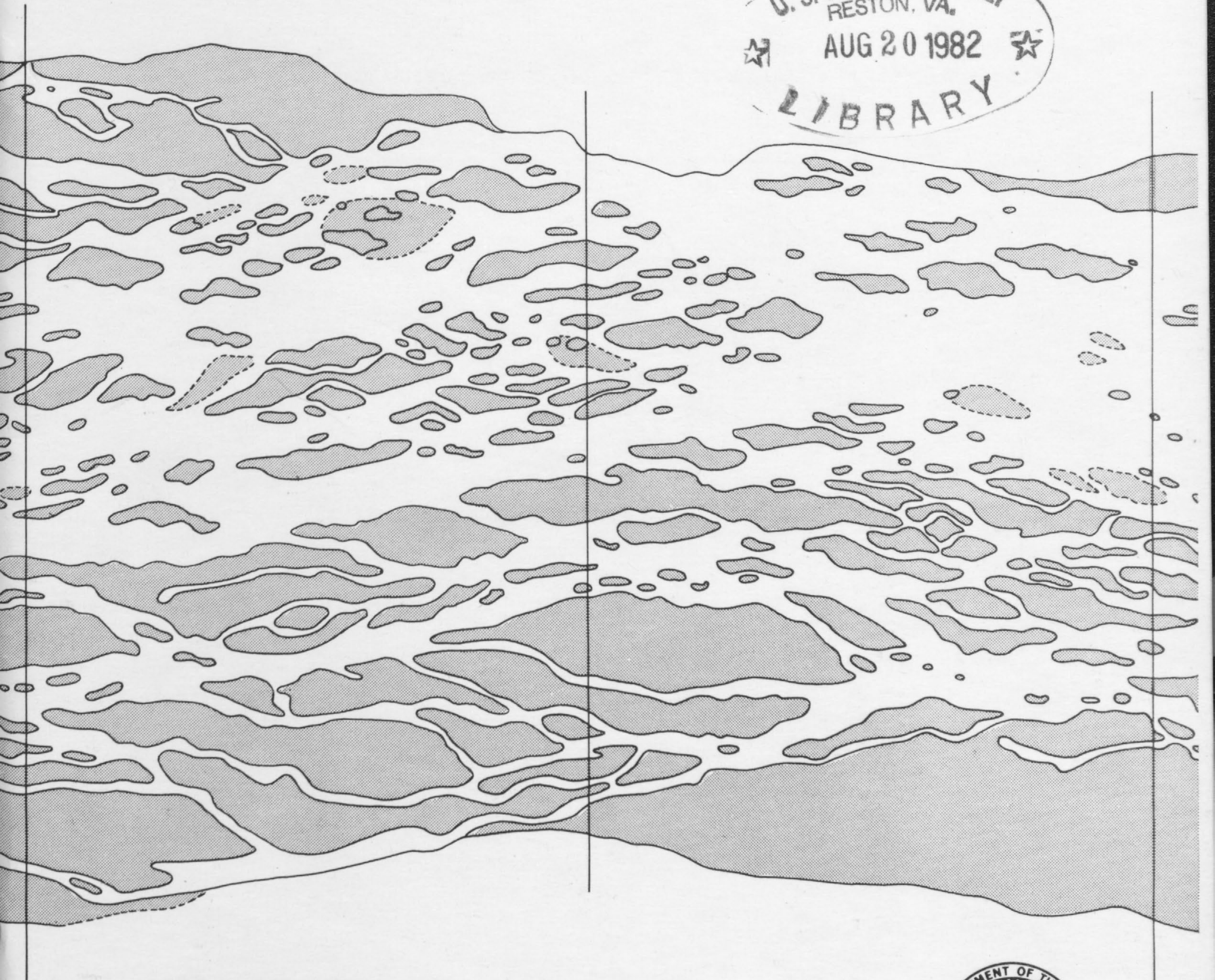
AT-A-STATION HYDRAULIC GEOMETRY OF THE PLATTE RIVER IN SOUTH-CENTRAL NEBRASKA



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Cover illustration -- A 2-km reach of the Platte River channel near Kearney, Nebraska from an aerial photograph taken in 1957.

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By T. R. Eschner

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Denver, Colorado

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PLATTE RIVER IN SOUTH-CENTRAL NEBRASKA

By

T. R. Eschner

ABSTRACT

At-a-station hydraulic-geometry relations were computed for a reach of the Platte River in south-central Nebraska containing habitat for sandhill and whooping cranes. The range of exponents of log-linear relations is large between different reaches of the river, and among different sections within a given reach. In general, simple linear regression of the logarithms of width, depth, and velocity on the logarithm of discharge yielded large proportionate reductions in the variances of the dependent variables. Examination of plots of the data indicates that, in many instances, the relations are log-linear, or power functions (Leopold and Maddock, 1953).

Use of the b-f-m diagram, a graphical representation of at-a-station hydraulic-geometry exponents (Rhodes, 1977), allows responses of width, depth, and velocity to changing discharge to be interpreted from physical considerations. In general, based on simple power functions, with increasing discharge for the Platte River in the study area: (1) Width-depth ratio increases; (2) velocity increases more slowly than channel cross-sectional area; and (3) roughness increases. The b-f-m diagram also allows the systematic variation of the hydraulic-geometry exponents with time to be assessed. In general, the width exponent has decreased with time. Trends in the velocity and depth exponents are less apparent.

For some sections, power functions do not appear to describe adequately the observed at-a-station relations. For these sections, breaks in the slopes of the hydraulic geometry relations serve to partition the data sets. Power functions fit separately to the partitioned data described the width-, depth-, and velocity-discharge relations more accurately than did a single power function. Plotting positions of the exponents from hydraulic geometry relations of partitioned data sets on b-f-m diagrams indicate that much of the apparent variation of plotting positions of single power functions results because the single power functions compromise both subsets of partitioned data. Although there is for some sections a suggestion of a decrease in the width exponent through time even for partitioned data, in general the differences in plotting positions between the subsets of partitioned data for a given time interval are at least as great as the differences in plotting positions between successive time intervals for non-partitioned data.

The shape of the complex at-a-station relations may have at least three causes: (1) Changes in bed roughness with discharge may not be linear (Richards, 1973); (2) channel shape may preclude constant rates of increase in water width and depth with increasing discharge; and (3) an insufficient

range of data values may account for apparent complex behavior. Complex hydraulic-geometry relations have significance for channel maintenance and preservation of sandhill- and whooping-crane habitat. Nearly the entire channel bed of sections exhibiting complex hydraulic-geometry relations can be covered with low-magnitude discharges. Vegetation encroachment may be inhibited, preventing further channel narrowing, where non-log-linear relations apply. Discharges required to cover the channel bed are lower than discharges estimated as necessary for channel maintenance by other methods, but the former may serve as minimum values for channel maintenance.

INTRODUCTION

The Platte River in south-central Nebraska in the mid-1800s exceeded 1 km (kilometer) in width. Descriptions of its appearance and its treacherous fords today seem exaggerations, because the present river width rarely exceeds 300 m (meters). Sandbars and islands have become vegetated, as have the banks and adjacent bottomlands. These morphologic and vegetative changes have resulted from continuous changes in the hydrology of the river. Annual discharge and annual peak discharge have decreased in many locations since the development of irrigation in the Platte River basin (Kircher and Karlinger, 1981). These changes in streamflow characteristics have decreased the capability of the river to shift sandbars and scour encroaching vegetation (Eschner, Hadley, and Crowley, 1981). Equally as important, irrigation practices apparently have changed the Platte River from an intermittent stream to a perennial stream in many locations.

Changes in hydrology and channel morphology of the Platte River have reduced its value as a wildlife habitat for some species and increased its value for others. The river presently is used by a wide variety of waterfowl, including ducks, geese, bald eagles, and sandhill and whooping cranes. Sandhillcranes (*Grus canadensis*) and the endangered whooping crane (*Grus americana*) use the Platte River as a staging area and stopover point. In March, these birds spend several weeks in the Platte River valley prior to completing their northward migration to breeding grounds in Canada. In the fall, the river is used as a stopover point when the birds return to wintering grounds in the southern United States (U.S. Fish and Wildlife Service, 1981).

Two features of the Platte River especially are desirable as crane habitat. Unvegetated sandbars in broad, shoal reaches of the river provide ideal night-roosting sites; the open character of these sites decreases the likelihood of predation. Wet meadows adjacent to the river provide important nutrients, in the form of invertebrates, for the cranes.

In general, changes in the hydrology and channel morphology of the Platte River have been detrimental to crane habitat (U.S. Fish and Wildlife Service, 1981). As vegetation increases in height and channel width decreases, the river loses its suitability as a night-roosting area. Changes in river water level affect the quality of the wet meadows. If these meadows are not subirrigated adequately, they may be converted to pasture or cropland, and, therefore, will be lost as feeding grounds.

Not all of the Platte River valley in south-central Nebraska is presently prime habitat. Frith (1974) classified crane habitat along the Platte River and found a broad range of habitat quality. The U.S. Fish and Wildlife Service (1978) determined that the 100-km reach of the Platte River downstream from Lexington, Nebraska was critical habitat for the whooping crane; maintaining the crane habitat along this reach of the river is essential for the preservation of the whooping crane.

Studies of channel changes of the Platte River basin have been undertaken, at least at a preliminary level. Schumm (1968) described the reduction in channel width of the North Platte River and attributed it to the decrease in annual peak flows of the river. Nadler (1978) showed that the South Platte River had decreased in width and increased in sinuosity, the ratio of channel length to valley distance, since the beginning of irrigation. Changes in channel width, channel pattern, and vegetative encroachment on the North Platte and Platte Rivers were described by Williams (1978b). The processes of width reduction of the Platte River were documented by Eschner and others (1981).

The primary objectives of this study were to compute at-a-station hydraulic-geometry relations at selected sites, to examine how the relations have changed with time, and to determine the significance of the relations for channel maintenance.

DESCRIPTION OF THE STUDY AREA

The Platte River is formed by the confluence of the North Platte and South Platte Rivers, about 6 km east of the city of North Platte, Nebraska. From this confluence, the Platte River flows generally toward the east. Initially the river arcs to the north to Duncan, then it arcs south to Ashland. From Ashland, the Platte River flows 80 km east to its confluence with the Missouri River (fig. 1). The total area drained by the Platte River is about 233,000 km^2 (square kilometers). The Loup River, the primary tributary to the Platte River, drains 39,400 km^2.

Field Study Area

The field study area is a 72-km reach of the Platte River in south-central Nebraska, extending from the town of Cozad to the town of Odessa (fig. 2). The entire area lies within the High Plains Section of the Great Plains Province of the Interior Plains (Fenneman, 1931).

Annual precipitation decreases to the west across the study area, ranging from about 560 mm (millimeters) at Kearney to about 510 mm at Cozad. Most of the precipitation falls as spring and summer rains, and the largest amount falls in June. Total lake evaporation is about 1,270 mm per year throughout the area.

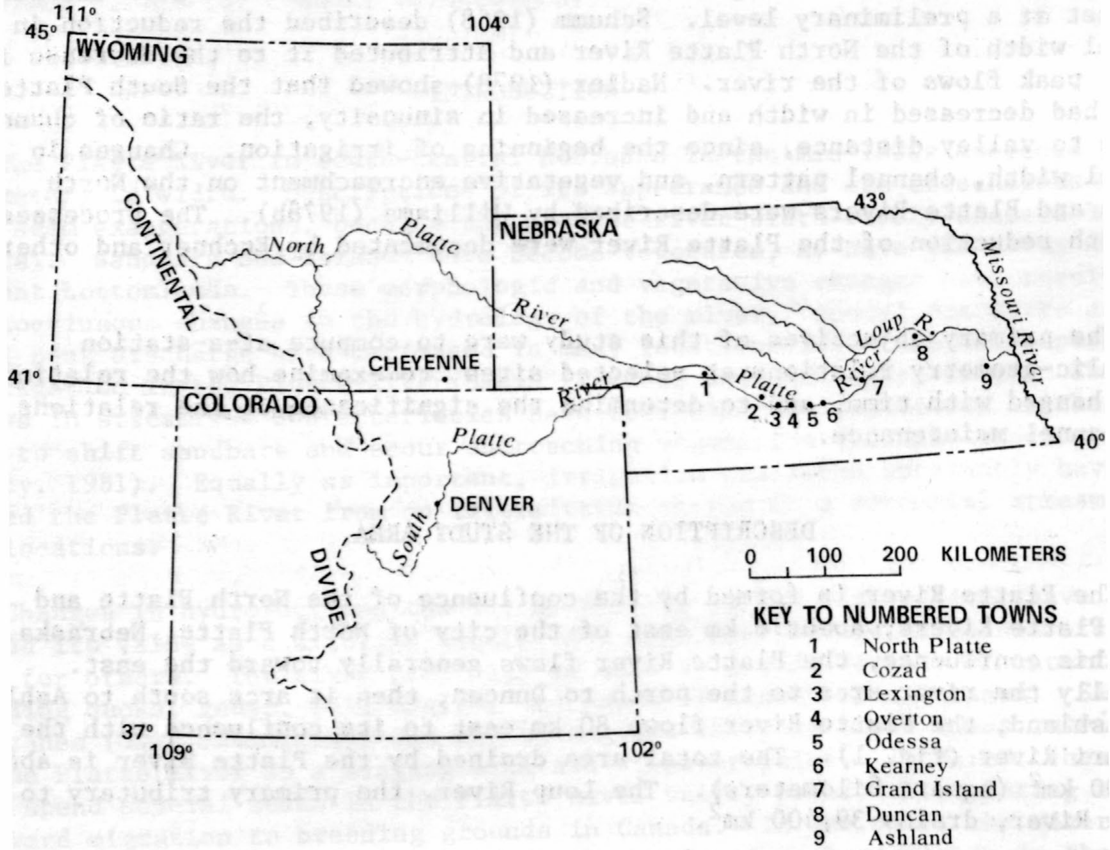

Figure 1.--Index map of the Platte River basin.

The Platte River in the study area is affected by man to varying degrees. Gravel pits, both active and abandoned, dot the river bottom. Water is diverted for the Dawson County Canal immediately upstream of the study area. Water from the Tri-County Supply Canal that has been used for hydropower generation and for cooling is returned to the South Channel of the river through the Johnson-2 power return at a point about midway between Lexington and Overton. The amount of water returned depends on irrigation demand and power generation at hydropower plants. About 3 km east of the town of Elm Creek, water is diverted by the Kearney Canal for irrigation and hydropower. The banks of the river have been riprapped at various locations to reduce the erosive effect of the river against the banks.

Three gaging stations, operated by the U.S. Geological Survey and the Nebraska Department of Water Resources, are within the study reach. The river at the gage near Cozad, at the western edge of the study area, has a drainage area of approximately 146,300 km^2. Two channels are present at Cozad, and each channel is gaged separately. Only the north channel is considered in the discussion of at-a-station hydraulic geometry in this report. These gages produced records from April 1939, with irrigation-season records for 1932, and 1937 to 1938. The gage near Overton, although not occupying the same site for the period of record, produced records from October 1914 to the present, and gage heights from the period July to September 1914. The drainage area of the Platte River at this gaging station is about 149,400 km^2. The gaging station near Odessa, at the eastern end of the study area, has had a recording gage since October 1938. The basin area at this gage is approximately 150,500 km^2.

Cross-Section Locations

Six river cross sections have been established within the study reach for field observations (fig. 2). These sections will be referred to as Cozad (section 1), Lexington (section 2), Johnson 2 (section 3), Overton (section 4), Elm Creek (section 5), and Odessa (section 6), in downstream order. The location of the Johnson-2 power return also is indicated in figure 2.

Channel Characteristics

The channel of the Platte River in the study area ranges in width from about 120 m to over 500 m. Water depth varies from a few millimeters over bars at low flow to over 2 m in the thalweg at high flow.

Vegetated sandbars occur throughout the river at average flows (near mean annual); the width of these bars approaches two-thirds of the channel width; their length approaches twice the channel width. Vegetation comprises low weeds and grasses, with willow or cottonwood seedlings at various stages of development; these seedlings, if not destroyed by flood, become firmly established and cause the sandbar eventually to become an island. Permanent islands also occur.

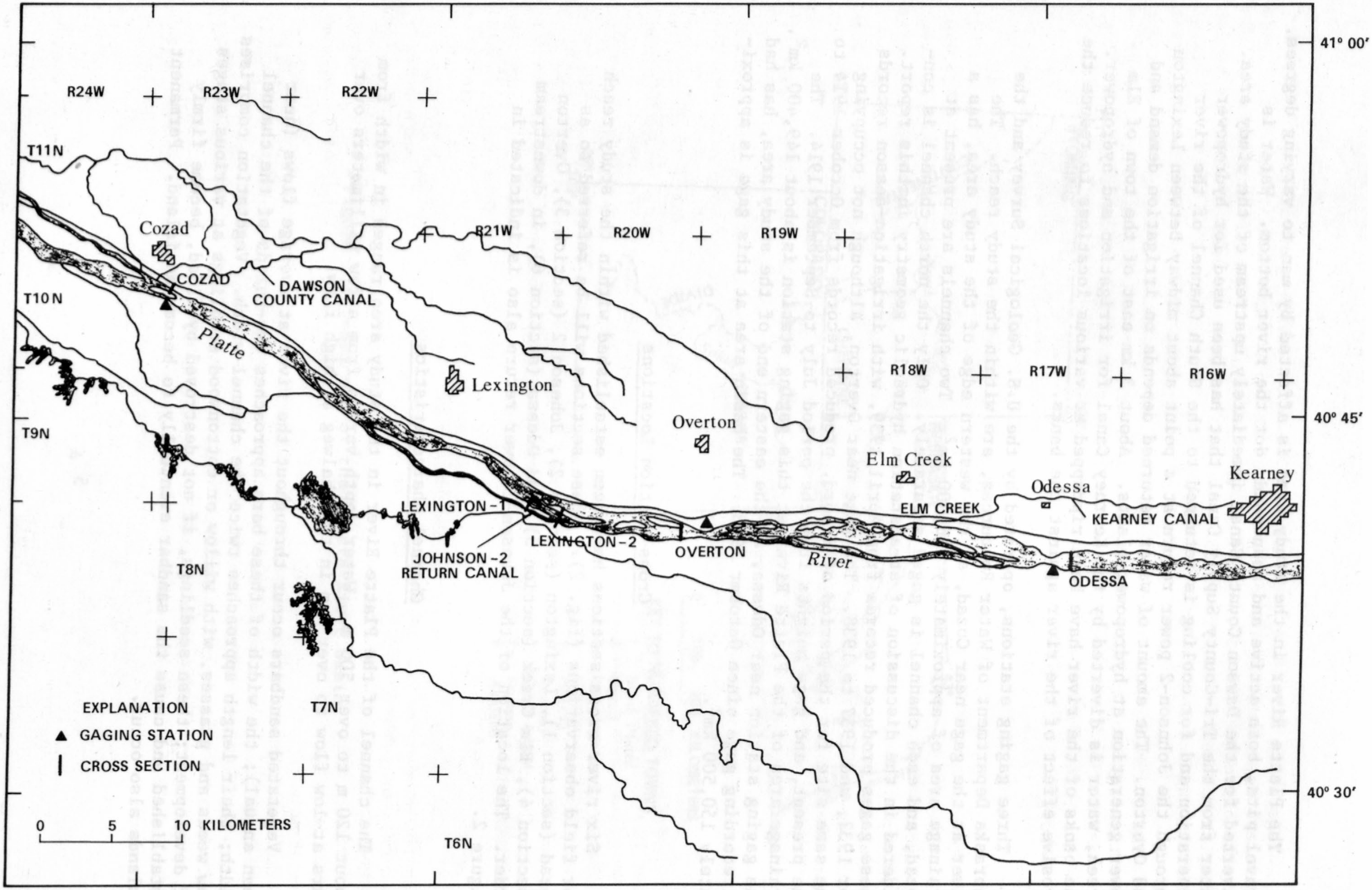

Figure 2.--Location of the study area in south-central Nebraska.

Vegetation along the river bank consists of grasses, shrubs, and trees. The trees most commonly found are species of willow, cottonwood, and ash. Russian olive and red cedar trees grow in areas not frequently inundated. Tamerisk has been seen infrequently, and only within the last decade (Joe Jeffrey, rancher, oral commun., 1979).

The Platte River channel is braided at low flows, with threads of water intertwining among ripples, dunes, and sandbars. At the highest flows, water extends from bank to bank and flows straight through the channel. At many locations, the channel pattern appears to be meandering or anastomosing, that is, consisting of branches that separate and rejoin around islands.

THE CONCEPT OF HYDRAULIC GEOMETRY

The term hydraulic geometry was introduced by Leopold and Maddock (1953) to describe the way in which channel characteristics vary with discharge. In essence, hydraulic geometry is an empirical model expressing the changes in channel and hydraulic variables as simple power functions of discharge. The resulting equations have the form:

$$w = aQ^b \tag{1}$$

$$d = cQ^f \tag{2}$$

$$v = kQ^m \tag{3}$$

where

w = width,
d = mean depth,
v = mean velocity,
Q = instantaneous discharge,
b, f, and m = the exponents of the equations, and
a, c, and k = the coefficients.

For continuity, the product of width, mean depth, and mean velocity must be the discharge:

$$Q = wdv \, . \tag{4}$$

Then the product of the hydraulic-geometry coefficients and the sum of the exponents must be:

$$Q = ack \, Q^{b + f + m} \tag{5}$$

Hydraulic-geometry relations can be defined for both specific cross sections on a river (at-a-station hydraulic geometry) and different cross sections on a river at a constant frequency of discharge (downstream hydraulic geometry), although not necessarily in downstream order. The exponents of both the at-a-station and downstream relations have been studied in various physiographic and climatic regions. In addition, expected exponents under ideal conditions have been derived theoretically for both downstream and at-a-station geometry.

At-a-Station Hydraulic Geometry

Exponents for at-a-station hydraulic geometry, reported in the literature, range at least from 0.0 to 0.84 for the width exponent, b; 0.01 to 0.84 for the depth exponent, f; and 0.03 to 0.99 for the velocity exponent, m (Rhodes, 1978). Park (1977) calculated modal class values for 139 at-a-station data sets for streams in proglacial, humid temperate, semiarid, tropical, and "unspecified" regions. Park found that exponent values for width fell within the class 0.0 to 0.1, for depth within the class 0.3 to 0.4, and for velocity within the class 0.4 to 0.5. Knighton (1975) reported average exponents for 206 cross sections in the United States as 0.16 for width, 0.43 for depth, and 0.42 for velocity. Perhaps the most commonly cited average exponent values are those computed by Leopold and Maddock (1953) for "* * * a large variety of rivers * * *." The values are b = 0.26, f = 0.40, and m = 0.34.

Computed exponent values have been compared to theoretically derived at-a-station values. Theoretical at-a-station exponent values will vary with the channel shape assumed for their derivation. The "most probable values" as generally cited (Park, 1978; Rhodes, 1978) are b = 0.23, f = 0.42, and m = 0.35 (Langbein, 1964). Wolman and Brush (1961) derived theoretical at-a-station cross-sectional area (A), and width exponents based on flume studies of coarse noncohesive sands. For channels at or above the critical velocity of incipient motion, $A = Q^{0.9}$ and b = 0.90. For channels below the point of incipient motion, $A = Q^{0.9}$ and b = 0.75. Wolman and Brush (1961) cited the Platte River near Grand Island, Nebraska at moderate stages as an example of a river in coarse noncohesive sands that behaves according to their derivation.

Downstream Hydraulic Geometry

Computed downstream exponents range at least from 0.03 to 0.89 for width, 0.09 to 0.70 for depth, and -0.51 to 0.75 for velocity. These values are those reported by Park (1978) for 72 observations. The modal classes of these observations are 0.4 to 0.5 for width, 0.3 to 0.4 for depth, and 0.1 to 0.2 for velocity. Leopold and Maddock (1953) listed the average exponents calculated for their classic study as b = 0.5, f = 0.4, and m = 0.1. Carlston (1969) computed least-square solutions for Leopold and Maddock's data and found the mean of the exponents to be 0.461 for width, 0.383 for depth, and 0.155 for velocity.

Theoretical exponents have been derived for downstream hydraulic geometry. Leopold and Langbein (1962) obtained values of b = 0.55, f = 0.36, and m = 0.09. Langbein (1964) calculated the exponents as b = 0.53, f = 0.36, and m = 0.10. Using a different method, Smith (1974) obtained average downstream exponent values of b = 0.6, f = 0.3, and m = 0.1.

The use of average hydraulic-geometry exponents, even for rivers within one basin, has led to the theory that rivers have similar geometries despite different physiographic and climatic settings. Recently, however, the validity and usefulness of average hydraulic-geometry exponents have been questioned (Knighton, 1975; Rhodes, 1977; Park, 1978). The large range of all three exponent values suggests that mean geometry may be an attractive, but more or less meaningless, concept.

Assumptions

The concept of hydraulic geometry is based on assumptions, which may include the following (Thornes, 1977; Knighton, 1977):

1. A direct causal relationship exists in the system, with discharge as the primary independent variable.
2. A change in the independent variable will cause a specific change to occur in the dependent variables.
3. The changes are continuous and reversible.
4. Mean-stream characterisitics are represented by the relations at a particular site.
5. Simple log-linear relationships accurately describe the observed changes.

Although channel width is determined largely by discharge, at-a-station hydraulic geometry is a function of channel shape for low flows (Richards, 1976). Channel shape is (in turn) determined by physical properties of channel-perimeter sediment (Schumm, 1960) and past flow events (Pickup and Rieger, 1979). Thus, despite the ultimate cause of channel size, the channel yields an at-a-station hydraulic geometry that is a relic of larger flows.

Hydraulic geometry relations describe observed changes in a channel with changing discharge; the relations are best-fit lines for the data used and do not necessarily represent unique values. A given change in discharge need not always produce the same response in the channel; width may adjust slightly more than depth on one occasion, but the reverse may occur on another occasion. In the same manner, channel response may not be reversible in a strict sense. This fact was documented by Leopold and Maddock (1953) with their example of the passage of a single flood on the San Juan River in Utah. Hydraulic-geometry plots from this flood show hysteresis, that is, channel depth, mean velocity, suspended-sediment load, streambed elevation, and water surface all responded differently to the same discharge on the rising and falling stage.

Knighton (1977) has studied the theory that mean stream characteristics are represented by at-a-station relations. He concluded that four factors were responsible for short-term variation at a given site. Measurement error is present in all discharge measurements; mean depth and velocity particularly are susceptible to error because they are computed from point measurements. Random error is also a source of variation in all discharge observations. Hysteresis is a random variation. Systematic variation, or variation resulting from progressive change of the channel, in hydraulic geometry is a third source of short-term variation at a site. Knighton suggests that systematic variation can be examined by looking at discrete time phases of the sample from a given site. The final source of short-term variation in at-a-station hydraulic geometry lies in analytical error.

The existence of analytical error would be a refutation of the assumption that simple log-linear relations adequately describe channel changes with discharge. Richards (1973) pointed out that, because depth and velocity are functions of roughness, they also should be functions of bed sediment and channel geometry. He suggested that higher-order equations, specifically log-quadratic equations, may express more accurately hydraulic-geometry relations.

Log-quadratic or log-polynomial equations are appropriate for use in hydrologic geometry because they allow use of the continuity relationship. For example, the width-discharge power-function relation (equation 1) can be rewritten as:

$$(\text{Log } w) = \log a + b_1 (\text{Log } Q) . \qquad (6)$$

Generalization to a log-quadratic equation yields:

$$(\text{Log } w) = \log a + b_1 (\text{Log } Q) + b_2 (\text{Log } Q)^2 \qquad (7)$$

By analogy to equation 6, the first derivative of equation 7 with respect to Log Q,

$$\frac{d(\text{Log } w)}{d(\text{Log } Q)} = b_1 + 2b_2 (\text{Log } Q) \qquad (8)$$

is the instantaneous slope of the curve. The continuity equation using first derivatives of log-quadratic functions becomes:

$$(b_1 + f_1 + m_1) + 2(b_2 + f_2 + m_2)\text{Log } Q = 1 \qquad (9)$$

(Richards, 1973). The first derivative, therefore, is analogous to the exponent of the power function.

The b-f-m Diagram

Two methods of graphically representing hydraulic-geometry exponents have been proposed. Park (1978) presented tri-axial graphs of both at-a-station and downstream hydraulic-geometry exponents to allow consideration of the simultaneous variations in the three exponents. Park concluded that there is not a tendency within an area or environment to establish a unique hydraulic-geometry relation or series of relations, either at-a-station or downstream.

Rhodes (1977) graphically represented hydraulic-geometry exponents by plotting them on a triangular-coordinate system, which he termed a b-f-m diagram. The arrangement of the b-f-m diagram was different from the tri-axial graphs proposed by Park. Rhodes' research indicated that comparison of channels through assessing the similarity of exponents was inadequate. He proposed a series of subdivisions of the b-f-m diagram based on hydraulic and morphologic considerations (fig. 3). The ten fields of the diagram are created with five lines, as follows:

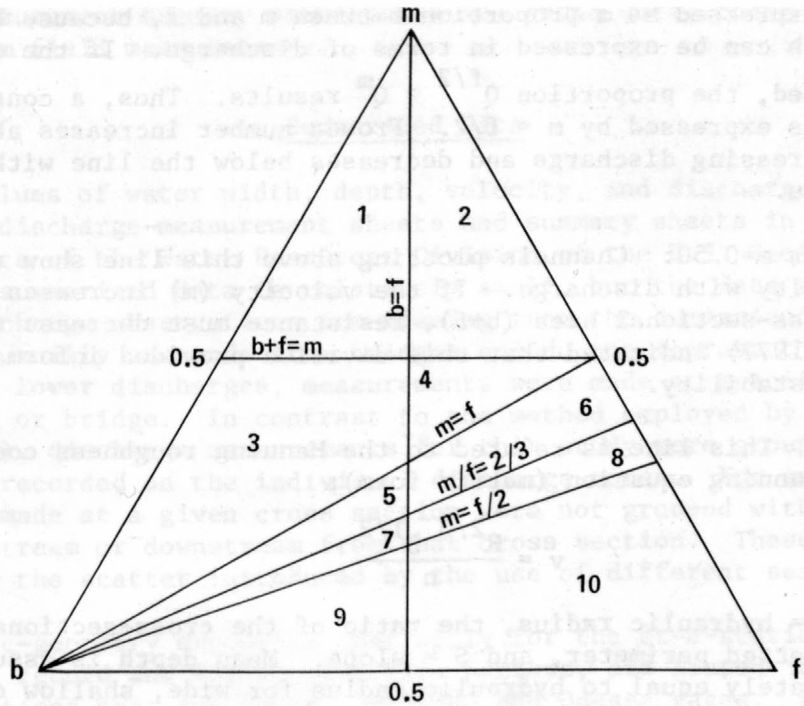

Figure 3.--Divided b-f-m diagram, showing fields that represent different channel types.

1. b=f: This line represents no change in the width-depth ratio with changing discharge. To the right of this line, width-depth ratios decrease with discharge, and to the left of this line, width-depth ratios increase with discharge. Location of a point relative to this line may provide information about channel shape and stability, and bedload transport.

2. m=f: Rhodes (1977) suggested that the competence of channels plotting above this line should increase with discharge. This statement was based on an analysis of competence and the rates of change of velocity and depth by Wilcock (1971), and on work by Leopold and Maddock (1953), associating the ratio of the rates of change in velocity to depth with the rate of change of suspended load.

3. m=f/2: This division is based on Froude number and represents a constant value. The Froude number, defined as:

$$F = \frac{v}{\sqrt{gd}} \quad (10)$$

where

v = velocity,
g = gravitational constant, and
d = water depth,

can be expressed as a proportion between m and f, because both velocity and depth can be expressed in terms of discharge. If the constants are eliminated, the proportion $Q^{f/2} \propto Q^m$ results. Thus, a constant Froude number is expressed by m = f/2. Froude number increases above this line with increasing discharge and decreases below the line with increasing discharge.

4. m=b + f, or m=0.50: Channels plotting above this line show rapid increase in velocity with discharge. If the velocity (m) increases more rapidly than cross-sectional area (b+f), resistance must decrease rapidly. Rhodes (1977) indicated that this division provided information about channel stability.

5. m/f = 2/3: This line is related to the Manning roughness coefficient, n, in the Manning equation (metric form):

$$v = \frac{R^{2/3} S^{1/2}}{n} \qquad (11)$$

where R = hydraulic radius, the ratio of the cross-sectional area to the wetted perimeter, and S = slope. Mean depth is assumed to be approximately equal to hydraulic radius for wide, shallow channels, such as those of the Platte River.

Expressing slope, $S \propto Q^z$, and roughness, $n \propto Q^y$, as functions of discharge, Manning's equation may be rewritten as:

$$Q^m \propto Q^{(2/3)f} \times \frac{Q(1/2)^z}{Q^y} \qquad (12)$$

If m = 2/3 f, the ratio $\frac{S^{1/2}}{n}$ is constant with changing discharge. Rhodes assumed (from data from several sources) that slope varies little with discharge; thus, roughness may change appreciably. This assumption, although true for limited ranges of discharge, is probably not true for the full range of flows. Points below the line m/f = 2/3 on the b-f-m diagram represent channels in which roughness increases with discharge.

AT-A-STATION HYDRAULIC GEOMETRY

Hydraulic-geometry relations were computed both for the six field-study sections and for several cross sections near the Cozad, Overton, and Odessa gages. The exponents were calculated using linear regression techniques on log-tranformations of the data. Initially, first-order log equations (power functions) were assumed to represent the hydraulic-geometry relations. In addition, log-quadratic equations were fitted to the data sets, and separate power functions were fitted to discrete segments of the data sets for these purposes: (1) To decrease the residual error of the regressions; (2) to approximate more closely the apparent trend of the data; and (3) to meet physical constraints observed in the field. For the purpose of discussion, the data are grouped as: (1) Summarized data, those data obtained from discharge measurement summary sheets; and (2) field data, those data collected from field measurements.

Summarized Data

These values of water width, depth, velocity, and discharge were summarized from discharge-measurement sheets and summary sheets in the Nebraska District Office of the Water Resources Division of the U.S. Geological Survey. The range of summarized data is relatively small, but the data set is large. High-flow discharge observations are missing from the summarized data; such measurements usually are made from bridges and do not represent natural sections. At lower discharges, measurements were made at specified distances from the gage or bridge. In contrast to the method employed by Leopold and Maddock (1953), discharge measurements for this study were grouped by specific location, as recorded on the individual discharge notes. For example, discharge measurements made at a given cross section were not grouped with measurements made 20 m upstream or downstream from that cross section. These data groupings should reduce the scatter introduced by the use of different sections.

Hydraulic-geometry exponents that apply for the at-a-station case, for the period of record and for shorter time periods, are listed in table 1 for data from sections near the Cozad, Overton, and Odessa gages. Exponents for power functions based on whole data sets and partitioned data sets are listed in table 1; corresponding significance levels and corresponding correlation coefficients are listed in the summary of statistical data at the end of the report (table 2).

The range of exponents for the sections near Cozad, Overton, and Odessa is relatively large for each of the hydraulic-geometry relations computed from simple linear regression: The width exponent varies from 0.22 to 0.80, the depth exponent varies from 0.11 to 0.63, and the velocity exponent varies from 0.09 to 0.44. The amount of variation of the exponent varies from area to area. For example, the width exponent ranges from 0.21 to 0.66 for the sections near Cozad, but the width exponent ranges only from 0.48 to 0.68 for the sections near Odessa. Variability of all three exponents is least for the three sections near Odessa.

For the period of record, simple linear regression of the logarithms of width, depth, and velocity on the logarithm of discharge yielded large reductions in the variances of the dependent variables relative to the variances of the logarithms of width, depth, and velocity alone. Similar reductions were found for the period since 1969 in most instances.

The reduction of variances of the dependent variables does not necessarily indicate that the relations between discharge and width, depth, and velocity are power functions, because the correlation coefficient is not a measure of the appropriateness of the straight-line model. However, examination of representative plots of the data (figs. 4-12) indicates that some of the relations are log-linear, or plot as straight lines on log-log plots.

Table 1.--*At-a-station hydraulic-geometry exponents for summarized data, expressed as coefficients of power functions of the form:* $(\log w) = \log a + b(\log Q)$

Platte River near:	Distance downstream from gage (meters)	Period of record	Coefficients b	f 1/	m
Cozad	30	1961-1979	0.5282	0.2939	0.1778
		1961-1963	.5560	.2804	.1636
		1964-1969	.492	.2169	.2913
		1970-1979	.4893	.3405	.1702
Cozad	45	1954-1979	.5082	.3537	.1381
		Low	.795	.127	.078
		High	.3741	.4905	.1354
		1954-1969	.5492	.297	.153
		Low	.755	.245	.015
		High	.5998	.4002	.1521
		1970-1979	.2782	.6274	.0944
		High	.2351	.6847	.0801
Cozad	60	1953-1979	.5339	.2720	.1941
		Low	.6788	.1273	.1939
		High	.3576	.4503	.1921
		1953-1957	.6610	.1637	.1753
		1958-1963	.4944	.3473	.1583
		1953-1963	.5728	.2450	.1822
		Low	.6801	.1395	.1805
		High	.435	.4359	.1295
		1964-1969	.4468	.2831	.2701
		Low	.772	-.101	.329
		High	.3738	.4071	.2190
		1970-1979	.3809	.4551	.1640
		Low	.997	-.0161	.0192
		High	.1772	.5717	.2511
Cozad	75	1961-1979	.4345	.3625	.2030
		Low	.5848	.0414	.3739
		High	.5188	.3560	.1252
		1961-1963	.4999	.3580	.1421
		Low	.510	.2106	.2798
		High	.6425	.2859	.0717
		1964-1969	.5086	.2832	.2082
		Low	.751	-.111	.3599
		High	.5435	.3543	.1023
		1970-1979	.2155	.5151	.2694
		High	.2553	.4705	.2742
Cozad	120	1951-1979	.4998	.3131	.1871
		Low	.6224	.2067	.1709
		High	.2281	.5790	.1930

Table 1.--*At-a-station hydraulic-geometry exponents for summarized data, expressed as coefficients of power functions of the form: (log w) = log a + b(log Q)*--Continued

Platte River near:	Distance downstream from gage (meters)	Period of record	Coefficients b	Coefficients f[1/]	Coefficients m
Cozad	120	1951-1963	0.6168	0.2198	0.1634
		Low	.6585	.1863	.1551
		1964-1969	.2345	.5147	.2508
		Low	.4669	.3629	.1702
		High	.1636	.6166	.2198
		1970-1979	.3184	.5334	.1482
		Low	.4380	.5240	.0380
		High	.2165	.5833	.2024
Overton, north channel	30	1968-1976	.4294	.3497	.2210
Overton, north channel	45	1968-1976	.3850	.3608	.2543
		Low	.305	.307	.388
		High	.2139	.5465	.2396
Overton, north channel	60	1968-1976	.4100	.3658	.2242
		Low	.5226	.2684	.2090
		High	.0474	.7883	.1643
Overton, north channel	75	1968-1978	.0813	.4815	.4372
		Low	.770	.139	.091
		High	.4161	.2456	.3383
Overton, north channel	90	1968-1978	.3154	.4331	.2514
		Low	.654	.1923	.1538
		High	.1665	.4806	.3529
Overton, south channel	30	1968-1976	.5332	.3974	.0694
Overton, south channel	90	1968-1978	.3870	.3229	.2901
Overton	30	1961-1967	.8011	.1165	.0824
Overton	45	1961-1963	.914	-.048	.134
Overton	60	1954-1967	.6523	.1984	.1493
		Low	.462	.503	.034
		High	.4637	.3150	.2213
		1954-1963	.7303	.1384	.131
		Low	.948	-.114	.166
		High	.5152	.2705	.2143

Table 1.--*At-a-station hydraulic-geometry exponents for summarized data, expressed as coefficients of power functions of the form: (log w) = log a + b(log Q)*--Continued

Platte River near:	Distance downstream from gage (meters)	Period of record	Coefficients b	Coefficients f[1/]	Coefficients m
Overton	60	1964-1967	0.6047	0.247	0.1484
		Low	.251	.721	.028
		High	.4550	.3435	.2014
Overton	75	1962-1967	.4878	.2386	.2736
		Low	.770	.139	.091
		High	.4161	.2456	.3383
		1962-1963	.386	.347	.267
		1964-1967	.4973	.2264	.276
		Low	.768	.177	.0552
		High	.4282	.2227	.3491
Overton	90	1962-1967	.4729	.3207	.2064
		Low	.7072	.1686	.1242
		High	.1961	.5819	.2219
		1962-1963	.5092	.3010	.1898
		Low	.8478	.0432	.1090
		High	.1283	.5905	.2812
		1964-1967	.4602	.327	.2123
		Low	.6402	.2307	.1292
		High	.2157	.5787	.2056
Odessa	60	1962-1979	.6286	.2218	.1496
		Low	.6508	.1805	.1687
		High	.3701	.548	.082
Odessa	60	1962-1963	.6807	.1362	.1832
		Low	.7100	.0994	.1906
		High	.320	.383	.297
		1964-1969	.5868	.2940	.1193
		1970-1979	.4829	.4028	.1143
Odessa	75	1961-1979	.6018	.2033	.1949
		Low	.6138	.1718	.2144
		High	.256	.551	.193
		1961-1963	.5963	.1615	.2922
		1964-1969	.5869	.2691	.1442
		Low	.6224	.2258	.1519
		High	.254	.600	.146
		1970-1979	.5692	.3084	.1224
Odessa	90	1953-1979	.6183	.2074	.1743
		Low	.6804	.1540	.1656
		High	.3077	.4817	.2106

Table 1.--*At-a-station hydraulic-geometry exponents for summarized data, expressed as coefficients of power functions of the form: (log w) = log a + b(log Q)*--Continued

Platte River near:	Distance downstream from gage (meters)	Period of record	Coefficients b	Coefficients f[1/]	Coefficients m
Odessa	90	1953-1963	0.6343	0.1974	0.1683
		Low	.6562	.1623	.1814
		High	.2662	.565	.169
		1964-1969	.5514	.2521	.1966
		Low	.7244	.1233	.1523
		High	.2719	.4782	.2499
		1970-1979	.5007	.3295	.1698

[1/] Negative values for the depth exponent occur only in the low range of discharges for partitioned data sets. The values result as discharge increases; spreading flow over previously unwetted streambed, and they reflect the fact that mean depth may decrease as width increases rapidly.

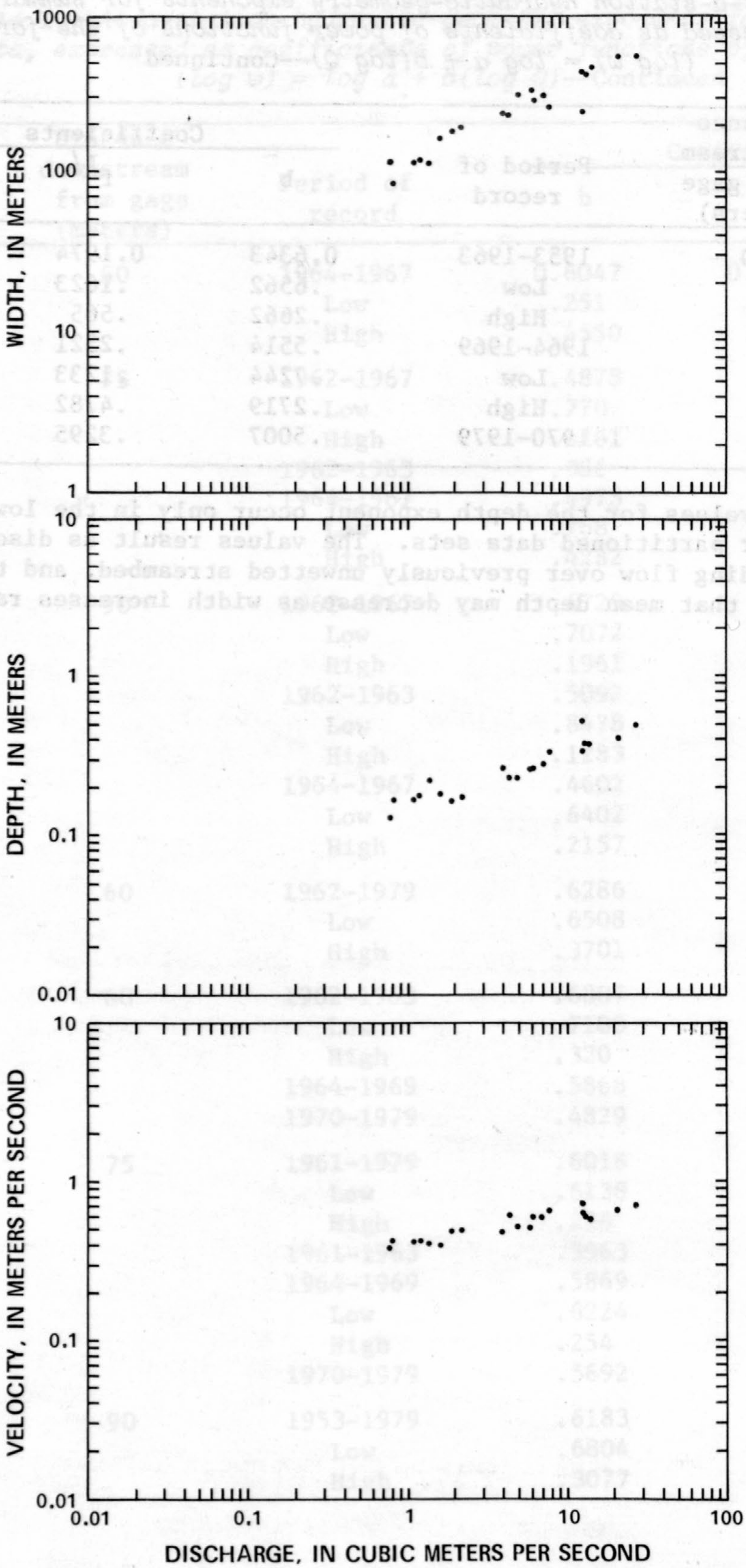

Figure 4.--Relation of width, depth, and velocity to discharge, Platte River 30 meters downstream from gage near Cozad, Nebraska, post-1969 record.

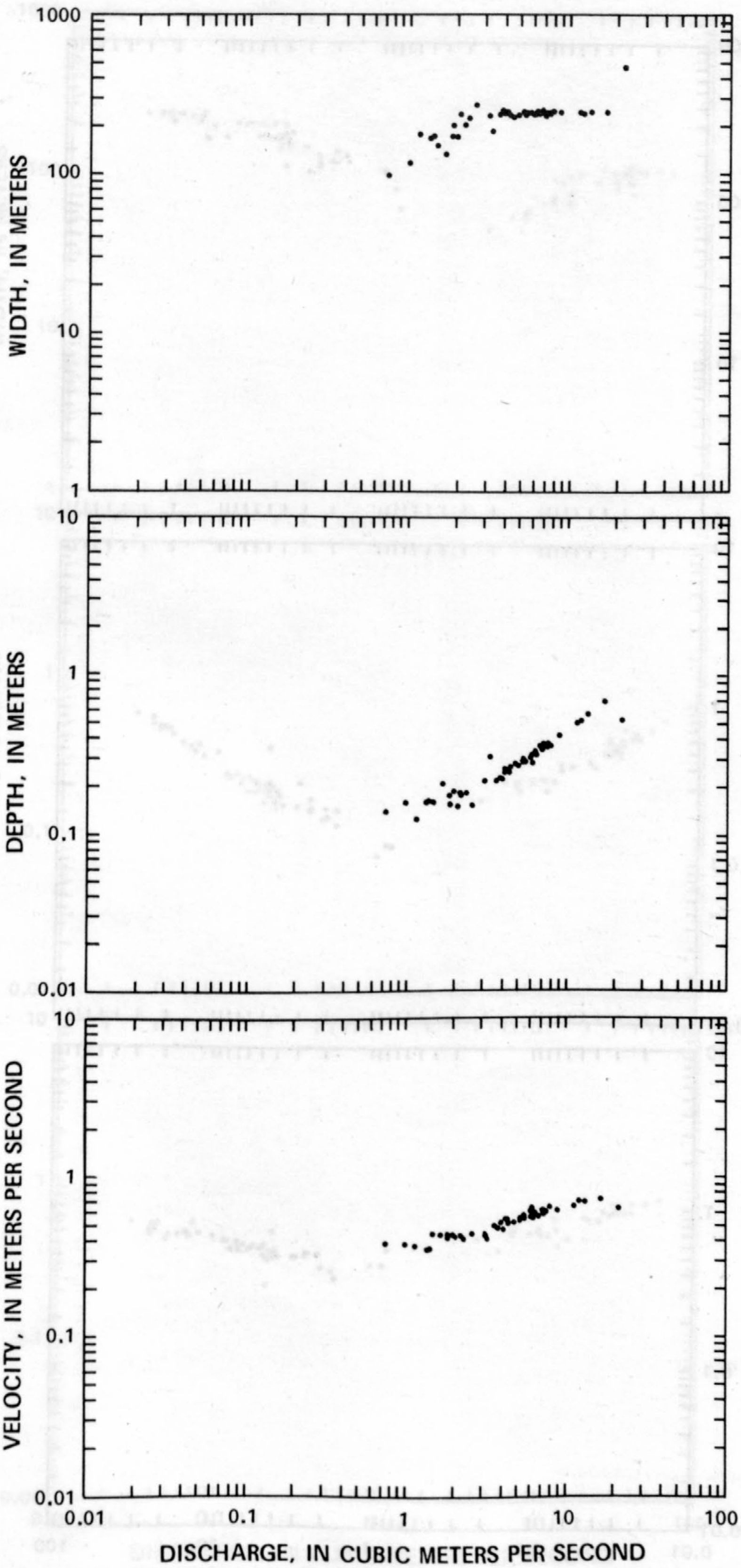

Figure 5.--Relation of width, depth, and velocity to discharge, Platte River 120 meters downstream from gage near Cozad, Nebraska, 1964-1969.

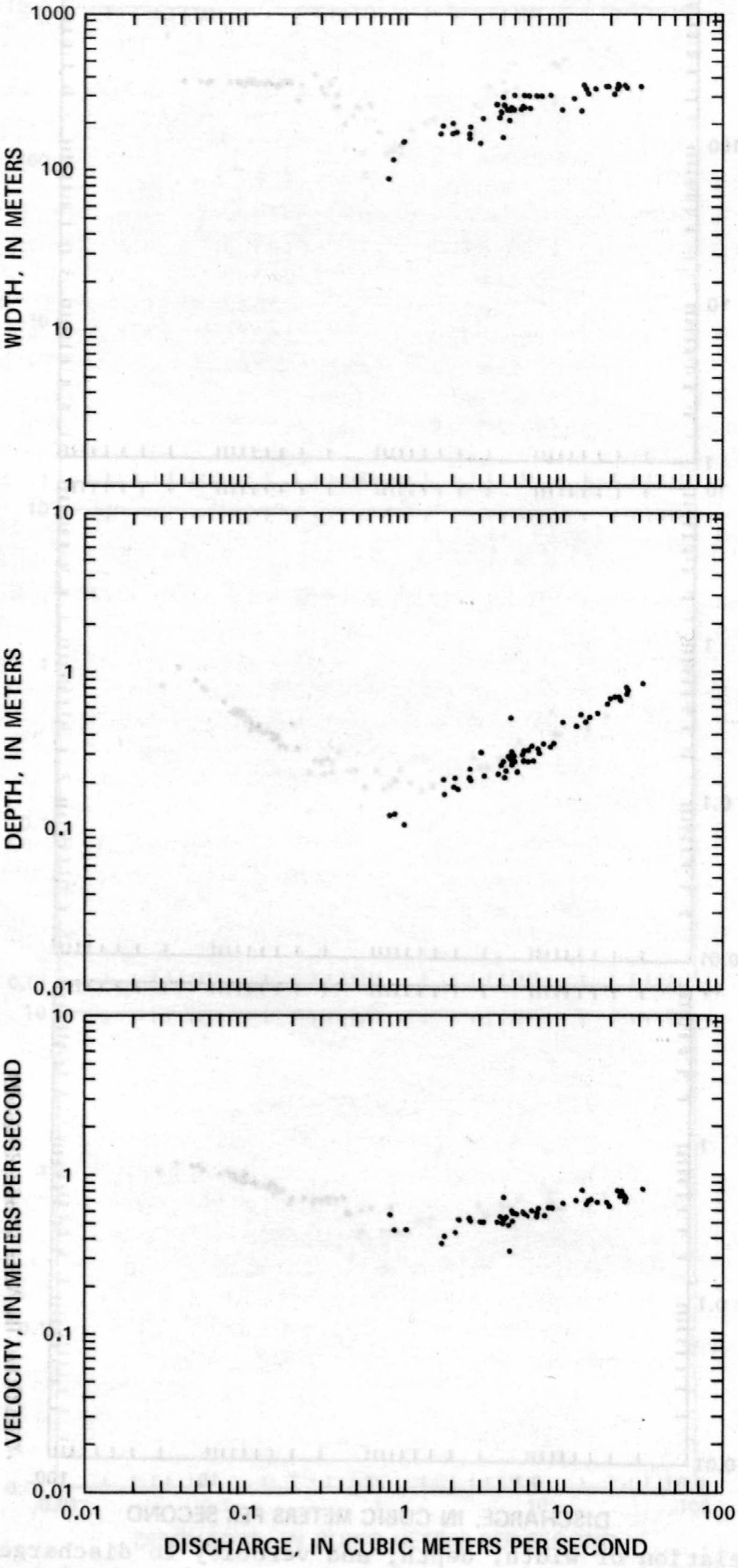

Figure 6.--Relation of width, depth, and velocity to discharge, Platte River 120 meters downstream from gage near Cozad, Nebraska, post-1969 record.

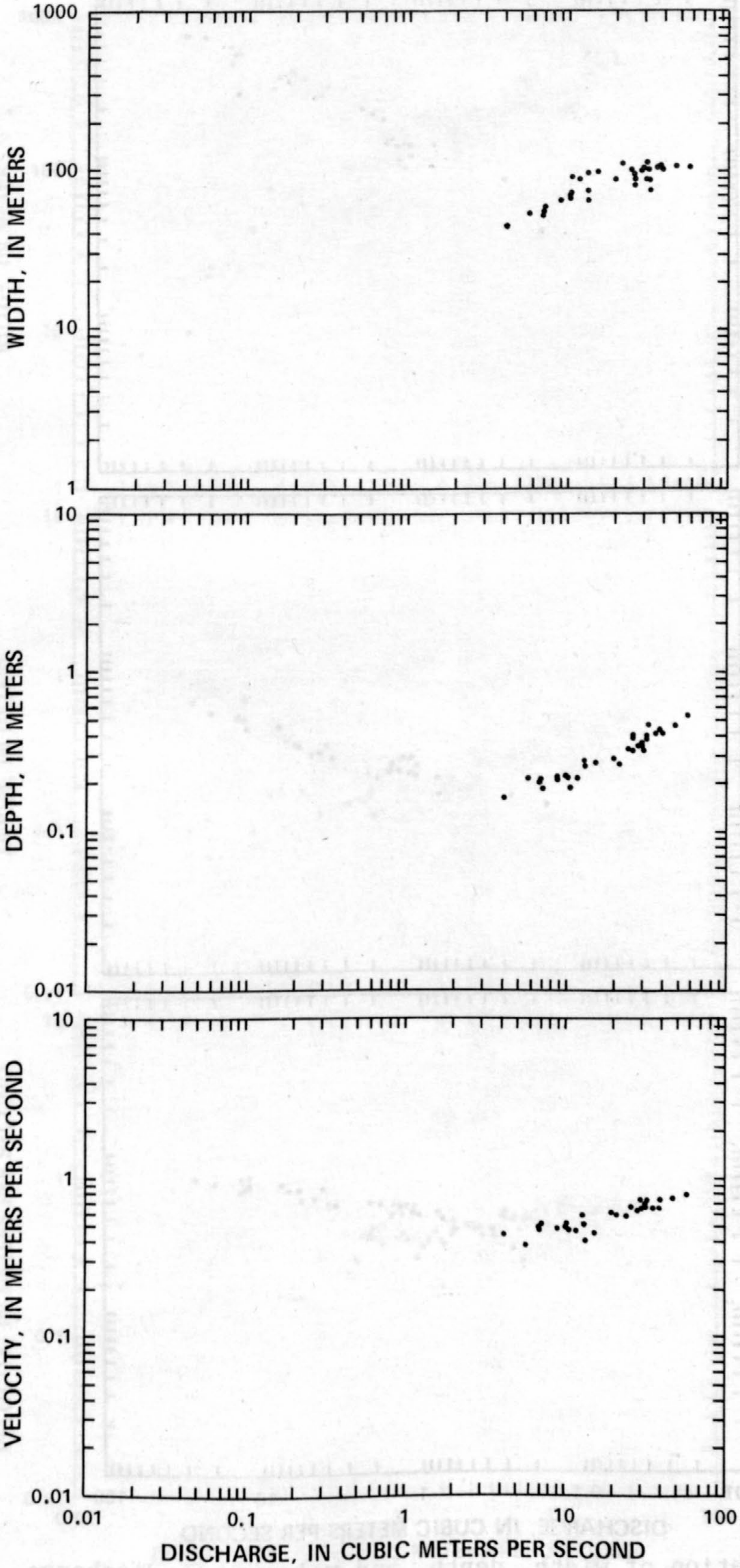

Figure 7.--Relation of width, depth, and velocity to discharge, north channel of the Platte River 90 meters downstream from gage near Overton, Nebraska, post-1969 record.

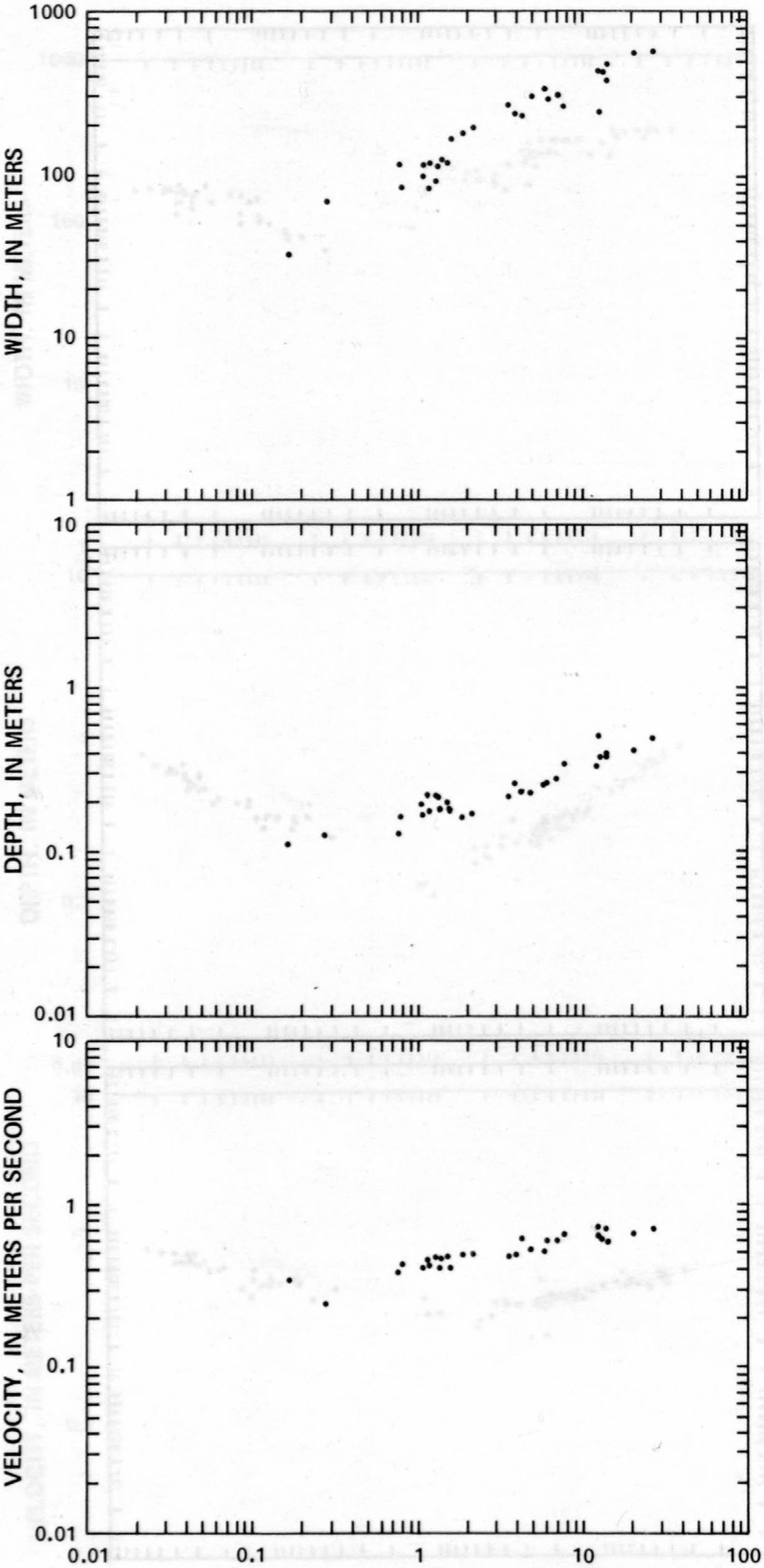

Figure 8.--Relation of width, depth, and velocity to discharge, Platte River 30 meters downstream from gage near Cozad, Nebraska, for the period of record.

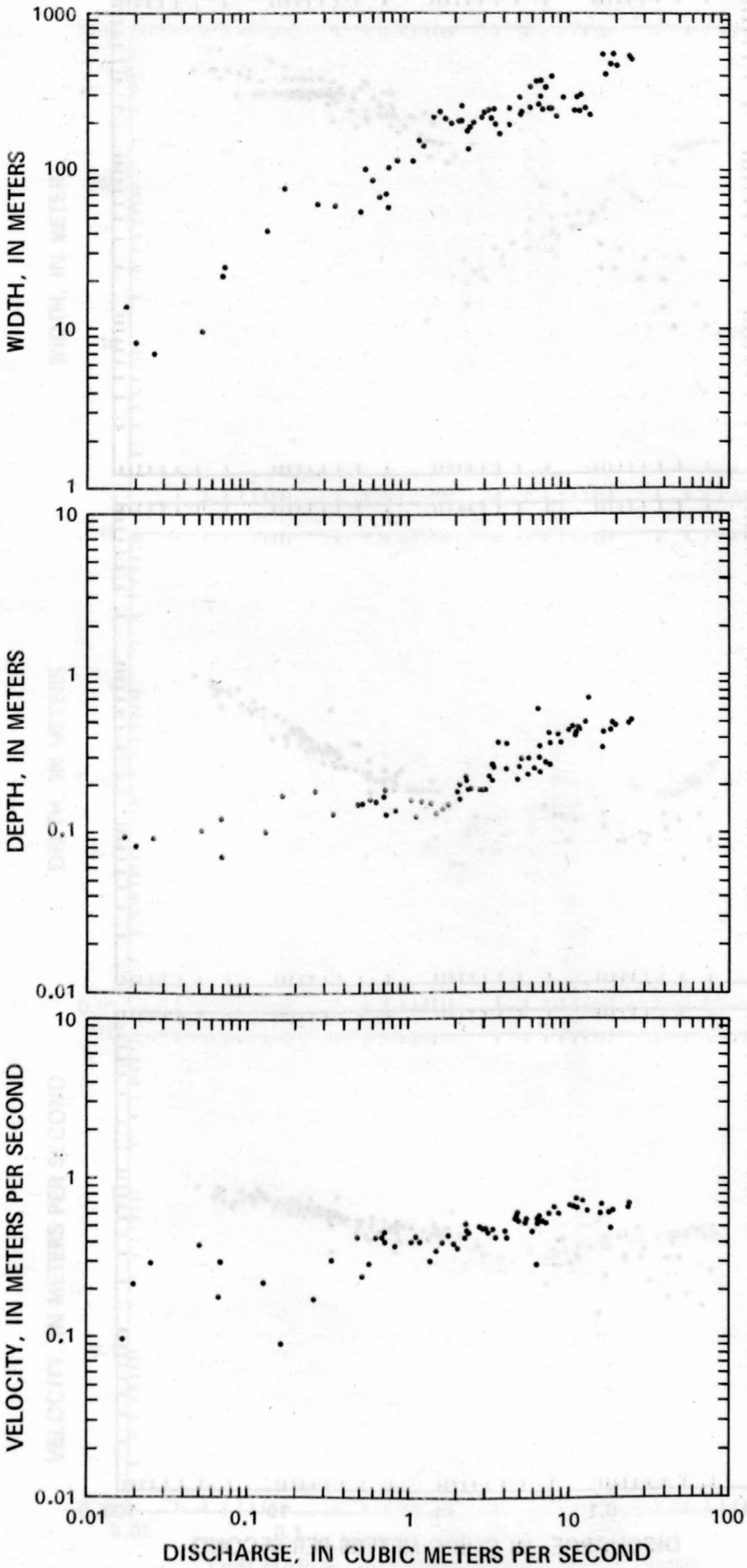

Figure 9.--Relation of width, depth, and velocity to discharge, Platte River 60 meters downstream from gage near Cozad, Nebraska, for the period of record.

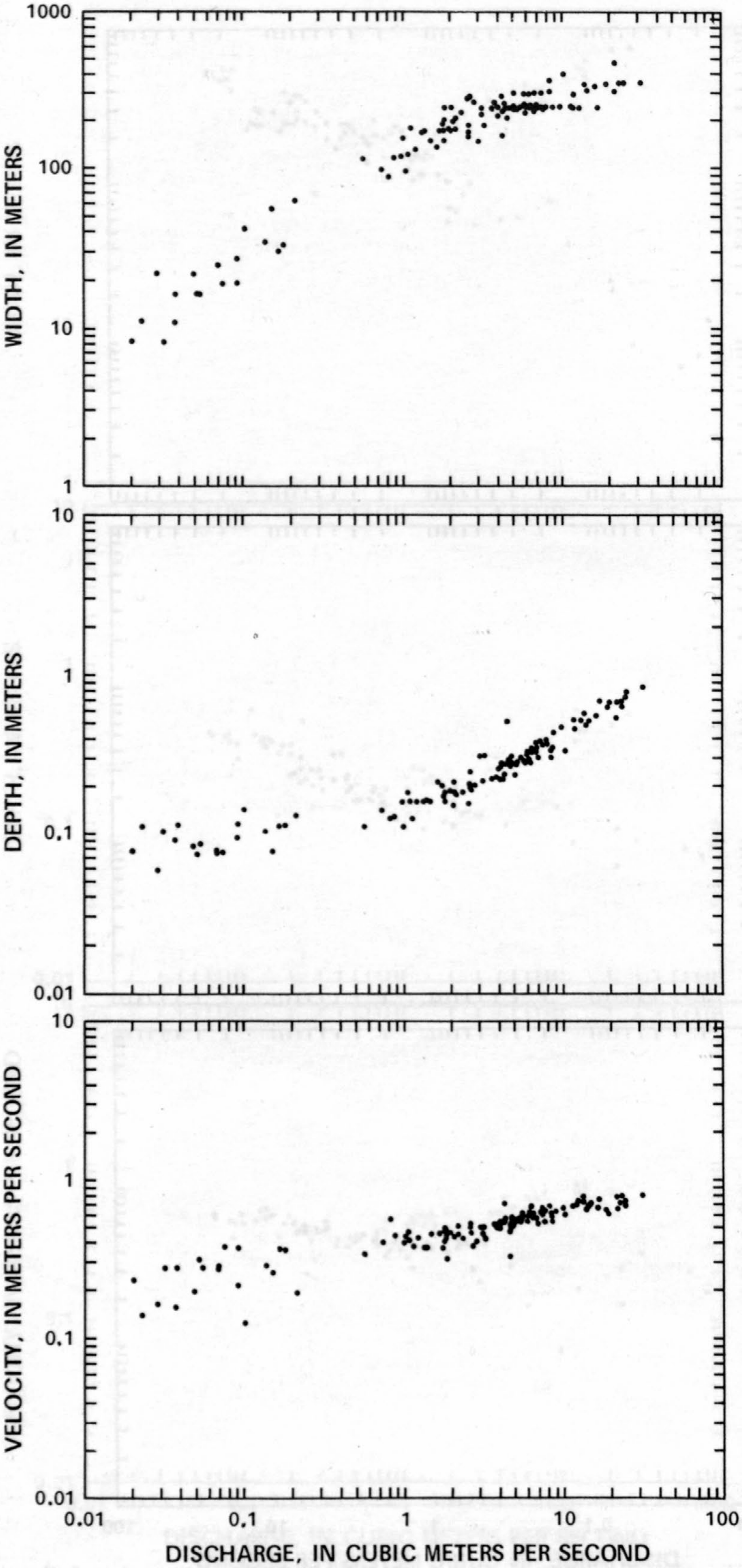

Figure 10.--Relation of width, depth, and velocity to discharge, Platte River 120 meters downstream from gage near Cozad, Nebraska, for the period of record.

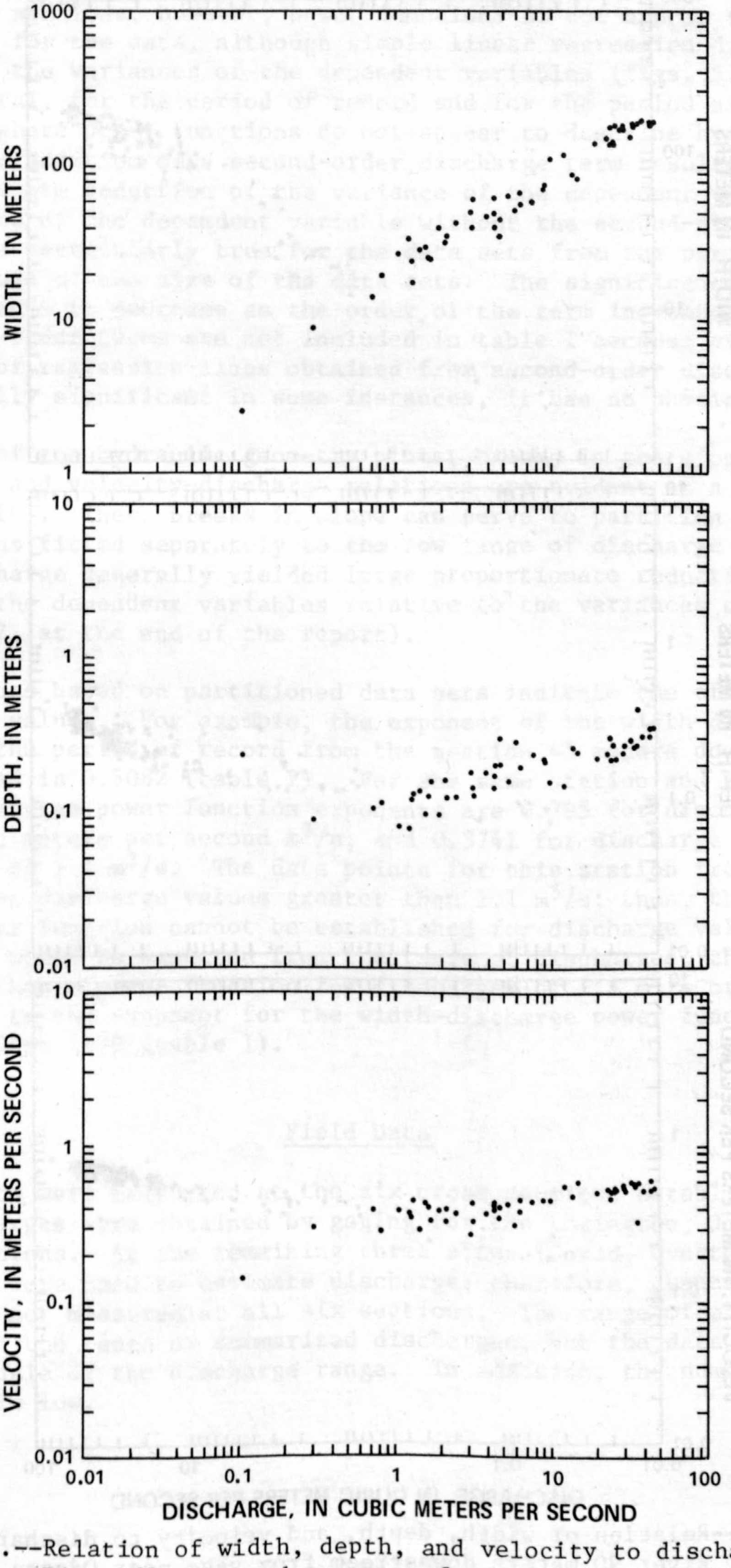

Figure 11.--Relation of width, depth, and velocity to discharge, Platte River 60 meters downstream from gage near Odessa, Nebraska, for the period of record.

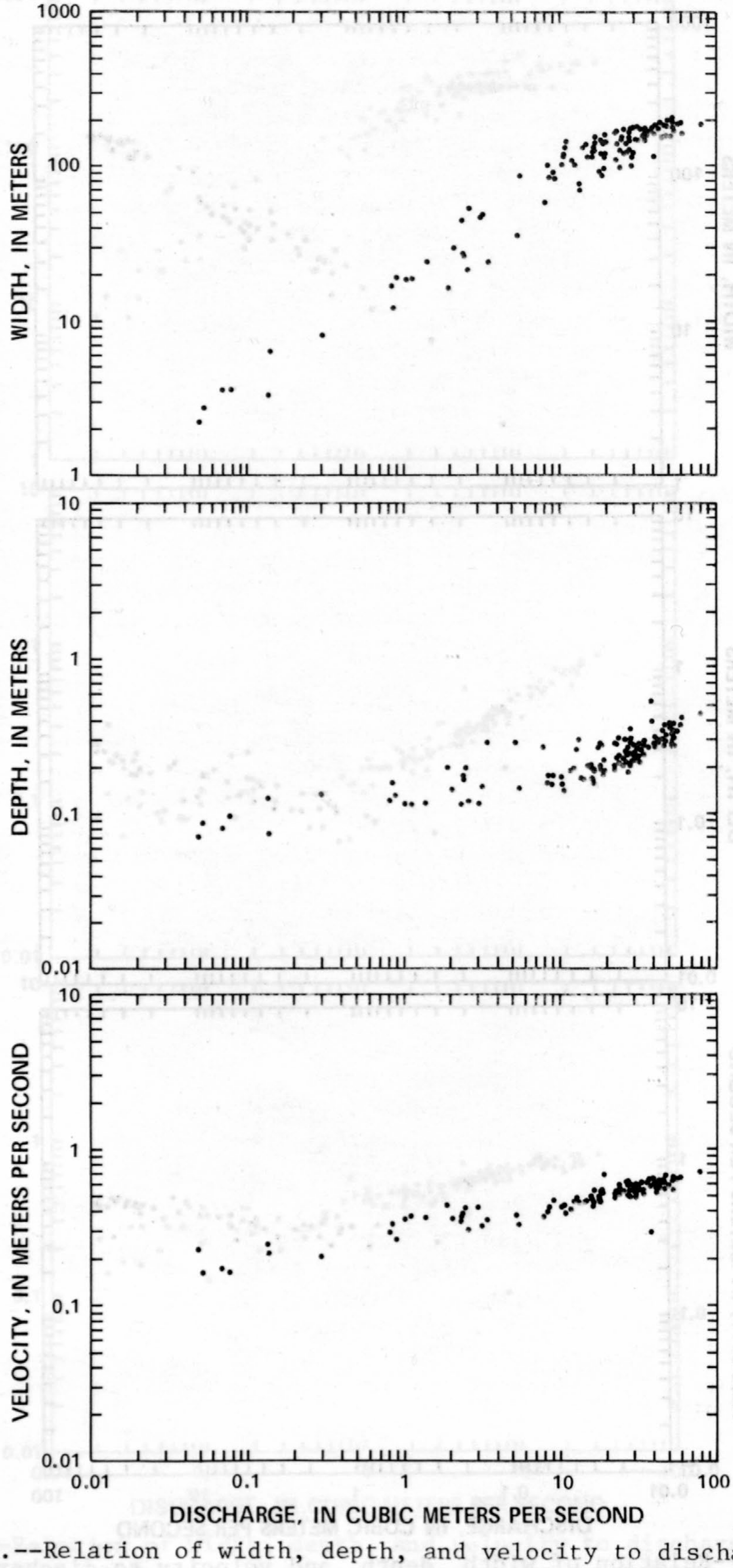

Figure 12.--Relation of width, depth, and velocity to discharge, Platte River 90 meters downstream from gage near Odessa, Nebraska, for the period of record.

For some sections, however, power functions do not appear to be the correct model for the data, although simple linear regression did reduce significantly the variances of the dependent variables (figs. 5, 6, 7, 9, and 10). In general, for the period of record and for the period since 1969 for the sections where power functions do not appear to describe hydraulic-geometry relations, the addition of a second-order discharge term results in a significant proportionate reduction of the variance of the dependent variable relative to the variance of the dependent variable without the second-order discharge term. This is particularly true for the data sets from the period of record, probably because of the size of the data sets. The significance of higher-order terms tends to decrease as the order of the term increases. Statistics on the second-order terms are not included in table 1 because although the improved fit of regression lines obtained from second-order discharge terms is statistically significant in some instances, it has no physical meaning.

On many of the hydraulic geometry plots, breaks in the slopes of the width, depth, and velocity-discharge relations are evident at a certain discharge (fig. 10). These breaks in slope can serve to partition the data sets. Power functions fitted separately to the low range of discharge and to the high range of discharge generally yielded large proportionate reductions in the variances of the dependent variables relative to the variances of the variables alone (table 2, at the end of the report).

Regressions based on partitioned data sets indicate the effect of the range of data values. For example, the exponent of the width-discharge power function for the period of record from the section 45 meters downstream of the gage near Cozad is 0.5082 (table 1). For the same station and period of record, the width-discharge power function exponents are 0.795 for discharge values less then 1.1 cubic meters per second m^3/s, and 0.3741 for discharge values greater than or equal to 1.1 m^3/s. The data points for this station from 1970 to 1979 almost all have discharge values greater than 1.1 m^3/s; thus, the width-discharge power function cannot be established for discharge values less than 1.1 m^3/s. As would be expected from the range of discharges, the exponent for the width-discharge power function for discharges of 1.1 m^3/s or greater is quite similar to the exponent for the width-discharge power function for all data from 1970 to 1979 (table 1).

Field Data

Field data were collected at the six cross sections established for this study. Discharges were obtained by gaging for the Lexington, Johnson-2, and Elm Creek sections. At the remaining three sites (Cozad, Overton, and Odessa), rating curves were used to estimate discharge; therefore, channel depth and velocity were not measured at all six sections. The range of observed discharges is larger than the range of summarized discharges, but the data are deficient toward the middle of the discharge range. In addition, the number of discharge observations is low.

Width-discharge relations were plotted for the six field sections. At the Cozad, Lexington, and Johnson-2 sections, sufficient data were collected to permit plotting of depth-discharge and velocity-discharge relations also. Plots of some of the field data are presented as figures 13 to 15.

The number of field data points is too small to be significant, but the figures suggest that, in some instances, power functions are not appropriate. Plots of the field data indicate that the power-function model adequately describes the velocity-discharge relation at Cozad, the width-, depth-, and velocity-discharge relations at the Johnson-2 section, and the width-discharge relation at the Odessa section. Power functions apparently describe all three hydraulic-geometry relations for the section near Lexington. There is a suggestion of a complex relation between width and discharge, and between depth and discharge, but the few data points do not define the relation well enough to make meaningful inferences about its nature. The width- and depth-discharge relations at Cozad do not appear to follow a single power-function model.

Complex At-a-Station Hydraulic Geometry

Hydraulic-geometry relations for the Platte River are not described adequately by power functions in all instances. This complex hydraulic geometry is not peculiar to the Platte River. Wolman (1955) stated of Brandywine Creek, in Pennsylvania, "There is a suggestion in some of the data * * * that the depth-discharge and velocity-discharge curves may actually plot as curved rather than straight lines on log-log paper. Such a relationship of the at-a-station curves is not uncommon." Richards (1973) noted that non-linear changes of depth and velocity with discharge may result from non-linear changes of roughness with discharge. Richards (1976) also proposed that channel cross-section shape can produce breaks or discontinuities in the width-discharge relationship. Williams (1978a) showed that all three hydraulic-geometry exponents vary with discharge for the Humbolt River in Nevada.

At least three causes may explain the complex hydraulic geometry in the study area. The first explanation may lie in the range of discharges observed. At some sections only a small range of discharges was observed (fig. 7). The scatter of the predicted variables (width, depth, and velocity) may be sufficient to make the relation appear to be complex. This explanation does not apply to all sections, because at some sections at which the range of observed discharges is low, there is little scatter of the data (figs. 5 and 7); and because at some sections at which the range of observed discharges is high, the relations are nevertheless complex (figs. 10 and 12). Conversely, it may be that changes in the rates of adjustment of width, depth, and velocity with increasing discharge were not observed because of the small range of observed discharges. Secondly, the velocity-discharge and depth-discharge relationships may be complex because of changes in roughness (Richards, 1973). In addition to changes in roughness associated with dunes and other small-scale bed forms, changes in roughness may occur as vegetated or unvegetated larger bed forms, such as macroforms (Crowley, 1981), are inundated. Finally, and for this study, most importantly, channel shape may preclude a constant rate of water-depth and water-width increase. Near Cozad, for example (fig. 16), the banks

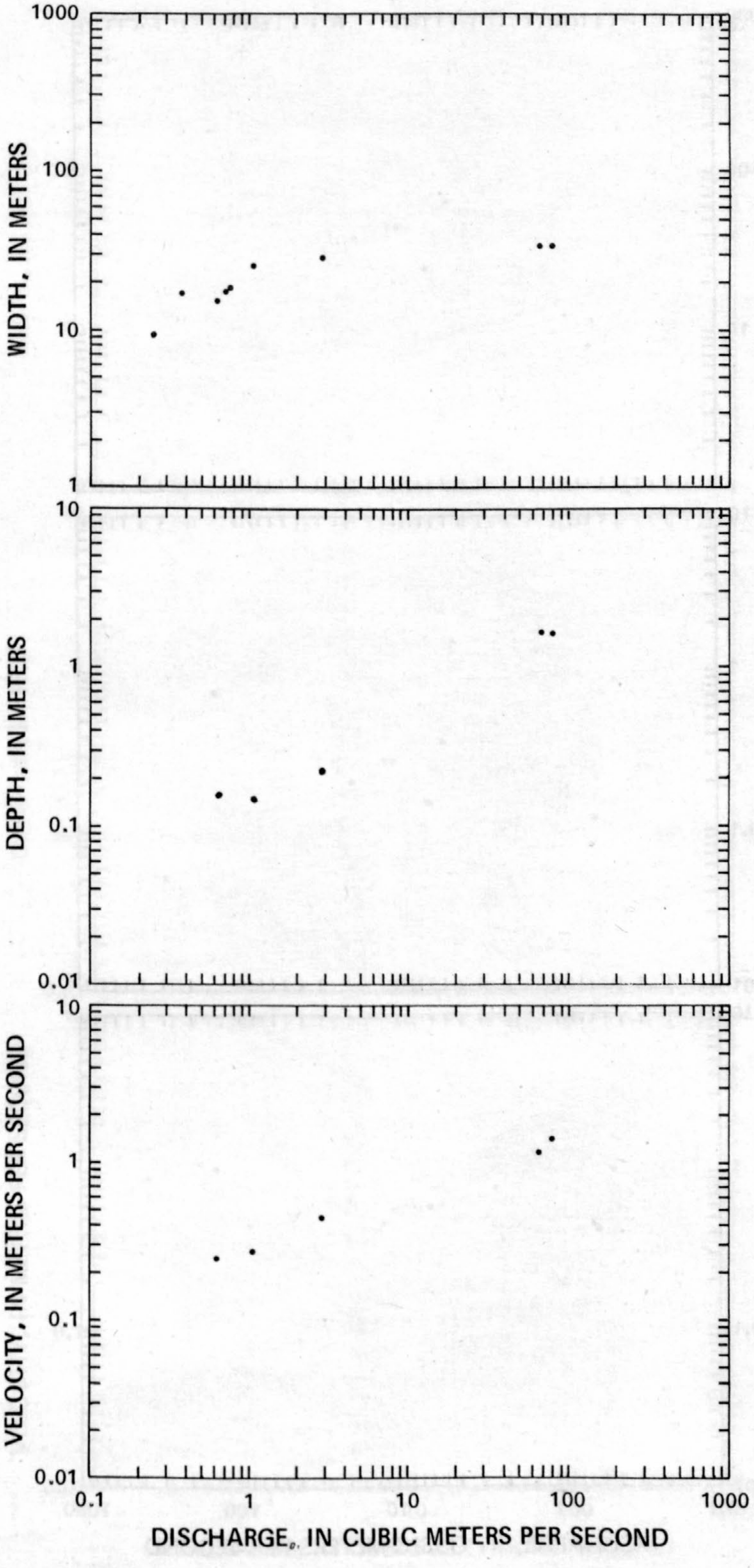

Figure 13.--Relation of width, depth, and velocity to discharge, Platte River near Cozad, Nebraska.

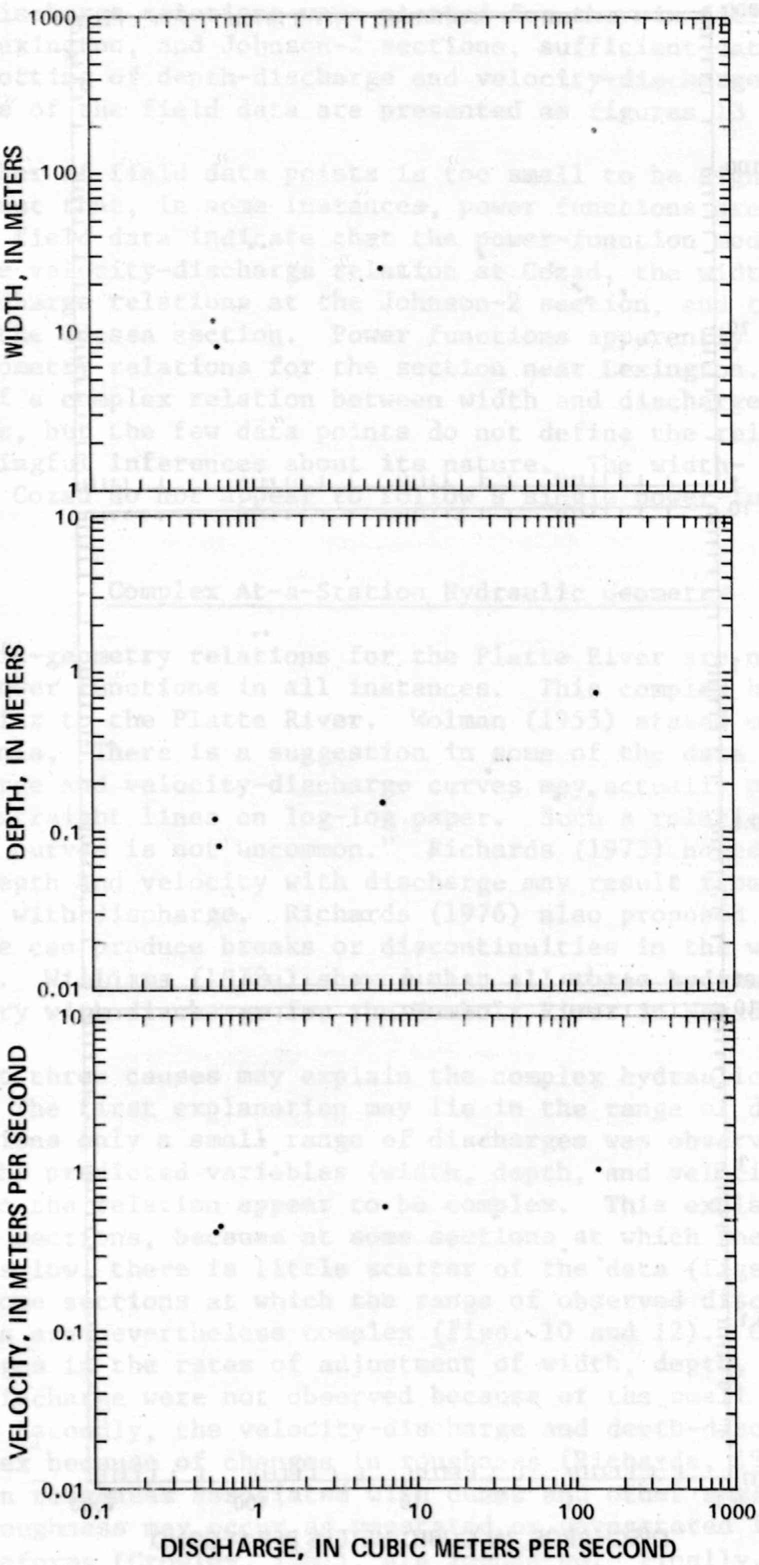

Figure 14.--Relation of width, depth, and velocity to discharge, Platte River near Lexington, Nebraska.

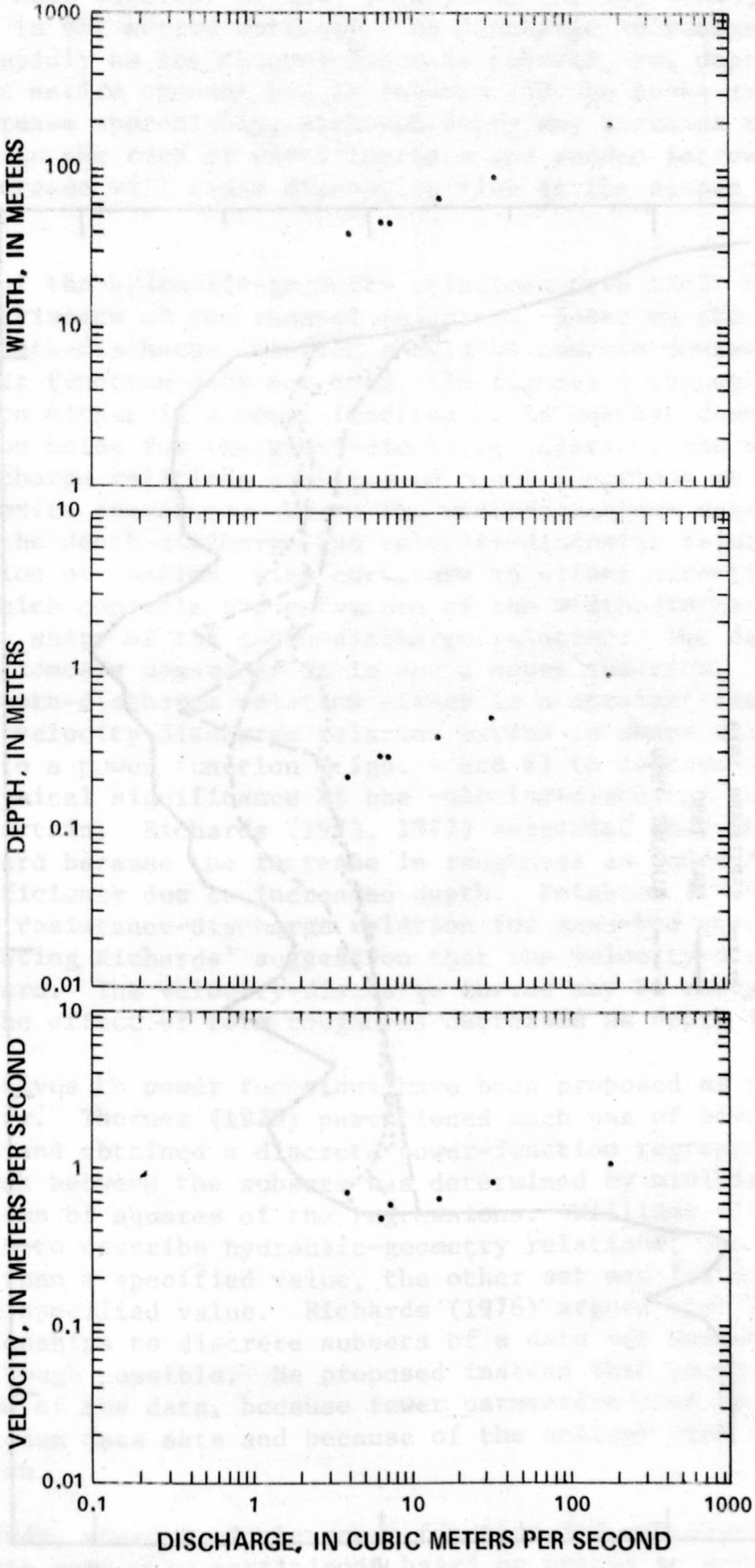

Figure 15.--Relation of width, depth, and velocity to discharge, Platte River downstream from Johnson-2 Return near Lexington, Nebraska.

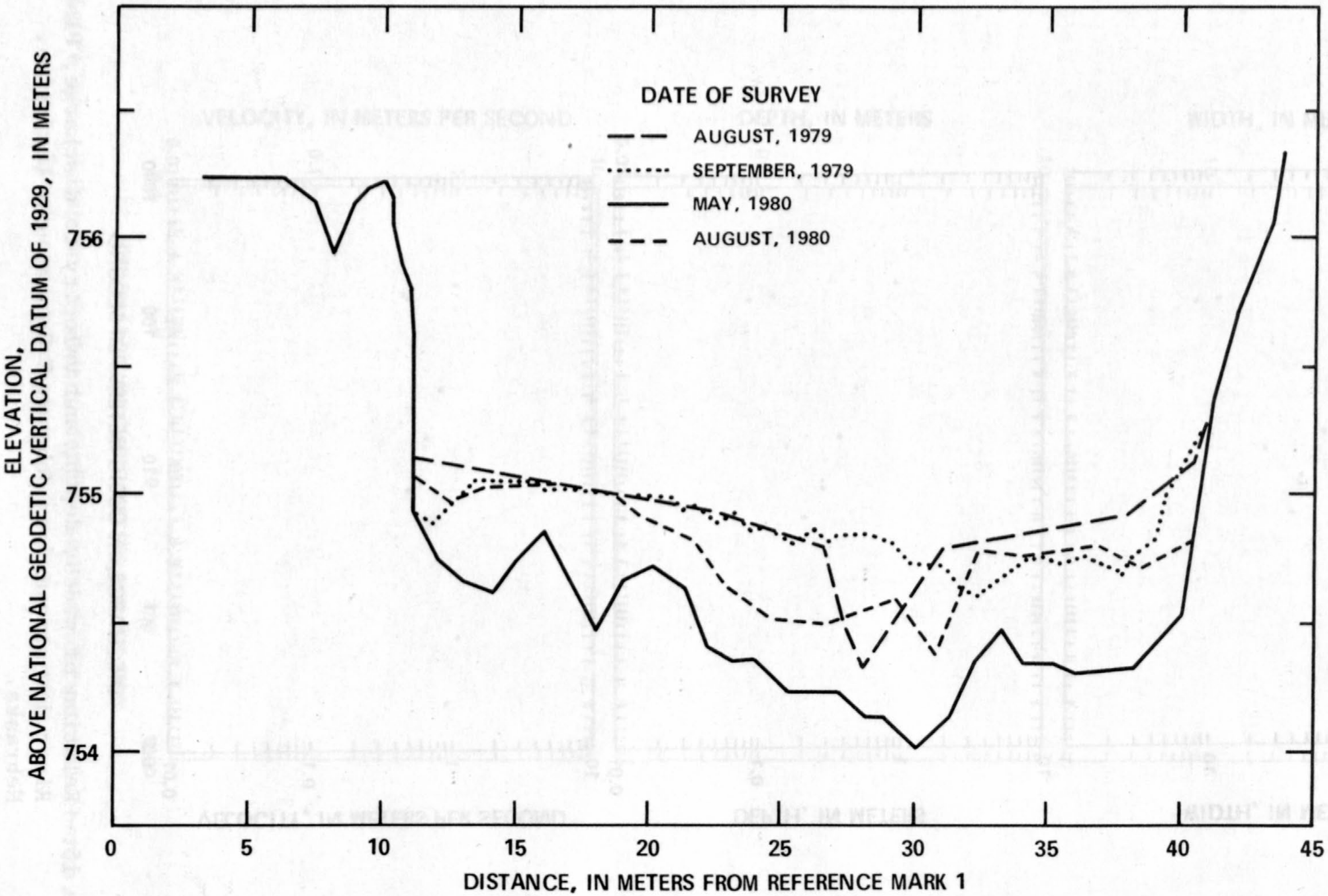

Figure 16.--Cross-section surveys of the Platte River at the Cozad field section.

are cohesive and near vertical at many locations. At low flows, the channel bottom generally is not wetted entirely. As discharge increases, width increases very rapidly as the channel floor is covered, but depth increases slowly. Once the entire channel bed is covered and the banks are reached, width cannot increase appreciably, although depth may increase rapidly. Such sudden decreases in the rate of width increase and sudden increases in the rate of depth increase will cause discontinuities in the slopes of hydraulic-geometry plots.

The shapes of the hydraulic-geometry relations have their bases in the physical characteristics of the channel and flow. Based on the channel shape (fig. 16), the width-discharge relation should be concave downward for sections at which the power function does not hold. In figures 4 through 15 the width-discharge relation either is a power function or is concave downward. Where the power function holds for the width-discharge relation, the depth-discharge and velocity-discharge relations both may be power functions or both may be complex with opposite curvature. Where the width-discharge relation is not a power function, the depth-discharge and velocity-discharge relations each may be a power function or complex, with curvature in either direction. The channel shape, which controls the curvature of the width-discharge relation, also controls the shape of the depth-discharge relation: The depth-discharge relation must be concave upward if it is not a power function. In figures 4 through 15 the depth-discharge relation either is a straight line or it is a concave up. The velocity-discharge relation varies in shape from concave up (figs. 5 and 7) to a power function (figs. 4 and 8) to concave down (figs. 9 and 10). The physical significance of the velocity-discharge curve shapes is different to ascertain. Richards (1973, 1977) suggested that the curves should be concave downward because the increase in roughness as dunes form offsets any increased efficiency due to increased depth. Knighton (1979) cited data showing that the resistance-discharge relation for sand-bed streams is concave upward, corroborating Richards' suggestion that the velocity-discharge curve is concave downward. The velocity-discharge curves may be concave upward at sections where the effect of form roughness decreases as depth increases.

Two alternatives to power functions have been proposed as models for hydraulic geometry. Thornes (1970) partitioned each set of bivariate data into two subsets and obtained a discrete power-function regression for each subset. The break between the subsets was determined by minimizing the combined error sums of squares of the regressions. Williams (1978a) used two sets of exponents to describe hydraulic-geometry relations; one set was for discharges less than a specified value, the other set was for discharges greater than the specified value. Richards (1976) argued that fitting of power-law relationships to discrete subsets of a data set was unnecessarily complicated, although possible. He proposed instead that polynomials be fit to the logarithms of the data, because fewer parameters need to be estimated than for partitioned data sets and because of the analogy with the power-function situation.

For this study, where a single power function did not adequately describe the relation, data sets were partitioned based on breaks in slope of the hydraulic geometry plots. Separate power functions were then fit to the different discharge ranges. Although cumbersome to apply, discrete power functions accurately describe the changes in hydraulic variables with increasing discharge. Polynomials compromise the relations that would be obtained from the partitioned data sets and do not allow the points to be identified at which the width-, depth-, and velocity-discharge relations change.

Meaning of the Exponents

Exponents of the first-order equations represent the rates of change of the dependent variables with changing discharge. Rewritten as power functions, for example:

$$(\log W) = \log a + b(\log Q) \;;$$

first derivatives of the equations are exponents of the first-order equations. Thus, exponents of the power functions are slopes of the first-order equations. Because of continuity, the first derivatives or exponents of the width-, depth-, and velocity-discharge relationships will sum to one.

The question then is: What do the slopes of the hydraulic-geometry relations mean? The slopes represent the rates of change of width, depth, and velocity with changing discharge. Comparison of numerical values of the exponent indicates which variables show greater rates of change at which sections. However, numerical comparison of the exponents does not provide information about the meaning of the exponents themselves or their implications about channel conditions.

The b-f-m diagram allows the similarity or difference in responses of width, depth, and velocity to changing discharge to be interpreted based on physical considerations (Rhodes, 1977). The use of the b-f-m diagram is possible only when the exponents sum to one. For power functions, this constraint presents no problems because the exponents sum to one; however, in some instances individual exponent values are either negative numbers or greater than one, making plotting on the b-f-m diagram impossible. Expansion of the diagram to include negative values and values greater than one would be possible, but would make interpretation of the exponents more difficult. Exponents for the first-order equations for entire data sets from table 1 for the periods of record and since 1969 are presented graphically on a b-f-m diagram (fig. 17). Although these exponents may not in all instances represent the correct model, they will serve as a starting point from which to examine the b-f-m diagram.

Hydraulic and Morphologic Information from the b-f-m Diagram

The b-f-m diagram not only allows hydraulic-geometry exponents to be presented graphically, but also allows inferences to be made about hydraulic and morphologic parameters. Hydraulic-geometry exponents for the summarized data (for the period of record and since 1969) plot in six of the ten fields of the b-f-m diagram.

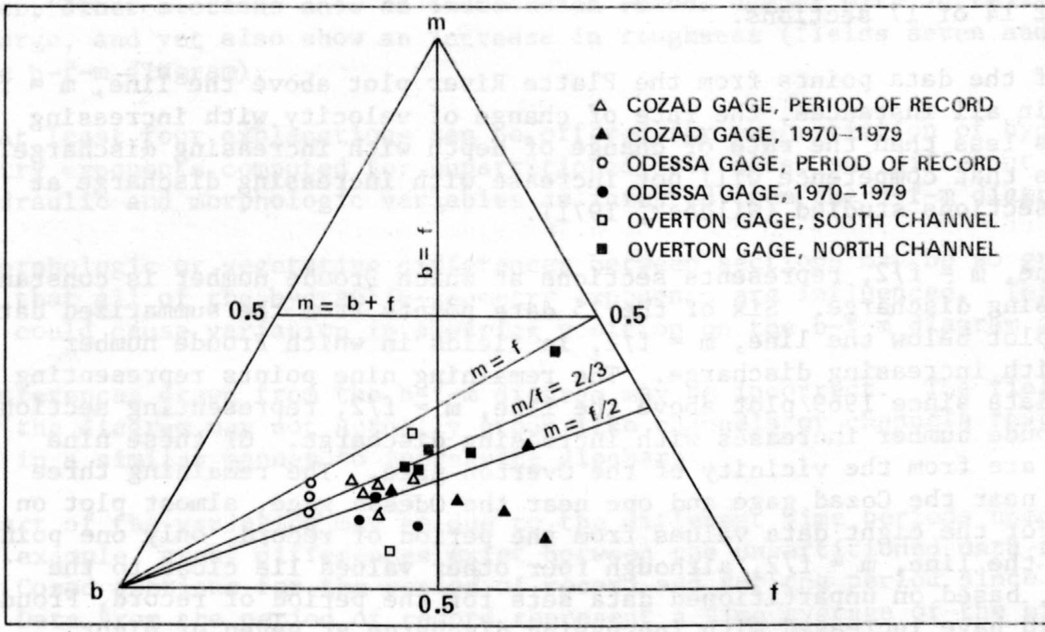

Figure 17.--B-f-m diagram showing plotting positions of current at-a-station hydraulic-geometry exponents and exponents from the period of record.

Only six of the 23 data points plot to the right of the line, b = f; at most sections the width-depth ratio increases with increasing discharge. Four of the six points to the right of the b = f line represent sections in the vicinity of the Cozad gage on the north channel of the Platte River. This reach of the river is deeper relative to width than any other river reach within the study area. The remaining points to the right of the line b = f are from the north channel near Overton. All of the points from the period of record, including those from the north channel near Cozad, plot to the left of the line, b = f.

None of the data points plot above the line, m = 0.50. Rapid velocity increases are not likely considering the shallow depth of the river and the increased wetted perimeter as discharge increases. In addition, vegetation present on many of the bars will increase roughness as it is inundated, further decreasing the possibility of rapid velocity increase.

Six data points plot above the line, m/f = 2/3, which represents the ratio $S^{\frac{1}{2}}/n$. Points above this line should represent sections at which roughness decreases with increasing discharge. Of these six points, one near Cozad and two near Odessa represent the entire period of record, and the other three represent sections near Overton. Thus, roughness apparently increased with increasing discharge at almost half of the sections for the period of record. However, for the period since 1969, plotting positions for exponents from unpartitioned data sets indicate that roughness increased with increasing discharge at 14 of 17 sections.

None of the data points from the Platte River plot above the line, m = f. Therefore, in all instances, the rate of change of velocity with increasing discharge is less than the rate of change of depth with increasing discharge. This implies that competence will not increase with increasing discharge at any of the sections studied (Wilcock, 1971).

The line, m = f/2, represents sections at which Froude number is constant with increasing discharge. Six of the 15 data points from the summarized data since 1969 plot below the line, m = f/2, in fields in which Froude number decreases with increasing discharge. The remaining nine points representing summarized data since 1969 plot above the line, m = f/2, representing sections at which Froude number increases with increasing discharge. Of these nine points, six are from the vicinity of the Overton gage. The remaining three points, two near the Cozad gage and one near the Odessa gage, almost plot on the line. For the eight data values from the period of record, only one point plots below the line, m = f/2, although four other values lie close to the line. Thus, based on unpartitioned data sets for the period of record, Froude number should have increased with increasing discharge at seven of eight sections.

The b-f-m diagram can be used to interpret, in a general sense, the way morphologic and hydraulic parameters adjust to increasing discharge. Exponent values from hydraulic-geometry relations from summarized data for unpartitioned data sets for the period of record plot only in fields five, seven, and nine of the b-f-m diagram. Thus, for these sections, the width-depth ratio increases with increasing discharge; the velocity-area ratio decreases with increasing discharge; Froude number generally increases with increasing discharge; and the slope-roughness ratio generally decreases, presumably indicating an increase in roughness with increasing discharge. Exponent values for the hydraulic geometry computed from summarized data for unpartitioned data sets since 1969 plot in fields five through ten of the b-f-m diagram. For these sections, the width-depth ratio may increase or decrease; in general, it increases. The velocity-area ratio decreased in all instances. In general, both Froude number and roughness increased with increasing discharge.

The meaning or significance of the fields of the b-f-m diagram is relatively clear; the meaning of the variation displayed by the hydraulic-geometry exponents and hydraulic variables is unclear. Note, for example, the inferred differences in roughness among the Cozad sections or the Overton sections, and the differences between the Cozad and Overton sections. Changes in bedforms with increasing discharge, such as from dunes to plane bed with transport, may cause roughness to decrease. The question of why this should occur at only a few sections remains. The different changes of the width-depth ratio can be understood, based on the morphology of the cross sections. Variations of m = f/2, indicative of the Froude number, also are less readily understandable. An inferred decrease in roughness may account for some of the sections showing an increase in Froude number with increasing discharge. However, other sections show an increase in Froude number with increasing discharge, and yet also show an increase in roughness (fields seven and eight of the b-f-m diagram).

At least four explanations can be offered for the variation of hydraulic-geometry exponents computed for unpartitioned data sets, and different reactions of hydraulic and morphologic variables as inferred from the b-f-m diagrams.

1. Morphologic or vegetative differences between sections may be so great that all of the hydraulic-geometry exponents are influenced. This could cause variation in plotting position on the b-f-m diagram also.

2. Inferences drawn from the b-f-m diagram may be incorrect. The fields of the diagram may not actually group like channels or channels that respond in a similar manner to increasing discharge.

3. Part of the variation may be due to the different time periods used. For example, great differences exist between the unpartitioned data from the Cozad sections for the period of record and for the period since 1969. Data from the period of record represent a time average of the hydraulic-geometry exponents; whereas, the data since 1969 presumably represent a more homogeneous period, due to the shorter time period. Changes in the plotting positions of the exponents then may show changes in the response of the river, both morphologically and hydraulically, with time.

4. Part or all of the variation of exponents and plotting positions may be due to the assumption in this section that single power functions are the appropriate model for hydraulic geometry.

Two of these four explanations for the variation in exponents, systematic variation (3) and analytic error (4), will be examined in more detail in the next section of this chapter.

Systematic Variation and Analytical Error

Changes in channel morphology should influence the rates of change of width, depth, and velocity with increasing discharge. As a result, the hydraulic geometry computed for short time intervals of a period during which a channel section was undergoing substantial change should show systematic variation with time. Unfortunately, long-term records either are not available or are unsuitable for use in hydraulic-geometry computations. In most instances, early discharge measurements were made near bridges. Bridge sections may have been unaltered near the turn of the century, but they were increasingly filled to facilitate bridge construction. Riprap generally has been placed on the banks immediately upstream and downstream of the bridge section. These factors tend to establish bridge sections as highly modified, almost rigid boundary sections, incapable of significant morphologic adjustment to changes in flow.

For this analysis, each location grouping of discharge measurements was further divided into time-period groups, the ends of which were coincident with the years of aerial photography. The equations of hydraulic geometry were computed for the individual time groupings at each location. Comparison of exponents and coefficients can be made between locations or between time periods, or both, if the limitation imposed by the limited ranges of data is recognized.

The hydraulic-geometry exponents for the different time groupings are listed in table 1. The success of time and location groupings varied from gage to gage. Five locations were separable from the Cozad measurements. At three of these locations sufficient records are available to make three time groupings. A series of gage location changes at Overton made the records difficult to compare directly with those from Cozad and Odessa. For most locations, records are available for the entire channel for two time periods, but starting in 1969 each channel was gaged independently. The records from Odessa allow three locations, each with three time periods, to be established.

In general, for the unpartitioned data the width exponent at each location for the Cozad and Odessa sites decreased with time. However, there are instances when the width exponent increased with time. The depth and velocity exponents for Cozad (fig. 18) and Overton generally do not show trends, either among stations or at a given station with time. This implies that depth and velocity adjust in different ways at different times. At Odessa depth appears to be increasing, while velocity is decreasing or remaining constant with time (fig. 19).

Interpretation of the changes in width exponents for the Overton section are not made easily. Width exponents decreased at three of the four locations for which records are available for the period prior to 1963 or for the period 1964 to 1969. At the fourth station, the width exponent increases. Records for the post-1969 period are available only for individual channels. In all cases, however, the individual channels have width exponents smaller than those computed for earlier periods.

Plots of the hydraulic-geometry exponents for unpartitioned data on b-f-m diagrams provide visual interpretations of the changes in hydraulic geometry with time (figs. 18 and 19). These plots show, as discussed above, a general decrease in the rate of width increase with discharge and, for Odessa, an increase in the rate of depth increase with discharge. The implication of the width change is that channel width is not as great for large discharges as it once was, a point borne out by the examination of aerial photographs. The hydraulic-geometry changes at Odessa indicate that the channel should be incising, as depth is increasing simultaneously with the width decrease. This conforms to Williams' (1978b) observed decrease in bed elevation at Odessa.

The apparent change in hydraulic geometry exponents with time (figs. 18 and 19) may result from changes in the range of discharges represented in each of the different time intervals, rather than from significant changes in the

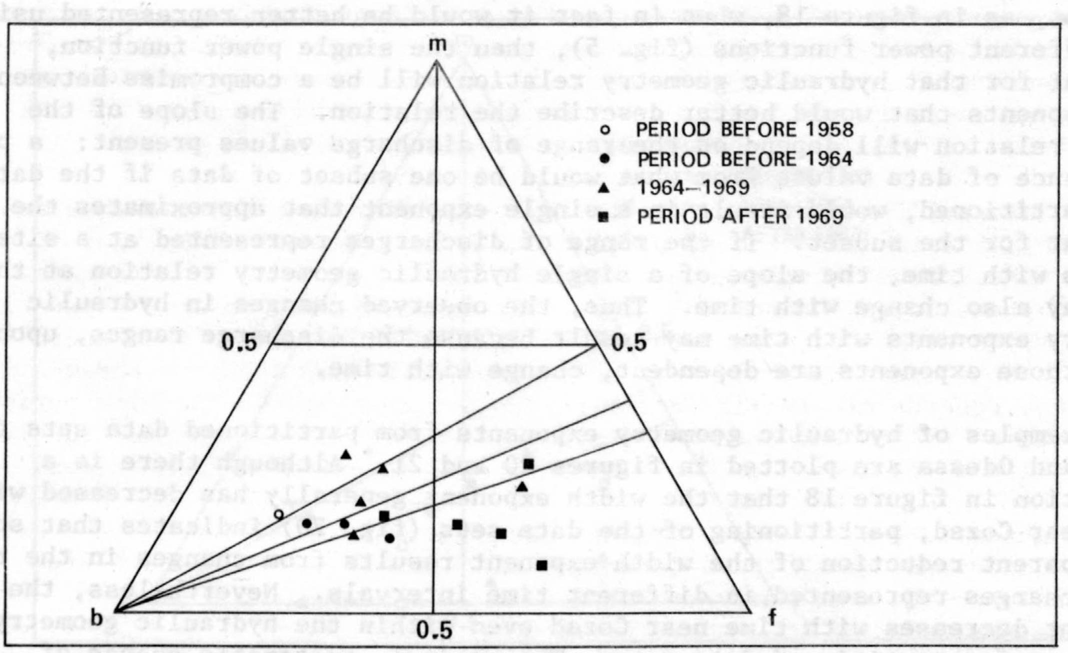

Figure 18.--B-f-m diagram showing changes in hydraulic-geometry exponents with time. Data from the north channel of the Platte River in the vicinity of the gage near Cozad, Nebraska.

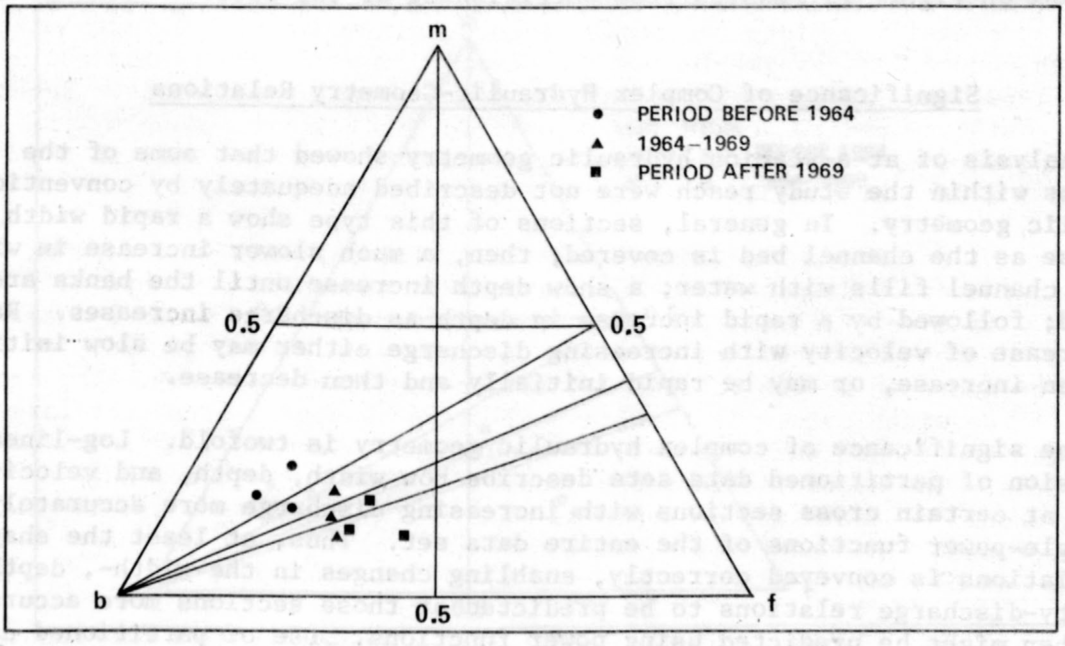

Figure 19.--B-f-m diagram showing changes in hydraulic-geometry exponents with time. Data from the Platte River in the vicinity of the gage near Odessa, Nebraska.

width-, depth-, and velocity-discharge relations themselves. If a hydraulic geometry relation at a site is assumed to be represented by a single power function, as in figure 18, when in fact it would be better represented using two different power functions (fig. 5), then the single power function, exponent for that hydraulic geometry relation will be a compromise between the two exponents that would better describe the relation. The slope of the single relation will depend on the range of discharge values present: a preponderance of data values from what would be one subset of data if the data were partitioned, would result in a single exponent that approximates the exponent for the subset. If the range of discharges represented at a site changes with time, the slope of a single hydraulic geometry relation at that site may also change with time. Thus, the observed changes in hydraulic geometry exponents with time may result because the discharge ranges, upon which those exponents are dependent, change with time.

Examples of hydraulic geometry exponents from partitioned data sets from Cozad and Odessa are plotted in figures 20 and 21. Although there is a suggestion in figure 18 that the width exponent generally has decreased with time near Cozad, partitioning of the data sets (fig. 20) indicates that some of the apparent reduction of the width exponent results from changes in the range of discharges represented in different time intervals. Nevertheless, the width exponent decreases with time near Cozad even within the hydraulic geometry relations for partitioned data sets. The gradual, systematic change of exponents through time near Odessa (fig. 19) does not occur when the data sets are partitioned (fig. 21). Although fewer points are plotted on figure 21 than on figure 19 because of small data sets, it is apparent that there is not change in exponent values through time. Rather, the change in plotting positions on figure 21 results from partitioning of the data.

Significance of Complex Hydraulic-Geometry Relations

Analysis of at-a-station hydraulic geometry showed that some of the sections within the study reach were not described adequately by conventional hydraulic geometry. In general, sections of this type show a rapid width increase as the channel bed is covered; then, a much slower increase in width as the channel fills with water; a show depth increase until the banks are reached; followed by a rapid increase in depth as discharge increases. Rate of increase of velocity with increasing discharge either may be slow initially and then increase, or may be rapid initially and then decrease.

The significance of complex hydraulic geometry is twofold. Log-linear regression of partitioned data sets describe how width, depth, and velocity change at certain cross sections with increasing discharge more accurately than do single-power functions of the entire data set. Thus, at least the shape of the relations is conveyed correctly, enabling changes in the width-, depth-, or velocity-discharge relations to be predicted at those sections more accurately than they might be predicted using power functions. Use of partitioned data sets in hydraulic-geometry equations, where appropriate, should reduce or eliminate autocorrelation of the residuals from the single linear relation, resulting in a more accurate estimation of standard errors.

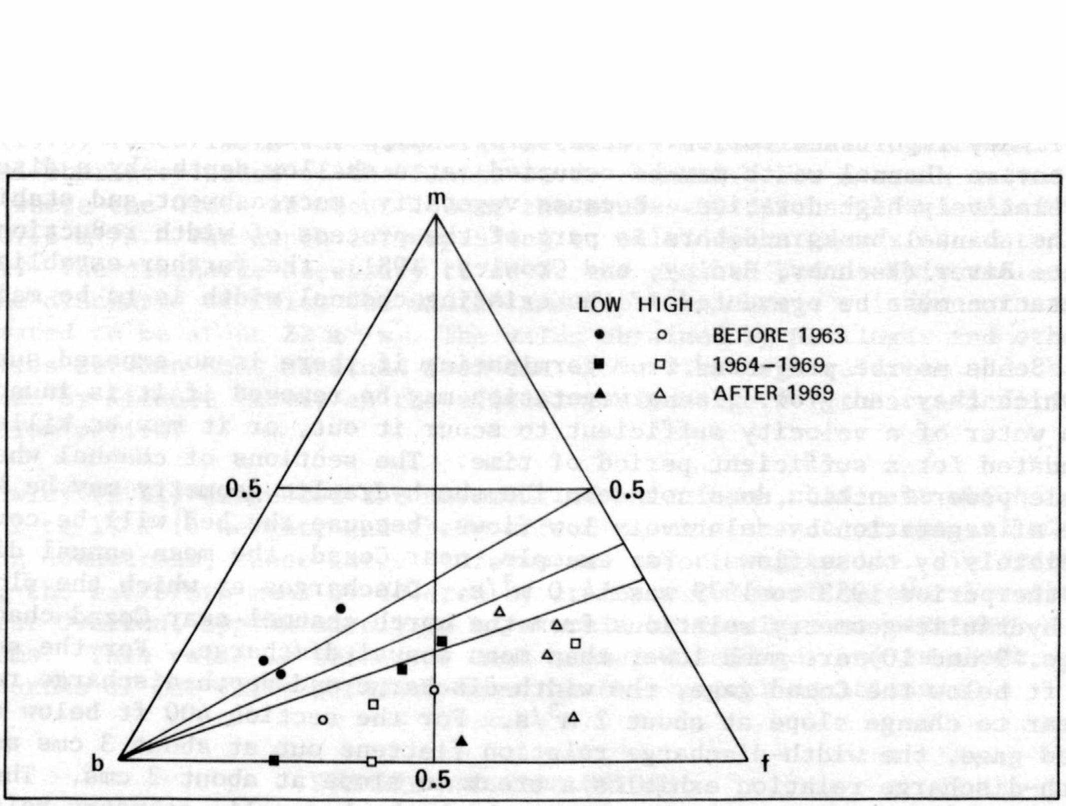

Figure 20.--B-f-m diagram showing changes in hydraulic-geometry exponents with time. Data from the north channel of the Platte River in the vicinity of the gage near Cozad, Nebraska; partitioned data sets.

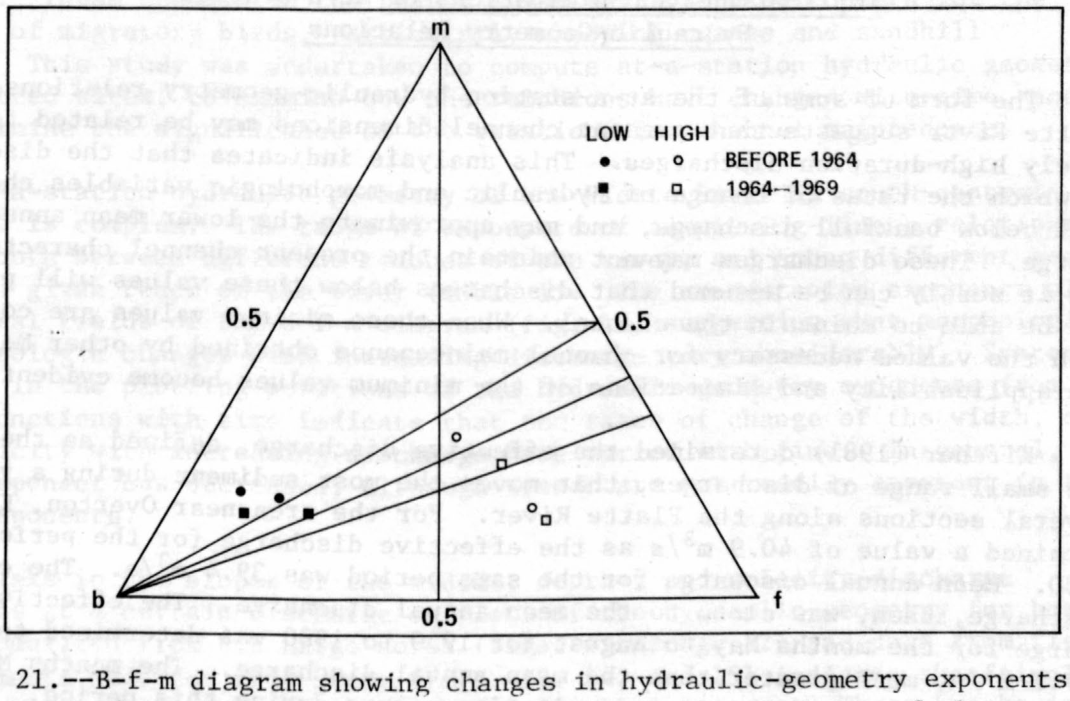

Figure 21.--B-f-m diagram showing changes in hydraulic-geometry exponents with time. Data from the Platte River in the vicinity of the gage near Odessa, Nebraska; partitioned data sets.

The existence of a break in the slope of the width-discharge relation is of primary importance for this study (for example, fig. 5). Above the break, the entire channel width may be occupied, at a shallow depth, by a discharge of relatively high duration. Because vegetative encroachment and stabilization of the channel banks and bars is part of the process of width reduction on the Platte River (Eschner, Hadley, and Crowley, 1981), the further establishment of vegetation must be prevented if the existing channel width is to be maintained.

Seeds may be prevented from germinating if there is no exposed substrate on which they can grow. Young vegetation may be removed if it is inundated with water of a velocity sufficient to scour it out, or it may be killed if inundated for a sufficient period of time. The sections of channel where a single power function does not describe the hydraulic geometry may be kept free of vegetation by relatively low flows, because the bed will be covered completely by those flows. For example, near Cozad, the mean annual discharge for the period 1953 to 1979 was 14.0 m^3/s. Discharges at which the slope of the hydraulic-geometry relations from the north channel near Cozad changes (figs. 9 and 10) are much lower than mean annual discharge. For the section 200 ft below the Cozad gage, the width-discharge and depth-discharge relations appear to change slope at about 2 m^3/s. For the section 400 ft below the Cozad gage, the width-discharge relation flattens out at about 3 cms and the depth-discharge relation exhibits a break in slope at about 3 cms. Thus, the discharge of the north channel at which the hydraulic-geometry relations change is less than half of the mean annual discharge for the entire channel near Cozad.

Implications and Limitations of At-a-Station Hydraulic-Geometry Relations

The form of some of the at-a-station hydraulic-geometry relations for the Platte River suggests that present channel dimensions may be related to relatively high-duration discharges. This analysis indicates that the discharges at which the rates of change of hydraulic and morphologic variables change are well below bankfull discharge, and may approximate the lower mean annual discharge. These discharges may not maintain the present channel characteristics, but it surely can be assumed that discharges below these values will probably not be able to maintain the channel. When these minimum values are compared with the values necessary for channel maintenance obtained by other methods, the applicability and limitations of the minimum values become evident.

Kircher (1981) determined the effective discharge, defined as the mean of the small range of discharges, that moves the most sediment during a year, for several sections along the Platte River. For the area near Overton, Kircher obtained a value of 40.9 m^3/s as the effective discharge for the period 1950-1980. Mean annual discharge for the same period was 39.4 m^3/s. The effective discharge, then, was close to the mean annual discharge. The effective discharge for the months May to August for 1950 to 1980 was determined to be 157.7 m^3/s, much greater than the mean annual discharge. The months May to August were selected, because germination occurs during this period. The effective discharge for this period should both prevent germination and uproot small seedlings.

Karlinger and others (1981) applied theoretical equations developed by Parker (1978) to estimate the discharge necessary for maintaining cross-sectional characteristics of the Platte River channel. For a reach near Overton where the width is about 180 m, the necessary discharge was determined to be 107.6 m^3/s. The depth corresponding to this discharge was estimated to be 0.6 m. The discharge necessary to cover the channel bed at this section, hence the discharge at which the width- and depth-discharge relations change, is estimated to be about 22 m^3/s. The value obtained by Karlinger and others (1981) lies between that obtained from the width-discharge relation and that determined by Kircher (1981) as the effective discharge for the critical germination period.

Crowley (1981) discussed the movement of macroforms, bedforms which average 1 to 1½ m in height, and their effect on maintenance of channel width. By moving downstream, these large bedforms can uproot vegetation. In order to move, the macroform must be covered by at least 20 cm of water. For the river near Overton, approximately 80 m^3/s would be required to move the macroforms. This value is twice the mean annual discharge, and is about three-fourths of the value obtained from the theoretical equations.

SUMMARY AND CONCLUSIONS

Hydrology and morphology of the Platte River in south-central Nebraska have changed since settlement of the river basin (Eschner, Hadley, and Crowley, 1981). Peak discharges have decreased, and the formerly wide, open channel has narrowed, as sandbars have become vegetated and formed permanent islands. These changes in the Platte River have prompted concern for the habitat of migratory birds, particularly whooping cranes and sandhill cranes. This study was undertaken to compute at-a-station hydraulic geometry at selected sites, to examine how the relations have changed with time, and to determine the significance of the relations for channel maintenance.

At-a-station hydraulic geometry of the Platte River in south-central Nebraska is complex. The range of exponents of simple log-linear relations is large, both between different reaches of the river, and among different sections within a given reach of the river (table 1). The at-a-station exponents plot in several fields of the b-f-m diagram (fig. 17) suggesting that morphologic and hydrologic changes with increasing discharge vary considerably. Systematic changes in the plotting positions of the hydraulic-geometry exponents from simple power functions with time indicate that the rates of change of the width, depth, and velocity with increasing discharge have varied with time. In general, the width exponent has decreased, although trends are not readily apparent in the other exponents.

Breaks in the slopes of the width-, depth-, and velocity-discharge relations at a certain discharge on plots of the hydraulic-geometry for both data summarized from discharge notes (figs. 4 through 12) and data from field measurements made for this study (figs. 13, 14, and 15) indicate that simple power functions are not the proper model in all instances. These breaks in slope can serve to partition the data sets. Power functions fit separately to the partitioned data fit the data significantly better than simple power functions for several locations. The exponents of hydraulic geometry relations based on partitioned data sets indicate the effect of the range of discharge values. Part of the observed change in plotting positions on the b-f-m diagram of the exponents from simple power functions results because the range of discharges for different time intervals is not the same. Much of the change of plotting positions is eliminated if the data sets are partitioned.

The shape of the channel cross section and, perhaps, changes in roughness with increasing discharge account for the shape of complex hydraulic-geometry relations. As the channel bed is inundated, width increases rapidly and depth increases slowly. Once the entire channel bed is covered and the banks are reached, width cannot increase appreciably but depth can increase rapidly.

Complex at-a-station hydraulic-geometry relations have significance for channel maintenance and suggest that existing channel dimensions may be related to relatively low-magnitude flows. Vegetation must not become established in the channel if the existing width is to be maintained. This can be accomplished by preventing germination of seeds or by uprooting young established seedlings. The discharge at which the entire channel bed is covered and at which the width- and depth-discharge relations change represents a minimum value for channel maintenance. Although this minimum discharge may not maintain the channel, discharges below this value will afford channel area for seed germination and thus cannot prevent vegetation establishment. For a given cross section, the discharge at which the hydraulic geometry relations change is generally less than annual mean discharge.

REFERENCES CITED

Carlston, C. W., 1969, Downstream variations in the hydraulic geometry of streams: Special emphasis on mean velocity: American Journal of Science, v. 267, p. 499-509.

Crowley, K. D., 1981, Large-scale bedforms in the Platte River: Structure process, and relation to channel narrowing: U.S. Geological Survey Open-File Report 81-1059, 33 p.

Eschner, T. R., Hadley, R. F., and Crowley, K. D, 1981, Hydrologic and morphologic changes in channels of the Platte River Basin: A historical perspective: U.S. Geological Survey Open-File Report 81-1125, 57 p.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Frith, Charles, 1974, The ecology of the Platte River as related to sandhill cranes and other waterfowl in southcentral Nebraska: MS thesis, Kearney, Nebraska, Kearney State College, 115 p.

Karlinger, M. R., Mengis, R. C., Kircher, J. E., and Eschner, T. R., 1981, Application of theoretical equations to estimate the discharge needed to maintain channel width in a reach of the Platte River near Lexington, Nebraska: U.S. Geological Survey Open-File Report 81-697, 16 p.

Kircher, J. E., 1981, Sediment transport and effective discharge for the North Platte, South Platte, and Platte Rivers in Nebraska: U.S. Geological Survey Open-File Report 81-53, 26 p.

Kircher, J. E., and Karlinger, M. R., 1981, Changes in surface-water hydrology for the Platte River basin: U.S. Geological Survey Open-File Report 81-818, 77 p.

Knighton, A. D., 1975, Variations in at-a-station hydraulic geometry: American Journal of Science, v. 275, p. 186-218.

_____ 1977, Short-term changes in hydraulic geometry, *in* Gregory, K. J., ed., River channel changes: Chichester, England, John Wiley, p. 101-119.

_____ 1979, Comments on log-quadratic relations in hydraulic geometry: Earth Surface Processes, v. 4, p. 205-209.

Langbein, W. B., 1964, Geometry of river channels: American Society of Civil Engineers Journal of Hydraulics Division, v. 90. p. 301-312.

Leopold, L. B., and Langbein, W. B., 1962, The concept of entropy in landscape evolution: U.S. Geological Survey Professional Paper 500-A, 20 p.

Leopold, L. B., and Maddock, Thomas, Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252, 57 p.

Nadler, C. T., Jr., 1978, River metamorphosis of the South Platte and Arkansas Rivers, Colorado: MS thesis, Fort Collins, Colorado, Colorado State University, 151 p.

Park, C. C., 1977, World-wide variations in hydraulic geometry exponents of stream channels: An analysis and some observations: Journal of Hydrology, v. 38, p. 133-146.

_____ 1978, World-wide variations in hydraulic geometry exponents of stream channels: An analysis and some observations--reply: Journal of Hydrology, v. 39, p. 199-202.

Parker, Gary, 1978, Self-formed straight rivers with equilibrium banks and mobile bed. Part I. The sand-silt river: Journal of Fluid Mechanics, v. 89, pt. 1, p. 109-125.

Pickup, G., and Rieger, W. A., 1979, A conceptual model of the relationship between channel characteristics and discharge: Earth Surfaces Processes, v. 4, p. 37-42.

Rhodes, D. D., 1977, The b-f-m diagram: Graphical representation and interpretation of at-a-station hydraulic geometry: American Journal of Science, v. 277, p. 73-96.

_____ 1978, World-wide variations in hydraulic geometry exponents of stream channels: An analysis and some observations--comments: Journal of Hydrology, v. 39, p. 193-197.

Richards, K. S., 1973, Hydraulic geometry and channel roughness: A non-linear system: American Journal of Science, v. 273, p. 877-896.

_____ 1976, Complex width-discharge relations in natural river sections: Geological Society of America Bulletin, v. 87, p. 199-206.

_____ 1977, Channel and flow geometry: a geomorphological perspective: Progress in Physical Geometry, v. 1, p. 65-102.

Schumm, S. A., 1960, The shape of alluvial channels in relation to sediment type: U.S. Geological Survey Professional Paper 352-B, p. 17-30.

_____ 1968, River adjustment to altered hydrologic regimen, Murrumbidgee River and paleochannels, Australia: U.S. Geological Survey Professional Paper 598, 65 p.

Smith, T. R., 1974, A derivation of the hydraulic geometry of steady state channels from conservation principles and sediment transport laws: Journal of Geology, v. 82, p. 98-104.

Thornes, J. B., 1970, The hydraulic geometry of stream channels in the Xingu-Araguaia headwaters: Geographical Journal, v. 136, p. 376-382.

_____ 1977, Hydraulic geometry and channel change, *in* Gregory, K. J., ed., River channel changes: Chichester, England, John Wiley, p. 91-100.

U.S. Fish and Wildlife Service, 1978, Determination of critical habitat for the whooping crane: Federal Register, v. 43, no. 94, p. 20938-20942.

_____ 1981, The Platte River ecology study: U.S. Department of the Interior, Fish and Wildlife Service Special Research Report, 187 p.

Wilcock, D. N., 1971, Investigation into the relations between bedload transport and channel shape: Geological Society of America Bulletin, v. 82, p. 2159-2176.

Williams, G. P., 1978a, Hydraulic geometry of river cross sections--theory of minimum variance: U.S. Geological Survey Professional Paper 1029, 47 p.

_____ 1978b, The case of the shrinking channels--the North Platte and Platte Rivers in Nebraska: U.S. Geological Survey Circular 781, 48 p.

Wolman, M. G., 1955, The natural channel of Brandywine Creek Pennsylvania: U.S. Geological Survey Professional Paper 271, 56 p.

Wolman, M. G., and Brush, L. M., Jr., 1961, Factors controlling the size and shape of stream channels in coarse noncohesive sands: U.S. Geological Survey Professional Paper 282-G, 28 p.

SUMMARY OF STATISTICAL DATA

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level			
									0.10	0.05	0.01	0.001
W	Cozad	30	Y on X	1961-1979	30	2.469174	0.006662	370.75	x	x	x	x
V	Cozad	30	Y on X	1961-1979	30	0.279886	0.001833	152.95	x	x	x	x
D	Cozad	30	Y on X	1961-1979	30	3.673960	0.007333	193.21	x	x	x	x
W	Cozad	30	Y on X	1961-1963	3	0.57133	0.00290	196.84	x	x		
V	Cozad	30	Y on X	1961-1963	3	0.04949	0.000031	1,594.40	x	x		
D	Cozad	30	Y on X	1961-1963	3	0.14535	0.00353	41.09	x			
W	Cozad	30	Y on X	1964-1969	6	0.15573	0.00960	16.24	x	x		
V	Cozad	30	Y on X	1964-1969	6	0.05462	0.00337	16.24	x	x		
D	Cozad	30	Y on X	1964-1969	6	0.03028	0.00228	13.32	x	x		
W	Cozad	30	Y on X	1970-1979	21	1.09755	0.005369	204.39	x	x	x	x
V	Cozad	30	Y on X	1970-1979	21	0.132768	0.001145	115.45	x	x	x	x
D	Cozad	30	Y on X	1970-1979	21	0.531339	0.003656	145.33	x	x	x	x
W	Cozad	45	Y on X	1954-1979	30	2.10585	0.01251	168.33	x	x	x	x
			Low		8	.59899	.01741	34.40	x	x	x	x
			High		22	.38114	.005845	65.21	x	x	x	x
V	Cozad	45	Y on X	1954-1979	30	0.155475	0.008515	18.26	x	x	x	x
			Low		8	.00560	.01163	.48				
			High		22	.04997	.00821	6.09	x	x		
D	Cozad	45	Y on X	1954-1979	30	1.01994	0.01442	70.73	x	x	x	x
			Low		8	.01542	.00710	2.17				
			High		22	.65535	.01281	51.16	x	x	x	x
W	Cozad	45	Y on X	1954-1969	9	1.7758	0.0199	84.49	x	x	x	x
			Low		5	.27336	.03425	7.98	x	x		
			High		4	.31156	.00460	67.75	x	x	x	
V	Cozad	45	Y on X	1954-1969	9	0.1384	0.0101	13.76	x	x	x	
			Low		5	.00011	.01826	.01				
			High		4	.02003	.00028	72.59	x	x	x	
D	Cozad	45	Y on X	1954-1969	9	0.52064	0.00394	132.25	x	x	x	x
			Low		5	.02872	.03425	.84				
			High		4	.13875	.00460	30.17	x	x		
W	Cozad	45	Y on X	1970-1979	21	0.138480	0.002437	56.82	x	x	x	x
			High		18	.06605	.00245	26.96	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
V	Cozad	45	Y on X	1970-1979	21	0.015929	0.008576	1.86				
			High		18	.00767	.00973	.79				
D	Cozad	45	Y on X	1970-1979	21	0.704423	0.008997	78.30	x	x	x	x
			High		18	.56005	.00963	58.13	x	x	x	x
W	Cozad	60	Y on X	1953-1979	73	11.49118	0.01671	687.68	x	x	x	x
			Low		25	4.45530	.01960	227.31	x	x	x	x
			High		48	.56799	.00827	68.69	x	x	x	x
V	Cozad	60	Y on X	1953-1979	73	1.51974	0.01029	147.69	x	x	x	x
			Low		25	.36342	.02412	15.07	x	x	x	x
			High		48	.16379	.00382	42.86	x	x	x	x
D	Cozad	60	Y on X	1953-1979	73	2.98305	0.01182	252.37	x	x	x	x
			Low		25	.15681	.00617	25.40	x	x	x	x
			High		48	.90036	.00739	121.88	x	x	x	x
W	Cozad	60	Y on X	1953-1957	11	2.7491	0.0389	70.56	x	x	x	x
V	Cozad	60	Y on X	1953-1957	11	0.1933	0.0497	3.88	x			
D	Cozad	60	Y on X	1953-1957	11	0.16872	0.00335	50.41	x	x	x	x
W	Cozad	60	Y on X	1958-1963	15	2.0328	0.0158	128.60	x	x	x	x
V	Cozad	60	Y on X	1958-1963	15	0.20856	0.00334	62.41	x	x	x	x
D	Cozad	60	Y on X	1958-1963	15	1.0032	0.0123	81.72	x	x	x	x
W	Cozad	60	Y on X	1953-1963	26							
			Low		15	3.03395	0.02966	102.29	x	x	x	x
			High		11	.26945	.01690	15.94	x	x	x	
V	Cozad	60	Y on X	1953-1963	26							
			Low		15	0.21365	0.03581	5.97	x	x		
			High		11	.02390	.00350	6.65	x	x		
D	Cozad	60	Y on X	1953-1963	26							
			Low		15	0.12763	0.00736	17.33	x	x	x	x
			High		11	.27101	.01106	24.50	x	x	x	x
W	Cozad	60	Y on X	1964-1969	13	0.93046	0.00483	179.02	x	x	x	x
			Low		3	.15643	.00649	24.11	x	x		
			High		10	.22226	.00126	176.09	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
V	Cozad	60	Y on X	1964-1969	13	0.34010	0.00230	147.62	x	x	x	x
			Low		3	.02848	.00909	3.13				
			High		10	.07628	.00120	63.36	x	x	x	x
D	Cozad	60	Y on X	1964-1969	13	0.37346	0.00721	51.70	x	x	x	x
			Low		3	.00268	.00022	12.39	x			
			High		10	.26363	.00157	167.44	x	x	x	x
W	Cozad	60	Y on X	1970-1979	34	0.675620	0.007885	85.68	x	x	x	x
			Low		7	.15766	.00403	39.06	x	x	x	x
			High		27	.03985	.00445	8.94	x	x	x	
V	Cozad	60	Y on X	1970-1979	34	0.125167	0.004224	29.63	x	x	x	x
			Low		7	.00006	.00060	.10				
			High		27	.08001	.00462	17.14	x	x	x	x
D	Cozad	60	Y on X	1970-1979	34	0.964612	0.007636	126.32	x	x	x	x
			Low		7	.00004	.00275	.01				
			High		27	.41468	.00706	58.68	x	x	x	x
W	Cozad	75	Y on X	1961-1979	46	1.585857	0.006428	246.71	x	x	x	x
			Low		15	.21177	.00505	41.99	x	x	x	x
			High		31	.67218	.00580	115.99	x	x	x	x
V	Cozad	75	Y on X	1961-1979	46	0.346376	0.002718	127.44	x	x	x	x
			Low		15	.08656	.00164	52.85	x	x	x	x
			High		31	.03916	.00219	17.81	x	x	x	x
D	Cozad	75	Y on X	1961-1979	46	1.103953	0.005522	199.92	x	x	x	x
			Low		15	.00106	.00321	.32				
			High		31	.31658	.00443	71.40	x	x	x	x
W	Cozad	75	Y on X	1961-1963	15	0.043926	0.00375	117.07	x	x	x	x
			Low		6	.04431	.00244	18.15	x	x	x	
			High		9	.28454	.00198	143.76	x	x	x	x
V	Cozad	75	Y on X	1961-1963	15	0.3549	0.00195	18.23	x	x	x	x
			Low		6	.01336	.00091	14.75	x	x		
			High		9	.05634	.00453	12.46	x	x	x	
D	Cozad	75	Y on X	1961-1963	15	0.22520	0.00371	60.68	x	x	x	x
			Low		6	.00757	.00075	10.05	x	x		
			High		9	.00354	.00205	1.72				

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
W	Cozad	75	Y on X	1964-1969	12	1.12738	0.00484	232.87	x	x	x	x
			Low		5	.10291	.00618	16.65	x	x		
			High		7	.16234	.00347	46.79	x	x	x	x
V	Cozad	75	Y on X	1964-1969	12	0.18892	0.00135	140.42	x	x	x	x
			Low		5	.02361	.00046	51.55	x	x	x	
			High		7	.00575	.00029	19.54	x	x	x	
D	Cozad	75	Y on X	1964-1969	12	0.34943	0.00526	66.42	x	x	x	x
			Low		5	.00225	.00352	.64				
			High		7	.06900	.00211	32.60	x	x	x	
W	Cozad	75	Y on X	1970-1979	19	0.085085	0.002278	37.35	x	x	x	x
			High		15	.004352	.00249	17.47	x	x	x	
V	Cozad	75	Y on X	1970-1979	19	0.132970	0.001599	83.16	x	x	x	x
			High		15	.05019	.00186	27.04	x	x	x	x
D	Cozad	75	Y on X	1970-1979	19	0.486102	0.003464	140.33	x	x	x	x
			High		15	.14776	.00400	36.97	x	x	x	x
W	Cozad	120	Y on X	1951-1979	153	19.87165	0.01202	1,653.22	x	x	x	x
			Low		63	12.66166	.00906	1,397.26	x	x	x	x
			High		90	.25444	.00272	93.70	x	x	x	x
V	Cozad	120	Y on X	1951-1979	153	2.785591	0.004004	695.70	x	x	x	x
			Low		63	.95552	.00746	127.92	x	x	x	x
			High		90	.18221	.00153	119.03	x	x	x	x
D	Cozad	120	Y on X	1951-1979	153	7.799154	0.009340	835.03	x	x	x	x
			Low		63	1.39596	.00603	231.65	x	x	x	x
			High		90	1.63983	.00243	676.00	x	x	x	x
W	Cozad	120	Y on X	1951-1963	32	8.4442	0.0129	656.38	x	x	x	x
			Low		28	5.388868	.01296	415.75	x	x	x	x
V	Cozad	120	Y on X	1951-1963	32	0.5925	0.0129	46.10	x	x	x	x
			Low		28	.29907	.01474	20.25	x	x	x	x
D	Cozad	120	Y on X	1951-1963	32	1.07189	0.00682	157.25	x	x	x	x
			Low		28	.43142	.00661	65.29	x	x	x	x
W	Cozad	120	Y on X	1964-1969	82	0.34519	0.00272	127.01	x	x	x	x
			Low		42	.18675	.00406	45.97	x	x	x	x
			High		40	.02623	.00153	17.14	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level			
									0.10	0.05	0.01	0.001
V	Cozad	120	Y on X	1964-1969	82	0.39503	0.00078	504.45	x	x	x	x
			Low		42	.02481	.00082	30.36	x	x	x	x
			High		40	.04738	.00055	86.68	x	x	x	x
D	Cozad	120	Y on X	1964-1969	82	1.66396	0.00208	800.89	x	x	x	x
			Low		42	.11284	.00370	30.47	x	x	x	x
			High		40	.37284	.00092	404.41	x	x	x	x
W	Cozad	120	Y on X	1970-1979	39	0.701922	0.004423	158.70	x	x	x	x
			Low		14	.11042	.00515	21.44	x	x	x	x
			High		25	.16778	.00218	76.91	x	x	x	x
V	Cozad	120	Y on X	1970-1979	39	0.151930	0.002814	53.99	x	x	x	x
			Low		14	.00083	.00256	.32				
			High		25	.14213	.00221	64.32	x	x	x	x
D	Cozad	120	Y on X	1970-1979	39	1.969314	0.004547	433.10	x	x	x	x
			Low		14	.15802	.00327	48.30	x	x	x	x
			High		25	1.21734	.00323	376.75	x	x	x	x
W	Overton, north channel	30	Y on X	1968-1976	14	0.196206	0.006256	31.36	x	x	x	x
V	Overton, north channel	30	Y on X	1968-1976	14	0.051963	0.001103	47.11	x	x	x	x
D	Overton, north channel	30	Y on X	1968-1976	14	0.130150	0.004312	30.18	x	x	x	x
W	Overton, south channel	30	Y on X	1968-1976	20	0.952106	0.002543	374.40	x	x	x	x
V	Overton, south channel	30	Y on X	1968-1976	20	0.0161493	0.0009511	16.98	x	x	x	x
D	Overton, south channel	30	Y on X	1968-1976	20	0.528872	0.002149	246.10	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
W	Overton	30	Y on X	1961-1968	11	0.67557	0.00997	67.73	x	x	x	x
V	Overton	30	Y on X	1961-1968	11	0.00714	0.00163	4.37	x			
D	Overton	30	Y on X	1961-1968	11	0.14293	0.00900	1.59				
W	Overton,	45	Y on X	1968-1976	25	0.326028	0.002975	109.59	x	x	x	x
	north		Low		10	.03135	.00533	5.86	x	x		
	channel		High		15	.01072	.00108	9.92	x	x	x	
V	Overton,	45	Y on X	1968-1976	25	0.142227	0.001261	112.79	x	x	x	x
	north		Low		10	.05074	.00159	31.92	x	x	x	x
	channel		High		15	.01344	.00070	19.18	x	x	x	
D	Overton,	45	Y on X	1968-1976	25	0.286354	0.003402	84.17	x	x	x	x
	north		Low		10	.03162	.00696	4.54	x			
	channel		High		15	.06995	.00101	69.22	x	x	x	x
W	Overton	45	Y on X	1961-1963	7	0.47005	0.00759	61.94	x	x	x	x
V	Overton	45	Y on X	1961-1963	7	0.00128	0.00592	.21				
D	Overton	45	Y on X	1961-1963	7	0.01013	0.00142	7.13	x	x		
W	Overton,	60	Y on X	1968-1976	53	0.680470	0.004211	161.59	x	x	x	x
	north		Low		20	.21689	.00700	31.02	x	x	x	x
	channel		High		33	.00064	.00134	.48				
V	Overton,	60	Y on X	1968-1976	53	0.203593	0.001548	131.52	x	x	x	x
	north		Low		20	.00762	.00043	9.73	x	x	x	
	channel		High		33			17.72	x	x	x	x
D	Overton,	60	Y on X	1968-1976	53	0.541680	0.004389	123.42	x	x	x	x
	north		Low		20	.05723	.00703	8.12	x	x		
	channel		High		33	.17544	.00125	139.95	x	x	x	x
W	Overton	60	Y on X	1954-1968	46	2.12162	0.00878	241.80	x	x	x	x
			Low		16	.02629	.01214	2.16				
			High		30	.3977	.00357	111.30	x	x	x	x
V	Overton	60	Y on X	1954-1968	46	0.11113	0.00301	36.97	x	x	x	x
			Low		16	.00014	.00424	.03				
			High		30	.09061	.00204	44.49	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level			
									0.10	0.05	0.01	0.001
D	Overton	60	Y on X	1954-1968	46	0.19631	0.00610	32.15	x	x	x	x
			Low		16	.03116	.00921	3.39	x			
			High		30	.18349	.00292	62.88	x	x	x	x
W	Overton	60	Y on X	1954-1963	18	1.57824	0.00813	194.04	x	x	x	x
			Low		7	.02303	.01267	1.82				
			High		11	.20046	.00215	93.32	x	x	x	x
V	Overton	60	Y on X	1954-1963	18	0.05105	0.00130	39.44	x	x	x	x
			Low		7	.00071	.00098	.72				
			High		11	.03467	.00097	35.64	x	x	x	x
D	Overton	60	Y on X	1954-1963	18	0.05669	0.00479	11.83	x	x	x	
			Low		7	.00033	.00846	.04				
			High		11	.05523	.00173	32.04	x	x	x	x
W	Overton	60	Y on X	1964-1968	28	0.67519	0.00465	145.20	x	x	x	x
			Low		9	.00608	.00080	7.56	x	x		
			High		19	.12427	.00449	27.67	x	x	x	x
V	Overton	60	Y on X	1964-1968	28	0.04065	0.00362	11.22	x	x	x	
			Low		9	.00007	.00617	.01				
			High		19	.02435	.00278	8.76	x	x	x	
D	Overton	60	Y on X	1964-1968	28	0.11258	0.00515	21.90	x	x	x	x
			Low		9	.05027	.00479	10.50	x	x		
			High		19	.07082	.00375	18.92	x	x	x	x
W	Overton	75	Y on X	1962-1968	51	0.85980	0.00436	197.20	x	x	x	x
			Low		17	.17490	.00492	35.52	x	x	x	x
			High		34	.21246	.003344	61.78	x	x	x	x
V	Overton	75	Y on X	1962-1968	51	0.27048	0.00234	115.59	x	x	x	x
			Low		17	.00246	.001129	2.19				
			High		34	.14042	.00258	54.46	x	x	x	x
D	Overton	75	Y on X	1962-1968	51	0.20581	0.00290	70.97	x	x	x	x
			Low		17	.00573	.00357	1.61				
			High		34	.07405	.00267	27.77	x	x	x	x
W	Overton, north channel	75	Y on X	1968-1976	8	0.0012756	0.0005457	2.34				

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
V	Overton, north channel	75	Y on X	1968-1976	8	0.0368640	0.0006871	53.65	x	x	x	x
D	Overton, north channel	75	Y on X	1968-1976	8	0.0447134	0.0003512	127.32	x	x	x	x
W	Overton	75	Y on X	1962-1963	8	0.05917	0.00877	6.76	x	x		
V	Overton	75	Y on X	1962-1963	8	0.02833	0.00061	46.79	x	x	x	x
D	Overton	75	Y on X	1962-1963	8	0.04782	0.00540	8.88	x	x		
W	Overton	75	Y on X	1964-1968	43	0.79032	0.00370	213.74	x	x	x	x
			Low		13	.11570	.00296	39.19	x	x	x	x
			High		30	.20058	.00355	56.55	x	x	x	x
V	Overton	75	Y on X	1964-1968	43	0.24402	0.00266	91.78	x	x	x	x
			Low		13	.00050	.00120	.50				
			High		30	.13332	.00285	46.79	x	x	x	x
D	Overton	75	Y on X	1964-1968	43	0.16379	0.00253	64.64	x	x	x	x
			Low		13	.00615	.00265	2.31				
			High		30	.05425	.00264	20.52	x	x	x	x
W	Overton, north channel	90	Y on X	1968-1978	33	0.281233	0.003713	75.74	x	x	x	x
			Low		10	.06885	.00167	41.09	x	x	x	x
			High		23	.02127	.00307	6.92	x	x		
V	Overton, north channel	90	Y on X	1968-1978	33	0.178685	0.001486	120.25	x	x	x	x
			Low		10	.00381	.00114	3.31				
			High		23	.09554	.00121	78.85	x	x	x	x
D	Overton, north channel	90	Y on X	1968-1978	33	0.530304	0.001724	307.60	x	x	x	x
			Low		10	.00595	.00157	3.80	x			
			High		23	.17726	.00142	124.99	x	x	x	x
W	Overton, south channel	90	Y on X	1968-1978	23	0.25592	0.01347	19.00	x	x	x	x
V	Overton, south channel	90	Y on X	1968-1978	23	0.143793	0.003713	38.73	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
D	Overton, south channel	90	Y on X	1968-1978	23	0.178088	0.009934	17.93	x	x	x	x
W	Overton	90	Y on X	1962-1968	160	2.71652	0.00421	645.25	x	x	x	x
			Low		75	1.15854	.00546	212.28	x	x	x	x
			High		85	.03305	.00076	43.56	x	x	x	x
V	Overton	90	Y on X	1962-1968	160	0.51750	0.00152	340.46	x	x	x	x
			Low		75	.03573	.00201	17.72	x	x	x	x
			High		85	.04231	.00088	47.89	x	x	x	x
D	Overton	90	Y on X	1962-1968	160	1.24976	0.00426	293.37	x	x	x	x
			Low		75	.06586	.00606	10.89	x	x	x	
			High		85	.29093	.00140	207.65	x	x	x	x
W	Overton	90	Y on X	1962-1963	41	0.80779	0.00549	147.14	x	x	x	x
			Low		22	.54046	.00400	135.26	x	x	x	x
			High		19	.00309	.00031	9.92	x	x		
V	Overton	90	Y on X	1962-1963	41	0.11225	0.00107	105.06	x	x	x	x
			Low		22	.00893	.00134	6.71	x	x		
			High		19	.01487	.00045	33.41	x	x	x	x
D	Overton	90	Y on X	1962-1963	41	0.28229	0.00363	77.79	x	x	x	x
			Low		22	.00141	.00274	.52				
			High		19	.06553	.00072	91.58	x	x	x	x
W	Overton	90	Y on X	1964-1968	119	1.90815	0.00380	501.76	x	x	x	x
			Low		53	.63762	.00581	109.83	x	x	x	x
			High		66	.03121	.00088	35.52	x	x	x	x
V	Overton	90	Y on X	1964-1968	119	0.40611	0.00168	241.49	x	x	x	x
			Low		53	.02596	.00232	11.16	x	x	x	
			High		66	.02836	.00101	27.98	x	x	x	x
D	Overton	90	Y on X	1964-1968	119	0.96578	0.00453	213.45	x	x	x	x
			Low		53	.08278	.00724	11.42	x	x	x	
			High		66	.22458	.00161	139.24	x	x	x	x
W	Odessa	60	Y on X	1962-1979	55	8.280655	0.006983	1,185.83	x	x	x	x
			Low		38	3.79507	.00929	408.85	x	x	x	x
			High		17	.01874	.00133	14.06	x	x	x	

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level			
									0.10	0.05	0.01	0.001
V	Odessa	60	Y on X	1962-1979	55	0.469099	0.004171	112.47	x	x	x	x
			Low		38	.25506	.00447	57.00	x	x	x	x
			High		17	.00091	.00360	.25				
D	Odessa	60	Y on X	1962-1979	55	1.03098	0.01269	81.24	x	x	x	x
			Low		38	.29176	.01567	18.58	x	x	x	x
			High		17	.041148	.00464	8.88	x	x	x	
W	Odessa	60	Y on X	1962-1963	26	5.39766	0.00600	900.00	x	x	x	x
			Low		15	2.55189	.00901	283.25	x	x	x	x
			High		11	.00632	.00133	4.75	x			
V	Odessa	60	Y on X	1962-1963	26	0.39093	0.00339	115.56	x	x	x	x
			Low		15	.18391	.00606	30.36	x	x	x	x
			High		11	.00546	.00012	45.70	x	x	x	x
D	Odessa	60	Y on X	1962-1963	26	0.21598	0.00846	25.50	x	x	x	x
			Low		15	.05000	.01351	3.69	x			
			High		11	.00907	.00137	6.66	x	x		
W	Odessa	60	Y on X	1964-1969	19	1.66754	0.00521	320.05	x	x	x	x
V	Odessa	60	Y on X	1964-1969	19	0.06890	0.00368	18.66	x	x	x	x
D	Odessa	60	Y on X	1964-1969	19	0.4186	0.0101	41.47	x	x	x	x
W	Odessa	60	Y on X	1970-1979	10	0.325985	0.006496	50.18	x	x	x	x
V	Odessa	60	Y on X	1970-1979	10	0.018275	0.005656	3.23				
D	Odessa	60	Y on X	1970-1979	10	0.22677	0.01112	20.39	x	x	x	
W	Odessa	75	Y on X	1961-1979	60	8.185083	0.006655	229.91	x	x	x	x
			Low		40	6.11130	.00952	641.61	x	x	x	x
			High		20	.00355	.00058	6.10	x	x		
V	Odessa	75	Y on X	1961-1979	60	0.858114	0.004192	204.70	x	x	x	x
			Low		40	.74553	.00544	137.12	x	x	x	x
			High		20	.00201	.00080	2.53				
D	Odessa	75	Y on X	1961-1979	60	0.934258	0.005211	179.29	x	x	x	x
			Low		40	.47876	.00594	80.64	x	x	x	x
			High		20	.01641	.00087	18.84	x	x	x	x
W	Odessa	75	Y on X	1961-1963	9	3.4736	0.0148	235.32	x	x	x	x
V	Odessa	75	Y on X	1961-1963	9	0.5731	0.0146	39.19	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level 0.10	0.05	0.01	0.001
D	Odessa	75	Y on X	1961-1963	9	0.25476	0.00424	60.06	x	x	x	x
W	Odessa	75	Y on X	1964-1969	45	2.74704	0.00482	569.78	x	x	x	x
			Low		27	1.91408	.00706	271.26	x	x	x	x
			High		18	.00329	.00065	5.02	x	x		
V	Odessa	75	Y on X	1964-1969	45	0.16580	0.00120	138.53	x	x	x	x
			Low		27	.00395	.00154	73.79	x	x	x	x
			High		18	.00109	.00075	1.44				
D	Odessa	75	Y on X	1964-1969	45	0.57759	0.00417	138.53	x	x	x	x
			Low		27	.25188	.00553	45.56	x	x	x	x
			High		18	.01842	.00083	22.28	x	x	x	x
W	Odessa	75	Y on X	1970-1979	6	0.300151	0.005752	52.18	x	x	x	
V	Odessa	75	Y on X	1970-1979	6	0.013869	0.001560	8.89	x	x		
D	Odessa	75	Y on X	1970-1979	6	0.088113	0.004935	17.85	x	x		
W	Odessa	90	Y on X	1953-1979	187	26.01329	0.00751	3,463.82	x	x	x	x
			Low		66	16.14536	.01115	1,448.56	x	x	x	x
			High		121	.14149	.00258	54.91	x	x	x	x
V	Odessa	90	Y on X	1953-1979	187	2.067655	0.001675	1,234.42	x	x	x	x
			Low		66	.95615	.00221	432.64	x	x	x	x
			High		121	.06631	.00136	48.86	x	x	x	x
D	Odessa	90	Y on X	1953-1979	187	2.925669	0.006222	470.21	x	x	x	x
			Low		66	.82710	.00838	98.80	x	x	x	x
			High		121	.34679	.00283	122.54	x	x	x	x
W	Odessa	90	Y on X	1953-1963	45	17.0072	0.0053	3,188.86	x	x	x	x
			Low		18	7.46218	.00899	829.44	x	x	x	x
			High		27	.01986	.00144	13.79	x	x	x	
V	Odessa	90	Y on X	1953-1963	45	1.19649	0.00353	338.93	x	x	x	x
			Low		18	.57036	.00333	171.09	x	x	x	x
			High		27	.00796	.00373	2.13				
D	Odessa	90	Y on X	1953-1963	45	1.64721	0.00739	222.90	x	x	x	x
			Low		18	.45667	.00881	51.84	x	x	x	x
			High		27	.08951	.00428	20.88	x	x	x	x

Table 2.--*Significance levels for at-a-station hydraulic-geometry equations from summarized data*--Continued

Variable	Platte River near:	Distance below gage (meters)	Testing regression	Period of record	n	Regression sum of squares	Error sum of squares	F-statistic	Significance level			
									0.10	0.05	0.01	0.001
W	Odessa	90	Y on X	1964-1969	134	4.53298	0.00701	646.68	x	x	x	x
			Low		43	2.52567	.01216	207.65	x	x	x	x
			High		91	.08429	.00185	45.70	x	x	x	x
V	Odessa	90	Y on X	1964-1969	134	0.576022	0.00093	619.01	x	x	x	x
			Low		43	.11170	.00155	72.25	x	x	x	x
			High		91	.07122	.00050	143.28	x	x	x	x
D	Odessa	90	Y on X	1964-1969	134	0.94740	0.00487	194.32	x	x	x	x
			Low		43	.07312	.00827	8.82	x	x	x	
			High		91	.26072	.00170	153.02	x	x	x	x
W	Odessa	90	Y on X	1970-1979	8	0.926422	0.003596	257.63	x	x	x	x
V	Odessa	90	Y on X	1970-1979	8	0.1065735	0.0007208	147.85	x	x	x	x
D	Odessa	90	Y on X	1970-1979	8	0.401328	0.004560	88.01	x	x	x	x

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