* Chapter 7
Sediment Properties

Section I
General

7-1. Purpose

This chapter focuses on the properties of inorganic noncohesive sediments. Generally, organics do not significantly affect sedimentation processes. The percentage of organics in field samples should be determined and then the organics should be removed before testing for the inorganic sediment properties. If a significant quantity of organic particles are present, then a suitable procedure for correcting the calculations must be developed.

7-2. Property Categories

Sediment properties can be divided into two categories: (a) those related to the particle itself and (b) those related to the sediment mixture or deposit.

Section II
Particles

7-3. General

When the sediment particles are noncohesive, mechanical forces dominate the behavior of the sediment in water. Particle hydrodynamics refers to the propensity of a particle to remain immobile or to become entrained if it is on the bed surface, and to remain in suspension or to cease movement if it is in motion. The three most important properties that govern the hydrodynamics of noncohesive sediments are particle size, shape, and specific gravity. Cohesive sediment behavior is dominated by electrochemical forces. Cohesive sediment behavior is primarily dependent on the particle size, water chemistry, and sediment mineralogy.

7-4. Particle Size

Particle size is the most significant sediment property of noncohesive natural sediments. Frequently, the particle size alone is used to characterize a sediment particle. This procedure is acceptable if the particle shape and density are “typical” of natural sediments.

a. Particle size definitions. Particle size is defined by one of four methods:

(1) The ***nominal diameter*** of a particle is the diameter of a sphere that has the same volume as the particle.

(2) The ***sieve diameter*** of a particle is the length of the side of the smallest square opening through which the given particle will pass.

(3) The ***sedimentation diameter*** of a particle is the diameter of a sphere that has the same specific gravity and has the same terminal settling velocity as the given particle in the same fluid under the same conditions.

(4) The ***standard fall diameter*** (or simply ***fall diameter***) of a particle is the diameter of a sphere that has a specific gravity of 2.65 and has the same terminal settling velocity as the given particle in quiescent distilled water at a temperature of 24 °C.

b. Particle classification. Sediment particles are classified, based on their size, into six general categories: *Clay, Silt, Sand, Gravel, Cobbles,* and *Boulders*. Because such classifications are essentially arbitrary, many grading systems are to be found in the engineering and geologic literature. Table 7-1 shows a grade scale proposed by the subcommittee on Sediment Terminology of the American Geophysical Union (Lane 1947). This scale is adopted for sediment work because the sizes are arranged in a geometric series with a ratio of two. This classification is different from the Unified Soils Classification System commonly used in geotechnical work.

7-5. Particle Shape

Particle shape is the second most significant sediment property in natural sediments and can be defined by the shape factor, SF.

$$SF = \frac{c}{\sqrt{a\ b}} \qquad (7\text{-}1)$$

where a, b, and c are the lengths of the longest axis, the intermediate axis, and the shortest axis, respectively. These axes are the mutually perpendicular axes of the particle. The shape factor for a sphere would be 1.0. Natural sediment typically has a shape factor of about 0.7. Particle shape affects the fall velocity and, hence, both the sedimentation diameter and fall diameter of particles. The relationship between sieve diameter and fall diameter as a function of shape for a specific gravity of 2.65 was determined by the Interagency Committee on Water Resources (1957) and is shown in Figure 7-1. *

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Table 7-1
American Geophysical Union Sediment Classification System

	Sediment Size Range		
Sediment	millimeters	microns	Inches
Very large boulders	4096 - 2048		160-80
Large cobbles	256 - 128		80-40
Medium boulders	1024 - 512		40-20
Small boulders	512 - 256		20-10
Large cobbles	256-128		10-5
Small cobbles	128-64		5-2.5
Very coarse gravel	64-32		2.5-1.3
Coarse gravel	32 - 16		1.3-0.6
Medium gravel	16 - 8		0.6-0.3
Fine gravel	8 - 4		0.3-0.16
Very fine gravel	4 - 2		0.16-0.08
Very coarse sand	2.0 - 1.0	2000-1000	
Coarse sand	1.0 - 0.5	1000-500	
Medium sand	0.5 - 0.25	500-250	
Fine sand	0.25 - 0.125	250-125	
Very fine sand	0.125 - 0.062	125-62	
Coarse silt	0.062 - 0.031	62-31	
Medium silt	0.031 - 0.016	31-16	
Fine silt	0.016 - 0.008	16-8	
Very fine silt	0.008 - 0.004	8-4	
Coarse clay	0.004 - 0.002	4-2	
Medium clay	0.002 - 0.001	2-1	
Fine clay	0.0010 - 0.0005	1.0 - 0.5	
Very fine clay	0.0005 - 0.00024	0.5 - 0.24	

7-6. Particle Specific Gravity

In natural soils, particle specific gravity will usually

> "range numerically from 2.60 to 2.80. Within this range, the lower values for specific gravity are typical of the coarser soils, while higher values are typical of the fine-grained soil types. Values of the specific gravity outside the range of values given may occasionally be encountered in soils derived from parent materials which contained either unusually light or unusually heavy minerals." [Ritter and Paquette 1960, p 182]

Due to its resistance to weathering and abrasion, quartz, which has a specific gravity of 2.65, is the most common mineral found in natural noncohesive sediments. Typically, the average specific gravity of a sediment mixture is close to that of quartz. Therefore, in sedimentation studies, specific gravity is frequently assumed to be 2.65, although whenever possible, site-specific particle specific gravity should be determined.

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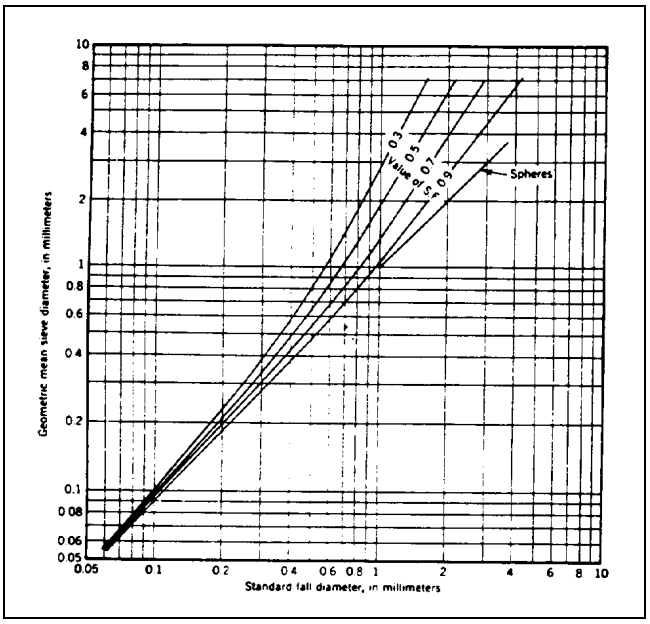

Figure 7-1. Relation of sieve diameter and fall diameter for naturally worn quartz particles (Interagency Committee 1957)

7-7. Particle Fall Velocity

Fall velocity is a general term describing the rate of fall or settling of a particle in a fluid. The standard fall velocity of a particle is the average rate of fall that the particle would finally attain if falling alone in quiescent distilled water of infinite extent and at a temperature of 24 °C. The fall diameter of a particle is the diameter of a sphere that has a specific gravity of 2.65 and has the same standard fall velocity as the particle. Fall velocity is the most fundamental property governing the motion of the sediment particle in a fluid; it is a function of the volume, shape, and density of the particle and the viscosity and density of the fluid. The fall velocity of any naturally worn sediment particle may be calculated if the characteristics of the particle and fluid are known. The relationship between sieve diameter and fall velocity of quartz particles in distilled water is shown in Figure 7-2. This figure shows the variation in this relationship with temperature and shape factor. These are average values, and fall velocities for individual particles may vary widely. Similar relationships can be developed for other shape factors and specific gravities using the method outlined by the Interagency Committee on Water Resources (1957). The Interagency Committee method has been computerized and is available as CORPS program H0910 (USAEWES - CORPS) and in the Hydraulic Design Package - SAM (Thomas et al. 1994).

7-8. Methods for Obtaining Particle Size

Particle sizes are determined using a variety of methods. Methodology is usually size-dependent. Diameters of particles larger than 256 mm may be obtained by measuring the intermediate or b-axis. Templates with square openings can be used to determine a size equivalent to the sieve diameter for particles between 32 and 256 mm.

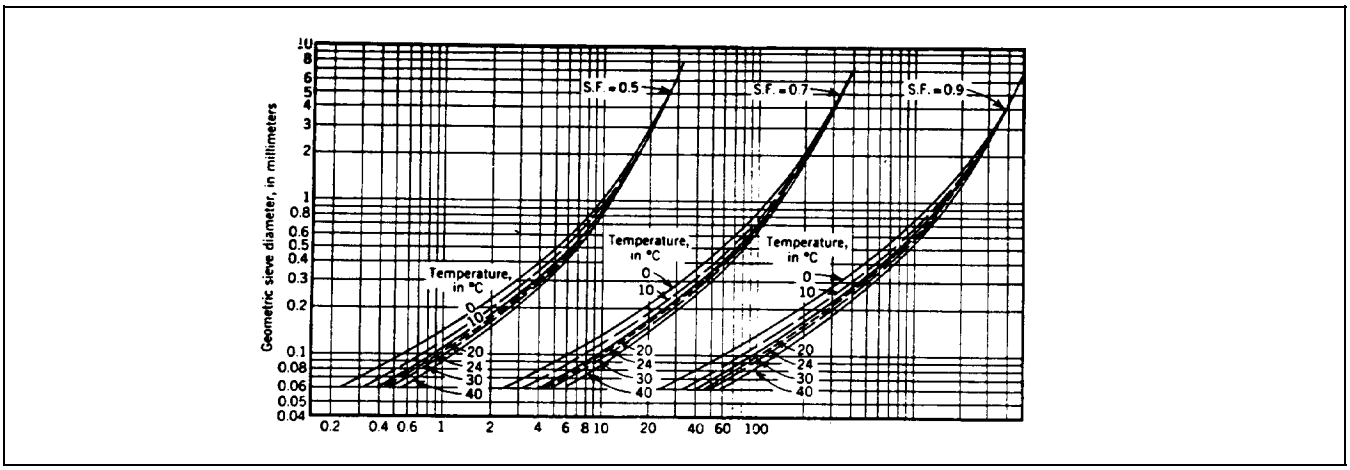

Figure 7-2. Relationship of sieve diameter and fall velocity for naturally worn quartz particles falling alone in quiescent distilled water of infinite extent (Interagency Committee 1957)

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* Sieve analyses are typically used for particles between 0.0625 and 32 mm. A visual accumulation tube may be used to determine fall diameter for particles between 0.0625 and 2.0 mm. Hydraulic settling methods are used for particles less than 0.0625 mm in diameter. These include the pipet method, which is considered the most reliable indirect method; the bottom withdrawal method, which can be used if there is not enough material for a pipet method; and the hydrometer method, which is relatively simple and can be accomplished at a lessor cost, but which requires a larger sample quantity. These methods are discussed in detail in Chapter III of ***Sedimentation Engineering*** (ASCE 1975).

7-9. Cohesiveness

The cohesion of a sediment particle is associated with soil type and particle size. The three most common minerals which have electrochemical forces causing individual particles to stick together are illite, kaolinite, and montmorillonite. Sediment studies in the coastal zone and in reservoirs must evaluate the behavior of cohesive sediments. Methods are generally labeled as "cohesive sediment transport." The boundary between cohesive and noncohesive sediments is not clearly defined. It can be stated, however, that cohesion increases with decreasing particle size for the same type of material. Clays are much more cohesive than silts. Cohesive sediment is characterized by the dispersed particle fall velocity, flocculated fall velocity of the suspension, the clay and nonclay mineralogy, organic content, and the cation exchange capacity. The fluid is characterized by the concentration of important cations, anions, salt, pH, and temperature. More detailed information is presented in EM 1110-2-1607 (USAEHQ 1991).

Section III
Sediment Mixtures

7-10. Gradation Curves

The variation in particle sizes in a sediment mixture is described with a gradation curve, which is a cumulative size-frequency distribution curve showing particle size versus accumulated percent finer, by weight (Figure 7-3). It is common to refer to particle sizes according to their position on the gradation curve. For example: d_{50} is the geometric mean particle size; that is, 50 percent of the sample is finer, by weight; $d_{84.1}$ is 1 standard deviation larger than the geometric mean size--in practice it is rounded to d_{84}; and $d_{15.9}$ is 1 standard deviation smaller then the geometric mean size and is rounded to d_{16} in practice.

a. AGU Classification. The gradation curve shown in Figure 7-3 is a standard form used in the Corps of Engineers. The size class classification shown on the form is the Unified Soils Classification System, which is commonly used in geotechnical engineering studies. Whereas particle sizes versus percent finer are the same in sedimentation studies as they are in geotechnical studies, the size classification terminology is different. Always clarify by stating the AGU size classification is being used when reporting sedimentation investigations. Although a standardized form using the AGU size classification system is not available, one can be created on one of several computer graphics packages as shown in Figure 7-4.

b. Distribution. Natural river sediments are typically distributed log-normally. Hence, gradation curves are plotted on semi-logarithmic paper, and the geometric mean and geometric standard deviation are used to describe the distribution. The geometric mean size is calculated as:

$$d_g = \sqrt{d_{84}\ d_{16}} \tag{7-2}$$

The geometric standard deviation is calculated as:

$$\sigma_g = 0.5 \left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}} \right) \tag{7-3}$$

It is common practice to use these definitions for mean sediment size and standard deviation in a mixture even if the distribution is not log-normal.

Section IV
Sediment Deposits

7-11. General

Properties of sediment deposits are defined in terms of the deposit's porosity, specific weight, and consolidation rate.

7-12. Porosity

Porosity of deposited sediment is volume of voids divided by the total volume of sample.

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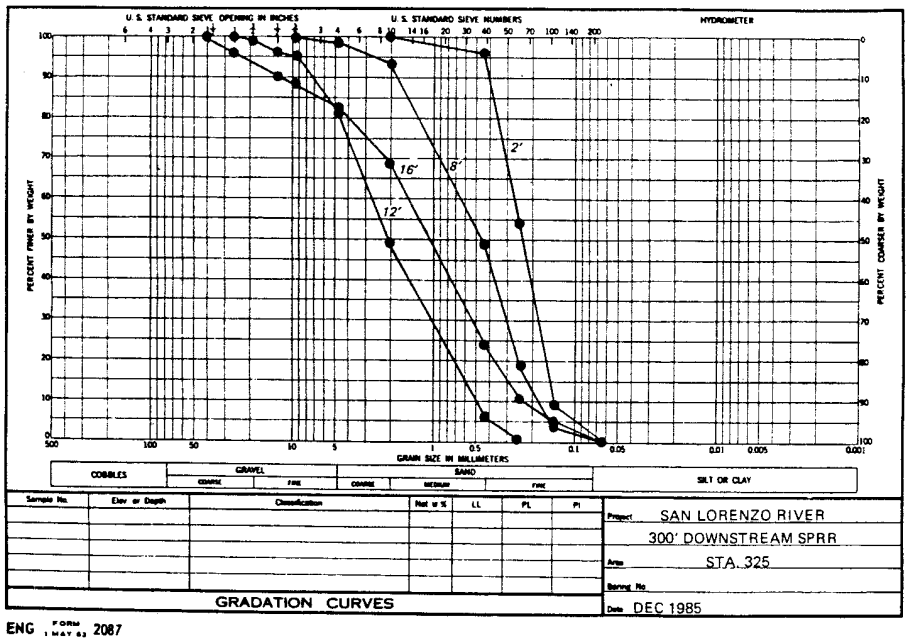

Figure 7-3. Gradation curve

$$P = \frac{V_v}{V_t} \tag{7-4}$$

where

P = porosity

V_v = void volume

V_t = total volume of sample

7-13. Specific Weight

Specific weight of a deposit is the weight per unit volume. It is expressed as dry weight.

$$\gamma_d = (1 - P)\ SG\ \gamma$$

$$or \tag{7-5}$$

$$\gamma_d = (1 - P)\ \gamma_s$$

where

γ_d = specific weight of deposit

SG = specific gravity of sediment particles

γ = specific weight of water (approximately 62.4 lb/ft^3)

γ_s = specific weight of sediment particles

Standard field tests are recommended when major decisions depend on the specific weight of the sediment deposit. When field data are not available for a project site, the tables on pages 39-40 of ***Sedimentation Engineering*** (ASCE 1975) may be used.

7-14. Consolidation

Consolidation is the process of compaction of a deposit with time or with overburden pressure.

$$\gamma_{dc} = \gamma_{di} + B \log_{10} T \tag{7-6}$$

where

γ_{dc} = consolidated weight of the deposit

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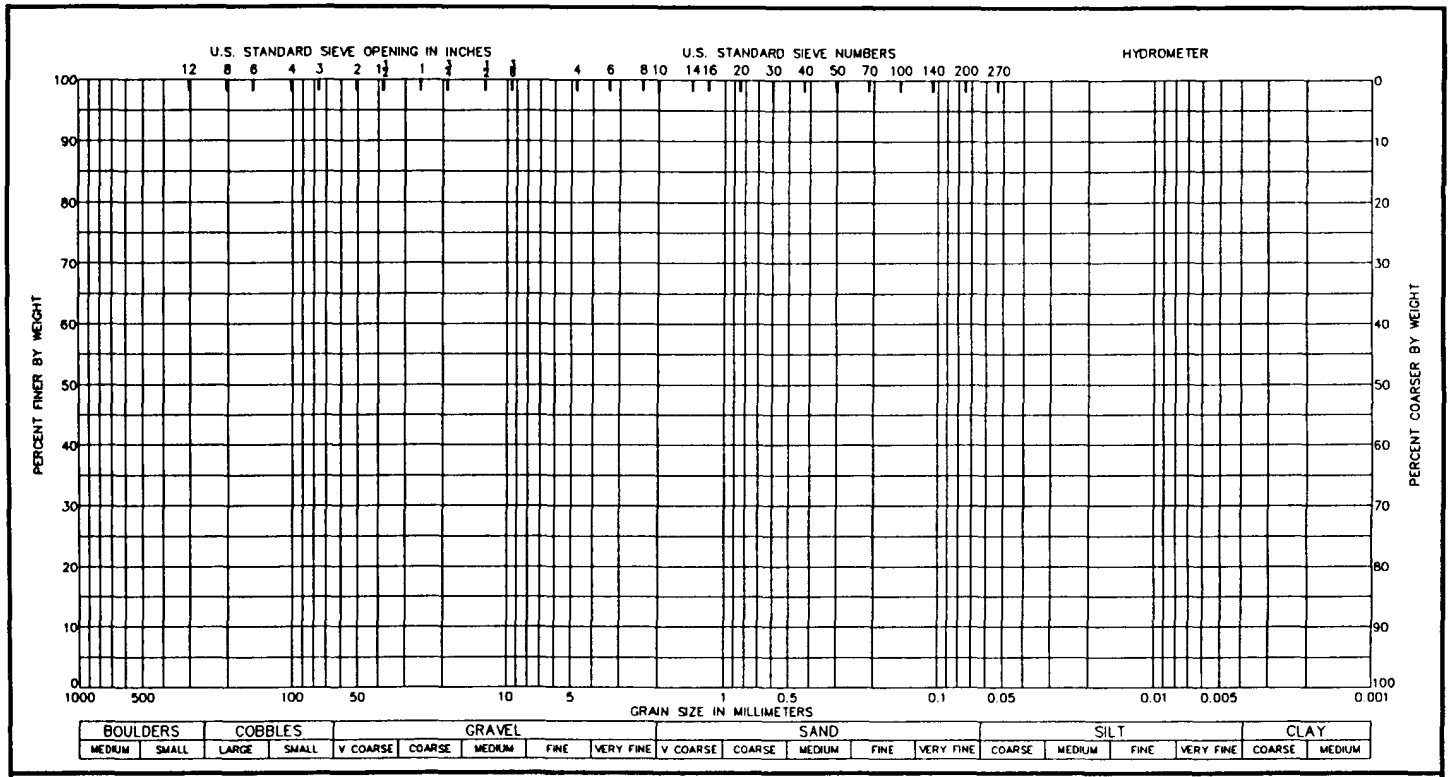

Figure 7-4. AGU gradation curve

* γ_{di} = specific weight of the initial deposit

B = coefficient of consolidation, which varies with size classification (suggested values can be found in ***Sedimentation Engineering*** (ASCE 1975) - p 43)

T = age of the deposit, years

When dealing with mixtures of particle sizes, calculate compaction for clay, silt, and sand fractions separately; then calculate the composite specific weight of the mixture using the following equation:

$$\gamma_d = \frac{1.0}{\left(\frac{F}{\gamma_d}\right)_{clay} + \left(\frac{F}{\gamma_d}\right)_{silt} + \left(\frac{F}{\gamma_d}\right)_{sand}} \tag{7-7}$$

where F is the fraction. Do not use the percent weighted specific weight in the γ_d terms of Equation 7-7. It does not conserve mass of the mixture.

Section V
Water-Sediment Mixtures

7-15. Sediment Concentration

Sediment concentration is the weight of dry sediment in a water-sediment mixture per volume of mixture and is expressed in milligrams/liter (mg/l). Sediment concentration sometimes is expressed in parts per million (ppm), which is the ratio of the mass of dry sediment in a water-sediment mixture to the mass of the mixture times 10^6. If the concentration is less than 16,000 mg/l, then concentration in part per million is essentially the same as milligrams/liter. For concentrations greater than 16,000 mg/l, milligrams/liter and parts per million are related by the following equations:

$$C_{ppm} = \frac{10^6}{SG_w\left(\frac{10^6}{C_{mgl}} + \frac{1.0}{SG_w} - \frac{1.0}{SG_s}\right)} \tag{7-8}$$

$$C_{mgl} = \frac{10^6}{\left(\frac{1.0}{SG_w}\frac{10^6}{C_{ppm}} - \frac{1.0}{SG_w} + \frac{1.0}{SG_s}\right)} \tag{7-9}$$

where

C_{ppm} = concentration, ppm

C_{mgl} = concentration, mg/l

SG_s = specific gravity of sediment particles

SG_w = specific gravity of water

7-16. Sediment Discharge

Sediment discharge is the quantity of sediment per unit of time passing a cross section. It is expressed as tons/day. The equation to convert from concentration to sediment discharge is

$$QS = kCQ \tag{7-10}$$

where

QS = sediment discharge, tons/day

k = 0.0027 when other variables are expressed in designated units

C = concentration, mg/l

Q = water discharge, cfs

Sometimes sediment discharge is expressed in units of cubic feet per second (cfs). Sediment discharge in tons per day can be converted to cubic feet per second using the following equation:

$$QS_{cfs} = 0.02315\frac{QS_{tons/day}}{\gamma_s} \tag{7-11}$$

where γ_s is the specific weight of the sediment in pounds per cubic feet (pcf).

7-17. Sediment Load

Sediment load denotes the material that is being transported, whereas sediment discharge denotes the rate of transport. Sediment load is described with a variety of terminology. Sediment load is generally defined based on *

* mode of transport, by its availability in the streambed, orby the method of measurement (Table 7-2). Based on the mode of transport, sediment load can be divided into bed load and suspended load. Bed load is the sediment load transported close to the bed where particles move intermittently by rolling, sliding, or jumping. Turbulence supports suspended load throughout the water column, and sediment is swept along at about the local flow velocity. Based on its availability in the streambed, sediment load can be divided into bed-material load and wash load. Wash load consists of the finest particles in the suspended load that are continuously maintained in suspension by the flow turbulence and, thus, significant quantities are not found in the bed. Particles that move as suspended load or bed load and periodically exchange with the bed are part of the bed-material load. This is the sediment load that can be calculated from the composition of the streambed. Based on measurement technique, sediment load is described as either measured or unmeasured. Typically, when depth-integrated suspended sediment samplers are used, the lower 0.5 ft of the water column is unmeasured. The unmeasured load includes some of the suspended and usually all of the bed load. Although the relative proportion of the total load indicated in Table 7-2 is typical of many streams, variation in these relative amounts does exist between sites and at different times at the same site.

Section VI
References for Chapter 7

American Society of Civil Engineers (ASCE) 1975. "Sedimentation Engineering," Manuals and Reports on Engineering Practice No. 54, Vito Vanoni, Ed., New York.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. 1957. "Measurement and Analysis of Sediment Loads in Streams: Report No. 12, Some Fundamentals of Particle Size Analysis," St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

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Ritter, Leo J., and Paquette, Radnor J. 1960. "Highway Engineering," The Ronald Press Company, New York.

Thomas, W. A., Copeland, R. R., Raphelt, N. K., and McComas, D. N. 1994. "Hydraulic Design Package for Channels - SAM," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Engineer Headquarters (USAEHQ). 1991. "***Tidal Hydraulics,***" EM 1110-2-1607, Office of the Chief of Engineers, Washington, DC.

Table 7-2
Explanation of Total Load

Mode of Transport	Availability in Streambed	Method of Measurement
Suspended	Wash	Measured
	Bed Material	
Bed		Unmeasured

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* U.S. Army Engineer Waterways Experiment Station (USAEWES). Conversationally Oriented Real-Time Program System (CORPS) Computer Programs. Available from ATTN: CEWES-IM-MI-C, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

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