

General Study of the Modified Einstein Method of Computing Total Sediment Discharge

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2066



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By D. E. BURKHAM and D. R. DAWDY

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*Method of computing sediment discharge
on stream sites*



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CONVERSION FACTORS

For readers who may prefer to use International System (SI) of units, rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

<i>Multiply inch-pound unit</i>	<i>By</i>	<i>To obtain SI (metric) unit</i>
ft (foot)	0.3048	m (meter)
ft/s (foot per second)	0.3048	m/s (meter per second)
ft ² /s (square foot per second)	0.0929	m ² /s (square meter per second)
lb/s (pounds per second)	456.6	g/s (grams per second)
ton/d (ton per day)	0.9072	Mg/d (megagram per day)
Temp °C = (Temp °F - 32)/1.8		

SYMBOLS

'	Single prime mark on A , J , or Q designates association with the sampling depth
"	Double prime mark on A , J , I , or Q designates association with the total depth through which suspended sediment is discharged
() _M	Subscript M designates a parameter associated with the modified Einstein procedure
() _{RM}	Subscript RM designates a parameter associated with the revised modified Einstein procedure
a	Thickness of bed layer
A	Ratio of bed layer thickness to water depth
A'	Ratio of d_n to d_s
A''	Ratio of $2D$ to d
A_*	Constant, scale of ϕ_*
b	Parameter related to turbulence; equals $1/\kappa$
B_*	Constant, scale of ψ_*
C	Constant
C_a	Sediment concentration for a particle having a diameter, D , at a distance a from the streambed
C_s	A variable coefficient which is a function of the median diameter of the bed material
C_y	Sediment concentration for a particle having a diameter, D , at a distance y from the streambed
C_0	A constant
C_1	A constant
$Conc$	Measured suspended-sediment concentration
d	Mean depth of water
d_n	Vertical distance not sampled
d_s	Vertical distance sampled
D	Diameter of a particle
D_{16}	Particle size at which 16 percent of the bed material by weight is finer
D_{35}	Particle size at which 35 percent of the bed material by weight is finer
D_{50}	Particle size at which 50 percent of the bed material by weight is finer
D_{50G}	A parameter used to represent D_{50} ; equals $\sqrt{(D_{65})(D_{35})}$
D_{65}	Particle size at which 65 percent of the bed material by weight is finer
D_{84}	Particle size at which 84 percent of the bed material by weight is finer
D_{95}	Particle size at which 95 percent of the bed material by weight is finer
e	Base of natural logarithms
f	Weisbach friction factor
g	Acceleration due to gravity
i_b	Fraction of bed material in a given grain size
i_B	Fraction of bedload in a given size range
i_s	Fraction of suspended material in a given size range
i_T	Fraction of total load in a given size range
$i_s q_s$	Rate at which a particle of diameter D moves in suspension through a unit width per unit of time
$i_B q_B$	Rate at which a particle of diameter D moves through a unit width of the bed layer per unit of time
$i_T q_T$	Rate at which a particle of diameter D moves through a unit width of channel per unit of time
$i_B Q_B$	Sediment discharge through the bed layer of particles of a given size range, in tons per day

$i_T Q_T$	Total sediment discharge through the bed layer of particles of a given size range, in tons per day
I_1	A mathematical abbreviation
I_2	A mathematical abbreviation
J_1	A mathematical abbreviation
J_2	A mathematical abbreviation
k	Effective height of the roughness elements in a channel
k_s	Equivalent sand roughness for a particular roughness k
K	A constant at a particular time and cross section
N_s	Number of measurements in a set
n	Number of data sets for the particle-size range and data group.
p	Probability of a particle of a diameter D being eroded
P	Mathematical abbreviation
q_B	Rate at which the bed layer moves through a unit width of cross section
q_s	Sediment load in suspension per unit of width, measured in weight, moving per unit of time between the water surface and the reference level $y = a$
Q_s	Suspended sediment through a cross section, in tons per day
Q_{SM}	Measured suspended-sediment discharge
Q_{Ss}	Sediment discharge in the sampled zone
Q_{TM}	Measured sediment discharge
Q_{TC}	Computed sediment discharge
R	Hydraulic radius
R'	Hydraulic radius with respect to the grain
R_B	Hydraulic radius with respect to the grains on the bed
(RS)	A hydraulic radius-slope parameter
S	Slope of the energy grade line
S_s	Specific gravity of sediment
SE	Standard error of estimate
SE_q	Square root of mean variance
SE_w	Weighted approximate standard error of estimate
$Temp$	Water temperature in degrees Fahrenheit
v_u	Average point velocity at a distance y from the closest boundary
v_*	Average shear velocity at the boundary; equals $\sqrt{\tau_0/\rho_f}$
v_s	Fall velocity for a sediment particle
V	Mean cross-sectional velocity of flow
V_s	Fall velocity for the geometric mean size for a size range
V_{sr}	Fall velocity for the geometric mean size for a reference-size range
V_{su}	Fall velocity for the geometric mean size for a size range other than the range
V_*	Mean cross-sectional shear velocity; equals \sqrt{gRS}
V'_*	Mean cross-sectional shear velocity with respect to grains on the bed
W	Weight of a particle
W_w	Underwater weight of a particle
w	Width of channel in feet
X	Einstein's characteristic grain size of a mixture
x	A dimensionless corrective factor
x_0	A variable; equals k_s/k
y	Distance from the streambed
Y	Pressure correction in the transition from smooth to rough flow
z	A theoretical exponent of the equation that describes the vertical distribution of suspended sediment of a size range
z_r	z for a reference size

z_u	z for size ranges other than that for the reference size
β_{x_1}	A logarithmic function
β	A logarithmic function
β_x	A logarithmic function
κ	Universal constant characterizing turbulence
δ	Thickness of laminar sublayer
Δ	k_s/x , the apparent roughness of a channel surface
Δ_1	D_{65}/x
η	Variability factor of lift; parameter varying with time which represents the fluctuation of velocity
η_0	Root-mean-square value of η
η_*	η measured in η values
λ	Constant used to describe step movement of particles
ν	Kinematic viscosity of water
ξ	"Hiding factor" for grains in a mixture
(ξY)	A correction factor
ρ_f	Density of fluid
ρ_s	Density of solids
τ	Shear stress
τ_0	Shear stress at the boundary
Φ	Intensity of transport
Φ_*	Intensity of transport for individual grain size for the Einstein procedure
$\Phi_{*/2}$	Intensity of transport for individual grain size for the modified Einstein procedure
ψ	Intensity of shear on particles; function for correlating the effects of flow with the intensity of bedload transport
ψ^*	Intensity of shear on individual grain size
ψ'	Intensity of shear on representative particle

GENERAL STUDY OF THE MODIFIED EINSTEIN METHOD OF COMPUTING TOTAL SEDIMENT DISCHARGE

BY D. E. BURKHAM AND D. R. DAWDY

ABSTRACT

The modified Einstein procedure was revised by applying corrections to two equations and by replacing two equations. The revision was made because D_{65} was used directly in the modified Einstein procedure to represent the equivalent sand roughness, k_s , whereas a much larger size apparently should have been used. For this study, $5.5 D_{65}$, an average value based on a best fit for data for several sites, was used.

The revised modified Einstein procedure apparently is an improvement over the modified Einstein procedure. For the sediment and flow conditions at sites in five sand channels, the sediment discharges computed according to revised modified Einstein procedure apparently are not significantly more accurate than those computed according to modified Einstein procedure; however, improvement is indicated because the corrections of pertinent equations eliminates some of the empirical adjustments contained in the modified Einstein procedure. The revised procedure eliminated the need to arbitrarily divide the bedload transport intensity, ϕ_* , by 2 which was done in the modified Einstein procedure. Values for ϕ_* are taken directly from a curve relating ψ_* to ϕ_* . The ψ_* to ϕ_* relation was developed theoretically by Einstein, and it was verified by his experimental data. Values of ϕ_* determined from the ψ_* to ϕ_* relation should be used directly in the Einstein bedload equation.

For the same data, the revised modified Einstein procedure gives shear velocities that are significantly larger and x values that are significantly smaller than the corresponding values computed using the modified Einstein procedure. The ratio of shear velocity for the revised modified Einstein procedure to shear velocity for the modified Einstein procedure ranges from 9.52 to 1.28 for stream velocities ranging from 0.50 to 15 feet per second. For the 292 data sets used in testing the two procedures, the value of x ranged from 1.00 to 1.14 for the revised modified Einstein procedure and from 1.00 to 1.62, the maximum value possible, for the modified Einstein procedure. The value of x is 1 for fully turbulent flow.

The approximate standard error of estimate for total sediment discharge determined for the five streams is about 22 percent for the two procedures. Except for the range for the largest particles tested, the weighted standard error is approximately equal in the two methods for the different sediment-size ranges. Weighted approximate standard errors for the different sediment-size ranges for the modified Einstein procedures and the revised modified Einstein procedures are: 17 percent and 17 percent for sizes smaller than 0.062 mm; 25 percent and 25 percent for sizes from 0.062 to 0.125 mm; 46 percent and 48 percent for sizes from 0.125 to 0.250 mm; 72 percent and 77 percent for sizes 0.250 to 0.500 mm; and 136 percent and 91 percent for sizes 0.500 to 1.00 mm. The standard error for wash load is relatively low because the wash load is determined directly by sampling and the accuracy of values determined by sampling is better than those determined indirectly by equations, which is done for relatively large particles

moving as bedload. The approximate standard error for total sediment discharge is only about 22 percent because a large fraction of the total sediment discharge was in suspension and the suspended-sediment discharge is determined directly by sampling. For a site on the Rio Grande conveyance channel, the amount of sediment in the size ranges of 0.062 to 0.125 mm, 0.125 to 0.250 mm, and 0.250 to 0.500 mm were significantly underestimated by the two procedures for periods when the bed form was flat or was in transition. Conversely, for these ranges of sediment sizes and for the total, the amount of sediment being moved was significantly overestimated for periods when the bed form was dunes.

For two sites on Fivemile Creek in Wyoming, the total sediment discharge is significantly overestimated. This statistic may be misleading. A sediment bed in motion at a normal section usually does not retain a fixed bed form for all flow conditions, therefore, the bed form at the sites on Fivemile River probably is dunes, flat, or in transition at different times. If so, the results found for the Rio Grande site probably apply for the other sites. The fact that the total sediment discharge is overestimated for a site may only indicate that a dune bed form was at the normal section during most of the periods when sediment transport data were being obtained.

INTRODUCTION

The development of a reliable method of computing sediment discharge at a site in a stream is one of the most important practical objectives of research in fluvial processes. The movement of sediment in an alluvial channel is complex, and because of this the rate of development of a reliable method has been slow. The engineer concerned with the movement of debris in a stream currently must rely strongly on experience and judgment in determining sediment discharge (American Society of Civil Engineers, 1975). Because of the expanding awareness of the effects of man on his environment, the need to develop better methods is increasing.

The U.S. Geological Survey is involved in research aimed at the development of new and reliable methods of measuring and computing sediment discharge. At the same time, it is attempting to improve methods that are already widely used. The study and the results described in this report are a part of the latter effort.

The modified Einstein method (Colby and Hembree, 1955) of computing total sediment discharge in open channels is widely used. The method is based on the excellent and original work of Einstein (1950). The MEP (modified Einstein method) is an improvement over the original Einstein method; it is simpler in computation and it uses parameters more readily available from actual stream measurements. The modified method, however, contains empirical adjustments and it requires much experience and judgment in order to obtain reliable results.

The primary objective of this investigation was to apply theoretical corrections to pertinent equations used in the modified Einstein method and to determine if significant improvement results. Sec-

dary objectives were to test the modified Einstein procedure for a wider range of flow and sediment conditions than had been previously applied, and to identify areas where additional research might be worthwhile. Two related criteria were used in the test for improvement resulting from the addition of the theoretical corrections. First, improvement is indicated if the accuracy of prediction for particle-size ranges and for total sediment discharge is improved. Second, improvement is indicated if the correction of pertinent equations eliminates some of the empirical adjustments contained in the method.

The study required extensive review of technical literature. The study procedure was as follows:

1. The basis for the theoretical correction was developed. This required a review of velocity and resistance equations developed by Keulegan (1938); Limerinos (1970); Leopold, Wilman, and Miller (1964); Einstein (1950); and Burkham and Dawdy (1976a). This part of the study is described in the section "Basis for Revision."

2. Pertinent equations and graphs used in the modified Einstein procedure for determining total sediment load were corrected. This required a review of the Einstein and modified Einstein procedures; identification of theoretical and empirical adjustments made by Einstein (1950) so equations and graphs for uniform particles would apply to mixtures; and identification of empirical adjustments made by Colby and Hembree (1955) to eliminate bias in the modified Einstein method. The review of the Einstein procedure is presented in the section "Einstein Method." The remainder of this part of the study is presented in the sections "Modified Einstein Procedure" and "Revised Modified Einstein Procedure."

3. Computer programs for MEP and RMEP (revised modified Einstein method) were developed. The computer programs are discussed briefly in the section "Computation Procedure."

4. Using test data, sediment discharges were computed and compared with measured values; comparisons were made by size ranges and for total sediment discharges. The standard errors of estimate for sediment discharges computed by the modified Einstein method were compared with the standard errors of estimate of discharges computed by the revised modified Einstein method to give an indication of improvement. The test data are for the following sites: Niobrara River near Cody, Nebr.; Middle Loup River at Dunning, Nebr.; Fivemile Creek near Riverton, Wyo.; Fivemile Creek near Shoshoni, Wyo.; and River Grande conveyance channel near Bernardo, N. M. Descriptions of this part of the study are presented in the sections "Comparison of Computed and Measured Sediment Discharges" and "Results of Comparison."

5. Finally, a summary and conclusions are presented.

BASIS FOR REVISION

The Einstein and the modified Einstein methods (Einstein, 1950; Colby and Hembree, 1955) of computing total sediment discharge in open channels involve several equations and graphs that are based on Keulegan's (1938) solution of the Prandtl-von Kármán velocity distribution equation (Prandtl, 1926; von Kármán, 1930). The Keulegan (1938) equations are:

$$v_y = v_* (8.5 + 5.75 \log y/k_s) \quad (1)$$

and

$$V = V_* [(8.5 - .9b) + 5.75 \log R/k_s] \quad (2)$$

in which

v_y = average point velocity at a distance y from the closest boundary;

v_* = average shear velocity at the boundary; equals $\sqrt{\tau_0/\rho_f}$ where τ_0 equals the shearing stress at the boundary and ρ_f equals the density of the fluid;

k_s = equivalent sand roughness for a particular roughness k ; k is the effective height of the roughness elements in a channel;

V = mean cross-sectional velocity of flow;

V_* = mean cross-sectional shear velocity; equals \sqrt{gRS} ;

R = hydraulic radius;

g = acceleration due to gravity;

S = slope of the energy grade line;

b = 1 divided by κ ; and

κ = universal constant characterizing turbulence; assumed to be 0.4.

A general form of equation 2 is (Keulegan, 1938):

$$V = V_* [(C - .9b) + 5.75 \log (R/k)] \quad (2A)$$

in which

C = a coefficient.

Equations 1 and 2 are applicable for fully developed turbulent flow in nonwavy rough uniform channels in which the resistance to flow is produced by the boundary surface. To use equations 1 and 2, however, it is necessary to know the relation between the roughness factor, k , for a data set of interest and the equivalent sand roughness, k_s . A general equation relating k and k_s is (Keulegan, 1938):

$$5.75 \log k_s = 8.5 - C + 5.75 \log k \quad (3)$$

Equation 3, according to Keulegan (1938), is the expression which gives the equivalent sand roughness k_s for the particular roughness k .

Physically, if a velocity v is observed at a distance y from a wall of arbitrary roughness k under a known shear, the same velocity will be obtained at the same point and for the same shear if the particular roughness is replaced by closely packed uniform sand grains of roughness k_s . It is not practical to compute the equivalent sand roughness, k_s , using equation 3, for every roughness height, k , found along the boundaries of uniform open channels. Instead, the effort traditionally has been to find a readily measurable parameter that could be used to approximate k_s in equation 3.

Equations 2A and 3 can be combined to give a general equation that is applicable directly to turbulent flow in nonwavy rough uniform channels. Note that equation 3 can be rearranged to give:

$$C = 8.5 - 5.75 \log (k_s/k). \quad (3A)$$

Equations 2 and 3A are combined to give:

$$V/V_* = (8.5 - 0.9b - 5.75 \log x_0) + 5.75 \log (R/k) \quad (4)$$

in which

$$b = 2.50, \text{ and} \\ x_0 = k_s/k.$$

The term x_0 is introduced to simplify later discussions. Equation 4 is Keulegan's theoretical resistance equation for turbulent flow in nonwavy rough uniform open channels. Burkham and Dawdy (1976a) have developed a relation from which, by using equation 3A, x_0 can be approximated for a wide range of sediment sizes.

Empirically defined resistance equations by Limerinos (1970) and Leopold, Wolman, and Miller (1964) can be put in the form:

$$1/\sqrt{f} = C_0 + 2.03 \log (R/k) \quad (5)$$

in which

f = Weisbach (1845) friction or resistance factor, equals $\frac{8gDS}{V^2}$,
and

C_0 = a constant.

The numerical value of the constant C_0 , however, is different for the different equations. The parameters used to represent the distance from the boundary and used to represent roughness height also are different. Data for turbulent flow in nonwavy rough uniform channels were used by the different authors to develop the resistance equation having the form of equation 5.

Limerinos (1970) proposed that an equation using D_{84} to represent roughness height, k , be used to compute resistance to flow in channels with coarse bed material. The equation is:

$$1/\sqrt{f} = 1.16 + 2.03 \log (R/D_{84}) \quad (6)$$

in which

D_{84} = particle size, referred to as intermediate diameter, that equals or exceeds that of 84 percent of the streambed particles by count; the sampling procedure was patterned after the Wolman (1954) method.

Using roughness values computed from equation 6, Limerinos (1970) determined the percentage difference between measured and computed roughness for each of 50 data sets; the standard deviation of the percentage differences amounted to 19 percent.

When Limerinos (1970) used D_{50} to represent the roughness height, k , the equation was

$$1/\sqrt{f} = 0.35 + 2.03 \log (R/D_{50}) \quad (7)$$

For equation 7 Limerinos determined that the standard deviation of the percentage difference between measured and computed roughness amounted to 22.4 percent.

An equation in which D_{16} is used to represent k can be approximated directly from equation 6 and data contained in table 3 in Limerinos' (1970) report (Burkham and Dawdy, 1976a). The mean of the ratios, D_{84}/D_{16} , is 7.3 for the Limerinos data. If the factor D_{84} in equation 6 is replaced with 7.3 D_{16} , the resulting equation is

$$1/\sqrt{f} = -0.59 + 2.03 \log (R/D_{16}) \quad (8)$$

Using the Limerinos data and the procedure outlined by Limerinos (1970), the standard deviation of the percentage difference for equation 8 was determined to be 27.6 percent.

Figure 1, developed using the Limerinos (1970) data, shows that the standard error of estimate apparently is significantly smaller when D_{84} is used to represent the roughness height in the Keulegan equation than when D_{50} or D_{16} is used. Further improvement in accuracy might result if another larger size, say D_{95} , were used to represent the roughness height rather than D_{84} .

Burkham and Dawdy (1976a) used data contained in reports by Wolman (1954); by Leopold, Wolman, and Miller (1964); and by Barnes (1967) to verify equation (6) for turbulent flow in fairly rigid,

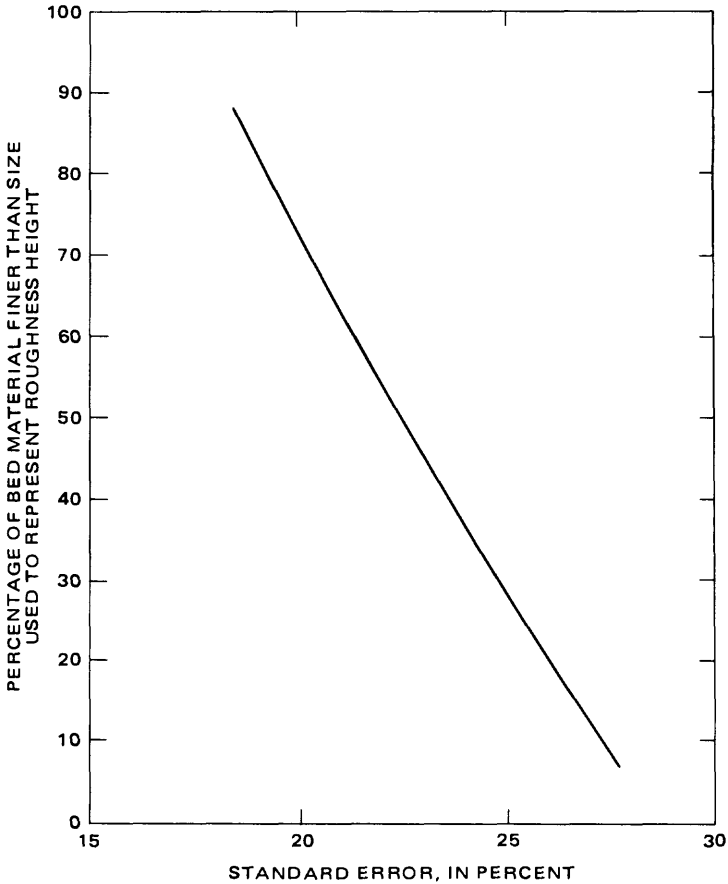


FIGURE 1.—Relation between percentage of bed material finer than size used to represent roughness height, and standard error of estimate, in percent, for the different resistance equations for flow in rigid-boundary streams. (From Burkham and Dawdy, 1976a, fig. 3).

nonway channels (fig. 2). They used data contained in reports by Culbertson and Dawdy (1964), and by Dawdy (1961) to extend equation 6 to include upper-regime flow for sand-bed streams. As shown in figure 2, the resistance to upper-regime flow in sand-bed streams apparently is fairly well represented by the extension of equation 6. The standard error of estimate for the sand-bed resistance for upper-regime flow, computed using the Culbertson and Dawdy (1964) data and the Limerinos (1970) procedure, is about 13 percent (Burkham and Dawdy, 1976a). Because $1/\sqrt{f} = V / (V_* \sqrt{8})$, equation 5 can be changed to

$$V/V_* = C_1 + 5.75 \log (R/k) \quad (9)$$

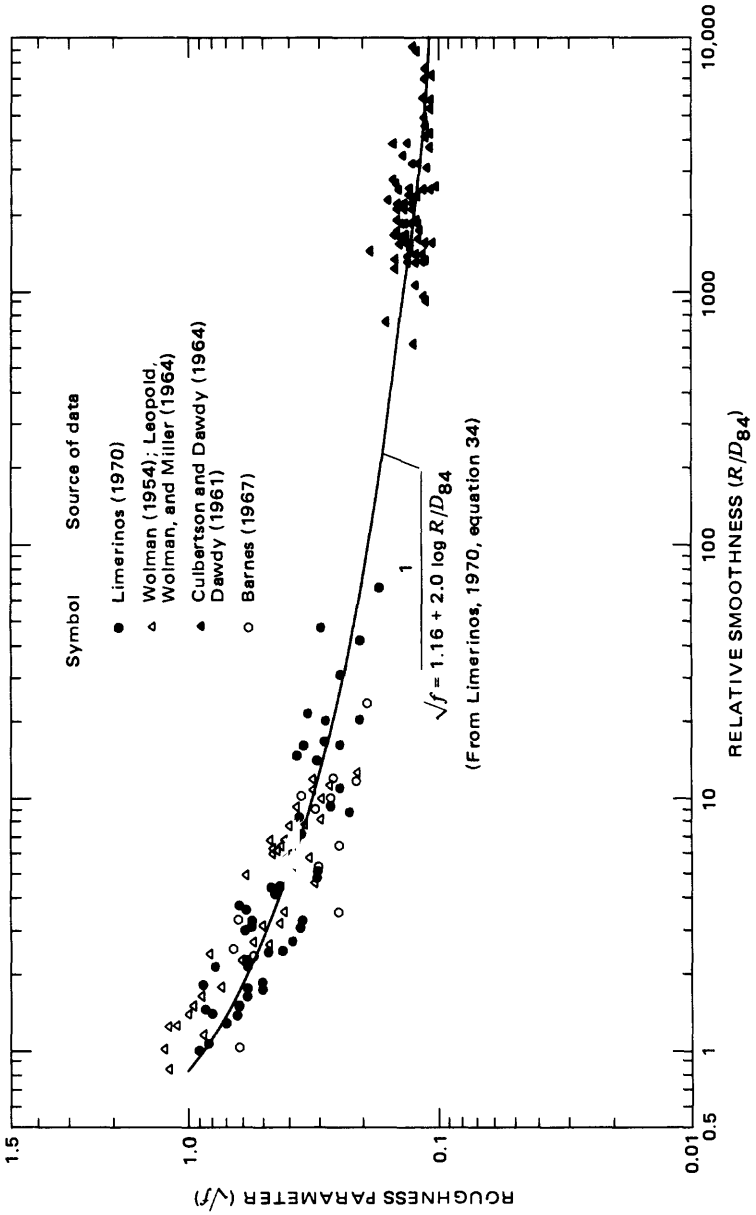


FIGURE 2.—Relation of roughness parameter to relative smoothness based on 84-percentile size of intermediate diameter of streambed particles. (From Burkham and Dawdy, 1976a, fig. 2.)

which is comparable directly with equation 4. The different constants for equations 2A, 4, 5 and 9 are related according to

$$C_1 = 8.5 - 0.9b - 5.75 \log x_0 = C - 0.9b = C_0/\sqrt{8} \quad (10)$$

Equation 10 and data from reports by Limerinos (1970); by Dawdy (1961); by Leopold, Wolman, and Miller (1964); and by Barnes (1967) were the basis for the development of the curve shown in figure 3 (Burkham and Dawdy, 1976a). The curve shows the relation between percentage of bed material finer than the size used to represent roughness height and the coefficient C in equation 2A.

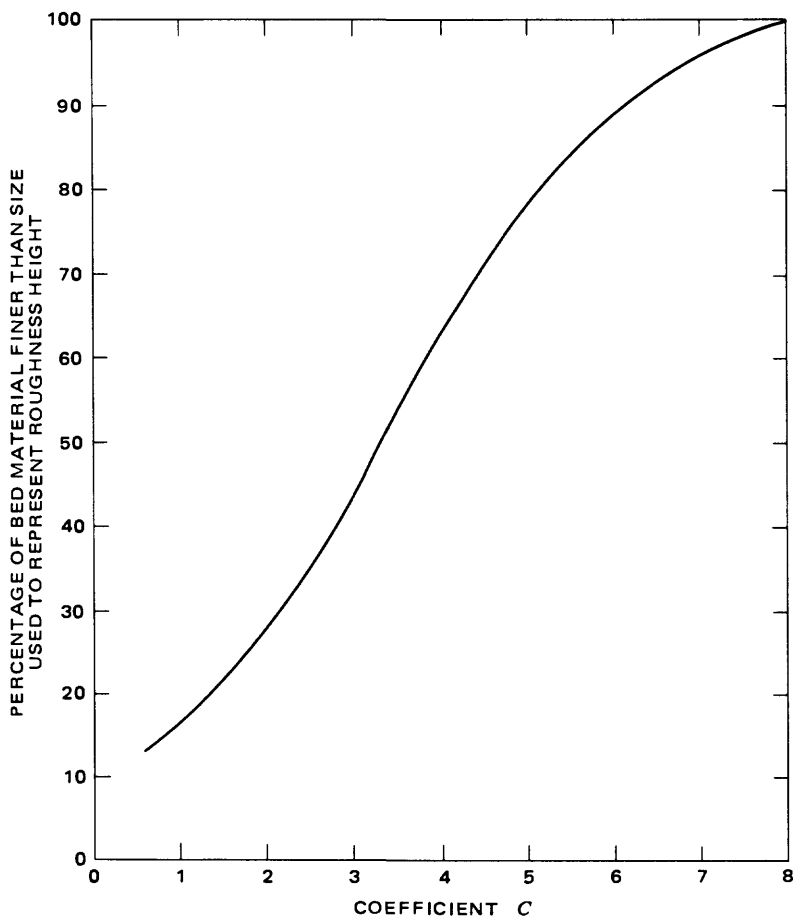


FIGURE 3.—Relation between percentage of bed material finer than size used to represent roughness height and the coefficient C in the Keulegan equation: $V/V_* = (C - 0.9b) + 5.75 \log R/K$. (From Burkham and Dawdy, 1976a, fig. 3.)

In the Einstein and the modified Einstein methods of computing total sediment discharge, D_{65} is used directly to represent the roughness height, k_s , in equations developed from equations 1 and 2 (Einstein, 1950; Colby and Hembree, 1955); the correction factor $-5.75 \log x_0$, which equals $-5.75 \log k_s/D_{65}$ when D_{65} is used to represent bed roughness, was not applied. The value of x_0 depends on the distribution of sediment-particle sizes in a mixture of interest; however, its value apparently decreases inversely with the percentile fractile used to represent channel roughness. On the basis of the relation in figure 3 and equation 10, the average value of x_0 is about 5.5 when D_{65} is used to represent the roughness height. The use of D_{65} to directly represent roughness height in the Einstein and modified Einstein methods (Einstein, 1950; Colby and Hembree, 1955) of computing total sediment discharge probably introduced significant bias; empirical corrections are needed to eliminate this bias.

EINSTEIN METHOD

INTRODUCTION

The Einstein method is for computing total sediment discharge in the size ranges that are found in significant quantities in the streambed (Einstein, 1950). The computed total sediment discharge is the sum of the bedload discharge and the suspended-sediment discharge. The bedload discharge is considered to be through a bed layer two grain diameters thick, and the suspended sediment is considered to be discharge from the water surface to the bed layer.

Einstein's (1950) computations are for a representative cross section of a channel and an average energy slope. The area and wetted perimeter for a representative cross section are determined by averaging the areas and the wetted perimeters of a number of sections in a typical reach that is of sufficient length to permit an adequate definition of the overall energy slope. The theoretical basis for the Einstein method can be presented as (1) equations pertinent to suspended-sediment discharge, (2) equations pertinent to the bedload discharge, and (3) equations pertinent to the transition between bedload and suspended-sediment discharges.

EQUATIONS PERTINENT TO SUSPENDED-SEDIMENT DISCHARGE

Suspended-sediment discharge is computed as the integration of the product of the theoretical velocity and suspended-sediment concentration along a representative vertical in a cross section. Einstein (1950) combined equations developed by Keulegan (1938) to describe the theoretical velocity distribution in his representative vertical.

The two equations are equation 1 and an equation to represent the velocity distribution for smooth boundaries which is

$$v_y/V_* = 5.50 + 5.75 \log \frac{yV_*}{\nu} \quad (11)$$

The results of combining equation 1 and 11 can be presented as

$$v_y/V_* = 5.75 \log \left[30.2 \left(\frac{yx}{k_s} \right) \right] = 5.75 \log (30.2y/\Delta) \quad (12)$$

which represents the velocity distribution for smooth and rough conditions and the transition between smooth and rough conditions, where parameters in equation 11 and 12 that have not been defined previously are:

- ν = kinematic viscosity of water;
- x = a dimensionless corrective factor; and
- $\Delta = k_s/x$, the apparent roughness of the channel surface.

The corrective factor x is represented in figure 4 as a function of k_s/δ in which δ is the thickness of the sublayer of a smooth boundary; equals $(11.6 \nu/V_*)$. The (k_s/δ) -to- x correction curve was developed using equation 12 and the relation in Kuelegan's figure 3 (Kuelegan, 1938).

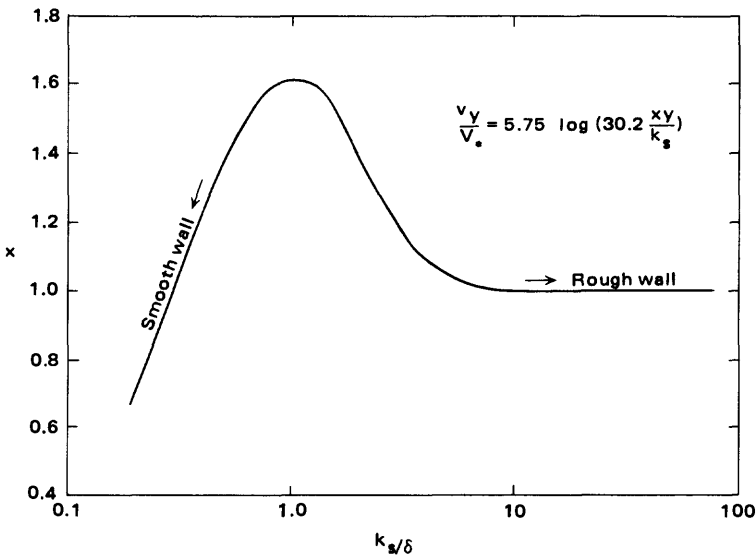


FIGURE 4.—Correction x in equation 12 in terms of k_s/δ . (From Einstein, 1950, fig. 4.)

The suspended-sediment concentration in Einstein's (1950) representative vertical can be represented by:

$$C_y/C_a = \left[\left(\frac{d-y}{y} \right) \frac{a}{d-a} \right]^z \quad (13)$$

in which

- C_y = sediment concentration for a particle having a diameter, D , at a distance y above the streambed;
- C_a = sediment concentration for a particle having a diameter, D , at a distance a above the streambed;
- z = an exponent.

Einstein (1950) used the formula $z = [v_s/(0.4V_*)]$ to determine values for z , where v_s represents the fall velocity for the particle.

An integral equation for the suspended load for a particle having a diameter, D , moving through a unit width of a cross section is obtained by combining equations 12 and 13 to give

$$q_s = \int_a^d C_y v_y dy \quad (14)$$

or

$$q_s = \int_y^d C_a \left[\left(\frac{d-y}{y} \right) \frac{a}{d-a} \right]^z 5.75V_* \log_{10} \left[\frac{(30.2yx)}{k_s} \right] dy \quad (14A)$$

Einstein (1950) simplified equation 14 by (1) referring the concentration to that at the lower limits of integration a ; (2) replacing a with a dimensionless expression $A = a/d$; and (3) using d , mean depth of water, as the unit for y . The resulting equation to the base e is:

$$q_s = 5.75V_* d C_a \left(\frac{A}{1-A} \right)^z \left[\log_{10} \left(\frac{30.2dx}{k_s} \right) \int_A^1 \left(\frac{1-y}{y} \right)^z dy + 0.434 \int_A^1 \left(\frac{1-y}{y} \right)^z \log_e(y) dy \right] \quad (15)$$

in which

q_s = the sediment load in suspension per unit of width, measured in weight, moving per unit of time between the water surface and the reference level $y = a$.

In order to present graphical solutions to the two integrals in equation 15, Einstein transformed equation 15 to:

$$q_s = 11.6V_*C_a a \left\{ 2.0303 \log_{10} \left(\frac{30.2dx}{k_s} \right) (I_1) + I_2 \right\} \quad (16)$$

in which

$$I_1 = 0.216 \frac{(A)^{z-1}}{(1-A)^z} \int_A^1 \left(\frac{1-y}{y} \right)^z dy \quad (17)$$

$$I_2 = 0.216 \frac{(A)^{z-1}}{(1-A)^z} \int_A^1 \left(\frac{1-y}{y} \right)^z \log_e(y) dy \quad (18)$$

According to Einstein (1950), the product, $11.6V_*$, is the flow velocity at the outer edge of the laminar sublayer in the case of a hydraulically smooth bed, or the velocity in a distance of 3.68 roughness diameters from the bed in case of a rough wall. The functions I_1 and I_2 in terms of A and z are shown in Einstein (1950, figs. 1 and 2), Colby and Henbree (1955, figs. 4 and 7), and Hubbell and Matejka (1959, figs. 11 and 13).

Equation 16 represents Einstein's (1950) theoretical basis for estimating suspended discharge per unit width for a size of sediment found in appreciable amounts in the bed. It does not consider wash load which consists of particles too small to be in the bed in appreciable amounts, nor is it applicable for computing sediment movement in the bed layer in which suspension is impossible.

Equations 1, 2, 11, and 12 are applicable for fully developed turbulent flow in nonwavy, rough, uniform channels; the resistance to flow is due to grain roughness only. Einstein's (1950) rationale for using equations 1, 2, 11, and 12 to develop a method of estimating sediment transport in sand channels having significant bed forms is based on the assumption that the energy of turbulence corresponding to shape resistance does not contribute significantly to bedload motion and may be largely neglected in the entire sediment picture.

EQUATIONS PERTINENT TO BEDLOAD

The quantity of sediment transported in a stream by rolling, sliding, or skipping within the bed layer is called the bedload. Einstein's (1950) theory for the rate of movement and concentration in the bed layer is based on the probability that a given particle will move from its position in the streambed and that the position in the bed will be occupied by another particle. By assuming that the bed is neither eroding nor scouring, Einstein (1950) developed a bedload equation that can be represented as:

$$i_B q_B = \phi_* i_b \rho_s g^{3/2} D^{3/2} (S_s - 1)^{1/2} \quad (19)$$

in which

$i_B q_B$ = the rate at which a particle of diameter D in a mixture moves through a unit width of the bed layer per unit of time; i_B is the fraction of bedload in a given size range; q_B is the rate at which the bedlayer sediment moves through the unit width of cross section;

ϕ_* = intensity of transport for an individual grain size;

i_b = fraction of bed material in a given grain size;

ρ_s = density of the solids and

S_s = specific gravity of the sediment.

For a given particle of diameter D , Einstein assumed that all parameters on the right side of equation 19 are constant except for ϕ_* . The intensity of transport, ϕ_* , is a function of the intensity of shear, ψ_* , for the individual grain size. A curve relating ψ_* and ϕ_* given in Einstein (1950 fig. 10), developed by Einstein (1950, p. 37, eq. 57) is entirely theoretical but was verified by experimental data. The numerical values of the constants used by Einstein (1950) to develop the curve are:

$$A_* = 1/0.023 = 43.5$$

$$B_* = 1/7 = 0.143$$

$$\eta_0 = 1/2 = 0.5.$$

The numerical values for the constants A_* and B_* were based on results of bedload experiments with uniform grains; η_0 is an assumed value.

The intensity of shear, ψ , for uniform sand, and fully turbulent flow is determined from;

$$\Psi = \frac{\rho_s - \rho_f}{\rho_f} \left(\frac{D}{R'_B S} \right) \quad (20)$$

in which

R'_B = hydraulic radius with respect to the grains on the bed. Einstein's (1950) reason for using R'_B instead of R is based on the

hypothesis that the energy of moving water is dissipated as friction in two ways: (1) along sediment grains of the surface as a rough wall with the representative grain diameter equal to k_s ; and (2) by separation of the flow from the surface at characteristic points of the ripples or bars. He assumed that the energy dissipation occurring at the sediment grains creates turbulence in the bed layer that has a great effect on bedload movement; this is the energy dissipation that must be accounted for in developing bedload equations. The term R'_B is used to represent the hydraulic radius with respect to the grains on the bed, and the expression $V'_* = \sqrt{gR'_B S}$ is used to refer to the shear velocity with respect to the grains on the bed.

Einstein (1950) developed correction parameters which could be used in conjunction with equation 20 to estimate values of ψ_* for particles in a mixture that were based on the following assumptions and criteria:

1. The velocity acting on all particles of a mixture must be measured at a distance $0.35D$ from the theoretical bed, where:

$$X = 0.77 \Delta \text{ if } \Delta/\delta > 1.80:$$

$$X = 1.39\delta \text{ if } \Delta/\delta < 1.80:$$

2. The particles smaller than $X(X > D)$ seem to hide between the other particles or in the laminar sublayer, respectively, and their lift must thus be corrected by division with a parameter ξ which itself is a function of D/X . X is Einstein's characteristic grain size of a mixture.

3. An additional correction factor Y was found to describe the change of the lift coefficient in mixtures with various roughness conditions.

Einstein's (1950) equation for determining ψ_* for particles in a mixture is:

$$\Psi_* = \xi Y (\beta^2 / \beta_r^2) \frac{\rho_s - \rho_f}{\rho_f} \frac{D}{R'_B S} \quad (21)$$

in which

$$\beta = \log (10.6)$$

$$\beta_r = \log (10.6 X/\Delta);$$

$$\Delta = D_{65}/x; \text{ and}$$

where

ξ is a function of D/X which is shown in Einstein (1950, fig. 7) and

Y is a function of D_{65}/δ which is shown in Einstein (1950, fig. 8).

The empirical relations shown in Einstein (1950, figs. 7 and 8) were based on flume experiments.

EQUATIONS FOR TRANSITION BETWEEN BEDLOAD AND SUSPENDED LOAD

Einstein's (1950) equation relating sediment transported as bedload to that in suspension for all particle sizes for which a bedload

function exists can be represented as.

$$i_s q_s = i_B q_B \left\{ PI_1 + I_2 \right\} \quad (22)$$

in which

$$P = \left(\frac{1}{0.434} \right) \log \left(\frac{30.2dx}{k_s} \right) = 2.303 \log \left(\frac{30.2dx}{k_s} \right) \quad (23)$$

Equation 22 was developed from equation 16 and an assumption that q_B can be represented by the expression $q_B = 11.6V_* C_a a$. The total load, $i_T q_T$, can be represented by

$$i_T q_T = i_B q_B + i_s q_s = i_B q_B (PI_1 + I_2 + 1). \quad (24)$$

MODIFIED EINSTEIN PROCEDURE

INTRODUCTION

The modified Einstein procedure (Colby and Hembre, 1955) of computing total load for the ranges of large particle sizes differs from that used for the ranges of small particle sizes. In the ranges of the large particles—ranges for the reference size and larger sizes (Colby and Hembre, 1955), the Einstein procedure is used except that different methods of computation are used for the shear with respect to the sediment particles, ψ_* ; the intensity of the bedload transport, ϕ_* ; and the exponent z . For ranges smaller than that for the reference size, the sediment discharge is obtained by multiplying the suspended-sediment discharge in the sampled zone by a ratio determined on the basis of equation 16.

EQUATIONS FOR RANGES OF LARGE PARTICLES

Colby and Hembre (1955) used a modified version of equation 24 to compute the total discharge of sediment in the ranges of large particles. The modified equation is:

$$(i_T Q_T)_M = (i_B Q_B)_M (PI_1 + I_2 + 1) \quad (25)$$

in which

$(i_T Q_T)_M$ = total sediment discharge through a cross section for a given range of particle sizes, in tons per day;

$i_B Q_B)_M$ = sediment discharge through the bed layer of particles of the given size range, in tons per day; equals $(i_B q_B)_M$ times $43.2w$;

where

$(i_b q_b)_M$ = sediment discharge through the bed layer of particles of the given size range, in pounds per second per foot of width; and

w = width of channel in feet.

The subscript M denotes a parameter that was obtained according to MEP. The 43.2 is a constant for converting pounds per second to tons per day.

The MEP equation for determining $(i_B Q_B)_M$ is based on equation 19. The value of the intensity of the bedload transport ψ_{*M} , used in entering the relation (See Einstein (1950, fig. 10)), however, is based on D_{35} and D_{65} ; and the value of ϕ_* obtained from the relation is arbitrarily divided by 2 (Colby and Hembree, 1955). The MEP equation for bed-layer discharge in a cross section of a stream is

$$(i_B Q_B)_M = \phi_{*M} 43.2 w 1,200 i_b D^{3/2} \quad (26)$$

in which

$$\phi_{*M} = \phi_*/2$$

The 1,200 represents the constants in equation 19 in which g is the gravitational constant, 32.2; ρ_s equals 5.17 and S_s equals 2.65 (Einstein, 1950). The quantity ψ_{*M} is computed using the equations:

$$\psi_{*M} = (1.65 D_{35})/(RS)_M; \text{ and} \quad (27)$$

$$\psi_{*M} = (0.66D)/(RS)_M; \quad (28)$$

and the larger ψ_{*M} from these equations is used for each geometric mean particle size for a range of sizes. The slope-hydraulic radius parameter, $(RS)_M$, is obtained by using Einstein's (1950) equation 9 except that the average depth, d , replaces R' ; D_{65} is used to represent k_s . Einstein's (1950) equation 9 was derived by combining a Keulegan velocity equation for a hydraulically smooth bed with another Keulegan velocity equation for a hydraulically rough bed. The MEP velocity equation is

$$V/V_{*M} = 5.75 \log \left(12.27 \frac{dx}{D_{65}} \right) \quad (29)$$

in which

$$V_{*M} = \sqrt{g(RS)_M} . \quad (30)$$

A value for $(RS)_M$ is obtained by solving equation 29 and 30 from a known value for V and where x is the same function of k_s/δ_M as given in figure 4 and

$$\delta = \frac{11.6\nu}{V_{*M}} \quad (31)$$

Solution of equation 29 and 30 to obtain a value for V_{*M} is by trial with x obtained from figure 4.

A value for z must be determined before the sum of $(PI_1'' + I_2'' + 1)$ can be evaluated for a size range of large particles. Colby and Hembree (1955) combined equations 16, 22 and 24 to develop an equation for determining z . They reasoned that, for a given time at a cross section of a stream, equation 16 can be presented as:

$$q_s = K(PJ_1 + J_2) \quad (32)$$

and

$$q_s'/q_s'' = Q_s'/Q_s'' = \frac{PJ_1' + J_2'}{PJ_1'' + J_2''} \quad (33)$$

or

$$Q_s'' = Q_s' \left[\frac{PJ_1'' + J_2''}{PJ_1' + J_2'} \right] \quad (34)$$

in which

Q_s = suspended sediment through the cross section, in tons per day, for a given range of particle sizes;

$$J_1 = \int_A^1 \left(\frac{1-y}{y} \right)^z dy \quad (35)$$

$$J_2 = \int_A^1 \left(\frac{1-y}{y} \right)^z \log_e(y) dy \quad (36)$$

K = a constant at a particular time and cross section; and

$$P = 2.303 \log \left(\frac{30.2 dx}{D_{65}} \right) \quad (37)$$

A single prime mark designates a symbol that is associated with sampling depth and a double prime mark designates a symbol that is

associated with the total depth through which suspended sediment is discharged. The function J_1 and J_2 in terms of A and z are presented in Colby and Hembree (1955, figs. 5 and 6) and Hubbell and Matejka (1959, figs. 9 and 10). Equation 22 can be put in the form

$$Q_s'' = i_B Q_B (PI_1'' + I_2'') \quad (38)$$

which can be combined with equation 34 to give:

$$\frac{Q_s'}{i_B Q_B} = \frac{I_1''}{J_1''} (PJ_1' + J_2') \quad (39)$$

The parameters Q_s' and $i_B Q_B$ are computed independently of z (Q_s' is determined from measurements, and $i_B Q_B$ is determined using equation 26). Equation 39 is used to compute z by trial for the reference size, the geometric mean size for a size range that is represented in appreciable quantities in both bedload discharge and suspended-sediment discharge. The z 's for the other size ranges are computed by proportion from the z for the reference-size range by using:

$$z_u = z_r \left(\frac{V_{su}}{V_{sr}} \right)^{0.7} \quad (40)$$

in which

$z_u = z$ for size ranges other than that for the reference size; the unknown;

$z_r = z$ for reference size;

V_{su} = fall velocity of the geometric mean size for the other size ranges; and

V_{sr} = fall velocity of the geometric mean size for the reference size.

EQUATIONS FOR RANGES OF SMALL PARTICLES

Equation 34 is used to compute total suspended-sediment discharge for ranges of particle sizes smaller than the range for the reference size. The z 's for the different ranges of sizes are determined using z for the reference size in equation 39. The suspended-sediment discharge for a range of particle sizes obtained using equation 34 normally represents the total sediment discharge for the range; if $i_B Q_B$ is significant for the range, however, it must be added.

REVISED MODIFIED EINSTEIN PROCEDURE

The RMEP (revised modified Einstein procedure) is similar to the MEP except several equations have been changed. Equations for shear velocity, bedload, exponent z , and total load are affected.

SHEAR VELOCITY

The equation used to compute shear velocity is derived from equation 29 by replacing D_{65} with $5.5 D_{65}$ (Burkham and Dawdy, 1976a) to give

$$V_{*RM} = V / \left(5.75 \log \left[2.23 \frac{dx}{D_{65}} \right] \right) \quad (41)$$

Values for V_{*RM} are obtained by using known values for V , d and D_{65} ; and trial values of x in equation 41. Values for $(RS)_{RM}$ are obtained using the equation

$$(RS)_{RM} = \left(\frac{V_{*RM}}{g} \right)^2 \quad (42)$$

The curve in figure 4 is assumed to be applicable when k_s/δ is represented by $5.5 D_{65}/\delta_{RM}$ and δ_{RM} is obtained using the expression $\delta_{RM} = 11.6 v/(V_{*})_{RM}$. The change in the representative size from D_{65} as used in the modified Einstein method to $5.5 D_{65}$ is based on results which indicate that the k_s used in the original Einstein development is a size fraction much larger than D_{65} , for which $5.5 D_{65}$ was found to be an average value (Burkham and Dawdy, 1976b). The subscript RM denotes a parameter that was obtained according to RMEP.

The shear velocity obtained according to RMEP is significantly larger than the shear velocity obtained according to MEP. The relation between the two shear velocities can be represented by:

$$(gRS)_{RM}^{1/2} = \left(1 + \frac{4.26}{V} \right) (gRS)_M^{1/2} \quad (43)$$

The ratio $(gRS)_{RM}^{1/2} / (gRS)_M^{1/2}$ ranges from 9.52 to 1.28 for velocities ranging from 0.50 to 15 feet per second.

Equation 41 is assumed to be valid for turbulent flow in open channels where the turbulence results totally from grain roughness. The rationale for using equation 41 to determine shear velocity in channels having significant bed form is based on Einstein's (1950) assumption that the energy of turbulence generated because of shape resistance does not contribute significantly to bedload motion and may be largely neglected in the entire sediment picture. Given a velocity, a depth, and a value for D_{65} for a site in a stream having significant form roughness, V_{*RM} would approximately represent the shear velocity that would have occurred if no form roughness had existed at the site.

Colby (1961) has shown that sediment transport for sand-channel streams is primarily related to velocity of flow, approximately to the

third power. Change of regime alters the form resistance and the velocity of flow, but the difference in transport is directly linked to the change in velocity. This tends to support Einstein's assumption that an effective shear computed without directly considering form roughness should be used to estimate transport of sand for all regimes of flow.

BEDLOAD

Equation 19 and the relation in Einstein (1950, fig. 10) are used in the RMEP to determine bedload. However, the procedure used to derive a value for the intensity of shear, $(\psi_*)_{RM}$, which is needed to use the ψ_* -to- ϕ_* relation, is different from the procedures used by Einstein (1950) and by Colby and Hembree (1955). The approach used in developing an equation to represent $(\psi_*)_{RM}$ was indirect, included several assumptions, and involved several steps. A general equation for $\psi_{*(RM)}$ was developed by first developing an equation for a uniform particle of size k_s and then applying corrections to this equation so that it would be applicable to mixtures. The equation for the uniform particle is

$$\Psi_{*(RM)} = 1.65 \frac{k_s}{(RS)_{RM}} \quad (44)$$

which was obtained by using Einstein's (1950) equation 49; replacing D with k_s and $(R'S)$ with $(RS)_{RM}$ and representing $\rho_s - \rho_f$ with 1.65.

The general equation for ψ_{*RM} for a mixture is

$$\Psi_{*RM} = 1.65 (\xi Y)_{RM} (\beta/\beta_x)^2 \frac{k_s}{(RS)_{RM}} \quad (45)$$

in which

$$\begin{aligned} \beta &= \log (10.6); \text{ and} \\ \beta_{x_1} &= \log (10.6x). \end{aligned}$$

In developing equation 45 a basic assumption was made that Einstein's hiding coefficient and lift correction can be represented by the single parameter $(\xi Y)_{RM}$.

Burkham and Dawdy (1976a) found that x_0 is approximately 1 when channel roughness in a hydraulically rough channel is represented by a relatively large particle in a mixture of sizes. For a hydraulically rough channel, k_s , therefore, is assumed to be equal to the diameter, D , for relatively large particles in a mixture and $(\xi Y)_{RM}$ is assumed to be 1 for the relatively large particles in a mixture. Considering these assumptions, ψ_{*RM} for relatively large particles in a mixture in a hydraulically rough channel can be represented as

$$\psi_{*RM} = 1.65 (\beta/\beta_{x_1})_2 D / (RS)_{RM} \quad (46)$$

For the RMEP, ψ_{*RM} from equation 46 is assumed to represent the largest value for the intensity of shear that is possible for a particle of size D in a mixture; the value of ϕ_{*RM} , obtained by using a value of ψ_{*RM} from equation 46 and the curve in Einstein (1950, fig. 10), would represent the lowest possible intensity of transport.

According to Einstein, ξ is a function of δ , D_{65} , D and X ; and Y is a function of δ and D_{65} . For the current study, $(\xi Y)_{RM}$ is assumed to be a function of δ_{RM} , D_{65} , D_{35} , D and k_s as represented by the equation;

$$(\xi Y)_{RM} = (\delta_{RM} + C_s D)/k_s \quad (47)$$

in which

C_s = a variable coefficient which is a function of the median diameter of the bed material (the geometric mean of D_{35} and D_{65} was used to represent the median diameter).

Equations 45 and 47 are combined to give

$$(\psi_*)_{RM} = 1.65 (\beta/\beta_r)^2 (\delta_{RM} + C_s D)/(RS)_{RM} \quad (48)$$

which is used to compute $(\psi_*)_{RM}$ for all ranges of particle sizes where $(\delta_{RM} + C_s D)$ is larger than the geometric mean diameter, D ; equation 46 is used when D is equal to or greater than $(\delta_{RM} + C_s D)$. Values of ϕ_* obtained by entering $(\psi_*)_{RM}$ in the relation shown in Einstein (1950, fig. 10) are used directly in equation 19 to compute bedload.

The empirically defined equation for C_s is

$$C_s = -0.62 + 3.12 [(D_{65})(D_{35})]^{1/2} \quad (49)$$

which is applicable in the range $0 < C_s < 1$. The coefficient C_s is zero when D_{50G} equals $[(D_{65})(D_{35})]^{1/2}$ - is smaller than about 0.2 mm; C_s is 1 when D_{50G} is 0.52 or larger. The development of equation 49 is described in the section "Computation Procedure."

EXPONENT Z AND TOTAL LOAD

The RMEP uses equation 39 with RM values inserted for the trial determination of z . The value of P_{RM} used in equation 39 is determined from equation 50 which is

$$P_{RM} = 2.303 \log \left(\frac{30.2 dx}{5.5 D_{65}} \right) = 2.303 \log \left(\frac{5.5 dx}{D_{65}} \right) \quad (50)$$

The total discharge of sediment in the range of large particle sizes is then computed as in equation 25, but with RMEP parameters in the equation:

$$i_t Q_t = \left(i_B Q_B \right)_{RM} \left((P_{RM}) I_1'' + I_2'' + 1 \right) \quad (51)$$

Similarly, equation 34 for the ranges of small sediment sizes is revised to

$$i_t Q_t = Q_s'' = Q_s' \left[\frac{P_{RM} J_1'' + J_2''}{P_{RM} J_1' + J_2'} \right] \quad (52)$$

COMPARISON OF COMPUTED AND MEASURED SEDIMENT DISCHARGES

BASIC DATA

Data sets for selected section in five river reaches are used in the comparison studies. The study sites are: Niobrara River at Cody, Nebr.; Middle Loup River near Dunning, Nebr.; Fivemile Creek at Shoshoni, Wyo.; Fivemile Creek near Riverton, Wyo.; and Rio Grande conveyance channel near Bernardo, N. M. In each reach the total sediment discharge was determined by sampling at a natural or manmade turbulence flume and data pertinent to the computation of total discharge were collected at nearby normal or natural sections. The total sediment discharge determined by sampling at the turbulence flume was taken to be total measured sediment discharge.

NIOBRARA DATA

The data, the flume, and the normal sections for the reach along the Niobrara River near Cody, Nebr. are described in a report by Colby and Hembree (1955). The data were used by them in the development of the MEP and in comparison of measured and computed total sediment discharges. They made comparisons for 24 sets of data, and these comparisons are summarized in their table 34. Only 21 of the 24 data sets, however, were used in the current study. According to Colby and Hembree (1955), two data sets for the normal sections contained "obviously incorrect suspended-sediment size distribution." These two sets of data were not used in the current study. For a third set, Colby and Hembree made "separate computations for each of the two parts of the cross section" in computing total sediment discharge for the normal section. The third set was not used in the current study because of the uncertainty of what cross-sectional properties should be used in computing total sediment discharge for the normal section. Of the remaining 21 sets, some of the data used by Colby and Hembree—stream width, depths, and velocity; concentration of suspended sediment; size distribution of suspended sediment; average depth at the verticals where the suspended-sediment samples were collected; size distribution of bed material; and water temperature—could not be duplicated exactly. The values of sediment discharge

computed for this study using the modified Einstein procedure, therefore, do not agree exactly with those contained in table 34 in the report by Colby and Hembree.

MIDDLE LOUP RIVER DATA

The data, the flume, and the normal sections for the reach along the Middle Loup River at Dunning, Nebr., are described in three reports. The flume, the normal sections, and the 46 sets of data for March 1950 to September 1952 are described in a report by Hubbell and Matejka (1959); the 6 sets of data for November 1955 to March 1956 are described in a report by Hubbell, Jordan, Culbertson, and Hembree (1956); and the 7 sets of data for August 6, 1956, to November 30, 1956, are described in a report by Hubbell (1960).

Hubbell and Matejka (1959, table 8) made comparisons of measured and computed total sediment discharges in which the MEP was used in determining computed values for 63 sets of data for the study reach of the Middle Loup River. According to Hubbell and Matejka (1959), the following information from each section was used for the computations of total sediment discharge:

The average bed-material size distribution that was determined from all available samples, other than special samples, collected at the section; the measured suspended-sediment concentration and size distribution; the measured sediment discharge computed from the rated water discharge, except when the load was computed by parts; multipliers based on fall velocities from Rubey's equation. Most of the computed total loads for section A and some of the computed total loads for section E were determined from individual computations for each of two parts or more of the section . . .

The data sets for section A and some for section E were not used in the current study because of the uncertainty of what cross-sectional properties should be used in computing total sediment discharges. Of the remaining 46 data sets, some of the data used by Hubbell and Matejka could not be duplicated exactly. The values of sediment discharge computed for this study using the MEP, therefore, do not agree exactly with those contained in the report by Hubbell and Matejka (1959).

Comparisons made by Hubbell, Jordan, Culbertson, and Hembree (1956) are shown in their table 13 and comparisons made by Hubbell (1960) are shown in his table 5. For these two tables, the computed values for each data set were obtained using the MEP.

FIVEMILE CREEK DATA

The flumes and the normal sections for the reaches along the Fivemile Creek near Shoshoni and near Riverton, Wyo., are described briefly in a report by Colby, Hembree, and Rainwater (1956). The 87 sets of data for September 1954 to June 1, 1963, for the Shoshoni

reach and the 64 sets of data for August 26, 1954, to September 1963 for the Riverton reach were copied directly from records in the files of the U.S. Geological Survey, Cheyenne, Wyo. Data for measured-sediment discharge for the different sediment-size ranges were included in 12 of the sets of data for the Shoshoni reach and in 14 for the Riverton reach.

RIO GRANDE REACH

The flumes, the normal sections, and the data for the reach along the Rio Grande conveyance channel near Bernardo, N. M., are described in reports by Harris and Richardson (1964); Gonzalez, Scott, and Culbertson, (1969); and Culbertson, Scott, and Bennett (1972). The 61 data sets for February 3, 1965, to May 4, 1966, for the Rio Grande reach which are used in the current study were obtained directly from the report by Culbertson, Scott, and Bennett.

COMPUTATION PROCEDURE

Colby and Hembree (1955) and Hubbell and Matejka (1959) have presented explanations for the total-load computational procedure for the MEP. For review and because the RMEP uses the MEP computational procedure, the explanation by Hubbell and Matejka (1959) is repeated here; however, references are made only to the RMEP equations. A total-load computation is made using the RMEP and the data from plate 7 in the report by Hubbell and Matejka (1959).

The computation form (fig. 5) is separated into three major computation blocks, which are headed: block I, preliminary data and computations; block II, computation of $i_B Q_B$; and, block III, computation by Z.

Step 1.—Fill in line 1, block I, with the basic data in pound-foot-second units; w , width; V , mean velocity; d , mean depth; d_s , average depth at the verticals sampled; D_{65} and D_{35} , particle size at which 65 and 35 percent, respectively, of the bed material by weight is finer; *Conc*, measured suspended-sediment concentration (in parts per million); Q_{SM} , measured suspended-sediment discharge (in tons per day); and *Temp*, water temperature in degrees Fahrenheit. (Except when noted otherwise, the English system of units is used throughout the computation.)

Step 2.—Solve equations 41 and 42, line 2, block 1, for $(RS)_{RM}$ after assuming a trial x where $\sqrt{(RS)_{RM}}$ equals $(V_*)_{RM}/\sqrt{8}$; x usually is about 1.0.

Step 3.—Compute $(RS)_{RM}$ from the value for $\sqrt{(RS)_{RM}}$ determined in step 2.

Step 4.—Compute the shear velocity, $(V_*)_{RM}$, using the expression $(V_*)_{RM} = \sqrt{g(RS)_{RM}}$ in which $\sqrt{(RS)_{RM}}$ is from step 2 and g is the gravity constant, 32.2 feet per second.

Station: Middle Loup River at Dunning, Neb.										Date: Dec. 14, 1960																		
Block I Preliminary data and computations										Block II Computation of $1g_{OB}$																		
Section: C2										Section: C2																		
(1)	$w = 81; V = 2.98; d = 2.10; d_g = 2.37; D_{eg} = 0.00161; D_{35} = 0.00104; \text{Conc.} = 1.160; Q_{SM} = 1.820; \text{Temp.} = 32^\circ F$										(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)										
(2)	$\sqrt{(RS)_{RM}} = \sqrt{252.6 \log 10 \frac{2.236x}{D_{85}}} \cdot \sqrt{(RS)_{RM}} = 2.99/32.6 \log 10 \frac{2.23 (2.10) (1.00)}{[0.00161]} = 0.0264; (RS)_{RM} = 0.00697; V_{RM} = \sqrt{(RS)_{RM}} = 0.1498$										$1g_{OB}$	ϕ_s	$12000/3/2$	$1g_{OB}$	$1g_{OB}$	$43.2w$	$1g_{OB}$											
(3)	$6 = \frac{11.6''}{V_{RM}} = \frac{11.6 (1.92 \times 10^{-5})}{0.001494} = 0.001484; k_s = 5.5 (0.00161) = 0.000906; \frac{5.5 (2.10) (1.03)}{[0.00161]} = 6.91$										$1g_{OB}$	ϕ_s	$12000/3/2$	$1g_{OB}$	$1g_{OB}$	$43.2w$	$1g_{OB}$											
(4)	$A = d_g/d_s = 0.3/2.37 = 0.127; \text{Percent of flow in sampled zone } (Q_{10}) = 1.383$										$1g_{OB}$	ϕ_s	$12000/3/2$	$1g_{OB}$	$1g_{OB}$	$43.2w$	$1g_{OB}$											
(5)	Size 000036 00029 00085 00116 00232 00464										Notes: d_g - Depth of sampled verticals, ϕ_s - Depth not sampled.																	
(6)	J ₁ % 11 19 54 15 1										1 From section size analysis, 2 From other than section size analysis																	
(7)	Z 6 13 49 24 6 2										3 From contracted section size analysis																	
(8)	Method										Total sediment discharge																	
(9)	Reference size is 0.00116										Computed																	
Block III Computation by Z										Mass. % Diff.																		
$O_1 = \frac{1}{1g_{OB}} = \frac{1}{(P_{RM})^{1/2}}$, solve for z										From																		
$1g_{OB} = (212) = 4.62, \text{Try } Z = 0.80$										From																		
$1.84 (6.88 (1.08) (1.38)) = 1.84 (8.24) = 4.74$										From																		
3.20										From																		
$\text{Use } z = 0.88$										From																		

FIGURE 5.—Computation of total sediment discharge. (Modified from Colby and Hembree, 1955, pl. 3, and Hubbell and Matejka, 1959, pl. 7.)

(Modified from Colby and Hembree, 1955, pl. 3 and Hubbell and Matejka, 1959, pl. 7.)

Step 5.—Compute δ_{RM} using the expression $\delta_{RM} = \frac{11.6\mu}{(V_*)_{RM}}$ in which μ is the kinematic viscosity, in square feet per second, at the indicated water temperature and $(V_*)_{RM}$ is from step 4.

Step 6.—Calculate $(5.5D_{65})/(\delta)_{RM}$ and enter figure 4 for x . If the trial x is not about the same as the x from figure 4, repeat steps 2 through 6.

Step 7.—Solve for P_{RM} using equation 51— $P_{RM} = 2.303 \log \left(5.5 \frac{dx}{D_{65}} \right)$

Step 8.—Determine A' on line 4 from $A' = d_n/d_s$, in which d_n is the vertical distance not sampled, in feet; that is, the distance from the bottom of the sampled zone to the streambed.

Step 9.—From figure 6, find the percentage of flow in the sampled zone by using the computed A' and P_{RM} .

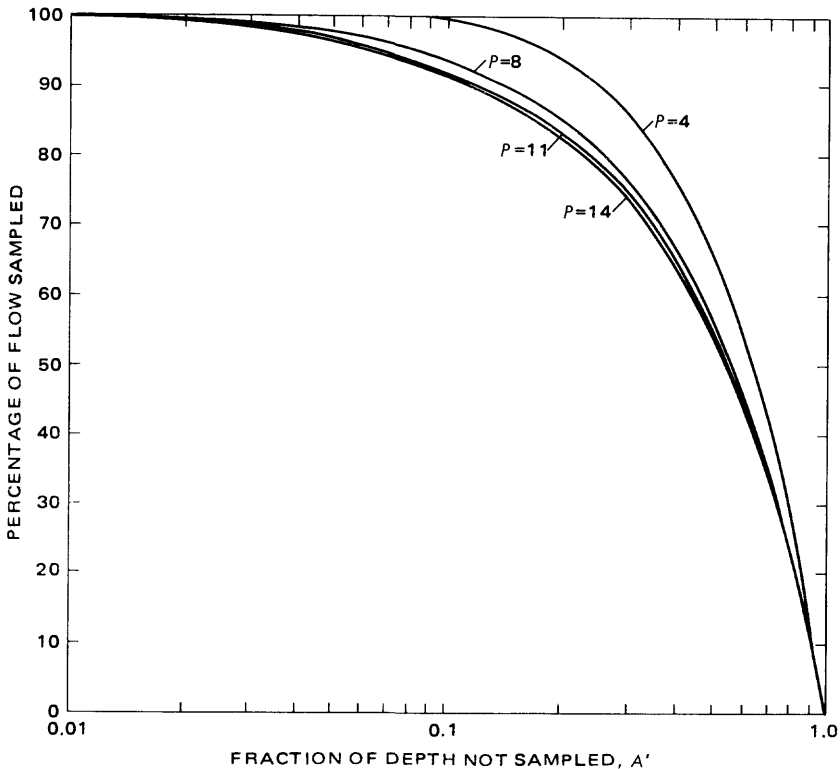


FIGURE 6.—Vertical distribution of streamflow. (From Colby and Hembree, 1955, fig. 45.)

Step 10.—Compute the load in the sampled zone (Q_{ts}') by multiplying the percentage of flow in the sampled zone by the measured suspended-sediment discharge (Q_{sm}).

Step 11.—List the percentage of measured suspended sediment in each size range under the geometric mean size of the range (line 5) on line 6 if the percentages were determined from an actual size analysis or on line 7 if they were determined by some other means. Line 8 is not completed unless the size distribution of the measured total load is known and is to be used in checking the accuracy of the computed total load.

Step 12.—List in column 1, block II, each geometric mean size of the size ranges that have appreciable bedload discharge ($i_R Q_R$).

Step 13.—Compute a value for $(\psi_*)_{RM}$ for each size range using the following expressions:

$$\begin{aligned} (\psi_*)_{RM} &= 1.65 (\beta/\beta_{x_1})^2 (\delta_{RM} + C_s D) / (RS)_{RM} \text{ or} \\ (\psi_*)_{RM} &= 1.65 (\beta/\beta_{x_1})^2 (D) / (RS)_{RM} \text{ if } D > (\delta_{RM} + C_s D) \end{aligned}$$

where

$$\begin{aligned} \beta &= \log (10.6) \\ \beta_{x_1} &= \log (10.6x) \\ C_s &= 0 \text{ if } [(D_{65})(D_{35})]^{1/2}, \text{ in millimeters, is less than } 0.20; \text{ and} \\ C_s &= 1.00 \text{ if } [(D_{65})(D_{35})]^{1/2}, \text{ in millimeters, is larger than } 0.52; \\ &\text{otherwise} \end{aligned}$$

$$C_s = -0.62 + 3.12 [(D_{65})(D_{35})]^{1/2} \quad (49)$$

in which D_{65} and D_{35} are in millimeters.

Equation 49 is based entirely on the data sets for sites on the Niobrara and the Middle Loup Rivers. The following steps were taken in developing the equation:

1. Using different numerical values for C_s in equation 49, total sediment discharges were computed for each set of data for the Niobrara and Middle Loup sites.

2. The difference between computed and measured total sediment discharge were determined for each data set, and the square root of the mean variance for the Niobrara and Middle Loup data were computed.

3. Graphs showing the relation between the value of C_s used in step 1 and the square root of the mean variance obtained in step 2 were developed.

4. The values of C_s for the minimum square root of the mean variance were determined from the relation developed in step 3; a value of 0.25 were determined for the Niobrara data and a value of 0.50 were determined for the Middle Loup data.

5. Averages of the geometric means of D_{35} and D_{65} , in millimeters, were determined for the Niobrara data and for the Middle Loup data; these averages were 0.28 and 0.36, respectively.

6. The values from step 3 and step 5 were plotted on a graph and a straight line was drawn through the two points; this line is represented by equation 49.

Step 14.—Determine ϕ_* for each size range from a curve in Einstein (1950, fig. 10) using the $(\psi_*)_{RM}$ from step 13.

Step 15.—List the value of $1,200D^{3/2}$ for each size range in column 4. D is the geometric mean size of the size range.

Step 16.—Enter the fraction of bed material in each size range (i_b) in column 5.

Step 17.—Compute $i_B Q_B$ for each size range using the expression $i_B Q_B = 1,200i_b D^{3/2} \phi_*$.

Step 18.—Compute the constant $43.2w$ for entry in column 7. The width, w , is the effective width—width determined by applying an appropriate horizontal angle correction to the width rather than the velocity or discharge, and 43.2 is a constant converting pounds per second to tons per day.

Step 19.—Compute $i_B Q_B$ for each size range and enter in column 8; $i_B Q_B$ is the product of $i_b Q_B$ and $43.2w$.

Step 20.—List in column 9, block III, the geometric mean size of all the size ranges that are transported. (Column numbers for block III are at the bottom of the table.)

Step 21.—Compute the load in the sampled zone of each size range (Q_s') as the product of the load in the sampled zone (Q_{ts}') (line 4, block I) and the percentage of measured suspended sediment in each size range (from line 6, block I). Enter the product in column 10.

Step 22.—Copy in column 12 each $i_B Q_B$ from column 8, block II.

Step 23.—Compute A'' for each size range from $A'' = 2D/d$ and enter in column 15. A'' is equal to the distance of the lower limit of integration above the stream bed, a , divided by d . Einstein (1950, p. 25) shows the relations, $a = 2D$.

Step 24.—The large box headed "Determination of Reference z ," in block III is used in this step. Select the reference size. The reference size should be the geometric mean size of a size range that is represented in appreciable quantities in both bedload discharge and suspended-sediment discharge. For streams in which the bedload discharge is a substantial part of the total load, the reference size range ordinarily will be the range that has the greatest total sediment discharge. Once the reference size is selected, it can be used for all subsequent computations. Compute the value of the ratio $Q_s'/i_B Q_B$ (the left-hand side of the formula $Q_s'/i_B Q_B = \frac{I''}{J} (P_{RM} J_1' + J_2')$) for the

reference size. Assume a z for the reference size (figure 7 will aid in a first approximation for many shallow streams) and solve the right-hand side of the above formula with values determined by using A' and A'' and the assumed z with figures 5, 6, and 7 of Colby and Hembree (1955) or figures 9, 10, and 13 of Hubbell and Matejka (1959). When the right and left sides of the equation balance, the assumed z is the proper z for the reference size range.

Step 25.—Because z varies with about the 0.7 power of fall velocity and because flow characteristics that might cause z to vary are constant at a given cross section and time, the z for the other size ranges can be computed by using equation 40 and z for the reference size range. Curves for the different size ranges of $(V_{su}/V_{sr})^{0.7}$ (called multipliers) versus temperature were plotted by Colby and Hembree (1955, pl. 1); the 0.25 to 0.50 millimeter size range is the reference range. The z for any size range is the product of the z for the reference range and the multiplier at the indicated water temperature for the size range. List in column 13 the multiplier with each size range.

Step 26.—Compute the z for all size ranges from the z for the reference range and the multiplier.

Step 27.—Complete columns 16, 17, 18, and 19 for the ranges for sediment sizes smaller than size in the reference size range; use curves in Colby and Hembree (1955, figs. 5 and 6) and the z , A' , and A'' for each size range.

Step 28.—Compute the ratio $(P_{RM}J_1''+J_2'')/(P_{RM}J_1'+J_2')$. List the ratios in column 20.

Step 29.—Complete column 21 and 22 for the ranges of sediment sizes not included in Step 27; use curves in Colby and Hembree (1955, figs. 4 and 7) and the z and A'' for each size range.

Step 30.—Compute $P_{RM}I_1''+I_2''+1$ for entry in column 23 using the information in columns 21 and 22. I_2'' is always negative.

Step 31.—Compute the total sediment discharge for the ranges for sediment sizes smaller than the size in the reference size range; it is the product of the values in column 20 and in column 10. Enter the total sediment discharge in column 24.

Step 32.—Compute the total sediment discharge of all the size ranges not included in step 31; it is the product of the values in columns 12 and 23. Enter the total sediment discharge in column 24.

Computer programs analogous to the MEP and RMEP were used to compute sediment discharge. Documentation for the computer program for MEP, called MODEIN, is available in a report by Burkham, Kroll, and Porterfield (1977). The computer program for the RMEP, called RMODEIN, is the same as MODEIN except that pertinent equations have been changed.

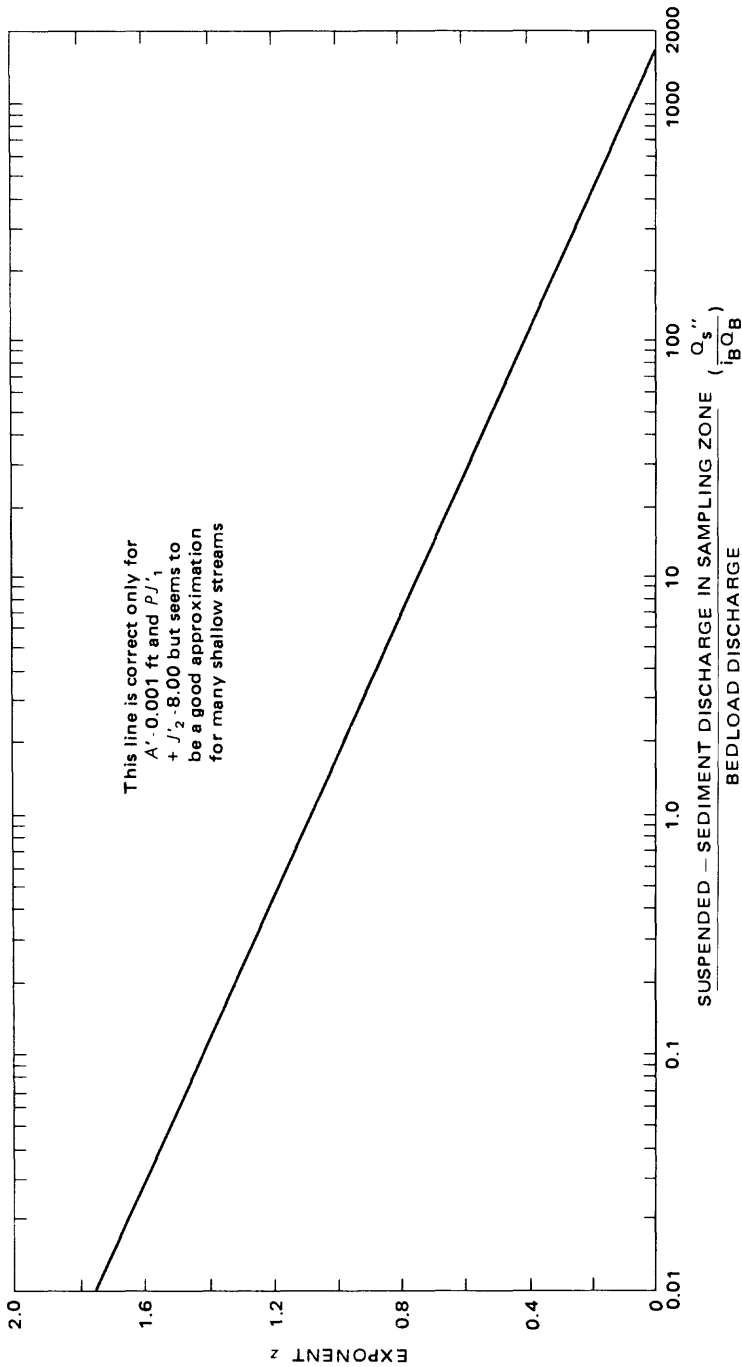


FIGURE 7.—Approximate relation of z to the ratio of suspended-sediment discharge in the sampling zone to bedload discharge. (From Colby and Hembree, 1955, fig. 46.)

RESULTS OF COMPARISON

INTRODUCTION

Sediment discharges, by size ranges and for the total, computed by the MEP and RMEP for each data set are compared with measured values. The following statistics were computed for the comparisons: the percentage of the total measured sediment discharge for each sediment-discharge computation; the average and standard deviation of these percentages for each of the five data groups; the square root of the mean variance for the computed values for the size ranges and for the total sediment discharge; mean of measured and computed sediment discharges for the size ranges and for the total sediment discharge; and ratio of square root of mean variance to mean of measured sediment discharges for the size ranges and for the total sediment discharge. The percentage of the total measured sediment discharge is the ratio of computed total sediment discharge to measured total sediment discharge multiplied by 100. The square root of the mean variance which was used as an approximation of the standard error was determined using the expression

$$SE_q = \sqrt{\sum_{i=1}^{N_s} (Q_{TM_i} - Q_{TC_i})^2 / (N_s - 1)}$$

in which

- SE_q = the square root of the mean variance;
- Q_{TM} = the measured sediment discharge;
- Q_{TC} = the computed sediment discharge; and
- N_s = the number of measurements in the set.

The measured-sediment data may contain significant errors; in which case, the standard error of estimate, SE , would be different than SE_q . The ratio of square root of mean variance to mean of measured sediment is used, when multiplied by 100, as a rough approximation of the standard error of estimate in percent.

NIOBRARA RIVER

The RMEP apparently gave better results than the MEP for the Niobrara site (table 1). This premise is based on the following facts and criteria:

1. For the total sediment discharge, the square root of the mean variance for the 21 data sets is 415 tons per day for the RMEP and 674 tons per day for the MEP.
2. The mean of the computed total sediment discharge determined according to the RMEP is more nearly equal to the measured mean

than that for computed totals determined according to the MEP. The percentage of measured sediment ranged from 55 to 137 and averaged 100 percent for the RMEP; the range was 70 to 148 and the average was 94 for the MEP.

3. Using the average of the measured sediment discharges, 2,310 tons per day, as a gage, the approximate standard error of estimate is about 18 percent for the RMEP and about 29 percent for the MEP.

4. For four of the five ranges of particle sizes, the approximate standard error of estimate for results obtained according to the RMEP apparently was better than that for the MEP. For most of the data sets for the other range, only a relatively small amount of sediment was being transported.

For the Niobrara site, the RMEP and the MEP give better results for the ranges of relatively small particles than for the ranges of relatively large particles. This should be expected because the computation for the small particles is based primarily on measured data while that for the large particles is based largely on theoretical considerations.

Statistics different from those in table 1 were reported in a previous paper (Burkham and Dawdy, 1976b). The previous paper was primarily a progress report and the statistics were of a preliminary nature.

MIDDLE LOUP RIVER

The RMEP and the MEP gave results for the site on the Middle Loup River that have about the same accuracy (table 1). The square root of the mean variance for the computed total sediment discharge is 298 tons per day for the RMEP and 310 tons per day for the MEP. Using the average of the measured total sediment discharges, 1,570 tons per day, as a gage, the approximate standard error of estimate is about 20 percent for both methods. The percentage of measured total sediment discharge ranged from 65 to 146 and average 105 for the RMEP; the range is 68 to 165 and the average is 106 for the MEP. As for the Niobrara data, both methods gave better results for ranges for relatively small particles than for ranges for relatively large particles.

Nine of the fifty-nine data sets were not used in determining the statistics for variance and ratios for the 1.00- to 2.00-mm range. This was done to minimize the possibility of introducing bias in estimating errors for the two methods. For the nine data sets, the measured or computed value of sediment discharge is 0. For unlimited sets of data containing 0, the mean of the deviations of computed values from measured values could not be 0, a requirement in determining an unbiased estimate of errors.

FIVEMILE CREEK AT SHOSHONI

The RMEP and the MEP yielded computed values for total sediment discharge for the Shoshoni site that have about the same approximate standard error of estimate (table 1). For the RMEP, the approximate standard error of estimate for total sediment discharge is 383 tons per day; it is 391 tons per day for the MEP. Using the average of the measured total sediment discharges, 1,730 tons per day, as a gage, the approximate standard error of estimate for total-sediment discharge is about 23 percent for both procedures.

Both procedures gave values for total sediment discharge that are significantly larger than measured values (table 1). The average of the percentage of measured sediment discharge is 115 for the RMEP and 122 for the MEP. The ratio of the average of computed total sediment discharge to the average of measured total sediment discharge is about 1.15 for both procedures.

The reason that the computed total sediment discharge is larger than the measured value is now known, however, it could result from either the total sediment discharge at the weir being significantly undermeasured, or the total sediment discharge being overcomputed, or both.

The data-set sample for the different sediment-size ranges for the Shoshoni site is relatively small, therefore, statistics for the sample probably are not meaningful. The different statistics, however, were computed (table 1).

FIVEMILE CREEK AT RIVERTON

The RMEP and the MEP gave computed values for total-sediment discharge for the Riverton site that have about the same approximate standard error of estimate (table 1). The approximate standard error of estimate for total sediment discharge is 249 tons per day for the RMEP and 228 tons per day for the MEP. Using the average of the measured total sediment discharges, 1,360 tons per day, as a gage, the approximate standard error of estimate for total sediment discharge is about 18 percent for both procedures.

Again, both procedures give values for total sediment discharge that are significantly larger than measured values. The average of the percentages of measured-sediment discharges is 107 for the RMEP and 112 for the MEP. The ratio of the average of computed total sediment discharge to the average of measured-total-sediment discharge is 1.11 for both procedures.

The statistics for the sediment-size ranges which are given in table 1 probably are not meaningful because the data-set sample is relatively small.

RIO GRANDE CONVEYANCE CHANNEL

The approximate standard error of estimate for total sediment discharge for the Rio Grande data is 2,510 tons per day for both procedures (table 1; fig. 8). Using the average of the measured total sediment discharge, 8,860 tons per day, as a gage, the approximate standard error of estimate for total sediment discharge is 28 percent for both procedures.

Both procedures gave average values for total sediment discharge that are significantly smaller than the average of measured values; the average of percentages is 86 for both procedures. The relatively low averages of computed values apparently result because the amount of sediment in the 0.062 to 0.125 mm, 0.125 to 0.250 mm and 0.250 to 0.500 mm size ranges is underestimated during periods when the bed form is flat or in transition (fig. 8 A, C). Conversely, for these size ranges, the amount of sediment being moved during periods when the bed form is dunes is overestimated (fig. 8 B).

Earlier it was noted that Einstein made the assumption that the energy of turbulence generated by form resistance does not contribute significantly to bed-material motion. These data tend to support that assumption and, in fact, tend to indicate that the form resistance actually may inhibit bedload transport. Perhaps a portion of the bed, that immediately downstream from the dunes which is influenced by upstream eddies, does not contribute to downstream motion. That area could easily comprise 10 percent of the bed and fully account for the underestimation evidenced for dune conditions.

The RMEP can be readily adjusted by applying empirical corrections so that it will give results that agree better with measured sediment discharges for the Rio Grande data. For example, the indicated better agreement shown in figure 8 D was obtained by using equation 46A to represent ψ_{*RM} for all data sets for the Rio Grande site for May 4, 1966. Equation 46A is

$$\psi_{*RM} = 0.50 (\beta/\beta_{x1})^2 D/(RS)_{RM} \quad (46A)$$

which was obtained by applying a correction, $C_6 = 0.30$, to equation 46. Other than to force an agreement, a rational reason for applying the correction, C_6 , is not apparent at this time. Because of this and because data for which bed form is described are not adequate for testing when an empirical correction is applied, other equations to force agreement between computed and measured-sediment discharge for the different bed forms were not developed. Equation 46A probably should not be used because it has not been tested.

A more fundamental approach to adjust RMEP would be to determine more exactly the proper representative particle size that should

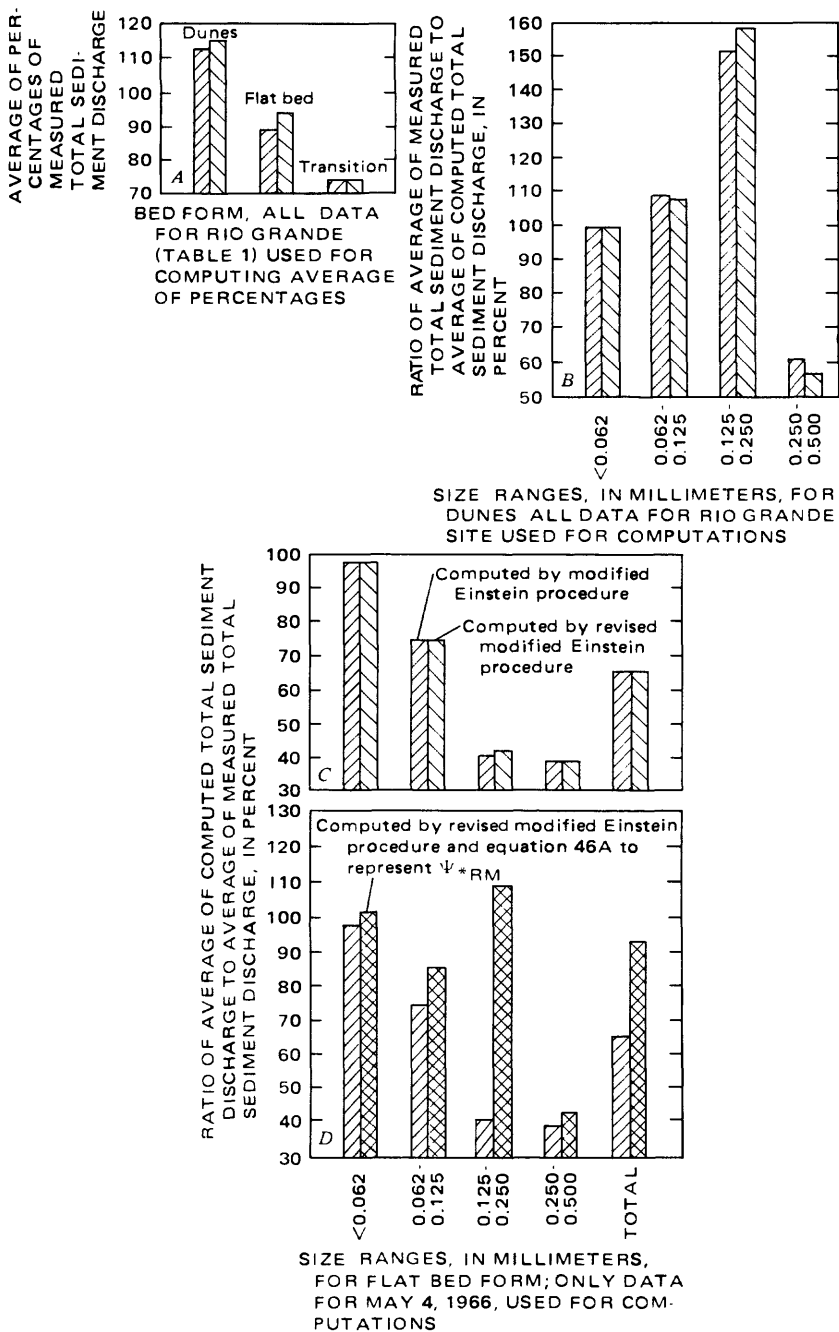


FIGURE 8.—Approximate standard error of estimate for the different bed forms and particle-size ranges, Rio Grande conveyance channel near Bernardo, N. Mex.

be used to represent k_s . The parameter $5.5 D_{65}$ is an average value based on a best fit for several sites (Burkham and Dawdy, 1976a). Certainly $k_s > D_{65}$, and on the average it is on the order of $5.5 D_{65}$. A future study which better determines k_s and allows the multiplier, x_0 , to be related to the size distribution may further improve the application of the RMEP.

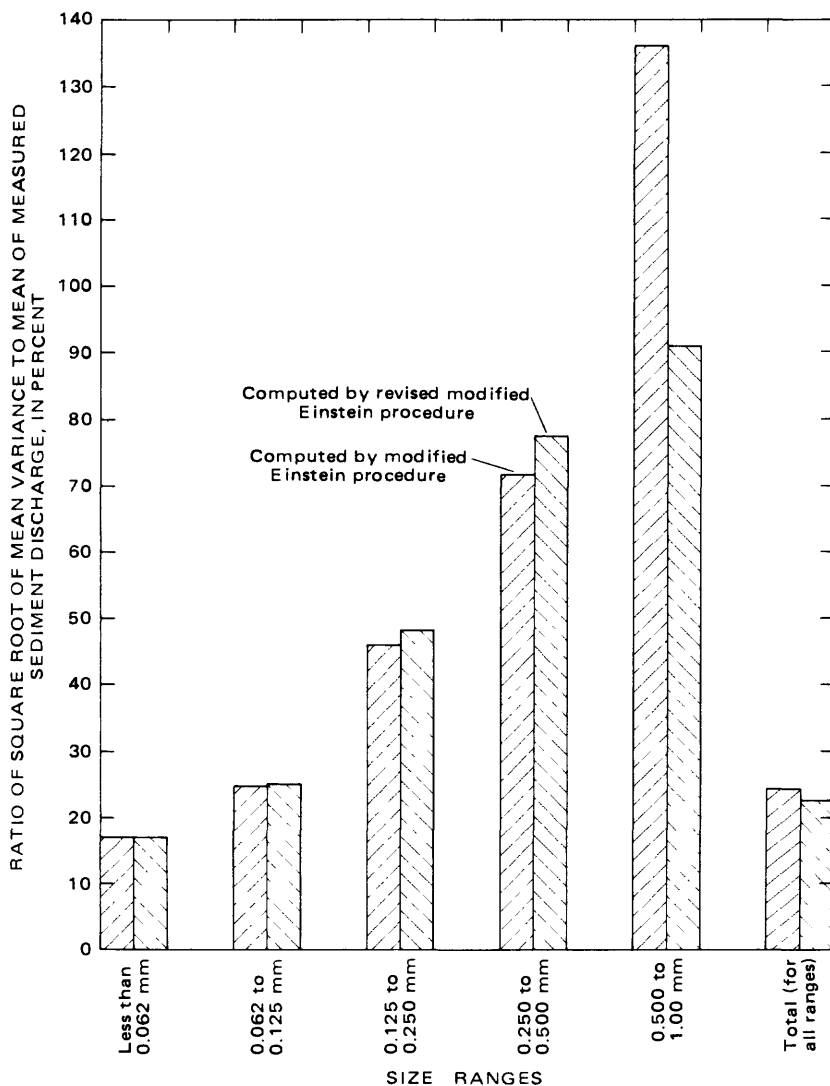


FIGURE 9.—Weighted approximate standard error of estimate for the different ranges of particle sizes and for the total sediment discharge for five data groups.

CHARACTERISTICS FOR THE FIVE DATA GROUPS

The weighted approximate standard error of estimate for the different ranges of particle sizes is given in figure 9. The weighted percentage for a range size was obtained using the equation

$$SE_w = \sqrt{\frac{\sum[(SE_1)^2(n_1) + \dots + (SE_5)^2(n_5)]}{\sum(n_1 + \dots + n_5)}} \quad (53)$$

in which $SE_1 \dots SE_5$ denotes the approximate standard error for the particle-size range for the five data groups and $n_1 \dots n_5$ represents the number of data sets for the particle-size range and data group. The Rio Grande data for the range for the 0.500 to 1.00 mm particle sizes were not used in computing a weighted approximate standard error of estimate; the quantity of sediment being transported for the range was small.

Figure 9 shows the weighted percentage error by size class for the total load of sands transported for the five data groups. For the smaller sizes, most of the sediment is moving in suspension, therefore large errors of estimation of that portion moving as bedload still result in small errors in terms of percent of total load for a class. For large sizes, almost all the sediment is moving as bedload, and any error in estimation of the bedload is translated almost directly into errors in total load.

The data for standard errors for the range of particle sizes less than 0.062 mm offers an excellent opportunity to approximate the standard sampling error for wash-load discharge for the diversified flow and sediment conditions found at the five study sites. A wash-load sampling error is the error introduced in determining the wash-load discharge by sampling. The wash-load sampling error depends on the accuracy of the water-discharge measurement, the sediment-sampling instrument, the sediment-sampling technique—including sampling time and the fluctuation in sediment concentration during this time—laboratory analysis, and the computation of concentration. In order to approximate the standard sampling error, the following assumptions were necessary:

1. The sampling error for wash load for a normal section is independent of the sampling error for wash load for a weir or contracted section.
2. The mean sampling error for wash load for a section is zero.
3. For comparable periods of records and discharges for a site, the true wash load at a normal section equals the true wash load at a weir.
4. For a site, the standard wash-load sampling error for a normal section equals the standard wash-load sampling error for a weir.

Considering these assumptions, the approximate standard error of 17 percent (the 17 percent is the weighted approximate standard error of estimate that is shown in figure 9 for the range of particle sizes less than 0.062 mm in diameter) is significantly larger than the standard error for wash load. The variances for independent errors are additive, therefore, the washload sampling error can be represented as:

$$\sqrt{2 (SE)_{w}^2} = 17 \text{ or } (SE)_{w} = 12.0 \text{ percent}$$

The 12.0 percent represents the standard wash-load sampling error for the five study sites.

The 12.0 percent for particle sizes less than 0.062 mm probably is a better approximation of the true standard error of estimate for the RMEP and MEP than the 17 percent that is shown in figure 9. The values shown in figure 9 for the other ranges of particle sizes also probably are slightly biased on the high side because they are computed as a difference of two terms. The amount of bias, however, cannot be determined because the relative sizes of the two components of error cannot be estimated as they were for the wash load.

Based on figure 10, the ratio of computed to measured total sediment discharge apparently increases with an increase in the median diameter of sediment particles in a mixture. Figure 10, however, may be misleading. As previously discussed for the Rio Grande site, the total sediment discharge is underestimated for periods when the bed form was flat or in transition and overestimated for periods when the bed form was dunes. A sediment bed in motion in a normal section usually does not retain a fixed bed form for all flow conditions, therefore, the bed form at the sites on the Niobrara, Middle Loup, and Fivemile Rivers probably is dunes, flat, or in transition at different times. If so, the results found for the Rio Grande site—overestimates for dunes and underestimates for flat bed—probably applies for the other sites. The fact that the total sediment discharge is overestimated for a site may only indicate that a bed form of dunes was at the normal section during most of the periods when sediment transport data were being obtained.

SUMMARY AND CONCLUSIONS

The modified Einstein procedure (Colby and Hembree, 1955) is revised by applying corrections to equations 29 and 39 and by replacing equations 27 and 28 with equations 46 and 48. The revision was made because D_{65} was used directly in the modified Einstein procedure to represent the equivalent sand roughness, k_s , whereas a much larger size apparently should have been used (Burkham and Dawdy, 1976a). For this study, $5.5 D_{65}$ an average value based on a best fit for data for

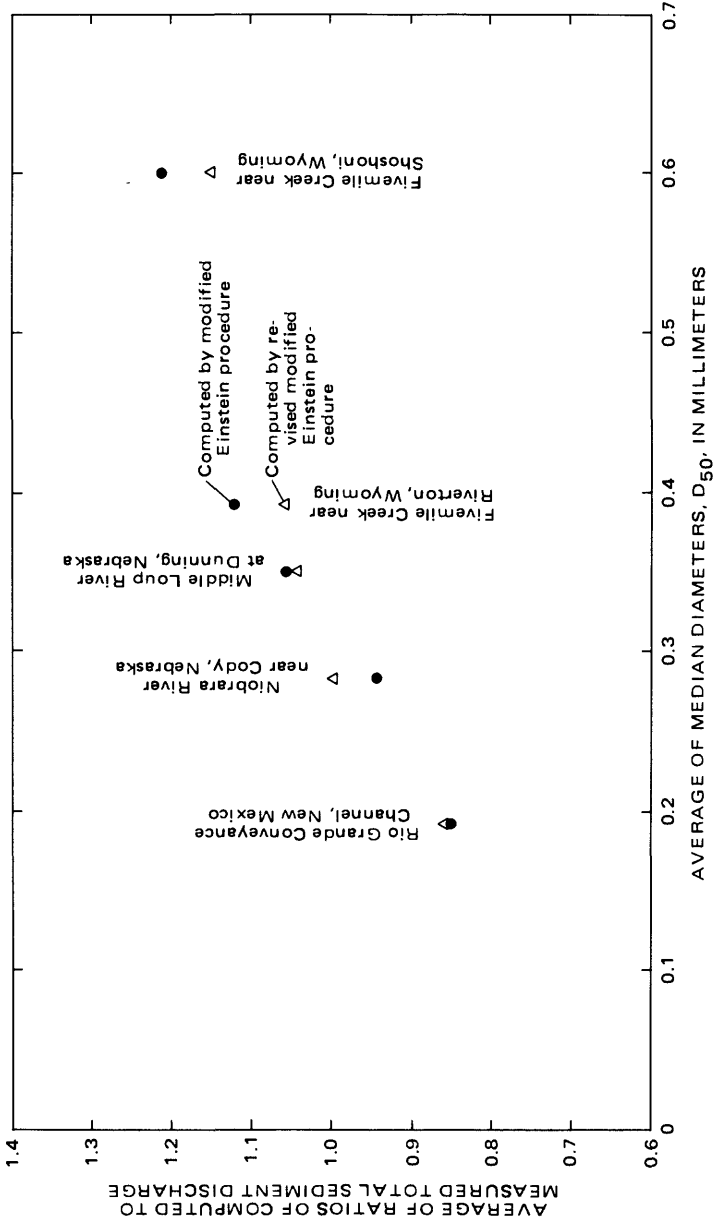


FIGURE 10.—Relation between the average of ratios of computed to measured total sediment discharge to the averages of median diameters for five data groups.

several sites, was used. The modified and the revised modified Einstein procedures were tested by comparing computed and measured sediment discharge for 292 sets of data for five sites in sand-channel streams.

Conclusions resulting from the study are:

1. The revised modified Einstein procedure apparently is an improvement over the modified Einstein procedure. For the sediment and flow conditions tested, the computed sediment discharges apparently are not significantly more accurate; however, improvement is indicated because the correction of pertinent equations eliminates some of the empirical adjustments contained in the modified Einstein procedure.

2. The revised procedure eliminated the need to arbitrarily divide the bedload transport intensity, ϕ_* , by 2 as was done in the modified Einstein procedure (Colby and Hembree, 1955). Values for ϕ_* are taken from a curve relating ψ_* intensity of transport, and ϕ_* . The ψ_* -to- ϕ_* curve is theoretical; however, it was verified by experimental data (Einstein, 1950). Einstein's equation for bedload (Einstein, 1950, p. 59, step 34) which was used in the modified and revised modified Einstein procedures requires that values taken from the ψ_* -to- ϕ_* curve be used directly to represent the bedload transport intensity.

3. For the same data, the revised modified Einstein procedure gives shear velocities that are significantly larger and x values that are significantly smaller than the corresponding values computed using the modified Einstein procedure. The ratio of shear velocity for the revised modified Einstein procedure to the shear velocity for the modified Einstein procedure ranges from 9.52 to 1.28 for stream velocities ranging from 0.50 to 15 feet per second. For the 292 data sets used in testing the two procedures, the value of x ranged from 1.00 to 1.14 for the revised modified Einstein procedure and from 1.00 to 1.62, the maximum value possible, for the modified Einstein procedure. The value of x is 1 for fully turbulent flow.

4. Based on data sets for the five sites, the approximate standard error of estimate for total sediment discharge determined by the two procedures is about 22 percent. Except for the range for the largest particles tested, the weighted standard error is approximately equal between the two methods for the different sediment-size ranges. Weighted standard errors for the different sediment-size ranges for the MEP and RMEP, respectively, are: 17 percent and 17 percent for sizes smaller than 0.062 mm; 25 percent and 25 percent for sizes from 0.062 to 0.125 mm; 46 percent and 48 percent for sizes from 0.125 to 0.250 mm; 72 percent and 77 percent for sizes 0.250 to 0.500 mm; and 136 percent and 91 percent for sizes 0.500 to 1.00 mm. The standard

error for wash load is relatively low because the wash load is determined directly by sampling and the accuracy of values determined by sampling is better than those determined indirectly by equations, which is done for relatively large particles moving as bedload. The approximate standard error for total sediment discharge is only about 22 percent because a large fraction of the total sediment discharge was in suspension and the suspended-sediment discharge is determined directly by sampling.

5. For a site on the Rio Grande conveyance channel, the amount of sediment in the 0.062 to 0.125 mm, 0.125 to 0.250 mm, and 0.250 to 0.500 mm sizes ranges were significantly underestimated by the two procedures for periods when the bed form was flat or was in transition. Conversely, for these ranges of sediment sizes and for the total, the amount of sediment being moved was significantly overestimated for periods when the bed form was dunes.

6. For two sites on Fivemile Creek in Wyoming, the total sediment discharge is significantly overestimated. This statistic may be misleading. A sediment bed in motion at a normal section usually does not retain a fixed bed form for all flow conditions, therefore, the bed form at the sites on Fivemile River probably is dunes, flat, or in transition at different times. If so, the results found for the Rio Grande site probably apply for the other sites (see conclusion 5). The fact that the total sediment discharge is overestimated for a site may only indicate that a dune bed form was at the normal section during most of the periods when sediment transport data were being obtained. Information on the type of bedform at the time samples were taken was not available.

7. The revised modified Einstein procedure needs further study before it is considered as a replacement for the modified Einstein procedure. The revised procedure has been tested for a wider range of flow and sediment conditions than those for which the modified Einstein procedure was originally tested. Basically, however, the revised procedure still has only been tested for sand-size sediments. Tests for conditions in which large amounts of coarse sediment—gravel and small boulders—are moved as bedload have not been made; these tests will be feasible only after good data (usable as measured values) for the bedload movement of coarse sediment are available.

8. Given more test data, a future study which determines more exactly the proper representative particle size to be used to represent k_s might be fruitful. The study should allow the multiplier x_0 to be related to the size distribution as well as the percentile fractile used to represent roughness height; the multiplier x_0 probably should gradually decrease from some positive value to 1 as the size distribu-

tion approaches uniformity and as the percentile fractile used to represent roughness height approaches 100.

9. The revised modified Einstein method, like the modified Einstein method, requires much experience and judgment in order to obtain reliable results.

10. New and innovative approaches for explaining the physical principles of the bed-form phenomena as related to sediment transport are needed in order that the method presented by Colby and Hembree—the modified Einstein method—can be moved towards the original intent of the Einstein procedure, an approach based on physical principles.

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TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir

[Methods: Meas.—measured; MEP—modified Einstein procedure; RMEP—revised modified Einstein procedure. Sections: flume-sediment samples taken at natural or manmade turbulence flumes; weir-sediment samples taken at manmade weir, normal-sediment samples taken at normal or natural sections. Symbols: B, B₁, C₁, C-2, C-6, D, E, 236, 240, 245, 250, 255, and 260 were assigned to sections by field engineers for identification purposes; G.S.—gaging station]

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge													
			Less than 0.062 mm		0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm		1.00 to 2.00 mm				2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm						
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm	mm	mm	mm	mm					
Niobrara River near Cody, Nebr.																													
1950																													
Mar. 3	Flume Normal	Meas.	243	374	842*	337	19	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,870	110		
		MEP	328	430	846	396	55	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,060	97	
		RMEP	301	435	930	437	39	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,170	116	
May 11	do	Meas.	320	698	1,470	969	100	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,340	90	
		MEP	320	719	1,260	637	92	11	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,020	104
		RMEP	320	719	1,550	790	70	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,460	104
Aug. 30	do	Meas.	475	229	493	493	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,760	101
		MEP	441	251	650	380	54	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,780	116
		RMEP	441	260	812	492	36	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,040	116
1951																													
Apr. 27	do	Meas.	269	448	829	582	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,240	97
		MEP	188	463	933	504	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,170	112
		RMEP	189	479	1,160	625	49	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,500	112
May 10	do	Meas.	93	213	559	426	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,330	88
		MEP	76	215	528	302	43	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,170	99
		RMEP	76	221	621	371	28	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,320	99
July 18	Flume Normal (C-2)	Meas.	72	126	405	261	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	900	96
		MEP	40	105	407	284	24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	861	96
		RMEP	40	112	534	336	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,030	114
Aug. 3	Flume Normal (C-6)	Meas.	344	213	525	492	33	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,640	77
		MEP	183	178	467	364	63	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,260	77
		RMEP	182	188	467	364	32	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,510	92
Sept. 6	Flume Normal (C-2)	Meas.	4,140	1,010	2,220	2,320	303	101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10,100	81
		MEP	4,010	1,025	1,820	1,130	143	22	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8,160	90
		RMEP	4,010	1,080	2,510	1,330	107	14	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,060	90
Sept. 6	Flume Normal (C-6)	Meas.	3,220	785	1,730	1,800	236	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,850	84
		MEP	2,880	758	1,490	1,260	180	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,610	84
		RMEP	2,880	764	1,660	1,590	128	17	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,040	90
1952																													
Apr. 1	Flume Normal (C-2)	Meas.	963	1,410	2,890	2,000	148	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,410	77
		MEP	1,020	1,030	2,270	1,210	138	20	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,700	77
		RMEP	1,020	1,080	2,930	1,410	102	12	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,570	90

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge								
			Less than 0.062 mm		0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm		1.00 to 2.00 mm				2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm	
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm	mm	mm	mm	mm
May 8	Flume Normal (C-2)	Meas.	284	304	832	568	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,030	81	
		RMEP	217	435	702	357	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,650	89
May 8	Flume Normal (C-6)	Meas.	262	280	767	524	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,870	79
		RMEP	189	330	483	273	30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,300	70
June 19	Flume Normal (G.S.)	Meas.	53	67	216	244	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,240	66
		RMEP	43	66	236	154	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	480	106
June 19	Flume Normal	Meas.	52	66	256	102	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	509	99
		RMEP	46	66	212	127	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	471	87
June 19	Flume Normal (C-6)	Meas.	51	64	207	109	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	405	86
		RMEP	42	48	100	135	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	73
Sept. 26	Flume Normal (G.S.)	Meas.	42	50	113	45	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	253	55
		RMEP	31	61	219	126	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	465	92
Sept. 26	Flume Normal (C-2)	Meas.	33	52	178	100	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	430	87
		RMEP	30	47	180	125	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	370	107
Sept. 26	Flume Normal (C-6)	Meas.	39	60	206	116	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	430	104
		RMEP	38	62	293	223	25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	642	148
1953			38	61	281	197	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	589	137
May 20	Flume Normal (C-2)	Meas.	182	362	589	347	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,510	101
		RMEP	183	313	546	415	54	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1,520	101
May 20	Flume Normal (C-6)	Meas.	172	346	562	331	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,910	126
		RMEP	145	186	538	399	76	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1,440	94
July 8	Flume Normal (G.S.)	Meas.	89	125	202	142	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,590	110
		RMEP	82	141	264	149	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	594	109
			82	144	299	147	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	677	114
Square root of mean variance for 21 data sets:																								
			97	109	206	362	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	674	101
			97	104	161	287	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	415	101

TABLE 1

Mean of measured sediment discharges for 21 data sets:		338	769	586	63	2,310
MEAS.	427	480	592	497	55	2,000
MEP	410	469	502	339	36	2,210
Ratio of square root of mean variance to mean of measured sediment discharge:						
MEAS.	0.18	0.32	0.27	0.62	0.68	0.29
MEP	18	31	0.21	0.49	0.87	0.18
Number of data sets used in computation of square roots, means, and ratios:	21	21	21	21	21	21

Middle Loup River at Dunning, Nebr.

Date	Flume (D) Normal (B)	MEAS.	MEP	471	1,090	676	176	88	29	0	0	0	0	0	0	0	0	0	2,940
Mar. 1	Flume (D) Normal (B)	412 427	480 427	480 480	1,090 1,110	617 708	187 151	45 27	12 4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2,860 2,900
Mar. 1	Flume (D) Normal (B)	410 411	469 575	469 575	1,080 1,590	674 675	176 282	88 67	29 15	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	3,540 3,630
Mar. 21	Flume (D) Normal (B)	211 267	542 653	581 653	1,630 1,500	758 766	212 180	38 60	4 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	3,010 3,390
Apr. 12	do	140 137	332 400	332 400	1,480 927	762 465	170 222	28 19	4 3	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	3,280 2,070
Apr. 25	do	155 178	398 417	398 417	925 1,200	484 493	77 150	9 31	0 6	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2,030 2,470
May 9	Flume (D) Normal (B)	127 150	366 550	366 550	1,210 550	560 99	111 28	16 28	2 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,410 1,520
June 6	do	50 57	334 124	321 124	534 186	350 345	141 25	20 10	2 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,560 826
June 20	Flume (D) Normal (B)	126 90	162 376	162 376	351 362	207 311	42 85	3 18	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	888 900
July 6	Flume (D) Normal (B)	62 73	124 156	124 156	216 287	361 197	44 73	3 6	1 12	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,020 1,030
Aug 26	Flume (D) Normal (B)	135 193	218 270	218 270	420 414	840 258	67 86	0 13	0 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,680 1,240
Aug. 26	Flume (D) Normal (B)	124 159	201 339	201 339	388 406	775 84	62 30	0 7	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,250 1,550
Oct. 4	do (D) do (B)	65 59	156 189	156 189	368 413	248 229	55 54	28 5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	920 950
Oct. 4	do (D) do (C ₂)	64 89	157 196	157 196	368 431	248 251	55 94	29 17	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	865 1,080
		89	196	196	437	269	47	6	0	0	0	0	0	0	0	0	0	0	1,040 1,113

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)										Total	Percentage of measured sediment discharge		
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm				
Oct 4	do (D)	Meas.	62	152	358	241	54	27	0	0	0	0	0	0	894	100
	do (E)	MEP	61	144	319	281	86	7	0	0	0	0	0	0	898	86
Nov. 8	Flume (D)	Meas.	126	316	648	363	111	16	0	0	0	0	0	0	1,580	146
	Normal (B)	MEP	84	303	858	867	170	29	3	0	0	0	0	0	2,320	140
Nov. 8	do (D)	Meas.	133	334	685	984	117	17	0	0	0	0	0	0	1,670	119
	do (C ₂)	MEP	106	347	782	553	167	35	4	0	0	0	0	0	1,990	112
Nov. 30	do (D)	Meas.	101	346	778	554	84	15	1	0	0	0	0	0	1,880	112
	do (B)	MEP	106	287	626	490	118	68	0	0	0	0	0	0	1,690	104
Nov. 30	do (D)	Meas.	106	288	656	558	137	20	0	0	0	0	0	0	1,770	98
	do (C ₂)	MEP	98	271	632	496	76	9	0	0	0	0	0	0	1,660	106
Dec. 14	do (D)	Meas.	102	291	633	496	120	68	0	0	0	0	0	0	1,710	103
	do (B)	MEP	88	252	951	466	116	39	0	0	0	0	0	0	1,940	93
Dec. 14	do (D)	Meas.	88	217	793	534	146	27	3	0	0	0	0	0	1,800	84
	do (C ₂)	MEP	138	299	769	478	62	12	0	0	0	0	0	0	1,620	103
1957	do (D)	Meas.	168	313	1,130	552	138	46	0	0	0	0	0	0	2,300	103
	do (E)	MEP	168	311	1,090	605	167	32	4	0	0	0	0	0	2,380	94
Jan. 24	do (D)	Meas.	103	310	1,260	748	103	52	0	0	0	0	0	0	2,580	113
	do (C ₂)	MEP	60	356	1,560	637	230	70	15	0	0	0	0	0	2,930	111
Feb. 20	do (D)	Meas.	128	256	525	294	64	13	0	0	0	0	0	0	1,280	162
	do (B)	MEP	165	342	670	563	338	19	1	0	0	0	0	0	2,100	146
Feb. 20	do (D)	Meas.	127	254	521	292	63	13	0	0	0	0	0	0	1,270	116
	do (C ₂)	MEP	126	283	444	432	149	34	4	0	0	0	0	0	1,470	110
Mar. 30	do (D)	Meas.	122	230	540	450	82	15	1	0	0	0	0	0	1,400	110
	do (E)	MEP	117	245	406	324	94	40	0	0	0	0	0	0	1,350	82
		MEP	117	247	429	174	37	3	0	0	0	0	0	0	1,010	75

Middle Loup River at Dunning, Nebr.—Con.

TABLE I

June 4	Flume (D)	170	301	485	275	79	0	0	0	0	0	1,310
	Normal (B ₁)	150	242	410	262	92	17	2	0	0	0	1,170
	MEP	156	355	685	470	202	61	13	0	0	0	1,960
	RMEP	172	357	720	590	154	30	0	0	0	0	2,090
June 4	do (D)	142	251	403	229	65	0	0	0	0	0	1,090
	do (C ₂)	128	267	442	232	98	1	0	0	0	0	1,180
	MEP	128	270	476	308	57	5	0	0	0	0	1,240
June 26	do (D)	100	138	276	192	38	23	0	0	0	0	767
	MEP	136	161	402	181	70	10	0	0	0	0	960
	RMEP	136	162	421	219	34	2	0	0	0	0	974
June 26	do (D)	98	134	260	193	37	22	0	0	0	0	744
	do (E)	115	138	300	240	97	10	0	0	0	0	901
	MEP	115	148	405	247	35	2	0	0	0	0	952
	RMEP	69	207	173	177	40	12	0	0	0	0	576
July 26	do (E)	62	71	179	149	55	3	0	0	0	0	519
	MEP	62	76	240	134	16	0	0	0	0	0	590
	RMEP	72	130	246	174	58	29	15	0	0	0	724
Aug. 16	do (D)	72	133	245	126	53	9	0	0	0	0	638
	do (B ₁)	72	134	263	162	29	2	0	0	0	0	663
	MEP	69	125	235	166	58	28	14	0	0	0	632
Aug. 16	do (D)	75	135	361	185	68	8	0	0	0	0	832
	MEP	74	136	374	212	30	2	0	0	0	0	828
	do (C ₂)	74	136	374	212	30	2	0	0	0	0	828
Aug. 16	do (D)	65	118	222	157	52	26	13	0	0	0	653
	do (E)	61	84	230	177	70	6	0	0	0	0	629
	MEP	62	90	302	170	26	1	0	0	0	0	650
	RMEP	72	94	332	224	50	29	0	0	0	0	721
Aug. 30	do (D)	83	121	328	233	84	7	0	0	0	0	866
	MEP	83	123	352	288	35	2	0	0	0	0	884
	RMEP	76	236	882	475	190	114	57	0	0	0	1,900
Oct. 31	do (D)	80	298	822	644	215	34	0	0	0	0	2,150
	do (E)	80	298	870	626	126	4	0	0	0	0	2,000
	MEP	87	327	936	545	114	87	22	0	0	0	2,180
Dec. 5	Flume (D)	109	367	1,200	596	219	45	2	0	0	0	2,330
	Normal (E)	109	365	1,190	607	148	23	0	0	0	0	2,450
1952												
Mar. 10	do (D)	156	294	571	450	121	86	52	0	0	0	1,730
	do (C ₂)	172	355	685	470	202	61	13	0	0	0	1,960
	MEP	172	357	720	590	154	30	0	0	0	0	2,090
Mar. 26	do (D)	327	731	731	554	101	76	3	0	0	0	2,520
	do (C ₂)	367	721	655	310	126	29	4	0	0	0	2,210
	MEP	367	720	661	352	75	12	0	0	0	0	2,190
May 6	do (D)	106	224	437	295	83	35	0	0	0	0	1,180
	do (B ₁)	98	186	423	258	99	19	2	0	0	0	1,080
	MEP	98	188	462	343	65	17	0	0	0	0	1,160
May 6	do (D)	94	200	388	262	74	32	1	0	0	0	1,050
	do (C ₂)	85	167	338	232	90	15	4	0	0	0	929
	MEP	85	168	354	277	47	4	0	0	0	0	936
May 6	do (D)	81	172	334	226	63	27	0	0	0	0	903
	do (E)	96	220	418	223	80	7	0	0	0	0	1,040
	MEP	96	220	426	244	37	2	0	0	0	0	1,020
May 22	do (D)	175	313	626	452	104	35	35	0	0	0	1,740
	do (E)	177	268	502	232	95	11	0	0	0	0	1,290
	RMEP	177	269	524	283	47	3	0	0	0	0	1,300

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)										Total	Percentage of measured sediment discharge										
			Less than 0.062 mm		0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm				1.00 to 2.00 mm		2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm	
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
June 18.	do (D)	Meas.	75	110	209	127	35	23	0	0	0	0	0	0	0	0	0	0	0	0	0	579	118	
	do (E)	MEP	74	114	235	181	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	685	118
July 18	do (D)	RMEP	74	121	305	172	30	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	707	122
	do (E)	Meas.	76	107	259	198	69	38	15	0	0	0	0	0	0	0	0	0	0	0	0	0	762	84
Aug. 13.	do (D)	MEP	77	97	213	181	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	643	87
	do (E)	RMEP	77	102	290	174	22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	665	87
Sept. 24.	do (D)	Meas.	93	124	247	208	69	31	772	0	0	0	0	0	0	0	0	0	0	0	0	0	1,010	131
	do (E)	MEP	92	147	338	288	125	15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1,120	145
Sept. 24.	Flume (D)	Meas.	58	135	298	317	86	48	19	0	0	0	0	0	0	0	0	0	0	0	0	0	961	105
	Normal (B ₁)	RMEP	63	168	423	249	93	18	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1,020	106
Sept. 24.	do (D)	MEP	59	137	304	324	88	49	20	0	0	0	0	0	0	0	0	0	0	0	0	0	981	80
	do (C ₁)	MEP	65	136	317	181	76	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	786	80
1955 Nov. 24.	do (D)	RMEP	65	137	326	207	38	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	775	79
	do (B ₁)	Meas.	222	388	1,220	721	166	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,770	89
Nov. 24.	do (D)	MEP	173	434	1,095	623	142	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2,480	89
	do (C ₁)	RMEP	173	432	1,090	651	94	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,440	89
1956 Jan. 7	do (D)	Meas.	152	329	1,140	683	152	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,530	94
	do (C ₁)	RMEP	177	378	1,260	486	76	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,300	94
Jan. 8	do (D)	Meas.	119	382	1,350	506	116	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,480	98
	do (C ₁)	RMEP	119	376	1,332	554	78	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,480	98
Mar. 7	do (D)	Meas.	182	424	1,390	545	242	242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,030	88
	do (C ₁)	MEP	288	479	1,220	585	96	14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2,660	88
Mar. 8	do (D)	RMEP	288	484	1,290	578	73	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,700	89
	do (C ₁)	Meas.	242	364	1,610	697	61	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,030	89
Mar. 7	do (D)	MEP	119	378	832	554	242	35	8	0	0	0	0	0	0	0	0	0	0	0	0	0	2,170	71
	do (C ₁)	RMEP	119	376	832	560	154	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,060	68
Mar. 8	do (D)	Meas.	443	818	1,230	648	205	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,410	116
	do (C ₁)	MEP	454	836	1,150	503	854	171	15	0	0	0	0	0	0	0	0	0	0	0	0	0	3,990	116
Mar. 8	do (D)	RMEP	454	836	1,150	536	570	83	4	0	0	0	0	0	0	0	0	0	0	0	0	0	3,640	107
	do (B ₁)	Meas.	356	819	1,570	641	178	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,560	107
Mar. 8	do (D)	MEP	298	940	1,400	583	111	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,360	94
	do (B ₁)	RMEP	298	948	1,500	610	86	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,460	97

Middle Loup River at Dunning, Nebr.—Con.

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm	32.00 mm			
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			
Sept. 8 1956	Flume	Meas.	1,250	653	199	114	28	0	0	0	0	0	0	2,840	146	
	Normal	MEP	1,370	750	581	330	208	169	61	6	0	0	0	4,160	141	
		RMEP	1,370	1,000	489	214	119	76	17	0	0	0	0	4,010		
Aug. 22	Flume	Meas.	884	736	546	153	219	202	107	8	0	0	2,680	121		
	Normal	MEP	884	806	795	166	178	176	90	4	0	0	3,500	131		
		RMEP	800	241	52	0	883	0	0	0	0	1,740	0			
Sept. 14	Flume	Meas.	824	364	324	191	48	13	0	0	0	0	2,030	117		
	Normal	MEP	824	271	364	191	48	13	0	0	0	0	2,030	117		
		RMEP	824	273	384	102	12	2	0	0	0	0	2,010	116		
Oct. 8	Flume	Meas.	528	342	242	163	24	3	0	0	0	0	1,310	114		
	Normal	MEP	528	188	342	189	10	0	0	0	0	0	1,490	114		
		RMEP	528	360	302	99	10	0	0	0	0	0	1,490	114		
Oct. 22	Flume	Meas.	39	17	27	16	2	0	0	0	0	0	106	116		
	Normal	MEP	40	5	22	2	0	0	0	0	0	0	79	87		
		RMEP	40	5	22	2	0	0	0	0	0	0	91			
1957 Mar. 29	Flume	Meas.	175	10	4	0	0	0	0	0	0	0	201	213		
	Normal	MEP	185	25	90	27	1	0	0	0	0	0	429	213		
		RMEP	184	53	29	8	0	0	0	0	0	0	296	147		
Apr. 24	Flume	Meas.	129	22	22	10	0	0	0	0	0	0	216	126		
	Normal	MEP	129	21	22	6	0	0	0	0	0	0	204	119		
		RMEP	5,320	1,270	316	237	79	0	0	0	0	0	7,910	107		
May 4	Flume	Meas.	4,720	840	1,430	397	53	6	0	0	0	0	8,470	107		
	Normal	MEP	4,720	1,200	1,030	397	53	15	0	0	0	0	9,900	107		
		RMEP	4,720	1,056	1,009	388	0	0	0	0	0	0	9,000	107		
June 26	Flume	Meas.	836	341	455	192	21	6	0	0	0	0	2,970	119		
	Normal	MEP	836	455	409	192	21	6	0	0	0	0	3,320	122		
		RMEP	838	366	392	99	8	0	0	0	0	0	4,330	117		
July 18	Flume	Meas.	2,290	736	619	346	43	40	7	0	0	0	5,060	123		
	Normal	MEP	1,830	674	991	316	47	15	0	0	0	0	5,310	123		
		RMEP	1,830	665	1,100	320	47	15	0	0	0	0	5,060	98		
Aug. 7	Flume	Meas.	2,930	759	405	152	34	4	0	0	0	0	4,970	97		
	Normal	MEP	1,800	390	1,320	578	122	34	4	0	0	0	4,900	97		
		RMEP	1,800	395	1,530	346	57	10	0	0	0	0	2,990	113		
Sept. 5	Flume	Meas.	1,170	478	867	340	67	3	0	0	0	0	3,370	116		
	Normal	MEP	922	417	872	184	19	7	0	0	0	0	3,460	116		
		RMEP	922	420	1,010	96	0	0	0	0	0	0	3,460	116		

Five mile Creek near Shoshoni, Wyo.—Con.

Sept. 20	Flume Normal	Meas. MEP RMEP	284 290 291	510 505 519	359 536 596	38 191 119	19 22 9	0 0 0	0 0 0	0 0 0	1,890 2,220 2,211
Oct. 23	Flume Normal	Meas. MEP RMEP	11 62	44 44	41 40	43 14	9 1	0 0	0 0	0 0	137 210 172 126
Nov. 20.	Flume Normal	Meas. MEP RMEP	44 99	39 34	46 28	26 4	4 0	0 0	0 0	0 0	167 259 208
1958 Feb. 24	Flume Normal	Meas. MEP RMEP	36 37	72 76	74 91	50 28	7 4	1 0	0 0	0 0	391 444 441
Apr. 21	Flume Normal	Meas. MEP RMEP	22 70	26 26	31 28	17 5	1 0	0 0	0 0	0 0	123 157 167 122
May 12	Flume Normal	Meas. MEP RMEP	511 503	331 318	190 318	95 75	10 8	1 0	0 0	0 0	933 1,470 1,550 1,889
June 3	Flume Normal	Meas. MEP RMEP	186 188	168 177	134 156	80 32	28 5	0 0	0 0	0 0	966 925 104
June 14	Flume Normal	Meas. MEP RMEP	1,180 1,220	628 733	320 246	188 88	67 24	45 11	8 0	0 0	7,400 7,280 3,120
July 3	Flume Normal	Meas. MEP RMEP	600 580	962 872	298 605	189 162	35 20	11 3	0 0	0 0	3,600 3,740 2,830
July 17	Flume Normal	Meas. MEP RMEP	636 663	876 1,120	386 424	149 100	30 16	1 3	0 0	0 0	3,370 3,610 1,350
Sept. 9	Flume Normal	Meas. MEP RMEP	206 207	324 339	371 427	208 95	29 9	3 0	0 0	0 0	1,670 1,610 1,200
Sept. 19	Flume Normal	Meas. MEP RMEP	534 534	295 304	316 358	160 86	26 10	3 0	0 0	0 0	1,570 1,330 1,740
Oct. 2	Flume Normal	Meas. MEP RMEP	222 223	295 304	316 358	160 86	26 10	3 0	0 0	0 0	1,570 1,330 1,740
Oct. 2	Flume Normal	Meas. MEP RMEP	219 220	268 274	240 274	91 57	10 3	1 0	0 0	0 0	1,790 1,790 172
Oct. 15	Flume Normal	Meas. MEP RMEP	21 93	50 47	52 43	25 7	2 0	0 0	0 0	0 0	243 211 123
Nov. 7	Flume Normal	Meas. MEP RMEP	21 93	50 47	52 43	25 7	2 0	0 0	0 0	0 0	243 211 123
Nov. 7	Flume Normal	Meas. MEP RMEP	48 209	87 89	52 33	44 10	9 2	0 0	0 0	0 0	448 390 119
Dec. 8	Flume Normal	Meas. MEP RMEP	48 94	87 137	52 54	44 17	9 1	0 0	0 0	0 0	448 385 492
Mar. 10	Flume Normal	Meas. MEP RMEP	189 316 316	189 185 138	189 74 53	34 21 14	3 2 1	0 0 0	0 0 0	0 0 0	437 649 710 650

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm				
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm				
Apr. 28	Flume Normal	Meas. MEP	710	214	184	88	77	12	0	0	0	0	0	0	1,150	111
1959		RMEP	710	214	187	96	31	3	0	0	0	0	0	0	1,280	111
May 13	Flume Normal	Meas. MEP	403	96	115	109	95	21	2	0	0	0	0	0	639	132
		RMEP	403	96	121	119	33	4	0	0	0	0	0	0	776	121
May 28	Flume Normal	Meas. MEP	791	312	270	189	120	19	2	0	0	0	0	0	1,420	120
		RMEP	793	313	277	208	47	5	0	0	0	0	0	0	1,640	115
June 10	Flume Normal	Meas. MEP	1,150	73	145	98	97	33	5	0	0	0	0	0	1,480	108
		RMEP	1,150	75	165	108	45	6	0	0	0	0	0	0	1,590	105
June 26	Flume Normal	Meas. MEP	1,870	784	663	397	242	60	14	1	0	0	0	0	3,050	117
		RMEP	1,870	788	692	461	139	26	4	0	0	0	0	0	3,760	110
July 10	Flume Normal	Meas. MEP	1,130	458	548	313	283	93	26	2	0	0	0	0	2,850	132
		RMEP	1,130	464	582	394	166	29	5	0	0	0	0	0	2,770	128
Aug. 3	Flume Normal	Meas. MEP	1,770	545	508	298	233	71	13	1	0	0	0	0	3,440	115
		RMEP	1,770	552	534	357	117	18	2	0	0	0	0	0	3,350	112
Aug. 20	Flume Normal	Meas. MEP	754	241	542	337	226	52	7	1	0	0	0	0	1,560	138
		RMEP	754	246	609	372	145	22	2	0	0	0	0	0	2,150	138
Sept. 14	Flume Normal	Meas. MEP	370	98	194	170	119	47	6	0	0	0	0	0	1,000	125
		RMEP	370	100	208	215	54	4	0	0	0	0	0	0	953	119
Oct. 2	Flume Normal	Meas. MEP	203	64	190	173	134	46	6	0	0	0	0	0	612	133
		RMEP	203	64	196	195	59	8	0	0	0	0	0	0	725	118
Oct. 19	Flume Normal	Meas. EMP	43	3	15	35	28	6	0	0	0	0	0	0	95	137
		RMEP	43	3	15	37	7	0	0	0	0	0	0	0	105	111

Five mile Creek near Shoshoni, Wyo.—Con.

TABLE 1

Dec. 3	Flume Normal	Meas. MEP RMEP	146 146	33 32	52 50	40 33	21 4	8 0	0 0	0 0	0 0	273 300 265
1960 Mar. 24	Flume Normal	Meas. MEP RMEP	878 878	165 165	45 47	36 20	40 10	11 1	1 0	0 0	0 0	1,200 1,180 1,120 93
Apr. 18	Flume Normal	Meas. MEP RMEP	301 300	117 105	155 109	101 50	79 24	18 17	2 0	0 0	0 0	643 602 602 94
May 6	Flume Normal	Meas. MEP RMEP	469 469	136 141	135 154	60 98	64 44	46 7	6 0	0 0	0 0	913 914 914 112
May 16	Flume Normal	Meas. MEP RMEP	535 534	137 131	165 141	127 88	82 117	31 12	5 0	0 0	0 0	1,080 1,020 1,870 104
June 9	Flume Normal	Meas. MEP RMEP	1,260 1,260	286 299	190 223	192 309	303 82	145 8	20 1	0 0	0 0	2,400 2,180 2,180 117
June 24	Flume Normal	Meas. MEP RMEP	504 504	242 240	174 175	105 104	60 17	13 2	1 0	0 0	0 0	1,100 1,100 1,040 107
July 7	Flume Normal	Meas. MEP RMEP	638 638	205 202	177 184	130 133	280 220	55 20	15 2	1 0	0 0	1,500 1,400 1,400 101
Aug. 3	Flume Normal	Meas. MEP RMEP	427 427	156 157	180 186	124 135	75 27	19 3	4 0	0 0	0 0	985 985 935 95
Sept. 21	Flume Normal	Meas. MEP RMEP	337 337	123 124	202 209	110 127	69 23	19 1	1 0	0 0	0 0	756 861 821 109
Sept. 30	Flume Normal	Meas. MEP RMEP	119 119	35 37	68 82	137 169	52 23	41 6	4 0	0 0	0 0	446 456 436 98
Nov. 1	Flume Normal	Meas. MEP RMEP	56 56	3 3	15 15	8 10	8 2	6 0	0 0	0 0	0 0	87 96 110 100
1961 Apr. 25	Flume Normal	Meas. MEP RMEP	184 184	57 57	54 56	27 18	21 8	3 1	0 0	0 0	0 0	287 346 325 113
May 11	Flume Normal	Meas. MEP RMEP	209 209	46 45	35 35	35 34	22 4	4 0	0 0	0 0	0 0	345 351 327 95
May 19	Flume Normal	Meas. MEP RMEP	274 274	88 87	98 97	102 93	68 18	13 2	1 0	0 0	0 0	474 645 6571 120
June 8	Flume Normal	Meas. MEP RMEP	820 820	317 327	246 291	102 82	63 26	31 11	14 3	2 0	0 0	1,400 1,590 1,560 113
June 22	Flume Normal	Meas. MEP RMEP	393 393	231 231	485 490	408 406	165 62	50 13	14 2	1 0	0 0	1,180 1,740 1,600 136

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir.—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge								
			Less than 0.062 mm		0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm		1.00 to 2.00 mm				2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm	
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm	mm	mm	mm	mm
July 10	Flume Normal	Meas.	370	129	320	547	547	547	107	107	20	1	0	0	0	0	0	0	0	0	0	1,760	116	
		RMEP	371	136	387	858	103	16	4	0	0	0	0	0	0	0	0	0	0	0	0	2,040	106	
July 27	Flume Normal	Meas.	263	101	305	408	414	91	23	2	0	0	0	0	0	0	0	0	0	0	0	1,180	136	
		RMEP	263	105	346	569	108	13	2	0	0	0	0	0	0	0	0	0	0	0	0	1,410	119	
Sept. 14	Flume Normal	Meas.	228	90	182	258	148	100	32	4	0	0	0	0	0	0	0	0	0	0	0	1,040	145	
		RMEP	228	91	200	353	104	25	6	0	0	0	0	0	0	0	0	0	0	0	0	1,010	141	
Sept. 26	Flume Normal	Meas.	279	109	185	250	125	48	14	1	0	0	0	0	0	0	0	0	0	0	0	731	138	
		RMEP	279	110	196	302	65	10	2	0	0	0	0	0	0	0	0	0	0	0	0	1,010	138	
1962 May 10	Flume Normal	Meas.	242	100	96	60	58	25	3	0	0	0	0	0	0	0	0	0	0	0	0	503	116	
		RMEP	241	97	86	50	85	7	0	0	0	0	0	0	0	0	0	0	0	0	0	566	113	
June 29	Flume Normal	Meas.	1,110	527	594	304	162	82	31	2	0	0	0	0	0	0	0	0	0	0	0	2,310	122	
		RMEP	1,110	529	605	318	69	22	5	0	0	0	0	0	0	0	0	0	0	0	0	2,660	115	
July 19	Flume Normal	Meas.	2,370	1,080	1,040	469	314	185	164	68	5	0	0	0	0	0	0	0	0	0	0	4,930	116	
		RMEP	2,370	1,130	1,320	338	180	100	68	17	0	0	0	0	0	0	0	0	0	0	0	5,700	112	
July 30	Flume Normal	Meas.	1,190	483	751	1,200	1,130	466	142	44	2	0	0	0	0	0	0	0	0	0	0	5,380	118	
		RMEP	1,180	482	771	1,260	1,140	217	47	7	0	0	0	0	0	0	0	0	0	0	0	5,710	112	
Aug. 13	Flume Normal	Meas.	868	485	674	363	236	107	56	12	0	0	0	0	0	0	0	0	0	0	0	2,800	109	
		RMEP	868	500	793	310	128	40	14	1	0	0	0	0	0	0	0	0	0	0	0	2,650	103	
Sept. 11	Flume Normal	Meas.	499	183	416	392	216	110	29	2	0	0	0	0	0	0	0	0	0	0	0	1,850	105	
		RMEP	499	186	439	483	120	24	4	0	0	0	0	0	0	0	0	0	0	0	0	1,750	99	
Oct. 12	Flume Normal	Meas.	18	3	14	87	83	10	0	0	0	0	0	0	0	0	0	0	0	0	0	215	145	
		RMEP	18	3	14	81	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	184	124	
1963 May 7	Flume Normal	Meas.	299	104	130	325	363	68	7	0	0	0	0	0	0	0	0	0	0	0	0	1,190	109	
		RMEP	299	107	147	414	67	7	0	0	0	0	0	0	0	0	0	0	0	0	0	1,040	87	

Five mile Creek near Shoshoni, Wyo.—Con.

TABLE I

May 23	Flume	Meas.	971	409	690	444	176	50	4	0	0	2,240
	Normal	MEP	971	438	838	259	50	10	0	0	0	3,010
		RMEP	274									2,840
June 12	Flume	Meas.	550	661	331	257	124	48	5	0	0	3,040
	Normal	MEP	1,390	706	426	170	40	10	0	0	0	3,370
		RMEP										3,300
July 11	Flume	Meas.	785	956	532	215	40	17	3	0	0	3,040
	Normal	MEP	1,280	1,220	568	133	20	6	0	0	0	3,830
		RMEP										4,060
July 25	Flume	Meas.	838	924	1,700	666	111	51	9	0	0	4,610
	Normal	MEP	838	992	2,100	498	57	18	1	0	0	4,820
		RMEP										3,500
Aug. 9	Flume	Meas.	1,110	933	645	366	112	50	10	0	0	3,510
	Normal	MEP	1,110	1,020	831	290	64	19	1	0	0	3,830
		RMEP										2,310
Aug. 22	Flume	Meas.	639	587	389	259	107	36	4	0	0	2,300
	Normal	MEP	639	629	519	176	34	8	0	0	0	2,810
		RMEP										3,460
Sept. 11	Flume	Meas.	1,120	578	450	398	342	148	29	1	0	3,370
	Normal	MEP	1,120	639	667	365	129	43	4	0	0	3,370
		RMEP										131
Oct. 28	Flume	Meas.	91	26	22	22	15	1	0	0	0	131
	Normal	MEP	91	17	18	8	1	0	0	0	0	142
		RMEP										712
1964	Flume	Meas.	320	152	93	50	20	2	0	0	0	754
May 15	Normal	MEP	320	165	82	16	3	0	0	0	0	708
		RMEP										2,190
June 5	Flume	Meas.	882	467	323	192	169	84	20	0	0	2,500
	Normal	MEP	882	567	332	138	64	24	2	0	0	2,390
		RMEP										1,730
June 19	Flume	Meas.	686	380	288	202	112	32	6	0	0	1,980
	Normal	MEP	686	405	416	155	37	7	0	0	0	1,980
		RMEP										1,610
July 23	Flume	Meas.	807	282	231	240	148	41	4	0	0	1,980
	Normal	MEP	808	344	247	166	43	8	0	0	0	1,860
		RMEP										1,640
Aug. 6	Flume	Meas.	696	348	350	297	158	49	5	0	0	2,120
	Normal	MEP	695	320	309	645	85	14	0	0	0	2,280
		RMEP										668
1965	Flume	Meas.	434	171	236	118	8	0	0	0	0	1,020
June 1	Normal	MEP	434	174	241	37	1	0	0	0	0	941
		RMEP										391
		Meas.	416	123	398	308	94					383
		MEP	416	228	543	112	43					1,730
		RMEP										2,010
		Meas.	1,670	568	279	96	43					1,980
		MEP	1,480	637	545	336	108					
		RMEP	1,480	677	642	188	54					

Square root of mean variance for 12 data sets:

Mean of measured and computed sediment discharges for 12 data sets:

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)										Total	Percentage of measured sediment discharge	
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm			
Five mile Creek near Shoshoni, Wyo.—Con.															
Ratio of square root of mean variance to mean of measured sediment discharge:															
		Meas.	0.28	0.26	0.22	1.43	3.21	2.19						0.23	
		RMEP	0.28	0.27	0.40	1.95	1.17	1.00						0.22	
			12	12	12	12	10	6						87	
Number of data sets used in computations of square roots, means, and ratios:															
Five mile Creek near Riverton, Wyo.															
1954	Aug. 26	Flume Normal	896	357	364	352	120	23	5	0	0	0	0	1,940	104
		Meas.	896	379	390	472	10	10	1	0	0	0	0	2,920	109
		RMEP	1,850	254	254	177	25	25	2	0	0	0	0	2,510	116
	Sept. 15	Flume Normal	2,120	341	340	203	22	12	0	0	0	0	0	3,940	116
		Meas.	2,120	365	340	276	16	16	0	0	0	0	0	3,130	123
		RMEP	573	294	222	117	23	0	0	0	0	0	0	1,170	
	Sept. 28	Flume Normal	688	315	213	99	69	12	2	0	0	0	0	1,400	120
		Meas.	688	326	258	105	44	16	0	0	0	0	0	1,430	122
		RMEP	85	25	88	88	0	22	0	0	0	0	0	314	
	Oct. 28	Flume Normal	101	38	169	66	9	1	0	0	0	0	0	384	122
		Meas.	101	38	165	60	6	0	0	0	0	0	0	369	118
		RMEP	67	14	24	15	6	0	0	0	0	0	0	126	
	Nov. 23	Flume Normal	62	14	37	25	12	1	0	0	0	0	0	151	120
		Meas.	62	13	33	16	6	0	0	0	0	0	0	129	102
		RMEP													
1955	Apr. 21	Flume Normal	186	36	22	19	11	3	0	0	0	0	0	277	
		Meas.	211	44	18	19	16	1	0	0	0	0	0	309	112
		RMEP	211	48	23	16	6	0	0	0	0	0	0	305	110
	May 24	Flume Normal	1,930	248	248	83	0	0	0	0	0	0	0	2,760	115
		Meas.	2,090	583	342	129	25	8	3	0	0	0	0	3,180	118
		RMEP	1,590	605	413	140	18	4	1	0	0	0	0	3,270	118
	July 8	Flume Normal	1,590	404	404	215	81	4	0	0	0	0	0	2,690	109
		Meas.	1,760	340	448	209	79	23	2	0	0	0	0	2,920	114
		RMEP	1,760	370	608	222	56	12	0	0	0	0	0	3,080	114
	Aug. 4	Flume Normal	878	370	429	254	20	0	0	0	0	0	0	1,950	102
		Meas.	892	358	157	157	59	9	7	1	0	0	0	1,980	102
		RMEP	892	527	456	187	44	5	2	0	0	0	0	2,110	108

TABLE 1

Aug. 29.	Flume Normal	Meas. MEP	959 934	351 530	538 701	351 166	117 29	23 9	0 0	0 0	0 0	0 0	0 0	2,340 2,370
Oct. 12	Flume Normal	Meas. MEP	79 935	556 888	58 888	170 21	21 5	5 12	0 0	0 0	0 0	0 0	0 0	2,580 2,333
Nov. 4	Flume Normal	Meas. MEP	79 935	26 80	58 79	49 34	17 3	3 1	0 0	0 0	0 0	0 0	0 0	2,19 490
1956 Apr. 27	Flume Normal	Meas. MEP	274 251	39 39	88 71	64 40	20 24	5 2	0 0	0 0	0 0	0 0	0 0	427 407
June 8	Flume Normal	Meas. MEP	462 513	132 177	81 100	44 64	15 47	5 5	0 0	0 0	0 0	0 0	0 0	734 906
July 17	Flume Normal	Meas. MEP	946 2,330	140 627	220 717	78 101	47 32	31 2	0 0	0 0	0 0	0 0	0 0	1,570 1,560
Aug. 23.	Flume Normal	Meas. MEP	946 2,260	148 776	390 1,010	101 242	20 24	2 2	0 0	0 0	0 0	0 0	0 0	1,610 4,480
Sept. 13	Flume Normal	Meas. MEP	2,250 607	731 264	820 320	555 139	224 74	16 15	1 4	0 0	0 0	0 0	0 0	4,530 1,420
Oct. 22	Flume Normal	Meas. MEP	820 824	172 205	283 575	1,090 364	320 75	8 2	2 0	0 0	0 0	0 0	0 0	1,860 2,700
1957 Apr. 8	Flume Normal	Meas. MEP	39 197	19 35	58 23	28 12	17 6	1 0	0 0	0 0	0 0	0 0	0 0	130 162
May 15	Flume Normal	Meas. MEP	7,400 7,400	1,420 1,450	739 829	263 273	126 88	18 9	4 1	0 0	0 0	0 0	0 0	9,970 10,050
June 26.	Flume Normal	Meas. MEP	423 1,700	197 862	223 678	113 299	56 124	6 34	0 8	0 0	0 0	0 0	0 0	920 1,020
July 18.	Flume Normal	Meas. MEP	1,700 2,300	824 531	533 464	255 270	184 117	34 16	3 2	0 0	0 0	0 0	0 0	3,670 3,380
Aug. 7	Flume Normal	Meas. MEP	2,290 3,000	502 808	354 850	250 346	212 209	38 20	7 5	0 0	0 0	0 0	0 0	3,700 4,680
Aug. 20	Flume Normal	Meas. MEP	3,010 657	839 252	1,040 297	368 154	137 186	10 14	2 3	0 0	0 0	0 0	0 0	5,240 1,450
Sept. 4	Flume Normal	Meas. MEP	658 658	267 401	401 297	199 154	118 118	17 17	1 1	0 0	0 0	0 0	0 0	1,560 1,650

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Less than 0.062 mm	Sediment discharge (tons per day)										Total	Percentage of measured sediment discharge								
				0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm		1.00 to 2.00 mm				2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm	
				Meas.	RMEP	Meas.	RMEP	Meas.	RMEP	Meas.	RMEP	Meas.	RMEP			Meas.	RMEP	Meas.	RMEP	Meas.	RMEP	Meas.	RMEP
Sept. 20.	Flume Normal	Meas. MEP	464 464	245 255	291 354	185 198	79 46	6 2	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,120 1,270	113 118				
Oct. 11.	Flume Normal	Meas. MEP	182 182	82 86	155 191	111 119	66 39	5 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	601 620	117 121				
Oct. 23.	Flume Normal	Meas. MEP	39 39	20 20	52 49	48 41	20 8	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	160 179	112 98				
Nov. 20.	Flume Normal	Meas. MEP RMEP	52 51	21 19	40 30	64 31	33 19	1 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	211 151	122 87				
1958 Jan. 30.	Flume Normal	Meas. MEP RMEP	27 27	5 5	7 6	2 1	2 0	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	65 44	68 62				
Feb. 25.	Flume Normal	Meas. MEP	380 380	82 84	30 33	38 22	33 8	2 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	582 565	97 90				
Apr. 21.	Flume Normal	Meas. MEP	91 91	34 38	20 29	23 20	26 9	3 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	169 197	117 111				
May 12.	Flume Normal	Meas. MEP	299 299	83 86	42 50	30 27	23 12	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	478 475	101 101				
June 4.	Flume Normal	Meas. MEP	320 320	124 130	81 95	55 38	57 19	4 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	530 641	121 114				
June 14.	Flume Normal	Meas. MEP	3,760 3,760	951 974	453 524	128 137	66 39	11 5	2 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	4,830 5,370	111 113				
July 3.	Flume Normal	Meas. MEP	1,040 1,050	344 364	268 354	159 171	176 95	20 8	2 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2,010 2,040	110 112				
July 17.	Flume Normal	Meas. MEP	783 784	344 362	364 462	192 205	110 54	11 4	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1,570 1,870	115 119				

Fivemile Creek near Riverton, Wyo.—Con.

TABLE 1

July 28	Flume Normal	Meas. MEP	925	447	497	167	139	29	8	0	0	0	1,830
		RMEP	926	469	628	186	85	13	2	0	0	0	2,210
Aug. 14	Flume Normal	Meas. MEP	549	270	300	199	123	20	3	0	0	0	2,310
		RMEP	550	283	390	234	74	74	9	1	0	0	1,330
Sept. 5	Flume Normal	Meas. MEP	247	102	178	101	85	8	1	0	0	0	1,460
		RMEP	247	106	209	97	42	3	0	0	0	0	1,540
Sept. 19.	Flume Normal	Meas. MEP	437	130	178	151	117	16	2	0	0	0	634
		RMEP	437	134	208	155	58	6	0	0	0	0	720
Oct. 2.	Flume Normal	Meas. MEP	783	230	306	258	204	22	5	0	0	0	875
		RMEP	794	241	385	189	104	9	1	0	0	0	1,030
1959 June 26.	Flume Normal	Meas. MEP	1,320	704	488	272	125	28	6	0	0	0	997
		RMEP	1,320	739	624	314	79	14	2	0	0	0	1,14
1960 Apr. 18	Flume Normal	Meas. MEP	133	27	33	18	18	3	0	0	0	0	1,530
		RMEP	133	27	34	15	4	0	0	0	0	0	1,820
May 16	Flume Normal	Meas. MEP	336	80	41	22	22	4	0	0	0	0	2,900
		RMEP	335	79	41	22	5	0	0	0	0	0	3,090
June 24.	Flume Normal	Meas. MEP	395	190	203	81	39	6	1	0	0	0	227
		RMEP	395	194	220	62	23	2	0	0	0	0	232
July 21	Flume Normal	Meas. MEP	377	151	183	79	55	12	4	0	0	0	102
		RMEP	376	156	208	52	18	3	0	0	0	0	214
Sept. 21	Flume Normal	Meas. MEP	233	77	92	68	31	4	0	0	0	0	516
		RMEP	233	79	103	40	8	1	0	0	0	0	505
1967 Apr. 28	Flume Normal	Meas. MEP	137	24	11	8	5	0	0	0	0	0	483
		RMEP	137	24	11	4	1	0	0	0	0	0	846
May 19	Flume Normal	Meas. MEP	219	64	40	31	30	4	0	0	0	0	897
		RMEP	219	69	52	21	7	1	0	0	0	0	133
June 21	Flume Normal	Meas. MEP	682	248	158	81	50	15	4	0	0	0	815
		RMEP	678	206	92	20	26	27	2	0	0	0	500
July 14	Flume Normal	Meas. MEP	635	258	244	130	84	17	3	0	0	0	464
		RMEP	636	272	307	122	47	7	1	0	0	0	193
Oct. 26	Flume Normal	Meas. MEP	11	2	5	37	73	17	0	0	0	0	185
		RMEP	11	3	11	11	4	0	0	0	0	0	178

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge	
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm	32.00 to 64.00 mm	64.00 to 128.00 mm			
1962																	
May 10	Flume Normal	Meas. MEP	119	57	43	20	22	4	0	0	0	0	0	0	0	227	117
		RMEP	119	58	48	12	4	0	0	0	0	0	0	0	0	265	106
June 29	Flume Normal	Meas. MEP	575	171	382	352	61	10	3	0	0	0	0	0	0	1,280	121
		RMEP	574	161	320	220	114	9	0	0	0	0	0	0	0	1,400	109
July 30	Flume Normal	Meas. MEP	1,060	439	537	434	182	41	17	3	0	0	0	0	0	2,320	117
		RMEP	1,060	442	550	446	97	20	5	0	0	0	0	0	0	2,620	113
Aug. 13	Flume Normal	Meas. MEP	413	240	319	115	79	18	6	0	0	0	0	0	0	1,180	101
		RMEP	414	250	378	102	48	8	1	0	0	0	0	0	0	1,200	102
Sept. 11	Flume Normal	Meas. MEP	193	73	138	143	80	8	1	0	0	0	0	0	0	542	118
		RMEP	193	74	144	161	44	3	0	0	0	0	0	0	0	620	114
Oct. 12	Flume Normal	Meas. MEP	46	9	24	22	16	1	0	0	0	0	0	0	0	118	100
		RMEP	46	10	27	13	3	0	0	0	0	0	0	0	0	99	84
1963																	
May 8	Flume Normal	Meas. MEP	301	138	148	73	54	11	3	0	0	0	0	0	0	611	119
		RMEP	302	143	167	43	14	2	0	0	0	0	0	0	0	728	110
July 11	Flume Normal	Meas. MEP	744	384	461	198	56	10	2	0	0	0	0	0	0	1,520	122
		RMEP	744	411	642	213	38	5	0	0	0	0	0	0	0	1,850	135
July 25	Flume Normal	Meas. MEP	560	259	297	176	63	5	0	0	0	0	0	0	0	1,230	111
		RMEP	561	273	381	203	29	2	0	0	0	0	0	0	0	1,450	118
Aug. 22	Flume Normal	Meas. MEP	282	86	140	187	116	10	1	0	0	0	0	0	0	694	118
		RMEP	281	86	148	202	49	3	0	0	0	0	0	0	0	820	118
Sept. 27	Flume Normal	Meas. MEP	250	110	155	109	50	4	0	0	0	0	0	0	0	647	105
		RMEP	251	113	181	74	18	1	0	0	0	0	0	0	0	638	99

Square root of mean variance for 14 data sets:
Meas.

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	MEP	108	90	106	105	40	105	40	228
	RMEP	108	94	138	72	41			249
Mean of measured and computed sediment discharges for data sets:									
Feb. 3	Meas.	873	234	242	146	40			1,360
1320	MEP	922	276	293	293	49			1,510
	RMEP	921	288	333	141	37			1,520
Ratio of square root of mean variance to mean of measured sediment discharge:									
Feb. 3	Meas.	0.12	0.38	0.44	0.72	1.00			0.17
1700	MEP	0.12	0.40	0.57	0.49	1.02			0.18
0945	RMEP	14	14	14	14	13			64
Number of data sets used in computation of square roots, means, and ratios:									
1965	Meas.	1,070	269	1,620	405	0	0	0	3,370
Feb. 3	Weir	1,200	329	1,120	103	2	0	0	2,760
0945	'Normal (236)	1,200	320	962	75	2	0	0	2,560
1320	RMEP	1,070	319	878	373	27	0	0	2,660
	Meas.	1,150	316	1,070	99	2	0	0	2,650
Feb. 3	Weir	1,150	308	922	73	1	0	0	2,460
1700	MEP	1,130	321	1,320	417	33	0	0	3,210
0945	RMEP	1,050	289	1,000	97	2	0	0	2,440
1320	Meas.	1,070	282	871	74	1	0	0	2,280
0945	Weir	1,210	269	1,620	405	0	0	0	3,370
1320	MEP	1,210	370	1,280	240	22	0	0	3,080
	RMEP	1,070	319	1,320	281	16	0	0	3,200
1320	Meas.	1,150	353	1,210	373	27	0	0	2,660
Feb. 3	Weir	1,150	357	1,330	285	23	0	0	2,980
1305	MEP	1,060	331	1,540	735	17	0	0	3,130
1505	RMEP	1,090	337	1,160	238	22	0	0	2,840
Feb. 3	Weir	1,210	341	1,270	272	16	0	0	2,990
0750	MEP	1,100	321	1,320	217	33	0	0	3,210
1700	RMEP	1,100	346	1,350	249	30	0	0	3,000
0830	Meas.	1,200	348	1,740	579	17	0	0	3,870
Feb. 4	Weir	1,350	337	1,620	278	24	0	0	3,610
0830	'Normal (255)	1,350	337	1,690	313	18	0	0	3,730
Feb. 4	Meas.	1,160	501	2,130	376	0	0	0	4,180
1000	Weir	1,250	310	1,520	272	24	0	0	3,380
Feb. 4	RMEP	1,210	314	1,620	317	18	0	0	3,520
1220	Meas.	1,190	390	1,550	354	36	0	0	3,540
Feb. 4	Weir	1,190	300	1,480	274	24	0	0	3,270
1415	RMEP	1,210	303	1,600	312	18	0	0	3,430
0750	Meas.	1,210	404	2,020	404	0	0	0	4,040
1415	Weir	1,210	305	1,490	280	25	0	0	3,320
0750	RMEP	6,720	309	1,640	311	18	0	0	3,490
	Meas.	6,630	1,410	1,030	187	0	0	0	9,340
	Weir	6,620	1,480	1,380	148	5	0	0	9,640
	'Normal (240)	6,620	1,480	1,390	146	3	0	0	9,640

See footnotes at end of table.

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total	Percentage of measured sediment discharge		
			Less than 0.062 mm	0.062 to 0.125 mm	0.125 to 0.25 mm	0.25 to 0.50 mm	0.50 to 1.00 mm	1.00 to 2.00 mm	2.00 to 4.00 mm	4.00 to 8.00 mm	8.00 to 16.00 mm	16.00 to 32.00 mm	to 16.00 mm	to 32.00 mm				
May 12 0900	Weir	Meas.																
	'Normal (240)	MEP	6,050	1,240	746	249	0	0	0	0	0	0	0	0	0	0	8,290	
May 12 1000	Weir	Meas.	5,940	1,330	1,270	140	4										8,690	
	'Normal (240)	MEP	5,940	1,330	1,280	138	2	0	0	0	0	0	0	0	0	0	8,110	
May 12 1100	Weir	Meas.	5,720	1,300	890	243	0										8,360	
	'Normal (240)	MEP	5,720	1,280	1,310	133	4	0	0	0	0	0	0	0	0	0	8,340	
May 12 1200	Weir	Meas.	5,890	1,240	913	249	0										8,300	
	'Normal (240)	MEP	5,720	1,280	1,210	134	4	0	0	0	0	0	0	0	0	0	8,360	
May 12 1335	Weir	Meas.	5,940	1,120	723	241	0										8,080	
	'Normal (240)	MEP	5,720	1,280	1,210	135	4	0	0	0	0	0	0	0	0	0	8,360	
May 12 1430	Weir	Meas.	5,730	1,070	688	153	4										7,940	
	'Normal (240)	MEP	5,720	1,280	1,210	135	4	0	0	0	0	0	0	0	0	0	8,360	
May 12 1530	Weir	Meas.	5,920	1,280	1,220	130	2										8,360	
	'Normal (240)	MEP	5,840	1,310	1,260	134	4	0	0	0	0	0	0	0	0	0	8,540	
May 12 1630	Weir	Meas.	7,830	1,890	1,100	221	0										11,030	
	'Normal (240)	MEP	8,350	1,850	1,650	171	5	0	0	0	0	0	0	0	0	0	12,020	
May 12 1730	Weir	Meas.	7,330	1,490	891	158	3										12,060	
	'Normal (240)	MEP	7,750	1,720	1,560	187	5	0	0	0	0	0	0	0	0	0	9,900	
May 13 0800	Weir	Meas.	6,300	1,230	875	350	3										11,210	
	'Normal (240)	MEP	6,970	1,560	1,420	350	3	0	0	0	0	0	0	0	0	0	11,260	
May 13 0900	Weir	Meas.	5,250	1,240	656	146	0										8,750	
	'Normal (240)	MEP	5,140	1,320	1,720	167	4	0	0	0	0	0	0	0	0	0	10,120	
May 13 1000	Weir	Meas.	5,080	1,230	726	218	2										7,290	
	'Normal (240)	MEP	5,070	1,300	1,690	157	2	0	0	0	0	0	0	0	0	0	8,350	
May 13 1110	Weir	Meas.	5,150	1,250	735	220	4										8,230	
	'Normal (240)	MEP	5,070	1,300	1,690	156	2	0	0	0	0	0	0	0	0	0	8,230	
May 13 1110	Weir	Meas.	5,070	1,300	1,710	155	2										7,350	
	'Normal (240)	MEP	5,180	1,280	900	150	2	0	0	0	0	0	0	0	0	0	8,240	
May 13 1110	Weir	Meas.	5,070	1,300	1,690	166	4										7,500	
	'Normal (240)	MEP	5,070	1,300	1,690	166	4	0	0	0	0	0	0	0	0	0	8,230	

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May 13	RMEP	5,070	1,300	1,710	155	2	0	0	0	0	8,240	110
1200	Weir	5,340	1,190	1,742	148	0	0	0	0	0	7,420	108
	Normal (240)	5,070	1,301	1,690	166	4	0	0	0	0	8,230	111
May 13	RMEP	5,070	1,300	1,710	155	2	0	0	0	0	8,240	108
1345	Weir	5,200	1,280	820	226	0	0	0	0	0	7,530	111
	Normal (240)	5,140	1,320	1,710	170	5	0	0	0	0	8,350	108
May 13	RMEP	5,140	1,320	1,750	156	2	0	0	0	0	8,370	111
1440	Weir	5,270	1,110	816	222	0	0	0	0	0	7,420	111
	Normal (240)	5,220	1,340	1,740	172	5	0	0	0	0	8,470	114
June 2	RMEP	4,700	2,080	1,780	158	2	0	0	0	0	8,490	98
0850	Weir	4,800	1,850	1,710	452	90	0	0	0	0	9,030	114
	Normal (250)	4,800	1,840	1,480	685	53	0	0	0	0	8,870	98
June 2	RMEP	4,790	2,080	1,620	688	29	0	0	0	0	8,860	98
1045	Weir	4,800	1,840	1,490	452	90	0	0	0	0	9,030	98
	Normal (250)	4,800	1,840	1,490	695	53	0	0	0	0	8,890	98
June 2	RMEP	4,510	1,960	1,510	697	29	0	0	0	0	8,880	98
1145	Weir	4,800	1,850	1,770	531	89	0	0	0	0	8,850	100
	Normal (250)	4,800	1,840	1,490	695	53	0	0	0	0	8,880	100
June 2	RMEP	4,800	1,840	1,510	696	29	0	0	0	0	8,890	100
	Normal (250)	4,540	1,930	2,410	678	97	0	0	0	0	9,650	91
1350	Weir	4,760	1,840	1,480	685	52	0	0	0	0	8,810	91
	Normal (250)	4,760	1,830	1,500	684	28	0	0	0	0	8,800	91
June 2	RMEP	4,830	1,860	1,240	310	0	0	0	0	0	7,740	113
1500	Weir	4,760	1,840	1,490	685	52	0	0	0	0	8,820	114
	Normal (250)	4,760	1,830	1,500	676	27	0	0	0	0	8,790	114
June 2	RMEP	4,410	2,010	2,300	767	96	0	0	0	0	9,590	91
1600	Weir	4,760	1,830	1,470	672	51	0	0	0	0	8,790	91
	Normal (250)	5,840	1,830	3,560	662	26	0	0	0	0	8,760	91
Nov. 29	RMEP	5,910	4,280	4,720	1,440	133	0	0	0	0	14,240	115
1100	Weir	5,270	3,700	4,130	1,140	0	0	0	0	0	16,490	117
	Normal (245)	5,900	3,660	3,690	1,100	117	0	0	0	0	14,240	101
Nov. 29	RMEP	5,890	3,650	3,770	1,170	92	0	0	0	0	14,460	102
1400	Weir	4,990	2,960	4,050	755	94	0	0	0	0	14,580	83
	Normal (245)	4,990	2,960	4,100	835	78	0	0	0	0	15,390	83
Nov. 30	RMEP	5,270	3,560	4,100	835	78	0	0	0	0	12,860	84
1000	Weir	5,270	4,010	3,740	2,170	96	0	0	0	0	12,970	84
	Normal (245)	5,270	4,000	3,790	860	78	0	0	0	0	13,490	89
Nov. 30	RMEP	2,990	2,750	4,590	803	344	0	0	0	0	14,000	90
1966	Weir	3,140	1,800	1,400	554	10	0	0	0	0	11,470	60
	Normal (240)	3,140	1,800	3,830	548	106	0	0	0	0	6,910	60
May 4	RMEP	3,080	2,500	3,800	1,060	106	0	0	0	0	10,640	65
0830	Weir	3,140	1,800	1,400	548	10	0	0	0	0	6,910	65
	Normal (240)	3,080	2,690	3,070	768	6	0	0	0	0	9,610	65
May 4	RMEP	3,140	1,800	1,400	554	10	0	0	0	0	6,910	72
0900	Weir	3,140	1,800	1,430	548	6	0	0	0	0	6,910	72
	Normal (240)	3,090	2,530	2,900	842	0	0	0	0	0	9,360	74
May 4	RMEP	3,140	1,800	1,400	554	10	0	0	0	0	6,910	74
0930	Weir	3,140	1,800	1,430	548	6	0	0	0	0	6,910	74
	Normal (240)	3,140	1,800	1,430	548	6	0	0	0	0	6,910	74

See footnotes at end of table.

TABLE 1.—Comparison of computed sediment discharge from the modified Einstein procedure and revised modified Einstein procedure applied to normal sections with measured sediment discharge at contracted section or weir—Continued

Date	Section	Method	Sediment discharge (tons per day)												Total sediment discharge	Percentage of measured sediment discharge								
			Less than 0.062 mm		0.062 to 0.125 mm		0.125 to 0.25 mm		0.25 to 0.50 mm		0.50 to 1.00 mm		1.00 to 2.00 mm				2.00 to 4.00 mm		4.00 to 8.00 mm		8.00 to 16.00 mm		16.00 to 32.00 mm	
			mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm	mm	mm	mm	mm
May 4 1000	Weir *Normal (240)	Meas. RMEP	3,140	2,530	4,700	1,690	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12,080	57	
May 4 1030	Weir *Normal (240)	Meas. RMEP	3,140	3,800	4,430	348	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,910	57
May 4 1100	Weir *Normal (240)	Meas. RMEP	3,140	1,800	5,080	1,960	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13,760	53
May 4 1130	Weir *Normal (240)	Meas. RMEP	3,210	2,850	4,430	348	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,910	53
May 4 1200	Weir *Normal (240)	Meas. RMEP	3,140	1,800	4,640	1,190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,890	58
May 4 1230	Weir *Normal (240)	Meas. RMEP	3,140	1,800	1,410	554	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,910	58
May 4 1300	Weir *Normal (240)	Meas. RMEP	3,010	2,550	4,400	1,500	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,920	60
May 4 1330	Weir *Normal (240)	Meas. RMEP	3,140	1,800	1,410	554	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,540	60
May 4 1400	Weir *Normal (240)	Meas. RMEP	3,140	1,800	3,790	1,840	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,920	60
May 4 1430	Weir *Normal (240)	Meas. RMEP	3,210	2,520	3,790	1,840	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,470	60
May 4 1500	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,410	555	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,920	60
May 4 1530	Weir *Normal (240)	Meas. RMEP	3,280	2,580	4,340	545	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,930	60
May 4 1600	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,410	555	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,720	59
May 4 1630	Weir *Normal (240)	Meas. RMEP	3,140	1,800	1,410	545	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,920	59
May 4 1700	Weir *Normal (240)	Meas. RMEP	3,230	2,650	4,500	1,150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,930	60
May 4 1730	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,420	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,540	60
May 4 1800	Weir *Normal (240)	Meas. RMEP	3,140	1,800	1,450	544	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,930	60
May 4 1830	Weir *Normal (240)	Meas. RMEP	3,130	2,320	4,410	1,740	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,610	60
May 4 1900	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,420	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,930	60
May 4 1930	Weir *Normal (240)	Meas. RMEP	3,140	2,600	4,450	544	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,930	60
May 4 2000	Weir *Normal (240)	Meas. RMEP	3,290	2,600	4,540	907	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,340	61
May 4 2030	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,430	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,940	61
May 4 2100	Weir *Normal (240)	Meas. RMEP	3,250	2,100	3,060	1,150	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,570	73
May 4 2130	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,430	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,940	73
May 4 2200	Weir *Normal (240)	Meas. RMEP	3,140	1,990	1,450	542	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,940	70
May 4 2230	Weir *Normal (240)	Meas. RMEP	2,880	1,990	3,870	1,190	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,920	70
May 4 2300	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,430	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,950	70
May 4 2330	Weir *Normal (240)	Meas. RMEP	3,070	2,120	1,460	540	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,950	66
May 4 2400	Weir *Normal (240)	Meas. RMEP	3,140	1,810	3,600	1,690	106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10,580	66
May 4 2430	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,460	555	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,950	66
May 4 2500	Weir *Normal (240)	Meas. RMEP	3,140	1,810	1,460	540	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,950	66

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May 4	Weir	Meas.	2,960	2,750	4,590	803	344	0	0	0	0	0	0	0	0	0	0	0	0	11,470	68
0800	Normal (260)	MEP	3,240	2,010	2,170	346	15	0	0	0	0	0	0	0	0	0	0	0	0	7,750	68
		RMEP	3,240	2,000	2,160	341	9	0	0	0	0	0	0	0	0	0	0	0	0	7,750	68
May 4	Weir	Meas.	3,080	2,550	3,850	1,060	106	0	0	0	0	0	0	0	0	0	0	0	0	10,640	73
0830	Normal (260)	MEP	3,240	2,010	2,170	346	15	0	0	0	0	0	0	0	0	0	0	0	0	7,750	73
		RMEP	3,240	2,000	2,160	341	9	0	0	0	0	0	0	0	0	0	0	0	0	7,750	73
May 4	Weir	Meas.	3,060	2,690	3,070	768	15	0	0	0	0	0	0	0	0	0	0	0	0	9,610	81
0900	Normal (260)	MEP	3,240	2,000	2,170	346	15	0	0	0	0	0	0	0	0	0	0	0	0	7,790	81
		RMEP	3,240	2,000	2,160	341	9	0	0	0	0	0	0	0	0	0	0	0	0	7,750	81
May 4	Weir	Meas.	3,290	2,600	4,540	907	0	0	0	0	0	0	0	0	0	0	0	0	0	11,340	69
1400	Normal (260)	MEP	3,240	2,020	2,220	346	16	0	0	0	0	0	0	0	0	0	0	0	0	7,850	69
		RMEP	3,240	2,010	2,200	336	9	0	0	0	0	0	0	0	0	0	0	0	0	7,800	69
May 4	Weir	Meas.	3,250	2,100	3,060	1,150	0	0	0	0	0	0	0	0	0	0	0	0	0	9,560	82
1430	Normal (260)	MEP	3,250	2,020	2,220	346	16	0	0	0	0	0	0	0	0	0	0	0	0	7,850	82
		RMEP	3,240	2,010	2,200	336	9	0	0	0	0	0	0	0	0	0	0	0	0	7,800	82
May 4	Weir	Meas.	2,880	1,980	3,870	1,190	0	0	0	0	0	0	0	0	0	0	0	0	0	9,920	79
1500	Normal (260)	MEP	3,250	2,030	2,240	346	16	0	0	0	0	0	0	0	0	0	0	0	0	7,870	79
		RMEP	3,240	2,010	2,220	336	9	0	0	0	0	0	0	0	0	0	0	0	0	7,820	79
May 4	Weir	Meas.	3,070	2,120	3,600	1,690	106	0	0	0	0	0	0	0	0	0	0	0	0	10,580	74
1530	Normal (260)	MEP	3,240	2,030	2,240	346	16	0	0	0	0	0	0	0	0	0	0	0	0	7,870	74
		RMEP	3,240	2,010	2,220	334	9	0	0	0	0	0	0	0	0	0	0	0	0	7,820	74
Square root of mean variance for 61 data sets:																					
		MEP	206	440	1,600	587	130	0	0	0	0	0	0	0	0	0	0	0	0	2,510	
		RMEP	206	443	1,590	587	135	0	0	0	0	0	0	0	0	0	0	0	0	2,510	
Mean of sediment discharge for 61 data sets:																					
		Meas.	3,810	1,780	2,470	762	109	0	0	0	0	0	0	0	0	0	0	0	0	8,850	
		MEP	3,880	1,580	1,680	402	24	0	0	0	0	0	0	0	0	0	0	0	0	7,560	
		RMEP	3,880	1,570	1,710	404	14	0	0	0	0	0	0	0	0	0	0	0	0	7,580	
Ratio of square root of mean variance to mean of measured sediment discharges:																					
		MEP	0.05	0.25	0.65	0.77	1.19	0	0	0	0	0	0	0	0	0	0	0	0	0.28	
		RMEP	0.05	0.25	.65	0.77	1.24	0	0	0	0	0	0	0	0	0	0	0	0	.28	
Number of data sets used in computation of square roots, means, and ratios:																					
			61	61	61	61	61	18												61	

1Dunes.
2Flat.
3Transition.