	0.93	0.001
$Q_2=1.9W^{1.22}$	109	.81	.001
$Q_5=5.8W^{1.10}$	112	.77	.001
$Q_{10}=9.9W^{1.04}$	116	.74	.001
$Q_{25}=18W^{0.97}$	120	.71	.001
$Q_{50}=25W^{0.94}$	124	.68	.001
$Q_{100}=32W^{0.94}$	129	.66	.001

TABLE 4.—*Width-gradient-discharge relations for channels of specified sediment properties*

[SC_{bd} is silt-clay percentage of bed material; SC_{bk} is silt-clay percentage of bank material; and d_{50} is median particle size of bed material, in millimeters. $\bar{Q}$ is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; W is active-channel width, in meters; and G is channel gradient (nondimensional). Too small level of significance for gradient to justify computation indicated by leaders ( )]

Channel type (table 1)	Equation	Standard error of estimate, SE (percent)	Coefficient of multiple correlation, R	Level of significance (from *F*-ratio for width, gradient)
Low silt-clay bed (SC_{bd}= 11.30; d_{50}<2.0)	$\bar{Q}=0.0012W^{1.36}G^{-0.59}$	67	0.94	0.001, 0.001
	$Q_2=0.065W^{0.80}G^{-0.69}$	87	.85	.001, .005
	$Q_5=0.24W^{0.68}G^{-0.66}$	84	.83	.001, .005
	$Q_{10}=0.57W^{0.64}G^{-0.61}$	84	.81	.001, .005
	$Q_{25}=1.6W^{0.60}G^{-0.54}$	86	.78	.005, .01
	$Q_{50}=3.3W^{0.58}G^{-0.49}$	88	.75	.005, .025
	$Q_{100}=6.6W^{0.56}G^{-0.43}$	91	.72	.005, .05
Sand bed, silt banks, (SC_{bd}⩽10; SC_{bk}= 70.100; d_{50}<2.0)	$\bar{Q}=0.0018W^{1.43}G^{-0.49}$	49	0.96	0.001, 0.005
	$Q_2=0.56W^{0.95}G^{-0.34}$	43	.94	.001, .025
	$Q_5=1.6W^{0.87}G^{-0.33}$	42	.93	.001, .025
	$Q_{10}=2.9W^{0.81}G^{-0.33}$	41	.93	.001, .025
	$Q_{25}=5.4W^{0.75}G^{-0.32}$	42	.91	.001, .025
	$Q_{50}=8.6W^{0.72}G^{-0.30}$	46	.89	.001, .05
	$Q_{100}=12W^{0.68}G^{-0.31}$	50	.87	.001, .05
Sand bed, sand banks, (SC_{bd}⩽10; SC_{bk}<70; d_{50}<2.0)	$\bar{Q}=0.032W^{1.34}G^{-0.44}$	65	0.95	0.001, 0.001
	$Q_2=0.13W^{1.02}G^{-0.42}$	101	.86	.001, .005
	$Q_5=0.27W^{0.94}G^{-0.46}$	117	.82	.001, .005
	$Q_{10}=0.47W^{0.88}G^{-0.46}$	125	.80	.001, .005
	$Q_{25}=0.91W^{0.83}G^{-0.44}$	134	.77	.001, .01
	$Q_{50}=1.4W^{0.80}G^{-0.43}$	140	.74	.001, .025
	$Q_{100}=2.2W^{0.77}G^{-0.42}$	146	.72	.001, .025
Gravel bed (d_{50}= 2.0. 64)	$\bar{Q}=$	.....	.....	....
	$Q_2=$	.....	.....	....
	$Q_5=1.9W^{0.75}G^{-0.27}$	77	0.79	0.001, 0.05
	$Q_{10}=2.8W^{0.63}G^{-0.32}$	79	.74	.001, .025
	$Q_{25}=4.6W^{0.50}G^{-0.35}$	85	.68	.001, .025
	$Q_{50}=6.6W^{0.42}G^{-0.36}$	91	.63	.005, .025
	$Q_{100}=9.3W^{0.35}G^{-0.37}$	97	.57	.025 .025,
Cobble bed (d_{50}>64)	$\bar{Q}=0.024W^{1.82}G^{-0.01}$	25	0.99	0.001, ...
	$Q_2=0.14W^{1.39}G^{-0.34}$	69	.93	.001, .025
	$Q_5=0.40W^{1.13}G^{-0.38}$	58	.92	.001, .005
	$Q_{10}=0.79W^{0.99}G^{-0.38}$	55	.91	.001, .005
	$Q_{25}=1.8W^{0.85}G^{-0.36}$	60	.87	.001, .01
	$Q_{50}=3.3W^{0.76}G^{-0.34}$	70	.82	.001, .025
	$Q_{100}=5.8W^{0.68}G^{-0.31}$	83	.74	.001, .10

rated easily into width-discharge relations to yield multiple power-function equations. This problem largely is eliminated when the data are separated into groups of specified channel-sediment characteristics. The particle-size limits for each group can be selected to minimize the possibility of nonlinear effect on the width-discharge relation by gradient.

Equations that relate discharge characteristics to active-channel width and gradient for the several channel types (table 1) are presented in table 4. Comparison of tables 2 and 4 shows that (1) gradient is generally a statistically significant variable that gives improved results compared with the use of width only as the independent variable, (2) the significance of gradient is greatest for the relatively unstable (sandy) channels but provides little or no improvement for cohesive or armored channels, (3) the mean-discharge and smaller flood relations for the relatively sandy channels are improved more by considering gradient than are the relations for the infrequent flood discharges; and (4) negative exponents generally are associated with the gradient term, indicating an inverse relation with discharge. In some instances, the level of significance for gradient is too small to justify computation of a power-function equation, a situation indicated by blank (leaders) entries in table 4. The level of significance for gradient in all of the high and medium silt-clay bed relations is small, and these equations are not provided.

To illustrate again the effect that sediment properties have on discharge-geometry relations, width-gradient-discharge equations for the entire data set (tables 8, 9) are provided in table 5 as comparisons to those of table 4. Using the relations for mean discharge as an example, the standard errors of estimate for the channel-type equations (table 4) are from 34 to 92 percent of that for all data (table 5). A general improvement in precision, as indicated by the standard errors, is evident also for the flood relations, although it is less pronounced than that for mean discharge.

TABLE 5.—*Width-gradient-discharge relations resulting from analysis of all data*

[$\bar{Q}$ is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; W is active-channel width, in meters; and G is channel gradient (nondimensional)]

Equation	Standard error of estimate, SE (percent)	Coefficient of multiple correlation, R	Level of significance (from *F*-ratio for width, gradient)
$\bar{Q} = 0.0074W^{1.54}G^{-0.26}$	73	0.94	0.001, 0.001
$Q_2 = 0.24W^{0.96}G^{-0.40}$	98	.84	.001, .001
$Q_5 = 0.53W^{0.82}G^{-0.45}$	98	.82	.001, .001
$Q_{10} = 0.85W^{0.75}G^{-0.47}$	101	.80	.001, .001
$Q_{25} = 1.5W^{0.69}G^{-0.48}$	105	.77	.001, .001
$Q_{50} = 2.1W^{0.65}G^{-0.48}$	110	.75	.001, .001
$Q_{100} = 2.9W^{0.61}G^{-0.48}$	114	.73	.001, .001

The width-gradient discharge relations of tables 4 and 5 are difficult to compare directly with similar width-discharge relations of tables 2 and 3. Owing to weak intercorrelation of gradient with width and discharge, a width exponent from table 4 or 5 must differ from the corresponding exponent of table 2 or 3.

IMPLICATIONS OF THE COMPUTER ANALYSES

The practical result of this study is the presentation of sediment-dependent equations for the purpose of general (nonregionalized) estimates of discharge characteristics (tables 2, 4). Of perhaps greater consequence, however, is the demonstration that sediment variables of the channel perimeter have a quantitative, statistically significant correspondence with active-channel width. Previously cited studies have demonstrated that correspondence, but because the data were of limited number or of regional scope, the results have been subject to question. Owing to the extensive range of hydrologic, climatic, and geologic-topographic conditions represented by the data in tables 8 and 9, the differences among corresponding discharge equations of tables 2 and 4 principally appear to be the result of differences in fluvial-sediment conditions. Local or regional differences in variables, such as climate and geology, no doubt account for a part of the standard errors, but it appears unlikely that they are the major cause of the differences among the equations.

EFFECT OF SEDIMENT

Comparisons of the equations of tables 2 and 4 indicate several generalizations regarding the effect of channel sediment on geometry-discharge relations of alluvial stream channels. The generalizations are advanced as observations only, with little attempt to relate them to theoretical considerations of hydraulics and sediment movement. It is noted, however, that the observations generally are consistent with established theory.

(1) Just as the widest streams, relative to discharge characteristics, occur in highly sandy channels, the smallest exponent for the width-mean-discharge relation is associated with highly sandy channel material. These trends are illustrated in figure 3, a graphical representation of the equations that relate active-channel width and mean discharge for the seven channel types (table 1). For channels of similar width, the largest discharges and exponents occur for the high silt-clay bed channels; discharges and exponents steadily decrease for channels of increasing sandiness and increase again as increasing median particle sizes and armoring provide channel stability (table 2; fig. 3). The coefficients, of course, reflect the changes in width relative to discharge, but they are difficult to compare owing to the variable exponents.

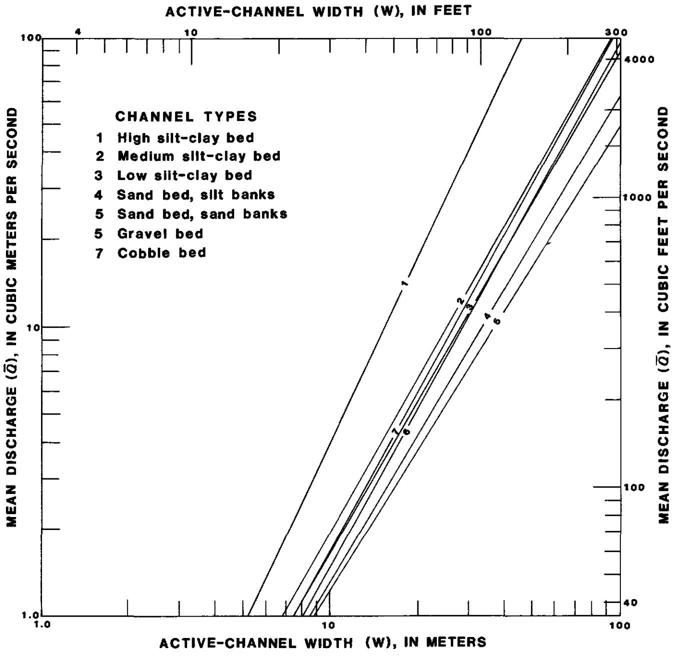

FIGURE 3.—Structural relations between active-channel width and mean discharge for stream channels of specified sediment characteristics.

(2) The general instability of the sandiest channels is reflected by relatively large standard errors of estimate; whereas, the relations for the most stable channels (high silt-clay bed and cobble-bed channels) tend to have the smallest standard errors (table 2). It is inferred that flood discharges generally have minimal effect on widths of the relatively stable channels but cause substantial erosion and widening of the sand channels. Depending on recent discharge histories, therefore, the widths of the sand channels show significant variation relative to discharge characteristics, causing large standard errors of estimate.

(3) The exponents for the mean-discharge equations (table 2) show an apparent inverse relation with the sand content of the channel material. The results of this study and previous studies (Hedman and Kastner, 1977; Osterkamp, 1979a), however, indicate that variation in the exponents principally is the result of differences in the amount of bed-material load transported by the stream. This conclusion is supported also by a variety of laboratory (flume) studies, particularly an exhaustive study of channel morphology by Khan (1971). Streams that transport a small amount of sediment as bed load, such as the high silt-clay bed streams and well-armored (cobble-bed) streams, give relatively large exponents for the width-mean-discharge relation. Because sand sizes generally account for a large part of the bed-material movement (of those streams in which bed load is a significant part of the total sediment load), channels formed primarily of sand ordinarily have relatively small exponents for width-mean-discharge relations. Exceptions occur where stream flow on sand but are largely incapable of moving the sand. An example is many spring-effluent channels that have very steady discharges, a lack of erosive flood peaks, relatively narrow and stable geometries, and an exponent for the width-mean-discharge relation of about 2.0 (Osterkamp, 1979a).

(4) For streams of specified discharge characteristics, the widths of stable channels in large part appear to be a function of the sediment that is moved by traction forces. Streams that discharge relatively large amounts of sand as bed-material load, therefore, require a large channel width to maintain sediment movement. As extreme examples of streams that convey a large part of the total sediment discharge as bed-material load, structural analyses were made for two small groups of data from the Sand Hills area of Nebraska (table 6; fig. 4). The two groups of data both represent highly sandy (dune sand) basin conditions but are treated separately owing to differences in the content of silt sizes in the soils and, therefore, in the runoff characteristics. Consistent with the observations presented here, most of the Sand Hills channels are very wide relative to discharge, and the data have relatively small exponents for the width-mean-discharge equations (table 6).

TABLE 6.—*Width-discharge relations for selected stream channels of the Sand Hills area, Nebraska*

[$\bar{Q}$ is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; and W is active-channel width, in meters]

Data source	Equation	Standard error of estimate, SE (percent)	Coefficient of correlation, R	Level of significance (from *F*-ratio for width)
North and Middle Loup Rivers.	$\bar{Q}=0.46W^{0.90}$	10	0.98	0.001
	$Q_2=0.031W^{1.86}$	26	.97	.001
	$Q_5=0.13W^{2.18}$	35	.97	.001
	$Q_{10}=0.0075W^{2.37}$	40	.96	.001
	$Q_{25}=0.0040W^{2.59}$	47	.96	.001
	$Q_{50}=0.0025W^{2.74}$	52	.95	.001
	$Q_{100}=0.0016W^{2.90}$	56	.95	.001
Calamus, Cedar, Elkhorn, North Fork Elkhorn, and South Loup Rivers.	$\bar{Q}=0.27W^{0.86}$	16	.95	.001

(5) Owing to increases of basin size and attenuation of flood discharges in the downstream direction, exponents of width in table 2 for the various channel types of table 1 typically decrease as the recurrence interval increases. Thus, for a specified channel type, the percentage differences among the various flood magnitudes generally are greatest for floods with a small recurrence interval and progressively decrease as the flood magnitudes increase (table 2). These trends for the seven channel types (table 1) are represented in figures 5-11. Exceptions to these generalizations are provided by streams of the Sand Hills (table 6; fig. 4). Owing largely to the unique geology of the area, streams of the Sand Hills have (1) increasing discharge variability, (2) an increasing tendency for braided channel patterns, and (3) increasing exponents with flood magnitudes in the downstream direction (Osterkamp, 1978).

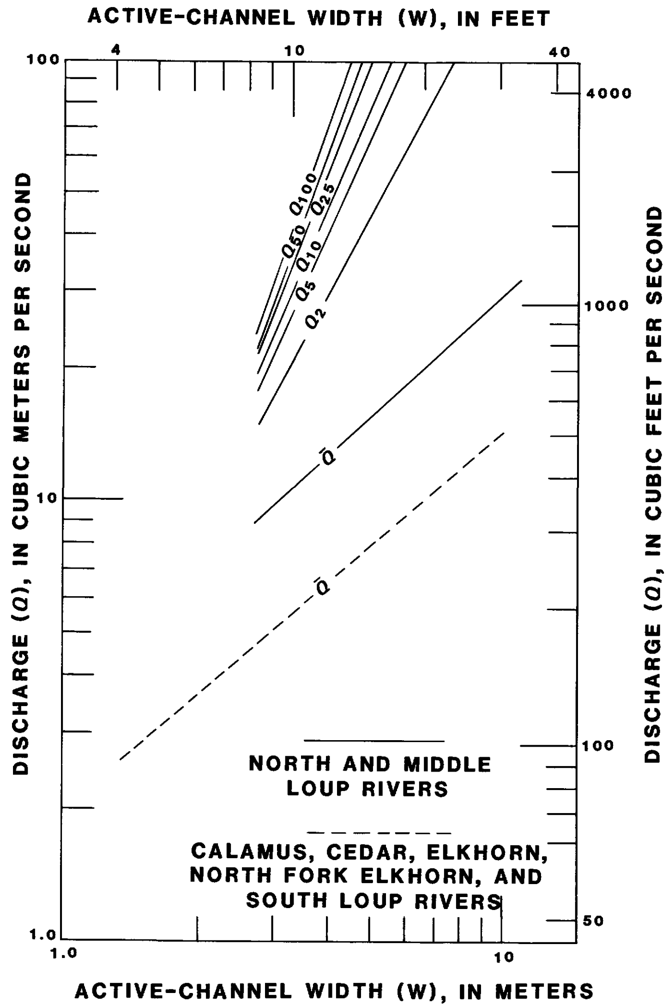

FIGURE 4.—Structural relations between active-channel width and discharge characteristics for selected streams of the Sand Hills area, Nebraska.

EFFECT OF GRADIENT AND OTHER VARIABLES ON WIDTH-DISCHARGE RELATIONS

In tables 4 and 5 channel gradients are treated as independent variables, although it is acknowledged that they are dependent chiefly on the water and sediment discharge of a channel. Previous studies (Lane, 1957; Osterkamp, 1978) have established gradient-discharge relations and the manner in which they vary according to differences in bed-material sizes. If channel-sediment characteristics were presented as power functions in the equations of this paper instead of as ranges or groups of width-discharge data, the insertion of a gradient expression would be redundant. Within each channel-type group (table 1), however, no sediment-size distinctions are made, and the use of a gradient term is valid. For each channel type, it is assumed that gradient has an approximately linear effect (after logarithmic transformations) on the width-discharge relations; although, as previously noted, this assumption is invalid when applied to the spectrum of sediment conditions (table 5).

It was established (Osterkamp, 1978) that:

$$G \approx a\bar{Q}^{-0.25}, \tag{3}$$

or, in terms of mean discharge ($\bar{Q}$) as the dependent variable,

$$\bar{Q} \approx a'G^{-4.0}, \tag{4}$$

thereby indicating that with an increase of mean discharge in the downstream direction a general decrease in channel gradient (G) occurs. The coefficients, a and a', in large part vary with the characteristics of channel sediment (Osterkamp, 1978). When included in a multiple power-function equation, the gradient exponent is reduced, of course, in absolute value, but it must retain a negative value to provide a meaningful physical relation to discharge estimates. In general,

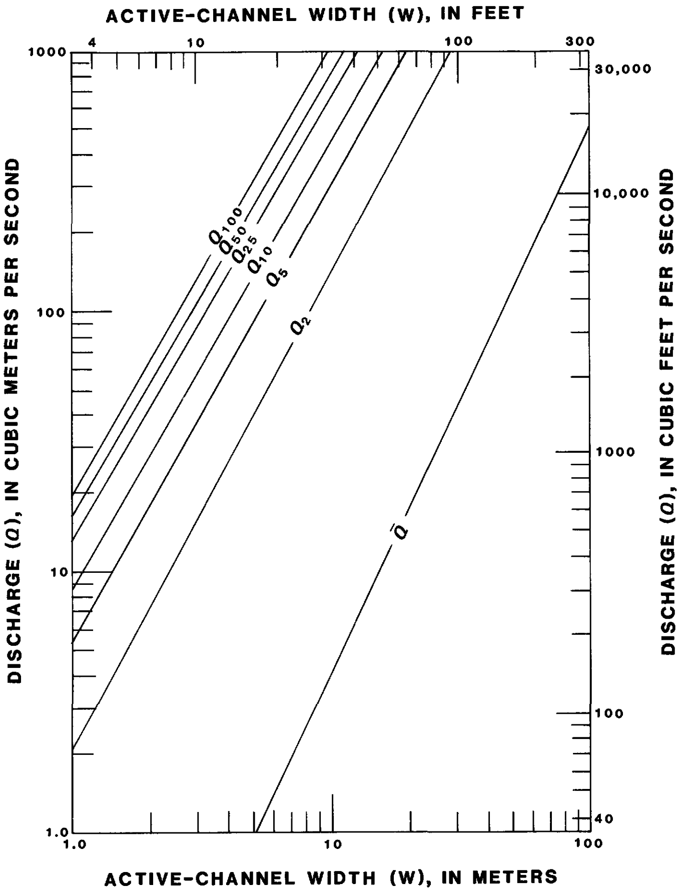

FIGURE 5.—Structural relations between active-channel width and discharge characteristics for high silt-clay bed channels.

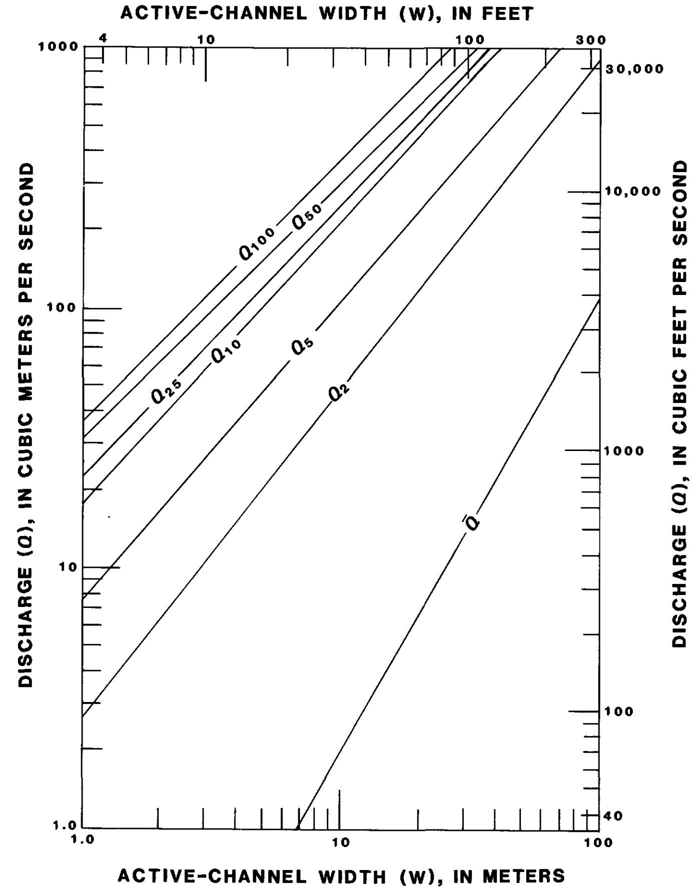

FIGURE 6.—Structural relations between active-channel width and discharge characteristics for medium silt-clay bed channels.

the gradient exponents (table 4) range from −0.3 to −0.7, regardless of flow frequency. These exponents result in as much as a three-fold variation for typical ranges in gradient within the several channel-type groups. As examples, width-discharge equations for sand-bed, sand-banks channels (table 4) are illustrated in figure 12 for mean discharges and floods of 25-year recurrence intervals using representative values of gradient for that channel type. These examples show about a two-fold difference in predicted discharges for the range of gradients selected (fig. 12).

Numerous studies of downstream hydraulic geometry and channel geometry demonstrate that mean depth ($\overline{d}$), like width, has a general power-function relation with discharge characteristics:

$$Q \approx \overline{d}^{f}, \qquad (5)$$

where f is a positive exponent.

For most channel types, mean depth increases with mean discharge but at a slower rate than does width. Mean depths were depths that were measured (or, in some instances, estimated) at all sites included in this study, and the depths are listed in table 9. Channel depth, however, can be variable within relatively short reaches, as well as through time at the same section. Hence, representative depths cannot be defined reliably; thus, depth shows little statistical significance (Schumm, 1961; Hedman, Kastner, and Hejl, 1974). Despite this difficulty, a number of computer analyses that included considerations of depth were made to determine whether mean depth could provide improvement to the width-discharge relations. The resulting relations are not shown because the exponent for depth was not statistically significant and was unrealistically negative.

Two variables that can have a large effect on width-discharge relations but which receive limited attention here are climate, particularly as reflected by riparian vegetation, and stream flashiness. The amount, type, and maturity of riparian vegetation are known to have measurable effects on the sizes and shapes of alluvial channels (Schumm and Lickty, 1963; Burkham, 1972; Osterkamp, 1977). Because the stablizing effect that a

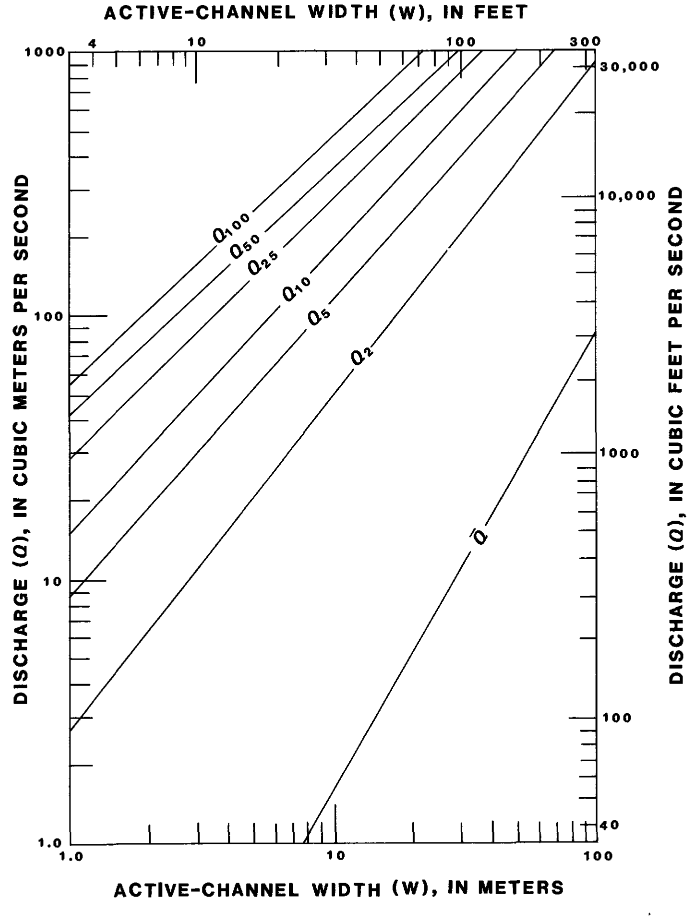

FIGURE 7.—Structural relations between active-channel width and discharge characteristics for low silt-clay bed channels.

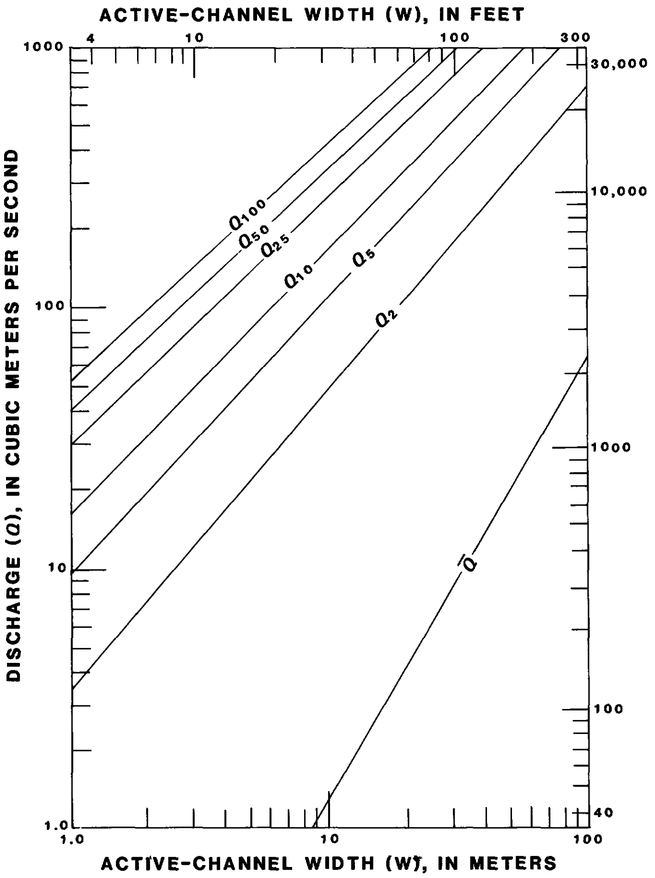

FIGURE 8.—Structural relations between active-channel width and discharge characteristics for sand-bed, silt-banks channels.

community of riparian vegetation has on channel banks is virtually the same regardless of channel size, the relative effect on width-discharge relations decreases as mean discharges increase. Quantative techniques for measuring the effects of vegetation have not been developed yet, and therefore vegetation is not considered in the equations of this paper.

In general, unregulated stream channels are widened only during erosive discharge and have a tendency to narrow at all other times of discharge (Burkham, 1972; Osterkamp, 1977, 1979a). Relatively stable, narrow channels, therefore, are more likely to occur for streams of steady discharge than for those of highly variable and periodically erosive discharge. Natural examples of the two extremes are the channels of very steady spring effluent and the channels of highly ephemeral streamflow in an arid or semiarid region.

Because the discharge characteristics of most partly regulated streams do not differ greatly from many natural streams of discharge with small variability, data from some partly regulated streams are incorporated into this study. Except to provide examples, the relations presented here are not separated into groups based on discharge variability because: (1) additional grouping within most of the channel-type classes (table 1) would result in data sets too small to provide dependable results, (2) the use of discharge characteristics as a basis (independent variable) for estimating other discharge characteristics is a questionable practice, and (3) commonly, little is known of the discharge characteristics when the channel-geometry equations are used in practical manner.

The results of computer analyses for sand-bed, sand-banks channels when the data are divided into two groups according to discharge variability are given in table 7. Sand-channel streams are used to illustrate the effect of stream flashiness because sufficient data (96 sets) are available. They represent a wide range of geologic and hydrologic conditions. Results (tables 2, 4) show general instability and large standard errors of estimate, and the channels are easily widened by erosive discharges. The data were separated into two groups, those that have low variability of discharge and those that have highly variable discharge, which are defined as having ratios of the 10-year flood to

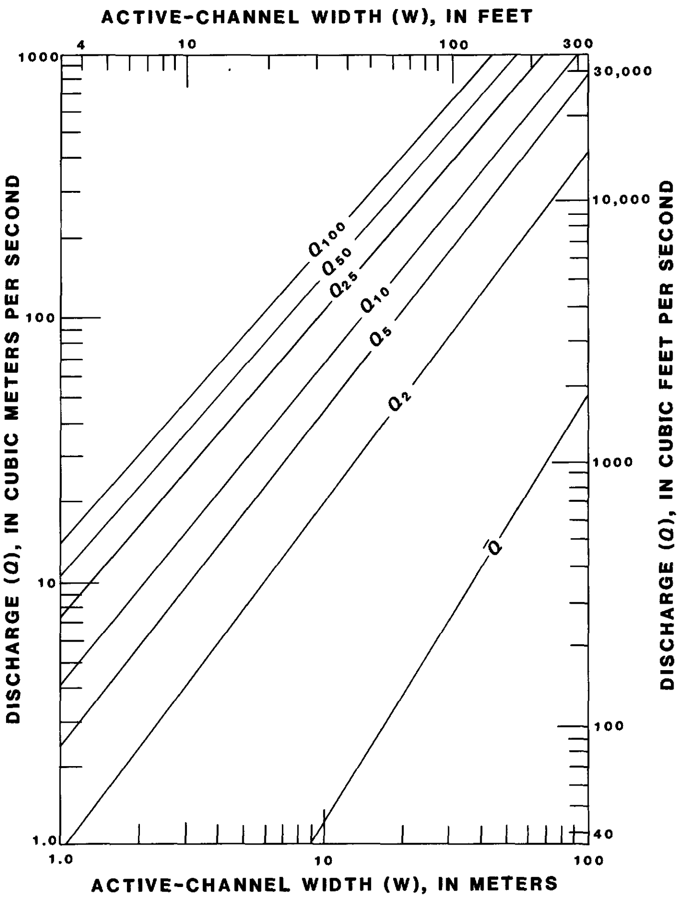

FIGURE 9.—Structural relations between active-channel width and discharge characteristics for sand-bed, sand-banks channels.

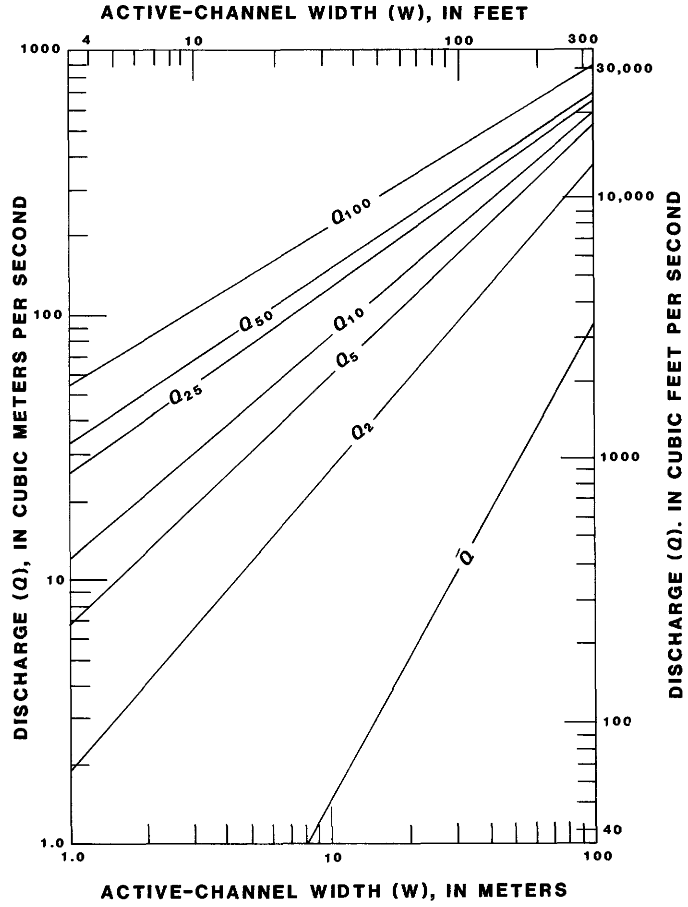

FIGURE 10.—Structural relations between active-channel width and discharge characteristics for gravel-bed channels.

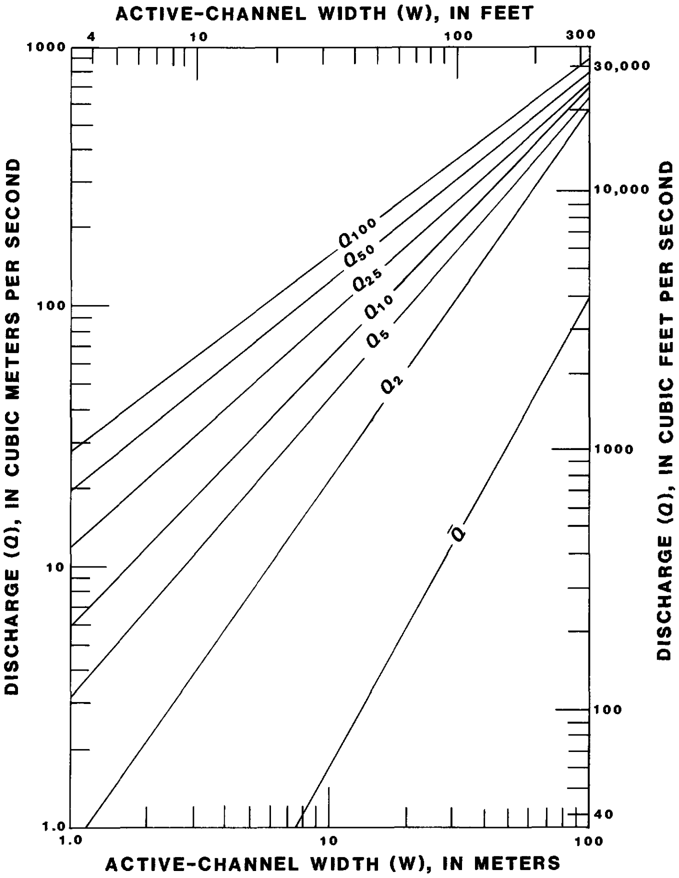

FIGURE 11.—Structural relations between active-channel width and discharge characteristics for cobble-bed channels.

mean discharge ($Q_{10}/\bar{Q}$) of less than or equal to 60, and more than 60, respectively.

Comparisons of the results in table 7 with the corresponding results of tables 2 and 4 show significant differences in both the equations and standard errors of estimate. Relative to the equations of tables 2 and 4, relations for the low-variability streams have larger width exponents and smaller coefficients, indicating slower transport rates of bed-material load, and the high-variability streams have smaller width exponents and larger coefficients, indicating faster transport rates of bed-material sizes. Thus, the equations confirm the expected result that little discharge variability favors relatively narrow channels, whereas increased variability and erosive flood discharges produce wider channels. It is inferred that the width exponents for the low-variability data would be even larger if the somewhat anomalous data from the Sand Hills area, Nebraska, were not disproportional in that group. Probably because of the unusual geologic conditions of the Sand Hills, channels there convey very low-variability discharge yet tend to be relatively wide. For this reason, the standard errors of estimate for the low-variability streams (table 7) remain large, being only moderately smaller than those of the sand-bed, sand-banks' channels in general (tables 2, 4). The highly variable discharge streams, however, appear to yield a representative set of data and show standard errors substantially less (table 7) than those of the entire data set for sand-channel streams (tables 2, 4).

Width-discharge and width-gradient-discharge relations no doubt are affected by other variables that are not considered here. Among these complicating variables are land-use practices (for example, the effect of livestock), water salinity (and its potential for flocculation of clay particles), and particularly the elapsed time since the last erosive flood. Suitable methods presently are not available to evaluate quantitatively the effects of these or other potential effects of geometry-discharge relations.

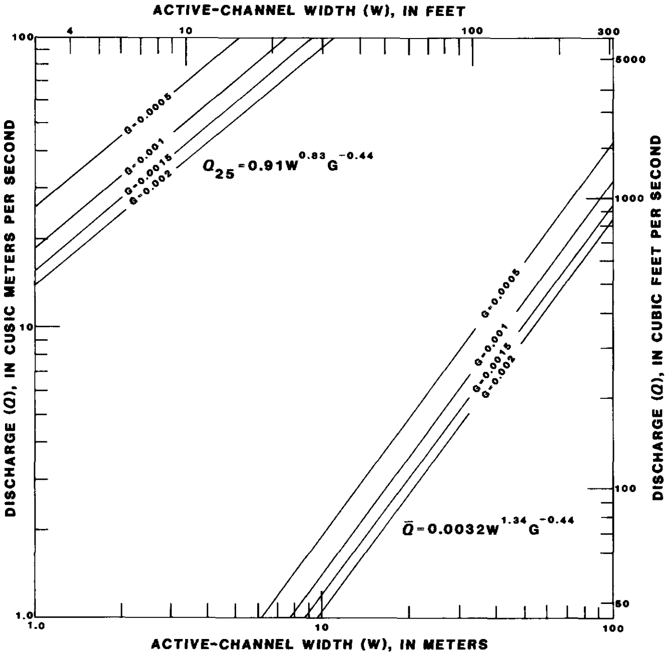

FIGURE 12.—Width-gradient-discharge relations for mean discharges ($\bar{Q}$) and the 25-year floods (Q_{25}) for sand-bed, sandbanks channels using representative values of gradient (G).

VARIABILITY AND ERROR ANALYSIS

Statistical summaries for the equations given in tables 2, 4, 6, and 7 show large ranges for the standard errors of estimate, correlation coefficients, and levels of significance. Numerous causes or sources of error appear to contribute to the standard-error values; these include: (1) inaccurate or misleading discharge data, (2) inconsistent geometry data resulting from improper site selection or differences in measuring technique between sites, (3) discharge variability and elapsed time since the previous erosive flood, (4) improper collection and analysis techniques for the channel-material samples, (5) grouping of channels by ranges of channel-sediment properties, and (6) other complicating variables, only some of which have been mentioned. Of these, the first three sources of error appear to be the most significant.

As previously mentioned, most measurement sites for this study were selected at streamflow-gaging stations that have at least 20 years of continuous discharge records. For this length of record, it is calculated for Kansas streams, as an example, that the standard errors of estimate for accuracy of mean discharge is about 0.10 log unit, or roughly 25 percent (average) (Jordan and Hedman, 1970, p. 16). Thus, a similar part of the standard error for each equation in tables 2, 4, and 7 can be assumed to be the result of inaccurate values for mean discharge. (Owing to close similarities for discharge and channel data, the same generalization is not true for the relations in table 6.)

TABLE 7.—*Width-discharge and width-gradient-discharge relations for sand-bed, sand-banks channels of differing discharge variability*

[Q is mean discharge, in cubic meters per second; Q_2 through Q_{100} are flood discharges, in cubic meters per second, of recurrence intervals 2 through 100 years; W is active-channel width, in meters; and G is channel gradient (nondimensional)]

Discharge variability	Equation	Standard error of estimate, SE (percent)	Percentage reduction of average SE from corresponding value in table 2 or 4
Low,	$\bar{Q}=0.035W^{1.62}$	71	2
$Q_{10}/\bar{Q}\leqslant 60$	$\bar{Q}=0.0044W^{1.36}G^{-0.42}$	65	0
(55 data	$Q_2=0.32W^{1.51}$	94	13
sets)	$Q_2=0.029W^{1.18}G^{-0.49}$	86	15
	$Q_5=0.60W^{1.50}$	101	23
	$Q_5=0.038W^{1.13}G^{-0.56}$	91	26
	$Q_{10}=0.92W^{1.47}$	104	28
	$Q_{10}=0.055W^{1.09}G^{-0.58}$	94	31
	$Q_{25}=1.5W^{1.43}$	110	30
	$Q_{25}=0.088W^{1.05}G^{-0.58}$	99	35
	$Q_{50}=2.1W^{1.41}$	115	31
	$Q_{50}=0.12W^{1.01}G^{-0.58}$	105	35
	$Q_{100}=2.6W^{1.40}$	121	31
	$Q_{100}=0.17W^{0.99}G^{-0.58}$	111	35
High,	$\bar{Q}=0.047W^{1.36}$	59	14
$(Q_{10}/\bar{Q})>60$	$\bar{Q}=0.0042W^{1.03}G^{-0.49}$	45	20
(41 data	$Q_2=3.9W^{1.04}$	57	50
sets)	$Q_2=1.6W^{0.81}G^{-0.23}$	55	46
	$Q_5=15W^{0.89}$	50	74
	$Q_5=7.3W^{0.69}G^{-0.19}$	49	68
	$Q_{10}=30W^{0.81}$	48	84
	$Q_{10}=17W^{0.62}G^{-0.16}$	47	78
	$Q_{25}=64W^{0.71}$	47	93
	$Q_{25}=46W^{0.55}G^{-0.12}$	47	87
	$Q_{50}=100W^{0.66}$	48	98
	$Q_{50}=85W^{0.50}G^{-0.09}$	48	92
	$Q_{100}=140W^{0.64}$	50	102
	$Q_{100}=160W^{0.45}G^{-0.06}$	50	96

The data in tables 2 and 4 also show that, in general, the smallest standard errors of estimate and largest correlation coeffients are associated with the most stable channels, those formed of abundant fine-grained material and those that are well armored. Ostensibly because sand channels are the most vulnerable to widening by flood discharges, they have the poorest correlations between width (and gradient) and the various discharge characteristics. Hence, the sand-channel relations show relatively large standard errors of estimate. When discharge variability is considered, even in an approximate manner, substantial improvement in the standard errors results (table 7).

Similarities in the equations in table 5 and most of the equations in table 4 indicate that the exponent value for gradient ordinarily should be −0.4 to −0.5. When values differ significantly from this range, use of a gradient term in a width-discharge relation does not lead to reduction of standard error, and the levels of significance for gradient are very small (tables 2, 3, 4, 5, 7). For the high and medium silt-clay bed channels, the values and ranges of gradient probably are too small and the errors due to measurement too great to permit statistically significant results. For those two channel types, therefore, gradient exponents are anomalous (of positive value), lead to an increase in standard errors of estimate, and show little significance. For these reasons, width-gradient-discharge relations for the high and medium silt-clay bed channels have been omitted from table 4. The other width-gradient-discharge relations presented in this paper (table 4, 7) appear to be preferrable alternatives to the width-discharge equations if gradient information is available.

Comparisons of the standard errors of estimate for the relations presented here with those of analogous equations for regions of the Missouri River basin (Hedman and Kastner, 1977) are variable. For those equations that do not compare favorably, several possible causes can be cited:

(1) The data sets, thus equations, of Hedman and Kastner (1977) were determined in part by regionalization of the Missouri River basin for mean discharge and flood characteristics, resulting in the smallest standard errors that could be achieved while maintaining reasonably consistent regional boundaries. The process of dividing the basin into regions serves to minimize the differences in discharge variability, topography, and climate within each region, as well as isolating data, such as those of the Sand Hills, that could appear anomalous in other data groupings.

(2) The data of Hedman and Kastner (1977) were limited to gage sites on unregulated streams with a minimum of 20 years of continuous records. For reasons previously mentioned, the data of this report include those from some partly regulated streams and from several streams with fewer than 20 years of record. The standard errors for the flood equations, in particular, can be expected to be increased by the inclusion of data from partly regulated streams.

(3) The defined ranges of sediment characteristics for several of the channel types (table 1) in this analysis may be too broad to provide small standard errors. More importantly, when streams transport significant amounts of both the silt-clay and sand sizes, bed-and-bank samples can be variable through time as well as within short channel distances at the same time. Thus, it is difficult to obtain representative samples for these types of streams. This difficulty is inferred to be much of the cause for the relatively large standard errors of estimate for the relations of the medium and low silt-clay bed channels (tables 2, 4).

UTILITY AND CONCLUSIONS

The results of this study demonstrate that sediment characteristics have a quantitative effect on geometry-discharge relations of alluvial channels, but it has been shown that regionally defined relations sometimes provide better results than do the equations given here. For practical purposes, perhaps discharge characteristics for the Missouri River basin need to be estimated using both the equations in tables 2 and 4 and regionalized relations, such as those of Hedman and Kastner (1977). A benefit of the present study is that the equations probably are applicable to ungaged perennial, alluvial streams of other areas.

Similar to relations developed by channel-geometry techniques, the equations provided here yield estimates of discharge characteristics quickly and inexpensively. Unlike the equations of most other studies, they require knowledge, generally particle-size analyses, of the channel-sediment characteristics. For reconnaissance purposes, however, it is sometimes impractical to collect and analyze the necessary samples. By making qualitative evaluations of the sediment characteristics of a channel and by generalizing the equations in table 2, immediate onsite estimates of discharge are feasible. For example, onsite observations generally are adequate to identify sand-bed, silt-banks channels; sand-bed, sand-banks channels; and channels that are bedded by gravel or cobbles. The appropriate equations from table 2 (or table 7) then can be applied directly. Discharges for the remaining channels, with relatively muddy streams, can be generalized by

$$\overline{Q} = 0.03W^{2.0}; \quad (6)$$

$$Q_2 = 2W^{1.5}; \quad (7)$$

$$Q_5 = 7W^{1.4}; \quad (8)$$

$$Q_{10} = 14W^{1.3}; \quad (9)$$

$$Q_{25} = 22W^{1.2}; \quad (10)$$

$$Q_{50} = 30W^{1.1}; \qquad (11)$$

and

$$Q_{100} = 37W^{1.1}. \qquad (12)$$

The above equations, which are composites modifying the high and medium silt-clay bed equations of table 2, express discharge (Q) in cubic meters per second and width (W) in meters; equivalent equations, in inch-pound units, are given in table 10 (p. 36).

Besides the effect of channel-sediment properties on width-discharge relations, the results of this study demonstrate that discharge variability can have a measurable effect on channel geometry. Sand channels lacking sufficient fine or coarse material to form resistant banks are most susceptible to differing geometries due to discharge variability (table 7). Thus, as indicated earlier, channel size and shape are the integrated results of all water and sediment discharges conveyed by the channel, and when applied to the active-channel section, the concept of a specific channel-forming discharge seems inappropriate. It follows from these results that at least qualitative predictions are feasible for the channel changes that might occur as a result of upstream alterations, such as dam and reservoir construction, changes in land-use practices, diversion of streamflow, or channelization. Furthermore, if the channel material and discharge characteristics of reservoir releases or a controlled drainage system can be anticipated, the results given here can be used for design purposes of the channel. As noted previously, regime studies (for the design of irrigation canals) date back many decades, but the present study includes much broader ranges of discharges and channel- sediment properties than do the canal studies.

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SUPPLEMENTAL INFORMATION

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*

[$\bar{Q}$, mean discharge; Q_2, 2-year flood discharge; Q_5, 5-year flood discharge; Q_{10}, 10-year flood discharge; Q_{25}, 25-year flood discharge; Q_{50}, 50-year flood discharge; Q_{100}, 100-year flood discharge. All discharges are in cubic meters per second]

Map No.	Station No.	Station Name	$\bar{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
1	06018500	Beaverhead River near Twin Bridges, Mont.	11.6	30.3	41.9	49.8	60.0	67.6	75.4
2	06025500	Big Hole River near Melrose, Mont.	32.5	207	309	374	456	518	578
3	06027200	Jefferson River at Silver Star, Mont.	55.9	183	342	383	424	448	468
4	06050000	Hyalite Creek at Hyalite Ranger Station near Bozeman, Mont.	1.89	11.6	16.0	18.9	22.5	25.3	28.1
5	06052500	Gallatin River at Logan, Mont.	29.6	141	188	217	251	275	299
6	06115200	Missouri River near Landusky, Mont.	262	850	1389	1868	2647	3375	4250
7	06120500	Musselshell River at Harlowton, Mont.	4.57	30.3	57.8	78.5	106	128	151
8	06123500	Musselshell River near Ryegate, Mont.	5.01	38.8	81.3	118	175	225	280
9	06126500	Musselshell River near Roundup, Mont.	5.61	50.7	95.8	132	185	229	278
10	06127500	Musselshell River at Musselshell, Mont.	5.64	46.5	92.3	132	185	234	278
11	06185500	Missouri River near Culbertson, Mont.	297	683	1000	1320	1820	2320	2890
12	06191500	Yellowstone River at Corwin Springs, Mont.	88.4	487	620	697	785	844	898
13	06192500	Yellowstone River near Livingston, Mont.	107	584	720	802	892	958	1017
14	06197500	Boulder River near Contact, Mont.	10.8	105	125	137	150	159	167
15	06200000	Boulder River at Big Timber, Mont.	17.6	173	215	239	268	289	309
16	06205000	Stillwater River near Absarokee, Mont.	27.6	192	245	277	314	343	368
17	06233000	Little Popo Agie River near Lander, Wyo.	2.27	17.5	28.9	37.1	47.9	56.4	64.9
18	06235500	Little Wind River near Riverton, Wyo.	17.0	139	217	272	345	402	460
19	06244500	Fivemile Creek above Wyoming Canal, near Pavillion, Wyo.	.064	2.89	7.65	12.7	21.8	31.0	42.5
20	06258000	Muddy Creek near Shoshoni, Wyo.	.555	12.1	23.6	33.5	48.6	61.9	76.8
21	06270000	Nowood River near Ten Sleep, Wyo.	3.14	34.0	59.0	78.5	106	130	155
22	06290500	Little Bighorn River below Pass Creek, near Wyola, Mont.	6.03	38.2	58.6	73.4	92.4	107	123
23	06294000	Little Bighorn River near Hardin, Mont.	8.81	58.6	102	136	182	220	259
24	06294700	Bighorn River at Bighorn, Mont.	112	407	577	683	809	898	983
25	06305500	Goose Creek below Sheridan, Wyo.	5.21	46.4	75.4	97.2	127	151	177
26	06308500	Tongue River at Miles City, Mont.	12.5	130	219	286	377	448	518
27	06309000	Yellowstone River at Miles City, Mont.	326	1544	1952	2184	2439	2612	2768
28	06317000	Powder River at Arvada, Wyo.	7.76	214	416	599	898	1176	1506
29	06318500	Clear Creek near Buffalo, Wyo.	1.78	19.1	30.0	38.5	50.1	59.8	70.0
30	06323500	Piney Creek at Ucross, Wyo.	2.48	28.6	45.3	56.9	79.3	99.2	109
31	06326500	Powder River near Locate, Mont.	17.6	266	538	776	1020	1220	1420
32	06329200	Burns Creek near Savage, Mont.	.094	6.83	37.4	88.7	218	385	637
33	06332000	White Earth River at White Earth, N. Dak.	.816	17.1	39.1	59.0	90.7	118	149
34	06334500	Little Missouri River at Camp Crook, S. Dak.	3.82	70.2	132	182	256	317	385
35	06335000	Little Beaver Creek near Marmarth, N. Dak.	1.12	96.6	168	221	292	346	402

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\bar{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
36	06335500	Little Missouri River at Marmarth, N. Dak.	9.63	268	516	711	991	1218	1459
37	06336000	Little Missouri River at Medora, N. Dak.	13.4	289	578	810	1144	1416	1705
38	06336500	Beaver Creek at Wibaux, Mont.	.632	25.5	98.3	193	391	606	898
39	06337000	Little Missouri River near Watford City, N. Dak.	17.0	428	793	1074	1462	1770	2093
40	06339500	Knife River near Golden Valley, N. Dak.	2.73	90.7	199	289	416	521	629
41	06340000	Spring Creek at Zap, N. Dak.	1.24	51.0	98.9	135	184	223	261
42	06340500	Knife River at Hazen, N. Dak.	5.10	139	297	428	623	782	955
43	06341400	Turtle Creek near Turtle Lake, N. Dak.	.0213	1.39	3.71	5.92	9.43	12.5	16.0
44	06341800	Painted Woods Creek near Wilton, N. Dak.	.212	8.30	23.4	38.2	62.6	84.4	109
45	06343000	Heart River near South Heart, N. Dak.	.790	44.5	104	156	234	297	368
46	06345000	Green River near Gladstone, N. Dak.	1.01	42.5	100	149	223	283	351
47	06345500	Heart River near Richardton, N. Dak.	2.92	105	217	295	392	459	521
48	06347000	Antelope Creek near Carson, N. Dak.	.456	28.3	80.7	133	219	297	385
49	06348000	Heart River near Lark, N. Dak.	6.06	109	276	436	693	922	1183
50	06349000	Heart River near Mandan, N. Dak.	7.16	127	336	526	812	1049	1304
51	06349500	Apple Creek near Menoken, N. Dak.	.960	16.9	47.6	77.6	127	171	221
52	06350000	Cannonball River at Regent, N. Dak.	1.26	52.3	148	248	416	569	748
53	06351000	Cannonball River below Bentley, N. Dak.	2.47	77.6	228	382	637	872	1142
54	06352000	Cedar Creek near Haynes, N. Dak.	.731	30.6	96.9	170	300	428	583
55	06354000	Cannonball River at Breien, N. Dak.	6.82	141	337	504	742	935	1136
56	06354500	Beaver Creek at Linton, N. Dak.	1.15	30.6	81.6	130	208	276	351
57	06355500	North Fork Grand River near White Butte, S. Dak.	1.57	38.5	172	363	784	1269	1943
58	0635600	South Fork Grand River at Buffalo, S. Dak.	.233	18.1	41.3	63.2	98.6	131	168
59	06356500	South Fork Grand River near Cash, S. Dak.	1.56	48.4	117	183	295	397	516
60	06357800	Grand River at Little Eagle, S. Dak.	6.51	143	258	334	426	488	546
61	06359500	Moreau River near Faith, S. Dak.	3.82	104	262	422	619	949	1258
62	06394000	Beaver Creek near Newcastle, Wyo.	.929	31.5	57.8	80.2	114	144	179
63	06395000	Cheyenne River at Edgemont, S. Dak.	2.86	83.8	185	289	476	668	915
64	06402500	Beaver Creek near Buffalo Gap, S. Dak.	.199	3.40	15.8	38.0	103	204	385
65	06406000	Battle Creek at Hermosa, S. Dak.	.270	9.06	29.7	52.1	90.9	127	169
66	06409000	Castle Creek above Deerfield Reservoir, near Hill City, S. Dak.	.286	1.78	4.11	6.43	10.6	14.7	19.8
67	06410500	Rapid Creek above Pactola Reservoir, at Silver City, S. Dak.	1.14	6.77	15.8	26.1	47.0	69.8	102
68	06414000	Rapid Creek at Rapid City, S. Dak.	1.76	11.2	33.4	74.2	210	457	993
69	06421500	Rapid Creek near Farmingdale, S. Dak.	1.56	18.5	40.8	64.4	108	154	213
70	06430500	Redwater Creek at Wyo.-S. Dak.State line	1.04	8.35	23.1	39.1	68.5	98.7	137
71	06431500	Spearfish Creek at Spearfish, S. Dak.	1.45	7.84	20.2	35.4	67.7	106	162

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\overline{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
72	06433000	Redwater River above Belle Fourche, S. Dak.	3.82	23.4	55.5	87.8	144	198	265
73	06437000	Belle Fourche River near Sturgis, S. Dak.	7.73	105	214	307	450	573	712
74	06444000	White River at Crawford, Nebr.	.572	10.2	23.8	38.5	66.8	97.2	138
75	06447000	White River near Kadoka, S. Dak.	7.87	274	436	569	768	941	1130
76	06447500	Little White River near Martin, S. Dak.	.541	5.15	12.1	20.0	35.7	53.2	77.3
77	06448000	Lake Creek above Refuge, near Tuthill, S. Dak.	.549	2.26	3.03	3.60	4.36	5.01	5.69
78	06449100	Little White River near Vetal, S. Dak.	1.48	9.15	17.4	25.0	37.7	50.1	65.7
79	06449500	Little White River near Rosebud, S. Dak.	3.12	20.9	45.6	72.2	123	177	250
80	06450500	Little White River below White River, S. Dak.	3.57	48.2	109	179	323	488	724
81	06453500	Ponca Creek at Anoka, Nebr.	1.40	48.1	94.9	140	218	295	391
82	06453600	Ponca Creek at Verdel, Nebr.	2.19	53.2	122	197	337	487	688
83	06454000	Niobrara River at Wyo.-Nebr. State line	.123	2.14	7.42	15.4	35.7	63.7	110
84	06454100	Niobrara River at Agate, Nebr.	.413	1.81	2.97	3.96	5.52	6.91	8.58
85	06454500	Niobrara River above Box Butte Reservoir, Nebr.	.872	6.03	14.0	23.1	41.1	60.9	88.4
86	06461000	Minnechaduza Creek at Valentine, Nebr.	.963	6.06	10.2	14.0	20.0	25.7	32.3
87	06462500	Plum Creek at Meadville, Nebr.	3.03	11.7	20.4	28.3	41.4	53.5	68.3
88	06464500	Keya Paha River at Wewela, S. Dak.	1.93	19.4	45.0	74.8	134	201	295
89	06464900	Keya Paha River near Naper, Nebr.	3.77	58.6	111	161	244	323	422
90	06466500	Brazile Creek near Niobrara, Nebr.	2.47	134	433	759	1340	1898	2561
91	06467600	James River near Manfred, N. Dak.	.0818	2.92	8.78	14.9	25.1	34.6	45.6
92	06469500	Pipestem Creek near Pingree, N. Dak.	.552	11.8	43.8	77.7	133	179	228
93	06470000	James River at Jamestown, N. Dak.	1.65	17.0	42.4	65.2	100	129	160
94	06470500	James River at La Moure, N. Dak.	2.53	22.1	57.9	92.7	150	201	260
95	06471500	Elm River at Westport, S. Dak.	1.31	21.0	80.7	153	292	428	600
96	06473000	James River at Ashton, S. Dak.	4.39	10.9	28.5	45.6	73.3	98.1	128
97	06477000	James River near Forestburg, S. Dak.	7.87	32.1	94.8	172	331	512	764
98	06477500	Firesteel Creek near Mount Vernon, S. Dak.	.654	11.3	42.2	83.0	168	265	397
99	06478500	James River near Scotland, S. Dak.	10.6	56.1	126	192	297	391	501
100	06480000	Big Sioux River near Brookings, S. Dak.	4.33	60.9	172	282	462	623	804
101	06481000	Big Sioux River near Dell Rapids, S. Dak.	7.16	87.5	234	377	603	804	1031
102	06481500	Skunk Creek at Sioux Falls, S. Dak.	1.31	41.1	118	198	331	456	600
103	06483500	Rock River near Rock Valley, Iowa	8.50	166	456	736	1190	1589	2040
104	06485500	Big Sioux River at Akron, Iowa	23.8	274	615	904	1323	1668	2034
105	06486000	Missouri River at Sioux City, Iowa	904	963	1643	1870	2125	2380	2550
106	06600100	Floyd River at Alton, Iowa	1.33	48.4	137	299	388	538	717
107	06600300	West Branch Floyd River near Struble, Iowa	.864	51.8	124	188	283	365	453
108	06600500	Floyd River at James, Iowa	5.07	97.1	224	348	561	765	1011
109	06601000	Omaha Creek at Homer,							

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\bar{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
		Nebr.	1.02	166	227	314	436	533	635
110	06606600	Little Sioux River at Correctionville, Iowa	19.9	193	360	479	631	748	861
111	06607000	Odebolt Creek near Arthur, Iowa	.445	29.2	57.2	79.0	109	132	156
112	06607200	Maple River at Mapleton, Iowa	6.60	182	320	416	538	629	719
113	06608000	Tekamah Creek at Tekamah, Nebr.	.188	52.1	113	163	237	297	362
114	06608500	Soldier River at Pisgah, Iowa	3.57	258	419	530	666	768	869
115	06609500	Boyer River at Logan, Iowa	8.86	354	510	603	711	785	853
116	06610000	Missouri River at Omaha, Nebr.	830	1811	2341	2729	3265	3696	4157
117	06628900	Pass Creek near Elk Mountain, Wyo.	1.16	13.4	21.2	26.9	34.7	41.0	47.5
118	06632400	Rock Creek above King Canyon Canal near Arlington, Wyo.	2.33	41.9	60.9	73.6	90.1	102	114
119	06639000	Sweetwater River near Alcova, Wyo.	3.57	19.4	31.4	40.2	51.3	59.8	68.5
120	06649000	La Prele Creek near Douglas, Wyo.	1.14	16.1	36.9	58.5	97.6	138	189
121	06670500	Laramie River near Fort Laramie, Wyo.	4.08	24.5	54.6	81.9	125	162	205
122	06671000	Rawhide Creek near Lingle, Wyo.	.609	5.78	14.5	24.0	42.1	61.3	88.4
123	06677500	Horse Creek near Lyman, Nebr.	1.87	19.1	36.3	52.1	78.7	104	135
124	06678000	Sheep Creek near Morrill, Nebr.	1.55	5.49	7.65	9.12	11.1	12.5	13.9
125	06679000	Dry Spottedtail Creek at Mitchell, Nebr.	.963	9.72	20.3	31.4	51.5	72.8	100
126	06680000	Tub Springs near Scottsbluff, Nebr.	1.05	14.4	23.8	32.0	48.7	66.6	90.4
127	06681000	Winters Creek near Scottsbluff, Nebr.	1.51	10.9	17.8	23.0	30.0	35.4	41.1
128	06684000	Red Willow Creek near Bayard, Nebr.	2.46	22.7	38.8	50.7	66.8	79.3	92.6
129	06685000	Pumpkin Creek near Bridgeport, Nebr.	.869	4.67	12.1	20.8	38.5	58.6	86.9
130	06687000	Blue Creek near Lewellen, Nebr.	1.97	6.20	9.46	12.1	16.1	19.6	23.5
131	06692000	Birdwood Creek near Hershey, Nebr.	4.33	11.7	17.1	21.3	27.5	32.9	38.5
132	06712000	Cherry Creek near Franktown, Colo.	.251	21.7	68.5	124	232	348	498
133	06776500	Dismal River at Dunning, Nebr.	9.09	14.6	17.0	18.6	20.6	22.1	23.7
134	06779000	Middle Loup River at Arcadia, Nebr.	18.2	79.3	126	166	227	283	348
135	06782500	South Loup River at Ravenna, Nebr.	5.44	102	230	374	651	955	1368
136	06783500	Mud Creek near Sweetwater, Nebr.	1.17	31.7	65.7	92.1	128	156	185
137	06784000	South Loup River at St. Michael, Nebr.	6.88	96.9	230	382	688	1031	1510
138	06785000	Middle Loup River at St. Paul, Nebr.	34.0	235	402	555	799	1028	1310
139	06786000	North Loup River at Taylor, Nebr.	13.0	39.3	52.1	61.2	74.2	84.4	95.4
140	06787500	Calamus River near Burwell, Nebr.	8.47	16.9	22.8	27.2	33.4	38.5	43.9
141	06788500	North Loup River at Ord, Nebr.	24.4	75.1	115	147	196	238	286
142	06790500	North Loup River near St. Paul, Nebr.	27.4	181	340	490	751	1008	1328
143	06791500	Cedar River near Spalding, Nebr.	4.33	16.4	30.0	42.5	64.2	84.7	110
144	06792000	Cedar River near Fullerton, Nebr.	6.82	83.8	179	279	467	666	926

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\bar{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
145	06794000	Beaver Creek at Genoa, Nebr.	3.57	62.3	142	231	402	592	850
146	06795500	Shell Creek near Columbus, Nebr.	1.20	43.3	84.3	116	161	196	232
147	06797500	Elkhorn River at Ewing, Nebr.	4.90	32.3	84.1	148	283	442	674
148	06798500	Elkhorn River at Neligh, Nebr.	7.99	45.6	103	193	357	544	813
149	06799000	Elkhorn River near Norfolk, Nebr.	14.3	108	238	377	643	929	1314
150	06799100	North Fork Elkhorn River near Pierce, Nebr.	2.51	49.6	119	182	278	360	450
151	06799500	Logan Creek near Uehling, Nebr.	5.21	166	329	459	640	782	935
152	06800000	Maple Creek near Nickerson, Nebr.	1.71	70.0	143	201	283	351	419
153	06803000	Salt Creek at Roca, Nebr.	1.20	75.3	194	300	459	586	725
154	06803555	Salt Creek at Greenwood, Nebr.	7.65	297	762	1176	1787	2292	2827
155	06804000	Wahoo Creek at Ithaca, Nebr.	2.17	111	233	338	456	555	654
156	06806500	Weeping Water Creek at Union, Nebr.	2.31	99.4	227	331	482	598	719
157	06807000	Missouri River at Nebraska City, Nebr.	990	2554	3377	3970	4776	5418	6097
158	06808500	West Nishnabotna River at Randolph, Iowa	15.6	484	674	787	921	1011	1096
159	06809500	East Nishnabotna River at Red Oak, Iowa	10.6	275	484	637	836	989	1142
160	06813000	Tarkio River at Fairfax, Mo.	5.24	189	334	436	558	643	728
161	06814000	Turkey Creek near Seneca, Kans.	3.48	136	295	431	637	819	1014
162	06817000	Nodaway River at Clarinda, Iowa	9.09	278	470	598	753	864	969
163	06817500	Nodaway River near Burlington Junction, Mo.	14.9	382	685	895	1153	1337	1516
164	06818000	Missouri River at St. Joseph, Mo.	1100	2790	5635	6790	8578	9447	10624
165	06819190	East Fork One Hundred and Two River near Bedford, Iowa	1.43	57.7	163	206	265	299	338
166	06819500	One Hundred And Two River at Maryville, Mo.	5.83	209	334	422	535	620	705
167	06820500	Platte River near Agency, Mo.	24.5	409	688	904	1195	1428	1672
168	06821500	Arikaree River at Haigler, Nebr.	.697	69.4	186	331	649	1028	1589
169	06823000	North Fork Republican River at Colo.-Nebr. State line	1.37	8.36	16.8	25.4	40.8	56.7	77.3
170	06823500	Buffalo Creek near Haigler, Nebr.	.221	.934	1.56	2.15	3.06	3.94	4.96
171	06824000	Rock Creek at Parks, Nebr.	.402	1.25	2.29	3.31	5.01	6.66	8.72
172	06824500	Republican River at Benkelman, Nebr.	2.56	40.5	106	186	357	558	853
173	06825500	Landsman Creek near Hale, Colo.	.108	42.2	96.3	148	235	317	414
174	06827500	South Fork Republican River near Benkelman, Nebr.	1.54	80.2	201	297	425	518	609
175	06828500	Republican River at Stratton, Nebr.	3.91	104	235	357	550	725	926
176	06831500	Frenchman Creek near Imperial, Nebr.	1.93	7.59	16.3	25.5	42.8	61.2	85.5
177	06835000	Stinking Water Creek near Palisade, Nebr.	1.21	10.1	22.3	35.7	60.9	88.4	125
178	06836000	Blackwood Creek near Culbertson, Nebr.	.188	12.1	28.9	48.2	86.7	130	191
179	06838000	Red Willow Creek near Red Willow, Nebr.	.892	11.5	23.2	34.8	55.5	76.2	102
180	06841000	Medicine Creek above Harry Strunk Lake, Nebr.	1.94	59.8	145	245	448	677	1000
181	06844500	Republican River near Orleans, Nebr.	9.29	110	195	263	360	442	530
182	06845000	Sappa Creek near Oberlin, Kans.	.501	24.6	71.1	124	223	329	462

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\bar{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
183	06845200	Sappa Creek near Beaver City, Nebr.	1.08	39.9	83.6	122	180	231	289
184	06846500	Beaver Creek at Cedar Bluffs, Kans.	.632	17.0	40.2	63.5	103	142	187
185	06847000	Beaver Creek near Beaver City, Nebr.	.770	16.1	41.6	66.3	111	153	203
186	06847500	Sappa Creek near Stamford, Nebr.	1.93	37.7	89.5	139	221	297	385
187	06848500	Prairie Dog Creek near Woodruff, Kans.	1.17	66.6	143	213	326	425	544
188	06851000	Center Creek at Franklin, Nebr.	.200	7.79	30.3	60.3	124	195	292
189	06853500	Republican River near Hardy, Nebr.	17.7	130	235	340	538	736	991
190	06855800	Buffalo Creek near Jamestown, Kans.	2.28	66.3	164	261	425	578	759
191	06855900	Wolf Creek near Concordia, Kans.	.357	30.3	57.5	79.3	111	137	166
192	06856000	Republican River at Concordia, Kans.	22.0	224	397	538	765	991	1246
193	06859500	Ladder Creek below Chalk Creek near Scott City, Kans.	.241	21.0	75.1	145	289	450	671
194	06860000	Smoky Hill River at Elkader, Kans.	.974	55.0	203	397	802	1250	1870
195	06861000	Smoky Hill River near Arnold, Kans.	2.04	144	368	558	821	1023	1227
196	06862700	Smoky Hill River near Schoechen, Kans.	.977	58.1	170	287	490	682	911
197	06863500	Big Creek near Hays, Kans.	1.19	51.8	102	150	227	300	391
198	06864050	Smoky Hill River near Bunker Hill, Kans.	5.81	193	397	538	765	963	1133
199	06864500	Smoky Hill River at Ellsworth, Kans.	7.42	238	482	623	765	906	1020
200	06866500	Smoky Hill River near Mentor, Kans.	12.4	130	238	340	482	562	821
201	06867000	Saline River near Russell, Kans.	3.37	107	249	380	578	753	952
202	06867500	Paradise Creek near Paradise, Kans.	.549	26.0	88.9	167	326	499	725
203	06869500	Saline River at Tescott, Kans.	6.26	88.7	197	297	459	606	776
204	06870200	Smoky Hill River at New Cambria, Kans.	18.2	167	410	722	1520	2630	4390
205	06871000	North Fork Solomon River at Glade, Kans.	.957	65.1	185	317	561	810	1125
206	06871500	Bow Creek near Stockton, Kans.	.436	38.2	93.5	148	240	329	433
207	06872500	North Fork Solomon River at Portis, Kans.	4.11	113	255	368	567	736	906
208	06873000	South Fork Solomon River above Webster Reservoir, Kans.	2.04	126	354	598	1031	1456	1977
209	06874000	South Fork Solomon River at Osborne, Kans.	3.80	51.0	155	272	482	680	906
210	06876700	Salt Creek near Ada, Kans.	1.58	35.7	127	235	439	646	901
211	06876900	Solomon River at Niles, Kans.	15.9	192	397	589	912	1218	1586
212	06877600	Smoky Hill River at Enterprise, Kans.	45.7	281	544	790	1200	1600	2080
213	06878000	Chapman Creek near Chapman, Kans.	2.40	107	204	281	394	487	586
214	06878500	Lyon Creek near Woodbine, Kans.	3.06	183	510	853	1450	2030	2720
215	06879900	Big Blue River at Surprise, Nebr.	.830	48.1	123	191	295	380	473
216	06880000	Lincoln Creek near Seward, Nebr.	1.28	34.6	75.1	108	154	191	229
217	06880500	Big Blue River at Seward, Nebr.	3.17	81.3	194	291	433	550	674
218	06880800	West Fork Big Blue River near Dorchester, Nebr.	5.01	89.2	162	214	281	331	382

TABLE 8.—*Discharge characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	$\overline{Q}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
219	06881000	Big Blue River near Crete, Nebr.	9.94	195	408	578	813	1000	1187
220	06883575	Little Blue River near Alexandria, Nebr.	6.74	182	343	459	612	728	841
221	06884200	Mill Creek at Washington, Kans.	2.82	132	258	363	516	643	782
222	06884400	Little Blue River near Barnes, Kans.	18.6	346	660	923	1314	1652	2028
223	06885500	Black Vermillion River near Frankfort, Kans.	3.88	210	487	739	1142	1496	1898
224	06887500	Kansas River at Wamego, Kans.	138	1080	2080	2920	4109	5300	6520
225	06888000	Vermillion Creek near Wamego, Kans.	2.57	141	297	425	612	768	935
226	06889000	Kansas River at Topeka, Kans.	155	1312	2465	3399	4787	5977	7252
227	06891000	Kansas River at Lecompton, Kans.	200	1561	2889	3881	5326	6459	7677
228	06891500	Wakarusa River near Lawrence, Kans.	5.61	184	360	496	688	841	1002
229	06892000	Stranger Creek near Tonganoxie, Kans.	6.17	164	312	431	598	734	875
230	06892350	Kansas River at DeSoto, Kans.	196	1420	2830	3680	4530	5670	6800
231	06894000	Little Blue River near Lake City, Mo.	3.82	113	180	226	286	329	371
232	06895500	Missouri River at Waverly, Mo.	1370	3200	6955	8389	10458	11484	12773
233	06897500	Grand River near Gallatin, Mo.	32.3	700	1105	1380	1720	1969	2212
234	06898100	Thompson River at Mount Moriah, Mo.	15.6	419	623	753	915	1028	1139
235	06898400	Weldon River near Leon, Iowa	2.07	109	360	471	623	724	833
236	06899500	Thompson River at Trenton, Mo.	26.3	640	1074	1371	1739	2011	2272
237	06899700	Shoal Creek near Braymer, Mo.	7.39	199	300	368	450	507	567
238	06902000	Grand River near Sumner, Mo.	108	1513	2340	2889	3626	4136	4674
239	06902200	West Yellow Creek near Brookfield, Mo.	3.09	87.8	144	184	234	271	309
240	06905500	Chariton River near Prairie Hill, Mo.	32.4	394	561	663	785	870	949
241	06907700	Blackwater River at Valley City, Mo.	12.8	683	1263	1702	2297	2759	3229
242	06908000	Blackwater River near Blue Lick, Mo.	20.5	283	499	666	901	1096	1306
243	06909000	Missouri River at Booneville, Mo.	1640	2148	8167	10521	12748	16477	19328
244	06910500	Moreau River near Jefferson City, Mo.	10.3	385	521	603	697	762	824
245	06911900	Dragoon Creek near Burlingame, Kans.	1.95	153	245	309	394	456	521
246	06913500	Marais Des Cygnes River near Ottawa, Kans.	18.4	314	711	1110	1810	2501	3371
247	06914000	Pottawatomie Creek near Garnett, Kans.	6.54	303	561	779	1105	1388	1705
248	06925200	Starks Creek at Preston, Mo.	.101	21.9	34.3	42.8	53.0	60.6	68.0
249	06930000	Big Piney River near Big Piney, Mo.	15.5	342	581	751	969	1133	1300
250	06931500	Little Beaver Creek near Rolla, Mo.	.154	38.8	66.0	85.5	111	131	151
251	06932000	Little Piney Creek at Newburg, Mo.	4.30	177	357	504	722	906	1108
252	06934500	Missouri River at Hermann, Mo.	2260	4941	111716	14452	18413	20570	23193

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*

[ACW, active-channel width, in meters; DEP, average depth, in meters, BUS, silt-clay content of the bed, in percent, d_{50}, median particle size of the bed, in millimeters; BSH, bank silt-clay content, in percent (high); BSL, low bank silt-clay content, in percent; GRA, channel gradient, dimensionless]

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
1	06018500	Beaverhead River near Twin Bridges, Mont.	16.2	1.07	2	6.0	51	51	0.0016
2	06025500	Big Hole River near Melrose, Mont.	51.8	1.73	1	150	50	50	.0028
3	06027200	Jefferson River at Silver Star, Mont.	64.0	1.68	1	38	50	50	.00080
4	06050000	Hyalite Creek at Hyalite Ranger Station near Bozeman, Mont.	10.7	1.07	1	250	70	70	.028
5	06052500	Gallatin River at Logan, Mont.	44.2	1.46	1	25	5	5	.0018
6	06115200	Missouri River near Landusky, Mont.	190	6.33	15	.18	40	40	.00049
7	06120500	Musselshell River at Harlowton, Mont.	18.3	.74	1	130	40	19	.0029
8	06123500	Musselshell River near Ryegate, Mont.	22.9	.64	1	14	33	25	.0020
9	06126500	Musselshell River near Roundup, Mont.	20.4	.98	1	10	34	34	.0018
10	06127500	Musselshell River at Musselshell, Mont.	30.5	.91	12	8.6	29	13	.00097
11	06185500	Missouri River near Culbertson, Mont.	320	10.7	10	.19	55	55	.00016
12	06191500	Yellowstone River at Corwin Springs, Mont.	82.3	3.05	1	130	70	70	.0023
13	06192500	Yellowstone River near Livingston, Mont.	88.4	3.66	1	100	60	60	.0027
14	06197500	Boulder River near Contact, Mont.	31.4	.61	1	150	36	30	.0018
15	06200000	Boulder River at big Timber, Mont.	36.6	1.46	1	130	50	50	.0110
16	06205000	Stillwater River near Absarokee, Mont.	33.5	1.37	1	230	60	60	.0062
17	06233000	Little Popo Agie River near Lander, Wyo.	14.0	.88	1	51	30	30	.0054
18	06235500	Little Wind River near Riverton, Wyo.	46.6	1.37	1	120	66	44	.00096
19	06244500	Fivemile Creek above Wyoming Canal, near Pavillion, Wyo.	2.99	.27	1	11	35	17	.0052
20	06258000	Muddy Creek near Shoshoni, Wyo.	6.86	.74	1	6.8	33	33	.0039
21	06270000	Nowood River near Ten Sleep, Wyo.	11.3	1.98	43	.074	51	51	.0016
22	06290500	Little Bighorn River below Pass Creek, near Wyola, Mont.	22.6	1.74	1	38	40	40	.0028
23	06294000	Little Bighorn River near Hardin, Mont.	42.7	1.42	1	19	50	50	.0020
24	06294700	Bighorn River at Bighorn, Mont.	82.3	3.2	1	10	77	22	.00045
25	06305500	Goose Creek below Sheridan, Wyo.	22.6	1.28	1	25	60	60	.0027
26	06308500	Tongue River at Miles City Mont.	47.2	1.10	2	4.2	47	47	.00066
27	06309000	Yellowstone River at Miles City, Mont.	219	7.30	5	10	33	33	.00068
28	06317000	Powder River at Arvada, Wyo.	45.7	1.92	12	.16	54	25	.00087
29	06318500	Clear Creek near Buffalo, Wyo.	10.7	.54	1	20	31	31	.024
30	06323500	Piney Creek at Ucross, Wyo.	16.3	.62	1	50	34	34	.0043
31	06326500	Powder River near Locate, Mont.	62.5	1.79	3	.35	30	30	.00095
32	06329200	Burns Creek near Savage, Mont.	3.32	.63	13	8.3	38	14	.0032
33	06332000	White Earth River at White Earth, N. Dak.	5.18	.88	4	3.0	41	34	.00069
34	06334500	Little Missouri River at Camp Crook, S. Dak.	17.7	.68	3	1.4	57	25	.00080

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
35	06335000	Little Beaver Creek near Marmarth, N. Dak.	9.30	1.02	3	12	28	9	.00090
36	06335500	Little Missouri River at Marmarth, N. Dak.	57.9	1.28	3	.62	32	32	.00071
37	06336000	Little Missouri River at Medora, N. Dak.	61.0	1.43	1	.60	29	25	.00063
38	06336500	Beaver Creek at Wibaux, Mont.	6.40	.65	7	4.8	12	11	.0018
39	06337000	Little Missouri River near Watford City, N. Dak.	70.1	1.73	3	.17	65	65	.00078
40	06339500	Knife River near Golden Valley, N. Dak.	13.7	1.22	2	.50	41	17	.00040
41	06340000	Spring Creek at Zap, N. Dak.	6.71	.79	11	.26	33	29	.00090
42	06340500	Knife River at Hazen, N. Dak.	16.2	1.36	2	.46	32	26	.00050
43	06341400	Turtle Creek near Turtle Lake, N. Dak.	.762	.049	76	.02	95	58	.0011
44	06341800	Painted Woods Creek near Wilton, N. Dak.	3.05	.19	1	100	27	16	.0014
45	06343000	Heart River near South Heart, N. Dak.	2.59	.58	12	.47	55	39	.00050
46	06345000	Green River near Gladstone, N. Dak.	6.10	.38	1	15	24	23	.0010
47	06345500	Heart River near Richardton, N. Dak.	10.4	.90	1	50	40	25	.00056
48	06347000	Antelope Creek near Carson, N. Dak.	5.79	1.28	3	5.6	46	40	.0014
49	06348000	Heart River near Lark, N. Dak.	29.0	1.09	1	.42	41	34	.00093
50	06349000	Heart River near Mandan, N. Dak.	30.5	1.38	5	.22	40	33	.00045
51	06349500	Apple Creek near Menoken, N. Dak.	6.40	.79	23	.18	42	26	.00028
52	06350000	Cannonball River at Regent, N. Dak.	6.40	.50	15	.40	48	24	.00054
53	06351000	Cannonball River below Bentley, N. Dak.	14.9	1.40	5	.29	22	22	.00046
54	06352000	Cedar Creek near Haynes, N. Dak.	7.32	.82	5	1.4	49	46	.0014
55	06354000	Cannonball River at Breien, N. Dak.	30.5	1.58	11	.14	42	36	.00056
56	06354500	Beaver Creek at Linton, N. Dak.	8.53	.79	5	1.5	78	59	.0016
57	06355500	North Fork Grand River near White Butte, S. Dak.	10.1	.85	1	8.1	8	8	.0010
58	0635600	South Fork Grand River at Buffalo, S. Dak.	5.18	.87	9	.51	16	16	.0014
59	06356500	South Fork Grand River near Cash, S. Dak.	7.92	.70	20	1.7	41	41	.0012
60	06357800	Grand River at Little Eagle, S. Dak.	42.7	.38	4	.24	18	2	.00046
61	06359500	Moreau River near Faith, S. Dak.	18.6	.69	5	.35	27	18	.00043
62	06394000	Beaver Creek near Newcastle, Wyo.	7.62	1.09	10	25	68	64	.00066
63	06395000	Cheyenne River at Edgemont, S. Dak.	21.3	.48	1	.65	28	24	.0014
64	06402500	Beaver Creek near Buffalo Gap, S. Dak.	3.20	.46	6	17	55	47	.0054
65	06406000	Battle Creek at Hermosa, S. Dak.	3.51	.22	1	180	10	1	.0022
66	06409000	Castle Creek above Deerfield Reservoir, near Hill City, S. Dak.	3.66	.40	5	1.8	61	57	.0082
67	06410500	Rapid Creek above Pactola Reservoir, at Silver City, S. Dak.	7.92	.37	1	100	73	66	.0052
68	06414000	Rapid Creek at Rapid City, S. Dak.	10.7	.54	2	130	53	28	.0072
69	06421500	Rapid Creek near Farmingdale, S. Dak.	7.92	.44	1	60	50	50	.0031
70	06430500	Redwater Creek at Wyo.—S. Dak. State line	6.40	.92	8	3.4	44	39	.0022

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
71	06431500	Spearfish Creek at Spearfish, S. Dak.	10.4	.44	1	110	5	5	.014
72	06433000	Redwater River above Belle Fourche, S. Dak.	13.4	.53	1	40	64	53	.0029
73	06437000	Belle Fourche River near Sturgis, S. Dak.	25.9	.55	1	50	70	58	.0011
74	06444000	White River at Crawford, Nebr.	4.57	.84	3	.28	70	44	.0043
75	06447000	White River near Kadoka, S. Dak.	47.2	.56	9	.32	81	81	.00093
76	06447500	Little White River near Martin, S. Dak.	4.88	.61	11	.21	69	63	.0018
77	06448000	Lake Creek above Refuge, near Tuthill, S. Dak.	3.66	.38	1	.30	24	10	.0017
78	06449100	Little White River near Vetal, S. Dak.	11.6	.52	1	.31	50	22	.0013
79	06449500	Little White River near Rosebud, S. Dak.	15.2	.73	1	.28	36	23	.0021
80	06450500	Little White River below White River, S. Dak.	16.8	.24	1	.44	66	52	.0010
81	06453500	Ponca Creek at Anoka, Nebr.	13.7	.63	1	.58	43	17	.0018
82	06453600	Ponca Creek at Verdel, Nebr.	21.6	.68	1	.51	42	40	.0014
83	06454000	Niobrara River at Wyo.-Nebr. State line	3.66	.66	17	.16	31	28	.0055
84	06454100	Niobrara River at Agate, Nebr.	4.57	.70	9	.25	27	27	.0024
85	06454500	Niobrara River above Box Butte Reservoir, Nebr.	5.79	.60	1	.35	41	40	.0013
86	06461000	Minnechaduza Creek at Valentine, Nebr.	10.7	.70	18	.25	22	13	.0038
87	06462500	Plum Creek at Meadville, Nebr.	25.3	1.22	4	.31	39	36	.0018
88	06464500	Keya Paha River at Wewela, S. Dak.	15.8	.79	1	.33	35	32	.0012
89	06464900	Keya Paha River near Naper, Nebr.	35.7	.89	1	.29	36	24	.0012
90	06466500	Brazile Creek near Niobrara, Nebr.	36.3	1.06	1	.41	49	25	.0015
91	06467600	James River near Manfred, N. Dak.	1.83	.20	40	100	30	24	.00047
92	06469500	Pipestem Creek near Pingree, N. Dak.	3.96	.36	1	2.9	39	32	.00042
93	06470000	James River at Jamestown, N. Dak.	12.5	1.03	5	1.8	28	28	.00044
94	06470500	James River at La Moure, N. Dak.	21.3	1.52	3	8.0	48	48	.000094
95	06471500	Elm River at Westport, S. Dak.	10.7	.29	1	2.1	5	4	.00035
96	06473000	James River at Ashton, S. Dak.	18.3	.53	55	.059	61	40	.000072
97	06477000	James River near Forestburg, S. Dak.	31.1	1.58	5	.26	57	16	.000060
98	06477500	Firesteel Creek near Mount Vernon, S. Dak.	8.53	.95	2	.99	32	21	.00060
99	06478500	James River near Scotland, S. Dak.	33.5	1.92	47	.055	39	39	.000082
100	06480000	Big Sioux River near Brookings, S. Dak.	22.0	1.27	5	1.6	54	10	.00028
101	06481000	Big Sioux River near Dell Rapids, S. Dak.	22.9	1.86	1	.40	82	62	.00058
102	06481500	Skunk Creek at Sioux Falls, S. Dak.	14.0	1.52	5	.95	22	22	.00069
103	06483500	Rock River near Rock Valley, Iowa	34.4	1.52	1	.89	38	14	.00049
104	06485500	Big Sioux River at Akron, Iowa	54.9	2.70	31	.17	63	48	.00025
105	06486000	Missouri River at Sioux City, Iowa	350	17	1	.34	60	60	.00021
106	06600100	Floyd River at Alton, Iowa	20.1	.52	19	.27	57	47	.00066
107	06600300	West Branch Floyd River near Struble, Iowa	9.75	.50	6	.44	58	37	.0012
108	06600500	Floyd River at James, Iowa	24.7	1.10	3	.52	86	67	.00032

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
109	06601000	Omaha Creek at Homer, Nebr.	8.53	1.01	49	.067	82	70	.0012
110	06606600	Little Sioux River at Correctionville, Iowa	33.8	2.44	20	.18	75	44	.00023
111	06607000	Odebolt Creek near Arthur, Iowa	7.32	.35	32	.29	77	60	.0014
112	06607200	Maple River at Mapleton, Iowa	35.0	1.01	5	.35	79	55	.00083
113	06608000	Tekamah Creek at Tekamah, Nebr.	5.73	.51	24	.68	79	75	.0012
114	06608500	Soldier River at Pisgah, Iowa	29.3	1.46	2	.37	82	76	.00074
115	06609500	Boyer River at Logan, Iowa	32.9	2.29	1	.42	90	86	.00058
116	06610000	Missouri River at Omaha, Nebr.	290	11.6	1	.18	65	65	.00016
117	06628900	Pass Creek near Elk Mountain, Wyo.	8.69	.98	1	150	23	20	.0092
118	06632400	Rock Creek above King Canyon Canal near Arlington, Wyo.	11.9	.79	1	230	50	50	.017
119	06639000	Sweetwater River near Alcova, Wyo.	24.4	.80	1	1.7	33	25	.0010
120	06649000	La Prele Creek near Douglas, Wyo.	9.30	.53	1	180	60	60	.0030
121	06670500	Laramie River near Fort Laramie, Wyo.	19.2	1.02	10	.41	28	14	.0018
122	06671000	Rawhide Creek near Lingle, Wyo.	3.93	.82	3	.17	50	49	.0026
123	06677500	Horse Creek near Lyman, Nebr.	17.1	1.01	7	.11	45	39	.0017
124	06678000	Sheep Creek near Morrill, Nebr.	5.64	.92	1	.25	43	24	.00079
125	06679000	Dry Spottedtail Creek at Mitchell, Nebr.	7.01	.64	1	.32	42	37	.0043
126	06680000	Tub Springs near Scottsbluff, Nebr.	5.94	.65	3	6.6	50	29	.0041
127	06681000	Winters Creek near Scottsbluff, Nebr.	5.33	.86	1	9.2	42	23	.0015
128	06684000	Red Willow Creek near Bayard, Nebr.	14.0	.59	1	7.3	60	51	.00091
129	06685000	Pumpkin Creek near Bridgeport, Nebr.	5.49	.24	10	.16	44	17	.0013
130	06687000	Blue Creek near Lewellen, Nebr.	11.7	.57	1	.38	46	40	.0039
131	06692000	Birdwood Creek near Hershey, Nebr.	15.2	.80	1	.29	42	28	.0024
132	06712000	Cherry Creek near Franktown, Colo.	3.96	.22	8	1.0	44	44	.025
133	06776500	Dismal River at Dunning, Nebr.	26.2	.91	1	.26	61	50	.0010
134	06779000	Middle Loup River at Arcadia, Nebr.	62.5	1.22	1	.20	53	39	.0015
135	06782500	South Loup River at Ravenna, Nebr.	38.4	1.25	1	.19	54	42	.0010
136	06783500	Mud Creek near Sweetwater, Nebr.	10.4	1.52	38	.16	86	61	.00051
137	06784000	South Loup River at St. Michael, Nebr.	45.1	1.19	1	.18	76	67	.00086
138	06785000	Middle Loup River at St. Paul, Nebr.	134	1.07	1	.32	58	51	.0010
139	06786000	North Loup River at Taylor, Nebr.	47.2	1.19	1	.27	46	45	.0013
140	06787500	Calamus River near Burwell, Nebr.	70.7	.25	1	.28	38	24	.0010
141	06788500	North Loup River at Ord, Nebr.	75.6	.98	1	.38	63	36	.0013
142	06790500	North Loup River near St. Paul, Nebr.	85.3	1.52	1	.27	70	43	.0011
143	06791500	Cedar River near Spalding, Nebr.	24.7	.26	1	.27	21	15	.00083
144	06792000	Cedar River near Fullerton, Nebr.	31.1	1.37	2	.26	63	46	.00085

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
145	06794000	Beaver Creek at Genoa, Nebr.	16.0	1.28	1	.28	84	84	.0014
146	06795500	Shell Creek near Columbus, Nebr.	6.86	1.00	25	.30	66	65	.00054
147	06797500	Elkhorn River at Ewing, Nebr.	32.0	.97	1	.34	22	13	.00073
148	06798500	Elkhorn River at Neligh, Nebr.	54.9	.92	1	.28	15	7	.00094
149	06799000	Elkhorn River near Norfolk, Nebr.	80.8	1.01	2	.24	24	15	.00069
150	06799100	North Fork Elkhorn River near Pierce, Nebr.	12.8	.90	11	.25	63	17	.00052
151	06799500	Logan Creek near Uehling, Nebr.	23.2	1.31	1	.24	79	48	.00039
152	06800000	Maple Creek near Nickerson, Nebr.	15.7	.68	2	.31	64	50	.0014
153	06803000	Salt Creek at Roca, Nebr.	7.01	1.30	77	.03	77	68	.00066
154	06803555	Salt Creek at Greenwood, Nebr.	51.8	1.56	1	.59	66	64	.00051
155	06804000	Wahoo Creek at Ithaca, Nebr.	10.2	1.06	1	.38	73	70	.00063
156	06806500	Weeping Water Creek at Union, Nebr.	8.23	1.58	29	.50	79	75	.00086
157	06807000	Missouri River at Nebraska City, Nebr.	270	10	1	.43	65	59	.00024
158	06808500	West Nishnabotna River at Randolph, Iowa	62.5	1.07	13	.34	75	72	.00051
159	06809500	East Nishnabotna River at Red Oak, Iowa	41.2	1.52	1	.42	80	61	.00040
160	06813000	Tarkio River at Fairfax, Mo.	29.3	1.49	2	.41	77	71	.00090
161	06814000	Turkey Creek near Seneca, Kans.	9.14	1.83	14	.42	82	81	.00073
162	06817000	Nodaway River at Clarinda, Iowa	43.3	1.43	1	.46	68	54	.00056
163	06817500	Nodaway River near Burlington Junction, Mo.	60.4	1.37	3	.35	70	66	.00072
164	06818000	Missouri River at St. Joseph, Mo.	270	10	1	.40	83	76	.00021
165	06819190	East Fork One Hundred and Two River near Bedford, Iowa	14.3	.87	22	.40	69	35	.00080
166	06819500	One Hundred and Two River at Maryville, Mo.	24.7	1.04	2	.50	66	59	.00049
167	06820500	Platte River near Agency, Mo.	41.2	2.35	6	.33	51	30	.00036
168	06821500	Arikaree River at Haigler, Nebr.	5.94	.61	1	.36	33	25	.0015
169	06823000	North Fork Republican River at Colo.-Nebr. State line	5.79	.55	1	.48	47	37	.0011
170	06823500	Buffalo Creek near Haigler, Nebr.	1.92	.47	4	.34	29	13	.0025
171	06824000	Rock Creek at Parks, Nebr.	2.74	.37	2	.30	41	25	.0025
172	06824500	Republican River at Benkelman, Nebr.	36.8	.30	1	.30	22	22	.0018
173	06825500	Landsman Creek near Hale, Colo.	3.81	.71	24	.34	37	14	.0027
174	06827500	South Fork Republican River near Benkelman, Nebr.	35.1	.30	1	.34	30	30	.0020
175	06828500	Republican River at Stratton, Nebr.	38.1	.30	1	.30	30	30	.0020
176	06831500	Frenchman Creek near Imperial, Nebr.	11.0	.50	11	2.4	45	39	.0014
177	06835000	Stinking Water Creek near Palisade, Nebr.	8.23	.70	19	.47	88	71	.0023
178	06836000	Blackwood Creek near Culbertson, Nebr.	3.84	1.08	40	.090	79	50	.0013
179	06838000	Red Willow Creek near Red Willow, Nebr.	5.49	1.04	51	.058	55	37	.0013
180	06841000	Medicine Creek above Harry Strunk Lake, Nebr.	12.3	.65	17	.72	68	64	.0011
181	06844500	Republican River near Orleans, Nebr.	43.9	1.71	1	.59	58	56	.00066

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	BSH	BSL	GRA
182	06845000	Sappa Creek near Oberlin, Kans.	4.88	.62	2	.80	89	89	.0013
183	06845200	Sappa Creek near Beaver City, Nebr.	7.92	.65	5	.45	94	94	.00080
184	06846500	Beaver Creek at Cedar Bluffs, Kans.	4.11	.64	92	.02	98	98	.0010
185	06847000	Beaver Creek near Beaver City, Nebr.	4.27	.43	34	.56	58	26	.0013
186	06847500	Sappa Creek near Stamford, Nebr.	8.08	.38	8	.56	46	35	.00067
187	06848500	Prairie Dog Creek near Woodruff, Kans.	4.88	.40	62	.030	80	67	.00064
188	06851000	Center Creek at Franklin, Nebr.	6.00	.75	1	.28	30	29	.0048
189	06853500	Republican River near Hardy, Nebr.	42.7	.86	1	.71	43	43	.00072
190	06855800	Buffalo Creek near Jamestown, Kans.	7.32	.47	82	.03	94	94	.00028
191	06855900	Wolf Creek near Concordia, Kans.	3.35	.29	88	.02	96	96	.00061
192	06856000	Republican River at Concordia, Kans.	57.9	2.9	1	.46	62	13	.00066
193	06859500	Ladder Creek below Chalk Creek near Scott City, Kans.	2.74	.17	4	1.7	63	33	.0026
194	06860000	Smoky Hill River at Elkader, Kans.	6.86	.40	19	.74	34	32	.0028
195	06861000	Smoky Hill River near Arnold, Kans.	37.2	.40	1	.80	30	30	.0012
196	06862700	Smoky Hill River near Schoechen, Kans.	6.71	.18	1	1.2	30	8	.0010
197	06863500	Big Creek near Hays, Kans.	7.01	1.01	29	.41	66	54	.00081
198	06864050	Smoky Hill River near Bunker Hill, Kans.	33.5	.47	1	.78	69	66	.00074
199	06864500	Smoky Hill River at Ellsworth, Kans.	30.5	.65	1	.77	55	52	.00055
200	06866500	Smoky Hill River near Mentor, Kans.	33.2	1.27	10	.33	90	52	.00021
201	06867000	Saline River near Russell, Kans.	13.7	.63	4	.64	62	58	.00058
202	06867500	Paradise Creek near Paradise, Kans.	6.10	.50	27	.51	78	59	.0013
203	06869500	Saline River at Tescott, Kans.	13.0	1.29	37	1.7	52	52	.00038
204	06870200	Smoky Hill River at New Cambria, Kans.	24.4	2.44	5	.20	77	70	.00027
205	06871000	North Fork Solomon River at Glade, Kans.	7.01	.14	7	.47	86	73	.0013
206	06871500	Bow Creek near Stockton, Kans.	7.01	.16	1	.72	33	33	.0019
207	06872500	North Fork Solomon River at Portis, Kans.	15.5	.38	1	.57	85	45	.00054
208	06873000	South Fork Solomon River above Webster Reservoir, Kans.	11.0	.25	2	.59	28	9	.0015
209	06874000	South Fork Solomon River at Osborne, Kans.	11.6	.28	9	.88	18	11	.0010
210	06876700	Salt Creek near Ada, Kans.	7.01	.45	51	.04	87	59	.00038
211	06876900	Solomon River at Niles, Kans.	23.5	1.74	13	.58	57	36	.00016
212	06877600	Smoky Hill River at Enterprise, Kans.	59.4	2.29	2	.43	94	57	.00031
213	06878000	Chapman Creek near Chapman, Kans.	9.75	1.98	52	.05	97	83	.00054
214	06878500	Lyon Creek near Woodbine, Kans.	7.92	.61	90	.02	92	46	.00079
215	06879900	Big Blue River at Surprise, Nebr.	6.10	.59	44	1.2	76	42	.00044
216	06880000	Lincoln Creek near Seward, Nebr.	7.62	1.12	74	.03	74	63	.00046
217	06880500	Big Blue River at Seward, Nebr.	11.0	1.01	42	.22	82	75	.00039

TABLE 9.—*Geometry measurements and sediment characteristics of selected streams in the Missouri River basin*—Continued

Map No.	Station No.	Station Name	ACW	DEP	BDS	d_{50}	$\widetilde{\text{BSH}}$	BSL	GRA
218	06880800	West Fork Big Blue River near Dorchester, Nebr.	16.5	1.28	2	.27	74	73	.00025
219	06881000	Big Blue River near Crete, Nebr.	26.8	1.37	1	.35	84	23	.00028
220	06883575	Little Blue River near Alexandria, Nebr.	39.6	2.00	1	.62	70	65	.0012
221	06884200	Mill Creek at Washington, Kans.	11.1	.84	9	.42	73	58	.00062
222	06884400	Little Blue River near Barnes, Kans.	52.4	1.22	10	.66	91	81	.00052
223	06885500	Black Vermillion River near Frankfort, Kans.	12.8	.92	78	.03	84	60	.00049
224	06887500	Kansas River at Wamego, Kans.	223	11.0	1	.65	12	12	.00025
225	06888000	Vermillion Creek near Wamego, Kans.	7.47	.75	64	.04	79	63	.00072
226	06889000	Kansas River at Topeka, Kans.	159	8.0	1	.80	90	64	.00027
227	06891000	Kansas River at Lecompton, Kans.	171	8.5	1	.86	93	75	.00027
228	06891500	Wakarusa River near Lawrence, Kans.	12.8	1.54	84	.03	95	95	.00039
229	06892000	Stranger Creek near Tonganoxie, Kans.	12.8	1.22	87	.03	76	76	.00018
230	06892350	Kansas River at DeSoto, Kans.	165	8.5	1	.55	83	82	.00034
231	06894000	Little Blue River near Lake City, Mo.	8.84	1.16	65	.03	73	52	.00034
232	06895500	Missouri River at Waverly, Mo.	320	13	1	.38	61	60	.00015
233	06897500	Grand River near Gallatin, Mo.	51.8	2.6	1	.27	62	40	.00034
234	06898100	Thompson River at Mount Moriah, Mo.	43.9	2.01	1	.43	61	38	.00076
235	06898400	Weldon River near Leon, Iowa	21.0	.58	9	.35	70	65	.00079
236	06899500	Thompson River at Trenton, Mo.	82.3	2.13	1	.32	42	21	.00076
237	06899700	Shoal Creek near Braymer, Mo.	11.9	2.01	28	.43	45	39	.00089
238	06902000	Grand River near Sumner, Mo.	70.1	3.96	26	.36	62	12	.00013
239	06902200	West Yellow Creek near Brookfield, Mo.	11.4	1.37	10	.48	47	41	.00052
240	06905500	Chariton River near Prairie Hill, Mo.	53.3	2.17	1	.41	57	50	.00032
241	06907700	Blackwater River at Valley City, Mo.	18.0	2.44	38	.50	61	57	.00027
242	06908000	Blackwater River near Blue Lick, Mo.	18.3	3.66	80	.03	97	65	.00035
243	06909000	Missouri River at Booneville, Mo.	430	17.2	1	.35	58	58	.00016
244	06910500	Moreau River near Jefferson City, Mo.	33.5	2.23	44	1.0	56	52	.00028
245	06911900	Dragoon Creek near Burlingame, Kans.	9.14	.70	1	80	81	81	.00063
246	06913500	Marais Des Cygnes River near Ottawa, Kans.	33.5	1.74	19	.19	70	70	.00039
247	06914000	Pottawatomie Creek near Garnett, Kans.	9.75	1.16	83	.03	93	93	.00020
248	06925200	Starks Creek at Preston, Mo.	2.29	.18	2	8.6	32	30	.0056
249	06930000	Big Piney River near Big Piney, Mo.	44.2	1.77	1	17	37	17	.0011
250	06931500	Little Beaver Creek near Rolla, Mo.	4.27	.28	1	18	9	2	.0056
251	06932000	Little Piney Creek at Newburg, Mo.	15.2	.85	1	15	9	6	.0014
252	06934500	Missouri River at Hermann, Mo.	424	17.0	1	.48	44	44	.00013

TABLE 10.—*Width-discharge and width-gradient-discharge relations expressed in inch-pound units*

[SC_{bd} is silt-clay percentage of bed material; SC_{bk} is silt-clay percentage of bank material; and d_{50} is median particle size of bed material, in millimeters. $\bar{Q}$ is mean discharge, in cubic feet per second; Q_2 through Q_{100} are flood discharges, in cubic feet per second, of recurrence intervals 2 through 100 years; and W is active-channel width, in feet]

Channel type	Equation	Channel type	Equation
Table 2			
High silt-clay bed $SC_{bd}=$ 61.100; $d_{50}<2.0$).	$\bar{Q}=0.088W^{2.12}$ $Q_2=7.7W^{1.86}$ $Q_5=23W^{1.77}$ $Q_{10}=36W^{1.74}$ $Q_{25}=60W^{1.71}$ $Q_{50}=74W^{1.71}$ $Q_{100}=85W^{1.74}$	Sand bed sand banks ($SC_{bd}\leqslant 10$; $SC_{bk}<70$; $d_{50}<2.0$).	$\bar{Q}=0.15W^{1.62}$ $Q_2=7.1W^{1.32}$ $Q_5=19W^{1.26}$ $Q_{10}=34W^{1.21}$ $Q_{25}=68W^{1.15}$ $Q_{50}=100W^{1.12}$ $Q_{100}=130W^{1.12}$
Med. silt-clay bed ($SC_{bd}=$ 31−60; $d_{50}<2.0$).	$\bar{Q}=0.14W^{1.76}$ $Q_2=20W^{1.27}$ $Q_5=64W^{1.16}$ $Q_{10}=180W^{1.08}$ $Q_{25}=220W^{1.05}$ $Q_{50}=340W^{0.99}$ $Q_{100}=380W^{1.02}$	Gravel bed ($d_{50}=$ 2.0−64).	$\bar{Q}=0.095W^{1.81}$ $Q_2=17W^{1.15}$ $Q_5=75W^{0.95}$ $Q_{10}=160W^{0.84}$ $Q_{25}=380W^{0.70}$ $Q_{50}=510W^{0.67}$ $Q_{100}=930W^{0.60}$
Low silt-clay bed ($SC_{bd}=$ 11−30; $d_{50}<2.0$).	$\bar{Q}=0.14W^{1.73}$ $Q_2=22W^{1.25}$ $Q_5=85W^{1.11}$ $Q_{10}=160W^{1.05}$ $Q_{25}=330W^{0.97}$ $Q_{50}=500W^{0.93}$ $Q_{100}=640W^{0.93}$	Cobble bed ($d_{50}>64$).	$\bar{Q}=0.095W^{1.84}$ $Q_2=5.3W^{1.43}$ $Q_5=28W^{1.16}$ $Q_{10}=62W^{1.03}$ $Q_{25}=150W^{0.89}$ $Q_{50}=270W^{0.80}$ $Q_{100}=410W^{0.75}$
Sand bed silt banks ($SC_{bd}\leqslant 10$; $SC_{bk}=$ 70−100; $d_{50}>2.0$).	$\bar{Q}=0.13W^{1.69}$ $Q_2=29W^{1.16}$ $Q_5=92W^{1.07}$ $Q_{10}=170W^{1.02}$ $Q_{25}=330W^{0.96}$ $Q_{50}=470W^{0.93}$ $Q_{100}=600W^{0.92}$		

Channel type	Equation
Table 3	
All data	$\bar{Q}=0.13W^{1.71}$ $Q_2=16W^{1.22}$ $Q_5=55W^{1.10}$ $Q_{10}=100W^{1.04}$ $Q_{25}=200W^{0.97}$ $Q_{50}=290W^{0.94}$ $Q_{100}=370W^{0.94}$

TABLE 10.—*Width-discharge and width-gradient-discharge relations expressed in inch-pound units*—Continued

Channel type	Equation	Channel type	Equation
Table 4			
Low silt-clay bed $SC_{bd}=$ 11−30; $d_{50}<2.0$).	$\bar{Q}=0.0084W^{1.36}G^{-0.59}$ $Q_2=0.89W^{0.80}G^{-0.69}$ $Q_5=3.8W^{0.68}G^{-0.66}$ $Q_{10}=9.4W^{0.64}G^{-0.61}$ $Q_{25}=28W^{0.60}G^{-0.54}$ $Q_{50}=58W^{0.58}G^{-0.49}$ $Q_{100}=120W^{0.56}G^{-0.43}$	Sand bed, sand banks ($SC_{bd}\leqslant$ 10; $SC_{bk}<$ 70; $d_{50}<2.0$).	$\bar{Q}=0.023W^{1.34}G^{-0.44}$ $Q_2=1.4W^{1.02}G^{-0.42}$ $Q_5=3.1W^{0.94}G^{-0.46}$ $Q_{10}=5.8W^{0.88}G^{-0.46}$ $Q_{25}=12W^{0.83}G^{-0.44}$ $Q_{50}=19W^{0.80}G^{-0.43}$ $Q_{100}=31W^{0.77}G^{-0.42}$
Sand bed, silt banks ($SC_{bd}\leqslant$ 10; $SC_{bk}=$ 70−100; $d_{50}<2.0$).	$\bar{Q}=0.012W^{1.43}G^{-0.49}$ $Q_2=6.4W^{0.95}G^{-0.34}$ $Q_5=20W^{0.87}G^{-0.33}$ $Q_{10}=39W^{0.81}G^{-0.33}$ $Q_{25}=78W^{0.75}G^{-0.32}$ $Q_{50}=130W^{0.72}G^{-0.30}$ $Q_{100}=190W^{0.68}G^{-0.31}$	Gravel bed ($d_{50}=$ 2.0-64).	$Q_5=28W^{0.75}G^{-0.27}$ $Q_{10}=47W^{0.63}G^{-0.32}$ $Q_{25}=90W^{0.50}G^{-0.35}$ $Q_{50}=140W^{0.42}G^{-0.36}$ $Q_{100}=220W^{0.35}G^{-0.37}$
Cobble bed ($d_{50}>64$).	$\bar{Q}=0.098W^{1.82}G^{-0.01}$ $Q_2=0.95W^{1.39}G^{-0.34}$ $Q_5=3.7W^{1.13}G^{-0.38}$ $Q_{10}=8.6W^{0.99}G^{-0.38}$ $Q_{25}=23W^{0.85}G^{-0.36}$ $Q_{50}=47W^{0.76}G^{-0.34}$ $Q_{100}=91W^{0.68}G^{-0.31}$		

Data source	Equation
Table 5	
All data	$\bar{Q}=0.042W^{1.54}G^{-0.26}$ $Q_2=2.7W^{0.96}G^{-0.40}$ $Q_5=7.1W^{0.82}G^{-0.45}$ $Q_{10}=12W^{0.75}G^{-0.47}$ $Q_{25}=23W^{0.69}G^{-0.48}$ $Q_{50}=34W^{0.65}G^{-0.48}$ $Q_{100}=50W^{0.61}G^{-0.48}$

Data source	Equation	Data source	Equation
Table 6			
North and Middle Loup Rivers.	$\bar{Q}=5.6W^{0.90}$ $Q_2=0.12W^{1.86}$ $Q_5=0.34W^{2.18}$ $Q_{10}=0.016W^{2.37}$ $Q_{25}=0.0065W^{2.59}$ $Q_{50}=0.0034W^{2.74}$ $Q_{100}=0.0018W^{2.90}$	Calamus, Cedar, Elkhorn, North Fork Elkhorn, and South Loup Rivers.	$\bar{Q}=3.4W^{0.86}$

TABLE 10.—*Width-discharge and width-gradient-discharge relations expressed in inch-pound units*—Continued

Discharge variability	Equation	Discharge variability	Equation
Table 7			
Low, $Q_{10}/\bar{Q}\leqslant 60$ (55 data sets).	$\bar{Q}=0.18W^{1.62}$	High, $Q_{10}/\bar{Q}>60$ (41 data sets).	$\bar{Q}=0.33W^{1.36}$
	$\bar{Q}=0.031W^{1.36}G^{-0.42}$		$\bar{Q}=0.044W^{1.03}G^{-0.49}$
	$Q_2=1.9W^{1.51}$		$Q_2=40W^{1.04}$
	$Q_2=0.25W^{1.18}G^{-0.49}$		$Q_2=22W^{0.81}G^{-0.23}$
	$Q_5=3.6W^{1.50}$		$Q_5=180W^{0.89}$
	$Q_5=0.35W^{1.13}G^{-0.56}$		$Q_5=110W^{0.69}G^{-0.19}$
	$Q_{10}=5.7W^{1.47}$		$Q_{10}=400W^{0.81}$
	$Q_{10}=0.53W^{1.09}G^{-0.58}$		$Q_{10}=290W^{0.62}G^{-0.16}$
	$Q_{25}=9.7W^{1.43}$		$Q_{25}=970W^{0.71}$
	$Q_{25}=0.89W^{1.05}G^{-0.58}$		$Q_{25}=840W^{0.55}G^{-0.12}$
	$Q_{50}=14W^{1.41}$		$Q_{50}=1,600W^{0.66}$
	$Q_{50}=1.3W^{1.01}G^{-0.58}$		$Q_{50.}=1,700W^{0.50}G^{-0.09}$
	$Q_{100}=17W^{1.40}$		$Q_{100}=2,300W^{0.64}$
	$Q_{100}=1.9W^{0.99}G^{-0.58}$		$Q_{100}=3,300W^{0.45}G^{-0.06}$

Equation No.	Equation
Equations for Muddy Stream Channels	
6	$\bar{Q}=0.098W^{2.0}$
7	$Q_2=12W^{1.5}$
8	$Q_5=47W^{1.4}$
9	$Q_{10}=110W^{1.3}$
10	$Q_{25}=190W^{1.2}$
11	$Q_{50}=290W^{1.1}$
12	$Q_{100}=350W^{1.1}$

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