CHAPTER 8

Interpretations: The Impact of Soil Properties on Land Use

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Introduction

This chapter explains the concepts and principles used in the interpretation of soil property data to evaluate or predict suitabilities, limitations, or potentials of soils for a variety of uses. Soil survey information answers a wide range of soil-related questions, such as which crops will grow where and what are the best locations for infrastructure. Soil information can be used alone or as one layer of information in integrated systems that also consider other natural resources, demographics, climate, and ecological and environmental factors in decision making.

In the United States, soil survey data and soil interpretive information from the official Soil Survey Geographic Database (SSURGO) are a major part of a growing number of geographic information systems (GIS) and models. These systems and models are used in regional planning, erosion prediction, estimating crop yields, timber and energy management, urban planning, public health considerations, and determining a soil's ability to perform certain ecosystem services (such as carbon storage) that can affect global climates. Historically, soil survey interpretations primarily have been used to provide the public with soil interpretive predictions specific to a land use. Soil interpretation in the U.S. aims to quantify the soil function parameters expounded by the Food and Agriculture Organization of the United Nations. Ecosystem services performed by soil include provision of construction materials, filtering of water, providing habitat for organisms, sequestering carbon, flood mitigation, anchoring human infrastructure, supporting the growth of crops, and being a reservoir of genetic resources.

For the National Cooperative Soil Survey (NCSS) program, interpretive information is available in a public database and displayed in Web Soil Survey (WSS) (Soil Survey Staff, 2016). The baseline data and criteria are revised and refined continuously. The interpretive information is kept up to date by yearly refreshes. (The appendices provide examples of soil interpretations available through WSS, including thematic maps of soil properties and suitability ratings as well as tabular reports.) Soil interpretation reflects the capacity of the soil to support various uses and management practices. The level of data collection needed to execute the current interpretations program of the NCSS is outlined in relevant parts of the *National Soil Survey Handbook* (USDA-NRCS, 2016).

Generally, preparation of interpretations involves the following steps: (1) assembling information about soils and their landscapes, (2) deriving inferences, rules, and models for predicting the impact of soil properties on soil behavior under specific land uses, and (3) integrating these predictions into generalizations for each map unit component.

Soil interpretations provide numerical and descriptive information pertaining to a wide range of soil interpretive predictions. This information can be expressed as classes, indexes, or values with different units of measure. For example, particle-size data can be inferred from soil separates of sand, silt, and clay; USDA texture classes; or Unified soil classes. Generally, soil interpretations are made for specified uses and are reported in the form of limitations, suitabilities, or potentials. For limitations, soil properties that limit land use or establish the severity of limitation are typically indicated. For suitabilities, soil properties that determine a soil's suitable characteristics may be given. In addition, soil interpretations, either as limitations or suitabilities, may be incorporated into potential ratings along with other resource data and interpretive information. The interpretive results can be presented in tables or in maps that depict the spatial extent at scales appropriate for a specific application.

The predicted practicality of alternative management options can be derived from soil interpretations. For any particular land use, soil responses to management alternatives can be predicted, the kinds of management needed can be identified, and the benefit-to-cost relationship for the management selected can be evaluated.

Considerations for Developing Soil Interpretations

An interpretation, such as limitations for septic tank absorption fields, provides information for a specific purpose and rarely is adaptable without modification to other purposes. Application of interpretations for a specific land area has an inherent constraint related to the scale of mapping and the composition variability within a map unit. This constraint is related to how soil surveys are made and the spatial relationship of the area of interest to the map unit delineations. These concerns are particularly significant for land areas for which large capital expenditures are contemplated (e.g., homesites). These areas are typically small relative to the size of map unit delineations and may occur on a dissimilar minor component that has interpretations that differ from those of the major components of the unit. These concerns are even greater for multi-taxa units. See chapter 4 for a complete discussion of map units, map unit components, and mapping scale.

Inherent soil property spatial variability defines the resolution of soil interpretations and the precision of soil behavior predictions for specific areas. Soil survey interpretations are rarely suitable for such onsite evaluations as homesites without further evaluations at the specific site. Soil interpretations do provide information on the likelihood that an area is suitable for a particular land use and so are valuable for screening areas for a planned use. This likelihood may be expressed as a suitability or a limitation.

Specific soil behavior predictions are commonly presented as the degree of limitation imposed by one or more soil properties. Limitations posed by a particular soil property must be considered along with those of other soil properties to determine which property poses the most serious limitation. A high shrink-swell potential, for example, may be the only limiting soil property for building houses with basements for some soils. However, other soils that have a high shrink-swell potential may also have bedrock at shallow depths, and shallow depth to bedrock may represent a greater limitation than shrink-swell. Relatedly, some soils that have a low shrink-swell potential, which is favorable for homesites, may have limitations because of wetness, flooding, slope, etc. The degree of limitation imposed by a soil property on a land use may be thought of in terms of the added cost to perform the land use relative to a less limiting soil. If necessary, any limitation may be overcome, but the additional expense of installation, maintenance, and decreased performance may be prohibitive.

Other soil behavior predictions are presented in terms of how suitable a soil is for a particular land use. Historically, soils have been rated for their suitability as a material, such as topsoil or a source of sand. Soil productivity indices for crops and plants are also typically reported in terms of suitability. The underlying principle is that the soil will be used as it exists with no measures to overcome whatever makes the soil less suitable for a function. The major disadvantage of a suitability interpretation is that all of the soil and site properties that might impact the land use must be identified and evaluated. If a property that does not exist in the database is identified as being important, it must be derived or included in some manner in the rating process. Omission of a soil property that is not suitable will cause invalid positive ratings.

Certain considerations that determine economic value of land are not part of soil interpretations but are an integral part of determining soil potentials for a given land use. For example, local groups consider the location of a land area in relation to roads, markets, and other services when developing soil potential ratings based on costs to maintain the soil resource versus benefits derived.

Interpretations are sensitive to changes in technology and land uses. Crop yields generally have increased over time, and new practices may reduce limitations for nonagricultural uses. For example, the introduction of reinforced concrete slab-on-ground house construction has markedly reduced the limitation of shrink-swell for small building construction. Additionally, new uses of land or changes in technology will require new prediction models for soil interpretations.

Soil properties can also be interpreted in terms of the favorability of a soil for the growth of certain fungi, bacteria, and other organisms that are either unwanted (such as a disease-causing organism) or economically desirable. While the land is not necessarily managed for a particular organism, prediction of the presence or absence of the organism can be useful. Also, soil properties can be used to assess the propensity of a soil to retain or transmit certain chemicals or energy (heat and cold). This propensity is not a limitation or a suitability, because it does not indicate a hazard or desirability, but rather a tendency.

Finally, interpretations based on properties of the soil in place are only applicable if characteristics of the land area are similar to what they were when soil mapping was done. New interpretations may be required if the soil and site properties have been affected by physical movement, compaction, or bulking of soil material or changes in patterns of water states by irrigation, drainage, or alteration of runoff by construction.

Interpretive Models

Interpretations are models that predict soil behavior based on soil physical and chemical attributes. The spectra of soil, site, and climatic properties that are available are addressed later in the chapter. The generalizations of soil behavior are based largely on a known or obtainable set of soil and site properties that are maintained in a database or predicted for each soil component. These soil properties or characteristics can be used to predict other attributes of soil, such as potential for frost heave or concrete corrosion. In addition, documented experiences with soils having certain sets of properties are used to generalize or predict soil behavior for many land uses. These generalizations are commonly formalized in interpretive models for computer-generated ratings.

Interpretive models may be based on knowledge of how soils perform under different uses or based on research data and/or inferences. These models may contain a narrow set of inferences for specific uses or applications (e.g., limitation of the soil for trench-type sanitary landfill), or they may have a highly integrated set of inferences about complex practices that are based on a large number of considerations, only some of which are interpretive soil properties (such as the land capability classification system; Klingebiel and Montgomery, 1961). Like other processes in a soil survey, the process of developing interpretations for a specific land use follows a scientific method. The soil scientist or group preparing the criteria reviews the literature, interviews experts, makes observations of soil performance under the specific use, develops a set of criteria using basic soil properties, tests the criteria, and finally adopts the system. The process rarely becomes static; as new technologies become available, the criteria must be reevaluated.

Developing a Soil Interpretation

One of the first tasks in developing an interpretation is to create a criteria table of the soil, site, and climatic attributes that are thought to impact the land use. Table 8-1 provides an example. It contains a comprehensive set of criteria for interpreting soils for septic tank absorption fields. Some of the included criteria may not be applicable in some places (e.g., areas of permafrost). Using this example, the soil scientist or group developing an interpretation first determines a list of soil properties that are known, or thought to be, important for septic tank absorption fields. Depth to water table, saturated hydraulic conductivity, depth to bedrock, depth to cemented pan, depth to permafrost, slope, flooding, ponding, fragments > 75 mm, and susceptibility to downslope movement or subsidence are considered important properties. After determining the list of soil properties, the soil scientist or group develops limits for each property and each class. This iterative phase is commonly the most difficult. The initial set of criteria is tested in different areas of the country under a wide variety of soil conditions. Results of the tests may require adjustments to the criteria and retesting. Once the limits are set, they may be arrayed in the table according to degree of severity or importance. Soil interpretations are models for predicting

Table 8-1

Interpretive Soil Properties and Limitation Classes for Septic Tank Absorption Fields

Interpretive soil property	Limitation class			Limiting feature
	Not limited	Somewhat limited	Very limited	
Total subsidence (cm)	---	---	> 60	Subsidence
Flooding	None	Rare	Very frequent, frequent, occasional	Flooding
Bedrock depth (m)	> 1.8	1–1.8	< 1	Too shallow
Cemented pan depth (m)	> 1.8	1–1.8	< 1	Too shallow
Free water occurrence (m)	> 1.8	1–1.8	< 1	Depth to saturation
Saturated hydraulic conductivity (µm/s)—				
Minimum 0.6 to 1.5 m [a/]	10–40	4–10	< 4	Slow water movement
Maximum 0.6 to 1 m [a/]			> 40	Poor filter
Slope (pct)	< 8	8–15	> 15	Too steep
Fragments > 75 mm [b/]	< 25	25–50	> 50	Large stones
Downslope movement			[c/]	Landslides
Permafrost			[d/]	Permafrost

[a/] 0.6 to 1.5 m pertains to the water transmission rate; 0.6 to 1 m pertains to filtration capacity.
[b/] Weighted average to 1 m.
[c/] Rate "severe" if occurs.
[d/] Rate "severe" if occurs above a variable critical depth (see discussion of the interpretive soil property).

how soils respond under a specific use. They use a set of rules or criteria that are based on the basic soil properties, modeled properties, or classes of properties. In some cases, it may be necessary to model a subset or intermediate interpretation to evaluate such properties as potential frost action, corrosivity, or potential for mass movement.

Interpretations are mostly developed in response to user needs; thus, the development process must include input from users and professionals in other disciplines. User feedback is crucial in the iterative process of refining a specific interpretation.

The "interpretive soil property" is the attribute to be provided to the model, generally by extraction from the database. However, the criteria in the table can be applied to individual soils without the use of a computer, depending on the circumstances. The "limitation classes" are determined by the team of experts in collaboration with the projected users of the interpretation. The magnitudes of the soil attributes at the critical thresholds of impact and the presence or absence of some condition are also established by the team of experts. The "limiting feature" is the reason that particular soil attribute limits the land use.

Table 8-2 illustrates how criteria are applied locally to a component of Aksarben soils. Tables 8-1 and 8-2 illustrate the process of developing an interpretation. Note that in table 8-2, only those soil properties that are applicable to the local area are required, so the number of properties evaluated is less than the number included in table 8-1.

Table 8-2

Values of Applicable Interpretive Properties for Septic Systems for an Aksarben Component

Property	Limitation Class			Values
	Not limited	Somewhat limited	Very limited	
Flooding	X			None
Bedrock depth	X			> 1.8 m
Free water occurrence	X			> 1.8 m
Saturated hydraulic conductivity—				
Min. 0.6 to 1.5 m			X	2 µm/s
Max. 0.6 to 1 m	X			6 µm/s
Slope		X		8 percent
Fragments > 75 mm	X			0 percent

In the example above, flooding, soil depth, depth to free water, and rock fragment content are not limiting. The slope, at 8 percent, presents some limitation. The maximum saturated hydraulic conductivity in the depth range of 0.6 to 1.0 m (i.e., 6 micrometers per second) is not limiting. However, the minimum saturated hydraulic conductivity in the depth range of 0.6 to 1.5 m (i.e., 2 micrometers per second) is a severe limitation as it causes slow water movement.

Testing and Reevaluation

The interpretive model is under continuous scrutiny through user feedback, ranging from local homeowners' associations and units of government to national environmental agencies and organizations. Soil scientists continue testing of interpretations through observations and discussions with local user groups during the soil survey process.

Current U.S. Interpretive System

This section describes how soil interpretations are developed and managed in the National Cooperative Soil Survey (NCSS). The commonly used system of placing the soil into an interpretive limitation or suitability class is discussed briefly, then a newer and more sophisticated system is explained. The newer system uses fuzzy system concepts to more fully express the degree of membership of a soil in a particular interpretive class.

Overview of the Interpretations System

Historically, soil interpretation results were expressed as limitation or suitability classes. *Limitation style* interpretations typically placed soils into three interpretive classes, such as "slight," "moderate," or "severe," and reported which soil properties or features were restrictive to the land use. An example would be a "severe" rating for dwellings with basements for soils with a high shrink-swell potential. *Suitability style* interpretations placed soils into "good," "fair," or "poor" interpretive classes and reported the soil properties or features that make the soil least suitable for the use or management practice. An example would be a "good" rating for potential sand source. Actually, the class names for interpretive results may take any form that suits the needs of the user. Some users prefer a positive statement with a listing of limiting properties. Many U.S. soil surveys were made with interpretations expressed this way.

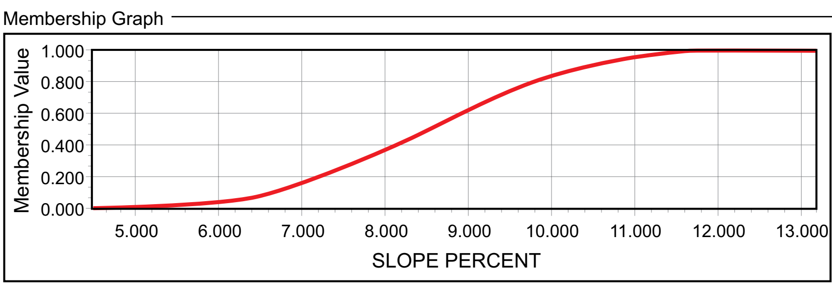
Fuzzy System Concepts

The current methodology for developing and processing interpretive information allows not only class names to be reported but also numeric ratings that indicate the degree of limitation or suitability of a soil for a land use or management practice. These index numbers are based on fuzzy system concepts (Cox and O'Hagan, 1998) that describe a soil's membership in the set of soils that are either limiting or suitable for the specified use. Using this technology, soil map units and map unit components can be described as full members, partial members, or non-members of a defined interpretive group. This membership is presented as a numeric index ranging from 0 to 1, where the higher the index number the more fully a soil is a member of the set and thus the greater the degree of limitation or suitability for a specific use.

A team of subject matter experts evaluates the impact of each soil property on the specific land use and sets the interpretive thresholds. For a limitation style interpretation, an attribute such as slope gradient may have a level that is not limiting and the associated index is 0, meaning it is absolutely false that this soil is a member of the set of soils limited by slope gradient. As slope increases, a level is reached where the soil cannot be successfully used for a particular land use and the associated index is 1, meaning it is absolutely true that this soil is in the set of soils limited by slope gradient. This relationship is depicted by a curve called an evaluation or a membership function (see figure 8-1).

Figure 8-1

	Low Value	High Value
Data	5	12



Membership function for slope percent for a limitation style interpretation where a membership value of 1 denotes limiting and lower values denote less limiting (i.e., more gentle slopes).

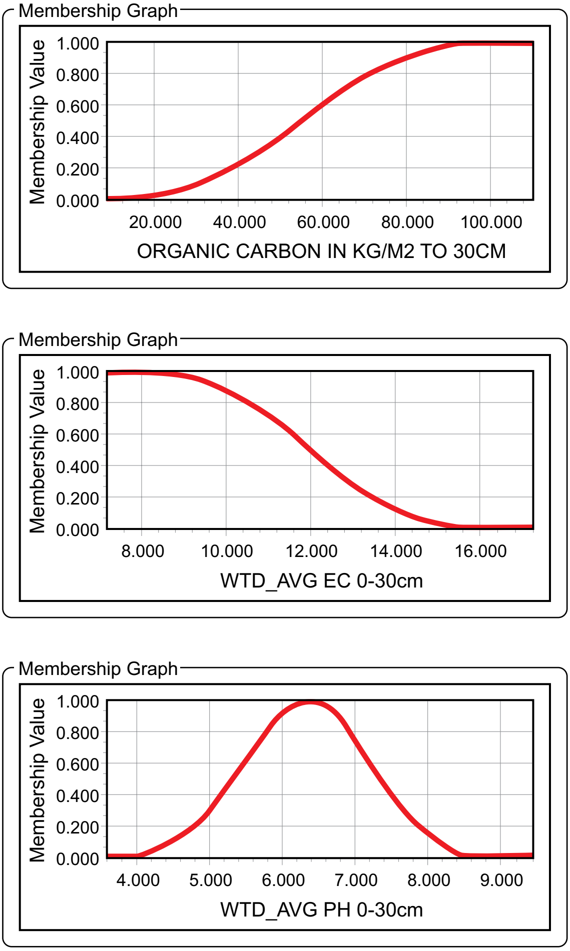
In the example given in figure 8-1, when a soil has a slope of 12 percent or greater, it is absolutely true that this soil is limited for the land use. When the slope is 5 percent or less, it is absolutely false that this soil is limited. Slopes between 5 and 12 are given numerical ratings that indicate the degree of partial membership in the set of soils that are limited due to slope. The character of the curve is also determined by the team of experts.

The overall automated system has three parts: (1) an attribute that is extracted from the database, (2) an evaluation of the membership value of the attribute, and (3) a reason or descriptive term assigned to the membership value (referred to as a "rule"). A set of these is associated with each soil, site, or climatic attribute. A particular depth range can be specified for horizon data, and items such as seasonal wetness, flooding, and ponding can be parsed by month. If needed, existing data can be used to model a piece of data that is not captured in soil survey. The piece of soil, site, or climate data extracted from the database undergoes an evaluation in which the estimated data is rated against a curve like that in figure 8-1. These curves have three basic forms: more is better, less is better, or a mid-range concentration is better for an intended use (fig. 8-2). Carbon sequestration or maximizing crop yields are examples of intended uses.

From the evaluation, the rating for a particular property is sent to the corresponding child rule where a rating reason is attached to the membership value. Rating reasons are phrases that describe the nature of the limiting factor, such as "too steep," "floods," "too wet," or "too expansive." Since normally more than one rating makes up an interpretation, the rules are referred to as "child rules" in the U.S. system. The membership values produced by the set of child rules that make up an interpretive model (parent rule) are combined using fuzzy math to produce an overall membership value from 0 to 1 (index number). The final membership value and its associated verbal limitation or suitability rating are assigned in the parent rule.

Figure 8-3 is a diagram of a simplified parent rule for dwellings with basements. The "or" operator dictates that according to the rules of fuzzy math for a limitation style interpretation, the highest membership value from the set of child rules will be returned as the overall rating (index number) for a particular component. The rectangles represent the child rules for the restrictive features. The "and" operator, which returns the lowest of the child rule membership values, is typically used for suitability style interpretations where the least suitable attribute defines how well a soil may function for a land use. Other operators include "mean," "sum," and "product." The operator used in an interpretive model depends on what makes most sense for the system being modeled.

Figure 8-2



Graphs representing the three basic suitability styles. Top.—More is better. In this case, more organic carbon content (kg/square meter) in the upper 30 cm of the soil is better. Middle.—Less is better. In this case, less electrical conductivity (ds/m) in the upper 30 cm of the soil is better. Bottom.—Mid-range is better. In this case, a mid-range average pH in the upper 30 cm of the soil is better.

Limitation Ratings

Soils may be rated according to limitations for soil uses. Limitation ratings typically are based on hazards, risks, or obstructions presented by properties or characteristics of undisturbed soil. The rating consists of a

Figure 8-3

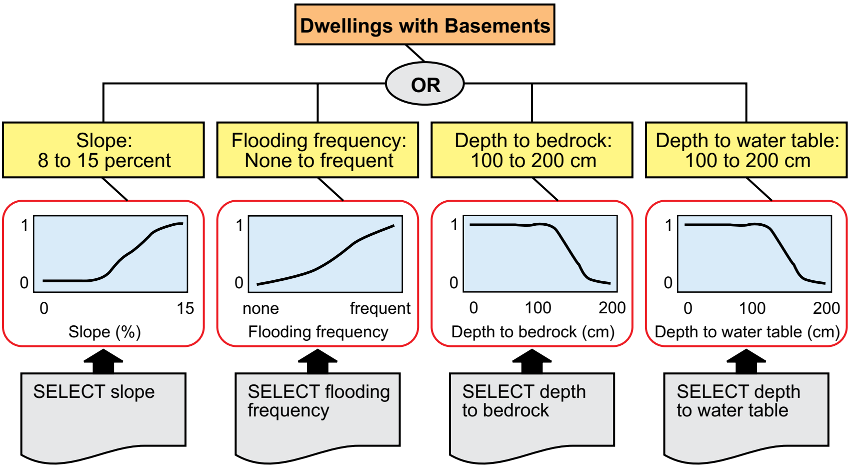


Diagram of a hypothetical parent rule for Dwellings with Basements (a limitation style interpretation).

combination of descriptive terms and membership values that define a soil's membership in the set of soils that have limiting features.

Not limited.—Soils in this interpretive class are not members of the set of soils that have limitations. They are assigned an index number of 0. These soils give satisfactory performance with little or no modification. Modifications or operations dictated by the use are simple and relatively inexpensive. With normal maintenance, performance should be satisfactory for a period of time generally considered acceptable for the use.

Somewhat limited.—Soils in this interpretive class are partial members of the set of soils that have limitations. The membership value is more than 0 but less than 1.0. In this case, the greater the membership value the greater the soil's membership in the set of soils that have limiting features or characteristics. For example, two soils (A and B) have partial membership in the set of soils that are limited and have slope as a restrictive feature. Soil A has a membership index of 0.13 while soil B has a membership index of 0.87. Although both soils have slope as a restrictive feature, soil A is less restricted than soil B. Soils that are partial members of the set of soils that are limited for a specific use do not involve exceptional risk or cost for the specified use. However, they do have certain undesirable properties or features. Modification of the soil itself, special design, or maintenance is required for satisfactory performance over an acceptable period of time. The needed measures typically increase the cost of establishing or maintaining the use, but the added cost is generally not prohibitive.

Very limited.—Soils in this interpretive class are members of the set of soils that are limited for the specified use or management practice. They have an index number of 1.0. These soils, if not appreciably modified, have a high risk for the use. Special design, a significant increase in construction cost, or an appreciably higher maintenance cost is required for satisfactory performance over an acceptable period of time. A limitation that requires removal and replacement of the soil would be rated "very limited." The rating does not imply that the soil cannot be adapted to a particular use, but rather that the cost of overcoming the limitation would be high.

Not rated.—Not rated is a special interpretive class used only when data essential for producing a rating is missing.

Suitability Ratings

Soils may be rated according to the degree of suitability for specific uses. Suitability ratings are based on soil characteristics that influence the ease of using or adapting a soil for a specific use. Suitability ratings also use a combination of descriptive terms (classes) and indexed scoring functions to define a soil's membership in the set of soils that have features or properties that support the intended use or management of the soil. Suitability ratings differ from limitation ratings in that the interpretive model design reports soil features that support the intended application rather than restrictive soil features.

Good.—Soils in this interpretive class are members of the set of soils that have characteristics that sustain the intended use or management practice. They are assigned an index number of 1.0. Satisfactory performance and low maintenance cost can be expected.

Fair.—Soils in this interpretive class are partial members of the set of soils that have characteristics that sustain the intended use. The index number is more than 0 and less than 1.0. In this case, the greater the index value the greater the soil's membership in the set of soils suitable for the use or management practice and the better the soil characteristics. For example, two soils (A and B) have partial membership in the set of soils that are suitable as a source of sand. Soil A has a membership index of 0.27 while soil B has a membership index of 0.78. Although both soils are partial members of the set of soils that are a "fair" source of sand, soil B is better suited. Soils that are partial members of the set of soils that are suitable for a specific use require additional cost because they have certain undesirable properties or features. That cost is generally proportional to the membership index.

Poor.—Soils in this interpretive class are not members of the set of soils that are suitable for the specified use or management practice. They have an index number of 0. These soils have one or more properties that are unfavorable for the specified use. For example, a soil that does not contain sand is rated as a poor source of sand. Unlike other soil limitations, there are no means or treatment for correcting the lack of sand in a soil. In this respect, unfavorable suitabilities generally do not have remedial solutions. Suitability ratings may also be supplemented with the restrictive features that affect soil performance for a specific use. These restrictive features may be a list of soil properties that are important for a specific use and be listed with each class for which they apply. Examples are "fair—water table at depths of 25 to 50 cm" and "poor—bedrock at depths of less than 50 cm." Listing suitabilities with restrictive features in this manner gives the user more complete information by identifying other properties or features that may need treatment for the given use.

Most interpretations designed for general widespread use (such as those used within a large geographic region or a nation) have narrowly defined objectives that can be stated as either limitations or suitabilities. Some users may prefer interpretive expressions that use both approaches, such as a statement of the suitability and also a listing of limiting properties according to severity or difficulty to overcome.

Computer-generated interpretations are commonly made separately for each component in a map unit for any size of area. An aggregated summary rating for each map unit may also be given. Current technologies permit users to map interpretive output for the most limiting component, least limiting component, dominant condition, weighted average, or a specific limiting soil property. Current geographic information systems (GIS) also permit interpretive results to be displayed over broad geographic areas and in a variety of ways, including thematic maps, charts, and standard tables.

Map Units and Soil Interpretations

This section discusses the relationships between the terminology and conventions employed to define and describe map units (see chapter 4) and soil interpretations. The components of map units are the entities for which interpretations are provided. The application of interpretive information to areas of land is through map unit descriptions and depends on an understanding of the map unit concept as it applies to interpretations.

Consociations, Associations, and Complexes

For map units that are *consociations*, the interpretations generally pertain to a single, named soil and are applicable throughout the delineation, although minor components may be rated if the associated data is deemed reliable. For *associations* and *complexes,* the interpretations may be given for each named component as well as the unnamed components or may be given for the map unit as a whole, depending on the objective. In the description of the map unit, information is commonly provided about the geographic occurrence on the landscape of the named components. From this information, interpretations for each of the named components of the map unit may be applied to the portion of the landscape on which it occurs. However, such an application requires information beyond what the soil map alone can provide. The location of each soil within the map unit delineation is needed. The map unit description provides information on the location and extent of each named component of the map unit.

Map units differ in specificity of the named soils and therefore in the broadness of the ranges for various interpretive soil properties. Phases of soil components that are based on series are more specific soil concepts than are phases of soil components that are based on a higher categorical level, such as a great group, e.g., Haplaquods. Consequently, the interpretive information for a phase of a soil component based on soil series has narrower ranges than one based on a higher taxonomic category.

Similar Soils

Similar soils differ so little from the named soil in the map unit that there are no important differences in interpretations. These soils are not named components in the map unit. Recognition is limited to a brief description of the feature or features by which the soil in question differs from the soils in the map unit name. For example: “In places, the upper part of the material is silty clay. In a few areas, the underlying material contains a few lime concentrations.”

Dissimilar Soils

Map units are permitted to have certain proportions of included soils that differ sufficiently from the named soil to affect major interpretations.

These soils are referred to as *dissimilar* soils (see chapter 4). Typically, the dissimilarities are such that the soils behave differently. Dissimilar soils are named in the map unit description if they are part of the name of another map unit in the soil survey area. Otherwise, the dissimilar soil is briefly described in a generic fashion, for example, "medium textured soil with bedrock at a depth of less than 50 cm." Location of the dissimilar soils relative to landscape position may be given. Inferences as to the influence of the dissimilar soils on behavior of the map unit may be obtained from their interpretive properties and their location on the landscape. The map unit descriptions may state how the dissimilar soils affect soil behavior. Tabular soil properties and related interpretations do not include properties and interpretations of dissimilar soils. Yield estimates are, in principle, influenced by the occurrence of dissimilar soils if based on field-scale measurement. However, if yields were significantly affected, the dissimilar soil would likely be a named component of the map unit.

For *consociations*, the interpretations pertain to a single, named soil and soils similar to the named soil. Thus, they have a higher possibility of being applicable throughout the delineation than map units named for more than one taxon. For *associations* and *complexes*, the possibility of different kinds of interpretations is higher than for consociations, unless the soils are similar. The interpretations may need to be presented on a probability or possibility basis. Where the soils are related to specific landforms or parts of landforms, interpretations can be related to soils and landforms.

Aggregation

In the context of the modern soil survey database, very few map units are composed entirely of one component; some minor components almost always occur and are interpreted. This presents a challenge for displaying interpretive output in a geographic information system, since only one value can be tied to a polygon. Some method of aggregating the data across components is needed. Depending on the context of the interpretation and what makes sense to display, one of several methods can be used on either the rating classes or the membership values. Historically, for example, the rating class (e.g., slight, moderate, or severe) of the dominant component (component having the highest component percentage) was displayed in either green, yellow, or red for the map unit delineation. For multi-taxa map units, this may represent as little as 40 percent of the map unit area. In the case of multi-taxa map units, a dominant condition aggregation can be used to describe more of the map unit. In this method, the rating class associated with the highest sum of the component percentages is displayed. In some cases, it makes sense to display either the least limiting or most limiting condition for a map unit. It is also possible to reclassify the membership values to make more classes for mapping to represent a gradation of the moderately limited class. If a large proportion of the area of the map unit will be used in the context of the land use, such as in agricultural applications like productivity indices, a weighted average of the membership values by component percentage may be most appropriate. (For additional information, see appendix 4, table A-4.)

Interpretive Soil Properties

Soil survey interpretations are provided for specific soil uses. Interpretations for each soil use are based on a set of interpretive soil properties. These properties include site generalities (e.g., slope gradient), measurements on individual horizons (e.g., particle-size distribution), and temporal repetitive characteristics that pertain to the soil as a whole (e.g., depth to free water).

Abbreviated descriptions for many commonly used interpretive soil properties used in the NCSS are explained below. For logical presentation, they are grouped into categories: site, component, and horizon data; physical features or processes; erosion; and corrosivity. Formal classes have been assigned to several interpretive soil properties. These classes generally are not given unless they are used in field morphological descriptions. All classes are described in the *National Soil Survey Handbook* (USDA-NRCS). Local conditions may dictate other interpretive soil properties or a greater emphasis on a subdivision of some of the interpretive properties here listed.

Site Data

Climate

Mean annual air temperature.—The mean air temperature for the calendar year.

Frost-free period.—The average length of the longest time period per calendar year that is free of killing frost.

Mean annual precipitation.—The mean annual moisture received per calendar year, including rainfall and solid forms of water.

Landscape

Slope.—The range in slope gradient, in percent.

Slope aspect.—The direction in which the slope faces, in degrees.

Slope shape.—Whether the land surface is convex, concave, or linear in the up-down or across planes.

Elevation.—The height above sea level.

Geomorphic component.—The part of the landform the soil occupies (e.g., interfluve, head slope, nose slope, side slope).

Hillslope position.—The position the soil occupies on the landscape (e.g., summit, shoulder, backslope, footslope, toeslope).

Component Data

Field Water Characterization

Available water capacity (AWC).—The volume of water that a soil layer retains between the tensions of 10 kPa (sandy soils) or 33 kPa and 1500 kPa. The water is considered to be available to most common agronomic plants. The amount of water is reduced depending on the volume of rock fragments and the osmotic effects of high salt concentration. Volumes are expressed both as a volume fraction and as a thickness of water. The standard of reference is the *water retention difference* (under 4C in Soil Survey Staff, 2014a). Reductions are made in water retention difference for incomplete root ramification that is associated with certain taxonomic horizons and diagnostic and/or restrictive features (such as fragipans) and for chemical properties that are indicative of root restriction (such as high content of salts, low levels of available calcium, or high levels of extractable aluminum). The amount of available water to the expected maximum depth of root penetration (commonly either 1 or 1.5 m) or to a physical or chemical root limitation, whichever is shallower, has been formulated into a set of classes for root-zone available water storage. For the class sets, the depth of rooting that is assumed and the class limits that are stipulated differ among the taxonomic moisture regimes.

Hydrologic soil groups (HSG).—Interpretive classes that have similar runoff potentials under conditions of maximum yearly wetness. It is assumed that the ground surface is bare and that ice does not impede infiltration and transmission of water downward. In some cases, HSG is used as a soil property.

Flooding.—Inundation by flowing water. The frequency and duration of flooding are placed in classes.

Ponding.—Inundation by stagnant water. The duration and month(s) of the year that ponding occurs are recorded.

Moisture status.—The thickness of the zone with a particular water state, the kind of water state, and the months of year that the water state is present within the soil. Three general water state classes are used in the soil survey database—dry, moist, and wet. Chapter 3 presents more refined classes. In the soil survey database, the wet class is wet-satiated and the moist class includes wet-nonsatiated. Both wet-satiated and wet-nonsatiated are subclasses of wet in chapter 3. There is also a set of classes (see chapter 3) for the occurrence of internal free water. These classes include depth to, kind, and months of the year that a zone of free water is present within the soil. Free water is defined as satiated through saturation.

Horizon Data

Particle Size and Fragments > 2 mm

USDA texture classes and modifiers.—Texture is the relative proportion, by weight, of sand-, silt-, and clay-sized particles (texture classes). The texture classes are modified by adjectival classes based on proportion, size, and shape of rock fragments and by the proportion of organic matter, if the content is high.

Particle-size separates (based on < 2 mm fraction).—The particle-size separates recorded in the soil survey database are percent total sand (2.0–0.05 mm), very coarse sand (2.0–1.0 mm), coarse sand (1.0–0.5 mm), medium sand (0.5–0.25 mm), fine sand (0.25–0.10 mm), very fine sand (0.10–0.05 mm), total silt (0.05–0.002 mm), coarse silt (0.05–0.02 mm), fine silt (0.02–0.002 mm), total clay (< 0.002 mm), and carbonate clay. Percentages are expressed as a weight percent and are based on the < 2 mm fraction. For soils that disperse with difficulty, the total clay percentage is commonly evaluated based on the ratio of 1500 kPa water retention to clay.

Soil fragments > 250 mm (based on whole soil).—This quantity is expressed as a weight percent of the horizon occupied by fragments up to an unspecified upper limit (size of rock fragments does not exceed the size of the pedon). Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils). Fragments larger than 250 mm are not included in the determination of Unified or AASHTO class placements, but they may significantly influence suitability for certain soil uses.

Soil fragments 75–250 mm (based on whole soil).—This quantity is expressed as a weight percent of the horizon occupied by fragments 75–250 mm in size. Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils). The upper fragment size limit cannot exceed the size of the pedon. Fragments greater than 75 mm do not affect the Unified and AASHTO class placements, but they may have a large influence on suitability for certain uses.

Soil fragments > 2 mm (based on whole soil).—This quantity is expressed as a volume percent (whole soil base) of the horizon occupied by the > 2 mm fragments. Associated data include the kind, size, shape, roundness, and hardness of the fragments. Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils).

Percent passing sieve numbers 4, 10, 40, and 200 (based on < 75 mm fraction).—The weight percentage of material passing each sieve. Sieve openings are 4.8 mm (no. 4), 2.0 mm (no. 10), 0.43 mm (no. 40), and 0.075 mm (no. 200) in diameter. Quantities are expressed as a percentage of the < 75 mm material. Material passing the number 4 and 10 sieves may be estimated in the field (see chapter 3) or measured in the office or laboratory. Material passing the number 40 and 200 sieves may be measured directly in the laboratory. Percent passing sieves also may be estimated from USDA particle-size and rock fragment measurements made in the field or laboratory.

Soil Fabric-Related Analyses

Moist bulk density.—The oven-dry weight in megagrams divided by the volume of soil in cubic meters at or near field capacity, exclusive of the weight and volume of fragments > 2 mm.

Linear extensibility percent (LEP).—The linear reversible volume difference of a natural clod between field capacity and oven dryness, inclusive of rock fragments. The volume change is expressed as a percent change for the whole soil. Actual LEP (shrink-swell), in contrast, is dependent on the minimum water content that occurs under field conditions. Organic soils typically do not have reversible volume changes when oven dried. Shrink-swell classes are defined based on LEP.

Water retention (10, 33, and 1500 kPa).—The water content that is retained at 10, 33, and 1500 kPa tension, expressed as a percentage of the oven-dry soil weight inclusive of rock fragments (whole soil). Measurements are conducted in the laboratory on clods (for 10 and 33 kPa tension) and sieved samples (for 1500 kPa tension). Pedotransfer functions are also used to estimate the water content at 10, 33, and 1500 kPa tensions.

Available water capacity.—This is defined in the section “Field Water Characterization” above as the volume of water that should be available to plants if the soil, inclusive of rock fragments, were at field capacity. Field capacity is the volume of water that remains in the soil 2 or 3 days after being wetted and after free drainage becomes negligible. Contents of water are expressed both as a volume fraction and as a thickness of water. Available water is estimated as the amount of water held between 10 or 33 kPa and 1500 kPa tension. Reductions in water retention difference should be made for root-restricting layers that are associated with certain taxonomic horizons and features (such as fragipans) and for chemical properties that are indicative of root restriction (such as low levels of available calcium and high levels of extractable aluminum). Adjustments may also be made for the osmotic effect of high salt concentrations, if present.

Saturated hydraulic conductivity (K_{sat}).—The amount of water that would move downward through a unit area of saturated in-place soil in unit time under unit hydraulic gradient. It is used to convey the rate of water movement downward through the soil under saturated conditions (and unit hydraulic gradient). Saturated hydraulic conductivity classes are defined in chapter 3.

Engineering Classification

Liquid limit (LL) .—The water content at the change between liquid and plastic states. It is measured on thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm) and is expressed on a dry weight basis. Values are typically placed in interpretive classes.

Plasticity index (PI).—The range in water content over which soil material is plastic. The value is the difference between the liquid limit and plastic limit of thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm). The plastic limit is the water content at the boundary between the plastic and semisolid states. Values are typically placed in interpretive classes.

Unified classification.—An interpretive classification system of soil material designed for general construction purposes. It is dependent on particle-size distribution of the < 75 mm, liquid limit, and plasticity index and on whether the soil material has a high content of organic matter. There are three major divisions: mineral soil material having less than 50 percent particle size < 0.074 mm (passing 200 mesh), mineral soil material having 50 percent or more particle size < 0.074 mm, and certain highly organic soil materials. The major divisions are subdivided into groups based on liquid limit, plasticity index, and coarseness of the material more than 0.074 mm in diameter (retained on 200 mesh).

AASHTO classification.—An interpretive classification system of soil material for highway and airfield construction (Procedure M 145-

91; AASHTO, 1997). It is based on particle-size distribution of the < 75 mm fraction and on the liquid limit and plasticity index. The system separates soil materials having 35 percent or less particles passing the no. 200 sieve (< 0.074 mm in diameter) from those soil materials having more than 35 percent. Each of these two divisions is subdivided into classification groups based on guidelines that employ particle size, liquid limit, and volume change. A group index may be computed based on the liquid limit and plasticity index in addition to percent of particles < 0.074 mm. The group index is a numerical quantity based on a set of formulas.

Chemical Analysis

Calcium carbonate equivalent.—The quantity of carbonate in the soil expressed as $CaCO_3$ and as a weight percentage of the < 2 mm fraction. The available water capacity and availability of plant nutrients are influenced by the amount of carbonates, which affect soil pH.

Cation-exchange capacity (CEC).—The amount of exchangeable cations that a soil can adsorb at pH 7.0. Effective CEC (ECEC) is reported in soils where the pH in 1:1 water is 5.5 or less.

Gypsum.—The gypsum content pertains to amount in the < 20 mm fraction. The methods of reference are under 6F (Soil Survey Staff, 2014a).

Organic matter.—Measured organic carbon is multiplied by the Van Bemmelen factor of 1.72 to obtain organic matter content.

Reaction (pH).—The standard method for pH is the 1:1 water extraction. For organic soil materials, the pH in 0.01M $CaCl_2$ is used. Typical agronomic classes are in discussed chapter 3.

Salinity.—A set of classes is used to indicate the concentration of dissolved salts in a water extract. Classes are expressed as electrical conductivity (EC). The measurement of reference is made on water extracted from a saturated paste. Units are decisiemens per meter (dS/m).

Sodium adsorption ratio (SAR).—SAR is evaluated for the water extracted from a saturated soil paste. The numerator is the concentration of water-soluble sodium, and the denominator is the square root of half of the sum of the concentrations of water-soluble calcium and magnesium.

Sulfidic materials.—Upon exposure to air, soil materials that contain significant amounts of reduced monosulfides develop very low pH. The requirements are defined in the latest edition of the *Keys to Soil Taxonomy* (Soil Survey Staff, 2014b). Direct measurement of the pH after exposure to air is also used.

Physical Features or Processes

Depth to Restrictive Horizons or Layers

Depth to bedrock.—The depth to unweathered, continuous bedrock. The bedrock is commonly indurated but may also be strongly cemented, and excavation difficulty is very high or higher (see chapter 3).

Depth to cemented pan.—The depth to a pedogenic zone that is weakly cemented to indurated (see chapter 3). Thin and thick classes are distinguished. The thin class indicates a pan that is less than 8 cm thick if continuous and less than 45 cm thick if discontinuous or fractured. Otherwise, the thick class applies.

Depth to permafrost.—The critical depth is determined by the active layer (the top layer that thaws in summer and freezes again in fall). Utilities, fencing, footings, etc. are placed below the active layer. The minimum depth is affected by depth of annual freezing. Permafrost depth may be strongly influenced by soil cover.

Process Features

Total subsidence.—The potential decrease in surface elevation resulting from the drainage of wet soils having organic layers or semifluid mineral layers. Subsidence may result from loss of water and resultant consolidation, mechanical compaction, wind erosion, burning, or oxidation (of particular importance for organic soils).

Potential frost action.—The likelihood of upward or lateral movement of soil caused by the formation of ice lenses and the subsequent loss of soil strength upon thawing. Large-scale collapse that forms pits is excluded and considered mass movement. Predictions are based on soil temperature, particle size, and pattern of water states.

Erosion

Factors and Groupings Related to Water or Wind Erosion

The K factor.—A relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. This interpretive factor is used in the Revised Universal Soil Loss Equation (Renard et al., 1997). Measurements are made on plots of standard dimensions. Erosion is adjusted to a standard of 9 percent slope. K factors are currently measured by applying simulated rainfall on freshly tilled plots. Earlier measurements integrated the erosion for the year for cultivated plots under natural rainfall. The K factor may be computed from the composition of the soil, saturated hydraulic conductivity, and soil structure.

The T factor.—The maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely (the soil loss tolerance). It can be used in the Revised Universal Soil Loss Equation (Renard et al., 1997). T factors are integer values from 1 through 5 indicating tons per acre per year. The factor of 1 ton per acre per year is used for shallow or otherwise fragile soils, and that of 5 tons per acre per year is used for deep soils that are least subject to damage by erosion.

Wind erodibility groups.—A set of classes, using integer designations from 1 through 8, based on compositional properties of the surface horizon that affect susceptibility to wind erosion. Texture, presence of carbonates, content of iron oxides, materials with andic soil properties, and the degree of decomposition of organic soils are the major interpretive criteria. Each wind erodibility group is associated with a wind erodibility index, expressed in tons per acre per year. The *wind erodibility index* is the theoretical, long-term amount of soil lost per year through wind erosion. It assumes a soil that is bare, lacks a surface crust, occurs in an unsheltered position, and is subject to the weather at Garden City, Kansas (Woodruff and Siddoway, 1965). Tillage frequency and practices are not specified.

Corrosivity

Corrosivity Ratings for Steel or Concrete Structures in Contact with the Soil

Uncoated steel.—This rating depends on soil texture, drainage class, extractable acidity, and either resistivity of a saturated soil paste or electrical conductivity of the saturation.

Concrete.—This rating depends on soil texture, occurrence of organic horizons, pH, and amounts of magnesium and sodium sulfate or sodium chloride in the saturated soil paste.

Dynamic Soil Properties

The previous section dealt almost entirely with soil properties that do not typically change dramatically with use and management. Some soil properties are sensitive to use and management and may change temporally and spatially. These properties are termed dynamic soil properties (DSP) and discussed thoroughly in chapter 9. DSPs are valid and useful as variables in soil interpretations, especially if the outcomes of various management options are being predicted.

Interpretive Applications

In this section, kinds of soil interpretations or groupings of soils are presented. Soil interpretations may be developed at many levels of generalization or abstraction. Commonly, standard interpretations have been developed for wide use and application. Because many soil survey professionals use these interpretive criteria, interpretive results can be consistently produced from place to place. These standard criteria, however, may be too general for applications at some local or regional levels. If appropriate, the standard criteria may provide an effective template from which to adjust interpretive limits or add further criteria to better address local conditions.

Local Relative Placements

The soil properties and model criteria used in making interpretive generalizations are applicable to a very wide range of soils on a regional or national basis. For local decisions, relative rankings within the same interpretive placement may be extremely important. The interpretive model may have to be adjusted to reflect regional or local requirements, legislation, or land use codes. If interpretations are made locally, it is possible to rank soils on a strictly relative basis and to introduce local knowledge about soil behavior that may have been excluded from more general national ratings. The term “local interpretations” is used to describe locally controlled numerical ratings that give relative ranking of soils for a given use. In contrast, the national specific-use interpretive system emphasizes criteria that apply nationwide and thus provides more general rankings.

Local soil interpretations are of greatest value in implementing ordinances for the local planning of specific tracts of land. If comparative ratings of every soil in a specific tract for a particular use are available, then a rational decision can be made whether to proceed, to change plans, or to find another area that has soils with higher potential. In some cases, the best soils in the specific tract for the particular use may be among those with low potential in the soil survey area overall.

The extent to which a given property is limiting and, in many cases, the practices that can be used to overcome the limitation are influenced by other soil properties. An example is the low strength of some soils in coarse-silty families. Such soils may not be limiting for dwelling foundations if the shallowest depth of free water exceeds 2 m. If, however, the shallowest depth of free water is within 25 to 50 cm of the base of the foundation, these soils may be decidedly limiting for foundations. Because the process of determining soil potentials involves input from knowledgeable local people, local interpretations can use more sophisticated criteria.

Steps for Developing Local Interpretations

Local soil interpretations are presented either as a set of qualitative classes, as a numerical index, or as both. The first step is to define the local interpretive product and the information that will be provided to the user. For example, a local sanitary district may request soil interpretations that are based on their sanitary codes. Is the information to be provided as discrete classes or as membership values? Are the coded criteria such that the first requirement can be met or are changes needed? What is the exact intent of each requirement contained in the local code? One requirement may be “depth to water table.” What is the local code’s definition of water table? What is meant by depth? What months, if any, can the water table be present? Is a layer of near saturation considered a water table for the specified use?

The second step is to identify soil properties that significantly impact or effect the particular use or management of the soil. Critical values for each property are defined locally and are generally based on local code, laws, or administrative regulations, for example, “depth to water table will not be less than 16 inches.” Is water table depth of 17 inches significant? Working with the local interpretation sponsor, these and other questions need to be addressed.

The third step is to develop the interpretive model. In this step, the effect of each criterion on the overall rating is described along with the interpretive output. A criterion can be weighted or given precedence over another criterion, or criterion interaction can be described. Once the model is created, extensive testing and a complete technical review are needed before the interpretive products are delivered to the sponsor.

Management Groups

Management groups identify soils that require similar kinds of practices to achieve acceptable performance for an identified use. Historically in the U.S., management groups were limited to uses that involve the growth of plants. Management groups, however, can pertain to both agricultural and nonagricultural uses. The major advantage of management groups is that a user only needs to understand the concepts embodied in a relatively few groups of soils to make management decisions rather than understand and evaluate specific details of all the individual soils in the area. Not all soils in a management group are expected to have identical characteristics or management needs; however, the requirements of each management group must apply to all included soils. Generally, the broader the groups the less specific the descriptions of management needs. The number of classes for a management group depends on the range of soil properties, intensity of use and scale, purpose of the grouping, intended users, and availability of pertinent information. The number of classes must balance the need for homogeneity within a class against the complexity that results from increasing the number. The advantages of management groups are diminished if the classes are so broad that soils within a group differ greatly or so narrow that the number of classes is large and the differences among classes too small.

The most generally applied soil management group in the U.S. is the land capability classification system, which is widely used in the development of conservation plans for farming. Other management groups common in the U.S. are woodland suitability groups, pasture and hayland groups, and ecological sites. Recently, management groups have been defined for purposes of a national soil inventory. Prime farmland, for example, is a kind of management group. Highly integrated generalizations are made for so-called management groups. Groupings of soils may be made for various national land management programs and inventories. These groupings may be highly integrated (such as prime farmland) or be based on a few, quite specific criteria (such as highly erodible lands). Because such interpretive groups are frequently referenced in legislation, their applicability and maintenance have become important in achieving national environmental objectives in the United States. As a result, the official NCSS soil survey database has been designated as the only source of these and other data.

Current U.S. Inventory Groupings

Technical soil groupings have been developed as criteria for application of national legislation concerned with the environment and with agricultural commodity production. Groupings may pertain to agricultural productivity and diversity, erosion potential, quality of surface and ground waters, maintenance of wetlands, or other national needs. Four national groupings are described below: prime farmland, unique farmland, hydric soils, and highly erodible land. Refer to the *National Soil Survey Handbook* to see how various map unit criteria, coupled with interpretive soil properties, have been employed to construct definitions for national inventory purposes.

Prime farmland.—Land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops. It must also be available for these uses. It has the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed according to acceptable farming methods, including water management. In general, prime farmland has an adequate and dependable water supply from precipitation or irrigation, favorable temperatures and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks. It is permeable to water and air. Prime farmland is not excessively erodible or saturated with water for a long period of time, and it either does not flood frequently or is protected from flooding.

Unique farmland.—Land other than prime farmland that is used for the production of specific high-value food and fiber crops. It has the special combination of soil quality, location, growing season, and moisture supply needed to economically produce sustained high quality and/or high yields of a specific crop when treated and managed according to acceptable farming methods. Examples of crops are tree nuts, olives, cranberries, citruses and other fruits, and vegetables.

Hydric soils.—Soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. They make up one of three criteria needed for qualification as wetlands.

Highly erodible land.—This land has been defined in order to identify the areas on which erosion-control efforts should be concentrated. The definition is based on erosion indexes derived from certain variables of the Revised Universal Soil Loss Equation (Renard et al., 1997) and the Wind Erosion Equation (Woodruff and Siddoway, 1965). The indexes are the quotient of tons of soil loss by erosion predicted for bare ground divided by the sustainable soil loss (T factor).

Land Use Planning

Land use planning is the formulation of policies and programs for guiding public and private land use in areas of any size where different uses compete for land. The word "land" in this context implies attributes of place and other factors besides soil. Planners must consider place, size of area, relation to markets, social and economic development, skill of the land users, and other factors. Soil surveys can help in land use planning by identifying soil resources in the area and providing information for the evaluation of environmental and economic effects of proposed land uses. They can be interpreted for land use planning through groupings or ratings of soils according to their limitations, suitabilities, and potentials for specified uses.

Local Planning

Local government units, such as those of cities, towns, and counties, do local planning. The planning applies to complexes of farms and ranches, to housing developments, to shopping centers, to industrial parks, and to entire communities or political units.

Local planners use soil interpretations and other information to develop recommendations on alternatives for land use, patterns of services, and public facilities. Planners may need interpretive maps at different scales, depending on their objective. Interpretations of small areas for local planning can rate limitations, identify management or treatment needs, and predict performance and potential of individual kinds of soils identified on detailed soil survey maps. Interpretations of areas that include entire governmental units evaluate soils for all competing uses within the planning area. These maps are smaller in scale, and the map units are associations of soil series or of higher taxa. Local planners commonly need ratings of the whole association for alternative uses. Special maps showing the location of areas having similar potentials or limitations for certain uses may be helpful for planners. Information about amounts and patterns of soils having different potentials within each association can be given in tables or in the text of a soil survey report.

Regional Planning

Geographically extensive soil-limiting factors may pertain to areas that cover several political units. For these situations, regional planning is appropriate. Principal functions of regional planning are collection, analysis, and dissemination of planning and engineering information, preparation of long-range plans, and coordination among the agencies involved.

Most soil maps for regional planning are medium-scale maps generalized from detailed soil survey maps. Soil interpretations show differences between map units in terms of suitabilities and limitations for the principal competing uses. The distribution of map units having similar behavior for a given use is commonly shown on special maps. An accompanying text describes the units, explains the basis for the ratings, and may also describe effects of the pattern of associated soils on the use of specific parcels. Regional planners commonly need information about the suitability of small parcels that is more specific than that provided by generalized soil maps. For example, they may locate an area that is generally good for recreation but also need to know that a potential site for a reservoir has soils suitable for storing water before they can complete the regional plan.

Farmland

Soil surveys in agricultural areas identify soil characteristics that determine suitability and potential of soils for farming. Interpretations for farming involve placement of soils into management groups (such as the land capability classification system) and identification of important soil properties that pertain to crop production, application of conservation practices, and other aspects of agriculture. Other aspects of agriculture include yield potential, susceptibility to erosion, depth to layers that restrict roots, available water capacity, saturated hydraulic conductivity, annual pattern of soil water states (including soil drainage class, inundation, and free water occurrence), qualities that describe tilth, limitations to use of equipment (including slope gradient and complexity, rock fragments, outcrops of bedrock, and stickiness), salinity and sodium adsorption ratio, presence of toxic substances, deficiency of plant nutrients, capacity to retain and release plant nutrients, capacity to retain soluble substances that may cause pollution of ground water, capacity to absorb or deactivate pesticides, and pH as related to plant growth and the need for liming.

The fate of added nutrients and pesticides, as related to farm management and cropping systems, is an important consideration in nonpoint water pollution. Identification of critical soil properties as related to resource management systems is crucial in the wise use of land. The land capability classification system indicates suitability of soils for agricultural uses (Klingebiel and Montgomery, 1961). The system classifies soils for mechanized production of more commonly cultivated field crops—corn, small grains, cotton, hay, potatoes, and field-grown vegetables. It does not apply directly to farming systems that produce crops, such as some fruits and nuts, that require little cultivation or to crops that are flooded, such as rice and cranberries. It also cannot be used for farming systems that depend on primitive implements and extensive hand labor.

Soil productivity.—Soil productivity is the output of a specified plant or group of plants under a defined set of management practices. It is the single most important evaluation for farming. In general, if irrigation is an optional practice, yields are given for both irrigated and non-irrigated conditions. Productivity can be expressed in quantity of a product per unit land area, such as kilograms or metric tons per hectare. For pasture, productivity can be expressed as the carrying capacity of standard animal units per unit area per season or year, or as live-weight gain. Productivity may be expressed as a rating or index related to either optimum or minimum yields, or it may be indexed to a set of soil qualities (properties) that relate to potential productivity. Productivity indices have the advantage of being less vulnerable to changes in technology than expressions of productivity based on yields.

Productivity ratings express predicted yields of specified crops under defined management as percentages of standard yields. They are calculated as follows:

$$\text{Productivity rating} = \frac{\text{predicted yield per unit area}}{\text{standard yield per unit area}} \times 100$$

Such a rating provides a scale for comparing productivity of different kinds of soils over large areas. Ratings lend themselves to numerical treatment. Productivity ratings permit comparison of the productivity of crops having yields that differ markedly in numerical values. For example, a certain soil has a yield of 60,000 kg/ha for silage corn and of 9,000 kg/ha for grain corn. Because these quantities represent similar levels of production, the productivity ratings are similar. Selection of the standard yield of a crop depends on the purpose of the rating. For national comparison, standard yields should be for a high level of management on the best soils of the region for the crop. For potential production, yields under the best combination of practices are used.

Productivity ratings for individual crops can be combined to obtain a general rating for soil over its area of occurrence. Individual ratings are weighted by the fraction of the area occupied by each crop, and a weighted average is calculated that characterizes the general productivity of the soil.

Productivity indices tied to soil properties are used as a relative ranking of soils. Typically, soil properties important to favorable rooting depth and available water capacity are chosen. Some productivity models rely on a few critical soil properties, such as pH and bulk density, to rate soils (Kiniry et al., 1983). The National Commodity Crop Productivity Index (Dobos et al., 2012) uses soil, site, and climatic information to provide an array of the soils of the United States on the basis of their inherent ability to foster crop growth.

Resiliency.—Resiliency of soils is an interpretation that relates to the ability of a soil to rebound from depletion of plant nutrients or organic matter or to rebound from degradation of physical or chemical soil properties (Seybold et al., 1999). Resiliency ratings are based on estimates of the natural fertility of the soil, soil carbon content, available water capacity, favorable rooting depth, particle-size distribution, and distribution of salts in the profile, if present. Resiliency ratings are important in evaluating alternative management systems that are based on lower chemical and energy inputs. Traditional practices that use high inputs of chemical fertilizers and pesticides commonly offset deficiencies in some soil properties that are important to crop production. Resiliency of soils is also important in evaluating long-term effects of management systems on soils.

Rangeland

Rangeland is land on which the historic climax vegetation was predominantly grasses, grass-like plants, forbs, or shrubs as the consequence of a dry climate. It includes land revegetated naturally or artificially to provide a plant cover that is managed like native vegetation (introduced forage species are also managed as rangeland). The vegetation is suitable for grazing and browsing by animals. Rangeland includes natural grasslands, savannahs, many wetlands and deserts, tundra, and certain shrub and forb communities.

Soil-ecological site correlation within a soil survey gives the suitability of the soil to produce various kinds, proportions, and amounts of plants. This knowledge is important in developing management alternatives needed to maintain site productivity. Rangeland interpretations in the U.S. are normally produced as ecological site descriptions.

Ecological site descriptions (ESD).—An ESD commonly contains the following information:

1. Physiographic features that describe the position of the site on the landscape and whether the site generates or receives water runoff.
2. Climate factors that typify the site, as well as characterize the dynamics of the site, including storm intensity, frequency of catastrophic storm events, and drought cycles.
3. Influencing water features where the site is associated with wetlands or streams.
4. Representative soil features that significantly affect plant, soil, and water relationships and site hydrology, such as major soil families, geologic formation, soil surface features, surface horizon and texture, soil depth, thickness and available water capacity of major root zone, kind and amount of accumulations, rock fragments in the profile, reaction, salinity, sodicity, soil water states, water table, and flooding.
5. Plant communities of the site, including a description of the vegetation dynamics, the common vegetative states of the site, and the transitions between states. Thresholds are identified as boundaries of the vegetative states. Other plant community information includes a state-and-transition diagram, plant community composition, ground cover and structure, annual production, growth curves, and photos of each vegetative state (see appendix 4).

6. Site interpretations for the animal community (livestock and wildlife), hydrologic functions, recreational uses, wood products, and other potential uses.

Forestland

Forestland is land dominated by native or introduced trees with an understory that commonly consists of many kinds of woody plants, forbs, grasses, mosses, and lichens. Some forest communities produce enough understory vegetation to provide forage.

Soil-ecological site correlation within a soil survey gives the suitability of the soil to produce wood products or other ecosystem services. If forestland is part of a soil survey, estimated productivity of the common trees is given for each individual soil. The understory vegetation is described at the expected canopy density most representative of the site. Determination of the soil's productivity requires close collaboration between foresters and soil scientists.

Wood production or yield is commonly expressed as the *site index* or as some other measure of the volume of wood produced annually. Site index is the average height of dominant and codominant trees of a given species at a designated age. Measurements of site index are typically extended to several similar soils for which data are unavailable. The site index is correlated to each soil and may be further interpreted in terms of cubic meters per hectare.

Soils may be grouped using the *woodland ordination system*. This system uses symbols to indicate productivity potential and major limitations for the use and management of individual soils or groups of soils. The first part of the ordination symbol, a number, is the class designator. It denotes potential productivity in terms of the nearest whole cubic meter of wood growth per hectare per year for the soil, based on the site index of an indicator tree species. For several species, data are available for converting site index to average annual wood growth. The second part of the ordination symbol (the subclass) indicates soil or physiographic characteristics that limit management—stoniness or rockiness, wetness, or restricted rooting depth. The ordination symbol may also have a third part to distinguish groups of soils that respond similarly to management. Soils with the same group symbol have about the same potential productivity, are capable of producing similar kinds of trees and understory vegetation, and have similar management needs.

Soils may be rated for such factors as susceptibility to mechanical compaction or displacement during forestry operations, limitations due to burning, hazards from soil-borne pests and diseases, and limitations due to specific soil properties such as wetness. In the management of trees, one must first understand the soil on which the trees grow or are to be grown. Soil surveys include information that can be used effectively in the management of forestland. This information includes:

Erosion hazard.—The possibility that erosion damage may occur as a result of site preparation and the aftermath of cutting operations, fires, and overgrazing.

Equipment limitations.—Limits on the use of equipment either seasonally or year-round due to soil characteristics such as slope, surface rock fragments, wetness, and surface soil texture.

Seedling mortality.—A rating that considers soil properties that contribute to the mortality of naturally occurring or planted tree seedlings, such as droughtiness, drainage class, and slope aspect. It does not consider plant competition.

Windthrow hazard.—A determination based on soil properties that affect the likelihood of trees being uprooted by wind as a result of insufficient depth of the soil for adequate root anchorage. A fragipan, bedrock, gravel, or high water table may affect soil rooting depth. Differences in root systems related to tree species are not considered. The rating is typically independent of the probability of high winds unless the soil is typically in landscape positions susceptible to high winds.

Plant competition.—The likelihood of invasion or growth of undesirable plants in openings within the tree canopy. Depth to the seasonal water table and available water capacity are the soil properties having the greatest effects on natural regeneration or suppression of the more desirable plant species.

Windbreaks

Windbreaks are made up of one or more rows of trees or shrubs. Well placed windbreaks of suitable species protect soil resources, control snow deposition, conserve moisture and energy, beautify an area, provide wildlife habitat, and protect homes, crops, and livestock. The plant species used in windbreaks are not necessarily indigenous to the area. Because each tree or shrub species has certain climatic and physiographic limits, a particular species may be well suited or poorly suited based on soil characteristics. Therefore, correlation of soil properties and adaptable windbreak species is essential.

A listing of adaptable species is given for each kind of soil, or grouping of soils by ecological site or suitability group, where windbreaks can serve a useful purpose—such as open field-planting, interplanting in existing woodland, and environmental modifications like wind or water barriers and development of wildlife habitat. The plant species identified for these purposes are grouped by height classes at 20 years of age.

Recreation

Interpretations in urban and suburban areas are made for golf fairways, picnic sites, playgrounds, paths, trails, and campsites. Interpretations for ski slopes, snowmobile trails, and off-road vehicles are made in some places. Ratings are typically based on restrictive soil interpretive properties, such as slope, occurrence of internal free water, texture of surface horizons, and soil resiliency.

Interpretations for recreation must be applied cautiously. Many recreational areas in the U.S. that are on large tracts of publically owned lands have only order 3 or higher soil surveys. Map units for such soil surveys are commonly associations or complexes of soils that may differ markedly in their limitations and suitabilities. Furthermore, general suitability of the map unit must take into consideration not only the qualities of the individual kinds of soil but also the soil pattern and potential interactions. Suitability may depend on a combination of several kinds of soil in a pattern appropriate to the intended use. Finally, factors other than soils are important in recreational planning. Aesthetic considerations, accessibility, land values, access to water and public sewer lines, presence of potential impoundment sites, and location relative to existing facilities may be important even though none of these factors is evaluated for map units.

Wildlife Habitat

Soils influence wildlife primarily through control over vegetation diversity. Descriptions of the soil as wildlife habitat have two parts. In one part, suitability class for different vegetation groups is recorded. These vegetation groups are called habitat elements. Each habitat element is a potential component of the environment of wildlife. Hardwood trees and shallow water areas are examples of habitat elements. In the other part of the description, soils are rated separately for several kinds of wildlife, including animals adapted to openland, woodland, wetland, and rangeland. Current land use and existing vegetation are not considered because these factors are subject to change and cannot be determined from a soil map. Wildlife population is also not considered because of the mobility of wildlife and the possibility of changes in population during the year. The ratings show where management for wildlife can be applied most effectively and which practices are appropriate. The ratings may also show why certain objectives (e.g., the production of pheasants) may not be feasible. Some soil surveys include explicit management recommendations.

Construction Materials

Soil survey interpretations estimate suitability of the soil as construction material and show where to locate material that can be mined. Material that compacts readily and has high strength and a low shrink-swell potential is preferred as base material for roads and foundations. Material for fill has to be evaluated for the potential for acid-sulfate formation, which can corrode steel and concrete and form unfavorable pH conditions for lawns and landscaping. Gravel and sand are used for concrete, road surfacing, and filters in drainage fields. Organic soil material is used widely as horticultural mulch, potting soil, and soil conditioner. Mineral soil is generally rich in organic matter and is applied to lawns, gardens, and roadbanks. Soils can be rated as probable sources of these materials. The quality of a particular site, however, typically cannot be specified.

Building Sites

Interpretations are made for construction of small buildings; for installation of roads, streets, and utilities; and for establishment of lawns, landscaping, and stormwater management. Such soil uses involve high capital expenditures in relatively small areas. Onsite evaluation typically is necessary.

Soil survey interpretations are useful for comparing alternative sites, in planning onsite investigations and testing, and in land use planning. Soil maps can assist in selecting building sites that are near areas suitable for utilities, parks, and other needs.

The preparation of building sites may alter soil properties markedly. As a result, some interpretive soil properties for the undisturbed sites must be applied cautiously. Upper horizons may have been removed and locally translocated, and the depth to horizons important to soil behavior may have been increased or decreased. The pattern of soil water states may have changed. Areas may have been drained and, therefore, are not as wet as indicated in the survey. Irrigation may have been used to establish and maintain vegetation and resulted in a more moist soil and deep movement of water. Pavements, roofs, and certain other aspects of construction increase runoff and may cause inundation at lower elevations where such hazards are not indicated in the survey.

Building construction.—Construction and maintenance of buildings belongs primarily to the fields of architecture and engineering.

Additionally, large multistory structures are generally supported by footings placed below the depth of soil survey examination. Therefore, soil survey interpretations are not a definitive source of information for building construction. Important interpretive soil properties for small buildings and accessory installations, such as roads and utilities, include slope, inundation, mass movement, potential frost action, depth to bedrock and cemented pans, shrink-swell potential, rock fragments > 75 mm, erodibility, subsidence, and soil strength.

Roads, streets, and utilities.—Performance of local roads and streets, parking lots, and similar structures is directly related to performance of the underlying soil in many cases. Pipelines and conduits commonly are buried in soil at shallow depth. Soil properties may affect cost of installation and rate of corrosion. Soil material is used directly as topsoil, roadfill, and aggregate for concrete. Soil interpretations can predict some suitabilities and limitations of different kinds of soil for these uses, although they cannot predict performance of highways, major streets, and similar structures. For these structures, onsite testing is necessary. Use of soil survey information, however, may reduce the number of borings and engineering tests needed.

Soil information in conjunction with engineering testing can identify soils that can be stabilized in place for a road base and establish where gravel or crushed stone will be needed. Soil surveys can be helpful in deciding methods of stabilizing cuts and fills. Soil properties may affect the cost of installation and length of service of buried pipelines and conduits. For example, shallow bedrock greatly increases the cost of installation. Rate of corrosion is related to wetness, electrical conductivity, acidity, and aeration. Differences in properties between adjacent horizons, including aeration, increase corrosion in some soils. Soil properties affect the cathodic protection provided by sacrificial metal buried with pipes. Rock fragments can break protective coatings on pipes. Shrinking and swelling of some soils may preclude the use of certain kinds of utility pipe.

Soil survey interpretations may be particularly useful in the prediction of potential problems along proposed routes. Hydrologic information and other data combined with interpretive soil properties, such as hydrologic groups, can be helpful in estimating potential runoff for designs of culverts and bridges. The probability of bedrock and unstable soils that require removal or special treatment can be determined from soil surveys.

Lawns and landscaping.—Soil survey interpretations give general information about sources of fill and about planning, planting, and maintaining grounds, parks, and similar areas. Particularly important are the suitability of the soil for turf, ornamental trees, and shrubs; the ability to withstand trampling and traffic; the suitability for driveways and other surfaced areas; and the ability to resist erosion. A number of soil chemical properties may be critical, especially for new plantings. Interpretations for particular plants and the treatments for a specific site require input from other disciplines.

Many lawn and ornamental plantings are made in leveled areas on an exposed subsoil or substratum or on excavated material that has been spread over the ground. Interpretations can be made for the suitability of such soil materials for lawns and other plantings, the amount of topsoil that is necessary, and other treatments required for satisfactory establishment of vegetation. Highway departments use soil interpretations when establishing and maintaining plantings on subsoil material in rights-of-way.

Stormwater management.—Building of infrastructure (such as roads, sidewalks, and rooftops) creates impervious surfaces, which greatly increase runoff and can contribute to flooding. Soils can be interpreted for various practices for stormwater retention and infiltration that can reduce the threat of flooding and the pollution of surface waters. The ability of the soil to transmit water and retain harmful materials while not contributing to landscape instability are important site considerations.

Waste Disposal

Waste disposal practices either place the waste in a relatively small area of soil or distribute the waste at low rates over larger areas.

Localized placement.—In this context, waste includes a wide range of material, including household effluent, solid waste, and industrial wastes of various kinds. Effluent from septic tanks is distributed in filter fields. Liquid wastes are stored and treated in lagoons constructed in soil material. Solid wastes are deposited in sanitary landfills and covered with soil material.

Extremes in saturated hydraulic conductivity and free water at a shallow depth limit the use of soil for septic tank absorption fields. (Table 8-1 shows the criteria for septic tank absorption fields.) Sewage lagoons require a minimum saturated hydraulic conductivity to prevent rapid seepage of water, a slope within certain limits, and a slight or no possibility of inundation or the occurrence of free water at shallow depths.

Soils are used to dispose of solid wastes in landfills, either in trenches or in successive layers on the ground surface. For trench disposal, properties that relate to the feasibility of digging the trench (i.e., depth to bedrock and slope) and factors that pertain to the likelihood of pollution of ground water (i.e., shallow zone of free water, inundation occurrence, and moderate and high saturated hydraulic conductivity) have particular importance. For disposal on the soil surface, saturated hydraulic conductivity, slope, and inundation occurrence are important.

Low-intensity distribution.—Soil is used to render safe either solid or liquid waste that is spread on the ground surface or injected into the soil. This waste includes manures, sewage sludge, and various solids and wastewaters (particularly from factories that process farm products). In general, the physical process of distribution is limited by steep slopes, rock fragments > 75 mm, rock outcrops, and wetness. The rate at which wastes can be applied without contaminating ground water or surface water is called the "loading capacity." Low infiltration values limit the rate at which liquid wastes can be absorbed by soil. Similarly, low saturated hydraulic conductivity through most of the upper meter limits the rate at which liquid wastes can be injected. Shallow depth of a hardpan or bedrock or coarse particle size reduces the amount of liquid waste that a soil can absorb in a given period. The time that wastes can be applied is reduced by frozen soil or occurrence of free water at shallow depths. Low soil temperatures reduce the rate at which the soil can microbiologically degrade the material.

Soils differ in their capacity to retain pollutants until they are deactivated or used by plants. Highly pervious soils may permit movement of nitrates to ground water. Similarly, saturated or frozen soils allow runoff to carry phosphates absorbed on soil particles or in waste deposited on soil directly to streams without entering the soil. Soils that combine a limited capacity to retain water above slowly permeable layers and a seasonal water excess may allow water that is carrying pollutants to move laterally at shallow depths. Such water may enter streams directly.

Large quantities of waste may change the soil. Heavy loading with liquid waste may reduce the oxygen supply so that yields of certain crops decrease. Conversely, heavy loadings can provide beneficial irrigation and fertilization for other kinds of soil and crop combinations. Animal wastes improve most soils, but effects differ according to the kind of soil.

Typically, the first step in making soil interpretations for disposal of wastes is to determine how disposal systems for each kind of waste have performed on specific kinds of soil in the area. Data may come from practical operations or from research. Which properties are critical and how to appraise the effects of the properties need to be determined. Limiting values of critical properties can be determined through experience and may be used in making interpretations where data on soil performance are scarce or lacking.

Water Management

Water management, as discussed here, relates to construction of relatively small- or medium-sized impoundments, control of waterways of moderate size, installation of drainage and irrigation systems, and control of surface runoff to minimize erosion. These activities may require large capital expenditures. In most cases, onsite evaluation should be conducted, particularly for soil properties at depth. Order 2 or order 3 soil surveys can be helpful in evaluation of alternative sites, but onsite investigations are required to design engineered projects.

Ponds and reservoirs.—Soil information is used in predicting soil suitability for ponds and reservoir areas. Impoundments contained by earthen dikes and fed by surface water have somewhat different soil requirements than those that are excavated and fed by ground water. Separate interpretations are commonly made.

Soil seepage potential, as determined by the minimum saturated hydraulic conductivity and the depth to pervious soil material, is an important factor for design of ponds and reservoirs. Slope is also important because it affects the capacity of the reservoir. The soil's hydrologic group (see chapter 3) pertains to the prediction of runoff into a pond or reservoir.

Embankments, dikes, and levees.—These are raised structures made of disturbed soil material constructed to impound water or to protect land from inundation. Soils are evaluated as sources of material for construction. Particle-size distribution and placement in the Unified system are important considerations. Interpretations do not consider whether the soil in place can support the structure. Performance and safety may require onsite investigation to depths greater than are typically considered in a soil survey.

Irrigation.—Important considerations for the design of irrigation systems are feasible water application rates, ease of land leveling and the resultant effect on the soils, possibility of erosion by irrigation water, physical obstructions to use of equipment, and susceptibility to flooding. An order 1 soil survey may be needed for observations and measurements of infiltration rates at depths greater than typically surveyed. The interpretations may be based on various soil properties, including saturated hydraulic conductivity, available water capacity, erodibility, slope, stoniness, effective rooting depth, salinity, sodium adsorption ratio (SAR), gypsum content, and other properties that may affect the level of crop response.

Interpretations for irrigation in arid and semiarid regions may be more complex than in humid regions, because irrigation changes the soil water regime more in arid and semiarid areas. Salinity and SAR of soils can be particularly significant, as can the quality of irrigation water. In arid and semiarid areas, small differences in slope and elevation can lead to an accumulation of salt-laden drainage water in low places or to development of a high water table if a proper drainage system is not provided.

Drainage.—Drainage refers to the removal of excess water from soils for reclamation or alteration. Engineers establish the criteria for drainage construction. The criteria include spacing and depth of subsurface drains, depth and width of open ditches and their side slopes, and allowable gradient. Soil properties important to drainage include water transmission, soil depth, soil chemistry, potential frost action, slope, and presence of rock fragments > 75 mm.

Public Health and Safety

Soil and site properties can profoundly influence the distribution of pathogenic organisms, the risk of mass movement and earthquake-induced hazards, and disease vectors related to mosquito habitat. The suitability of soils as habitat for soil-borne fungi and bacteria that affect human or animal health may be determined with increased resolution of maps showing various hazards and propensities of soils at soil survey scales.

Soil-Borne Diseases

Valley Fever is an example of a soil-borne disease. It is caused by the fungi *Coccidioides immitis* and *Coccidioides posadasii*. Because these fungi have very specific soil and climate requirements, areas that are suitable as habitat for these organisms can be predicted. Therefore, areas of likely habitat can be avoided or measures can be taken to prevent creating dust during times that the fungi are releasing spores.

Mass Movement

The likelihood of soil slippage using shear strength and shear stress concepts can be inferred from the slope, land surface shape, and soil depth to planes of weakness. The propensity of some soils to liquefy during earthquake events is influenced by the age and wetness of the landscape. These attributes and their relationships can be modeled using soil survey data. Care is needed in evaluating the relevance of the predictions if the depth of inference for the soils data is not deep enough to characterize the affected soil material.

Geophysical Tools and Site Suitability

Ground-penetrating radar (GPR) and other geophysical tools (discussed in chapter 6) are widely used for locating underground infrastructure, soil features, and burial sites and other applications in which large areas must be investigated without disturbing the soil. Soil properties such as electrical conductivity, clay content, and mineralogy influence the attenuation and penetration of electromagnetic energy. Where and how well GPR will work can be predicted using soil properties. The U.S. has developed a series of interpretive maps illustrating soil suitability for GPS use throughout the country (USDA-NRCS, 2009).

Subaqueous Soils

Subaqueous soils form in water-deposited material and can be mapped, characterized, and interpreted like terrestrial soils. These deposits undergo pedogenic processes (Demas and Rabenhorst, 2001). They occur in predictable patterns and have predictable soil properties that are useful for interpretation. This section discusses some soil interpretations that have been developed for subaqueous soils in the United States. Chapter 10 provides more information on the nature and properties of subaqueous soils. Because land use does not end at the water's edge, interpretations have been developed for the subaqueous environment. Mapping and characterizing subaqueous soils helps ensure the wise use of the near offshore soil resource. Below are a few examples of interpretations for subaqueous soils.

Moorings

A stable place to tie up watercraft is essential during a storm. The type of mooring that can be used for securing watercraft depends on the nature of the subaqueous soil (Surabian, 2007). In areas where the bottom is fluid (soft bottom), a mushroom anchor will suffice to hold the vessel in place. In areas where the bottom is composed primarily of sand and gravel (hard bottom), a deadweight anchor is needed.

Eelgrass Restoration

Eelgrass is an important species in the subaqueous environment because it supplies food and cover for desirable fish and shellfish. It requires a sandy soil matrix free of reduced monosulfides. The water column must be shallow enough to allow light penetration but deep enough to avoid freezing.

Land Disposal of Dredged Material

Sediment is removed from navigation channels to facilitate the movement of vessels. If this material is placed on land, it will oxidize in the subaerial environment. If reduced monosulfides are present in the dredged material, these compounds will oxidize and form sulfuric acid, which can have severe environmental effects.

Hard Clam Substrate

Aquaculture is an important agricultural sector in coastal areas. Hard clams require a sandy substrate since fine soil particles can clog their filtering apparatus.

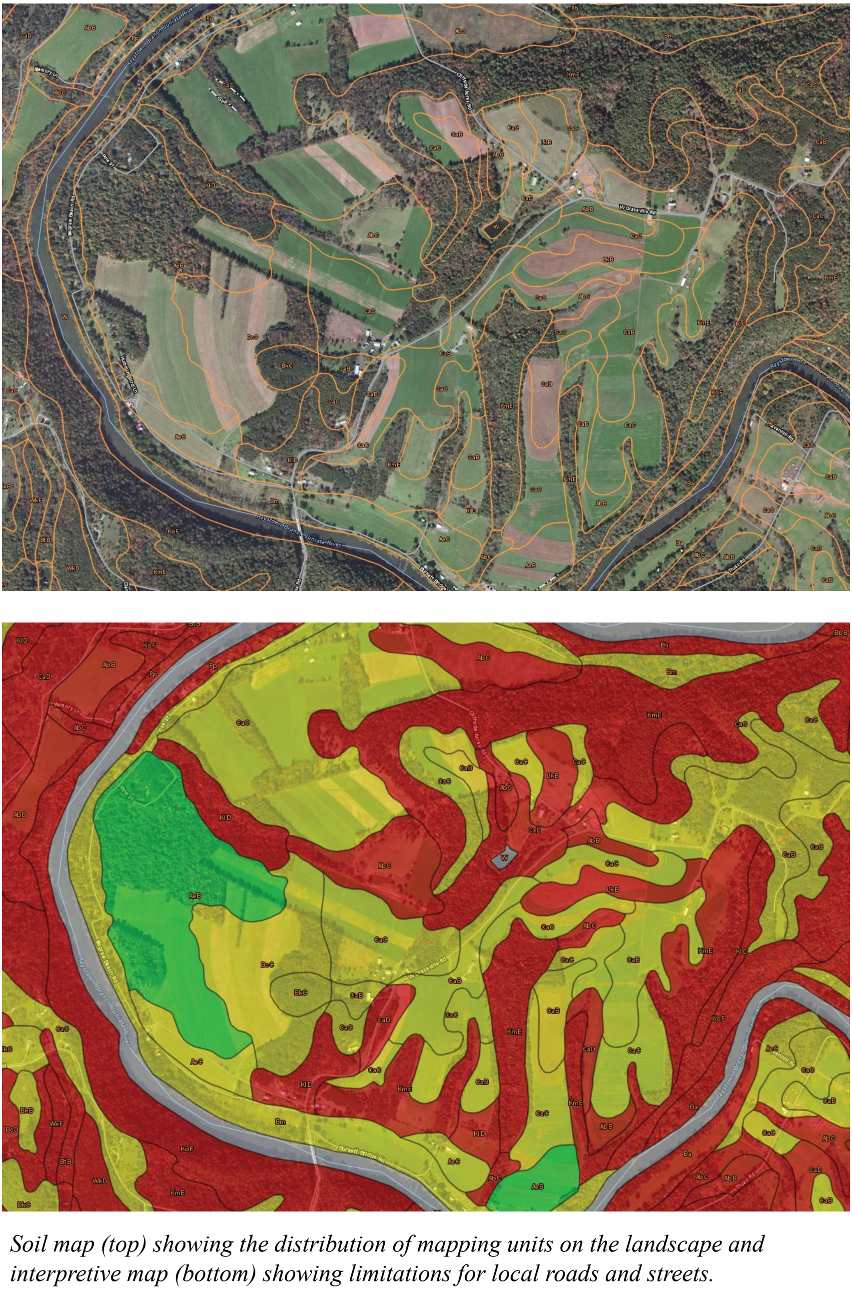
Areal Application of Interpretations

The objective of soil surveys is to provide interpretations for areas delineated on soil maps. This section discusses the relationship of interpretations to map unit terminology and conventions (described in detail in chapter 4), the interpretive basis of map unit design, and the uncertainty of interpretive predictions for specific areas within the map unit.

Polygon-Based Soil Interpretations

Polygon-based interpretations are applied uniformly to an entire map unit delineation. The top image in figure 8-4 is a soil map that shows the delineations of map units and depicts other features on the landscape. The bottom image in figure 8-4 shows the same area as the top image and illustrates the ratings of the soil map units for local roads and streets. Green indicates not limited, yellow somewhat limited, and red very limited. Gray areas are not rated because there were not enough data to derive a rating (in this case they are water bodies). Table 8-3 indicates which soil properties (in the column "Rating reasons") are limiting for local roads and streets for the Albrights map unit (AbB). The numeric values give an estimate of the degree of limitation posed by each reason. Note that even though one component is given in the map unit name (i.e., Albrights), it is understood that more than one component exists in the map unit. In this case, the included Brinkerton soil is estimated to make up about 5 percent of the map unit (listed in the column "Component name").

Figure 8-4



Soil map (top) showing the distribution of mapping units on the landscape and interpretive map (bottom) showing limitations for local roads and streets.

Table 8-3

Limitation Ratings for Local Roads and Streets for the Albrights Map Unit (AbB)

Local Roads and Streets—Summary by Map Unit—Bedford County, Pennsylvania (PA009)						
Map unit symbol	**Map unit name**	**Rating**	**Component name** *(percent)*	**Rating reasons** *(numeric values)*	**Acres in AOI**	**Percent of AOI**
AbB	Albrights silt loam, 3 to 8 percent slopes	Very limited	Albrights (90%)	Depth to thick cemented pan (1.00)	43.6	3.1%
				Depth to thin cemented pan (1.00)		
				Frost action (0.50)		
				Depth to saturated zone (0.48)		
			Brinkerton (5%)	Depth to thick cemented pan (1.00)		
				Depth to saturated zone (1.00)		
				Depth to thin cemented pan (1.00)		
				Frost action (1.00)		
				Low strength (1.00)		

Raster-Based Soil Interpretations

The processes used in digital soil mapping (see chapter 5) present intriguing possibilities for the future development and display of spatially explicit soil interpretations. The current U.S. interpretation system has two primary shortcomings that limit the precision and accuracy of the derived predictions. First, the system is constrained to use only data from within the database. While this is reasonable for the soil attribute data, ideally climatic and geomorphic data would be obtained from more authoritative sources. Second, the interpretive output can only be displayed as aggregated values for the polygons of the original mapping. Any fine detail of the landscape cannot be represented. Digital soil mapping (DSM) offers the opportunity to overcome both of these limitations by allowing the use of authoritative data layers and displaying results at the resolution of the digital soil map. The interpretive models themselves are generally scale-independent, and higher resolution input data would allow greater confidence in the spatial location of the results.

The advantages of raster-based interpretations relate to the scale of the land use. Land uses such as farming, ranching, and forestry are relatively extensive operations (10 to 1,000 hectares) with a relatively low investment per hectare (although some farming systems are more intense than others). For these uses, a scale of 1:20,000 may be adequate. Other land uses, such as homesites and animal waste facilities, are on a more intensive scale (0.1 to 1 hectare) and have a higher monetary investment per hectare. They occupy a discrete portion of the landscape, which may fall into an area that is not accounted for on an aggregated 1:20,000 soil map. A linear land use, such as a pipeline or road, may involve a long, narrow segment of the landscape that encompasses several kilometers of length and traverses portions of many map units. Accounting for the inherent homogeneity of the landscape for these types of land use could allow routing the right-of-way to avoid obstacles and sensitive areas that might not be displayed on a soil map.

In a raster environment, continuous soil data would allow depiction of interpretive results limited only by the pixel size of the DSM. Environmental covariates, such as climate and topographic data, as well as the soil attribute data would be processed by the interpretation modeling system for each pixel (fig. 8-5). These data would already be available from the DSM process.

Spatially explicit raster-based interpretations would be subject to the same issues of data quality and confidence as the DSM from which it was derived. The confidence level would be indicated in the DSM, and the interpretive results would also have a reportable confidence interval. The processing workload would be much larger than what is currently needed and would vary depending on the resolution of the DSM.

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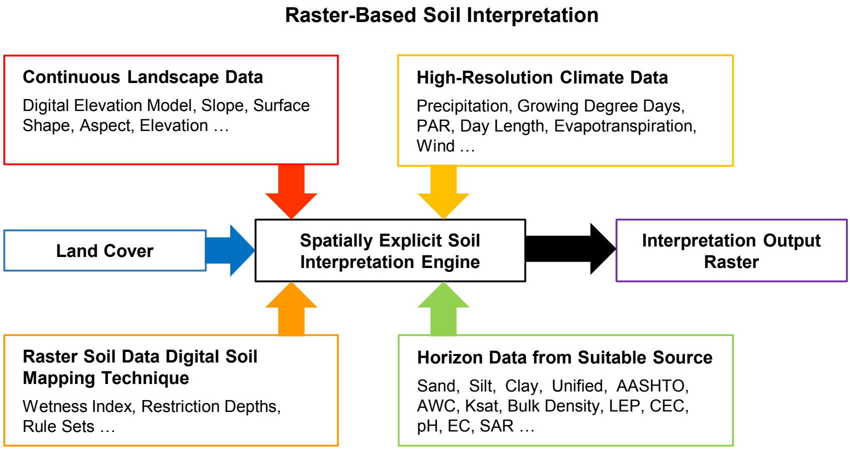
Figure 8-5



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