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Soils2026 and digital soil mapping – A foundation for the future of soils information in the United States

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ABSTRACT

Soils are our most critical natural resource. However, urgent social, economic, and environmental issues such as carbon sequestration, drought mitigation, and nutrient management are forcing us to seek answers to questions using incomplete soil data and/or inappropriate soil information. The United States (US) Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), Soil and Plant Science Division has launched Soils2026, an ambitious initiative to provide a new inventory of soils and provisional ecological sites for all areas of the United States by 2026. Soils2026 aims to provide basic soil and ecological site information that will be useful to land managers, ecologists, modelers, and other natural resource professionals. This effort will rely heavily on digital soil mapping (DSM) to produce the next generation of raster-based soil information products for the interpretation of soil physical, chemical, and biological properties across the United States.

The USDA-NRCS Digital Soil Mapping Focus Team was formed to support Soils2026 and includes collaborating members from the National Cooperative Soil Survey representing the NRCS, US Geological Survey, USDA Forest Service, West Virginia University, and New Mexico State University. The DSM Focus Team is applying the latest DSM methods to produce continuous soil property predictions and estimates of uncertainty for all areas of the United States. Initially, the 30-m resolution products will include predictions for 12 key soil properties at six depth intervals, conforming to GlobalSoilMap specifications, with the option to expand properties or add class predictions as user needs demonstrate. Interpretations for use and management will be derived from the continuous properties products and provided to users. Fundamental pedology and communication of soil knowledge will be the primary focus of this effort, yielding a framework for delivery of seamless raster-based soils data for all areas of the United States on yearly cycles. This framework will foster an environment of continuous improvement and support a complete, consistent, correct, comprehensive, and current inventory of the soil resources of the United States.

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1. Introduction

Traditional soil survey in the United States "describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organized database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems" (Soil Science Division Staff, 2017, p. 1). This definition, however, implies that soil survey map products are restricted to polygon-based maps of soil classes (polygon-class maps). While this paradigm has sufficed for much of the 120-year history of the National Cooperative Soil Survey (NCSS) program in the United States, advances in technology and expansion of end-user requirements have prompted the NCSS to consider raster-based maps of soil classes (raster-class maps) and soil properties (raster-property maps). The raster-class maps were initially seen as intermediate products that were precursors to the desired polygon-class maps. More recently, the raster-property maps have been recognized not merely as site-specific research projects with little or no utility for soil survey, but as broadly-applicable products suitable for management applications involving user-defined management interpretations (e.g., Nauman et al., 2015, 2017).

In response to the growing recognition of the vital role of soils in supporting and maintaining critical Earth systems (McBratney et al., 2014; Adhikari and Hartemink, 2016), there is growing demand from decision-makers for more accurate and higher resolution soils information (Grunwald et al., 2011; Folberth et al., 2016). The recent trend is for raster-based maps of individual soil properties (Wood et al., 2011; Arrouays et al., 2014a; Hengl et al., 2014, 2017) that are compatible with other environmental geospatial data as input into geographic information systems and other decision support systems (Grunwald et al., 2011).

1.1. About Soils2026

Building on a 120-year history of creating and maintaining the inventory of soil and ecological resources of the United States, the USDA-NRCS has made a renewed commitment to a nationwide soil and ecological site knowledgebase. Known as Soils2026, this overarching commitment includes investments of time and resources targeted across multiple aspects of the NCSS to ensure that the inventory remains relevant to internal and external customers—both current and potential future users of soil and ecological site (Bestelmeyer and Brown, 2016) products and services.

Soils2026 is an initiative to complete the resource inventory for all areas of the United States by 2026. This effort will include both the soils and ecological site inventory and will provide publicly-available basic soils information that will be useful to land managers, ecologists, modelers, and other natural resource professionals. Soils2026 is an ambitious effort that will add to the available soil resource information for the United States through development of a new generation of soil information products to provide flexible, raster-based digital maps for interpretation of soil physical and chemical properties across the United States. The goal of these efforts is to collect, quantify, interpret, and communicate knowledge of soil science to a diverse community of scientists, modelers, land managers, and decision-makers dependent upon soil resources. This initiative is motivated by an overall purpose of increasing our geospatial knowledge of the soil resources of the United States at local, regional, and continental scales. The USDA-NRCS DSM Focus Team provides leadership within the NRCS Soil and Plant Science Division (SPSD) for development of current and future DSM activities by establishing standards for DSM products, developing and delivering training to SPSD and NCSS soil scientists, providing support to SPSD and NCSS DSM practitioners, and establishing mechanisms to deliver new DSM products and ancillary data to internal and external customers. By advancing our understanding of soil use and management practices at all scales, these new soil data products will better inform and guide decision making by the research community and the public. Therefore, it is critical that research and development efforts investigate both the spatial and temporal scaling of soils across the landscape. Individual projects will conform to the larger agenda of improving the digital soil geographic knowledge base of the United States. The technical expertise of the NRCS National Soil Survey Center (NSSC) staff, as well as that of university partners, state and local NRCS staff, and other NCSS collaborators will direct research efforts towards projects related to developing products that provide more consistent and detailed interpretation of soil-landscape processes using terrain analysis, remote sensing, and DSM techniques (McBratney et al., 2003; Minasny and McBratney, 2016).

2. Products

2.1. Existing products

2.1.1. National scale

While soil survey in the United States is, practically speaking, about producing a localized tool for land management, there is value in having regional- and national-scale soil information products, whether that is for the purposes of broader planning and decision-making, or for inventory and accounting (e.g., C stocks, crop yield projections, degradation risk assessment). Efforts to produce complete and consistent national-scale interpretive soil maps for the United States began in the 1980s. As local-level soil surveys were becoming more common, some attention was given to the development of state-wide soil maps and databases (i.e., the State Soil Geographic, or STATSGO, database) (Soil Conservation Service, 1991), which were then generalized to national soil map products (i.e., the National Soil Geographic, or NATSGO, database) (Bliss et al., 1995).

More recently in the United States, in part driven by initiatives like GlobalSoilMap (GSM) (Sanchez et al., 2009; Arrouays et al., 2014a) and in part driven by increasing needs for more accurate and precise estimates of soil resources for the United States, new national-scale soil maps have been developed. Odgers et al. (2012) began by reinterpreting the polygon class maps of the STATSGO database to develop raster maps of individual soil properties at a 90-m resolution. While Odgers et al. (2012) presented only the soil organic C map products, all 12 GSM properties were derived from the STATSGO database. Helmick et al. (2014) demonstrated that the prediction intervals derived from the STATSGO database also approximated the specification for the 90% prediction intervals for GSM products.

Seeking greater spatial detail than offered by the STATSGO-derived products but wanting to avoid problems associated with SSURGO (e.g., Thompson et al., 2012), Chaney et al. (2016) capitalized on contemporary developments in the area of spatial disaggregation (Sun et al., 2010; Subburayalu et al., 2014; Odgers et al., 2014; Nauman and Thompson, 2014; Nauman et al., 2014) to develop POLARIS, a disaggregated version of SSURGO that depicts soil series at a 30-m resolution for all of the continental United States. Chaney et al. (2019) later extended the POLARIS raster-class maps to provide predictions of 13 selected soil properties for six depth increments (0–5, 5–15, 15–30, 30–60, 60–100, 100–200) at a resolution of 30 m. In contrast, following the example of Hengl et al. (2014, 2017), a set of national-scale soil map products at 100 m resolution for the continental United States were derived directly from point observations by Ramcharan et al. (2018). These products included grids for six soil properties (organic C, total N, bulk density, pH, sand, clay) at seven standard depths (0, 5, 15, 30, 60, 100, 200 cm) as well as predictions of taxonomic great group and particle size class (Ramcharan et al., 2018).

2.1.2. Local scale

As previously stated, soil survey in the United States is largely focused on producing a localized tool for land management. Over the past two decades, DSM methods have gradually been incorporated into local-level mapping projects to provide information on unmapped lands, as well as update existing SSURGO soil maps. Some of these projects have resulted in a published Raster Soil Survey (RSS), which is a raster-class product with a supporting database that mirrors SSURGO data, while other projects have merely used DSM techniques to support the development of a traditional vector-based SSURGO product. These projects have implemented a variety of classification approaches, but most commonly machine learning and knowledge-based classification were employed. Two notable examples of these RSS projects include soil surveys of Essex County, Vermont, and the Boundary Waters Canoe Area, Minnesota.

Knowledge-based soil inference classification (Shi et al., 2004) was used to develop the Essex County, Vermont, soil survey (Shi et al., 2009, 2012; McKay et al., 2010). When it was first published in 2011 the Essex County soil survey was the first SSURGO product developed with DSM methods. For the 175,000-ha survey, a variety of raster classes were modeled, ranging from single component-level classes in the easiest-to-model areas of loamy lodgment till to broader, landform-based classes in other areas. These raster classes were aggregated and processed as needed to produce the vector-based traditional soil survey. In addition to SSURGO, a component-level RSS was published for the loamy lodgment till catena, an area of about 75,000 ha.

The Boundary Waters Canoe Area Wilderness soil survey was a unique project with a goal of mapping approximately 400,000 ha of limited access wilderness along the Canadian border in northern Minnesota. A team of DSM practitioners collaborated on this project and employed a variety of classification techniques, including machine learning, knowledge-based classification, unsupervised classification, logistic regression, and heads-up digitizing for the most difficult to model but important classes, such as glacial eskers. The final raster map was a hybrid of results from the various classification techniques and is published as a RSS. The final raster map was used to inform the creation of a vector-based product that is published as part of the SSURGO database.

2.2. New products

A complete, consistent, correct, comprehensive, and current inventory of the soil resources of the United States is needed. The emphasis on developing soil property layers at predefined depths is in keeping with the needs of users (Sanchez et al., 2009; Grunwald et al., 2011; Arrouays et al., 2014a). The primary deliverables for Soils2026 will be spatial predictions of selected soil properties at a 30-m spatial resolution for six standard depth intervals (0–5, 5–15, 15–30, 30–60, 60–100, 100–200 cm) following GSM specifications (Arrouays et al., 2014b). A resolution of 30 m was selected for two reasons. First, this will ensure that the soil property grids developed for the United States will be compatible with other spatial dataset used for environmental analysis, modeling, and decision-making (Arrouays et al., 2014), which in the United States include the National Elevation Dataset, the Landsat Archive, and the National Land Cover Database. Second, a resolution of 30 m provides a balance between the desire for greater spatial detail and the need to minimize file size (which impacts both data processing requirements and data storage requirements). The target properties will be: pH, organic C (g kg^{-1}), sand (g kg^{-1}), silt (g kg^{-1}), clay (g kg^{-1}), rock fragments (m^3 m^{-3}), effective cation exchange capacity ($cmol_c$ kg^{-1}), bulk density of the fine earth fraction (Mg m^{-3}), bulk density of the whole soil (Mg m^{-3}) and available water capacity (mm) at all six depth intervals plus plant-exploitable soil depth (i.e., depth to root limiting layer) and total profile depth (i.e., depth to rock). In addition, the uncertainty associated with each prediction will be provided in the form of a 90% prediction interval. Predictions of other soil properties, such as electrical conductivity (dS/m), may also be produced.

These efforts in the United States are a continuation of the work by Odgers et al. (2012) and Libohova et al. (2014), and because these efforts are aligned with the GSM initiative, the specifications are similar to those associated with other recent national-scale efforts to develop GSM-compatible products, such as in Australia (Grundy et al., 2015; Viscarra Rossel et al., 2015), Denmark (Adhikari et al., 2013, 2014), France (Mulder et al., 2016a, 2016b), and Chile (Padarian et al., 2017). The new products for the United States will be at a higher resolution than has been produced for Australia, France, and Chile, but approximately equal to those developed for Denmark. In part, this difference in resolution may be attributable to the higher resolution environmental covariates used in Denmark and available for the United States. As was the case in Australia, the US grids will encompass all of the targeted soil properties in the GSM specifications (Arrouays et al., 2014b). And, as was done in Australia, France, and Chile, the US products will include uncertainty information in the form of prediction intervals for all soil property maps.

Predictions will be derived from the application of machine learning models developed using soil profile databases (e.g., the NCSS Soil Characterization Database, the Rapid Carbon Assessment (RaCA) database, the National Soil Information System (NASIS) database) and a range of geospatial datasets that are expected to influence patterns of soil variability across the landscape, including (i) terrain covariates (e.g., slope gradient, slope curvature, topographic wetness index, multiresolution valley bottom flatness), (ii) PRISM (PRISM Climate Group, 2015) climate covariates (e.g., precipitation, mean temperature), (iii) Landsat products (e.g., NDVI), and (iv) soil properties and classes (e.g., SSURGO). The NCSS Pedon Characterization Database (https://ncsslabdatamart.sc.egov.usda.gov/) alone contains entries for ~400,000 soil horizons from ~65,000 pedons, ~52,000 of which are georeferenced (J. Nemecek, personal communication, March 2019). These data will require further scrutiny to remove duplicate pedons, update classification, address missing data, and/or harmonize property data measured using different methods (e.g., Sulaeman et al., 2013; Libohova et al., 2014). Over time, new pedons will be added, either through ongoing field observations or the capture and rescue of legacy pedons (e.g., Arrouays et al., 2017).

The modeling and mapping process will follow standard protocols that have been developed and implemented for many DSM initiatives. We will begin with assembling all available point and pedon data. Prior to modeling these data will be cleaned (e.g., missing or erroneous values corrected or removed, coordinates verified, consistency checks) and prepared (e.g., harmonized to the six standard depths). A model training matrix will be extracted from the covariate stack and the predictive models will be built and validated. These models will be evaluated using sample points not included in the training matrix.

Developing predictive soil maps for the United States at such a high resolution has not been previously attempted at a national scale; however, there are recent examples demonstrating that soil properties can been modeled and predicted successfully at a resolution of 30 m (Nauman and Duniway, 2016, 2019; Nauman et al., 2017). Also, it should be noted that, unlike conventional polygon mapping, the resolution of the raster spatial prediction is not an indication of the accuracy or precision associated with the prediction (Arrouays et al., 2014a, Arrouays et al., 2020). Higher resolutions are feasible with increased computing power. These efforts will benefit from the >120-yr history of the US soil survey program, which has resulted in a rich legacy of polygon soil maps that cover >90% of the country. A disaggregation of soil surveys resulted in high resolution predictions of some, but not all, of the targeted soil properties across the continental United States (Chaney et al., 2016, 2019). It is unclear specifically how these will be included in the final analysis, but model averaging (Malone et al., 2014) is a possibility.

While the goal is a nationally-consistent set of soil property grids, the DSM Focus Team is still evaluating the merits of developing single national models for each property or developing multiple regional models that will be joined together to produce national maps. Mulder et al. (2016b) compared predictions derived from national models for France to predictions derived from global models (SoilGrids1km; Hengl et al., 2014) and concluded that the national models were superior to the global models.

2.3. Covariate stacks

An initial step in almost every DSM initiative is to prepare and compile a collection of environmental covariates to be used in developing predictive models of soil variability, with terrain derivatives and spectral derivatives being the most common covariates (McBratney et al., 2003). At regional, national, or continental scales, these covariates are most frequently derived from authoritative sources. In the United States, the US Geological Survey (USGS) National Elevation Dataset is the authoritative source for digital elevation data, with digital elevation models (DEM) available at 30 m resolution for the entire country (and at higher resolutions for selected areas). Similarly, for spectral data the Landsat dataset is the authoritative source for surface reflectance products. However, while most DSM initiatives use the same source data, there is a multitude of individual terrain derivatives that can be prepared from gridded DEM data; and for some of these terrain attributes, there are multiple methods for calculating or representing them (e.g., slope gradient, slope aspect, slope curvature). To both ensure the availability of a standard set of environmental covariates for current and future DSM projects, and to reduce the amount of repeated effort distributed to individual DSM practitioners, the DSM Focus Team has created a standard covariate stack for the United States at a resolution of 30 m. Currently 56 seamless terrain covariates have been derived for the continental United States including elevation, slope gradient, slope curvature (profile, plan, longitudinal, cross-sectional, minimum, maximum, and total), mass balance index, convergence index, diurnal anisotropic heating, multi-scale topographic position index, multiresolution valley bottom flatness, multiresolution ridge top flatness, terrain ruggednesss index, terrain surface convexity, catchment area, catchment slope, modified catchment area, topographic wetness index, SAGA wetness index, positive openness, relative position (multiple window sizes), relative height (multiple window sizes), and stream power index. Additionally, 13 seamless surface reluctance products that cover the continental United States have been created, including a 6-band Landsat composite image (with disturbance removed), variations of the normalized difference vegetation index (NDVI), and variations of the soil adjusted total vegetation index (SATVI). All covariates will be stacked to ensure consistent extents and alignment.

By ensuring that all DSM practitioners have access to the same set of environmental covariates we can maintain consistency of the DSM inputs and, presumably, greater reproducibility in the DSM outputs. Among other benefits, this will allow these DSM practitioners to maintain the emphasis on soil science and not geographic information science. Scripts that implement geoprocessing routines (as well as other aspects of DSM) have been made available via GitHub (https://github.com/ColbyBrungard/Geoprocess-by-area) to further improve the adoption rate of DSM practices, reduce barriers to implementation, and provide method transparency.

3. Institutions

In some ways, data collection, management, and analysis are the easy parts of operational DSM. While more and better data will always be a goal, and while analysis and modeling techniques will continue to evolve, it is the human capacity that has limited the adoption and dissemination of DSM at an institutional level in the United States. Consequently, the NRCS has invested time and resources in building capacity among soil scientists through both top-down and bottom-up approaches.

The motivation of the DSM Focus Team is to produce the next generation of soil information products that will provide a flexible raster-based product for interpretation of soil physical, chemical, and biological properties across the United States. The focus will be fundamental pedology, i.e., understanding the soil resource as a natural body. The primary difference will be inclusion of the latest technological resources—hardware, spatial data, quantitative methods—adaptively applied throughout the process. Consequently, we aim to emphasize that this effort is about soil knowledge. The resulting data and information will be a product of our knowledge of the soil resource. Furthermore, we are focused on the users of soils data.

The DSM Focus Team works to coordinate DSM activities across the SPSD, and is charged with updating soil survey standards (e.g., NSSH Part 648 – Digital Soil Mapping – Raster Products), assembling existing data, identifying training needs, developing and delivering training, and producing raster-based soil information products. The DSM Focus Team maintains a web site (https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/focusteams/), which serves as an online information portal for the various training and outreach activities of the DSM Focus Team and a gathering place for DSM practitioners. From the website those with an interest in DSM activities can obtain links to progress reports, job aids, recorded webinars, presentations, applications for assistance, and other resources. Within the DSM Focus Team there are three sub-teams: one responsible for the development of the national-scale raster property grids (the Properties Sub-team), one to help facilitate the application of DSM techniques to creating raster products for currently unmapped areas of the United States (the Initial Mapping Sub-team), and one to assist in the application of DSM techniques to creating raster products for areas with existing soil maps (the Update Mapping Sub-team).

3.1. Training

At a national level, in addition to the DSM Focus Team, the NRCS has created 11 other Focus Teams through the Soils2026 initiative, including one charged with coordinating the training needs across the SPSD. The DSM Focus Team has worked with the Training Focus Team to review the existing training offerings, make recommendations on new and improved courses and means of delivery, and expand the training opportunities available to soil scientists with an interest in DSM.

3.1.1. Curriculum

In order to build capacity in DSM among soil scientists in the NCSS and SPSD, the DSM Focus Team has developed a training curriculum (Fig. 1) that progresses from basic concepts to advanced application of DSM in soil survey activities. The curriculum was largely built from existing formal training courses with the addition of the foundational

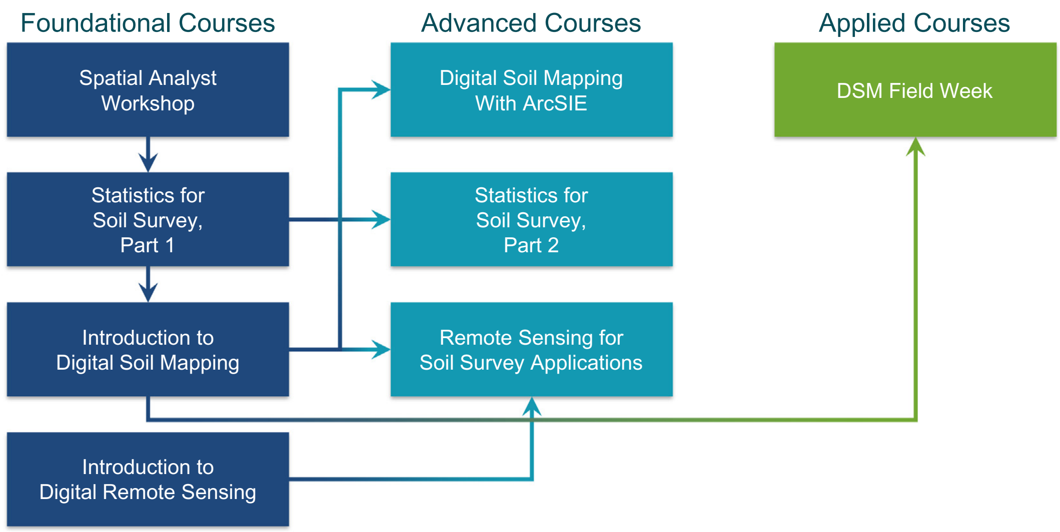

Fig. 1. The current DSM training curriculum for NRCS soil scientists.

Introduction to DSM course and implemented in 2018. This introductory course is viewed as a basic requirement for all soil scientists in the SPSD, regardless of position in the organization. The basic concepts presented in this course allow for consistent understanding of the DSM framework and process, and how it can be effectively applied in soil survey activities to produce raster-based soil information products. Once the introductory course is completed, and depending on their career goals and expectations, soil scientists may choose to move on to the advanced courses, which present deeper inspection of concepts, methods, and application of topics presented in the introductory course.

3.1.2. DSM Field Weeks

While a complete training sequence that provides the theory and practical skills for conducting DSM projects has been available to the NCSS and SPSD staff since 2018, feedback from DSM trainees has indicated that they often have difficulty taking the next step of implementation after training and note the small network of similarly knowledgeable collaborators. In response, the DSM Focus Team designed and implemented a new applied training opportunity within the DSM training curriculum known as DSM Field Weeks. These intensive training exercises help soil scientists successfully initiate and complete DSM-centric projects. These project-focused training opportunities are offered in one or two locations every year to bring together DSM practitioners from NRCS, universities, and cooperating agencies to work with field soil scientists that are pursuing DSM-centric projects and building capacity in DSM. As such, the objectives for conducting the DSM Field Weeks are to:

i) Develop a nationwide network of soil scientists informed by DSM techniques,
ii) Cross-train local soil scientists and DSM experts while helping deliver soil survey products,
iii) Develop knowledge and expertise of soil scientists embarking on their first DSM efforts,
iv) Target sparsely investigated project areas or modeling problems, and
v) Increase the network of point observations across the United States and Territories.

Selection of field week sites and projects is based on an open application process soliciting Soil Survey Offices interested in hosting the Field Week. Eligible offices must have staff who have completed the Introduction to DSM training course, a project with clearly defined objectives that include application of DSM methods, and corresponding support from the Regional Office. Offices must be able to demonstrate the availability of covariate and pedon observation data, clearly outline expectations of the DSM Focus Team participants, identify expected deliverables and timelines, and explain how participation in the field week will support the goals of Soils2026.

Teleconferences take place prior to the Field Weeks to ensure that participants are familiar with the project (background, project design, goals, etc.). These teleconferences are supplemented by other preparatory work related to covariate data development, compiling available pedon data, and sampling design to be completed by project staff and DSM Focus Team members. This maximizes the benefit of funds and time allocated to the field week and project. Activities during the Field Weeks include field-based investigations, data analysis, and model development. Field efforts include an introduction to the project area, particularly the soil-landscape relationships, and collection of new pedon data. Additional training on modeling techniques is also provided during the week.

The weeks and months following completion of the Field Weeks are used for continued training, support, and collaboration between the DSM Focus Team members and the Soil Survey Office to achieve their project goals as outlined in the Field Week application. The Field Week participants will deliver a spatial product in raster format according to the project timetable. Each DSM Field Week targets a specific project, but the contributions of soil scientists from across the country helps spread the knowledge far beyond the targeted project area. The opportunity for participants to share and apply their gained experience and knowledge in their local projects, offices, and regions is significant. Reporting on the outcomes of each DSM Field Week to broader audiences is also encouraged, such as through webinars, presentations at regional and national meetings, and participation in international workshops.

3.2. Support

In addition to providing formal training opportunities through the DSM curriculum, the DSM Focus Team has implemented a project support system for DSM practitioners within the NCSS and the SPSD. A community of DSM practitioners engage in monthly discussions led by the DSM Focus Team. The discussion topics vary from theoretical to operational, but always focus on a topic of practical interest such as sampling design, covariate selection, or validation. The dialog is led by DSM practitioners and often presented in the context of an ongoing mapping project. These monthly sessions offer the opportunity for exchange of ideas, solicitation of advice, and general learning. More importantly, a growing community of scientists are connecting through a common interest in DSM. And this connectedness extends beyond the monthly teleconferences through sharing of tools and resources, such as custom R scripts to implement various DSM workflows (e.g., covariate development, pedon cleaning), which are housed in a GitHub repository where users can share scripts they have developed or ideas that they have tried.

Another avenue of support for ongoing DSM activities is being delivered through a project mentoring program. As capacity in DSM is building in the NCSS and SPSD, there is a recognized lag time between receiving training, implementing skills in mapping projects, and becoming proficient enough to conduct DSM projects independently. The mentoring program is meant to fill that gap by providing a mentor with the appropriate DSM skillset to eligible projects. Soil Survey Offices may request to have a mentor assigned to them to help them achieve their project goals. Requests may vary in intensity from specific tasks, like sampling design, to general project support from start to finish. The DSM mentor is meant only to be available for guidance and questions as needed; the Soil Survey Office staff is expected to complete the project tasks independently. The intent is that the Soil Survey Office staff become more proficient and confident in DSM through the process, and in turn can become mentors for other projects. As capacity in DSM builds and reaches a critical point through training, application, practitioner discussions, and the mentoring program, the expectation is that the project mentoring program will become unnecessary and DSM will be standard mapping practice for all soil survey activities.

4. Summary

The USDA-NRCS, through its Soils2026 initiative, has made a commitment to a complete, consistent, correct, comprehensive, and current nationwide soil and ecological site knowledgebase for the benefit of land managers, ecologists, modelers, and other natural resource professionals. Facilitated by the DSM Focus Team, progress to date has included improved communication of DSM objectives and methodologies within the SPSD, the development of resources for training and support for DSM practitioners, and the compilation of DSM data and tools. Biweekly or monthly teleconferences facilitate discussion, collaboration, and support for ongoing projects among the DSM Focus Team members and DSM practitioners; while presentations by members of the DSM Focus Team at conferences, workshops, and through webinars increases the awareness of DSM initiatives to soil scientists and natural resources professionals both within and outside the NRCS. The DSM training curriculum within the NRCS has significantly increased the number of soil scientists in the SPSD with the necessary foundational skills to begin to implement DSM workflows in their mapping projects. Support for aspiring DSM practitioners is being provided through a formal mentoring program, published job aids, and other training materials. Among advanced DSM practitioners, access to a standard covariate stack for the continental United States and fully vetted modeling scripts will ensure well-documented, consistent, and reproducible DSM products. As a result, the DSM Focus Team is producing continuous soil properties predictions and estimates of uncertainty for all areas of the United States, with updates to these seamless raster-based soil maps on yearly cycles. In addition, interpretations for use and management will be derived from the continuous properties products and provided to users.

Despite this progress, there remain multiple challenges to fully operational development, delivery, and adoption of DSM products in the United States. First and foremost is having staff with both the skillset and the time to create the various DSM products, deliver the DSM training, and provide support to both DSM practitioners and end-users. At present there exists a relatively small group of DSM practitioners that are doing most of the work. However, the goal of the training efforts is to expand the size of that group. Most of the newly-trained field soil scientists throughout the SPSD will be developing local-scale models, with most of these being raster-class products that will integrate DSM into soil survey production. However, a growing number of DSM experts will be involved in the development of the national continuous property products. To provide the desired training from within the DSM training curriculum to all SPSD staff it will be necessary to increase the current frequency at which some training courses are offered. Furthermore, it will be necessary for training instructors and other mentors to provide continuing support to trainees after the completion of the courses to ensure that the lessons learned and skills gained during the training are correctly and effectively put in to practice by the trainees. There will also need to be a significant investment in computing resources to facilitate the storage, access, analysis, and delivery of DSM products and ancillary data. In particular, protocols for the effective delivery of the new raster-property maps with their associated uncertainty information will need to be developed. Finally, it will be imperative that the DSM Focus Team, DSM practitioners within the NCSS, and SPSD leadership continue to communicate to value of these DSM products to end users. These efforts will ensure that the NRCS continues to be recognized as the authoritative source for a dynamic soil survey that provides a relevant soil and ecological site inventory, as well as associated products and services.

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