CHAPTER 7

Soil Survey Data Collection, Management, and Dissemination

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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.

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.

Automated Data Processing in Soil Survey

A powerful tool for handling accumulated soil survey data is automated data processing (ADP), which uses computers with word-processing, database, spreadsheet, statistical, geographic information system (GIS), and other specially designed software packages. ADP facilitates data collection and entry, data editing, and timely summaries, comparisons, and analyses of data that otherwise would be impractical or impossible to do. It enables frequent and inexpensive updating of long lists, such as lists of soil series for various geographic regions, in any order or sequence, and other output products. The summaries can provide information to guide important policy decisions. ADP can quickly perform routine and otherwise time-consuming computations. It allows for easy editing of descriptive materials, manuscripts, and narrative or tabular data and information.

In recent years, with the increased use of computers and the development of computer applications such as geographic information systems, more and more soil survey data are being delivered to end users in electronic or digital format (see chapter 5). Data also are, at least partially, being collected and recorded in electronic format in the field using a variety of tools (see chapter 6). Managing the data in digital format allows greater flexibility in data delivery. Products can be delivered to users in either hard-copy or electronic formats. The remainder of this chapter will be primarily devoted to the electronic format of soil data management and delivery.

Soil scientists need to know the fundamentals of ADP just as they need to know the fundamentals of chemistry, botany, geology, mathematics, economics, and other subjects that support the work of soil survey. Literature on the fundamentals of ADP is readily available. Automated data processing can be used for many soil survey tasks, but this does not mean that it should be used for all of them. Before any decision is made to use ADP, an objective study (systems analysis) is needed to determine what combination of equipment, personnel, and other factors will be the most useful and economical. The selection of any new system must take into account its compatibility with systems used by cooperating agencies to handle soil survey data and related physical and environmental data. Many combinations of computers, storage media, input-output devices, and communication facilities are possible.

Even after an ADP system has been designed and implemented, continuous study, testing, and improvement are needed. ADP technology is changing rapidly, and new equipment and new procedures are being developed constantly. As experience is gained, an existing system may need to be improved or replaced.

Automated data processing can manipulate data in many ways. Because most of the data are likely to be needed in different combinations, the basic use of ADP will probably be data storage and retrieval. For this use, precisely and consistently defined records need to be entered into some medium readable by computers and arranged in cataloged files.

These files of soil records are collectively referred to as a soil survey database.

Databases can be distributed between multiple locations or kept in a centralized system, depending on system requirements and facilities available. For example, in the early versions of the National Soil Information System (NASIS) used by the U.S. National Cooperative Soil Survey (NCSS), the database was divided (distributed) among 17 regional databases and each region managed soil survey data for their respective area. In later versions of NASIS, the database was merged (centralized) into a single national database. Currently, all users access the single database to create and manage the data for which they are responsible. A uniform coding system is essential for a consistent format of the data. It permits direct transfer and sharing of data and the use of computer programs to manipulate the data.

Databases can also be classified as transactional or publication. In *transactional database*s, ongoing edits and additions are made to the data. Generally, these databases are used only internally by members of the organization responsible for the database. NASIS is a transactional database. In *publication databases*, the database content is certified and made available to the public. The NCSS's Soil Data Mart is a publication database.

After soil information has been systematically entered into the database and the necessary equipment and operating instructions have been organized, the data are available for many kinds of operations. Computer programs (software) may need to be developed if they do not already exist. Software development is typically the most expensive and time-consuming aspect of data processing. A good data management system can reduce the amount of software needed. Important applications for soil survey include:

1. Answering questions. Examples are: What soils have certain sets of properties? What soils are mapped in specified localities? What soils will produce corn yields of more than 100 bushels per acre (approximately 6,700 kilograms per hectare) under a particular management system?
2. Performing statistical studies, particularly multiple correlations, for many purposes, including testing the numerical limits of values in Soil Taxonomy, determining what soil properties observable in the field correlate well with laboratory results, and determining what observable soil properties reliably indicate soil behavior.
3. Preparing summaries (e.g., summaries of interpretations by soil families, phases of soil families, subgroups, etc.; summaries

of the extent of the different soils in various geographic areas; summaries of the number and extent of soils having selected features such as a fragipan).

4. Arranging and printing out tabular material for soil survey manuscripts and other reports (see appendices). Text that is repeated in published surveys of a given State or region can be stored in finished form and reused as needed.
5. Storing and easily updating lists, such as the classification of soil series.
6. Generating interpretive maps and printing them on demand (see appendix 4). This application is becoming increasingly valuable for soil management and land use planning.

Users of ADP outputs must be aware of the importance of reliable and accurate original information. High-quality data must be entered at the outset. ADP cannot improve the quality of the data; only people can. However, it can be a valuable tool in finding data inconsistencies.

To store soil survey data in electronic format, one or more electronic databases are needed. These databases can become very complex, depending on how many soil attributes are to be recorded and stored and to what degree of resolution or frequency the data are to be collected.

Database design is an important consideration. A database can succeed or fail because of data consistency or the lack thereof. Standards need to be established to help ensure data consistency. It is important that the various tables and attributes or columns within the database be sufficiently defined so that there is no ambiguity as to what information is to be recorded in each table and/or column and in what format. This information describing the database, referred to as "metadata," needs to be made available to those individuals who are collecting and inputting the data into the database as well as to end users. The metadata can prevent the misunderstanding and misuse of the resulting soil data.

The electronic database can also employ a variety of data validation tools and rules to help ensure data integrity and data quality. For example, the database can allow only numeric values to be entered into a data field that is defined as requiring a numeric entry. The system can ensure that only values within a particular numeric range be entered (e.g., only values between 1 and 14 are allowed for pH). Choice lists can be developed to ensure that only approved terms are used for specified data elements and that data entries are consistently spelled.

The actual design and structure of the database is somewhat dependent on the type(s) of data being collected and/or needing to be stored and delivered to end users. It can also vary somewhat based on the database management software (DBMS) that will be used to manage the database.

Standard methodologies or protocols for data collection are needed to ensure that data collected from different locations, at different times, and by different people can be appropriately combined and summarized or evaluated as needed. For example, slope should be measured in the same way and clay content should be determined using the same procedures throughout the survey area.

Recording Data and Information—Field and Lab

Information gathered during the course of a soil survey is recorded in a variety of formats and content. In addition to the basic soil map, important forms of data include field notes, soil profile descriptions, laboratory analytical results, photographs, and drawings. These forms of information work together to ensure a quality survey. The data fall into three basics categories: point data, aggregated data, and spatial data. Each category is discussed in more detail in the following paragraphs.

Point Data

Point data are data that are collected, measured, or observed at a particular geographic location in the field. They generally record a single value for each attribute recorded about the soil map unit as a whole, or an individual soil map unit component, and the landscape in which it occurs. At a specific geographic location at a particular point in time, each attribute only has one value. Attributes may include slope, landform setting, depth to each soil horizon, pH or texture of each horizon, etc. Also included in point data are photographs taken at the sample location and sketches and drawings of the landscape and/or soil profile. Point data can be the results of direct field observations or measurements, analytical result of laboratory measurements from soil samples collected at the location, or the results from ongoing monitoring tools that collect data (such as soil temperature or soil moisture content) at regularly scheduled intervals.

Each piece of point data collected should include a reference to the soil map unit and/or soil map unit component that it represents. This is a part of the correlation process that takes place during the course of the soil survey project (see section titled "Correlation Steps" in chapter 4). The system developed to manage soil survey data needs to have the capability to manage all forms of point data that will be collected.

Soil Map Units vs. Soil Map Unit Components

When conducting a soil survey, the areas outlined on the soil map represent a segment of the natural landscape and are generally referred to as a map unit polygon or delineation. Each polygon is labeled with a map unit symbol that indicates which soil map unit it represents. It displays the extent of the soil map unit on the landscape and is defined as a collection of soil types that occur together in a regularly repeating pattern on the landscape. Each soil type within a particular soil map unit is referred to as a soil map unit component. The soil map unit component generally comprises approximately the same proportion of the map unit in each polygon of the soil map unit (e.g., for soil map unit "10," soil component A makes up 75% of the map unit, soil component B makes up 15%, and soil component C makes up 10%). Map units rarely are 100% composed of any particular soil type.

The level of detail of each map unit component is generally dependent upon the scale at which the soil map is being developed. Small-scale maps (e.g., those at 1:100,000) generally will have more broadly defined map unit components than larger scale maps (e.g., those at 1:12,000). For a more detailed discussion of soil map units and map unit components, see chapter 4.

Field Notes

Field notes include soil profile and landscape descriptions, descriptions of the relationship and interactions between soil components or map units, information on the behavior of the soils, and inferences about how the soils formed. The information delivered to end users to accompany the soil maps for each soil survey is developed based on the field notes. Field notes are used for preparing standard definitions and descriptions of soil series, soil map units, and map unit components and for correlating soils in the national program. They are as important as the map base on which soil map unit boundaries are plotted.

The best notes are recorded while field observations are fresh in the mind of the observer. For example, the description of a soil profile is recorded as it is being examined. Information from a conversation with a farmer is recorded during the conversation or immediately thereafter. Unless notes are recorded promptly, information may be lost. All field notes should be clearly identified. The survey area, date, location, and author are necessary for each note. Each note should be related to an identified soil map unit or map unit component. The source of the information, if not from direct observations, should also be identified.

To be available and useful, field notes must be organized and stored in a standardized manner. Electronic storage is a good solution. Notes that are handwritten in the field can later be scanned and stored in a computer database. Notes can also be recorded on handheld devices using word-processing or note-taking computer software in the field, and the resulting files stored in a standardized file folder structure on the computer.

Field notes must be understandable to all survey personnel. Shorthand notes need to be transcribed to standard terminology. Only common words and expressions, as found in a standard dictionary or technical reference, should be used.

The most important notes record the commonplace, such as the extensive kinds of soils and their properties, the common crops or vegetation, the performance of septic systems, etc. The tendency to record anything other than the commonplace should be avoided, because subsequent efforts to prepare a descriptive legend or make interpretations from such notes will be unsuccessful. However, in the early stages of a soil survey project, differentiating between the "commonplace" and "oddities" may be difficult. As work in the survey area progresses, what appear to be oddities in the beginning may later become commonplace as other parts of the survey area are mapped. Field notes should indicate how closely something represents the commonplace. Survey personnel must first learn to see and record the commonplace, then identify departures from the usual.

Field notes record observations as well as complete descriptions of pedons at specially selected sites. Notes that are made during daily mapping typically are not full descriptions. They may record only color, texture, and thickness of major horizons as seen in auger cores. This information is used to supplement detailed examinations. Notes of this kind are especially important for soils that are not well known and for soils of potential, but questionable, map units.

Field notes include information about the relationship of map units and map unit components to one another, to landforms, and to other natural features. The setting of a soil—its position in the landscape—is important. Landscape features strongly influence the distribution of soils. The properties and extent of the soil and the location of soil boundaries can be deduced from the landscape. The kind of landform or the part of the landform that a particular soil occupies and how the soil fits into the landscape should be described. Soil patterns and shapes of soil delineations are important in relation to large-scale soil management. Landscape identification is discussed in chapter 2.

The kinds and amounts of the various soil map unit components in each map unit, as well as their positions in the landscape, are noted and recorded during fieldwork. The soil map unit components are either identified by name or their contrasting properties are described. Although the kinds and amounts of map unit components vary somewhat from delineation to delineation, an experienced surveyor has little difficulty in maintaining an acceptable level of interpretive purity within a soil map unit. This is due to the fact that most contrasting map unit components (i.e., dissimilar soils and miscellaneous areas) occupy specific, easily recognized positions in the landscape. If a precise estimate of the taxonomic purity of a given delineation is needed, special sampling techniques, such as line transects or point intercept methods, are required.

Notes should be made on soil erosion in particular map units. They could include descriptions of eroded areas, degrees of erosion within and between soil phases, differences in variability among soils and landscape positions, extent of soil redistribution and deposition in map units, and effect of erosion on crop yields and management of the soil.

Soil behavior concerns the performance of a soil as it relates to vegetative productivity, susceptibility to erosion, and a particular land use (such as a foundation for houses or a waste disposal site). Notes on soil behavior, unlike those on the nature and properties of the soil, are obtained largely from the observations and experiences of local land users. Direct observations by field scientists and inferences made from them should be labeled as such.

Notes on behavior focus on the current and foreseeable uses of the important soils in an area. For example, if range is the primary land use in a survey area, information on range production along with plant community descriptions may be needed for all of the soils of the area. Notes on the performance of soils under irrigation, however, would probably be needed as well as where the soils are irrigated or may be irrigated in the future. Information on probable forest growth and plant community descriptions might be pertinent to the purposes of the survey even though it comes from the experience of only a few individuals or a few kinds of soils. An area with a rapidly expanding population needs data on the engineering performance of soils, such as how well the different soils would support houses, what kinds of subgrades would be required for streets and roads, and whether onsite waste disposal systems would function satisfactorily.

Valuable information about the performance of soils can be obtained from observations made in the field while surveying. Soil scientists can see poor crop growth on a wet soil or in an eroded area. They note the failure of a road subgrade or of an onsite waste disposal system in specific kinds of soil. However, data on yields and management practices for specific crops typically come from farm records or experimental fields. If records are not available, such as records that compare crop productivity between eroded and uneroded phases of a soil, special studies and data collection may be needed.

Information on forest growth or range production and the composition of a vegetative plant community also is commonly derived from observations made by others, but it can be supplemented by information recorded by the soil scientist. Most information on the engineering performance of a soil comes from people who work with structures and soil as a construction material. During fieldwork, a special effort should be made to obtain this kind of information from knowledgeable people.

The source of information about soil behavior is evaluated and recorded in the field notes. Inferences are to be clearly distinguished from observations of soil morphology, vegetation, landform, etc. Most notes about how soils formed, for example, are inferences. The condition of growing crops is observable, but statements about soil productivity based on such observations are inferences. That some soil material is nearly uniform silt loam and lacks coarse fragments is directly observed; the conclusion that the soil formed from loess is inferred. Theories formed on the basis of inference should not unduly influence the choice of observation sites or the properties to be observed.

Soil Profile Descriptions

Soil profile descriptions are basic data in all soil surveys (see chapter 3 for a detailed discussion). They provide a major part of the information required for correlation and classification of the soils of an area. They are essential for interpreting soils and for coordinating interpretations between soil survey areas. The soil descriptions and the soil map are the parts of a soil survey project that have the longest useful life.

Field descriptions of soil profiles range from partial descriptions of material removed by a spade or an auger to complete descriptions of pedons seen in three dimensions (from intersecting pits where horizontal layers were removed sequentially from the surface downward). Because most field descriptions of soil profiles are the former, care in making them is essential.

Field descriptions should include, but are not limited to:

- The date, time of day, and weather conditions;
- The name of the describer;
- The geographic location of the site;
- Observed external attributes of the pedon, such as landscape position, landform, and characteristics of slope;

- Inferred attributes of the pedon, such as origin of soil parent material and the annual sequence of soil water states;
- The plant cover or land use of the site;
- Observed internal properties of the pedon, such as horizon thickness, color, texture, structure, and consistence;
- Inferred genetic attributes of the pedon, such as horizon designations and parent material;
- Inferred soil drainage class; and
- The classification of the pedon in the lowest feasible taxonomic category.

The degree of detail that is recorded is somewhat dependent upon whether the description is intended to provide a complete soil profile description for comparisons with other pedons placed in the same taxonomic class or simply to determine the variation of a selected property within a taxon. One should keep in mind that the majority of the time and expense in collecting a description is in finding and getting to the sample site and exposing the soil profile. It is much more economical to get a complete description during the initial visit than to return to the site later. This is especially true when mapping remote areas.

The attributes of pedons, procedures for describing their internal properties, and standard terminology are described in chapter 3. When standard terms are not adequate to characterize all properties and attributes of a soil, common descriptive words are used.

Standard Forms and Terminology

Standard forms are useful for recording the observations and data required in a soil survey. They permit recording of information in a small space. A standard form used to record soil profile descriptions is illustrated in figure 7-1. This is merely an example; no standard form can cover all situations. Forms require modification as more is learned about soils and how to evaluate data. They can be automated to permit electronic recording of the information and limit the need for later data entry. Handheld computers can be programmed, following a standard format, to allow soil information to be entered by workers while in the field. The information can be uploaded later to a computer in the office or to a central database. The office computer can be used for storage of information, sorting, and printing out descriptions. Automated forms can avoid data transcription errors that occur during data entry, thereby improving data quality.

Figure 7-1

USDA-NRCS **PEDON DESCRIPTION** **PEDON ID#:** **2/2012**

Series or Component Name:	**Map Unit Symbol:**	**Photo #:**	**Classification:**	**Soil Moist. Regime (Tax.):**

Describer(s):	**Date:**	**Weather:** **Temp.:** *Air:* *Soil:* *Depth:*	**Latitude:** ° ' " **N** **Longitude:** ° ' " **W**	**Geodetic Datum:**	**Location:** Sec. T. R.

UTM: *Zone:* *mE:* *mN:*	**Topo Quad:**	**Site ID:** *Yr:* *State:* *County:* *Pedon #:*	**Soil Survey Area:**	**MLRA/LRU:**	**Transect:** *ID:* *Stop#:* *Interval:*

Landscape:	**Landform:**	**Microfeature:**	**Anthro:**	**Elevation:**	**Aspect:**	**Slope (%):**	**Slope Complexity:**	**Slope Shape:** *(Up & Dn / Across)*

Hillslope Profile Position:	**Geom. Component:**	**Microrelief:**	**Physio. Division:**	**Physio. Province:**	**Physio. Section:**	**State Physio. Area:**	**Local Physio. Area:**

Drainage:	**Flooding:** **Ponding:**	**Soil Moisture Status:**	**K_{sat}:**	**Land Cover / Use:**

Parent Material:	**Bedrock:** *Kind:* *Fract.:* *Hard.:* *Depth:*	**Lithostrat. Units:** *Group:* *Formation:* *Member:*

Erosion: *Kind:* *Degree:*	**Surface Frag %:** *GR:* *CB:* *ST:* *BD:* *CN:* *FL:* *Kind:*	**P.S. Control Section:** *Ave. Clay%:* *Ave. Rock Frag %:* *Depth Range:*

Diagnostic Horz. / Prop.: *Kind:* *Depth:*

VEGETATION:

SYMBOL	COMMON NAME	% GD COVER

MISCELLANEOUS FIELD NOTES / SKETCH:

Figure 7-1.—continued

Component Name:		Map Unit Symbol:		Date:	

	Obser. Method	Horizon	Depth (in) (cm)	Bnd	Matrix Color Dry	Matrix Color Moist	Texture	Rock Frags Knd % Rnd Sz	Structure Grade Sz Type	Consistence Dry	Consistence Mst	Consistence Stk	Consistence Pls	Notes
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	Redoximorphic Features % Sz Cn Hd Sp Kd Loc Bd Col	Concentrations % Sz Cn Hd Sp Kd Loc Bd Col	Ped / V. Surface Features % Dst Cont Kd Loc Col	Roots Qty Sz Loc	Pores Qty Sz Shp	pH, method Effer (agent) Clay % Sand %	Notes
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

A standard form can serve as a checklist of characteristics that should be recorded. A checklist is especially valuable for beginning soil scientists because it reminds them to record, at minimum, data for the listed properties. Observations, however, should not stop with the listed properties. There is a strong tendency to record the information required by the form and no more. Thus, a form designed to set a minimum on the amount of information recorded also tends to set a maximum. Good soil profile descriptions typically require information beyond that needed to complete the form. Free-form notes are commonly used for this purpose.

Standard forms are useful for recording the day-to-day observations made during mapping. Many such notes are not full descriptions of pedons. These abbreviated descriptions typically can be made on a standard form more easily than they can be written in narrative form. Abbreviated notes are also useful in recording many observations during field reviews and when transecting. For these and similar purposes, the forms make note-taking easier and lessen the risk of recording an inadequate description. Complete descriptions of pedons, such as those made when soils are sampled for special studies or those of the typical pedons of soil series or map unit components, generally require a more comprehensive form or recording device so that all characteristics can be adequately described.

Standard forms, whether in hard-copy or electronic format, generally require the use of abbreviations or symbols due to limited space. These abbreviations or symbols should follow a standard format so that the recorded information can be readily and accurately interpreted by others and correctly transcribed to standard terminology. The codes in the *Field Book for Describing and Sampling Soils* are examples (Schoeneberger et al., 2012).

All soil profile descriptions, regardless of their completeness or the format in which they are recorded, should become a part of the permanent record of the soil survey area so that they are available for use by others.

Photographs

Photographs are a significant component of soil survey data collection and documentation. They can illustrate important things about an individual soil or a soil catena in soil survey reports, scientific journals, textbooks, and periodicals. They can be included in any electronic presentation of soil survey data to end users. Good photographs provide records and reference sources of basic soil information. Taking photographs needs to be planned early in the soil survey.

Photographs that include a scale are useful in estimating volume, area, or size distribution. The comparison of coarse fragments in a soil against photographs of known quantities of coarse fragments improves the reliability of estimates. Similar photographic standards can be used to estimate volume or size of nodules and concretions, mottles, roots, pores, and rock fragments. In a similar manner, photographic standards can be used in estimating area or the special arrangement of surface features and land use.

Equipment for Field Use

A good-quality camera is important in obtaining high-quality photos. Digital cameras are the general norm today. A digital camera allows the image file, along with its respective metadata, to be stored in a database file system for later use. The camera needs to provide resolution greater than 8 megapixels (at least 16 megapixels is preferred) to produce high-quality images. The ability to vary the aperture and exposure time settings is desirable. Many of the larger point-and-shoot cameras and 35-mm single-lens reflex digital cameras are adequate.

A tripod is generally necessary, especially at shutter speeds below 1/50 second. It reduces camera movement and enables the photographer to concentrate on composition and focus. A flash is needed in some poorly lighted situations or to eliminate shadows.

Certain other items are necessary for good pictures of soil profiles. A scale that indicates horizon depth or thickness is important. A scale that does not contrast greatly with the soil, such as an unvarnished and unpainted wood rule or a brown or khaki colored cloth tape that is 5 cm by 2 m works well. Large black or yellow figures at 50-cm intervals, large ticks at 10-cm intervals, and small ticks at 5-cm intervals complete the scale. A perfectly vertical scale increases the quality of the photo, in contrast to a tilted scale.

A small spatula, kitchen fork, or narrow-bladed knife is useful in dressing the soil profile. Paint brushes of various widths and a tire pump can help clean dust from peds. A sprayer can be used to moisten the profile when necessary.

Photographing Soil Profiles

Careful planning is essential for obtaining high-quality photographs of soil profiles. A representative site is selected on a vertical cut face or in an area where a pit can be dug large enough for adequate lighting of all horizons and for the camera to be 1.5 to 2.5 m from the profile. The pit or cut face should be oriented so that the maximum amount of light will strike the prepared face at the proper angle when photographed. Better images are generally obtained when the soil profile is either in full sun or full shade. Subtle differences in soil color are often more apparent on cloudy days than in full sun. Direct exposure to full sunlight often results in a washed out image.

The profile needs to be properly prepared to bring out significant contrast in structure and color between the soil horizons. Beginning at the top, fragments of the soil can be broken off with a spatula, kitchen fork, or small knife to eliminate digging marks and expose the natural soil structure. Dust and small fragments can be brushed or blown away. Moistening the whole profile or part of it with a hand sprayer helps to obtain uniform moisture content and contrast.

Every profile should be photographed three or four times with different aperture settings, angles of light, and exposure times. Notes should be made immediately after each photograph is taken to record location and date, complete description of the subject, time of day, amount and angle of light, camera setting, method of preparing the profile, and other facts that are not evident in the photograph. Besides increasing the ways the photograph can be used, good notes provide information for improving technique. If possible, a landscape photograph should accompany the soil profile photograph.

Photographing Landscapes

Landscape photographs illustrate important relationships between soils and geomorphology, vegetation, and land use and management. They should be clear and in sharp focus and have good contrast. Photographs representative of the area being mapped are the most useful.

The most important thing in landscape photography is lighting. The best pictures are made at the time of day and during the time of year when the sun lights the scene from the side. The shadows created by this lighting separate parts of the landscape and give the picture depth. If the sun is at a low angle to the horizon, shadows are generally amplified and give an image more contrast and depth. Photographs taken at midday or with direct front lighting can lack tonal gradation and, therefore, appear flat. Photographs taken on overcast days can have the same problem. A small aperture should be used to gain maximum depth of focus.

Photo composition is important. A good photograph has only one primary point of interest. Objects that clutter the photograph (e.g., utility poles, poorly maintained roads and fences, signs, and vehicles) detract from the main subject. The point of interest should not be in the center of the photograph. The "rule of thirds" for composition is useful when looking at the scene through the viewfinder. The image area can be visualized as divided into thirds both horizontally and vertically.

The center of interest should be one of the four points where these lines intersect. Sky should make up less than one-third of the image, and the camera should be kept level with the horizon. In addition, landscape photographs should be taken from a variety of angles (e.g., from a kneeling position, on a ladder, on top of a car or low building, etc.).

Close-up Photography

Many soil features, such as peds, pores, roots, rock fragments, krotovinas, redoximorphic features, concretions, and organisms, can be photographed at close range. The minimum focusing distance for most cameras used in the field allows small features to be photographed. Many cameras have a built-in macro focus feature that enables focusing within a few inches. Macro lenses are available for most 35-mm cameras. Close-up attachments for conventional lenses are also available. As with landscape photography, the lighting angle is important. Direct front lighting tends to blend texture, separation, and contrast in the photograph.

Photographing clay films and other minute soil features requires special equipment and techniques of photomicrography that are outside the range of this manual.

Metadata

For each photograph, metadata should be recorded, including the date of the photo, the geographic location, a description (caption) of what the image is intended to show, and a reference to the map unit(s) and soil components of the area.

Aggregated Data

Aggregated data capture the ranges of various physical and chemical properties of soil map units as a whole and individual soil map unit components. They include the descriptions of each soil map unit and map unit component; the detailed physical, chemical, and morphological attributes of each soil; and descriptions of the relationship of one soil map unit to another on the landscape. Aggregated soil property data generally are the data used to generate interpretive ratings for each map unit and its components.

Aggregated data are developed by summarizing the various pieces of point data that have been collected during the soil survey and referenced to a particular soil map unit or map unit component. Values for a particular soil property are commonly expressed as a range. Depending on mapping scale, map unit design, and the level of specificity of data needed for the purpose of the soil survey, the upper and lower limits and, in most cases, a representative value (RV) of the range of each soil property need to be stored in the database (e.g., clay content ranges from 18 to 27%, with an RV of 22%). The representative value is the value most likely to be found for a particular soil property and is useful in computerized interpretive models. The RV can be determined by summarizing the values recorded on the individual pieces of point data. Tacit knowledge from individual soil mappers can be used to augment recorded point data measurements.

The physical, chemical, and morphological properties of the soils included in the aggregated data generally are most or all of those that are included in the point data. They should include any properties that are used to generate interpretive ratings.

Values for many physical and chemical soil properties of a particular soil map unit or map unit component commonly vary from one topographic position to another, or from one geographic location to another, within a particular map unit or even a single delineation of a map unit. Properties can also vary from one time of the year to another, from year to year, and from one land use and/or management system to another (see chapter 9 for a discussion of dynamic soil properties). The database must have the capability to record this variability.

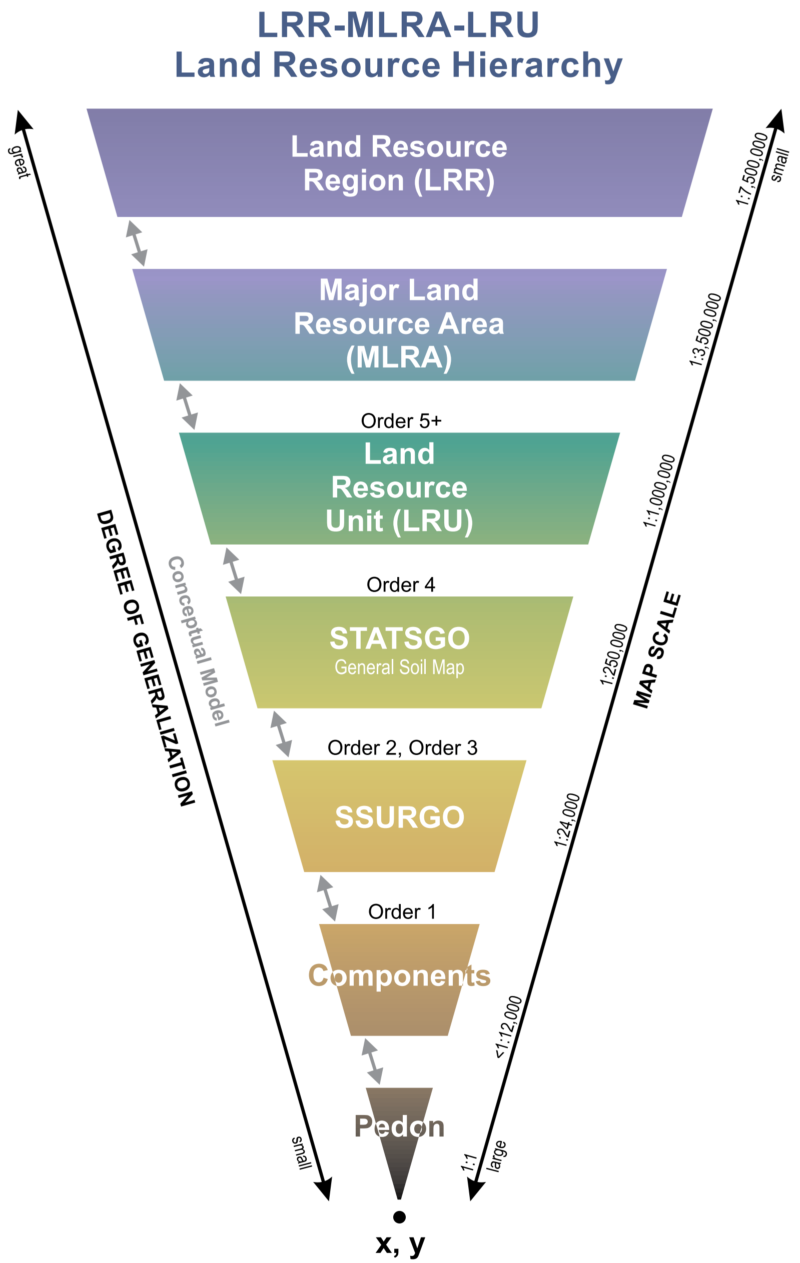
Aggregated data may represent map units that cover a particular geographic area at different map scales, for example, 1:12,000 or 1:24,000 and also 1:100,000 or 1:250,000. The differences in scale may represent a "detailed" soil map of the area and a "generalized" soil map of the same area. Map unit design and the respective map unit components will generally differ between the larger (e.g., 1:24,000) and smaller (e.g., 1:250,000) map scales. Types of soil map units and map unit design are described in more detail in chapter 4.

The U.S. National Cooperative Soil Survey and NRCS routinely produce and maintain soil data and map products at a variety of map scales. Figure 7-2 illustrates the hierarchical relationship between these aggregated data products and the original point data. The two primary soil survey products are SSURGO (Soil Survey Geographic Database) and STATSGO (U.S. General Soil Map).

Also included in the aggregated data are the various interpretive ratings for each soil map unit and each map unit component. Some ratings are applicable to the map unit as a whole (e.g., prime farmland rating), while others are applicable to the individual map unit components (e.g., limitations for building site development).

In order for soil survey data to be delivered to end users, aggregated data are commonly stored in a relational database. The database must be designed to store data for delivery and to support the various soil interpretations that are needed. Determining what will be delivered to users

Figure 7-2



Conceptual model showing the relationships and degree of generalization of data between different map scales and products. (See chapter 4 for a discussion of orders of mapping.)

at the end of the soil survey project (such as which chemical, physical, and morphological soil properties and which landscape relationships) helps in determining what data needs to be collected as point data.

Spatial Data

Spatial data is a major portion of the data collected or developed during a soil survey. It includes the geographic coordinates (e.g., latitude and longitude) that define the boundary of each map unit polygon on the soil map, whether it is in vector or raster format. It also includes the geographic coordinates for each point on the landscape where point data were collected. Boundaries of various political and physiographic areas may also be included as ancillary data layers. Other ancillary data layers, such as vegetative cover, digital elevation model (DEM) data, aerial photography, land use, and geology, are commonly used in a geographic information system (GIS) when conducting a soil survey. Derivative data layers (those developed from other data layers), such as wetness index, slope, and aspect, are also commonly used. Various soil property and interpretive maps can be developed using a GIS. A detailed discussion of digital soil mapping is provided in chapter 5. The appropriate scale and level of resolution or detail are important considerations when choosing which data layers to use.

The design of databases to house soil survey data must include a mechanism to link each individual map unit polygon on the soil map with the appropriate set of aggregated data describing the characteristics of the map unit represented by the polygon. The map unit symbol on the soil map is commonly used for this purpose.

To ensure that resulting spatial data are consistent and practicable to end users, standards for spatial data layers must be developed and/or adopted just as they are for collecting soil property data in the field. This includes the digitizing of soil maps. Establishing standards is especially important for large soil survey projects, which involve many soil survey parties. In order to get a consistent data set, the various soil survey parties must use standardized methods and techniques.

Because spatial data sets tend to be very large, adequate storage space must be considered when developing a computer system to manage soil survey data. In the U.S. soil survey database, the spatial data layer for the detailed soil maps occupies approximately one-third of the whole database. Another third is occupied by the associated aggregated soil attribute data, and another third by the included generated soil interpretation ratings. Additional storage space must be available for other data layers used in conducting the soil survey.

Soil Information Systems

As described earlier, a soil information system not only includes the actual soil survey data and information but also the various methods, computer applications, and processes used to collect, manage, store, and disseminate the data to end users. A variety of tools are available for electronically collecting soil data in the field. Data recorders can be connected to monitoring equipment to measure and record soil temperature and soil moisture at regular time intervals over an extended period of time. The data can then be imported into a permanent database.

Handheld, tablet, and laptop computers can be programmed to display a variety of field forms. Data can be manually entered into digital memory in the field and later uploaded to a central soil database. Analytical instruments in the laboratory can be connected to a computer to automate the recording of analytical test results. Global positioning systems (GPS) and digital cameras can be connected to these computers so that geographic coordinate data and photographs can be linked to other data being collected. Computers with GIS software allow the user to draw the soil map electronically in the field instead of manually on a hard copy. Capturing data electronically eliminates the need to later key the data values into the computer. This greatly increases work efficiency and eliminates a possible source of data entry error.

Techniques are being developed to allow the field soil scientist to generate a preliminary soil map using computer algorithms or programs that replicate the interaction of the five soil-forming factors, i.e., topography, climate, parent material, living organisms (especially native vegetation), and time. These algorithms use logic developed by soil scientists knowledgeable of the area being surveyed. This approach to developing the soil map, referred to as digital soil mapping, is discussed in detail in chapter 5.

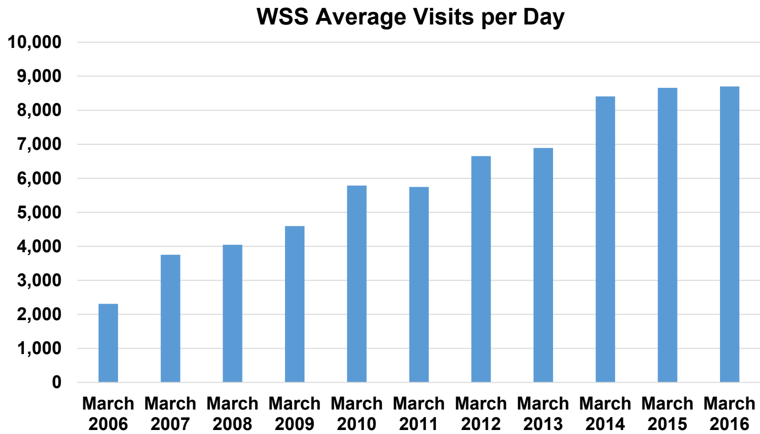
Computer applications are very useful in managing, editing, and delivering soil survey data collected in the field. They provide the capability to more readily update the soil maps and associated data and to keep the information current. Thus, they allow quicker and easier regeneration of end products and publication of the updated information.

As with any computerized system, the system itself needs to be kept up-to-date. New versions of software will need to be installed. Computer hardware eventually will need to be repaired or replaced. People will need to be trained on how to use the system. Issues and questions will occur on a day-to-day basis as problems arise with the system. They will require personnel with information technology skills as well as those with soil business skills.

Uses of Soil Survey Information

The demand and use of soil data and information is growing at a rapid pace. Figure 7-3 illustrates the increased number of users of NRCS's Web Soil Survey application. Web Soil Survey (Soil Survey Staff, 2016) was implemented in 2005 and is the agency's primary public distribution tool for official soil survey data and information. The variety of users is also expanding. Soil surveys most commonly are made for areas that have more than one kind of important land use and for users who have varied interests and needs. These needs may be few and noncomplex, as in areas of extensive land use where change is not expected, or they may be many and complex, as in areas of intensive land use where changes are expected.

Figure 7-3



An illustration of the increased number of users of NRCS's Web Soil Survey (WSS) application.

Predictions for uses of soils other than farming, grazing, wildlife habitat, and forestry have tended to concentrate on limitations of soils for the intended uses. Where investment per unit of area is high, modifying the soil to improve its suitability for the intended use may be economically feasible. Soil scientists work with engineers and others to develop ways of improving soils for specific uses. Such predictions are increasingly important in areas where the demand on soil resources is high.

The information assembled in a soil survey may be used to predict or estimate the potentials and limitations of soils for many specific uses. The information must be interpreted in forms that can be used by professional planners and others. A soil survey represents only part of the information that is used to make land management plans, but it is an important part. Chapter 8 discusses soil interpretations in detail.

The predictions of soil surveys serve as a basis for decisions about land use and management for both small tracts and for regions consisting of several million acres. They must be evaluated along with economic, social, and environmental considerations before recommendations for land use and management can be valid.

Soil surveys are used to appraise potentials and limitations of soils in local areas having a common administrative structure. Planning at this level is sometimes called *community planning*. It applies to community units (villages, towns, townships, counties, parishes, etc.) and to trade areas that include more than one local political unit.

Soil surveys also may be used to evaluate soil resources in multi-county or multi-State areas that have problems that cannot be resolved by local political units. *Regional planning* involves land use in broad perspective and appraises large areas. It is done in less detail than community planning. Soil surveys and their interpretations for regional planning are correspondingly less detailed and less specific. Soil maps and their interpretations for regional planning must provide graphic presentations of the predominant kinds of soil of corresponding large areas.

Soil surveys provide basic information about soil resources needed for planning development of new lands or conversion of land to new uses. This information is important in planning specific land uses and the practices needed to obtain desired results. For example, if recreational use is being considered, a soil survey can indicate the limitations and potential of the soil(s) in the area of interest for recreational uses, such as playgrounds, paths and trails, or off-road vehicle use. It can help a landscape architect properly design the area. A contractor can use the soil survey in planning, grading, and implementing an erosion-control program during construction. A horticulturist can use it in selecting suitable vegetation for landscaping.

Soil surveys provide a basis for decisions about the kind and intensity of land management, including those operations that must be combined for satisfactory soil performance. For example, soil survey information is useful in planning, designing, and implementing an irrigation system for a farm. Information regarding the kind of soil(s) and associated characteristics helps in determining the length of run, water application rate, soil amendment needs, leaching requirements, general drainage requirements, and field practices for maintaining optimum soil conditions for plant growth.

Soil surveys are also useful in locating possible sources of sand, gravel, or topsoil. They are an important component of technology transfer from agricultural research fields and plots to other areas with similar soils. Knowledge about the use and management of soils has been spread by applying experience from one location to other areas with the same or similar soils and related conditions.

The hazards of nutritional deficiencies for plants, and even animals, can be predicted from soil maps if the relationships of deficiencies to individual soils are established. In recent years, important relationships have been discovered between many soils and their deficiencies of copper, boron, manganese, molybdenum, iron, cobalt, chromium, selenium, and zinc. The relationships between soils and deficiencies of phosphorus, potassium, nitrogen, magnesium, and sulfur are widely known. Relationships of soils to some toxic chemical elements have also been established. However, many soils have not been characterized for these conditions (especially for trace elements) and more research is needed.

Soil surveys commonly provide essential data and information for the compilation of general soil maps. Many soil surveys are done for purposes that require relatively intense field investigation and map scales of about 1:12,000 to 1:24,000. However, a smaller scale soil map with more broadly defined units may be better for developing land use plans for large areas. General soil map scales range from about 1:100,000 to 1:1,000,000 and provide an overview of the location and extent of dominant soils in a large area. A general soil map can be made by grouping units of the large-scale soil maps and generalizing the map detail. The resulting map units may be more useful for the intended use. The amount of information that can be given about the units on a general soil map—and, therefore, the number of feasible interpretations—depends on the degree of generalization of the map units, which is determined by the map scale. Computer applications such as GIS greatly facilitate the summarization and generalization of detailed soil survey data during the development of the smaller scale soil map units.

Small-scale soil maps can provide a basis for comparison of broadly defined capabilities and limitations that relate to the soil on regional, national, and even worldwide scales. International cooperation among soil scientists has accomplished much in relating the different soil classification systems of various countries to one another using small-scale maps. This permits the findings of research on soils of one country to be extended to similar kinds of soil elsewhere. *Soil Taxonomy* (1975 and 1999) and the *Soil Survey Manual* (1951 and 1993) have guided soil scientists worldwide for many years. Many have contributed ideas and data to the soil survey system. As a result, the uses of soil survey data have been extended far beyond the boundaries of the countries where the data were originally obtained.

Dissemination of Soil Survey Information

Mechanisms are needed to deliver completed soil survey information to end users. Depending on the needs of the users, a variety of types, content, and formats of soil survey products may be needed. Each type of product may require a somewhat different mechanism for delivery.

Some users may want the raw data collected during the course of the soil survey project delivered to them in digital format. Others may want hard-copy printed soil maps along with the associated descriptive information of each soil map unit and the respective map unit components and interpretations. Some users may need access to the most up-to-date information available for the area and want to see it in an online computer application that allows them to zoom into a particular tract of land. They may not need or care about the data for the whole soil survey area. They may only be interested in soil survey data and interpretations that pertain to a particular land use. Other users may only be interested in soils data for larger areas for regional planning.

Some users prefer to have direct online access to soil data so that they can integrate this data with other data systems and applications on their local computer. Web services are tools that have been developed to accommodate such access. With these services, the user can connect to the database in a read-only mode and then query the spatial and tabular data for the geographic area of interest. These services also allow the user to have access to the most up-to-date data available without having to acquire and maintain the data on their local system. With the increased use of computers and geographic information systems and other applications, this method of disseminating soil survey data and information is becoming more widespread and popular.

Requests for soil survey data and information are commonly received while the survey is still in progress. Decisions must be made as to how to handle such requests and what data and/or information is suitable to be released at the time of the request. Any information provided should be marked as “preliminary” and “subject to change” until it has been fully reviewed and certified. Some requests may include the need for specialized interpretations of the data, and a mechanism should be available to provide those interpretations if at all possible.

Soil survey data and information, including both tabular and spatial data, can be delivered to end users in various formats. Tabular data include the map unit and map unit component descriptions; their physical, chemical, and morphological data; and interpretations of each soil for a variety of uses. Spatial data include the soil map unit boundaries and location for any point data that were collected within the survey area. Photographs are commonly included to illustrate the different soil landscapes within the survey area and to show significant features of the different soils. Narrative text is also included to convey information to the end users that may not be represented in the tabular data and to describe relationships between the different soils of the area.

Tabular data can be delivered to users as raw data in electronic database format, either online or in a standalone database file that can be loaded onto their local computers. The data can also be presented as formatted reports of various content. These reports can be delivered as electronic files for viewing or as hard-copy printouts. Tabular data can also be presented as thematic maps that incorporate the spatial data for the map unit delineations (see appendix 4 for examples). Depending on the scale of mapping and the map unit design, individual delineations may be represented on the map as polygons, lines, or points.

Thematic maps display a rating for each map unit delineation. If a particular soil map unit has multiple map unit components and the components may have different interpretive ratings for a particular interpretation, ratings need to be aggregated so that a single overall rating for the map unit can be delivered. This aggregated rating can then be assigned to the applicable delineations for that map unit. Various aggregation methods may be used, such as dominant component and dominant condition. For example, a map might show the distribution of a soil property, such as surface layer pH or surface layer clay content. The various interpretations, such as suitability or limitations of each soil map unit for septic tank absorption fields, can also be presented in formatted reports or as thematic maps.

Soil maps can be presented as digital files for use on a local computer. The digital files can be the raw data representing the soil map unit boundaries or contain formatted soil maps that can be viewed on the local computer or printed locally. The map unit boundaries can be presented in vector or raster format. In vector format, the map unit boundaries are defined by a series of x y coordinates (such as latitude and longitude) that, once plotted, replicate the shape of the original map unit boundaries drawn on the map. In raster format, the soil map is divided into a gridded format in which each grid cell is at a resolution that best represents the shape of the original soil map unit polygons. Popular resolutions include 10- and 30-meter, meaning that each grid cell represents an area 10 by 10 or 30 by 30 meters on the Earth's surface. Corners of each grid cell are defined by standard latitude and longitude or UTM coordinates. Both vector and raster formats have advantages and disadvantages. Soil maps can also be delivered as printed hard copies.

During the course of the soil survey project, special studies of selected soils within the survey area or region may be conducted. These studies may involve detailed laboratory examination of the physical, chemical, and mineralogical composition of the soils. Other studies may focus on the genesis of the soils or the geomorphology of the area. Results of such studies are used to help populate the soil database for the survey area and are commonly published in special soil investigative reports and scientific papers in technical journals. Papers discussing the studies are commonly presented at meetings of professional scientific organizations.

Whatever system is developed to collect, store, manage, and deliver soil survey data and information, the variability of formats and content of information disseminated must be considered. Demands for soil survey information are changing and are expected to continue to change at an even faster pace. The system will likely need to be changed to meet future needs and demands. The idea of "one size fits all" or "one product meets all user needs" is no longer appropriate. Any system that is developed to deliver soil survey information must have built-in flexibility so that it can be updated and modified to meet the ever changing needs of users. However, it is important to remember that the more flexibility one builds into the delivery system the more maintenance and upkeep cost will be required in the years to come.

History of Soil Data Management in the U.S.

The development and evolution of a national system to collect, store, manage, and disseminate soil survey data and information for the U.S. National Cooperative Soil Survey (NCSS) began in the late 1960s and early 1970s and included several iterations. As with other information technology, the pace of development and functional capacity has steadily accelerated since the mid-1990s.

The First Generation

The USDA Soil Conservation Service (SCS), renamed the Natural Resources Conservation Service (NRCS) in 1994, first established a national soil database in the early 1970s through a cooperative agreement with the Statistical Laboratory at Iowa State University (ISU) (Fortner and Price, 2012). ISU was chosen because of its long history of cooperative work with the SCS, dating back to the 1940s. Programming work for a soil database began in 1972 with automation of the soil interpretations record (SIR), or SOI-5 form, which was used primarily as an input form to generate tables on engineering uses of soils for published soil survey reports. The SOI-5 form was first developed in the late 1960s. At least one SIR was developed for each soil series recognized in the soil survey of the United States. Some soil series had more than on SIR, depending on how many phases of the series were recognized and mapped.

Computer programs were developed to store, check, and print the data. The soil interpretation record for the Cecil soil series (NC0018) was the first one stored on the ISU mainframe in 1973. In 1974, the generation of manuscript tables of soil properties for inclusion in soil survey reports was introduced. Initially, all data processing was done at ISU and a printed copy of the tables was sent through the mail. The SOI-5 forms, along with the SOI-6 forms, which were used to enter specific map unit information for the soil surveys, were mailed from SCS offices to ISU for processing. Printed copies of revised records and generated tables were mailed back to the SCS office requesting the tables. This automated table generation system replaced the very tedious, time-consuming manual process of creating tables for the published reports.

With the availability of this useful product came a much greater interest in storing data in the computer system. In 1977, the system gained the capability to automatically generate soil interpretations for 26 selected (mostly engineering) uses from the soil data stored in the database using programmed criteria. These interpretive ratings were stored in the database and printed on the hard-copy SOI-5 forms. After 1977, other enhancements were developed, including the addition of the Official Soil Series Description (OSD) and Soil Series Classification (SC) databases.

Computerization in SCS offices for processing soil survey data began in 1977 with Linolex word-processing equipment in SCS National Technical Center offices. This equipment was used to prepare manuscript tables received on magnetic tape from ISU for final publication. Remote access to ISU from SCS, in both State and regional offices, began in the early 1980s with Harris Remote Job Entry equipment. Communication was through 4800-baud dial-up communication ports. It was a time of significant change as batch software had to be redesigned for remote usage and data entry. Processing and printing of manuscripts shifted from ISU to SCS offices.

The SIR database remained operational until 1996, when it was retired after the release of the new National Soil Information

System (NASIS) software and database. About 35,000 SIRs were developed during the 24 years that the SIR database was active.

The Second Generation

Work on the second generation of the national soil database began in 1978, when SCS developed a computer program to rate soils for prime farmland and other important farmland classes and create maps for the Colorado Important Farmlands project. This project required the rating of about 4,500 soil map units in Colorado. It used national criteria for prime farmland and State criteria for farmland of State importance and unique farmland. The most difficult problem was making ratings consistent across soil survey areas. The program evaluated 10 soil characteristics and was fairly accurate in its ratings. However, a large database was required to make the ratings and the effort required to develop the database made the project unfeasible. The need for a large database, which would also be readily accessible and easy to manipulate, resulted in the development of concepts for the second generation of soil information management.

These concepts were first documented in 1980 in the first technical report for the Colorado Soil Resource Information System (SRIS). SRIS demonstrated the feasibility of integrating several natural resource databases into a common, easy-to-use data environment. SRIS included: (1) a soil map unit component database, (2) a soil interpretation database, (3) a pedon characterization database, (4) a climatology database, (5) a plant database, (6) a soil management component, and (7) a schema for the data and description of the system. SRIS was the first effort to manage soil data using a new technology called database management systems (DBMS). The new information system allowed questions relating to more than one natural resource to be answered. It facilitated easy access to soil information and allowed the data to be managed independently of the application software that accessed it, while the SIR database required a computer program to be written for each unique request. In 1982, the SRIS soil database was implemented in Colorado.

As an outgrowth of the SRIS effort, SCS established the software development staff at Fort Collins, Colorado, in 1985. The mission of this staff was to develop computer software to assist the SCS field offices. In 1987, this effort resulted in the deployment of the Computer Assisted Management and Planning System (CAMPS) field office software and the State Soil Survey Database (SSSD). SSSD, which was a UNIX-based application and used Prelude RDBMS software, was the culmination of the SRIS effort and was populated using map unit specific information and querying the SIR database. The resulting soil survey data collectively were called the Map Unit Interpretation Record (MUIR) database.

With the release of SSSD in 1987, SCS State offices were equipped with UNIX computers. The SSSD software allowed the State offices to manage their portion of the soil survey databases, which were downloaded from Iowa State University via telecommunications. The primary function of the first release of SSSD was to review the included soil data, make necessary edits, and provide a download of the MUIR database to CAMPS. The first release of SSSD provided the ability to develop reports through standard database queries and manage nontechnical soil descriptions. With this software release also came the recognition that a soil scientist position (soil dataset manager) was needed at each SCS State office to manage the soil information system.

Using SSSD, the SCS State offices could edit the soil map unit property and interpretation (MUIR) data at ISU and thus more accurately represent local conditions. The offices returned a copy of the edited data to ISU. This editing capability provided for a national collection of MUIR data in 1993. SSSD releases in 1988 through 1993 added additional capabilities. In 1988, the Pedon Description Program, version 1.0, and the Official Soil Series management and soil reports modules were released.

In 1989, the interface between the Soil Survey Geographic Database (SSURGO) and the Geographic Resource Analysis Support System (GRASS) was released. In 1989, a UNIX mail system called SoilNet and an automated version of the SOILS-6 form, which was used to record map unit data and facilitate the downloading and managing of MUIR data from ISU, were released. In 1991, the Soil Survey Schedule module was released. This module provided management, scheduling, and record-keeping software for SCS State and national offices to use in soil survey efforts. In 1993, the Hydric Soils, Range Site, and MUIR incremental update modules were released.

Although table generation remained its primary purpose, the MUIR database was soon used for more than developing soil interpretation tables for reports. SCS began to use the database to answer questions on a wide range of soil-related issues across the United States, for example, the extent of salt-affected soils, soil loss tolerance and erosion potential for determination of highly erodible land, and identification of hydric soils (wetlands). The uses of the soil database continued to expand and change until it became apparent in 1988 that SSSD and MUIR could not meet the changing needs. New information systems technology was available that could advance the use of soil survey information.

The SIR and MUIR soil database system was remarkable in that it was able to evolve in many ways over time but still kept its basic system design for about 25 years, until it was retired in 1996. At that time, the MUIR database contained data from about 2,900 soil survey areas and included approximately 250,000 soil map units. Implementation of the replacement system, the National Soil Information System (NASIS), began in 1994. Before the SSSD system was retired, the soil information in the MUIR database was converted to the new NASIS database.

The Third Generation

Development of NASIS began with the analysis and documentation of the business of soil survey from beginning to end. Teams from various levels in the U.S. National Cooperative Soil Survey (NCSS) were established to complete the requirements analysis. Using structured systems analysis, these teams documented requirements, which were passed on to contract software programmers. This analysis documented the important shift of the NCSS from producing static, printed soil survey reports to providing a dynamic database of soil information that could meet a wide range of needs and the ever growing demand for soil survey data and information.

A field data collection system was needed to ensure the integrity and completeness of the data, including geographic coordinates. The system was designed to provide users accurate and complete soil survey information based on what was observed during the soil survey process. Implicit in this idea was the ability to describe accurately the variability of soils and their properties as they occur on the landscape. This new system had to provide for a continuous update of the database as new information was gathered, so that one version of these data would be available to users at the field, State, and national levels.

NASIS had to provide a means for a variety of scientists to develop interpretation criteria and generate soil interpretations based on local, State, or national requirements. For example, at the local level there might be a need for an interpretation of soil suitability for animal waste disposal and at the national level there may be a need for a soil productivity index. To ensure consistency, these interpretations must be applied to only one nationally consistent version of the data. The system had to provide for effective and efficient data delivery, including easy access by both internal and external (non-NCSS) users. This information needed to be delivered with a common data structure, data dictionary definitions, and appropriate metadata so that users could understand the information and apply it appropriately.

NASIS System Objectives

Many weeks of analysis (discussion) and numerous follow-up meetings identified the following specific system objectives (Soil Survey Staff, 1991):

- The placement of automated tools in the hands of field office staff
- One-time data entry, so that data could be retrieved by multiple software modules in various computer programs
- A simple means of entering data in the same format as that used during data collection
- Validations to ensure proper entry of data and algorithms to provide default values
- Automated procedures for correlation and quality assurance
- Flexibility of the system to adapt to changes in procedure and standards and to new data needs and policies
- Capability to aggregate large-scale digital soil maps to smaller scales based on user-defined criteria
- Data manipulation and retrieval options for all databases and software modules that include modeling capability
- The ability to use single property values or representative values, in addition to ranges, in models
- Capability to indicate confidence limits and the reliability of map unit data
- Continuous update of national, State, and field office soil survey databases
- Access to State and national databases to enter or edit data managed at appropriate office level
- Permanent storage of all soil survey documentation
- Capability to transfer data files between various kinds of equipment
- Two-way linkages to other natural resource databases
- Software modules that are interactive, menu driven, and user friendly
- Training on how to use the new system

NASIS Software Development and Implementation

As with the SSSD software, the initial releases of the NASIS software were in successive yearly versions. New or updated functions and capabilities were added with each release.

- Version 1.0, released in 1994, was implemented in each SCS State office. Each State held and managed the data for their respective soil survey areas. NASIS 1.0 was developed in the C+ programming language using the X Window system, a UNIX-based graphics window system. Similar to the Microsoft Windows application that comes on many personal computers, the X Window system is a graphical user interface (GUI). INFORMIX was selected as the NASIS database management software (DBMS) largely because of its security features. This proprietary design enabled the construction of a system that prevents most accidental or intentional corruption of data. NASIS allows different data records in the database to be owned by different individual users or groups of users, so that only qualified scientists can edit or create data. The owner of an object has the authority to change data as needed. Individual or group ownership can be established as needed.

  Version 1.0 provided validation and conversion of MUIR data to the NASIS database structure; a security system and controls; an operational data dictionary; editors for areas, legends, and data map units; and online help. Individual NASIS users accessed the system using a Web-browser-based interface that connected to their respective State database for data input and editing.
- Version 2.0, released in 1995, provided Cut, Copy, and Paste functions for data objects, a query editor and manager, global assign functions, report generation, and an enhanced online help system.
- Version 3.0, released in 1996, provided calculation and validation routines for data and the ability to create criteria for interpretations and generate interpretations. This was a major step that allowed for the creation of specialized interpretive criteria and the evaluation of each map unit component against those criteria.
- Version 3.1, released in 1997, provided for the replacement of the national MUIR data with NASIS data and consolidated NASIS databases from individual State offices to the original 17 MLRA soil survey regional offices. It provided downloads to the NRCS field office computing system (FOCS) and downloads of SSURGO-format datasets. Releases of versions 1.0 through 3.1 primarily addressed the development and management of map unit data.

- Version 4.0, released in 1998, provided data tables for storing site and pedon description data and incorporated capabilities for input of and access to pedon descriptions and soil site information. It also replicated storage of national map unit data via the Internet at ISU and data sharing via the Internet.
- Version 5.0, released in 2001, further consolidated the NASIS database to a central server environment at the NRCS Information Technology Center in Fort Collins, Colorado. Data storage at ISU was discontinued.
- Version 5.2, released in 2003, included the capability to export datasets to the Soil Data Warehouse for each soil survey area.
- Also in 2003, Version 2.0 of the Soil Survey Geographic (SSURGO) data model was adopted and implemented for the distribution of official soil survey tabular attribute data. Concurrently with this release, the Soil Data Warehouse and Soil Data Mart were implemented (see below).
- Beginning in 2004, development of a new generation of NASIS began. As a result, NASIS 6.0 was released in 2010. This version introduced a client-server-based environment where the user interacted with the national soil database on the central server using a version of the NASIS application on their local personal computer. It is a Microsoft Windows-based system using a .NET operating system and SQL Server DBMS.

  NASIS 6.0 introduced the concept of managing soil survey data by projects rather than the traditional soil survey areas (typically county-based legends). This concept promoted designing map units on the basis of their natural geographic occurrence rather than limiting their spatial extent to geopolitical boundaries. A process of data updating and recorrelation was begun to ensure a seamless join of spatial and attribute data between soil survey areas. As a result, soil properties, qualities, and interpretations of map units and their components extend across geopolitical boundaries to their full natural extent.
- Periodic minor releases of NASIS continued to add new functionalities to the system and refine the data model as needs changed.
- In 2014, Version 7.0 of the NASIS database was released. It included the addition of data tables to house vegetation-related point data collected as part of the Ecological Site Inventory. These data will be used to develop Ecological Site Descriptions of the

U.S. The data model allows pedon descriptions and laboratory analysis data from a given location to be related to vegetation data from the same location. Existing vegetation inventory data from other existing databases will be converted and imported into the new NASIS tables.

- In 2016, Version 7.0 of the NASIS application was released. It gave NASIS users the ability to create user-specific forms, which they could use (instead of the traditional NASIS edit screens) to create, view, and edit data.

Digitization of Soil Survey Maps

Interest in digitizing NCSS soil maps began with the introduction of the Map Information Assembly and Display System (MIADS) to SCS in 1971. MIADS was a cell-based method of digitizing and was primarily used for creating interpretive data. Oklahoma was one of the States that digitized most or all of their soil surveys using this system. Efforts to find an efficient, feasible, and consistent method to digitize soil maps using the line-segment method continued. Various methods were tested. In 1990, standard policies and procedures for digitizing new and updated soil surveys, issued as "National Instruction No. 170-303 CGI—Technical Specifications for Digitizing Detailed Soil Maps," were adopted by the SCS Soil Survey Division. The intent of these standards was to establish a set of policies and procedures for everyone to use and so ensure products have consistent quality. Getting soil maps digitized was a slow progress and involved a variety of in-house personnel as well as contractors.

NRCS started the SSURGO Soil Survey Digitizing Initiative in 1995 with a special appropriation of funds. Although some soil surveys had been digitized as early as 1975, the SSURGO initiative was the first concerted effort to digitize all of the soil surveys in the U.S. It began a massive 12-year project to convert hard-copy soil maps to SSURGO and lasted through 2007. During this period, many soil surveys were updated as they were digitized. Digitizing centers were established to do the actual digitizing work or to conduct quality reviews of work done by others.

Beginning in the mid- to late-1990s, digitizing soil maps became part of the actual soil survey project work. Digital maps are one of the initial products of new or updated soil surveys. A soil survey project is not considered complete until the digital maps are available and meet established standards.

Soil Data Warehouse and Soil Data Mart

Early business analysis for a national soil information system identified the need for a single point of delivery of official soil survey data and information and the ability to archive versions of official data. (The NASIS database and application are intended primarily for internal use in developing and managing soil survey data and not for public access or delivery of data.) To meet this need, the Soil Data Warehouse (SDW) and Soil Data Mart (SDM) were deployed in 2003. By that time, significant progress was being made in digitizing soil survey maps.

The SDW is designed to hold all versions of official soil survey data (both SSURGO2 and STATSGO) produced since 2003, including not only tabular attribute data and digital spatial data but also metadata files that comply with the standards of the Federal Geographic Data Committee (FGDC). The SDM database contains only the most current version of official data and initially served as the data-distribution site. It provided a public access point for the data and allowed the user either to download digital SSURGO datasets in a standard format for use in a local geographic information system (GIS) or to run standard soil survey reports on selected datasets. In 2013, the data distribution function of the SDM was migrated to the Web Soil Survey (see below).

SSURGO Access Database Template

When data were downloaded from the Soil Data Mart, the attribute data tables were in a series of unrelated text files. For the data to be used, they first had to be loaded into a relational database format of the user's choosing. A database template in Microsoft Access format was developed for this purpose. The template includes macros for loading the data as well as standard queries and reports for viewing the data. It was included with each data download.

Soil Data Viewer

Soil Data Viewer (SDV) is an application developed as a plug-in extension of ESRI ArcMap for viewing digital soil maps downloaded from the Soil Data Mart and later from Web Soil Survey. It requires the SSURGO Access Database Template (described above) for accessing the attribute data. It was developed to help shield the user from some of the complexity of the attribute data structure. SDV includes a series of rules for aggregating soil properties and interpretations of individual map unit components to a single value for the respective map units for display in the GIS-generated thematic maps. This tool is available to the public.

Web Soil Survey

As the digitizing of soil survey maps progressed and the Soil Data Mart became more fully populated with data, users began to ask questions (e.g., Why could they not view the soil maps from the SDM online? Why did they need to download the data?). Many users did not have the equipment or expertise to work with the data themselves. To address this issue, the Web Soil Survey (WSS) was developed and first deployed in August 2005. It provides a publicly accessible online interface to the national collection of SSURGO datasets in the SDM database. In WSS, the user must first delineate the area of interest (AOI) for which they want to obtain soil survey data and information. The AOI may be an individual farm or ranch, an individual farm field, a watershed drainage area, or a whole soil survey area. It is also not limited to part of a single soil survey area but can span multiple survey areas. Users can define their AOI by using graphical tools that are part of the WSS interface, or they can upload a boundary developed in their local GIS.

After delineating the AOI, the WSS user can display the soil map for the selected area, generate interpretive or thematic maps for a wide variety of uses or selected soil properties, print individual maps or accumulate them into a composite report, or download the SSURGO data for the selected area. Data related to thematic maps are also included with SSURGO data downloads so that the user can generate similar maps using their local GIS software.

WSS merges the datasets and displays data and maps in a single layer. It uses the same rule set that Soil Data Viewer uses for aggregating data for display at the map unit level. It also provides the capability to download the underlying SSURGO dataset clipped to the AOI boundary for use in a local GIS.

In 2013, Version 3.0 of WSS was released. With this release the process of downloading official soil survey data, both SSURGO2 and STATSGO, was transferred from the Soil Data Mart to Web Soil Survey. SSURGO2 datasets are available for whole soil survey areas for the United States. STATSGO data are available as individual State datasets or for the whole U.S. As was the case with SDM, each data download includes a copy of the SSURGO Access Database Template.

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