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THE HYDRAULIC GEOMETRY OF SOME ALASKAN STREAMS SOUTH OF THE YUKON RIVER

By
William W. Emmett

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ABSTRACT

Channel geometry surveys were conducted to determine bankfull stage, discharge, and other hydraulic parameters at 22 locations along the proposed route of the trans-Alaska pipeline corridor south of the Yukon River. Combined with the records from gaging stations located at some of the sites, the data are sufficient to describe some of the channel and flow characteristics typical of each of two major hydrologic areas, the Yukon River Region and the South-Central Region. Although each region follows general hydrologic trends, least squares relations indicate each exhibits its own particular deviations.

Average values of the hydraulic and geometric properties of rivers were used to illustrate their application to practical engineering problems, namely the computation of depth of channel scour and of bedload discharge. For design purposes, caution is recommended when making computations based on average values. In the absence of other data, however, the average data become useful predictive tools.

THE HYDRAULIC GEOMETRY OF SOME ALASKAN STREAMS SOUTH OF THE YUKON RIVER

INTRODUCTION

Background

Discovery and development during the late 1960's of vast petroleum reserves on Alaska's North Slope and subsequent proposals to construct a 48-inch diameter oil pipeline from Prudhoe Bay to the southern port city of Valdez have necessitated an intensive effort by earth scientists to collect and assess information regarding the terrain along the proposed pipeline corridor. The pipeline route crosses nearly 350 streams, and about one-fourth of these may be classified as major crossings; that is, the channels are large enough and convey sufficient volumes of water to warrant hydrologic analysis of streamflow characteristics and channel behavior. Thus, to assure adequate pipeline design and construction at channel crossings, criteria regarding magnitude and frequency of river flows must be available.

Unfortunately, as important as reliable predictions for values of magnitude and frequency of flow may be, very few hydrologic data exist to determine these values for channels that are of interest to the pipeline companies. Prior to 1970, less than ten stream-gaging stations were located along the 800-mile length of the pipeline route, and for approximately half of the route (that portion north of Fairbanks), no stream-gaging stations were operated. To help alleviate this inadequacy, six new gaging stations were constructed during 1970 along the pipeline route north of Fairbanks. In the southern part, especially in the Copper River basin, several additional stations were either established or reactivated. However, it was evident that data from the new stations would not provide sufficient areal coverage or be operated long enough to provide reasonable measures of streamflow characteristics needed for planning and design. This deficiency in data led to the present study wherein channel geometry is related to known flow characteristics at existing gaging stations and, thereby, provides a basis for estimates of flow characteristics at ungaged locations based on measurements of channel geometry. The technique involves surveys of channel geometry at selected sites, and manipulation and computation of data. Figure 1 illustrates the hydrologic subregions of Alaska and the proposed route of the trans-Alaska pipeline. (All figures are included in appendix B of this report.)

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SELECTION OF STUDY SITES

The principal channel feature involved in the survey of channel geometry is the bankfull stage, or the stage at which the channel just begins to overflow the flood plain. Thus, a flood plain on one or both banks is a basic criterion for site selection. The river must be unconfined by rock walls; if terraces exist, they must be distinguishable from the active flood plain. The active flood plain is defined as a flat area near the channel, constructed by the river, and overflowed by the river at a recurrence interval of about two years or a little less (Wolman and Leopold, 1957). Although the flood plain is often difficult to visualize in the field, other evidence is often useful to help distinguish it. Vegetation, for example, is either absent or annual on surfaces lower than the flood plain. On the flood plain, vegetation may be perennial but is generally limited to typical streamside types such as young willow and alder. The higher-elevation surfaces, including terraces, support more mature woody vegetation; where trees grow along nearly vertical banks leading to these higher surfaces, the bottom of the tree line is often indicative of the flood plain. (Note that the bankfull stage as defined is generally less, perhaps considerably, than "flood stage", a term often used by forecasting services.

With this flood plain criterion, channel geometry survey data are useful at three types of locations. These are:

1. Gaging station locations with long-term records sufficient to define the stage-discharge relation and with flood frequency and flow duration analyses available. Such locations are used to relate known flow characteristics to the channel geometry.
2. Gaging station locations with short-term records. Data from these stations are used to relate flow characteristics

(excluding flow frequency and duration) to the channel geometry.

3. Ungaged streams where the channel geometry is surveyed and the relations established at locations 1 and 2 above are used to predict flow characteristics based on the surveyed channel geometry. The surveys on ungaged channels are, in fact, an application of channel geometry surveys as a hydrologic tool. The reliability of flow predictions based on channel geometry is determined largely by the consistency of data obtained at gaging stations.

For the present study, site selection was also limited to locations south of the Yukon River and along the proposed pipeline corridor. A total of 22 sites were selected. These locations are shown on figure 2 and listed in table 1. (All tables are included in appendix A of this report.) Stations 1 through 11 are in the Copper River basin of the South-Central hydrologic subregion, 12 and 13 in other basins in the South-Central hydrologic subregion, and 14 through 22 are in the Tanana River or Upper Yukon River basins of the Yukon River hydrologic subregion. Ten of the sites are at long-term gaging stations, seven sites are at short-term gaging stations, and five sites are on ungaged streams. Throughout this report, frequent comparisons will be made between streams in the "South-Central Region" and the "Yukon River Region".

Photographs 1 through 24 of appendix C illustrate each of the study streams. The caption for each photograph describes the location of the flood plain, a key element in the analysis of the channel geometry surveys. Maps 1 through 11 of appendix D give greater topographic details at the selected sites.

All surveys reported in this study were conducted during a two-week period in September, 1970, and a two-week period in September, 1971.

CHANNEL GEOMETRY SURVEYS

Complete measurements of channel geometry consist of surveying the long profiles of river bed, water surface, flood plain, terraces, and highwater marks. In addition, a discharge measurement is made and the particle size distribution of the bed and bank material is determined.

The riverbed survey is conducted along the approximate center of the channel for a distance equivalent to about 20 river widths. Sightings are spaced no greater than one river width apart. This distance and spacing is generally sufficient to average out variability due to pools and riffles and to determine the mean slope for the surveyed reach of river. The water-surface profile is determined at the same time by the rodman's observing the depth of water at each shot location and adding this value to the bed elevation. A similar traverse is conducted downvalley on the flood plain through the same distance. Profiles of other channel features are surveyed the same as for the flood plain.

If wading is not possible, depths determined by soundings from a boat may be subtracted from corresponding water-surface elevations determined along the shore to obtain the riverbed profile. At gaging station locations where average depth at the measuring section is known for the water-surface elevation at the time of survey, the riverbed profile may be omitted. However, because the measuring section may not be typical, average depth at the time of survey is not as accurately determined at this single section compared to the average difference in elevation of the riverbed and water-surface profiles.

All surveying is tied into the gage datum (zero of staff gage). Channel stationing of the gage location is noted. At ungaged locations, a reference marker is installed and the survey datum and channel stationing tied to this marker.

The longitudinal profile data are plotted on arithmetic coordinate paper and straight-line profiles are drawn through each set of points. These straight lines generally must be parallel for riverbed, water surface, and flood plain, and this criterion is considered when determining the best fit. Where the plotted profiles pass the channel stationing or location of the gage, the gage height corresponding to the elevation of each channel feature can be determined. Of primary interest is the gage height at bankfull stage (flood plain elevation).

At a gaging station, usually the cross-section at the cable or bridge is sufficiently representative of the channel in the reach surveyed. However, the cross-section as determined from discharge measurements may have to be extended from the water's edge to cover the flood plain. At ungaged locations, the cross-section is surveyed at a representative reach while the longitudinal profile is being surveyed.

Particle size distribution of bed material from streams with coarse particles is best sampled by pebble counting (Wolman, 1954; Leopold, 1970; Kellerhals and Bray, 1971). A count of 100 particles is taken by pacing a reach of river and randomly picking up a pebble at each step. The intermediate axis of the pebble is measured. Where pool and riffle reaches are composed of different size particles, counts are made separately in each reach. Where bed material sizes are fine-grained, a bulk surface sample is obtained for sieve analysis. Likewise, a sample of bank material is obtained for sieve analysis.

For ungaged streams, a discharge measurement is made at the location of the surveyed cross-section.

More details of the techniques for making channel geometry surveys may be found in Leopold, Wolman, and Miller (1964), and Leopold and Skibitzke (1967).

ANALYSIS OF DATA

In the following discussion, the more important data, or data available only from the present study, are tabulated completely. Data which are of lesser importance or are easily obtainable elsewhere are exemplified by a sampling for a particular station, generally both tabular and graphically.

The analysis is based on the assumption that river channels are shaped by, and to accommodate, a dominant discharge, and that this dominant discharge occurs with some regularity in frequency. In this study, bankfull discharge, as previously defined, was selected as being indicative of this dominant discharge. Since it has been assumed that bankfull discharges among rivers have a constant frequency of occurrence, it is reasonable to assume further that discharges of magnitude equal to a given percentage of bankfull discharge will have a constant frequency of occurrence. This role of bankfull discharge has tended to be substantiated in the recent literature. See, for examples, Leopold, Wolman, and Miller (1964); Leopold and Skibitzke (1967); Brown (1971); Woodyer (1968); Dury (1961); Kilpatrick and Barnes (1964); and Nixon (1959).

Gaging Stations

In the first step of the analysis, field notes of individual discharge measurements at a gaging station are scanned to select five to ten sets of notes which are representative of the full range of discharges measured. Pertinent data of these measurements are then summarized as exemplified in table 2 for the Tonsina River. These data are then plotted in the manner described by Leopold and Maddock (1953) to obtain the at-a-station hydraulic geometry as exemplified in figure 3 by the data for the Tonsina River. It is the graphs of figure 3 which enable the determination of surface width, W, in feet, mean depth, D, in feet, and mean velocity, V, in feet per second, for any desired discharge, Q, in cubic feet per second.

As previously described, data from the channel surveys of long profiles are then plotted and parallel lines of best fit are drawn through the plotted data of bed, water surface, flood plain, and any other surveyed surfaces such as terraces or high water marks. In determining the best fit, bias or prominence was given to a surface containing the most surveyed points or extending for the greatest length of survey. An example of such plots is illustrated in figure 4 for the Klutina River at Copper Center, Alaska. Bankfull stage is defined as the elevation of the flood plain at the location of the gage. Bankfull discharge is determined from the stage-discharge relation developed for the station. Note that only the flood plain profile on figure 4 was used to determine bankfull stage; however, all profiles, especially the water surface, were instrumental in determining the best fit to the flood plain data. Note also that a different bankfull gage height would have been determined if the average height of the flood plain above the water surface was added to the gage height at the time of survey because the actual water surface at the gage location is lower by several tenths of feet than the average water-surface profile through the reach.

With bankfull discharge, Q_B, known, values of bankfull width, W_B, depth, D_B, and velocity, V_B, can be determined from the at-a-station curves of hydraulic geometry (figure 3). Further, letting

$$W = aQ^b \qquad (1)$$

$$D = cQ^f \qquad (2)$$

$$V = kQ^m \qquad (3)$$

values of width, depth, and velocity at any value of discharge can be computed from equations 1 through 3 or read from the graphical presentation (figure 3). As a check on computations, since

$$W \times D \times V = Q \qquad (4)$$

then

$$a \times c \times k = 1 \qquad (5)$$

and

$$b + f + m = 1 \qquad (6)$$

The bankfull values of the hydraulic parameters and the exponents, b, f, and m, of hydraulic geometry are listed in table 3.

The curves of hydraulic geometry for some rivers show a break in slope at bankfull discharge. That is, at stages just over bankfull, width increases rapidly as the flood plain becomes inundated. There is a corresponding decrease in the rate of increase in depth and sometimes in velocity. However, in the present study, either the flood plain width was too small to indicate this or too few overbank measurements were available to document a break in slope. Thus, for the entire range of within-channel and overbank flows, single curves with slope values of b, f, and m were used to define the relations of W, D, and V to Q for each stream.

If the hydraulic geometry data are expressed as non-dimensional ratios to bankfull data, a single dimensionless set of hydraulic geometry curves can be expressed as

$$D/D_B = (Q/Q_B)^f \qquad (7)$$

$$W/W_B = (Q/Q_B)^b \qquad (8)$$

$$V/V_B = (Q/Q_B)^m \qquad (9)$$

Likewise, since flow area A = DW,

$$A \propto Q^{b+f} \qquad (10)$$

and

$$A/A_B = (Q/Q_B)^{b+f} \qquad (11)$$

Equations 7 and 11 define dimensionless rating curves based on depth or cross-sectional area of flow. They are valid for streams having the same values of b and f (table 3) or serve as average dimensionless ratings for regions having the same average values of b and f. As average dimensionless rating curves, they are as reliable as the maximum scatter in the values of b and f (table 3). Generally, if the value of b is somewhat less than average, the value of f is somewhat greater. Thus, the values of b+f among rivers are somewhat more consistent than b alone and equation 11 may be considered a little more reliable average rating than equation 7.

The mean values of the exponents b, f, and m in table 3 are b = 0.19, f = 0.39, and m = 0.42. Although there is considerable variability in values of b, f, and m among individual streams, the average values for a group of streams are generally consistent. For comparison, the average values for 158 gaging stations in the United States are b = 0.12, f = 0.45, and m = 0.43 (Leopold, Wolman, and Miller, 1964). In the upper Salmon River drainage, Idaho, 39 stations gave average values of b = 0.14, f = 0.39, and m = 0.47 (Emmett, 1972).

Utilizing the mean values of b and f from table 3, figure 5 illustrates the dimensionless rating curves of equations 7 and 11 as average curves for the 17 gaging station locations included in the present study.

Ungaged Locations

The dimensionless rating curves now enable determination of bankfull discharge for ungaged locations. For these sites, at the time of the channel geometry survey, a discharge measurement was made as well as the survey of channel cross-section. From the cross-sectional survey, flow area, A_B, depth, D_B, and surface width, W_B, at bankfull stage are determined. Using the depth, D, and width, W, data from the discharge measurement, the ratios A/A_B and D/D_B are computed and, using the dimensionless ratings from figure 5, Q/Q_B is determined using either or both the equation 7 or equation 11 curve. If there is a significant difference in the two (equation 7 versus 11), an intermediate value of Q/Q_B may be assumed. With the value of Q known from the discharge measurement, Q_B may be computed. These computations are shown in table 4. These values of bankfull data for the ungaged locations are now added to table 3. Values of b, f, and m cannot be determined, but the technique implies that each exponent equals the average value of that exponent for the region.

Flow Frequency and Duration

It now becomes desirable to establish flow frequency and duration for the dimensionless ratings of figure 5. Stations which have been in operation for sufficient lengths of time to establish flow frequency include seven in the South-Central Region and three in the Yukon River Region. Flow frequency beyond the length of station record was extended by the log Pearson method (U.S. Water Resources Council, 1967; Benson, 1968). To establish flow duration, there are five stations in the South-Central Region and two in the Yukon River Region. For selected values of flow frequency and duration, tables 5 and 6 list values of discharge and the ratio of discharge to bankfull discharge for rivers in the South-Central Region. Tables 7 and 8 list the same data for rivers in the Yukon River Region. The average values for each of the two regions in the study are superimposed on the dimensionless ratings as shown on figure 5.

Further analysis of flow frequency and duration yields values at bankfull stage and these are also listed in tables 5 and 7 for the available stations. The average value of bankfull frequency is about 1.5 years and for bankfull duration is a little over 1 percent of the time.

Cross-Section Surveys

Other data available for the analysis are the cross-sectional surveys. Their usefulness has been demonstrated earlier in the computation of bankfull data at ungaged locations. An example of cross-sections for the Klutina River at Copper Center, Alaska, is illustrated in figure 6 by data from discharge measurements. Discharge and flow duration are shown for each of the sets of data. Bankfull stage is two-tenths of a foot greater than the highest measurement plotted.

Particle-Size Distributions

Finally, there exist the data for the particle-size distribution of the bed and bank material. Bed material was sampled primarily by pebble counting and the size distribution was based on the number of particles. For fine-grained material, a sieve analysis was made and the size distribution was based on the weight of each size classification. Size classifications for pebble counting began with four millimeters and each category increased by a factor equal to the square root of two (4, 5.7, 8, 11.3, 16 mm, etc.). For the sieve analysis, each size category differed by a factor of two (0.125, 0.25, 0.5, 1, 2, 4 mm, etc.).

The particle-size data were then plotted as illustrated in figure 7 for the Klutina River at Copper Center, Alaska. Pertinent data from the particle-size distribution graphs are summarized in table 9 for all of the data collected. The particle sizes at the five distributions listed in table 9 are the most common used in various formulas and also are sufficient data to prepare size-distribution curves so that particle size at other percentage distributions may be obtained.

DISCUSSION OF DATA

Runoff and Drainage Area

With the data now available from the streamflow records and the channel geometry surveys, further analysis, interpretation, and comparison of the data are possible. If unit runoff, R, is defined as the discharge per unit of drainage area, DA, values of unit runoff at bankfull stage, R_B, may be computed. For the streams studied, these values are tabulated in table 3. Figure 8 is a plot of these values as a function of drainage area. Curves fitted by the method of least-squares indicate data from the South-Central Region may be described by the relation

$$R_B = 11.5\ DA^{-0.03} \qquad (12)$$

or

$$Q_B = 11.5\ DA^{0.97} \qquad (13)$$

For the Yukon River Region, the relation is

$$R_B = 27.1\ DA^{-0.21} \qquad (14)$$

or

$$Q_B = 27.1\ DA^{0.79} \qquad (15)$$

Collectively, the data may be described by the approximate relation

$$R_B = 20\ DA^{-0.15} \qquad (16)$$

The relations described by equations 12 and 14 coincide at a drainage area of about 100 square miles and for that size of drainage area indicate a bankfull unit runoff of about 10 cfs per square mile. For drainage areas smaller than this size, no data were available for the Yukon River Region to test the validity of equation 14. For larger drainage areas, unit runoff from the South-Central Region is progressively greater than for the Yukon River Region. At a drainage area of 20,000 square miles, the upper limit of data available for the South-Central Region, unit runoff in the South-Central

Region is approximately 250 percent greater than for the Yukon River Region. This difference is primarily related to the physiographic setting and rainfall characteristics of the two regions.

Figure 9 shows the four major climatic zones for Alaska. The differentiation is based primarily on the records of precipitation. The South-Central Region lies within the transition and maritime climatic zones. The Yukon River Region is within the continental climatic zone. Figure 10 is an isohyetal map of mean annual precipitation for Alaska. For much of the Yukon River Region included in this study, mean annual precipitation is about 20 inches per year. Although this is about the same precipitation received in the valley lowlands of the South-Central Region, these lowlands are nearly surrounded by mountainous areas receiving over 80 inches of precipitation per year. The effective large-scale precipitation in the South-Central Region is more than double that of the Yukon River Region and results in the greater unit runoff.

Much of the scatter in the values of data plotted in figure 8 for the South-Central Region can be explained by the orographic effects in the precipitation pattern. For example, the plotting position for station 13 (Maclaren River near Paxson) is higher than predicted by equation 12 and the field location is in a high precipitation area on the south flank of the Alaska Range of mountains. Conversely, the plotting position for station 7 (Squirrel Creek near Tonsina) is lower than predicted by equation 12 and its field location is in a low precipitation area in the Copper River lowlands.

The combination of figure 8 with figure 5 allows the approximation of runoff for any frequency of occurrence. For example, if the 50-year flood, Q_{50}, for a 10,000 square mile drainage area in the Yukon River Region is desired, from figure 8, R_B = 3.9 cfs per square mile or Q_B = 39,000 cfs.

From figure 5, or table 8, Q_{50}/Q_B = 4.0 and therefore Q_{50} = 156,000 cfs.

Using this technique, values of runoff were computed for various sizes of drainage areas and for a duration of 80 percent of time, mean annual flow, bankfull stage, and the 200-year flood. The data are tabulated in table 10. Over a range in size of drainage area from 100 to 100,000 square miles, there is little change in the values of unit runoff for the South-Central Region but there is a four-fold difference in values of unit runoff in the Yukon River Region. The closest agreement between the two hydrologic regions for values of unit runoff listed in the data of table 10 is for a drainage area of about 1,000 square miles. For a given value of Q/Q_B, it is the difference in average values of duration and frequency of flow between the two regions (as illustrated on figure 5 or listed in tables 6 and 8), that when combined with the appropriate runoff relation (equation 12 or 14), the unit runoff for a given frequency of flow is most nearly equal between the two regions for the runoff from a drainage area of 1,000 square miles.

The data of table 10 can be compared to the data of figures 11 through 13 and for a 1,000 square mile drainage area, there is reasonable agreement between the maps and the table 10 data. Obviously, runoff maps of the type illustrated in figures 11 through 13 must be prepared for a given size drainage area, but these were prepared using all available data. Thus, it is likely that data computed from figures 5 and 8 may give more reliable values of unit runoff than maps such as figures 11 through 13. However, figures 11 through 13 have the advantage of showing orographic effects.

It should be remembered that values of runoff discussed above are average values. Annual runoff varies widely. For example, mean annual runoff from the Chena River at Fairbanks, Alaska, was measured at 0.36 cfs per square mile in 1958 and at 1.32 cfs per square mile in 1962. The long-term average for mean annual runoff from the Chena River at Fairbanks is 0.77 cfs per square mile, somewhat less than the average value shown in table 10 for the Yukon River basin.

The use of frequency and duration data as illustrated above must be accompanied with caution. Referring back to table 6, it is noted, for example, that the value of Q/Q_B at larger recurrence intervals is much smaller for the Klutina River (station 4) than for the Tazlina River (station 3). This difference is related to the magnitude of flows being dampened or regulated by Klutina Lake on the Klutina River and being amplified by the bursting of glacially-dammed lakes on the Tazlina River. About half of the annual peak flows on the Tazlina River were caused, in part, by glacial lake outbursts. Other techniques for estimating magnitude and frequency of flow contain this same deficiency. A method utilizing regression equations (Childers, 1970) illustrates this with the data of table 11. In this instance, the 50-year flood based on the record for the Tazlina River is 228 percent of that calculated from the regression equation. For the Klutina River, the ratio is only 61 percent. The frequency distributions shown on figure 5 are averages for the regions based on station data. When making computations involving flow frequency for stream channels with characteristics known to be different from those of the "average" river in the area, the magnitude and frequency of flow data can be modified using the data of tables 5 through 8 for the stream which best fits the behavior of the stream under study. Further caution is also suggested in extrapolating data beyond the range of values presented in this study.

Since figure 8 indicates differing values of unit runoff between the South-Central Region and the Yukon River Region, it would be interesting to know which of the hydraulic geometry parameters contribute to the different values of unit runoff. Figures 14 through 17 are graphs of the bankfull values of width, depth, cross-sectional flow area, and velocity, respectively, as a function of drainage area. Least-squares fit to the plotted data giving the following relations:

A. South-Central Region

$$W = 9.00\ DA^{0.48} \tag{17}$$

$$D = 0.68\ DA^{0.30} \tag{18}$$

$$A = 6.16\ DA^{0.77} \tag{19}$$

$$V = 1.89\ DA^{0.20} \tag{20}$$

B. Yukon River Region

$$W = 9.63\ DA^{0.43} \tag{21}$$

$$D = 1.43\ DA^{0.24} \tag{22}$$

$$A = 13.7\ DA^{0.67} \tag{23}$$

$$V = 2.01\ DA^{0.12} \tag{24}$$

C. All data

$$W = 11.16\ DA^{0.42} \tag{25}$$

$$D = 0.71\ DA^{0.31} \tag{26}$$

$$A = 7.90\ DA^{0.73} \tag{27}$$

$$V = 2.67\ DA^{0.11} \tag{28}$$

Lines fitted according to equations 17 through 28 are shown on the appropriate graphs of figures 14 through 17. Although the relations developed using all of the data collectively, equations 25 through 28 are not greatly different from the relations developed for each region, the separate runoff versus drainage area relations shown on figure 8 dictate that a single set of equations (such as equations 25 through 28) are not adequate to express the width, depth, area, and velocity versus drainage area plots of figures 14 through 17. Inspection of the curves for the separate regions as shown on figures 14 through 17 shows the following relative trend for values of the hydraulic parameters:

Drainage Area (sq mi)	Ratio (South-Central Region/Yukon River Region)			
	Width	Depth	Area	Velocity
100	1.17	0.62	0.73	1.33
10,000	1.47	.80	1.17	1.89

Generally, for the South-Central Region compared to the Yukon River Region, stream widths are somewhat greater, depths are somewhat less, flow areas are about the same, but velocities are considerably greater. Thus, the larger values of runoff in the South-Central Region are accommodated more by higher stream velocities than by larger stream channels (flow area). Apparently, the steeper average channel slope in the South-Central Region (0.0072 ft/ft versus 0.0012 ft/ft) more than compensates for the smaller (smoother) mean bed particle size in the Yukon River Region (13.5 mm versus 33.5 mm). But regardless of cause and effect, maximum reliability for figures 14 through 17 can be assumed by using the appropriate regional relations (equations 17 through 24).

Hydraulic Geometry in Downstream Direction

The downstream hydraulic geometry is also plotted as suggested by Leopold and Maddock (1953). Since the discharge axis of the plot must be for discharges of a given frequency of occurrence, bankfull discharge was used. Figures 18 through 21 relate bankfull values of width, depth, flow area, and velocity to bankfull discharge. Least-squares fit to the plotted data give the following relations:

A. South-Central Region

$$W_B = 2.55\ Q_B^{0.50} \qquad (29)$$

$$D_B = 0.33\ Q_B^{0.30} \qquad (30)$$

$$A_B = 0.85\ Q_B^{0.80} \qquad (31)$$

$$V_B = 1.19\ Q_B^{0.20} \qquad (32)$$

B. Yukon River Region

$$W_B = 1.70\ Q_B^{0.54} \qquad (33)$$

$$D_B = 0.53\ Q_B^{0.30} \qquad (34)$$

$$A_B = 0.89\ Q_B^{0.84} \qquad (35)$$

$$V_B = 1.14\ Q_B^{0.16} \qquad (36)$$

C. All data

$$W_B = 2.39\ Q_B^{0.50} \quad (37)$$

$$D_B = 0.26\ Q_B^{0.35} \quad (38)$$

$$A_B = 0.63\ Q_B^{0.85} \quad (39)$$

$$V_B = 1.62\ Q_B^{0.15} \quad (40)$$

As in the previous discussion relating the hydraulic parameters, W, D, A, and V, to drainage area, the relations developed using all of the data collectively, equations 37 through 40, are not greatly different from the relations developed for each region, equations 29 through 36. The relative trend of data for the two separate regions, equations 29 through 32 compared to equations 33 through 36, is as follows:

Bankfull Discharge (cfs)	Ratio (South-Central Region/Yukon River Region)			
	Width	Depth	Area	Velocity
1,000	1.16	0.63	0.73	1.37
100,000	.98	.63	.62	1.64

Thus, in a range of bankfull discharge common to the two regional sets of data in figures 18 through 21, streams in the South-Central Region compared to streams in the Yukon River Region tend to have bankfull widths about the same or slightly greater and bankfull depths consistently less. For the same bankfull discharge, flow areas for streams in the South-Central Region are only about two-thirds (but slightly variable with discharge) of that for streams in the Yukon River Region but compensate by having velocities about 1.5 times greater (again slightly variable with discharge).

As described in equations 1 through 6, the exponents of hydraulic geometry must total to 1.0. Represented by the least-squares fit to the collective data, equations 37 through 40, the present study shows values of $b = 0.50$, $f = 0.35$, and $m = 0.15$. By comparison, Leopold and Maddock (1953) found the average value for a number of streams in the midwestern United States to be $b = 0.50$, $f = 0.40$, and $m = 0.10$.

When bankfull discharge is determined as previously described, bankfull values of the other parameters may be read from the curves in figures 18 through 21. Maximum reliability can be assumed by using the separate relations established for the two regions of study.

APPLICATION OF RESULTS

The data available from the channel geometry surveys and gaging station records enable determination of values of the hydraulic and geometric parameters for any reasonably homogeneous region. The higher the degree of homogeneity between sub-areas of the region, the more nearly equal are the values of a given exponent, and hence the more representative the value becomes. Graphs illustrating characteristics of the hydraulic geometry for the channels included in this study indicate that average relationships are reliably predictive for the parameters involved. Separate relationships are needed to describe differences between regions of different physiographic setting. For example, in the present study, a single curve relates runoff to drainage area for all streams measured in the South-Central Region; however, a different curve is needed to define the relation for all streams measured in the Yukon River Region.

Channel Scour

These average type data may now be used in various formulas to predict other channel behavioral phenomena. The problem of determining depth of riverbed scour (as associated with the depth of burial of a pipeline at a river crossing) was one question which prompted the present study. Formulas for determining depth of channel scour are, at best, an empirical fit to a very limited amount of data. However, the purpose of this paper is not to discuss the validity of scour formulas, but to illustrate the use of the acquired data with any available formula. One equation available to compute channel scour is a modification of the Laursen (1963) formula,

$$Y = 0.13 \left(\frac{q}{d^{1/3}}\right)^{6/7} - D \qquad (41)$$

where Y is depth of scour in feet, q is the discharge in cubic feet per second per foot of width, d is the mean bed material particle size (d_{50}) in feet, and D is the mean depth. Since q varies with drainage area, DA, recurrence interval, RI, and region, and d is variable, Y is a function of region, DA, RI, and d.

In graphical presentations of computed values of scour, one of the above parameters must be held constant as the other three are plotted. For maximum reliability, separate curves must be prepared for each region of study. For the South-Central Region, figure 22 illustrates the computed value of scour from equation 41 for a constant size of drainage area (1,000 sq mi) as a function of recurrence interval and particle size. Alternatively, the influence of recurrence interval on the computed values of scour could be shown by holding particle size constant and allowing size of drainage area to vary.

For most engineering purposes involving computations of channel scour, a design flood is known. Thus, perhaps the most useful presentation is illustrated in figures 23 and 24 for a constant recurrence interval (50 years), and depth of scour is presented as a function of particle size and drainage area. Figure 23 illustrates values computed from equation 41 for the South-Central Region and figure 24 illustrates values computed from equation 41 for the Yukon River Region. Figure 25, a comparison of the two regions, well illustrates the need to use the most reliable input data. Especially as bed material particle size increases, the more competent streams in the South-Central Region (larger discharge per foot of width of channel) have the ability to scour greater depths.

Considerable caution should be exercised in using curves of the types in figures 22 through 25. It must be remembered that computed values of scour are for the "average" river in the region. Some rivers will have less scour and other rivers will have more scour. Furthermore, few observations of scour are available for Alaska streams. Fortunately, several factors of safety are built in. Primarily, these are that as scour progresses, the finer-sized particles will be removed first and lead to armoring of the streambed and a resistance to further scouring, and by the fact that at greater depths of scour the channel may be geologically constrained by bedrock against further scour.

One should not be lulled into a false sense of security by the design flood. For example, the recurrence interval of 50 years used in figures 23 through 25 may be adequate for a secondary road bridge, but not for major engineering works. If the useful life of the engineering works is known, the probability of the design flood occurring during the useful life can be predicted (Markowitz, 1971; Laursen, 1969). To illustrate, assume the useful life of the project is 50 years. The probability that the 50-year flood will occur within 50 years is about 62 percent, that it will occur twice within 50 years is about 27 percent, and that it will occur 3 times in 50 years is about 8 percent. These odds are, perhaps, sufficient for the secondary road bridge, but for a project like the proposed trans-Alaska pipeline, a failure would result in economic and ecologic damage. Assuming a useful life of this project of about 50 years, even the 1,000-year flood has a probability of about 5 percent of occurring within 50 years. Considering the number of rivers crossed by the pipeline, the chances that the 1,000-year flood will occur on one of the streams are increased. These probabilities have led the pipeline companies to use the Standard Project Flood (in essence, a flood with a recurrence interval greater than 1,000 years) for design purposes at pipeline river crossings (Alyeska Pipeline Service Corp., 1971).

By way of comparison with the Laursen formula (equation 41), Blench (Alyeska Pipeline Service Corp., 1971) has proposed a modification of his basic scour equation (Blench, 1966) for use with gravel bed streams in Alaska. This equation takes the form

$$Y = \frac{0.212\ q^{4/5}}{d^{1/5}} - D \qquad (42)$$

where Y, q, and d are the same parameters as in the Laursen formula. For the South-Central Region, figure 26 presents computed values of scour for a recurrence interval of 50 years and figure 27 compares these values to the values determined by the Laursen equation (figure 23). For the middle range of size of drainage area (values of q) and of bed particle sizes, the agreement between the two equations is very close. The Laursen equation yields slightly higher values of scour for larger drainage areas ($q^{6/7}$ versus $q^{4/5}$) and for smaller particle sizes ($d^{1/3}$ versus $d^{1/5}$). The Blench equation yields larger values of scour for larger particle sizes. A degree of validity is given the two methods of computing scour by their close agreement for the range of particle sizes and drainage areas illustrated.

An additional consideration should be given to the above computed values of scour. The previous analysis has lent itself to the use of mean data from gaging stations. Referring to figure 28, the cross-section for the Tazlina River, a given width of channel has a deeper mean depth than for the entire width and also, at some place across the width, a maximum depth occurs. The net effect of these sections of deeper depths is to increase the area of flow and velocity and results in a higher discharge per foot of width. Values of scour computed from equations 41 and 42 are accordingly higher. Computations of channel scour have been made for the Tazlina River using the deep section data from the left bank to the bridge pier (about 70 feet wide - see figure 28) and for the maximum depth at a point (using the width centered around a single velocity measurement, usually about 10 feet). These computations show depths of scour in the deep section to be approximately 165 percent of the mean scour depth and the maximum point scour is approximately 210 percent of the mean depth of scour. The first value above is in agreement with a value of 170 percent suggested by Blench (1966). It should be noted that the above percentages are not safety factors but take into account variability of scour depth across the channel widths. To minimize this variability, one would plan a design for a long, straight reach of channel, and to minimize average scour, one would consider a wide reach of river. Any safety factor would be added to computed values of scour.

Bedload Transport

Another example of the usefulness of the hydraulic geometry data provided by the present study is in computation of bedload transport. Again, a host of formulas is available for computation of bedload transport, but there exist few field data for verification (Jordan, 1965; Vanoni, 1971). The formula selected for the present paper is the one by Schoklitsch (Shulits, 1935). The values predicted by this formula often approximate the values predicted by other equations. The basic Schoklitsch equation is

$$q_Y = \frac{86.7}{(12d)^{1/2}} S^{3/2} \left(q - 0.00532 \frac{12d}{S^{4/3}}\right) \quad (43)$$

where q_Y is the bedload discharge in pounds per second per foot of width, S is the channel slope in feet per foot, and q and d are as defined for the scour computations. For a recurrence interval of 50 years and a channel slope of 0.005 ft/ft, figure 29 illustrates bedload discharge, q_Y, as a function of bed material particle size and drainage area. Figure 30 illustrates the same data as total bedload discharge over the full width of channel, Q_Y, in tons per day. The quantities of total bedload discharge are staggering. For example, for RI = 50 years, S = 0.005 ft/ft, d_{50} = 10 mm, and DA = 20,000 square miles, Q_Y is approximately one million tons per day.

Alternatively, in figure 31, the bedload discharge is presented for a constant bed particle size, d_{50} = 20 mm, and recurrence interval, RI = 50 years, as a function of channel slope and drainage area. Figure 32 presents the same data as total bedload discharge. The influence of channel slope is very apparent. For a drainage area of about 5,000 square miles, the ten-fold increase in slope (from 0.001 to 0.01 ft/ft) is responsible for about a 40-fold increase in total bedload discharge.

As a final exercise, the bedload discharge from figures 29 through 32 for RI = 50 years, S = 0.005 ft/ft, d_{50} = 20 mm and DA = 1,000 square miles is about 4.0 pounds per second per foot of width (36,000 tons per day). Channel scour from figure 27 for RI = 50 years, d_{50} = 20 mm, and DA = 1,000 square miles is about 5.4 feet (average of Blench and Laursen equations). At 100 pounds per cubic foot for the immersed weight of sediment, the bedload discharge is 0.04 cubic feet per second per foot of width. This volume divided by the 5.4-foot depth of scour gives a downstream sediment velocity of 0.0074 feet per second or 26.7 feet per hour. This description of channel scour is in agreement with an earlier description (Emmett and Leopold, 1965) which states: "Scour is associated with dilation of the grain bed through the scour depth, but individual particles may move intermittently, and at a speed much less than that of the water. The volume of the material scoured and moved may be large, but because of its low mean speed downstream, the whole volume does not move entirely out of a long reach but, in effect, is shifted downstream only a limited distance."

CONCLUSIONS

Gaging station records were utilized to develop dimensionless rating curves of depth/bankfull depth and flow area/ bankfull flow area against discharge/bankfull discharge. Station flow frequency and duration analyses were used to assign frequency of occurrence and duration of flow to the dimensionless ratings. Channel geometry surveys were conducted to determine bankfull stage and discharge. Bankfull discharge has a recurrence interval of about 1.5 years and a duration of about 1 percent of the time. The channel geometry surveys at ungaged locations provided bankfull data for ungaged streams. The hydraulic and geometric parameters (width, depth, velocity, etc.) were plotted against drainage area and bankfull discharge. Relationships between these parameters were established, and in some cases they approximate closely the averages found for other locations in the United States. For dimensional plots, separate relations are needed to describe different major drainage basins depending on their physiographic setting. In the present study, the major physiographic factor was the orographic effect on precipitation patterns and this resulted in a greater unit runoff in the South-Central Region than in the Yukon River Region. Another effect is to decrease the value of discharge/bankfull discharge in the South-Central Region over that in the Yukon River Region as both flow frequency approaches very rare events and as flow duration approaches very common flows.

Average values of the hydraulic and geometric properties of rivers were used to illustrate their application to practical engineering problems, namely, the computation of depth of channel scour and of bedload discharge. For design purposes, caution is recommended when making computations based on average values. In the absence of other data, however, they become useful predictive tools.

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LIST OF SYMBOLS

A	flow area of stream, square feet
D	mean depth of stream, feet
Q	discharge of stream, cubic feet per second
R	unit runoff, cubic feet per second per square mile
S	stream slope, feet per foot
V	mean velocity of stream, feet per second
W	surface width of stream, feet
Y	depth of channel scour, feet
a,c,k	coefficients of channel geometry
d	particle size, intermediate axis, millimeters
q	discharge, cubic feet per second per foot of stream width
DA	drainage area, square miles
RI	recurrence interval, years

Superscripts

b,f,m	exponents of hydraulic geometry

Subscripts

B	reference to value at bankfull stage
Y	reference to bedload discharge

APPENDIX A

TABLES OF DATA

Tables 1-11

Table 1.- Station Number, Name, and Drainage Area of Rivers Included in Study

Station No.	USGS No. (15-)	Station Name	Drainage Area DA (sq mi)
1	2000	Gakona R at Gakona	620
2	2004	Gulkana R at Gulkana	1,966
3	2020	Tazlina R nr Glenallen	2,670
4	2060	Klutina R at Copper Center	880
5	--	Little Tonsina R nr Tonsina	33
6	2080	Tonsina R at Tonsina	420
7	2081	Squirrel Cr at Tonsina	70
8	--	Bernard Cr nr Tonsina	70
9	2120	Copper R nr Chitina	20,600
10	--	Tiekel R nr Tiekel	52
11	--	Stuart Cr nr Tiekel	20
12	--	Lowe R nr Valdez	350
13	2912	Maclaren R nr Paxson	280
14	4578	Hess Cr nr Livengood	662
15	4680	Yukon R at Rampart	199,400
16	4810	Tanana R at Harding Lake	17,240
17	4840	Salcha R nr Salchaket	2,170
18	4930	Chena R nr Two Rivers	941
19	5110	Little Chena R nr Fairbanks	356
20	5140	Chena R at Fairbanks	1,980
21	5155	Tanana R at Nenana	27,500
22	--	Chatanika R nr Fairbanks	490

Table 2.- Sampling of Discharge Measurement Notes for Tonsina River at Tonsina, Alaska

Date of Measurement	Discharge Measurement Number	Gage Height (ft)	Discharge Q (cfs)	Flow Area A (ft^2)	Surface Width W (ft)	Mean Velocity V (fps)	Mean Depth D=A/W (ft)
8-19-70	169	2.32	1,690	391	145	4.32	2.70
7-09-70	168	2.88	2,390	486	172	4.92	2.83
8-14-69	164	1.76	790	278	135	2.84	2.06
7-06-68	157	3.47	3,120	556	180	5.98	3.09
7-12-63	118	3.82	5,040	709	179	7.11	3.96
10-24-60	94	1.39	388	212	117	1.61	1.81
6-10-58	68	5.13	7,210	883	192	8.16	4.60

Table 3.- Summary of Bankfull Stage Data for Rivers Included in Study

Station No.	Slope S (ft/ft)	Discharge Q_B (cfs)	Flow Area A_B (ft^2)	Width (Surface) W_B (ft)	Depth (A_B/W_B) D_B (ft)	Velocity (Q_B/A_B) V_B (ft)	Runoff $R_B = \frac{Q_B}{DA}$ (cfs/sq mi)	b $W\ Q^b$	f $D\ Q^f$	m $V\ Q^m$
1	0.0041	4,500	770	200	3.85	5.80	7.26	0.24	0.42	0.34
2	.0042	18,000	1,650	500	3.30	11.10	9.16	.38	.18	.44
3	.0031	22,250	2,698	355	7.60	8.40	8.33	.15	.54	.31
4	.0040	7,050	737	152	4.85	9.45	8.01	.23	.31	.46
5	.0005	220	108	45	2.40	2.05	6.97	--	--	--
6	.0044	5,400	738	180	4.10	7.30	12.86	.16	.36	.48
7	.0156	300	61	38	1.60	5.20	4.29	.16	.30	.54
8	.0200	860	117	45	2.60	7.35	12.29	--	--	--
9	.0015	158,000	17,250	750	23.00	9.40	7.67	.12	.73	.15
10	.0062	760	221	80	2.75	3.45	14.62	--	--	--
11	.0159	245	78	37	2.10	3.15	12.25	--	--	--
12	.0040	4,000	568	167	3.40	7.25	11.43	.22	.43	.35
13	.0007	5,700	1,150	295	3.90	5.10	20.36	.09	.38	.53
14	.0020	5,000	1,035	90	11.50	4.95	7.55	.05	.29	.66
15	.0004	408,000	56,550	1,950	29.00	7.30	2.05	.30	.27	.43
16	.0015	69,000	7,950	530	15.00	8.90	4.00	.11	.36	.53
17	.0008	13,000	2,974	325	9.15	4.50	5.99	.24	.26	.50
18	.0017	5,750	907	224	4.05	6.00	6.11	.13	.38	.49
19	.0020	2,600	1,380	120	11.50	1.95	7.30	.34	.54	.12
20	.0007	9,110	2,254	280	8.05	4.20	4.60	.13	.63	.24
21	.0001	80,000	10,900	645	16.90	7.25	2.91	.18	.28	.54
22	.0017	3,870	517	152	3.40	7.50	7.89	--	--	--

Table 4.- Summary of Data and Computations at Ungaged Locations

Station Number	Discharge Measurements				
	Q (cfs)	A (ft^2)	W (ft)	D (ft)	V (fps)
5	47.3	45.3	37	1.22	1.04
8	53.3	25.4	34	.75	2.10
10	129.5	65.7	45	1.46	1.98
11	63.7	35.2	29	1.21	1.81
22	457.0	186.1	148	1.26	2.46
	Cross-sectional Survey				
	A_B (ft^2)	A/A_B	W_B (ft)	D_B (ft)	D/D_B
5	107	.42	45	2.38	.51
8	117	.22	45	2.60	.29
10	221	.30	80	2.75	.53
11	78	.45	37	2.10	.58
22	517	.36	152	3.40	.37
	Dimensionless Rating Curve Data				
	Q/Q_B (Area)	Q/Q_B (Depth)	Q/Q_B (avg)	Q_B (cfs)	V_B (fps)
5	.24	.18	.21	220	2.06
8	.08	.04	.06	860	7.35
10	.13	.21	.17	760	3.45
11	.26	.26	.26	245	3.15
22	.16	.08	.12	3,870	7.50

Table 5.- Values of Discharge in cfs at Selected Flow Frequency and Duration; South-Central Region

Event	Station Number 1	3	4	6	7	9	13
Recurrence Interval (yr)							
1.01	2,520	10,180	5,080	2,770	235	122,770	3,440
1.05	3,000	12,830	5,610	3,375	260	129,200	4,045
1.11	3,320	14,700	5,910	3,745	280	133,400	4,410
1.25	3,800	17,540	6,280	4,240	315	139,350	4,900
2.0	5,040	25,560	7,035	5,345	440	153,850	5,980
5	6,960	39,270	7,835	6,690	725	173,640	7,295
10	8,380	50,250	8,270	7,510	1,020	186,720	8,095
25	10,330	66,490	8,750	8,475	1,555	203,230	9,040
50	11,920	80,440	9,065	9,150	2,115	215,550	9,710
100	13,610	96,090	9,355	9,800	2,860	227,910	10,355
200	15,440	113,690	9,625	10,430	3,840	240,410	10,985
Duration (percent of time)							
0.5	4,800	24,500	7,600	5,450	(N/A)	155,000	(N/A)
1.0	4,000	19,500	7,200	4,850		150,000	
2	3,550	16,700	6,800	4,250		142,000	
5	3,000	14,500	5,900	3,400		130,000	
10	2,530	12,500	5,100	2,640		117,000	
20	1,890	8,600	3,850	1,790		80,000	
30	1,340	4,800	2,100	1,000		48,000	
50	300	1,450	600	270		11,500	
80	100	385	225	105		5,050	
Avg. Annual	909	4,143	1,686	871		36,990	
Bankfull	4,500	22,250	7,050	5,400	300	158,000	5,700
Recurrence	1.55	1.65	2.00	2.00	1.20	2.25	1.70
Duration	0.8	0.7	1.5	0.5		0.5	

Table 6.- Values of Ratio of Discharge to Bankfull Discharge at Selected Flow Frequency and Duration; South-Central Region

Event	Station Number 1	3	4	6	7	9	13	Average
Recurrence Interval (yr)								
1.01	0.56	0.46	0.72	0.51	0.78	0.78	0.60	0.64
1.05	.67	.58	.80	.63	.87	.82	.71	.73
1.11	.74	.66	.84	.69	.93	.84	.77	.79
1.25	.84	.79	.89	.79	1.05	.88	.86	.87
2.0	1.12	1.15	1.00	.99	1.47	.97	1.05	1.11
5	1.55	1.77	1.11	1.24	2.42	1.10	1.28	1.50
10	1.86	2.26	1.17	1.39	3.40	1.18	1.42	1.81
25	2.30	2.99	1.24	1.57	5.18	1.29	1.59	2.31
50	2.65	3.62	1.29	1.69	7.05	1.36	1.70	2.77
100	3.02	4.32	1.33	1.82	9.53	1.44	1.82	3.33
200	3.43	5.11	1.36	1.93	12.80	1.52	1.93	4.01
Duration (percent of time)								
0.5	1.07	1.10	1.08	1.01	(N/A)	.98	(N/A)	1.05
1.0	.89	.88	1.02	.90		.95		.93
2	.79	.75	.97	.79		.90		.84
5	.67	.65	.84	.63		.82		.72
10	.56	.56	.72	.49		.74		.62
20	.47	.39	.55	.33		.51		.44
30	.30	.22	.30	.19		.30		.26
50	.07	.07	.09	.05		.07		.07
80	.02	.02	.03	.02		.03		.02
Avg. Annual	.20	.19	.24	.16	(N/A)	.23	(N/A)	.20

Table 7.- Values of Discharge in cfs at Selected Flow Frequency and Duration; Yukon River Region

Event	Station Number 15	20	21
Recurrence Interval (yr)			
1.01	258,530	5,560	66,670
1.05	321,580	6,070	67,700
1.11	360,980	6,540	69,040
1.25	414,930	7,390	72,010
2.0	540,470	10,530	85,000
5	702,080	18,105	117,070
10	804,090	26,145	149,010
25	928,500	41,410	204,840
50	1,018,470	57,935	260,520
100	1,106,490	80,485	331,280
200	1,193,410	111,215	421,210
Duration (percent of time)			
0.5	740,000	12,000	(N/A)
1.0	645,000	10,400	
2	550,000	8,200	
5	420,000	5,350	
10	315,000	3,600	
20	240,000	2,300	
30	175,000	1,650	
50	47,000	680	
80	21,500	305	
Avg. Annual	129,800	1,520	24,690
Bankfull	408,000	9,110	80,000
Recurrence	1.25	1.65	1.70
Duration	5.2	1.4	

Table 8.- Values of Ratio of Discharge to Bankfull Discharge at Selected Flow Frequency and Duration; Yukon River Region

Event	Station Number 15	20	21	Average
Recurrence Interval (yr)				
1.01	0.63	0.61	0.83	0.69
1.05	.79	.67	.85	.77
1.11	.89	.72	.86	.82
1.25	1.02	.81	.90	.91
2.0	1.33	1.16	1.06	1.18
5	1.72	1.99	1.46	1.72
10	1.97	2.87	1.86	2.23
25	2.28	4.55	2.56	3.13
50	2.50	6.36	3.26	4.04
100	2.71	8.84	4.14	5.23
200	2.92	12.21	5.27	6.80
Duration (percent of time)				
0.5	1.81	1.32	(N/A)	1.57
1.0	1.58	1.14		1.36
2	1.35	.90		1.12
5	1.03	.59		.81
10	.77	.40		.58
20	.59	.25		.42
30	.43	.18		.31
50	.12	.08		.10
80	.05	.03		.04
Avg. Annual	.32	.17	.31	.26

Table 9.- Summary of Particle Size Data

Station No.	Particle size (mm) at given percentage d_{16}	d_{35}	d_{50}	d_{65}	d_{84}	Remarks
1	8.7	15.5	21.0	26.0	36.0	(1)
2	3.5	11.0	21.0	33.5	52.0	(1)
	2.2	4.8	6.5	8.6	12.2	(2)
3	17.5	32.0	40.0	45.0	58.0	(1)
	.4	6.4	9.2	13.0	21.0	(2)
	<.10	.11	.14	.18	.30	(3)
4	13.5	22.5	30.0	41.0	98.0	(1)
	4.3	15.0	22.0	29.5	43.0	(2)
	.5	2.7	8.0	15.5	25.5	(3)
5	3.7	5.6	8.3	13.0	25.0	(1)
	<.10	<.10	.11	.14	.27	(3)
6	17.0	37.0	48.0	64.0	96.0	(1)
7	6.0	11.5	18.0	22.0	42.0	(1)
8	6.6	22.0	66.0	82.0	115.0	(1)
10	4.0	38.0	64.0	90.0	140.0	(1)
11	6.0	14.0	19.0	28.0	42.0	(1)
12	21.0	35.0	50.0	68.0	102.0	(1)
13	2.7	5.6	8.5	11.8	16.4	(1)
	.3	1.8	3.5	5.9	10.4	(2)
14	4.0	7.0	11.5	17.0	25.0	(1)
	.5	5.5	11.5	16.5	24.5	(2)
	<.10	<.10	<.10	<.10	.21	(3)
15	4.0	10.0	13.4	18.0	31.0	(1)
	6.8	9.5	11.1	14.0	18.5	(2)
	<.10	<.10	<.10	.11	.34	(3)
17	8.2	14.5	18.8	22.0	31.0	(1)
18	4.9	13.0	19.0	24.0	34.0	(1)
	.7	1.9	3.5	6.0	10.5	(2)
19	4.2	10.0	13.5	16.5	22.5	(1)
	.04	.12	.14	.17	.25	(2)
21	<.02	<.02	<.02	.02	.04	(2),(4)
22	4.0	13.0	18.2	24.0	34.8	(1)

Remarks
(1) Bed Material - Pebble Count
(2) Bed Material Fines - Sieve Analysis
(3) Bank Material - Sieve Analysis
(4) No coarse particles on bed

Note: No samples at stations 9, 16, and 20; particle size predominantly 1 mm and less.

Table 10.- Comparison of Values of Runoff for Several Occurrences of Flow; South-Central Region versus Yukon River Region

	Unit Runoff in cfs/sq. mile							
	80%		mean annual (35%)		bankfull (1.5 yr)		200 yr	
Drainage Area (sq mi)	South-Cen. Q/Q_B=.024	Yukon R. Q/Q_B=.043	South-Cen. Q/Q_B=.206	Yukon R. Q/Q_B=.265	South-Cen. Q/Q_B=1.0	Yukon R. Q/Q_B=1.0	South-Cen. Q/Q_B=4.0	Yukon Q/Q_B=
100	0.24	0.44	2.1	2.7	10.0	10.3	40	70
1,000	.22	.27	1.9	1.7	9.3	6.3	37	43
10,000	.21	.17	1.8	1.0	8.7	3.9	35	27
100,000	.20	.10	1.7	.6	8.0	2.4	33	16

Table 11.- Summary of Magnitude of Floods; Station Data Versus Regression Equation Computation

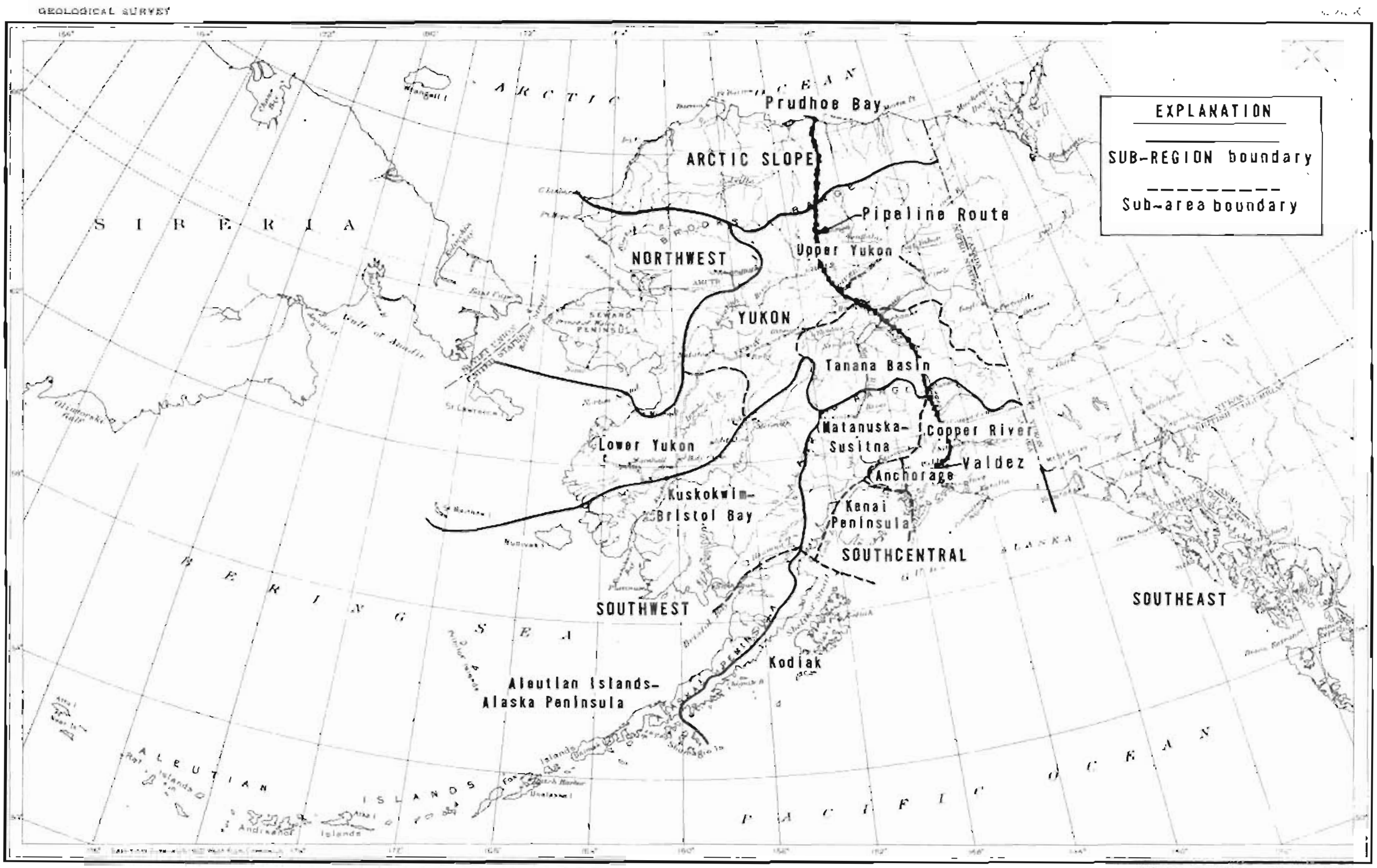
Flow Frequency (yr)	Discharge in cfs			
	Tazlina River		Klutina River	
	Station	Equation	Station	Equation
50	80,441	35,318	9,076	14,749
25	66,500	48,245	8,750	10,864
10	50,300	38,956	8,270	9,490
5	39,300	33,158	7,830	8,237
2	25,600	25,771	7,030	6,341

Flow Frequency (yr)	Station Data as Percent of Computed Value	
	Tazlina River	Klutina River
50	228	61
25	138	81
10	129	87
5	118	95
2	100	111

APPENDIX B

ILLUSTRATIONS OF DATA

Figures 1-32



After Feulner, et. al. (1971)

Figure 1.--Hydrologic subregions.

Figure 2.--Location of study sites.

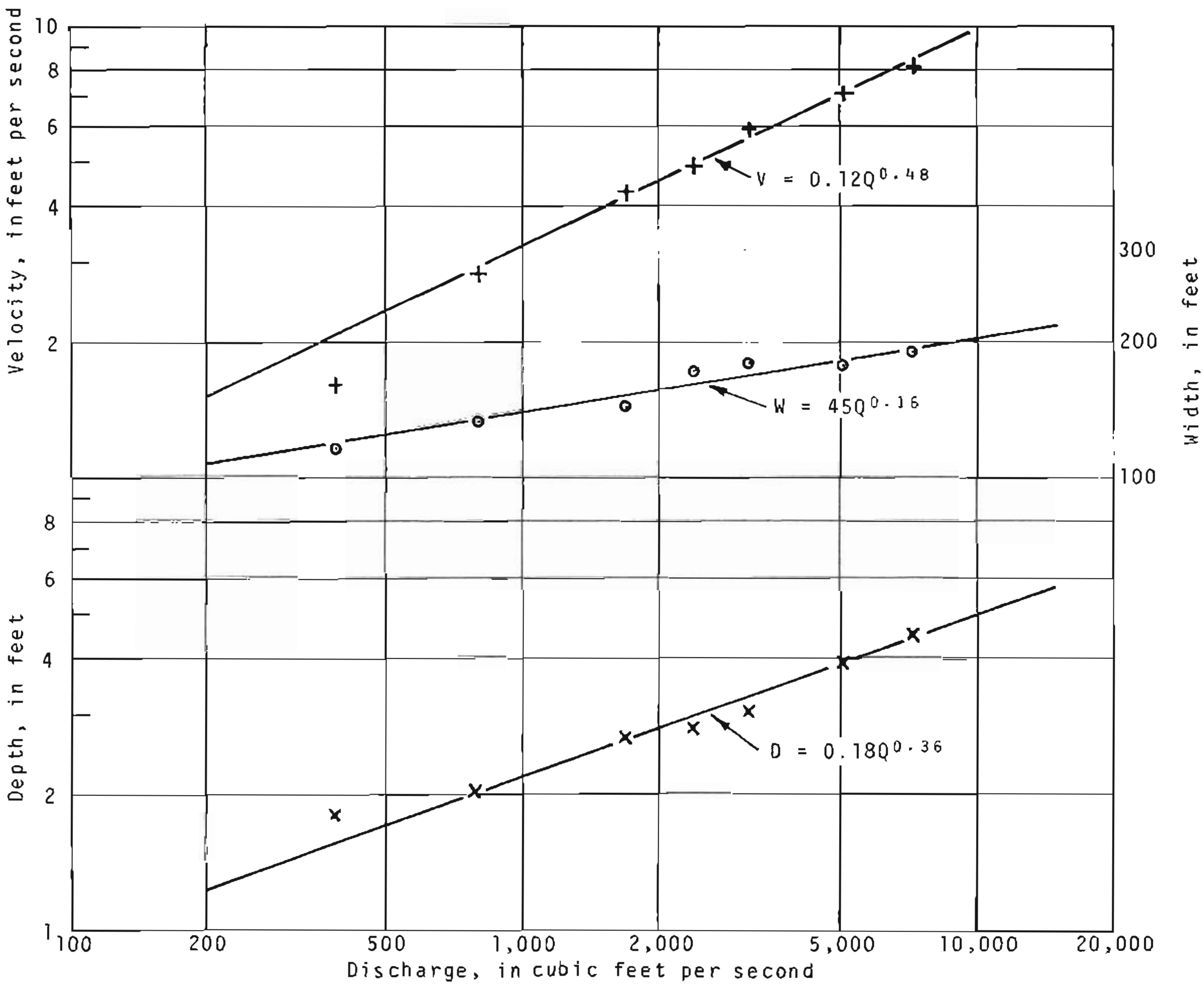


Figure 3.--At-a-station hydraulic geometry for Tonsina River at Tonsina, Alaska.

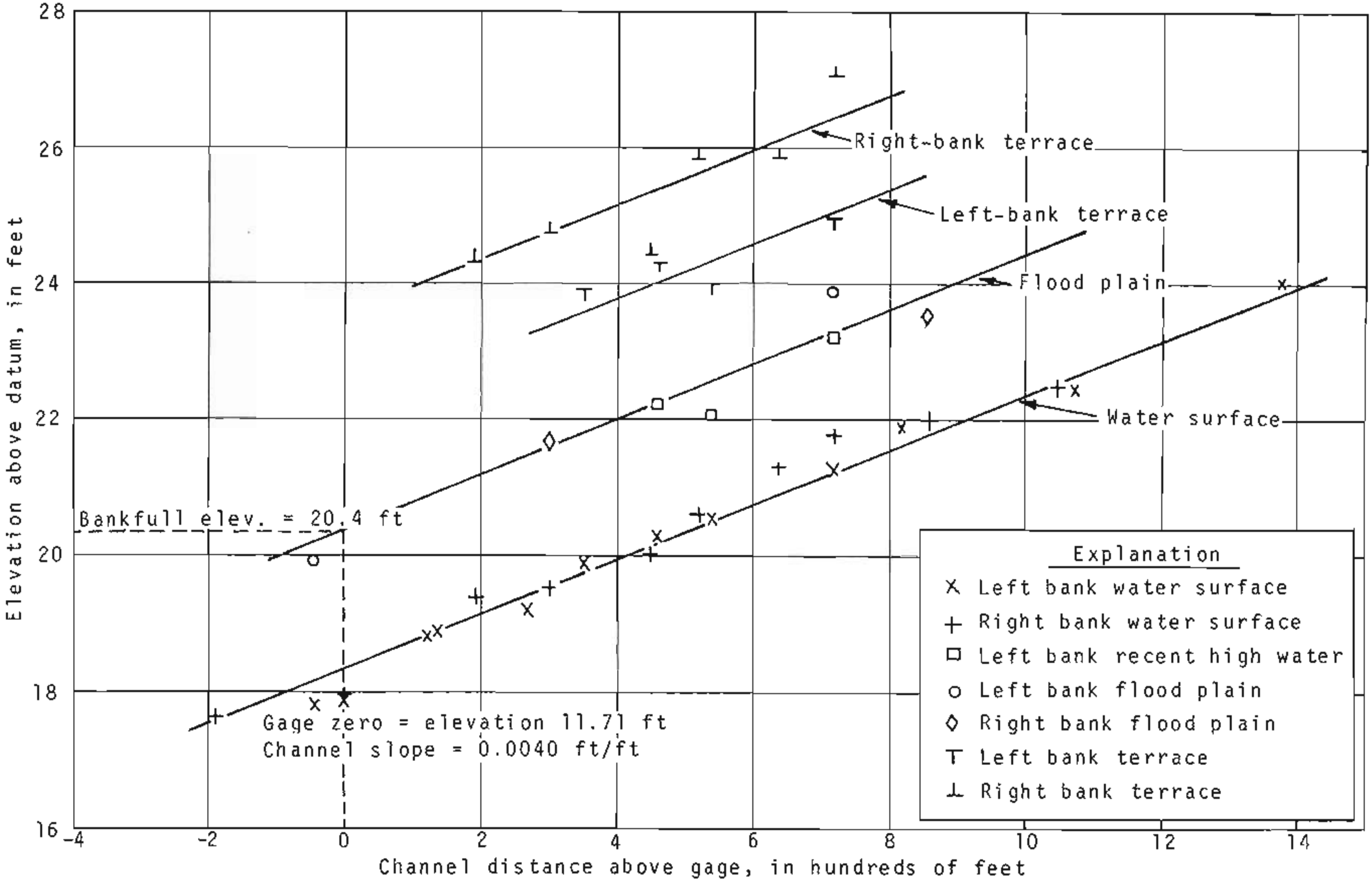


Figure 4.--Long profiles from channel geometry surveys for Klutina River at Copper Center, Alaska.

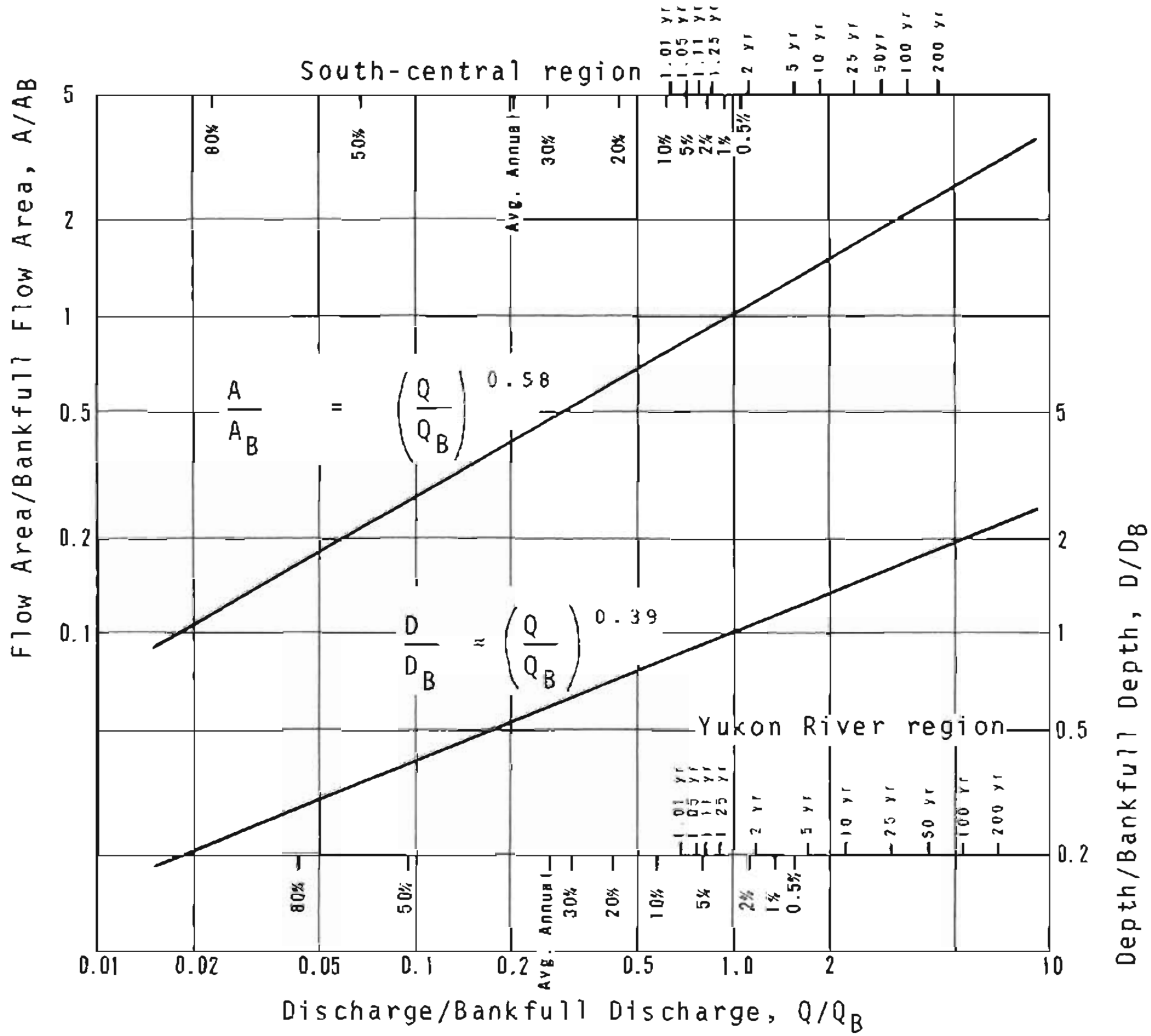


Figure 5.--Dimensionless rating curves and values of flow frequency and duration for gaging stations included in study.

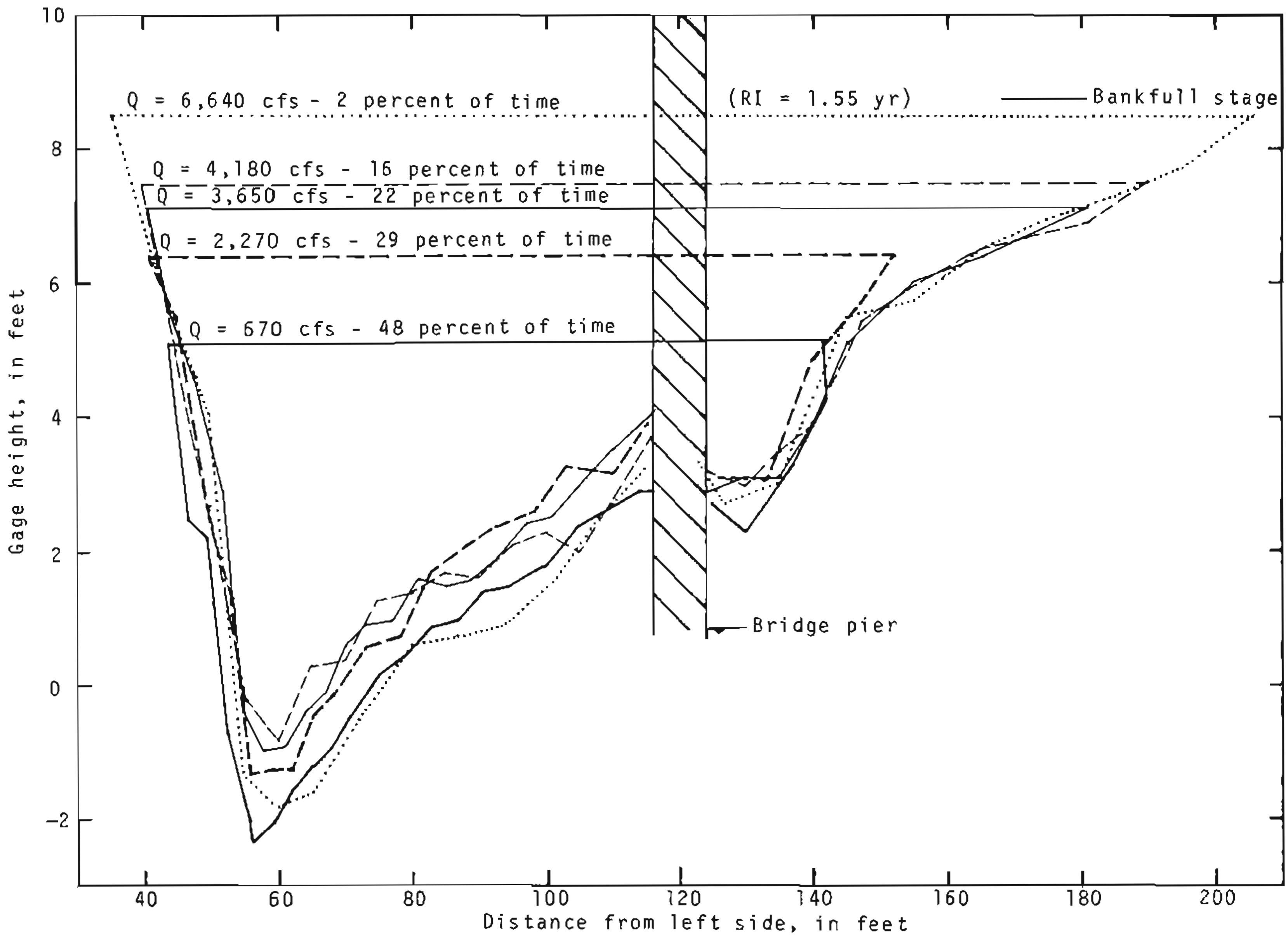


Figure 6.--Channel cross sections for Klutina River at Copper Center, Alaska.

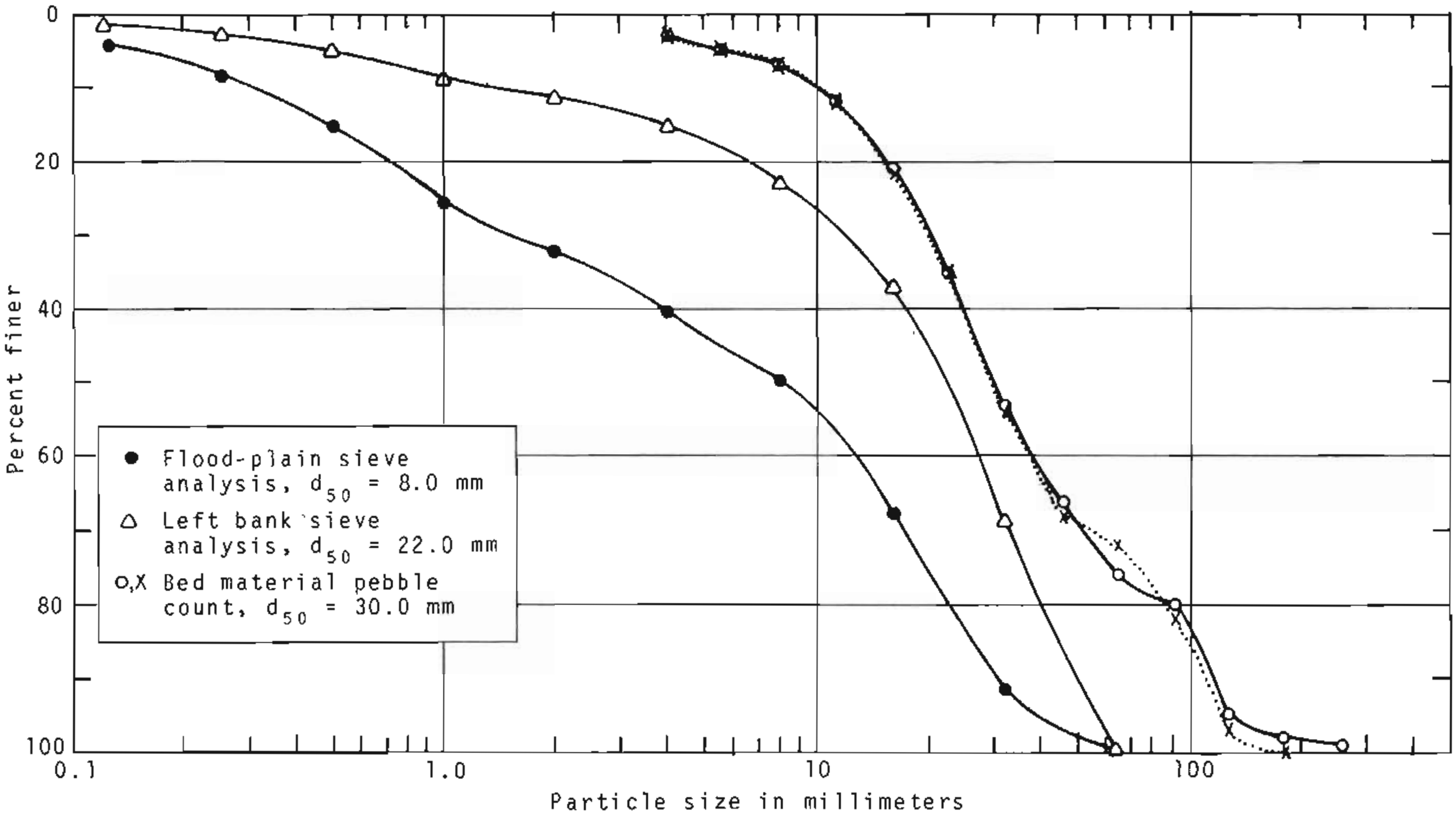


Figure 7.--Particle-size distributions for the Klutina River at Copper Center, Alaska.

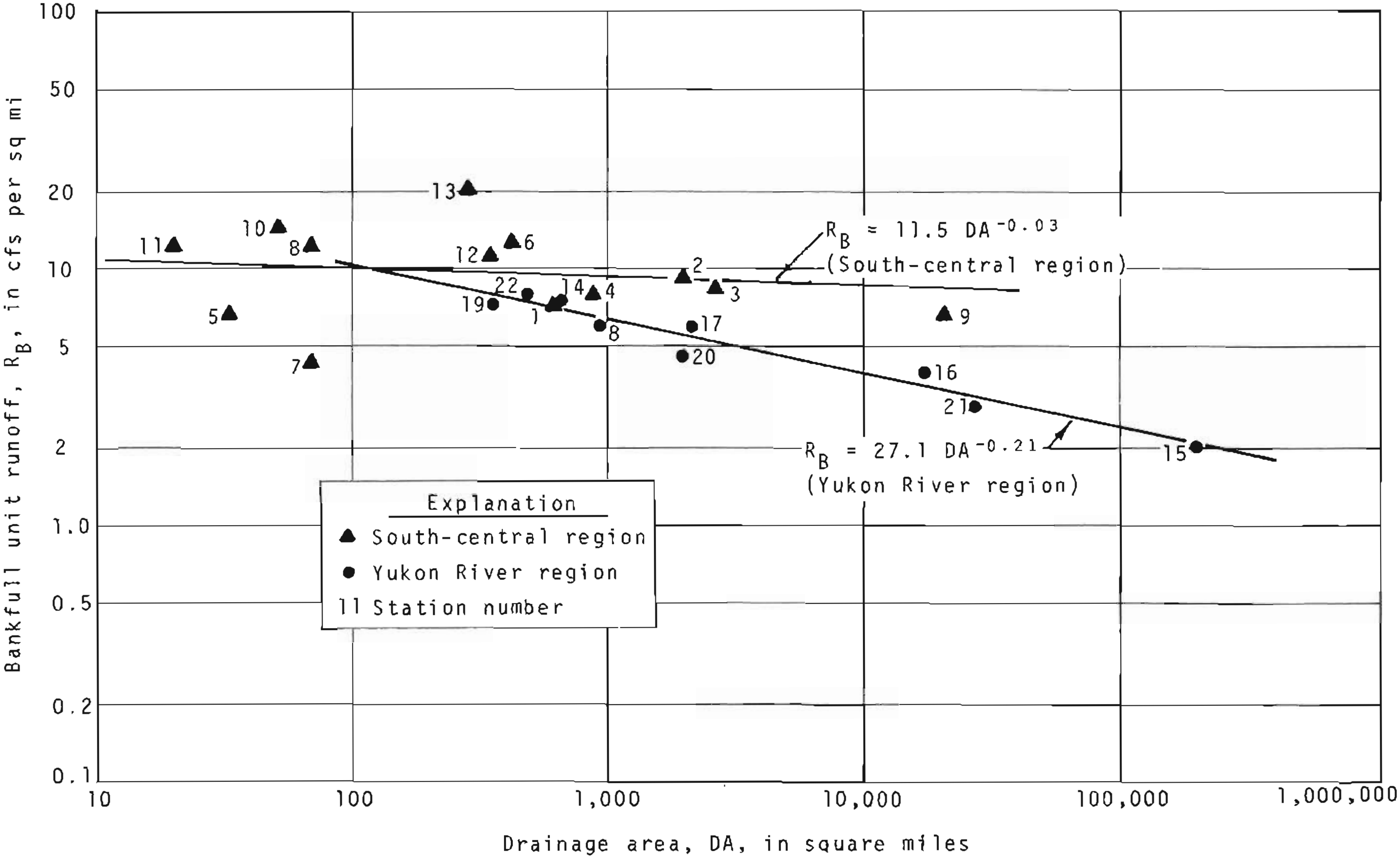
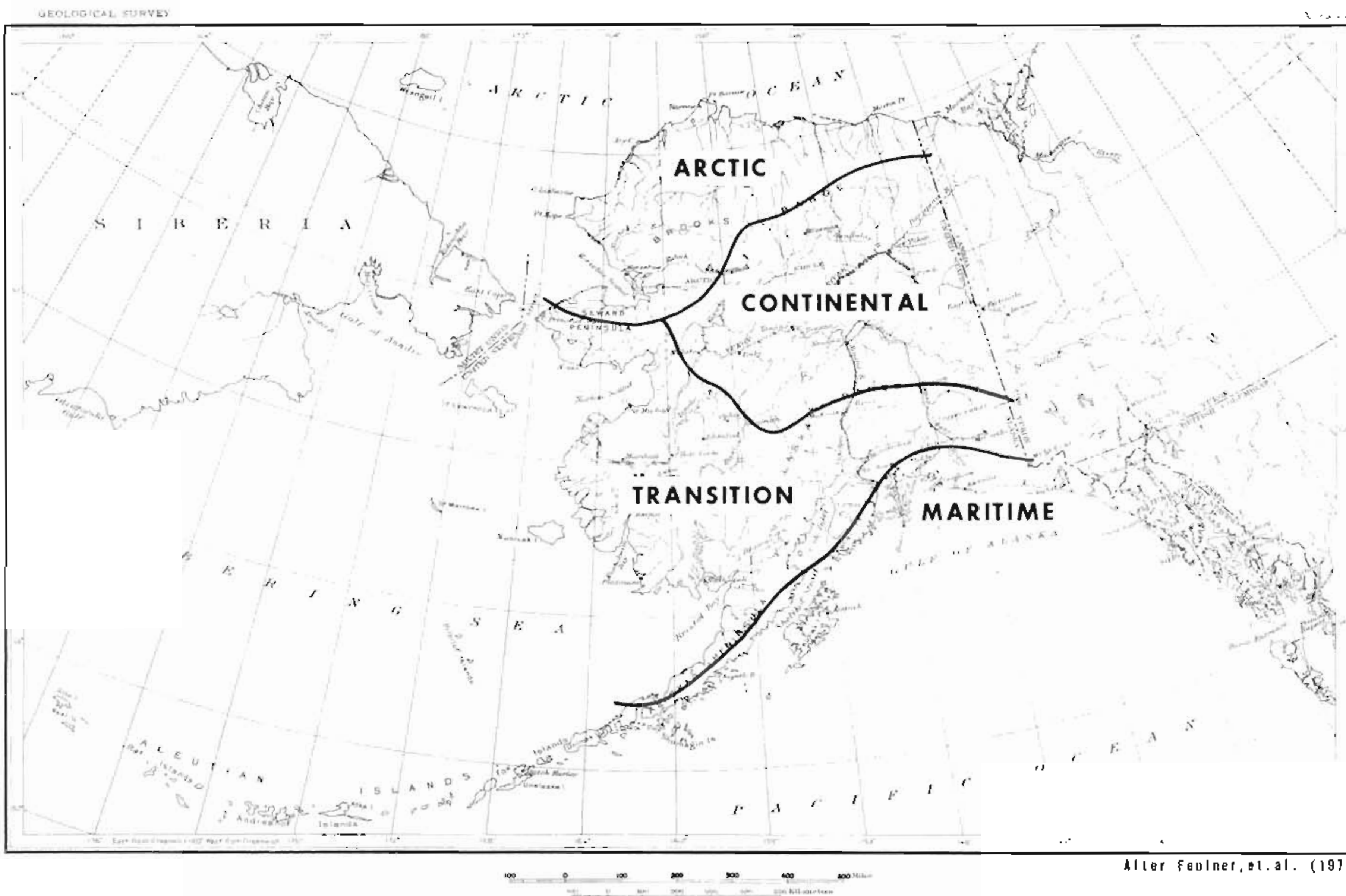
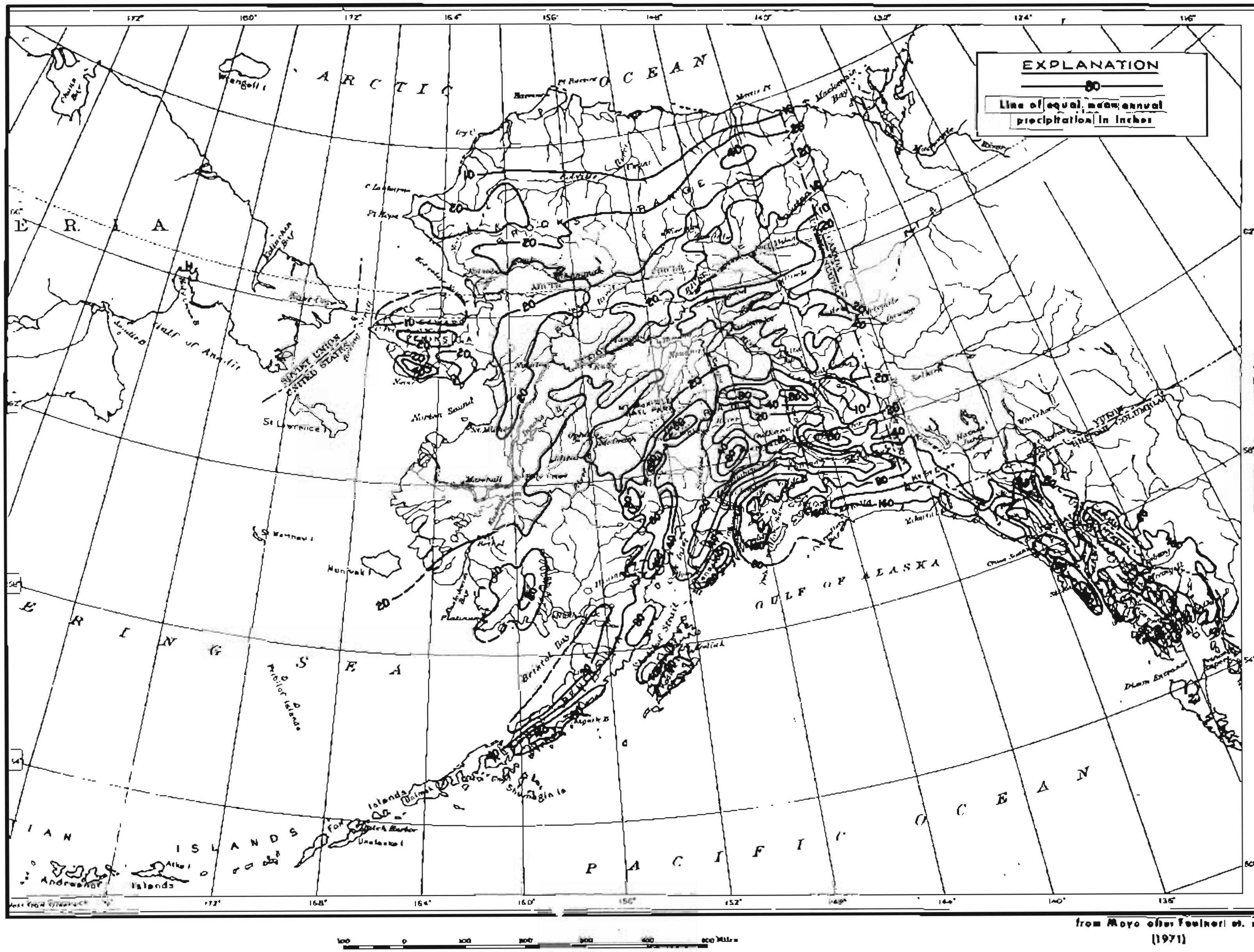


Figure 8.--Bankfull runoff as a function of drainage area.



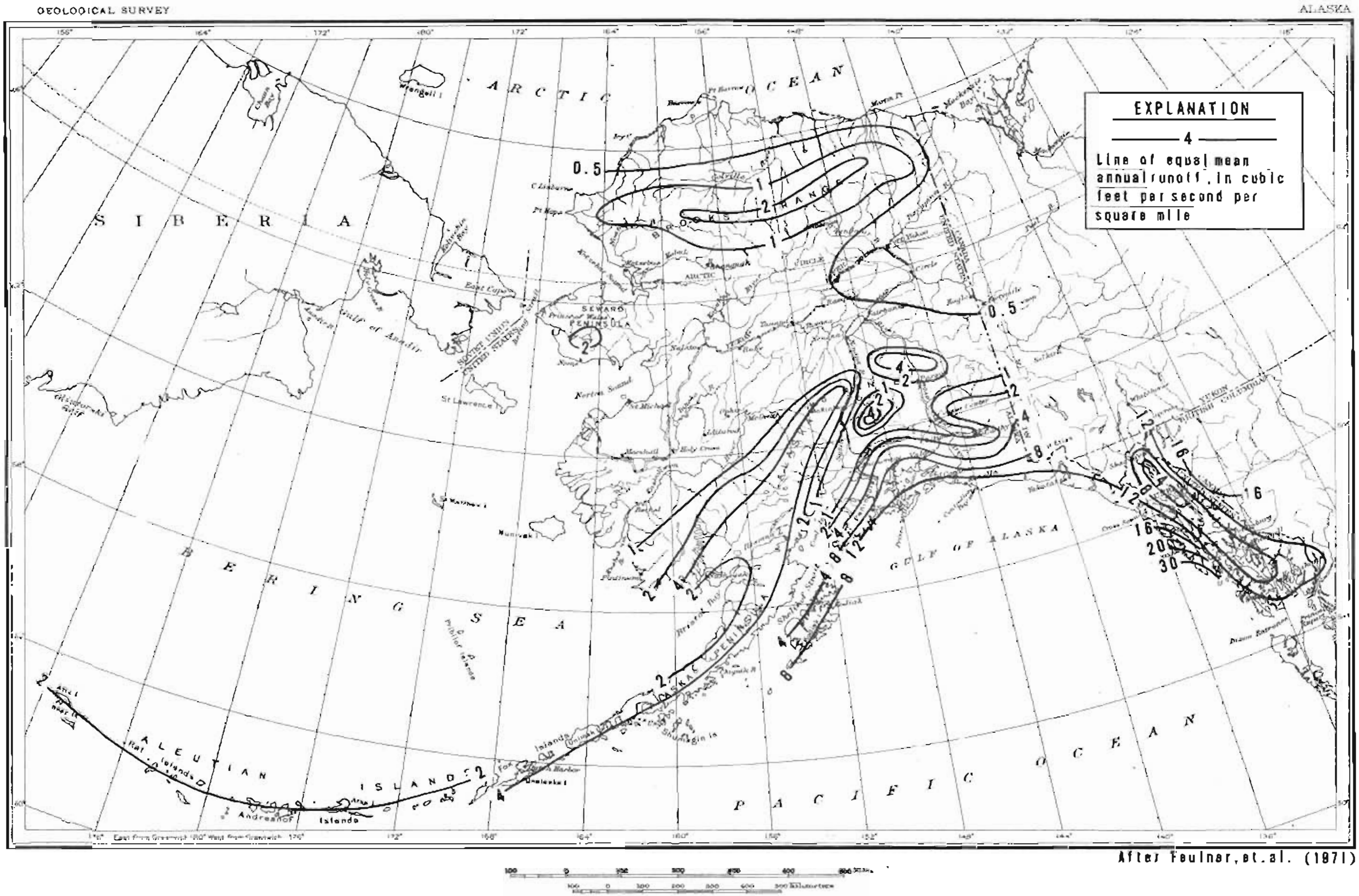
After Fenlner,et.al. (1971)

Figure 9.--Climatological zones.



from Moyo after Feulner et. al. (1971)

Figure 10.--Mean annual precipitation.



After Feulner, et.al. (1971)

Figure 11.--Mean annual runoff.

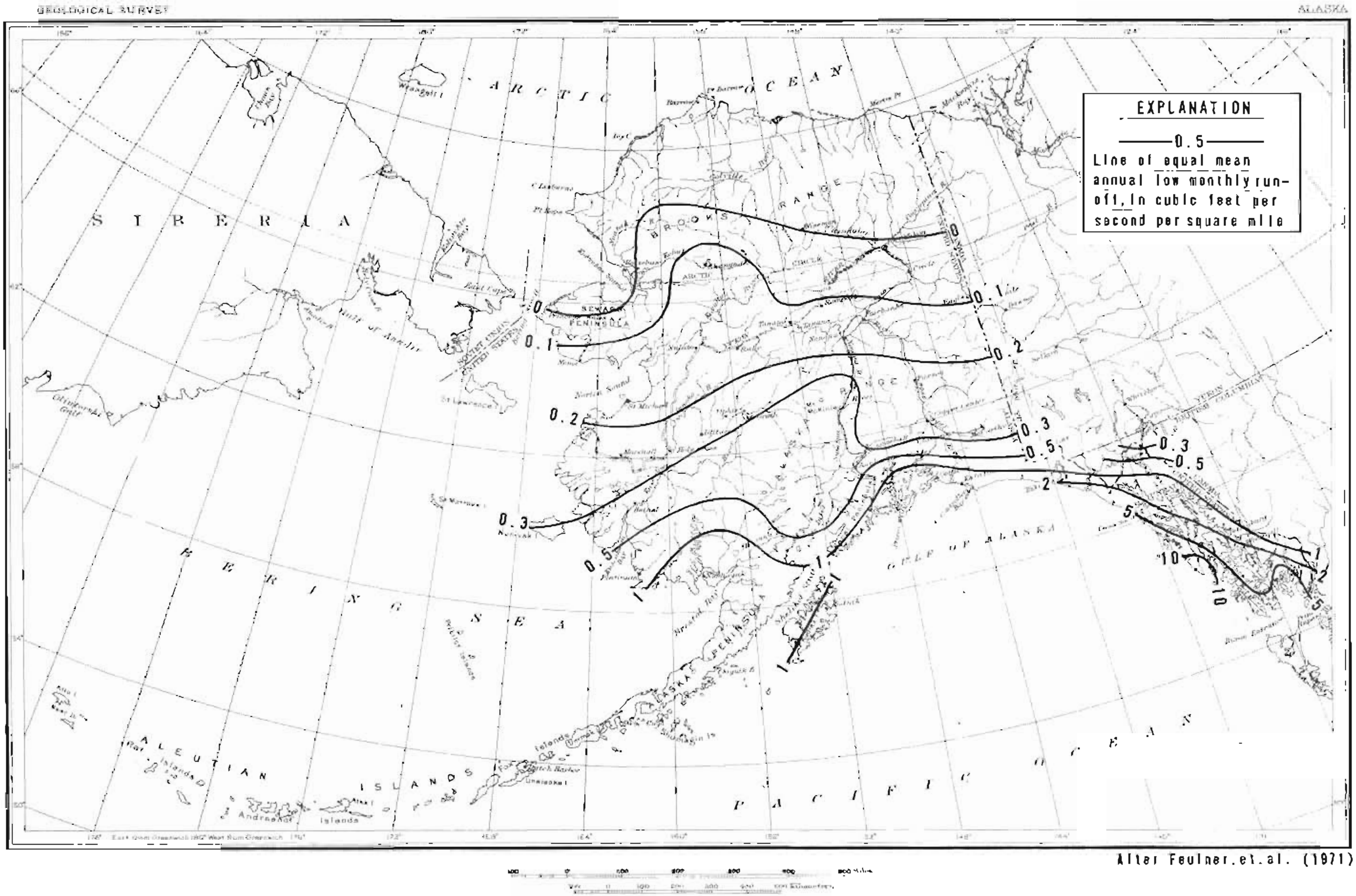
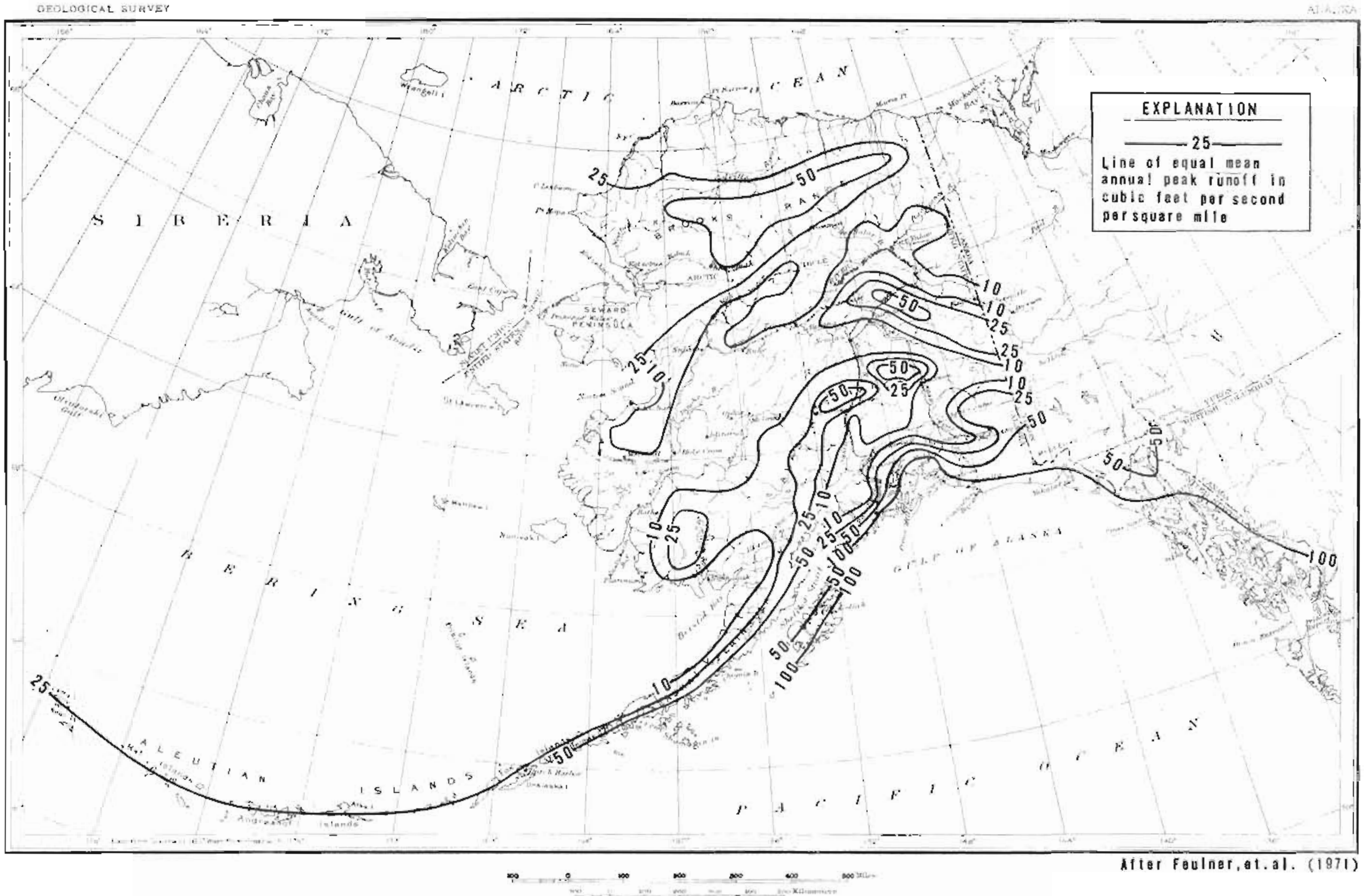


Figure 12.--Mean annual low monthly runoff.



After Feulner, et. al. (1971)

Figure 13.--Mean annual peak runoff.

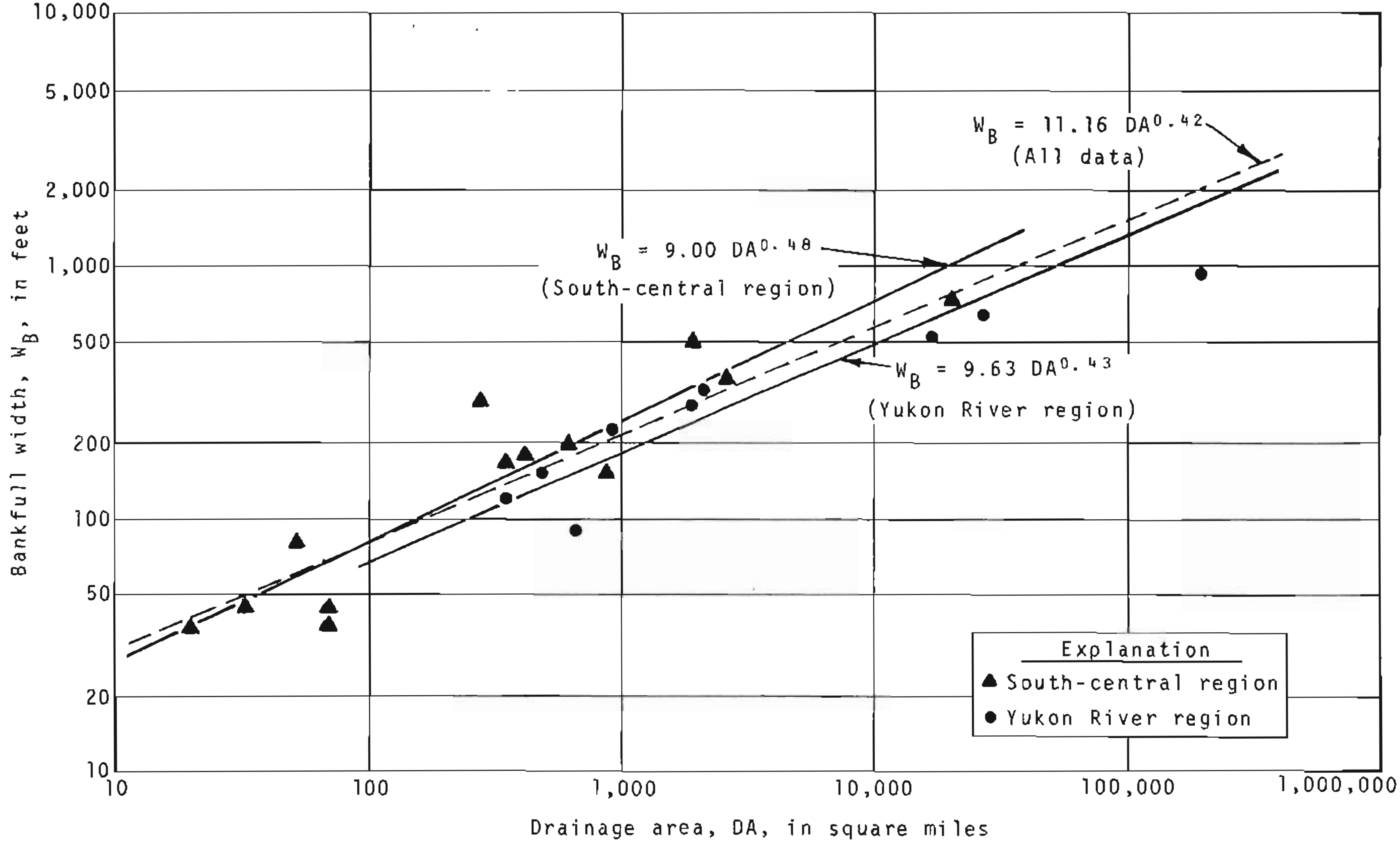


Figure 14.--Bankfull width as a function of drainage area.

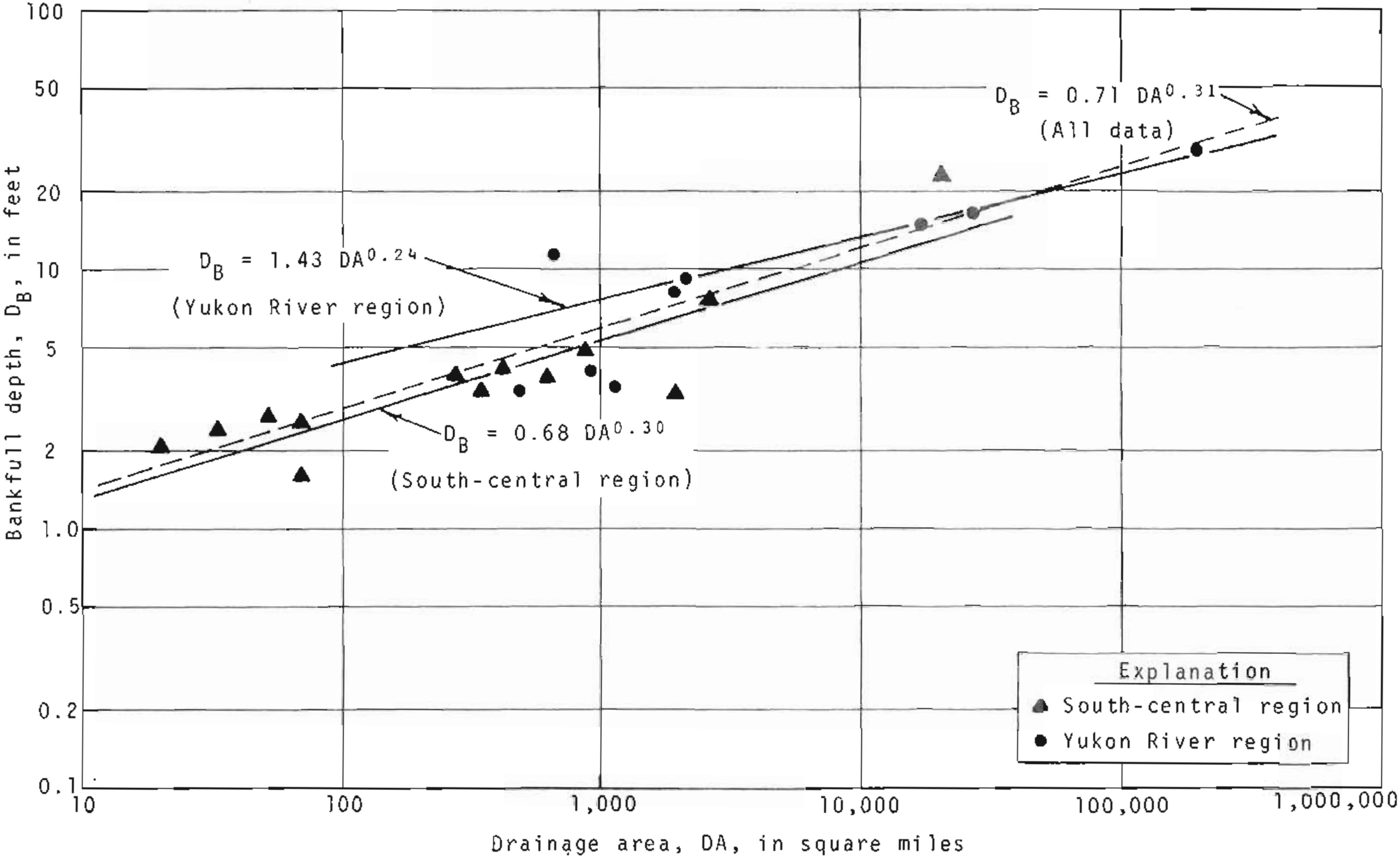


Figure 15.--Bankfull depth as a function of drainage area.

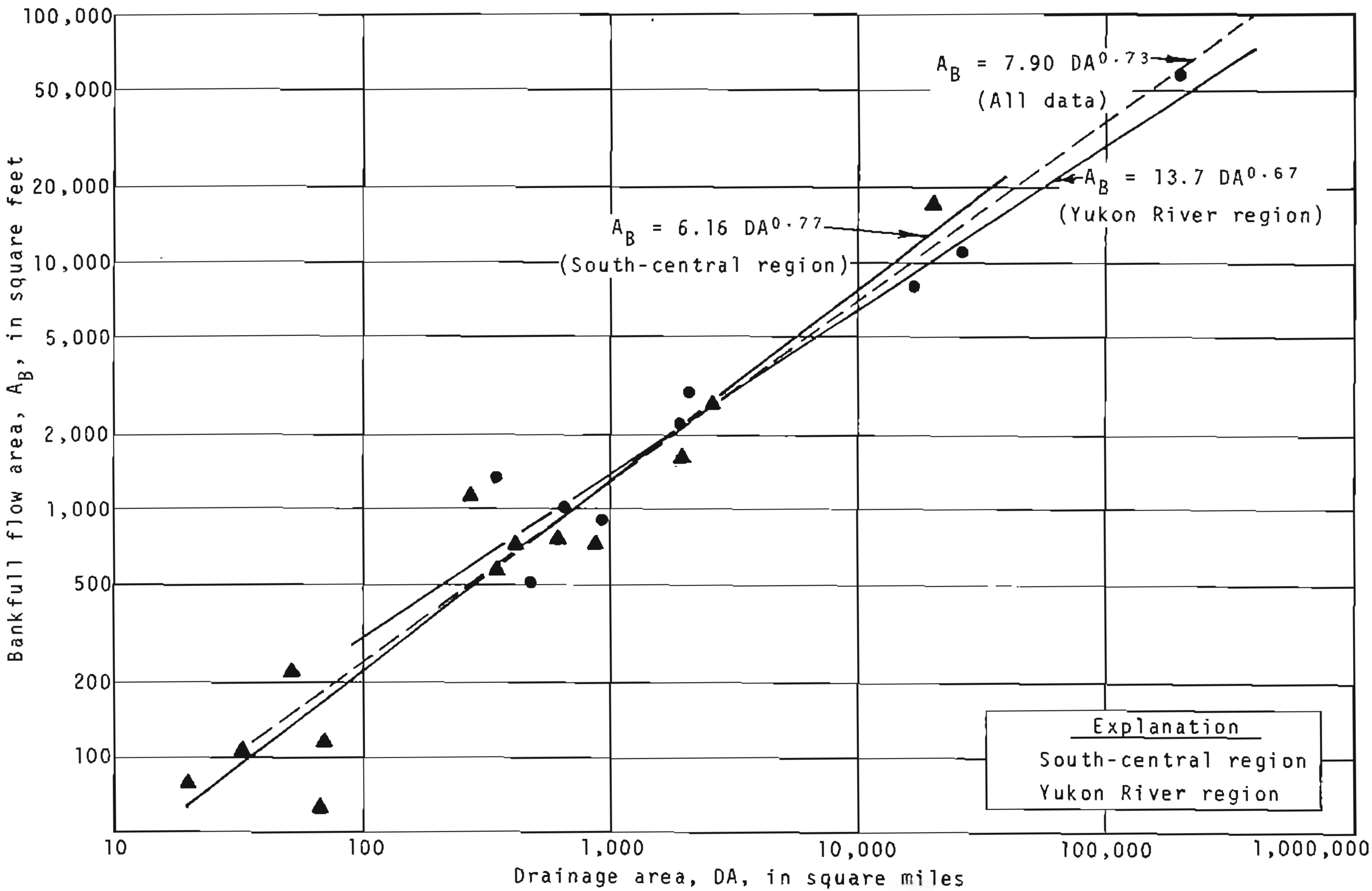


Figure 16.--Bankfull flow area as a function of drainage area.

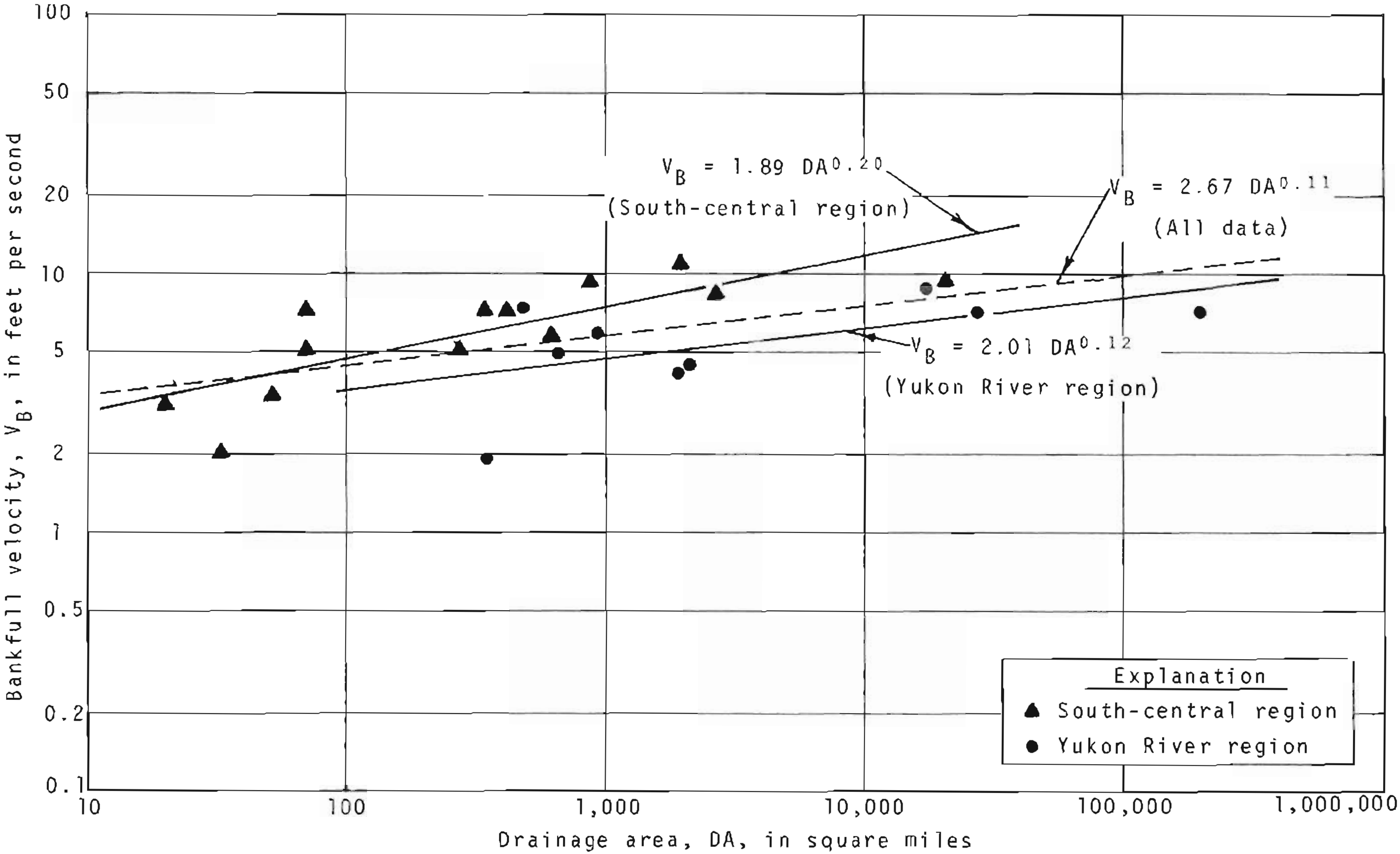


Figure 17.--Bankfull velocity as a function of drainage area.

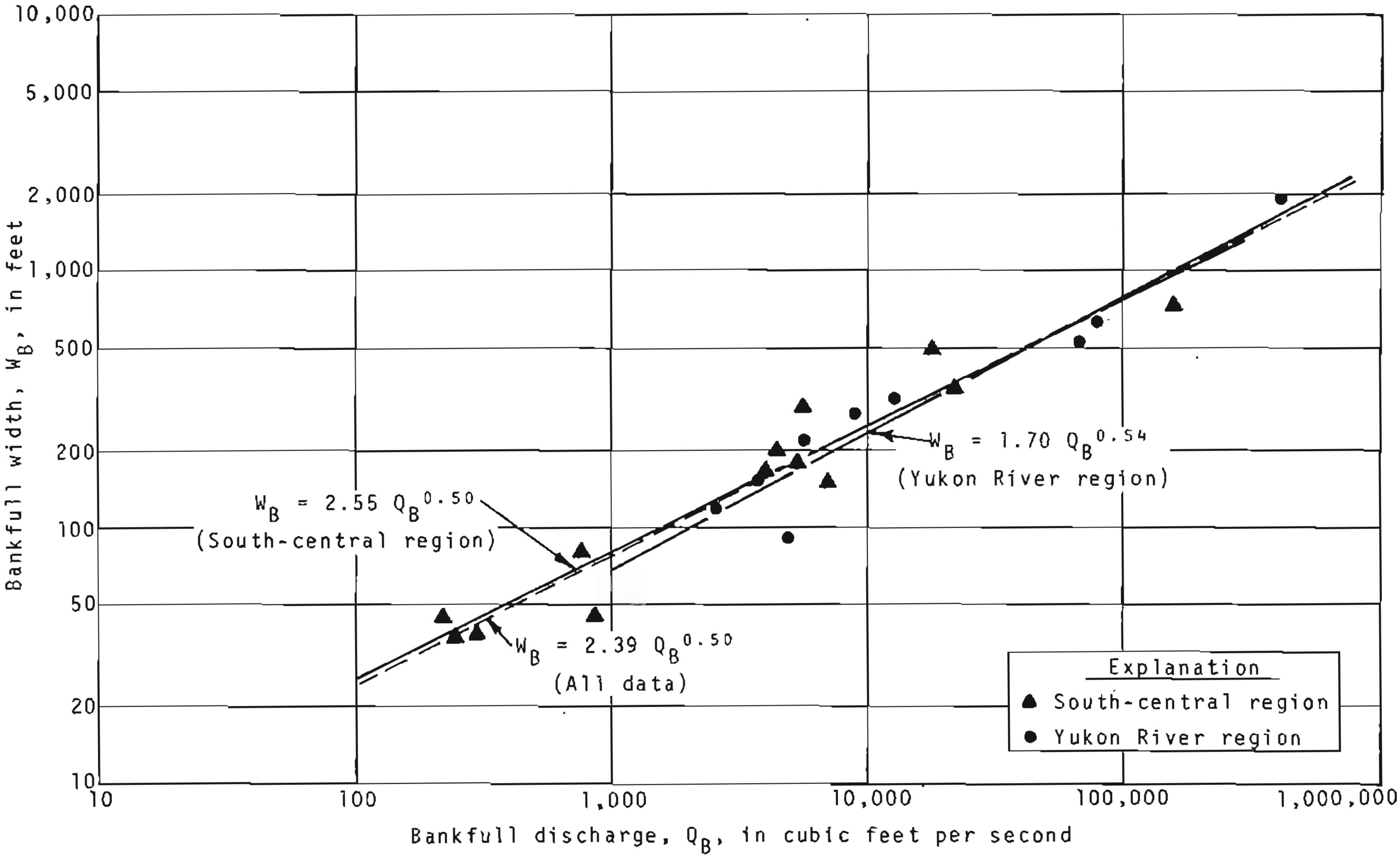


Figure 18.--Bankfull width as a function of bankfull discharge.

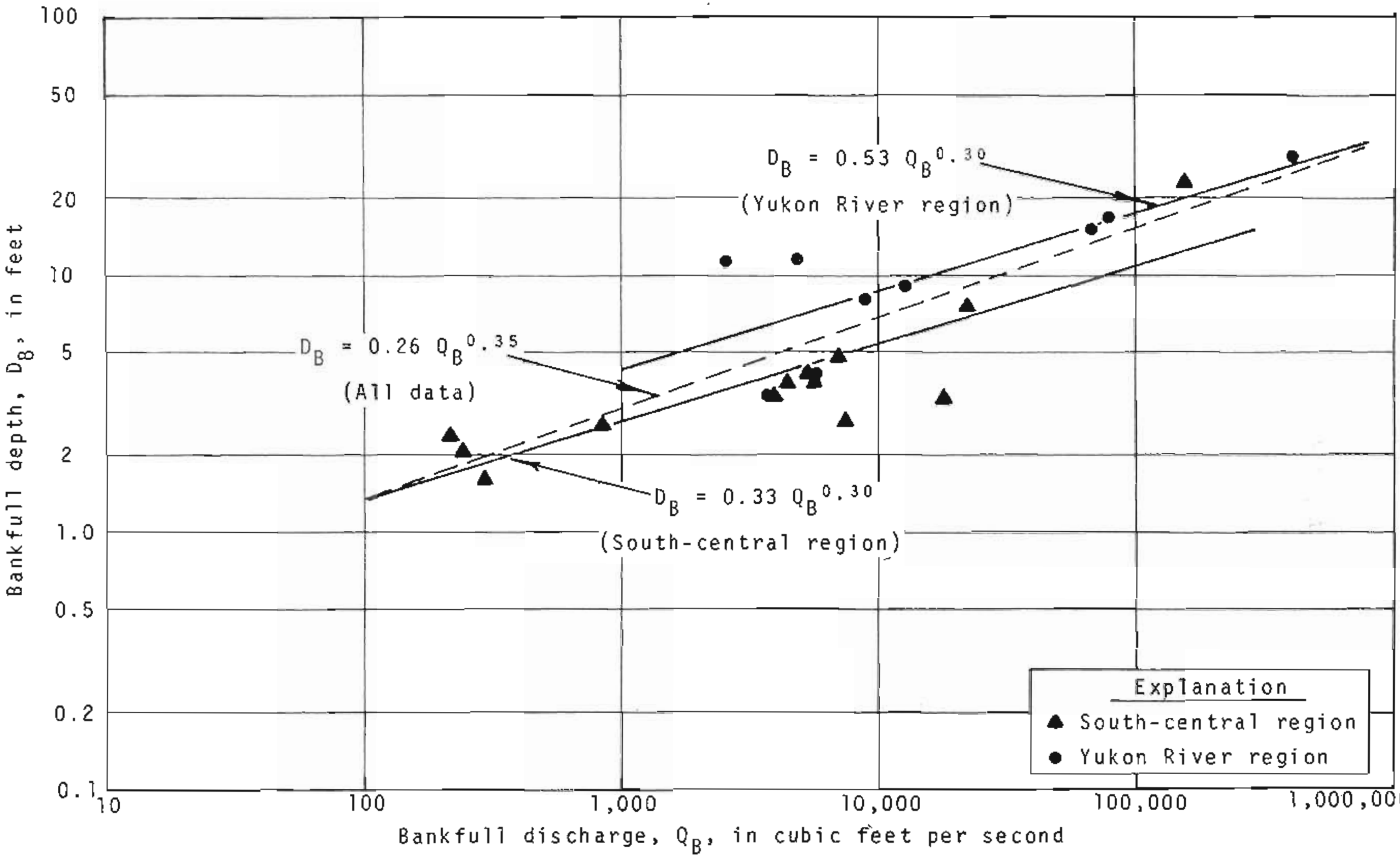


Figure 19.--Bankfull depth as a function of bankfull discharge.

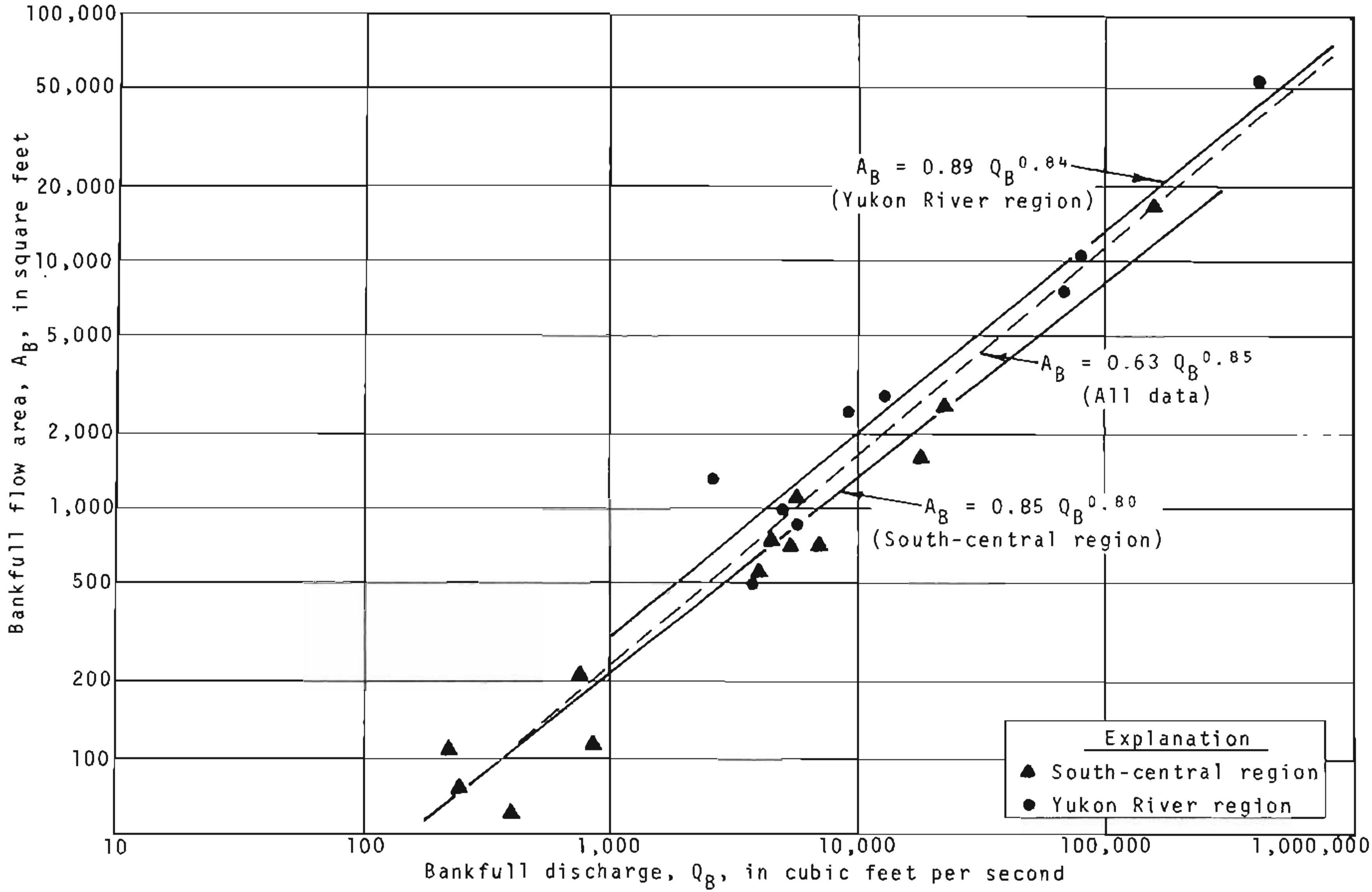


Figure 20.--Bankfull flow area as a function of bankfull discharge.

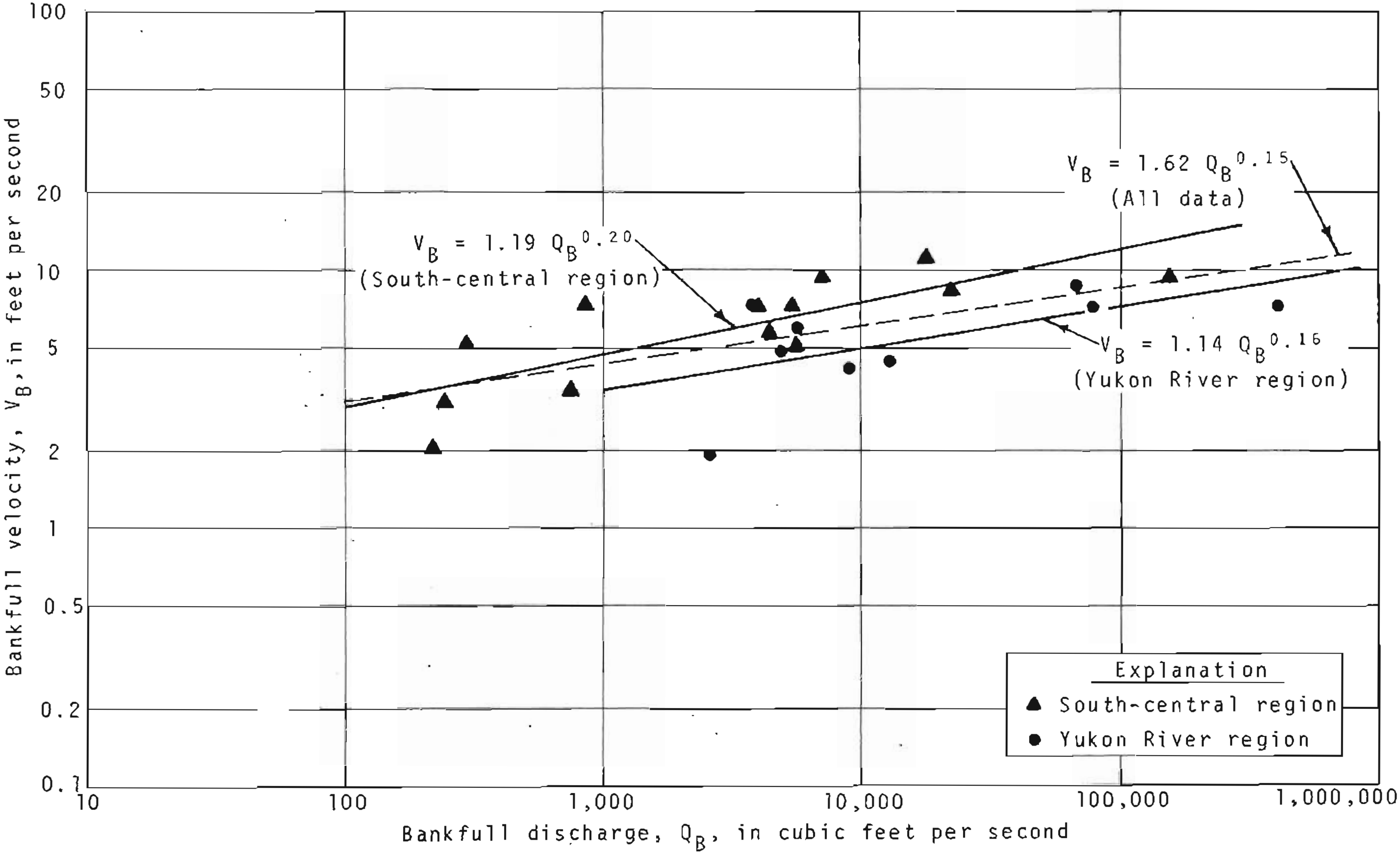


Figure 21.--Bankfull velocity as a function of bankfull discharge.

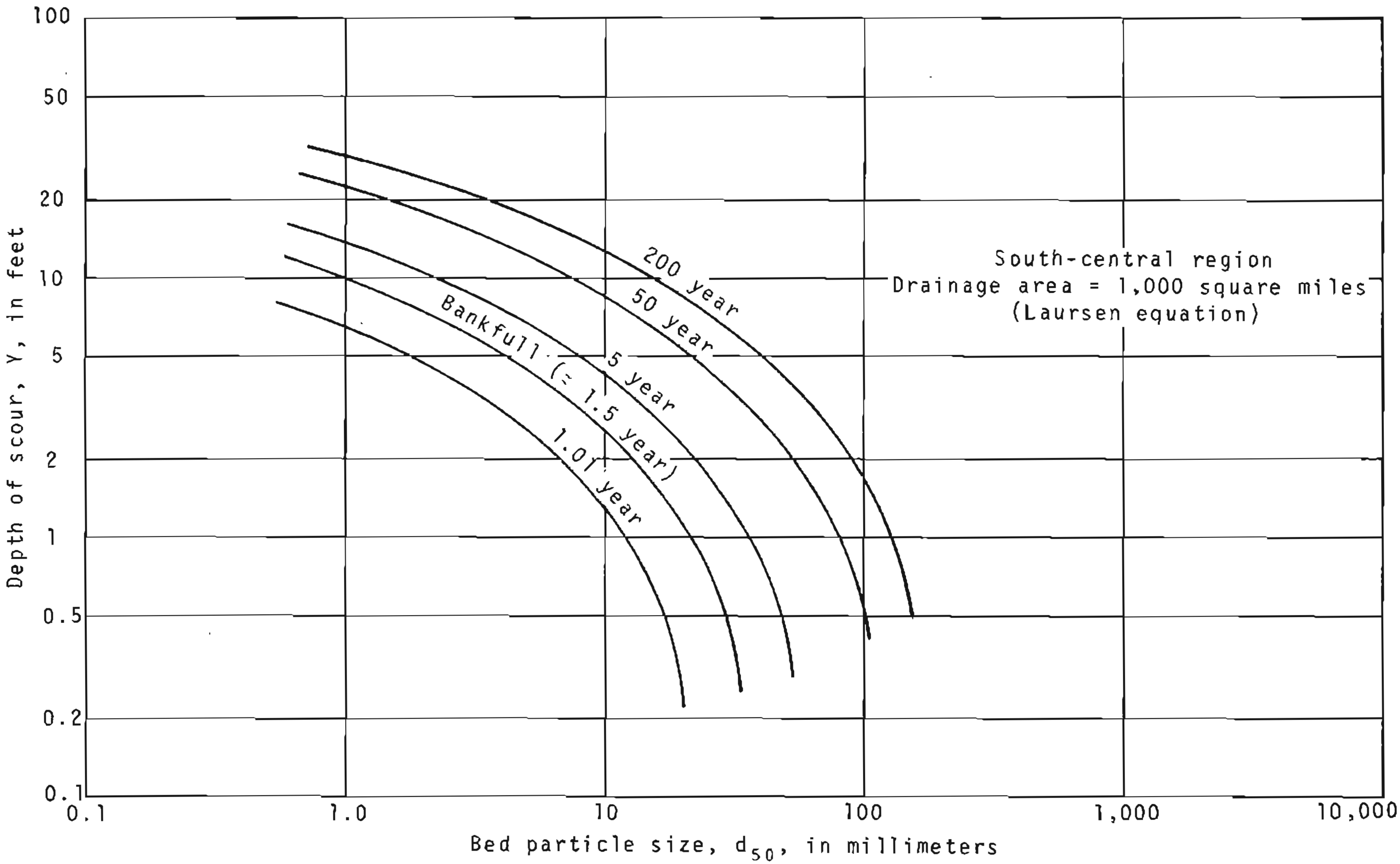


Figure 22.--Depth of channel scour as a function of recurrence interval and particle size, South-central region.

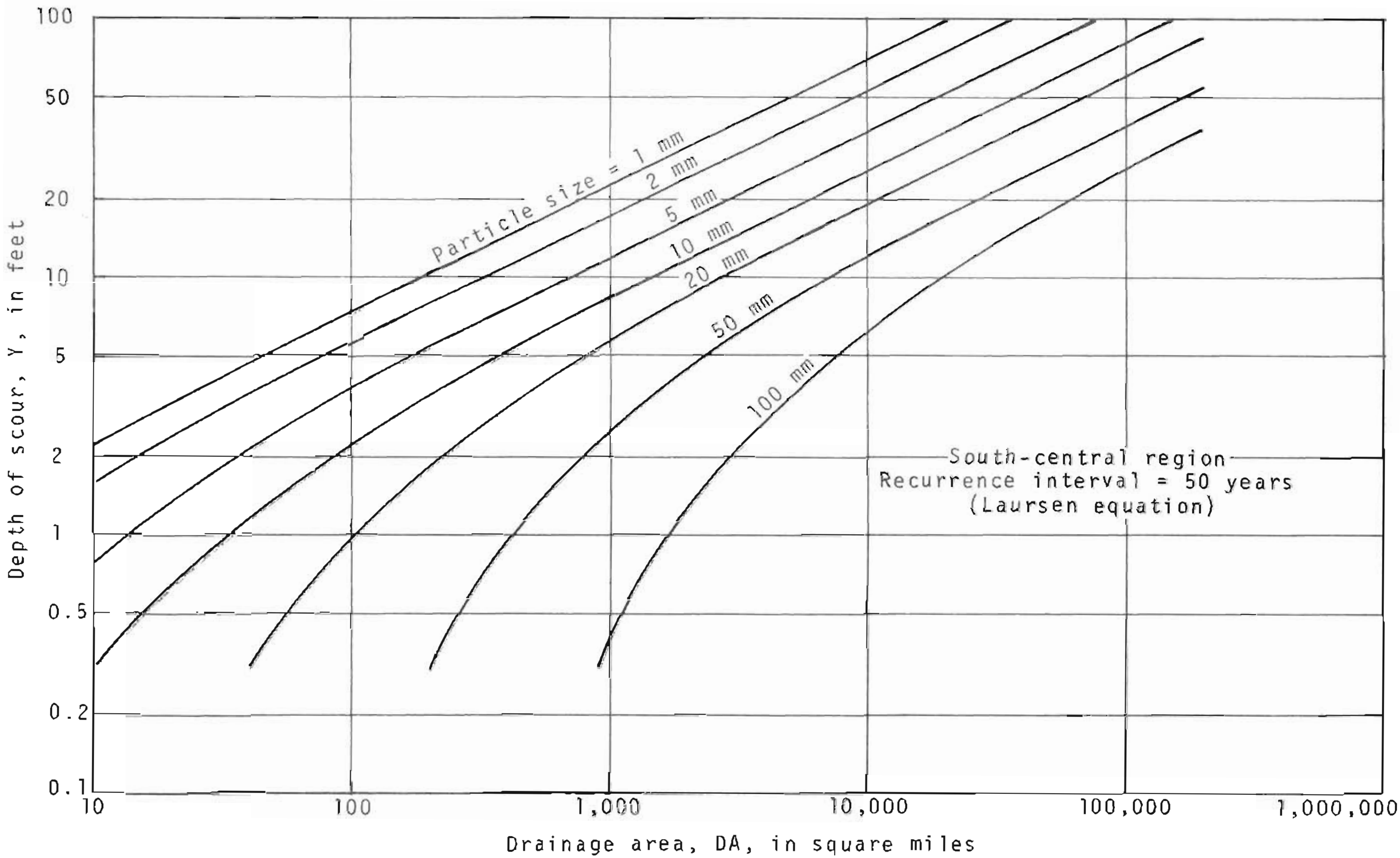


Figure 23.--Depth of channel scour as a function of particle size and drainage area, South-central region.

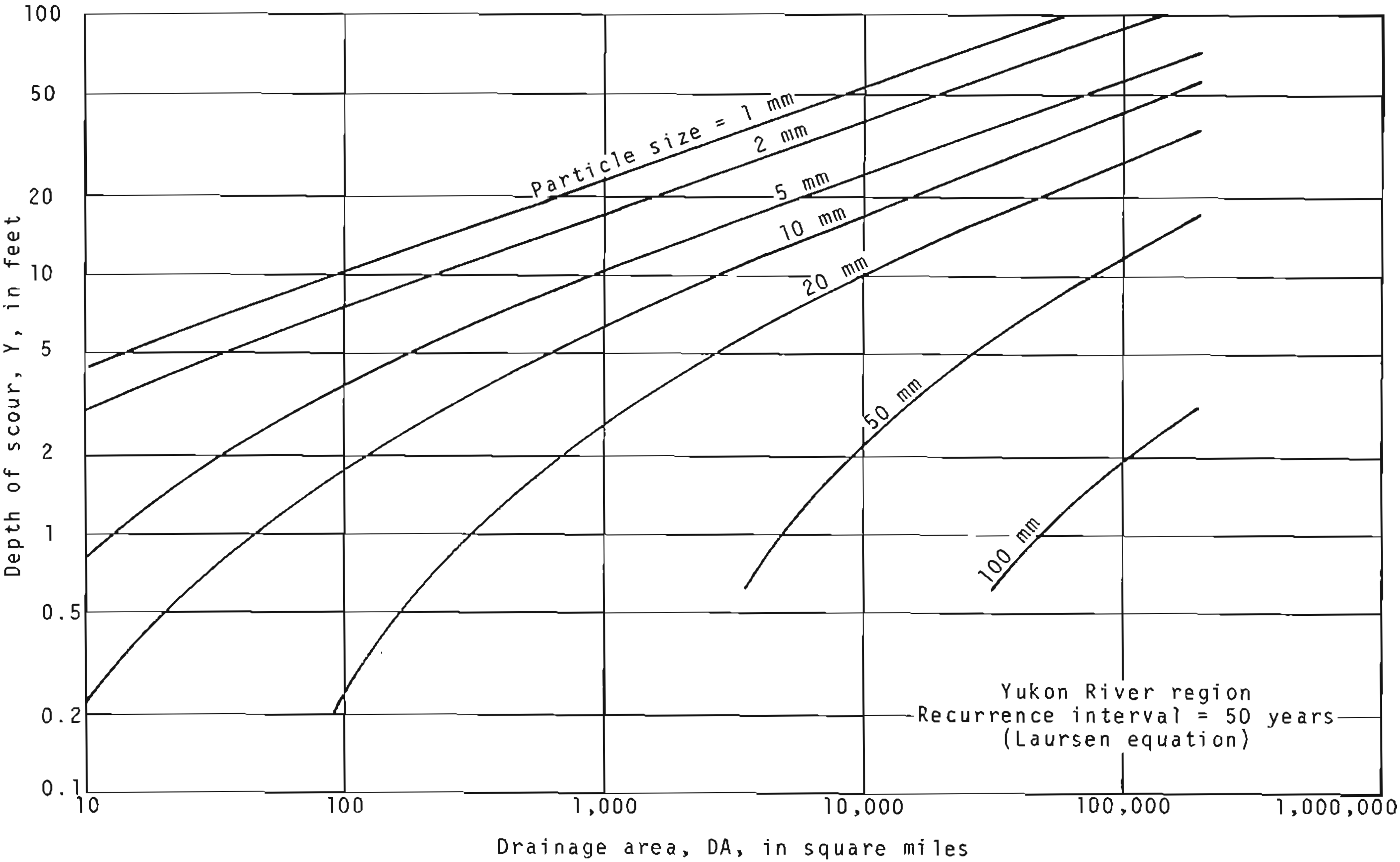


Figure 24.--Depth of channel scour as a function of particle size and drainage area, Yukon River region.

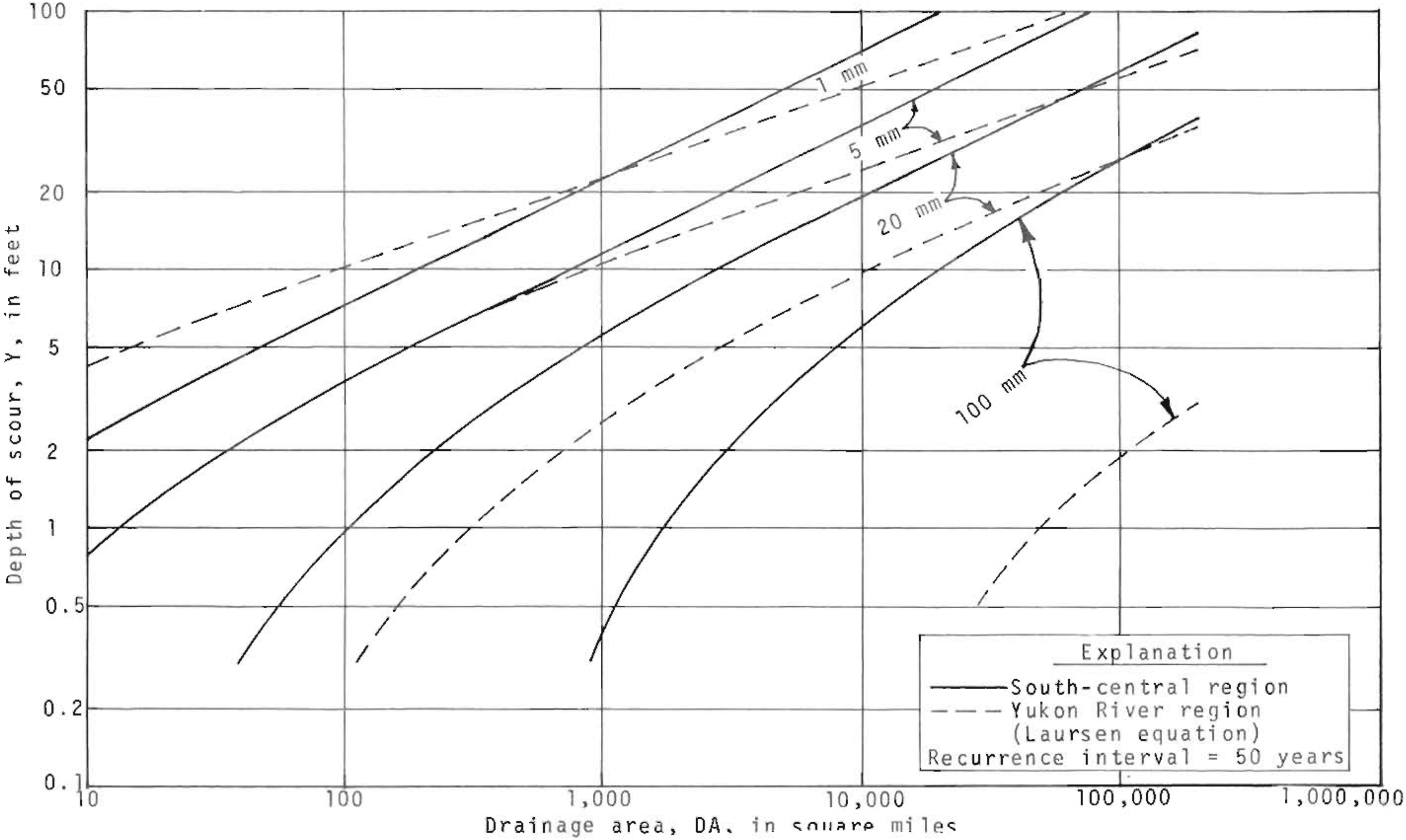


Figure 25.--Comparison of depth of channel scour as a function of particle size and drainage area; South-central region versus Yukon River region.

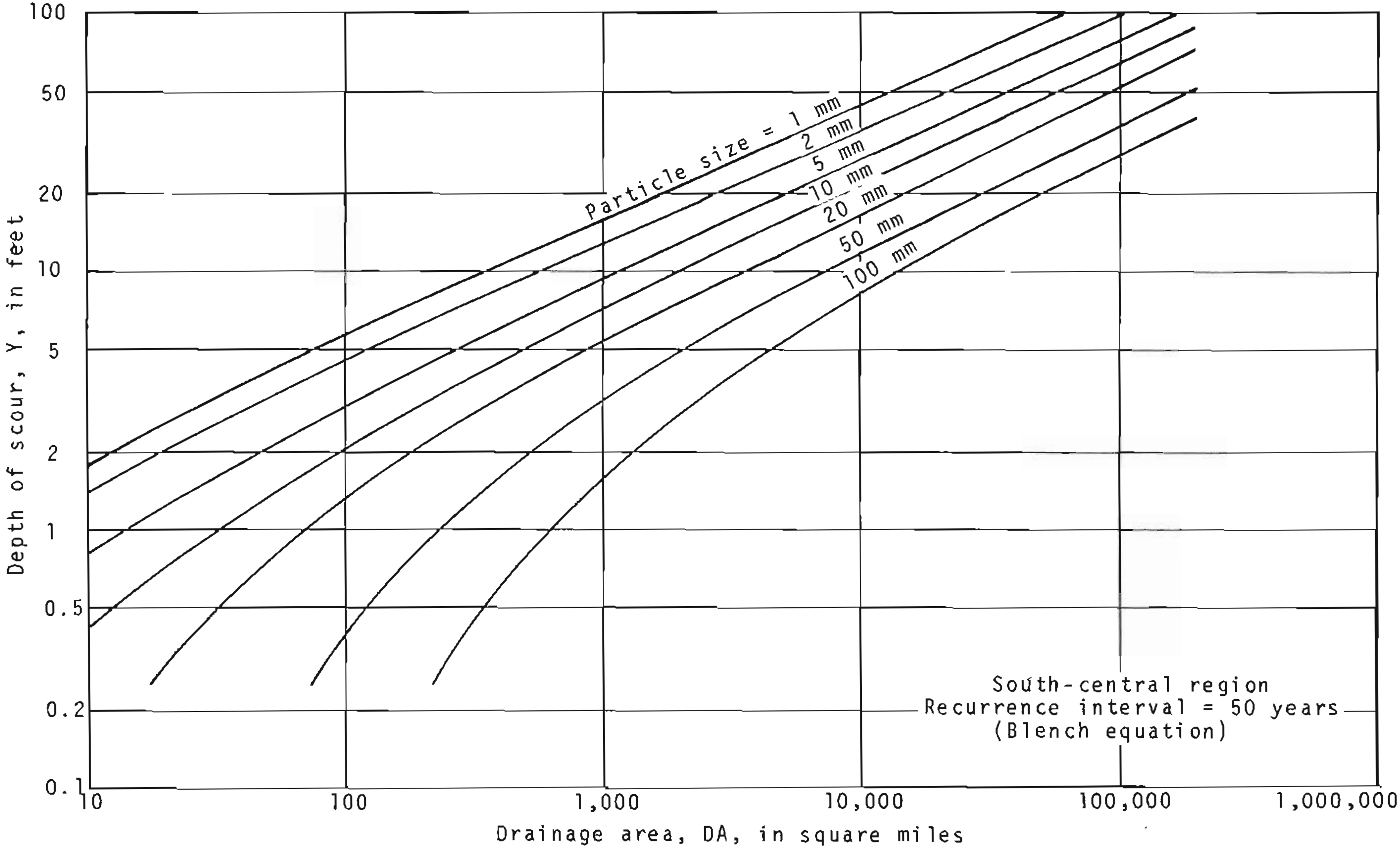


Figure 26.--Depth of channel scour computed by the Blench equation as a function of particle size and drainage area, South-central region.

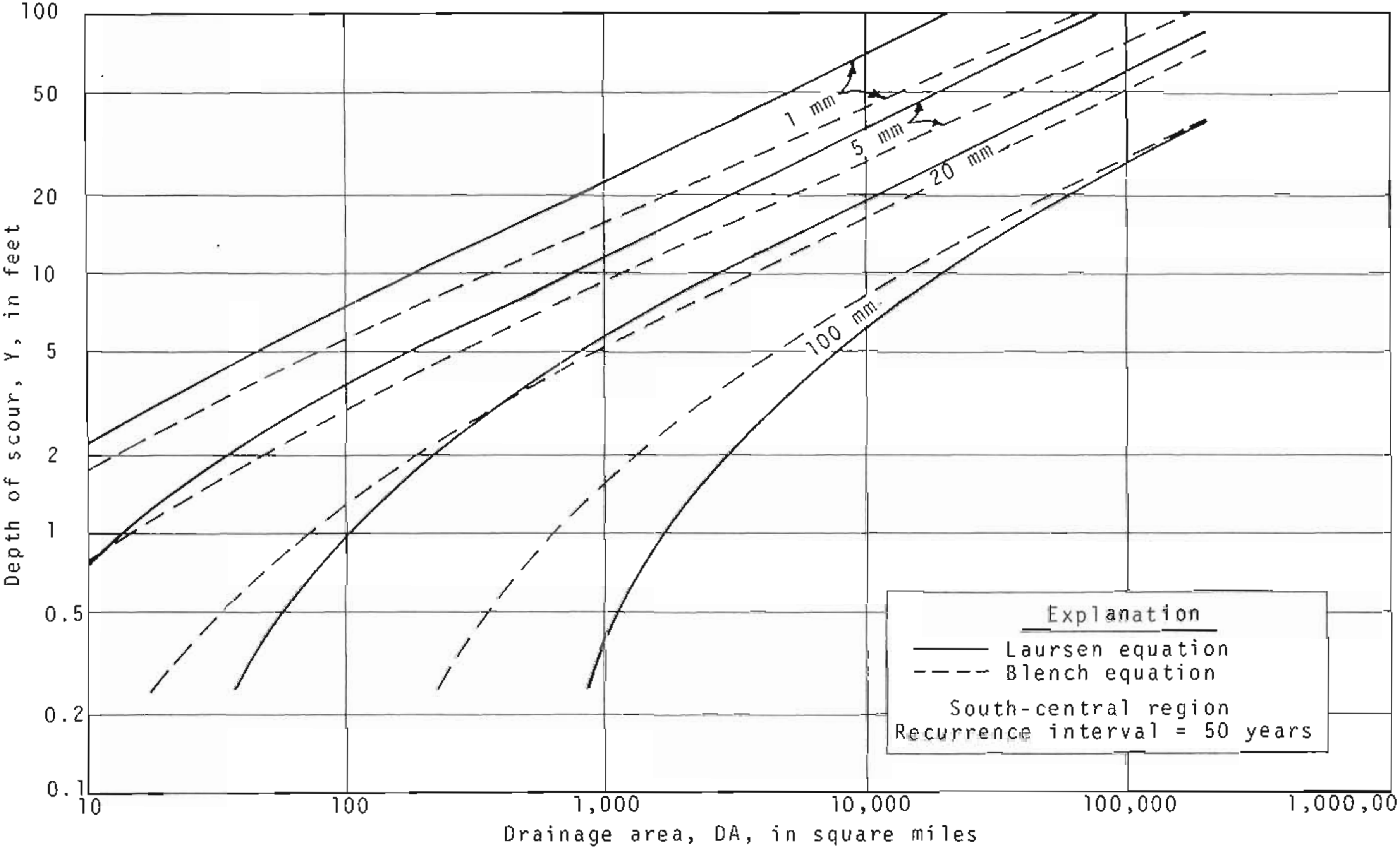


Figure 27.--Comparison of depth of channel scour as a function of particle size and drainage area, South-central region, Blench equation versus Laursen equation.

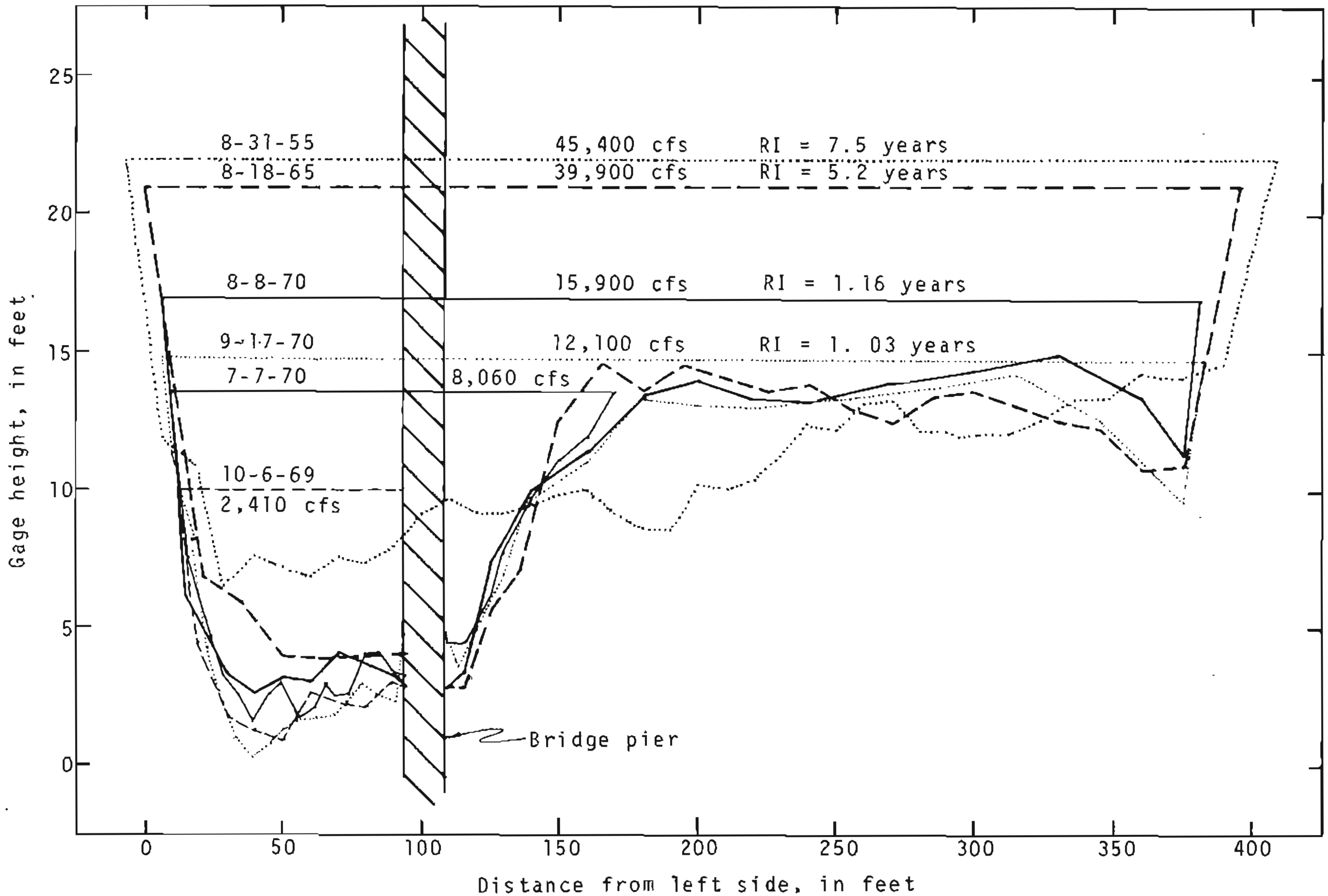


Figure 28.--Channel cross sections for Tazlina River near Glennallen, Alaska.

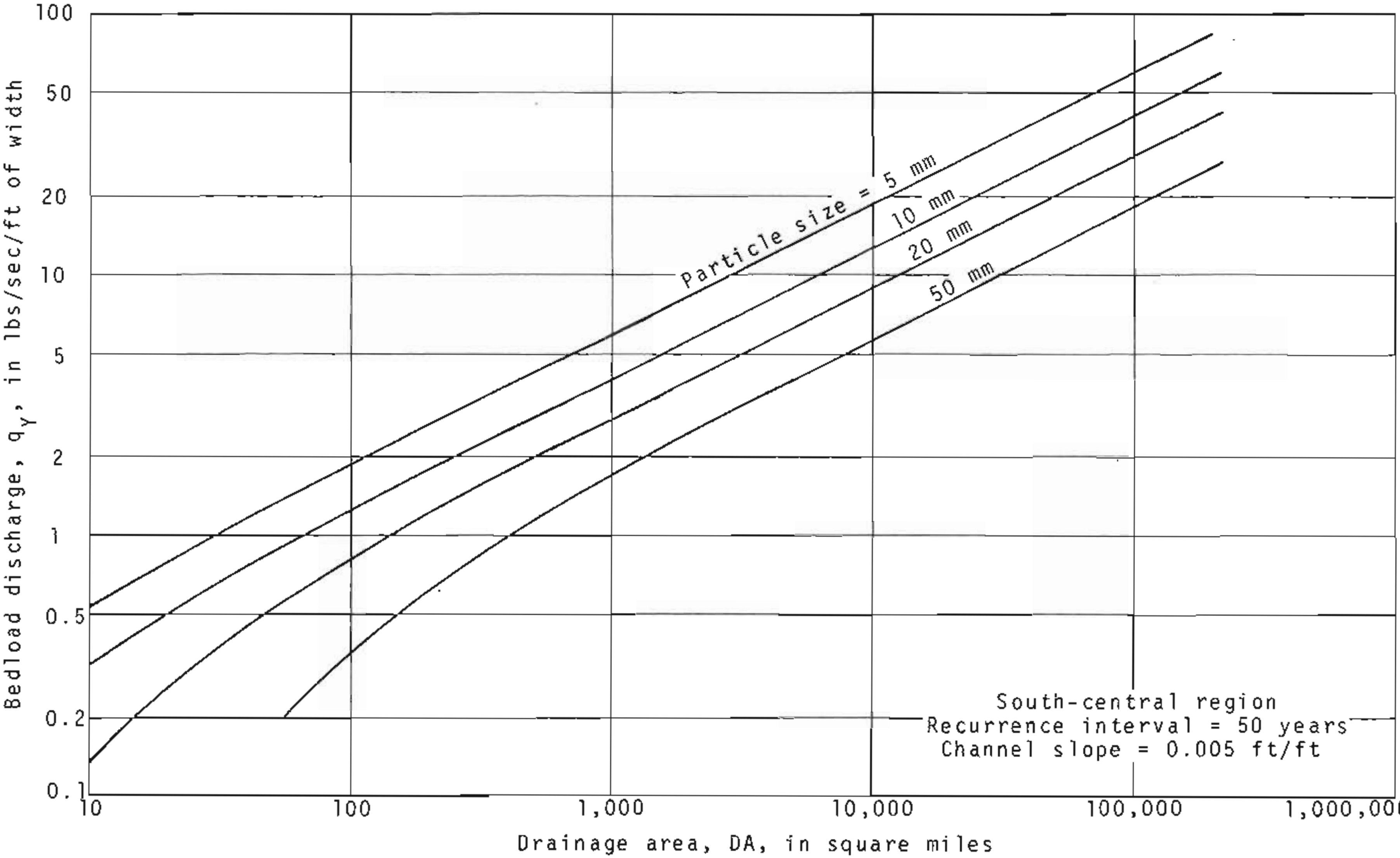


Figure 29.--Bedload per foot of channel width as a function of particle size and drainage area.

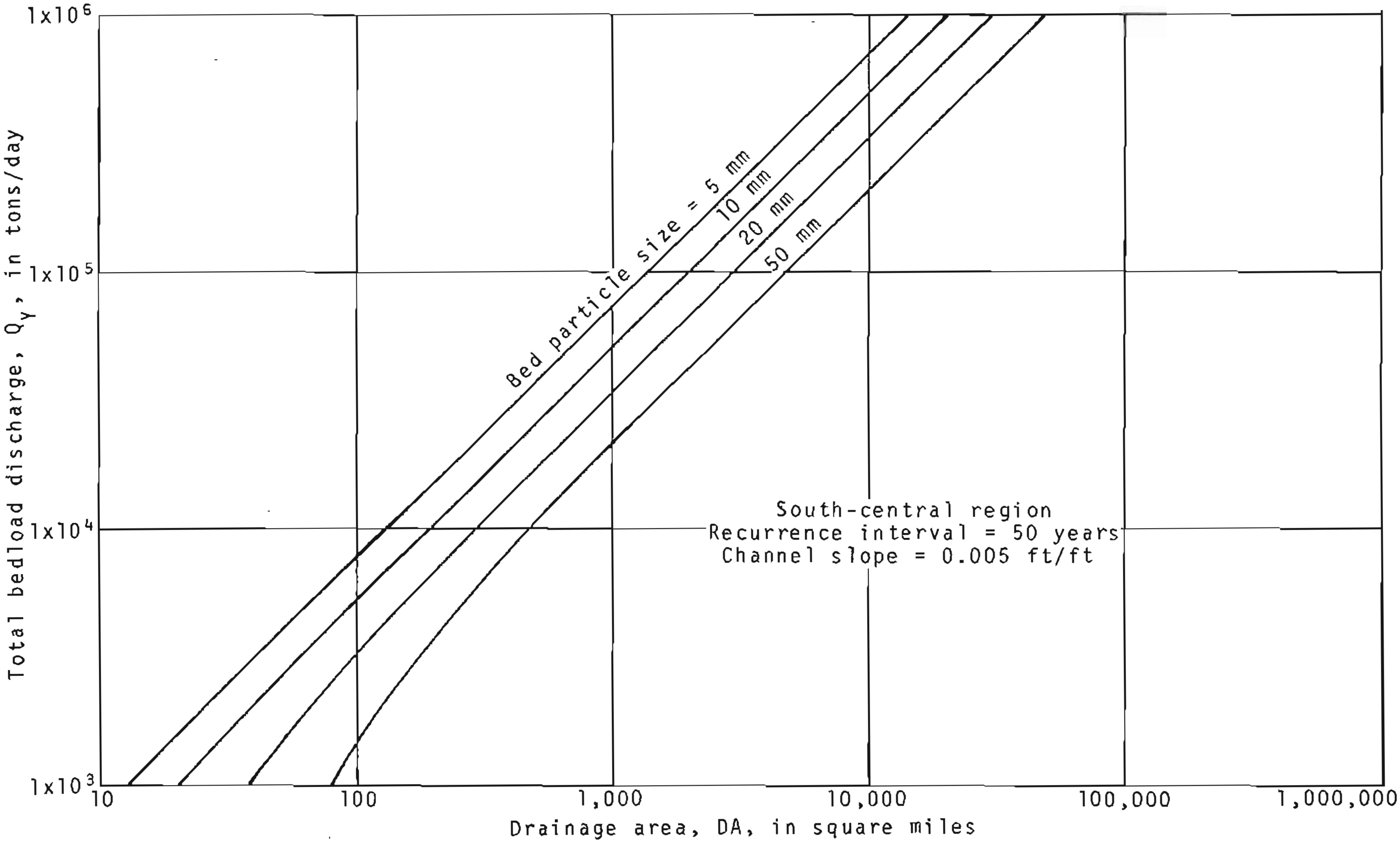


Figure 30.--Total bedload discharge as a function of particle size and drainage area.

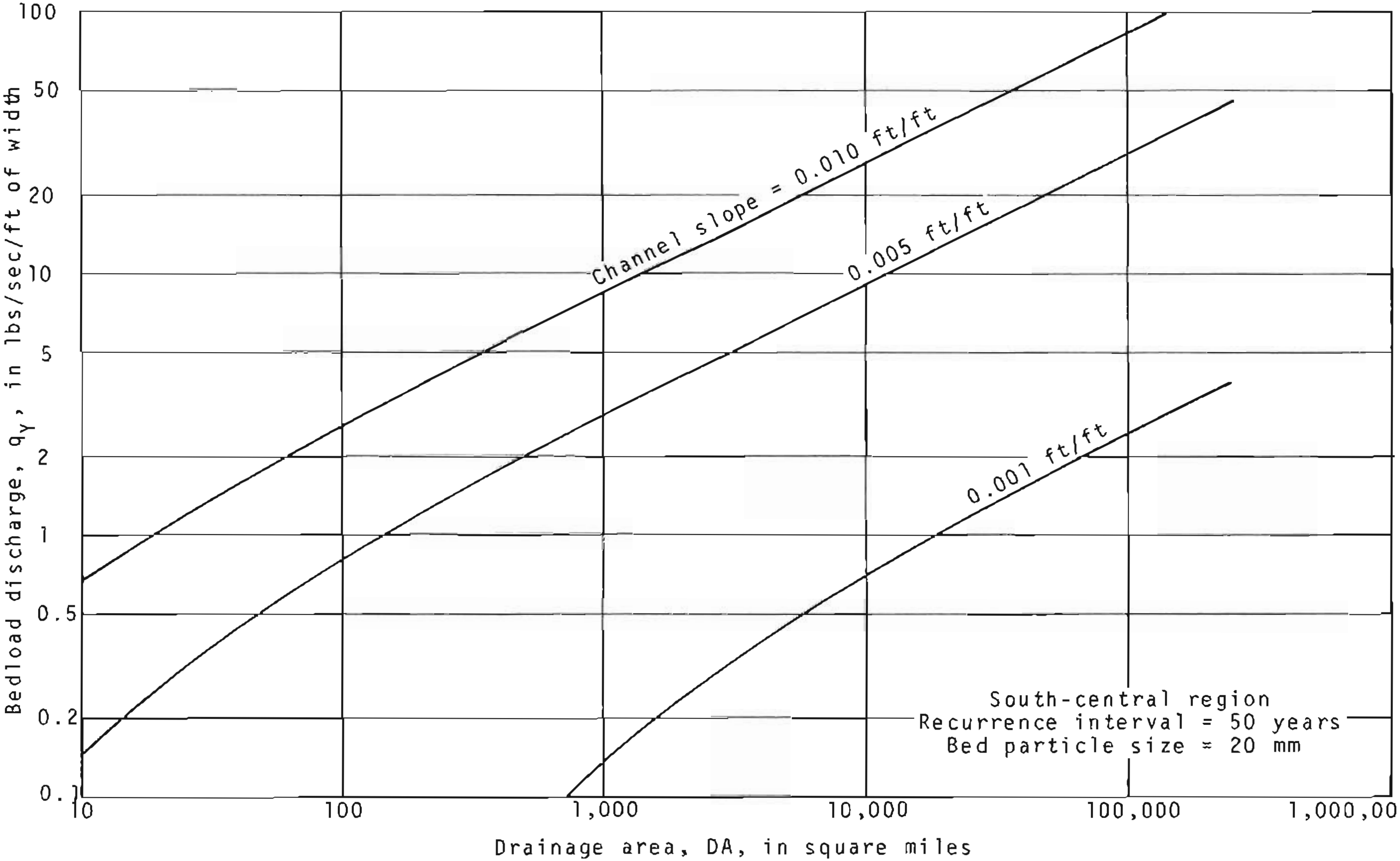


Figure 31.--Bedload discharge per foot of channel width as a function of channel slope and drainage area.

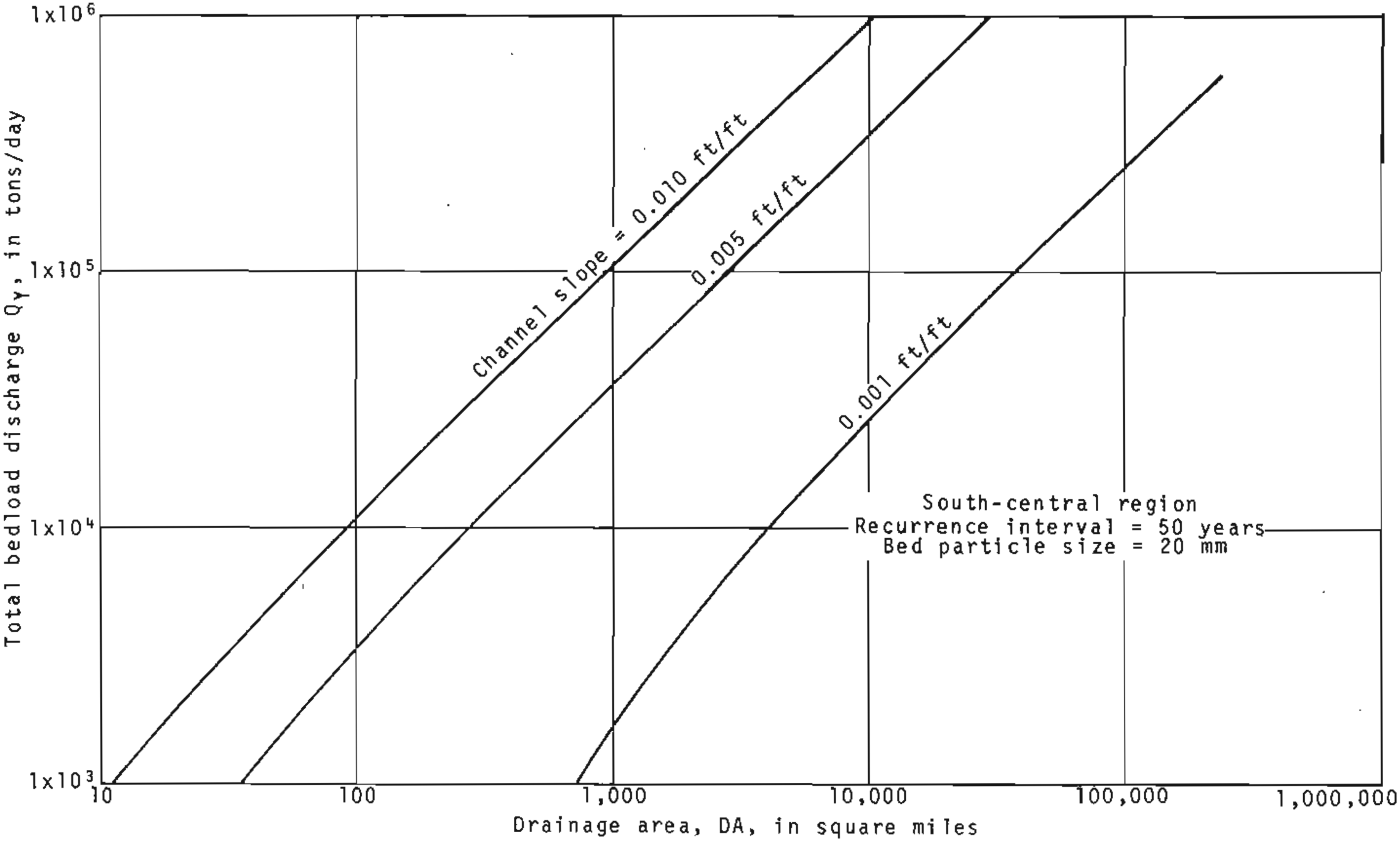
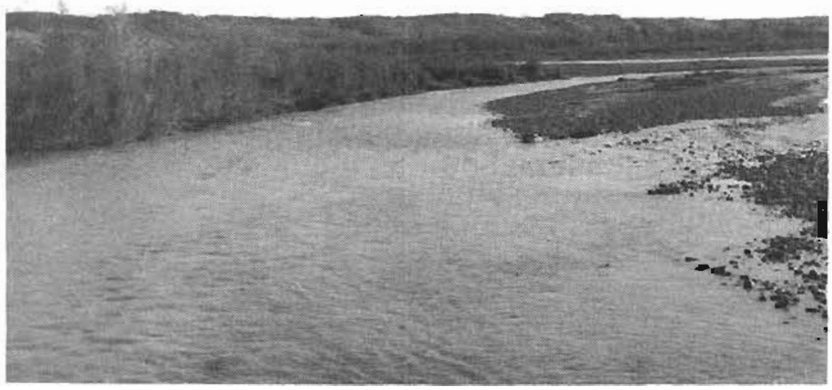


Figure 32.--Total bedload discharge as a function of channel slope and drainage area.

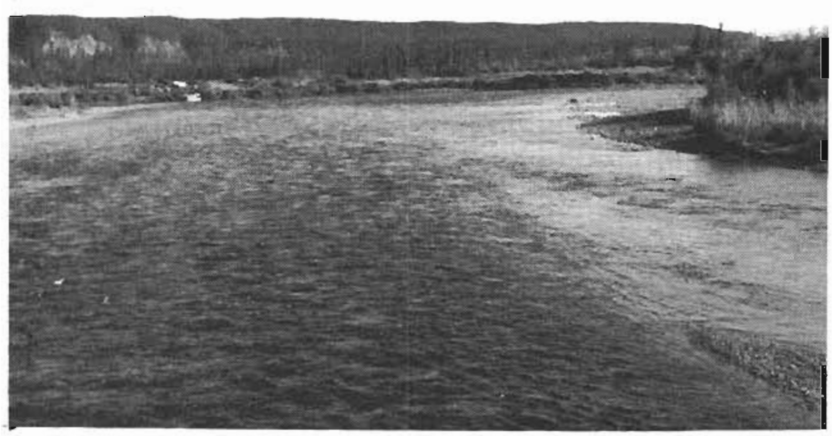
APPENDIX C

PHOTOGRAPHS OF STUDY SITES

Photographs 1-24

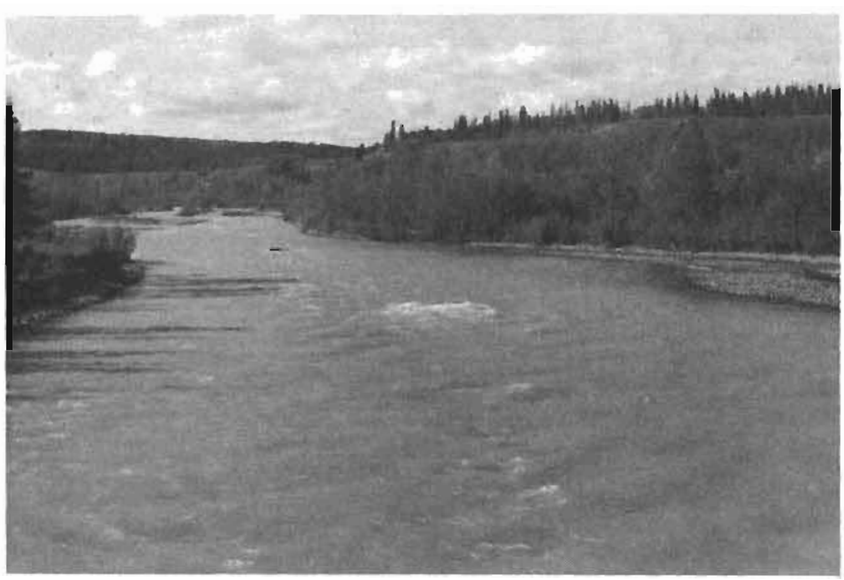


Photograph 1.- Gakona River at Gakona, Alaska. View is downstream; flood plain on left bank and approximately corresponds to highest elevations on island gravel bar.



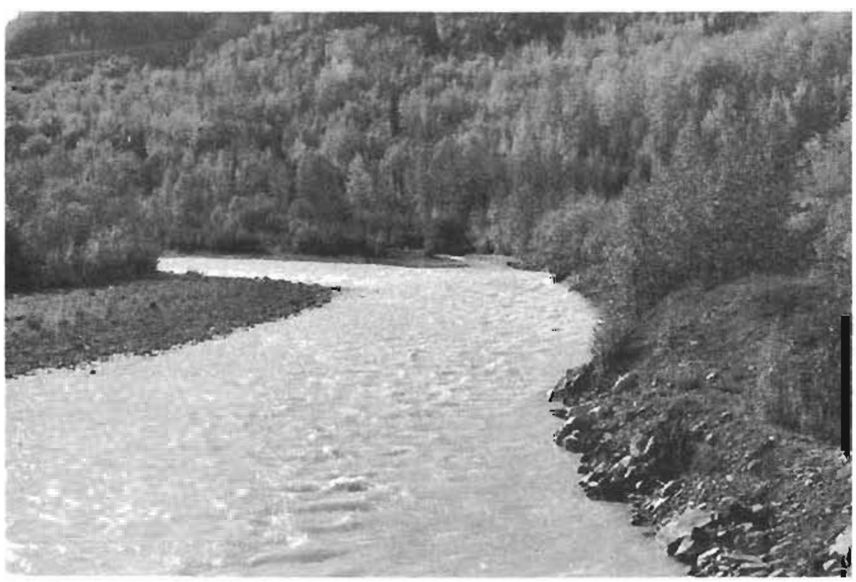
Photograph 2.- Gulkana River at Gulkana, Alaska. View is downstream; flood plain corresponds to the lower vegetated surface on right bank point bar.

Photograph 3.- Tazlina River near Glenallen, Alaska. View is downstream; flood plain is visible along both banks and is approximately three feet higher than gravel bar.



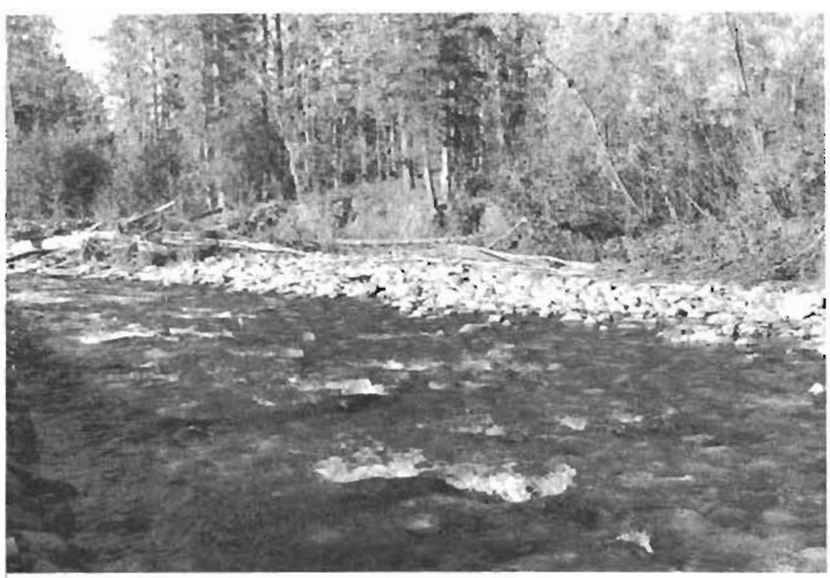
Photograph 4.- Klutina River at Copper Center, Alaska. View is upstream; narrow flood plain is visible along both banks and vegetated portion of distant gravel bars.

Photograph 5.- Little Tonsina River near Tonsina, Alaska. View is upstream; flood plain corresponds to bottom of leaning trees on left bank.

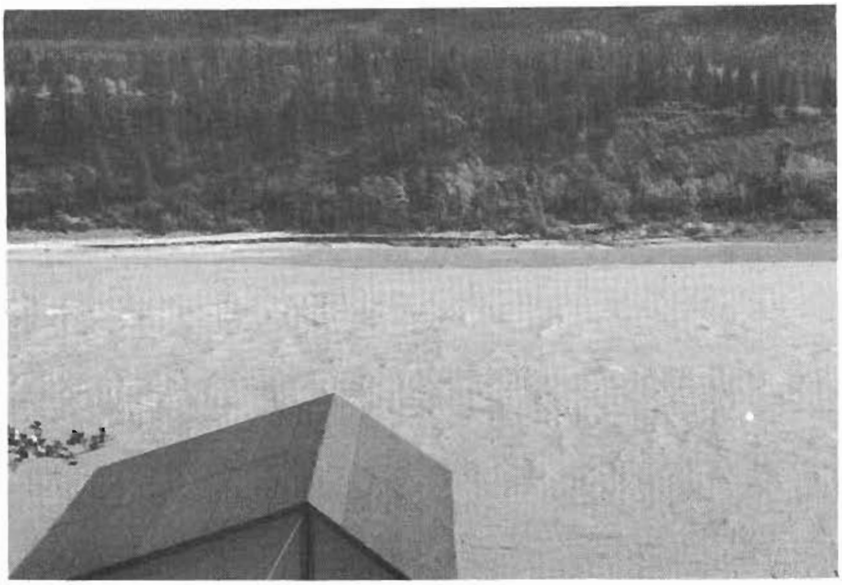


Photograph 6.- Tonsina River at Tonsina, Alaska. View is downstream; flood plain corresponds to vegetated surface on left bank point bar and distant gravel bar.

Photograph 7.- Squirrel Creek at Tonsina, Alaska. View is downstream; flood plain is hidden by vegetation but corresponds to the bottom of three trunks adjacent to the channels.



Photograph 8.- Bernard Creek near Tonsina, Alaska. View is downstream; flood plain corresponds to the elevation of debris on right bank gravel bar.



Photograph 9.- Copper River near Chitina, Alaska, at gaging station cableway. View is across channel to narrow flood plain on left bank which corresponds to vegetated surface with vertical cut face.

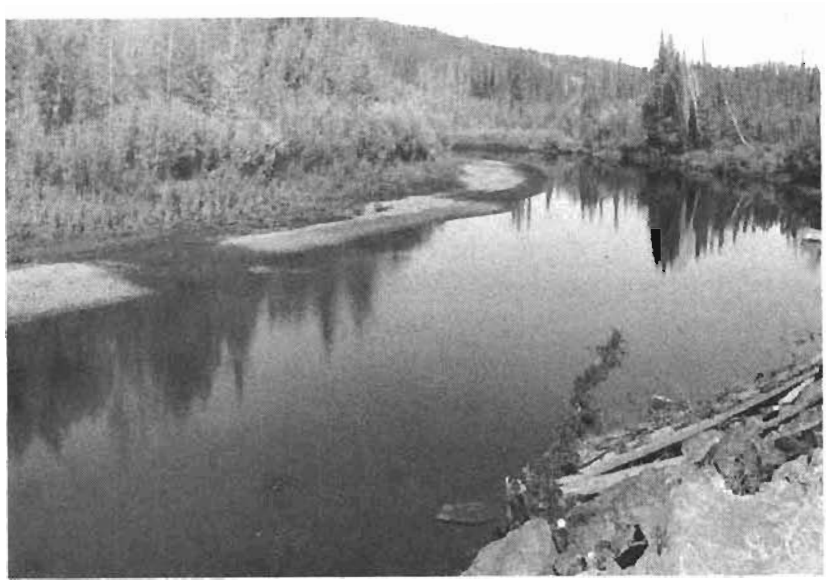
Photograph 10.- Copper River several miles upstream of above photograph. Note braided pattern compared to confined flow above. View is downstream; flood plain corresponds to vegetated surface on island sand bar.

Photograph 11.- Tiekel River near Tiekel, Alaska. View is downstream; flood plain corresponds to vegetated surface on right bank gravel bars in foreground and distance.

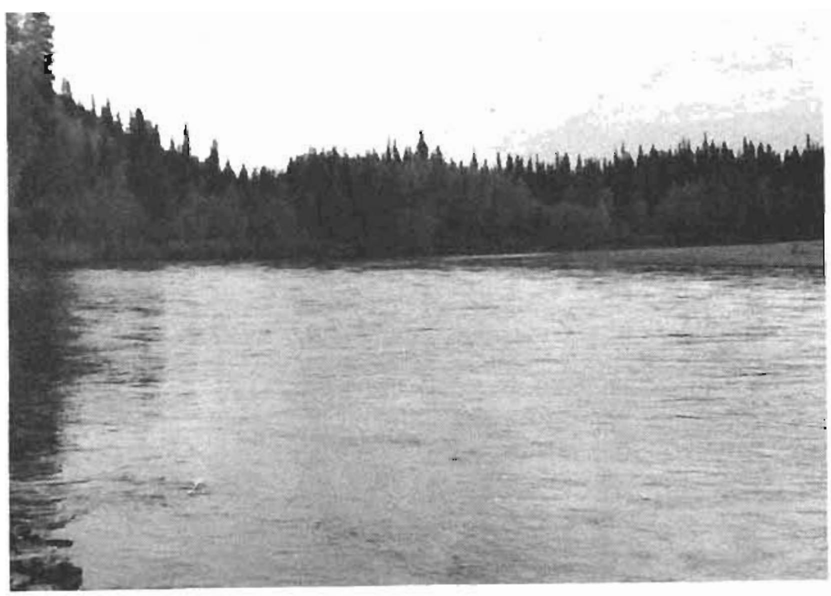
Photograph 12.- Stuart Creek near Tiekel, Alaska. View is downstream; flood plain corresponds to vegetated surface on right bank gravel bar.

Photograph 13.- Lowe River near Valdez, Alaska. View is downstream; flood plain corresponds to vegetated surface on right bank. Colluvial slopes near bluff merge into flood plain. Bear Creek tributary has incised into flood plain in right foreground.

Photograph 14.- Maclaren River near Paxson, Alaska. View is upstream toward Maclaren Glacier; flood plain corresponds to vegetated surface in background and on center island.

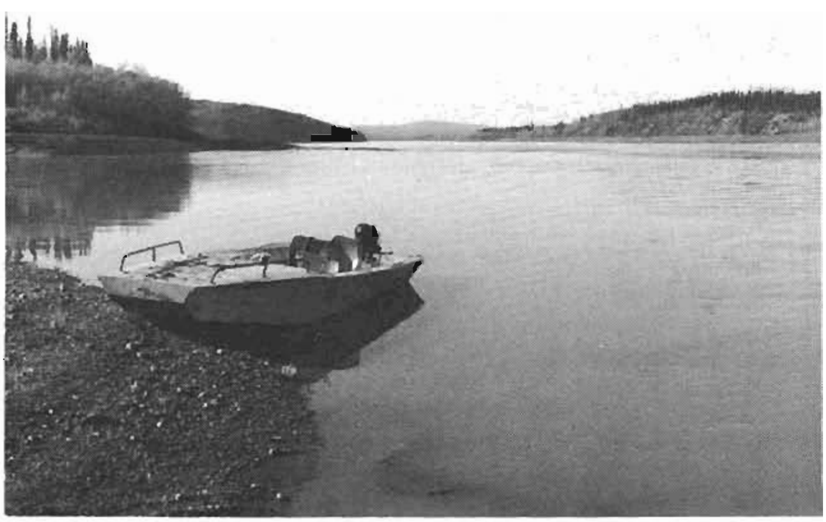


Photograph 15.- Hess Creek near Livengood, Alaska. View is upstream; flood plain corresponds to the surface of lower vegetation on right bank point bar.



Photograph 16.- Salcha River near Salchaket, Alaska. View is upstream; flood plain corresponds to the surface of lowest vegetation on right bank at outside of curve and small patch of vegetation at extreme right on left bank point bar.

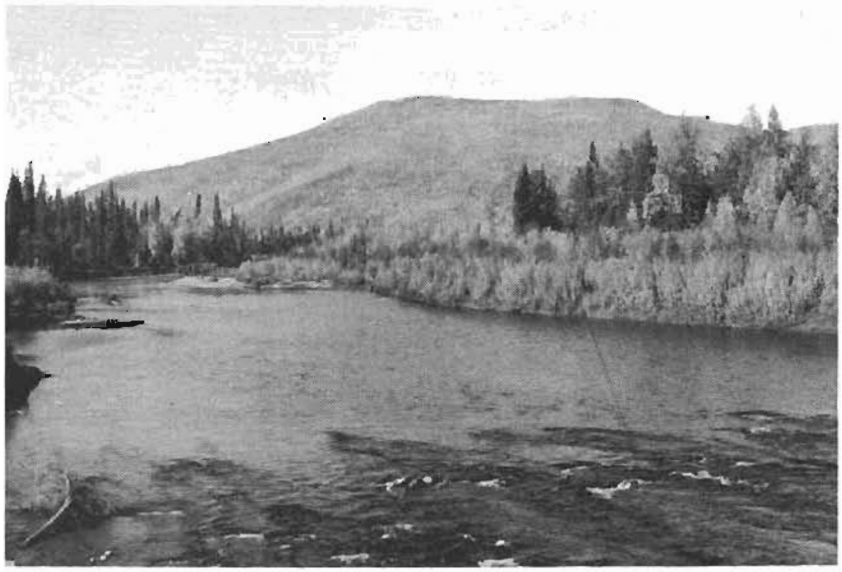
Photograph 17.- Yukon River near proposed trans-Alaska pipeline crossing. View is upstream; flood plain is just below surface of decidious trees on left bank.



Photograph 18.- Yukon River near proposed trans-Alaska pipeline crossing. View is downstream toward proposed crossing; flood plain corresponds to small patch of lower vegetation on left bank foreground.

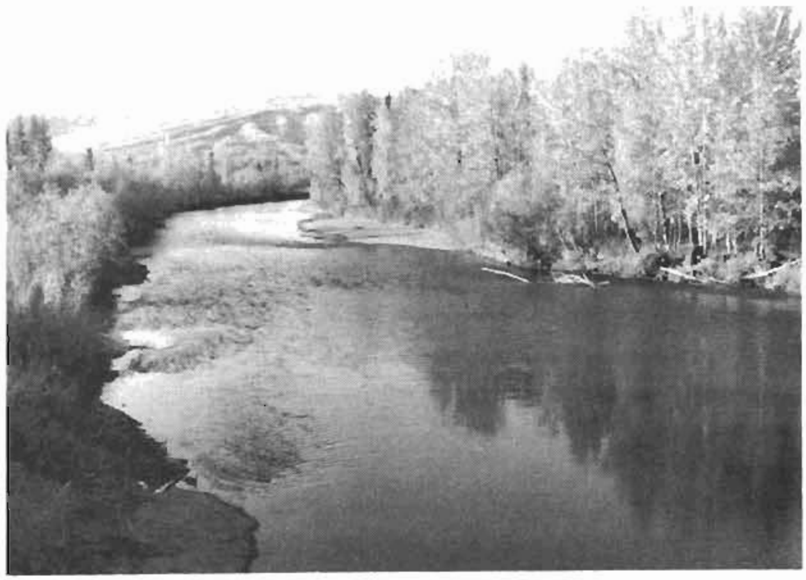
Photograph 19.- Tanana River at Harding Lake, Alaska. View is across and upstream; flood plain corresponds approximately to surface of scattered patches of vegetation on islands in the braided channel.

Photograph 20.- Tanana River at Nenana, Alaska. View is upstream; flood plain corresponds to vegetated surface about three feet above highest mud flat.



Photograph 21.- Chena River near Two Rivers, Alaska. View is upstream; flood plain corresponds to vegetated surface on left bank.

Photograph 22.- Little Chena River near Fairbanks, Alaska. View is upstream; flood plain corresponds approximately to bottom of vegetation on right bank.



Photograph 23.- Chatanika River near Fairbanks, Alaska. View is downstream; flood plain corresponds approximately to bottom of streamward-most trees and beginning of vegetation on right bank gravel bar.

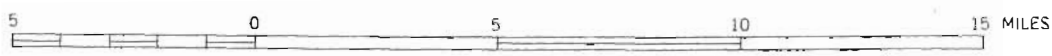
Photograph 24.- Chena River at Fairbanks, Alaska.

APPENDIX D

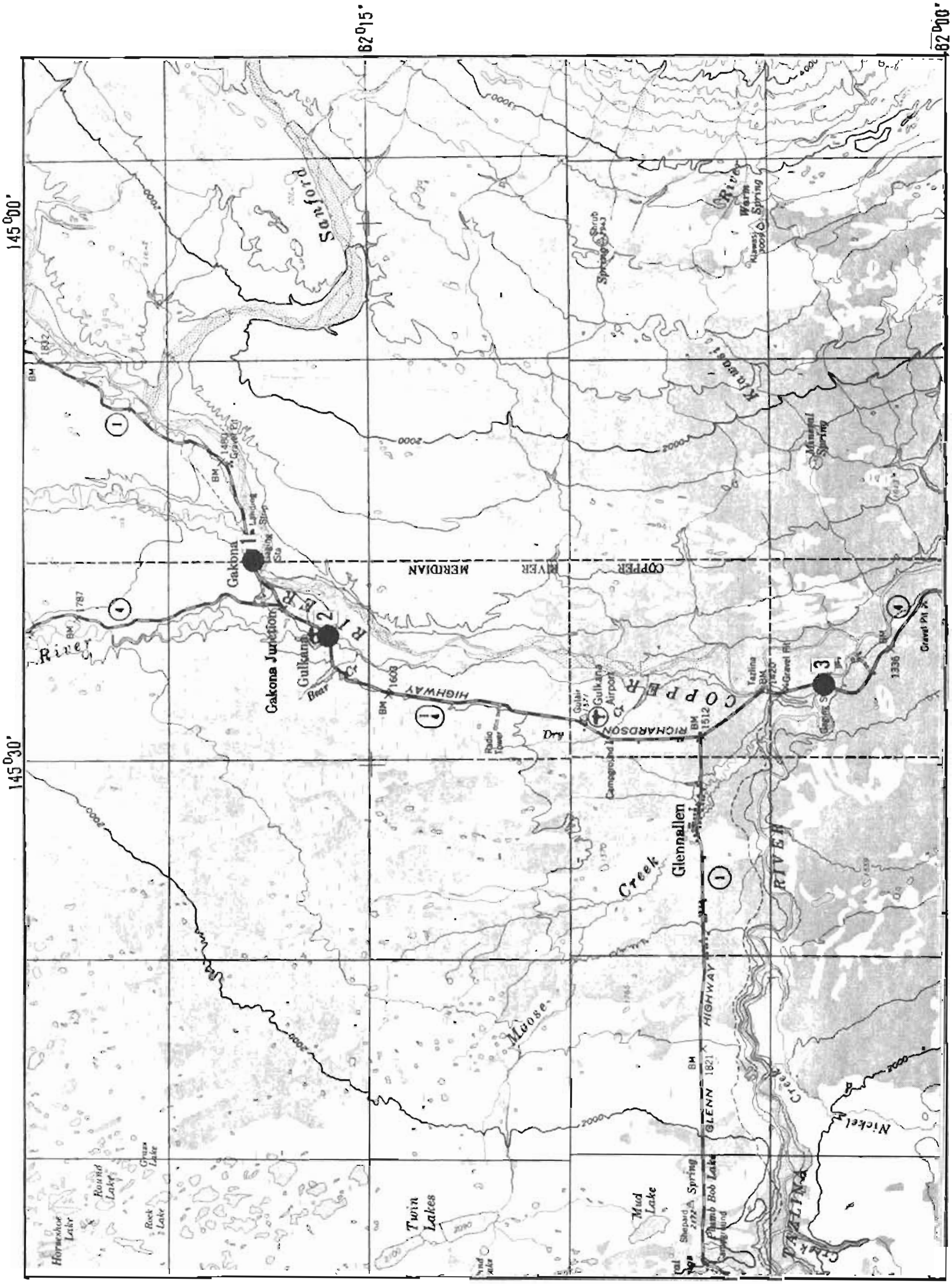
TOPOGRAPHIC MAPS OF STUDY SITES

Maps 1-11

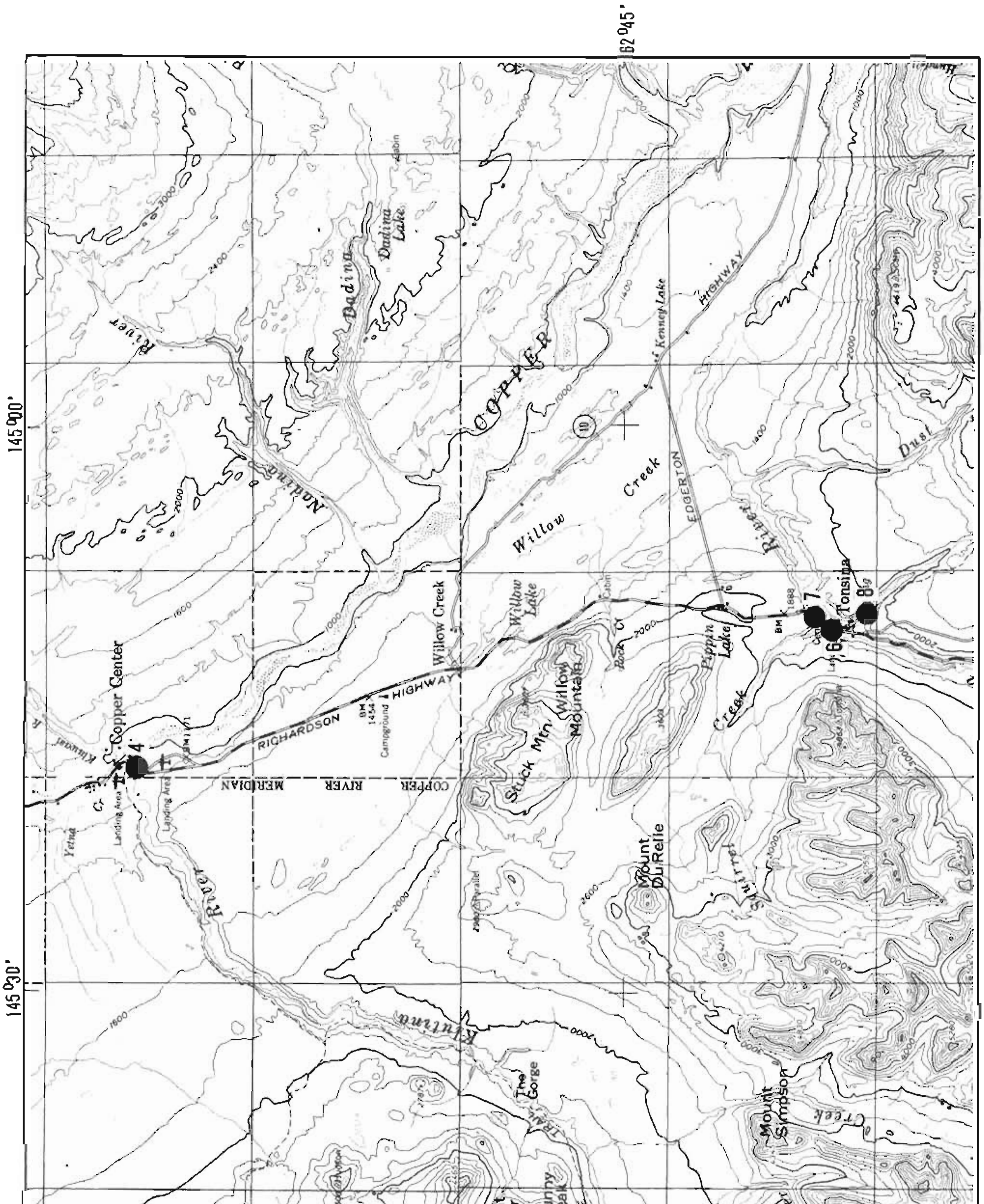
SCALE 1:250000



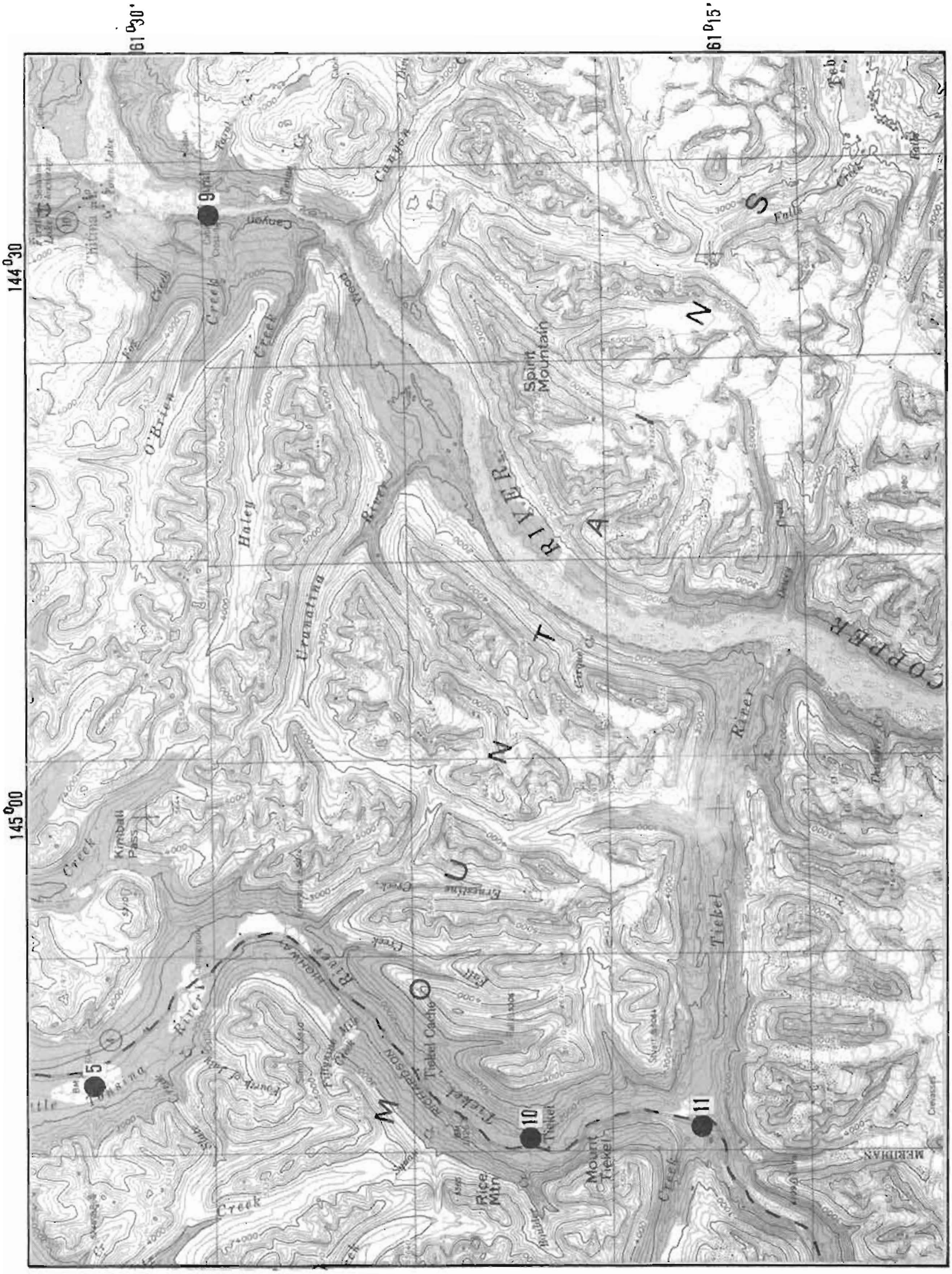
CONTOUR INTERVAL 200 FEET
DATUM IS MEAN SEA LEVEL


145°00'
145°30'
62°15'
62°00'
Gakona
Gakona Junction
Gulkana
Glennallen
Sanford
River
COPPER
RIVER
COPPER RIVER MERIDIAN
RICHARDSON HIGHWAY
GLENN HIGHWAY
Moose Creek
Twin Lakes
Mud Lake
Klawasi River
Warm Spring
Shrub Spring
Mineral Spring
Gulkana Airport
Campground
Radio Tower
Tazlina
Nickel Creek
Horseshoe Lake
Round Lake
Grass Lake
Rock Lake
Plumb Bob Lake
Dry
Bear Cr

Map 1

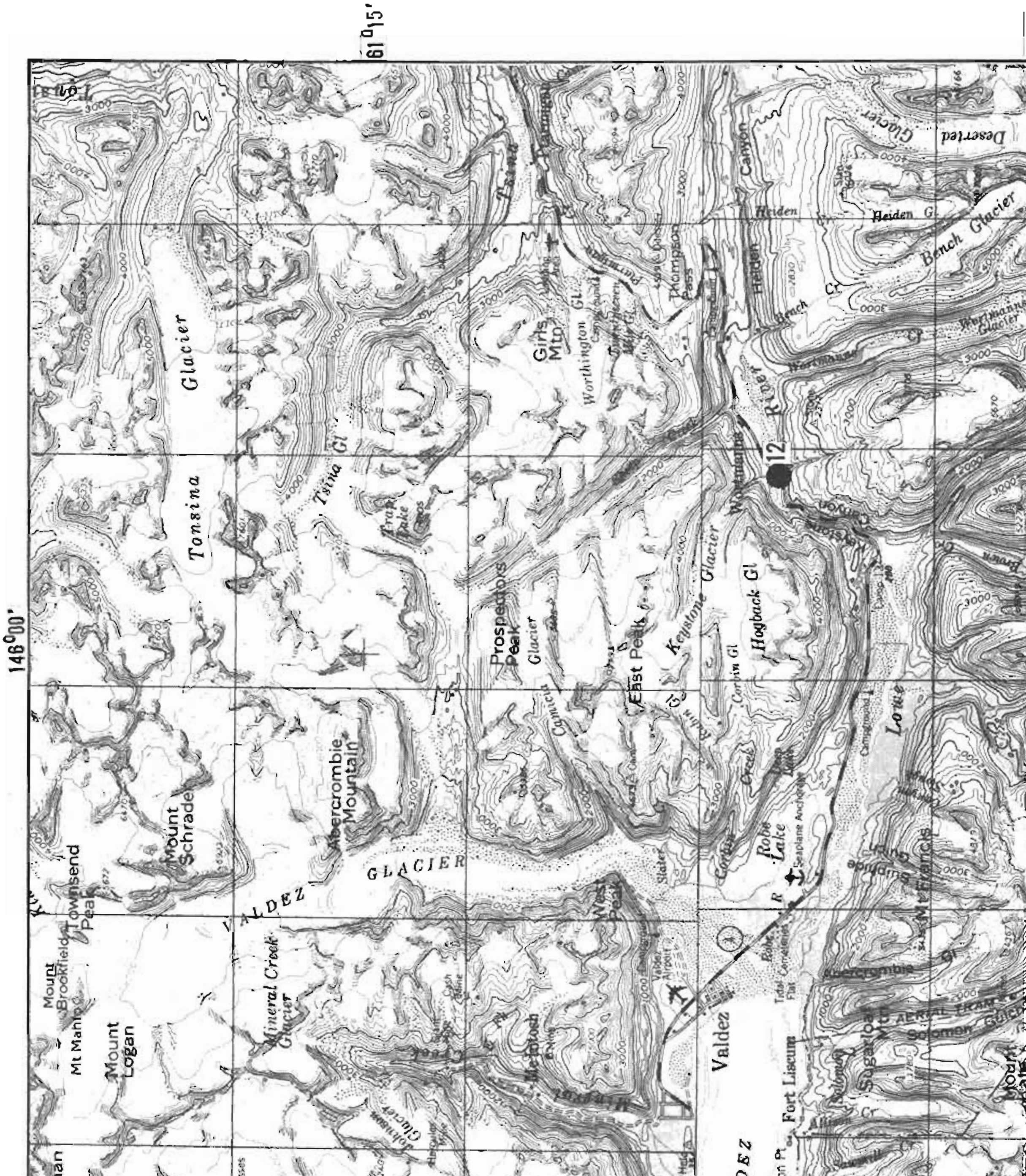

145°00'
145°30'
62°45'
Copper Center
Willow Creek
RICHARDSON HIGHWAY
COPPER RIVER MERIDIAN
Willow Lake
Willow Mountain
Stuck Mtn.
Pippin Lake
Tonsina
EDGERTON HIGHWAY
Kenney Lake
COPPER
Willow Creek
Dadina Lake
Dadina
River
Mount DuRelle
Mount Simpson
Mount Carter
Sunny Peak
Dowling Peak
Hudson Lake
The Gorge
Klutina
Dust
Rock Cr
Squirrel Creek
Campground
Landing Area
4
6
7
8

Map 2



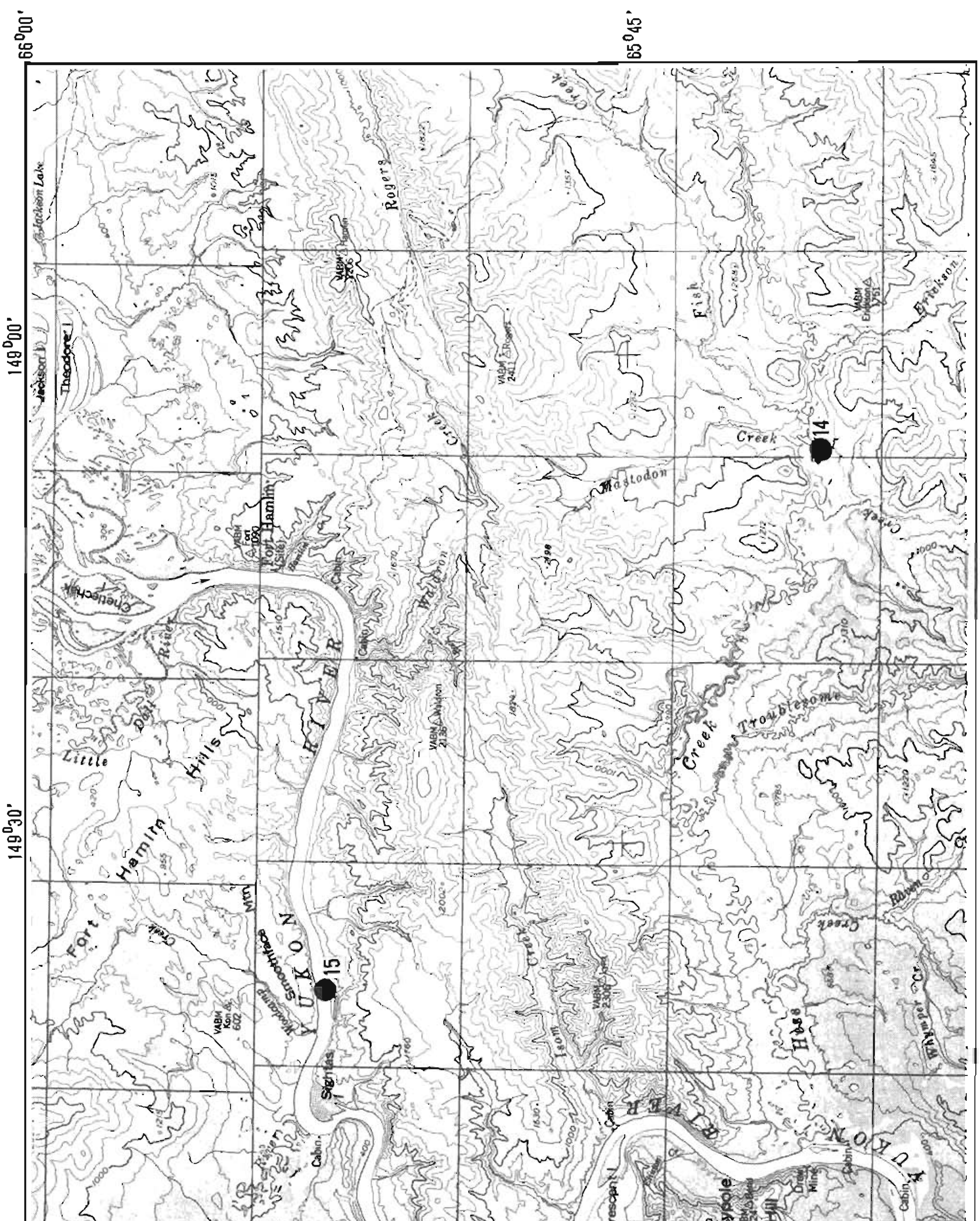
61°30'
61°15'
144°30
145°00
5
9
10
11
M O U N T A I N S
COPPER
RIVER
Tonsina
River
Tiekel
River
Kimball Pass
Spirit Mountain
Mount Tiekel
Rice Mtn
Tiekel Cache
Haley
Creek
O'Brien
Uranatina
Canyon
Creek
MERIDIAN

Map 3

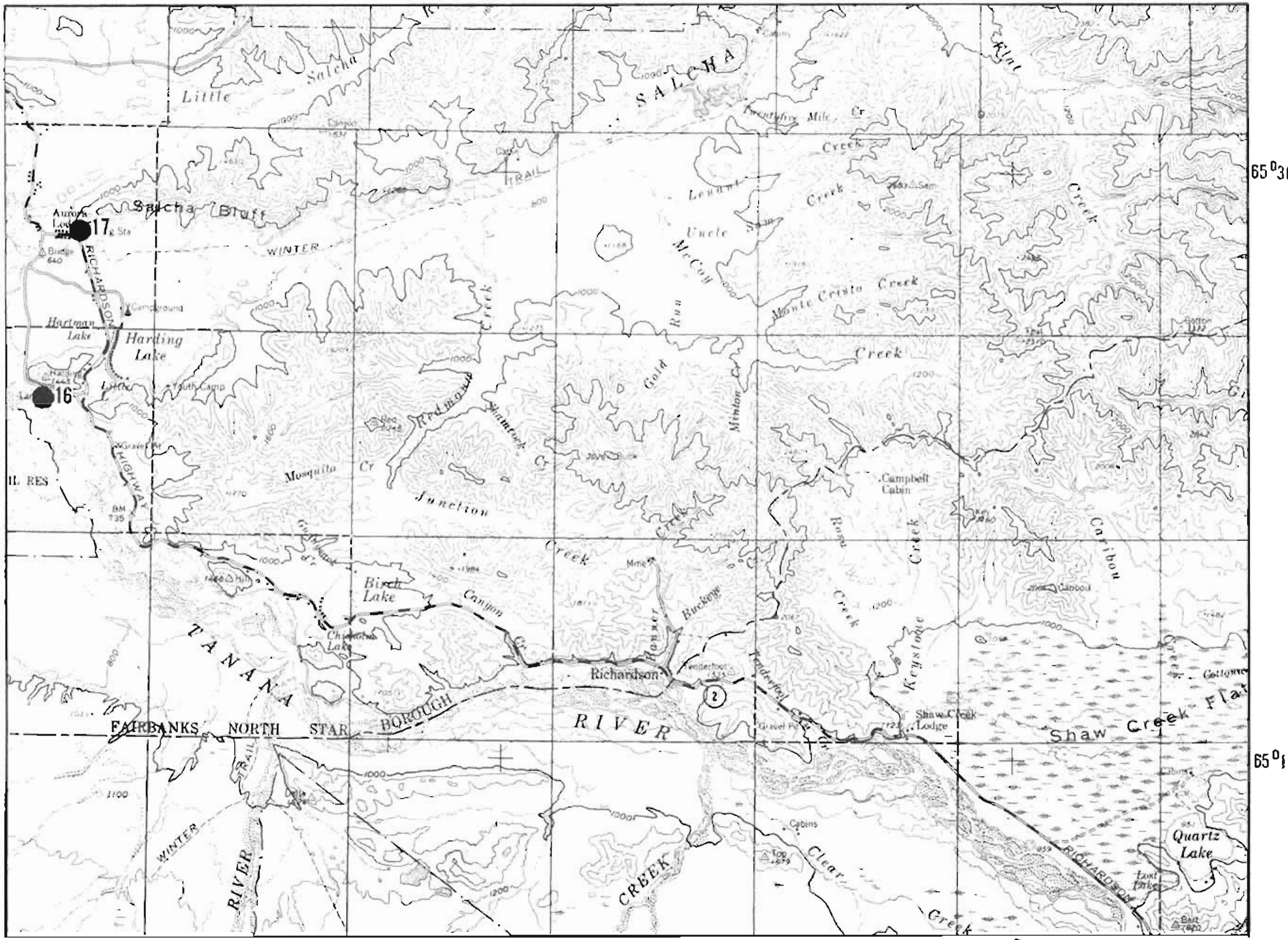

146°30'
146°00'
61°15'
61°00'
Tonsina
Glacier
Tsina Gl
Prospectors Peak
Girls Mtn
Worthington Gl
Thompson Pass
Keystone Glacier
Hogback Gl
East Peak
Corbin Gl
Heiden Canyon
Bench Glacier
Deserted Glacier
Lowe
Robe Lake
Seaplane Anchorage
Abercrombie Mountain
Mount Schrader
Townsend Peak
Mount Brookfield
Mt Manilo
Mount Logan
Mineral Creek Glacier
VALDEZ GLACIER
Valdez
Valdez Airport
PORT VALDEZ
Fort Liscum
Jackson Pt
Mount Cashman
Mount Shouplina
Crevasses
SHOUP GLACIER
Mt Hogan
Mt Shasta
Shoup Bay
Tazcol Pk
Entrance Island
Anderson Bay
Jack Bay
Sugarloaf Mt
Mt Francis
Abercrombie
Solomon Gulch
AERIAL TRAM
FOREST
12

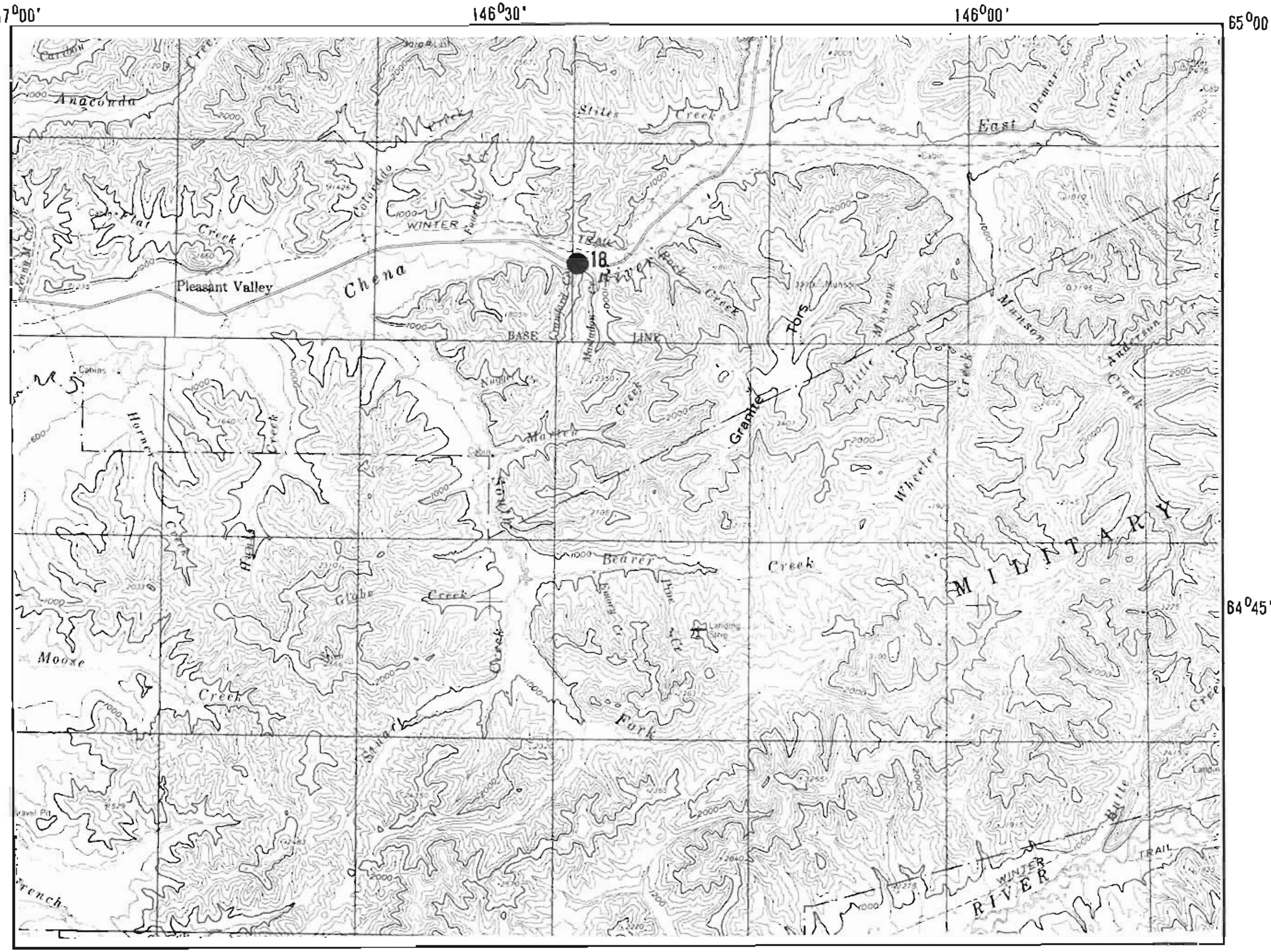
Map 4

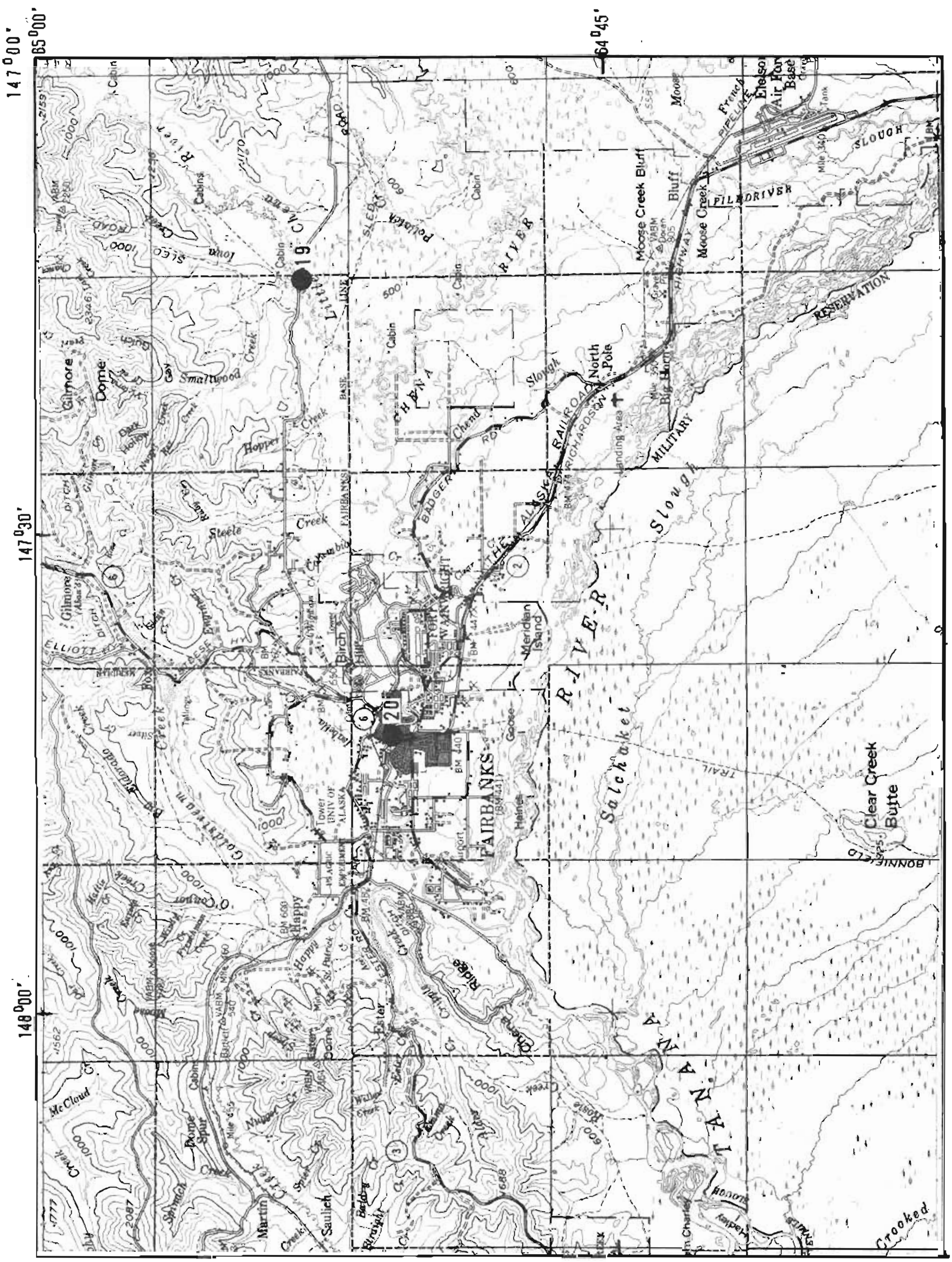

145°30'
146°00'
146°30'
63°15'
63°00'
Map 5
Summit Lake
Rainbow Mountain
Canwell
Broxson Gulch
Eureka
Fish Lake
Sevenmile Lake
Sugarloaf Mountain
Long Tangle Lake
Round Tangle Lake
Landmark Gap
Paxson Mountain
Two Bit Lake
Glacier
Maclaren
MACLAREN
RIVER
MATANUSKA
SUSITNA
BOROUGH
Rock
Valley
Creek
Octopus Lake
Upper Tangle Lakes
Wait-A-Bit Lake
Fourteenmile Lake
Little Swede Lake
Swede Lake
Mud Lake
Gulkana


66°00'
65°45'
149°00'
149°30'
150°00'
YUKON
RIVER
Fort
Hamlin
Hills
Little
Dall
River
Rogers
Creek
Mastodon
Creek
Fish
Troublesome
Creek
Erickson
Maypole
Hill
Crescent I
Jackson Lake
Theodore I
14
15

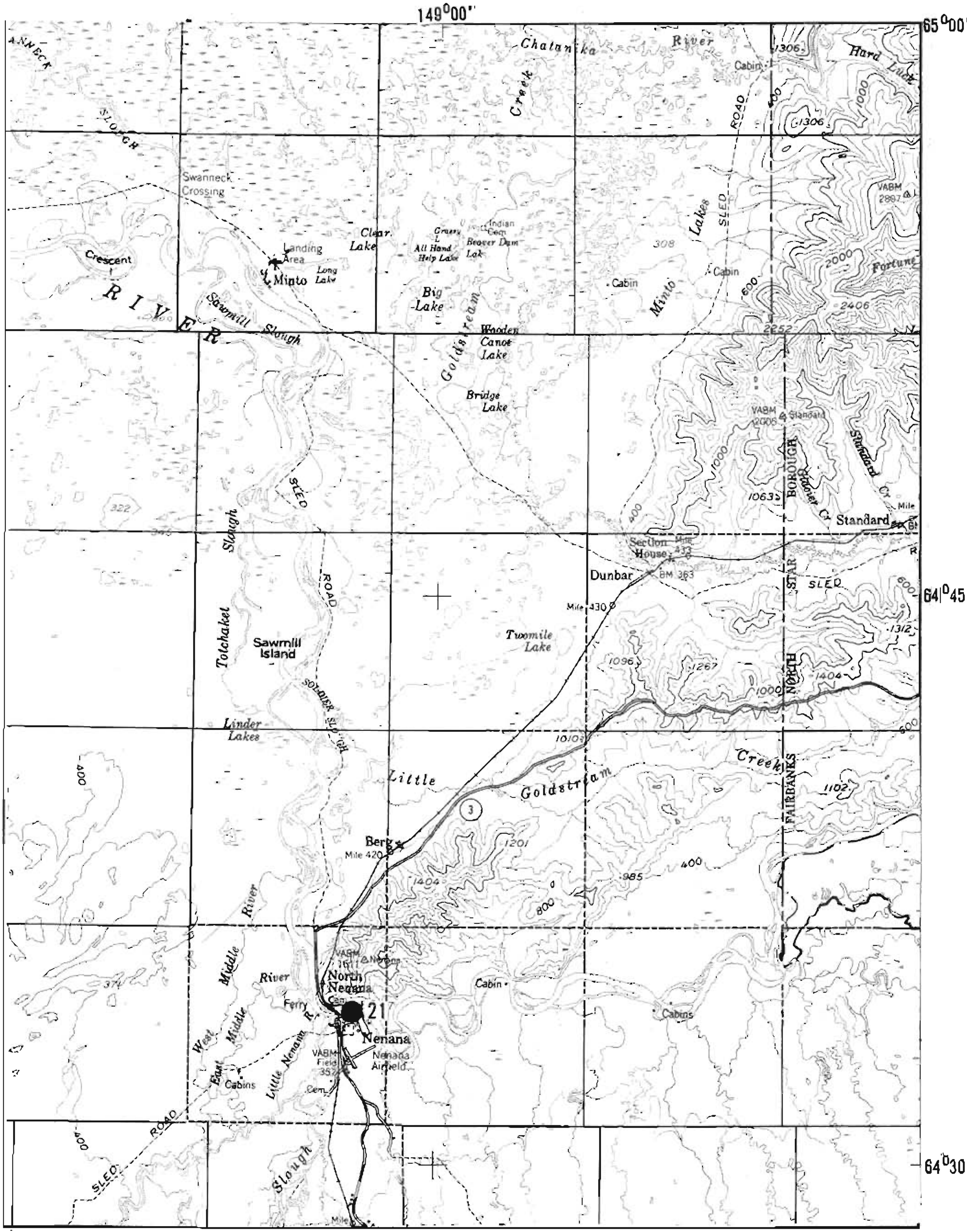
Map 6


65°30'
65°15'
147°30'
147°00'
Little
Salcha
SALCHA
Salcha Bluff
Aurora Lodge
17
16
RICHARDSON
HIGHWAY
Campground
Hartman Lake
Harding Lake
Youth Camp
WINTER
TRAIL
IL RES
Mosquito Cr
Redmond Creek
Shamrock Cr
Junction
Creek
Gold Run
Uncle
McCoy
Monte Cristo Creek
Minton Cr
Campbell Cabin
Rosa Creek
Keystone Creek
Caribou
Flat
Birch Lake
Canyon Cr
Bonner
Buckeye
Richardson
Tenderfoot
Shaw Creek Lodge
Shaw Creek Flat
TANANA
RIVER
FAIRBANKS NORTH STAR BOROUGH
CREEK
Clear Creek
Cabins
Quartz Lake
Lost Lake
Map 7

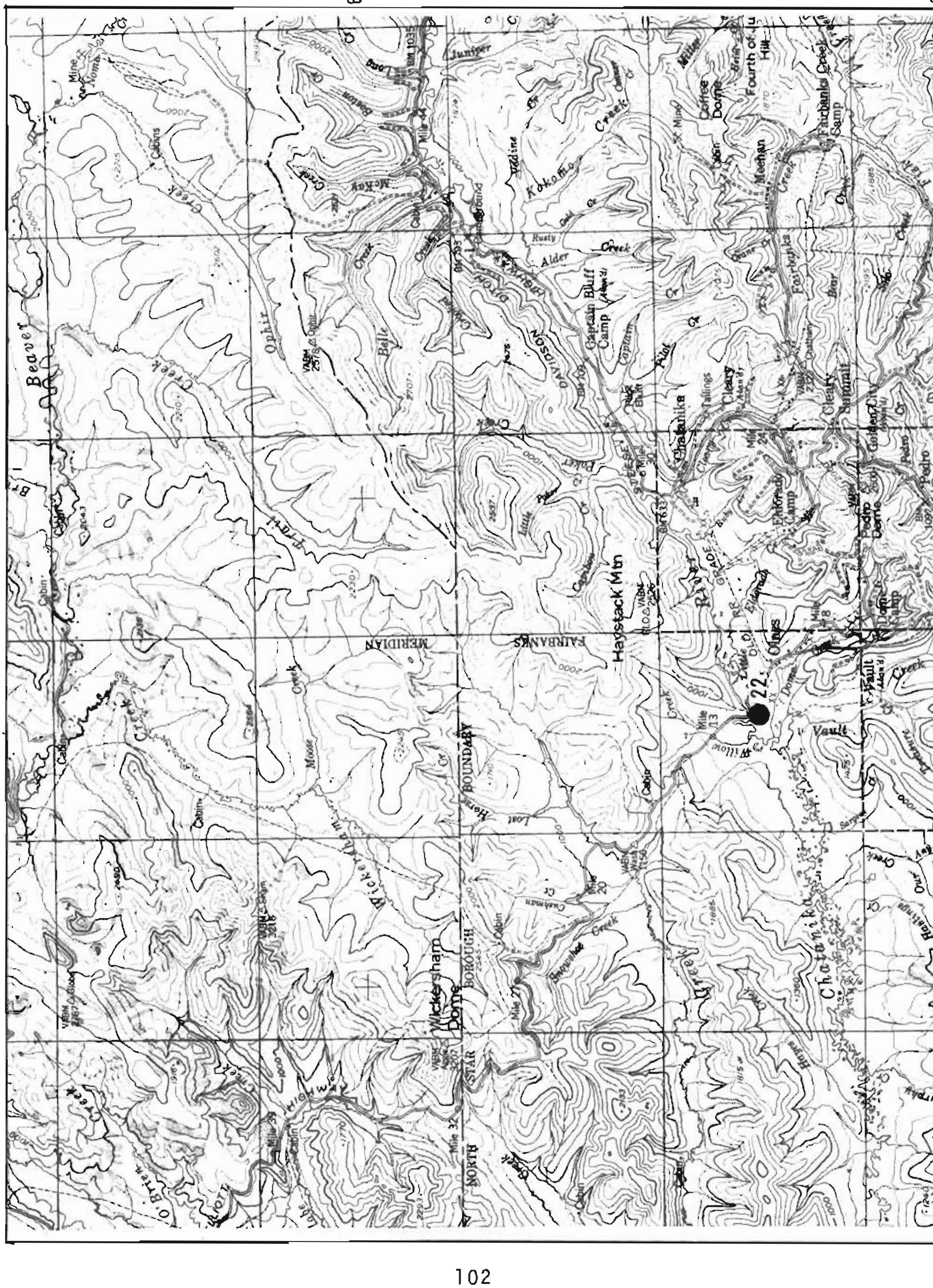

147°00'
146°30'
146°00'
65°00'
64°45'
Caribou
Anaconda
Flat
Creek
Pleasant Valley
Chena
River
WINTER
TRAIL
Colorado
Stiles
Creek
East
Otterfall
18
Rock
Creek
Tors
Munson
Little
Granite
BASE
LINE
Nugget Cr
Creek
Cabin
Cabins
Horner
Creek
Beaver
Creek
Wheeler
Creek
Anderson
MILITARY
Pine
Emory Cr
Landing Strip
Fork
Globe
Creek
Moose
Creek
French
Butte
WINTER
TRAIL
RIVER
Map 8


147°00'
65°00'
64°45'
147°30'
148°00'
FAIRBANKS
North Pole
Moose Creek Bluff
Moose Creek
Eielson Air Force Base
MILITARY
RESERVATION
RICHARDSON HIGHWAY
THE ALASKA RAILROAD
Salchaket
Slough
Clear Creek Butte
Gilmore Dome
Ester Dome
Ester
Happy
Birch Hill
UNIV OF ALASKA
Smallwood Creek
Steele Creek
Meridian Island
Goose Island
Crooked

Map 9


149°00"
65°00'
64°45'
64°30'
Chatanika River
Creek
Hard Luck
Cabin
ROAD
SLED
1306
1000
VABM 2887
Fortune
2000
2406
2252
600
Swanneck Crossing
Crescent
RIVER
Landing Area
Minto
Long Lake
Sawmill Slough
Clear Lake
Grassy L
All Hand Help Lake
Indian Cem
Beaver Dam Lak
Big Lake
Goldstream
Minto Lakes
308
Cabin
Wooden Canoe Lake
Bridge Lake
VABM 2606
Standard
Standard Cr
Dozier Cr
BOROUGH
1063
400
322
Tolchakel Slough
Section House
Mile 433
Dunbar
BM 363
Mile 430
STAR
SLED
NORTH
FAIRBANKS
1312
Sawmill Island
Twomile Lake
1096
1267
1404
1000
SOLDIER SLOUGH
Linder Lakes
1010
Little Goldstream Creek
1102
3
Berg
Mile 420
1201
1404
985
400
800
River
Middle River
West Middle
East
Little Nenana R.
Ferry
North Nenana
VABM 1611
Nenana
21
Cabin
Cabins
VABM Field 357
Nenana Airfield
Cabins
Cem
374
SLED ROAD
Slough
Mile

Map 10


65°15'
65°00'
147°00'
147°30'
148°00'
Beaver
Ophir
Haystack Mtn
Wickersham Dome
Chatanika
Cleary Summit
Olnes
Fairbanks Creek Camp
Captain Bluff Camp
Eldorado Camp
Pedro Dome
Vault
22

Map 11