REPORT ON SOIL INFORMATION SYSTEMS OF THE USDA
NATURAL RESOURCES CONSERVATION SERVICE

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ABSTRACT

The development and applications of the National Soil Survey Information System (NASIS) for the United States Department of Agriculture (USDA) are described in this report by examining the overall characteristics of the USDA system and related information on soil survey maps and associated databases, soil interpretations, and natural resource applications. The National Cooperative Soil Survey (NCSS) and its various regional, state and local affiliates provide direction, leadership, and scientific collaborative research and applications to increase the usefulness of soil survey information for society's needs. Soil mapping ranges in scale from detailed county levels to major land resource areas or states with digital products such as Soil Survey Geographic Database (SSURGO) and State Soil Geographic Database (STATSGO) published for public distribution and direct use on the internet. Transferring soil survey information to a wide spectrum of users is accomplished using benchmark soils and soil survey interpretations from rule-based methods within the NASIS. Soil survey interpretations consider large-scale variability in soil properties and land use and management parameters to refine the interpretations for local conditions. An overview of NASIS soil properties and qualities also describes the statistical summary of soil properties and thematic maps created from map unit data. Selected examples of GIS-based applications reveal the basic functions and primary components of the Soil Information System (SIS). Soil classification focuses on an example of soil correlation with USDA Soil Taxonomy and the World Reference Base for Soil Resources. Technical references and applications of SIS for soil use and management interpretations provide natural resources information at multiple scales ranging from farm to watershed and larger areas such as nations, ecological regions or continents.

Key words: national soil information survey system, NASIS, soil geography, USDA

INTRODUCTION

Starting in 1935, the Natural Resources Conservation Service or NRCS (originally called the Soil Conservation Service) has provided leadership in a partnership effort to help America's private landowners and managers conserve their soil, water, and other natural resources. NRCS employees provide technical assistance based on sound science and suited to a customer's specific needs. The Agency makes financial assistance available for many conservation activities. Participation in Agency programs is voluntary. Since the Dust Bowl of the 1930s, NRCS has worked with conservation districts and others throughout the U.S. to help landowners, as well as Federal, State, Tribal, and local governments and community groups.

The NRCS manages natural resource conservation programs that provide environmental, societal, financial, and technical benefits. Agency science and technology activities provide technical expertise in such areas as soil conservation, animal husbandry and clean water, ecological sciences, engineering, resource economics, and social sciences. The NRCS has expertise in soil science and leadership for soil surveys and for the National Resources Inventory, which assesses natural resource conditions and trends in the United States.

With the mission of “Helping People Help the Land,” the NRCS provides products and services that enable people to be good stewards of the Nation’s
soil, water, and related natural resources on non-
Federal lands. The NRCS has six mission goals:
high quality, productive soils; clean and abundant
water; healthy plant and animal communities;
clean air; an adequate energy supply; and working
farms and ranchlands. Our locally-based staff
works directly with farmers, ranchers, and others
to help landowners develop conservation plans and
supplies technical assistance on the design, layout,
construction, management, operation, maintenance,
and evaluation of the recommended, voluntary
conservation practices. The Agency conducts soil
surveys, conservation needs assessments, and the
National Resources Inventory to provide a basis
for resource conservation planning activities and
to present an accurate assessment of the condition
of the United States private (non-Federal) lands.
As the leading source of natural resources
conservation technology applied on private lands,
NRCS develops technical guides, natural resources
data, and other web-delivered tools to help enhance
natural resource conservation efforts.

**Soil Survey and Resource Assessment**

The Soil Survey and Resource Assessment Deputy
Area of the USDA-NRCS provides national
leadership of the U.S. soil survey program and
the development and implementation of the
National Resources Inventory. These two major
data collection activities produce valuable natural
resources and conservation information on local
to national scales for a wide variety of user groups
ranging from agricultural producers (farmers and
ranchers); field offices; soil and water conservation
districts; drainage districts; water management
groups; rural and urban communities; other local,
state, regional and federal agencies and offices;
international governments; and non-government
organizations (NGOs).

Soil as defined in the USDA Soil Taxonomy
(USDA 1999) is a natural body comprised of solids
(minerals and organic matter), liquid, and gases
that occurs on the land surface, occupies space, and
is characterized by one or both of the following:
horizons, or layers, that are distinguishable from
the initial material as a result of additions, losses,
transfers, and transformations of energy and matter
or the ability to support rooted plants in a natural
environment. This definition is expanded from the
1st edition of Soil Taxonomy to include soils in
areas of Antarctica where pedogenesis occurs but
where the climate is too harsh to support the higher
plant forms.

The upper limit of soil is the boundary between
soil and air, shallow water, live plants, or plant
materials that have not begun to decompose. Areas
are not considered to have soil if the surface is
permanently covered by water too deep (typically
more than 2.5 m) for the growth of rooted plants.
The horizontal boundaries of soil are areas where
the soil grades to deep water, barren areas, rock, or
ice. In some places, the separation between soil and
nonsoil is so gradual that clear distinctions cannot
be made.

The lower boundary that separates soil from
the nonsoil underneath is most difficult to define.
Soil consists of the horizons near the earth’s
surface that, in contrast to the underlying parent
material, have been altered by the interactions of
climate, relief, and living organisms over time.
Commonly, soil grades at its lower boundary to
hard rock or to earthy materials virtually devoid
of animals, roots, or other marks of biological
activity. The lowest depth of biological activity,
however, is difficult to discern and is often gradual.
For purposes of classification, the lower boundary
of soil is arbitrarily set at 200 cm. In soils where
either biological activity or current pedogenic
processes extend to depths greater than 200 cm, the
lower limit of the soil for classification purposes
is still 200 cm. In some instances the more weakly
cemented bedrocks (paralithic materials, defined
later) have been described and used to differentiate
soil series, even though the paralithic materials
below a paralithic contact are not considered soil
in the true sense. In areas where soil has thin cemented
horizons that are impermeable to roots, the soil
extends as deep as the deepest cemented horizon,
but not below 200 cm. For certain management
goals, layers deeper than the lower boundary of
the soil that is classified (200 cm) must also be
described if they affect the content and movement
of water and air or other interpretative concerns.

In the humid tropics, earthy materials may
extend to a depth of many meters with no obvious
changes below the upper 1 or 2 m, except for an
occasional stone line. In many wet soils, gleyed
soil material may begin a few centimeters below
the surface and, in some areas, continue down
for several meters apparently unchanged with
increasing depth. The latter condition can arise
through the gradual filling of a wet basin in which
the A horizon is gradually added to the surface and
becomes gleyed beneath. Finally, the A horizon
rests on a thick mass of gleyed material that may
be relatively uniform. In both situations, there is no
alternative but to set the lower limit of soil at the arbitrary limit of 200 cm (USDA 1999).

**National Cooperative Soil Survey (NCSS)**

The NCSS is a nationwide partnership of federal, regional, state, and local agencies, and institutions. This partnership works cooperatively to investigate, make an inventory, document, classify, and interpret soils and to disseminate, publish, and promote the use of soils information for the United States and its trust territories. The USDA- NRCS leads soil survey activities of the USDA, leads and coordinates NCSS activities and performs extension of soil survey technology to global applications (NSSH 2003). The program of the NCSS can be divided into soil mapping, description of the mapping concepts, and the prediction of the behavior of these mapping concepts for various uses.

The NCSS has systems of descriptive terminology, class definitions, hierarchical soil groupings, and operations that are applicable to various scales and appropriate to a wide variety of uses. Development of such flexibility has, in turn, required a fairly complex system in which it is important to understand many philosophical, conceptual, and operational relationships. Foremost among these are the relationships between mapping units and taxonomic units, site data and mapping unit data, conceptual models and the real entities in the landscape. Predictions of soil behavior are based on the evaluated and named soil properties to interpret the soil map units (NSSM 1993).

**Soil Mapping**

A map unit is a geographic representation of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Individual areas on the soil map are delineations. Map units consist of one or more components. An individual component of a map unit represents the collection of polypedons or parts of polypedons that are members of the taxon or a kind of miscellaneous area. Parts of polypedons are common when phases are used to divide a taxon. Classes of miscellaneous areas are treated the same as soil taxa in soil surveys.

A taxonomic unit description describes the ranges in soil properties exhibited in the polypedon for the maps in a survey area that are referenced by that taxonomic unit. The limits of these ranges are set for the taxonomic class of which a taxonomic unit is a member, but generally, the full range allowed by the taxonomic class is not exhibited in a small survey area (<200,000 ha).

A delineation of a map unit generally contains the dominant components in the map unit name, but it may not always contain a representative of each kind of inclusion. A dominant component is represented within 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 a slope, requires that a polypedon be divided. A complete polypedon is present when 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 inclusion 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 dominant component(s). Soil boundaries can seldom be shown with complete accuracy on soil maps, hence parts and pieces of adjacent polypedons are inadvertently included or excluded from delineations.

A few delineations of some map units may not contain any of the dominant components named in the map unit description, but contain very similar soils. In most surveyed areas few soils occur as mappable bodies, but they have very limited total extent. They are normally included in other map units, if, for all practical purposes, interpretations are the same.

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. It must be remembered that soil interpretations are made for areas of land and the most useful map units are those that group similarities (NSSM 1993).

**Kinds of map units.** Soils differ in size and shape of their areas, in degree of contrast with
adjacent soils, and in geographic relationships. Four kinds of map units are used in US soil surveys to show the relationships: consociations, complexes, associations, and undifferentiated groups.

1) Consociations - In a consociation, delineated areas are dominated by a single soil taxon (or miscellaneous area) and similar soils. As a rule, at least one-half of the pedons in each delineation of a soil consociation are of the same soil components that provide the name for the map unit. Most of the remainder of the delineation consists of soil components so similar to the named soil that major interpretations are not affected significantly. The total amount of dissimilar inclusions of other components in a map unit generally does not exceed about 15% if limiting and 25% if nonlimiting. A single component of dissimilar limiting inclusion generally does not exceed 10% if very contrasting. The amount of dissimilar inclusions in an individual delineation of a map unit can be greater than this if no useful purpose would be served by defining a new map unit. The soil in a consociation may be identified at any taxonomic level. A consociation named for a kind of miscellaneous area is dominated by the kind of area for which it is named to the extent that inclusions do not significantly affect the use of the map unit. Generally, this means that less than about 15% of any delineation is soil or less than about 25% is other kind of miscellaneous areas. Percentages may vary, depending on the kind of miscellaneous area and the kind, size, and pattern of the inclusions.

2) Complexes and associations - Complexes and associations consist of two or more dissimilar components occurring in a regularly repeating pattern. Only the following arbitrary rule related to mapping scale determines whether the name complex or association should be used. The major components of a complex cannot be mapped separately at a scale of about 1:24,000 while the major components of an association can be separated at a scale of about 1:24,000. In either case, the major components are sufficiently different in morphology or behavior that the map unit cannot be called a consociation. In a delineation of either a complex or an association, each major component is normally present, though their proportions may vary appreciably from one delineation to another. The total amount of inclusions in a map unit that are dissimilar to any of the major components does not exceed about 15% if limiting and 25% if nonlimiting, and a single kind of dissimilar limiting inclusion generally does not exceed 10% if very contrasting.

3) Undifferentiated groups - Undifferentiated groups consist of two or more taxa components that are not consistently associated geographically and, therefore, do not always occur together in the same map delineation. These taxa are included as the same named map unit because use and management are the same or very similar for common uses. Generally, they are included together because some common feature such as steepness, stoniness, or flooding determines use and management. If two or more very steep soils geographically separated are so similar in their potentials for use and management such that defining two or more additional map units would serve no useful purpose, they may be placed in the same unit. Every delineation has at least one of the major components and some may have all of them. The same principles regarding proportion of inclusions apply to undifferentiated groups as to consociations.

In all soil surveys, virtually every delineation of a map unit includes areas of soil components or miscellaneous areas that are not identified in the name of the map unit. Many areas of these components are too small to be delineated separately. The location of some components cannot be identified by practical field methods. Some mapping inclusions are deliberately placed in delineations identified as another map unit to avoid excessive detail of the map or the legend (NSSM 1993).

Orders of soil survey. The elements of a soil survey can be adjusted to provide the most useful product for the intended purposes. Different intensities of field study, different degrees of detail in mapping, different phases or levels of abstraction in defining and naming map units, and different map unit designs produce a wide range of soil surveys. Adjustments in these elements form the basis for differentiating five orders of soil surveys (Table 1).

Recognition of these different levels of detail is helpful for communicating about soil surveys and maps, even though the levels cannot be sharply separated from each other. The orders are intended to aid in the identification of the operational procedures used to conduct a soil survey. They also indicate general levels of the quality control that is applied during the survey. These levels affect the kind and precision of subsequent interpretations and predictions. The orders differ in the following elements:
Table 1. Orders of soil survey in the United States (adapted from USDA-NRCS 2003)

<table>
<thead>
<tr>
<th>Level of data needed</th>
<th>Field procedures</th>
<th>Minimum-size delineation (hectares)</th>
<th>Typical components of map units</th>
<th>Kind of map units</th>
<th>Appropriate scales for field mapping and publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st order - Very intensive (experimental plots or individual building sites)</td>
<td>The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data are used as an aid in boundary delineation.</td>
<td>1 or less</td>
<td>Phases of soil series, miscellaneous areas.</td>
<td>Mostly consociations, some complexes, miscellaneous areas.</td>
<td>1:15,840 or larger</td>
</tr>
<tr>
<td>2nd order - Intensive (general agriculture, planning)</td>
<td>The soils in each delineation are identified by field observations and by remotely sensed data, at closely spaced intervals.</td>
<td>0.6 to 4</td>
<td>Phases of soil series, miscellaneous areas, few named at a level above the series.</td>
<td>Consociations, complexes; few associations and undifferentiated groups.</td>
<td>1:12,000 to 1:31,680</td>
</tr>
<tr>
<td>3rd order - Extensive (range land or community planning)</td>
<td>Soil boundaries plotted by observation and interpretation of remotely sensed data. Soil boundaries are verified by traversing</td>
<td>1.6 to 16</td>
<td>Phases of soil series or taxa above the series; or miscellaneous areas.</td>
<td>Mostly associations or complexes, some consociations and undifferentiated groups.</td>
<td>1:20,000 to 1:63,360</td>
</tr>
<tr>
<td>4th order - Extensive (general soil information for broad statements concerning land use potential and general land management)</td>
<td>Soil boundaries plotted by interpretation of remotely sensed data. Boundaries are verified by traversing representative areas and by some transects, mapping representative</td>
<td>16 to 252</td>
<td>Phases of soil series or taxa above the series or miscellaneous areas.</td>
<td>Mostly associations; complexes, consociations and groups.</td>
<td>1:63,360 to 1:250,000</td>
</tr>
<tr>
<td>5th order - Very extensive (regional planning, selections of areas for more intensive study)</td>
<td>The soil patterns and composition of map units are determined by mapping representative ideas and like areas by interpretation of remotely sensed data. Soils verified by occasional onsite investigation or by traversing.</td>
<td>252 to 4,000</td>
<td>Phases of levels above the series, miscellaneous areas.</td>
<td>Associations; some consociations and undifferentiated groups.</td>
<td>1:250,000 to 1:1,000,000 or smaller</td>
</tr>
</tbody>
</table>

I. The soil survey legend, including
   • the kinds of map units: consociations, complexes, associations, and undifferentiated groups, and
   • the kinds of soil taxa for identifying the map units: soil series, families, subgroups, great groups, suborders, orders, and phases of them;

II. The standard for purity of delineated soil areas, including
   • the minimum area of a limiting dissimilar soil that must be delineated separately and thus excluded from areas identified as another kind of soil, and
   • the maximum percentage of limiting dissimilar inclusions that is permissible in a map unit;

III. The field operations necessary to identify and delineate areas of the map units within prescribed standards of purity; and

IV. The minimum map scale required to accommodate the map units of the legend, the standards of purity, and the map detail justified by field methods (NSSM 1993).

The order of a survey is a consequence of field procedures, the minimum size of delineation, and the kinds of map units that are used. Table 1 is a key for identifying orders of soil surveys. First-order surveys are made for very intensive land uses requiring very detailed...
information about soils, generally in small areas. Order 1 soil surveys are also known as "site-specific" or "high intensity" soil surveys (Slater 2004, SSSNE 1999). The information can be used in planning for irrigation, drainage, truck crops, citrus or other specialty crops, experimental plots, individual building sites, and other uses that require detailed and very precise knowledge of the soils and their variability.

Field procedures permit observation of soil boundaries throughout their length. The soils in each delineation are identified by traversing and transecting. Remotely sensed data are used as an aid in boundary delineation. Map units are mostly consociations with few complexes and are phases of soil series or are miscellaneous areas. Some map units named at a categorical level above the series may be appropriate. Delineations have a minimum size of about 1 hectare (2.5 acres) or less, depending on scale, and contain a minimum amount of contrasting inclusions within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 or larger with typical map scales ranging from 1:1,000 to 1:10,000.

Second-order surveys are made for intensive land uses that require detailed information about soil resources for making predictions of suitability for use and of treatment needs. The information can be used in planning for general agriculture, construction, urban development, and similar uses that require precise knowledge of the soils and their variability.

Field procedures permit plotting of soil boundaries by observation and by interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals, and the soils in each delineation are identified by traversing and in some map units by transecting. Map units are mostly consociations and complexes. Occasionally undifferentiated groups or associations are also used. Components of map units are phases of soil series or phases of miscellaneous areas; map units named at a categorical level above the series can be used. Delineations are variable in size with a minimum of 0.6-4 hectares (1.5-10 acres), depending on landscape complexity and survey objectives. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 - 1:31,680, depending on the complexity of the soil pattern within the area.

Third-order surveys are made for land uses that do not require precise knowledge of small areas or detailed soils information. Such survey areas are usually dominated by a single land use and have few subordinate uses. The information can be used in planning for range, forest, recreational areas, and in community planning.

Field procedures permit plotting of most soil boundaries by observation and interpretation of remotely sensed data. Boundaries are verified by some field observations. The soils are identified by traversing representative areas and applying the information to like areas. Some additional observations and transects are made for verification. Map units include associations, complexes, consociations, and undifferentiated groups. Components of map units are phases of soil series, taxa above the series, or they are miscellaneous areas. Delineations have a minimum size of about 1.6-16 hectares (4-40 acres), depending on the survey objectives and complexity of the landscapes. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:20,000 - 1:63,360, depending on the complexity of the soil pattern and intended use of the maps.

Fourth-order surveys are made for extensive land uses that need general soil information for broad statements concerning land-use potential and general land management. The information can be used in locating, comparing, and selecting suitable areas for major kinds of land use, in regional land-use planning, and in selecting areas for more intensive study and investigation.

Field procedures permit plotting of soil boundaries by interpretation of remotely sensed data. The soils are identified by traversing representative areas to determine soil patterns and composition of map units and applying the information to like areas. Transects are made in selected delineations for verification. Most map units are associations, but some consociations and undifferentiated groups may be used in some surveys. Components of map units are phases of soil series, taxa above the series, or are miscellaneous areas. Minimum size of delineations is at least 16-252 hectares (40-640 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:63,360 - 1:250,000.

Fifth-order surveys are made to collect soils information in very large areas at a level of detail suitable for planning regional land use and interpreting information at a high level of generalization. The primary use of this information is selection of areas for more intensive study.
Field procedures consist of mapping representative areas of 39-65 square kilometers (15-25 square miles) to determine soil patterns and composition of map units. This information is then applied to like areas by interpretation of remotely sensed data. Soils are identified by few onsite observations or by traversing. Most map units are associations, but some consociations and undifferentiated groups may be used. Components of map units are phases of taxa at categorical levels above the series and miscellaneous areas. Minimum size of delineations is about 252-4,000 hectares (640-10,000 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base-map scale ranges from about 1:250,000 - 1:1,000,000 or smaller (NSSM 1993).

Generalized Soil Maps

Some users need soils information about areas larger than individual fields or tracts, as large as perhaps several square kilometers, but a detailed map tends to obscure the broad relationships. Generalized soil maps are made to reveal geographic relationships that cannot be seen readily on detailed maps. Most soil survey reports include a general soil map for the area. The scale of these maps depends on the intended uses.

Generalized soil maps are made by combining the delineations of existing soil survey maps to form broader map units. Scrutiny of a detailed map usually will find large areas in which a few soil series, commonly two or three, are consistently associated. A detailed map is generalized by enclosing those larger areas within which a few kinds of soil predominate in relatively consistent proportions and patterns. These larger areas are described in terms of the dominant soils. The map is interpreted to show the combined effects of the constituent soils of each map unit.

Some of the possible uses for generalized soil maps are for appraising the basic soil resources of whole counties, for assisting farm advisors in the geographic emphasis of their educational programs, and for guiding commercial interests. Increasingly, these maps are compiled for county and regional land-use planning. Other possible uses include predicting the general suitability of large areas of soils for residential, recreational, wildlife, and other nonfarm uses, as well as for agriculture. Suggesting alternative routes for roads and pipelines where the least problems with soils are expected is also a potential use. The information in generalized soil maps may be useful as one basis for zoning.

Soil maps that are already less detailed can be generalized further for purposes that require very broad perspective. For example, 4th-order soil surveys for individual counties at scales of less than 1:250,000 can be combined and generalized to provide maps of States or regions at a scale of 1:1,000,000 or smaller. Soil maps that show the soils of areas of a few square kilometers can be converted to maps having delineations of a few hundred square kilometers, or more. Areas defined as associations of soil series or their phases are combined in this process into larger areas that can be defined in terms of associations of taxa at higher categories. These broad soil associations can be divided into phases to specify ranges in physiography, soil texture, or other features if such distinctions are useful. Soil maps at such levels of abstraction are designed for very broad regional planning and other uses that focus on areas of hundreds of square kilometers (NSSM 1993).

Soil Survey Geographic Database (SSURGO)

The SSURGO is the most detailed geographic database in the United States and is freely available to its users. It contains digital data developed from detailed soil survey maps that are generally mapped at scales of 1:12,000, 1:15,840, 1:20,000, 1:24,000, or 1:31,680. The SSURGO database was designed for natural resources planning and management at the farm and ranch, landowner/user, township, county or parish levels. SSURGO soil maps contain map unit delineations which are typically one to three named soil components.

The SSURGO data consists of two primary data sets: 1) geospatial data, such as the georeferenced digital soil survey map; and 2) attribute data, such as the soil survey area map unit record data from NASIS and associated source information (metadata).

The development of the soil survey geographic database in conjunction with digitizing the soil maps are integral parts of the modern soil survey procedures. Both are completed concurrently with other activities in either initial and maintenance soil survey projects. A soil survey geographic database is one of the products of a completed soil survey and is maintained in the field office. [NSSH 2003; http://soils.usda.gov/survey/geography/ssurgo/].
State Soil Geographic Database (STATSGO)

The STATSGO is a smaller map scale with more general information than the SSURGO. It contains digital data developed at a uniform scale of 1:250,000 for the 48 conterminous states and for Hawaii and Puerto Rico. For Alaska, the scale is 1:1,000,000. The STATSGO data has been applied for regional, statewide and national scale studies (Bliss and Reybold 1989, Reybold and TeSelle 1989). The database was designed primarily to conduct regional, multistate, river basin and multicounty natural resources planning, management and monitoring (USDA-NRCS 1994). The STATSGO consists of spatial data, such as the digital soil maps compiled on the 1:250,000 U.S. Geologic Survey base map for an entire state, and attribute data, such as the statewide map unit record data from the state subset of the national soil information system.

In STATSGO, the number of soil polygons per 1:250,000 quadrangle is typically from 100 to 200 and with a maximum of 400 allowed (USDA-NRCS 1994). The minimum sized area mapped is 625 hectares (1,544 acres) and linear delineations are not less than 0.5 cm (0.2 inches) in width to allow for proper symbol placement and identification (NSSH 2003). Components of map units are generally phases of soil series that allow for development of the most precise interpretations. STATSGO map units consist of multiple soil components (maximum of 21) with each component containing multiple soil horizons. Soil interpretive maps using STATSGO require aggregation from the soil horizons level for soil components and display using the percentage composition that meets a specific criterion or criteria (Bliss and Reybold 1989).

Fig. 1 illustrates the spatial distribution of apparent soil water tables using the STATSGO database. The location of soil water tables helps us to understand the hydrologic interaction among soils, landscapes and climate. This STATSGO-derived map depicts the spatial distribution of soils with “apparent” water tables or saturated zones within the top 1-2 meters. The base map is a 1-km cell size Digital Elevation Model (DEM).

[http://soils.usda.gov/survey/geography/statsgo/]

National Resources Inventory (NRI)

The NRI is a scientifically designed, longitudinal panel survey of the nation’s soil, water, and related resources designed to assess conditions and trends in both the spatial and temporal domains. The NRI is conducted by USDA-NRCS, in cooperation with the Iowa State University (ISU) Statistical Laboratory. The 1997, NRI contains data that are nationally consistent for all nonfederal lands for four points in time – 1982, 1987, 1992, and 1997 on nonfederal lands and water areas within the 48 conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands.

The NRI data can be used in developing statistical estimates of natural resource conditions, and in conducting geospatial and temporal analyses.
of these conditions (Fig. 2). The NRI database has data that are not in a summarized or aggregated form and should be aggregated at the appropriate geospatial scale to develop statistical information for natural resources analyses.

Tabulations made from the NRI database are estimates. These tabulations produce statistical estimates because they are based upon sample data derived from a survey – rather than data coming from a census, or complete measurement. Each estimate has some degree of statistical uncertainty associated with it; this statistical uncertainty affects analyses of the data and interpretation of results. [http://www.nrcs.usda.gov/technical/NRI/1997/docs/1997CD-UserGuide.doc]

SOIL CLASSIFICATION - OFFICIAL SOIL SERIES DESCRIPTIONS DATABASE

Official soil series descriptions record definitions of soil series and other relevant information about each series. The format, the kind, and the amount of detail may change from time to time, but detailed definition and a series interpretation record are essential. General, descriptive information is also needed to aid the reader in identifying the soil in the landscape and relating it to other kinds of soil. Each soil series must be defined as fully and accurately as existing knowledge permits. This applies to proposed soil series used in an individual survey as well as to established series. To ensure the inclusion of essential information and to permit comparison of series definitions, a standard format for recording specific kinds of information is used.

An official soil series description should include at least the following:

1. Full taxonomic name of the family taxon for which it is a member. This indicates the classes that provide limits of properties that are diagnostic for the series at all categorical levels, except for those between series of the same family.
2. A description of a typical pedon and its horizons, describing each in as much detail as necessary to recognize its taxonomic class. Horizons that are diagnostic for the pedon must be described.
3. A statement of the ranges of properties of the series. This section also contains statements about the relationship of the series control section and diagnostic horizons to vertical subdivisions of the typical pedon.
4. A statement distinguishing the series from "competing series" with which it might be confused. Competing series are mainly those that share common limits with the series described or are members of the same family.
5. A statement that identifies at least one specific place that represents a norm for the series — a "type location." A type location should be described accurately enough so that it can be located in the field.
Descriptive parts of an official soil series description are not required to define the series, but they aid the reader. All parts are not equally important for all soils. Many descriptions include the following:

1. Landform and physiographic position of the series, including its position relative to other landscape elements with which it is associated.
2. Evolution of the landscape. Influences of the soil-forming factors on the genesis of the series should be identified.
3. Parent-material: The kind of mineral or organic material in which the soil formed, including kinds of rock from which the regolith was derived if that can be determined.
4. Drainage of the soil by drainage class or other means of description relative to soil moisture regimes. Seasonal wetness or dryness may be important.
5. Other kinds of soil with which the series is closely associated geographically.
6. Major uses of the soil and dominant kinds of vegetation that grow on it. Native plants are identified, if known.
7. Rationale for classification. Implicit assumptions related to family classification may be described when laboratory data are not available.
8. Distribution and extent: the known geographic distribution and whether the soil occupies a large, small, or intermediate aggregate area.
9. Year and the survey area where the series was proposed or established.
10. Name of the person who prepared and approved the series description and the date it was prepared or approved.
11. References to available laboratory data.
12. Interpretations for common uses of the soil.

The Soil Series Extent Mapping Tool (SEM_TOOL) is a new Internet-distributed GIS tool to query the official soil series database and allow the user to search and visualize the geographic distribution of a specific soil series or higher taxonomic category (i.e. Great Group) and compute the total area of the soil selected (Fig. 3). The Soil Series Extent Mapping Tool has been applied to update older soil survey maps by identifying the regional geographic distribution of a soil series and searching for spatial gaps in the regional pattern among older and newer soil survey areas. Other uses for this type of tool can be developed for soil science education and conducting soil landscape analysis with landscape ecological metrics. Available at [http://www.cei.psu.edu/soiltool/semtool.html](http://www.cei.psu.edu/soiltool/semtool.html).

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**Fig. 3.** Soil Series Extent Mapping Tool displaying a Great Group query for Argiaquolls.
TRANSFER OF SOIL SURVEY INFORMATION

Studies of benchmark soils are essential for extending soil property information to soils that are similar to benchmark soil series because the costs of field investigations and the large number of combinations of soil uses and management practices prevents laboratory and field studies of all soils.

Benchmark Soils

A benchmark soil is a soil series of large extent, one that holds a key position in the soil classification system, one for which there is a large amount of data, or one that has special significance to farming, engineering, forestry, ranching, recreational development, urban development, wetland restoration, or other uses. A benchmark soil represents other soils. Knowledge of the properties and behavior of benchmark soils contributes to the understanding and interpretation of other soils with similar properties. This knowledge is important to transfer of soil technology and the use of soil surveys. Figure 4 illustrates the spatial distribution of benchmark soils within the STATSGO map units for the conterminous United States.

Benchmark soils help to focus the investigative effort on soils that have the greatest potential for extending collected data and resultant interpretations to other soils. Lists of benchmark soils are useful in planning many kinds of soil studies. Included studies are physical and chemical properties, fertility, crop adaptation and yield, range plant adaptation and yield, erodibility factors for wind and water, and the effectiveness of agronomic practices, such as minimum tillage, on yields and soil erosion (NSSH 2003).

The soil series that represent the range of soil conditions within a geospatial resource domain such as a major land resource area serve as benchmark soils. The criteria are:

**Extent.** The soil series that are selected as benchmark soils are commonly of large extent; they are normally extensive soils in each major land resource area. This kind of representation ensures that any collected data are widely applicable. Soil series of moderate or small extent that are designated as benchmark soils represent the soils within the major land resource area.

**Key soils.** Certain soils occupy key positions in the soil classification system, and research on these can be easily applied to other soils. Benchmark soils represent the extensive soil series in classes of the higher categories of the soil classification system.

**Important soils.** Certain soils are especially important because of their use for specialty crops or engineering purposes. If these soils are essential to the understanding of and interpretations for

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Fig. 4. Distribution of benchmark soils within the STATSGO map units for the conterminous United States.
Soil survey interpretations predict soil behavior for specified soil uses and under specified soil management practices. They help to implement laws, programs, and regulations at local, State, and National levels. They assist the planning of broad categories of land use, such as cropland, rangeland, pastureland, forestland, or urban development. Soil survey interpretations also help to plan specific management practices that are applied to soils, such as irrigation of cropland or equipment use.

Soil interpretations provide users of soil survey information with predictions of soil behavior to help in the development of reasonable and effective alternatives for the use and management of soil, water, air, plant, and animal resources.

Prediction of soil behavior results from the observation and record of soil responses to specific uses and management practices, such as seasonal wet soil moisture status and the resultant effect in a basement. Recorded observations validate predictive models. The models project the expected behavior of similar soils from the behavior of observed soils.

Soil interpretations use soil properties or qualities that directly influence a specified use or management of the soil. Soil properties and qualities that characterize the soil are criteria for interpretation models. These properties and qualities used as criteria include: 1) site features, such as slope gradient; 2) individual horizon features, such as particle size; and 3) characteristics that pertain to soil as a whole, such as depth to a restrictive layer.

Laboratory and field measurements, models and inferences from soil properties, morphology, and geomorphic characteristics provide the values used for estimating soil properties. Sources of laboratory data commonly are the Soil Survey Laboratory, Agricultural Experiment Station laboratories, and State Highway Department testing laboratories. Pedon descriptions record field measurements, field observations, and descriptions of soil morphology.

**SOIL CHARACTERIZATION DATA**

The National Soil Survey Center - Soil Survey Laboratory provides public-accessible pedon data from analyses for soil characterization and research within the NCSS. Less than complete characterization data are available for many pedons because only selected measurements were planned. The repository contains completed project information of the Soils Survey Laboratory. Information is provided as NRCS-SOI-8 forms and returned to NSSC-SSL, laboratory analyses are completed, suspect measurements are identified and rerun, and errors are found and corrected. The database includes pedons that represent the central concept of a soil series, pedons that represent the central concept of a map unit but not of a series, and pedons sampled to bracket a range of properties within a series or landscape. For research purposes, all such data are retained in the database.

Pedon Database

The pedon database of the Soil Survey Laboratory (SSL), NSSC, currently contains analytical data for more than 20,000 pedons of U. S. soils and about 1,100 pedons from other countries. Standard morphological pedon descriptions are available for about 15,000 of these pedons. Partial data for pedons currently being analyzed may be unavailable. Soil fertility measurements, such as those made by Agricultural Experiment Stations, were not made. Most of the data were obtained over the last 40 years. About 3/4 of the data is less than 20 years old. Analytical data for most of the pedons is fairly...
complete. Pedons were sampled and analyzed from all 50 US states, Puerto Rico, Virgin Islands, Trust Territories, and 89 other countries.

**Soil Geochemistry Database**

The USDA-NRCS Soil Geochemistry Spatial Database contains data collectively produced by the NCSS. Sites were generally selected and sampled by soil survey personnel in respective states. Laboratory data were produced by the USDA-NRCS Soil Survey Laboratory, located in the National Soil Survey Center, Lincoln, NE. [http://soils.usda.gov/survey/geochemistry/index.html](http://soils.usda.gov/survey/geochemistry/index.html)

The geographic display consists of two major sets of geochemistry data:

1. **Current Geochemistry Project** - This project is ongoing and the website is updated periodically to reflect additional available data. Pedons were sampled and analyzed by horizons. Pedons represent either the central concept of a soil series, the central concept of a map unit, or unspecified sites on a project specific basis. These data include both sites that are contaminated and non-contaminated.

2. **Holmgren Dataset** - A second group of data was produced by the SSL during the 1970s and 1980s for a project documenting the content of selected trace elements in agricultural soils of the U.S. This dataset contains over 3,400 sites in conterminous U.S. These data are available as a separate spatial layer on a county centroid basis (Holmgren et al. 1993).

**USDA-NRCS NATIONAL SOIL INFORMATION SYSTEM (NASIS)**

The NASIS stores information on soils from soil survey activities. It is a collection of basic information on soil properties, interpretations, and the predicted performance of soil under specific land uses. A soil scientist prepares database entries with the interdisciplinary assistance of engineers, agronomists, foresters, biologists, resource conservationists, range conservationists, and others. Soil interpretations attach to map unit components. The soil interpretations information prepared for soil components contain all necessary criteria for computer generated interpretations. The consistency of the entry of specific soil properties leads to the coordination of soil interpretations for map units with other offices.

The method by which soil interpretations are presented, such as in tables, databases, interpretative sheets, and special reports provides easily understood soil limitations, suitabilities, or potentials for a specific use. Thematic maps effectively present soil limitations and potentials. A series of thematic maps, each focusing on a single soil attribute or interpretation, help many users. For more general use, tables or narrative forms of soil interpretations and potentials are the more common technique. Figures and tables in the other sections of this report illustrate examples of various thematic maps with soil interpretations.

The evaluation and updating of soil interpretations is a dynamic process. Changes in soil use or land management practices require new, revised, or updated interpretations. These changes initiate the revision and updating of soil interpretations. Although the soil maps contained in published soil surveys generally remain valid for many years, the information about the soils that are delineated on the maps is continually updated and enhanced as research is conducted or as new kinds of data are collected. New uses for a soil or new practices that have no existing soil interpretations may become important in an area and thus require the development of new interpretations or the modification of an existing interpretation for a similar use or practice (NSSH 2003).

The USDA-NRCS NASIS is a generic software tool for managing data in a relational database system. The data NASIS manages are defined in a data dictionary that includes information about a particular business area, its policies, and procedures. The current NASIS data dictionary contains information about the soil survey database. New sections address site-specific information such as plant or soil profile descriptions.

NASIS will eventually encompass the four major areas of soil survey plus operations and maintenance. Soil survey operations comprise an interaction of spatial data, map unit attributes, point or site attributes, and concept or aggregation criteria. Early releases of NASIS addressed the map unit attributes. Currently, NASIS includes objects and tables for database management, map unit attributes, and site and point attributes. NASIS uses a consistent interface throughout each of its areas (NASIS 2001).

The NASIS software provides generic tools and functionality for editing data, querying the NASIS database, generating reports, creating
custom reports, and exporting data. With NASIS, you can calculate several data elements, such as taxonomic classifications. NASIS also validates the completeness and integrity of the data. Underlying it all, NASIS provides functionality for managing the ownership and security of data.

The National Soil Information System integrates soil survey information, operations, and management. It divides soil survey data into four major categories: 1) map unit records; 2) geographic area records; 3) point characteristics; and 4) standards, criteria, and guidelines. The system also includes ancillary tools, functions, and records to assure the security, integrity, and utility of the soil survey data.

The NASIS is the official depository for the latest soil survey information. The MLRA office maintains official changes. Distribution of information is through this official file. A file of all nationwide data is stored at Iowa State University Statistical Laboratory and other locations. [http://soils.usda.gov/technical/nasis/downloads/index.html]

**Soil Survey Area Database Format**

Map unit records include soil survey area legends, map units, and the physical, chemical, and morphological properties and interpretations for map units and their components. Map unit records are subdivided into three parts: the legend object, the data map unit object, and the map unit record text.

The NASIS introduces some new terminology to soil survey. The phrases "legend map unit" and "data map unit" are invented terms for concepts to describe data relationships. The term "legend map unit" has now been shortened to "legend." An object is either a record or a collection of records. Within NASIS the legend object contains the map unit symbol, map unit name, kind of map unit (consociation, complex, etc.), and correlation notes. The identification used for the legend is the map unit symbol that is common to the soil survey map and the soil survey legend. The data map unit object includes the map unit composition, physical, chemical, morphological, and interpretation records for a map unit and its components. The identification used for the data map unit is a system assigned unique number that is used only in the database to identify a set of map unit attributes. The map unit record text contains additional notes, nontechnical descriptions, and other documentation related to either the legend or the data map unit and is a part of the records of either the legend object or the data map unit object.

The purpose of the legend object is to maintain map unit symbol, name, and correlation records for each map unit in the legend and provide a link to both areas and data map units. It provides a continuous record of legend development and correlation decisions made throughout the survey. These records are used to create the map unit identification legend, conversion legends, and correlation status reports for the survey area. The legend object is created at the beginning of the survey and retained as part of the historical records.

The legend object includes several tables in the NASIS. Responsibility and ownership of a specific legend is indicated by the database and group columns in the legend table. Authority to edit the legend object is limited to users who are members of the group that is responsible for the legend. The user who creates or changes any part of the legend object is recorded in the legend table, as well as the date and time of that change. Generally, the legend in an ongoing survey is the responsibility of the soil survey project office. Responsibility is transferred to the MLRA office at completion of the survey. The tables in the legend object are defined below. Descriptions for legend object data elements are available in the NASIS on-line help. Some data elements are restricted to specific entries; others allow any appropriate entry.

In NASIS, the soil survey area is separated into two parts: the **area** and the **legend**. The area includes the soil survey area name and total acres for the soil survey area. The legend includes the legend name (for example, detailed soil map legend), status, and correlation date. Legends are linked to survey areas, allowing several legends to be recorded for each soil survey area. Multiple legends are possible within a single soil survey area in NASIS. Because there are several kinds of areas in NASIS, areas are organized by **area type**.

The map unit is also separated into two parts: the **map unit** and the **data map unit**. The map unit includes the map unit symbol, map unit name, and correlation history. The data map unit includes the map unit composition, physical and chemical properties. Data map units are linked to one or more map units through the **Correlation** table, allowing map unit symbols in different legends to be linked to the same data. Conversely, map units are linked to one or more data map units allowing map units to be correlated and conversion legends to be produced.
### NASIS Database Table Organization

<table>
<thead>
<tr>
<th>Area type</th>
<th>NASIS Table Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Soil Survey Area (SSA) Name</td>
</tr>
<tr>
<td>Legend</td>
<td>Legend name</td>
</tr>
<tr>
<td>Map unit</td>
<td>Map unit symbol</td>
</tr>
<tr>
<td>Correlation</td>
<td>--- Map unit composition</td>
</tr>
<tr>
<td>Component</td>
<td>--- Interpretation ratings</td>
</tr>
<tr>
<td>Horizon</td>
<td>--- Physical, chemical and morphological properties</td>
</tr>
</tbody>
</table>

### Soil Properties and Qualities

Soil properties are measured or inferred from direct observations in the field or laboratory. Soil properties include, but are not limited to, examples such as soil reaction, particle-size distribution, cation exchange capacity, and salinity. Soil qualities are behavior and performance attributes that are not directly measured but are inferred from observations of dynamic conditions and from soil properties. Soil qualities include, but are not limited to, corrosivity, natural drainage, frost action, and wind erodibility. Soil properties and soil qualities are the criteria used in soil interpretation rating guides, as predictors of soil behavior, and for classification and mapping of soils. The soil properties entered should be representative of the soil for the dominant land use for which interpretations will be based. [NSSH part 618]

**NASIS soil property and soil quality data.** Table 2 lists the basic soil properties and soil qualities (marked by *) provided in NASIS.

**Statistical summary of geospatial data.** Most tabular data exist in the soil information databases as a range of soil properties, depicting the range for the geographic extent of the map unit. In addition to low and high values for most data, a representative value is also included for these soil properties. A representative value (RV) is a single value for the data element which best represents it, typically a mean or mode of observed values.

### Thematic maps and map unit interpretation probability.

Creating maps to represent and visualize soil component interpretations or soil properties, either with a geographic information system (GIS) or with an electronic soil survey viewer, requires that each map unit delineation have a single value to display. However, soil map units commonly consist of several major and minor components, which result in the need to make decisions on how to process a map unit with multiple components. Processed components represent a portion of the total components in the map unit delineation and thus their interpretation represents only a portion of the map unit. The probability the user will encounter that interpretation can be estimated by the percent composition the interpretation occupies within the map unit.

A user may want to process multiple component map unit interpretations using four common methods:

1. Dominant component by percent;
2. Most limiting major component;
3. Least limiting major component; or
4. Weighted average of major components.

Connotative color maps provide the user with the easiest way to view and use interpretation maps. Implementing connotative colored interpretation maps for ranked limitation, the classic green to red for slight to severe provides a practical example. The use of probability classes is a method to rank each limitation rating class with gradation of color.
Table 2. NASIS soil property and soil qualities(*) data

- Albedo, Dry
- Available Water Capacity
- Bulk Density, One-Tenth Bar or One-Third Bar
- Bulk Density, 15 Bar
- Bulk Density, oven dry
- Calcium Carbonate Equivalent
- Cation Exchange Capacity NH4OAc pH7
- *Climatic Setting
- *Corrosion
- *Crop Name and Yield
- Diagnostic Horizon Feature Depth to Bottom
- Diagnostic Horizon Feature Depth to Top
- Diagnostic Horizon Feature Kind
- *Drainage Class
- Effective Cation-Exchange Capacity
- Electrical Conductivity
- *Elevation
- *Engineering Classification
- *Erosion Accelerated, Kind
- *Erosion Class
- *Excavation Difficulty Classes
- Extractable Acidity
- Extractable Aluminum
- *Flooding Frequency, Duration, and Month
- Fragments in the Soil
- Free Iron Oxides
- *Frost Action, Potential
- Gypsum
- Horizon Depth to Bottom
- Horizon Depth to Top
- Horizon Designation
- Horizon Thickness
- *Hydrologic Group
- *Landform
- Linear Extensibility Percent
- Liquid Limit
- Organic Matter
- Parent Material, Kind, Modifier, and Origin
- Particle Density
- Particle Size
- Percent Passing Sieves
- Plasticity Index
- *Ponding Depth, Duration, Frequency Class, and Month
- Pores
- Reaction, Soil (pH)
- *Restriction Kind, Depth, Thickness, and Hardness
- Saturated Hydraulic Conductivity
- Slope Aspect
- Slope Gradient
- Slope Length
- Sodium Adsorption Ratio
- *Soil Erodibility Factors, USLE, RUSLE2
- *Soil Erodibility Factors for WEPP
- Soil Moisture Status
- *Soil Slippage Hazard
- Soil Temperature
- *Subsidence, Initial and Total
- Sum of Bases
- Surface Fragments
- *T Factor
- *Wind Erodibility Group and Index

Table 3. Probability classes mapped by graduation of color intensity

<table>
<thead>
<tr>
<th>Classes (%)</th>
<th>Intensity</th>
<th>Rating Class</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 to 100</td>
<td>Darkest</td>
<td>Very Severe</td>
<td>Red</td>
</tr>
<tr>
<td>50 to 75</td>
<td>*</td>
<td>Severe</td>
<td>Pink</td>
</tr>
<tr>
<td>25 to 50</td>
<td>*</td>
<td>Moderate</td>
<td>Yellow</td>
</tr>
<tr>
<td>0 to 25</td>
<td>Lightest</td>
<td>Slight</td>
<td>Green</td>
</tr>
</tbody>
</table>

intensity (light to dark) and gives the user useful information about the interpretation probability of the map unit. An example of how this might be implemented is shown in Table 3.

Map units with a 75-100% probability of severe would be the darkest pink, while map units with a 25-50% probability of severe would be nearly the lightest pink. This method would create a map, grouping interpretation ratings with the same color hue and separating their probabilities with the intensity of hue.

Examples of the four methods to process map unit interpretations are discussed below [http://nasis.nrcs.usda.gov/future/muinterp/muinterp.htm]. The user can dynamically define the minimum percent composition of major components to be used for the interpretation. The examples use the same theoretical map unit data set, with 10% defined as the major component and the resulting soil interpretation map shown for each method.

1. Dominant Component by Percent

The component that makes up the largest percent composition is used to interpret the map unit delineation. The probability for the interpretation of the map unit delineation is based on the percent composition of the dominant component plus the percentage of components with the same interpretation rating (Table 4 & Fig. 5).
2. Most Limiting Major Component

The most limiting interpretation rating of a major component can also be used to interpret the map unit delineation. The probability for the interpretation of the map unit delineation is based on the percent composition of the component with the least limiting rating plus the percentages of components with the same rating (Table 4 & Fig. 6).

3. Least Limiting Major Component

The least limiting interpretation of a major component is used to interpret the map unit delineation. The probability for the interpretation of the map unit delineation is based on the percent composition of the component with the least limiting rating plus the percentages of components with the same rating (Table 6 & Fig. 7).

4. Weighted Average Interpretation

Weighted average interpretation for major components is calculated based on the percent composition (on a 100% base) and the interpretation fuzzy value. The weighted average fuzzy value is reclassed into appropriate rating class (Table 7 & Fig. 8).

NASIS Soil Interpretation Generator

In NASIS, applying interpretive criteria to soil data generates interpretive results. Interpretive criteria are divided into four parts: interpretations, base rules, evaluations, and properties. Because interpretations, base rules, evaluations, and properties are simply data, NASIS allows you to copy and link to them to create new interpretive criteria. This makes local interpretations possible. Users can create or copy and modify existing evaluations, interpretations, and base rules to meet your local needs. Properties are retrieved by complex SQL-like statements available from the NSSC Pangaea site. Because of their complexity, users frequently choose existing queries from a drop-down choice list.

**Overview of interpretation criteria.** An interpretation is a type of rule in NASIS. It is a logical statement about land use, limiting features, and the relationship among limiting features. Interpretations are stored in the Rule
Table 5. Example data for the most limiting major component method

<table>
<thead>
<tr>
<th>Map Unit Symbol</th>
<th>Component</th>
<th>Percent Composition</th>
<th>Value</th>
<th>Rating Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbA</td>
<td>Able</td>
<td>50</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Beta</td>
<td>30</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>20</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td>AbC</td>
<td>Able</td>
<td>40</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>40</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>15</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>5</td>
<td>0.35</td>
<td>Moderate</td>
</tr>
<tr>
<td>BdA</td>
<td>Beta</td>
<td>75</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>10</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>10</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Able</td>
<td>5</td>
<td>0.60</td>
<td>Severe</td>
</tr>
</tbody>
</table>

Table 6. Example data for the least limiting major component method

<table>
<thead>
<tr>
<th>Map Unit Symbol</th>
<th>Component</th>
<th>Percent Composition</th>
<th>Value</th>
<th>Rating Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbA</td>
<td>Able</td>
<td>50</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Beta</td>
<td>30</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>20</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td>AbC</td>
<td>Able</td>
<td>40</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>40</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>15</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>5</td>
<td>0.35</td>
<td>Moderate</td>
</tr>
<tr>
<td>BdA</td>
<td>Beta</td>
<td>75</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>10</td>
<td>0.60</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>10</td>
<td>0.40</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Able</td>
<td>5</td>
<td>0.60</td>
<td>Severe</td>
</tr>
</tbody>
</table>

Table 7. Example data for the weighted average interpretation method

<table>
<thead>
<tr>
<th>Map Unit Symbol</th>
<th>Component</th>
<th>Percent Composition</th>
<th>100% Base</th>
<th>Value</th>
<th>Wt. Calc.</th>
<th>Rating Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbA</td>
<td>Able</td>
<td>50</td>
<td>50</td>
<td>0.60</td>
<td>0.30</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Beta</td>
<td>30</td>
<td>30</td>
<td>0.40</td>
<td>0.12</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>20</td>
<td>20</td>
<td>0.40</td>
<td>0.08</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wt. ave.</td>
<td></td>
<td></td>
<td>0.50</td>
<td>Severe</td>
</tr>
<tr>
<td>AbC</td>
<td>Able</td>
<td>40</td>
<td>42</td>
<td>0.60</td>
<td>0.252</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>40</td>
<td>42</td>
<td>0.40</td>
<td>0.168</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>15</td>
<td>16</td>
<td>0.60</td>
<td>0.096</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>5</td>
<td></td>
<td>0.35</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wt. ave.</td>
<td></td>
<td></td>
<td>0.516</td>
<td></td>
</tr>
<tr>
<td>BdA</td>
<td>Beta</td>
<td>75</td>
<td>79</td>
<td>0.40</td>
<td>0.316</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Fox</td>
<td>10</td>
<td>10.5</td>
<td>0.60</td>
<td>0.063</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Delta</td>
<td>10</td>
<td>10.5</td>
<td>0.40</td>
<td>0.042</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Able</td>
<td>5</td>
<td></td>
<td>0.60</td>
<td></td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wt. ave.</td>
<td></td>
<td></td>
<td>0.421</td>
<td></td>
</tr>
</tbody>
</table>
A base rule is a logical statement about one limiting feature. A base rule says nothing about the land use; therefore, the same base rule can be used in building different interpretations. Base rules are aggregated into an interpretation and are considered the basis, or building blocks, of an interpretation. Like interpretations, base rules are stored in the Rule table. The limiting feature is stored as the Rule Name. A naming guideline helps you distinguish base rules from interpretations. Base rules have at least one evaluation linked to them. The linked evaluation(s) are depicted graphically in the Rule Editor. In order to report interpretive results, an evaluation must be linked to a base rule. The base rule gives you the flexibility of reusing evaluations for different interpretations.

An evaluation is an assessment of a particular soil property for its relative impact as a limiting feature. Using the principles of fuzzy logic, you can graph the impact of a limiting feature in an Evaluation Editor. The graph (Fig. 9) helps you evaluate the soil property and its relative truthfulness as a limiting feature. For example, if a soil percs absolutely too slowly, the fuzzy value would be 1. If it percs absolutely not too slowly, the fuzzy value would be 0. Fuzzy logic allows you to evaluate the property when it falls in the range between absolutely too slowly (1) and absolutely not too slowly (0). For example, if the soil percs moderately slowly, you might plot it as 0.5, meaning that the soil has a 0.5 truthfulness of percolating absolutely too slowly. An evaluation is the relationship between the property and its impact on the interpretive application. Evaluations specify the ranges used to assess the relative truthfulness of a statement about a soil property. For example, the evaluation criteria set the limits for determining whether the statements “soil percs too slowly” and “soil filters too poorly” are absolutely not true, absolutely true, or somewhere in between.

Fuzzy logic allows the user to deal with relative statements about soil properties. For example, in a traditional view, the logical statement A AND B means that both A and B must be absolutely true for the statement to be true. However, with fuzzy logic, each of A and B represent some degree of truthfulness, from absolutely not true to absolutely true. The statement...
A AND B evaluates the minimum truthfulness for either of A and B. Thus, if a soil must be deep and dry in March to be suitable for early tillage, and the soil is deep but moist, the statement that the soil is deep is true but the statement that the soil is dry is only partly true. Therefore, the soil is partly suited to early tillage. This statement about soil behavior can be articulated in terms of relative truthfulness. If the soil is very nearly dry then its degree of truthfulness is very nearly 1 (perhaps 0.9) and it is very nearly suited (0.9) to early tillage. The degree of truthfulness is numerical and can be used in mathematical operations or converted into classes such as slight, moderate, and severe. Regardless of how it is used, fuzzy logic allows you to deal with relative statements about soil properties and make more intuitive, more precise, and more useful interpretations.

A property is the specified soil data retrieved from the soil database. The term property can sometimes refer to the SQL-like statement that retrieves the soil data. Properties are stored in the Property table.

**Relationship to earlier systems.** Although the names are new and the capabilities are different, soil scientists have been using the concept of interpretation/base rule/evaluation/property to make interpretations for many years. In the *National Soil Survey Handbook* (NSSH), interpretive criteria are typically represented in table form as shown in Table 8. The shaded areas in Table 8 represent an interpretation with two base rules which state that the limitation for septic tank absorption fields is based on percolation or filter fields between the depths of 61-152 cm (24-60 inches).

**Fuzzy logic.** Soil survey interpretations (suitability, limitation, potential) can be grouped into two distinct classes for logic purposes – ones with crisp or clearly defined rating class limits (e.g., limitation is severe above specified slope value) or interpretations which vary as the soil property changes (e.g., limitation increases continuously as slope increases). The NRCS NASIS can calculate and store both types of interpretations. Fuzzy logic or “approximate reasoning” allows the development of soil interpretations along a continuum. Interactions can be handled using fuzzy math for soil interpretations. For example, you can do interpretations on the interaction of slope and water table, where, as slope increases, depth to water decreases. Fuzzy logic also allows applying relative weights, such as when degree of slope may be more important to the overall interpretation than depth to water table. [NRCS 430-739 2001]
The NASIS has been used to model various productivity indices. O'Geen and Southard (2005) developed a model that computed a revised Storie Index for multiple counties in California. The Storie Index was developed in California as a soil rating tool for land use and productivity. Their model combined both discrete and fuzzy logic functions to calculate more precise factor scores as input into the Storie Index.

The National Crop Commodity Productivity Index (NCCPI) version 1.0 was recently described by Dobos et al. 2008. The NCCPI is an interpretation in NASIS currently available for nonirrigated commodity crops only. The interpretation uses natural relationships of soil, landscape, and climate factors to model the response of commodity crops. The NASIS interpretations generator uses a fuzzy systems approach to modeling. Each soil, climate, or landscape characteristic is given a rating (score) determined by a comparison of its value to an empirical optimum value. These scores are mathematically manipulated in various ways to produce the index. Ratings scores are multiplied together in a similar manner to the Storie Index developed in California. The model only uses data available in the NASIS data structure. There are three main submodels, which represent the response of a suite of crops to soil, landscape, and climatic conditions. This system has the flexibility to add more crop submodels if needed. The three current submodels (categories) are Corn and Soybeans, Small Grains, and Cotton, which represent the three major divisions of commodity crops in terms of climate, landscape and soil adaptation. Within

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Slight µm/sec (in/hr)</th>
<th>Moderate µm/sec (in/hr)</th>
<th>Severe µm/sec (in/hr)</th>
<th>Restrictive Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability minimum in depth</td>
<td>14-42 (2.0-6.0)</td>
<td>4.0-14 (0.6-2.0)</td>
<td>&lt;4.0 (&lt;=0.6)</td>
<td>Percs slowly (percution)</td>
</tr>
<tr>
<td>61-152 cm (24-60&quot;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability maximum in depth</td>
<td>---</td>
<td>---</td>
<td>&gt;42 (&gt;=6.0)</td>
<td>Poor filter (filter fields)</td>
</tr>
<tr>
<td>61-152 cm (24-60&quot;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: There are several other restrictive features for septic tank absorption fields. For this example, however, only two were used.

LEGEND:
Base rules (bold)
Properties evaluated (italic)
Evaluation criteria (underlined)

NASIS and Database Management Training for Soil Scientists

Training in database management software and its applications is not traditionally taught in modern college and university soil science curriculums. For NASIS, training modules within the USDA-NRCS include basic, and intermediate courses, basic query and report writing, advanced report writing, site/pedon data, and soil interpretations. Indorante (2007) discusses the magnitude of updating and populating all the data records in NASIS. Indorante argues that a clear case exists for creating and linking basic soil properties and interpretations with the Official Soil Series Description using the NASIS. Livingston (2006) discusses soil data population within NASIS relative to data quality, quantity and integrity, science, ethics and data population methods. He recommends the addition of a “data qualifier flag” to document each value as to its source - measured in the laboratory, calculated by algorithm, or estimated by expert judgment or similar value to benchmark soils. Statistical results such as the “representative value” should be clearly defined and consider the use of ranges for interpretations as well as calculated values such as the mean, median, and mode.

Selected Examples of NASIS Applications

Data for the NASIS soil information is used to develop input for various model calculations (RUSLE2), pedotransfer functions, and computer simulation models such as the Soil and Water Assessment Tool (SWAT), and Geo WEPP.
each submodel, subrules were developed for soil chemical and physical properties, water, soil climate, and landscape attributes.

**Soil Resource Inventory Toolbox**

The Soil Resource Inventory Toolbox is a new ArcGIS tool and toolbar that is designed to increase the speed and efficiency of soil data collection. Tools are grouped according to the following functions: (1) Auto Population; (2) GPS and location data capture to NASIS; (3) Digital editing; (4) Quality control/quality assurance; and (5) 3D viewing. [http://nasis.usda.gov/downloads/]

**Pedon PC**

Pedon PC is a stand-alone Microsoft Access database application. It is a client database application that contains a front end Graphical User Interface and a link to a back end database. Pedon PC provides a user-customizable interface for entering soil survey point data. The actual pedon_pc.mdb database file is considered a Microsoft Access database, but only contains administrative table data and links to the actual database that holds the user-entered data. This user-entered data resides in a database file called pedon.mdb. Site, pedon and transect data can be entered and managed by using Pedon PC. Periodically, a filtered set of records can be exported into an empty pedon.mdb file and uploaded to NASIS using procedures that are currently in place to handle uploads.

Pedon PC has an intuitive and easy-to-use, Graphical User Interface (GUI) based on forms that were developed from field notes. Pedon PC contains two main data entry forms: the PC Data Entry Form and the Tablet Data Entry Form. They both use the exact same database, but present the data differently. The PC Data Entry Form contains all input fields on one form, while the Tablet Data Entry Form contains six tabs for site, pedon and pedon horizon input fields. Both forms may be used on a laptop, desktop PC or Tablet PC. One scenario is to use the Tablet Form in the field and then use the PC Form in the office.

The Pedon PC back-end database (pedon.mdb) is based on the same table structure as NASIS. This database design compatibility allows the user to easily upload Pedon PC data into NASIS. Also, data from NASIS can be exported into an ASCII text file for direct importation into Pedon PC.

**APPLICATIONS OF GIS FOR SOIL USE AND MANAGEMENT INTERPRETATIONS**

Digital soil survey in combination with geographic information systems (GIS) software provides the options to deliver soil map data and interpretations using either an Internet-based approach (Web Soil Survey) or stand-alone distribution on a compact disk or similar electronic media (Soil Data Viewer).

The Soil Data Mart (SDM) is the Internet-based service, which distributes, stores and maintains a national coverage of soil data as the single point of delivery for official soil survey data. This information is utilized for soil science and soil conservation work with the Field Office Technical Guide (FOTG/electronic FOTG), Customer Service Toolkit, Soil Data Viewer, and computer modeling. The SDM contains tabular data, including interpretations, digitized spatial data (SSURGO and STATSGO), soil map units where available, soil survey area boundaries, and Federal Geographic Data Committee (FGDC) compliant SSURGO metadata files. Soil data on the SDM is certified by each State Technical Guide Committee.

The Soil Data Warehouse contains both current and archived copies of the soil data. The SDM contains only the current, certified version of soil survey data which is Internet-accessible, can be linked to the eFOTG and is also used for Web Soil Survey. Various SDM functions include generation of standard reports for selected map units or the entire soil survey area, downloading SSURGO and STATSGO data using FTP, and downloading an Access database management template which is either nationally or state-specific in extent. The Access database is used to conduct queries and generate reports. [http://soildatamart.nrcs.usda.gov/]

**Web Soil Survey**

Web Soil Survey (WSS) provides soil data and information produced by the NCSS. It is operated by the USDA- NRCS and provides access to the largest natural resource information system in the world. NRCS has soil maps and data available online for more than 95% of the nation’s counties and anticipates having 100% in the near future. The website is updated and maintained online as the single authoritative source of soil survey information (Figs. 10 & 11, Table 9).
Soil Data Viewer

Soil Data Viewer is a tool built as an extension to ArcGIS that allows a user to create soil-based thematic maps. The application can also be run independent of ArcGIS, but output is then limited to a tabular report. The soil survey attribute database associated with the spatial soil map is a complicated database with more than 50 tables. Soil Data Viewer provides users access to soil interpretations and soil properties while shielding them from the complexity of the soil database. Each soil map unit, typically a set of polygons, may contain multiple soil components that have different use and management. Soil Data Viewer makes it easy to compute a single value for a map unit and display results, relieving the user from the burden of querying the database, processing the data and linking to the spatial map. Soil Data Viewer contains processing rules to enforce appropriate use of the data. This provides the user with a tool for quick geospatial analysis of soil data for use in resource assessment and management.

Conservation Planning Toolkit

Customer Service Toolkit 2004 (Toolkit; http://www.itc.nrcs.usda.gov/toolkit/) is the primary conservation planning tool used by NRCS, conservation districts, and technical service providers (TSP) such as private consultants. The Toolkit is used for creating conservation plan documents, including planned practice schedules and conservation program contract documents. It is also used for creating conservation plan maps, site-specific thematic soils maps, or other resource maps.

Animal Waste (Manure) Management

Manure Management Planner (MMP) is a Windows-based computer program developed at Purdue University that is used to create manure management plans for crop and animal feeding operations. The user enters information about the operation's fields, crops, storage, animals, and application equipment. MMP helps the user allocate manure (where, when and how much) on a monthly basis for the length of the plan (1-10 years). This allocation process helps determine if the current operation has sufficient crop acreage, seasonal land availability, manure storage capacity, and application equipment to manage the manure produced in an environmentally responsible manner. MMP is also useful for identifying changes that may be needed for a non-sustainable operation to become sustainable, and determine what changes may be needed to keep an operation sustainable if the operation expands.

MMP is nationally supported by both USDA-NRCS and EPA for nutrient management planning. Manure Management Planner (MMP) is free. It can be downloaded from this web site: http://www.agry.purdue.edu/mmp

Nutrient Management

AFOProTM is a standalone nutrient management planning tool for animal feeding operations with optional connections to GIS (ArcMap© and ArcView©) and the NRCS’s Animal Waste Management (v 2.0.2 or higher) engineering software. The application allows the user to plan manure and commercial fertilizer allocation decisions in compliance with the NRCS's 590 Standard, which requires the documentation of form, source, timing, method, and placement of nutrients. The design of the application is open, transparent, and flexible which enables it to be adapted to specific state crop removals, nutrient risk ratings, and nitrogen accounting requirements. Additionally, the application uses modular Phosphorus Indices, state-specific fertility recommendations and state-specific CNMP templates.

Small Farm Pond Design - WinPond

WinPond is a computer program used for the design of small farm ponds and other runoff impoundments. WinPond represents an upgrade of the Missouri Pond Program from a Disk Operating System (DOS) to a Windows XP operating environment.

Hydrology and Engineering

Rawls et al. (2007) used the NASIS soil database to estimate soil hydraulic properties for engineering applications. Soil water relationship parameters were predicted with pedotransfer functions and the readily available variables of soil texture and organic matter. Saxton and Rawls (2006) developed an interactive model, which has a web-based graphical user interface tool to perform site-specific estimates. The hydraulic properties calculator
Fig. 10. Soil survey map and legend from Web Soil Survey.
Fig. 11. Soil survey interpretation for “Dwellings with Basements.”
### Table 9. Soil interpretation for “Dwellings with Basements”

<table>
<thead>
<tr>
<th>Soil Survey Map Unit Name</th>
<th>Map Unit Symbol</th>
<th>Rating</th>
<th>Component Name Rating (Percent)</th>
<th>Reasons</th>
<th>Total Acres in AOI</th>
<th>Percent of AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CdB</td>
<td>Catoctin-Highfield complex, 3 to 8 percent slopes, very rocky</td>
<td>Not limited</td>
<td>Highfield (40%)</td>
<td>15.2</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>CgA</td>
<td>Codorus and Hatboro silt loams, 0 to 3 percent slopes</td>
<td>Very limited</td>
<td>Codorus (60%)</td>
<td>Flooding</td>
<td>17.1</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Hatboro (40%)</td>
<td></td>
<td>Depth to saturated zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HgB</td>
<td>Highfield gravelly silt loam, 3 to 8 percent slopes</td>
<td>Not limited</td>
<td>Highfield (85%)</td>
<td>54.9</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>HgC</td>
<td>Highfield gravelly silt loam, 8 to 15 percent slopes</td>
<td>Somewhat limited</td>
<td>Highfield (*5%)</td>
<td>Slope</td>
<td>87.4</td>
<td>16.8</td>
</tr>
<tr>
<td>HgD</td>
<td>Highfield gravelly silt loam, 15 to 25 percent slopes</td>
<td>Very limited</td>
<td>Highfield (85%)</td>
<td>Slope</td>
<td>7.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

### Notes
- MYERSVILLE (10%)
- Depth to hard bedrock
solves a sequential series of 24 multiple regression equations to readily estimate soil water holding and transmission characteristics by selecting a soil texture, and adjusting the inputs of organic matter, salinity, gravel content and density. The Soil Water Characteristics Hydraulic Properties Calculator (Fig. 12) is available on the Internet at [http://hydrolab.ars.usda.gov/soilwater/index.htm](http://hydrolab.ars.usda.gov/soilwater/index.htm).

**NRCS ENERGY TOOLS**

The Natural Resources Conservation Service (NRCS) has developed four energy tools designed to increase energy awareness in agriculture and to help farmers and ranchers identify where they can reduce their energy costs. The results generated by these tools are estimates based on NRCS models and are illustrative of the magnitude of savings. Energy Estimator Tools are currently available in the Internet for animal housing, irrigation, tillage, and nitrogen fertilizer use. ([http://energytools.sc.egov.usda.gov/](http://energytools.sc.egov.usda.gov/))

**Energy Estimator: Irrigation**

The Energy Estimator for Irrigation tool enables you to estimate potential energy savings associated with pumping water for irrigation (Fig. 13). NRCS technical specialists developed this model to integrate general technical information farm-specific crops, energy prices, and pumping requirement. However, this tool does not provide field-specific recommendations.

**Energy Estimator: Tillage**

The Energy Estimator for Tillage tool estimates diesel fuel use and costs in the production of key crops in your area and compares potential energy savings between conventional tillage and alternative tillage systems. The crops covered are limited to the most predominant crops in 74 Crop Management Zones (CMZ's). NRCS agronomists have identified these crops and estimated the fuel use associated with common tillage systems. The

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**Fig. 12.** Soil water characteristics calculator – estimates soil water tension, conductivity and water holding capability based on the soil texture, organic matter, gravel content, salinity, and compaction (Saxton and Rawls 2006).
Energy Estimator gives the user an idea of the magnitude of diesel fuel savings under different levels of tillage.

**ENVIRONMENTAL ASSESSMENTS**

Study of ecological sites in conjunction with soil survey and natural resources inventory will increase our knowledge of the interactions among soils, climate and ecosystems. The Ecological Site Information System is a database under development to improve the ecology and management of forests and rangelands. Soil resource hazards associated with human activity include accelerated soil erosion and removal/concentration of heavy metals (e.g., Pb, Cu, Zn) and other geochemical constituents (e.g., As, Hg). Estimation of soil erosion is based primarily on the Revised Universal Soil Loss Equation, version 2 (RUSLE2). The distribution of soil geochemical constituents is an ongoing research activity with results for pedons previously analyzed at the Soil Geochemistry Spatial Database.

**Ecological Sites**

An ecological site is defined as “a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation.” The Ecological Site Information System (ESIS) is the repository for the data associated with the collection of forestland and rangeland plot data and the development of ecological site descriptions. ESIS is organized into two applications and associated databases: Ecological Site Description (ESD) and Ecological Site Inventory (ESI). The ESD application provides the capability to
produce automated ecological site descriptions from the data stored in its database. The ESD is the official repository for all data associated with the development of forestland and rangeland ecological site descriptions by the NRCS.

The data for an Ecological Site Description is collected and presented in four major categories: 1) Site Characteristics - identifies the site and describes the physiographic, climate, soil, and water features associated with the site; 2) Plant Communities - describes the ecological dynamics and the common plant communities comprising the various vegetation states of the site. The disturbances that cause a shift from one state to another are also described; 3) Site Interpretations - interpretive information pertinent to the use and management of the site and its related resources; and 4) Supporting Information - provides information on sources of information and data utilized in developing the site description and the relationship of the site to other ecological sites.

The Ecological Site Inventory (ESI) application provides the capability to enter, edit, and retrieve rangeland, forestry, and agroforestry plot data. The ESI data are used to develop inventories for planning, to monitor ecological change and make management decisions, for the development of ecological site descriptions, hydrologic models, studies of conservation treatment effects, and for many other purposes. ESI contains inventory data collected on thousands of plots over the past 40 years. Inventory data collected on rangeland plots includes the total annual production of all plant species of a plant community, as well as the production (by weight measurement) and composition of individual plant species comprising the plant community. The inventory data collected on forestland plots includes: composition and relative abundance of the overstory and understory plant species; stand densities (basal area); and site productivity, as measured by site index. In addition to plant community data, ecological site inventories on both rangeland and forestland plots includes data relative to the physiographic features of the site (soil, slope, aspect, landform, etc.). [http://esis.sc.egov.usda.gov/ESIS/About.aspx]

Soil Erosion – RUSLE2

Version 2 of the Revised Universal Soil Loss Equation (RUSLE2) estimates soil loss, sediment yield, and sediment characteristics from rill and interrill (sheet and rill) erosion caused by rainfall and its associated overland flow. RUSLE2 uses factors that represent the effects of climatic erosivity, soil erodibility, topography, cover, management and support practices to compute erosion. RUSLE2, like other mathematical models, uses a system of empirical equations to compute erosion. The RUSLE2 database and its rules and procedures are applied to describe a site-specific condition and, given a description to estimate erosion. RUSLE2 is not a process-based simulation model that attempts to mathematically replicate field processes.

RUSLE2 is used to guide conservation planning, inventory erosion rates over large areas, and estimate sediment production on upland areas that might become sediment yield in watersheds. It can be used on cropland, pastureland, rangeland, disturbed forestland, construction sites, mined land, reclaimed land, landfills, military lands, and other areas where mineral soil is exposed to raindrop impact and surface overland flow produced by rainfall intensity exceeding infiltration rate.

The RUSLE2 computer program, a sample database, a tutorial that describes program mechanics, a slide set that provides an overview of RUSLE2, and other supporting information are available for download from Official RUSLE2 Internet Sites supported by the University of Tennessee at [http://bioengr.ag.utk.edu/RUSLE2/], the USDA-Agricultural Research Service (ARS) at [http://www.sedlab.olemiss.edu/RUSLE/] and the USDA-Natural Resources Conservation Service (NRCS) at [ftp://fargo.nserl.purdue.edu/pub/RUSLE2/].

RUSLE2 was developed primarily to guide conservation planning, inventory erosion rates and estimate sediment delivery. RUSLE2 is an upgrade of the text-based RUSLE DOS version 1. It is a computer model containing both empirical and process-based science in a Windows environment that predicts rill and interrill erosion by rainfall and runoff. Values computed by RUSLE2 are supported by accepted scientific knowledge and technical judgment, are consistent with sound principles of conservation planning, and result in good conservation plans. RUSLE2 is also based on additional analysis and knowledge that were not available when RUSLE1 was developed. RUSLE2 is based on science and judgment that is superior to that of RUSLE1. We learned things from RUSLE1 that are incorporated into RUSLE2.

RUSLE2 has evolved from a series of previous erosion prediction technologies. The USLE was entirely an empirically based equation and was limited in its application to conditions where experimental data were available for
deriving factor values. A major advancement in RUSLE1 was the use of subfactor relationships to compute C factor values from basic features of cover-management systems. While RUSLE1 retained the basic structure of the USLE, process-based relationships were added where empirical data and relationships were inadequate, such as computing the effect of strip cropping for modern conservation tillage systems.

RUSLE2 is another major advancement over RUSLE1. While RUSLE2 uses the USLE basic formulation of the unit plot, the mathematics of RUSLE2 are on a daily basis. Improved cover-management subfactor relationships are used in RUSLE2, a new ridge subfactor has been added, and the deposition equations have been extended to consider sediment characteristics and how deposition changes these characteristics. It includes new relationships for handling residue, including resurfacing of residue by implements like field cultivators.

SOIL CLASSIFICATION AND APPROXIMATE CORRELATION OF INTERNATIONAL SYSTEMS

Table 10 shows the list of Soil Orders and Suborders for the different countries participating at this workshop, while Table 11 shows the distribution of Soil Suborders for each country represented at this workshop. These country-specific lists were developed from the USDA Soil Map of the World adapted from the FAO 1.5M Soil Map of the World (Eswaran and Reich, 2005) using the 1.0M country boundaries from the Digital Chart of the World Server at Penn State University (accessed at http://www.maproom.psu.edu/dcw/)

Table 11 lists each country and the various Suborders distributed among the workshop countries. The results illustrate a large range in soil diversity among the various islands and coastal nations. For example, Indonesia has 32 Suborders within its geographic area.

Tables 12a and 12b gives an example of the approximate soil correlation between the USDA Soil Taxonomy and the WRB systems for Andisols, Vertisols, Planosols, Histosols and Cambisols. The soil moisture and soil temperature regimes are arrayed with selected examples of lower units of the Reference Soil Groups.

These two tables should be aligned horizontally (placed side by side) to increase their overall usefulness for all soil climatic regimes. The correlation process using WRB Reference Soil Groups and their respective lower level units is built from an array with the soil moisture and soil temperature regimes of USDA Soil Taxonomy. This procedure was published in 2003 by Eswaran and others for a soil correlation exercise between 1981 FAO Soil Map of the World and USDA Soil Taxonomy for a soil map of Mexico. A comprehensive soil correlation project among the various national systems and the WRB would improve and increase communication among all users of the soil resource. This project would develop a revised, global scale soil correlation table with the WRB, USDA Soil Taxonomy and other available systems with results comparable to the recently published report on the soils of Russia (Stolbovoi 2000) and others.

TERRAIN MODELS AND THEIR APPLICATIONS

Terrain data are now available on a global scale (e.g. SRTM) and frequently obtained in numerous site-specific projects by remote sensing tools (i.e. LiDAR, SLR, RTK-GPS, etc.) providing elevation data at detailed locations that reveal micro topographic highs and lows (Fig. 14).

Terrain or digital elevation model (DEM) data are readily processed using GIS to prepare various primary and secondary derivative attribute layers. The basic products from DEMs include elevation, contour, slope, and aspect and slope curvature (profile, tangential and platform) data layers. The elevation data serves as the input for calculating various hydrologic variables such as the topographic wetness indices, stream power indices, flow path length, contributing area, and catchment length, slope and area. Drainage basin analyses using DEMs include ridgeline; watersheds; sediment transport factor; viewedsh; local drain direction; upstream elements/ area/specific catchment area; stream length; stream channel; and drainage network classification.

Soil geomorphometric analyses were described by Olson and Effland (2006). Soil geomorphic studies require three investigative steps: 1) knowledge of the surficial stratigraphy and parent materials; 2) geomorphic surfaces defined in time and space; and 3) correlation of soil and sediment properties to landscape features. Previously, illustration of these three aspects was largely confined to two-dimensional products such as graphs, stratigraphic sections, fence diagrams, and flat maps of geomorphic surfaces and landscape relief. Access to a wide array of three-dimensional visualization products provides additional interpretative information in
Table 10. Soil orders and suborders of the 2008 SIS workshop countries

<table>
<thead>
<tr>
<th>Soil Orders</th>
<th>Suborders</th>
</tr>
</thead>
<tbody>
<tr>
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Table 11. Distribution of suborders for the 2008 SIS workshop countries

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Table 12a. Soil correlation between USDA and WRB systems using soil climate

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Table 12b. Soil correlation between USDA and WRB systems using soil climate

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a GIS-structured environment. Three-dimensional diagrams can display additional critical information not immediately apparent or possible to examine in two-dimensional renderings. Soil geomorphometric analysis using digital elevation models (DEM) and associated derivative products offer possibilities for quantitative description and characterization of soil geomorphic relationships. Olson and Effland examined several areas in the central USA for which soil-geomorphic data are available over a few 10’s of km (Fig. 15). Using 30-meter DEMs, the most commonly available elevation data in the USA, more quantitative relationships between geomorphic surfaces, soils, and sediments were visualized for a traverse across southwestern Iowa.

**TRANSFER OF SOIL INFORMATION TO SMALL SCALE FARMERS AND OTHER USERS**

Eswaran et al. 1999, describe how the transfer of agrotechnology innovations in developing countries has typically resulted in a low level of acceptance by farmers, especially when compared to adoption of germplasm transfer technology. They propose this mixed success is related to problems with integrating modern scientific techniques with conventional farming practices. They further recommend increased direct involvement of farmers in technology development and implementation to achieve more widespread acceptance of agrotechnology transfer.

Internet-based applications such as the NRCS Web Soil Survey tool provide access to soil information using a GIS-based user interface. The tool allows the user to select a discrete parcel of land for soil information visualization and preparation of color-coded thematic maps for various soil property, land use and management activities. However, advanced spatial analysis techniques of the various soil data bases (e.g., STATSGO and SSURGO) are typically reserved for more sophisticated GIS practitioners because of the complexity of the underlying database management structure.

Customized soil information reports with applications specifically designed to small-scale farmers and other users can serve as an effective tool to report site-specific soil information. Figures 16-18 are examples of a customized soil information report based on the NRCS Web Soil Survey application.

**ACKNOWLEDGMENTS**

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Fig. 15. Application of DEMs for soil geomorphometric analyses (Olson and Effland 2006).

Fig. 16. Custom soil resource report.
Fig. 17. Custom Soil Resource Report – Soil Map and Map Unit Legend.
Fig. 18. Custom Soil Resource Interpretation Report – Septic Tank Absorption.
REFERENCES


Olson, C.G. and W.R. Effland. 2006. Visualization techniques in soil geomorphology. 18th World Congress of Soil Science, Philadelphia, PA.


