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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SEDIMENT TRANSPORT AND EFFECTIVE DISCHARGE OF THE NORTH PLATTE, SOUTH PLATTE, AND PLATTE RIVERS IN NEBRASKA

By J. E. Kircher

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GEOLOGICAL SURVEY

Doyle G. Frederick, Acting Director

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Water Resources Division
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SEDIMENT TRANSPORT AND EFFECTIVE DISCHARGE OF THE NORTH PLATTE, SOUTH PLATTE, AND PLATTE RIVERS, IN NEBRASKA

By J. E. Kircher

ABSTRACT

Sediment discharge was computed for four locations along the North Platte, South Platte, and the Platte Rivers between North Platte and Grand Island, Nebraska in order to determine the effective discharge. The total-sediment discharge was computed by the Colby method and modified Einstein method so that comparisons could be made with the measured total-sediment discharge. The results agreed closely. The Colby method is the simplest and most convenient to use. The mean annual total-sediment discharge for the four sites investigated ranged from 150 tons per day for the South Platte River at North Platte to 1,260 tons per day for the Platte River near Grand Island.

Effective discharge values for four sites in the Platte River basin are presented. Only average values are presented because it was found that the computed effective discharge value could vary by as much as 33 percent depending on the type and degree of discretization used in the numerical integration.

INTRODUCTION

The Platte River is one of the most important rivers of the Great Plains, not only because it is a source of irrigation water for agriculture within its basin, but also because, in Nebraska, it is unique as a habitat for various species of migrating waterfowl. Among these species are the sandhill and whooping cranes, which roost in the wide and shallow channels of the river. Changes in channel characteristics have caused concern in recent years; the Platte River channel has narrowed appreciably since the early 1950's.

The formation and maintenance of channel cross-sections is accomplished by movement of sediment. The water discharge that forms and maintains a channel cross section by transporting the most sediment throughout a significant period of time has been defined in the past as the effective discharge (Benson and Thomas, 1966, Andrews, 1980). Effective discharge may be computed by combining information from a sediment-rating curve and a discharge-duration curve. This report provides a description and evaluation of appropriate sediment-discharge relations and flow-duration curves. The relations and curves were used to compute effective discharges for the North Platte River at North Platte, the South Platte River at North Platte, the Platte River near Overton, and the Platte River near Grand Island. This report was prepared as part of the U.S. Geological Survey's study of the upper Platte River basin.

PHYSICAL SETTING

The North Platte and South Platte Rivers originate as snowmelt runoff streams in the Rocky Mountains of Colorado. They flow across the Great Plains to form the Platte River at their confluence at North Platte (fig. 1).

From its origin in north-central Colorado, the North Platte River flows northward into east-central Wyoming near Casper, and then flows southeastward to the confluence with the South Platte River. The North Platte River drains about 80,000 km^2 (square kilometers) and is about 1,050 river km (kilometers) long.

The South Platte River originates in the central part of Colorado, flows southeastward to a point about 100 km southwest of Denver, flows northeastward, leaves the mountains about 50 km southwest of Denver, flows through Denver and continues northeastward to the confluence with the North Platte River. Total drainage area of the South Platte River is about 62,900 km^2, and the river is about 720 river km long (Bentall, 1975, p. 6).

Downstream from North Platte, the Platte flows generally eastward through Nebraska to the Missouri River at the eastern edge of the State. The Platte River, downstream of North Platte, has a drainage area of about 79,000 km^2 and is about 460 river km long.

SEDIMENT-DISCHARGE CALCULATIONS

The total-sediment discharge is the sum of the suspended-sediment discharge and the bedload discharge. It is the total quantity of sediment, as measured by dry weight or volume, that is discharged during a given time.

Suspended Sediment

Suspended sediment is the sediment that is carried in suspension by the turbulent components of streamflow. The concentration of suspended sediment was sampled by standard methods using either a DH-48 or D-74 suspended-sediment sampler at equal-width increments (Guy and Norman, 1970). Samples were collected at 15 to 20 verticals to determine the average concentration and particle-size distribution of the sediment in the streamflow.

The suspended-sediment discharge, in metric tons per day, was computed by multiplying the concentration, in milligrams per liter, by the water discharge, in cubic meters per second, and a units conversion constant, 0.0864. Suspended-sediment discharge curves were developed for the North Platte River and the South Platte River at North Platte, the Platte River near Overton, and the Platte River near Grand Island, by relating suspended-sediment discharge and water discharge by a least-square regression analysis on the log-transformed data. These suspended-sediment discharge curves are presented in figure 2 and the equations of the curves are presented in table 1.

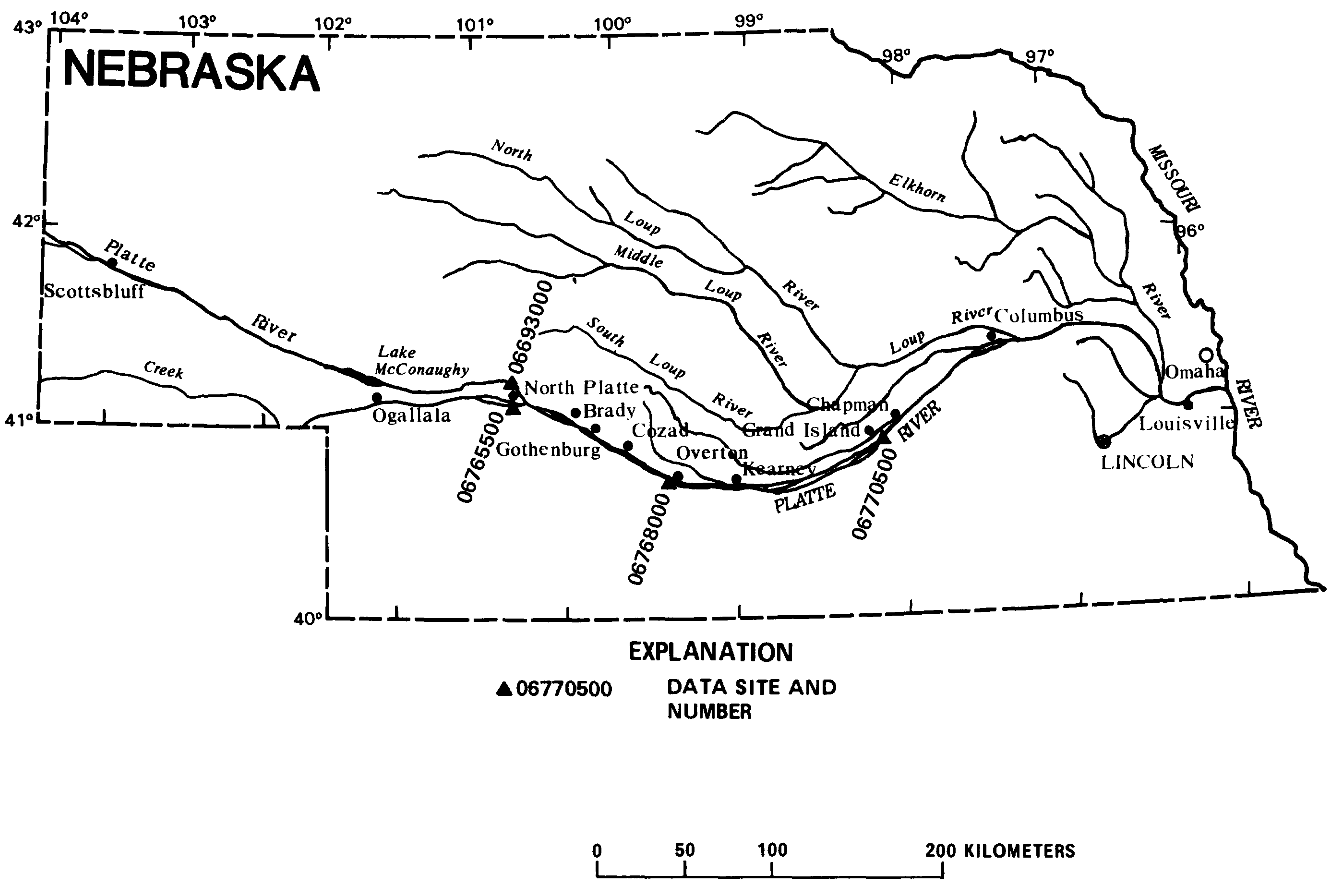

Figure 1.--Location of data sites along the North Platte, South Platte, and Platte Rivers.

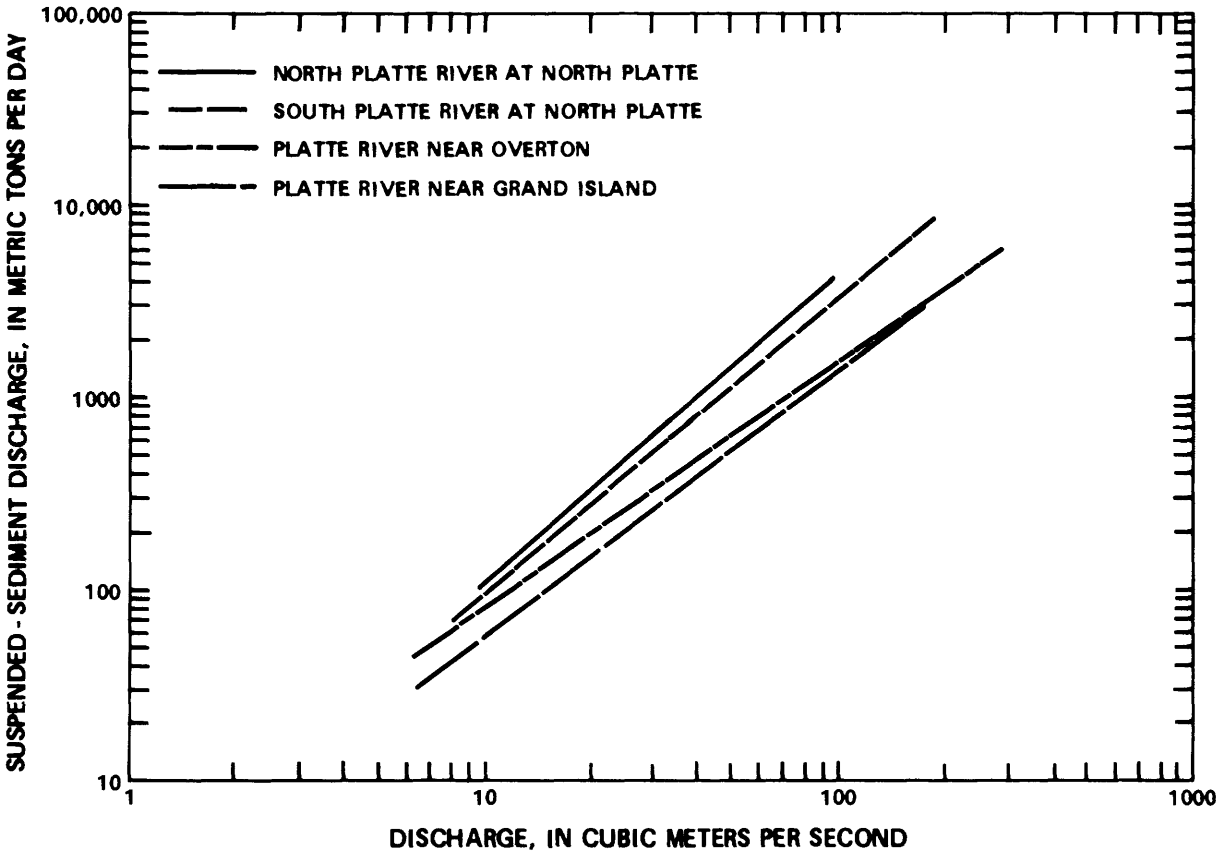

Figure 2.--Suspended-sediment discharge relations for the North Platte, South Platte, and Platte Rivers.

Table 1.--*Results of regression analysis for the sediment-discharge equations*

[Qs = sediment discharge, in metric tons per day; Q = water discharge, in cubic meters per second; LN = natural logarithm of function]

U.S. Geological Survey station number	Station name	Regression equation*	Type of equation (see footnotes)	Correlation coefficient	Standard error (LN units)	Number of data points
6693000	North Platte River at North Platte, Nebraska	LN(Qs) = 0.92 + 1.61 LN(Q)	(1)	0.95	0.345	5
		LN(Qs) = 2.36 + 1.03 LN(Q)	(2)	.84	.427	5
		LN(Qs) = 2.45 + 1.29 LN(Q)	(3)	.94	.306	5
		LN(Qs) = 2.44 + 1.39 LN(Q)	(4)	.94	.312	5
		LN(Qs) = 1.77 + 1.58 LN(Q)	(5)	.99	.041	3
06765500	South Platte River at North Platte, Nebraska	LN(Qs) = 0.98 + 1.53 LN(Q)	(1)	0.99	0.200	7
		LN(Qs) = 2.42 + 1.19 LN(Q)	(2)	.98	.404	7
		LN(Qs) = 2.55 + 1.32 LN(Q)	(3)	.99	.253	7
		LN(Qs) = 2.72 + 1.32 LN(Q)	(4)	.99	.142	7
		———		———	———	2
06768000	Platte River near Overton, Nebraska	LN(Qs) = 0.84 + 1.38 LN(Q)	(1)	0.98	0.316	7
		LN(Qs) = 1.93 + 1.23 LN(Q)	(2)	.97	.364	7
		LN(Qs) = 2.12 + 1.29 LN(Q)	(3)	.99	.235	7
		LN(Qs) = 2.23 + 1.27 LN(Q)	(4)	.99	.172	7
		LN(Qs) = 1.74 + 1.36 LN(Q)	(5)	.99	.072	4
06770500	Platte River near Grand Island, Nebraska	LN(Qs) = 1.45 + 1.27 LN(Q)	(1)	0.98	0.332	8
		LN(Qs) = 2.36 + 1.15 LN(Q)	(2)	.99	.167	8
		LN(Qs) = 2.34 + 1.26 LN(Q)	(3)	.99	.159	8
		LN(Qs) = 2.74 + 1.19 LN(Q)	(4)	.99	.212	8
		LN(Qs) = 1.44 + 1.45 LN(Q)	(5)	.99	.117	6

*The dependent variable in the regression equation is:
(1) Suspended-sediment discharge.
(2) Bedload discharge.
(3) Total-measured sediment discharge.
(4) Total-sediment discharge computed using the Colby (1957) method.
(5) Total-sediment discharge computed using the modified Einstein method (Colby and Hembree, 1955).

Bedload

Bedload is the material moving on or near the stream bed by rolling and sliding, and sometimes making brief excursions into the flow a few particle-size diameters above the bed. Several sets of bedload-discharge measurements were obtained during the summers of 1979 and 1980. These measurements were obtained to supplement the suspended-sediment measurements so a determination of total-sediment discharge could be made.

The sampler used was the Helley-Smith bedload sampler (Helley and Smith, 1971). Procedures for the collection of bedload samples described by Emmett (1980) were followed. The channel width was divided into 20 increments of equal width. The bedload was measured at the midpoint of each increment to integrate spatial variations in bedload and to define average-bedload discharge for the cross section. The results of these measurements for several locations in the Platte River basin are presented by Kircher (1981). The bedload-discharge relations for the North Platte River and the South Platte River at North Platte, the Platte River near Overton, and the Platte River near Grand Island, are presented in figure 3 and the equations of the curves are presented in table 1. These relations were developed by using a least-square regression of the log-transformed data. The bedload discharge seems to be well correlated to water discharge (table 1), and the rate of change in bedload discharge with water discharge is less than that for the measured suspended-sediment discharge (figs. 4-7).

Total-Sediment Discharge

The total-sediment discharge was computed by combining the suspended-sediment and bedload discharges. However, this cannot be done by simply adding the suspended-sediment and bedload discharges, because the estimate of suspended-sediment discharge in the unsampled depth [bottom 0.091 m (meter)] of flow is included in both the measured suspended-sediment discharge and the bedload discharge. In the calculation of the measured suspended-sediment discharge, measured suspended-sediment concentration is multiplied by the entire water discharge. Hence, part of the suspended sediment in the bottom 0.091 m of flow is included in the measured suspended-sediment discharge. Suspended-bed material, however, also may be trapped in the Helley-Smith sampler. The calculated suspended-sediment discharges for the North Platte, South Platte, and Platte Rivers were adjusted to represent only the fraction in the sampled part by a method described by Colby and Hembree (1955). The corrected suspended-sediment discharge then was added to the bedload discharge to get the total-sediment discharge. A least-squares regression on the log-transformed data then was performed to obtain the total-sediment discharge curves shown in figure 8 and the equations of the curves are presented in table 1.

On the basis of a field calibration of the sediment-trapping characteristics of the Helley-Smith bedload sampler (Emmett, 1980), bedload transport rates as measured with the sampler are considered reliable estimates. Because the Helley-Smith bedload sampler has not been sanctioned officially by the U.S.

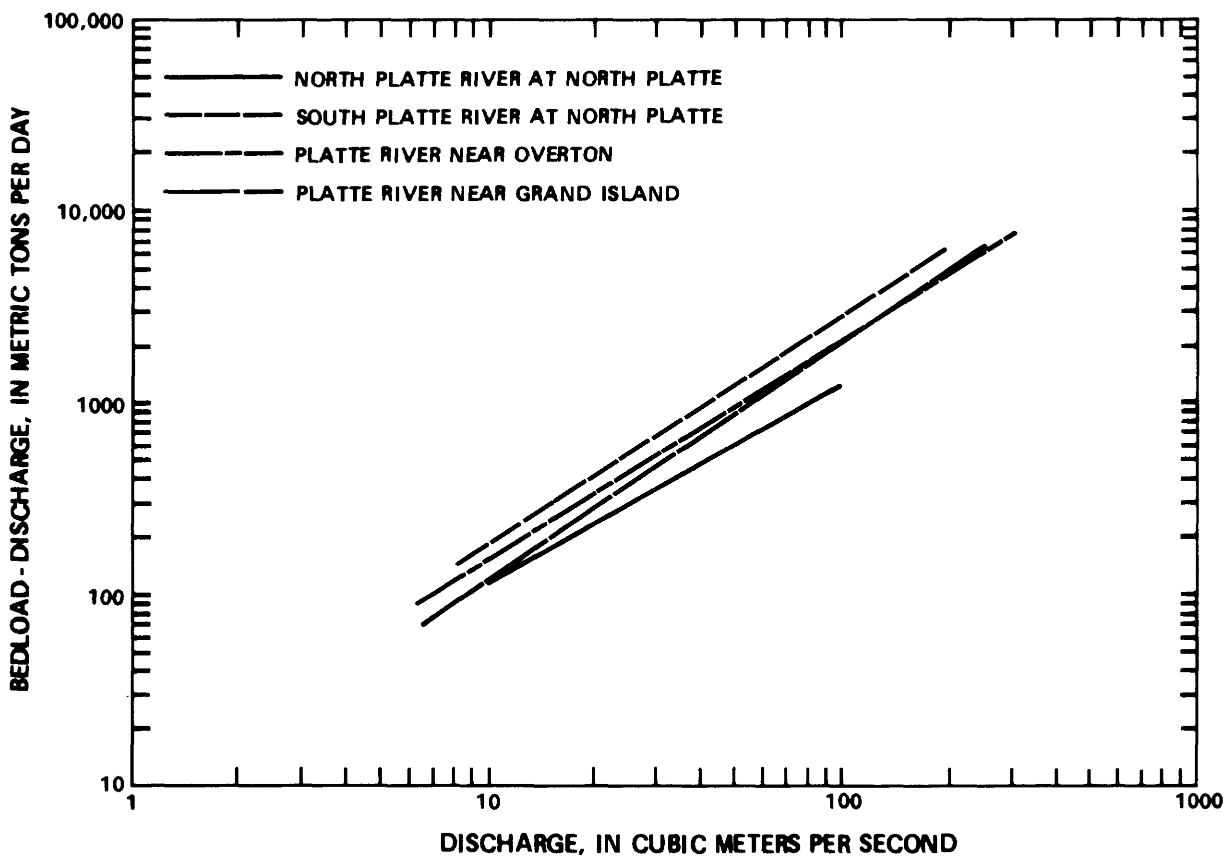

Figure 3.--Bedload-discharge relations for the North Platte, South Platte, and Platte Rivers.

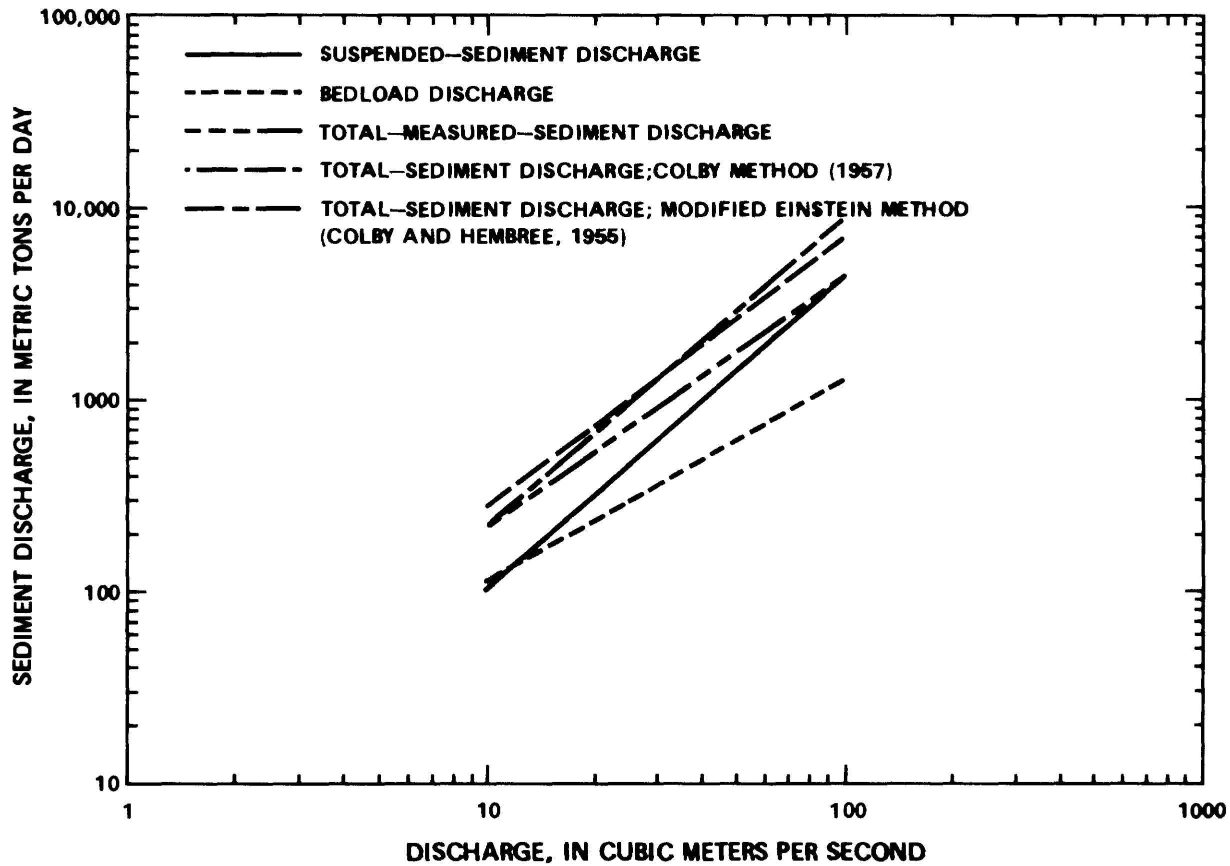

Figure 4.--Sediment-discharge relations for the North Platte River at North Platte.

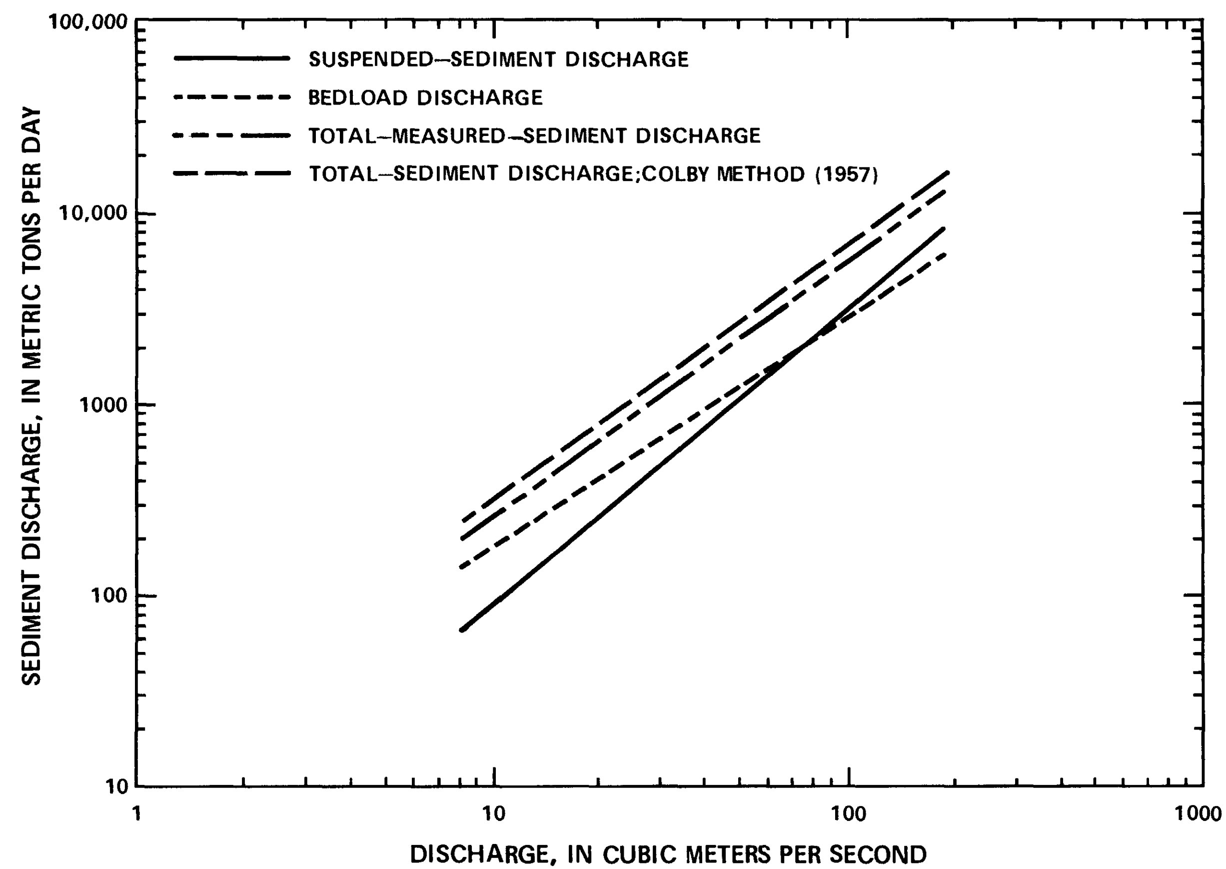

Figure 5.--Sediment-discharge relations for the South Platte River at North Platte.

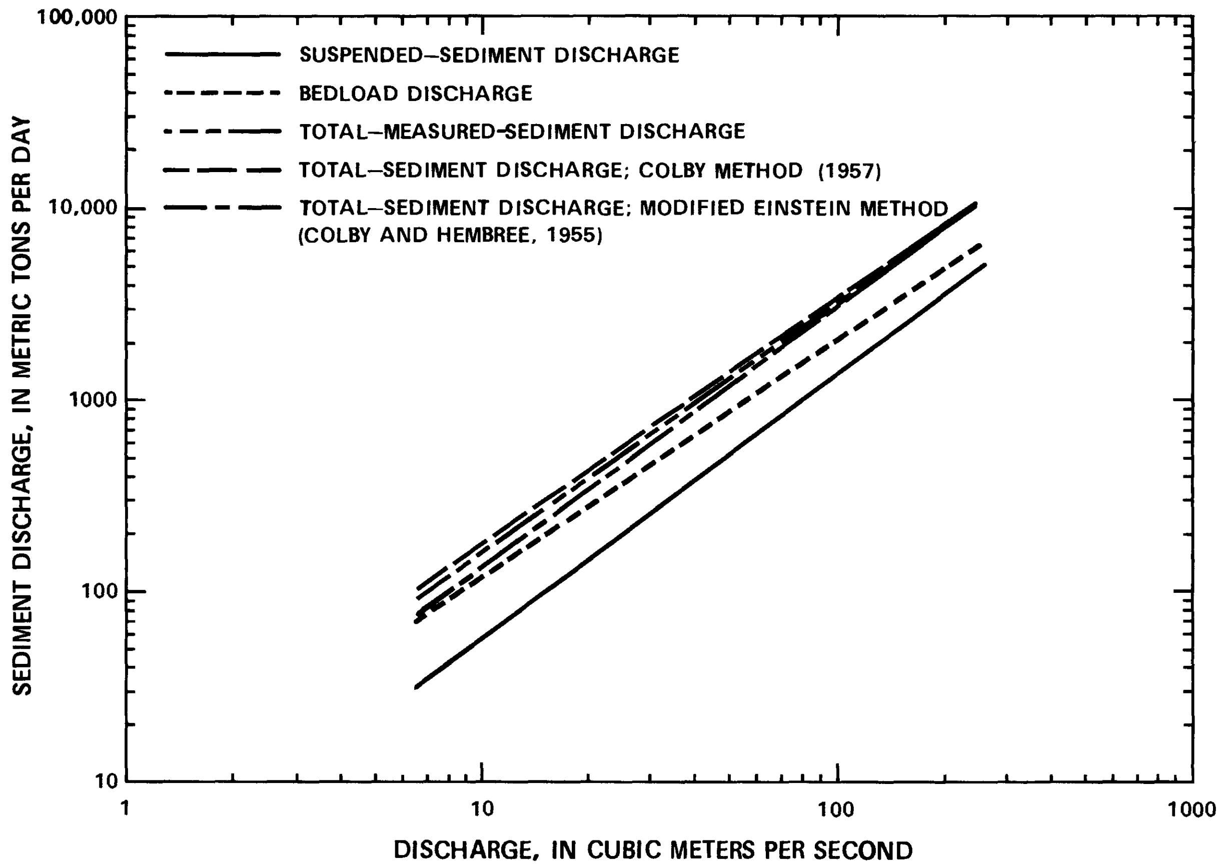

Figure 6.--Sediment-discharge relations for the Platte River near Overton.

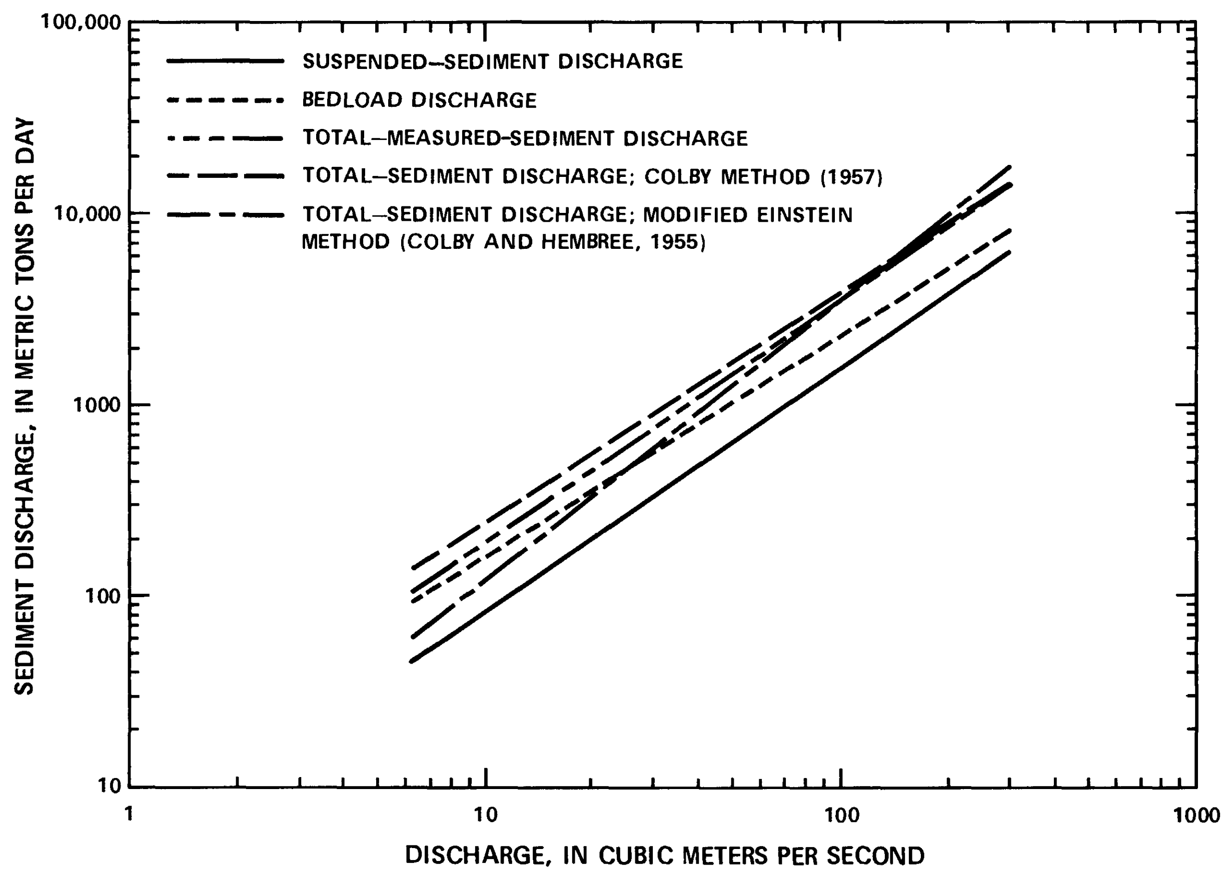

Figure 7.--Sediment-discharge relations for the Platte River near Grand Island.

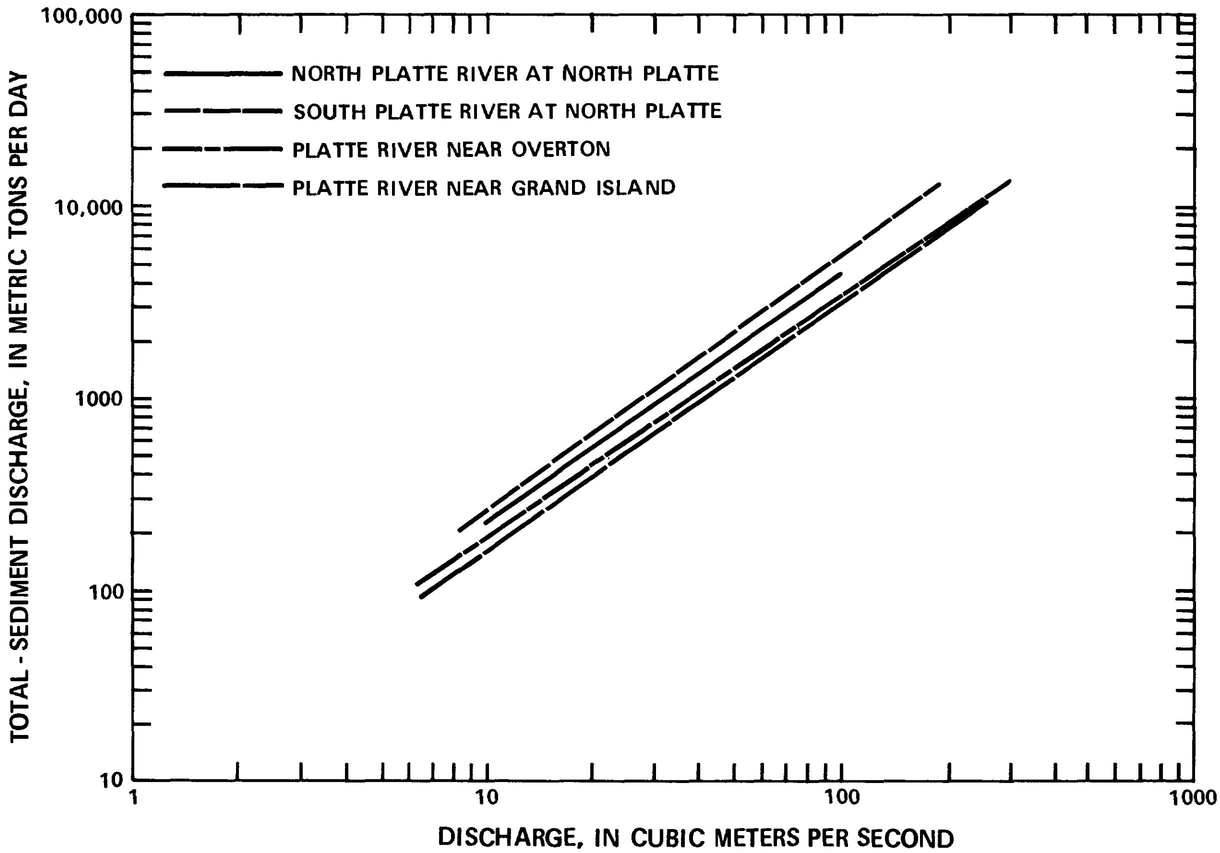

Figure 8.--Total-sediment discharge relations for the North Platte, South Platte, and Platte Rivers.

Geological Survey, and results obtained by its use cannot be certified for their accuracy. Therefore, the measured data were compared to relations defined by computational methods, to see how the Helley-Smith data compared to accepted methods. In the first technique, unmeasured sediment discharge was computed by Colby's (1957) method and added to the measured suspended-sediment discharge to give the total-sediment discharge. (Total-sediment discharge computed by this method hereafter are referred to as total-sediment discharges by the Colby method.) The other technique, the modified Einstein method (Colby and Hembree, 1955), was used to compute total-sediment discharge by sediment-size class, and then summed to obtain the total-sediment discharge for the entire range of sediment sizes.

Measured sediment-discharge relations are compared in figures 9 through 11 to total-sediment discharge relations based on computations by the Colby method and the modified Einstein method. Relations in these figures are defined by data from Kircher (1981), which include data from 17 sites in addition to the four mentioned in this report. Agreement among relations is very good. This may be expected due to the similarities of the North Platte, South Platte, and Platte Rivers to the Loup and Niobrara Rivers, where Colby developed the two methods. These relations, however, indicate that Colby and modified Einstein methods might be used for bed sizes beyond the size for which they were developed, because the North Platte, South Platte, and Platte Rivers do contain coarser bed material than the Loup or Niobrara Rivers.

For future estimates of sediment discharge, if the hydraulic and sediment conditions are within the range for which the Colby and modified Einstein methods were developed, use of the computational methods is preferable because the time and expense involved in measuring the bedload discharge can be eliminated. Of the two methods, the Colby (1957) method is the easier to use and could be used for estimates of total-sediment discharge within the study reach investigated in this report. However, when the hydraulic conditions and sediment characteristics deviate from the conditions for which the total-discharge methods were formulated, the advantages of measuring bedload increase.

FLOW-DURATION CURVES

The cumulative frequency of daily mean water discharges at a gaging station defines a flow-duration curve. Flow-duration curves show the percentage of time a specific water discharge was equaled or exceeded during the period of record. When many years of record are used, flow-duration curves describe the probable occurrence of various ranges of water discharge during any given year. Flow-duration curves used in this report are shown in figures 12 through 15. They pertain to a period when conditions appeared to have stabilized (Kircher and Karlinger, 1981) and large changes in flow and channel morphology no longer occur.

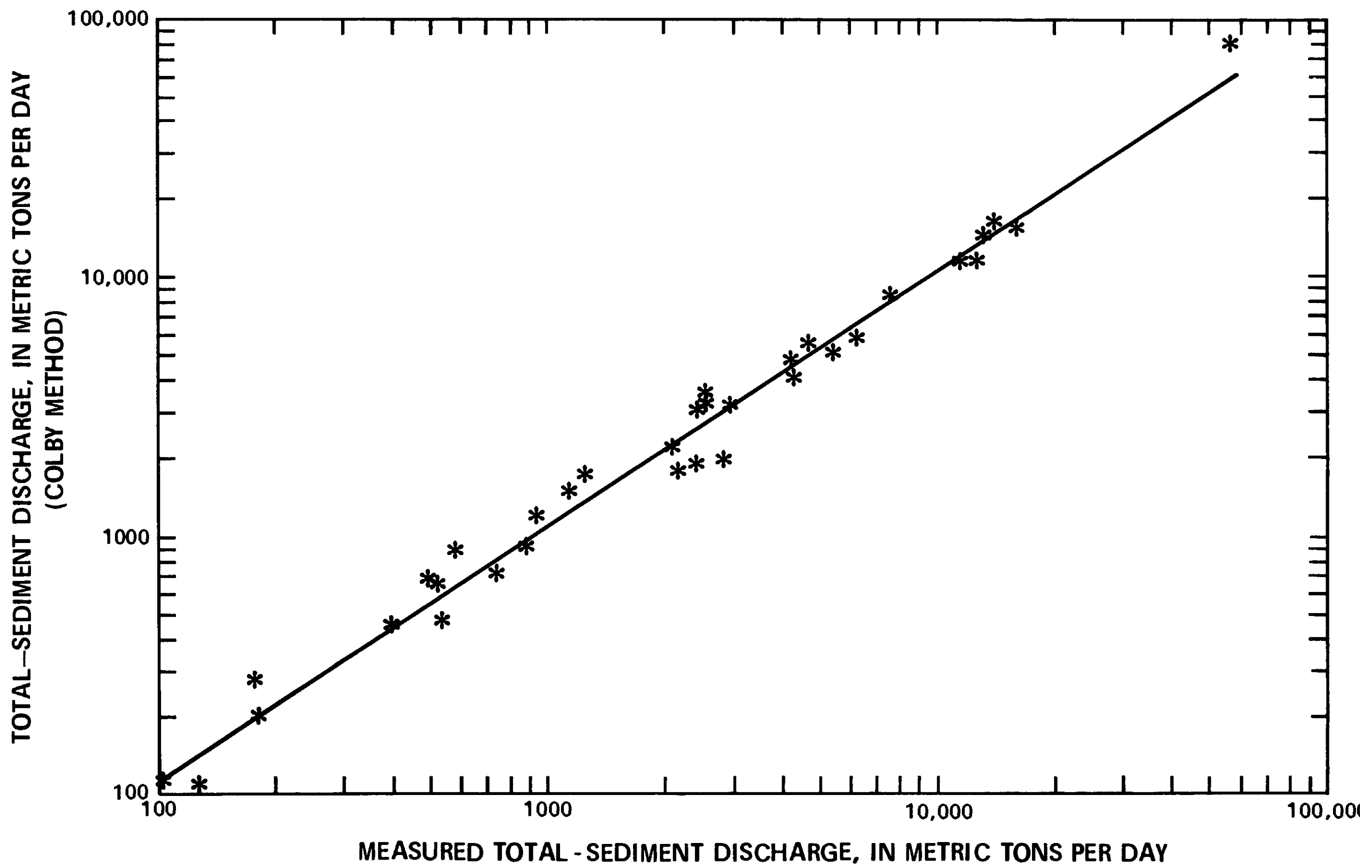

Figure 9.--Comparison of measured total-sediment discharge computed by the Colby (1957) method.

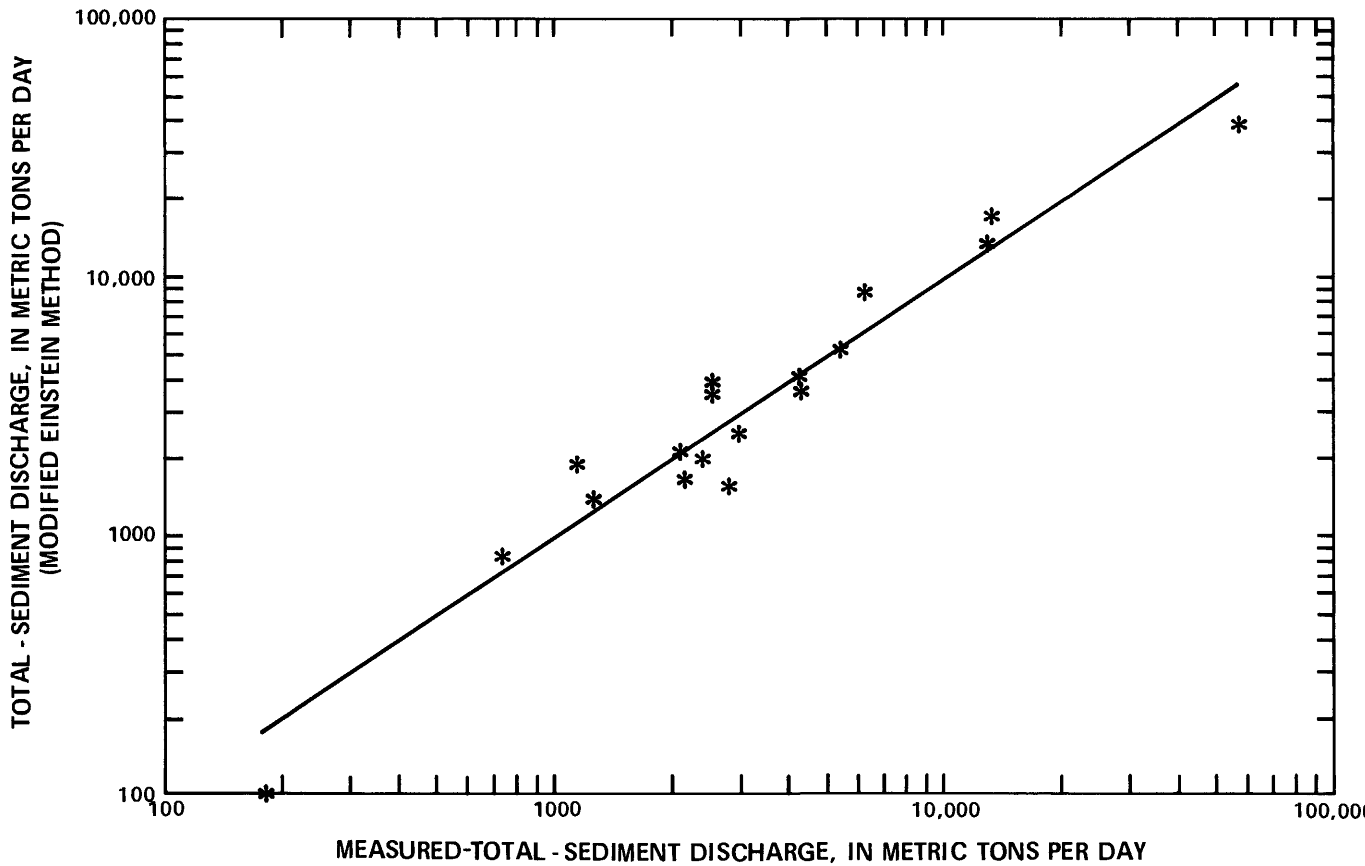

Figure 10.--Comparison of the measured-total-sediment discharge to the total-sediment discharge computed from the modified Einstein method (Colby and Hembree, 1955).

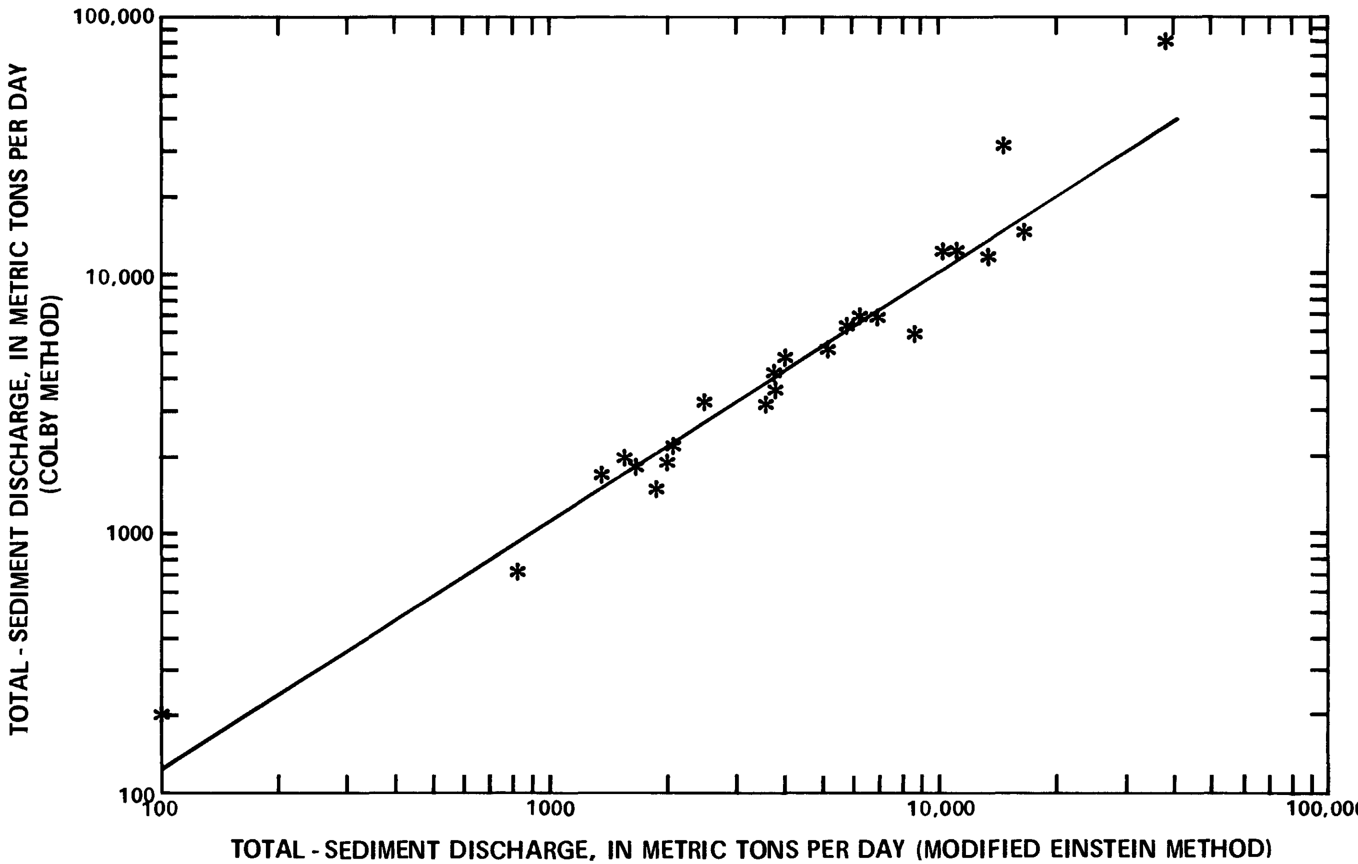

Figure 11.--Comparison of the total-sediment discharge computed by the modified Einstein method (Colby and Hembree, 1955) to the total-sediment discharge computed by the Colby (1957) method.

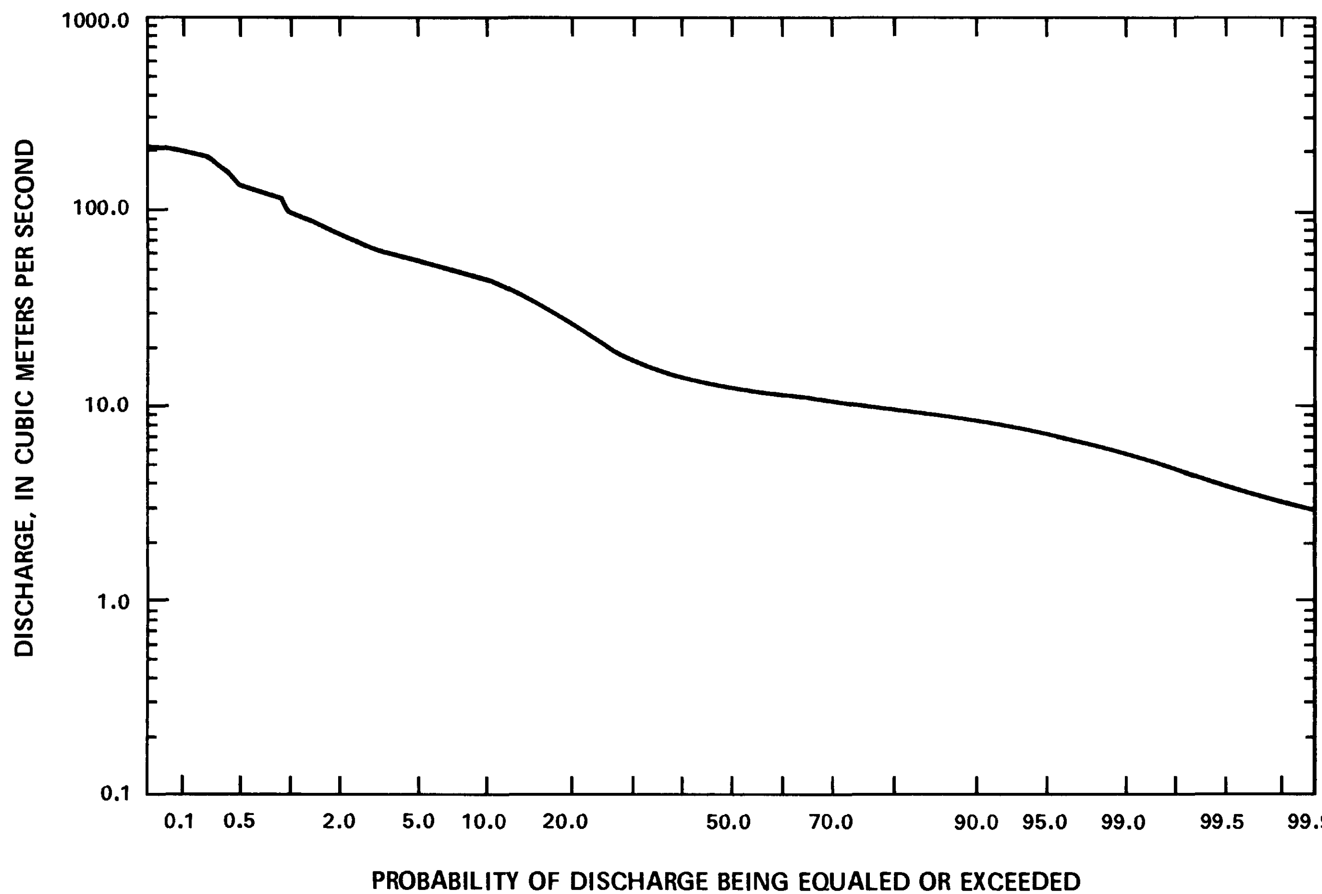

Figure 12.--Flow-duration curve for the North Platte River at North Platte (1941-79).

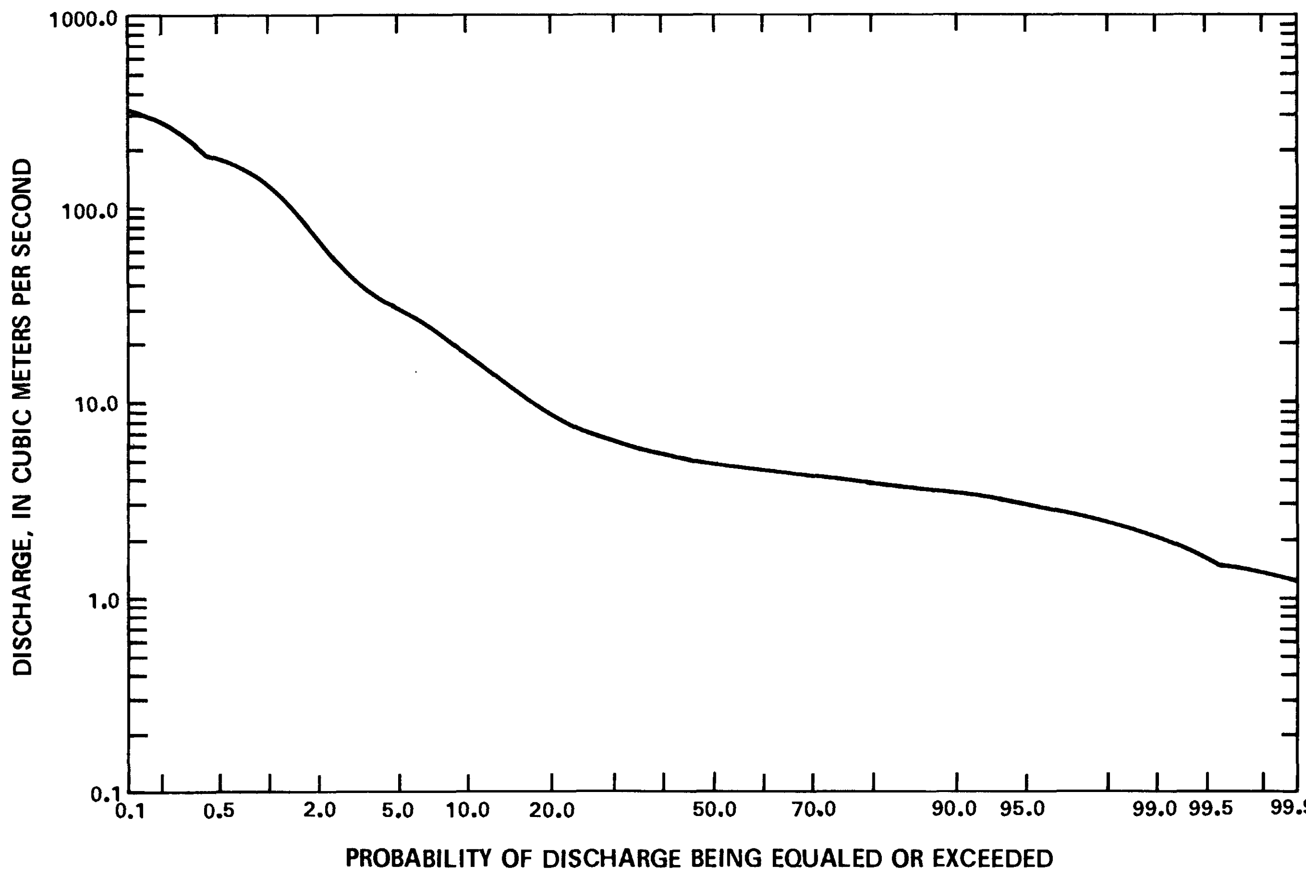

Figure 13.--Flow-duration curve for the South Platte River at North Platte (1941-79).

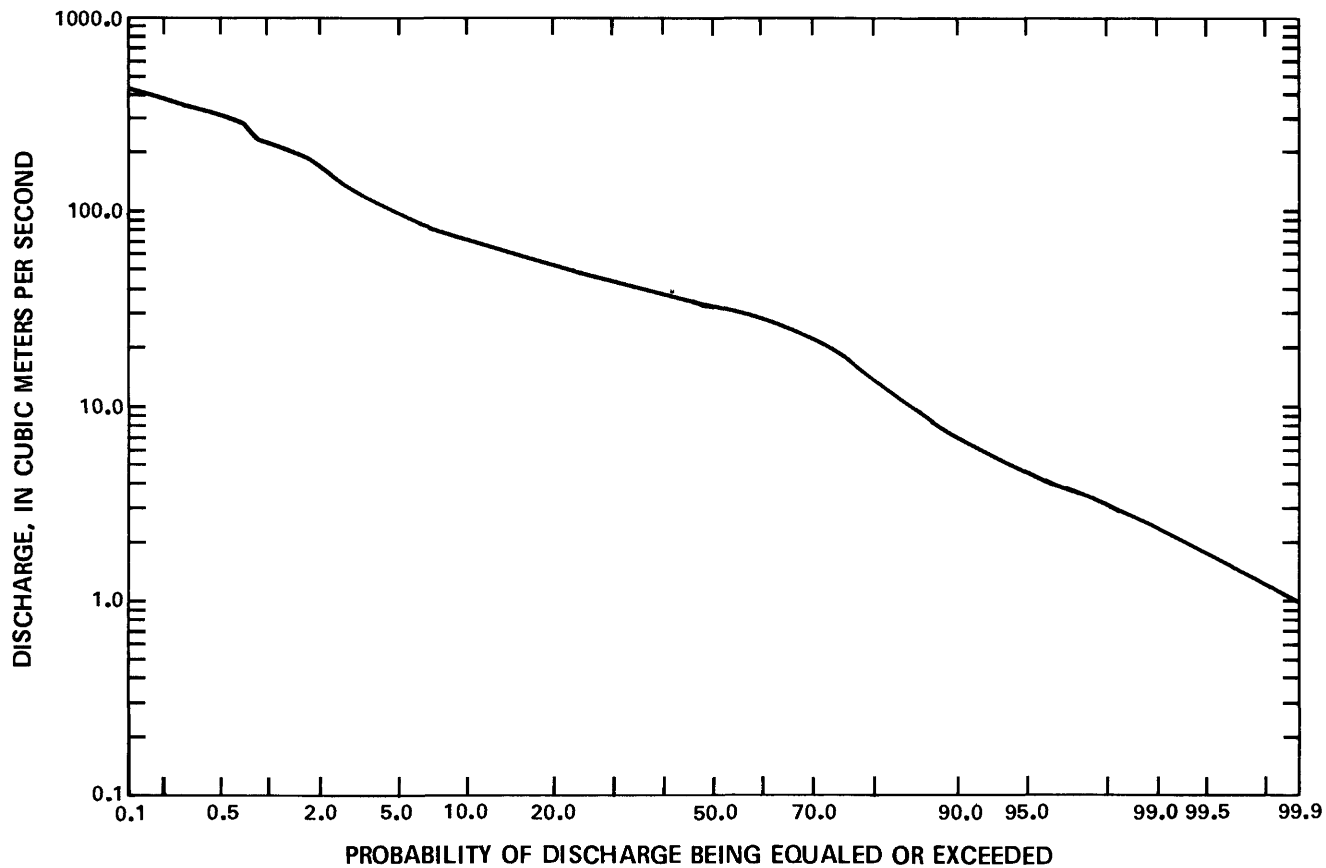

Figure 14.--Flow-duration curve for the Platte River near Overton (1950-79).

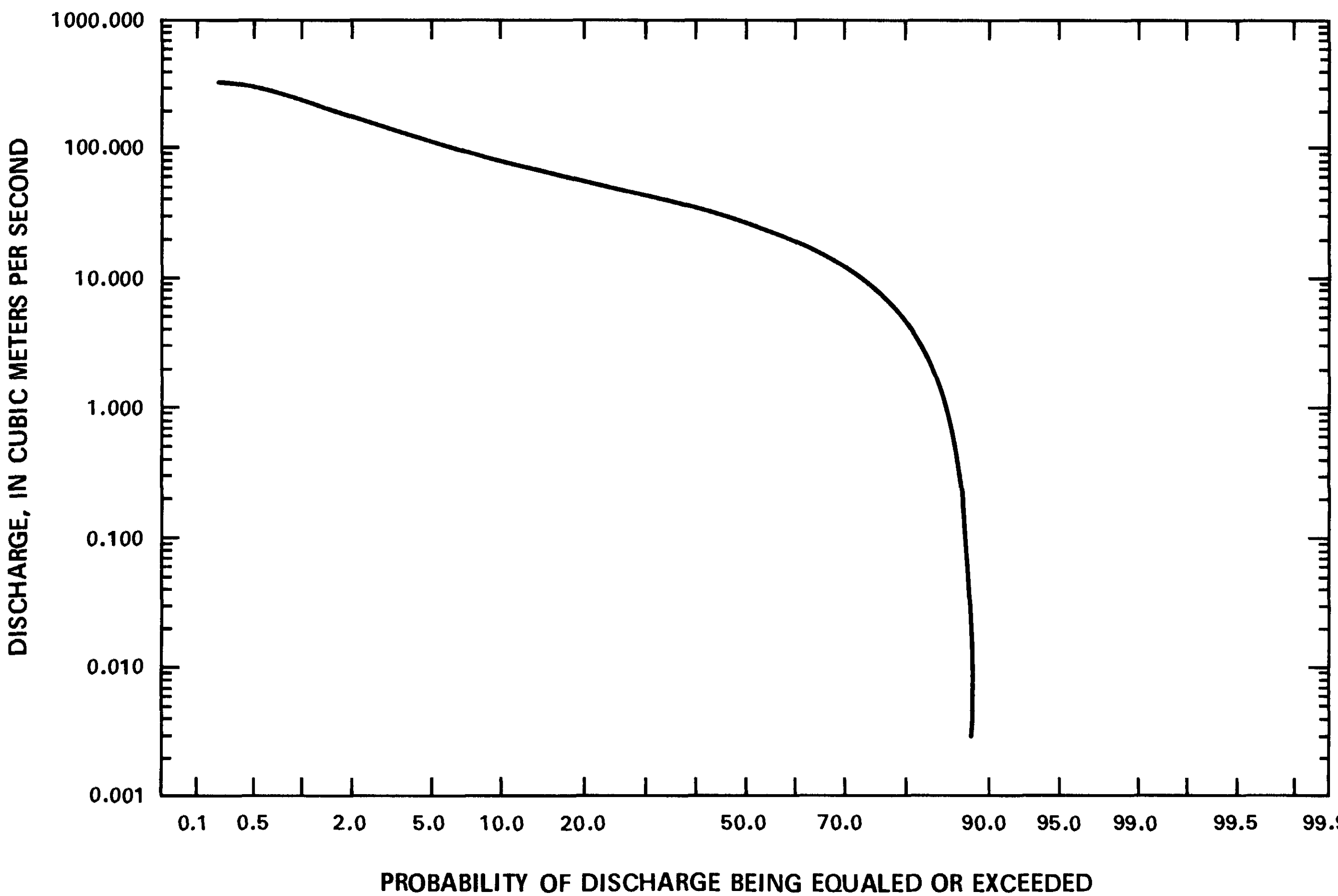

Figure 15.--Flow-duration curve for the Platte River near Grand Island (1935-79).

MEAN ANNUAL SEDIMENT DISCHARGE

Mean annual sediment discharge can be determined by calculating the expected value of sediment discharge [E(Qs)]. The expected value is defined as:

$$E(Qs) = \int_{o}^{\infty} Qs\ h(Qs)dQs \qquad (1)$$

where Qs = sediment discharge in metric tons per day;
h(Qs) = sediment density function;
and E(Qs) = expected value of the sediment discharge or mean annual sediment discharge in tons per day.

The sediment-density function is unknown, but Qs is a known function of water discharge from the sediment-discharge versus water-discharge relations. Therefore, by probability theory, the following substitution can be made for equation 1:

$$E(Qs) = \int_{o}^{\infty} g(Q)f(Q)dQ \qquad (2)$$

where g(Q) = Qs, in metric tons per day;
and f(Q) = the water-discharge density function.

The water-discharge density function can be obtained from the flow-duration curve. Although the analytical form of the flow-duration curve is unknown, the integral in equation 2 can be approximated by a summation of the discretized integrand, which has the following form:

$$E(Qs) \approx \sum_{j=1}^{N} g(Q_j)f(Q_j)\Delta Q_j \qquad (3)$$

With this form, the flow-duration curve could be divided into N equal intervals and the midpoint of each interval determined. The midpoint of each interval is then inserted into the sediment-discharge relations for each station, and a sediment-discharge value determined. This sediment-discharge value is then multiplied by the probability of occurrence of that associated water discharge $f(Qj)\ \Delta Qj$ to yield a weighted quantity of sediment. These weighted sediment-discharge values for N=69 are plotted against the water-discharge midpoint values (fig. 16). The summation of each of the plotted ordinate values gives an approximation of the expected value of the sediment discharge. The mean annual sediment discharge or expected value of sediment discharge is shown in tables 2 and 3.

EFFECTIVE DISCHARGE

The formation and maintenance of channel cross sections must be accompanied by the movement of sediment. Therefore, it seems logical to suggest a definition of effective discharge as the mean value of a narrow range of water

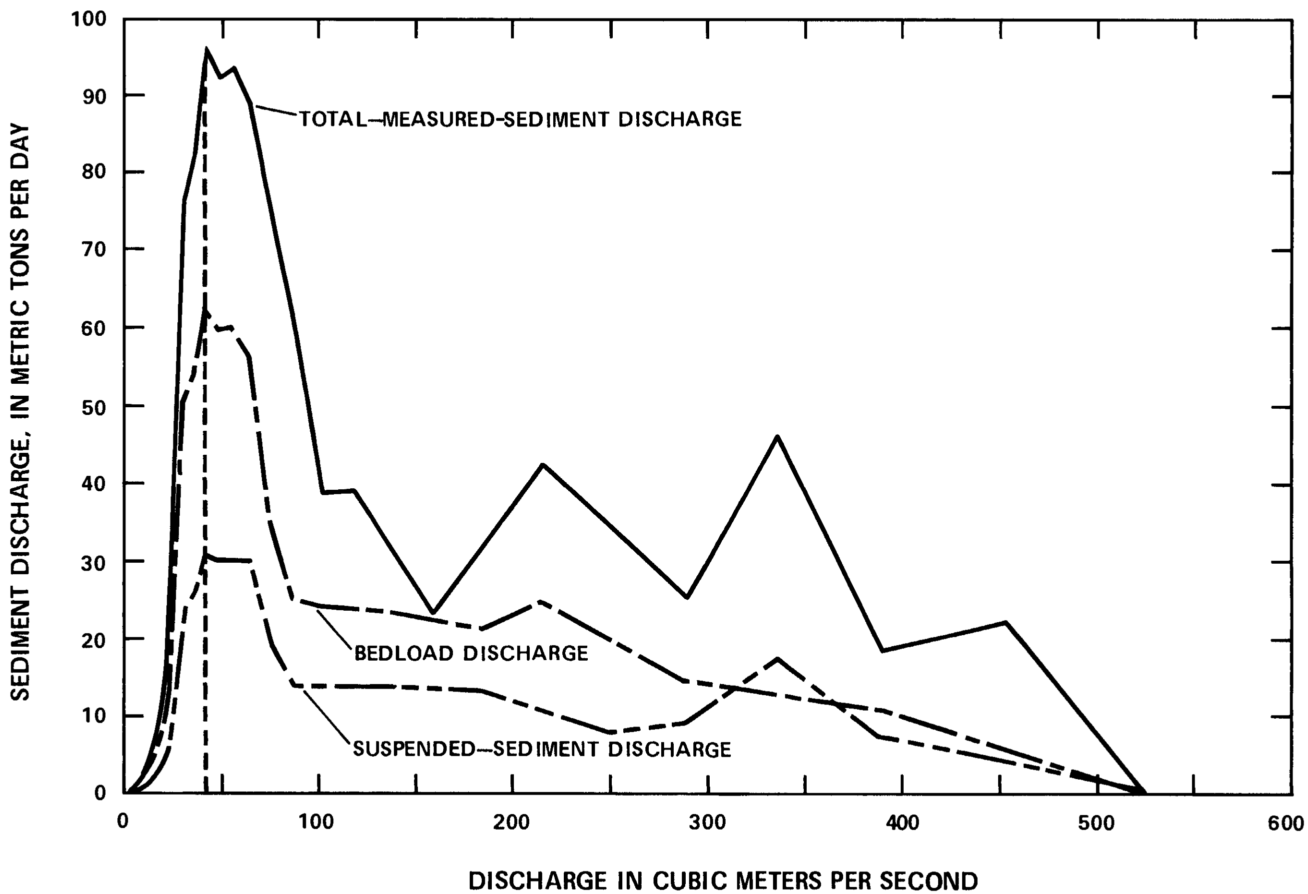

Figure 16.--Mean annual sediment-discharge transported by increments of discharge for the Platte River near Overton.

Table 2.--*Summary of effective discharge and expected value of sediment discharge for various categories of sediment transport at the four sampling sites*

[Q_E = effective discharge; m^3/s = cubic meters per second; E(X) = expected value of sediment discharge (mean annual total-sediment discharge); t/d = metric tons per day]

Sediment discharge category	North Platte River at North Platte, Nebraska		South Platte River at North Platte, Nebraska		Platte River near Overton, Nebraska		Platte River near Grand Island, Nebraska	
	Q_E (m^3/s)	E(X) (t/d)	Q_E (m^3/s)	E(X) (t/d)	Q_E (m^3/s)	E(X) (t/d)	Q_E (m^3/s)	E(X) (t/d)
Suspended-sediment discharge	48	415	158	150	41	445	55	514
Bedload discharge	48	226	158	178	41	694	55	732
Total measured sediment discharge	48	597	158	307	41	1,100	55	1,130
Total-sediment discharge computed by the Colby method (Colby, 1957)	48	848	158	370	41	1,120	55	1,260
Total-sediment discharge computed by the modified Einstein method (Colby and Hembree, 1955)	48	887	---	---	41	980	55	1,080

Table 3.--*Summary of mean annual water discharge and total-sediment discharge at the four gaging stations*

[km^2 = square kilometers; m^3/s = cubic meters per second; t/d = metric tons per day]

U.S. Geological Survey station number	Station name	Drainage area (km^2)	Mean annual water discharge (m^3/s)	Mean annual total-sediment discharge (t/d)	Effective discharge (m^3/s)	Probability of exceedance of effective discharge (percent)
06693000	North Platte River at North Platte, Nebraska	80,000	23.5	597	48	6
06765500	South Platte River at North Platte, Nebraska	62,900	9.5	307	158	1
06768000	Platte River near Overton, Nebraska	149,400	39	1,100	41	30
06770500	Platte River near Grand Island, Nebraska	152,300	35.6	1,130	55	22

discharge that, by virtue of its frequency of occurrence and transporting capacity, transports on the average more sediment during the period of record than any other comparable water discharge. The discharge that carried the most sediment during the period of record is the peak of the integrand of equation 2, or the peak summand in equation 3. This discharge is called the effective discharge, and is given in table 2 for the four sites in the Platte River basin between Grand Island and North Platte. The effective discharge was also computed for each of five sediment-discharge relations for each of the four sites shown in table 2. The effective discharge for each site using the total-measured sediment-discharge relation is summarized in table 3.

The effective discharge values computed and shown in tables 2 and 3 are based on 69 equal ln(Q) intervals and should be used with caution. The author found that the effective discharge values could vary by as much as 33 percent depending on the type (equal discharge or equal log of discharge) and degree of discretization used in the numerical integration. The effective discharge value shown is therefore an average and the actual value of effective discharge could be greater or less than the value shown.

EFFECTIVE DISCHARGE AND CHANNEL GEOMETRY

Changes in the channel characteristics of the Platte River can be examined by considering the effective discharge at each site. The formation and maintenance of channel cross-sectional characteristics are accomplished by sediment movement; and, as defined earlier, the water discharge that transports the most sediment is the effective discharge. Therefore, a direct relationship exists between channel size and effective discharge. If effective discharge is changed because of hydrologic changes, then a similar direction of change in channel cross-sectional area could be expected.

Effective discharge is a function of the flow distribution. The magnitude of the effective discharge most likely will be greater than the median of the distribution if the sediment-discharge curve is monotonically increasing, and the flow distribution has been divided into equal discharge intervals. If streamflow characteristics are changed by regulation such that high flows occur less frequently and low flows occur more frequently, then the difference between the median of the distribution and effective discharge can become smaller.

SUMMARY

Streamflow and sediment records from four gaging stations, (North Platte River and the South Platte River at North Platte, the Platte River near Overton, and the Platte River near Grand Island) were used to compute sediment discharge and to determine the effective discharge. Total-sediment discharge was determined by three methods: (1) By summing the measured bedload and suspended-sediment discharge; (2) by computing the Colby (1957) method; (3) and by computing the modified Einstein method (Colby and Hembree, 1955), for all four gaging stations. These three methods were then compared and found to agree closely; the Colby (1957) method was the easier to use.

The expected values of the total-sediment discharge (mean annual total-sediment discharge for the period of record) computed by combining flow frequencies and sediment-transport relations for the three total load methods ranged from 597 to 887 t/d (metric tons per day) for the North Platte River at North Platte, from 307 to 370 t/d (two methods) for the South Platte River at North Platte, from 980 to 1,120 t/d for the Platte River near Overton, and from 1,080 to 1,260 t/d for the Platte River near Grand Island.

Effective discharge values were computed for four sites in the Platte River basin based on 69 equal ln(Q) intervals. It was found that the effective discharge determined is highly dependent on the type and degree discretization used in the numerical integration. Therefore, caution should be used when determining an effective discharge for management purposes using the methodology presented in this report.

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