Sediment Transport in the Rio Grande New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 462-F

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By CARL F. NORDIN, JR., *and* JOSEPH P. BEVERAGE

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GLOSSARY OF TERMS

Bed material: The material composing the channel bed. For this study, bed material is considered all sediment coarser than 0.062 mm.

Bedload: Sediment that moves on or very near the streambed, in almost continuous contact with the bed. It moves by skipping, sliding, and rolling. Motion is derived from tractional and gravitational forces.

Concentration: The ratio of the dry weight of sediment to the weight of water sediment mixture of which it is part. Sediment concentration is commonly expressed in parts per million (ppm).

Fine material: All sediment finer than 0.062 mm; also called "wash load."

Sediment discharge: A time rate of movement of sediment passing a cross section; also called "sediment transport rate" or "sediment load." In this report, all sediment discharges are given in tons per day.

Suspended load: Sediment that is generally supported by turbulence and is transported at about the velocity of the water.

Total sediment load: All the sediment being moved by the stream, that is, suspended load and bedload.

Unit water discharge: Water discharge for unit width of a stream.

Unit bed-material discharge: Discharge of bed material (material coarser than 0.062 mm) per unit width of a stream.

SYMBOLS

Symbol	Definition	Unit
a	A coefficient	0
B	Width	ft
b	An exponent	0
C	Chezy discharge coefficient	ft$^{1/2}$ per sec
$c/\sqrt{g}$	Dimensionless Chezy coefficient	0
C_T	Bed-material concentration	0
D	Mean depth	ft
d	Median diameter of bed material	mm
d_{65}	Diameter of bed material for which 65 percent by weight, is finer	mm
g	Acceleration due to gravity, assumed constant and equal to 32.2	ft per sec^2
k_s	Representative grain roughness, d_{65}	ft
Q	Water discharge	ft^3 per sec
Q_T	Total bed-material discharge	tons per day
q	Unit water discharge	ft^3 per sec per ft
q_T	Unit bed-material discharge	tons per day per ft
S	Water-surface slope	0
S_e	Standard error of estimate	0
T	Water temperature	°F
U_*	Shear velocity, $\sqrt{gDS}$	ft per sec
U'_*	Shear velocity associated with the grain roughness	ft per sec
V	Mean velocity	ft per sec
X	An independent variable	0
x	A correction factor for transition from smooth to rough boundary	0
Y	A dependent variable	0
γ	Unit weight of water	lbs per ft^3
γ_s	Unit weight of sediment	lbs per ft^3
ρ	Density of the fluid	slugs per ft^3
ρ_s	Density of the sediment	slugs per ft^3
τ_0	Bed shear stress, γDS	lbs per ft^2
τ'	An effective shear, $\rho(U'_*)^2$	lbs per ft^2
ϕ_T	A dimensionless transport function	0
ψ'	A dimensionless shear parameter	0

SEDIMENT TRANSPORT IN ALLUVIAL CHANNELS

SEDIMENT TRANSPORT IN THE RIO GRANDE, NEW MEXICO

By Carl F. Nordin, Jr., and Joseph P. Beverage

ABSTRACT

This report describes hydraulic data, observed and computed sediment concentrations, and size distributions of bed-material samples for 293 observations and presents the results of a series of investigations at six sediment stations on the Rio Grande in New Mexico.

The Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex., the farthest upstream station, has a typical pool-and-riffle channel configuration, and the bed material consists of both sand and gravel. The Rio Grande at Cochiti and at San Felipe has a sand-gravel channel, but the marked controlling influence of riffles is lacking. The three downstream stations, near Bernalillo, at Albuquerque, and near Belen, have sand-bed channels. Slopes through the 110-mile reach range from about 12 feet per mile at Otowi to 4 feet per mile near Belen.

Transport rates of bed material computed by the modified Einstein method are related to the simple hydraulic variables, discharge, unit discharge, and velocity, for each of the stations. The sediment transport relations are found to vary systematically in a downstream direction, that is, with bed-material size, and to fall into two distinct groupings, one for the confined or partially confined sections and the other for the laterally unrestricted sections. Sediment transport rates are greater at the wide sections for higher discharges and greater at the narrow sections for the lower flows, probably because the wider sections have a tendency to aggrade and channelize at the lower flows.

Flow characteristics differ markedly for the pool-and-riffle channel at Otowi and the sand-bed channel near Bernalillo. At Otowi, the depth, slope, bed shear stress, resistance to flow, and the bed-material size all increase with increasing discharge. Near Bernalillo, slope and bed-material characteristics are approximately constant, flow resistance, which is dependent upon bed configuration, decreases with increasing discharge, and the range in bed shear stress, compared to Otowi, is very limited.

The mean velocities and sediment discharges for the two stations are comparable, in spite of the wide differences in flow characteristics. Sediment transport rates are found to relate reasonably well to "effective shear," a measure of the shear stress resisted by the grain roughness only. However, the variable size distribution of the bed material introduces considerable scatter for the Otowi relation. The scatter is reduced by converting the shear-transport relations to dimensionless form, similar to the parameters used by Einstein (1950, Bagnold (1956). and A. A. Bishop ("Sediment transport in alluvial channels: a critical examination of Einstein's theory: Colorado State Univ. Ph. D. thesis, 1961). Consideration of the curves developed by Bishop to predict total bed-material discharge and of the dimensionless relations for the Rio Grande indicate that to be generally applicable, the shear stress-transport functions probably should include additional parameters to explain the influence of temperature and the effects of flow depth. Systematic changes in bed-material characteristics for Otowi introduce changes in the sediment transport, independent of the hydraulics of the flow; a single simple parameter such as median diameter or a representative grain size is, therefore, not sufficient for characterization of the bimodal distribution of the bed material in the shear stress-transport functions.

The influence of temperature on sediment transport for the Rio Grande data is apparent, but a precise quantitative evaluation is impossible because the effects of temperature changes are not independent of the effects of interrelated changes in other variables.

INTRODUCTION

The sediment transported by natural streams often is an important factor in the design of reservoirs, conveyance channels, river rectification works, and related projects. To assist in understanding the complex phenomena of the mechanics of flow and sediment transport in alluvial channels and to provide basic data for the development of design methods and criteria, numerous laboratory and field studies have been undertaken. The Rio Grande in New Mexico has been the site of several investigations in sediment transport. This report presents the results of a series of investigations at six gaging stations on the middle Rio Grande in New Mexico.

PURPOSE AND SCOPE

The purpose of this report is to present observed sediment transport relations and to discuss some of the parameters describing the sediment and the flow which influence transport relations.

Sediment transport rates computed by the modified Einstein method (Colby and Hubbell, 1961) are given for 293 observations at the six gaging stations. The transport rates are related to simple hydraulic variables for each station, and the differences in the relations, from station to station, are discussed in terms of the bed-material size distributions and of the geometry of the cross sections.

The characteristics of flow and transport for a station with a pool-and-riffle channel configuration and for a sand-bed channel are compared, and the influence of bed-material size distribution and water temperature on sediment transport is considered briefly.

ACKNOWLEDGMENTS

The data presented for the period 1952–58 were collected as a part of a joint program between the U.S. Geological Survey and the U.S. Bureau of Reclamation.

This report was prepared under the supervision of J. M. Stow, district chemist, Albuquerque, N. Mex. W. L. Heckler, district engineer, Santa Fe, N. Mex., furnished the flow-duration curves and much of the basic hydraulic data from streamflow measurements.

DESCRIPTION OF THE REACH

Figure 1 is a location map of six gaging stations which are considered in this report. The stations, in downstream order, are:

Rio Grande at Otowi Bridge, near San Ildefonso
Rio Grande at Cochiti
Rio Grande at San Felipe
Rio Grande near Bernalillo
Rio Grande at Albuquerque
Rio Grande near Belen

From Otowi Bridge to Cochiti, through White Rock Canyon, the Rio Grande has a typical pool-and-riffle configuration. The riffles are composed of coarse gravel, cobbles, and boulders, and appear to be fairly stable and permanent features of the channel. Large cobbles and even boulders evidently move from the riffles during flood flows, but the relative shape and position of the riffles do not appear to change appreciably from year to year. At low discharges, the water-surface slope through the riffles is steep, the depth is shallow, and flow is supercritical. Because the riffles serve as controls, the water-surface slope through the pools may be very low, the depth is greater, and flow is subcritical. The bed material in the pools is sand at low flows and sand and gravel (a bimodal distribution) at high flows. At the Otowi station, the channel is confined, and the maximum width at the measuring section is about 150 feet.

Between Cochiti and San Felipe, the channel is braided between many bars and islands composed of coarse gravel and cobbles. As at Otowi, the bed is composed of sand at low discharges and of sand and gravel at higher flows. The cross section at Cochiti is relatively wide and unconfined; flow width varies upward to about 350 feet. At San Felipe, the channel is confined by a volcanic talus on the right bank and stable clay banks on the left; the maximum width at the measuring section is about 210 feet.

Downstream from the confluence of the Jemez River, the Rio Grande is a sand-bed stream. The Bernalillo station has a confined measuring section, and for all discharges more than about 2,000 cfs (cubic feet per second), the flow width is approximately constant at 270 feet.

During high flows, the discharge measurements and samples were obtained from highway bridges for the Rio Grande at Albuquerque and near Belen. However, except for local influence near the bridge piers, both of the sections are relatively unconfined, and flow widths range upward to about 400 feet at both sections.

A profile of the cannel from Otowi to Belen, a reach of about 110 miles, is shown in figure 2. Channel slopes range from 12 feet per mile near Otowi to about 4 feet per mile near Belen. The rate of change in slope with distance is nearly constant from Belen upstream to the Jemez River. From the Jemez River to White Rock Canyon, about 2 miles upstream from Cochiti, the slope increases rapidly. Through White Rock Canyon, the slope is nearly constant.

Nordin and Culbertson (1961) showed that the characteristics of the bed material in the middle Rio Grande change systematically with distance downstream from Otowi. This systematic variation is indicated by the average size distribution curves plotted in figure 3.

The behavior of the three downstream sections, which are sand-bed channels, and that of the three upstream sections, which are sand-gravel channels, differ significantly. These differences and some of their effects on the sediment-transport relations for the various sections will be discussed subsequently.

Three of the sections, Otowi, San Felipe, and Bernalillo, are confined or partially confined, but the other three stations are laterally unrestricted. The influence of width restrictions upon bed configuration and flow resistance has been demonstrated (Nordin, 1964), and sediment transport relations are also affected by lateral channel confinement, as will be shown.

BASIC DATA

The basic hydraulic data from water-discharge measurements and the water temperatures used in the modified Einstein calculations are given in tables 1–6. Also shown in the tables are the suspended-sediment concentrations from depth-integrated samples and computed total concentrations determined from modified Einstein calculations.

Tables 7–12 show the particle-size distribution of bed-material samples for each of the observations listed in tables 1–6. Most of the particle-size analyses of suspended-sediment samples used in the modified Einstein calculation have been previously published. Table 13 shows the sources in which these published data may be found. A few particle-size analyses not previously published are given in table 14.

Water-surface slopes were determined for many of the observations and are listed in tables 1–6. If water-

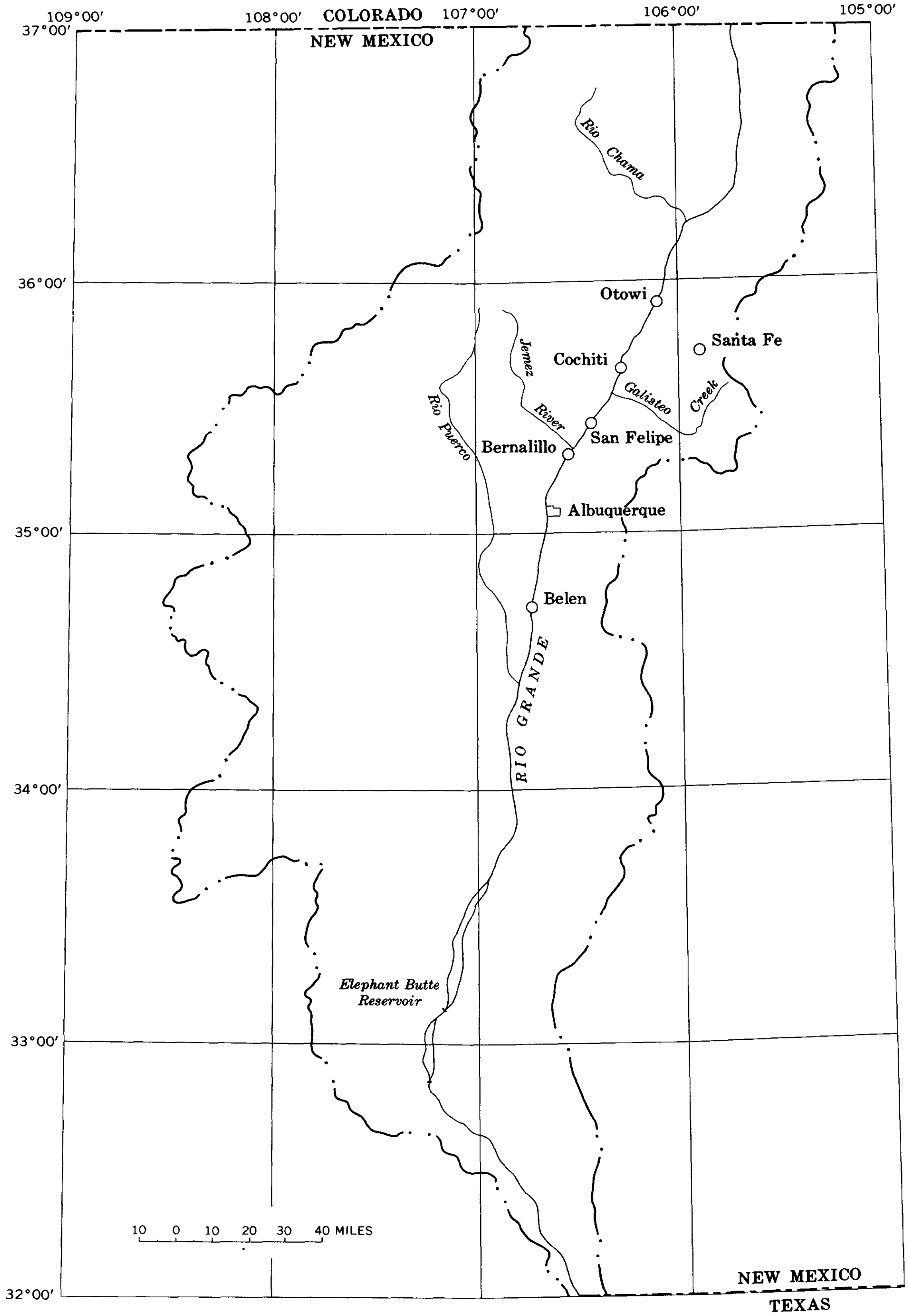

FIGURE 1.—Map showing part of the Rio Grande drainage basin. Adapted from U.S Geological Survey New Mexico base map, scale 1:500,000.

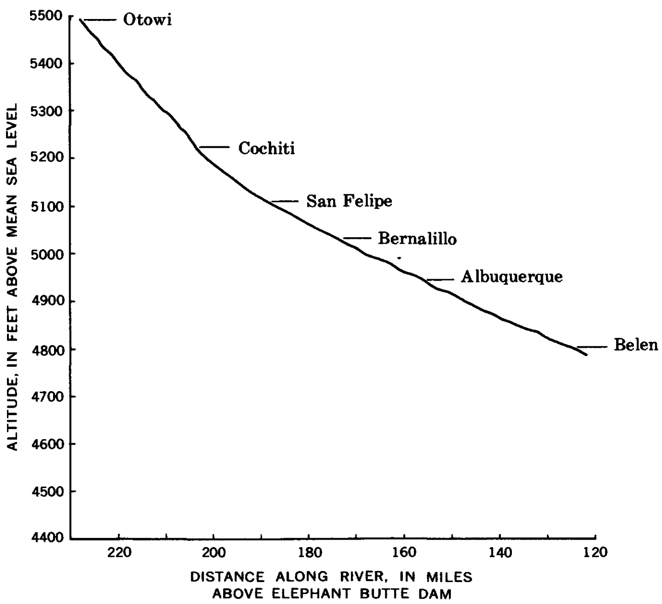

FIGURE 2.—Channel profile of the Rio Grande from Otowi Bridge to Belen.

surface slopes were not observed, the average water-surface slope or the average bed slope determined from Bureau of Reclamation aggradation-degradation studies are shown.

Streamflow records for the six stations are given in Part 8 of the Geological Survey Water-Supply Paper series "Surface-Water Supply of the United States." The station near Belen was discontinued in June 1957.

The stations at Otowi and near Bernalillo are daily sediment stations. Suspended-sediment loads for these stations and the results of miscellaneous observations at the other four stations are listed in Part 8 of the Water-Supply Paper series, "Quality of Surface Waters of the United States."

In addition to the Water-Supply Papers noted above and listed in table 13, the writers have drawn freely from data used or presented in previous studies of the Rio Grande (Culbertson and Dawdy, 1964; Nordin and Culbertson, 1961; Nordin and Dempster, 1963; Nordin, 1964).

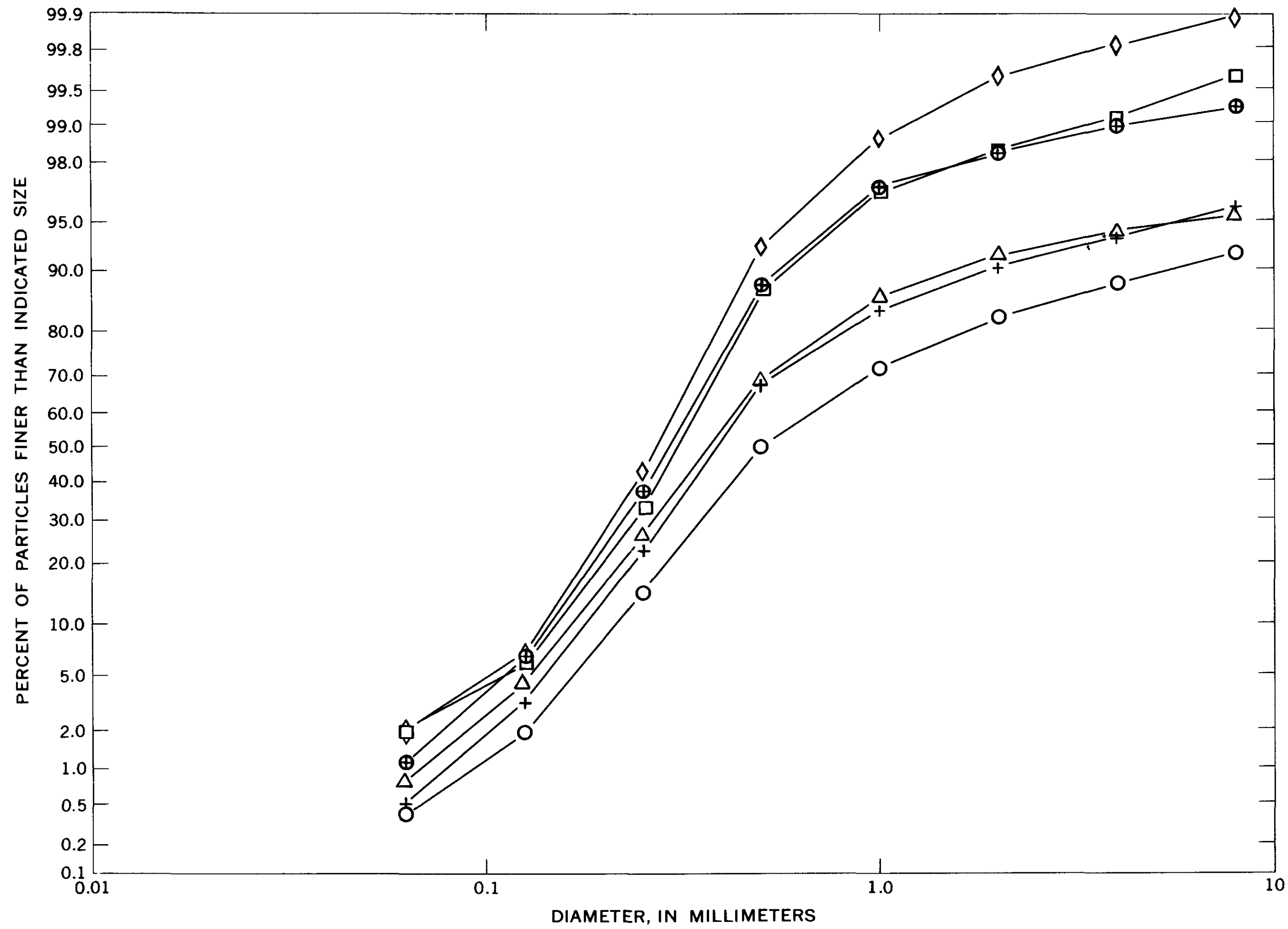

FIGURE 3.—Graph showing average size distribution of bed material. ○, Otowi; +, Cochiti; △, San Felipe; ⊕, Bernalillo; □, Albuquerque; ◇, Belen.

FLOW CHARACTERISTICS AND SEDIMENT CONCENTRATION

Flow in the Rio Grande is derived principally from snowmelt from the high mountains of northern New Mexico and southern Colorado. The spring runoff commences usually in March and persists for several months. El Vado Reservoir controls the flow of the Rio Chama and, within the limitations of the Rio Grande Compact, permits the regulation of continuous flow in the Rio Grande below Otowi during the irrigation season. Releases from El Vado Reservoir to downstream storage occasionally result in several months of sustained winter flow.

From Cochiti downstream, flow in the Rio Grande is depleted heavily by irrigation and by natural losses. Although the flow is generally perennial at Otowi and Cochiti, it is usually intermittent at Albuquerque and Belen. Flow-duration curves for the period of record through 1959 or 1960 (fig. 4) show clearly the influence of irrigation and natural losses during the lower discharges.

Although by far the greatest volume of flow in the Rio Grande is from spring runoff and reservoir releases, tributary inflow from summer storms of short duration and high intensity may contribute appreciable quantities of flow and large quantities of sediment. Galisteo Creek, entering the Rio Grande from the east about 8 miles downstream from the Cochiti station, is the largest tributary between Otowi and Belen and contributes heavy sediment loads to the Rio Grande. The Jemez River, joining the Rio Grande from the west about 8 miles north of the Bernalillo station, has been

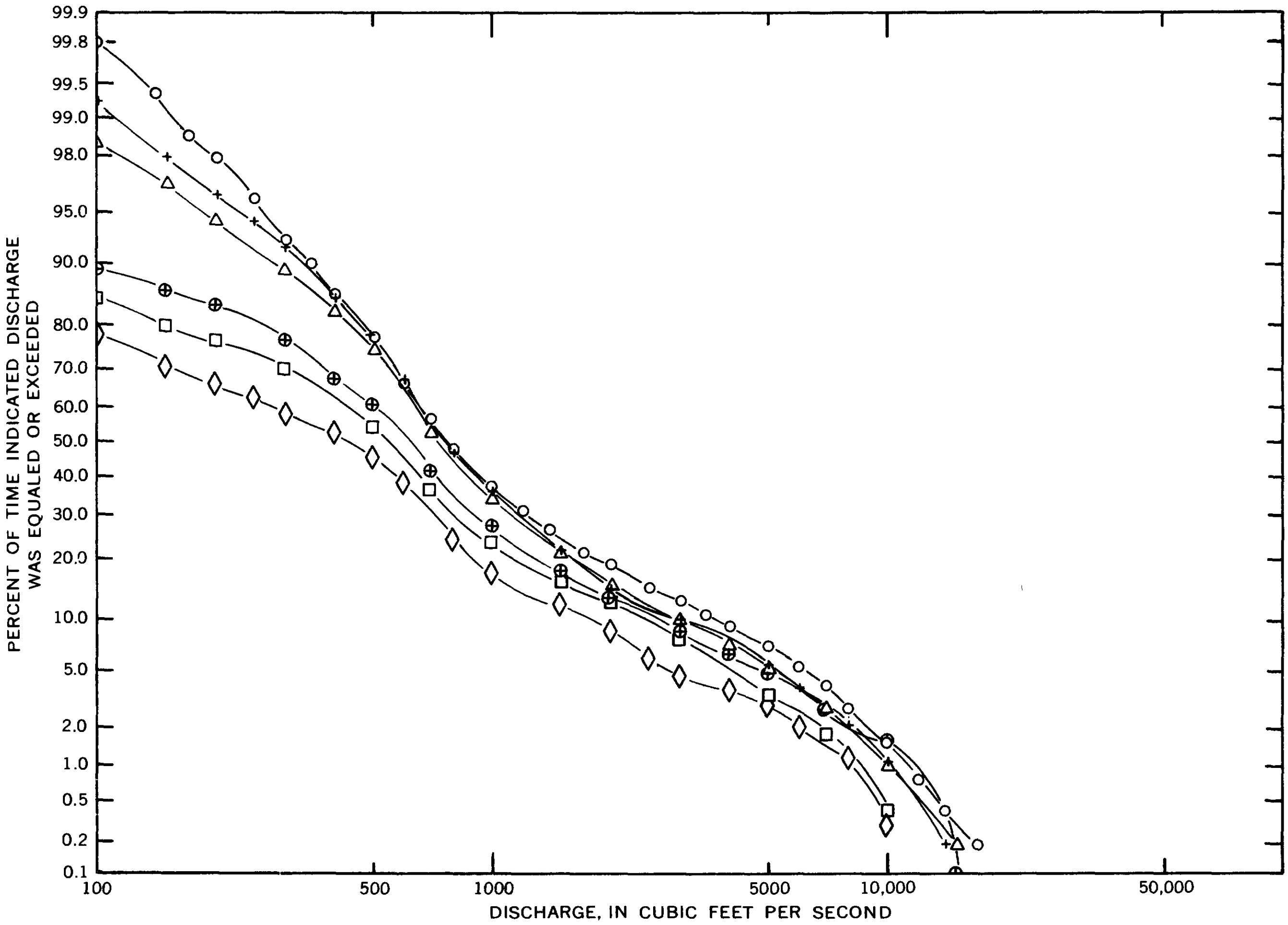

FIGURE 4.—Flow-duration curves for the period of record.

Station	*Period of record*
○ Otowi	1896–1905, 1910–14, 1919–59
+ Cochiti	1927–60
△ San Felipe	1928, 1931–60
⊕ Bernalillo	1942–59
□ Albuquerque	1943–60
◇ Belen	1943–56

regulated by the Jemez Canyon Reservoir since October 1953, hence inflow from this tributary did not influence appreciably the sediment transport relations presented herein.

Tributary runoff from "thunderstorm" rainfall imposed upon main-channel flow will create a sharp peak in both the flow and the concentration of suspended sediment. The instantaneous peak discharge from such storm runoff is often as great as or even greater than the peak discharge during spring runoff from snowmelt, but the duration is brief, persisting from a few hours to a few days. After the peak of the storm runoff passes a measuring section, both the discharge and the concentration attenuate with time, approaching the more or less stable condition which persisted before the inflow, provided, of course, that the main-channel flow is reasonably constant. The concentration attenuates much more slowly than the water discharge (Nordin, 1964). The time dependency of the concentration is noticeable in either the total concentration or in the concentration of any particular size class, but the rate of attenuation with time appears to vary directly with the size class of the suspended sediment.

Variations of daily mean water discharge, concentration, and water temperature for the Rio Grande at Otowi Bridge and Rio Grande near Bernalillo, New Mex., are shown in figures 5 and 6, respectively. The general shapes of the hydrographs and of the temperature and concentration curves for the two stations are similar, and during the spring runoff, as during storm runoff, the sediment concentration tends to decrease with time, independent of flow conditions. However, during spring runoff, changes in concentration are usually accompanied by changes in water temperature, whereas during a storm-runoff event in late summer or fall, changes in concentration may be independent of temperature changes.

The similarity in the discharge and concentration curves for the two stations suggests that the sediment transport relations for the stations should also be similar but some noticeable differences in the hydraulic variables of the two sections merit consideration.

HYDRAULIC VARIABLES

Pertinent hydraulic variables, so far as sediment transport is concerned, are the mean velocity (V), the mean depth (D), the product of depth and slope, or the shear stress on the bed (γDS), and the ratio of velocity to shear, which is a measure of the channel flow resistance. More specifically, the ratio of mean velocity (V) to shear velocity (U_*) may be taken as a measure of the overall channel roughness and is equal to Chezy's dimensionless coefficient $C/\sqrt{g}$.

Except for the bank friction, the overall channel roughness in a natural channel with a movable bed depends upon (1) the grain roughness and (2) the roughness due to bed configurations—the ripples, dunes, and bars which form on the bed. In general, only the part of the overall shear which is resisted by the grain roughness is effective in moving the bed material (Einstein, 1950; Laursen, 1958). Thus, the size distribution of the bed material, which determines the grain roughness, is a major factor in determining the effective shear stress. Strictly speaking, grain size cannot be classified as a hydraulic variable, but, because of the close relation of grain size to hydraulic factors, the size distribution of bed material will be considered in this section.

Some of the basic differences in behavior between the sand-bed channels of the Rio Grande and the channels that have a pool-and-riffle configuration and a bimodal distribution of bed material may be detected by considering the relations of simple hydraulic variables to discharge. For comparison, Otowi may be taken as a typical pool-and-riffle channel and Bernalillo as a typical sand-bed channel.

Figure 7 shows the observed water-surface slopes plotted against water discharges for Otowi and Bernalillo. The plotted points represent the data for 1958–62 from tables 1 and 4, excluding the June 24, 1958, observation at Otowi, which was not at the cable section, and the February 15, 1960, observation at Bernalillo, for which no slope was obtained. The slope at Bernalillo was approximately constant at about 0.0008, but the slope at Otowi increased with discharge and, for the range of discharge considered, varied by a factor of about 3.

Water-surface slopes at Otowi, plotted in figure 7, were measured over a relatively short reach, about 10 to 15 times the channel width, and are representative of the slopes through the pools, not the overall slope through a long reach. At low flows, the riffles serve as controls. At higher discharges, the controlling influence of the riffles is drowned out, and the water-surface slope approaches the natural topographic slope of the channel, about 12 feet per mile (0.0023).

At Bernalillo, the water-surface slope is about constant regardless of the length of reach considered, although the scatter about the average value is much greater when the slope is measured over shorter reaches.

Figure 8 shows mean velocity, depth, and width plotted against discharge, after the manner of Leopold and Maddock (1953). Lines were drawn through the plotted points, and the equations for the lines are shown on figure 8. The lines for Bernalillo were not extended below 2,000 cfs because there is an apparent break in

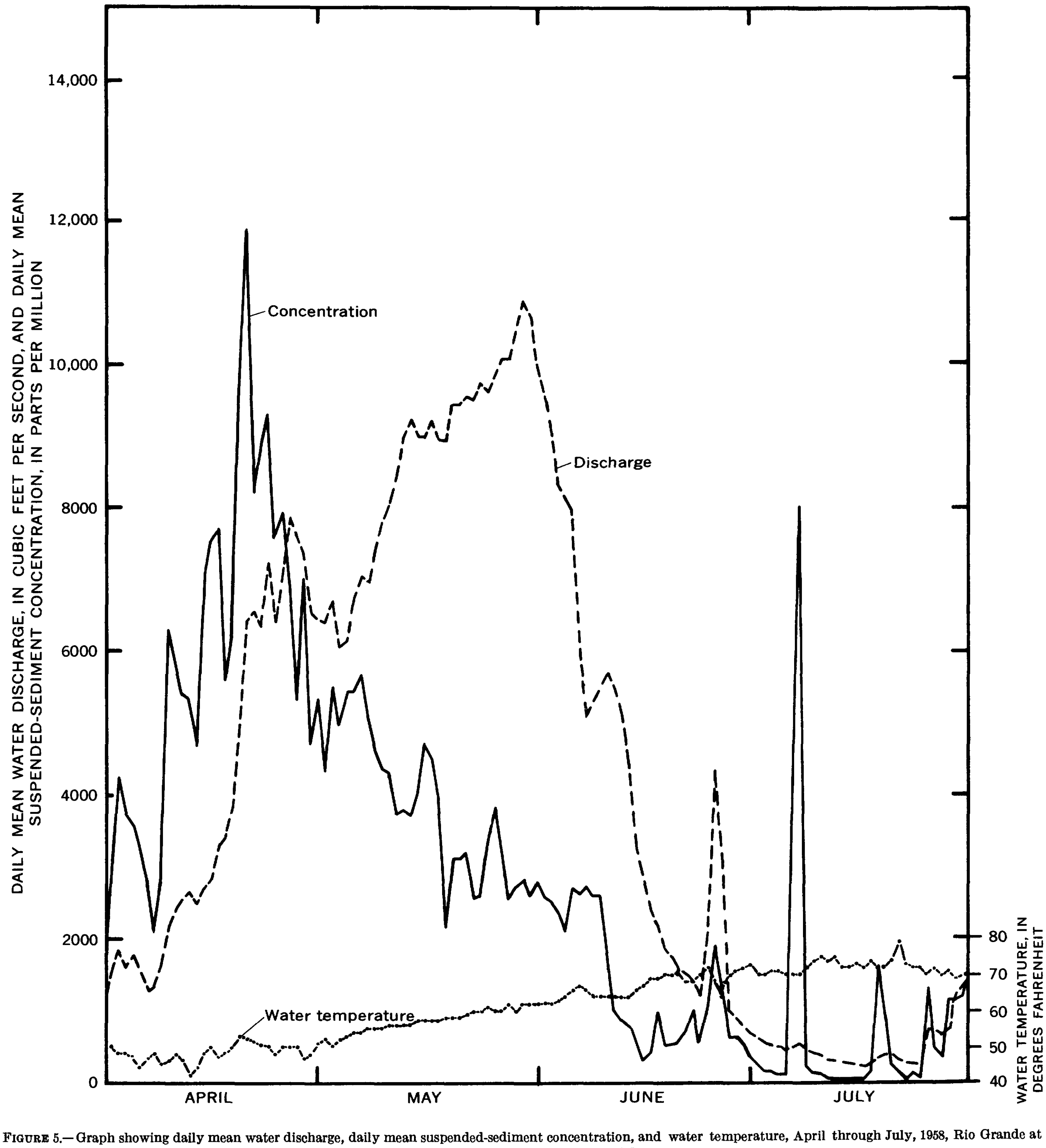

FIGURE 5.—Graph showing daily mean water discharge, daily mean suspended-sediment concentration, and water temperature, April through July, 1958, Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.

the relation at lower discharges when channelization occurs.

The exponents for the equations relating velocity to discharge are greater than the average exponents given by Leopold and Maddock (1953, p. 9) because, for the range of discharge considered, the measuring sections at both Otowi and Bernalillo are partially confined.

Figure 8 shows that the depth is greater and increases more rapidly with discharge at Otowi and that the range in velocity is about the same at both stations.

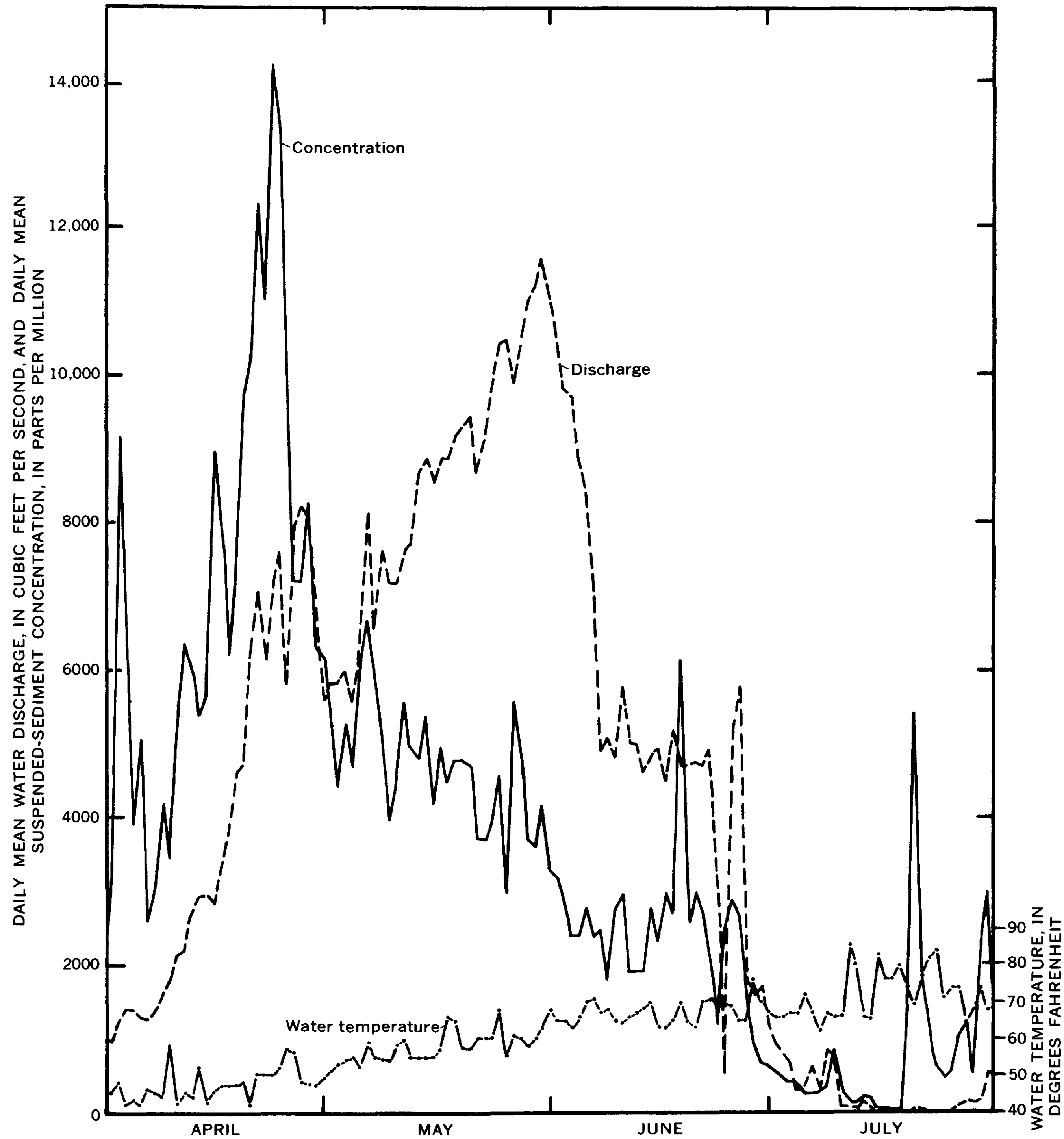

FIGURE 6—Graph showing daily mean water discharge, daily mean suspended-sediment concentration, and water temperature, April through July, 1958, Rio Grande near Bernalillo, N. Mex.

Because both depth and water-surface slope increase with discharge more rapidly at Otowi than at Bernalillo, it may be concluded that the relation of the velocity to the shear stress is different for the two stations. Figure 9 shows the bed shear stress ($\tau_0=\gamma DS$) for Bernalillo and Otowi plotted against discharge. For the same range in velocities, the shear stress at Bernalillo varies from about 0.05 to 0.24, or by a factor of 5, while the shear stress at Otowi varies from about 0.03 to 1.50, by a factor of 50. Because shear stresses for

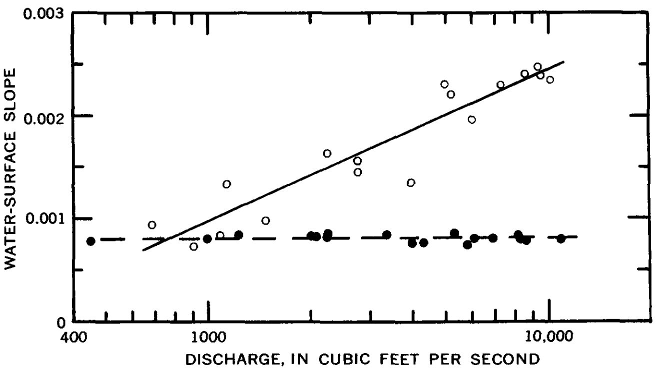

FIGURE 7.—Graph showing relation of water-surface slope to discharge for the Rio Grande at Otowi Bridge and near Bernalillo. (○, Otowi; ●, Bernalillo.)

Otowi were computed using local water-surface slopes through a pool, the range in shear stress is greater than if an average water-surface slope including both pools and riffles had been used.

These observations show the basic distinction between the hydraulics of the pool-and-riffle channels and of the sand-bed channels of the Rio Grande—the difference in the relation of flow resistance to discharge In the sand-bed channels, flow resistance is dependent mostly upon bed configuration. Flow may be classified conveniently into lower regime flow over a dune bed and upper regime flow over a plane bed (Culbertson and Dawdy, 1964). Between upper and lower regimes of flow is a transition region in which bed configurations and flow resistance vary widely. Lower regime flow is characterized by low sediment discharge and high flow resistance. Conversely, for upper regime flow, the sediment transport rate is high and the flow resistance is extremely low, dependent mostly upon grain roughness (Dawdy, 1961).

In pool-and-riffle channels, however, the flow resistance often increases with discharge, and the influence of the bed configuration at low flows appears to be completely overshadowed by the controlling influence of the riffles. A distinguishing feature of a pool-and-riffle channel is that at low discharges the energy dissipation is nonuniformly distributed along the channel and is concentrated at the riffles, whereas, at higher discharges, the distribution of energy dissipation approaches a more uniform condition along the channel.

Figure 10 shows the relation of $C/\sqrt{g}$ to discharge for Bernalillo and Otowi. The dashed lines show the approximate average values of $C/\sqrt{g}$ for lower and upper regime flow at Bernalillo; the solid line shows the trend of $C/\sqrt{g}$ values for Otowi. A $C/\sqrt{g}$ value of about 8 for the highest discharges at Otowi represents an extremely high flow resistance, greater than the resistance for flow over a well-defined dune bed.

The increase in the flow resistance with discharge at Otowi is due in part to the influence of bank roughness and in part to changes in the size distribution of the bed material which accompany the higher flows. The effects of the bank roughness may be accounted for, at least crudely, by the method outlined by Einstein (1942). The influence of the changing size distribution of the bed material requires additional consideration.

For most practical purposes, the particle-size distribution of the bed material for the sand-bed channels of the Rio Grande may be considered invariant and independent of discharge (Nordin and Culbertson, 1961). At Otowi, on the other hand, the size distribution of the bed material varies widely and erratically. The deviation of the median diameter about the average value from figure 3 is shown in figure 11, where median diameter (d) is plotted against water discharge.

As table 7 shows, the distribution of the bed material at Otowi sometimes is bimodal, and, although the dominant mode is composed of sand and the median diameter is usually in the sand size class (0.062–2.00 mm), the percentage of gravel is appreciable. The percentage of gravel in the bed material appears to vary roughly with discharge and also with time during a single runoff event. Antecedent conditions are probably important.

The size distributions of bed material in table 7, however, represent only material from the measuring section at Otowi—that is, from the pool. The material composing the riffles is much coarser, ranging in size from coarse gravel to boulders many feet in diameter.

At high flows, above 4,000 cfs, the overall flow resistance at Otowi is practically constant in spite of wide variations in the percentage of gravel in the bed material. Possibly, the flow resistance is independent of grain roughness at these higher discharges. However, the bed material generally becomes coarser with higher discharges, hence the grain roughness is at least partially responsible for the high flow resistance. The difficulties of obtaining representative samples of coarse gravel beds preclude adequate evaluation of a representative grain roughness.

For sand-gravel channels of the Rio Grande where riffle controls are lacking, the hydraulic behavior is between that of a sand-bed channel and that of a pool-and-riffle channel. Cochiti and San Felipe, for example, have the characteristics of sand-bed channels at discharges below about 2,000 cfs. The bed configuration is dunes, the size distribution of the bed material and the water-surface slope vary conservatively, and the flow resistance, which depends mostly upon bed configuration, decreases with discharge. At flows above 2,000 cfs, the bed material becomes coarser and flow resistance increases with discharge.

An increase in the size of the bed material is not necessarily accompanied by a decrease in the bed

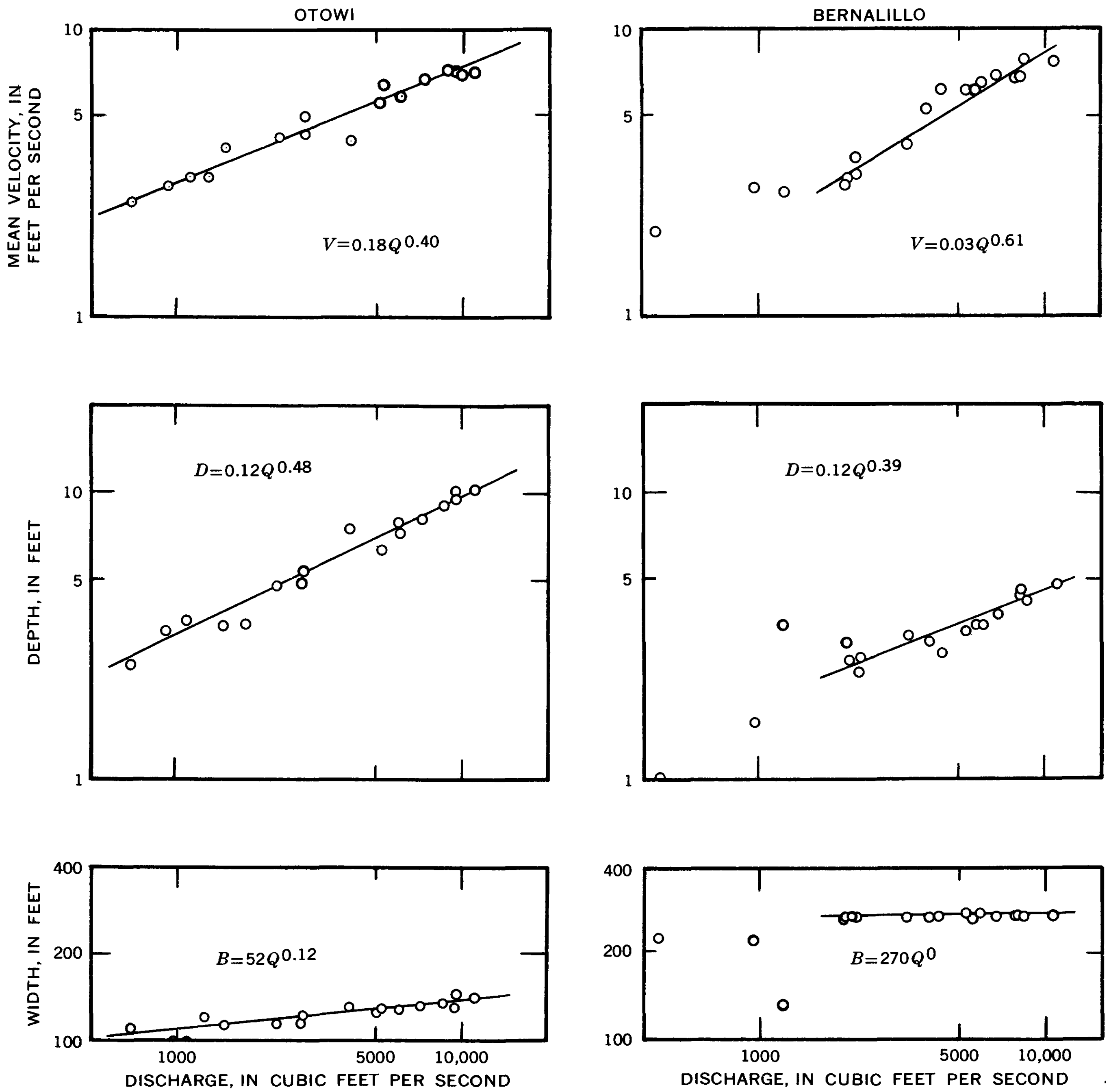

FIGURE 8.—Graph showing relation of width, depth, and velocity to discharge for the Rio Grande at Otowi Bridge and near Bernalillo.

elevation. The channel does not need to scour to the source of the coarser material; the gravel is actually transported into the reach from an upstream source, probably from the gravel bars and temporary islands which form at low and intermediate discharges.

Summarizing, for the sand-bed channels of the Rio Grande, the characteristics of the bed material and the water-surface slope are approximately constant. The flow resistance is dependent upon bed configuration and decreases with discharge until a plane bed occurs, whereupon the resistance, measured by $C/\sqrt{g}$, becomes approximately constant. At Otowi, where the channel has a pool-and-riffle configuration, the size of the bed material, the water-surface slope, and the flow resistance all increase with increasing discharge. The stations at Cochiti and San Felipe behave as sand-bed channels at lower flows, whereas, at higher flows, the size of the bed material and the flow resistance increase with discharge.

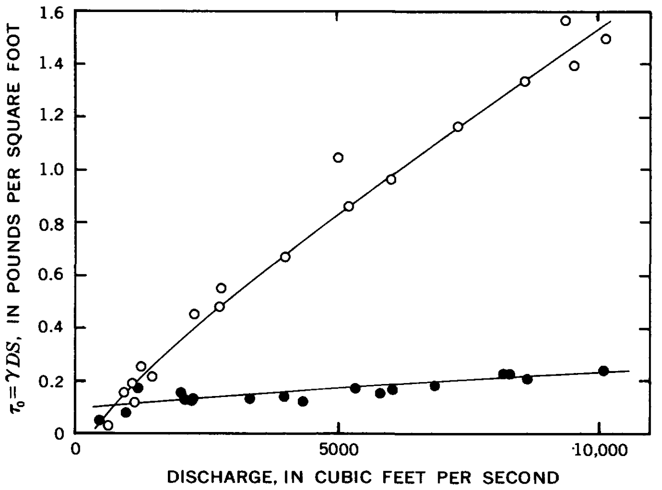

FIGURE 9.—Graph showing relation of bed shear stress (τ_0) to discharge for Rio Grande at Otowi Bridge and near Bernalillo. ○, Otowi; ●, Bernalillo.

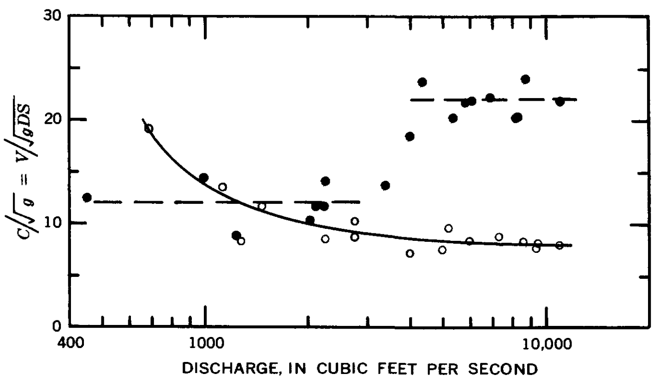

FIGURE 10.—Graph showing relation of $C/\sqrt{g}$ to discharge for the Rio Grande at Otowi Bridge and near Bernalillo. ○, Otowi; ●, Bernalillo.

TRANSPORT RELATIONS

The various components of the sediment load of streams, which is the total quantity of sediment being moved by a stream, can be defined in terms of (1) the method of movement and (2) the source. In defining the components by method of movement, a distinction is made between the suspended sediment, or suspended load, and the bedload. The suspended load is the sediment in suspension which is transported at about the velocity of the water. The bedload is the sediment that moves by sliding, rolling, or skipping on or very near the streambed.

In defining the sediment load by source, a distinction is made between the fine material, which is commonly called "wash load" (Einstein, 1950), and the coarse material, which is usually referred to as the "bed-material load." The bed-material load is that part of the sediment load of a stream which is composed of particle sizes found in appreciable quantities in the shifting portions of the streambed. The fine-sediment load is that part of the sediment load of a stream which

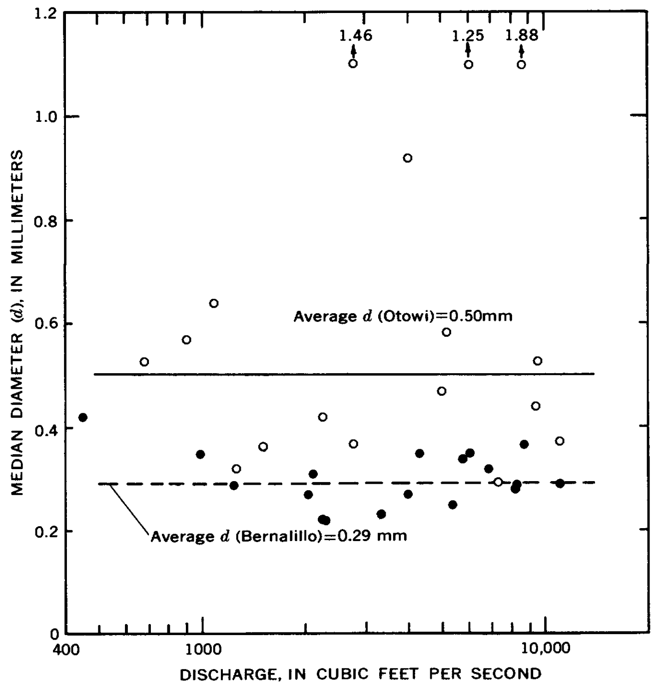

FIGURE 11.—Graph showing relation of median diameter of bed material to discharge for the Rio Grande at Otowi Bridge and near Bernalillo. ○, Otowi; ●, Bernalillo.

is composed of particle sizes finer than those generally found in shifting portions of the streambed.

As defined above, the only distinction between the fine-sediment load and the coarse-sediment load is one based upon the size distribution of the bed material. Such a definition gives little insight into the mechanics of sediment transport. Arbitrary definitions are therefore adopted which are based upon the properties of the two types of loads.

In general, the fine material is delivered to a channel by surface runoff, its transport rate is governed by the rate at which it is made available, and it is never transported at stream capacity, except in the upper limiting case of a mudflow. On the other hand, the transport rate of bed material moving past a given cross section in a stream presumably is governed solely by the ability of the flow to move the material. Bed material is always transported at the stream capacity, bacause any material in excess of stream capacity is immediately deposited and any deficit of material may be replenished by scouring the bed.

From a practical viewpoint, then, the bed material may be defined as that part of the sediment load for which a functional relation exists between the transport rate and the flow. The transport rate of fine material is not functionally related to the flow.

The distinction between the bed material and the fine material sometimes is quite obvious from histograms of the size distributions of bed-material samples and suspended-sediment samples, as shown in figure 12.

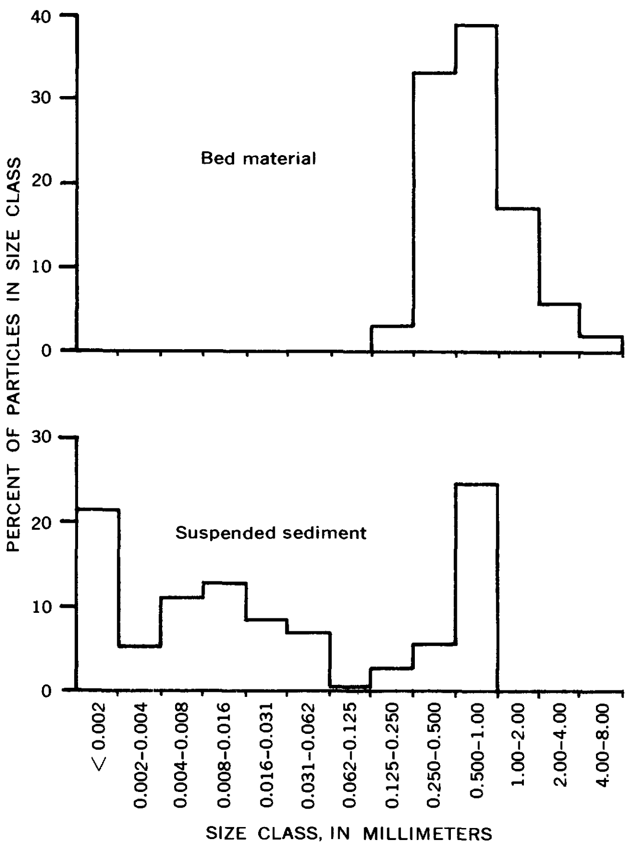

FIGURE 12.—Histograms of size distributions of bed material and suspended sediment for Rio Grande at Otowi Bridge, July 20, 1961.

Because none of the material finer than 0.062 mm is found in the bed material, it must be assumed that all material finer than this size is wash load. At other times, especially if large quantities of fine sand are transported, the distinction is not so simple. Material in the size class from 0.062 to 0.125 mm may behave as bed-material load at low flows and as wash load at higher flows, especially in the reaches that have pool-and-riffle channel configurations and in reaches in which extremely low discharges or periods of no flow occur. However, even though a functional relation between the flow and the discharge of finer sand sizes is not always readily apparent, observations show that decreases in the transport rates of these sand sizes are accompanied by decreases in the percentage of the same size classes in the composition of the bed material (Nordin and Beverage, 1964). These observations support the conclusions of Einstein and Chien (1953), who suggested that there is basically no difference in the interrelations of the flow, transport rate, and bed composition for the so-called wash load and the bed-material load, provided the composition of the surface layer of the bed is adequately defined. However, because it is virtually impossible, under most field conditions, to obtain adequate samples of the surface layer of the bed, the distinction between bed-material load and fine-material load must be maintained.

In this report, all material coarser than 0.062 mm is considered bed material. Of course, inclusion of the finer sand sizes may introduce some unexplained scatter in the transport relations, but the relation between the flow and the transport rate of material coarser than 0.062 mm is as well defined as are the relations for only the coarser fractions. Figure 13 is a plot of unit discharge (water discharge per foot of width) against unit bed-material discharge (bed-material discharge per foot of width) for transported materials (*A*) coarser than 0.062 mm, (*B*) coarser than 0.125 mm, and (*C*) coarser than 0.250 mm for the Rio Grande at Otowi Bridge. The lines shown were fitted by least squares. The standard errors of estimate were computed for each relation and are shown by the broken lines on the graph. The standard error is a measure of the relative scatter of the plotted points about the line of relation—that is, approximately two-thirds of the points fall within plus or minus one standard error, in log units.

The use of the 0.062-mm size as the break between bed material and fine material has the practical advantage of coinciding with the break between the sand sizes and the silt-clay sizes. Also, in general, material finer than 0.062 mm is uniformly distributed, vertically and laterally, in a cross section. Thus, a sample at any point in the cross section usually will give a representative picture of the transport rate of the fine material.

TRANSPORT RATES RELATED TO SIMPLE HYDRAULIC VARIABLES

For comparison purposes, transport rates can be related to hydraulic variables as simple power functions of the form

$$Y = aX^b. \tag{1}$$

Station-to-station differences can be investigated in terms of the intercepts (a) and slopes (b) of the various relations. The formulas can be determined by fitting a straight line through logarithmic plots of the variables considered.

For this report, lines were fitted to the plotted points by the method of least squares. For some practical applications, lines fitted to the arithmetic averages of the dependent and independent variables for selected intervals of the independent variable might be more desirable (Colby 1956, 1957); however, group averages often yield curvilinear relations, which are difficult to compare, rather than the simple linear relation in terms of logarithms of equation 1.

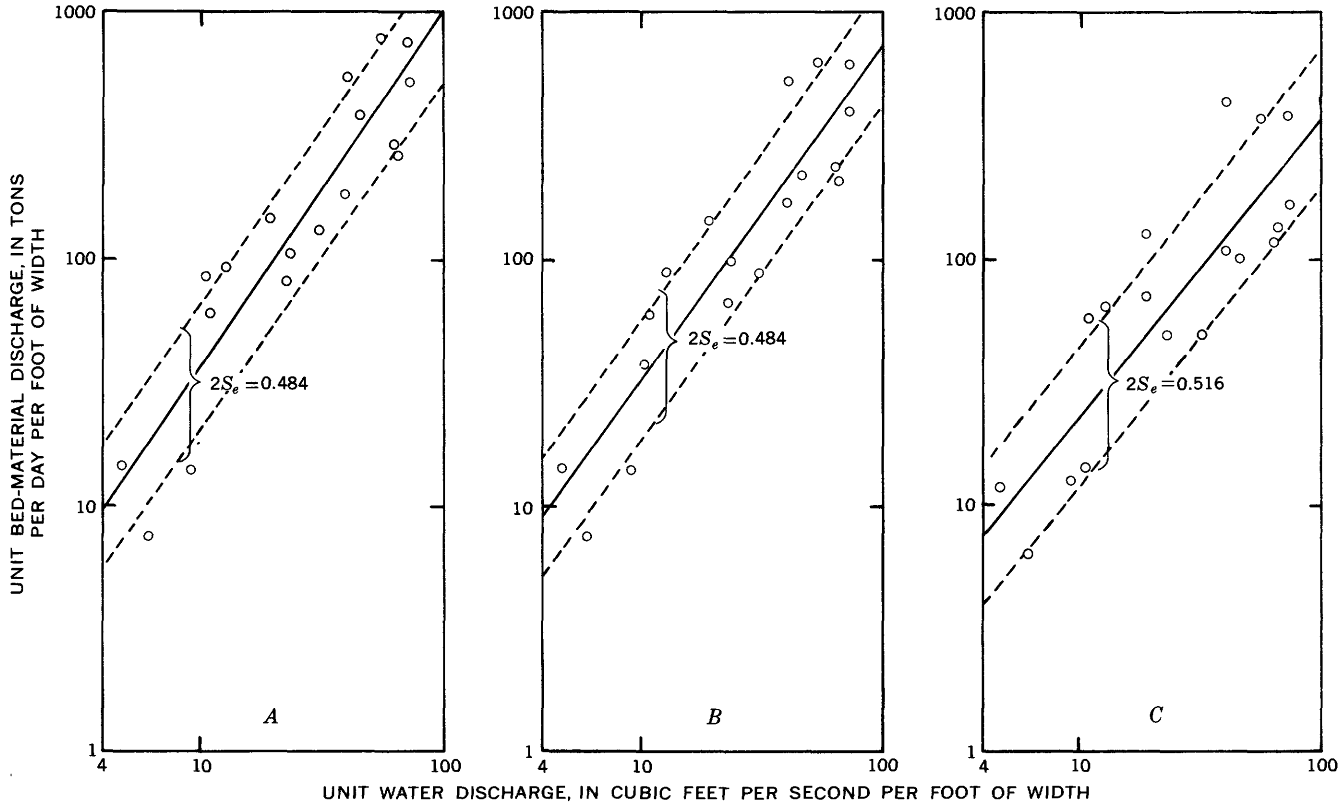

FIGURE 13.—Graphs showing unit bed-material transport rates for the Rio Grande at Otowi Bridge for material. *A* coarser than 0.062 mm; *B* coarser than 0.125 mm; and *C* coarser than 0.250 mm.

The relations for a given station are not directly comparable to the relations for another station unless the data for both stations cover the same periods of time, runoff events, and range of flow conditions. These qualifications are met only for Cochiti and San Felipe. For the other stations, especially Otowi and Belen, for which only a limited number of observations were available, the validity of the comparisons are open to question. In the following discussion, therefore, emphasis is given to the qualitative aspects of the relations.

From the data in tables 1–6, four types of transport equations were determined for each station; the following relations were defined: bed-material discharge (Q_T) to water discharge, (Q) (fig. 14*A*), unit bed-material (q_T) to unit water discharge (q) (fig. 14*B*), unit bed-material discharge to mean velocity (V) (fig. 14*C*), and (4) bed-material concentration (C_T) to mean velocity (fig. 14*D*).

The individual observations for each of these relations, together with the lines determined by the method of least squares, are plotted for the Rio Grande near San Felipe in figure 14. The amount of scatter about the lines is typical of such relations and gives a reasonable indication of the magnitude of errors which might be introduced if such relations are used to estimate transport rates.

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Table 15 gives the equations for each of the relations for the six stations and the standard error of the estimate (S_e) in terms of log units and percentages (of the values given by the curve).

Logically, the relations, in terms of the standard errors, are better defined for the narrow confined sections than for the wider sections because both the simple hydraulic variables and the factors entering the total load calculations are more difficult to measure or sample accurately at the wider sections.

Figures 15–18 show the plotted lines for each of the computed relations in table 15. The lines are drawn through the approximate range for which they were defined.

Two important features of the curves are immediately apparent: (1) the slopes of the curves (the exponent b in eq. 1) tend to increase with distance downstream from Otowi and (2) the curves fall into two distinct groups, one group representing the confined sections at Otowi, San Felipe, and Bernalillo and the other group representing the unconfined sections at Cochiti, Albuquerque, and Belen.

Both of these characteristics of the curves might be expected, at least for some of the relations. The increasing exponent in a downstream direction may result from the decreasing bed-material size. For a

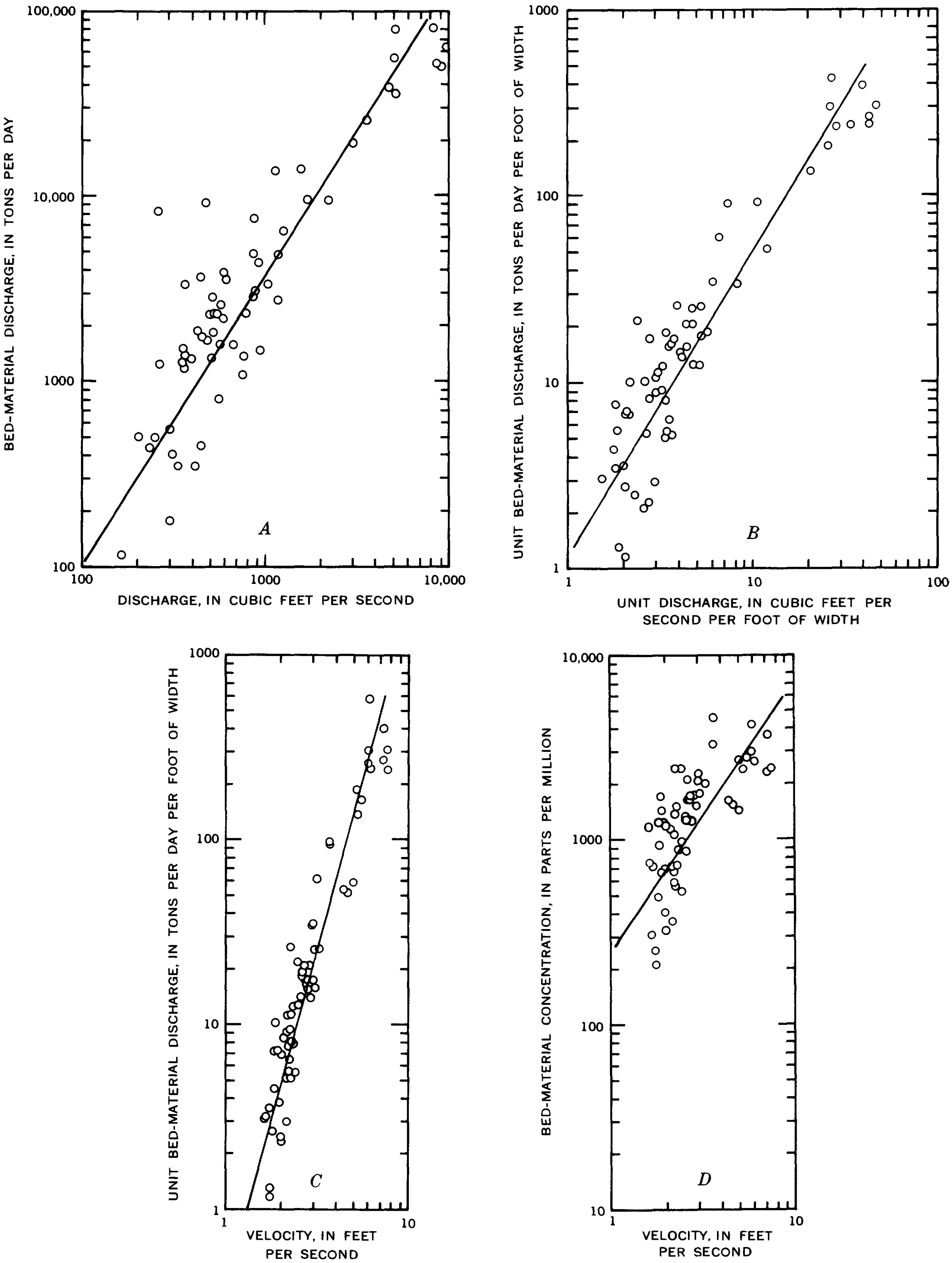

FIGURE 14.—Graph showing transport relations for Rio Grande at San Felipe, N. Mex.

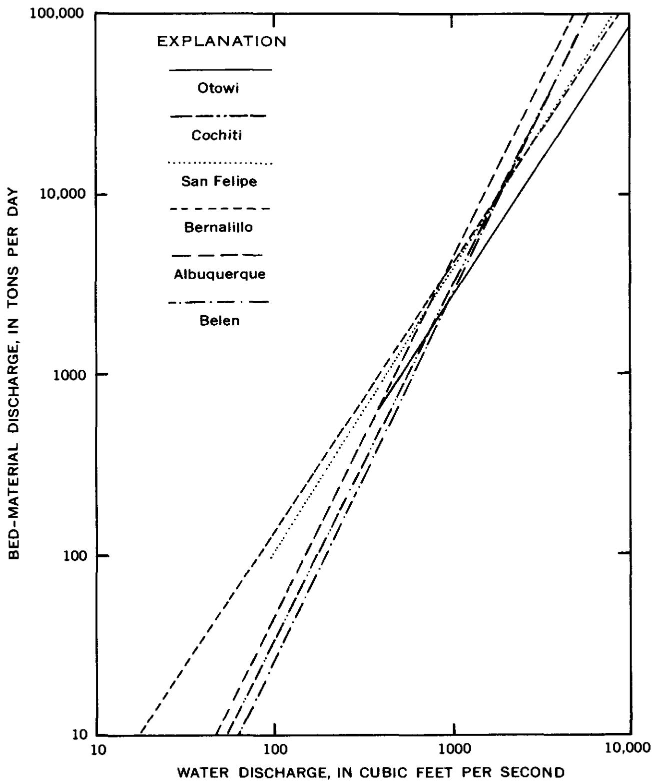

FIGURE 15.—Graph showing relation of bed-material discharge to water discharge.

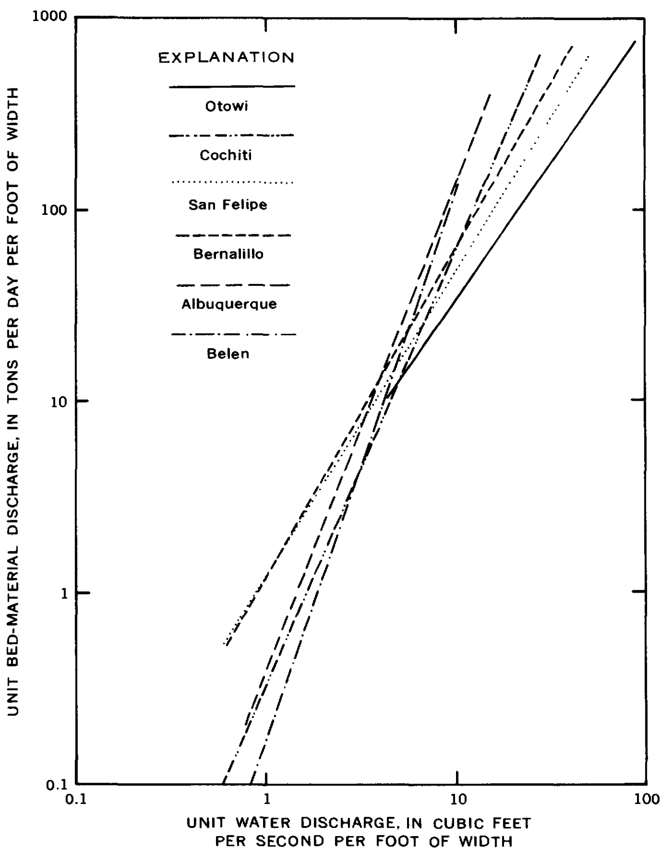

FIGURE 16.—Graph showing relation of unit bed-material discharge to unit water discharge.

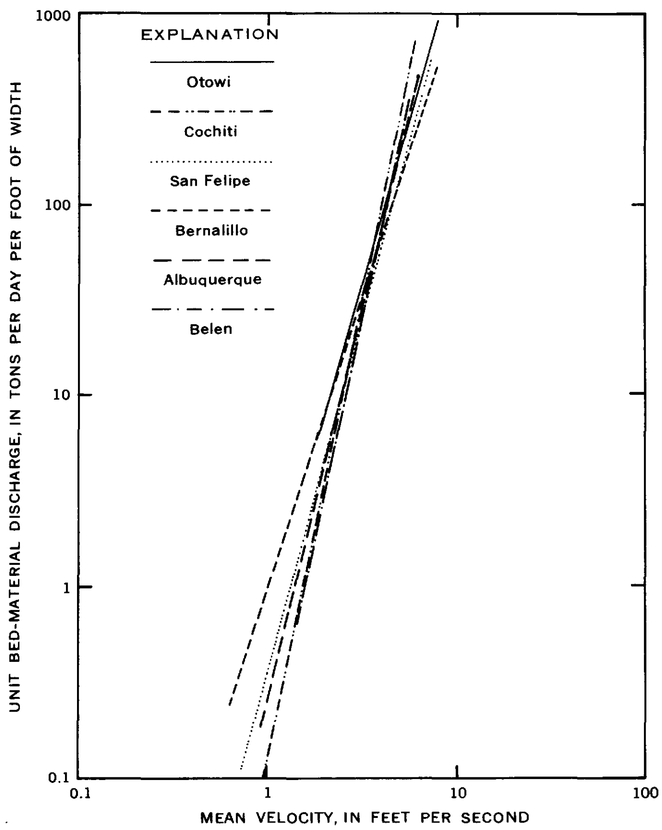

FIGURE 17.—Graph showing relation of unit bed-material discharge to mean velocity.

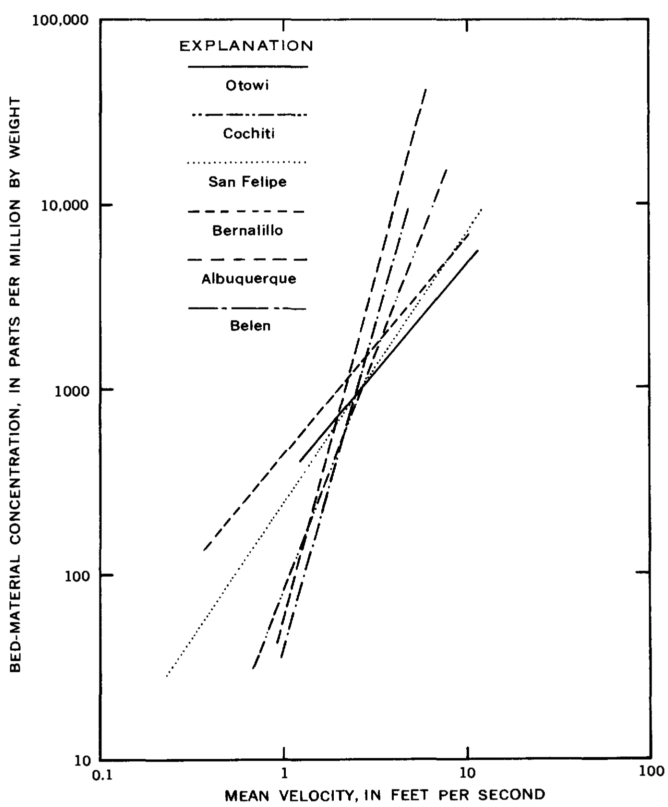

FIGURE 18.—Graph showing relation of bed-material concentration to mean velocity.

given increase in discharge, the percent increase in the transport of finer material is greater than the percent increase in the transport of coarser material. The groupings of the curves in terms of the confined and unconfined sections is logical for the relations involving mean velocity and unit water discharge because these two variables are closely interrelated with the ability of the flow to adjust its width. Velocity and depth will increase with increasing discharge more rapidly at sections of constant width than at sections where the width increases with discharge. Both the slopes and the intercepts of the curves involving unit discharge and velocity reflect the rate of change in velocity and depth with discharge.

The reason is not obvious for such marked differences between the confined and unconfined sections for the relations of total bed-material discharge (Q_T) to water discharge (Q). Figure 15 shows that for any discharge below 1,000 cfs, more sediment is transported at the narrow sections than at the wide sections. At discharges greater than about 4,000 cfs, the reverse is true; greater sediment loads are carried at the wider sections.

Figure 15 suggests that for any given period of time, say a spring runoff event, the pattern of scour and fill throughout the length of the reach will depend partly upon the nature of the cross section of the channel. During floods, scour occurs generally throughout a reach (Leopold and Wolman, 1956), and whereas the depth of scour will depend to a large extent upon local factors, greater volumes of material obviously should move from the wider sections than from the narrower sections if the trends shown in figure 15 are correct. Conversely, at low flows, greater volumes of material are moved through the narrow sections. At intermediate flows, shown by the converging lines in figure 15, the sediment-transport rates are about the same at all sections.

Observations of the Rio Grande near Bernalillo (Nordin, 1964) indicated that at low and intermediate flows, deposition and channelization occur concurrently with a decrease in width at the wider sections. These observations tend to confirm the general low-flow relations shown on figure 15.

Downstream from Cochiti, flow decreases in a downstream direction because of depletion by irrigation and channel losses from infiltration and evapotranspiration, and therefore, comparisons of the curves in figure 15 at equal discharges may be misleading. However, a comparison of transport rates from figures 4 and 15 at equal frequencies of discharge shows almost the same trends. At high flows, greater sediment loads are carried by the wide sections; at low flows, greater sediment loads are transported at the narrow sections.

The basic differences in the transport relations in figures 15–18 appear to be related directly to the nature of the cross sections—that is, to whether the channel is confined or laterally unrestricted. Even the plot of mean velocity and unit bed-material discharge (fig. 17), which is the most closely knit relation, indicates that the curves separate into groups for the confined and unconfined sections. This separation is a direct result of the effect of depth upon the transport of bed material, as shown by Colby (1961).

The most elemental relation, shown in figure 18, is the plot of mean velocity and bed-material concentration. Here, the influence of width restrictions and of concomitant depth effects are especially obvious. At the higher velocities, the effects of particle size are also readily apparent. For a given velocity, the higher concentrations are associated with the finer bed materials.

Bogardi (1961) furnished values of exponents for the concentration-velocity relations at six stations on the Danube River. The exponents given by Bogardi are of the same order of magnitude as those for the reach from Otowi to Bernalillo. His values, however, decreased from the upper station to the third station downstream and then remained constant. Bogardi found that, for any given velocity, the concentration increased in a downstream direction. This relation does not hold for the Rio Grande data shown in figure 18, except at the high velocities.

Any of the relations in figures 15–18 could be useful in practical applications. Curves such as those in figure 15 may be used in conjunction with a flow-duration curve to estimate long-term sediment yields (Miller, 1951). Relations based on unit discharge or mean velocity (figs. 16–18) are useful for estimating bed-material discharge at cross sections for which the curves were drawn or at similar cross sections (Colby, 1964).

The relations of mean velocity to unit bed-material discharge (fig. 17) appear the most logical type of sediment-transport curve to use for practical applications because the curves are about the same for all the stations, a point emphasized by Colby (1964). However, inasmuch as the curves have a relatively steep slope, any error in estimating mean velocity, width and depth being known, will introduce a larger percentage of error into the estimates of total bed-material discharge from the curves of figure 17 than is in estimates for any of the other transport relations shown.

The method of least squares is not always ideally suited for defining sediment-transport relations for practical applications, especially for the relations shown in table 15, because the data were not screened to eliminate unrepresentative sediment samples or concentrations which reflect the influence of tributary inflow.

The important features of the curves, however, are in the qualitative aspects of the relations. The sediment discharge apparently is greater at the wide sections at high flows and greater at the narrow sections at low flows. This difference is probably due to the tendency for the wide sections to aggrade and channelize at low flows. These differences in transport relations, which appear to reflect the characteristics of the cross sections, carry into the relations which are expressed on a unit width basis. Thus, the transport rates related to simple hydraulic variables for a particular cross section, such as the V-q_T relations of figure 17, may require considerable adjustment to be applicable to other types of cross sections.

The transport relations in figures 15–18 are useful for qualitative comparisons, but no single simple hydraulic variable can be expected to describe adequately the complex processes of bed-material transport. In the following section, some of the more complex factors and parameters which influence sediment transport are considered.

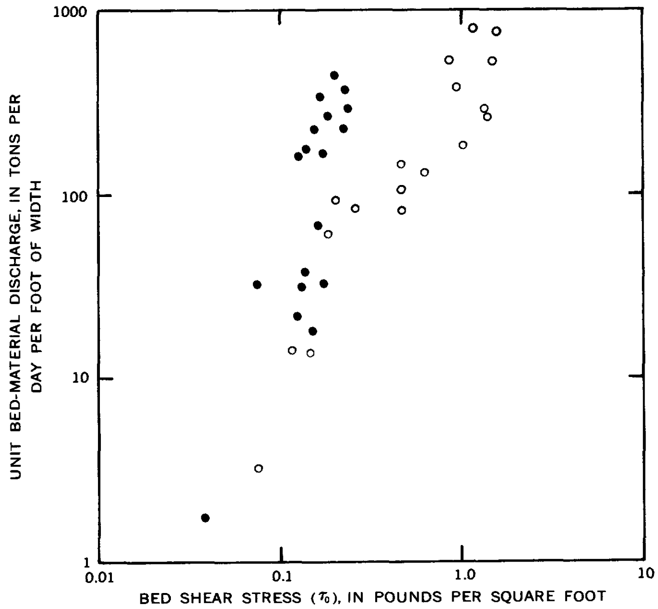

FIGURE 19.—Graph showing relation of unit bed-material discharge to bed shear stress for the Rio Grande at Otowi Bridge (○) and near Bernalillo (●).

TRANSPORT PARAMETERS

Many factors influence sediment transport, and the parameters which describe the sediment, the channel geometry and the flow may be expressed either in dimensional or dimensionless forms. Dimensionless parameters are especially useful in reducing to comparable terms systems with variables of different orders of magnitude. On the other hand, it is often desirable to investigate the very simplest relations because the more complex parameters sometimes mask the interrelations of the variables considered, especially in investigations of field data, where controls of the factors usually considered as independent variables are lacking.

For this report, consideration was given only to some of the hydraulic parameters through the simpler relations for the stations at Otowi and near Bernalillo. No attempt was made to analyze, in detail, all the basic data.

SHEAR STRESS AND EFFECTIVE SHEAR STRESS

The transport curves in figures 15–17 are remarkably similar for Otowi and Bernalillo, especially in view of the extreme differences in the flow characteristics for the two stations. In figure 19, the relations of the unit bed-material discharge to the bed shear stress ($\tau_0=\gamma DS$) show different trends for Bernalillo and Otowi (the plotted points are for the same data compared in the previous discussion of flow characteristics). The steep slope in the trend of points for Bernalillo is indicative of the narrow range in shear stress for which there exists a relatively wide range of velocity and sediment-transport rates. Such a trend (rapidly increasing bed-material discharge with respect to shear stress) is characteristic of shallow sand-bed streams in which the velocity-depth relation is controlled mostly by the bed configuration of the channel. For Otowi, the points follow the Bernalilo trend up to transport rates (q_T) of about 100 tons per day per foot of width; then there is a break in the trend for the higher transport rates. The break in the relation corresponds roughly with the flow conditions during which the controlling influences of the riffles is drowned out and during which the bed material begins to exhibit a marked bimodal distribution.

As mentioned previously, in the discussion of hydraulic variables, however, only the shear stress resisted by the grain roughness is effective in transporting sediment.

The concept of an effective shear stress or shear velocity has been utilized in transport relations by Meyer-Peter and Muller (1948), Einstein (1950), Colby and Hembree (1955), Laursen (1958), and perhaps others. The effective shear stress may be considered the bed shear stress which would yield the observed mean velocity if the flow resistance were due only to grain roughness. Effective shear stress may be estimated by selecting a representative grain size as a characteristic roughness length and introducing this grain size into some velocity-shear stress-roughness relation.

For this report, only one method of estimating effective shear was considered, the equation given by

Colby and Hembree (1955, equation E, p. 83) as

$$U'_* = \frac{V}{5.75 \log_{10} (12.27Dx/k_s)} \qquad (2)$$

where U'_* = the shear velocity with respect to the particles,

x = a correction factor for the transition from smooth to rough boundary, and

k_s = the representative grain roughness, taken as d_{65}, the diameter of bed material for which 65 percent by weight is finer.

The parameter x is given as a function of shear velocity (U'_*), the grain roughness (k_s), and the kinematic viscosity of the fluid.

Assuming that equation 2 applies to the flow, U'_* is the shear velocity which would produce the observed mean velocity for flow with mean depth D and grain roughness k_s. The effective shear stress may be computed as $\tau' = \rho(U'_*)^2$.

When transport rates are plotted against effective shear stress (fig. 20), the reason for the similarity in transport relations at the two stations is readily apparent—the range in effective shear stress at the two stations is about the same. Although both depth and slope increase more rapidly at Otowi than at Bernalillo, the increase in flow resistance at Otowi offsets the increase in bed shear stress (γDS); hence the mean velocity is about the same as the mean velocity at Bernalillo for comparable discharges. Depth is greater and increases more rapidly with discharge at Otowi, but the bed material also becomes coarser with discharge, and the logarithm of the ratio D/k_s changes very little. The adjustments in the relations of velocity, depth, slope, and flow resistance for Bernalillo and Otowi are completely dissimilar; yet, so far as transport relations are concerned, the end results are about the same.

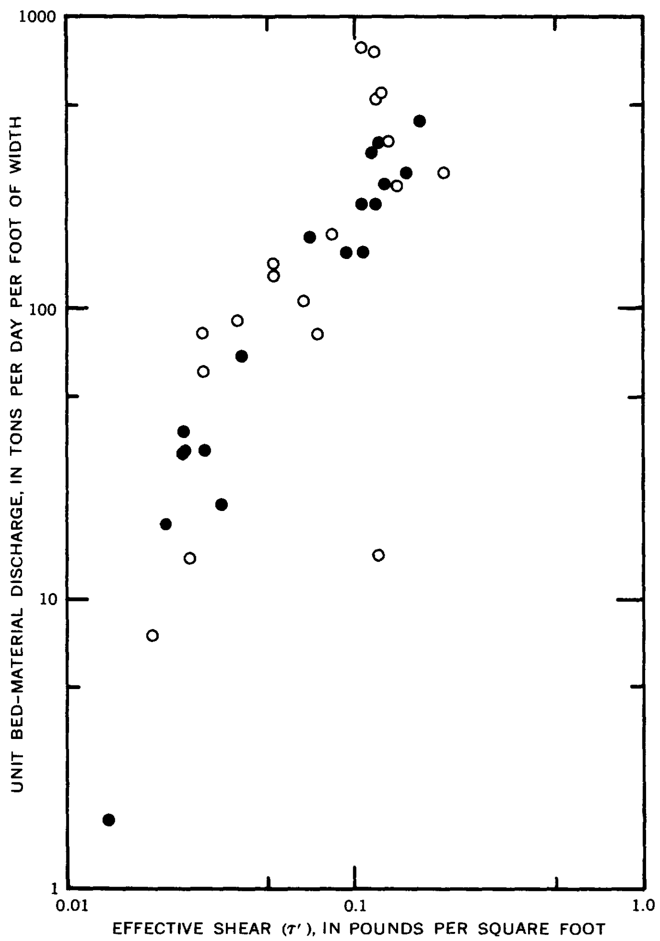

FIGURE 20.—Graph showing relation of unit bed-material discharge to effective shear stress for the Rio Grande at Otowi Bridge (O) and near Bernalillo (●).

There are still some erratic points in figure 20 for Otowi which might be expected to relate in some way to the variable size distribution of the bed material. Some of the scatter can be reduced by converting figure 20 to the form of a dimensionless shear stress-transport relation, as shown in figure 21. In this figure, abscissa values become

$$\frac{\tau'}{(\gamma_s - \gamma)d} \qquad (3)$$

and the ordinate values are

$$\phi_T = \frac{q_T}{d^{3/2}\rho_s g^{3/2}\left(\frac{\rho_s - \rho}{\rho_s}\right)^{1/2}} \qquad (4)$$

where ρ_s = the density of the sediment, assumed equal to 5.14 slugs per cubic foot,

ρ = the density of the fluid, 1.94 slugs per cubic foot,

g = acceleration due to gravity, 32.2 feet per second squared,

d = the median diameter of the bed material, in feet,

$\gamma = \rho g$, and

$\gamma_s = \rho_s g$.

Equations 3 and 4 are very similar in form to Bagnold's dimensionless shear-transport relation (Bagnold, 1956, eq. 42), and to Einstein's $\psi' = \phi$ relation (Einstein, 1950, equations 11, 42). Equation 3 is analogous to $1/\psi'$. However, both Einstein and Bagnold used the bed-load discharge in equation 4 rather than the total bed-material discharge, and Bagnold employed the total bed shear, rather than an effective shear.

A. A. Bishop (Sediment transport an alluvial channels: a critical examination of Einstein's theory: Colorado State Univ. Ph. D. thesis, 1961) suggested

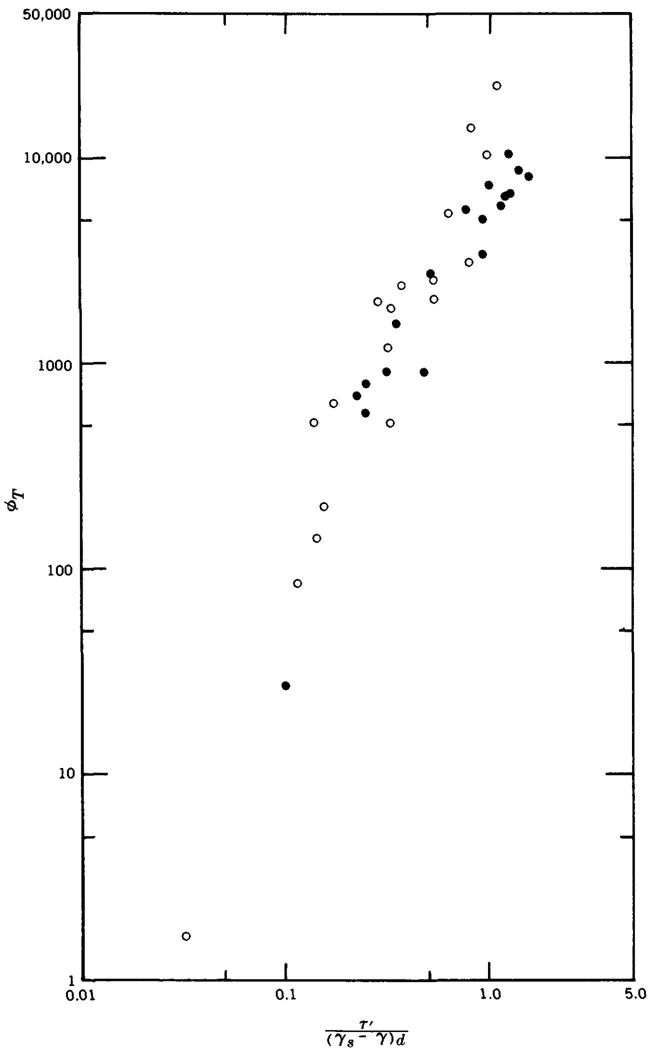

FIGURE 21.—Graph showing a dimensionless shear stress-transport relation for the Rio Grande at Otowi Bridge (○) and near Bernalillo (●).

that the total bed-material discharge (q_T) should be used in a dimensionless shear-transport relation similar to figure 21, and he proceeded to develop a family of curves from flume data for various sizes of bed material. The shear parameter ψ' is not directly comparable to equation 3 because different velocity equations were used to define the effective shear stresses, but a qualitative comparison shows that several differences exist between the relations in figure 21 and Bishop's curves. First, Bishop's curves show unrealistically high transport rates for the fine bed material at the higher effective shear stress values (low ψ' values); and second, for a given shear intensity (ψ') Bishop's curves show greater ϕ_T values for the finer sand than for the coarser material, whereas for figure 21, the reverse is true. The transport function ϕ_T is generally greater for Otowi than for Bernalillo.

The high transport rates in Bishop's relations may be attributable to the influence of standing waves and antidunes present in the flume at the high effective shears. Antidunes and standing waves are often observed in the Rio Grande but, because standing waves seldom occupy the full width of a natural channel, their influence on bed-material transport is usually local and transient (Nordin, 1964).

The trends of the plotted points in figure 21 suggest that Bishop is perhaps correct in attempting to develop a shear-transport relation in which the total bed-material transport rate rather than the bedload only is employed in the transport function. However, if Bishop's curves are applicable to the Rio Grande data, the Otowi points should fall below the Bernalillo points.

A consideration of equations 3 and 4 or of Bishop's $\Psi'=\phi_T$ curves shows two major shortcomings in the effective shear stress-transport relations. First, there is no direct consideration of temperature, which may have considerable influence on sediment transport through its direct effect on particle-fall velocity and its indirect effect on bed form (Straub and others, 1958; Kennedy, 1961); second, for any given value of effective shear stress, the bed-material discharge increases with increasing depth (Colby, 1961). To be generally applicable, the shear-transport relations of equations 3 and 4 should contain some correction for the effects of temperature and depth. Laursen (1958) gives the ratio of shear velocity to fall velocity as a major factor in determining both the bed-load concentration and the total bed-material concentration, and it seems likely that some form of this ratio should be introduced in the shear-transport parameters of figure 21. The ratio is a measure of the relative concentration distribution of suspended sediment and is commonly used in sediment transport relations.

This consideration of effective shear stress and transport for Otowi and Bernalillo leads to several important conclusions. The relations of velocity, shear, and roughness at the two stations are completely dissimilar, but the effects are compensating. At Otowi, the depth, bed shear stress, and roughness increase rapidly with discharge, whereas at Bernalillo, the depth and bed shear stress increase slowly and flow resistance decreases with increasing discharge. As a result, the velocity and effective shear at the two stations are about the same and the sediment transport relations are similar.

Either effective shear stress or mean velocity may be considered major parameters in sediment transport, as pointed out by Colby (1964). More specifically, the dimensionless transport function of equation 3, which is actually a measure of the ratio of the effective shear stress at the bed to the resistance of the topmost layer of the bed (Bagnold, 1956), would seem to be more suitable than the effective shear stress only.

Probably, the total bed-material transport may be considered a function of some shear-stress parameter as suggested by Bishop and as indicated by figure 21. However, some factors apparently would have to be introduced to explain the effect of temperature and depth.

No attempt was made to determine the most suitable method of estimating effective shear stress, to assess the grain size which should be used in equations 2, 3, and 4, or to introduce any corrections for the influence of temperature and depth in equations 3 and 4. These are questions which certainly deserve further study, but because total transport rates cannot generally be measured directly in the field, they are more suited to controlled laboratory investigations than to field studies. Actually, the lack of precision with which unit bed-material discharge (q_T) may be determined in the Rio Grande precludes any precise definition of the transport function (ϕ_T).

It might be pointed out that plotting the bed-material discharge (q_T) against effective shear stress in figures 20 and 21 is not exactly accurate, because the effective shear stress, or rather, the effective shear velocity from equation 2, is used to compute q_T in the modified Einstein method. However, Nordin (1964) has also pointed out that the total transport rate of bed material given by the modified Einstein method is dependent mostly upon the concentrations of bed material from suspended-sediment samples and that for a given cross section, excluding very shallow depths, the computed transport rates of material coarser than 0.062 mm bear a nearly constant ratio to the measured transport rates. Thus, the same qualitative conclusions could be drawn from figures 20 and 21, even if only the measured bed-material discharge had been considered.

BED-MATERIAL CHARACTERISTICS

For most sand-bed channels, the characteristics of the bed material change slightly with discharge or with time, and the bed-material characteristics to be used in transport parameters may often be expressed in terms of the median diameter or of some representative grain size. Even for some of the more complicated transport formulas, it is usually sufficient to specify only the median diameter and some simple gradation coefficient, or, as in the Meyer-Peter and Muller (1948) transport relations, an effective diameter which is weighted in terms of the percentage of each size class considered. For sand-gravel channels, however, in which the bed material exhibits a bimodal distribution and in which the distribution changes with time and discharge, such a simple representation of the bed-material characteristics does not seem adequate. Furthermore, it is difficult to relate, except in a general qualitative manner, the observed changes in the bed-material distribution to the observed changes in the transport relations. For example, from the data in table 1, the concentration of the bed material for Otowi decreases with time for the first five observations in 1958, but the temperature, velocity, depth, water-surface slope, and flow resistance change only a little. This apparent lack of a definable relationship between hydraulic variables and sediment transport was also obvious in figures 20 and 21.

The changes with time of the transport rates shown in table 1 must be directly related to the systematic changes with time of the characteristics of the bed material, shown in figure 22. Obviously, the median diameter and some simple gradation coefficient are not sufficient to describe the distributions in figure 22.

The lowest mean bed elevation (Culbertson and Dawdy, 1964) was for the second observation, on May 12, 1958. For the next three observations, the bed elevation increased somewhat—an indication that the coarse material was being transported into the reach from an upstream source and that some sort of selective transport process was depleting the material in the size range from about 0.5 mm to 2.0 mm. Field observations indicate that at low flows, sand is stored in the pools of pool-and-riffle channels. At higher flows, this sand is swept into suspension or otherwise moved from the pools, and some concurrent scour reduces the bed elevation, whereas the coarser gravel appears to move more or less continuously, independent of the bed elevation—that is, independent of channel scour. These observations explain, in part, why some of the cross sections of the Rio Grande exhibit the characteristics of sand-bed channels at low flows and of sand-gravel channels at high flows (Nordin and Culbertson, 1961). However, the problems of determining what causes systematic changes in bed-material characteristics in sand-gravel and pool-and-riffle channels, of describing methods to predict these changes, and of evaluating parameters to represent adequately the characteristics of the bed material in transport relations remain to be solved.

TEMPERATURE EFFECTS

The influence of temperature on sediment transport has been well documented by Straub and others (1958) and by Kennedy (1961), who have shown that a 50°F decrease in temperature will approximately triple the transport rate of bed material, other factors constant.

Figures 5 and 6 show that, for the Rio Grande, an increase in temperature accompanies a decrease in concentration during the spring-runoff event. The

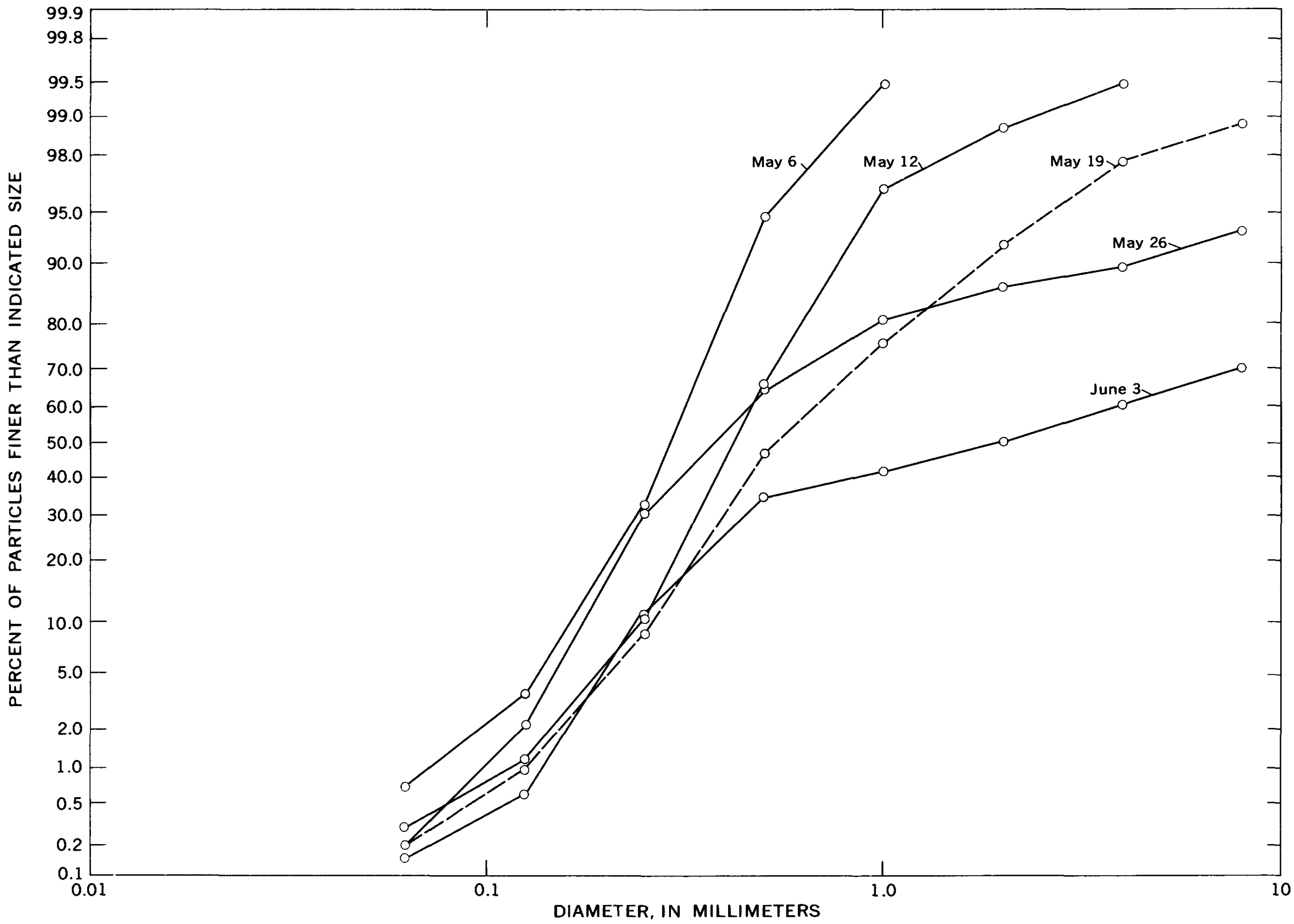

FIGURE 22.—Graph showing systematic changes in bed-material size distribution between May 6 and June 3, 1958, Rio Grande at Otowi Bridge.

decreasing concentration reflects changes in both the wash load and the bed-material load. Generally the bed-material concentration decreases less rapidly than the fine-material concentration.

Straub and others (1958) found that at a constant discharge, a decrease in temperature caused an increase in the slope, whereas the velocity and depth remained about constant. In a natural sand-bed channel, slope usually varies conservatively; hence a change in temperature for a given discharge results in a change in the velocity-depth relation. During a rising stage, a high bed-material discharge is accompanied by a high velocity, low depth, low flow resistance, and low water temperature. During receding stages, a lower bed-material discharge is accompanied by a low velocity, greater depth, greater flow resistance, and higher water temperature. In pool-and-riffle channels, temperature effects may be further complicated by changes in bed-material characteristics and by variations in slope with discharge.

Figure 23 shows the ratio of the computed bed-material concentration to the concentration from the velocity-concentration curve for Bernalillo (fig. 18) plotted against water temperature. Except in the four highest points, which were influenced by tributary inflow and are considered unrepresentative, the tendency for low ratios to accompany high water temperatures is apparent, but the relation is too poorly defined to yield a quantitative evaluation of the temperature effects.

Temperature effects would probably be more apparent if ratios were plotted from the q-q_T curves in figure 16 because, as noted previously, for a given water discharge, low temperatures usually accompany high sediment discharges, high velocities, and low depths. On the other hand, temperature effects on the V-C_T relations or on the V-q_T relations are complicated by the fact that temperature is not independent of flow resistance—that is, of the velocity-depth relation for a given cross section and a given water discharge.

Temperature is generally considered a factor of importance in sediment transport relations, but a precise quantitative evaluation of temperature effects is not possible, at least insofar as this investigation is

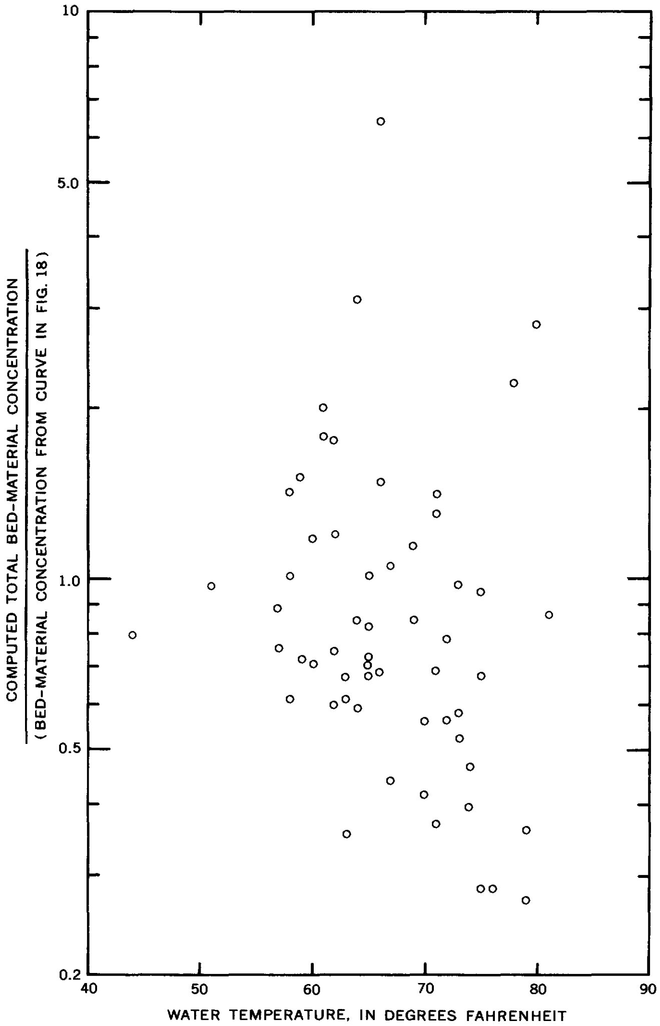

FIGURE 23.—Plot showing apparent effect of temperature on concentration, Rio Grande near Bernalillo, N. Mex.

concerned, for the Rio Grande data because the effects of temperature changes cannot be isolated from the effects of apparently interrelated changes in other variables.

OTHER CONSIDERATIONS

Many variables which influence sediment transport were not considered in this report. Studies of some of these factors, for the Rio Grande, have been presented elsewhere. Culbertson and Dawdy (1964) discussed depth-discharge discontinuities, and described the influence of changes in bed configuration and flow regime on sediment transport. Nordin and Dempster (1963) investigated vertical distributions of velocity and suspended-sediment concentration, and Nordin (1963) evaluated the influence of high concentrations of fine sediments on the relative concentration distribution of suspended sands.

Colby (1961, 1964) investigated many of these factors for a wide range of flow conditions, and developed several graphical relations to be used as a basis for the practical computations of bed-material discharge (Colby, 1964).

So far as the writers know, this report presents the first detailed information on the flow characteristics and transport relations for reaches of the Rio Grande with pool-and-riffle channel configurations and bimodal distributions of bed material. Additional studies in this area are highly desirable.

Finally, this investigation was of a single southwestern stream with a limited range of flow conditions. The findings of this study are probably not applicable to other flow conditions, especially to streams of great depth.

CONCLUSIONS

Bed-material discharge, computed by the modified Einstein method, is related to simple hydraulic variables for observations at six sediment stations through a 110-mile reach of the Rio Grande in New Mexico. Transport relations vary in a downstream direction, or with decreasing particle size, and fall into two distinct groups, one group representing the confined sections and the other representing sections without lateral restrictions. At low flows, greater sediment loads are transported at the narrow sections, while at high flows, greater loads are carried at the wide sections. This difference reflects the tendency for the wide sections to aggrade and channelize at low flows.

Flow characteristics at Otowi, which is the farthest upstream station and which has a pool-and-riffle channel configuration and a bimodal distribution of bed material, differ markedly from the flow characteristics at Bernalillo, which has a sand-bed channel. At Otowi, the depth, water-surface slope, bed shear stress, resistance to flow, and bed-material size increase with increasing water discharge. Near Bernalillo, water-surface slope and bed-material characteristics are approximately constant, flow resistance decreases with discharge, and the range in bed shear stress, compared to that at Otowi, is very limited.

The mean velocity and bed-material discharge for the two stations are comparable, and sediment-transport rates relate reasonably well to effective shear. However, the variable size distribution of bed material introduces considerable scatter in the relation for Otowi. Converting the shear-transport relations to a dimensionless form, in which the shear parameter is a measure of the ratio of the effective shear to the resistance of the topmost layer of the bed, reduces much of the scatter. This relation is very similar to the curves developed by A. A. Bishop (Sediment transport in alluvial channels: a critical examination of Einstein's theory, Colorado State Univ. Ph. D. thesis, 1961) to predict total bed-material discharge. A qualitative comparison of the Rio Grande relations with Bishop's curves indicates that, to be generally applicable, the dimensionless shear-transport relations for predicting total bed-material transport should probably include parameters to explain the effects of temperature and flow depth.

In addition, systematic changes in bed-material characteristics at Otowi appear to be related to changes in transport which are independent of flow variables. Changes in the bed material may be caused by some selective transport process which depletes material in the size range from about 0.5 to 2.0 mm. A single representative grain size in the shear-transport relations probably does not adequately represent the complex bimodal size distribution of sand-gravel channels.

A consideration of water-temperature effects indicates that high bed-material discharge is associated with low temperatures. However, a quantitative evaluation of the influence of temperature was impossible because the effects of temperature changes are not independent of the effects of changes in flow resistance and in the velocity-depth relations.

TABLE 1.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.*

Date	Time	Q (cfs)	B (ft)	V (ft per sec)	D (ft)	S	T (°F)	Measured concentration of suspended load, ppm		Computed total concentration, ppm	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1958											
May 6	1720	7,320	132	6.84	8.11	0.00230	59	7,440	4,960	7,790	5,310
May 12	1245	9,340	130	7.02	10.23	.00246	58	5,020	2,920	6,030	3,920
May 19	1720	9,490	145	6.98	9.38	[1].00240	62	2,390	834	3,050	1,500
May 26	1240	10,100	140	7.08	10.21	.00235	61	2,990	2,140	3,540	2,700
June 3	1015	8,590	135	7.10	8.96	.00240	62	1,720	1,240	2,190	1,710
June 9	1045	5,210	129	6.44	6.27	.00220	60	3,180	2,810	5,350	5,190
June 12	1040	5,000	125	5.56	7.19	.00231	62	1,110	942	1,860	1,690
June 17	0920	2,240	113	4.23	4.69	.00163	67	1,860	1,770	2,780	2,690
June 24	1030	1,130	234	3.35	1.44	.00131	72	316	262	1,150	1,100
1959											
Aug. 8	1145	1,270	120	3.04	3.47	-----------	73	24,000	2,210	24,700	2,910
1961											
Apr. 25	1310	2,780	121	4.34	5.30	.00144	52	1,350	819	1,830	1,300
May 2	1415	4,000	128	4.10	7.63	.00133	57	2,480	1,180	2,840	1,540
May 17	1145	2,750	115	5.03	4.75	.00159	56	1,120	829	1,910	1,620
June 21	1440	908	97	2.82	3.32	.00072	76	284	146	689	551
July 20	1245	1,090	98	3.08	3.61	.00081	74	3,590	1,210	4,380	2,000
1962											
Apr. 19	1350	6,000	130	5.88	7.85	.00196	59	4,240	2,500	4,800	3,060
May 31	1350	1,460	112	3.87	3.37	.00098	59	1,660	1,540	2,740	2,620
July 2	1345	684	109	2.50	2.51	.00092	78	203	159	488	445

[1] Estimated.

TABLE 2.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande at Cochiti, N. Mex.*

Date	Time	Q (cfs)	B (ft)	V (ft per sec)	D (ft)	S	T (°F)	Measured concentration of suspended load (ppm)		Computed total concentration (ppm)	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1954											
Mar. 10	1200	416	208	1.70	1.17	[1]0.00129	54	83	45	217	178
Mar. 23	1200	309	177	1.74	1.01	[1].00129	51	57	11	90	43
Apr. 7	1135	541	288	1.91	.98	[1].00129	58	290	32	400	135
Apr. 20	1135	709	300	1.94	1.22	[1].00129	58	581	105	765	273
May 4	1000	1,170	300	2.26	1.73	[1].00129	63	1,780	392	2,430	1,030
May 20	1210	1,590	284	2.97	1.89	[1].00129	67	2,000	800	2,630	1,400
June 1	1150	881	300	2.19	1.34	[1].00129	67	425	191	711	469
June 14	1045	667	204	1.89	1.73	[1].00129	65	298	179	434	314
July 12	1150	784	295	2.14	1.24	[1].00129	77	1,270	152	1,660	499
Aug. 10	1145	264	172	1.50	1.02	[1].00129	73	750	352	878	472
Aug. 24	1125	252	175	1.50	.96	[1].00129	70	2,920	29	3,080	149
Sept. 8	1105	500	178	1.87	1.50	[1].00129	70	3,130	31	3,530	639
Sept. 23	1205	67.8	77.0	.97	.91	[1].00129	71	118	37	212	129
Oct. 5	1245	144	88.0	1.38	1.18	[1].00129	72	186	41	239	92
Oct. 19	1205	294	100	1.84	1.60	[1].00129	58	182	107	351	276
Nov. 17	1330	347	115	2.03	1.49	[1].00129	49	637	382	1,140	877
Dec. 15	1340	327	115	1.98	1.43	[1].00129	38	362	261	1,390	1,290
Dec. 29	1510	464	124	2.27	1.65	[1].00129	36	561	381	2,030	1,850
1955											
Jan. 11	1455	464	126	2.16	1.71	[1].00129	37	1,030	865	1,970	1,800
Jan. 26	1515	468	128	2.14	1.71	[1].00129	36	792	420	1,580	1,200
Feb. 9	1540	503	130	2.18	1.78	[1].00129	40	670	436	1,620	1,390
Feb. 23	1445	517	124	2.28	1.83	[1].00129	38	422	118	907	598
Mar. 8	1410	529	133	2.29	1.74	[1].00129	49	540	173	1,700	1,330
Mar. 22	1500	414	120	2.17	1.59	[1].00129	49	300	81	766	543
Apr. 6	1450	154	95.0	1.50	1.08	[1].00129	53	66	7	99	39
Apr. 19	1310	272	114	1.84	1.30	[1].00129	58	261	44	595	374
May 17	1530	1,040	280	2.45	1.52	[1].00129	60	2,320	1,210	3,350	2,220
June 14	1045	514	164	1.80	1.74	[1].00129	75	189	112	301	222
June 29	1205	262	90.0	1.66	1.76	[1].00129	72	28	9	65	46
July 11	1315	420	100	2.16	1.94	[1].00129	75	222	73	396	244
July 25	1425	161	86.0	1.32	1.42	[1].00129	81	621	6	644	24
Aug. 8	1425	883	271	2.68	1.22	[1].00129	76	15,700	628	16,900	1,410
Sept. 6	1150	1,150	279	2.84	1.46	[1].00129	71	3,340	1,740	4,270	2,600
Sept. 19	1410	232	89.0	1.77	1.47	[1].00129	74	623	137	734	234
Oct. 3	1500	205	90.0	1.65	1.38	[1].00129	70	924	388	1,130	585
Oct. 18	1320	171	84.0	1.51	1.20	[1].00129	63	170	126	295	248
Nov. 2	1400	173	92.0	1.59	1.18	[1].00129	52	192	156	381	344
Nov. 15	1250	352	135	2.03	1.28	[1].00129	42	1,160	974	1,890	1,700
Nov. 28	1150	385	104	2.77	1.34	[1].00129	40	748	568	1,540	1,360
Dec. 14	1130	484	114	3.36	1.26	[1].00129	36	947	701	2,250	2,000
Dec. 27	1100	558	125	3.15	1.42	[1].00129	39	999	739	2,000	1,740
1956											
Jan. 24	1130	555	130	2.64	1.62	[1].00129	41	895	770	1,690	1,560
Feb. 7	1140	583	140	2.67	1.56	[1].00129	37	1,260	995	2,120	1,850
Feb. 22	1030	478	130	2.21	1.66	[1].00129	42	3,170	2,880	3,630	3,350
Mar. 7	1220	938	259	2.28	1.59	[1].00129	43	3,630	1,780	7,840	5,990
Apr. 3	1420	964	300	2.23	1.44	[1].00129	47	5,000	3,750	5,750	4,470
Apr. 18	1430	919	241	2.63	1.45	[1].00129	52	5,030	4,070	5,970	5,000
May 2	1530	1,250	281	2.73	1.63	[1].00129	59	2,200	1,210	2,950	1,930
May 15	1315	556	256	2.31	.94	[1].00129	59	939	639	1,940	1,640
May 29	1145	943	233	3.09	1.31	[1].00129	66	969	669	2,040	1,730
June 12	1345	711	264	2.18	1.23	[1].00129	73	1,060	901	1,370	1,210
June 26	1115	64.6	52.5	.88	1.40	[1].00129	77	36	15	40	19
July 10	1200	34.7	61.0	.63	.90	[1].00129	80	30	2	31	2
1957											
May 16	1600	3,470	283	4.81	2.55	[1].00129	54	2,550	1,890	3,600	2,920
May 29	1500	3,350	287	4.65	2.51	[1].00129	62	2,770	2,240	4,170	3,630
June 12	1700	5,520	297	5.61	3.31	[1].00129	62	5,410	4,330	6,310	5,210
June 26	1740	4,800	291	5.27	3.13	[1].00129	67	3,940	3,390	5,300	4,740
1958											
May 7	1210	7,960	308	6.58	3.93	[1].00129	55	6,090	3,330	6,980	4,220
May 12	1550	8,900	328	6.64	4.09	.00120	58	4,550	2,700	6,030	4,160
May 20	1205	8,920	316	6.51	4.34	.00120	58	3,110	1,980	3,810	2,680
May 26	1630	9,810	335	6.67	4.39	.00127	61	3,110	2,100	3,490	2,480
June 3	1315	8,680	295	6.07	4.85	.00127	63	3,110	2,580	3,670	3,140
June 9	1340	4,990	297	4.62	3.64	.00123	62	7,670	7,170	11,200	10,700
June 12	1240	5,060	298	4.22	4.03	.00113	63	8,840	8,740	11,500	11,400
June 17	1205	2,040	285	3.20	2.24	.00118	70	5,240	5,050	7,410	7,230
June 24	1340	1,000	263	2.23	1.71	.00118	75	247	140	663	556
1961											
Apr. 26	1050	2,090	285	3.36	2.18	.00134	52	1,210	713	2,130	1,630
May 2	1155	3,680	288	4.54	2.82	.00137	57	2,370	1,040	3,150	1,820
May 18	1150	2,620	281	3.90	2.39	.00137	59	2,750	2,450	3,600	3,300
June 22	1110	674	280	2.25	1.09	.00128	76	153	30	491	304

[1] Average bed slope from aggradation-degradation studies.

TABLE 3.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande at San Felipe, N. Mex.*

Date	Time	*Q* (cfs)	*B* (ft)	*V* (ft per sec)	*D* (ft)	*S*	*T* (°F)	Measured concentration of suspended load (ppm)		Computed total concentration (ppm)	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1954											
Mar. 10	1445	457	153	2.17	1.38	[1]0.00150	56	250	115	507	367
Mar. 23	1525	414	153	2.00	1.35	[1].00150	53	308	166	464	320
Apr. 7	1500	562	153	2.42	1.52	[1].00150	62	405	162	778	529
Apr. 20	1510	762	212	2.22	1.62	[1].00150	64	790	245	1,230	667
May 4	1335	1,170	225	2.58	2.02	[1].00150	64	1,770	425	2,260	879
May 20	1515	1,710	276	3.00	2.07	[1].00150	74	2,010	764	3,340	2,090
June 1	1515	919	266	2.21	1.56	[1].00150	71	513	262	857	596
June 14	1445	755	223	2.25	1.51	[1].00150	68	339	197	699	553
July 12	1510	787	262	2.19	1.37	[1].00150	81	1,560	468	2,230	1,120
Aug. 13	1330	330	145	1.98	1.15	[1].90150	76	13,500	351	13,600	405
Aug. 24	1525	361	198	2.20	.83	[1].00150	73	12,200	488	13,700	1,550
Sept. 8	1400	563	176	2.23	1.43	[1].00150	73	4,220	591	4,780	1,080
Sept. 23	1505	169	90	1.75	1.07	[1].00150	69	263	68	456	256
Oct. 5	1520	294	150	1.81	1.08	[1].00150	74	639	198	950	496
Oct. 19	1445	305	150	1.96	1.04	[1].00150	60	865	372	1,200	681
Nov. 3	1305	252	166	1.64	.93	[1].00150	52	656	407	1,010	748
Nov. 17	1120	360	172	1.83	1.15	[1].00150	44	1,280	858	1,690	1,260
Nov. 30	1025	369	172	2.02	1.06	[1].00150	41	849	577	1,470	1,190
Dec. 15	1100	358	172	1.95	1.07	[1].00150	34	954	725	1,540	1,280
Dec. 30	1450	386	75	2.80	1.84	[1].00150	32	1,030	834	1,460	1,260
1955											
Jan. 11	1205	485	174	2.19	1.27	[1].00150	36	926	630	1,420	1,120
Feb. 28	1555	515	169	2.27	1.34	[1].00150	47	726	421	1,680	1,360
Mar. 7	1430	581	178	2.33	1.40	[1].00150	48	935	552	1,820	1,420
Mar. 22	1120	480	178	2.18	1.24	[1].00150	42	670	315	1,090	722
May 3	1155	446	176	1.67	1.52	[1].00150	59	636	134	824	311
May 17	1050	1,180	143	2.97	2.78	[1].00150	57	2,370	1,040	2,870	1,530
June 2	1245	1,580	146	3.69	2.93	[1].00150	70	3,080	2,130	4,260	3,290
June 29	1500	309	151	1.77	1.16	[1].90150	76	444	89	579	213
July 11	1010	453	174	1.90	1.37	[1].00150	71	1,550	1,320	1,690	1,450
July 25	1005	366	155	2.44	.97	[1].00150	71	38,300	1,150	41,100	3,410
Aug. 9	1405	862	128	3.13	2.15	[1].00150	84	35,700	2,140	37,000	3,350
Sept. 6	1430	1,140	152	3.69	2.03	[1].00150	74	5,670	3,800	6,500	4,580
Sept. 19	1145	264	146	1.62	1.12	[1].00150	70	631	442	1,370	1,180
Oct. 4	1500	206	116	1.84	.97	[1].00150	73	1,170	573	1,540	924
Oct. 19	1430	235	130	1.73	1.05	[1].00150	64	712	278	1,160	719
Nov. 2	1115	273	124	1.88	1.17	[1].00150	44	2,040	1,530	2,210	1,700
Nov. 14	1435	372	126	2.21	1.33	[1].00150	52	1,510	846	2,100	1,380
Nov. 28	1500	426	111	2.70	1.42	[1].00150	44	1,440	893	2,250	1,680
Dec. 14	1515	497	111	2.70	1.66	[1].00150	40	1,480	1,080	2,140	1,730
Dec. 27	1335	615	115	3.03	1.77	[1].00150	40	1,510	1,030	2,280	1,780
1956											
Jan. 10	1510	571	157	2.79	1.31	[1].00150	43	1,100	781	2,010	1,670
Jan. 24	1440	523	150	2.78	1.25	[1].00150	43	938	732	1,890	1,660
Feb. 7	1415	605	213	3.00	.95	[1].00150	40	1,200	792	2,680	2,260
Feb. 22	1345	478	118	2.58	1.57	[1].00150	47	867	685	1,490	1,300
Mar. 6	1405	863	258	2.61	1.28	[1].00150	47	3,870	1,160	4,900	2,110
Mar. 21	1045	508	105	2.47	1.96	[1].00150	51	916	522	1,380	981
Apr. 4	1425	892	215	2.84	1.46	[1].00150	51	1,650	528	2,370	1,230
Apr. 19	1030	929	214	2.88	1.50	[1].00150	50	1,780	890	2,660	1,750
May 2	1020	1,250	263	3.23	1.47	[1].00150	58	2,170	1,020	3,190	2,000
May 15	1615	599	150	2.25	1.77	[1].00150	66	2,550	2,170	2,820	2,430
May 29	1420	888	202	2.57	1.71	[1].00150	70	1,190	702	1,830	1,320
June 12	1630	667	197	2.34	1.45	[1].00150	76	641	397	1,130	876
July 10	1415	104	142	.85	.86	[1].00150	80	84	3	86	5
July 24	1345	256	108	1.94	1.22	[1].00150	80	608	91	1,200	671
1957											
May 15	1430	3,580	140	5.19	4.93	[1].00150	57	3,360	2,180	3,900	2,710
May 28	1320	3,010	144	5.25	3.98	[1].00150	61	2,250	1,780	2,890	2,410
June 13	1100	5,160	150	6.18	5.57	[1].00150	64	2,670	1,900	3,400	2,620
June 28	1400	4,760	149	5.96	5.36	[1].00150	73	2,160	1,620	3,580	3,030
1958											
May 12	1720	8,200	205	7.19	5.56	.00176	59	4,410	2,780	5,330	3,700
May 21	1250	9,140	210	7.43	5.86	.00180	65	2,790	1,670	3,140	2,020
May 26	1335	9,720	209	7.53	6.17	.00193	67	2,580	1,550	3,490	2,460
June 3	1630	8,590	200	7.16	6.00	.00168	67	2,430	1,610	3,130	2,310
June 9	1700	5,120	188	6.06	4.49	.00151	66	6,300	5,780	8,390	7,880
June 12	1710	5,010	187	5.99	4.47	.00151	66	2,740	2,400	4,510	4,170
June 17	1345	2,200	182	4.44	2.73	.00091	75	1,100	898	1,820	1,620
June 24	1600	1,020	181	2.60	2.17	.00100	80	577	418	1,390	1,230
1961											
Apr. 26	1350	2,200	177	4.60	2.70	.00115	57	1,360	797	2,100	1,540
May 2	1535	3,580	163	5.49	4.00	.00126	62	2,890	1,480	4,150	2,740
May 18	1110	2,510	168	4.99	3.10	.00108	62	1,040	685	1,800	1,450
June 22	1440	680	162	2.31	1.76	.00197	76	519	371	877	729

[1] Average bed slope from aggradation-degradation studies.

TABLE 4.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande near Bernalillo, N. Mex.*

Date	Time	Q (cfs)	B (ft)	V (ft per sec)	D (ft)	S	T (°F)	Measured concentration of suspended load (ppm)		Computed total concentration (ppm)	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1952											
Apr 25	----------	2,730	272	4.06	2.46	0.00089	58	3,320	1,860	4,640	3,130
May 12	----------	6,490	272	6.57	3.63	.00084	62	3,160	2,120	5,390	4,330
June 17	----------	6,140	272	5.96	3.79	.00083	70	1,990	1,550	2,590	2,150
June 20	----------	4,830	272	5.09	3.49	.00079	72	1,690	1,320	2,710	2,340
June 26	----------	2,760	269	3.71	2.76	.00076	70	1,040	853	1,700	1,520
July 24	----------	2,060	270	2.84	2.69	.00080	75	2,490	872	2,860	1,260
1953											
Apr. 29	----------	1,540	270	2,65	2.15	[1].00086	57	2,450	735	3,190	1,470
May 5	----------	551	265	1.66	1.25	[1].00086	63	554	288	809	544
June 1	----------	2,570	270	3.58	2.66	.00093	65	2,530	835	3,400	1,710
June 2	----------	2,150	270	3.11	2.56	[1].00086	71	2,010	724	2,750	1,460
June 4	----------	2,090	270	3,12	2.48	.00083	62	1.600	672	2,220	1,290
June 17	----------	1,340	268	2.34	2.14	.00086	69	1,060	615	1,640	1,200
1956											
Apr. 2	1520	759	237	2.23	1.44	[1].00086	47	3,560	2,140	4,030	2,570
Apr. 14	1235	610	262	1.98	1.18	[1].00086	51	1,840	589	2,390	1,100
Apr. 16	1615	623	266	1.91	1.23	[1].00086	62	2,360	920	2,790	1,310
Apr. 21	1410	741	280	2.05	1.29	[1].00086	65	2,100	672	2,700	1,230
Apr. 23	1505	653	255	1.94	1.32	[1].00086	64	3,330	2,060	4,510	3,210
May 1	1430	920	274	2.37	1.42	[1].00086	61	3,890	2,100	4,710	2,880
May 5	1330	1,000	266	2.51	1.50	[1].00086	69	2,600	1,010	3,450	1,810
May 12	1305	986	263	2.90	1.29	[1].00086	66	1,120	549	1,900	1,310
May 14	1415	395	244	1.44	1 12	[1].00086	61	2,040	857	2,520	1,310
May 18	1320	199	79.0	1.70	1.48	[1].00086	75	319	128	452	261
May 22	1325	98.4	89.0	1.40	.79	[1].00086	71	199	105	347	262
May 26	1330	564	262	2.01	1.07	[1].00086	71	1,720	688	2,600	1,520
May 29	1115	573	171	1.97	1.70	[1].00086	66	4,410	3,700	7,950	7,240
June 2	1630	496	260	1.85	1.03	[1].00086	75	926	444	1,490	985
June 4	1120	493	214	1.76	1.31	[1].00086	72	1,010	465	1,320	759
June 8	1200	612	294	1.89	1.10	[1].00086	78	2,090	1,250	3,240	2,370
June 12	1050	479	160	1.76	1.70	[1].00086	73	718	323	970	562
June 15	1230	186	46.0	2.09	1.94	[1].00086	80	3,820	2,250	5,040	3,460
June 29	1245	270	180	1.62	.93	[1].00086	81	3,350	402	3,750	741
Aug. 24	1040	17.6	29.0	1.17	.52	[1].00086	79	855	68	1,000	200
Sept. 7	1140	81.2	108	1.30	.58	[1].00086	76	1,000	60	1,140	183
1957											
Apr. 29	1500	1,580	275	3.73	1.54	[1].00086	59	3,680	2,240	5,460	4,160
May 13	1800	4,150	271	5.00	3.06	[1].00086	58	6,320	4,040	8,140	5,830
May 16	1800	3,080	272	5.17	2.19	[1].00086	60	4,460	3,120	6,430	5,050
May 27	1555	2,850	271	4.31	2.44	[1] 00086	64	2,540	1,730	3,640	2,810
June 11	1600	5,160	271	5.86	3.25	[1].00086	65	3,570	2,610	5,120	4,140
June 24	1630	4,570	271	5.56	3.03	[1].00086	73	1,900	1,290	3,080	2,460
1958											
May 8	1035	6,860	270	6.91	3.68	.00080	58	4,420	2,480	5,860	3,930
May 13	1035	8,320	271	6.88	4.46	.00080	60	4,740	3,180	6,050	4,500
May 21	1530	8,680	270	7.82	4.11	.00079	67	3,400	2,240	6,240	5,080
May 27	1130	10,100	273	7.71	4.80	.00080	74	3,040	2,070	3,920	2,940
June 4	1145	8,160	272	6.92	4.34	.00083	67	2,580	1,880	3,510	2,800
June 10	1015	5,800	270	6.27	3.43	.00074	65	3,480	2,850	4,570	3,950
June 13	1030	4,340	266	6.10	2.67	.00076	63	2,080	1,710	3,990	3,610
June 18	0945	4,000	267	5.06	2.96	.00076	67	5,980	2,930	7,460	4,390
June 25	1110	6,040	273	6.50	3.40	.00080	73	5,410	3,950	7,240	5,760
1960											
Feb. 15	1430	602	128	2.55	1.84	[1].00086	44	1,430	940	1,760	1,270
Apr. 6	1320	2,100	269	3.04	2.56	.00083	59	1,900	950	2,430	1,480
May 24	1220	1,240	133	2.71	3.44	.00083	65	1,200	768	1,720	1,280
June 22	0950	2,030	268	2.89	2.93	.00082	74	781	523	1,170	894
1961											
Apr. 27	1230	2,230	267	3.16	2.64	.00083	57	1,790	1,150	2,290	1,640
May 3	1430	3,360	270	3.99	3.12	.00083	66	2,670	1,320	3,400	2,040
May 1[illegible]	1120	2,260	268	3.62	2.33	.00085	63	1,250	755	1,310	934
1962											
Apr. 30	1315	5,340	276	6.01	3.22	.00086	64	4,360	2,000	5,250	3,160
June 1	1430	987	223	2.88	1.54	.00080	71	1,720	1,490	2,960	2,730
June 25	1245	453	227	2.00	1.00	.00079	79	185	73	410	315

[1] Average of observed water-surface slopes.

TABLE 5.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande at Albuquerque, N. Mex.*

Date	Time	Q (cfs)	B (ft)	V (ft per sec)	D (ft)	S[1]	T (°F)	Measured concentration of suspended load (ppm)		Computed total concentration (ppm)	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1954											
Mar. 8	0930	268	77.0	1.99	1.75	0.00110	44	659	165	967	466
Mar. 11	1010	101	84.0	.99	1.21	.00110	49	588	6	598	6
Mar. 26	1045	670	333	1.83	1.10	.00110	47	2,890	578	3,420	1,060
Apr. 6	1150	386	338	1.63	.70	.00110	57	2,520	227	3,060	729
Apr. 8	1010	128	96.0	1.16	1.15	.00110	51	572	29	613	63
Apr. 19	1110	721	362	1.90	1.05	.00110	62	2,220	577	2,540	851
Apr. 22	1010	429	136	2.03	1.55	.00110	58	1,250	325	1,480	539
May 3	1330	1,420	332	2.72	1.57	.00110	65	3,780	643	4,670	1,450
May 6	1030	635	340	1.69	1.10	.00110	63	1,320	264	1,650	572
May 17	1620	1,420	333	2.61	1.63	.00110	67	3,190	510	3,770	1,060
May 21	1045	1,300	350	2.15	1.73	.00110	67	2,450	588	2,930	1,040
June 2	1025	388	115	1.63	2.07	.00110	67	523	120	612	204
June 4	1100	318	130	1.89	1.29	.00110	67	510	168	766	415
June 14	1000	427	135	1.89	1.67	.00110	67	635	254	958	574
June 18	1035	68.8	55.0	1.64	.76	.00110	61	307	227	732	651
July 12	1025	523	172	2.00	1.52	.00110	81	5,970	239	6,510	700
July 27	1000	172	96.0	1.31	1.36	.00110	82	2,970	89	3,080	149
Aug. 10	0900	236	103	1.69	1.36	.00110	70	9,370	94	9,510	94
Aug. 24	1545	1,040	246	3.18	1.33	.00110	75	56,300	1,130	58,800	2,900
Sept. 7	1030	366	128	1.98	1.45	.00110	71	19,600	784	21,700	2,640
Oct. 4	1630	71.9	31.5	1.67	1.37	.00110	78	2,390	96	2,600	274
Oct. 18	1440	81.0	58.0	1.52	.92	.00110	64	1,830	55	2,070	252
Nov. 2	1610	23.9	26.0	1.30	.71	.00110	57	525	32	601	99
Nov. 16	1125	247	154	1.87	.86	.00110	48	1,780	142	2,170	509
Dec. 13	1430	348	178	1.71	1.14	.00110	42	1,560	218	1,880	505
1955											
Jan. 10	1305	444	236	1.92	.98	.00110	37	1,720	413	2,350	996
Jan. 24	1150	242	135	1.70	1.05	.00110	34	893	277	1,230	594
Feb. 25	0925	558	355	1.86	.85	.00110	35	2,030	731	3,060	1,730
Mar. 7	1350	395	155	1.88	1.35	.00110	50	1,260	164	1,520	406
Mar. 22	1315	293	159	1.60	1.15	.00110	47	947	104	1,130	268
Apr. 4	0950	132	87.0	1.37	1.11	.00110	45	672	27	710	53
May 2	1420	281	98.0	2.01	1.43	.00110	58	1,630	244	2,050	637
May 31	1120	902	400	1.88	1.20	.00110	63	1,800	468	2,210	831
June 13	1400	205	96.0	1.40	1.52	.00110	60	1,070	749	1,140	816
June 27	1220	73.7	78.0	1.40	.67	.00110	61	211	34	327	140
July 11	1345	143	110	1.13	1.15	.00110	72	351	42	414	97
July 25	1330	265	97.0	1.80	1.52	.00110	72	14,600	584	15,100	1,070
Aug. 11	1400	2,520	327	3.91	1.97	.00110	76	49,800	3,980	51,800	5,820
Aug. 23	1130	1,380	325	3.45	1.23	.00110	75	39,800	1,190	42,300	3,080
Sept. 6	1215	791	327	1.67	1.45	.00110	73	3,960	990	5,930	2,920
Sept. 19	1510	51.0	71.0	1.21	.59	.00110	67	107	5	155	53
Oct. 4	1445	101	110	1.39	.66	.00110	68	1,420	28	1,560	143
Dec. 1	1430	406	155	2.01	1.30	.00110	49	1,310	236	1,680	570
Dec. 12	1450	430	133	2.04	1.59	.00110	42	1,900	513	2,230	807
Dec. 27	1430	602	169	1.92	1.85	.00110	48	2,680	858	3,060	1,210
1956											
Jan. 9	1545	582	149	2.24	1.74	.00110	48	2,210	597	2,720	1,060
Jan. 23	1555	605	166	2.63	1.39	.00110	43	1,910	707	2,900	1,650
Feb. 7	1545	676	186	2.59	1.40	.00110	45	4,130	1,240	5,440	2,460
Feb. 20	1600	570	224	1.93	1.32	.00110	50	3,090	1,050	3,850	1,420
July 20	1200	3,750	332	4.08	2.77	.00110	70	62,300	3,740	67,700	6,820
1957											
May 14	1515	4,030	320	4.17	3.02	.00110	62	9,490	6,260	10,800	7,550
May 27	1210	3,040	320	3.96	2.40	.00110	65	3,910	2,740	4,930	3,730
June 10	1245	5,500	324	4.20	4.04	.00110	67	5,540	3,930	6,610	4,990
June 24	1545	5,050	325	3.37	4.62	.00110	75	8,490	7,470	9,500	8,470

[1] Average bed slope from aggradation-degradation studies.

TABLE 6.—*Basic hydraulic data with measured and computed sediment concentrations, Rio Grande near Belen, N. Mex.*

Date	Time	*Q* (cfs)	*B* (ft)	*V* (ft per sec)	*D* (ft)	*S* [1]	*T* (°F)	Measured concentration of suspended load (ppm)		Computed total concentration (ppm)	
								All sizes	>0.062 mm	All sizes	>0.062 mm
1954											
Mar. 22	1405	94.4	82.0	1.09	1.05	0.00069	55	248	15	260	24
Apr. 6	1510	213	104	1.61	1.27	.00069	64	702	63	832	176
May 5	1810	404	265	1.66	.92	.00069	77	1,080	119	1,340	371
June 2	1410	188	150	1.11	1.13	.00069	71	217	4	229	11
June 14	1345	143	53.0	1.16	2.32	.00069	68	320	144	394	199
June 28	1430	74.4	45.0	1.58	1.04	.00069	75	149	34	245	128
July 12	1515	47.9	66.0	1.06	.68	.00069	78	123	27	162	63
Aug. 10	1345	108	72.0	1.58	.95	.00069	79	14,100	141	15,400	1,270
Sept. 21	1520	37.4	39.0	1.23	.77	.00069	74	68	7	98	35
Oct. 19	1625	86.4	61.0	1.05	1.35	.00069	63	1,400	28	1,440	48
Nov. 16	1510	164	65.0	1.72	1.46	.00069	53	1,460	15	1,540	81
1955											
Jan. 12	1235	543	204	1.74	1.53	.00069	38	1,750	262	2,010	497
Jan. 25	1210	316	117	2.00	1.35	.00069	40	1,240	223	1,590	558
Feb. 9	1350	454	208	1.54	1.42	.00069	41	1,380	262	1,680	549
Feb. 24	1445	382	161	1.78	1.33	.00069	45	1,120	224	1,470	557
Mar. 9	1635	184	86.0	1.63	1.31	.00069	57	676	88	827	229
Mar. 25	1600	103	98.0	1.32	.80	.00069	60	277	24	334	87
May 20	1625	459	272	1.57	1.08	.00069	73	2,190	153	2,500	407
Aug. 9	1145	651	207	2.54	1.24	.00069	76	23,900	478	25,200	1,350
Aug. 23	1520	1,180	258	2.93	1.56	.00069	79	27,100	542	28,400	1,500
1957											
May 15	1500	3,790	390	3.79	2.56	.00069	61	7,960	3,580	9,320	4,890
May 27	1230	2,950	395	3.50	2.14	.00069	64	5,210	2,240	6,390	3,350
June 24	1410	4,200	395	4.16	2.56	.00069	75	3,200	1,730	4,330	2,820

[1] Average bed slope from aggradation–degradation studies.

TABLE 7.—*Particle-size analyses of bed material, Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.*

[Method of analysis: S, sieve; V, visual accumulation tube]

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1958													
May 6	1	59	0.7	3.8	33.2	94.8	99.5	100	----	----	----	----	S
May 12	1	58	.3	1.2	10.3	66.3	96.6	98.8	99.5	100	----	----	S
May 19	2	62	.2	1.0	8.9	47.5	76.3	92.1	97.8	98.9	100	----	S
May 26	1	61	.2	2.2	30.9	64.8	80.9	86.8	89.9	93.7	100	----	S
June 3	3	62	.1	.6	11.2	34.5	42.1	50.6	61.2	70.6	89.5	100	S
June 9	3	60	1.1	5.0	16.3	45.7	66.6	85.8	96.8	99.2	100	----	S
June 12	3	62	.1	.5	9.8	54.7	74.3	81.3	84.9	88.7	100	----	S
June 17	3	61	2.2	8.4	30.5	57.0	74.5	87.8	94.9	98.1	99.5	100	S
June 24 [1]	3	72	.1	.4	4.1	26.8	36.6	39.8	42.3	47.1	54.1	72.2	S
1959													
Aug. 8	5	73	1.5	8.7	34.9	76.0	92.1	96.9	98.6	100	----	----	S
1961													
Apr. 25	5	52	0	.1	3.1	15.7	40.5	57.9	72.1	85.2	95.8	100	S
May 2	5	57	.1	.2	3.5	21.2	54.0	75.7	89.2	96.0	99.2	100	S
May 17	4	56	.1	.3	23.0	71.7	85.7	96.5	99.6	99.9	100	----	V
June 21	6	76	----	.2	4.4	43.7	73.5	83.5	89.2	93.5	95.6	100	S
July 20	5	74	.2	.4	3.2	35.8	74.0	91.2	97.3	99.7	100	----	S
1962													
Apr. 19	6	59	.4	1.1	6.8	25.8	46.2	58.2	67.1	75.6	87.4	100	S
May 31	6	59	.1	.2	23.8	72.1	87.7	92.9	95.9	98.5	99.5	100	S
July 2	6	78	.1	.1	5.9	46.8	80.4	92.8	97.3	98.8	99.4	100	S

[1] 100 percent <64mm.

TABLE 8.—*Particle-size analyses of bed material, Rio Grande at Cochiti, N. Mex.*

[Method of analysis: S, seive; V, visual accumulation tube]

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1954													
Mar. 10	3	54	0.0	0.1	6.1	55.9	86.3	96.8	99.3	99.9	100	--------	S
Mar. 23	3	51	.0	.1	12.3	40.2	70.8	87.7	96.4	99.4	100	--------	S
Apr. 7	3	58	.1	.3	3.4	19.8	36.5	45.6	52.1	61.2	82.0	100	S
Apr. 20	3	58	.5	2.1	9.0	26.2	43.3	54.0	61.1	69.8	85.9	100	S
May 4	3	63	.2	1.2	9.4	40.3	75.6	90.4	95.9	98.8	100	--------	S
May 20	3	67	.4	4.1	35.2	69.8	81.0	88.5	93.4	96.0	99.0	100	S
June 1	3	67	.4	4.4	34.5	76.3	85.8	92.1	96.4	98.9	100	--------	S
June 14	3	65	.2	3.4	32.9	65.4	71.4	78.9	87.3	95.1	99.5	100	S
July 12	3	77	.5	3.1	47.1	94.3	96.5	97.8	98.6	99.4	100	--------	S
Aug. 10	3	73	.5	2.7	31.5	93.3	96.2	97.4	98.2	98.9	100	--------	S
Aug. 24	3	70	2.2	9.2	39.9	96.3	98.6	99.2	99.4	99.8	100	--------	S
Sept. 8	3	70	1.5	3.8	28.9	88.9	96.0	98.5	99.5	100	--------	--------	S
Sept. 23	3	71	4.9	19.8	36.6	89.4	94.6	97.2	98.8	100	--------	--------	S
Oct. 5	3	72	.4	2.1	15.8	82.0	91.7	96.6	99.0	99.9	100	--------	S
Oct. 19	3	58	2.3	11.9	24.3	92.3	98.2	98.9	99.6	100	--------	--------	S
Nov. 17	3	49	.3	2.2	14.2	86.5	97.6	99.2	99.7	100	--------	--------	S
Dec. 15	3	38	.2	.7	7.2	73.8	96.7	98.5	99.5	100	--------	--------	S
Dec. 29	3	36	.1	.4	4.6	77.6	94.3	99.3	99.8	100	--------	--------	S
1955													
Jan. 11	3	37	.0	.7	6.9	79.1	97.1	99.2	99.8	100	--------	--------	S
Jan. 26	3	36	.0	1.0	7.3	87.6	96.3	97.6	98.5	99.7	100	--------	S
1955													
Feb. 9	3	40	.1	1.0	6.7	78.7	95.7	98.3	99.3	100	--------	--------	S
Feb. 23	2	38	.2	.8	4.0	55.7	85.2	89.8	94.6	99.0	100	--------	S
Mar. 8	3	49	.0	.2	3.4	50.2	86.4	95.6	98.1	99.2	100	--------	S
Mar. 22	3	49	.1	.2	3.0	36.1	76.7	90.0	95.9	99.2	100	--------	S
Apr. 6	3	53	.1	.2	2.1	39.4	76.5	91.0	96.7	99.2	100	--------	S
Apr. 19	3	58	.1	.6	3.6	47.2	85.0	96.3	99.1	99.8	100	--------	S
May 17	3	60	.3	2.5	10.3	35.3	67.8	88.4	95.9	98.8	100	--------	S
June 14	1	75	.2	2.3	36.7	84.4	93.0	97.7	99.1	99.7	100	--------	S
June 29	2	72	.1	2.3	42.4	89.7	97.4	99.2	99.8	100	--------	--------	S
July 11	1	75	.2	4.3	72.8	99.1	99.8	100	--------	--------	--------	--------	S
July 25	4	81	.2	.8	19.3	66.8	85.4	96.2	98.9	99.6	99.9	100	S
Aug. 8 [1]	3	76	2.2	5.2	24.1	63.7	74.1	82.7	87.0	89.0	91.2	93.0	S
Sept. 6	2	71	1.2	7.2	25.4	81.0	89.4	92.9	95.2	97.4	99.3	100	S
Sept. 19	3	74	.8	4.3	16.5	53.1	78.0	88.5	94.3	97.1	100	--------	S
Oct. 3	3	70	.6	6.3	28.4	71.7	84.5	88.6	91.3	93.7	97.8	100	S
Oct. 18	3	63	1.2	8.4	52.4	78.2	85.7	91.9	97.1	99.5	100	--------	S
Nov. 2	3	52	.4	5.3	51.3	92.8	99.0	99.4	99.8	100	--------	--------	S
Nov. 15	3	42	.3	2.3	20.4	64.2	84.7	92.4	97.2	99.1	100	--------	S
Nov. 28	3	40	.3	3.4	27.8	96.5	99.4	99.7	99.8	100	--------	--------	S
Dec. 14	3	36	.2	2.7	19.3	93.9	98.0	99.3	99.8	100	--------	--------	S
Dec. 27	3	39	.2	3.2	18.3	79.9	99.1	100	--------	--------	--------	--------	S
1956													
Jan. 24	3	41	.0	1.6	16.0	76.8	95.8	98.8	99.3	99.5	100	--------	S
Feb. 7	3	37	.2	1.6	17.7	65.1	82.2	89.0	94.3	97.1	99.0	100	S
Feb. 22	3	42	.1	2.0	23.6	74.9	93.3	97.5	99.1	99.9	100	--------	S
Mar. 7	3	43	.1	1.3	10.3	52.4	85.6	95.0	97.6	98.8	99.7	100	S
Apr. 3	3	47	.2	1.1	6.9	58.1	81.6	92.4	97.4	99.6	100	--------	S
Apr. 18	3	52	.5	3.4	35.8	75.3	91.0	95.7	98.2	99.5	100	--------	S
May 2	3	59	.8	7.2	49.1	63.9	76.5	85.5	91.2	94.8	99.6	100	S
May 15	3	59	.2	3.1	44.8	88.5	93.8	95.1	97.6	98.5	99.2	100	S
May 29	3	66	.4	3.1	27.9	65.6	79.9	89.7	95.3	97.9	99.8	100	S
June 12	3	73	.5	6.4	37.9	66.2	77.8	85.4	93.4	98.0	100	--------	S
June 26	3	77	2.0	13.8	48.4	82.0	94.8	98.2	99.6	99.9	100	--------	S
July 10	3	80	.5	7.9	23.3	90.8	98.2	99.3	99.8	100	--------	--------	S
1957													
May 16	3	54	.8	5.8	50.4	94.2	99.6	99.9	100	--------	--------	--------	S
May 29	3	62	.2	1.5	21.5	85.5	99.1	99.7	99.9	100	--------	--------	S
June 12	3	62	4	1.8	23.0	68.5	91.9	96.8	98.8	99.5	100	--------	S
June 26	2	67	.3	1.5	18.5	90.6	99.4	99.7	99.8	100	--------	--------	S
1958													
May 7	3	55	.4	2.7	25.4	64.2	72.0	77.7	82.7	86.6	93.4	100	S
May 12	3	58	.4	2.3	17.0	59.7	69.9	77.0	83.2	88.9	96.5	100	S
May 20 [1]	6	58	.6	3.7	23.9	45.2	57.1	62.7	69.1	74.5	78.1	83.8	S
May 26	3	61	2.6	15.9	43.4	63.7	66.4	66.7	66.8	66.8	100	--------	S
June 3	3	63	.1	.7	10.3	44.2	57.4	66.4	72.4	78.9	85.5	100	S
June 9	3	62	.1	1.0	11.6	42.8	66.9	79.6	87.5	94.4	96.9	100	S
June 12	3	63	.1	.6	8.7	39.8	66.0	80.8	84.6	87.4	90.0	100	S
June 17	3	70	.2	1.1	12.7	54.5	81.1	92.7	95.3	98.2	99.3	100	S
June 24	3	75	.1	.5	8.0	38.2	59.9	75.2	83.6	90.1	96.2	100	S
1961													
Apr. 26	6	52	.1	.9	34.0	73.0	90.0	95.3	97.8	99.0	99.8	100	S
May 2	6	57	.2	1.6	23.1	56.6	79.4	89.4	93.0	95.6	98.6	100	S
May 18	6	59	.1	.5	22.3	60.7	73.1	80.1	86.1	91.7	96.6	100	S
June 22 [1]	6	76	.2	.8	11.3	34.3	49.2	55.2	59.6	66.6	79.7	98.5	S

[1] 100 percent <64mm.

TABLE 9.—*Particle-size analyses of bed material, Rio Grande at San Felipe, N. Mex.*

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1954													
Mar. 10	3	56	0.1	0.6	19.2	71.7	93.0	98.5	99.6	100	--------	--------	S
Mar. 23	3	53	.2	.9	14.8	45.6	61.4	68.7	74.1	81.0	91.6	100	S
Apr. 7	3	62	.1	.9	19.5	71.5	84.0	89.3	91.0	93.3	95.7	100	S
Apr. 20	3	64	.2	1.0	11.7	76.2	98.4	99.6	99.8	99.8	100	--------	S
May 4	3	64	.2	1.2	13.8	48.5	78.9	95.3	98.8	99.7	100	--------	S
May 20	3	74	.2	.8	6.3	50.0	84.2	93.3	96.0	98.3	100	--------	S
June 1	3	71	.2	2.3	25.8	77.4	93.2	97.3	98.8	99.4	100	--------	S
June 14	3	68	.1	1.0	19.7	70.5	94.0	98.1	99.1	99.8	100	--------	S
July 12	3	81	.2	1.9	27.9	84.3	96.9	99.1	99.6	99.8	100	--------	S
Aug. 13	3	76	2.0	5.5	13.9	57.0	85.3	94.3	97.9	99.2	100	--------	S
Aug. 24	3	73	12.7	33.3	73.1	90.2	97.0	99.3	99.9	100	--------	--------	S
Sept. 8	3	73	.9	4.4	16.8	57.5	89.8	98.3	99.6	100	--------	--------	S
Sept. 23	3	69	.4	1.8	14.6	75.6	94.9	98.4	99.5	99.9	100	--------	S
Oct. 5	3	74	.4	2.1	12.7	62.6	84.3	94.3	98.4	99.8	100	--------	S
Oct. 19	3	60	.7	5.5	24.2	53.1	84.8	95.7	98.5	99.9	100	--------	S
Nov. 3	3	52	1.2	8.8	51.2	70.5	86.3	95.0	98.8	100	--------	--------	S
Nov. 17	3	44	.7	6.3	30.3	80.6	94.8	98.5	99.2	99.8	100	--------	S
Nov. 30	3	41	.4	2.9	17.2	72.8	91.0	97.1	99.2	99.9	100	--------	S
Dec. 15	3	34	2.1	11.0	41.8	79.2	93.9	97.7	98.8	99.4	100	--------	S
Dec. 30	3	32	.2	2.2	23.5	80.0	93.0	98.7	99.8	99.9	100	--------	S
1955													
Jan. 11	3	36	.8	5.2	31.2	59.9	78.1	89.1	94.0	97.3	99.5	100	S
Feb. 28	3	47	.2	1.1	12.9	76.5	94.8	97.4	98.1	98.6	98.8	100	S
Mar. 7	3	48	.1	1.4	14.5	86.5	98.7	99.4	99.7	100	--------	--------	S
Mar. 22	3	42	.7	6.4	40.4	73.8	91.3	95.7	97.2	98.5	100	--------	S
May 3	3	59	.9	2.3	11.7	46.5	73.4	87.4	94.8	98.6	100	--------	S
May 17	2	57	.7	3.9	21.2	67.0	85.5	91.9	94.5	97.2	98.6	100	S
June 2	2	70	1.0	8.4	39.6	98.0	99.6	99.8	99.9	100	--------	--------	S
June 29	3	76	.1	1.7	13.8	67.3	94.6	98.5	99.5	99.9	100	--------	S
July 11	3	71	.4	2.9	15.3	59.7	83.2	93.6	98.2	99.7	100	--------	S
July 25	3	71	.6	2.1	14.8	68.9	90.3	94.2	95.6	97.6	100	--------	S
Aug. 9	3	84	1.0	5.4	22.5	55.8	74.9	85.9	91.5	94.7	97.5	100	S
Sept. 6	3	74	1.0	6.0	29.0	68.7	85.3	91.6	93.8	95.6	96.6	100	S
Sept. 19	3	70	.4	3.0	21.9	77.5	93.7	97.7	99.2	99.9	100	--------	S
Oct. 4	3	73	.7	2.2	7.1	44.6	94.3	98.6	99.5	99.9	100	--------	S
Oct. 19	3	64	.6	3.0	10.8	47.1	92.6	98.5	99.5	99.9	100	--------	S
Nov. 2	3	44	1.4	6.1	25.2	75.1	94.9	98.8	99.7	100	--------	--------	S
Nov. 14	3	52	.7	7.7	33.2	93.0	98.1	99.0	99.4	99.8	100	--------	S
Nov. 28	3	44	1.5	7.7	36.1	87.3	98.2	99.3	99.6	99.9	100	--------	S
Dec. 14	3	40	.2	2.3	11.9	62.8	91.7	97.6	98.6	99.2	100	--------	S
Dec. 27	3	40	.8	5.4	29.5	76.0	96.0	98.7	98.9	99.1	100	--------	S
1956													
Jan. 10	3	43	.5	5.1	40.2	86.5	97.4	99.0	99.6	99.8	100	--------	S
Jan. 24	3	43	4.4	23.8	65.5	91.4	94.0	94.4	94.5	94.7	95.2	100	S
Feb. 7	3	40	1.6	13.9	63.9	98.2	99.9	99.9	99.9	100	--------	--------	S
Feb. 22	3	47	.4	4.2	32.3	79.4	96.8	99.2	99.6	99.8	100	--------	S
Mar. 6	3	47	.8	4.8	17.7	50.6	58.0	60.0	62.5	68.7	84.3	100	S
Mar. 21	3	51	.6	5.7	55.3	96.9	99.3	99.9	100	--------	--------	--------	S
Apr. 4	3	51	.9	5.1	28.8	67.1	93.1	98.4	99.3	100	--------	--------	S
Apr. 19	3	50	.4	3.6	30.1	88.1	98.2	99.1	99.5	99.7	100	--------	S
May 2	3	58	1.5	8.4	40.1	78.4	82.2	83.0	84.4	87.4	96.3	100	S
May 15	3	66	.4	3.7	24.1	68.9	83.5	92.7	97.7	99.4	100	--------	S
May 29 [1]	3	70	.4	2.9	18.1	70.7	88.6	91.9	92.8	93.3	93.6	94.5	S
June 12	3	76	.6	5.4	39.1	87.4	96.9	99.5	100	--------	--------	--------	S
July 10	3	80	1.1	5.1	29.5	81.8	95.3	98.3	99.4	99.9	100	--------	S
July 24	3	80	.1	.5	3.2	41.5	83.6	93.8	97.5	99.1	100	--------	S
1957													
May 15	3	57	.5	2.7	28.9	65.9	72.6	77.3	81.8	87.3	96.9	100	S
May 28	3	61	2.0	6.7	40.9	86.8	99.0	99.8	99.9	100	--------	--------	S
June 13	3	64	.2	1.8	31.2	65.3	71.5	77.7	84.4	89.8	94.7	100	S
June 28	3	73	.3	.7	6.2	34.6	65.4	82.5	89.5	93.6	97.2	100	S
1958													
May 12	3	59	2.6	6.1	13.4	23.8	33.6	39.6	46.9	55.8	59.5	100	S
May 21 [1]	2	65	.3	2.0	31.1	50.9	51.6	51.9	52.2	52.5	55.2	74.4	S
May 26	3	67	.2	.9	9.0	27.0	48.1	63.2	68.5	71.2	74.9	100	S
June 3	2	67	.1	1.0	9.6	44.9	66.6	76.4	83.9	92.0	100	--------	S
June 9	3	66	.1	.8	12.5	48.7	81.9	93.5	96.3	98.3	98.7	100	S
June 12	3	66	1.2	2.5	14.5	40.7	50.0	60.9	70.9	77.8	82.9	100	S
June 17	3	75	.3	2.1	21.9	59.2	80.2	90.2	93.2	94.5	95.9	100	S
June 24	3	80	.1	.8	9.3	47.3	65.2	66.9	67.5	69.6	74.4	100	S
1961													
Apr. 26	6	57	.4	3.4	58.2	94.0	99.9	100	--------	--------	--------	--------	S
May 2	6	62	.1	2.5	41.2	79.2	88.7	93.4	95.5	97.0	98.7	100	S
May 18	6	62	.1	5.4	54.8	82.7	86.0	90.6	94.7	97.3	98.9	100	S
June 22 [1]	6	76	.3	1.0	12.3	58.5	82.5	90.4	93.2	95.6	97.6	98.5	S

[1] 100 percent < 64 mm.

TABLE 10.—*Particle-size analyses of bed material, Rio Grande near Bernalillo, N. Mex.*

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1952													
Apr. 25	3	58	2.1	10.8	56.5	93.4	98.2	98.8	99.2	99.2	100	----------	S
May 12	3	62	.2	1.5	15.2	70.6	93.7	97.8	99.1	99.3	100	----------	S
June 17	3	70	.4	3.0	37.4	93.0	98.9	99.4	99.5	99.6	100	----------	S
June 20	3	72	.4	2.8	26.7	86.4	95.3	97.3	98.2	98.7	99.9	100	S
June 26	3	70	.3	2.8	32.7	87.4	97.7	99.2	99.6	100	----------	----------	S
July 24	3	75	1.0	5.6	45.5	86.9	98.2	99.5	99.7	100	----------	----------	S
1953													
Apr. 29	15	57	.5	3.2	28.3	86.5	98.0	99.1	99.5	99.8	100	----------	S
May 5	15	63	.7	5.4	41.1	82.3	95.8	98.5	99.4	99.8	100	----------	S
June 1	3	65	.6	3.5	25.7	86.7	98.5	99.3	99.6	99.9	100	----------	S
June 2	15	71	.7	4.0	27.7	86.5	97.8	99.0	99.4	100	----------	----------	S
June 4	3	62	.5	3.6	34.1	74.3	91.0	94.4	96.2	97.4	98.4	100	S
June 17	3	69	.3	2.8	30.7	87.7	95.6	97.3	98.2	98.8	99.7	100	S
1956													
Apr. 2	3	47	1.6	9.1	24.1	77.3	91.2	93.1	99.0	99.6	100	----------	S
Apr. 14	3	51	2.0	9.8	44.4	88.1	97.1	98.6	99.4	100	----------	----------	S
Apr. 16	3	62	.9	5.3	22.3	81.4	95.2	98.2	99.3	99.8	100	----------	S
Apr. 21	3	65	.9	4.9	31.5	90.1	96.9	98.8	99.5	99.9	100	----------	S
Apr. 23	3	64	1.1	6.3	30.5	90.6	97.8	98.9	99.5	99.8	100	----------	S
May 1	3	61	.9	4.9	32.4	99.1	99.9	100	----------	----------	----------	----------	S
May 5	3	69	4.5	17.3	51.1	90.3	98.6	99.2	99.5	100	----------	----------	S
May 12	3	66	1.2	7.0	43.3	91.0	97.4	99.2	99.7	99.9	100	----------	S
May 14	3	61	2.3	17.1	62.5	91.4	98.3	99.5	99.9	99.9	100	----------	S
May 18	3	75	.5	4.1	21.2	87.1	96.7	98.0	98.7	99.2	99.5	100	S
May 22	3	71	.4	4.7	28.9	88.1	97.7	99.1	99.6	99.9	100	----------	S
May 26	3	71	2.2	12.8	79.0	96.7	99.2	99.6	99.8	100	----------	----------	S
May 29	3	66	.6	2.9	19.0	88.3	98.5	99.4	99.9	100	----------	----------	S
June 2	3	75	5.9	19.8	58.2	92.4	98.9	99.6	99.8	99.9	100	----------	S
June 4	3	72	1.8	8.6	37.2	94.8	99.4	99.8	99.9	100	----------	----------	S
June 8	3	78	1.1	4.7	24.9	92.1	98.2	99.0	99.5	99.9	100	----------	S
June 12	3	73	8.6	30.5	39.8	79.2	96.5	98.8	99.5	99.9	100	----------	S
June 15	3	80	1.2	9.0	43.5	95.6	99.2	99.7	99.9	100	----------	----------	S
June 29	3	81	5.1	24.2	54.7	93.2	98.6	99.2	99.7	100	----------	----------	S
Aug. 24	3	79	.6	9.9	39.1	87.7	97.9	99.5	99.9	100	----------	----------	S
Sept. 7	3	76	.9	5.0	38.2	96.0	99.8	100	----------	----------	----------	----------	S
1957													
Apr. 29	3	59	1.2	7.3	28.1	82.7	94.3	96.7	97.8	98.6	100	----------	S
May 13	3	58	1.1	9.6	41.6	93.4	99.7	99.9	100	----------	----------	----------	S
May 16	3	60	.6	4.9	38.4	87.0	96.0	98.1	99.4	100	----------	----------	S
May 27	3	64	.5	6.2	46.4	93.1	99.6	100	----------	----------	----------	----------	S
June 11	3	65	.7	5.2	43.0	94.2	98.9	99.5	99.8	100	----------	----------	S
June 24	3	73	.6	4.9	48.9	98.4	100	----------	----------	----------	----------	----------	S
1958													
May 8	4	58	.7	3.2	34.2	77.9	91.4	94.5	95.7	96.3	96.6	100	S
May 13	3	60	.8	6.1	39.0	83.0	97.0	98.4	98.8	99.2	100	----------	S
May 21	3	67	.2	1.3	12.8	78.9	98.5	99.6	99.8	99.8	100	----------	S
May 27	3	74	.3	2.4	38.0	88.6	97.1	98.8	99.6	99.7	100	----------	S
June 4	3	67	.4	3.3	33.4	97.3	99.9	100	----------	----------	----------	----------	S
June 10	3	65	.2	2.2	20.9	86.1	94.6	96.7	97.7	98.6	100	----------	S
June 13	3	63	.3	2.4	22.4	78.0	93.9	97.9	98.9	99.7	100	----------	S
June 18	3	67	.9	7.3	45.2	80.5	94.8	98.1	99.1	99.6	100	----------	S
June 25	3	73	.3	1.4	16.1	83.1	98.1	99.2	99.4	99.7	100	----------	S
1960													
Feb. 15	4	44	1.2	7.5	34.1	77.8	92.2	95.2	96.5	96.6	100	----------	S
Apr. 6	[1] 18	59	.5	3.7	32.2	84.7	95.6	97.4	98.2	99.0	100	----------	S
May 24	[2] 9	65	.3	3.3	35.6	89.4	96.9	98.4	99.4	99.9	100	----------	S
June 22	[3] 12	74	.2	4.3	42.6	86.8	96.9	98.8	99.4	99.8	100	----------	S
1961													
Apr. 27	6	57	.4	9.8	61.1	97.4	99.6	100	----------	----------	----------	----------	V
May 3	6	66	.4	6.4	58.8	96.6	99.8	100	----------	----------	----------	----------	V
May 19	6	63	.2	4.1	67.2	97.8	99.9	100	----------	----------	----------	----------	V
1962													
Apr. 20 [4]	6	64	1.6	7.1	49.2	80.5	83.3	83.8	84.0	84.3	85.1	93.8	V
June 1	3	71	.2	.8	23.6	77.3	96.1	98.5	98.9	99.3	100	----------	V
June 25	5	79	.1	1.3	18.8	62.8	93.8	97.9	99.3	99.9	100	----------	V

[1] Average of samples from 5 sections in the reach.
[2] Average of samples from 3 sections in the reach.
[3] Average of samples from 4 sections in the reach.
[4] 100 percent <64mm.

TABLE 11.—*Particle-size analyses of bed material, Rio Grande at Albuquerque, N. Mex.*

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1954													
Mar. 8	3	44	0.1	.8	14.4	85.6	98.1	99.3	99.7	100	--------	--------	S
Mar. 11	3	49	.1	1.3	16.8	74.0	93.3	96.9	98.3	99.4	100	--------	S
Mar. 26	3	47	.2	2.2	37.5	88.5	96.9	98.5	99.0	99.8	100	--------	S
Apr. 6	3	57	.7	7.3	56.0	84.8	92.6	95.7	97.7	99.2	100	--------	S
Apr. 8	3	61	.3	3.4	43.5	89.1	97.9	99.4	99.9	100	--------	--------	S
Apr. 19	3	62	.3	3.1	31.4	87.6	97.6	98.9	99.5	99.8	100	--------	S
Apr. 22	3	58	.2	2.4	33.8	96.2	99.3	99.6	99.7	100	--------	--------	S
May 3	3	65	1.5	7.1	57.2	96.8	99.5	99.9	100	--------	--------	--------	S
May 6	3	63	.3	2.9	34.2	82.8	95.2	97.4	98.4	99.2	100	--------	S
May 17	5	67	.6	3.8	29.9	84.7	91.0	92.1	92.7	93.9	96.6	100	S
May 21	3	67	.4	2.4	28.6	80.2	95.0	97.6	98.5	99.4	100	--------	S
June 2	3	67	1.4	10.1	50.5	85.2	96.3	98.7	99.4	99.9	100	--------	S
June 4	3	67	.3	2.2	28.5	78.1	93.1	96.5	98.0	99.0	100	--------	S
June 14	3	67	.1	1.1	20.8	80.4	93.2	96.5	98.0	99.6	100	--------	S
June 18	3	61	.2	2.5	46.2	93.1	98.2	99.5	99.9	100	--------	--------	S
July 12	3	81	16.8	30.2	41.4	73.8	88.4	94.9	98.3	99.3	100	--------	S
July 27	3	82	1.2	6.3	43.1	83.9	92.8	94.6	96.2	98.4	100	--------	S
Aug. 10	3	70	.2	1.8	19.8	77.0	97.6	99.2	99.7	99.9	100	--------	S
Aug. 24	5	75	10.4	15.0	52.6	95.9	99.4	99.9	100	--------	--------	--------	S
Sept. 7	3	71	9.4	10.2	22.0	88.1	95.8	97.2	98.1	98.7	99.9	100	S
Oct. 4	3	78	.1	1.7	29.2	93.2	98.8	99.5	99.7	99.9	100	--------	S
Oct. 18	3	64	.2	1.2	14.3	75.9	95.7	98.3	99.2	99.8	100	--------	S
Nov. 2	3	57	.3	1.5	21.4	85.3	97.3	99.0	99.6	100	--------	--------	S
Nov. 16	3	48	.7	3.9	31.1	91.4	97.8	98.5	99.0	99.3	100	--------	S
Dec. 13	3	42	1.6	5.4	21.6	78.0	96.6	99.0	99.8	100	--------	--------	S
1955													
Jan. 10	3	37	1.8	9.2	56.0	87.1	96.2	98.8	99.7	100	--------	--------	S
Jan. 24	3	34	.9	5.1	37.9	93.0	98.2	98.9	99.3	99.9	100	--------	S
Feb. 25	3	35	.2	2.1	27.0	88.2	96.6	98.1	99.2	100	--------	--------	S
Mar. 7	3	50	.3	2.4	25.8	95.2	99.2	99.8	100	--------	--------	--------	S
Mar. 22	3	47	.7	5.6	46.1	92.7	97.8	98.8	99.5	100	--------	--------	S
Apr. 4	3	45	.2	1.5	16.8	91.2	99.1	99.6	99.9	100	--------	--------	S
May 2	3	58	.2	1.1	16.9	96.6	99.4	99.6	99.8	100	--------	--------	S
May 31	3	63	.6	3.0	38.5	92.6	98.4	99.5	99.8	100	--------	--------	S
June 13	3	60	.5	3.4	23.9	80.0	95.6	98.7	99.5	99.8	100	--------	S
June 27	3	61	1.3	2.9	39.6	88.6	97.4	99.4	99.8	100	--------	--------	S
July 11	3	72	25.5	32.7	57.9	95.4	98.2	99.5	99.9	100	--------	--------	S
July 25	3	72	1.9	4.9	28.6	91.8	98.6	99.3	99.6	99.9	100	--------	S
Aug. 11	3	76	2.6	8.9	38.8	89.2	96.6	98.6	99.5	99.9	100	--------	S
Aug. 23	2	75	3.1	12.0	49.9	96.0	98.7	99.4	99.8	100	--------	--------	S
Sept. 6	3	73	.6	2.5	14.4	64.9	90.3	95.6	97.6	99.0	100	--------	S
Sept. 19	3	67	.2	.7	5.4	61.4	94.8	96.4	99.3	99.8	100	--------	S
Oct. 4	3	68	.0	1.1	14.5	90.7	98.6	99.5	99.8	99.9	100	--------	S
Dec. 1	3	49	.6	2.3	18.0	91.9	98.7	99.1	99.3	99.6	100	--------	S
Dec. 12	3	42	1.4	4.6	31.0	77.2	92.6	97.0	99.0	99.8	100	--------	S
Dec. 27	3	48	1.3	5.1	35.8	81.1	97.7	99.0	99.4	99.6	100	--------	S
1956													
Jan. 9	3	48	1.1	4.2	29.8	93.5	99.7	99.9	99.9	100	--------	--------	S
Jan. 23	3	43	.5	2.4	22.7	96.7	99.7	99.9	100	--------	--------	--------	S
Feb. 7	3	45	.5	2.1	15.2	72.7	93.6	96.5	97.4	98.3	100	--------	S
Feb. 20	3	50	1.3	4.4	19.1	82.4	97.4	99.1	99.6	99.9	100	--------	S
July 20	3	70	3.3	9.7	42.7	92.5	97.9	99.3	99.9	100	--------	--------	S
1957													
May 14	3	62	2.8	11.7	40.1	85.0	95.8	97.1	98.0	98.8	99.4	100	S
May 27	3	65	4.2	24.4	73.1	95.6	99.3	99.9	100	--------	--------	--------	S
June 10	3	67	.6	4.2	28.0	74.7	87.9	92.2	95.4	98.0	100	--------	S
June 24	3	75	.6	4.6	29.9	93.5	99.1	99.8	100	--------	--------	--------	S

TABLE 12.—*Particle-size analyses of bed material, Rio Grande near Belen, N. Mex.*

[Methods of analysis: S, sieve; V, visual accumulation tube]

Date	Sampling points	Water temperature (°F)	Percent finer than indicated size, in millimeters										Method of analysis
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00	
1954													
Mar. 22	3	55	1.0	4.3	22.9	87.2	97.4	99.1	99.4	99.8	100	----------	S
Apr. 6	3	64	.2	2.0	35.1	87.7	99.4	99.9	99.9	100	----------	----------	S
May 5	3	77	.1	1.3	32.4	96.9	98.9	99.9	100	----------	----------	----------	S
June 2	3	71	.3	2.5	31.7	88.4	98.9	99.8	99.8	100	----------	----------	S
June 14	3	68	3.0	21.7	97.3	99.8	100	----------	----------	----------	----------	----------	S
June 28	3	75	.1	1.8	38.6	89.7	98.7	99.9	100	----------	----------	----------	S
July 12	3	78	.8	6.9	58.2	96.6	99.3	99.7	100	----------	----------	----------	S
Aug. 10	3	79	.6	5.8	47.9	91.5	98.6	99.7	100	----------	----------	----------	S
Sept. 21	3	74	.4	3.9	35.8	88.0	98.1	99.1	99.2	99.2	99.4	100	S
Oct. 19	3	63	1.1	6.3	37.4	89.2	98.6	99.6	99.9	100	----------	----------	S
Nov. 16	3	53	.3	2.8	31.2	88.9	97.1	98.8	99.5	100	----------	----------	S
1955													
Jan. 12	3	38	2.0	9.6	47.9	96.9	99.4	99.8	100	----------	----------	----------	S
Jan. 25	3	40	.1	1.3	20.5	90.2	98.1	99.4	99.8	100	----------	----------	S
Feb. 9	3	41	25.1	36.8	69.8	97.7	99.7	100	----------	----------	----------	----------	S
Feb. 24	3	45	.1	1.9	21.0	94.0	98.2	99.0	99.5	99.8	100	----------	S
Mar. 9	3	57	.2	3.4	41.6	93.0	99.1	99.8	100	----------	----------	----------	S
Mar. 25	3	60	.3	3.1	30.9	88.7	98.7	99.7	99.9	100	----------	----------	S
May 20	3	73	5.0	15.0	49.8	91.0	98.9	99.7	99.8	99.9	100	----------	S
Aug. 9	3	76	.2	1.1	32.4	92.2	98.2	99.3	99.8	100	----------	----------	S
Aug. 23	3	79	.8	4.0	28.9	98.2	99.8	99.9	100	----------	----------	----------	S
1957													
May 15	3	61	1.0	4.2	40.7	89.7	96.7	98.1	98.9	99.7	100	----------	S
May 27	3	64	1.3	5.2	48.1	93.1	99.6	99.9	100	----------	----------	----------	S
June 24	3	75	1.1	8.3	61.4	97.4	99.6	100	----------	----------	----------	----------	S

TABLE 13.—*Sources of published particle-size analyses of suspended sediment used in the modified Einstein calculations*

Sediment station	Water year	Source: USGS Water Supply Paper—
Rio Grande at Otowi Bridge near San Ildefonso, N. Mex.	1958	1573.
Rio Grande at Cochiti, N. Mex.	1954, 1955	1402, p. 515–517.
	1956	1452, p. 459–460.
	1957	1522, p. 486.
	1958	1573.
Rio Grande at San Felipe, N. Mex.	1954, 1955	1402, p. 517–518.
	1956	1452, p. 460–461.
	1957	1522, p. 487.
	1958	1573.
Rio Grande near Bernalillo, N. Mex.	1952	1498–H (Nordin, 1964).
	1956	1452, p. 365–366.
	1957	1522, p. 410.
	1958	1573.
Rio Grande at Albuquerque, N. Mex.	1954, 1955	1402, p. 523–525.
	1956	1452, p. 461–462.
	1957	1522, p. 488.
Rio Grande near Belen, N. Mex.	1954, 1955	1402, p. 530–531.
	1957	1522, p. 489.

TABLE 14.—*Previously unpublished particle-size analyses of suspended sediment used in the modified Einstein calculations*

[Method of analysis: P, pipette; S, sieve; W, in distilled water; C, chemically dispersed; V, visual accumulation tube]

Date	Time	Water discharge (cfs)	Water temperature (°F)	Suspended sediment: Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percent finer than indicated size, in millimeters: 0.002	0.004	0.016	0.062	0.125	0.250	0.500	1.000	2.000	Method of analysis
Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.															
1959															
Aug. 8	1300	1,270	73	24,000	3,980	--	54	77	91	97	99	100	--	--	VPWC
1961															
Apr. 25	1310	2,780	52	1,350	1,980	13	16	24	39	56	80	95	100	--	VPWC
May 2	1415	4,000	57	2,480	3,890	14	16	28	52	73	90	96	100	--	VPWC
May 17	1145	2,750	56	1,120	--	--	--	--	26	36	67	92	100	--	V
June 21	1440	908	76	284	--	--	--	--	48	52	65	96	99	100	S
July 20	1245	1,090	74	3,590	3,010	21	27	51	66	67	70	75	100	--	VPWC
1962															
Apr. 19	1350	6,040	59	4,240	4,510	10	13	19	41	70	91	98	100	--	VPWC
May 31	1350	1,460	59	1,660	--	--	--	--	7	11	44	94	100	--	V
July 2	1345	684	78	203	--	--	--	--	22	25	51	97	100	--	V
Rio Grande at Cochiti, N. Mex.															
1961															
Apr. 26	1050	2,090	52	1,210	--	--	--	--	41	53	89	100	--	--	V
May 2	1155	3,680	57	2,730	3,530	16	18	31	56	68	91	99	100	--	VPWC
May 18	1150	2,620	59	2,750	1,920	3	4	6	11	16	36	73	96	100	VPWC
June 22	1110	674	76	153	--	--	--	--	80	85	96	100	--	--	S
Rio Grande at San Felipe, N. Mex.															
1961															
Apr. 26	1350	2,220	57	1,360	2,310	13	16	25	41	53	87	100	--	--	WPVC
May 2	1535	3,580	62	2,890	2,710	15	17	28	49	59	82	98	100	--	VPWC
May 18	1110	2,510	62	1,040	--	--	--	--	34	51	90	100	--	--	V
June 22	1140	680	76	519	--	--	--	--	28	34	58	91	100	--	V
Rio Grande near Bernalillo, N. Mex.															
1953															
Apr. 29	--	1,540	57	2,450	--	--	--	--	70	83	96	100	--	--	V
May 5	--	551	63	554	--	--	--	--	48	73	98	100	--	--	V
June 1	--	2,570	65	2,530	--	--	--	--	67	87	100	--	--	--	V
June 2	--	2,150	71	2,010	--	--	--	--	64	84	97	100	--	--	V
June 4	--	2,090	62	1,600	--	--	--	--	58	80	99	100	--	--	V
June 17	--	1,340	69	1,060	--	--	--	--	42	64	93	100	--	--	V
1962															
Apr. 20	1315	5,340	64	4,360	3,510	12	16	24	54	77	97	100	--	--	VPWC
June 1	1430	987	71	1,720	--	--	--	--	13	20	44	80	100	--	V
June 25	1245	453	79	453	--	--	--	--	60	76	98	100	--	--	V

TABLE 15.—*Equations relating transport rates to simple hydraulic variables, with standard error of estimate in log units and percentages*

Station	Q vs Q_T: Equation	S_e Log units	Percent +	Percent −	q vs q_T: Equation	S_e Log units	Percent +	Percent −	V vs q_T: Equation	S_e Log units	Percent +	Percent −	V vs C_T: Equation	S_e Log units	Percent +	Percent −
Otowi	$Q_T=0.169Q^{1.43}$	0.228	69	41	$q_T=1.257q^{1.44}$	0.242	75	43	$q_T=0.605V^{3.48}$	0.255	80	44	$C_T=318V^{1.17}$	0.236	72	42
Cochiti	$Q_T=0.00361Q^{1.98}$	.433	171	63	$q_T=0.321q^{2.37}$	.498	215	68	$q_T=0.105V^{4.89}$	.370	134	57	$C_T=80.4V^{2.55}$	.514	226	69
San Felipo	$Q_T=0.0764Q^{1.56}$	.340	118	54	$q_T=1.186q^{1.62}$	.320	109	52	$q_T=0.359V^{3.69}$	.276	89	47	$C_T=250V^{1.46}$	.346	122	55
Bernalillo	$Q_T=0.137Q^{1.49}$	.258	81	45	$q_T=1.232q^{1.73}$	.175	50	33	$q_T=0.877V^{3.08}$	.286	93	48	$C_T=446V^{1.19}$	.260	82	45
Albuquerque	$Q_T=0.00435Q^{2.00}$	.376	138	58	$q_T=0.391q^{2.57}$	.374	136	58	$q_T=0.219V^{4.54}$	.313	106	51	$C_T=58.8V^{3.58}$	.554	258	72
Belen	$Q_T=0.00224Q^{2.03}$	.412	158	61	$q_T=0.165q^{2.91}$	.421	164	62	$q_T=0.104V^{5.13}$	.375	137	58	$C_T=41.3V^{3.54}$	.355	126	56

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