Soil Design Protocols for Landscape Architects and Contractors

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Foreword

Twenty-five years ago in the practice of landscape architecture, hiring a soil scientist seemed exotic; it usually meant having a client who was open to the risks of a rooftop garden. Today it is difficult to imagine building most landscapes without the business of soil science, particularly as we develop and redevelop urban sites made up of lifeless anthropogenic soils. For landscape architects, the earth beneath our feet links the living media of our work. Air, water, and soil intermingle to nurture the soft roots of plants and to stabilize their sturdy branch roots. The dynamism of this exchange is remarkable but fragile. Not just any dirt will do.

I owe my understanding and appreciation of soil science to the Crauls. Together, we have tackled difficult soil conditions on sites all over the United States. In Pittsburgh we encountered solid slag, Cleveland brought clay soils, Boston offered a bony mantle of urban fill, and New York City challenged with steep slopes and high winds. The Crauls provided the brainpower to analyze tough conditions and then designed manufactured soil mixes that made possible the lush landscapes that hallmark my firm's work. My job was to educate and convince clients that the extra expense of manufactured soils was a smart investment. Sometimes my firm would horse-trade other parts of the project for good planting soil. We never regretted the sacrifice (too much).

Like fine cooking, building with manufactured planting soils requires the best ingredients, preparation, and execution to make a great meal. Finding the right soil components takes time, as does the necessary laboratory testing, because the alchemy of soils is complex and delicate. But soil science is also intuitive. Test results reassure, but the Crauls know that the senses give honest measure too: the feel, taste, and smell of soil are as revealing as the science. Installing manufactured planting soils requires vigilance also, each job site having its own peculiarities and each contractor having his/her own methods. Still, the results for my firm's projects have been astonishing. We not only believe, we advocate. With this book, soil science becomes accessible, expands our understanding of nature, and gives hope that future landscapes will flourish and endure.

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CHAPTER ONE

Introduction to the Soil

Soil protocols for landscape architects and contractors are presented here to aid the landscape architect in the design and installation of a more successful and sustainable project based on an appropriate and adequate planting soil design.

The landscape contractor, being familiar with these protocols, will be better able to carry through the entire process of planting soil source acquisition, sample submittal approvals, and meeting specified installation procedures in a timely manner, according to the various project phase deadlines.

Cooperation among the landscape architect, the soil scientist (if one is part of the design team), and the landscape contractor is enhanced with the existence of soil protocols on every project.

The protocols also greatly assist the smaller landscape architecture firm to meet the same objectives on small projects without the benefit of a consulting soil scientist as part of the design team. However, this book will also alert landscape architects when they should not go it alone and must recommend that their client hire a soil scientist.

What is first required is a review of basic soil properties, genesis, and morphology. There are various soil properties that are interrelated. For example, there is an inverse relationship between compaction and pore space. When soil compaction is increased, pore space decreases. When there is an increase in rock fragment content, there is less soil surface to hold nutrients and water. A case in point is that the surface area of 1 gram of clay is at least 1,000 times that of 1 gram of coarse sand (Brady 1990). One gram of rock has an even greater disparity. According to conservative estimates, 1 acre furrow slice (43,450 sq ft by 0.5 ft deep) of a clay loam soil has a surface area equivalent to the land area of the state of Florida, with 53,997 square miles (Brady 1974).

Planting Soil Axioms

- The soil must be plant-root friendly.
  - The soil is the most important aspect of the sustainability of any landscaping project.
  - It has been reported by a liability insurer that 60 percent of liability cases are due to soil failures by landscape architects.
- The soil is a natural system in itself.
  - The soil exists as the interface between the earth's atmosphere and its lithosphere.
  - The creation of life-sustaining substances and the exchange of energy, water, and gases occur there.
  - Organisms unique to the soil exist there.
- All soils are not created equal.
  - Natural soil varies in its properties and characteristics across the landscape, but its composition and extent is predictable by trained soil scientists.
  - Soil of urban areas and restoration sites has been altered to varying degrees by human activity and is unpredictable.
  - Soil of urban areas and restoration sites mostly has characteristics that limit or preclude plant growth, and is thus not plant-root friendly.

Introduction

The proper and appropriate soil design is just as important for success on small landscape projects as it is for large projects. In fact, it may even be more important for a successful and sustainable landscape project in a small but very highly visible or valuable site, where the appearance of failure would have a very serious detrimental aesthetic, economic, and professional impact.

Past experience has shown that some landscape architects and landscape contractors have had little concern in "getting the soil right" for the design and its plant palette. Too often a very limited "cookbook" approach has been employed, or the landscape contractor has simply offered "stuff that was found to be okay for other plantings and will work here"—in others words, soil of unknown characteristics and probably cheap! Neither approach really met the specific needs for the objectives of the design and its sustainability beyond

the plant guarantee, if that long. Properly designed soil specifications and these protocols ensure "getting the soil right"!

There is no one soil design that can be applied to any and all landscape architecture designs. A soil material must be found or a soil specifically designed for a given landscape architecture project.

A complex project with varied design attributes (slope, wind, exposure, plant palette) may require several different soil materials—not just one—as was the case for the J. Paul Getty Fine Arts Center in Los Angeles (Craul 1999). Therefore, detailed specifications are required to ensure that the proper soil material is acquired and installed properly for each planting element of the design. Protocols provide the process for fulfilling the specifications by the landscape architect, the soil scientist, if one is retained, and the landscape contractor.

Before we discuss the soil design and protocol process, it should be helpful to most landscape architects and contractors to briefly review the very basic fundamentals of soil science, in order to place the protocols in the proper context of soil design for landscape architecture projects.

The Soil As a Planting Medium

- The soil is the most important aspect of sustainability to any landscaping endeavor.
- The most intricate and aesthetically pleasing landscape design will fail if the soil medium in which plants are placed does not provide sustainable growth conditions with no more than common maintenance effort.

Therefore, it is necessary to provide a brief overview to the soil as a natural body. This will then be contrasted to the soil conditions found in urban/restoration situations.

Figure 1-1 (see color insert) shows an excellent prime agricultural soil of Pennsylvania that is capable of growing almost any plant adapted to a near-neutral (pH 6.5–7.1), well-drained soil. The soil profiles of Figure 1-2 (see color insert) are from a former steel mill site in St. Helens, England. Storage of limestone over a period of more than 100 years created an alkaline soil. Where pickling liquor was dumped, an acid soil formed over the same period. Thus, there are two widely varying plant-rooting conditions within the site, determined only by intensive sampling. This variability is not uncommon within restoration sites and occurs on other types of sites as well.

The development of much information and long-term experience has provided reliable guidelines for the planting and management of natural soil.

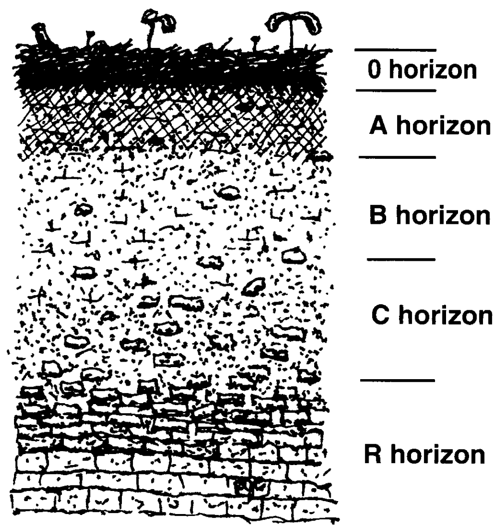
However, the soils found on restoration sites and in urban areas that have a constructional or industrial history become sufficiently altered so that they are unlike their natural landscape counterparts (Craul 1992). In other cases, nonsoil materials have been imported or left as residues from industrial activity. Conventional soil interpretations for use and management do not apply. Modifications may be made to existing materials, provided it is found feasible to do so from a scientific and economic viewpoint. In many cases a distinct soil must be designed and specified for the project (Craul 1999). If we understand the characteristics of these altered urban materials, we are better able to design and specify a soil, making use of our knowledge of appropriate natural soils as a guideline that will successfully overcome the constraints presented by the human-induced alterations.

The Soil As a Natural System

The natural soil is created as the interface between the atmosphere and the lithosphere of our biosphere and its various ecosystems; hence, its inherent profile form exhibits gradients from top to bottom.

The profile in its simplest form consists, with very wide variations over the terrestrial landscape, of five basic layers called *horizons.*

Using commonly employed soil science designations, there is the O (organic) horizon, the A (topsoil) horizon, the B (subsoil) horizon, the C (parent material) horizon, and the R (regolith, or bedrock) horizon (Figure 1-3).



1-3 The simplified natural soil profile model

In some soil profiles, one or several of these horizons may be absent, or one of several of the horizons may be more developed than others. For example, arid or desert soils do not have an organic horizon, while a soil on deep beach sands may not have an R horizon, simply because bedrock is found only at an extreme depth, well beyond any potential effects on near-surface processes. The major portion of the profile may be nearly pure sand.

The phenomenon that must be recognized about the soil profile is that it exists as a *system.* This implies that there are important interrelationships among the horizons, which are interdependent and necessary for the entire profile to fulfill its function as a rooting medium both in nature and in the designed landscape project.

It may be said that the function of the soil begins "at the top," meaning the A horizon or topsoil, which initially in soil formation does not exist as such in time *zero.* Some scattered organic litter may lie on the surface, but a true organic horizon has not yet been created. It is here that plant roots first proliferate as the seed germinates, or where they extend after the specimen is planted in the soil, anchoring the plant. The roots absorb water and nutrients from the soil, while their extension loosens the soil and creates aggregation as root gum exudates cement soil particles, along with the clinging action of the intertwining of the roots.

As the plant matures, litter from the foliage and shoots is deposited on the surface of the soil, forming a layer of decaying organic material (natural litter). The various organisms that roam on the soil surface or inhabit the soil begin decomposing the fallen litter as a food source. Mites, ants, earthworms, and mice begin the process, along with microorganisms such as bacteria, algae, and fungi. The ants and earthworms begin the incorporation of the partially decomposed materials into the soil, where the microorganisms continue and complete the process, transforming the organic matter into soil humus.

The entire process is a simplification process, reversing the formation of tissue within the plant. The humus enhances the water-holding capacity of the soil, loosens it, and acts as a reservoir for nutrients that become available first to the microorganisms themselves, then to the plant roots, completing what is known as the organic matter (carbon) cycle.

The color of the A horizon is generally a dark brown to gray brown, and may even be nearly black in some cases. The A horizon, a mixture of organic and mineral material, can always be distinguished from the other horizons by its darker color (except for the O horizon of all organic material, which may rest on top of it—see below). The thickness of the A horizon may range from as little as 1 inch in a forest soil (the Spodosols or Inceptisols of northeastern United States) to more than several feet in the plains of central United States (the Mollisols).

Most agricultural soils exhibit a plow layer, which appears as a topsoil that has a thickness equal to the normal plowing depth in that field. The normal plow depth is about 8 to 10 inches, and is sometimes as deep as 14 inches.

As more litter is produced than the soil organisms are able to transform into food and humus, the litter in various stages of decomposition begins to accumulate on the surface of the soil, or what is now the A horizon. Sometimes an O horizon may form before the A horizon itself is formed, where the decomposition process is very slow. These layers of partially decomposed litter become the O horizon. The O horizon may contain very fine plant rootlets, together with active soil organisms. It becomes a reservoir for future decomposition and release of nutrients and contributions to the humus content. It also acts as a protective layer to the A horizon. The O horizon may be likened to the mulch layer of a garden soil. The color of the O horizon may vary from dark gray or black to very dark brown.

It should be mentioned here that not all natural soils have an O horizon or an A horizon; they may not have either. The thickness of the O horizon is very variable, from nonexistent to several inches in a forest soil to several feet in an organic bog. The thickness also fluctuates according to the season of the year. In northern hardwood forests, the litter that was present in the spring season is nearly completely incorporated and decomposed by a very active soil organism population by the fall season.

The B horizon, or subsoil, is characterized by much reduced organic matter content as compared to the A horizon, and thus exhibits relatively bright colors in various shades of reds, browns, and grays, depending on the parent material color and the degree of aeration/drainage within that portion of the soil profile. Stones, if present, usually increase in content within the B horizon. Although the organic matter content may be reduced, the B horizon serves as a reservoir of water and nutrients and as additional mechanical support to the root systems, especially of trees, supplementing these features of the A horizon. Its thickness is quite variable but is nearly always thicker than the A horizon.

The C horizon, or parent material, is relatively unweathered and reflects this state in its color and physical properties. It usually has less brilliant colors and may have more stones and very little aggregation or structure. It may contribute little to the nutrient condition of the soil profile but may be important to the drainage of the profile and provide additional rooting depth. If the soil is derived from unconsolidated sediments such as glacial outwash or alluvial deposits along streams or rivers, the C horizon may be a series of layers, each having its own depositional history and, hence, stratification.

The R horizon, or bedrock, designation is given when bedrock is present within approximately five feet. At this depth or less, the bedrock can have influence on the drainage, rooting depth, and other features of the soil profile that affect plant growth.

How Does the Soil Profile Form?

Soil formation occurs at two distinct scales in nature, due to its three-dimensional nature:

1. Within what is termed the soil profile, as described above, with features measured primarily vertically in centimeters to several meters (inches to several feet). The major soil-forming processes, discussed immediately below, and the resulting soil profile are termed *pedogenesis*, or the weathering of the soil (Buol et al. 1989).
2. Across the landscape, with features measured primarily horizontally in meters to tens of meters (feet to tens of feet), resulting in three-dimensional bodies forming discernible patterns, discussed subsequently. Although some soil scientists include this phase within pedogenesis, others prefer to term this phase of soil formation as *pedology*, when the principles of geomorphology interact to lead to landscape evolution (Gerrard 1981).

Five major processes are involved in the formation of the soil profile (pedogenesis):

1. Leaching of soluble substances
2. Translocation of materials
3. Cycling of organic matter
4. Synthesis of new compounds
5. Formation of soil structure

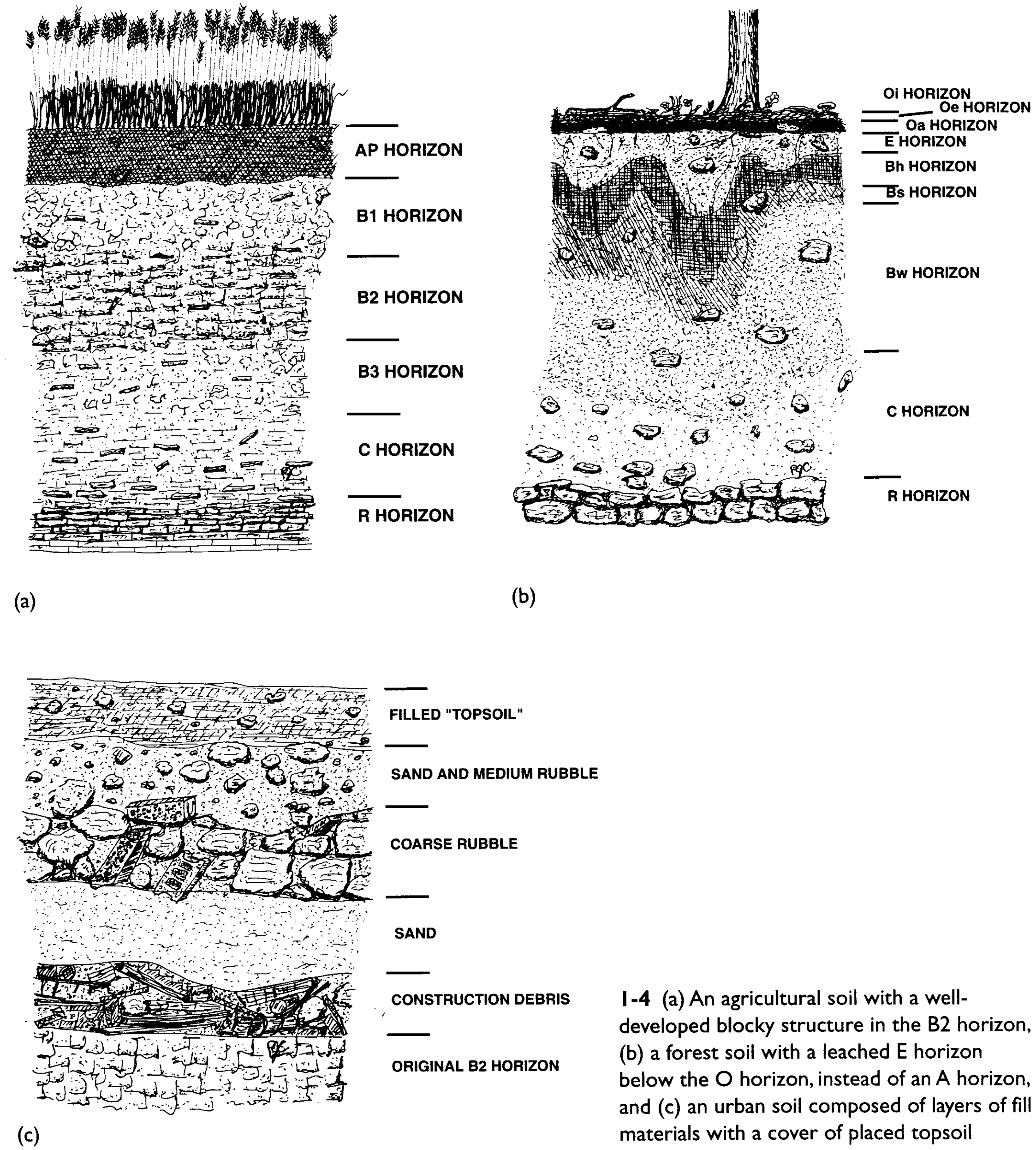
The processes may be summarized as follows:

- As water infiltrates into the surface of the soil and percolates downward in response to gravity, it dissolves water-soluble substances in the upper portion of the profile, and either deposits them in the lower portion (the subsoil) as the water dissipates among the voids, or carries them into the watertable below.
- An example of this process is the accumulation of calcium carbonates or sodium salts in the midprofile portion of semiarid soils, or the accumulation of clays in the subsoil portion of soil under relatively intensive weathering in humid conditions.

- The physical translocation of materials occurs when organic and clay colloids (extremely small particles less than 0.002 mm in diameter and chemically very active) are carried by water from the upper profile to a lower position in the subsoil. The colloids may have originated in the A horizon. This accumulation of colloids then forms distinct horizons of its own, thus creating a soil profile more complex than that shown in Figure 1-3 and more like those in Figure 1-4.
- The cycling of organic matter begins with the deposition of litter on the soil surface. Here, the litter is attacked by various organisms, becoming decomposed in a series of stages as a food source. This simplification process releases nutrients that are absorbed by the soil organisms and plant roots, completing the cycle. The undecomposed residue becomes the soil humus, which greatly contributes to the favorable physical condition of the topsoil, or A horizon. Some of the colloidal forms may be translocated to lower portions of the profile, as described earlier.

Soil organisms are those that exist within the soil throughout their entire life cycle. A healthy soil contains several species of vertebrate animals (mice, gophers, snakes, and so on), a half dozen species of earthworms, 20 to 30 species of mites, 50 to 100 species of insects (collembella, beetles, ants, and so on), dozens of nematodes, hundreds of species of fungi, and perhaps thousands of species of bacteria and actinomycetes (Brady and Weil 2002). Great organism diversity is possible because of the wide variety of food sources and habitat conditions found in the range of soil physical and chemical conditions of good and poor aeration, high and low acidity, cool and warm temperatures, moist and dry conditions, and localized concentrations of dissolved nutrients, organic substances, and a wide variety of competing organisms. Plant roots are considered a soil organism due to their influence on soil physical conditions and the interactions between root exudates and the soil organisms. The beneficial effects of the soil organisms include: decomposition of organic matter, the granulation and aggregation of the soil (development of soil structure), fixation of nitrogen, breakdown of toxic substances, and transformation of inorganic compounds into plant-available forms.

The soil organism system consists of four tiers of function and activity. The primary producers are the above ground green plants that combine carbon from the atmospheric carbon dioxide with water absorbed through their roots, and using energy from the sun, produce living tissue. The tissue becomes the food source for other organisms, thus, creating the food base for the entire food web found in nature. The primary consumers are those organisms that immediately attack dead plant residue such as termites, ants, mice,



1-4 (a) An agricultural soil with a well-developed blocky structure in the B2 horizon, (b) a forest soil with a leached E horizon below the O horizon, instead of an A horizon, and (c) an urban soil composed of layers of fill materials with a cover of placed topsoil earthworms, mycorrhizal fungi, and bacteria. The secondary consumers are those organisms that feed on the bodies of the primary consumers. These organisms include some bacteria, fungi, protozoa, nematodes, mites, springtails, and earthworms. The tertiary consumers are predators on the secondary consumers, with ants as an example, preying on centipedes, mites, and spiders, and so forth. Ants, termites, earthworms, moles, groundhogs, and dung beetles are burrowing animals that modify soil structure through loosening of the soil and creating continuous channels. By their action, the soil is mixed and granulated, creating the favorable open condition that aids aeration, root penetration, and the infiltration and movement of water.

The soil as an environment for organisms is a three-phase porous medium consisting of: (1) solid or mineral inorganic phase that is often associated with organic matter, (2) a liquid or solution phase, and (3) a gas phase or atmosphere (Maier et al. 2000). The relative proportion of the three phases changes downward through the soil profile. The implications for the soil organism population are: aeration of the soil is reduced with depth, changing the dominance of oxidation processes to greater proportion of reduction processes. The aerobic microorganisms are prevalent in the upper profile with the anaerobic microorganisms dominating the lower horizons. The quantity and variety of microorganisms varies among the horizons, being most numerous and diverse in the surface soil, and both factors being reduced in the lower horizons, and especially modified in the vadose or saturated zone.

- A great many different kinds of chemical and physical reactions occur in the presence of various acids, carbonates, sulfides and sulfates, nitrogen, phosphorus and potassium compounds, and many others. Through these reactions, new compounds not formerly present in the geologic material are formed as the result of the development of the soil profile, providing a more beneficial condition for plant growth.
- The last process is the formation of *soil structure* (aggregation of soil particles into geometric patterns or forms). The combination of (1) roots intertwining through the soil matrix and their exudates acting as glues, (2) organism activities such as earthworms ingesting the soil and their casts aggregating particles at a small scale, and (3) the freezing and thawing and/or wetting and drying of the soil, which first push soil particles together, causing them to adhere, then release the pressure, creating spaces (voids), provides physical and chemical processes for the formation of recognizable soil patterns from what was originally a more or less randomly dispersed arrangement. Root extension and proliferation are enhanced by the creation of voids. These voids also serve as pathways for water movement and the diffusion of gases, mainly oxygen and carbon dioxide, into and out of the soil.

It is seen that the soil profile exhibits distinct locations or positions where certain processes dominate or have their origin. The products of these processes may remain in that location or may influence other locations in the profile, thus illustrating the interrelationships among the various horizons, and confirming the fact that the soil exists as a system.

As will be shown in Chapter 2, a simple designed soil will, over time, evolve into a more complex soil profile, becoming a "natural" soil. The object of the designed soil is to establish the initial conditions to support plant growth and form the basis for the evolution of the soil, thus providing sustainability to the landscape design.

The Formation of Soil across the Landscape (Pedology)

So far we have discussed only the vertical aspect of the soil system (pedogenesis). Because the soil body is three-dimensional, we must consider also the horizontal aspect, although this is somewhat less important than the vertical aspect since the soil is actually *anisotropic* in nature. That is, the soil is generally more uniform horizontally than vertically at a limited extent of several yards (two meters).

THE SOIL BODY—THE LANDSCAPE UNIT OF SOIL

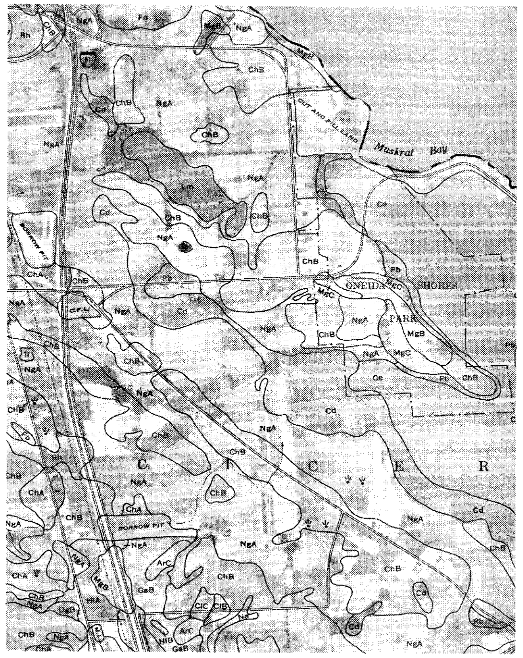
Since soils differ from one location to another, they must have dimensions—thus, the concept of the soil body.

Unfortunately, soil bodies do not have fixed dimensions as do garden plants and trees. The size of an individual soil body is determined by the very local effect of the factors of soil formation, such as how long and how high a hill may be, or how extensive a rock formation, which may also influence the local topography.

The shape will generally become that of the elements of topography, such as a plateau, a hillside, a river terrace, or even smaller segments of each. Soil scientists are able to differentiate soil bodies by examining soil profiles over the landscape and establishing the boundaries between soil bodies.

Unfortunately, most urban soil bodies are very complex and intricate; they may not even exist, as the result of haphazard excavation and filling. This is the major reason that very few soil maps exist of urban areas.

The soil bodies are spread across the landscape in various arrangements and patterns, depending on the formative factors that exist in each location. The boundaries between the soil bodies that can be delineated by trained soil scientists result in soil maps (Figure 1-5).



1-5 The soil boundary map of a local natural landscape

THE FACTORS INVOLVED IN SOIL FORMATION

These are the factors that are at work to form a soil—its environment. They are at work through various scales in the biosphere. Some are mostly regional, some are local in their dominant influence, while others may be dominant at all scales in some situations (T. A. Craul 2000). These interrelationships become very significant to the field of landscape ecology. In an ecological classification of landscapes (Forman and Godron 1986, Wertz and Arnold 1972), climate and vegetation are the highest categories, as indicated in Table 1.1.

Table 1.1. THE FACTORS OF SOIL FORMATION

Factor	Parameter	Relative Action	Scale
Climate	Rainfall, temperature	Active	Regional
Vegetation	Organic matter, organisms	Active	Regional/local
Parent material	Fabric, nutrients	Passive	Mostly local
Topography	Exposure, drainage	Modifier	Local
Time	Duration, age	Integrator	Mostly local

The *active* factors are those that affect physical, chemical, or biological processes on the earth's mantle.

The presence and amount of rainfall, or its absence, governs numerous physical and chemical processes that weather rock and unconsolidated materials. These processes include simple solution, hydration, and hydrolysis of compounds. The freezing and thawing of water contained in mantle material causes physical disintegration of the mineral particles. Water adsorbed into the mantle moves soluble compounds from one location to another.

Heat absorbed by the mantle from solar radiation during daylight raises temperatures, increasing the rates of chemical reactions. Cooling of the mantle material, as at night or in the winter season of temperate climates, decreases the chemical reaction rate.

Climate is the primary controlling factor for vegetation, the second *active* factor. Vegetation introduces the biological factor into the realm of physical factors. To simplify the discussion, some authors prefer to use the term *organisms*, which is more inclusive.

Vegetation and the associated organisms produce organic matter and its cycling of carbon and nitrogen so essential to plant and human life. The plant roots penetrate the mantle, physically and chemically breaking down the mineral material, producing soluble compounds that may be absorbed by plant roots and the soil-inhabiting organisms, contributing to the nutrient cycle.

All of these processes are basically governed by water and temperature. The interaction and its influence on vegetation are shown in Table 1.2. Parent material, or the geologic material exposed at the mantle surface from which the soil is derived, is acted upon by the active factors of climate and vegetation. Thus, the parent material is the *passive* factor.

The geology of the earth's surface is varying and complex. Each type of rock formation gives rise to a different kind of soil, even within the same cli-

Table 1.2. CLIMATIC ZONES AND THEIR CLIMAX VEGETATION (CRAUL 1999)

General Climate Zones	Climax Vegetation
Cold, wet	Tundra, taiga
Cool, moist	Spruce/fir
Warm, moist	Temperate hardwoods
Hot, wet	Tropical hardwoods
Hot, dry	Succulents/none
Warm, semidry	Grassland/conifers
Cold, dry	Tundra, alpine/ice

matic region. Change the climatic region, and the type of soil formed from the same rock formation is different.

Soil formed on unconsolidated material proceeds through a different pathway from that formed on solid rock. The former precedes much faster than the latter, and far different soils are formed.

Topography is the *modifying* factor to the other factors. If the earth's surface was all flat, the influence of the active factors would be uniform within each of the climatic zones. However, sloping or hilly surfaces change these effects so that the soil profile characteristics vary from the top of a hill slope to the bottom, and around circular hills, even on relatively uniform geology. The conditions for soil formation are different at the top of a hill from those on the slope itself, and still different at the bottom of the slope. Even nearness to a stream or river has similar effects.

For humid climates, soil at the top of the slope tends to be well drained, relatively deep, and stable. Soil on the slope may be shallow and unstable due to increased erosion potential, and somewhat drier or more moist, depending on the orientation of the underlying bedrock and the depth to the watertable. The soil at the foot of the slope is deep, moist to wet, and potentially very productive.

Time is termed the *integrating* factor. The period of time that the active and passive factors have had their combined, interactive effects determines the type of soil that evolves. Some soils proceed through the life cycle very rapidly, while others proceed very slowly. The life cycle stage in which the soil presently exists determines its usefulness and productivity.

Generally, natural soils that are termed immature to mature are usually the most productive for plant production. However, there are some soils that never will become very productive under present global environmental conditions, due to extremes of temperatures, stoniness, shallowness, the presence of high concentrations of plant-inhibiting substances, and so forth.

The difficulty in dealing with many urban soils is that they have been recently disturbed and have not yet proceeded very far along the soil formation process; if badly disturbed, they may have been set back or regressed in their life cycle, making restoration more difficult.

THE DISTRIBUTION OF NATURAL SOILS IN THE UNITED STATES

All of the preceding information suggests that there are many different soils in the United States, with different capabilities and limitations for plant growth. This geographic and characteristic diversity is described in the following summaries of the *Order* taxonomic category (the highest, most generalized category). These descriptions suggest only the gross differences among the various soil regions, but provide an initial natural guide to the soil design for application in each region. Further adjustments in the soil design by the soil scientist are required to "fit" the soil to the site conditions presented by the landscape project in each region.

The Order category is described here for simplicity (there are 12 Orders) and because it reflects most strongly the interrelationships of climate, vegetation, and soil. By comparison, there are over 12,000 soil series (the lowest and most specific category of classification) in the United States (Buol et al. 1989). The USDA-Natural Resources Conservation Service and other agencies are developing soil series descriptions applicable to urban soils, together with their capabilities and limitations, but the process is very slow. Thus, the soil scientist, designing soil for a landscape project, needs to emulate existing appropriate natural soil series whose capabilities and limitations are already known.

Good natural soils for plant growth can be found in most areas of the United States, but because of inherent characteristics, some are better than others; thus, their capabilities and limitations for plant growth and use as landscape soils also vary. Most of the characteristics are due to the effects of climate, the mode of weathering or deposition, and the predominant vegetation over time. Urbanization tends to alter these characteristics (discussed later in this chapter) so that in most cases the capabilities for plant growth are reduced and the limitations are increased.

Alfisols

These are soils that exhibit high base nutrient content and high clay concentration in the subsoil; therefore, they are very fertile and respond well to agricultural management. They occur mostly in the temperate zones, but some are found in tropical and subtropical areas. Alfisols originated under broadleaf deciduous forest, mixed deciduous and needle evergreen forest, and grass, depending on the climate of the region. The organic horizons follow an annual cycle of accumulation and decomposition. Accelerated erosion presents a serious hazard, creating a droughty condition on the eroded soil, and increased flood hazard on the lower portions of the Alfisol landscape. The greatest concentration of Alfisols occurs in the Mississippi Valley and uplands elsewhere underlain by calcareous bedrock, northeastern Texas, the northern great valleys of California, and portions of the basins in the Rocky Mountains.

Andisols

Andisols are derived from volcanic ash and therefore are associated with volcanic areas of the United States. They form in lava flows, tephras, pyroclastic flows, volcanic alluvium, and volcanic loess. The volcanic ash is undergoing continual transformation from its youthful condition when moisture is adequate. They may be fertile or not fertile, depending on the degree of profile development and evolution. Where these soils exist in drier climates, they are relatively skeletal, and have large quantities of pumice, greatly reducing their plant growth capabilities.

The Andisol areas occur in the Cascade Mountains and to the east in the Palouse region of eastern Washington and Oregon, northern Idaho, and the eastern portion of northern California; they are not widespread.

Aridisols

As their name implies, these soils occur in the arid and semiarid areas of the country, mainly the Basin and Range provinces of Nevada, Utah, Arizona, New Mexico, central Wyoming, and portions of Colorado. Most are vegetated, though limited, with only a small portion in actual desert. The profile of these soils is dry in all parts for more than 50 percent of most years, and not moist in any part for as much as 90 consecutive days when the soils are warm enough for plant growth. Plant roots of the native plants are able to penetrate the soil to great depth; plant competition for moisture is fierce. Patterns of runoff and runon are intricate, with interspersing of vegetative patches and saltation flats, interrupted by drainage channels that flood in the cloudbursts of these areas. The soils are alkaline to saline. Horizonation of the profile is not well developed, and usually the profile does not exhibit a distinct A horizon, or "topsoil." Surface crusting is common, and some areas have a "desert mulch" of pebbles or small stones with the fine particles having been blown away by windstorms. Irrigation tends to leach the salts to lower portions of the profile, but they can return to the surface by means of the strong evaporative forces and form a salt crust, when irrigation is withdrawn.

Entisols

The Entisols are characterized by youthful, simple profiles in most locations where they are found, or they may not have evidence of any horizons other than a surface layer of organic matter. They are found on landscapes that are very youthful, recently developed or emerged from water or a receding glacier, or "not soil." These landscapes include wetlands, sandy lands such as glacial outwash and terraces, rocky lands, mudflows, and recent alluvium. Entisols generally contain a high content of stone or rock fragments. Most of these soils present engineering problems of one kind or another. Unstable slopes, rockiness, and flooding in lowlands are common. These soils on level terrain with adequate rainfall do form fertile soils that are agriculturally valuable. The geographic concentration of Entisols is on the higher plains of the upper and western Midwest and the Southwest in Arizona and New Mexico. Local areas of Entisols are found elsewhere on youthful landscapes of the eastern and southern United States.

Gelisols

The Gelisols are found in areas of permafrost; thus, permafrost is a characteristic of the soil profile. These soils are found almost exclusively in Alaska. Construction engineering on these soils is extremely complex, and agriculture is almost excluded due to the presence of the permafrost. They are mostly devoted to wildlands, of various plant communities ranging from scattered trees and shrubs to arctic tundra, with development limited only to routes of communication through the areas. Even construction of a simple house on these soils is a major undertaking. Useful soil depth is limited by the variable depth of permafrost, which should not be disturbed and should be protected by an insulating layer.

Histosols

Histosols are soils composed mainly of organic materials derived from tissues of plants and animals and their decomposition products. The soils are mostly under saturated anaerobic conditions of poor drainage. They persist in a state of various degrees of organic decomposition unless drained. There are two conditions under which Histosols may exist: (1) in depressions or low areas depending on seepage and stream inflow, independent of climate, which may result in relatively deep deposits of several feet, and (2) blanket peats and raised bogs that depend on rainfall but are never saturated except for a few days following heavy rain; they are either shallow or extremely rocky, and the plant roots grow only in the organic material. Histosols are concentrated in the northern Lake States of Minnesota, Wisconsin, and Michigan, but exist scattered elsewhere in Maine, northern New York, and Florida. They also occur in coastal areas.

Obviously, these soils are not for development, but may serve useful purposes as buffer zones, treatment wetlands, and wildlife areas. The Histosols have agricultural use as "muck land farming" when they are drained. Greater aeration created by drainage increases the decomposition of the organic matter at a rapid rate, releasing nutrients for excellent crop growth. However, the loss of the organic matter causes these soils to subside, eventually reducing the productivity. The organic matter layer becomes so thin or removed that the productivity is seriously impaired. The soil layer that lies below is usually poorly drained so that flash flooding occurs when it is exposed, whereas the original soilscape stored water.

Inceptisols

The Inceptisols are defined as immature soils that have not yet formed a complex profile. They primarily occur in the Appalachian Mountains of the eastern United States, northward into the Adirondacks of New York, the Green Mountains of Vermont and the White Mountains of New Hampshire, and the Cascade Mountains of Washington, Oregon, and northern California. They are scattered elsewhere. They are found in several settings of highly resistant parent material such as quartzite sandstone, abundance of volcanic ash, extreme landscape positions such as on steep or unstable slopes and depressions, and geomorphic surfaces so young as to limit soil development. Their agricultural capabilities vary widely, as do their capabilities and limitations for development. The poorly drained Inceptisols may be used for agriculture if artificially drained, but productivity is usually moderate at best. There are some very isolated small areas of good farmland. The best uses for most of these soils include forestry, wildlife, and recreation. Planned development must take into account the limitations of these soil areas.

Mollisols

The Mollisols of the United States form the "breadbasket" of the nation, if not the world. They occur mainly in the central plains of the midwestern United States, ranging from the Mexican border northward to the Canadian border, with large areas in Montana, Wyoming, Washington, and Oregon. They are derived from mainly calcareous shales and some sandstones overlain by glacial till and by a thick topsoil (A horizon) that is measured in feet! The thick topsoil, especially of Iowa, western Illinois, northern Missouri, and sections of adjacent states, is the result of the combination of the nutrient-containing bedrock and glacial sediments, the moderate rainfall, and the annual complete organic matter turnover of the tall grass prairie that has existed for 10,000 years. The topsoil is thinner outside of these areas due to the reduced rainfall and shorter, more bunched grasslands. Obviously, the best use of the Mollisols is for agriculture, with dryland farming or good rangeland on the shorter grass areas. Development should be limited to those portions of the economy that support the agricultural sector in these areas.

Oxisols

Oxisols do not occur in the continental United States, but are present in Puerto Rico, Hawaii, and the Virgin Islands. The soils are high in iron and other sesqueoxides, contributing to their fertility. However, the reserve is limited and they quickly lose their fertility unless fertilization is a major practice. They are very extensive in the tropical portions of the world, with very extensive

areas in Brazil and western Africa. Oxisols support tropical rain forest, scrub and thorn forest, semideciduous forest, and savanna. They usually occur on stable, upland positions. Main uses include shifting agriculture, low-intensity grazing, and plantations of sugar cane, pineapples, bananas, and coffee. Extensive development for agriculture is now under way in Brazil and elsewhere where rainfall is not limited. The soils are very stable, and development such as road building and the like is facilitated.

Spodosols

The Spodosols are not widespread, being concentrated in Maine, areas of the Adirondacks of New York, the Lake States, portions of central Florida, and limited areas of Oregon and Washington. Their profile exhibits a combination of a leached, ashy gray horizon with an iron-rich horizon below it and a humic layer at the bottom. These profiles are the most photogenic of all soils, with the spectacular ashy gray leached horizon, the reddish brown of the spodic (iron) horizon, and the dark gray to black of the humic (translocated organic humates) horizon. This condition causes low fertility, in addition to the fact that Spodosols form mainly on sandy, coarse-textured materials or stony to very stony soils mainly of quartzite and the like. Many of these soils are very old, one in North Carolina being more than 25,000 years old, and one in California at one million years (Buol et al. 1989). The major uses of these soils are forestry, pasture, hay land, and, where the coarse fragments do not interfere too badly, some intertilled crops. Development is difficult on some of these soils, due to rockiness.

Ultisols

As the term implies, these soils exhibit ultimate soil development with distinct, well-developed horizons. Much clay is translocated to the subsoil, or to the soil formed in clay-bearing initial materials. Ultisols develop in warm to hot climates with plentiful rainfall and exhibit a bright red color. The soil was formerly covered with pine and Southern hardwood forests with scattered grasslands (almost a savanna) where wildfire was ignited by lightning or deliberately set by Native Americans for hunting purposes. As a result, the Ultisols are found primarily in the southeastern quarter of the United States, mainly in the Piedmont region, with some extending northward to Pennsylvania and westward to Missouri, Arkansas, northern Louisiana, and east Texas. Because of the intensive weathering, most of the bases have been removed from the profile, and they are not as fertile as would normally be expected with the high clay content. Thorough fertilization programs overcome the problem. Generally, these are rich agricultural areas, but erosion was a severe problem before the 1930s. Timber production is the second most important use of the Ultisols.

Development of these soils is limited primarily by the need for good erosion control practices, without which many catastrophic events can occur. The soils lose some of their stability when disturbed, and slope stabilization is necessary on steeper, longer slopes.

Vertisols

The Vertisols are so named because they form very distinct, long vertical cracks upon drying. The shrinkage forces are sufficient to tear plant roots, including alfalfa and tree roots. Upon rewetting they swell with great force and can upset bridge abutments, turn over trees, and destroy foundations of structures. The surface of the Vertisol soilscape has a rolly, rilly appearance due to the expansion forces. Leaning fence posts and electric/telephone poles are characteristic of these areas. Fortunately, these soils are limited in extent within the United States, being found mainly in sections of valleys in Texas, and along the Mississippi Valley of Missouri, Arkansas, and northern Louisiana. An annual dry period typifies the climate in which these soils are found. They also occur in southern Minnesota and isolated areas of California, and have been mapped around major urban areas of Arizona (Phoenix and Tucson) and parts of New Mexico. Their use has been limited to grazing and some agricultural cropping. Urban development is extremely difficult on these areas and should be avoided. The Vertisols are extremely unstable when disturbed. The junior author of this book was involved in a study on zoning for the city of Houston, Texas, to prohibit certain types of development on the Vertisols of that metropolitan area, mainly the Houston black clay soil series.

For additional information on the geographic locations of the Soil Orders of the United States and their typical soil profiles the United States Department of Agriculture Natural Resources Conservation Service Web site should be consulted at:

ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil Taxonomy/maps.pdf

Or, search using keyword "Soil Taxonomy Orders."

The Urban/Restoration Soil

As was shown in Figure 1-4(c), there is no real soil-forming (*pedologic*) sequence to the horizons of the urban soil, because most urban soil materials have not been in place long enough for any formation processes to occur, with rare exceptions. The only sequence that is present arises from the sequence of disturbance and deposition by human activity. Further, the horizons have not

been in place long enough for any soil-forming interrelationships to develop. However, there are interrelationships present of drainage, co-contamination by migration between adjacent horizons, and so forth.

It is useful to distinguish urban soils that have been extensively altered from those that retain most of their natural characteristics and have only been subject to relatively minor near-surface alterations produced by activities associated with urban environments.

Derelict land is defined by Bridges (1987) as "land which has been so damaged by extractive or other industrial processes or by any form of urban development that in default of special attention it is unlikely to be effectively used again within reasonable time and may well be a public nuisance in the meanwhile." Restored soil implies a process of reversing the extreme damage to soils of derelict lands so as to render them suitable for one or more specific urban land uses.

Humankind, through alteration of the natural soilscape and activity on it, becomes the predominant active agent for the placement of soil material and its alteration, rather than one or several of the natural agents such as water, wind, ice, gravity, and heat.

In the urban environment, the detrimental effects on the soil are (1) removal of more plant and animal nutrients than are replaced, (2) addition of materials toxic to plants and animals, (3) causing soil subsidence by drainage or mining, (4) excavation and compaction, (5) subjecting soil to excessive heat and wind, (6) altering aspects by land-forming, (7) clearing and burning of organic matter with removal of plants and animals, and (8) burying soil under solid fill or water.

DEFINITION OF RESTORATION/URBAN SOIL

> *A soil material having a non-agricultural man-made surface layer more than 50 cm thick, that has been produced by mixing, filling, or by contamination of land surface in urban and suburban areas or drastically disturbed land. (modified from Bockheim, 1974)* In Craul, 1992.

THE CHARACTERISTICS OF URBAN SOILS

There are eight attributes that differentiate urban soils from natural soils (Craul 1992). These are contrasted to natural soil attributes in Table 1.3. Table 1.4 lists the eight specific characteristics of urban soil.

Discussion of each of the eight urban soil characteristics (Table 1.4) is

Table 1.3. THE CONTRASTING ATTRIBUTES OF NATURAL VERSUS URBAN SOILS

Natural Soil Characteristics	Urban Soil Characteristics
1. Formed by natural processes	1. Formed by intense human urban activity
2. Predictable patterns and boundaries	2. Very variable and unpredictable boundaries
3. Continuous vegetative cover	3. Usually sparse, weedy cover, if any, exposing the soil to high temperatures
4. High level of microorganism activity	4. Limited microorganism activity
5. Mostly gradual property changes in depth	5. Mostly abrupt property changes in depth
6. Few rooting barriers	6. Many potential barriers to root growth, including compaction
7. Few contaminants present	7. Potentially many contaminants present
8. Normal pH for the natural soils	8. Generally elevated pH for the urban soil

necessary to provide a better understanding of the conditions that may be present when a project is proposed for an urban site. The contrasts presented in Table 1.3 should be kept in mind.

Unpredictable Great Vertical and Spatial Variability

The constructional history and varying methods of placement of cut and file material cause great vertical and spatial variability. Soil materials with various mixes of soil and demolition debris creates the spatial variability, while the grading of these various mixes of earthy materials by bulldozer creates the vertical variability. Cuts of soil expose the natural vertical variability of the various

Table 1.4. THE CHARACTERISTICS OF URBAN SOILS

Unpredictable great vertical and spatial variability
Altered soil structure leading to compaction
Presence of a surface crust on bare soil that is usually hydrophobic
Altered soil pH, usually elevated
Restricted aeration and drainage leading to anaerobic conditions
Interrupted nutrient cycling
Presence of anthropromorphic materials and contaminants
Highly modified soil temperature regimes, usually elevated

soil horizons to the spatial context. Therefore, soil conditions are nearly unpredictable. If the in situ soil is to be used as part of the planting soil, a detailed soil investigation is required to determine the extent of the variability and the properties of the soils in question.

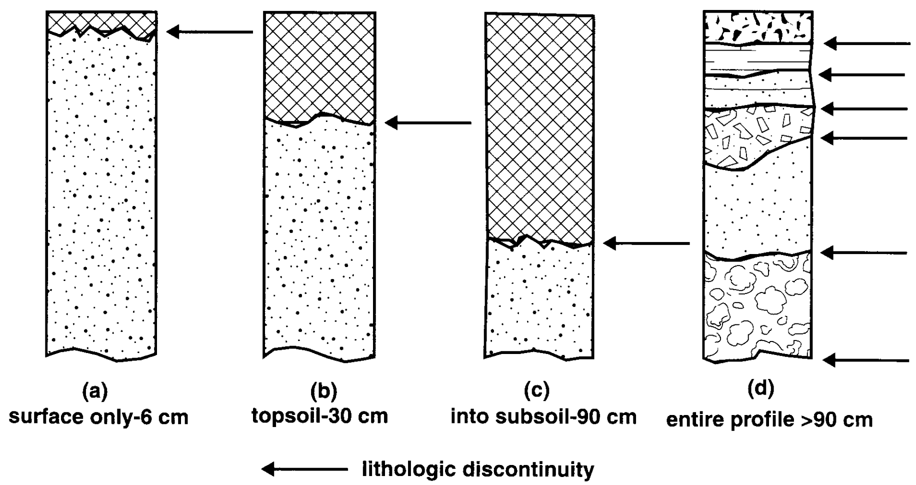
Altered Soil Structure Leading to Compaction

Disturbance of the soil by stripping, grubbing, dumping, storage, and spreading destroys any natural pedologic structure that maintains water infiltration, gas exchange, soil density that is conducive to root penetration, and water-holding capacity.

Medium- to fine-textured soils compact more easily than coarser-textured soils. Also, vehicular and pedestrian traffic compacts soil, along with vibrational forces that exist in the urban environment. Most natural soils fall into the medium- and fine-textured category.

The various interrupted profiles of urban soils caused by disturbance, excavation, or filling are illustrated in Figure 1-6. The data are based on an actual survey of streetside and front yard soils in the city of Syracuse, New York. Thus, what is observed at the surface is not a reliable indication of what lies below the surface, as indicated earlier in Figure 1-4(c). The variation in continuity/discontinuity of soil materials in the profile could range from the same soil profile type as the surface, as indicated in Figure 1-6(a), to the unpredictable gross mix of materials indicated in Figure 1-6(d).

The profile of Figure 1-6(a) could probably be evaluated as performing the same as the undisturbed soil, while the profiles of Figure 1-6(b) and Figure 1-6(c) would require modification of expected plant-growing performance from known indices. The performance of the profile in Figure 1-6(d) would



1-6 Lithologic discontinuities of urban soils in Syracuse, New York (Craul 1992) be totally unknown The real soil profile of Figure 1-7 (see color insert) shows the multiple discontinuities illustrated in Figure 1-6(d).

It is suggested that roots can enter pores that are at least 0.01 mm in diameter. If voids (pores) exist as continuous channels or connected chambers, as in a well-aggregated soil, roots can elongate with ease. In addition, roots elongate by moving soil material aside (nutation) by exerting pressure on soil particles to make space for growth. In dense soil, the pores may be too small for penetration by the root tips, or the channels may be discontinuous and the chambers disconnected, or the soil may be too dense to be pushed aside. The bulk density (dry soil weight per unit of volume, which consists of megagrams per cubic meter—Mg/m^3—or pounds per cubic foot—lbs/ft^3) of the soil in this condition is equal to or exceeds 1.55 Mg/m^3 for fine-textured soils and 1.75 Mg/m^3 for sandy soils. If the root tip encounters an obstruction such as a stone, it attempts to grow around it and continue in the same axis of direction, if the bulk density permits it (Lyford 1980).

Presence of a Surface Crust

Bare surface soil is common in urban areas due to wear by traffic or the absence of protective vegetative cover as compared to natural vegetated areas (Craul 1992). Lack of adequate sunlight is a further cause. Compaction is the major result from the effects of pedestrian and vehicle traffic on the unprotected soil surface. Absence of the binding and lightening effect of root systems, especially turf, and the destruction of organic matter within the soil contributes to the compaction. The infiltration capacity of the soil surface is sharply reduced causing water ponding at the surface during heavy rains. Restoration of favorable soil conditions for satisfactory plant growth is achieved only by drastic tillage of the soil, coupled with incorporation of a sufficient amount of organic matter prior to replanting.

Altered Soil Reaction (pH)

The flow of rainwater down building facades and over concrete sidewalks dissolves many alkaline compounds such as calcium and sodium carbonates or bicarbonates. When these compounds are added to the soil by infiltration and cation adsorption, the soil pH is raised above levels found in local native soils. Masonry and concrete debris contained in the soil also contribute to the elevated pH. The situation may lead to unavailability of some nutrients, the increased solubility of undesirable compounds, and a pH range too high for certain plants. Many urban soils have elevated pH levels, leading to the development of chlorosis in some tree and shrub species.

In other cases, the soil pH may be acid due to the presence of manufacturing or industrial processes. For example, former steel mill restoration sites

may have very to extremely low pH where steel-making acids were dumped. Elsewhere on the same sites, the soil pH may be elevated where the slag was dumped. Neither condition is favorable for the more commonly used plant palettes. There is good reason to maintain the soil reaction close to neutral or at least 5.5 to 6.5—mainly the increased availability of nutrients, as suggested in Figure 1-8.

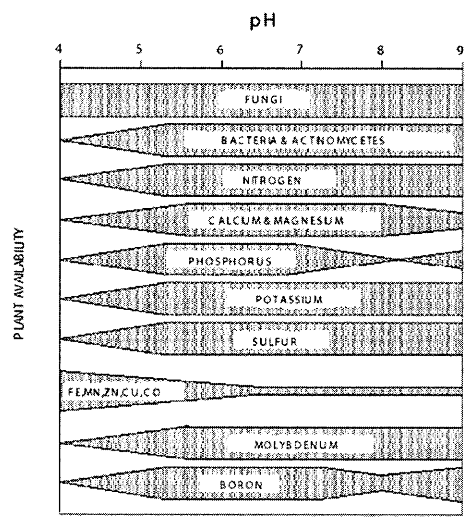
Restricted Aeration and Drainage

As a result of the extensive compaction found in restoration/urban soils, restricted drainage and aeration are common (Craul 1992).

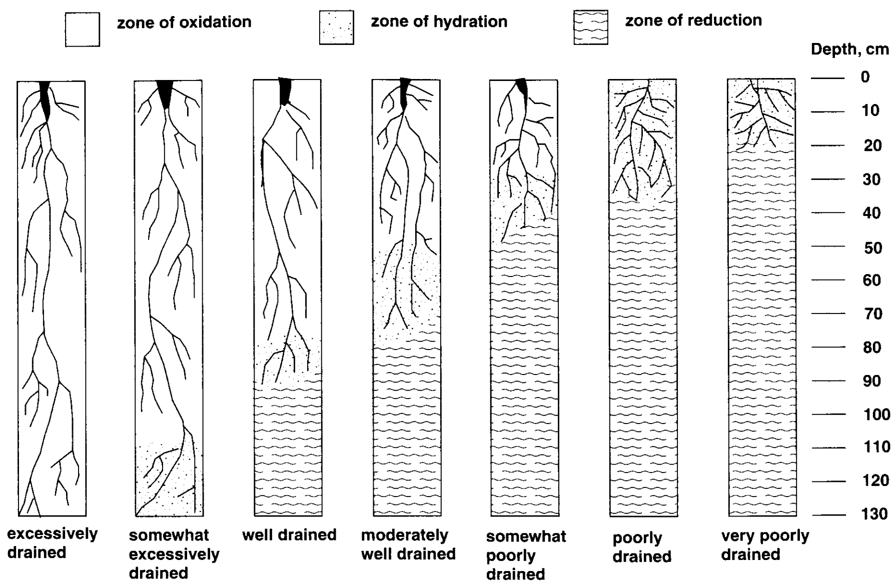
Compaction reduces the total pore space through which water and air may move. In addition, the average diameter of the pores is reduced, with most of the reduction in the larger pores. Just as reduction in pipe diameter reduces water flow, the same phenomenon occurs in smaller soil pores. The percentage of retained water increases, decreasing the air-filled pore space. Restricted aeration results.

The discontinuities described under the section on compaction create interfaces and compacted layers that restrict percolation of water through the profile. If the soil is wetted to near saturation, oxygen deficiency becomes a reality and plant roots suffocate. Many urban soils have the characteristics of poorly drained to very poorly drained soils of the natural landscape (Figure 1-9). Most commonly used plants require a well-drained soil.

Poor soil aeration affects the metabolic activities of both plant roots and soil microorganisms. Short periods of anaerobic conditions in the soil irreparably damage the root system of many plants, induce microorganisms to form



1-8 Soil reaction and plant nutrient availability (Craul 1992)



1-9 The common soil drainage classes (Craul 1992)

large quantities of toxic materials, and cause considerable losses of nitrates. Fortunately, the products of anaerobic metabolism are rapidly oxidized in the soil and rendered nontoxic if oxygen is restored even to low concentrations. An adequate supply of oxygen in the soil throughout the growing season is a prerequisite condition for the good long-term growth of many plant species.

Interrupted Nutrient Cycling

Urban soils are commonly covered by impervious layers (concrete, asphalt, gravel, etc.) that prevent any plant litter deposited on the surface from becoming part of the soil through decomposition. The soil organic matter content and the nutrient status tend to remain static or become depleted over time.

The impervious surface also blocks water movement, gas exchange, and the infiltration of deposited atmospheric nitrogen. Studies have shown that almost all additional nitrogen (except nitrogen obtained through decomposition of organic mater) needed for growth comes from atmospheric deposition.

The organic matter and nutrient cycles are grossly interrupted. Without this continual renewal, fertility from root uptake decreases over time, if plants are present, or nutrients are transformed into unavailable forms in the greatly restricted rooting volume and limited nutrient amounts common to many urban soils.

Additional nutrients become available to a street tree only if the root system escapes from the confinement of the pavement into adjacent open areas, or intrudes into a storm sewer or a pipe trace, or if the tree is intentionally fertilized by some method.

Presence of Anthropomorphic Materials and Contaminants

Because the material has been "urbanized," most urban soils, through their constructional history, contain metal, glass, plastic, wood, asphalt, masonry, stones, and organic debris.

Some of these soils may contain heavy metals, pesticides, PCBs, and so forth (Craul 1992). Sampling (USEPA 1991) and testing for the latter contaminants should take precedence before any design is begun, if cleanup procedures have not already been carried out (Craul 1999). The presence of these contaminants greatly influences the potential use of the site and its design, if removal is not feasible.

This situation also adds complexity to the soil protocols, which must be followed to create a safe environment for the new design. The protocols must be strictly enforced in order to comply with federal, state, and local regulations. The protocols promulgated by government agencies are contained in the appropriate regulations and are only referenced in the soil protocols provided here.

Fortunately, most contaminated sites have been cleaned up by the time the sites are proposed for restoration; however, there are exceptions where the contamination is undetected. Close scrutiny of the constructional history may reveal clues to contamination on the site.

Highly Modified Soil Temperature Regimes

Large amounts of reflected heat from buildings, streets, and sidewalks, as well as heat from vehicles, subways, and heating lines, are absorbed by the soil, raising the daytime and nighttime temperatures.

Soil organism activity may be harmed and great physiological stress placed on the associated vegetation, leading to greater susceptibility to insect pests and disease (Sperry et al. 2001).

Emphasis must be placed on providing a sufficient moisture supply for trees surrounded by hardscape. This may be accomplished by providing greater rooting volumes, modifying the soil design itself, creating more open soil surface, reducing the design of the surrounding hardscape, or installing irrigation.

SUMMARY

The necessity for designed soils entails the need for protocols to ensure that the appropriate source materials are obtained and compiled according to the specifications. The protocols provide a prescribed schedule for completion of all soil work in conjunction with other work phases of the project.

An appreciation of the contrast between natural and urban/restoration soils assists the landscape architect and contractor to understand that soil specifications and the accompanying protocols are necessary for successful projects. The existence of a wide diversity of natural soils across the United States indicates that one soil design cannot fit all landscape projects in all regions. The existence of urban/restoration soils on many proposed landscape architecture sites within these soil regions also suggests the need to consider the site conditions as additional factors in the soil design process. The design and installation of an appropriate soil, following the applicable protocols, ensures sustainability of the landscape project.