Chapter 1

Trails Embedded in Ecosystems

Introduction

All recreational trails are human constructs embedded in an ecological matrix. Just as it is critically important for surgeons to understand the anatomy and physiology of the human body, it is important for trail builders to have at least some awareness and understanding of "bodies" in which they will embed trails.

Among nonmotorized uses of trails, recreational horse use is the most frequently criticized for ecosystem damage. All trail users have impacts on soils, water, and vegetation. Equestrian use may have some unique impacts compared to other uses. Proper trail design, construction, maintenance, and use can prevent these impacts from becoming significant.

People working with and using trails must become aware of and conversant about what it is in the ecological matrix they are trying to protect as they establish and use trail systems. Furthermore, failure to become proficient in the most fundamental terms and concepts of ecology establishes a vulnerability to entities that are dogmatically opposed to recreational horse trails on the grounds of incompatibility with natural ecosystem components and processes.

The following brief introduction to some fundamental ecological terms and concepts will give the reader the basic tools for thinking about and arguing the case for establishment and management of recreational horse trails. This is only a primer, but hopefully, it will be a starting point for further development for those seriously interested in the *preservation of a cultural heritage in a natural heritage setting.*

Guiding Principles

The most fundamental unit in ecology is the *ecosystem.* An ecosystem is the *biotic community* (the assemblage of living things) embedded in its *abiotic environment* (the environment as defined by particular geological substrates, soils, water, atmosphere, topography, and climate). The abiotic environment defines the limitations for the assemblage of living things.

Interactions between plants, animals, and microorganisms and their abiotic environment result in a flow of energy and nutrients via such processes as photosynthesis, nutrient uptake by plants, herbivore foraging, predation, fire, and decay, and transfer of genetic material (breeding and reproduction) within and between ecosystems. These processes are collectively called the *ecosystem dynamic.*

Disruption of the ecosystem dynamic is called *ecosystem fragmentation* (often shortened to *fragmentation*). It is not unusual to hear the fragmentation charge brought against proposals for trails. Because of the very small scale of physical disturbance caused by recreational horse trails, and assuming that the trail is not proposed for a highly fragile environment, such charges typically lack merit. However, there are situations, such as small stream and bog crossings, where the possibilities for fragmentation of the aquatic community, at least at the micro-scale, should be given serious consideration.

Biodiversity is an ecosystem characteristic defined as the array of ecosystem components (species) and processes (the various interactions within and between species and their environment). Biodiversity may be naturally high, such as in rainforests, or naturally low, such as in deserts. What becomes important in the context of trails is that construction, maintenance, and use of the trail system must not adversely impact biodiversity. The National Forest Management Act of 1976 clearly mandates the maintenance of biodiversity on National Forest System lands.[1] The Endangered Species Act of 1973 explicitly mandates the preservation of the ecosystems[2], thus their biodiversity, upon which threatened and endangered species depend. Arguments against recreational trails will usually have a biodiversity conservation aspect. Except in very fragile systems, or fragile areas within ecosystems, such charges usually can be effectively countered on a scientific basis.

Ecosystems are also characterized by a range of *capacities* to withstand disturbance without undergoing major change. Systems that can withstand little disturbance without significant change are classified as *fragile.* Those that can withstand substantial disturbance are classified as *robust.* Deserts and alpine ecosystems tend to be fragile. In contrast, hardwood forests on stony soils are gen-

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[1] See National Forest Management Act of 1976 § 6(g)(3)(B).

[2] See Endangered Species Act of 1973 §2(b).

erally robust relative to their capacity to accommodate recreational trails.

Ecosystem capacities to accommodate recreational trails can be thought of in the same manner as evaluating the capacities of various people to perform challenging physical tasks in a range of different environmental conditions. For example, a football linebacker can be expected to lift heavy loads and carry them for long distances in rain or in sunshine and remain healthy. In contrast, a ballerina, a different type of athlete having a more delicate bone structure and musculature, would be seriously injured if forced to perform the same physically arduous tasks as those readily accomplished by the linebacker.

The principle of *cumulative effects* is related to the concept of ecosystem capacities. The principle of cumulative effects states that while a single disturbance may not cause a significant adverse effect, that disturbance repeated many times or in combination with other types of disturbance has a sum total effect that is significant. In the context of trail riding activities, many, probably most, ecosystems can withstand a single person on a horse going just about anywhere at any time once, or maybe even a few times, without any significant adverse effects. However, when the event happens hundreds or thousands of times, the impacts can be cumulatively significant in a given ecosystem under certain conditions.

The term *ecosystem health* has been around since the 1940s, but it was only in the 1990s that its use became common. Ecosystem health is about the capacity of the system to either resist change, or to recover from change and be at least as biologically productive as it was before disturbance, but not necessarily look like the old system. The former condition is called *resistance*, and the ecosystem is *robust*. The latter health capacity is called *resilience*. Southern maritime forest ecosystems dominated by live oak and cabbage palmetto are resistant systems that evolved in the presence of the high level stresses of cyclonic winds and oceanic salt spray associated with hurricanes. Barrier island flats with communities of grasses, sedges and rushes tend to be resilient, as even when buried by oceanic overwash, they quickly recover to about the same level of productivity as before disturbance.

If there is one place where horse trails might be charged, with some credibility, with adversely impacting ecosystem health, it will be in the area of water quality. Management of the public lands has moved increasingly to an ecosystem management approach. Ecosystem management is being implemented with a watershed unit approach. It is assumed that if a watershed is undergoing adverse changes, these changes will be reflected in changes in its water quality. Trail construction and use that result in excessive stream siltation might be charged with adversely impacting ecosystem health.

One of America's most prominent pioneering ecologist, Dr. Eugene Odum (1913-2002), proposed that there are three types of ecosystems: a) *natural*, b) *developed*, and c) *fabricated*. Natural ecosystems have biodiversity characteristics that are the result of evolution with relatively minor impacts by modern humans, although aboriginal humans may have had substantial impacts on them. Interestingly, Mann (2005) reports that landscapes of the Americas were substantially developed by aboriginal peoples prior to 1492. Developed landscapes are those heavily influenced by agricultural practices, including farm and range management, and intensive forest management. Fabricated landscapes are the urban and suburban areas where human communities are fed, clothed, and sheltered with products from natural and developed ecosystems that also supply them with clean water and clean air. It is in natural ecosystems that most people seek their wildland recreational trail experiences, including recreational horse trail experiences. Because of both their aesthetic and ecological values, contemporary societies tend to be very protective of natural ecosystems, thus protective of wildlands.

In summary, recreational horse trails on wildlands are embedded mainly in natural ecosystems that are largely under government agency jurisdiction. Since the 1960s, statutory provisions such as the Multiple-Use Sustained Yield Act, Wilderness Act, National Trail Systems Act, National Environmental Policy Act, Endangered Species Act, Clean Water Act, Forest and Rangelands Renewable Resources Planning Act, National Forest Management Act, Federal Land Policy Management Act, etc., have directed how agencies must protect ecosystems and manage activities that may impact these ecosystems. Our ability to maintain the availability of existing trails, as well as establish new ones, for horse use will critically hinge on our ability to clearly demonstrate compatibility between recreational trail horse use and ecosystem protection. To make the compatibility argument, we must know and effectively use the most fundamental terminology and concepts of ecology.

The Ecosystem: The Abiotic Environment

Soils

When a trail is embedded in an ecosystem, its initial point of contact is the soil. People who spend their lives working with soils find it very awkward to use the term "dirt." To them, and it should be to all of us, soil is a highly complex ecological entity that has evolved over long periods of time during which it was shaped by the interactions of physical, chemical, and biological processes. Furthermore, soil is the growth medium for green plants that make possible life as we know it on this planet. The famous soil chemist, Hans Jenny (1904-1972), once said: "No man can know all there is to know about even a teaspoon of soil." To a soil scientist, dirt is misplaced soil. Natural soils are to be respected and treated ethically.

Knowledge of soils is a highly evolved and evolving science and no one can know all of the existing science. Trail builders need not be soil scientists, but they do need to be aware of some basic soil properties. The four most important of these properties are *texture*, *drainage*, *structure*, and *bulk density*.

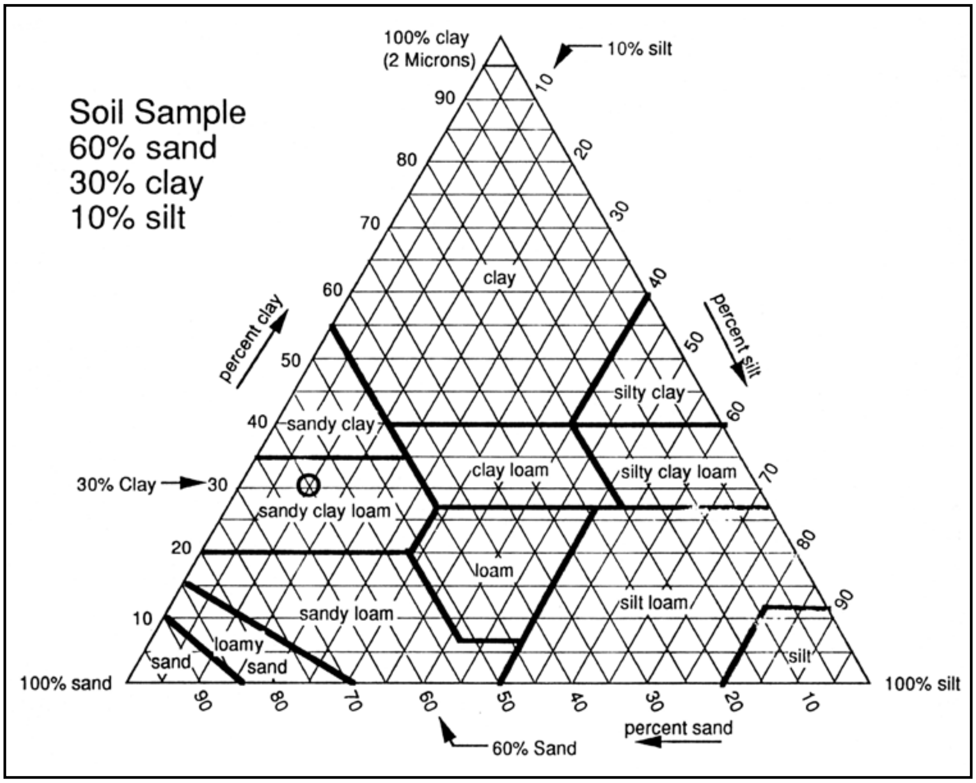

Figure 1.1. Soil texture triangle describing soil texture classes as recognized by the U. S. Department of Agriculture (Soil Survey Staff 1993). Example demonstrates the determination of texture of a soil sample as a sandy clay loam.

Texture

While soils have physical, chemical, and biological properties, it is the physical properties with which trail builders and managers are most concerned. Soils contain mineral particles, organic matter, water, and air. *Mineral particles* are the primary components of the soil and are separated by diameter size classes: a) *sand* – 0.05-2.0 mm, *silt* – 0.05-0.002 mm, and *clay* – less than 0.002 mm. *Soil texture* is a term describing the various mixtures of mineral particles by percentages of sand, silt and clay. The *soil texture triangle* places all of the possible combinations into texture classes and gives us easily understandable terms for describing the property of texture (Figure 1.1).

A common, although incomplete and often inadequate, way of referring to soil texture is with the terms *light* (or *coarse*), *medium*, and *heavy* (or *fine*). Light textured soils are those with physical properties determined primarily or entirely by the sand component. Medium textured soils are typically loams with substantial proportions of at least two primary particle sizes. Heavy textured soils are those with physical properties that are determined primarily by the clay component.

The particle size that has the greatest influence on the soil's properties, and not necessarily the one in greatest proportion, gives the texture class its name. For example, any soil that is at least 40% clay is a clay soil although it may be a sandy clay or a silty clay where in each case the sand or silt percentages may be greater than the clay percentage.

For the trail builder to understand why some texture classes are better than others for trail construction, it is important to understand some of the properties of the primary particles as they are described below:

Sand: Sand is often subdivided into five classes based on particle size: very coarse, coarse, medium, fine, and very fine. For a soil to be called a sand, sand particles must make up at least 70% of the soil. Sand has little water holding capacity, therefore it drains readily and we never get mudholes on sands. However, sands have no *cohesion*, i.e., no capacity to bind one particle to another - the particles do not stick together. Therefore, the *tread* (bare surface) of a trail in a sand is easily reshaped by mechanical forces, the most important of which will be water movement, trail traffic, and, in open areas, wind. Wet sands tolerate trail traffic better than do dry sands. Treads on fine sands will have greater durability than will those on coarse sands.

Silt: Silt has some cohesion due to a film of water that surrounds each particle, but the water is held with little tension. It has some *plasticity*, a property that allows it, when moist, to be shaped or molded into a form, but it does not hold this form well due to its low cohesion. Because of these properties, trails on soils dominated by silt characteristics should be considered as sensitive to types, intensities, and timing of use relative to soil moisture conditions. Silts are also highly erodible. Even when appropriately constructed, treads on these soils will be sensitive to water movement and trail traffic, particularly the latter when the soil is wet.

Clay. Clay binds soil particles together. It gives the soil body form and the capacity to maintain that form. Soils low in clay content have little ability to maintain a form such as a trail tread.

While there are a number of types (*mineral types*) of clays, three are of most concern: *kaolinite*, *illite*, and *montmorillonite*. In the context of trail tread considerations, the most important differences in properties between these three types are in plasticity, cohesion, and *adsorption*[3] of water. Montmorillonite has the highest values for these properties, while kaolinite has the lowest. This makes the kaolinite the superior of the three for road and trail construction purposes.

Kaolinite is a non-expanding clay mineral. That is, the kaolinite particle (*micelle*) adsorbs an envelope of water around its outer surface, but the lattice structure of the particle is fixed, so it does not expand from inside the particle. In contrast, montmorillonite is an expanding, double lattice clay that can *absorb*[3] water in the interior of its structure as well as adsorbing it to the exterior surface. Illite is also a double lattice clay but the lattice is fixed and it does not expand. Because of its large surface area, illite holds a fairly large amount of water, consequently it has more stickiness and plasticity than kaolinite. The expansion characteristic is usually referred to as the shrink/swell potential. A tendency to undergo large amounts of shrinking and swelling with varying moisture levels will cause substantial trail tread maintenance problems.

Because of their size and potential for electrochemical activity, all clays have substantial cohesiveness. However, the double lattice clays have it to a greater extent because of the physical structure, chemical composition, and distribution of electrically charged sites on their particles. This has consequences for trail use. For comparison, a horse walking on a moist soil high in kaolinitic clay is likely to be on a slippery surface, and there will be some accumulation of mud on its hooves due to *adhesion*[3] of clay to hoof. On a moist soil high in montmorillonite, the horse's hooves will likely sink well into the soil, a result of the soil's plasticity, and they will be quickly burdened with lots of mud due to the high cohesion among the clay particles, i.e. clay particles sticking to clay particles for a mudballing effect.

In the context of trail construction, in regions where the kaolinitic clays predominate, the best treads will have very high levels of clay. In regions where the double lattice clays predominate, loamy soils with substantial amounts of sand but with sufficient clay to suppress potential for erosion are likely to be the best.

Coarse Fragments

Coarse fragments in a soil include *gravel*, *cobble*, *stones, and boulders*. Coarse fragments are the detached fragments of *bedrock*. (Technically, *rock* is bedrock.) Just as in the description of primary soil particles, coarse fragments are separated by size classes. Gravel is larger than sand particles but less than 3 in. in diameter. Cobble is 3 to10 in. in diameter. Stones are greater than 10 in. but less than 24 in. in diameter. Fragments greater than 24 in. in diameter are *boulders*. Table 1.1 gives the names for soil conditions with coarse fragments of various sizes.

Soils with predominant coarse fragments that are rounded, sub-rounded, or angular and greater than 10 in. but less than 24 in. in diameter are *stony*, as are those with thin, flat fragments greater than 15 in. but less than 24 in. long. When the predominant coarse fragments are greater than 24 in. in diameter or length, the condition is called *bouldery*.

Soils that are gravelly, cherty, cobbly, slatey, shaley, or flaggy with these materials occupying 25 – 75% of the

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[3] Adsorption is the process of a substance sticking to the surface of another substance. In contrast, absorption is the process of a substance penetrating the body of another substance. Water may adhere (process of adhesion) to the surface of glass, but it will be absorbed by the fibers of a piece of wood.

Table 1.1 Descriptions of Coarse Fragment Fractions of Soil

Shape and Kind of Fragment	Name			
	Diameter (inches)		Length (inches)	
	up to 3	3 -10	up to 6	6-15
Rounded/Sub-Rounded (all kinds of rock)	gravelly	cobbly		
Irregular shaped, angular fragments: Chert Other	 cherty angular gravelly	 coarse cherty angular cobbly		
Thin, flat fragments: sandstone, limestone, schist Slate Shale			 channery slatey shaley	 flaggy flaggy flaggy

surface soil volume will usually sustain good trail treads, although at the upper end of this range, the cherty and cobbly materials may present some construction challenges. The best treads are flaggy with the thin, flat fragments functioning as a lattice of pavers with soil compacted in the interspaces. These coarse fragments might occupy up to 75% of the surface soil volume without causing major problems for trail construction and use. Treads in this condition are highly resistant to erosion as well as being resistant to being reshaped by trail horse traffic (Table 1.2).

As the gravel, chert, and cobble exceed 75% of the surface soil, new problems may begin to occur. Gravel materials will tend to roll over each other, especially as the trail grade increases. Footing for the trail horse may be unstable on moderate grades of 6-8%. In addition, the gravel and chert materials will be prone to movement by water on grades of 10-15%.

Organic Matter

Organic matter associated with the soil is grossly described as being in two conditions, incorporated and unincorporated. *Unincorporated organic matter* is either the relatively recently deposited plant litter in various stages of decay lying on the surface of the soil, or the dead and decaying roots surrounded by soil. *Incorporated organic matter* is actually *humus* and is incorporated into the mineral soil body where it is physically and chemically interacting with the mineral soil particles. Humus particles are *colloidal*[4] in size, i.e., they are comparable to the size of clay particles.

From the standpoint of trail tread construction and maintenance, organic matter is not a desirable component of the surface soil. Organic matter in the form of humus can absorb an amount of water that exceeds its own dry weight by a factor of 8 to 10. This is a good thing when you are growing plants. It's a bad thing when you want a trail tread that does not retain water so that a boggy or mucky spot is likely to develop with use.

Unincorporated organic matter can be a problem for the trail tread if it is not removed in the construction process. When left in place with the expectation that trail traffic will simply wear through it, a mulching process is initiated with the mulch holding moisture to the tread and usually creating a mucky trail.

Soils that are referred to as organic soils are of two main types commonly called *peats* (*peatland* soils) and *mucks* (*muckland* soils). Peat soils are soils with deep organic layers where much, if not most, of the organic material has not decayed beyond the point of recognition of its origin. This condition is likely to prevail in wetlands and very cold soils in northern latitudes and at high elevations. Muck soils have large accumulations of organic matter that has decayed to the humus condition and is not recognizable with respect to its origin. In the modern soil classification system (Appendix E), these soils are collectively called *Histosols*. Histosols, particularly those that are mucks, often have been drained and used for crop and commercial tree production. However, Histosols should be avoided for recreational horse trail construction.

Drainage

There are two types of drainage – surface and vertical. Surface drainage relates to how water moves across the surface of the soil. Vertical drainage is how water moves vertically through (or *percolates* through) the soil profile. The rate at which water moves through or accumulates

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[4] That is, they are equal to or less than 0.002 mm in diameter and exhibit strong electro-chemical activity.

Table 1.2 Surface soil stoniness and rockiness and levels of concern for a trail tread that will be ecologically sound and user safe.

Levels: 1 = no concern, 2= moderate concern, 3 = concern, 4 = major concern, 5 = special engineering required, and 6 = avoid.

Percent of Surface Soil	Stoniness			Rockiness
	Rounded, Sub-Rounded, Angular, Sub-Angular		Flattened	
	Dia. = 10-15 in.	Dia. = 16-14 in.	Len. = 16-24 inches	(exposed bedrock)
less than 1	1	1	1	1
1-5	1	2	1	2
6-10	2	3	2	3
11-25	3	4	3	5
26-50	4	5	4	5
51-75	5	6	5	6
more than 75	6	6	6	6

in the soil profile defines its drainage characteristics (Table 1.3).

These class names indicate conditions that range from droughty to moisture saturated where the water table is at or near the surface of the soil for substantial portions of the year.

Drainage is determined by four primary sets of factors. The first set is the soil texture in combination with structure which determines the amount and size of pore spaces that allow water to make vertical movement. The second factor is the existence of various kinds of soil pans. Soil pans are places in the soil profile where the soil particles are compacted or cemented together sufficiently to impede vertical flow of water, thus the water accumulates above the pans. The third factor is slope position. Soil moisture content is always higher at the bottom of a slope than at the top. Surface water flow accumulates at the bottom of the slope, so the amount of water penetrating and percolating through the soil is the sum of rainfall plus flow from upslope. And fourth, there is often subsurface lateral flow from upslope that accumulates at the bottom of the slope. These factors, plus the occasional emergence of bedrock at the bottom of the slope, may individually or cumulatively cause an accumulation of water that saturates much or all of the soil profile.

Table 1.3 Soil Drainage Classes

Drainage Class	Description
Very poorly drained **	Water table remains at or near the soil surface for the greater part of the year. Surface layers are usually dark gray or black and subsurface layers are light gray.
Poorly drained **	Water table is near the soil surface for a substantial portion of the year. Soils are light gray in color throughout the profile.
Somewhat poorly drained *	Soil is wet for significant periods of the year. Surface soils are grayish, brownish or yellowish and mottled below about the 6-in. depth.
Moderately well drained	Soil is wet for a small, but significant portion of the year due to somewhat slow drainage. Uniform colors in A and upper B horizons with mottling in lower B.
Well-drained	Water drains readily, but not rapidly. Normal soil colors in A and B horizins.
Somewhat excessively drained	Water moves rapidly through the soil. Soils are very sandy and very porous.
Excessively drained	Water moves very rapidly through the soil. The soil is steep or highly porous, or both.

** Avoid these soils with trail construction to the extent possible. Usually protected as wetlands under section 404 of the Clean Water Act.

* Special engineering usually will be required if used for trail construction.

Structure

Structure is the arrangement of soil particles into *aggregates* or clumps of soil. Structural types describe the characteristic shapes of the aggregates. The four primary types are: a) prismatic, b) columnar, c) blocky, and d) granular. Prismatic aggregates are typically 2-3 in. wide and about twice as long as wide. Columnar aggregates are about 1-2 in. wide and about twice as long as wide.

Blocky is like a crushed gravel in shape and about 1 in. across all dimensions. Granular is somewhat rounded (like cookie crumbs), and is the smallest structure type.

Prismatic and columnar structures are preferred for road and trail construction purposes. Blocky and granular are preferred for agricultural crop production because of superior aeration and drainage characteristics important to plant growth.

Bulk Density

Bulk density is the weight of a unit volume of dry soil. The bulk density value is expressed in grams of soil weight per cubic centimeter of soil volume. Sandy soils generally have higher bulk densities than do fine textured soils, such as silt loams, clay loams, and clays.

Loamy surface soils tend to have bulk densities in the range of about 1.5, which is a desirable value for many agricultural crops. As clay content increases, the bulk density tends to go down. As sand and silt content increase, it tends to go up. Some road and trail construction techniques are aimed at increasing bulk density by compacting the soil to reduce pore space, which also affects its structure.

Soil Origins

Parent materials of soils are described in two broad categories – *residual* and *transported*. *Residuum materials* soils are those that have developed in place (*in situ*) from bedrock *parent material*. Physical, chemical and biological processes weather parent material into primary soil particles, thus the nature of the rock will determine the chemical and physical nature of the soil. For example, sandstone produces sandy soils that are low in nutrients. Limestone often weathers to clays that are typically higher in nutrients.

Transported materials have been moved from their place of origin to a place of deposition. The main modes of transport are glaciation (movement by glaciers), *alluviation* (movement by stream waters), *colluviation* (movement by surface water and gravity), and *aeolian* (movement by wind). Glacial movement transports materials that may further weather into soil and deposits them in *glacial moraines* (typical of the Upper Midwest) and *glacial outwash*. Outwash is the result of the movement of materials by water from the melting glacier as it retreats. *Glacial till* is the material transported and dropped by the glacier as it moved over an area. The Lake Plain of western New York and the Allegheny Plateau in northwestern Pennsylvania are examples of glacial till soils.

Alluvial materials are those that have been transported by stream water. Deltas of streams are *allvium*. In addition, the materials of areas adjacent to streams that are periodically covered by floodwaters are composed of the *allvium* dropped by water moving more slowly than that in the stream channel. Such areas bordering streams are called *riparian zones* and may be legally defined by the nature of the soil and the plant cover. Biological systems developing on alluvial soils are very productive and highly diverse. It is not only difficult to build and maintain trails in these areas, they are often protected under sections 401 and 404 of the Clean Water Act which regulates the use of wetlands.

Colluvial materials are those that have been transported downslope by gravity or surface water flow or both, thus these soils accumulate at the bases of slopes. Depending upon the geology of the upper slope terrain, they may or may not contain large amounts of coarse fragments. The soils are typically deep and support excellent plant growth, but because they are at the bottom of a slope, they are subject to water accumulation resulting from surface and subsurface flow. In cases where the coarse fragment content is relatively high, these soils may support sustainable trails. Where the soils are loamy, silty or clayey and largely devoid of gravel or coarse fragments, they should be avoided for trail construction to the extent practical.

Materials deposited as a result of movement by wind are *aeolian deposits*. The silt loams of the Mississippi bluffs in Tennessee are excellent examples of aeolian deposits blown from the Great Plains eastward during interglacial periods. The sandhills soils of the Carolinas are aeolian deposited sand dunes from several hundred million years ago. These soils are almost always light in texture being primarily silt or sand. They are difficult to work with for the construction and maintenance of sustainable trails.

The final main mode of material movement is called *mass movement*. Mass movement of materials ranges in magnitude from a small slippage that may cover a fraction of an acre to massive landslides. Typically, trail construction and maintenance across soils resulting from recent mass movement is difficult. User safety also is a major concern, particularly during rainy periods. Furthermore, their sustainability is problematical. Areas prone to mass movement of soils should be avoided in trail system design.

Soil Profile

Soil parent materials, whether residual or transported, are acted upon simultaneously by physical, chemical, and biological processes of weathering and soil formation.

Figure 1.2. Soil horizons demonstrated on two soil monoliths of old field soils. Ap = old plow layer; E = horizon of eluviation; Btg1 = first zone of heavy clay accumulation and gleying (gray coloration) which would indicate anaerobic conditions for a significant part of the year. Btg2 indicates a second distinguishable zone of heavy clay accumulation.(Photo by G. W. Wood.)

These processes result in the development of distinctive layers called *soil horizons.* A vertical exposure of these horizons is a *soil profile*. Horizons vary by color, texture, and structure. Figure 1.2 shows two soil monoliths that demonstrate horizons in a residual soil profile.

The organic layer (the O horizon) is the uppermost horizon in the soil profile of a natural, undisturbed soil. It is composed of three organic layer horizons that contain everything from recently deposited litter (dead plant parts) to the advanced levels of decay of these materials. The O_i horizon contains organic materials that are easily identified with respect to type of plant material to a point of degradation and decay where identification of most of the material is not possible. The O_e horizon contains organic material in an intermediate stage of decay. The O_a is the bottom layer of the organic horizon. It is the humus layer where there has been decay and a re-synthesis of fine textured organic material that is colloidal in nature. In the construction of a trail, the entire organic layer should be removed to create a bare mineral soil surface.

The A horizon is the uppermost mineral horizon. It often contains substantial amounts of humus. In cases where the A horizon is very sandy and drains well, the humus content may not pose a substantial problem in holding moisture to the trail tread. If the texture tends to be silty or clayey with substantial amounts of organic matter, the A horizon also may need to be removed in the trail tread construction process.

The E horizon is a zone of *eluviation*. Clay, humus, and oxides of iron that give the soil yellow and red colors have largely moved out of this layer. In soils under forest cover, particularly under coniferous forests, which produce litter that is highly acidic, this layer is usually gray as the iron oxyhydroxides have been *leached* out by the acidic, percolating water.

The B horizon is a zone of illuviation (zone of accumulation). It contains the highest concentrations of the smallest mineral soil particles (clay) to be found in the soil profile. Texture, structure, and color are usually substantially different from the horizons above it. The B horizon is as good as it is going to get at a particular site for soil materials that are going to form a trail tread.

The C horizon is little affected by soil formation. It is usually similar to the parent material from which the soil developed. The R layer (not shown in Figure 12) is the consolidated bedrock from which the parent materials are derived.

Aerobic and Anaerobic Zones

Soils contain both macropore and micropore spaces. These spaces are filled with either air or water. In an ideal condition for terrestrial plant growth, the micropore spaces will be filled with water and the macropore spaces will be filled with air. This condition is called *field capacity*. This is an *aerobic* condition as there is plenty of oxygen available to support soil chemical and biotic processes and plant root metabolism. The soil chemical processes are oxidative processes that produce the red and yellow colors as a result of the oxidation of iron.

Anaerobic soils or zones of the soil profile are those in which all pore space is filled with water for most, if not all, of the year. This soil condition is often called *saturation*, and the soil has a shallow water table. The zone of anaerobic conditions will be easily recognized in the soil profile by the blue gray color that denotes chemical reduction processes.

As depth to the water table becomes shallower, the soils become less usable for trail construction. Such trails can be guaranteed to be muddy throughout most of, if not the entire, year. In addition, such soils are characteristic of wetlands, including riparian zones, which may be regulated and may require government permits to disturb.

Anaerobic conditions may occur on microsites in forests and grasslands. In grasslands, they are usually, but not always, identifiable by changes in the vegetation. Under forest cover, these sites are often more difficult to detect. These conditions may exist in soils that contain layers or horizons that are very slowly permeable to water movement. Therefore water accumulates and *perches* on top of these layers. When these conditions are sufficiently extensive (no longer a microsite in scale), the condition is called a *perched water table*.

Unless these conditions produce vegetation characteristic of wetlands, it is unlikely that they will be regulated as such. Nevertheless, they will be a problem for the trail builder as the site will be predictably boggy. It may or may not be possible to redesign the trail to avoid the microsite. Special engineering will be required if the site has to be used.

Soil Names and Taxonomy

There are two approaches to identifying soils in a manner that makes a name or term descriptive. In all county soil surveys, the traditional approach of naming a soil is by its *series* name plus the prevailing texture class of the surface layer. A soil series is a group of soils having similar profiles and horizon characteristics, and that are derived from similar types of parent material. Series are separated by significant variations in the features and properties of the soils.

For a quick reference to descriptions of the soil series of the United States, see the following reference: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions, available URL: http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi.

Soil series are subdivided into soil phases based on the texture of the surface horizon. Thus on a soil map there may be more than one surface texture phase within a series. The series name plus the surface texture phase is the soil name. For example, in Oconee County, South Carolina a clay loam and a sandy loam are two phases of the Cecil series. The names are Cecil clay loam and Cecil sandy loam. When people with a common knowledge of soils refer to these names, a mental picture of the soil is immediately developed.

The second approach to terminology that describes soils is a systematic taxonomic approach that is somewhat similar to the taxonomic systems used for scientifically identifying and naming plants and animals. *Soil Taxonomy* was published in 1975 by the United States Department of Agriculture's Soil Survey Staff. The 2nd edition was published in 1999. The University of Idaho has established a website (http://soils.ag.uidaho.edu/soilorders/) that describes this system. The reader is referred to that website for detailed information.

While discussion of soil taxonomy is beyond the scope of this text, the trail builder does need to recognize some of the broadest terms of the system as they are frequently used in the literature of environmental assessments and impact statements. Appendix E provides some insight into the twelve soil orders and their suborder characteristics that will be important to people working with recreational horse trails.

County Soil Surveys and NRCS Website

The USDA-Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) has published a soil survey for every county in the United States. No one undertaking trail design, construction and maintenance should begin the process without critically reviewing the soil survey information for the area in which he/she will be working. (See Chapter 4.)

Each manual will describe the various soils in a county and provide maps showing their locations. The back-ground of these maps is a composite of the aerial photos of the area. Using current geographic information systems (GIS) the soil maps can be lifted from old photomaps and placed on more recent ones or on topographic maps. (See Appendix A.) The soil survey will also describe the capability classes for the various soils and their engineering properties. The latter will be very useful to the trail builder.

The NRCS introduced their web soil survey in January 2006. A discussion of the website and an introduction to its use for trails work is presented in Appendix A.

Watersheds

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Contemporary natural resource management takes its guidance from the principles of ecosystem management. In ecosystem management, the watershed is the fundamental unit of consideration. Water quality in the watershed is an index to how well the system is functioning. Trail construction and use, when done inappropriately, can adversely affect water quality. In the context of environmental protection, there is no greater concern in trail design, construction, maintenance, and regulation of use than that for the protection of water quality.

Bodies of surface water are important components of the landscape matrix. Freshwater systems are characterized as either *lotic* (streams, rivers, creeks) or *lentic* (lakes, ponds). This discussion will be limited to lotic systems with any reference to streams implying rivers, streams or creeks. Any discussion of streams should be made in the context of the entire *watershed*, as any activity anywhere in the watershed potentially could affect, and even have a profound effect on the stream system. The following discussion is a brief introduction to *watershed ecology* and streams.

Physical Aspects

Climate, hydrology and geomorphology are physical parameters that define the watershed. *Climate* is the integration of average and extremes in temperature, atmospheric moisture, cloud cover, and winds measured over an extended period of time. Climate affects streamflow patterns and vegetation characteristics in the watershed.

A diagram of the *hydrologic* cycle (water cycle) describes how a drop of water cycles from the ocean to clouds to precipitation to the ground and streams and finally back to the ocean. As seen in Figure 1.3, streams are mainly dependent on ground water to maintain a *baseflow*, i.e., the flow that streams maintain between rainstorms or snow melts.

Runoff, or overland surface flow, is another important source of water for streams. Runoff increases stream flow temporarily and affects the quality of the water. Runoff not only provides additional water to streams, it also provides nutrients and organic matter that are additional food sources for the aquatic plants and animals.

Too much runoff results in soil erosion, flooding, and excessive sediment deposits in streams (*sedimentation*). Disturbance of streambank soils or even soils in the vicinity of streambanks such as can occur in trail construction, particularly at stream crossings, can result in sedimentation.

One of the most obvious results of sedimentation is the accumulation of excessive loads of silt, sand, and clay in the streambed. A not so obvious effect of increased sedimentation is the process of sediments covering fish spawning areas in streams and habitat for aquatic insects that provide food for fish. In response to this decline in habitat, the fish may move, but the area to which they move may be less beneficial for their growth; therefore, they may survive, but they probably will not be as healthy as they would have been in their original home.

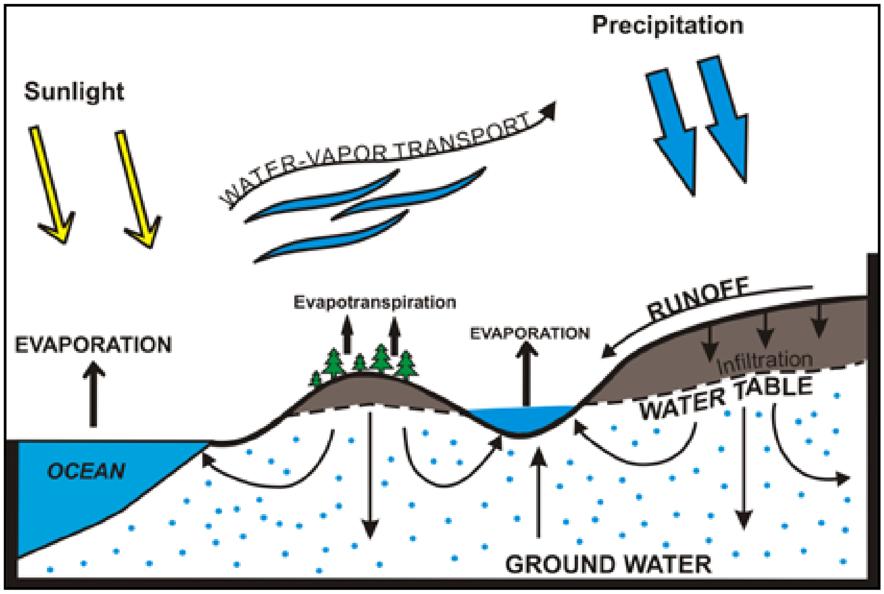

Figure 1.3. The hydrologic cycle. (Drawn after Manning 1997).

Geomorphology

Fluvial geomorphology is the study of the structure and dynamics of stream corridors, as well as the movement of stream channels and associated impacts on floodplain and upland transitional areas. Since streams are one of the most important ecological and hydrological features of a watershed, it is important to understand their physical structure and processes. A *stable stream* is defined as one that transports water and sediment produced by its watershed while maintaining its dimension, pattern, and profile.

Stream Dimensions

There are four dimensions to a stream: lateral, longitudinal, vertical, and temporal. The *lateral dimension* characterizes the stream across the channel and includes the floodplains and transitional uplands. The lateral structure of a stream corridor affects the movement of water, materials, energy, and organisms in the stream as well as in the associated uplands.

The *longitudinal dimension* characterizes the stream in an upstream/downstream direction. The longitudinal structure includes the entire length of the stream, from its headwaters to the mouth. The description includes channel form, sediment transport and deposition, and the adaptation of biota to the different areas or zones of the stream.

There are three zones in the longitudinal profile: *headwaters*, *transfer zone*, and *depositional zone*. The headwaters typically have the steepest gradient. In mountainous areas, the headwaters can be in deep valleys where waterfalls and rapids are common. The transfer zone is at a lower elevation with streams having less steep slopes. Meanders begin to occur in the streams as the valleys broaden. The stream valley is wide and nearly flat. The depositional zone of a stream is at the lowest elevation of the longitudinal dimension. These zones may be repeated numerous times along the longitudinal profile of a stream.

The *vertical dimension* of streams encompasses the surface water, groundwater, and their interactions. Streams are constantly interacting with groundwater by exchanging water, chemicals, and, at times, microorganisms. If the water table is lower than the baseflow, the stream is known as an *influent* stream, that is, it loses water to the groundwater table. If the water table is higher than baseflow, the stream is an *effluent* stream which means that it is receiving water from the groundwater table (Figure 1.4).

The *temporal dimension* of streams deals with the time factor, whether it is a temporary response or an evolutionary change over eons. Streams are constantly changing due to the force of the water, the geology, and climatic changes over time.

Stream Morphology

Stream morphology describes the size and shape of the stream. In cross-sectional view (Figure 1.5), the sloped bank is called the *scarp*. The deepest part of the stream is called the *thalweg*. The stream channel cross-section

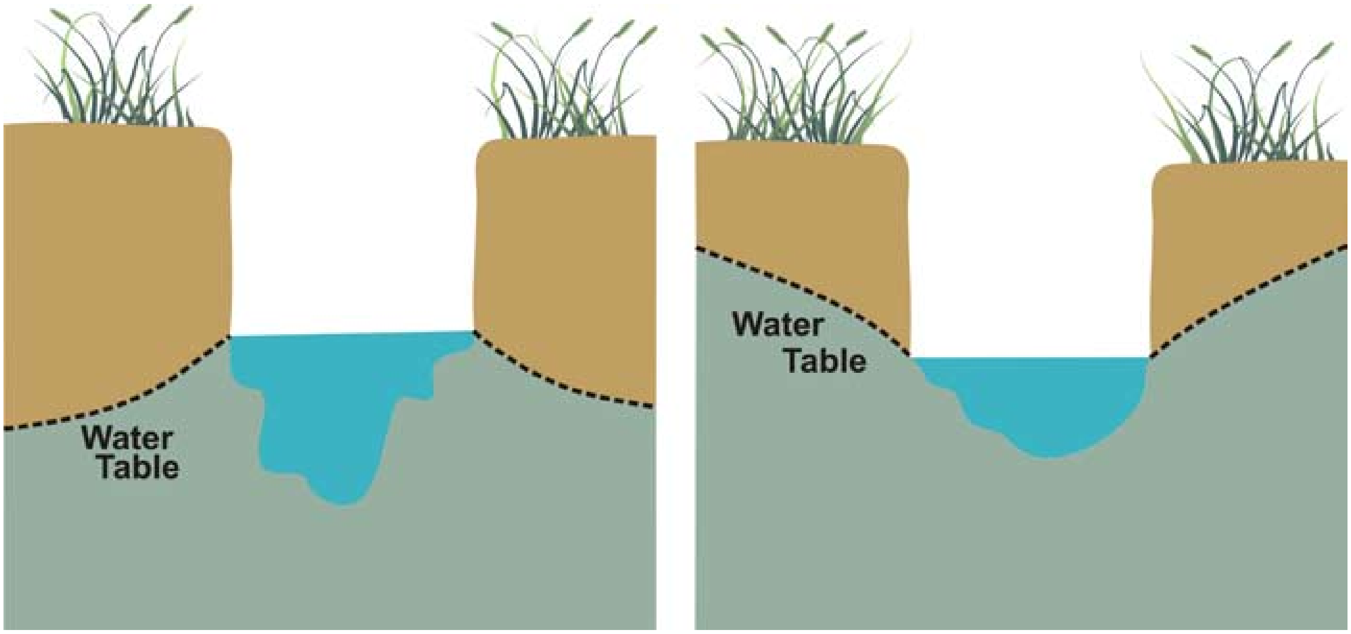

Figure 1.4. Water table in relation to base flow: *influent stream* (left) and *effluent stream* (right). (Drawn after Federal Interagency Stream Restoration Working Group 1998.)

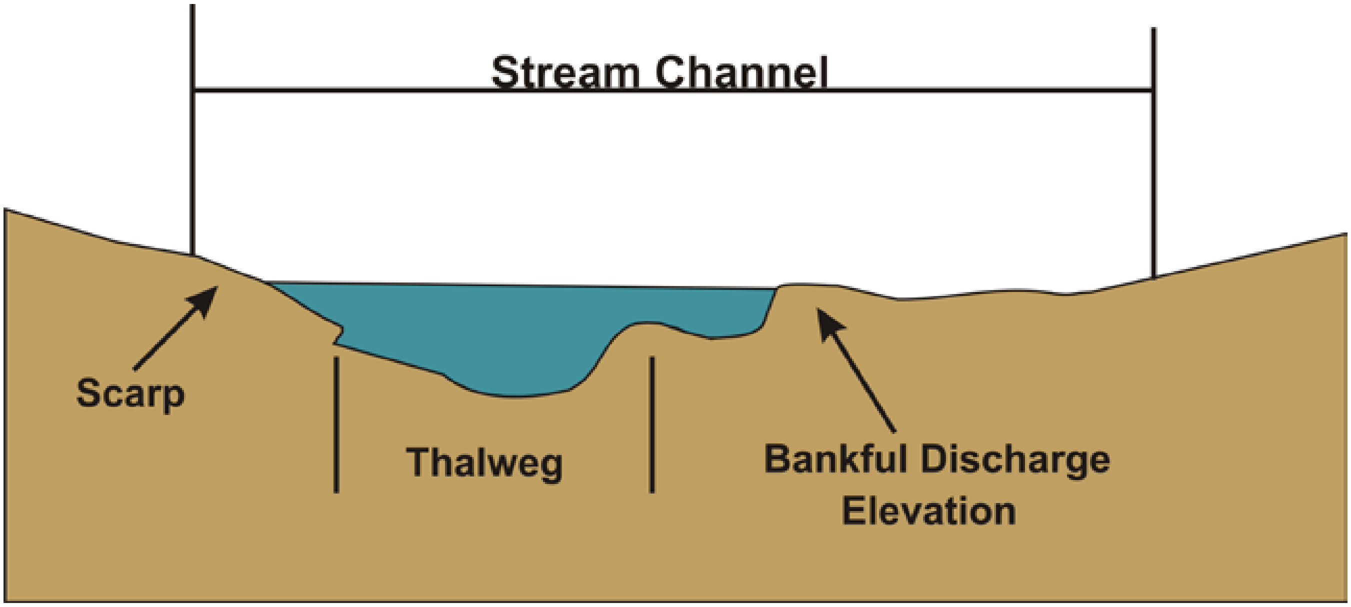

Figure 1.5. Stream morphology. (Drawn after Federal Interagency Stream Restoration Working Group 1998.)

controls the amount of water that can pass down the stream without going over the banks. When the cross-sectional area is filled with water, the stream condition is referred to as *bankfull discharge*.

Natural streams consist of riffles, runs, and pools. Riffles are those areas that contain rocks large enough to cause waves as the water flows fairly fast over them. These are typically where many aquatic insects live and are known as food producing areas. For some fish species, riffles are also spawning areas, as well as their primary habitat. Some fish spawn in *tailouts* of pools. While riffles are often primary feeding habitats, slower areas of streams are the primary resting habitats.

Pools are the deep areas where the water flows much more slowly. These are typically the resting areas for fish. Runs are the areas between riffles and pools. These areas help dissipate the energy of the water. Riffles and runs can be covered over when too much sediment has been deposited in the stream. This in turn causes riffles and pools to lose their functionality as habitat for fish and aquatic macroinvertebrates, and to lose functionality to dissipate energy of the flowing water.

Stream Equilibrium

Four variables determine the equilibrium of the channel: sediment discharge, sediment particle size, streamflow rate, and stream slope. If any one variable changes, the others will change in an equilibrium maintenance response. When the stream is reestablishing equilibrium, erosion of the bed and banks occurs. Except in steep, mountainous terrain, streams are constantly moving back and forth across the valley floor to maintain equilibrium.

Kinds of Streams

There are four basic kinds of streams based on flow:

- *Ephemeral* streams flow only in response to rainfall. These streams do not have a well-defined channel, nor does the flow continue for more than 29 days. (These streams do not typically show up on topographic maps.)
- *Intermittent* streams have a defined channel that has only seasonal flows of water. They have a continuous flow of at least 30 days per year. Ground water support for streamflow in these streams is minor. They dry up quickly during extended periods of drought. (These streams are typically represented by dashed lines on topographic maps.)
- *Perennial* streams are permanent streams that flow continuously throughout the year, even during periods of drought. Baseflow is supplied by groundwater. These streams have well defined banks and natural channels. (They are represented by solid blue lines on topographic maps.)
- *Braided* streams have multiple interconnected channels. Usually the slope of the streambed is less than 0.5%. The valleys are usually broad with well-defined floodplains. Most braided streams are found in the coastal plains.

Stream Classification

The most common method of stream classification is the Strahler method which defines stream *orders* by stream origin (Figure 1.6). *First order* streams are those that occur in the headwaters with springs being their primary origin. Two first order streams join to form a *second order* stream. When two second order streams join, they form a *third order* stream. First through third order streams are in the headwaters zone, fourth through sixth order streams are in the transfer zone, and seventh through twelfth order streams are in the deposition zone.

Another stream classification is the Rosgen scheme, where the streams are identified by their meander patterns, bank types (either *incised* or not), slopes, and *bed material*. This classification requires detailed data collection and will not be discussed here.

Chemical Aspects

Biogeochemical cycles explain how elements such as carbon, nitrogen and phosphorus are transported, used, and stored in a watershed, and how they change in form. Streams in a watershed are *open-ended* systems for the flow of energy and nutrients. This means that the system has both external inputs into the system and outflows that move materials out of the system. *Nutrient spiraling* implies that nutrients are being transported downstream from their original source and being exchanged between the terrestrial and aquatic environments, including abiotic and biotic components of the watershed. These nutrients are needed by the biota for growth, maintenance, and reproduction processes.

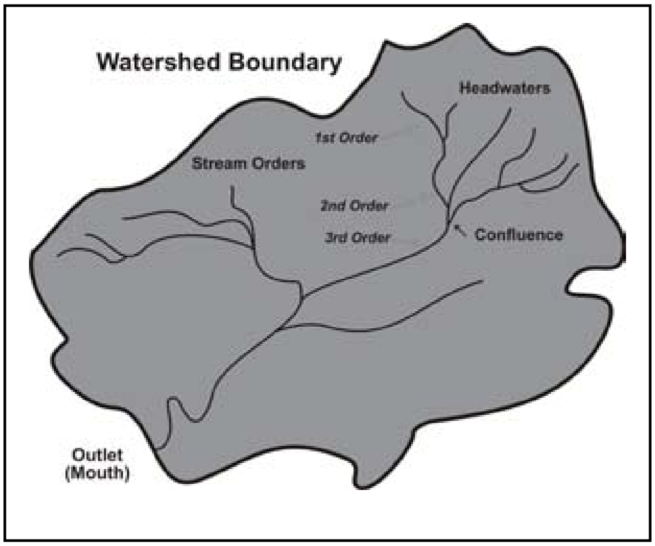

Figure 1.6. Strahler's stream order classification system. (Drawn after Federal Interagency Stream Restoration Working Group 1998.)

Dissolved oxygen is a critically important aspect of stream water chemistry. Because aquatic animals are limited to the confines of their stream, significant decreases in oxygen mean certain death. Decreases in oxygen in the water can be due to increased rates of sedimentation, increased algae production, decreased streamflow rates, and increased stream temperature.

Biological Aspects

The array of species and characteristics of populations of species in the aquatic environment are constrained by the characteristics of the stream corridor, including the associated soils, and water quality. Aquatic insects, microbes, and fish are highly adapted to specific water quality requirements, including sediment and organic matter, and will not persist if change in size, type, and frequency of sediment inputs is adverse to their requirements for growth, maintenance, and reproduction.

Riparian areas are transitional areas between streams and uplands. Vegetation in these areas is adapted to periodic flooding. Vegetated riparian areas slow down runoff and filter pollutants, thereby providing time for rainwater to infiltrate the soil. In addition, they protect the soil from erosion processes, and trap sediments. Wide, forested riparian areas provide the best protection to streams.

Macroinvertebrates (aquatic insects) and microbes break down the coarse particulate organic matter (leaves, bark, twigs, etc.) that falls into a stream. The organic matter that comes from outside the stream proper is known as *allochthonous* input. Organic matter (dead fish, crayfish, etc.) that comes from within the stream is known as *autochthonous* input. Macroinvertebrates that feed on these materials are an important food source for most species of fish.

Different macroinvertebrates have different ways of breaking down the coarse particulate matter and are grouped by their functional *feeding guilds* based on their eating habits:

- *Shredders* (stoneflies, caddisflies, crane flies): shred and chew coarse particulate organic matter.
- *Collector-Gatherers* (mayflies, stoneflies, midges, caddisflies, blackflies): collect (gather) or filter primarily fine particulate organic matter (detritus).
- *Scrapers* (mayflies, caddisflies): Scrape and graze biofilm, diatoms, and algae from exposed surfaces such as cobble and boulders.

- *Predators* (stoneflies, dragonflies): consume other insects and macroinvertebrates.

Fish continue the cycling of organic matter by eating macroinvertebrates as well as other fish. This hierarchical arrangement for feeding causes nutrient and energy flow through the system and is sometimes referred to as a *food chain*. Scientists sometimes evaluate the health of a stream by looking at the health and well-being of the top species in the food chain in order to assess how well the lower members are doing which in turn reflects the condition of the abiotic environment of the stream.

Certain species, such as trout, have adapted to live in cool, highly oxygenated, *low turbidity* (very low sediment) waters and will not survive in other conditions. Other species, such as green sunfish, have adapted to live almost anywhere, under almost any adverse condition, except in waters contaminated with toxic chemicals. Because these species are so adaptable, they often move in and replace species that are not as adaptive to environmental changes. A change in the top predators or loss of specialized feeders in the stream usually reflects an environmental change.

In summary, trail management and use must consciously guard against watershed degradation. Quality of the water in watershed streams reflects the kinds and degrees of watershed disturbance. With respect to trails embedded in watersheds, and particularly those that either cross or lie in close proximity to streams, the greatest threat to water quality is increased rates of deposition of soil sediments that result from trail and disturbed streambank erosion.

Increased rates of sedimentation may lead to adverse changes in physical, chemical, and biological characteristics of streams. Appropriate trail design, construction, maintenance, and regulation of usage must be implemented in order to harmonize the trail and trail users with natural watershed processes.

The Ecosystem: Biotic Community Terrestrial Ecosystems

As previously defined, the ecosystem is the biotic community embedded in its abiotic environment. Figure 1.7 illustrates the context of living things embedded in a non-living matrix of geological materials, soils, sunlight, and water. While the pyramid demonstrates relationships, it is a great oversimplification of how complex this picture can be in reality. However, for the purposes of this book, the trail builder needs only to be aware of these relationships and think in terms of integrating a trail into this system in a manner that does not degrade the components and processes inherent to it.

Terrestrial Plant Community

Our concern for the nature of the terrestrial biotic community in the context of trail construction and maintenance normally focuses on the nature of the plant community. Assuming that the trail is not in a fragile ecosystem, and will not be in the habitat of sensitive species, the *physical structure* of the plant community will be the primary consideration.

Plant community structure is divided into two aspects – *below-ground* and *above-ground*. While the above-ground structure is fairly obvious, it is the below-ground structure that is of greatest concern to the trail builder.

Below-Ground Structure: The below-ground structure defines the nature of the root systems. Different species have different root structures and these structures can become very complex (Figure 1.8).

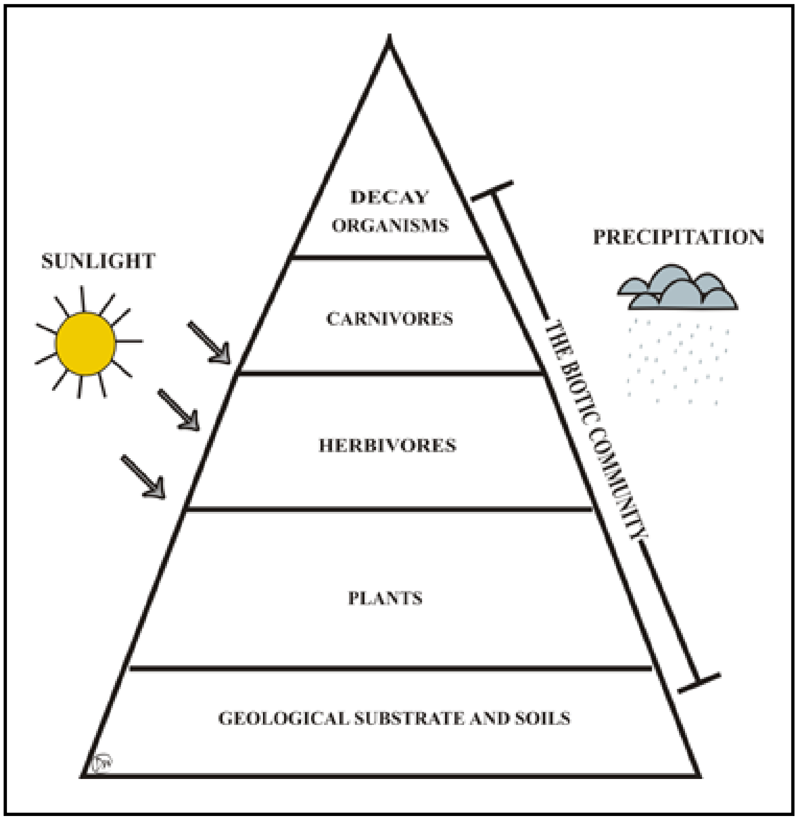

Figure 1.7. The ecosystem pictured as a pyramid with the biotic community cloaked in its abiotic environment.

Figure 1.8. The complex of roots near the surface of the soil where they will pose an issue for trail construction. (Photo courtesy of C. A. Gresham, Clemson University.)

Figure 1.9. Fibrous mat of grass, fern, and shrub roots exposed by gully erosion. (Photo by G. W. Wood.)

The basic divisions among species are *shallow-rooted* and *deep-rooted*. Deep-rooted species are suited to deep soils, but it is not unusual for them to occur on shallow soils or soils with an anaerobic zone near the soil surface. When this occurs among tree species, these trees are particularly subject to *windthrow* (being blown down). When characteristically deep-rooted species of grasses, sedges, herbs, and shrubs occur on shallow soils they cannot tolerate much root damage. Furthermore, they will be intolerant of drought conditions.

While shallow-rooted species are suited to survival on shallow soils, including soils with anaerobic zones near the soil surface, they also will grow well on deep soils so long as there is sufficient precipitation to keep them adequately hydrated. Shallow-rooted species are not generally suited to arid areas as moisture must be obtained from deep in the soil profile. However, some shallow-rooted species may do well on droughty soils in humid climates as they can obtain moisture through an extensive lateral "net" of roots that is efficient at capturing water as it percolates from the soil surface.

Most, but not all, shallow-rooted tree species are prone to windthrow when the crowns are exposed to substantial wind pressure. Tall, large crowned, shallow-rooted trees with their tops fully exposed to the wind will be wind-thrown sooner or later. With this as a given, the trail builder should, to the extent practical, set the trail tread well away from the base of such trees and on the up-wind side. This will not guarantee that the tree may not at sometime come back across the trail, especially when subjected to cyclonic winds, but it does hedge the bet.

Roots exist in a variety of sizes that are characteristic of their species. The roots of grasses, sedges and most shrubs are *fibrous*, i.e., they are numerous, very fine in size, and may interlace to form a *root mat* (Figure 1.9). Herbaceous species, particularly the *annuals*, may have fibrous root systems, or they may have tuberous root systems. The latter is more typical of perennial species. Root mats typical of dense colonies of shrubs and sods formed by grasses and sedges will normally have to be removed by the trail builder. Damage by trail traffic will normally kill at least the portion of the roots subjected to trampling. Therefore, to prevent the development of a ditch where a trail tread should exist, the root mat or sod should be appropriately removed and a sustainable tread prepared.

Among trees, deep-rooted species may or may not have a *taproot*, a large central root that grows straight down into the soil. Southern pine species have very large taproots that are important to giving them vertical stability when exposed to strong winds, and to obtaining adequate moisture and nutrients in deep soils (Figure 1.10). Windthrow is normally not a problem with tap-rooted species unless they occur on shallow soils or on soil pans where the taproot has not had a chance to develop to its full potential. Tap-rooted species tend to snap during high winds rather than be windthrown.

Some species are deep-rooted, but do not have a taproot. Members of the white oak group and hickories in

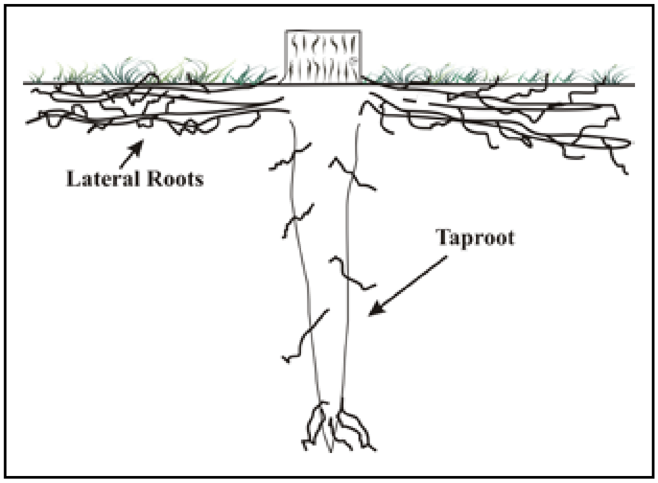

Figure 1.10. Illustration of a taproot system common to the southern pines.

the eastern forests, for example do not have a taproot at maturity, but their root systems may penetrate several feet into the soil profile of deep soils. They therefore normally have substantial resistance to being blown down.

Shallow-rooted tree species are of two major types: a) lateral roots that are large with numerous secondary roots of small diameter, and b) a dense mat of medium sized to small roots. Members of the red oak group of the eastern forests are examples of the first category (Figure 1.11) and the hemlocks, both eastern and western, typify the second. American beech would be a good example of the second category among hardwood species.

Shallow-rooted tree species, with a few exceptions, pose two main concerns for the trail builder. The first is proneness to windthrow, which has already been explained. Secondly, because these roots will normally need to be removed from the trail tread, what root damage means to the trees that are left standing should be taken into consideration. Some species are going to tolerate root damage better than others. Some realignment of the trail may be required if a large but sensitive overstory tree is going to be heavily affected. In some cases, it may be desirable to cut a tree that is likely to die later as a consequence of root damage. The trail builder should consult with local foresters and forest pathologists for advice on what to expect when dealing with local species.

Above-Ground Structure: Above-ground structure of plant communities, i. e., the vertical and horizontal distribution of plant biomass, varies widely among ecosystems. The simplest landscapes that are likely to have recreational horse trails are desert and alpine systems. The most complex are forests in humid regions. The trail builder who seeks minimal ecological impacts always considers plant structure because it affects layout and construction as well as future maintenance issues.

Figure 1.11. Members of the red oak group are examples of very shallow rooted species that are highly prone to wind-throw. All of these roots were within 12 in. of the soil surface. (Photo courtesy of C. A. Gresham, Clemson University.)

Terrestrial plant species fall into two broad categories in their tolerance for shade – *shade intolerant* (*sun loving*) and *shade tolerant*. Shade intolerant species need full sunlight in order to persist in the community. In contrast, shade tolerant species will do well in situations where the sunlight is filtered through a tree canopy that overshadows them.

Knowledge of shade tolerance is helpful in assessing the impact of removing trees and shrubs of various species in the construction of trails. Removal of members of species that are shade-intolerant when they are shaded by a tree canopy typically is of little consequence to the integrity of the community because they are going to die soon due to insufficient exposure to sunlight, although some are more persistent than others. In contrast, the removal of members of shade-tolerant species in this situation is different in that they are where they can carry on normal life processes. In the latter case, the impact considerations relate to the amount of removal relative to the total population of the species and what such removal might mean to specific sites.

Forest managers typically refer to specific forest communities as stands. A *stand* is a group of trees with an age, size class, and species composition that distinguishes it from neighboring groups of trees. Note that the emphasis is on the tree components of the community. Plant ecologists might subdivide stands into individual communities based on the composition of other plants associated with the trees.

The above-ground structure of a forest can be pictured as existing in four distinct layers – ground cover, understory, midstory, and overstory (Figure 1.12). *Ground cover* is composed of grasses, sedges, herbs, and low-growing shrubs that usually do not exceed 2 ft. in height. The non-woody portion of the ground cover is composed both of shade tolerant and intolerant species. Intolerant species will prevail in sunny spots in the forest, while shade tolerant species will tend to occur throughout most of the forest and over a wide range of sun-shade conditions. Ferns would be typical of non-woody species in this group. Low-bush blueberries would be typical of the woody species. These kinds of species tend to form very dense root mats that can pose significant trail construction issues.

The *understory* is typically composed of shrubs and seedlings greater than 2 ft. in height, and saplings less than 10 ft. in height. Except in cases of sparse overstories, all of the vigorous plants in this layer will be shade tolerant. Some non-vigorous shade intolerant trees and shrubs may be present in this layer, but they are of little ecological consequence as they are in the wrong place in the ecosystem and will have a relatively short life expectancy.

The understory can be substantially important to the trail builder in both the construction and maintenance phases. Understory shrubs often grow in dense patches that may be small or very large, sometimes covering many acres in one patch. Examples of species in such structures would be mountain laurel and rhododendron in the mountainous areas of the eastern forests, titi and wahoo thickets of the southeastern coastal forests, red ozier dogwood and spicebush of the Northeast and Lake States. These species all form dense root mats that may cause problems when the trail builder is attempting to create a tread that drains adequately. These species are usually vigorous sprouters and can pose maintenance issues when live stumps are left in the trail corridor.

Vines will cause maintenance concerns as they persistently re-invade the trail corridor. Vines of the briar type pose problems for horse and horseman alike.

Generally, species in the understory will either grow branches toward the center of the trail, or ice and snow will bend the branches, and even the main stems, over the trail. A careful assessment of the nature of the understory will be required for intelligent prediction of future maintenance issues, and what might be done in the construction stage to minimize maintenance problems.

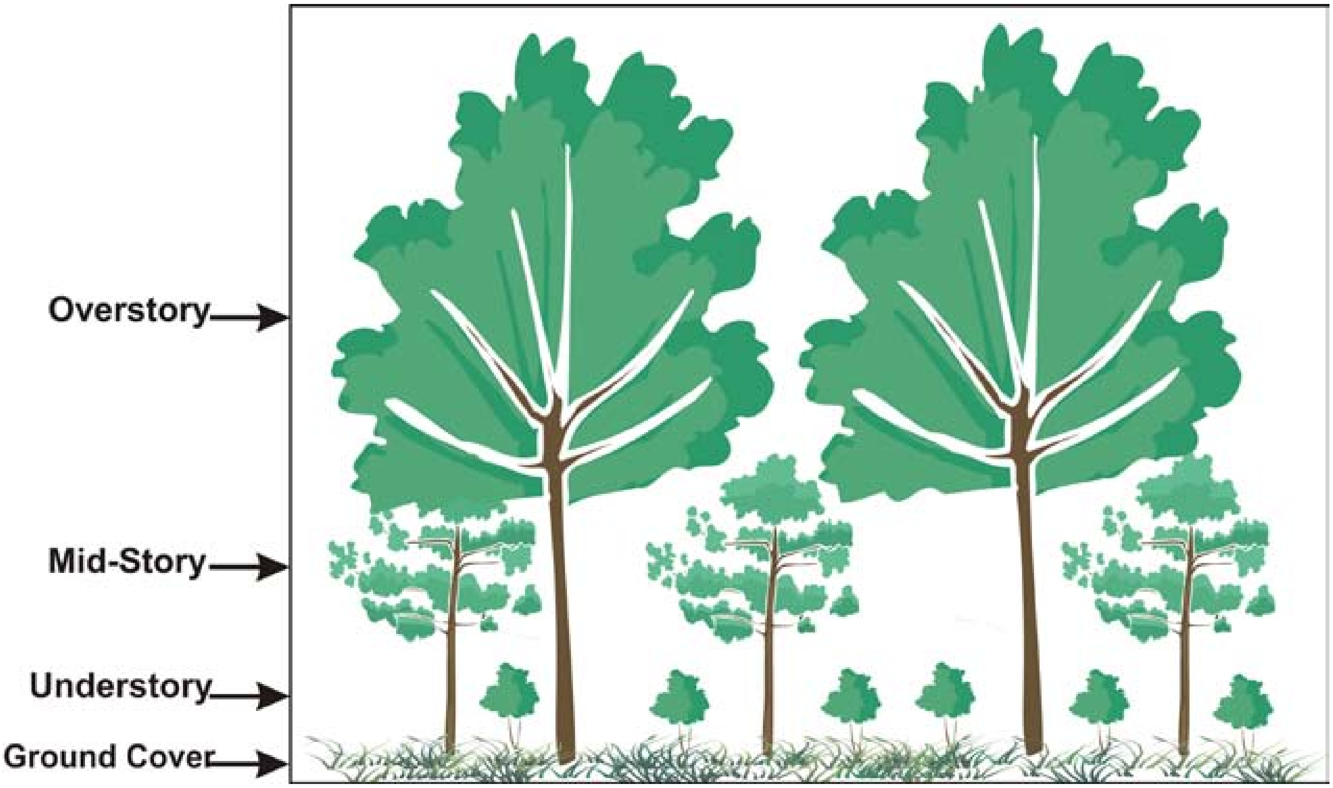

Figure 1.12. Profile of the above-ground structure of a forest plant community.

The *midstory* is composed of trees in a mixture of individuals of shade intolerant species that have been outcompeted for growing space by other associates, shade tolerant species, and dead or dying members of the first group. Examples of species that do well in this layer include American beech, flowering dogwood, American holly, and eastern hemlock in the eastern forests, and Pacific yew in western forests. In managed forests, several silvicultural practices may open the overstory sufficiently to grow shade intolerant trees into the mid-story and eventually into the overstory. In stands managed in this manner, typically the trees in both the overstory and midstory are healthy. Unmanaged stands in eastern forests usually have a healthy midstory of shade tolerant species whose niche is the shaded environment below the upper canopy.

The *overstory* is the topmost layer of the forest stand. Its density (number of trees per unit area) and species composition will have substantial effects on the nature of the other three layers. Under the best conditions for trails, overstory trees are large, fairly widely spaced, deep-rooted, and long-lived. In real life, the best conditions are unusual, and the trail builder works with what nature offers.

Sun-loving trees in the midstory and overstory exist in one of four crown classes – dominant, co-dominant, intermediate, and suppressed (Figure 1.13). Recognition of these crown classes is important to the trail builder and manager in assessing the ecological consequences of tree removal.

Individuals in the *dominant* crown class are those that receive full sunlight to the upper one-third to one-half of the crown. They are the tallest trees and the ones with the largest trunk (*bole*) diameters. Typically, these are the healthiest and most permanent members of the stand. They should be carefully protected from trail construction damage.

Trees in the *co-dominant* crown class have heights generally equal to that of dominants and diameters that approach those of the dominants. However, the sides of the crowns will be slightly flattened as they are slightly crowded by their nearest neighbors and prevented from getting full sunlight. These trees are also very healthy, long term members of the stand, and they should be well protected from damage.

Individuals in the *intermediate* crown class receive direct sunlight on only their topmost branches. They are substantially shorter in height and much smaller in diameter than are their dominant and co-dominant neighbors. Unless one or more of the dominant or co-dominant neighbors of these trees dies or is removed, these trees will undergo declining health. They are not long term members of the stand, thus their removal for trail construction or maintenance purposes is unlikely to have any significant ecological consequence.

Sun-loving trees that are in the suppressed crown class often can be characterized as being at death's door. Some are more persistent than others, but ultimately they have a bleak future. The removal of such individuals during construction or maintenance will normally have no adverse ecological consequence.

Another aspect of forest stand structure is *dead and dying* trees. Standing dead trees are a natural ecological

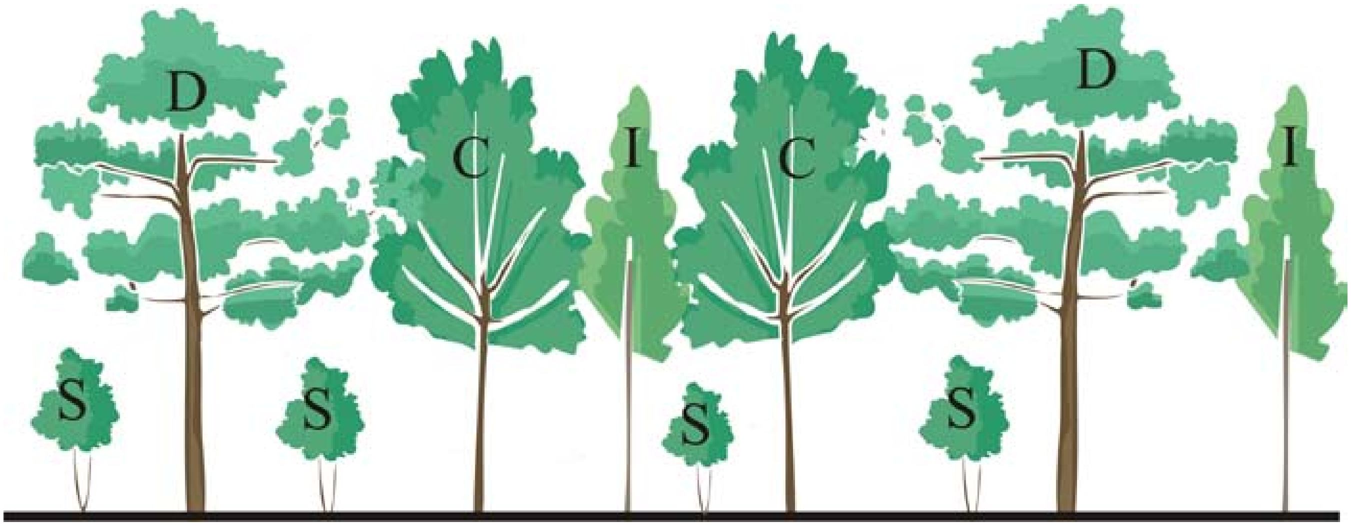

Figure 1.13. Crown classes of forest trees: D – dominant, C – co-dominant, I - intermediate, and S – suppressed.

component of forest communities. This component is critically important to many species of wildlife that use them for foraging substrate, such as birds feeding on insects in the decaying wood, and sites for shelter and reproduction, such as cavity nesting and roosting species. It is not uncommon for trail builders to not understand the ecological importance of dead trees and to automatically remove them.

There can be significant adverse ecological consequences to the indiscriminate, intensive removal of standing dead trees. In some cases, it may be unlawful. On the other hand, it is sometimes important to remove dead trees for safety reasons. This topic will be discussed further in the wildlife considerations section of this chapter, and in discussions of design and construction.

The final point in stand structure considerations is crown protection from wind. Except in stands with very large numbers of standing dead trees that have resulted from insect or disease outbreaks, most of the trees that fall across trails will be ones living at the time they were blown over. Windthrown trees are major problems in trail maintenance. Designing and laying out the trail to minimize the likelihood of a tree being blown across it or removing hazard trees in the construction phase are possible approaches to minimizing the problem. However, it must be kept in mind that nothing can be done to minimize the problems of cyclonic winds. In addition, while wind patterns for any given area are usually well known, freak storms can come out of an unusual direction and cause an abnormal direction of windthrow.

Crown protection is a composite of three factors - slope position, slope aspect, and configuration of nearest neighbors. The two extremes in the slope position factor are the top of the slope, i.e., the ridgeline, and the bottom of the slope, e.g., a cove or ravine location. On the ridgeline, trees are subjected to maximal wind stresses from every direction. As position on the slope becomes lower, the direct wind forces become lower. In ravines, coves, and narrow stream drainages exposure to wind is minimal.

Slope aspect refers to the direction that the slope faces. Trees on slopes that face into the prevailing winds experience more windthrow than do those on slopes that face in a direction opposite to that of the prevailing winds. Another consideration of slope aspect in cooler climates is that snow and ice loading is typically heavier on northern facing slopes. Trees loaded with ice or snow are more susceptible to wind damage.

Trees surrounded by neighbors of comparable height and size will be more stable in windstorms than those that have no neighbors. Trees that have grown up in an open environment are typically more wind resistant than are trees that have grown up in a forest stand and then lost those neighbors that once buffeted the winds around them.

Trail builders working in forested areas can never completely avoid windthrow problems, but they can suppress them by appropriately considering how severe those problems may be or become in the areas of their work. The observant trail builder will carefully survey the forest floor for windthrown trees, and note the directions of throw as well as the history of occurrence by examining the various stages of decay of different individuals as a clue to how long they have been on the ground.

High Mortality Areas in Forests

High mortality areas are areas with conspicuously high densities of standing dead and dying trees. These situations result from the effects of fire (usually wildfire), or disease or insect epidemics. The most intense wildfires are normally associated with extended droughts which have greatly elevated the combustibility of the fuels, including the organic layer of the soil. In such cases, tree mortality is typically high. Some mortality may occur in prescribed burns due to hot spots where there were excessive accumulations of fuel, or a change in wind behavior during the burning process.

The frequency of occurrence and total acreage affected by insects likely dwarfs that affected by diseases in the total American forest. Bark beetles such as southern and western pine beetles, and defoliators such as gypsy moth likely account for most of the problem, and their most devastating effects are correlated with prolonged droughts.

When high mortality situations arise where trails already exist, they can pose major trail maintenance problems. When dead trees have reached an advanced level of decay they can pose major safety problems for trail workers that may have to deal with them, as well as safety issues for trail users.

Dead and dying trees in high mortality areas are a different issue than when individual trees are more or less randomly and widely scattered along the trail. Where many dead trees exist in clumps, they begin to affect each other in rate of falling and direction of fall. Clumps of dead trees are less predictable as to when, where, and how they will fall than are trees standing alone. It is usually best to remove all dead and dying trees in the high mortality area as soon as possible after the mortality event, and at a distance from the trail equal to the height of the tallest individual trees.

Terrestrial Animal Community

The terrestrial animal community is collectively referred to as *wildlife*. Wildlife includes all vertebrate and invertebrate animals. Vertebrate wildlife includes mammals, birds, reptiles, and amphibians. Invertebrate wildlife includes all animals that are not either vertebrates or microorganisms.

Effects of trail construction and maintenance on wildlife are in two categories – direct and indirect. *Direct effects* are those that directly impact the animal and cause injury or death. Activities that result in harassment of a member of a species sufficiently to have adverse impacts on its basic ecological processes of feeding, breeding, or finding shelter also might be considered a direct adverse effect. It is important to note that direct effects include those impacts on all life stages of animals. For invertebrates this includes egg, larval, and pupal, as well as adult stages.

Direct adverse effects of trail construction and maintenance are improbable when work that will result in substantial changes in soil and vegetation are scheduled outside of the season of reproduction (i.e., nesting, brooding, fawning, calving, etc.), typically the spring and early summer months. However, even in fall and winter the trail builder needs to be advised by a local wildlife biologist on the probability of interfering with nesting of some owl species, as they are winter nesters in cavity trees, and hibernation of some bat species that use cavity trees.

On the other hand, in northern and high elevation ecosystems, trail work can only get done in the late spring and summer months due to weather constraints. Therefore, the trail builder will be left with the need for rational, common sense decisions with guidance from professional wildlife biologists.

Construction that may involve the movement of large logs that are lying on the ground and in a decaying condition could directly impact an array of invertebrates, small mammals, reptiles, and amphibians as these situations are important habitat for a wide array of these kinds of wildlife. A local wildlife biologist can provide guidance as to whether or not disturbance is likely to have a significant adverse impact on these populations in the area. (This consideration is almost always of significance only in locations inhabited by species officially recognized as either sensitive, threatened, or endangered.)

Indirect effects of trail construction and maintenance are almost entirely the effects of habitat alteration. The most extensive indirect effect in forest systems likely results from dead tree and living cavity tree removals. For example, *snag habitat* management is an important aspect of wildlife habitat management on public lands, and is mandated for National Forest System lands. Snags are dead and dying trees and living trees that have cavities in them. Some trail managers will undertake to fell every dead tree within some specified distance of the trail. For a perspective on the impact of this practice, if every dead tree within 66 ft. of the trail is cut, the snag habitat will be highly adversely altered on 16 ac. per mile of trail. Not only is this undesirable, it is unnecessary. We must remember that the trail is to be embedded in the ecological matrix with minimal adverse disturbance to that matrix.

In general, with only the application of common sense plus some expert advice from local wildlife biologists, trail builders are highly unlikely to adversely affect local wildlife populations. However, a cavalier attitude towards wildlife and wildlife habitat could result in undesirable effects, particularly where sensitive, threatened, or endangered species are present.

Sensitive, Threatened, and Endangered Species

It is important to recognize that the term species in the context of these considerations usually follows the definition as given under the ESA (Endangered Species Act of 1973):

> *Species – includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife.*[5]

Species classified as *sensitive* are placed in this consideration category by State or Federal agency regulations. In the case of Federal agencies, sensitive species include those *listed* as *threatened or endangered* by the State in which the particular Federal lands occur, although they are not federally listed under the ESA. Such species may have populations in sufficiently precarious situations that, in the foreseeable future, they may be considered for Federal listing. Under the ESA, to the extent possible, it is the duty of every Federal agency to prevent the

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[5] Endangered Species Act of 1973 §3(16).

need for listing of a species. Therefore, when it comes to any proposals for activities that may disturb their habitat, sensitive species get quite a bit of protection.

The highest level of protection that a species can get is to be listed as threatened or endangered under the ESA. This level of species protection applies to all lands, irrespective of ownership category, under the jurisdiction of the United States.

Land areas that have been classified as *critical habitat* are the most protected. Critical habitat is that geographic area that has been officially designated as needed for the recovery of a listed species.

Not all species have designated critical habitat, but some have areas designated for management of recovery populations. An example of the latter is the red-cockaded woodpecker in the southeastern U.S. Trail construction, maintenance, and use in critical habitat and recovery population areas will always be subject to meticulous scrutiny by the U. S. Fish and Wildlife Service, and may require special permitting processes.

Summary

The ecosystem is the biotic community embedded in its abiotic environment. Trails are embedded in ecosystems. Trail designs, construction, and maintenance are constrained by ecosystem characteristics and capacities to accommodate disturbances inherent to the establishment and use of trail systems.

Among non-motorized uses, recreational trail horse use is often viewed by land managers as that likely to have the greatest adverse impacts on ecosystems. This viewpoint is based on both imaginations and realities. In order to separate truth from fiction, land managers and horsemen will have to communicate intelligently about ecosystem components and processes. Furthermore, if recreational trail horsemen are to demonstrate ecosystem ethics, a critical requirement if their recreation is to have a long-term future, they need to have some knowledge of what it is that they are being ethical towards.

Important general principles that should always guide the development and use of trail systems are as follows:

1. Trails are embedded in ecosystems.
2. An ecosystem is a biotic community embedded in an abiotic environment.
3. Trail design, construction, maintenance, and use must not cause significant adverse changes in an ecosystem.
4. Ecosystem capacities to accommodate recreational horse trails range from those that are highly susceptible to damage, i. e., *fragile ecosystems*, to those that can accommodate substantial amounts of construction, maintenance, and use, i. e., *robust ecosystems*.
5. Nature of the soil is the first determinant of ecosystem capacity to accommodate recreational horse trails.
6. Soil characteristics that determine capacity to accommodate a recreational horse trail include: soil texture, type of clay, structure, bulk density, amount of organic matter, stoniness, types of coarse fragments, drainage, and depth to the anaerobic zone.
7. Soil erosion is a common problem resulting from poorly designed, constructed, maintained, and user-abused trails.
8. Eroded trails are aesthetically displeasing, often unsafe, and they are often the precursors of stream water quality degradation.
9. Ecosystem management is done at the watershed unit level, and water quality is a primary indicator of ecosystem health.
10. The most likely adverse impact of recreational trails on stream water quality is increased sedimentation rate.
11. Design, construction, maintenance, and use of trails must consider potential impacts on sensitive flora and fauna (invertebrate and vertebrate) in both terrestrial and aquatic systems.