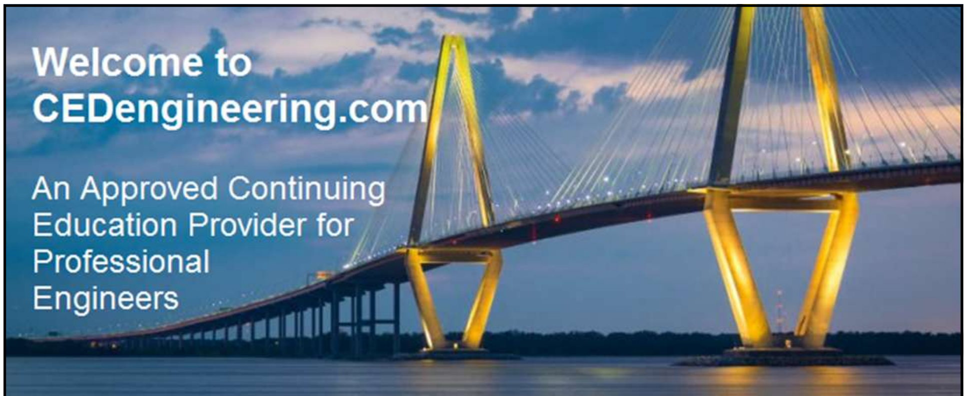

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SOIL SURVEY MANUAL

Course No: L03-304 - Course Credit: 3 PDH

Prepared by:

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LEARNING OBJECTIVES

1. To understand soil mapping concepts, including soil map units, kinds of map units, and the orders of soil surveys used to guide the intensity and scale of field investigations.
2. To explain the principles of digital soil mapping, including the SCORPAN model and the use of environmental covariates to predict the spatial distribution of soil properties.
3. To explore the role of proximal soil sensing technologies and soil survey data management systems in collecting, processing, and disseminating soil survey information.
4. To examine dynamic soil properties, their importance in reflecting soil health and land management, and the methods used to collect, analyze, and integrate DSP data into soil survey.
5. To analyze subaqueous soil survey methods, including sampling, description, classification, soil-landscape relationships, and the significance of subaqueous soil information for resource management.
6. To understand human-altered and human-transported soils, including their identification, classification, occurrence, and the survey methods used to characterize profoundly modified soil landscapes.

SOIL MAPPING CONCEPTS

Soil Mapping Process

- Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map.
- The soils and miscellaneous areas (e.g., Rock outcrop) in a survey area are in an orderly pattern that is related to the geology, landforms, topography, climate, and natural vegetation.
- Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform.
- Soil scientists delineate these repeating patterns of landform segments, or natural bodies, on a map.
- By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed.
- Thus, during mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape.

- The repetitive patterns imprinted in soils by the soil-forming factors can be observed at scales ranging from continental to microscopic.
- These patterns are the basis for soil identification and mapping at different scales.
- A system of terminology, definitions, and operations can be ascribed to the various scales.
- Hierarchical systems of classes and subclasses are established to produce groupings at the different scales.
- Commonly, individual soils on the landscape merge into one another as their characteristics gradually change.
- To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils.
- Some boundaries are sharp, where soils change over a few meters, while others are more gradual.
- Soil scientists can observe only a limited number of pedons.
- Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil and to determine their boundaries.

SOIL MAPPING CONCEPTS (CONT'D)

- Soil scientists record the characteristics of the pedons, associated plant communities, geology, landforms, and other features that they study.
- They describe the kind and arrangement of soil horizons and their color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to classify and identify soils.
- They describe plant species present (their combinations, productivity, and condition) to classify plant communities, correlate them to the soils with which they are typically associated, and predict their response to management and change.
- After the soil scientists identify and describe the properties of landscape components, or natural bodies of soils, the components are correlated to an appropriate taxonomic class, which is used for naming map units.
- Correlation, or comparison of individual soils with similar soils in the same taxonomic class in other areas, confirms data and helps the staff determine the need to assemble additional data.
- Taxonomic classes are concepts.
- Each taxonomic class has a set of soil characteristics with precisely defined limits.
- The classes are used as a basis for comparison to classify soils systematically.
- Soil Taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile.

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SOIL MAPPING CONCEPTS (CONT'D)

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- While a soil survey is in progress, samples of some of the soils in the area are collected for laboratory analyses.
- Soil scientists interpret the data from these analyses and tests as well as the field observed characteristics of the soil properties to determine the range of values for key soil properties for each soil.
- They also use these data to determine the expected behavior of the soils under different uses.
- Soil property data is organized and stored in a database, where it is used to generate soil interpretations for use and management.
- Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management.
- Special studies to document dynamic soil properties that are affected by use and management may be conducted.
- Data are assembled from other sources as well, such as research information and field experience of specialists.

SOIL MAPPING CONCEPTS (CONT'D)

- After survey staff locate and identify the significant natural bodies of soil in the survey area, they draw the boundaries of these bodies on a map and identify each as a specific map unit by name.
- Imagery showing trees, buildings, roads, and rivers is commonly used as a base map to help in locating boundaries accurately.
- Tonal shades and patterns on aerial photographs or digital images are used to indicate potential changes in vegetation, drainage conditions, parent materials, and other factors affecting surface reflectance.
- As digital mapping techniques are being increasingly integrated into mapping, additional sources of information, such as multispectral bands, digital elevation models, and other data layers (such as geology), along with global positioning systems (GPS) are used to accurately locate map unit boundaries.
- Although the processes used in digital mapping techniques are different from nondigital conventional methods, the principles are the same.

SOIL MAPPING CONCEPTS (CONT'D)

- In the United States, soil surveys vary in scale and in intensity of observations.
- The components of map units are designated by taxa in Soil Taxonomy (Soil Survey Staff, 1999) or as miscellaneous areas (i.e., nonsoil areas).
- In naming a map unit, soil taxa names (commonly a soil series name) are modified with phase terms (indicating surface texture, slope, flooding, stoniness, etc.) to convey information that is either more specific than the wider range of properties defined for the series (e.g., surface texture) or that represents a property outside of the soil itself (e.g., flooding).
- The phase commonly is a portion of the range of properties exhibited by the taxon.
- For example, a certain soil series may have slopes ranging from 3 to more than 60 percent but the map units are shown with narrower ranges (e.g., 3 to 8, 8 to 15, 15 to 25) to provide information that is useful in managing the soils in the area.

- Historically, soil surveys have classified entire polypedons and grouped their properties for interpretative output as vector maps (polygons).
- Some contemporary surveys classify only certain soil properties, such as surface rock fragment cover, and output the information as raster maps, in which each pixel represents a specific value of the property.
- With these maps, commonly called "soil property maps," the user can decide how to group or aggregate the information for their needs.
- Strictly speaking, maps of individual soil properties are not synonymous with soil surveys, which by definition delineate natural soil bodies.

Soil Mapping and the Scientific Method

- Soil mapping uses the scientific method, in which the scientist must: (1) develop questions, (2) generate hypotheses that answer those questions, (3) test the hypotheses, and (4) confirm or reject the hypotheses.
- After a tentative delineation of a soil body is drawn on an aerial photo or digital image, the soil mapper (step 1) questions what type of soil exists within that delineation.
- Typically, the delineation follows a landscape feature, such as a large flood plain or a ridge summit.
- Based on previous knowledge about the soils of the region, the mapper (step 2) develops hypotheses, such as the Alpha and/or Beta series occurs within the delineation.
- The mapper (step 3) tests those hypotheses by augering, backhoe trenching, or observing natural exposures and (step 4) confirms or rejects each hypothesis.
- After documenting the results, the mapper returns to step 1 (develops questions) and repeats the process for a neighboring area.
- This process allows the soil scientist to map soils efficiently.
- Rather than making a large number of observations on a regular grid pattern to discover the kind of soil present, the mapper selects a limited number of strategically located points in the landscape to make observations.
- The observations confirm or reject the previously developed model.
- The mapper essentially is predicting the soil beforehand and only making an observation to confirm the prediction, rather than discovering the soil only after each observation is made.
- As long as the model is accurate, relatively few observations are required to make an accurate map.

- The scientific method is also used when investigating soil genesis.
- Although soil mapping and soil taxonomic classes are based on quantifiable properties rather than soil genesis, it is nevertheless useful for the soil mapper to develop conceptual models about soil genesis throughout the mapping process.
- The most useful is the "multiple working hypotheses" method, which is based on the premise that when a scientist creates multiple hypotheses for an observed feature rather than one hypothesis, they are less likely to develop a parental attachment to "their" hypothesis.
- Instead, the scientist becomes engaged in finding evidence that disproves each of the competing hypotheses.
- The "working hypothesis" is the one that survives.
- This method of testing multiple hypotheses simultaneously not only enhances the quality of conceptual models but also lessens antagonistic debates between scientific colleagues.

Soil Maps

Historical Approach

- Aerial photographs were used as the mapping base in most soil survey areas in the United States during the 20th century.
- Conventional panchromatic (black and white) photography, color photography, and infrared photography were used for remote sensing and as base maps for the soil survey.
- Information on the applicability of each type of base map and how the older map products were used is covered in the 1993 Soil Survey Manual.

Aerial Photographs

- Even in the current digital age, the use of aerial photographs remains an effective means of mapping soils in areas where suitable digital imagery and data layers or the required skills, resources, or support for digital mapping techniques are not available.
- Aerial photographs are still a viable mapping base in soil survey.
- They provide important clues about kinds of soil from the shape and color of the surface and the vegetation.
- The relationships between patterns of soil and patterns of images on photographs for an area can be determined.
- These relationships can be used to predict the location of soil boundaries and the kinds of soil within them.

- Aerial photographs using spectral bands not visible to the eye, such as color infrared, enable subtle differences in plant communities to be observed.
- Other spectral bands in the infrared are useful in distinguishing differences in mineralogy and moisture on the soil surface and also have better cloud penetration.
- These data must be interpreted by relating the visual pattern on the photographs to soil characteristics found by inspection on the ground.
- Features, such as roads, railroads, buildings, lakes, rivers, and field boundaries, and many kinds of vegetation can be recognized on aerial photographs and serve as location aids.
- Cultural features commonly are the easiest features to recognize on aerial photos, but they generally do not coincide precisely with differences in soils, except in areas with significant anthropogenic alteration.
- Relief features are helpful in locating many soil boundaries on the map.
- Topographic maps also provide insight to relief, slope, and aspect. Relief also identifies many kinds of landforms commonly related to kinds of soil.

SOIL MAPPING CONCEPTS (CONT'D)

- Many landforms (e.g., terraces, flood plains, sand dunes, kames, and eskers) can be identified and delineated reliably according to their shapes, relative heights, and slopes.
- Their relationship to streams and other landforms provides additional clues.
- The soil scientist must understand geomorphology to take full advantage of photo interpretation.
- Accurate soil maps cannot be produced solely by interpretation of aerial photographs.
- Time and place influence the clues visible on the photographs.
- Human activities have changed patterns of vegetation and confounded their relationships to soil patterns.
- The clues must be correlated with soil attributes and verified in the field.

SOIL MAPPING CONCEPTS (CONT'D)

Contemporary Approach

- Digital imagery has replaced photographs as the mapping base in 21st century soil survey.
- The ability to overlay multiple imagery resources for comparisons, the ability to quickly adjust scale, and the use of raster-based soil maps have increased the speed of delivering soil survey products as well as the variety of products available.
- Customized soil survey products are enhanced by the choice of background imagery (e.g., color imagery and topographic imagery) used to display soil survey information.

Sources of Apparent Error on Existing Soil Maps

- Soil surveys in the United States. meet the technical standards and design requirements in place at the time they were completed.
- However, standards in use varied from State to State or regionally.
- In addition, standards evolved with increased knowledge about soils and changes in user needs.
- One should not assume that the soil survey data and maps completed many years ago, which did not have the benefit of recent evaluation and update, meet the standards and expectations of users today.
- Soil survey mapping scale and map unit design considerations likely cause the most apparent errors on soil maps.
- Projects were designed to collect and document soil distribution and properties based upon user needs and were not more detailed than necessary.
- For low-intensity uses of the soil (e.g., grazing on native rangeland, native forests, watershed, and wildlife habitat), soil mapping was performed on a small-scale photo base of 1:48,000 to 1:63,560, or smaller.
- Areas of soil that were markedly different in use and management but too small to be delineated at the scale of mapping were described as inclusions in map units or denoted by a spot symbol on the map.
- When the mapping is presented at a larger scale, these areas may appear to be errors in the map.

- Soil surveys in the U.S. were initiated with "memoranda of understanding" between National Cooperative Soil Survey (NCSS) partners and other local partners.
- These documents included agreed-to scheduled progress targets and completion date.
- The schedule dictated the scale of mapping and the mapping intensity or order.
- Map units were designed to meet specific user needs, and fieldwork was conducted to create soil maps that met those needs.
- If the user needs change due to changes in land use, the map unit design may not adequately meet the new needs.
- Soils with markedly different potentials or risks based upon use may not be adequately separated in mapping units.
- Standards used in the soil correlation process set minimum extent requirements for both a map unit and a soil series included in the soil survey legend.
- Setting these limits was done prior to computerization to ensure that data and information would remain manageable.
- At the end of a project, map units and series that did not meet the minimum extent requirements were combined with the most similar map unit or component in the legend and the concepts were expanded to include these soils and areas.

- Boundaries of the soil mapping legends generally coincided with county or State lines.
- Small areas of soils having a different bedrock geology, physiography, or major land resource area (MLRA) that crossed the political soil survey boundary (map legend boundary) were too small in extent to appear in the legend alone, so they were combined with the most similar map unit.
- When two adjacent survey areas are viewed at the join, fault lines may appear between the two surveys.
- Under the MLRA approach currently used to update soil survey in the U.S., these faults are being corrected.
- Significant changes in the soil resource itself may have occurred since the time of soil mapping.
- Extensive anthropogenic activities, including mining, excavation, land leveling, and construction, remove or bury native soils.
- Because of natural processes, such as changes in stream courses, landslides, and volcanic eruptions, soil materials at the surface may differ from those identified on soil maps completed earlier.
- These changes are generally dramatic and easily recognizable on the landscape.
- Some, however, may be subtle (e.g., filling of wet areas, alterations to hydrology, and mechanical alterations such as deep ripping and deep mixing).
- Other actual errors may be discovered on soil maps, including labeling errors done in the field and map compilation and publication errors.
- They should be documented and corrected.

Field Operation and Equipment

- The efficient operation of a soil survey requires the use of certain kinds of equipment.
- The three major equipment needs are: (1) tools to examine the soil profile; (2) soil testing, measuring, and recording devices for mapping; and (3) transportation vehicles.
- While some of the equipment used in soil survey reflects new technology, such as tools for proximal sensing of soil properties, many of the basic tools for observing soils in the field have changed little in recent years.
- The 1993 Soil Survey Manual contains a detailed discussion and description of many of these items.
- Short descriptions of commonly used field tools are also provided in the Field Book for Describing and Sampling Soils.

Tools for Examining and Testing the Soil

- A soil scientist examines the soil often in the course of mapping.
- Examination of both horizontal and vertical variations is essential.
- The most commonly used tools are spades and soil augers.
- Augers are used in most areas for routine mapping.
- In some areas, however, a spade is used to examine the soil.
- In soils with no rock fragments, samples can be collected quickly and relatively easily using truck-mounted or hand-operated probes.
- Backhoes and shovels are used to expose larger soil sections for examination, sampling, and photography.
- Where a probe or auger is regularly used for examining the soil, a large pit exposed by a backhoe can be used to ensure map unit concepts are as predicted and have not strayed from the conceptual model developed.

Figure 1: A truck-mounted hydraulic probe used to quickly obtain soil profiles.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Figure 2: A backhoe excavation and safety measures in deep trenches.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Backhoes, however, have limitations.
- Cost as well as time to perform needed maintenance must be considered.
- Where available locally, renting a backhoe and operator only when needed may be an option.
- Some property owners do not want large equipment on their property.
- Operators must be trained to use the equipment efficiently, and safety standards must be met.
- Overhead and underground power lines, which pose electrical hazards, and other utilities must be located and avoided.
- Slopes may be too steep for safe operation of machinery.
- It is important to recognize soil properties that make trench walls prone to collapsing and thus dangerous for anyone in a pit.
- Designing backhoe trenches with benching, shoring, and exit ramps can improve safety.

- Equipment for unique environments must be considered.
- Power equipment is commonly used to save time and effort.
- Vibracore samplers are used to obtain subaqueous soil samples several meters below the water surface.
- Devices such as core catchers are used to prevent the sandiest materials from falling out of the sample tube.
- Various small instruments can also be used to examine the soil, such as small handheld digital meters that determine salinity, soil reaction, sodicity, and soil nutrients.
- Proximal sensing tools, such as XRF meters, electromagnetic induction, and ground-penetrating radar, can also be used.

Measuring and Recording Devices for Mapping

- A handheld geographic positioning system (GPS) unit can assist in navigation and capture the location of soil descriptions.
- It can be indispensable as a navigation aide in remote or roadless areas.
- GPS provides both horizontal position in geographic coordinates and elevation.
- Most units can store and recall waypoints and so help workers identify and return to specific locations.
- Some provide background maps of geographic and cultural features to aid navigation.
- A small digital camera is useful in capturing quality images of soil profiles and features, landscape settings, and vegetation and documenting land use and management.
- Smartphones, tablets, and some laptops have built-in cameras that can be used for capturing and storing images.
- If digital images are used as the mapping base, laptop computers or tablet PCs (provided they are sufficiently ruggedized and suited to outdoor viewing) can be used to display and annotate maps.
- Waterproof data loggers can be installed at some study sites to automatically collect measurements of air and soil temperatures, water potential, and more.
- These data can be collected over 1 or more years as needed and summarized to characterize site conditions for classification and interpretation.

Transportation

- Field operations in soil survey require transportation of workers, equipment, supplies, and soil samples.
- Vehicles are provided to the soil survey team for their daily operations.
- The time spent by soil scientists traveling to and from the field can be lengthy and mainly unproductive.
- Enough vehicles are provided to keep travel time as short as possible.
- Additional equipment used for special purposes or for short periods is typically rented or supplied as needed.
- A passenger van, for example, may be furnished by one of the soil survey project's partners during a field review.
- Some vehicles must carry power equipment or pull trailers.
- All vehicles should be suited to the needs of the survey area, whether it be for use off road or in paved areas; to carry workers efficiently, comfortably, and safely; to hold the regularly used equipment; to accommodate an extra load; or to protect workers and equipment from adverse weather.

- Specialized vehicles are needed in some areas.
- Aircraft, particularly helicopters, are used in some soil surveys to transport workers and equipment and to provide broad views of landscapes and vegetation.
- Aircraft are useful for photographing landscapes, soil patterns, and land use.
- Availability, cost, and lack of conventional landing sites are the main limitations to using aircraft.
- Snowmobiles provide winter access where travel is impossible or impractical in other seasons.
- Tracked vehicles, trail bikes, and all-terrain vehicles (ATVs) may be needed in areas that otherwise can be reached only by walking.
- Pack horses may be the only viable means of transporting people and equipment in wilderness areas.
- Marsh buggies with large buoyant tires and airboats are used in swamps and marshes.
- Canoes and small boats may be used to navigate waterways or to access areas consisting of numerous islands.
- Shallow draft boats are useful in conducting soil surveys in areas consisting of subaqueous soils.
- Specialized vehicles must be reliable in remote areas.
- Costs of buying or renting equipment, maintaining the equipment, and training operators can be high. Time is needed for transport, maintenance, and training.
- Some equipment is hazardous to operate.
- In addition, sensitive ecosystems may be damaged by the equipment.

Soil Identification and Classification

- In soil surveys, the individual parts that make up the soil continuum are classified.
- The classes are defined for bodies of soil of significant kinds and extent.
- The taxonomic classes are conceptual.
- Their definitions are based on the knowledge of soils as they occur in nature and the understanding of the genetic processes responsible for their formation.
- The taxonomic classes themselves are not real soils, but they relate to their representatives in nature—the pedon and the polypedon.

Pedon

- A pedon is the smallest body of one kind of soil that is large enough to represent the nature and arrangement of horizons and the variability in the other properties.
- It lacks boundaries with neighboring pedons.
- It is a unit of observation, sampling, and classification.
- A pedon extends down to the lower limit of a soil, through all genetic horizons and, if the genetic horizons are thin, into the upper part of the underlying material.
- It includes the rooting zone of most native perennial plants.
- For purposes of most soil surveys, a practical lower limit of the pedon is bedrock or a depth of about 2 m, whichever is shallower.
- A depth of 2 m allows a good sample of major soil horizons, even in thick soil.
- It includes much of the volume of soil penetrated by plant roots, and it permits reliable observations of soil properties.

- The surface of a pedon is roughly polygonal and ranges from 1 to 10 m^2 in area, depending on the nature of the soil's variability.
- Where the cycle of variations is less than 2 m and all horizons are continuous and nearly uniform in thickness, the pedon has an area of approximately 1 m^2.
- Where horizons or other properties are intermittent or cyclic over an interval of 2 to 7 m, the pedon includes one-half of the cycle (1 to 3.5 m).
- If horizons are cyclic over an interval greater than 7 m, each cycle is considered to contain more than one soil.
- The range in size, 1 to 10 m^2, permits consistent classification by different observers where important horizons are cyclic or repeatedly interrupted over short distances.

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SOIL MAPPING CONCEPTS (CONT'D)
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Polypedon

- A pedon by itself is too small to be the unit of soil mapping because it cannot account for features such as slope and surface stoniness.
- In addition, it is too small to embody the full range of variability occurring within a soil series.
- Instead, the polypedon is used to define a soil series and is the unit of soil mapping.
- It is the three-dimensional soil body or soil individual that is homogeneous at the soil series level of classification.
- It is big enough to exhibit all the soil characteristics considered in the description, classification, and mapping of soils.

SOIL MAPPING CONCEPTS (CONT'D)

- The concept of the polypedon is, from a practical standpoint, more or less equivalent to the component in soil mapping, but with one technical difference.
- Since the polypedon is defined as being homogenous at the series level of classification, each pedon making up the polypedon must fall within the class limits for all the properties (texture, color, reaction, thickness, etc.) of that series.
- When the limits of taxa are superimposed on the pattern of soil in nature, areas of taxonomic classes rarely, if ever, coincide precisely with mappable areas.
- In contrast, the map unit component represents a miscellaneous area or a natural soil body that includes all of the pedons making up the polypedon, as well as other very similar pedons within the mapped area that are just slightly outside the property ranges assigned for the series.
- A polypedon and similar or noncontrasting soils occur within the concept and boundaries of the map unit component.
- Soil map units may consist of one or more components.

SOIL MAPPING CONCEPTS (CONT'D)

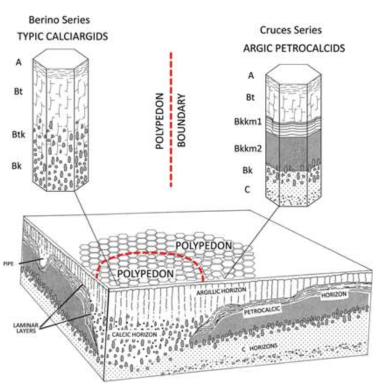


Figure 3: Polypedons vary in size. This figure illustrates a small polypedon formed in a pipe through a petrocalcic horizon. It also illustrates the concept that pedons have no lateral boundaries with neighboring pedons, unlike polypedons, which do have boundaries with neighboring polypedons.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The polypedon represents the minimum unit of interpretation and soil management.
- If the boundaries of an individual polypedon are gradual and diffuse, the polypedon is virtually impossible to delineate because its properties are confined by the taxonomic class it represents (series) and these properties vary in a sinuous or continuous manner in either vertical or horizontal dimensions.
- Boundaries between map unit components, however, are commonly evident where the differences produce contrasting native plant communities or changes in properties that impact soil use and management.
- Boundaries of both map unit components and polypedons may be easily observed at discontinuities, such as erosional facies and geologic contacts, and following human alteration.
- Polypedons link the real bodies of soil in nature to the mental concepts of taxonomic classes and are the basis of soil components used in mapping, interpreting, and managing soils.

Soil Map Units

- Soil map units are designed to efficiently deliver soil information to meet user needs for management and land use decisions.
- Map units can appear as individual areas (i.e., polygons), points, or lines on a map.
- A map unit is a collection of areas defined and named the same in terms of their soil components, miscellaneous areas, or both (components and miscellaneous areas are described below).
- Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map.
- A map unit description is a written characterization of the component within a map unit and the relationship of one map unit to another.

- Soil map units consist of one or more components (defined below).
- A delineation of a map unit generally contains the major (dominant) components included in the map unit name, but it may not always contain a representative of each kind of minor component.
- In older soil surveys, minor components were neither described nor interpreted in detail and were referred to as inclusions within a map unit.
- A dominant or major component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons.
- A part of a polypedon is represented when the phase criteria, such as slope, require that a polypedon be divided.
- A complete polypedon occurs if there are no phase criteria that require the subdivision of the polypedon or the features exhibited by the individual polypedon do not cross the limits of the phase.
- Several polypedons of a component may be represented if the map unit consists of two or more dominant components and the pattern is such that at least one component is not continuous but occurs as an isolated body or polypedon.
- Similarly, each minor component in a delineation is represented by a part of a polypedon, a complete polypedon, or several polypedons.
- Their extent, however, is small relative to the extent of the major component(s).
- Soil boundaries are often inaccurately depicted on soil maps, leading to the unintentional inclusion or exclusion of parts of adjacent polypedons.

- Some map unit delineations may not contain any of the dominant components named in the map unit description but contain what are termed "similar soils."
- In most survey areas, there are soils that occur as mappable bodies but have very limited total extent within a specific survey area.
- They are typically included with other map units if, for all practical purposes, their soil interpretations are the same.
- The allowance of similar soils in map units is by design—it permits the number of map units and named components to be reduced without reducing the interpretative value of the soil map.
- The kinds of map units used in a survey depend primarily on the purposes of the survey and the pattern of the soils and miscellaneous areas in the landscape.
- The pattern in nature is fixed, and it is not exactly the same in each delineation of a given map unit.
- In soil surveys, these patterns must be recognized and map units designed to meet the major objectives of the survey based upon known or projected user needs.
- It is important to remember that soil interpretations are made for areas of land and the most useful map units are those that group soils based upon their similarities.

Component

- Within the context of a map unit, a component is an entity that can be delineated at some scale.
- It is commonly a soil but may be a miscellaneous area.
- Components consisting of soil are named for a soil series or a higher taxonomic class.
- Those that are miscellaneous areas are given an appropriate name, such as "Rock outcrop" or "Urban land."
- In either case, each component that makes up a map unit can be identified on the ground and delineated separately at a sufficiently large scale.
- Map unit components describe the properties of natural bodies of soils, or miscellaneous areas of nonsoil, in a particular landscape.
- Components can be major or minor in extent, depending upon the kind of map unit and percent composition.
- Designation of components as major or minor in soil databases is helpful for interpretive groupings.
- Typically, only major components are used in a map unit name.

- The table here lists the kinds of map unit components used in soil survey.

Component kind	Description
Soil series	Most common component. It is the lowest categorical level of Soil Taxonomy.
Taxonomic categories above the series	Components given a taxonomic reference term that implies no specific range of properties beyond what is given in the map unit description.
Taxadjuncts	Components that are named for a soil series they resemble but have one or more differentiating characteristics that are outside the taxonomic class limits of that series. Their use and management is similar to that of the named soil series.
Miscellaneous areas	Components that are not soil as defined in *Soil Taxonomy* (such as Rock outcrop) or are bodies of soil that are no longer capable of supporting plants, such as soils heavily contaminated by toxic substances. Examples are given in table 4-2.
Phases of components	Components that are assigned a descriptive term to help distinguish between multiple components of the same taxonomic or miscellaneous area occurring within the same map unit legend or geographically associated map units.

Table 1: Kinds of Map Unit Components Used in Soil Survey.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Soil components typically represent less than the full range of some properties allowed in a taxonomic class, which is defined by limits of key diagnostic properties.
- They may also differ from taxonomic classes and be slightly outside the class limits of some properties that define the taxa.
- Soils having properties that are slightly outside the defined taxonomic limits but that do not adversely impact major land uses are called similar soils.
- Map unit components are commonly a subset of the dominant taxonomic class or series in the delineation and similar soils.
- By identifying and naming components in map units, a soil scientist can quickly communicate interpretive information about a map unit and still indicate its complexity.

Soil Series

- The series represents a three-dimensional soil body having a unique combination of properties that distinguish it from neighboring series.
- The soil series concept was developed more than 100 years ago and somewhat followed the logic of the series as used to describe sediments in the geologic cross-section.
- Like the geologic formation, the soil series has served as the fundamental mapping concept.
- In geology, strata closely related in terms of their properties and qualities were members of a series in the sedimentary record.
- Initially, the soil series did not conform to a specific taxonomic class nor property class limits but rather to the predominant properties and qualities of the soil landscape, climate, and setting in which the soil occurred.

SOIL MAPPING CONCEPTS (CONT'D)

- Today, the soil series category is the lowest level and the most homogeneous category in the U.S. system of taxonomy.
- As a class, a series is a group of soils or polypedons that have horizons similar in arrangement and in differentiating characteristics.
- The soils of a series have a relatively narrow range in sets of properties.
- Although part of Soil Taxonomy, soil series are not recorded in it.
- In the United States, they are in the Official Soil Series Descriptions database.
- The soil series is not the object mapped in soil survey.
- Natural soil bodies are mapped and then described and classified.
- Each map unit soil component is correlated to a soil series or other taxonomic class.
- Soil series serve as a bridge between real soil bodies and conceptual taxonomic classes.
- They are an important tool for naming, remembering, and communicating information about soils.
- They also serve as a tool for transferring knowledge about soil genesis, properties, and interpretations from place to place, wherever a given soil series was correlated to a map unit component.

SOIL MAPPING CONCEPTS (CONT'D)

- Soil series are differentiated on all the diagnostic features of the higher categories in Soil Taxonomy plus those additional and significant characteristics in the series control section.
- Some of the characteristics commonly used to differentiate series are the kind, thickness, and arrangement of horizons and their structure, color, redoximorphic features, texture, reaction, consistence, content of carbonates and other salts, content of humus, content of rock fragments, temperature, kinds and thickness of human-altered materials, and mineralogical composition.
- A significant difference in any one of these can be the basis for recognizing a different series.
- Very rarely, however, do two soil series differ in just one of these characteristics.
- Most characteristics are related, and generally several change together.

- Some soils are outside the limits of any recognized soil series and have unique sets of properties.
- These are potential new series.
- When such a soil is first recognized, it is described and identified as a taxon of the lowest category in which it can be classified.
- A phase of that taxon can be used to identify a map unit.
- In some surveys, including virtually all detailed surveys, definitions need to be further refined.
- For these, the soil is proposed as a new series.
- The new series remains tentative until its properties can be described in detail, its extent determined, and any conflicts with established series resolved.
- If the tentative series remains through the correlation process, it is established as a new series at the time of final correlation.
- A taxonomic unit description includes the ranges in soil properties exhibited within the mapped areas for that taxonomic unit.
- The limits of these ranges are set for the taxonomic class, but generally the full range allowed by the taxonomic class is not exhibited in a survey area.

Taxa Above the Soil Series

- The first level above the series is the family.
- Components mapped to the family level match the classification of a series, but not the series criteria.
- The name of a representative series belonging to the component taxonomic classification is used as the component name (e.g., Ezbin family).
- The component name represents the range in characteristics for many series within the family classification.
- Use of family-level components is generally limited to soil survey orders 3 and 4.
- Components mapped to levels higher than the family use the classification as a reference term and may include the range in characteristics for many families within the referenced classification.
- An example is coarse-loamy Typic Cryaquolls.
- In this example, the higher taxa is the subgroup Typic Cryaquolls and it is modified by the family-level particle-size class term “coarse-loamy” to provide additional information.
- These components are used especially on small-scale maps in soil survey orders 3 through 5.

- During a survey, the taxonomic system is tested and retested many times.
- The results of these tests are reported at field reviews and the field correlation.
- Problems in mapping or identifying soils and inconsistencies between the system and observed properties of the soils are recorded in field review reports and correlation memoranda.
- After appraising these reports, supervisory soil scientists bring any inadequacies to the attention of the office responsible for keeping the system up to date.

Taxadjuncts

- Taxadjuncts are polypedons that have properties outside the range in characteristics of any recognized series and are outside higher category class limits by one or more differentiating characteristics of the series.
- A taxadjunct is given the name of an established series that is most similar in characteristics.
- These components classify differently taxonomically but have the same interpretations for use and management as the named series.
- Because the differences in properties between the named series and its taxadjunct are small and do not affect major interpretations, a new series is not established.
- The taxadjunct is treated as if it were a member of the named series, and its interpretations are similar to those for comparable phases of the series for which it is named.
- Differences from the established series are described.
- For example, a fine-silty map unit component differs slightly from an established fine-loamy series in only particle size, and no current soil series exist to accommodate the fine-silty classification.
- The fine-silty soil is correlated as a taxadjunct to the established fine-loamy series and a new series is not proposed.

SOIL MAPPING CONCEPTS (CONT'D)

Miscellaneous Areas

- Miscellaneous areas are land that has little or no identifiable soil and thus supports little or no vegetation without major reclamation.
- Examples of miscellaneous areas are shown in the table here.

Area	Description
Badland	Moderately steep to very steep barren land dissected by many intermittent drainage channels in soft geologic material. Ordinarily, it is not stony and occurs in semiarid and arid areas.
Beaches	Sandy, gravelly, or cobbly shores washed and rewashed by waves. The areas may be partly covered with water during high tides or storms.
Chutes	Elongated areas on steep mountain slopes that lack vegetation and have exposed bedrock, rock fragments, and woody debris. Avalanche or mass movement activity is evident.
Cinder land	Loose cinders and other scoriaceous magmatic ejecta. The water-holding capacity is very low, and trafficability is poor.
Dams	Artificial structures that are oriented across a watercourse or natural drainage area for the purpose of impounding or diverting water.
Dumps	Areas of smoothed or uneven accumulations or piles of waste rock and general refuse. "Dumps, mine" is an area of waste rock from mines, quarries, and smelters.
Dune land	Unstable sand in ridges and intervening troughs that shifts with the wind.
Glaciers	Large masses of ice formed by the compaction and recrystallization of snow. The ice front may be advancing or retreating. Areas may include incidental amounts of soil or rock.
Gullied land	Areas where erosion has cut a network of V-shaped or U-shaped channels deep enough to inhibit or prevent crossing.
Lava flows	Areas covered with lava. Most flows have sharp, jagged surfaces, crevices, and angular blocks characteristic of lava. Others are relatively smooth and have a ropy, glazed surface. A small amount of earthy material may occur in a few cracks and sheltered pockets.
Mined land	Areas that are significantly altered by mining activities. Soil material and rock have been moved into, out of, or within the areas designated. Because access to mined land may be limited by permissions or hazardous materials, identification of soil components can be difficult or impossible.

Table 2: Miscellaneous Areas Used as Map Unit Components.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

SOIL MAPPING CONCEPTS (CONT'D)

Area	Description
Oil-waste land	Areas where liquid oily wastes, principally saltwater and oil, have accumulated. They include slush pits and adjacent areas affected by the liquid wastes. The land is barren, although some of it can be reclaimed at high cost.
Pits	Open excavations from which soil and commonly underlying material have been removed, exposing either rock or other material. Examples are "Pits, mine," "Pits, gravel," and "Pits, quarry."
Playas	Barren flats in closed basins in arid regions. Many areas are subject to wind erosion and many are saline, sodic, or both. The water table may be near the surface at times.
Riverwash	Unstabilized sandy, silty, clayey, or gravelly sediment that is flooded, washed, and reworked frequently by rivers.
Rock outcrop	Exposures of bare bedrock other than lava flows and rock-lined pits. If needed, map units can be named according to the kind of rock, e.g., "Rock outcrop, chalk," "Rock outcrop, limestone," and "Rock outcrop, gypsum." If small, they can be identified by spot symbols on maps.
Rubbleland	Areas of cobbles, stones, and boulders commonly at the base of mountains or left on mountainsides by glaciation or periglacial processes.
Slickens	Accumulations of fine textured material from placer-mine and ore-mill operations. They may have undergone chemical extractions. They are typically confined in constructed basins.
Urban land	Land mostly covered by streets, parking lots, buildings, and other structures of urban areas.
Water	Streams, lakes, ponds, and estuaries that are covered with water, deep enough or moving, that growth of rooted vegetation is precluded. Many areas are covered with water throughout the year.

Table 2: Miscellaneous Areas Used as Map Unit Components.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The areas can be a result of active erosion, washing by water, unfavorable soil conditions, or human activities.
- Some miscellaneous areas can be made productive but only after major reclamation efforts.
- Map units are designed to accommodate miscellaneous areas, and most map units named for miscellaneous areas include areas of soil.
- If the amount of soil exceeds the standards for minor components defined for the survey, the map unit is named as a complex or association of miscellaneous area and soil.
- One must be careful in determining that an area is a miscellaneous area rather than a soil.
- For example, not all areas that are mined should be named "Mined land."
- If they are able to support vegetation and thus meet the definition of soil, they should be classified as soil.
- This is particularly important if it is possible to populate at least some major soil property data in the soil database and so provide meaningful interpretive information.
- The National Cooperative Soil Survey maintains an official list of miscellaneous areas and their definitions for use in the U.S. soil survey.

Phases

- Phase terms added to map unit component names convey important information about a map unit and differentiate it from other map units on the map unit legend.
- A property of a taxon that has too wide a range for the interpretations needed or some feature outside the soil itself that is significant for use are a basis for phasing map units.
- Phases commonly include only part of the range of features exhibited by a taxon within a soil map unit.
- Soil phases can be based on attributes, such as frost hazard, character of the deeper substratum, or physiographic position, that are not characteristics used to identify taxa but nevertheless affect use and management.
- Common phases are slope, surface texture, flooding and ponding, surface fragments, degree of erosion, and climate.
- Overlying water depth is used as a phase term for some subaqueous soils.
- Phases such as "filled," "graded," or "landscaped" are used for some map units consisting of soils that formed in human-altered or human-transported material.

- Phase terms are devised and used as needed to differentiate map units.
- The usefulness of each phase must be repeatedly tested and verified during a survey. Separate phases of a taxon must differ significantly in behavior.
- If no useful purpose is served by separating them in mapping, similar phases of different taxa may be combined and the combination described.
- The interpretations prepared during the course of a survey provide evidence of similarities and differences among map units.
- The justification for most phases rests on the behavior of the soils under various uses.
- At least one statement about soil behavior must be unique to each phase of a taxon, and the differences of soil properties must exceed normal errors of observation.

Classes

- Classes of soil properties are not necessarily used directly as phases.
- Defined class limits of properties are designed for a convenient description of soil, but they can also be used to define phases of soil map units in some cases.
- For example, a map unit may be named as a moderately saline phase to distinguish it from another map unit with the same name but whose soils have no significant salinity.
- However, property class terms are not useful for all soils.
- Distinctions significant for one kind of soil are not significant for every other kind.
- Any single property is significant only through its interactions with other properties.

Building a Map Unit Name

Step 4: Phase

Step 3: Family / Taxadjunct / Higher Taxa

Step 2: Soil Series

Step 1: Component

DIGITAL SOIL MAPPING

Principles and Concepts

- Digital soil mapping is the generation of geographically referenced soil databases based on quantitative relationships between spatially explicit environmental data and measurements made in the field and laboratory.
- The digital soil map is a raster composed of two-dimensional cells (pixels) organized into a grid in which each pixel has a specific geographic location and contains soil data.
- Digital soil maps illustrate the spatial distribution of soil classes or properties and can document the uncertainty of the soil prediction.
- Digital soil mapping can be used to create initial soil survey maps, refine or update existing soil surveys, generate specific soil interpretations, and assess risk.
- It can facilitate the rapid inventory, re-inventory, and project-based management of lands in a changing environment.

SCORPAN Model

- The scientific foundation of soil mapping is Hans Jenny's (1941) conceptual model that soils (S) on a landscape are a function of five environmental factors, namely climate (cl), organisms (o), relief (r), parent material (p), and time (t):

$$S = f(\text{cl, o, r, p, t})$$

- While this model, sometimes known as CLORPT, has been useful in conventional soil mapping, it is not quantitative nor spatially explicit.
- To represent soil and the related environmental factors in a spatial context and express these relationships quantitatively, McBratney et al. (2003) proposed the SCORPAN model, where soil (as either soil classes, S_c, or soil attributes, S_a) at a point in space and time is an empirical quantitative function of seven environmental covariates: soil (s), climate (c), organisms (o), relief (r), parent material (p), age (a), and spatial location (n):

$$S_{c,a} = f(\text{s, c, o, r, p, a, n})$$

- The important advances of the SCORPAN model for use in digital soil mapping are: (1) the recognition that the environmental factors are not necessarily independent of each other and are thus defined as environmental covariates, (2) the inclusion of soil as an environmental covariate, (3) the spatially explicit nature of the model, and (4) the quantitative nature of the functional relationships.
- In the SCORPAN model, soil, either as point observational data, existing soil maps, or remotely sensed spectral properties, can be used as input data.
- Environmental covariates are digital and spatially explicit data in a raster that is processed using a geographic information system (GIS).
- The SCORPAN model facilitates the quantification of the relationships between spatially explicit digital environmental covariates and the soil classes or attributes to be predicted in a spatial context.
- It also facilitates the estimation of error or uncertainty of the spatial prediction of soil classes or properties.

Digital vs. Conventional Soil Mapping

- The availability and accessibility of geographic information systems (GIS), global positioning systems (GPS), remotely sensed spectral data, topographic data derived from digital elevation models (DEMs), predictive or inference models, and software for data analysis have greatly advanced the science and art of soil survey.
- Conventional soil mapping now incorporates point observations in the field that are geo-referenced with GPS and digital elevation models visualized in a GIS.
- However, the important distinction between digital soil mapping and conventional soil mapping is that digital soil mapping uses quantitative inference models to generate predictions of soil classes or soil properties in a geographic database (raster).
- Models based on data mining, statistical analysis, and machine learning organize vast amounts of geospatial data into meaningful clusters for recognizing spatial patterns.

DIGITAL SOIL MAPPING (CONT'D)

- Various digital soil mapping tools, methodologies, and inference models have been developed and tested in the U.S. and abroad to facilitate the rapid visualization and quantification of landscape patterns at multiple spatial scales.
- A significant amount of the data used in digital soil mapping can be archived in a spatially explicit digital format in a GIS, so the expert knowledge used to predict soil distribution on the landscape is retained.
- Objective sampling plans can be implemented to statistically capture variability of the landscape, representing it by digital environmental covariates.
- Probably the most exciting aspect of digital soil mapping is the ability to generate spatially distributed information on soil classes and/or properties and the associated estimate of uncertainty (the probability that a particular soil type and/ or property occurs at a specific point on the Earth's surface).
- There is a great demand globally for spatially distributed soil information.
- This is evidenced by the launch of GlobalSoilMap, a project to make a digital soil map of the world using state-of-the-art technologies for soil mapping and predicting soil properties at 100-m resolution.

DIGITAL SOIL MAPPING (CONT'D)

- Maps that predict the spatial distribution of soil classes or properties are of interest in many countries because they inform soil use and management decisions.
- Digital soil mapping better captures observed spatial variability and reduces the need to aggregate soil types based on a set mapping scale.
- An important component of digital soil mapping is the method of analysis used to define the relationship between soil observations and environmental covariates.
- Many types of methods have been investigated, including expert systems, unsupervised classification, and machine learning or predictive modeling.

Discrete vs. Continuous Models

Discrete Models

- A map of soil classes, such as soil map units, is a type of discrete, or crisp, model.
- Discrete models represent thematic or categorical data in which the values represent a predefined class with a finite number of possibilities.
- These models are typically nominal, ordinal, or binary and therefore lack numerical meaning.
- When applied in a raster, each pixel value represents the class associated with the pixel (e.g., soil class A, soil class B, soil class C, etc.).
- Mathematical operations cannot be applied directly to discrete data because the values do not have true numerical meaning (e.g., soil class B is not twice as great as soil class A).

- Soil mapping has traditionally used the discrete model to represent distinct soil types and groups of soil types on the landscape.
- In a raster environment, discrete models simplify the display of modeled classes and align conceptually with the conventional soil survey approach.
- However, discrete soil class models present the assumption that soils are constant across a class.
- Classes can be defined either narrowly or broadly for any soil landscape unit, similarly to how the traditional map unit can be categorized as a consociation or complex.
- Narrowly defined classes are best for providing site-specific interpretations and are most suitable in situations where sufficient field observations (training data) are available to adequately define the classes.
- Broadly defined soil classes may help bridge the gap from conventional (polygon, vector) to digital (raster) soil mapping and are most suitable in situations where field observations (training data) are limited.

Continuous Models

- A map of soil properties is a type of continuous model.
- Continuous models represent data in which the values are measurements or calculations that have numerical meaning and represent a continuum.
- In a raster environment, each pixel value represents a real quantitative value (measured, calculated, or inferred) and can have various levels of precision (e.g., integer or floating point).
- Continuous models allow for any value over a continuous range, whereas discrete models have only a finite number of predefined outcomes.
- Continuous soil models are designed to handle the continuous nature of soil properties more realistically than discrete models.
- In theory, continuous models eliminate the disadvantages of predefined classes and distinct boundaries in soil mapping.
- In practice, the continuity depends upon the cell size and the precision used.
- Predictions of soil properties are typically represented with a continuous data model.

- The majority of the environmental covariates used in digital soil mapping are continuous data models.
- Terrain attributes derived from a digital elevation model (DEM), such as slope gradient, curvature, and area solar radiation, are continuous models.
- Spectral data, such as reflectance, derived from satellite or aircraft remote-sensing platforms are also continuous models.

TOOLS FOR PROXIMAL SOIL SENSING

Introduction

- Proximal soil sensing is a collection of technologies that employ a sensor close to, or in direct contact with, the soil.
- The sensor measures a soil property directly or indirectly.
- Viscarra Rossel et al. provide a description of proximal soil sensing, sensing technologies, and the soil properties these technologies can measure.

- Soil properties vary in space and over time.
- As a consequence, they are seldom adequately described at field and landscape scales by traditional soil survey tools.
- Traditional methods of soil sampling and analyses provide detailed information at specific locations.
- This information, however, is limited in number, volume, and spatial coverage.
- At field and landscape scales, the characterization of the spatial and temporal variations is prohibitively time-consuming, expensive, and impractical using traditional point-sampling methods alone.
- Remote sensing (e.g., satellite images and aerial photos) can provide excellent spatial coverage, but measurements are mostly indirect and typically limited to the top 5–6 cm of soil.
- In addition, resolution is generally too coarse to characterize the spatial variability of soil properties at intermediate field and landscape scales.
- Because of these limitations, proximal soil sensing is becoming increasingly popular as a way to fill in the data gap between high-resolution point data and the lower resolution remote-sensing data.

- Data from proximal soil sensing technologies can be used in soil surveys of order 1, 2, or 3.
- They can be used to show how one or more soil properties vary over a portion of the landscape, to help estimate the range in property values for a particular soil series or map unit component, to refine the boundaries of soil map unit delineations, and to identify the location and extent of contrasting soil components within soil map unit delineations.
- Some of the methods can be used to document soil properties at specific locations (point data) when describing soil profiles.

- The table here shows the general application of various proximal soil sensing methods to soil survey activities.

Method	Primary soil survey application		
	Map unit (spatial) data		Point data
	Order 1	Orders 2 & 3	
Ground-penetrating radar	X	X	
Electromagnetic induction	X	X	
Electrical resistivity	X	X	
Magnetometry	X		
Magnetic susceptibility	X		
Portable X-ray fluorescence			X
Time domain reflectometry			X
Optical reflectance	X	X	X
Gamma-ray spectroscopy	X	X	X
Mechanical interactions	X		X
Ion-selective potentiometry	X		X
Seismic	X	X	

Table 3: Methods of Proximal Soil Sensing and Their Primary Application in Soil Survey.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- This chapter is divided into two major parts.
- The first part discusses three geophysical methods: ground-penetrating radar, electromagnetic induction, and electrical resistivity.
- These methods have been used widely in the United States by the National Cooperative Soil Survey (NCSS) to document soil property variability in specific landscape settings and to identify the locations of contrasting soil components within map units.
- The second part discusses nine other proximal soil sensing methods that, to date, have had limited application by the NCSS.
- These technologies are included in this chapter because they have potential for expanded future use, especially in high-intensity surveys (i.e., order 1) and in recording properties when describing soil profiles.

SOIL SURVEY DATA COLLECTION, MANAGEMENT, AND DISSEMINATION

Introduction

- During the course of a soil survey, a large amount of data, of various types and in various formats, is commonly collected or developed.
- These data include, but are not limited to, field notes, soil profile and landscape descriptions, drawings, laboratory data, photographs, descriptions of soil map units and map unit components, and, of course, the basic soil map.
- Before a soil survey project begins, a decision must to be made as to what type of system is going to be used to collect, store, manage, and disseminate the information to be gathered and/or developed.
- For example, the data and information may be maintained and distributed as hard copy, in electronic form, or by some combination of the two.
- Deciding how to manage these data can be a daunting task, but it is a very important one.

- First, a few questions need to be answered:
  - What is the purpose of the soil survey?
  - For whom is the information intended?
  - Is the information to be publicly available to anyone that wants it, or is it to be kept within the organization that is conducting the soil survey?
  - What types of products or output will need to be generated at the end of the project?
  - In what format are the products to be made available—electronic or hard copy, or both?
  - Do the end users of the information only need the summarized soil survey data, or will they also need access to the various pieces of point data collected at individual points on the landscape?
  - Will the data and/or generated information be delivered via the Internet?
  - What resources and expertise are available for maintaining and disseminating the data?

- The answers to these and other questions will help determine what sort of system is needed.
- To begin this discussion, a distinction needs to be made between "soil data" and a "soil information system."
- Soil data refers to the actual data that are collected or generated during the course of a soil survey.
- A soil information system includes not only the data, but also the various methods and/or systems used to collect, store, and manage the data and resulting interpretations and information and to disseminate them to end users.

SOIL SURVEY DATA COLLECTION, MANAGEMENT, AND DISSEMINATION (CONT'D)

- A database can be defined as "a collection of information or data that is organized so that it can easily be accessed, managed, and updated."
- In its crudest of forms, a database can be a collection of paper copies maintained in a file cabinet or box.
- With a crude database, the ease of accessing, managing, and updating such data is limited. In electronic format, a database is generally a series of related data tables maintained within some database management software (DBMS) on a computer.
- The data can be both tabular data (which describes the characteristics and proportions of soils in the soil survey area) and spatial data (which contains the locations of soil map unit boundaries and site locations where specific soil samples and soil profile descriptions were collected and other field observations were made, as well as other thematic data layers).
- If the decision is made to collect, store, and manage soil survey data in hard-copy format, the options for product delivery are minimal.
- If the decision is made to use an electronic format for data collection, storage, and management, then some type of electronic database(s) will be needed.
- There are numerous options for dissemination of data maintained in electronic format.

The SCORPAN Model: Mapping Soil With Data

INTERPRETATIONS: THE IMPACT OF SOIL PROPERTIES ON LAND USE

Introduction

- 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).
- The baseline data and criteria are revised and refined continuously.
- The interpretive information is kept up to date by yearly refreshes.
- 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.
- 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.

- 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 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.

ASSESSING DYNAMIC SOIL PROPERTIES AND SOIL CHANGE

- Dynamic soil properties (DSPs) are properties that change with land use, management, and disturbance over the human time scale (decades to centuries).
- In contrast, inherent soil properties (e.g., soil texture) change little, if at all, with changes in land use and management.
- The term "dynamic soil properties" was used by Tugel et al. (2005) to describe soil properties that can be documented as a part of soil survey activities.
- The procedures for measuring and recording DSPs were later outlined in the Soil Change Guide.
- The term DSPs has gained common usage among soil scientists when referring to properties that can be changed intentionally or inadvertently through human land use and management, either directly (as through tillage) or indirectly (as through causing acid rain).
- While many soil properties (such as moisture, temperature, and respiration) are dynamic on daily, or smaller, time scales, information about them is not included in current soil survey products.
- The DSPs addressed by soil survey include properties that reflect soil functions and can serve as indicators of soil quality (or health) or indicators of ecosystem services.
- Dynamic soil properties are more pronounced at or near the soil surface and can be used to evaluate changes and departure from a benchmark or set of reference soil properties.
- Conceptually, this allows DSPs to be correlated with map unit components used in traditional soil survey.

Importance of DSPs

- Many land and water conservation programs in the U.S. depend upon management of dynamic soil properties.
- Proven conservation practices are used to maintain the soil's productivity, health, and long-term sustainability.
- Conservation planning relies on the knowledge of the current state of the soil resource and what is achievable through conservation practices.
- DSP assessments provide a range of potential soil property values that define what is achievable.
- DSP data is used to document, explain, and predict the effects of land use and management on soil and ecosystem functions.
- It is collected in a way that documents both soil properties and classifications along with information on land use and management, then stored in an organized database.
- Information about past and current land use and management can be used to explain current soil properties.
- It can also be used, through inference or modeling, to predict future soil properties and functions.

ASSESSING DYNAMIC SOIL PROPERTIES AND SOIL CHANGE (CONT'D)

- Soil function is a way of describing the role of soil in the environment and has been used to define the concept of soil quality and soil health.
- Essential soil functions include nutrient cycling, water storage and release, biodiversity and habitat, filtering and buffering, and physical stability and support.
- Soil stores and moderates the cycling of nutrients and other elements.
- It regulates the drainage, flow, and storage of water and solutes (N, P, and pesticides).
- It supports biodiversity and habitat and promotes the growth of plants, animals, and microorganisms.
- It serves as a filter and buffer for toxic compounds and excessive nutrients and protects the quality of water, air, and other resources.
- It provides physical stability and support, allowing the passage of air and water through its porous structure, serving as a medium for plant roots, and providing an anchoring support for human structures.
- While many soil functions are complex and difficult to measure, some key soil properties can be considered indicators of specific soil functions.
- These indicator properties are the focus of soil survey DSP collection.

ASSESSING DYNAMIC SOIL PROPERTIES AND SOIL CHANGE (CONT'D)

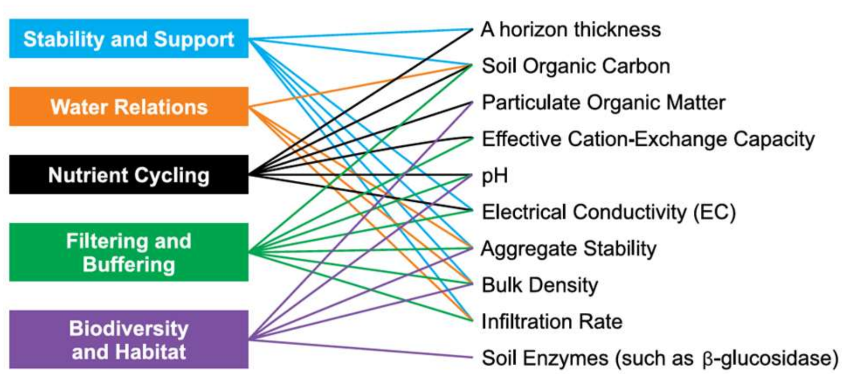


Figure 4: Relationship between soil functions and some dynamic soil properties.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The framework of soil survey offers an opportunity to collect and disseminate information about how DSPs (and the soil functions they support) change with vegetation, land use, and management across space and time.
- DSP data, such as bulk density values under various grazing schemes, enhances soil survey information by providing soil property potentials under various land use and management scenarios.
- By combining DSP information with spatially linked soil survey information (e.g., soil map unit components), soil survey provides spatial context (maps, areas affected, etc.) to land users, researchers, and decision makers regarding the expected impacts of changes in land use and management.
- Soil property and function potentials along with collated DSP datasets provide greater specificity of soil interpretations, target values for soil quality and health assessment, guidelines for indicator monitoring, and data for calibration and validation of resource modeling.

How to Collect DSPs for Soil Survey

- DSP projects organize data collection and analysis around specific soils, soil groups, and land management systems.
- The scope, specificity, and replication of each DSP project depend on the goals for that project.
- The overarching goal of data collection in a DSP project is to document the range and central tendencies of DSPs for a given set of soils and land management conditions (such as reference and degraded states or best and typical crop management practices).
- The project should provide information about typical and potential DSP values for soil map unit components and ecological site descriptions.
- With adequate replication, these projects can be conducted as soil change comparison studies in which alternate conditions are used in a space-for-time substitution framework to make inferences about how soils have changed over time under specific management scenarios.
- In this approach, all places with the same soil (or group of soils) are assumed to have had the same properties at time zero (i.e., before the specific land management practices were applied).
- The assumption is that any differences observed are due to management and not inherent spatial variability.
- Multi-scale replication limits the influence of any spatial variability observed when making conclusions about soil change.
- DSP projects may also seek to document baseline conditions (such as ecological site reference conditions), best and worst case management scenarios, or alternate conditions of interest.

- DSP information for soil survey must be collected, organized, and used in a way consistent with the soil survey protocols and standards used for inherent properties.
- Data collection for soil survey can be characterized in two ways: dispersed and project based.
- Dispersed DSP data collection refers to the integration of DSP data collection with other routine soil survey project operations.
- As a result, DSP and land management information is documented throughout a wide range of soil survey activities.
- Efforts are not concentrated on any single land use or management system but are dispersed throughout all situations in which the soil occurs.
- In contrast, project-based DSP data collection is designed to intensively evaluate specific land management conditions.
- The most robust DSP data collection includes both approaches and so provides both spatial and land management representation (from dispersed efforts) and detailed comparisons of management scenarios in specific soil landscapes (from project-based efforts).
- DSP data can be used to evaluate the soil data representativeness (across land use and management systems) and assess spatial variability.

- The goal of dispersed DSP collection is to build on other soil survey activities and increase the general knowledge of DSPs across all soils and land management conditions.
- In this context, “land management condition” is a general term that captures a range of possible situations, including ecological states and vegetative communities, land use, and specific crop and pasture management systems.
- Advantages of dispersed data collection are that it requires little additional resources and provides information on a wide range of soils and conditions to managers, modelers, and policy makers.
- Analysis of this data can be used to group soils and land management conditions for further evaluation through DSP projects.
- It can also be used to validate summaries and predictions made from completed projects.

Dispersed DSP Data Collection

- At the location of each observation, it is important to record, at minimum, information on the site, pedon, and land management condition and practice.
- This data includes any known information about general land use, ecological state, type and amount of vegetation, and cropping systems; e.g., tillage, crop rotation, and pesticide or fertilizer applications.
- Additional soil properties may be assessed on samples near the soil surface, e.g., enzyme activity and aggregate stability.
- Procedures and terminology for recording this information should be standardized.
- Robust soil information systems include data elements related to indicators of soil function and land use and management condition.

Project-Based DSP Data Collection

- Project-based DSP data collection requires thorough planning and typically is the most intense type of data collection.
- The type of project determines how data collection will proceed.
- Projects can be planned to meet multiple project goals.
- Site and pedon replication should be planned to meet all project goals on the smallest unit of soil and land management condition targeted.
- It is helpful if all stakeholders of the project (those who will collect and use the information) can meet to determine the DSP project goal(s) and the target soil(s) and condition(s).

Determining DSP Project Goals

- Project goals vary depending on the kind of project.
- Three kinds of projects are described below and examples are given for each.
- DSP range study.
  - The goal of this kind of project is to evaluate the entire range of values for DSP properties and so provide soil component information regardless of land management or use.
  - A single soil or group of closely related soils is selected.
  - Land management conditions are not closely controlled (i.e., not specifically targeted in sampling) but should be well documented.
  - This type of project requires the least amount of replication.
  - Therefore, while results apply across the area of interest (soil group), the data typically is not sufficient for statistical comparisons between land management conditions.
  - Example:
    - The soil of interest occurs in an area used for rangeland, pastureland, and cropland.
    - A DSP range study would sample a range of management systems across all three land uses, including those that are expected to have the smallest and highest DSP values.
  - Example:
    - A Midwestern U.S. State wanted to know typical values of DSPs across a region.
    - For 2 years, all projects included sampling for DSPs as well as documentation of land use and management information for at least one pedon.
    - The data provided a general idea of relative conditions across the region.
    - There were no pairs or replications that could be used to make statistical comparisons because this was not the purpose of the project.

- DSP baseline or reference study.
  - The goal of this kind of project is to establish baseline or reference DSP levels for a limited number of reference or land management conditions.
  - The baselines can be used to interpret onsite assessments of soil health as a starting point for modeling or monitoring projects.
  - Results apply across an area (a soil or group of soils) and the land management conditions of interest.
  - Extrapolation beyond these conditions requires expert knowledge and depends on the extent and representativeness of the selected land management conditions.
  - This type of project requires an intermediate level of replication across target soils and land management conditions.
  - Example:
    - Kirkland soil has particularly high soil function in a grazed native prairie with occasional fire (this is the reference condition of its ecological site).
    - A reference DSP study would target this condition, and future evaluations and assessments could be compared to the baseline, or reference, levels.

- DSP soil change study.
  - The goal of this kind of project is to assess soil change using the technique of space-for-time substitution.
  - Instead of evaluating the effects of a management system in one location over an extended period of time, this technique compares two different locations that have had different management systems over the same period of time.
  - It assumes that soil properties at the two locations were the same before the management system was applied.
  - Typically, this type of study also serves as a baseline or reference study for a soil or soil group.
  - In addition, soil change studies require the careful selection of land use and management conditions that represent a reference state and an alternative state.
  - Robust multi-scale replication is required to make statistical conclusions about the soil change caused by land management.
  - Pickett (1989) gives the theoretical background of space-for-time substitution, and Tugel et al. (2008) discuss the implementation of this technique in soil survey.
  - Example:
    - A group of soil scientists in Michigan wanted to investigate dynamic soil properties under two types of wetland restoration.
    - They determined that they needed to conduct a DSP soil change study that included a baseline or reference state (in this case an undisturbed reference wetland) and alternative land use conditions with a multi-scale sampling scheme to capture variability within individual wetlands and across the project area.

Determining the Target Soils and Conditions

- Studies can be designed to target soils, ecological sites, or land management conditions.
- Soils or ecological sites.
  - Targeting a specific soil(s) or ecological site(s) will determine the extent of the DSP project, where samples and observations might be collected, and where the results should be applied.
  - Approaches for targeting soils include single soil unit, soil system, and ecological site.
  - Single soil unit.
    - The smallest unit of the study interest is a map unit component represented by a soil series.
    - Benchmark soils that are representative of other soils in the area and/or represent important resource concerns and ecological processes are selected.
    - Example:
      - In an area of Michigan, the organic wetland soil Houghton is the most common soil in restored wetlands.
      - The Adrian soil is very similar taxonomically and occurs in the same landscape positions.
      - Both soils were therefore considered target soils for sampling and comparisons.

- Soil system.
  - A study of a soil system segments the landscape and evaluates appropriate hierarchies in a soil system or catena.
  - Soil components that represent similar portions of the landscape and/or respond similarly to land use and management conditions can be combined for sampling purposes.
  - Example:
    - In Renville County, Minnesota, the soil landscape was segmented into three parts based on topography, hydrology, and the reflected taxonomic classes.
    - One individual soil component was chosen to represent each of the three groups.
- Ecological site.
  - The study of an ecological site groups soil components into units that are meaningful for ecological processes and land management.

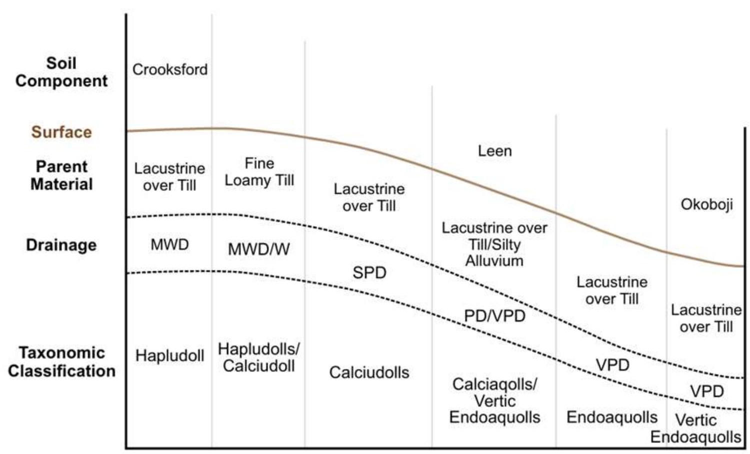


Figure 5: A generalized cross-section of a soil landscape near Olivia, Minnesota.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Land management conditions (for reference, baseline, or comparison).
  - The land management conditions are selected according to the soil and type of project and can include general land cover classes (e.g., rangeland or cropland) or specific management systems (e.g., 3-year burn cycle with moderate grazing or no-till corn with cover crops).
  - For each project, a similar level of variability within the specified land management conditions needs to be maintained.
  - For example, comparing forested conditions within a reference state to a specific cropland management system may be more appropriate than comparing all forested conditions under a specific management system.
  - When trying to document soil change, the chosen conceptual model should partition soil change into discrete frames of reference, conditions that can be put into separate categories and that can be sampled at separate physical locations (using the space-for-time technique).
  - The Soil Change Guide recommends using common models of soil disturbance and erosion, such as STIR, RUSLE2, and SCI.
  - Wills et al. outlined a potential framework for grouping management systems by primary production groups and types and amount of disturbance.

- Example:
  - A DSP planning team in Michigan determined that in order to meet their goals a baseline reference wetland needed to be sampled and documented in addition to two general types of wetland restoration and typical agricultural production.
- Example:
  - In Dodge County, Nebraska, two agricultural management systems were chosen as the target conditions.
  - The reference condition was the highest functioning agricultural land use.

Data Collection Plan

- A written plan serves as both a tool for organizing work and a record of how the project was conducted for future data use.

Formalizing Project Objectives

- Planning decisions are recorded.
- The project goals and the geographic and conditional constraints are clearly defined.
- This information includes identification of which soils and land management conditions will or will not be acceptable for sampling.

Gathering Existing Data

- Relevant data in soil survey and laboratory databases can be located by querying for the target soil taxa or spatial joins or by other means.
- Relevant information may also be located in journal publications, extension publications, or graduate student work through nearby universities, colleges, or other groups.

Additional Data Collection

- All DSP projects need to include a protocol for data collection across multiple scales.
- Sites (independent locations commonly sampled as plots) should capture the full range of soils and land management conditions of interest.
- Within each site, a minimum of three pedons should be located in a standard layout or in a random fashion.
- Methods, field forms, and equipment for field data collection are discussed in appendix 3 of the Soil Change Guide.
- All information should be provided as general metadata about how the project was designed and executed.

Determining Sources, Types, and Amount of Variability

- Expert knowledge of the system and existing data are used to identify sources of variability.
- Tools such as the Multi-Scale Sampling Requirement Evaluation Tool can be used, or estimates can be made for the number of sites (independent location) and pedons per site needed to meet project objectives.

Designing a Sampling Scheme

- The best arrangement of pedons within sites can be determined using the information about expected variability.
- The sampling scheme should include multiple sites or locations across the spatial extent of the study.
- The design should not under- or over-represent landscapes (e.g., hummocks or depressions) or microfeatures (e.g., trails or tree-throw) within a site.

- The figure here shows a sampling scheme.

Figure 6: Documentation from the Georgia Longleaf Pine Dynamic Soil Property project.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Locating Sites for Data Collection

- Field sites should represent both the central concept and the typical range of properties for the target soil and land management conditions.
- Care is needed to avoid bias in location selection.
- GIS techniques, such as conditioned Latin hypercube sampling, or other statistical sampling techniques can be used.
- Alternate locations should be chosen in case a site cannot be accessed or must be rejected.
- Brungard and Johanson describe a rigorous plan for substitution.
- Developing data collection and sampling plan.
    - The protocols and procedures for DSP project sampling need to be planned.
    - The data elements and terminology used must be compatible with the soil system.
    - The top image in the figure 6 here shows how sites can be distributed across a region.

- The figure here shows pedon distribution within a paired site in Dodge County, Nebraska.
- In this project, sites were located as pairs (with both target land management conditions present) to limit soil variability and improve condition comparisons.

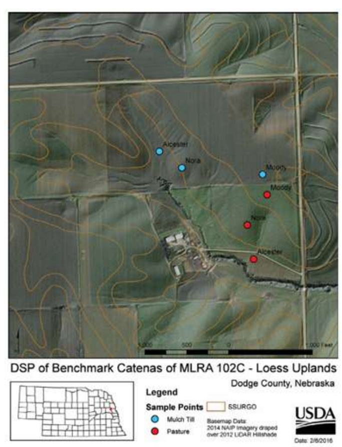


Figure 7: Example of pedon placement for a paired site in Dodge County, Nebraska.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Guidelines for accepting or rejecting a site for sampling.
  - For most soil survey applications, soils and conditions should be verified in the field to ensure that sampling will meet project objectives.
  - Guidelines should outline the ranges of soils, features, and land management conditions that are acceptable for inclusion in the project.
- List of data elements for site information.
  - Management and vegetation data are typically collected at the site scale.
  - All data elements to be measured or recorded at each site (location or plot) should be identified.
  - They may include vegetative cover, residue, site index, or other metrics of vegetation or management.
  - Common collection schemes for ecological site data in the project area can be used as a starting point.

  - The table here is an example of elements that might be collected at each site, location, or plot.

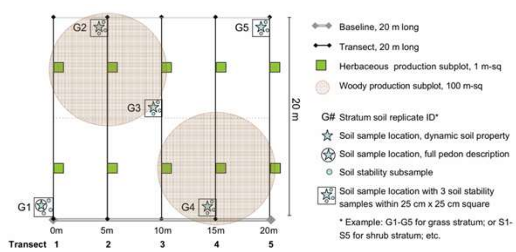
Type of data	Property/measurement
Management information	Crop rotation
	Tillage system
	General description
	Tillage operations (frequency and timing)
	Applications and other operations and treatments
	Grazing management
	Forestry management
Vegetation information (as appropriate)	Plant biomass or production
	Composition
	Understory
	Overstory
	Line-point intercept
	Canopy and basal gap
	Site index
Forest floor (when present in any part of study)	Woody debris
	Visual disturbance classes*
	Soil surface displacement, compaction, litter thickness, crust cover, etc.
Surface properties	Residue cover/bare soil
	Pedoderm and pattern class+

* Page-Dumroese et al., 2012
\+ Burkett et al., 2011

Table 4: DSP Project Data Elements Collected at Site (Across Plot) Scales.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Instructions for locating individual pedons and measurements.
  - A clear plan is needed to explain how pedons will be located within each site as well as where and how any associated surface properties will be measured.
  - It may include a standard plot layout, randomly positioned pedons within a plot area, or transects with pedons positioned at regular intervals along a catena contour.
  - A plan for measuring infiltration, hydraulic conductivity, and surface features (such as residue, pattern class, and soil crust) before pedons are disturbed improves data integrity.



Instructions: The baseline should be positioned obliquely to the slope and 5 transects should be positioned at approximately 90° from the baseline parallel to one another. The individual placing the flags will fill out the "Sample Locations and ID" portion of the "Plot Master" field form while identifying and flagging the soil sample locations. The flags will be pre-labeled with the Stratum-soil replicate ID (e.g., G1-G5). At each soil sample location, stability samples, penetrometer readings, bulk density samples, and soil samples for laboratory analysis will be collected. Line-point intercept and GAP will be completed along each transect. Place herbaceous subplots at meter marks 5 and 15 on each transect. Woody subplots are centered at transect 2, meter mark 15 and transect 4, meter mark 5. Complete 1 Pedoderm and Pattern Classes form for each plot (Tugel et al., 2008).

Figure 8: Example of detailed plot sampling instructions for a rangeland DSP project in Utah. Because the project involved both soil scientists and range scientists, a highly detailed plan was developed for sampling.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Instructions for pedon sampling and description.
  - Descriptions of pedons to a predetermined depth should follow standard procedures.
  - It is suggested that one pedon per site be observed, one pedon per condition be sampled to a depth necessary for soil series confirmation, and detailed high-quality information, such as bulk density and water retention analysis, be collected for those pedons.

Type of data	Property/measurement
Surface properties	Aggregate or soil stability
	Infiltration
	Single ring
	Double ring
	Crust description (when present)
	Pedoderm and pattern class
	Relevant microtopography
	Soil surface temperature
	Cover/bare soil
Pedon properties	Pedon description
	Horizon depths, colors, textures, fragment estimates
Pedon properties	Agronomic feature (furrow, wheel-track, etc. at pedon location)
	Soil horizon/depth increment
	Temperature
	Cover/bare soil
	Saturated hydraulic conductivity

Table 5: DSP Project Data Elements Collected at Pedons; Multiple Locations per Site/Plot.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Instructions for sample collection.
  - Collecting a sample from a predetermined depth (e.g., 0–5 cm) near the surface helps in making comparisons between conditions.
  - The kind of near surface horizon of the sample should be noted.
  - This sample can be treated as a subsample of the first horizon or described as a separate horizon.
  - All other samples should be collected by genetic horizon to capture the most variability within the profile and allow comparisons between horizons.
  - Because many DSPs are sensitive to disturbance, walking or using heavy equipment on sampling areas should be avoided.
  - A plan for labeling samples is needed to keep track of soil, condition, site, and pedon replication as well as information on horizons and layers.

- Instructions for sample handling.
  - Many of the properties measured in DSP studies are the same as those measured in standard soil survey procedures.
  - The emphasis is on targeting, tracking, and replicating certain conditions.
  - However, some measures are of particular interest for DSP sampling, such as bulk density, aggregate stability, and soil biology measures (e.g., enzyme activity).
  - The samples should be handled carefully and not exposed to crushing or warming.
  - Samples should be air dried as soon as possible if they are to be shipped and/or stored for more than 24 hours.

- Desired minimal dataset for laboratory samples.
  - The dataset should have information on standard inherent properties to allow for correlation and comparisons between soils and sites.
  - It may include standard pedon description information (such as horizon thickness, texture, and coarse fragments) and laboratory data (such as particle-size determination).
  - At minimum, the DSP dataset should include carbon (organic and inorganic), pH, EC, bulk density, aggregate stability, biological enzymes (β-glucosidase is recommended), particulate organic matter, and nutrients (N, P, K, etc., as appropriate).

  - The table here provides a potential list of properties to measure.
  - The Kellogg Soil Survey Laboratory currently analyzes standard interpretive and dynamic properties.

Type	Property/measurement
Standard interpretive	Standard laboratory characterization
	Particle-size determination
	Other properties *in lieu* of particle size
	Minerology (clay or other as appropriate)
	CEC
Standard dynamic	Organic carbon
	Derived from total and inorganic carbon
	Inorganic carbon
	Derived from calcium carbonate equivalent
	pH
	EC
	Bulk density
	Aggregate stability
	Water stable aggregates
	Total N
	P (Mehlich or other as appropriate)
	Water retention
	Extractable bases
	Extractable acidity
	ECEC
	Permanganate extractable carbon (POX-C or Active C)
	Soil enzymes
	β-glucosidase
	Particulate organic matter (POM)
Supplemental as needed and available	SAR
	Plant available P
	Dry sieve aggregates
	Potentially mineralizable N
Field lab	pH
	Active C (kit for permanganate extractable C)
	Aggregate stability
	Advanced soil structure and pore analysis
	CO_2 burst and respiration tests

Table 6: Measurements of Dynamic Soil Properties on Individual Samples.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Analyzing Dynamic Soil Property Data

- DSP data can be used for many purposes, some directly related to soil survey and many others that are indirectly related.
- The first and most long-lasting outcome of a DSP project is the collection and documentation of soil and vegetation data under various land use and management scenarios.
- This is an immediate product that can serve as input for many other products, such as conservation effects modeling and general geospatial analysis.
- Initial steps for DSP data analysis are the same as those for any aggregation of soil survey data.
- The data compilation is complicated by replication across sites and pedons.
- Good recordkeeping and labeling throughout the process help ensure reliable results.
- To allow for improvement over time, all data aggregation should be documented through written records, program scripts, and public databases.
- The following outline describes several important steps and considerations in analyzing DSP data.

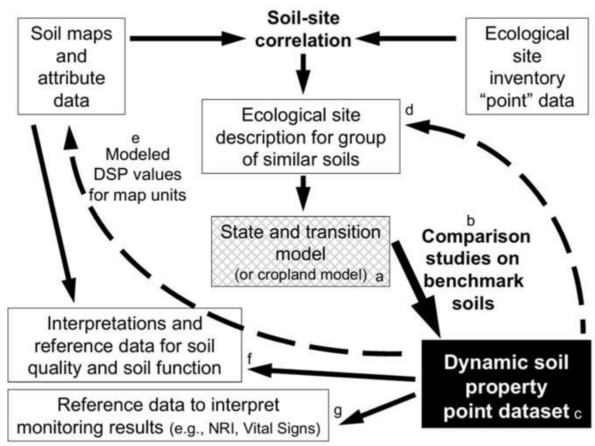


Figure 9: Dynamic soil property data in relation to ecological sites, soil interpretations, and monitoring data.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

DSP Data Handling

- 1. Maintain the project's data collection plan.
  - The data collection plan serves as the metadata for the project and will explain to future data users how and why the data was collected.
- 2. Enter and check data for errors.
  - Enter data into required programs and databases and examine it for errors.
  - This data includes information about the sites, pedons, samples collected, and land management systems.
  - Some information (such as infiltration rate) may be collected in the field and recorded later in a database or other file structure.
- 3. Compile or link data across common scales.
  - Link and label DSP data, as appropriate, to include site and observation information (e.g., vegetation and individual pedons from the same site are labeled with the same plot ID).
  - A robust database should allow for the association of data elements across conditions and locations.

- 4. Generalize horizons and other units of measure.
  - Data collected by samples that are individually labeled, such as by genetic horizon, must be grouped into common units so that properties can be analyzed and compared.
  - Add other data elements (such as comparable layer) that group all possible horizons in the project.
  - Keep scripts and rules as part of the project metadata and documentation.
- 5. Aggregate individual observations and measurements.
  - From the smallest individual data element (sample values) to the broadest level of interest (soil and land use or management system), select meaningful comparisons between conditions.
  - Aggregate horizons, pedons, and sites to make comparisons.
    - a. Create separate data elements for surface samples (0–5 cm) and comparable layers, such as all A horizons or all B horizons or other combinations outlined in the Soil Change Guide.
    - b. Use weighted averages by depth to combine horizons into pedon values.
    - c. Compute statistical measures for plots or sites.
    - d. Compute statistical measures for land use or management.

- 6. Analyze data.
  - a. Perform data evaluation and graphical comparisons.
    - Preliminary data is evaluated to gauge general trends, identify errors, and locate any outliers.
    - Graphs should include box plots by comparable layers, pedons, and sites and depth functions within pedons.

- The figure here shows a summary of two surface layer DSPs for two separate DSP projects.
- Data visualization can be used to explore, examine, and share general conclusions about the project.

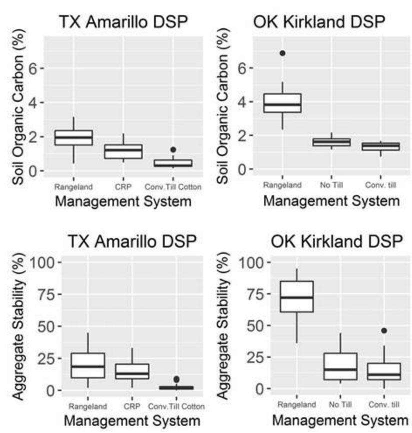


Figure 10: Dynamic soil properties of 0–2 cm samples for two DSP projects (Amarillo and Kirkland soils) for: a) soil organic carbon (%) measured as total carbon and b) water stable aggregates (%).
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- b. Calculate descriptive statistics across soil groups.
  - Initial summary statistics include central tendencies (mean, median, and mode) as well as measure of dispersion and variability (range, standard deviation, etc.).
- c. Calculate descriptive statistics for individual land management conditions (as appropriate).
  - Calculate measures of central tendencies, dispersion, and variability.
  - Use site averages or a mixed model to accurately reflect any autocorrelation between observations taken at the same site.
- d. Conduct statistical comparison and ascertain meaningful differences. Evaluate statistical differences between land management conditions.
  - i. Use T and F tests for differences.
    - Mixed models optimize use of fixed (condition) and random (plot replication) factors.
  - ii. Examine literature to determine if described differences are meaningful to soil function.
  - iii. Evaluate sampling sufficiency (e.g., were enough samples collected to detect a difference if one exists?).
    - If properties are more variable than originally anticipated, the sampling design may not have the power to detect anything other than a very large difference.
    - Additional sites can be chosen and samples collected so that meaningful statistical comparisons can be made to detect smaller (but important) differences in DSP values.

- 7. Make inferences about soil variability, land management conditions, and soil change.
  - A final report should summarize the project goals, the target soils and land management conditions, the data collection process, and the methods of data aggregation and analysis.
  - Final conclusions should include the most specific level of evaluation and the expected area of inference (i.e., other areas where the results might apply).
  - This report serves to document the process and support any conclusions.
- 8. Populate soil survey databases (such as information for soil map unit components) as appropriate.
  - Depending on the nature of the project, report results for the entire extent of the soil (or soil group) or report results as being limited to certain conditions.

- Care should be taken when incorporating DSP project data into standard data aggregation.
- Consider the distribution and representativeness of data when populating general component information, such as representative values (RV).
- If differing management conditions have statistically different DSPs, compare the distribution of the conditions assessed to the number of pedons available for aggregating.
- You may need to aggregate by land management condition and then weight the conditions by spatial prevalence to arrive at an overall value.

Summary of DSPs in Soil Survey

- Dynamic soil properties enhance soil survey by providing information about soil properties that change with land use and management.
- Information about DSPs improves the ability to document, explain, and predict the effects of land use and management on soil and ecosystem function.
- DSP data can be collected as general information or as projects designed to detect statistical differences between management and land use types.
- In both approaches, DSPs are collected in a way that documents both soil properties and classifications and land use and management information.
- Careful planning, sampling, and analysis ensure that DSP data enhances soil survey projects and allows for additional use of soil information.

SUBAQUEOUS SOIL SURVEY

Introduction

- Subaqueous soils differ from subaerial, or terrestrial, soils by having perennial water on the soil surface.
- These soils occur in shallow freshwater and marine environments, such as ponds, lakes, and the subtidal areas of estuaries and tidal embayments.
- The Soil Survey Staff defines “shallow” as approximately 2.5 m.
- At depths greater than 2.5 m, sunlight is typically attenuated and submerged aquatic vegetation (SAV) is typically absent.
- In especially clear waters, however, this depth may be much greater.
- Thus, for interpretive purposes, mapping is typically done to depths of 5 meters of water.
- Areas with extreme tidal ranges are also included as subaqueous soils even though they may be exposed for an hour or two during a neap tide or similar event.
- Subaqueous soils occur on a range of subtidal and limnic landforms, such as flood-tidal deltas, washover fans, and lake beds.
- These soils are currently classified in the Histosol and Entisol orders of Soil Taxonomy.

Occurrence

- Subaqueous soils occur worldwide, except in the driest inland areas where water does not pond permanently to form lakes or ponds.
- In coastal areas, these may be the most extensive soils on the landscape.
- For example, Rhode Island has approximately 700,000 acres of subaerial soils.
- If the area of subaqueous environments having water depths of less than 5 m are included, the total area of soils would almost double.

Importance

- The world's population centers are in coastal areas. In the United States, coastal watershed counties make up less than 10 percent of the land area, but more than 50 percent of the population lives in these counties.
- If the cities and towns within a short distance of the Great Lakes were included, that number would be significantly larger.
- Coastal and inland waters are used for transportation, recreation, farming, and other livelihoods.
- From an ecological perspective, shallow and inland waters are the nursery grounds for most of the animals that inhabit these ecosystems.
- The subaqueous soils in these shallow habitats provide the foundation and structure of the ecosystem.
- The many anthropogenic activities in the shallow water habitats disrupt, disturb, and may even destroy these habitats.
- Therefore, understanding the distribution and characteristics of the subaqueous soils is critical to properly managing and using these habitats so that these ecosystems properly function and continue to be healthy and vibrant.
- The use and management of subaqueous soils in shallow water ecosystems may include dredging, dredge placement, restoration of submerged aquatic vegetation, identification of areas for shellfish aquaculture, restoration of wild stocks of shellfish, and identification of areas for docks and moorings.

Sampling, Description, Characterization, and Classification

- The subaqueous soil environment presents unique challenges for observing soil profiles, collecting samples, and describing soil properties.
- This section provides information specific to subaqueous soils.
- The Field Book for Describing and Sampling Soils has a section that provides important information specific to mapping, describing, and sampling subaqueous soils.

Sampling

- Subaqueous soils can be sampled by several traditional soil approaches, but marine science approaches are best.
- For cursory descriptions and sampling, a standard bucket auger can be used.
- In order to sample from the exact location with depth, some soil mappers use a piece of PVC pipe with an inside diameter a little larger than the teeth on the bucket auger.
- The auger is placed into the pipe, and the sample is collected in the typical fashion.
- While the bucket is being removed, the PVC pipe is pushed deeper into the soil.
- The sample is retrieved and placed in a tray (typically a meter-long piece of vinyl gutter).
- The auger bucket is pushed down the pipe again, the spoil from pushing the PVC pipe down is removed, and then the next depth is sampled.
- This procedure is effective for sampling the upper 75 cm of the soil.
- Below this depth, however, collecting samples with a bucket auger becomes very difficult.

- In shallow water where soils are non-fluid, sampling with a bucket auger can be done while wading.
- A small light raft (typically made from floating dock material of Styrofoam) works well in holding the sample tray.
- A small anchor (e.g., a brick with holes) is used to keep the raft in place. In deeper water, samples can be collected from the side of a boat.
- A boat with a deck at the bow can be used, but a pontoon boat with a 60 x 60 cm sampling port cut into the deck between the two pontoons (i.e., a moon-pool) is preferred.
- The boat is anchored at two points, and the bow faces into the wind or the direction of oncoming waves to keep the boat in the place while sampling. Sampling should be avoided if there is significant wind or waves.
- In freshwater systems in northern climates, sampling can be done through ice.
- A standard ice auger is used to cut a hole in the ice, and the soil is sampled through the hole.

Figure 11: A pontoon boat used for subaqueous soil sampling.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- For organic soil materials or fluid mineral materials, a Macaulay peat sampler is very effective.
- Most Macaulay samplers have sampling chambers 50 cm long.
- Machine shops can construct auger chambers to longer lengths (such as 1 m), which work well for subaqueous soil sampling.
- These samplers can be used easily through the moon-pool, off the side of the boat, or through a hole in ice.
- Because water depths vary, extensions on the bucket auger or peat sampler should be easy to add on or remove.

- For detailed sampling and description of non-fluid materials, a vibracore sampler is ideal.
- Vibracore samplers consist of a concrete mixer motor, a cable that delivers the vibration from the motor to the sampling tube, and a vibration head that clamps onto the irrigation pipe (core barrel) to deliver the vibration to the core barrel that collects the sample.
- The vibration loosens (or liquefies) the soil material around the core barrel so that the core can be easily pushed into the soil with a minimal amount of pressure from the top of the pipe.
- This sampling approach is typically done from a pontoon boat with a moonpool.
- If the body of water is too small for a pontoon boat, or gas-powered boats cannot be used, a small barge with a moon-pool in the middle can be used.
- In this case, the concrete mixer motor is in the small boat used to pull the barge and the soil is collected and retrieved through the moonpool in the barge.
- There are "backpack" types of vibracores that can be used off barges or through the ice.
- In some cases, these types of corers are not powerful enough to push the tubes through dense soil materials.

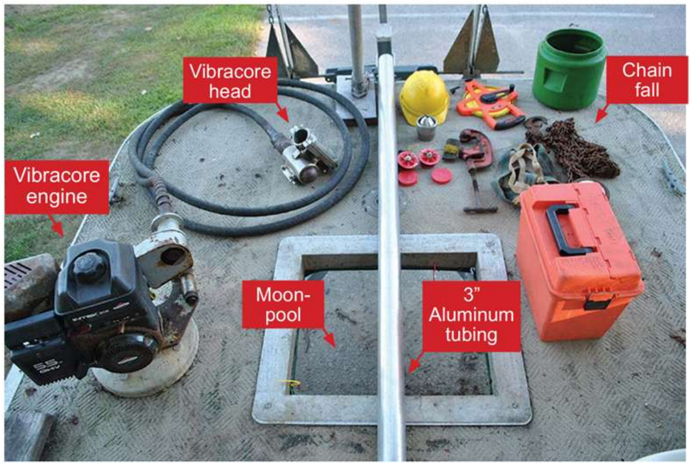


Figure 12: Equipment for vibracore sampling.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Core barrels used for vibracoring are typically 10 cm in diameter and should be long enough to accommodate both the soil sample and the overlying water.
- Once the barrel is pushed into the soil to the desired depth, a lead weight (sinker) attached to a string is dropped into the core barrel to measure the distance from the top of the core barrel to the soil surface in the tube.
- The same thing is done on the outside of the core.
- These measurements are made to determine the amount of collapse (settlement) that has occurred to the soil during coring.
- Significant collapse should be noted when recording horizon depths and reporting soil bulk density.

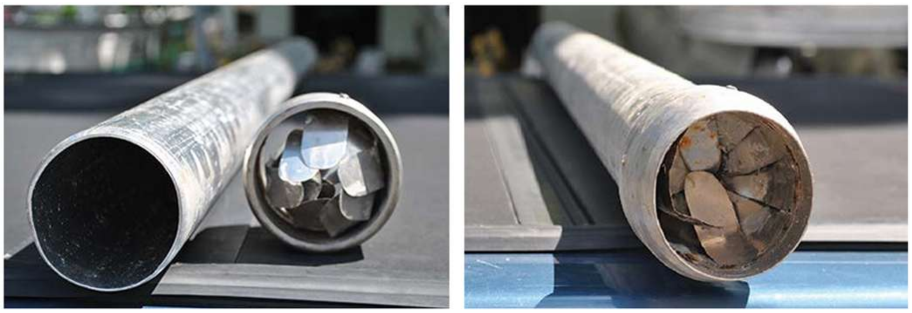


Figure 13: A core barrel and core catcher.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- To retrieve the soil, the core is first slowly filled with water.
- A cap (test plug) is placed on the top that, when tightened, seals the top of the core.
- This creates a suction and, for most materials, keeps all of the soil material in the core barrel when it is removed.
- In some soil materials, particularly those that are coarse textured with many rock fragments, some of the soil material may fall out of the bottom of the core barrel when it is retrieved.
- In these cases, a core catcher can be added to the base of the core before it is vibracored into the soil.
- Once the core is sealed, it is attached with a heavy strap to a winch or chain fall and pulled out of the soil.
- Using a chain fall attached to a tripod mounted over the moon-pool is the safest way to remove the core.
- For sampling off a barge or through the ice, an aluminum ladder is commonly used instead of the tripod because of its lighter weight.

- Once the core is pulled from the soil and sealed at the bottom (to prevent loss of the sample), a small hole is created in the irrigation pipe just above the top of the soil in the core barrel to allow the water on top of the core to drain slowly.
- After the water is drained, the tube is cut just above the soil surface with a tube cutter and the cap is screwed back in place to preserve the core.
- The bottom is sealed with a cap first to prevent loss of suction.
- The core barrel is dried and clearly labeled with a pedon number and the correct orientation.
- The core can be opened on the boat, or it can be stored in a rack and later described and sampled on land or in a lab.
- Vibracores in the lab should be maintained at 4 0 C to minimize drying and oxidation of sulfides prior to sampling and analysis.

- Core barrels are best opened by laying the core down on a table or lab bench and cutting lengthwise on opposite sides with electric metal shears.
- A circular saw works but creates safety issues and produces aluminum shavings, which need to be collected.
- A piano wire or steel guitar string is slid between the cuts in the aluminum tube to split the core in two.
- The two sides are lifted apart.
- One side is described and sampled, and the other is archived if needed.

Figure 14: A core from subaqueous sampling.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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Description

- In general, subaqueous soils are described the same way as subaerial soils but using the setting terminology, sampling method, and various chemical and morphological properties of subaqueous soils described by McVey et al. (2012).
- It is worth reiterating that caution is needed when estuarine soils are sampled and described since these soils typically have significant amounts of sulfides.
- Once soil materials containing sulfides are removed from their natural state (underwater), the sulfides begin to oxidize (even if stored in a sealed core barrel at 4^0C).
- Mono-sulfides are more reactive to oxidation than di-sulfides, such as pyrite.
- The oxidation of sulfides may cause a change in soil color and a rapid decrease in pH as the sulfides are converted to sulfuric acid (in some cases pH decreases from more than 7 to less than 3).
- If the materials have a very low pH, the aluminum pipe housing the soil core may start to corrode and create Al salts.
- If soil color, pH, salinity, and particle-size distribution are important to the soil characterization, the soils should be sampled and described as soon as possible or samples should be frozen immediately after sampling to minimize the amount of sulfide oxidation.

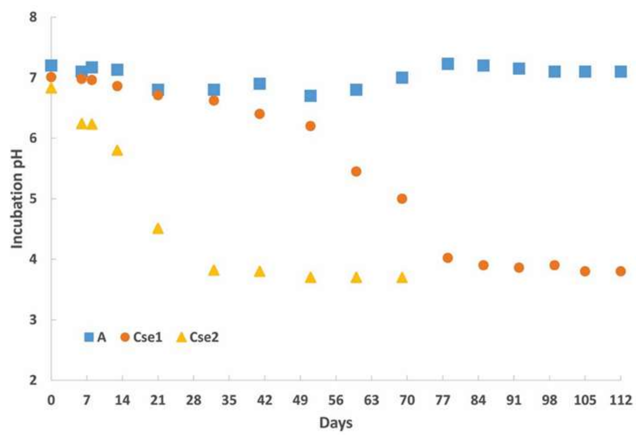

Figure 15: Incubation pH for three horizons (A, Cse1, and Cse2) from a Fluventic Sulfiwassent, collected from the Thimbles Island estuary in Connecticut.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Important Properties for Classification and Interpretation

- Soil properties important for classification and interpretations of subaqueous soils include type of organic soil materials, content of soil organic carbon, electrical conductivity (EC), fluidity, incubation pH, content of pore-water sulfides, particle-size distribution, mineralogy, and soil color.
- The presence of odors (such as sulfur or petroleum), the presence of shell fragments or former vegetation, and the nature of the depositional environment are also important.
- Subaqueous soils that are dominated by organic soil materials or are fluid cannot support dock pilings and typically require special moorings.
- Electrical conductivity is used to discern between freshwater and estuarine soils and to identify soils that may have halinity issues when dredged and placed on the soil surface.
- Incubation pH is a measure of the potential acidity of the soil materials.
- Subaqueous soils dominated by mono- and di-sulfides may have dramatic drops in pH when dredged and placed on the land surface.
- In some cases, pH values decrease to less than 4 and acid sulfate soils are created.
- High sulfide contents, especially in the pore waters, can be toxic to submerged aquatic vegetation and may indicate a highly anoxic environment uninhabitable for many benthic organisms.
- Subaqueous soils typically have low chroma (< 2) and a neutral (N), yellow (5Y), or blue-green (BG) hue.
- Brighter chromas (> 2) or redder hues commonly indicate aerobic inputs (from ground water or the water column) or relict subaerial soils that are now submerged.

Soil-Landscape Relationships

- Like subaerial soils, subaqueous soils form as a result of various additions, losses, transfers, and transformations occurring within the soil.
- The dominant processes that form a particular kind of soil depend on where the soil occurs on the subaqueous landscape.
- The figures on the following slide provide examples of coastal lagoons, which are very common in estuarine systems along the U.S. Eastern Seaboard.
- Large areas of the basins (bottoms) of coastal lagoons are dominated by fine textured (silt loam and silty clay loam) soils that are rich in sulfides, are very fluid, and have a high content of soil organic carbon to a depth of 2 m or more.
- Because the lagoon bottom is in a low-energy position, only fine particles (very fine sand or finer) and organic matter are deposited.
- Little oxygen is available for microbial respiration, and redox potentials are very low.
- As a result, the transformation of sulfate to sulfides dominates the soil processes.
- With continued additions of organic matter and little decomposition at the low redox potential, levels of soil organic carbon remain high.
- Because the silt- and clay-rich parent materials have such fine particles sizes, which are not readily compacted in the permanently inundated low-energy environment, very fluid soils form.

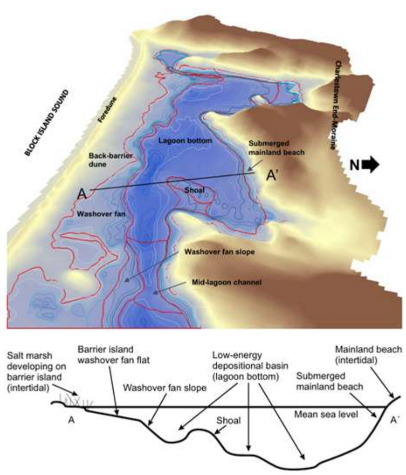

Figure 16: Examples of subaqueous landscape units across a coastal lagoon.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

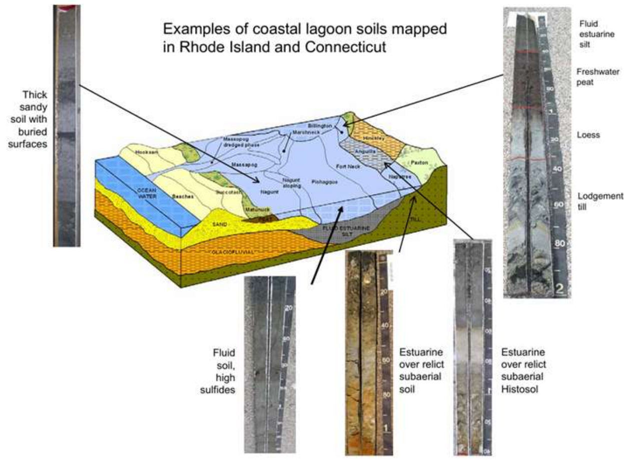

Figure 17: Soil-landscape relationships across a coastal lagoon in Rhode Island and Connecticut.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Higher on the coastal lagoon subaqueous landscape, typically between the deeper lagoon bottom and the shallower washover fan, water currents have more energy than those in the lagoon bottom where the finest particles and organic matter settle out.
- During storm events, there is even greater energy due to an increase in waves, fetch, and nearby overwash events and coarser (sand-sized) particles are deposited.
- Where benthic organisms are continuously mixing the upper part of the soil, textures are loamy and fluidity is low.
- In this part of the landscape, subaqueous soils develop A horizons and sulfidic materials are not typically found in the upper horizons because of the mixing and elevation (shallowest water depth).
- Adjacent to the barrier island that separates the lagoon from the open ocean, washover fans are the dominant landscape unit.
- The frequency of overwash events that reach the washover fan increase with decreasing distance to the barrier island, and the soils typically do not have A horizons.

- Freshwater systems such as ponds, reservoirs, and lakes are typically low energy.
- These environments typically do not have the highly depositional and erosional landscape units (such as deltas, washover fans, or current-formed channels) found in estuarine settings.
- Thus, the landscape patterns in the freshwater systems are much simpler than those in the estuarine systems.
- For example, Payne (2007) identified a total of 21 different landscape units in her study of three shallow estuarine embayments in Rhode Island.
- She noted that differences in geology, geomorphology, geography, wind, and tidal patterns accounted for much of the variation in landscape units.
- In contrast, Bakken (2012) studied six natural and impounded freshwater systems and found only four landscape units (cove, shoal, lakeshore, and lakebed).

- There have been two studies of freshwater subaqueous soils, and both found that soil characteristics in freshwater systems were more influenced by the geologic and anthropogenic history than by the landscape.
- The subaqueous soils in reservoirs were very similar to those prior to impoundment and flooding.
- The natural lakes were primarily kettle holes that slowly filled with rising ground water.
- In most cases, organic soil materials accumulated in the kettle holes when they were wetlands (subaerial soils) with little mineral inputs after permanent inundation and ponding.
- Thus, these soils typically were Histosols.
- In areas where there was significant anthropogenic input of nutrients, invasive species such as milfoil (Myriophyllum sp.) and fanwort (Cabomba caroliniana) proliferated and thick deposits of plant-derived organic materials accumulated, forming present-day subaqueous Histosols.

Survey Methods and Procedures

- Special methods and procedures are used to develop base maps for conducting subaqueous soil surveys.
- Additional remote sensing tools and techniques can also be useful for preparing subaqueous soil survey maps.

Bathymetry

- Developing soil-landscape relationship models is critical to the mapping of subaqueous soils.
- The first step is obtaining bathymetric data and creating a bathymetric map of the subaqueous landscape.
- The bathymetric map serves the same purpose as the topographic map.
- Aerial photos, if the water clarity was good on the day the photos were taken, can be helpful in the identification on the map of exact boundaries of landscape units, such as washover fans, shoals, and submerged beaches.

- In some areas, accurate bathymetric maps are already available; in other areas, they may need to be created.
- Bathymetric maps are created by systematically collecting water depth data while recording x and y coordinates.
- Water depth is typically determined using a fathometer mounted to the hull of a boat.
- The boat is slowly driven across the water body for a series of transects.
- Transects are spaced 20 to 30 m apart, and data are collected every 5 to 10 seconds, depending upon the speed of the boat.
- Each time a water depth is recorded, the x and y coordinates are also recorded with a global positioning system (GPS).
- A fairly simple fishfinder with GPS capabilities can collect the x and y data and the z (water depth) data at the same time.

- Caution is needed in areas with dense submerged aquatic vegetation (SAV) since the fathometer may read the top of the SAV as the soil surface.
- In these cases, manual readings of the water depth should be occasionally collected and checked against the fathometer values.
- Several transects are also completed parallel to the shoreline to augment the other transect data.
- In freshwater systems, the water depths can be corrected to the mean water level of the water body.
- In tidal systems, tidal fluctuations need to be recorded at the same time as the x, y, and z data to correct the water depth data.
- Any water-level recording device that has time-stamped data can serve this purpose.
- In areas where tidal fluctuations are complicated, as many as three waterlevel recording devices may need to be used at one time.
- In most cases, however, a single-water level measurement device can be used and moved to new locations as the bathymetric data are collected.
- Because of recent advances in Light Detection and Ranging (LiDAR) for underwater applications, accurate bathymetric maps may eventually be available for most coastal environments.

- The bathymetric data are imported into a GIS program to create the contour maps.
- They are typically kriged, and a stop line is set at the tidal datum chosen as the elevation where the water meets the land.
- All bathymetric data collected in tidal systems are normalized to NAVD-88 or new vertical datum if available.
- McVey et al. (2012) discussed the use of various datums for a bathymetric contour map.
- To normalize the data, the bottom depth (elevation) of each tide gauge must be determined using traditional land survey techniques from an order 1 benchmark.
- Changes in the shallow subaqueous landscapes are rarely abrupt; thus, contour intervals of the bathymetric maps are commonly on the order of 20 to 30 cm.
- Using the contour maps and aerial photographs, the various landscape units within the mapping area are delineated.
- Landscape units in coastal systems include lagoon bottom, bay bottom, flood tidal delta, washover fan, inlet, and shoal.
- Landscape units in freshwater lakes and ponds include submerged shoreline, lakebed, cove, and shoal.

- The bathymetric contour maps serve as the base maps for the subaqueous soil survey.
- The landscape unit is the primal factor in the delineation of soil distribution on the landscape.
- Each landscape unit should be visited in the field and a preliminary assessment done with a bucket auger and peat sampler.
- To develop initial metrics of soil variability within landscape units, larger units may need to be investigated at three or four random locations.
- Which units will need additional investigations will depend on the scale of mapping (order 1 or 2).
- Preliminary assessments can be used to establish initial soil-landscape relationships.
- Delineations that do not follow these relationships should be reassessed in the field, and additional delineations (soil polygons) added where appropriate.
- Representative soil types should be identified from the preliminary studies, and their locations established for vibracoring.
- Transects can be run across the largest units to assess variability within delineations.
- For stony or bouldery mapping units, a push probe can be used to quickly estimate boulders and stones and better identify boundaries between different phases.

Remote Sensing

- Although not necessary, several remote sensing tools can help improve mapping accuracy.
- In estuarine systems, side scan sonar is effective in identifying surface textures and features, such as stones, boulders, macroalgal cover, SAV, bottom type, and anthropogenic features.
- The side scan is towed behind a boat sending signals in 25- to 50-m swaths.
- Transects are set apart by the size of the swath to ensure complete coverage. Soundings are recorded and translated in the lab with the appropriate software into a map showing the mosaic of swaths.
- Surface samples from preliminary soil survey efforts are used as ground truth for the signals that are mapped.
- Easily identifiable features from the side scan data include extent of stones or boulders and surface textures.

- A simple tool that works well in areas with excellent water clarity (low turbidity) is the underwater video camera.
- The video camera can be towed slowly by the boat and tracked with a GPS.
- The images are projected onto a laptop.
- Points of interest (e.g., changes in surface texture or presence, absence, or abundance of coarse fragments or stones and boulders) are noted and the GPS coordinates recorded.
- Limitations for the video camera are the field-of-view and the possibility of fouling by algae or seagrasses.
- The field-of-view is often limited to a width of 25 cm because the camera needs to be close to the subaqueous soil surface to clearly observe it.
- Thus, many transects are necessary to delineate between two mapping units (e.g., soils with a high content of rock fragments and soils with a low content of rock fragments).
- The closer the camera is to the soil surface the more likely the lens will be fouled by detritus, algae, or seagrasses.

- Ground-penetrating radar (GPR) can be invaluable in freshwater systems (it cannot be used in saltwater because the salts attenuate the signal).
- The GPR antenna can be towed slowly behind a boat in a rubber or plastic raft or across ice.
- GPR is effective at identifying surface and subsurface stones and boulders, shallow depths to lithic materials, and the depth and distribution of organic soil materials.

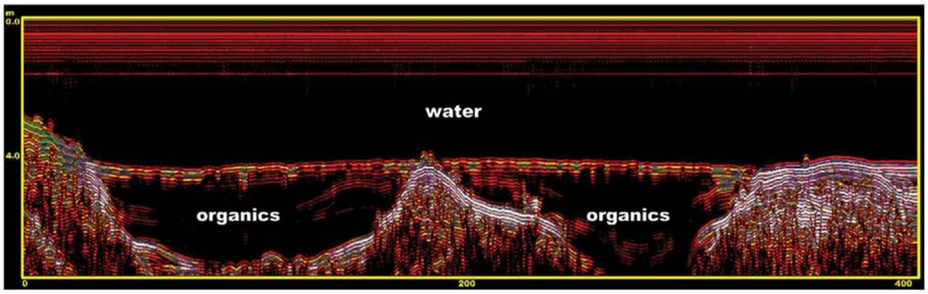

Figure 18: GPR output for a freshwater lake with thick organic materials. Water, mineral soil materials, and organic soil materials are easy to identify from the output.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Significance of Subaqueous Soil Information

- Subaqueous soil survey interpretations can have a wide variety of uses.
- This section provides a few examples.

Water depth characteristics.

- For use of a shallow water body, one of the most important spatial data layers is the bathymetry.
- Although bathymetric maps created for soil survey are not meant for navigation purposes (nautical charts include locations of buoys and other boating information), these maps can be used to understand the effects of storms on coastal systems or identify rapid changes in water depth for recreational purposes (mostly fishing).
- In most soil surveys of subaqueous soils, water depth is provided as a phase of each soil mapped (similar to slope phases in subaerial soil surveys).
- Although not perfect for navigation purposes, these data can help in identifying shallow areas boats should avoid or in identifying shallow areas suitable for wading activities, such as clamming.

Mitigation of dredging effects.

- Areas of subaqueous soils in estuarine or freshwater settings are dredged to allow boats and ships to move freely in and out of the system or for the development and construction of marinas.
- Issues related to dredging are primarily disruption of the benthic ecology, re-release of the contaminants and nutrients in the soils, and disposal of the dredge materials.
- If the dredged materials are placed someplace in the water, another subaqueous area is disturbed.
- The dredging process alone may re-suspend nutrients or contaminants that are stored in the subaqueous soils.
- Pruett (2010) showed that soils with high fluidity (Hydrowassents) and soils with sulfidic materials (Sulfiwassents) contained significantly higher concentrations of heavy metals (Pb, Zn, As, Cu, and Cr) than simple soils (Haplowassents) and sandy soils (Psammowassents).
- Hydrowassents are typically finer textured and contain high levels of soil organic carbon.
- The soil organic carbon forms a complex with the metals in the water column, and the complex is later deposited on the soil surface. In Sulfiwassents, the metals may also complex with the sulfides.
- Pruett (2010) found in some cases that the metal concentrations in Sulfiwassents were high enough to negatively affect the benthic ecology.
- In freshwater systems, Bakken (2012) found that there were significant differences in P concentrations among soil types.
- Where extractable P concentrations were greater than 200 $\mu g\ g^{-1}$, there was a significantly greater chance of the presence of invasive plants such as milfoil and fanwort.

- Commonly, the dredge materials are placed on the land surface.
- Knowing whether or not those materials contain contaminants or sulfides is critical to managing the dredge materials.
- When exposed to the air, sulfides will oxidize, release sulfuric acid, and may create acid sulfate conditions or soils.
- These acid sulfate soils may release metals if reaction approaches extremely acid (pH of 4 or 3). They are also extremely difficult to vegetate.
- Salisbury (2010) showed that soils in low-energy environments, such as coves, bayfloors, and lagoon bottoms, that contain high concentrations of sulfide may drop in pH from 7.5 to 3.0 in as little as 3 weeks following dredging and placement in an oxidized environment.

Suitability for moorings, docks, and other structures.

- Surabian (2007) showed how subaqueous soil properties, primarily fluidity and depth of fluid soil materials, affect the types of moorings that can be used to secure boats.
- If the soil materials are non-fluid, heavy moorings are required.
- If they are fluid, mushroom-type moorings are used.
- Similarly, areas for docks require soil materials that are non-fluid and can support pilings.

Aquaculture.

- Salisbury (2010) showed that certain subaqueous soils are more productive for aquaculture than others (in this study, hard shell clams and oysters).
- For example, an average of 58 percent of the oysters grown on sandy non-fluid soils reached harvestable size in two growing seasons while less than 12 percent of the oysters grown on soils dominated by sulfidic materials reached that size in the same period.
- Aquaculturists are now using subaqueous soil maps to identify new places to lease for growing oysters in coastal lagoons.

Ecological assessment and restoration.

- Seagrasses such as eelgrass (Zostera marina) are an important component of the estuarine ecosystem.
- They provide several ecosystem functions and services, including trapping sediment and pollutants in the water column and serving as habitat for a variety of shellfish, finfish, shrimp, and other benthic fauna.
- Because eelgrass habitat has been declining worldwide, there have been numerous studies focused on eelgrass distribution and restoration.
- Restoration of eelgrass has been difficult, with an average success rate of 30 percent.
- Because a major issue is site selection, subaqueous soil surveys can provide spatial soil data to use in site selection models for eelgrass restoration.

Carbon accounting.

- Another important current issue in soil science is carbon accounting.
- Subaqueous soils are typically not sampled and analyzed when carbon stocks are assessed.
- However, studies have shown that, although soil organic carbon concentration in subaqueous soils varies widely, some subaqueous ecosystems may have as much carbon as wetlands and forested ecosystems.
- These potential sinks for carbon should be inventoried, characterized, and considered in regional carbon budgets.

HUMAN-ALTERED AND HUMAN-TRANSPORTED SOILS

Introduction

- This chapter is a practical guide for soil scientists conducting or interpreting a soil survey that includes human-altered and human-transported (HAHT) soils and materials.
- HAHT soils include soils that were intentionally and substantially modified by humans for an intended purpose, commonly for terraced agriculture, building support, mining, transportation, and commerce.
- They do not include soils modified through standard agricultural practices (such as shallow plowing, liming, and fertilization) or farmed soils with unintended wind and water erosion.
- Evidence for HAHT soils includes manufactured items (e.g., artifacts) present in the profile, human-altered material (e.g., deeply excavated or plowed soil) or human-transported material (e.g., fill), and position on or above anthropogenic landforms (e.g., flood-control levees) and microfeatures (e.g., excavator scrape marks).
- Detailed criteria regarding the identification of anthropogenic (artificial) landforms, human-altered material, and human-transported material are in the Keys to Soil Taxonomy.

- Using position on or above very specific anthropogenic landforms and features as a property of the soil for classification purposes is somewhat of a departure from past conventions for defining classes in Soil Taxonomy.
- However, landscape- and landform-related criteria have been used for the identification of Fluventic and Cumulic subgroups (i.e., slope) and for the plaggen epipedon (i.e., raised landforms).
- The use of specific kinds of anthropogenic landforms for HAHT soils is an extension of these precedents.
- Destructional and constructional anthropogenic (human-constructed) landforms and microfeatures have evident purpose and are undeniably linked to the soil itself.
- Linear straightening of waterways, drainage ditches, sanitary landfill mounds, and geometric shaped excavation features are all tied to extreme soil modification or compilation.
- Regardless of the characteristics of the soil, if a soil is on or above an anthropogenic landform or microfeature, it can definitely be associated with a human activity and assigned to a unique taxa.
- For example, it would be hard to deny that the soil on the large public landfills in the figure on the following slide was transported by humans, whether manufactured items are found in the 2-meter profile or not.
- Historical records can provide additional supportive proof.
- The movement of soil by humans resets the soil-forming factor of time and commonly truncates or buries a more developed soil, thus strongly influencing soil properties.
- Soil development depends on all soil-forming processes, including those associated with the construction of the anthropogenic landform or microfeature.

Figure 19: Landfill complex in Virginia.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Soils in urban areas are commonly human-transported (e.g., fill) or human-altered (e.g., truncated or mixed in situ) to significant depth.
- They generally exhibit a wide variety of conditions, and many are covered with impervious surfaces (e.g., buildings and pavements).
- The same situation occurs in suburban and low-density urban areas, but the proportion of less altered soils is higher and the proportion of buildings and pavements is lower.
- In many areas with HAHT soils, surface geomorphology and hydrology have been intensely altered.
- Other highly modified landscapes contain significant amounts of human-transported materials, such as steep farmland with closely spaced hillslope terraces and areas of intense activity, such as mines, oilfields, and highway corridors.
- Spoils from land-leveling, filling, construction, mining, dredging, wastedisposal, and manufacturing operations become parent materials for new soils, which are commonly used to extend urban areas or airports into shallow water or to fill wetlands.
- Major areas of human-altered materials occur where agricultural areas have been deeply ripped to loosen impervious subsoil horizons, such as in the Central Basin of California.
- There is a need to identify, describe, and map HAHT soils because these soils have been modified enough from their original state that former soil maps do not provide the correct information or there is no information on them at all.

Figure 20: Machu Picchu, Peru.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Background

- Humans substantially modify or transform the physical, chemical, and biological properties and processes of the soil through anthropedogenesis.
- Because they can profoundly affect all five soil-forming factors (parent material, climate, organisms, time, and relief or topography), some authors have established a sixth factor, described as a "master variable capable of modifying or controlling the other five factors".
- In particular, humans excavate deeply enough to remove most or all soil horizons, impart manufactured materials and debris (artifacts) that become included in soil parent materials, and transport and deposit extensive amounts of soil, rock, and sediment that become new parent materials.

Figure 21: Profile of the Laguardia soil series showing artifacts in multiple deposits of human-transported material. The buried building debris contains brick, concrete, wire, steel, and asphalt.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Humans also level (cut and fill) large areas, destroying natural landforms and building anthropogenic landforms and microfeatures (e.g., drainage ditches).
- Archaeological evidence shows that humans have been altering soils for at least 8,000 to 10,000 years.
- Soil alterations have been slight (surficial) and collateral to standard agricultural practices (e.g., erosion) or been intentional and profound (e.g., mountaintop mining and extensive landform alteration through terracing or oilfield activity).
- Extensively modified areas with integrated land management are called "anthroscapes".

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HUMAN-ALTERED AND HUMAN-TRANSPORTED SOILS (CONT'D)

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Figure 22: An ancient Roman urban anthroscape, which reminds us that humans have been purposely modifying and moving soil in urban areas for millennia (the Colosseum is at the back on the right). Modern urban anthroscapes often include a mosaic of water, parks, buildings, and pavements (roads and sidewalks).

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Development of HAHT Soil Concepts in the U.S.

- The effort to formally describe and classify HAHT soils began in 1988 with the formation of the International Committee for Anthropogenic Soils (ICOMANTH).
- This committee was commissioned by USDA's Soil Conservation Service to introduce differentiae and taxa for classification and survey of observed human-altered and human-transported s oils (also called anthropogenic soils).
- The charge of the committee was to introduce HAHT soils into U.S. Soil Taxonomy, facilitate mapping of urban areas, introduce new terms and materials into USDA databases, enable meaningful interpretations of unique materials and soils, and facilitate establishment and correlation of new soil series.
- Between 1995 and 2010, seven circular letters were distributed internationally for feedback on committee ideas.
- The International Field Tour of Anthropogenic Soils of Nevada and California in 1998; the 5th Soils of Urban, Industrial, Traffic and Mining Areas (SUITMA) tour held in New York City in 2009; and the 4th IUSS Conference for Soil Classification held in Lincoln, Nebraska, in 2012 were used to test proposals and solicit feedback from diverse groups.
- ICOMANTH proposals were reviewed, accepted, and published in the 11th and 12th editions of the Keys to Soil Taxonomy.
- Major outcomes were the identification of human-altered material, human-transported material, and manufactured items as differentiae at both the subgroup and family levels in Soil Taxonomy.
- In addition, standard terms and conventions for describing anthropogenic features (artifacts) in soil profiles, as well as additional horizon nomenclature for identifying horizons impacted by human activity, were adopted.

Importance

- The human impact on the global environment since the Industrial Revolution has been so profound that a new geological epoch—the "Anthropocene"—has been proposed.
- As the human population increases, so does the degree and amount of land alteration by humans.
- About 3 percent of world's land surface is classified as urban, and the percentage is increasing as more people move into cities, especially along coastlines, where 10 percent of the land is urban.
- As of 2011, approximately 82 percent of the U.S. population and 52 percent of the world's population lived in urban areas.
- In many areas, humans grow food in or near heavily developed areas, in soils with undocumented or unpredictable properties.
- Human alteration of soil occurs worldwide.
- For example, humans are clearing land deep into South American jungles for agriculture and mining, thus driving settlement further north into previously undeveloped areas.
- Agriculture on modified soils occurs extensively on most continents.
- Rice is grown in human-irrigated and -flooded paddies (many of which are hillslope terraces) covering 153.7 million hectares.

- Little was previously known about the chemical and physical properties and behavior of profoundly altered soils.
- In the past, their classification was minimal because of high variability.
- For example, urban HAHT soils were commonly classified at higher taxa, such as Udorthents, and had almost no specific information in USDA databases to provide meaningful interpretations.
- In order to improve soil survey of HAHT soils, additional taxa were needed for their classification, new methods were needed for their analysis, and new terms were needed for describing their properties so that soil maps and proper interpretations for their use could be provided.

Resource Management Issues and HAHT Soils

- Important uses of soil survey information in urban areas include restoration and revegetation efforts, hydrologic interpretations for stormwater management, urban agriculture, and resource inventory (e.g., to identify wetlands).
- Urban soil surveys are used to advocate for best use and management practices for open space areas.
- Mined and drilled lands, farmlands, intensively used agricultural areas, and some urban areas contain contaminated HAHT soils.
- Now that over half of the world's population is in urban areas, soil-related health risks are increasingly important.
- Human health concerns occur from contact with or exposure to contaminated soils, many of which are HAHT soils.
- Soils may impact humans directly (e.g., dust inhalation or contact with bare feet) or indirectly (e.g., metal uptake by vegetables).
- Some highly contaminated soils are not safe for direct soil sampling except by trained and equipped specialists; less-contaminated soils are likely to be surveyed and mapped.
- Agricultural areas subject to heavy pesticide, herbicide, or fungicide application also have an adverse impact on soil water, surface water, and ground water.
- Developers, administrators, politicians, regulators, and planners need soil information in determining best management practices to protect water quality and public health.
- Potentially contaminated sites can be managed for human use.
- For example, some landfills and brownfields have been carefully constructed or reclaimed for use as parkland.

Occurrence

- HAHT soils occur on all continents, even Antarctica.
- They are common on intensively managed lands where humans have established civilizations, including some areas now underwater.
- New HAHT soils are being formed every day. In the future, HAHT soils may occur on other celestial bodies.
- There is no record on global distribution of HAHT soils besides maps using national classification systems or the World Reference Base for Soil Resources.
- Although HAHT soils are global in extent, they are commonly unmapped, unrecognized, and underappreciated.

Figure 23: McMurdo Station, Antarctica. Human alteration of landforms, relocation of soil for building of infrastructure, and alteration of soil profiles occur even in this remote location.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Identification

- By definition, HAHT soils have profound and purposeful alteration or occur on landforms with purposeful construction or excavation.
- The alteration is of sufficient magnitude to result in the introduction of a new parent material (human-transported material) or a profound change in the previously existing parent material (human-altered material).
- HAHT soils do not include soils with incidental or unintentional surficial changes due to standard agricultural practices or the shallow incorporation of artifacts through plowing.
- For example, a soil that has higher pH, fertility, or base saturation due to standard practices does not have long-term change, whereas a soil that was shaped into an agricultural conservation terrace is profoundly and intentionally altered for a long-term purpose.
- Some changes serve no useful purpose and can be judged as unintentional (e.g., cultivation can lead to wind or water erosion or salinization and discarded manufactured trash can end up in a plow layer).

- Many classification systems, including the World Reference Base and Soil Taxonomy, recognize HAHT soils at the highest levels, as Anthosols and as Technosols and Anthosols, respectively.
- Soil Taxonomy presently recognizes HAHT soils with a combination of taxa at the subgroup and family levels.
- Features of these soils include:
  - An anthropic or plaggen epipedon
  - Material between 25 and 50 cm thick that meets all the requirements of a plaggen epipedon except thickness
  - 50 cm or more of human-altered and human-transported material over the original soil material
  - HAHT material comprising the entire soil above a root-limiting layer or a contact that is shallower than 50 cm.

Human-Transported Material

- Human-transported material (HTM) is soil parent material (organic or mineral) that has been moved horizontally onto a pedon from a source area outside of that pedon by purposeful human activity.
- Since constructional anthropogenic landforms are built with transported material, HTM is associated with these landforms.
- Commonly, a lithologic discontinuity or a buried horizon can be observed just below HTM.
- It may be difficult to distinguish human-transported material and parent material from mass movement processes (e.g., landslides) without intensive onsite examination and analysis.

- Evidence of HTM includes:
  - Detached pieces of diagnostic horizons (such as argillic, calcic, histic, or spodic horizons) which are derived from the excavated source material
  - Presence of artifacts such as brick, asphalt, glass, metal, plastic, combustion by-products, mechanically abraded rocks, midden material, and scrape marks
  - Irregular distributions of artifacts or contaminants either with depth in the profile or with proximity away from an anthropogenic landform, feature, or constructed object, such as a road or building
  - Lithologic discontinuities at the contact between HTM and the underlying former surface
  - An underlying manufactured layer, such as a geotextile liner or concrete
  - Location of the material on a constructional anthropogenic landform or microfeature or within the boundary of a destructional anthropogenic landform or microfeature

Human-Altered Material

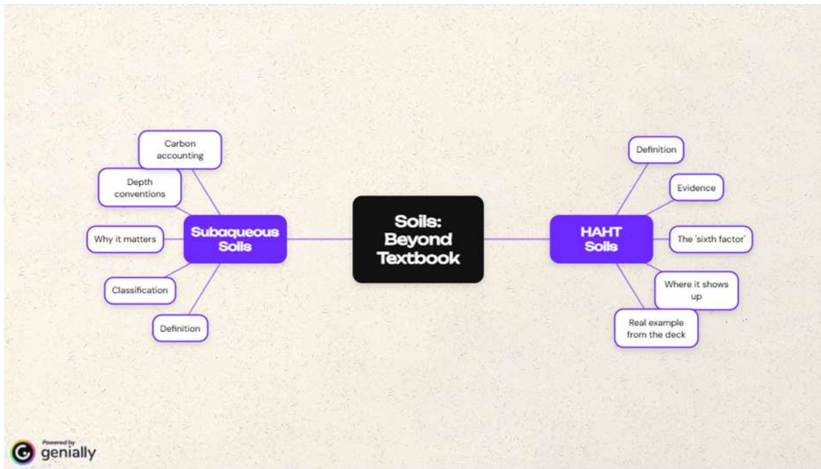
- Human-altered material (HAM) is soil parent material (organic or mineral) that has undergone anthroturbation (mixing or disturbance by humans).
- It differs from HTM in that it generally has been altered in place and contains little or no evidence of being transported from another location.
- Examples include agricultural soils that have been deeply mixed (e.g., by deep ripping of a root-restrictive subsoil layer such as a duripan) and soils that have been mechanically compacted to impound water (as in a rice paddy with anthric saturation).
- The concept also includes soils that have been removed, stockpiled, and replaced during reclamation (as in some surface mining or urban development activities) and soil materials that remain exposed after excavation (such as those on the floor of a gravel pit).

- Human-altered materials are commonly associated with destructional anthropogenic landforms.
- These landforms are in areas where soil material has been removed (pits, quarries, mined areas, etc.).
- In some cases, a destructional landform may be recognized by tracing a subsurface horizon (such as an argillic or spodic horizon) from adjacent non-human-altered soils laterally to the point where it disappears abruptly, which corresponds to the boundary of the destructional landform.
- Destructional anthropogenic landforms are excavated but may later be filled or covered.
- Where the excavations have been partially or totally filled with the original soil material, the material is considered HAM.
- Where they have been filled with different soil material, the material is considered HTM.

- Evidence of human-altered material includes:
  - Material occurs in an area impacted by the agricultural practices of deep plowing to rip a root-restrictve layer or of intentional compaction to puddle water.
  - Material occurs within an excavated area (destructional landform) such as a pit or quarry.
  - The soil profile has features such as reoriented pieces of diagnostic horizons; rock fragments that are mechanically abraded; scrape marks underlying soil material that was removed, stockpiled, and replaced on site; or purposely compacted layers formed during construction activities.

Manufactured Layers

- A manufactured layer is an artificial, root-limiting layer below the soil surface.
- These layers can be identified by their presence in or on an anthropogenic landform or microfeature, ranging from landfills to concrete-lined ditches to ponds.
- The soil above is HAHT material.
- The layers are used in construction (e.g., roof of an underground building) or to impede water, gas, or roots (e.g., landfill liner).
- There is a contact with HTM at the top of the manufactured layer, typically made out of geotextile liners, asphalt, concrete, rubber, or plastic.
- Below the layer, there may be more HTM, a layer of human-altered material, natural soil material, or rock.



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REFERENCES

This interactive presentation was adapted from Chapters 4 to 11 of the document by the Unified States Department of Agriculture (USDA), Soil Survey Manual, March 2017, USDA Handbook 18.

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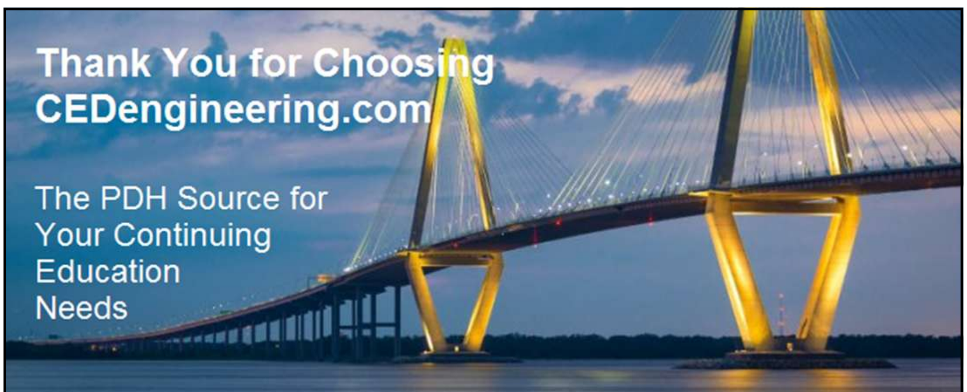

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