

WATERSHED SOILS



By Susan Pater & Kim McReynolds

“A river seems a magic thing. A magic, moving, living part of the very earth itself - for it is from the soil, both from its depth and from its surface, that a river has its beginning.” –Laura Gilpin, The Rio Grande, 1949

INTRODUCTION

Soils, their condition, and connective relationships play extremely important roles in controlling how water moves over and through a watershed. By studying the relationships among soil properties, soil positions in the landscape, and watershed hydrology, a better understanding can be gained and thus better decisions regarding watershed plans and activities can be made. Because soils affect so many practical activities such as agricultural production, home site development, road construction, gardening and landscaping, parks, and preserve areas, a general knowledge of soils is essential for implementation of a successful watershed enhancement or management activities.

SOIL BASICS: WHAT IS SOIL?

Soil. Earth. Dirt. No matter what we call it, it's the material that constitutes the outermost solid layer of the planet. Many people think of soil as dirt. When it is on our hands or clothing it may be called dirt, but when it is found in its natural place, in fields and gardens, it should be called soil. Soil – the unconsolidated **mineral** and **organic matter** on the immediate surface of the earth that serves as a natural medium for the growth of plants. Dirt is soil out of place.

Soil provides the major necessities of life for most life on the planet. It is the foothold for the food, fiber and feed crops we grow. All of our cereal crops such as wheat, oats, barley, rye, rice, sorghum, corn and millet are derived indirectly from soil. Meat, milk, wool and leather come from livestock which obtain their energy and a major portion of their nutrient needs from forage grasses. Our homes and many home furnishings are constructed from forest products that require soils for growth.

Although soil appears unchanging and lifeless,

In this section, you will learn:

- ❖ About soil formation.
- ❖ About key soil properties.
- ❖ How to read a soil survey for watershed basics.
- ❖ How soils function in watersheds.
- ❖ How soil erosion occurs.
- ❖ Some strategies to prevent soil erosion in watersheds.

soils are actually dynamic mixtures, teeming with life. One teaspoon of soil in temperate regions can contain billions of organisms ranging from simple bacteria and fungi to more advanced forms such as earthworms, insects, and spiders. Soils are also sites of constant chemical and physical change. Bedrock, the solid rock underlying the looser materials of the earth's surface, is continually fractured, dissolved, and changed into soil; but this process occurs so slowly we usually never notice. Chemicals dissolved in water or produced and consumed by various soil organisms are constant moving and reacting in soil.

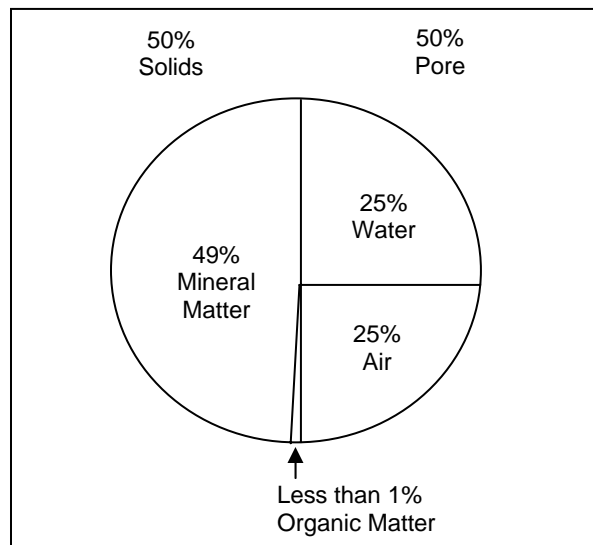


Figure 1. Composition of soil by volume.

The following sections will explain the basics of soil, including soil composition, formation, structure, physical properties, and soil ecosystems.

SOIL BASICS: SOIL COMPOSITION

Soil is a naturally occurring mixture of mineral and organic ingredients with a definite form, structure, and composition. The exact composition of soil varies widely from one location to another. The following is an average composition by volume of the major soil ingredients in Arizona: 49% mineral matter (clay, silt, sand, gravel, stones); 25% water (the amount varies depending upon precipitation and the water-holding capacity of the soil); 25% air; and less than 1% organic matter (both living and dead organisms) (Figure 1).

A soil is composed primarily of minerals which are produced from parent material that is weathered or broken into small pieces. Beyond occasional stones, gravel, and other rock debris, most of the mineral particles are typically sand, silt, or clay. These mineral particles give soil its texture.

Water and air occupy the pore spaces—the area between the mineral particles. From these small spaces, water and air are available for use by plants. These small pore spaces are essential to the life of soil organisms, to soil productivity, and to plant growth.

The final ingredient of a soil is organic matter. It is comprised of dead plant and animal material and the billions of living organisms that inhabit the soil.

SOIL BASICS: FORMATION

Soil formation proceeds in a series of stages, none of which is distinct or easily identifiable. It is often difficult to determine where one process ends and another begins. In the initial development of soil, the formation processes include: weathering, where new materials are produced through chemical transformations and the size of soil particles may be reduced; deposition or accumulation is where new ingredients are added to soil; translocation is the

process of elements moving within the soil; and losses such as leaching, is where components are removed from the soil. The kind of soil formed is determined by a combination of five important factors: (1) the nature of the parent material, (2) climate, (3) plant and animal life, (4) topography and (5) time.

Parent material refers to the organic and mineral material in which soil formation begins. Mineral matter includes partially weathered rock, ash from volcanoes, sediments moved and deposited by wind and water, or ground up rock deposited by glaciers. Mechanical and chemical weathering acts on the solid and massive rocks of the earth's crust to produce particles; sand, silt, and clay. Freezing and thawing are examples of mechanical weathering. The reactions produced by water and air in contact with the rock minerals are examples of chemical weathering.

Climate helps change parent material into soil. Precipitation, temperature, wind, and sunlight are the major climatic factors affecting soil formation. Frequent freezing and thawing will cause water trapped in cracks to expand, exerting pressures which fracture the rocks and smaller materials even further. Alternate wetting and drying also break down particles because not all minerals expand and contract at the same rate. Further, water tends to dissolve certain minerals from parent material. Areas with low rainfall tend to transform soil materials more slowly than areas with high rainfall. Where temperatures vary widely from daytime to nighttime, rocks tend to crumble more rapidly. The climate also affects the amount of life which occurs on a soil's surface and the rate at which these living organisms break down following their death.

Plant and animal life may include fungi, bacteria, other microorganisms, earthworms, insects, rodents, other animals, vegetation, and mammals including humans. Plants may begin to grow on parent rock even before it begins to crumble. Bacteria, fungi and lichens are the first to grow on rock surfaces. Shallow rooted plants soon become established, followed by deep rooted plants which become established in cracks and crevices as rock continues to crumble under the influence of climatic factors.

Soon insects, rodents, and mammals become a

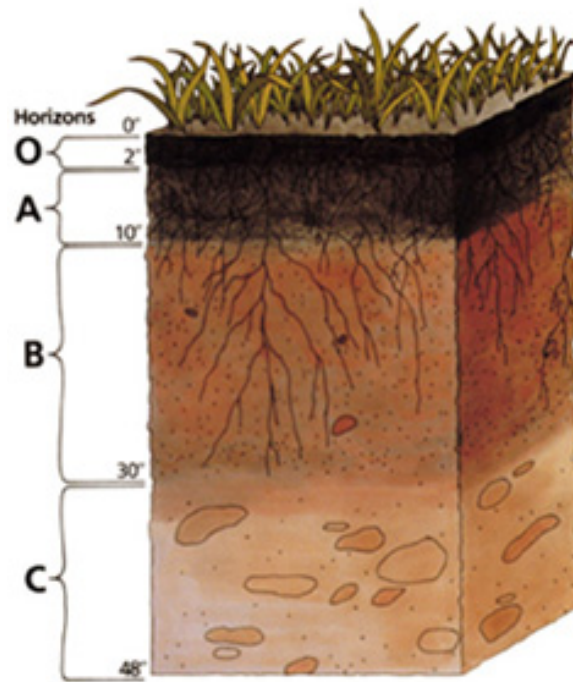
part of the system. As animals dig through the soil, they break it up, permitting more air and water to enter. They mix the organic matter throughout the soil. Plants and animals also enrich the soil by breaking down organic matter into simpler components, and releasing nutrients. These actions help form topsoil on moderately and well developed soils. The types of organisms living on and in the soil help to determine what kind of soil will develop; for example, very different soils form in prairies versus woodlands.

Topography is the hilliness, flatness, or amount of slope (gradient) of the land. Soils vary with topography primarily because of the influence of moisture and erosion. In many areas, moist, poorly drained soils are located in low areas, and depressions of the land. In contrast, soils in sloping areas can be drier and well drained. These soils tend to be moderately and well developed. Erosion can remove all or part of the topsoil and subsoil, leaving a weakly developed soil.

Time - the age of a soil must be considered in thousands and even millions of years since it may take hundreds of years to form one inch of soil from parent material. The length of time that climate and plants and animals act on a given parent material with a specific topography determines the degree of development. Generally, the longer soil materials stay in one place, the deeper and more developed (mature) the soil becomes.

SOIL BASICS: SOIL HORIZONS

Soils develop into layers. These layers, called **soil horizons**, can be observed by viewing a **soil profile** (a vertical section of soil from the surface slicing through all its horizons, including the parent material) along road cuts and other areas where the soil is exposed. Generally, there are two or more major horizons in a soil



profile depending on how well the soil has developed (Figure 2). The presence and thickness of each horizon varies with location. In poorly developed soils, such as those formed in recent parent material deposits, or those in disturbed conditions such as heavy agriculture, building sites, or severe erosion, not all horizons will be present.

The upper layer, called the O horizon, is made up of organic matter, including decayed leaves, grass and animals. This layer is dark because of the decomposing organic materials present. The second layer, called the A horizon, is the mineral horizon at the surface showing organic matter enrichment. This is generally the most productive layer of soil and is often called topsoil. There is some organic matter in this area, as well as most of the creatures that live in the soil. In most cultivated fields, the O horizon does not exist and the A horizon is the upper soil layer.

Textural Group		Textural Classes
Sandy	Coarse	Sand Loamy sand
Loamy	Moderately Coarse	Sandy loam
	Medium	Loam Silt loam Silt
	Moderately Fine	Clay loam Sandy clay loam Silty clay loam
Clayey	Fine	Sandy clay Silty clay Clay

Table 1. Soil texture groups and classes.

The next layer is the E horizon, a subsurface horizon. As water moves down through the soil, many soluble minerals and nutrients dissolve in the water and leach from this part of the soil. Thus, the E horizon is a zone of leaching.

The next layer is the B horizon or subsoil. Subsoils generally have more clay, are usually light colored, dense, and low in organic matter. The subsoil is a zone of accumulation since many of the materials leached from the topsoil accumulate here.

Still deeper is the C horizon. It is the soil parent material (from which the soil is formed). Below the C horizon bedrock may be found. The depth of each soil layer depends on the soil's age and the climatic conditions that formed the soil.

SOIL BASICS: PHYSICAL PROPERTIES

The physical properties of soil help determine, to a large extent, how a soil can best be used by humans in a watershed. A soil's physical properties are those factors which can be seen and felt. Important physical properties include texture, structure, depth, and color.

Soil texture refers to the relative proportion of sand, silt and clay particles in a soil. Sand

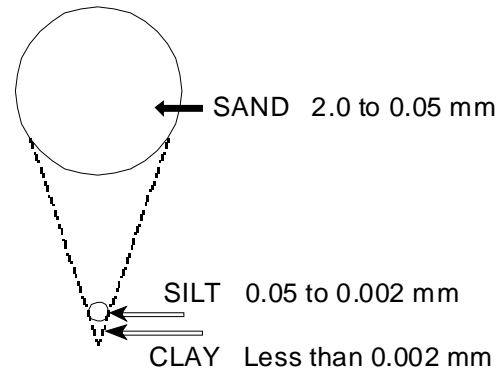


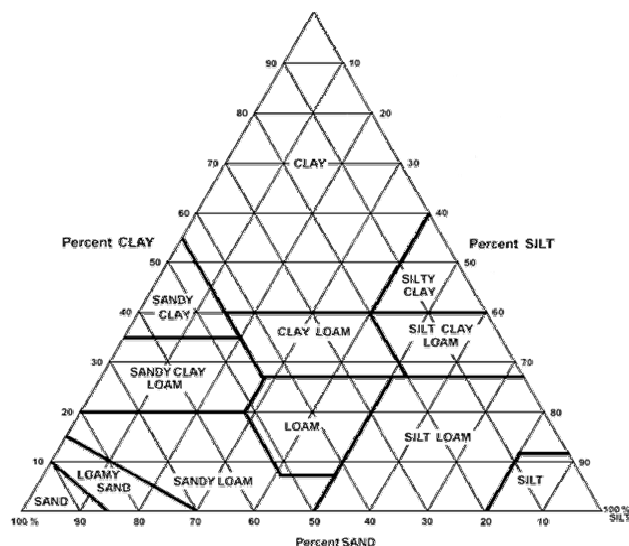
Figure 3. Relative size of soil particles.

particles are quite large and have a gritty feeling. Silt particles are much smaller than sand and feel smooth when wet. Clay particles are very small and feel greasy and sticky when wet. The relative size of soil particles is illustrated in Figure 3.

Soil texture affects how much water runs off a soil when it rains, how much soaks into a soil when it rains, how much moisture a soil can hold, and how much of this held moisture is available to a plant. Twelve soil texture classes are recognized in the United States. The texture triangle (Figure 4) indicates the relative proportion of sand, silt, and clay in a textural class.

Soil textural classes such as sand, loamy sand, and sandy loam soils have coarse soil particles and a limited ability to hold water for plant growth. Textural classes containing mainly clay and silt size particles possess a greater ability to hold water in the soil profile. Fine-textured soils,

Figure 4. Soil texture triangle.



clays and clay loams, may swell and shrink while drying. This causes cracking on the soil surface. With some types of clay, the shrink-swell movement is great enough to crack foundations or road beds built on the soil.

Soils are often referred to as coarse, medium, or fine textured. In general, the finer the texture:

- ☼ the more difficult a soil is to work or till,
- ☼ the greater the water holding capacity,
- ☼ the slower water will enter and move through the soil profile,
- ☼ the more difficult for roots to penetrate,
- ☼ the more readily surface soil will crust,
- ☼ the more nutrient rich the soil.

In addition, a soil containing 20 to 30 percent clay and 50 to 60 percent silt is quite resistant to erosion by both wind and water.

Soil structure refers to the way individual soil particles are grouped together to form larger pieces of soil structural groups, known as “peds” or “aggregates”. Sandy and other loose soils which contain very little clay or organic matter to bind soil particles together may not show structure. They are typically single grained. Soils that have large lumps, no visible structure and are hard to break apart are usually fine-textured clay soils.

The structure of soil horizons largely determines the ease with which plant roots can penetrate the soil. In addition, soil structure influences water absorption and movement in soil, the ease with which soil can be tilled, and its resistance to wind and water erosion. Soils that have a granular structure in the A and E horizon and prismatic and/or blocky structure in the B horizon are ideal for air and water movement and plant root penetration. These are important characteristics for watershed soils.

Soil depth refers to the total depth of soil material (A, E and B horizons) that is favorable for the growth of plant roots. The distance from the soil surface down to a growth limiting layer determines the effective rooting depth of soil. The effective depth of soil is described as deep, moderately deep, shallow, or very shallow.

Soil color is one of the most obvious characteristics of soil. It is most often used to

describe soil horizons. Dark colored surface soil usually indicates a soil high in organic matter and nutrients. Color also indicates the degree of internal drainage in soils. Soils with a uniform grayish brown to yellowish brown subsoil have good internal water movement. Poorly drained soils have gray and olive gray subsoil colors or they may possess mixed colors or “mottles” of gray, olive and yellow. Mottling is a color condition in which several colors occur in a splotted or spotty pattern. The mottled color condition indicates the occurrence of extended periods of excessive wetness in the soil layer in which it occurs, combined with alternating drier periods.

SOIL BASICS: LIFE UNDERGROUND

Plants and animals have important roles to play in soil. Both plants and animals change the composition and structure of soil in many different ways (Figure 5).

Plants obtain nutrients and moisture from soil through their roots. Roots are also a force for change in soil structure and properties. The combination of cellular division and elongation in the growing portion of these organs creates great pressures that move soil around. These pressures are often great enough to cause large boulders to fracture if a root grows into a crack.

Like the great energy recyclers that they are, plants transfer energy and chemicals around soil through their roots. Roots get energy to grow from carbohydrates or sugars that are made during photosynthesis--a process that occurs in plant leaves. As the roots grow, they use oxygen from the surrounding pore spaces for respiration. The carbon dioxide given off reacts with soil to form weak carbonic acid. Roots absorb nutrients and water primarily through tiny projections called root hairs. This is called the region of absorption. Nutrients held near clay and humus particles are transported to the root hairs by the soil water in which both are bathed. The weak carbonic acid produced by the root reacts with chemical nutrients on the surfaces of soil particles. These nutrients, including ions of magnesium, calcium, sodium, potassium, phosphorus, and nitrogen, are absorbed by root hairs. The chemical ion exchange through which soil nutrients are released to plant roots, called

nutrient exchange, occurs continuously around the roots.

Although plants are the most visible organisms, many fungi, bacteria, and animals also inhabit soils. Mites, spiders, yeast, slime molds, insects, protozoans, colonies of algae, worms, moles, and bacteria are among the millions of life forms found in a small patch of soil. In fact, some scientists believe that there is more than biodiversity in soil than in tropical rainforests or coral reefs. These members of complex soil ecosystems produce, consume, or digest organic matter and pass the nutrient-enriched products through their bodies and back into the soil itself. This activity recycles nutrients and makes soil richer. In addition, the movement of larger organisms through soil allows air and water to penetrate the soil more rapidly. In short, life is vital to keeping soils healthy.

SOIL SURVEYS

Soil surveys provide a scientific inventory of one of our most basic and important natural resources – the soil. The soil survey contains information in the form of detailed soil maps, data tables, photographs, and text narratives. Soil surveys provide a variety of users with information about soils and how to manage them properly. By investigating data on the chemical and physical properties of soil, interpretations can be provided for agricultural, forestry, and urban uses. The survey also highlights limitations and hazards inherent in the soil. A soil survey is fundamental for sound soil and water management, crop production, and land use.

Soil scientists have identified over 6,000 unique and distinctly different soils in Arizona. Each soil has characteristic physical and chemical properties. By studying these properties, soil scientists and other professionals can predict how a soil will respond to specific land use and management. Below are some of the important characteristics evaluated for various uses.

Evaluating Soil Drainage Characteristics

- ☛ Locating potential water recharge areas
- ☛ Soil limitations for on-site sewage disposal (septic systems)
- ☛ Locating potential pond reservoir areas

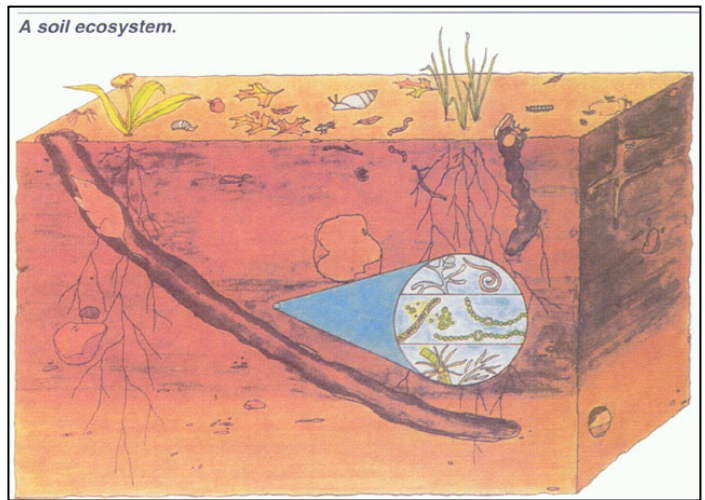


Figure 5. A soil ecosystem. Image courtesy NRCS.

Evaluating Soil Characteristics that Affect Construction

- ☛ Swelling and shrinking of certain clayey soils
- ☛ Depth to bedrock, stoniness
- ☛ Soil limitations due to slope
- ☛ Soil properties that affect load bearing capacity
- ☛ Soils that are subject to flooding or ponding

Evaluating Soils for Type and Location of Recreational Sites

- ☛ Surface texture of the soil (too clayey or sandy)
- ☛ Are the soils subject to flash flooding
- ☛ Feasibility of soils for sanitary facilities

Planning Land Use

- ☛ Determine the most appropriate areas for urban growth: soil maps serve to flag probable growth areas or soil poorly suited for urban use
- ☛ Reserving open areas: reserve suitable open space for future generations
- ☛ Identifying water recharge areas: soil maps can show various hydrological characteristics
- ☛ Recognizing potential use conflict areas:

urban encroachment on high quality agricultural soils

Soil survey maps are good for planning, initial decision making, and helping you understand what to expect when you visit the site. However, they are not detailed enough to make remote or in-office recommendations. A field investigation is necessary for proper site and soil evaluation.

KEY SOIL INTERPRETATIONS FOR WATERSHED MANAGEMENT

Watershed soils influence many aspects of management. Soils play pivotal roles in moving water through the landscape, whether above or below ground. Measuring these processes is a challenge that has not been successfully simplified. But it is possible to make estimations of how soils will react in a particular watershed. These management interpretations are based on knowledge of the soil's texture, structure, organic matter, density, and soil horizons.

Ground surface characteristics	Soil properties
Texture	Vegetation cover
Structure	Amount of duff and litter
Organic matter	Amount of impervious surface
Porosity	Surface roughness
Depth	Surface cracking
Layering	Surface crusting and sealing
Physical conditions	Water repellency
Water already in soil	Natural plant chemicals
Frozen soil	Fire-induced hydrophobicity
Trapped air	Extreme dryness

Table 3. Factors that influence infiltration rates.

Many of these interpretations can be found in soil surveys of your watershed. Specifically, the information will be found in tables on Physical and Chemical Properties and on Soil and Water Features. Some of these interpretations include permeability, depth to bedrock, depth of water table, and hydrologic group.

POROSITY, PERMEABILITY, & INFILTRATION

Soil porosity is influenced by the size, shape and arrangement of particles. The porosity (amount of space between the particles) allows for movement of air, water, mineral and organic materials, and living organisms. The number of pores and the size of the pores are determined by the soil texture and structure. The size distribution of pores is important because large pores act as conduits for water to move into the soil, whereas small pores hold water for plants to use when they need it.

Permeability (hydraulic conductivity) and infiltration rate are two closely related properties. Permeability is the rate of water movement in the soil, whereas infiltration is the rate that water enters into the soil from the surface. Infiltration happens when water contacts soil while permeability is governed by physical properties within the soil profile. Both of these processes are influenced by soil texture, changes in soil texture between surface and subsurface, impermeable layers, and depth to bedrock, as well as by soil management. Water can permeate between granular void or pore spaces, and fractures between rocks. In a given soil, the larger the pore space, the more permeable the material. Infiltration is important for storing water in the soil profile for plant growth and for reducing runoff and erosion. For these reasons, we will explore infiltration a little more in-depth.

Infiltration is a very complex process that is affected by many factors (see Table 3). One is time. You might observe that water readily enters soil, but as soil gets wetter, the rate of entry slows down. In other cases, water might run off a very dry soil until the soil becomes moistened.

Many other factors affect infiltration, including the kind and amount of vegetative cover, the amount of organic matter and the strength and stability of soil structure. Compaction, which reduces soil porosity, can slow infiltration substantially. Hot forest or range fires can create vapors of organic compounds that condense in soil, making it hydrophobic, or water resistant.

Because infiltration is such a complex and dynamic process, it's difficult to define the characteristic infiltration rate of a given soil, and you won't find infiltration data in a soil survey report. Sometimes we use permeability of the surface soil as an indicator of potential infiltration, but this is not true infiltration. More often, we evaluate infiltration in relative terms, based on key properties of the surface soil. Then we compare relative infiltration potentials among several soils in a watershed.

Permeability rates range from very slow (<0.06 inches/hour) in tight, clayey soils to very rapid (>2.0 inches/hour) in coarse, gravelly soils. Medium-textured soils (loams and silty loams) usually have moderately slow (0.2-0.6 inches/hour) to moderate (0.6-2.0 inches/hour) permeability. For a given texture, a high organic matter content and high porosity increase permeability. If soil with the same texture has very little organic matter or is more dense, permeability can be much slower.

Permeability is given in a soil survey for each three or four major layers in the soil. If the texture changes little with depth, permeability is similar in all layers. Many soils, however, have subsoils whose texture or density differs dramatically from that of the surface layer. Heavy, clay layers, layers of weathered bedrock, and naturally dense layers all have much slower permeability than layers above them. These restrictions cause water to perch above them, and the water is diverted laterally to flow parallel to and above the restricting layer. We refer to this type of flow as throughflow.

Water moving laterally through the landscape might break out at the surface, forming seeps or springs elsewhere in the watershed, or it might discharge directly into a stream, wetland or lake. In any case, throughflow is a major hydrological process directly influenced by soil structure.

Bulk density is a measure of the mass of particles that are packed into a volume of soil. Density increases when particles are pressed together, reducing overall pore space. Compaction can result from a natural event such as being under a heavy snow load or from wildlife or livestock trampling. It may also be the result of human activity such as constructing a building, driving a vehicle or even walking across a soil. In general, a soil with low bulk

density will allow water to flow through it with relative ease and have a high or fast infiltration rate and high permeability, whereas if that same soil has a high bulk density it will have slower infiltration rates and lower permeability. However, bulk density tells us nothing about pore size which has a critical effect on infiltration rate and permeability. For example, sandy soils usually have higher bulk densities than clay soils, yet because the pores in the sand are much larger than those in the clay, infiltration rate and permeability are generally higher in the sand.

LEACHING

Leaching is the process by which water moving through the soil carries with it soluble materials picked up en route. In humid regions, leaching removes soluble salts, gypsum, and carbonates. Under these conditions, the soil will eventually acidify. In the arid Southwest, where rainfall is not sufficient to do this, salts, carbonates and gypsum will often build up in soils. The carbonate or gypsum layers in upper soil horizons form caliche or calcified zones that form layers impenetrable to plant roots and sometimes water.

Leaching can carry **nitrate**s and other soluble fertilizer materials below the root zone. Leaching also can transport soluble residues from some chemical pesticides. Leaching can result in contamination of the groundwater if unwanted materials move within water downward through the soil. Later leaching also occurs as water moves through the landscape roughly parallel to the land surface. Throughflow discharge into streams and lakes as well as discharge from drainage lines in soil, can add contaminants to surface water bodies.

RUNOFF AND HYDROLOGIC GROUP

Runoff is simply overland flow that occurs when inputs from rainfall or irrigation exceed the infiltration capacity of the soil. The goal of watershed management is to conduct runoff water downslope in ways that minimize its potential to cause erosion on hillslopes and sedimentation in streams and lakes. Techniques for achieving this goal are discussed in the sections on erosion control.

Hydrologic group is a soil survey interpretation that groups soils with similar runoff potential given similar storm and groundwater conditions. Soil properties that influence runoff potential include texture, structure, depth to seasonally high water table, permeability after prolonged wetting, and depth to a very slowly permeable layer.

In soil surveys, there are four basic hydrologic groups—A, B,C, and D:

- ☂ Group A soils have low runoff potential. They have both high infiltration rates and high permeability rates and consist mainly of deep sands or gravels.
- ☂ Group B soils have moderately low runoff potential and moderate rates of infiltration and permeability. They consist mainly of silt loams, silty clay loams, loams, clay loams, and sandy loams that are more than 20 inches deep.
- ☂ Group C soils have moderately high runoff potential. Slow rates of infiltration and permeability are caused either by clayey textures or by a slowly permeable subsoil layer.
- ☂ Group D soils have high runoff potential because of very slow rates of infiltration and permeability. Because they drain so slowly, they remain wet for long periods and cannot absorb much additional water. High shrink-swell clays, soils with a permeable high water table, those with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material are in this group.

ERODIBILITY

Erodibility reflects a soil's susceptibility to the erosive force of water running over bare soil. Texture, structure, and organic matter content are the primary properties that influence erodibility of exposed soils. Sandy soils with adequate amounts of organic matter and well-developed structure are the least erodible. Silty soils with low amounts of organic matter and very weak structure in the surface soil are the most erodible.

Erodibility is characterized by the K factor of the Universal Soil Loss Equation (see side bar). K is simply a number that has been derived from numerous experiments in which simulated rainfall is applied to a wide variety of soils. Values of K range from 0.02 to 0.67, with higher numbers indicating higher erodibility. K values are provided in soil survey reports and are particularly useful for comparing the relative erodibility of two or more soils.

The Universal Soil Loss Equation

$A = RKLS\overline{C}P$

where A= erosion soil loss in tons per acre per year

R=the rainfall factor

K=the soil erodibility factor

L=the slope-length factor

S=the slope-gradient factor

C=the vegetative cover

P=the practices used in erosion control

DEPTH TO WATER TABLE

Water tables can be measured, but because of high seasonal and annual variability, only long-term records provide useful information. Because long-term data are scarce, water table information in soil surveys is based largely on an interpretation of color patterns in the soil.

Well-aerated soils have brown colors because iron oxides coat soil grains, much as rust coats a piece of iron. In saturated soils, some of the iron is removed in solution, leaving gray, uncoated soil grains. As the soil dries out and the air reenters the larger pores, iron might again oxidize, creating a bright yellowish-brown spot.

These patterns of gray and yellowish-brown colors are interpreted by soil scientists as indicators of the long-term average position of the seasonally high water table. These estimated depths are the numbers reported in soil survey reports.

The presence of a high water table might affect buildings, septic systems, crops, pastures, plant species, riparian areas, and the use of mechanized equipment.

The previous section was adapted with permission from the Oregon State University Extension Service publication EM 8714, Watershed Stewardship: A Learning Guide (Oregon State University, Corvallis, Oregon, new July 1998, revised January 2002), 485 pp. \$42.00.

WATERSHED SOIL FUNCTIONS

Soils are a key link between upland and lowland portions of watersheds. From a watershed stewardship perspective, they have at least four major functions. These include:

1. **Regulate watershed hydrology:** Soils regulate the balance between infiltration and runoff. All water that falls on the watershed can do one of two things: it can either run off the landscape, or soak into the soil. The latter is better of these two options. As water soaks into the soil, it continues to move within landscape according to the principles of permeability. From within the soil, water can move into the aquifer, where it can slowly recharge surface springs, lakes and streams as lateral throughflow. If water does not infiltrate and then move through the soil slowly, it can cause more erosion on the surface as runoff, depending on vegetation and topography. The most important lesson here is that any land-use activity that alters infiltration of watershed soils will change the balance between water soaking into soils or running off. Some of the practices that affect this balance include: soil compaction, covering soil with impermeable surfaces, removing topsoil, or removing organic matter from soil.
2. **Regulate nutrients in the environment:** Soils are the primary source for plant nutrients. The organic matter in soils is a major source of nitrogen, phosphorus, sulfur and a host of micronutrients. Soil organisms help break down this organic matter into nutrient forms available to plants. Soils also often contain sources of calcium, magnesium, and potassium.
3. **Regulate water quality:** Soils improve water quality by filtering out significant quantities of nonpoint source pollution before they are

carried into groundwater or discharged into streams as runoff. Sediment that is trapped in soils will not contaminate Arizona water bodies without some form of erosion taking place (see below).

4. **Provide habitat for life:** Soil is home to plant roots, burrowing animals and millions of organisms such as fungi, bacteria, algae, protozoa, insects, spiders, worms, etc. These organisms are important components in the ecosystems that maintain healthy watersheds. Soils are often the basis for that health.

SOIL EROSION PROCESSES

Erosion is the process which moves soil from one location to another by wind, water, or other natural action. It is a natural process unless accelerated by humans. From a human-centered perspective, soil erosion may have several harmful effects. Farmers harvest a smaller crop per acre, and fields become less productive if large gullies develop. Silt from eroded soil builds up in our waterways, causing more frequent flooding and higher costs for navigation. Costly dredging is often required to correct silt problems.

It is important to remember that soil erosion is a natural process and has benefits for watersheds. For example, seasonal flood deposition in river deltas, and along channels results in stable riparian communities, increased habitat, and rich floodplain soils. But accelerated soil erosion in the United States delivers an estimated 1 billion



Figure 6. Splash erosion. Photo courtesy NRCS.

tons of sediment to streams and lake each year.

Soil erosion is a three-step process. Detachment happens when energy—either by wind, water or physical/mechanical processes—is applied to soil particles. In the case of water-driven erosion, transport happens when the particle is suspended in the water column and moved down gradient (down hill). Deposition occurs when the energy used to move the soil particle drops sufficiently to allow it to settle into a stream bed, on a floodplain, or at the base of a slope. Of these three processes, the first is the easiest to deal with. That is why we must work hard to prevent soil particle detachment by conserving the forces that hold soils peds together: vegetation, soil organic matter, and soil structure.

It is usually easy to find evidence of soil erosion that is caused by moving water; soil scientists have identified four types: splash, sheet, rill, and gully.

Splash erosion (Figure 6) happens when rain falls on the bare soil surface and loosens soil particles. It is perhaps the most severe because it loosens and spreads soil particles which can then be readily carried off by water or wind.



Figure 7. Sheet erosion. Photo courtesy NRCS.

Sheet erosion is the most difficult to see. Water flows across the soil in a layer or sheet. It is the gradual wearing away of a thin, uniform layer (or sheet) of soil. There are no channels formed by the moving water. Sheet erosion occurs where there is not enough vegetation covering the soil to stop erosion completely, yet there is enough



Figure 8. Rill erosion. Photo courtesy NRCS.



Figure 9. Gully erosion. Photo courtesy USDA.

cover to prevent rill erosion. It is seen as muddy runoff water (Figure 7).

Rill erosion occurs on slopes where the runoff water accumulates into small channels. Rill erosion can be seen as many small channels of a few inches depth, yet the channels are not large enough to interfere with the movement of farm equipment. Rill erosion occurs on slopes that are gentle or have little protective vegetation (see Figure 8).

Gully erosion is the most dramatic form of soil erosion. Gullies form when the runoff water accumulates into channels. The rapidly moving water causes the channel to grow wider and deeper. Gullies may become too deep for farm equipment to cross. Gully erosion occurs on steeper slopes which have little or no vegetation (Figure 9).

Although gully erosion is the most evident and dramatic, sheet and rill erosion are a greater national concern. Sheet and rill erosion remove an average of 5 tons of soil from every acre of cultivated cropland each year. (A pickup truck can hold about 1-2 tons of material; and an acre is about the size of a football field.) In addition to sheet, rill, and gully erosion by water, soils are eroded two other ways. Wind erosion and land slippage also cause soils to move from one location to another.

Land slippage refers to blocks of saturated soil moving down slopes in response to gravity. It is usually seen as a cave-in of a cliff or bluff that overhangs a river or stream. Land slippage can also be seen as small landslides or mudslides along steep road embankments. The famous mudslides of southern California that damage homes and roads are recurring examples of land slippage. Less evident examples can be seen along cultivated fields. Blocks of soil tend to creep down slopes during the winter from frequent freezing and thawing. Dramatic land slippage is often caused by earthquakes.

PRACTICES TO PREVENT SOIL EROSION IN WATERSHEDS

Erosion is most likely to have significant environmental impact on bare, exposed or compacted areas. Important locations where such might be found include road rights-of-way, construction or development sites, recreational areas, agricultural fields, grazed areas, or logged areas. Preventing or controlling erosion and sedimentation from these critical areas is largely a matter of exercising common sense. The following sections detail some of the key concepts for doing so.

Consider Extreme Events

Extreme events are periods of very heavy precipitation or high stream flow that might trigger mass failures or major water erosion. While we cannot avoid them look to urban and rural landscapes with an eye to what will happen when they occur. One simple example is to be aware of the meander bed or high-water mark in a stream when you select the site for fields, home, trails, or roadways. Remember even a dry wash will respond to a strong downpour!

Promote Infiltration & Permeability

One method of restoring infiltration and permeability is deep tillage of heavily compacted areas. Another is to improve growing conditions for protective vegetation. Where topsoil has been lost or removed, the addition of organic matter, nitrogen-fixing plants (legumes) or planting annual and perennial grasses can restore productivity.

Use Physical Barriers & Sediment Traps

Infiltration is enhanced whenever water slows down as it runs across the landscape. Slow or low-energy water is better able to soak into soil, while fast runoff will barely soak into the top portion of the soil. You can see this when a heavy thunderstorm drops a lot of rain on the land but little of it penetrates beyond the first few inches of soil, while a deep, soaking rain produces wet soil often to well below the root zone.

Washes deliver a large portion of Arizona's runoff to major streams. Since washes drain upland areas these tributaries are often the sites of nature and accelerated erosion, depending upon the land use. One of the simplest means of slowing water in washes is through the construction of check dams (also called gabions—although this is a different structure composed of baskets filled with rock). As illustrated below (Figure 10), the check dam is constructed of materials that trap water between two points, slowing its flow slightly and allowing sediment to drop out of suspension. They also allow infiltration to take place.

Another even simpler method involves leaving organic matter, slash from logging operations, duff from grasslands, or crop residues on the surface of the soil. This slows the water flowing over it and helps prevent soil from moving off site and into streams. Adding mulch accomplishes the same thing—and is an effective tool with both urban landscaping and farms. These methods leave the land surface as rough as possible.

Gabions, as mentioned above, are wire baskets filled with rock that stabilize a slope or stream bank. In some cases, these can be constructed

of straw bales—a technique frequently employed by the US Forest Service to prevent soil erosion after fires.

Use Vegetation or Buffer Strips

Vegetation enhances infiltration with its roots holding soil in place and its complicated above-ground growth slowing precipitation. Plants and their litter shield the soil from raindrops, which can break down soil structure and clog large pores, resulting in surface runoff. Plants, roots, litter also help slow surface runoff (see above). Watershed enhancement thus should include measures to conserve and improve native vegetative cover and litter accumulation. Besides beautification, this is one of the primary reasons that Arizona Department of Transportation plants wildflowers, grasses, trees and shrubs along Arizona roadways. Vegetation near pastures, along streams, canals, and at the edges of logged areas serves similar purposes.



Figure 10. Check dam. Photo courtesy of ADEQ.

Keep in mind, however, that some revegetation projects can have unintended consequences. In some cases, young trees will use more water than previous established vegetation, while some species planted may prove to be invasive and difficult to eradicate. Because of these issues, do not recommend revegetation without consulting with experts in local plant ecology.

Control Erosion in Urban Areas

Most erosion in urban areas is associated with runoff originating from construction sites (where soil is exposed and structure is destroyed), and from impervious surfaces such as roofs, streets, parking lots and sidewalks. Controlling erosion from bare exposed soil at construction sites is largely a matter of common sense: minimize the amount of soil exposed, keep water off disturbed or compacted soil, plan for catch basins and sediment traps in case runoff does occur, mulch, and revegetate as soon as possible. Many communities now require silt fences, sediment basins, and covering piles of excavated soil.

Runoff from impervious surfaces causes erosion when large volumes of water are concentrated into very small channels that discharge onto the ground surface or into natural stream channels. Homeowners can help control this type of erosion by making sure gutter downspouts don't discharge directly onto bare soil, as well as by harvesting water for use on their landscape.

At the community level, runoff from houses, driveways, and streets usually enters the storm sewer system. The point of concern is where the steward enters a natural discharge channel. Because storm events such as thunderstorms can generate very high discharge volumes, soil in the channel and along banks is particularly vulnerable to erosion. The first line of defense is to make sure that these channels are well vegetated, and in some cases, anchored with rock, gravel or riprap.

The key take-home lesson here is that people living in urban areas can do their part to prevent erosion by collecting rainwater on-site and using this untapped asset to water their landscapes. Likewise, businesses can have a similar effect by keeping parking lot and roof runoff on-site and using it to water landscaped areas.

Controlling Erosion in Agricultural Areas

Erosion control strategies on agricultural soils focus on promoting infiltration, slowing runoff, and reducing stream bank erosion. Continuous vegetative cover promotes infiltration, so it may be good to use permanent cover crops or to

leave dry cover in place on highly erodible soils whenever possible. The one caveat with leaving live cover crops in place is that they will use more water than if a field were fallowed, therefore, this approach should be used only where appropriate and not in areas where aquifer depletion is imminent, or where irrigation restrictions apply. Minimum tillage practices that replace moldboard plowing can leave plant residues behind that will hold soils in place. Further benefits of this technique are that it tends to leave less soil exposed and that it minimizes machine compaction.

Runoff gains speed as it flows downhill over long slopes, and runoff velocities are higher on steeper grades. A major goal of erosion control is to slow down water as moves over the landscape. This can be done by contour tillage, where tilling is directed towards the slope and not against it. The effect is of creating a series of miniature check-dams that move water across the slope rather than directly down it. Bench terraces, which shorten the length of the slope down which water runs have a similar effect. Grassed waterways—although rare in Arizona—keep water from moving as rapidly and hold soil in place.

Controlling Erosion in Ranching Country

In ranching country, several techniques are critical to improving or maintaining watershed soils while preventing erosion. These include bank stabilization, riparian buffers, and rotating pastures.

Where grazing animals have unrestricted access to stream channels, soils immediately adjacent to the stream often become denuded, compacted, and less resistant to erosion. By locating water troughs, stockponds, and salt licks in uplands, you can attract livestock away from wet soils, streams, and small drainages.

The most important technique for checking erosion on rangelands is proper grazing management. This means keeping cattle off of sensitive areas, maintaining sufficient cover at all times of the year, and reducing grazing in riparian areas. Grazing management also includes pasture rotation, corralling livestock for periods of new forage growth, resting pastures,

selective irrigation, and limiting animals.





Control of Erosion of Forested Areas

Because undisturbed soils have the highest rates of infiltration, the most important goal is to disturb as little of the natural forest floor as possible. In timber harvest, this means controlling auto or machine traffic, designating and policing trails.


Forested areas are also usually the in the headwaters for streams, so maintaining healthy stream conditions is vital for the health of the watershed downstream. Controlling sediment is the primary key to watershed health in these areas. The practices that increase erosion increase sediment build up. These practices include anything that disturbs or opens the forest floor to erosive processes such as water, wind or mechanical impacts.

Most timber harvest operations will site roads away from streams, and leave vegetative buffers in place to capture any runoff before it reaches the water. Culverts need to be sited carefully to reduce high pressure runoff events and to keep equipment out of tributary streams (even if they are dry during operations). Slash and biomass need to be left on the soil wherever possible. After forest fires or controlled burns, check-dams may be constructed to slow down runoff from bare slopes (see **Fire in Watersheds** for more information).

TAKING ACTION: OTHER ACTIVITIES YOU CAN DO

-  Learn to recognize different types of soil erosion.
-  Look up a soil survey of your watershed. Use it to understand why erosion occurs in some parts of the watershed and not others. Soil surveys can be found through the USDA Natural Resources Conservation Service (NRCS) <http://soils.usda.gov/>
-  Learn more about the ways to prevent soil erosion by visiting the USDA Natural Resources Conservation Service website: <http://soils.usda.gov/>
-  Contact your local Natural Resource

Conservation District (NRCD) or Resource Conservation and Development area (RC & D) for more information on local soils.

 Get involved in local soil conservation projects such as check-dam construction, post-fire recovery efforts, or revegetation.

WORDS TO KNOW

Alluvium – the deposits of clay, silt, sand and gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a floodplain, delta or at the base of a mountain.

Bulk density - a measure of the mass of particles that are packed into a volume of soil.

Deposition – the act of depositing materials; in geology refers to materials that have been moved by some mechanical, biological, or other physical process.

Erodibility – a measure of the soil's susceptibility to the erosive force of water running over bare ground.

Erosion – the wearing away and removal of materials of the Earth's crust by natural means; includes weathering, solution, corrosion, and transportation.

Geology - the study of the planet Earth, its rocky exterior, its history, and the processes that act upon it.

Infiltration capacity – a measure of the soil's capacity to allow water to penetrate the surface and enter the lower soil profiles.

Leaching – the process by which water moving through the soil carries with it soluble materials picked up en route.

Mineral – a naturally occurring mixture of tightly bound, crystallized, inorganic elements that forms material with unique physical properties.

Nitrate – a chemical molecule combining one nitrogen and two oxygen atoms.

Organic matter – material composed of waste and decaying matter produced by living organisms.

Permeability - the rate of water movement in the soil; influenced by infiltration and porosity.

Rock - a basic geologic material made up of different minerals in hard or crystallized form.

Runoff - overland flow that occurs when inputs from rainfall or irrigation exceed the infiltration capacity of the soil.

Sediment - geologic deposits from water; mineral particles derived from soil, alluvial or rock materials moved by water; sediment also refers to material in suspension in water or recently deposited from suspension.

Sediment load - the total sediment, including bedload, being moved by flowing water in a stream at a specific cross section.

Sedimentation – the process of depositing sediment from suspension in water.

Soil horizon – a layer of soil distinct in color, texture or constituency from its neighboring layers.

Soil porosity – the amount of space between the soil particles that allows for movement of air, water, mineral and organic materials, as well as living organisms

Soil profile – a vertical section of the soil slicing through all of its horizons from surface to parent material.

Suspended sediment – particles suspended in the water column.

Turbidity – a measure of the reduced transparency of water due to suspended material; colloidal material, or dissolved color.

Weathering – the process of removing particles of a material—usually rock—through mechanical, biological or other physical processes (such as through the action of wind and water).

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