Sediment Properties

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Introduction

This course focuses on problems affecting the evaluation of erosion and sedimentation and sediment storage damages, formulation of programs for reducing these damages, and sediment-storage design criteria for conservation practices and systems.

Sediment in Fluvial Systems

Sediment is eroded soil or rock material that occurs naturally in most fluvial systems. The type and quantity of sediment largely determines the physical or geomorphic characteristics of most stream systems. Figure 1 shows accelerated cropland erosion processes.

When excessive erosion produces unnatural loads of sediment, streams and water bodies react by either filling up or changing their shape and form. Conversely, most stream systems in their "natural" condition are in a dynamic balance between the sediment transported and deposited and the energy of the flowing water, so that when sediment concentrations are unnaturally low, the stream system also reacts to reach another state of stability.

NRCS Programs

The Natural Resources Conservation Service (NRCS) administers conservation programs that promote the conservation of natural resources, including the reduction of soil erosion in order to keep fertile soil in place and maintain tilth, organic matter, and crop yields. Other reasons to reduce sediment production are to maintain conservation practices that function by containing, trapping, or detaining water with sediment.

NRCS uses the nine-step planning process for projects and implementing their programs. The purpose of the steps is to develop and implement plans that protect, conserve, and enhance natural resources within a social and economic perspective. The nine steps are:

1. Identify Problems and Opportunities
2. Determine Objectives
3. Inventory Resources
4. Analyze Resource Data
5. Formulate Alternatives
6. Evaluate Alternatives
7. Make Decisions
8. Implement the Plan
9. Evaluate the Plan

Figure 1. Sheet and rill erosion and ephemeral gully erosion deliver sediment to the edge of a crop field in Iowa.

Sediment Sources

Sediments and soils are the products of disintegration and decomposition of rocks. Material becomes detached and is transported to a deposition site where it may be affected by solution, cementation, consolidation, or biological action.

Physical Properties

The physical properties of sediments depend on several factors, including composition, texture, and structure of the original formation, topography, type of weathering, and sorting (Lobeck 1939). Sediments produced by erosion of soils in more humid and deeply weathered areas generally have a finer texture and a higher proportion of minerals produced by chemical weathering. Small grains of certain minerals resistant to chemical weathering, such as zircon, quartz, rutile, tourmaline, topaz, and ilmenite, remain in sediment relatively unchanged. These detrital mineral suites may reveal the source rock type (Krumbein and Sloss 1963).

Weathering and deterioration of rocks are considered the primary mechanisms of sediment formation. The processes and agents causing rock deterioration and soil formation are many and diverse, and only a brief summary is presented in this handbook as a guide to the proper interpretation of sediments.

Soil Formation

Most sediment with which NRCS is concerned results from erosion of soil that has taken many centuries to form. Weathered rock and soil differ in that soil contains organic as well as mineral matter and has more than one layer (horizon), roughly parallel to the land surface.

Soil formation begins when material weathered from bedrock develops two or more distinguishable horizons. Most soil profiles include three principal horizons, identified by the letters A, B, and C (USDA 2018).

Sediment-forming Processes

Disintegration and Decomposition

Moving water and ice are powerful disruptive forces on rock formations in several environments. These forces include wave action along shores of seas and lakes, abrasion of the banks and beds of streams, and scouring and plucking by glacial ice. The atmosphere is also a disruptive force, especially in arid regions where rocks in exposed positions are subject to attack by winds carrying abrasive mineral particles.

Biological agents have some disruptive effects on rocks, including widening of crevices by root growth, pitting of rock surfaces by lichens, and burrowing by some animals.

Hydration

The addition of water to many minerals in igneous rocks results in the formation of clay minerals, which are hydrous aluminum silicates. Many minerals formed by hydration become dull earthy masses that contrast with their former hard, crystalline nature. Hydration also nearly doubles the volume of material (Lobeck 1939). The transformation of feldspar to kaolinitic clay is an example.

Oxidation

Through oxidation, many secondary minerals are formed from igneous rocks. The oxides of aluminum and iron are among the most stable. The oxidation of rocks in air is accelerated in the presence of moisture.

Ferrous silicates in pyroxenes, amphiboles, and olivine are oxidized by air and water to hematite (ferric oxide, Fe_2O_3). Iron oxidation of iron is marked by color changes from green or black to red, yellow, or brown. Oxygen combines with other elements to form sulfates, carbonates, and nitrates, most of which are relatively soluble.

Solutioning

Solutioning is important in the alteration of igneous rock. Some minerals, such as quartz and its accessory minerals, are relatively insoluble. An accumulation of quartz grains therefore becomes sand or sandstone.

Clays and shales contain decomposition products of feldspars and other less common primary silicates. Some of the silica from any of the silicates may be removed in solution (see table 1).

Table 1. Chemical weathering products of common rock-forming silicate minerals.[1/]

Mineral	Composition	Important Decomposition products	
		Mineral	Others
Quartz	SiO_2	Quartz grains	Some silica in solution
Orthoclase	$K(AlSi_3O_8)$	Clay Quartz (finely divided)	Some silica in solution Potassium carbonate (soluble)
Albite (sodic plagioclase) Anorthite (calcic plagioclase)	$Na(AlSi_3O_8)$ $CaAl_2Si_2O_8$	Clay Quartz (finely divided) Calcite (from Ca)	Some silica in solution Sodium and calcium carbonates (soluble)
Biotite Augite Hornblende	Fe, Mg, Ca silicates of Al	Clay Calcite Limonite Hematite Quartz (finely divided)	Some silica in solution Carbonates of calcium and magnesium(soluble)
Olivine	$(Fe, Mg)_2SiO_4$	Limonite Hematite Quartz (finely divided)	Some silica in solution Carbonates of iron and magnesium (soluble)

[1/]Leet and Judson (1958), reprinted by permission, Prentice-Hall, Inc., Englewood Cliffs, N.J.

Sediment Particle Characteristics

Various characteristics of mineral grains composing sediments have different effects on the formation and subsequent development of deposits. Size, shape, hardness, specific gravity, chemical composition, and degree of weathering of the mineral grains affect the rate and place of deposition and the nature of the deposits ultimately formed. Table 2 lists some of the common minerals and their hardness, specific gravity, and relative abundance.

Size

Size is an important particle characteristic that is readily measured. Bulk properties tend to vary with particle size in a roughly predictable manner. In fact, size alone has been found to describe sediment deposits adequately for many practical purposes. Table 3 shows some of the more common particle size classifications.

Shape

The various shapes of sediment particles are formed in numerous ways. Some shapes, such as the roundness of river and beach pebbles or the facets of wind-abraded particles, indicate the environment in which they formed. Other shapes express mineralogic characteristics. Examples are the curving shards of volcanic glass and the unworn crystals of many resistant minerals.

Shape is defined numerically by sphericity and roundness (Figure 2). Sphericity is the ratio of the surface area of a sphere having the same volume as the particle to the surface area of the particle. Sphericity is also expressed as d_n/D_s, where d_n is the nominal diameter (diameter of a sphere having the same volume as the particle) and D_s is the diameter of a circumscribing sphere. A sphere has a sphericity of 1, and all other shapes have a sphericity of less than 1 (Pettijohn 1957, p. 56).

Roundness describes the sharpness of the edges and corners of a particle and is an indication of the wear of the particle. Roundness is defined as the average radius of curvature of the edges, r_a, divided by the radius of the maximum inscribed circle, R.

Table 2. Common minerals: their hardness, specific gravity, and frequency of occurrence in average igneous rocks and sediments.

Mineral	Composition	Mohs scale of hardness	Specific gravity	Frequency of Occurrence	
				Average igneous rock[1/]	Sediment
				Percent	Percent
Feldspars	$KAlSi_3O_8$ – $Na AlSi_3O_8$ – $CaAl_2Si_2O_8$	6 – 6.5	2.6 – 2.8	59.5	15.6
Hornblende Pyroxene	$(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH,F)_2$ $XYSi_2O_6$, where X is Ca, Na, Fe^{+2} or Mg and Y is Al, Fe^{+3} or Mg	5 – 6	2.9 – 3.3	16.8	–
Quartz	SiO_2	7	2.65	12.0	34.8
Micas	sheet silicate minerals	2 – 4	2.7 – 3.1	3.8	15.1
Titanium minerals	rutile (TiO_2), ilmenite ($FeTiO_3$)	5 – 6	3.4 – 5.5	1.5	trace
Clay minerals	hydrous aluminum phyllosilicates	–	2.0 – 3.0	–	14.5
Dolomite	$CaMg(CO_3)_2$	3.5 – 4	2.8 – 2.9	–	9.1
Calcite	$CaCO_3$	3	2.7	–	4.2
Limonite	$FeO(OH)\cdot nH_2O$	1 – 5.5	3.4 – 4.0	–	4.0
Apatite	$Ca_{10}(PO_4)_6(OH,F,Cl,Br)_2$	4.5 – 5	3.2	0.6	0.4
Gypsum	$CaSO_4\cdot 2H_2O$	1.5 – 2	2.2 – 2.4	–	1.0
Other				5.8	1.3
Total				100.0	100.0

[1/]Clarke (1924)

Table 3. Particle gradation scales for earth materials.

inches	U.S. Standard Sieve No.	mm	Unified Soil Classification System [1]	AASHTO [2]	AGU [3]	USDA [4]	Udden-Wentworth [5]
		4026					
		2048	boulders		boulders		
		1024				boulders	boulders
		512		boulders			
12		300					
10		256	cobbles		cobbles		
6		128				cobbles	cobbles
3		75					
		64					
		32	coarse gravel	coarse gravel			
1		25.4			coarse gravel		
0.75		19					
		16					pebble gravel
0.5		12.7	fine gravel	fine gravel	medium gravel	gravel	
0.375		9.5					
		8					
0.25		6.35					
	4	4.76			fine gravel		
		4	coarse sand				granule
	10	2		coarse sand			
		1	medium sand		coarse sand	coarse sand	coarse sand
		0.5					
	40	0.425			medium sand	medium sand	medium sand
		0.25	fine sand	fine sand			
		0.125			fine sand	fine sand	fine sand
	200	0.074			very fine sand	very fine sand	very fine sand
		0.0625					
		0.05					
		0.031		silt			
		0.0156			silt	silt	silt
		0.0078	silt or clay				
		0.005					
		0.0039		clay			
		0.001			clay	clay	clay
				colloids			

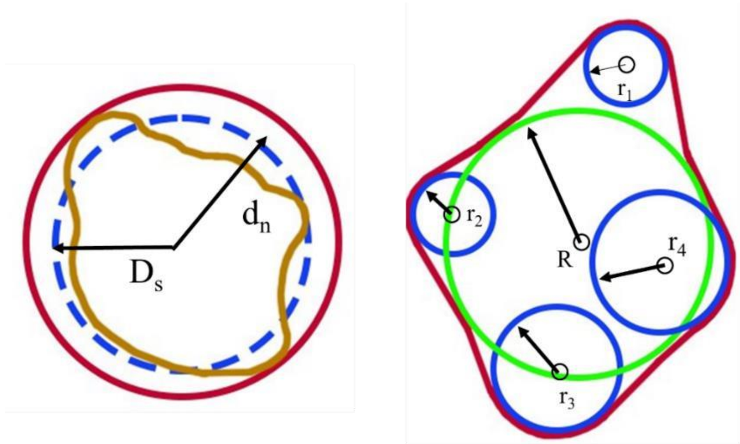
[1]Unified Soil Classification System, ASTM D2487

[2]AASHTO, American Association of State Highway and Transportation Officers (AASHTO, 1998)

[3]AGU, American Geophysical Union (Lane, 1947)

[4]USDA textural classification system (USDA, 2018)

[5]Udden-Wentworth classification system (Udden, 1914; Wentworth, 1922a)



$$Sphericity = \frac{d_n}{D_s} \qquad Roundness = \frac{r_a}{R} \qquad \frac{r_1 + r_2 + r_3 + r_4}{4}$$

Figure 2. Dimensions required for sphericity and roundness calculations.

Specific Gravity

The specific gravity of a mineral is the ratio of its weight to the weight of an equal volume of water. Most sediment consists of quartz or feldspar particles, which are about 2.65 times heavier than water. Specific gravity of 2.65 is generally considered characteristic of sediment. Heavy minerals (for example, magnetite with specific gravity of 5.18), of course, are found in many sediments, but they make up such a small percentage that their importance is minor. For NRCS geologists, the chief value of heavy minerals in sediment deposits is that they can provide a means of identifying the sediment source.

Five groups of soil sizes are presented in table 3: boulders and cobbles, gravel, sand, silt, and clay. The largest size is uncommon but is easily measured. Gravel-size particles are more important than boulders and cobbles and are transported in some streams as bedload. Gravel is measured directly by diameter or volume or by sieving. Sand-size sediment is common and is easily sized by sieving. The finest screen, No. 200, is used for accurate size separation of sand and silt. Silt and clay are best separated by measuring their rate of fall in a fluid. See section "Size Distribution of Sediments: Fine Grain Separation Method" below.

Silt and clay together make up most of the suspended load in streams, and they are usually distributed uniformly throughout the depth of the stream. Clay-size particles are important in their effect on density currents and on the change in volume-weight of sediment deposits during consolidation.

Size Distribution of Sediments

One of the most important properties of sediment deposits is the particle-size distribution of the mineral grains. The distribution is important in predicting the behavior of sediment and estimating its specific weight. Several precautions must be taken in studying deposits in the field and selecting samples for laboratory analysis. Laboratory studies cannot supply answers to many field problems. Problems such as selecting the beds or deposits to be sampled and determining the origin of deposits and the rate of deposition must be solved in the field. Field and laboratory data must be interpreted to determine the nature of the sediment and its texture, as well as its relationship to other formations, to soils, and to land use.

The size frequency distribution of a sediment sample can be measured several ways. The coarsest fraction is differentiated by direct measurement of gravels or larger sizes and by sieving sands. Fine-grained sediments can be separated by elutriation (the determination of settling velocity in a sediment-liquid mixture) or by microscopic examination.

Fine-Grain Separation Method

One method of fine-grain separation is by timing the settling rate of sediment particles in a column of water. A suspension of the sediment sample is treated with a deflocculant such as sodium carbonate, is thoroughly mixed, and is then put into a graduated cylinder containing a column of water 800 mm high. After 10 minutes, the upper part of the suspension is drawn off with a siphon. The coarse sediment containing grains 1/16 mm and larger remains at the bottom. This process is usually repeated about four times to achieve a clean separation. The coarse and fine separates can then be treated and studied separately.

A popular modification of the elutriation technique involves use of a bottom withdrawal tube (Howard 1948). The apparatus consists of a graduated glass cylinder with a constriction and a valve at the bottom, through which the coarse particles are withdrawn. From the separation thus obtained, a cumulative curve showing size distribution can be plotted on Form SCS-ENG-353, a grain-size distribution graph (figure 3). Other modifications include use of hydrometers to measure the density of the suspension at various time intervals and pipettes to withdraw fine fractions at definite time intervals.

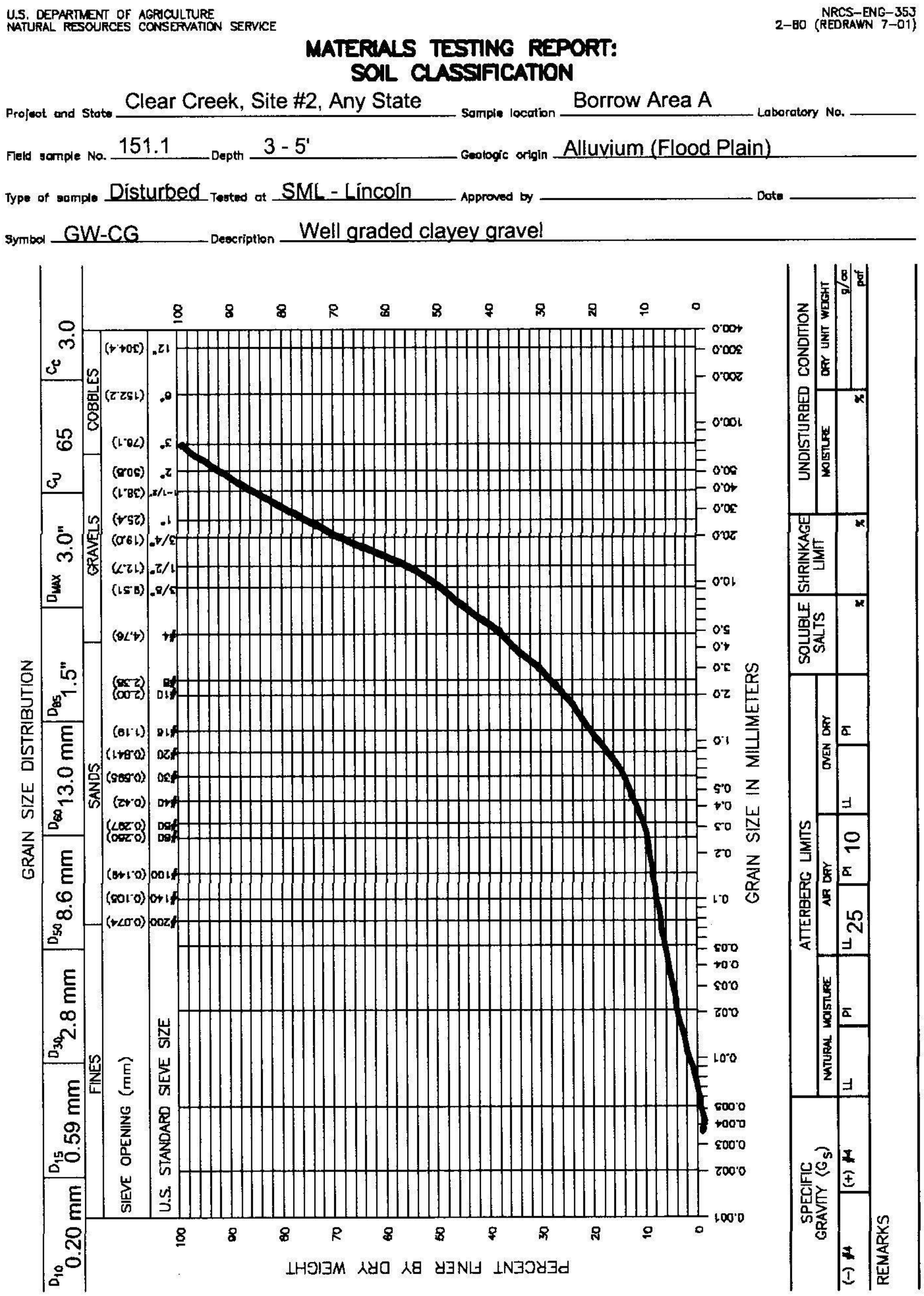
Sieve Separation Method

Coarse grains (larger than 0.062 mm) are ordinarily separated by sieves having mesh openings corresponding to the grain sizes measured. The U.S. standard sieve series is based on a 200-mesh screen with a diameter of 0.074 mm. Sets of sieves with openings larger than this diameter include 0.125 mm, 0.25 mm, 0.50 mm, 2 mm, and 4 mm sizes (Twenhofel and Tyler 1941). Grains of various sizes can be separated by this method according to the scales shown in Table 3. The dry sample is put in the top sieve of a stack and shaken. Usually, 10 minutes in a mechanical shaker is enough for good size separation. The material caught on each screen is weighed, and the results are expressed as a percentage of the total sample weight.

Fall Velocity Method

The settling rate of particles is influenced primarily by the size, shape, and specific gravity of the particles and by the viscosity and temperature of the medium. Of these characteristics, grain size is the most important for a given fluid. The settling rates of various minerals and aggregates vary widely.

Figure 4 has been developed from calculations of settling velocities and laboratory measurements to illustrate the fall velocity of particles in still water at 25°C. The viscosity of water varies with temperature. Settling rates of particles decrease as temperature falls and increase as temperature rises.

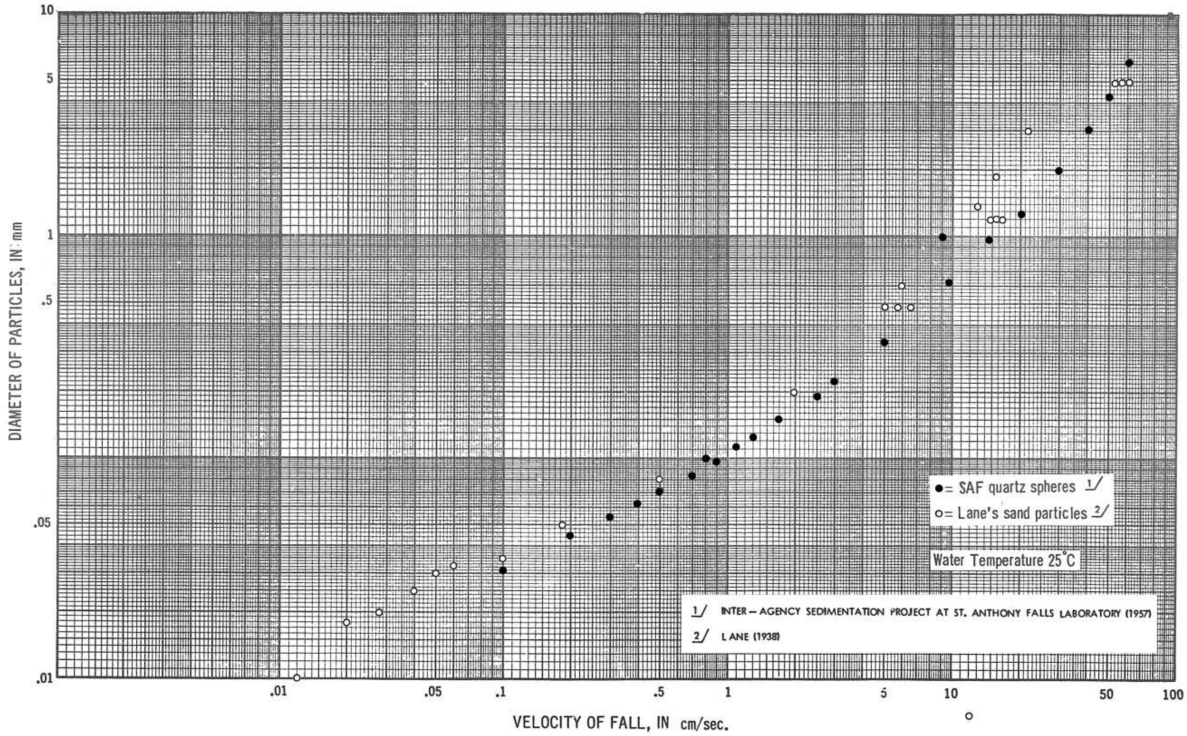

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

NRCS-ENG-353
2-80 (REDRAWN 7-01)

**MATERIALS TESTING REPORT:
SOIL CLASSIFICATION**

Project and State: Clear Creek, Site #2, Any State
Sample location: Borrow Area A
Laboratory No.:
Field sample No.: 151.1
Depth: 3 - 5'
Geologic origin: Alluvium (Flood Plain)
Type of sample: Disturbed
Tested at: SML - Lincoln
Approved by:
Date:
Symbol: GW-CG
Description: Well graded clayey gravel

Figure 3. Grain-size distribution graph.



1/Inter-Agency Sedimentation Project at St. Anthony Falls Laboratory (1957)
2/Lane (1938)

Figure 4. Settling rates of sediment particles.

Bulk Properties of Sediments

This discussion applies primarily to unconsolidated sediments, although sedimentary deposits range from loose deposits of mineral grains to consolidated formations of similar composition that have been lithified into indurated rocks such as sandstone, limestone, and shale. Sources of sediments studied in NRCS watershed investigations can be rocks, weathered zones, or soils. NRCS studies of eroded and transported debris primarily involve unconsolidated, mostly uncemented sediments. The characteristics of all such formations depend on the nature and arrangement of the individual grains in the aggregate. Hence, sorting, environment of deposition, mineral species, water-holding and water-transmitting capacity, and thickness of deposits affect the characteristics of the sediment deposit.

Sorting

The degree of sorting in a sediment deposit is determined by the similarity or dissimilarity of the component particles. Similarity can apply to several characteristics, including size, shape, specific gravity, and mineral or chemical composition. In most sediment studies the classification refers to size distribution. The engineering term "well graded" means poorly sorted and that the deposit contains several size grades.

The following genetic classifications of sediments includes a list of environments in which sediment deposits form, arranged approximately from the most poorly sorted to the best sorted deposits. This classification, like many others, is subject to many exceptions, some of which are indicated in the following summary descriptions.

Glacial and Other Ice-Action Deposits

Deposits formed by glacial action are among the most poorly sorted of all sediment deposits. Glacial till, left by melting glaciers, contains fragments of all sizes, from large boulders to finely ground fragments called rock flour. Moraines and glacial outwash deposits may be more uniform, but they almost always contain much gravel, as well as sand, silt, and clay.

Alluvial Fans

A wide range of sizes is characteristic of piedmont or alluvial-fan deposits. A lower gradient at the foot of steep slopes causes rapid deposition of most of the load of vigorous and rapid streams. Large rock blocks and boulders are commonly mixed with pebbles, sand, silt, and clay with little or no stratification.

Beach Deposits

Sorting of beach (littoral) deposits is usually poor. These deposits are primarily along shorelines and harbors along seacoasts, but they are also along the shorelines of large lakes. Locally, the sediments may be relatively well sorted and uniform in areas where conditions are stable, but in general the alternate rising and falling tides and the alternate dominance of tidal and river currents cause deposition of poorly sorted sediments.

Alluvial Deposits

Sediments composing alluvial deposits vary greatly in size and other characteristics. Alluvial deposits can range in area from a narrow strip in a small stream valley to a great plain such as the High Plains deposit that extends east from the Rocky Mountains.

In the upstream reaches of a valley where stream action is vigorous, alluvial deposits generally are coarse and poorly sorted. In the middle reaches of most streams, the coarsest and most poorly sorted parts of the alluvial deposit form in the channel. This coarse deposit is distributed to some extent over the valley bottom as the stream meanders. The deposits that occur farther downstream usually are better sorted and contain a relatively high percentage of fine sediments – fine sands, silts, and clays.

Colluvial Deposits

These products of upland erosion consist of heterogeneous materials of any particle size that accumulate on the lower part or base of slopes. Colluvium is transported there by gravity (talus), sheetwash, soil creep, and mudflows.

Marine Sediments

Marine sediments range from heterogeneous gravel and boulder deposits to vast widespread oozes in the deep sea. Deposits having the narrowest range of size distribution form where conditions of deposition remain uniform or vary only slightly for long periods. These conditions persist along slowly advancing or retreating shorelines, where great deposits of uniform sands are formed, and widespread deposits of clay are laid in the deeper water. Where conditions are favorable for chemical precipitation, with or without the action of biological agents, thick and extensive deposits of carbonates accumulate. These deposits eventually become crystalline limestone or similar rock.

Eolian Deposits

Most sedimentary deposits of eolian origin are among the better sorted groups of terrestrial deposits. The following four groups of eolian deposits are recognized.

Loess
Loess is one of the best sorted and most texturally uniform of the terrestrial deposits. Loess deposits can range from a featheredge to hundreds of feet thick and consist mainly of silt-size particles that have been transported by wind. Topographic irregularities such as a line of bluffs in a valley increase deposition.

Loess deposits cover wide areas in the United States. Since they are mostly unconsolidated, they are subject to rapid erosion and gully development, and they contribute to accelerated sediment deposition in reservoirs and stream channels and on flood plains.

Sand Dunes

Sand dunes are windblown deposits of grains moved mostly by traction or saltation, especially in semiarid and arid areas. Dunes form in areas such as lake shores, seacoasts, glacial plains, and lake beds as well as in deserts.

Sand dune deposits are generally well sorted and consist predominantly of fine- to medium-grain sands. As a result of the transporting power of the wind, the silt- and clay-size particles may be carried long distances, leaving the sand to accumulate as slow-moving dunes.

Desert pavement or wind-lag deposits

These deposits form in many desert areas where wind removes the sand and finer textured material. The resulting surface is a thin residual concentration of wind-polished, closely packed pebbles, gravel, and other rock fragments.

Lacustrine Deposits

Sediment deposition in lakes and reservoirs produces some of the best sorted nonmarine sedimentary deposits. The bulk of the sediment in most lakes – that found in all the larger and deeper parts of the basins, where currents are not vigorous – is almost entirely silt and clay size. Lacustrine deposits are well sorted and fine grained. The coarser and generally more poorly sorted lacustrine sediments are common along shore zones, where wave action is vigorous and coarse detritus is available, and in upstream segments, where inflowing streams deposit their coarse material.

Chemical Deposits and Evaporites

Sediment deposited from solution and evaporation is the best sorted of all sedimentary deposits. These deposits may consist of mineral crystals of almost uniform size. If organisms are incorporated in the deposit, the shells or skeletons add pieces of different sizes, reducing the degree of sorting.

Volcanic dust and ash

Wind carries great quantities of volcanic dust long distances after volcanic explosions. This material is well sorted. The particles that travel the farthest are all silt and clay size.

Sediment Texture

The size, shape, and arrangement of the particles composing a sediment deposit determine its texture. Differences in the texture of the many types of sediment deposits cause relatively large variations in the damage that results from accelerated deposition.

Coarse sediments of alluvial fans consist chiefly of gravel and boulders and cause major damage if deposited on agricultural land. Overbank flood deposits produce damage that usually increases, as the texture of the deposited sediment becomes coarser. Deposits of clays and silts usually have some fertility, but they may bury crops or impede drainage if thick enough. Regardless of their texture, sediment deposits occupy valuable space in reservoirs, obstruct bridge and culvert openings, decrease stream channel and ditch capacity, and cause many other types of damage.

Differences in the texture of sediment deposits control or modify the uses for which the deposits are suited in agriculture, industry, and construction. Sand and gravel formations are the most important as aquifers and are essential materials in concrete. The uses of sand in glass manufacture, of clays in the ceramics industry, and of combinations of sediment deposits having a variety of textures in construction are beyond the scope of this course.

Cumulative curves (Figure 3) are used for presenting data on particle-size distribution. Histograms relating pyramidal curves to texture are sometimes used. Because the distribution of grain size in most samples is not symmetrical, the amount of skew is also shown by the pyramids. This is well-explained by Pettijohn (1957).

Volume-Weight

One of the most important properties of sediment deposits is weight per unit volume, or volume-weight. Volume-weight – as it applies to measurement of eroded sediment, sediment in transport, and sediment deposits in place – has primary importance in the sedimentary cycle.

Information on the unit weight of sediment deposits for construction or other purposes reflects many variations in properties. For example, a cubic foot of quartz, which has a specific gravity of 2.65, weighs about 165 lb. Similarly, a cubic foot of solid magnetite, specific gravity 5.2, weighs 324 lb. Most sediment deposits, in contrast, weigh about 25 to 125 lb/ft^3 when water-free (USDA 1978). The volume weight of sediment deposits is largely determined by the proportion of voids present. If the sediment is below the water surface, the voids are filled chiefly with water. If the sediment is exposed to the atmosphere, there are fewer voids, and they are filled chiefly with air or a combination of air and water, depending on rainfall, seepage, and other factors.

Volume-weight has been measured in conjunction with many types of investigations, including construction projects, geological surveys, sedimentation surveys of reservoirs and valleys, and soil surveys. Table 4 shows the average volume-weight of some typical reservoir sediment deposits. This table is arranged in two parts: Part A shows the weight per cubic foot, determined by laboratory analysis, of sediment samples from reservoirs in which the water level is near the spillway crest most of the time (submerged sediment), and Part B gives the same information for undisturbed samples from reservoirs in which sediment is exposed to the air during repeated low water levels (aerated sediment).

Table 4. Volume-weight of sediment sampled in selected reservoirs.

Name	Physiographic section	Average volume-weight (lb/ft^3)	Mainstream	Nearest city
Submerged sediment (Part A)				
Lake Throckmorton	Redbeds Plains	31.6	Brazos River	Throckmorton, TX
Lake Ft. Phantom Hill	Red Hills	36.0	Clear Fork, Brazos	Abilene, TX
Grand Saline Reservoir	Forested Coastal Plain	38.7	Saline River	Grand Saline, TX
Lake Woodland	Coastal Plain	39.9	Camp Creek	DeSoto County, MS
Madison Lake	Central Till Plain	49.9	Ohio River	Madison, OH
Crab Orchard Lake	Central Till Plain	47.5	Big Muddy River	Carbondale, IL
White Rock	Black Prairie	49.0	Trinity River	Dallas, TX
Lake Williams	Appalachian Mountains	49.1	Susquehanna River	York, PA
Moran Reservoir	Osage Plains	49.2	Osage River	Moran, KS
Lake Issaqueena	Piedmont Plateau	50.9	Savannah River	Clemson, SC
Mountain Lake	Ozark Mountains	54.8	St. Francis River	Patterson, MO
Herman Lage Pond	Central Till Plain	54.8	Missouri River	Aspinwall, IA
Lake Harris	Piedmont Plateau	59.9	Black Warrior River	Tuscaloosa, AL
Sediment frequently aerated (Part B)				
Franklinton Reservoir	Piedmont Plateau	67.0	Sallie River	Franklinton, NC
White Manganese No. 6	Appalachian Mountains	87.5	Tallapoosa River	Cartersville, GA
Medina Lake	Edwards Plateau	75.0	San Antonio River	San Antonio, TX
Backbone Lake	Driftless Area	75.1	Mississippi River	Stawberrt Pt., IA
Lee Johnson Pond	Coastal Plain	76.1	Tallahatchie River	Holly Springs, MS
Castlewood Reservoir	High Plains	77.5	Arkansas River	Denver, Colo.
West Frankfort Reservoir	Central Till Plain	78.2	Big Muddy River	West Frankfort, IL
Gerber Lake	Sacramento Valley	78.3	Sacramento River	Corning, CA
Loring Lake	Coastal Plain	85.1	Mississippi River	Zwolle, LA
Cobb Creek No. 3	Osage Plains	90.0	Washita River	Colony, OK
Lake Medicine	Redbeds Plains	98.5	Chickaskia River	Medicine Lodge, KS

From USDA-ARS (1978)

Stability of Sediment Deposits

A high degree of angularity of individual sediment grains of silt size or larger promotes stability. A loose aggregation of angular grains is more stable in steeper slopes than an aggregation of more rounded grains. Similarly, angular particles in earth fills increase resistance to slumping and shear. Aggregates of mostly silt- and clay-size particles usually have predominantly angular or platy pieces, but their stability in a fill is determined more by water content and overburden pressure than by the shape of the grains.

Deposits of loess, which may be tens or hundreds of feet thick and are composed of highly angular silt-size particles, tend to stand in nearly vertical faces. Deposits of more rounded grains, such as alluvial or coarse-grained eolian deposits, have lower angles of repose and are usually less stable. Deposits of platy pieces, which have an abundance of grains with two long and one short dimension, are also readily susceptible to sliding. Figure 5 shows the conversions for tons to acre-feet for various volume-weights.

Porosity

Porosity, or the percentage of pore space, is determined by the distribution of fine grains between coarser grains, the shape of the particles, and their arrangement.

Grains of silt and clay occupy spaces between sand and gravel particles and can reduce porosity significantly. Both porosity and stability of sediment deposits are affected by the shape of their mineral grains. Many studies have shown that fine-grained sediments are subject to far more compaction and decrease in volume than are deposits of sand or larger grains.

Table 5 illustrates the range in average porosity of various materials. This table does not take into account the degree of cementation or the fact that, although a fine-grained deposit such as a clay may have high porosity, it permits little movement of water.

Table 5. Approximate average porosity of various formations.[1/]

Formation	Porosity (percent)
Clay	45
Silt	40
Sand	35
Gravel	25
Shale, sandstone	18
Limestone	10
Granite, basalt	1

[1/]From Leopold, Woman, and Miller (1964).

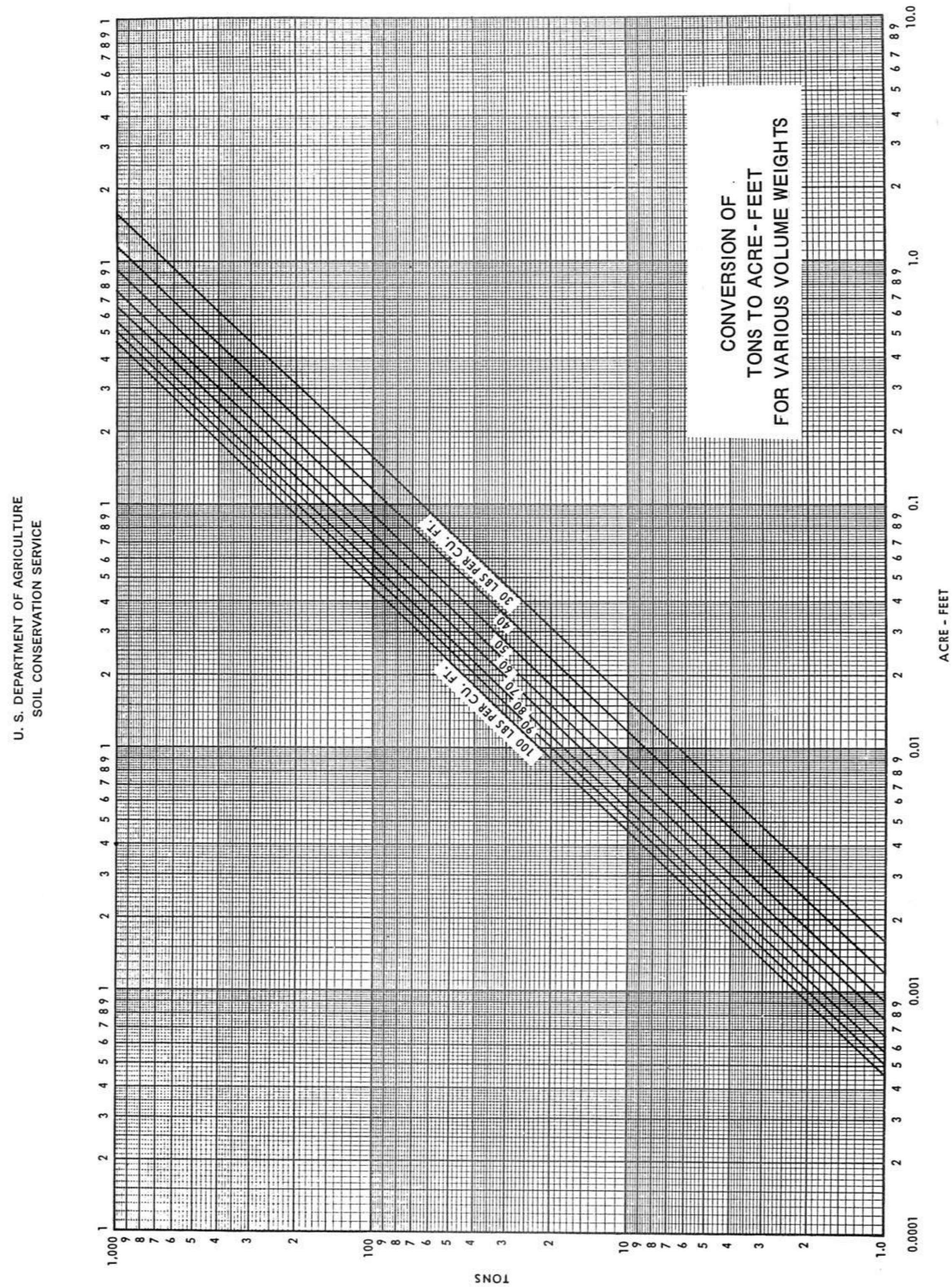


Figure 5. Conversion of tons to acre-feet for various volume-weights.

Permeability

The permeability of sediments varies widely. Permeability is extremely low in clay materials, even though they may have high porosity and be water saturated. The interstices between the clay particles are small enough for molecular attraction to hold water tightly. Permeability is highest for coarse, clean gravel. Table 6 indicates the relation of permeability and porosity to grain-size distribution. Table 7 is convenient for conversions of hydraulic or sedimentation data.

Table 6. Permeability and porosity related to grain-size distribution.[1/]

Percent smaller than indicated grain size by weight							Porosity (percent)	Coefficient of permeability (gal/day/ft²)
2.0 mm	**1.0 mm**	**0.5 mm**	**0.25 mm**	**0.125 mm**	**0.062 mm**	**0.005 mm**		
–	99.4	98.4	95.4	89.7	65.0	21.0	58.2	0.0002
–	–	–	97.5	95.6	94.6	49.3	55.5	0.2
–	93.9	67.8	18.4	3.2	1.3	–	46.6	60.0
84.3	69.1	48.9	29.4	13.0	6.0	1.5	26.3	150
77.6	59.9	34.1	10.6	0.9	0.2 [2/]	–	28.9	1,000
77.7	58.1	38.4	19.3	9.6	5.3	0.9	25.0	2,095
24.3	15.7	6.3	1.1	0.4	0.2 [2/]	–	23.4	4,200
20.2	19.1	16.9	12.0	7.5	4.8	1.2	25.1	20,663
8.4	0.5	0.4	0.3	0.2	0.1 [2/]	–	38.0	90,000

[1/]After Wenzel (1942)

[2/]Includes clay (<0.005mm)

Table 7. Conversion chart for hydraulic or sedimentation data.

Convert from	Multiply to obtain:				
	Cfs-days	**$Ft^3 \times 10^6$**	**$Gal \times 10^6$**	**Acre-ft**	**In/mi^2**
Cfs-days		0.08640	0.64632	1.9835	0.037190
$Ft^3 \times 10^6$	11.574		7.4805	22.957	0.43044
$Gal \times 10^6$	1.5472	0.13368		3.0689	0.05742
Acre-ft	0.50417	0.04356	0.32585		0.018750
In/mi^2	26.889	2.3232	17.379	53.33	

Units, Equivalents and Conversions

The following list of conversions factors is included in this section for the convenience of geologists compiling information on rates, volumes, and quantities of sediment, rock formations, and geologic processes.

Table 8. Conversion list of size, rates, and volumes.

To Convert	Into	Multiply By
acre	hectares or square hectometers square feet (ft^2) square meters (m^2) square miles (mi^2)	0.4047 43,560 4,047 1.562 x 1
acre-feet (acre-ft)	cubic feet (cu ft) cubic yards (cu yd), (yd^3) gallons (gal) megaliters (ML) cubic meters (m^3) cubic dekameters (dam^3) acre-inches	43,560 1,613 325,850 1.234 1,234 1.234 12.00
acre-feet/square mile (acre-ft/sq mi)	cubic feet/acre watershed inches cubic meters/square kilometer (m^3/km^2)	68.06 0.01875 476.3
acre-feet of water	tons cubic dekameters (dam^3) megagrams (Mg)	1,359 1.234 1,234
acre-inches	acre-feet (acre-ft) cubic feet (cu ft), (ft^3)	0.08333 3,630
Celsius (C)	Fahrenheit (F)	1.8°C + 32
centimeters (cm)	feet (ft) inches (in) meters (m) millimeters (mm)	0.03281 0.3937 0.010 10.00
centimeters/second (cm/s)	feet/minute (ft/min)	1.197
cubic centimeters (cm^3)	cubic feet (cu ft), (ft^3) cubic inches (cu in) U.S. gallons (U.S. gal) liters (L) U.S. pints U.S. quarts	3.531×10^{-5} 0.06102 2.642×10^{-4} 0.001 2.113×10^{-3} 1.057×10^{-3}
cubic dekameters (dam^3)	acre-feet (acre-ft)	0.8104

To Convert	Into	Multiply By
cubic feet (cu ft)	cubic centimeters (cm^3) cubic inches (cu in), (in^3) cubic meters (m^3) cubic yards (cu yd), (yd^3) U.S. gallons (U.S. gal) liters (L)	28,320 1,728 0.02832 0.03704 7.481 28.32
cubic feet/acre	acre-inches acre-feet (acre-ft)	2.754×10^{-4} 2.296×10^{-5}
cubic feet of water	pounds (lb) kilograms/square centimeter (kg/cm^2) kilograms/square meter (kg/m^2) pounds/square foot (lbs/ft^2) pounds/square inch (psi or lbs/in^2)	62.43 0.03048 304.8 62.43 0.4335
cubic feet/second (cfs)	acre-feet per day (acre-ft/d) acre-feet per year (acre-ft/yr) gallons/minute (gpm) million gallons/day (mgd) cubic meters/second (m^3/s) liters/second (L/s)	1.984 724.0 448.8 0.6463 0.02832 28.32
cubic feet/second/square mile (CSM)	liters/second/square kilometer ($L/s/km^2$)	0.0915
cubic feet/second-days	cubic feet	86,400
cubic inches (cu in)	cubic centimeters (cm^3) cubic feet (ft^3)	16.39 5.787×10^{-4}
cubic meters (m^3)	cubic feet (ft^3) U.S. gallons (U.S. gal) cubic yards (yd^3)	35.32 264.2 1.308
cubic meters/second (m^3/s)	million gallons/day (M gal/d)	22.83
cubic meters/square kilometer (m^3/km^2)	acre-feet/mi^2	21.0×10^{-4}
cubic mile (U.S. statute)	acre-feet (acre-ft)	3.379×10^{6}
cubic yards (cu yd)	cubic centimeters (cm^3) cubic feet (ft^3) cubic meters (m^3) acre-feet (acre-ft)	7.646×10^{-5} 27.0 0.7646 6.19×10^{-4}
days	seconds (s)	86,400
degrees Fahrenheit (ºF)	degrees Celsius (ºC)	(Fº - 32) 0.5556
Fahrenheit (F)	Celsius (C)	(Fº -32) 0.5556
feet (ft)	centimeters (cm) kilometers (km) meters (m) miles (mi)	30.48 3.048×10^{-4} 0.3048 1.894×10^{-4}

feet/minute (ft/min)	centimeters/second (cm/s) feet/second (fps) kilometers/hour (km/h) miles/hour (mi/h)	0.5080 0.01667 0.01829 0.01136

To Convert	Into	Multiply By
feet/second (ft/sec)	meters/minute (m/min) meters/second (m/s) miles/hour (mph) kilometers/hour (km/h)	18.29 0.3048 0.6818 1.097
gallons (U.S.)	cubic centimeters (cm^3) cubic feet (ft^3) cubic inches (in^3) cubic meters (m^3) gallons-British Imperial (gal Br. Imp.) liters (L)	3,785.0 0.1337 231.0 0.003785 0.8327 3.785
gallons of water	pounds of water	8.3453
gallons/minute (gpm)	cubic feet/second (cfs) cubic meters/day (m^3/d) liters/second (L/s) cubic feet/hour (cu ft/h)	2.228×10^{-3} 5.451 0.06308 8.0208
grams	pounds (lb)	2.205×10^{-3}
grams of water	cubic centimeters of water (cm^3 of H_2O)	1.0 (@ 4ºC)
grams/cubic centimeter (g/cm^3)	kilograms/cubic meter (kg/m^3)	1,000
grams/cubic meter (g/m^3)	parts/million (ppm)	1.0*
hectares	acres square feet (sq ft)	2.471 1.076×10^{-5}
hours (h)	days (d) weeks (wk)	0.04167 5.952 x 10-3
inches (in)	centimeters (cm)	2.540
inches (watershed)	cubic feet/second/square mile (CSM)	13.584
inches eroded	tons (t)[d]	1.815 x volume wt (lbs/ft^3) of upland soil
kilograms (kg)	pounds, avoirdupois (lb) tons (T) megagrams (Mg) or tones	2.205 1.102×10^{-3} 1×10^{-3}
kilograms/second (kg/sec) kilograms/cubic meter (kg/m^3kilometers (km)	tons/year (T/yr) pounds/cubic foot (lbs/ft^3) miles (mi)	34,786 0.06243 0.6214
liters (L)	cubic centimeters (cm^3) cubic feet (cu ft) gallons (gal)	1,000 0.03531 0.2642
liters/second	cubic feet/second (cfs)	0.03531

liters/second/square kilometer (L/s/km^2)	cubic feet/second/square mile (CSM)	10.93

To Convert	Into	Multiply By
megagrams (Mg)	tons (T)	1.1023
megagrams/square kilometer (Mg/km^2)	tons/square mile	2.8571
megaliters (ML)	acre-feet (acre-ft)	0.8104
meters (m)	yards (yd) feet (ft) inches (in) miles, U.S. Stat. (mi)	1.094 3.281 39.37 6.214 x 10^{-4}
meters/second (m/s)	feet/second (ft/sec)	3.281
micrometer (μm)	meters (m) cubic dekameters (dam^3)	1.0 x 10^{-6} 1.0
miles, U.S. Stat, (mi)	kilometers (km)	1.609
miles/hour (mph)	feet/second (ft/sec)	1.467
milliliters (ml)	liters (L)	1.0 x 10^{-3}
millimeters (mm)	inches (in) micrometers (*μ*m)	0.03937 1.0 x 10^{-3}
million gallons/day (mgd)	cubic feet/second (cfs or ft^3/sec) acre-feet/day cubic/meters/minute (m^3/min)	1.547 3.069 2.629
minutes, angular (min)	degrees (deg)	0.01667
ounces (oz)	grams (g) pounds (lb)	28.35 0.0625
ounces/gallon (U.S.) (oz/gal U.S.)	grams/liter (gm/L)	7.489
parts per million (ppm)	grams/cubic meter (g/m^3)	1.0*
pounds (lb)	grains grams (g) kilograms (kg) ounces (oz) tons	7,000 453.6 0.4536 16.00 0.0005
pounds of water	cubic feet (ft^3) cubic inches (in^3) gallons (gal)	0.01602 27.68 0.1198
pounds of water/minute	cubic feet/second (cfs or ft^3/sec)	2.670 x 10^{-3}
pounds/cubic foot (lb/ft^3)	grams/cubic centimeter (g/cm^3) kilograms/cubic meter (kg/m^3) tons/acre-foot (T/acre-ft) kilograms/cubic meter (kg/m^3)	0.01602 16.02 21.78 16.02
pounds/cubic inch	grams/cubic centimeter (g/cm^3)	27.68

pounds/gallon (U.S.)	grams/liter (g/L)	119.8

To Convert	Into	Multiply By
pounds/square foot (lb/ft^2)	pounds/square inch (psi or lb/in^2)	6.944×10^{-3}
pounds/second/foot	kilograms/second/meter	1.488
rods	feet (ft) miles (mi)	16.50 3.125×10^{-3}
seconds (s)	days	1.157×10^{-5}
square centimeters (cm^2)	square inches (in^2)	0.1550
square feet (ft^2)	acres square meters (m^2)	2.296×10^{-4} 0.0929
square inches (in^2)	square centimeters (cm^2)	6.452
square kilometers (km^2)	square miles (mi^2) acres	0.3861 247.1
square meters (m^2)	square feet (ft^2) square yards (yd^2)	10.76 1.196
square miles (mi^2)	acres square feet (ft^2) square kilometers (km^2) square meters (m^2) square yards (yd^2)	640 27.88×10^6 2.590 2.590×10^6 3.098×10^6
square yards (yd^2)	square feet (ft^2) square meters (m^2)	9.000 0.8361
tonnes	tons pounds (lb) megagrams (Mg)	1.103 2205 1,000
tons (long)	pounds (lb) tons pounds (lb)	2,240 1.102 2,205
tons	kilograms (kg) megagrams (Mg) pounds (lb) tons (long) tonnes	907.2 0.9072 2,000 0.8929 0.9072
tons/square mile	megagrams/square kilometer (Mg/km^2) tons/acre (T/acre)	0.350 1.5625×10^{-3}
tons of water/24 hr	pounds of water/hour gallons/minute (gpm) cubic feet/hour (ft^3/hr)	83.33 0.1664 1.335
tons/acre-foot	pounds/cubic foot (lb/ft^3)	0.04591
watershed inches	acre-feet/square mile ($acre\text{-}ft/mi^2$) acre-feet (total)	53.33 53.33 x drainage area in mi^2

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