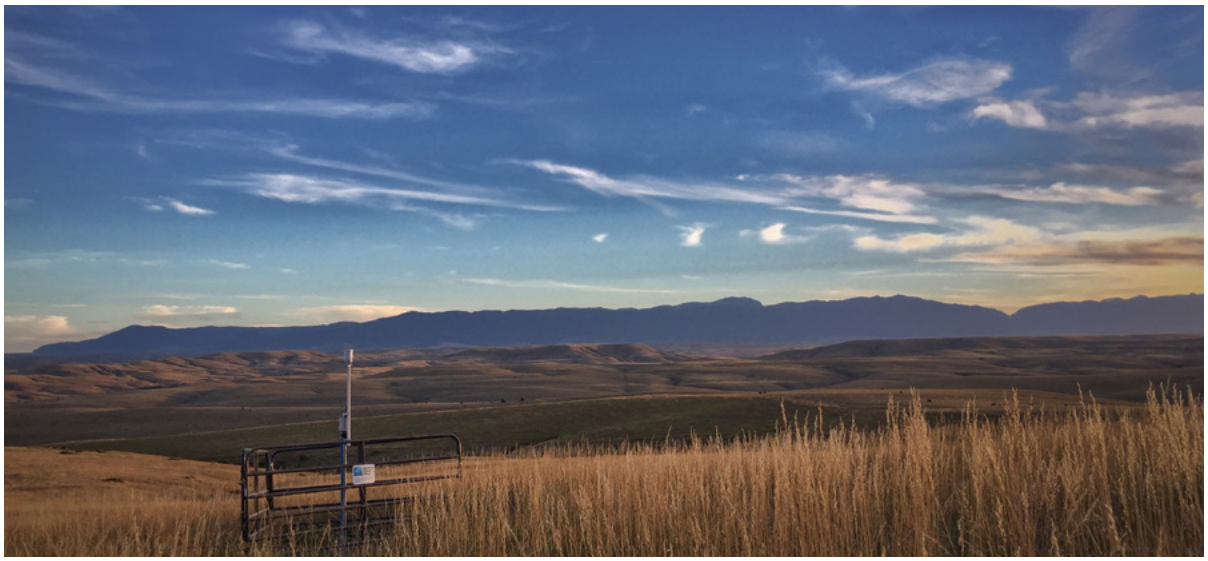

Montana Mesonet Station above Cooney Reservoir, Stillwater County, MT. Credit: Kevin D. Hyde

CHAPTER 6

IMPLEMENTATION OF THE NCSMMN: THE PATH FORWARD

6.1 NATIONAL NETWORK DESIGN

The work of the NCSMMN will leverage, collaborate with, and support existing Federal, state, multistate, and local monitoring efforts for soil moisture. The point-based (i.e., in situ) soil moisture data from participating networks will be enhanced by aggregating and integrating the datasets in one place, and by creating end products that add value by, for example, visually showing the current spatial status of soil moisture across the entire United States. The NCSMMN will support efforts to develop standardized and consistent metadata for monitoring networks, including sampling and characterization of soil physical properties necessary for quality assurance and interpretation of soil moisture observations. The NCSMMN effort will also continue to explore ways to merge the in situ soil moisture data with remotely-sensed and modeled soil moisture products in order to create real-time, high-resolution, gridded national soil moisture maps and other meaningful products and services. The NCSMMN does not replace existing monitoring programs, rather, it is focused on coordinating and improving the status of soil moisture monitoring efforts nationwide for the benefit of applications such as drought and flood monitoring, groundwater recharge estimation, streamflow forecasting, and fire danger ratings.

The overriding mission of the NCSMMN is to provide "… coordinated, high-quality, nationwide, soil moisture information for the public good." What follows in this implementation chapter are a set of steps or recommendations to allow NCSMMN to fulfill this mission.

The first step in the process of developing a national network is to continue to expand the community of experts schooled in the different aspects of soil moisture monitoring. Annual National Soil Moisture Workshops have brought together experts from across the United States to discuss the latest science research and technical innovations regarding soil moisture monitoring and applications.

These workshops provided the initial formation of a community of practice. As the implementation of this Strategy begins, a key recommendation is to support an annual meeting dedicated to improved soil moisture monitoring and new uses for soil moisture information. This would include information from in situ sensors, remote sensing, and modeling. These technologies interact and improve each other, building a better national coordinated network. The recently renamed, community-led, annual National Soil Moisture Workshops, which were initiated by Oklahoma State University and the USDA Agricultural Research Service in 2011, have evolved to a nationwide audience with close to 100 attendees annually. Recent workshops were held in Lincoln, NE (2018), and Manhattan, KS (2019), with the 2020 workshop already in planning and slated for Beltsville, MD, in August.

A near-term goal of the NCSMMN is to engage in situ monitoring networks to improve the availability of their data to user groups across the United States, as well as to improve the quality of soil moisture data by providing standards and quality assurance recommendations. This activity requires outreach to the current state and regional mesonets, some of which must generate their own revenue, in part through data fees. Securing Federal or encouraging sustained state funding is one possible means to encourage participation in the broader network. Since each mesonet is unique, individual discussions should be held with each mesonet, with a goal of being equitable across the national landscape. As a part of this process, an evaluation of current data quality is necessary to determine whether the data being collected is suitable, accurate, and representative for drought monitoring purposes, as this is one of the key objectives of the NCSMMN. The approach of Ford and Quiring (2019) provides one way to complete this evaluation.

There is an obvious need for more accurate, abundant, and real-time soil moisture information, which has led the NCSMMN to prioritize making real-time, high-resolution, gridded national soil moisture maps and other meaningful products available for user groups and other stakeholders across the country. The potential to create daily 800-m resolution soil moisture maps for multiple soil depths using data from in situ monitoring networks has already been demonstrated in Oklahoma (Ochsner et al., 2019). Creating similar maps at the national level may include developing new soil moisture products or operationalizing or increasing the visibility for high-quality products that already exist. The data sources for the products may include in situ, remotely-sensed, or modeled data, or merged product(s) that combine multiple sources of data.

A longer-term goal of a NCSMMN is to develop a process to guide the initiation and development of future in situ resources to maximize the societal benefits of soil moisture monitoring across the United States. An early case study of this process in the Upper Missouri River Basin has demonstrated a rapid expansion of in situ stations specifically to address data scarcity in that region (highlighted in Appendix A). This guidance will be ongoing and require a significant amount of representation and engagement with state mesonets, regional networks, commercial and private interests, and citizen science consortiums. The formation of an NCSMMN committee or board with the specific goal of maintaining broad engagement with individual partners is one possible pathway to achieving this goal.

6.2 NETWORK ESTABLISHMENT

6.2.1 Existing Networks

One immediate action of the NCSMMN is to establish working relationships with existing and emerging networks to provide soil moisture data to a central repository. Once agreements are in place, necessary hardware, software, and human oversight procedures must be put in place for the automated ingest, standardization, and integration of data from the networks and for creation of consistent nationwide in situ soil moisture data sets. This will be of immediate benefit to efforts such as the U.S. Drought Monitor. As such, a mechanism must be established to encourage participation in the National Coordinated Soil Moisture Monitoring Network, either via funding or additional resources.

Ideas and recommendations relating to incorporating data from existing networks were formed in collaboration with state mesonets listed in Table 6.1 (*next page*) through two different opportunities for feedback and discussion. The first opportunity was during an in-person meeting at the American Association for State Climatologists on June 26, 2019, in Santa Rosa, CA, and the second was a virtual meeting on July 8, 2019.

Table 6.1: Opportunities for state mesonets to participate in NCSMMN discussions specific to NCSMMN-mesonet collaboration occurred on June 26, 2019, at the American Association for State Climatologists Meeting in Santa Rosa, California and virtually on July 8, 2019.

List of State Mesonets that Participated in NCSMMN Discussions	
South Alabama Mesonet (AL)	Delta Agricultural Weather Center (MS)
California Irrigation Management Information System (CA)	Montana Mesonet (MT)
Colorado Agricultural Meteorological Network (CO)	North Carolina ECOnet (NC)
Delaware Environmental Observing System (DE)	North Dakota Agricultural Weather Network (ND)
Florida Automated Weather Network (FL)	New Jersey Weather and Climate Network (NJ)
Georgia Weather Network (GA)	New Mexico Climate Network (NM)
Iowa Soil Moisture Network (IA)	New York State Mesonet (NY)
Indiana Water Balance Network (IN)	Ohio Agricultural Research and Development Weather Network (OH)
Purdue Automated Agricultural Weather Stations (IN)	Oklahoma Mesonet – University of Oklahoma/ Oklahoma State University (OK)
Illinois Climate Network (IL)	Pennsylvania Mesonet (PA)
Kansas Mesonet – Kansas State University (KS)	South Dakota Mesonet – South Dakota State University (SD)
Kentucky Mesonet – Western Kentucky University (KY)	West Texas Mesonet – Texas Tech University (TX)
Michigan Enviro-Weather (MI)	

6.2.2 Data Aggregation

The primary goal of the NCSMMN is the aggregation of data from existing soil moisture monitoring networks into a curated, spatially representative database for the production of real-time, high-resolution, gridded national soil moisture maps and other meaningful products and services, the need for which is discussed in Section 6.4. Existing monitoring networks were created for a variety of purposes and provide data that are not uniform with respect to monitoring depth, sensor type, or accuracy, and are disparate with respect to metadata about the monitoring locations. Consequently, the NCSMMN must determine, in partnership with the data providers across the country, the most efficient, logical, and collaborative way to aggregate and mediate data from the various networks.

One potentially useful platform for data ingest, archiving and delivery, is NOAA's Meteorological Assimilation Data Ingest System (MADIS). MADIS, as its name implies, is a meteorological ingestion system, and it has the ability to bring together data from NOAA sources, other Federal sources, and non-Federal sources. Ingest, quality control, and archiving are done in near real-time. Data are homogenized by removing dissimilarities in time resolution, timestamps, units, and variable names, and data can be retrieved through a variety of channels, including: ftp/LDM (netCDF), API, web services, etc.[16] Gridded products for certain atmospheric variables are available as well. Finally, MADIS' observation portfolio of hydrometeorological variables related to soil moisture (soil temperature, precipitation, atmospheric variables for calculating evapotranspiration, etc.) further strengthen the case for using MADIS.

The portion of hydrometeorological data collected by non-Federal entities like state mesonets and commercial entities is increasing. NOAA's National Mesonet Program[17] (NMP) manages contracts with a coalition of mesonets to offset the costs of operation, while at the same time saving taxpayers by only paying for the data rights needed to produce derived products such as gridded data sets. The program has been very successful for NOAA, and has made large amounts of data available from a wide

[16] ftp and LDM are internet data transfer protocols; API or "application program interface" allows for direct application programming; and web services would include web-based data access.

[17] *https://madis.ncep.noaa.gov/national_mesonet.shtml*

variety of sources at reduced expense.[18] Acquisition of rights to soil moisture data is already a part of the mission of the NMP, and agreements stipulate delivery of the data to MADIS. It is noteworthy that the majority of quality stations in the country with soil instrumentation are non-Federal and mostly state mesonets.

The NMP grew from a National Academy of Sciences report that established the need for a nationwide "network of networks" for a Weather-Ready Nation. This report focused on the need to acquire high-resolution, lower-latency data from all available observational datasets, both Federal and non-Federal.[19] The NMP provides the National Weather Service (NWS) with data from approximately 35,000 real-time weather stations, including surface and upper-air data from mobile platforms such as vehicle- and aircraft-mounted sensors. Since its inception in 2009, the NMP has become an expansive network of 40+ partners nationwide including participants from the public, private, and academic sectors. By leveraging observations from these partners, the NMP is able to fill large temporal and spatial data gaps across the country for a fraction of the cost of establishing and maintaining stations. More high-quality data leads to more accurate forecasts and more well-informed decision-making during critical weather situations. A majority of the current state networks that measure soil moisture are partners of the NMP and are routinely providing data to this effort for other measured variables like temperature and precipitation.

6.2.3 Data Ownership

An important topic for the NCSMMN and its data aggregation and product development efforts is acknowledging that the existing monitoring networks will always own their data. The NCSMMN can serve as a national clearinghouse for NCSMMN-derived data products (e.g., a standardized nationwide in situ data set, gridded maps) and metadata from all contributors, but all data provenance and maintenance will be the responsibility of the data providers. Therefore, a set of protocols will need to be instituted that protect data ownership and manage other aspects of organizational engagement. As one example of such protocols, in order to ensure data consumers understand the proper authority for the data, source statements should be included in a consistent format for every distribution of data from the NCSMMN.

Many state monitoring networks rely on subscriptions (pay-for-data) to subsist, and for several, soil moisture data is the highest source of data income. Due to this, the NCSMMN will not distribute the raw data from the state monitoring networks unless the state network elects to do so.

6.2.4 Resources and Technical Assistance Needed for Monitoring Network Partnerships

For robust participation in the NCSMMN by non-Federal monitoring networks, financial compensation is required. Network operators have noted that this compensation would help support the following: network operations and maintenance in order to gather, disseminate, and sustain data collection, purchasing and installing new sensors to either start or expand soil moisture monitoring, personnel time to facilitate the automated data transfer process, and soil characterization expenses. The compensation might also be used to offset additional costs to meet NCSMMN requirements.

Networks have also requested technical assistance in siting stations, soil characterization, data interpretation, sensor selection and calibration, installation, QA/QC, and data management guidance, and communication. Partnerships with programs such as USDA's NRCS for necessary soil characterization (i.e., data by depth on soil type, bulk density, texture, wilting point, field capacity, etc.) at the monitoring sites would provide important information that would aid both the networks and the NCSMMN in data interpretation and communication. Communication of the value of their data, and useful ways to share data and educate others is an important topic for networks, and one which the NCSMMN and networks could explore together. The technical assistance described in this paragraph could provide benefits to the participating networks beyond financial compensation, as well as to the broader NCSMMN community.

[18] It should be noted that the NMP allows mesonets to constrain the use of their data to within NOAA.

[19] Further impetus for collaborating with non-Federal partners comes from the Weather Research and Forecast Innovation Act of 2017 (P.L. 115-25), which directs NOAA to seek out opportunities to enlist non-Federal partners to provide supplemental data services.

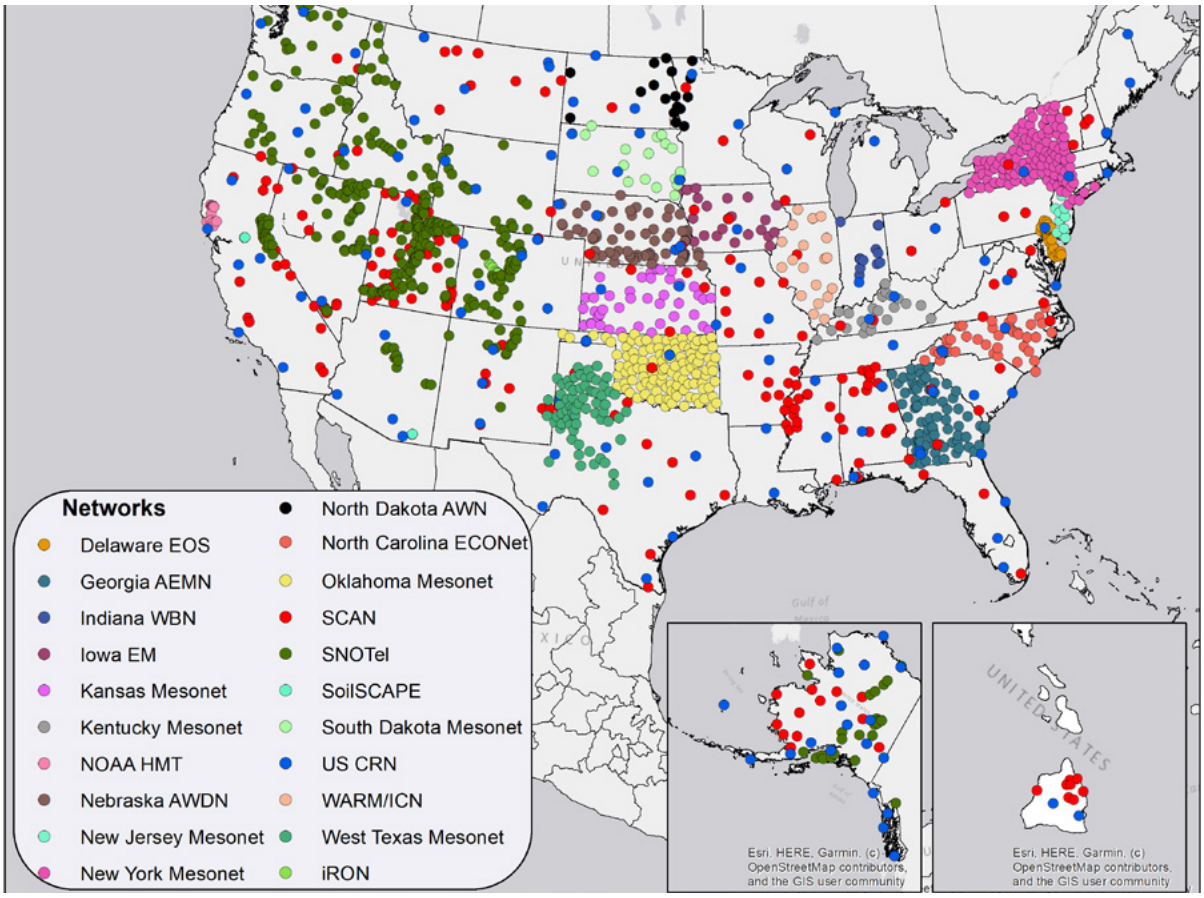

Figure 6.1: Locations of select in situ soil moisture sensor networks across the United States from federal- and state-level networks. (Source: *nationalsoilmoisture.com*)

6.2.5 Expanded Monitoring

The effort to standardize and integrate soil moisture data from existing monitoring networks is a necessary but not sufficient step for fulling the NCSMMN mission. There must be a strategic and coordinated increase of in situ soil moisture monitoring stations across the United States. New monitoring stations are essential because large areas of the United States have either no soil moisture monitoring stations or an inadequate density of stations (Figure 6.1, *above*). The roughly 2,000 long-term soil moisture monitoring stations in the United States today will need to be increased by 50% to reach the National Research Council's target of approximately 3,000 stations (National Research Council, 2009). Furthermore, the unequal distribution of the existing stations implies that the actual number of stations needed may be substantially higher than that target. Chapter 4 in this document describes approaches for determining where additional stations should be located.

New soil moisture monitoring stations are also needed because existing networks do not adequately represent the various major land cover types across the United States. Two notable deficiencies are forests and cropland. Few, if any, of the stations in the existing long-term monitoring networks are located under forest canopies, outside of the NEON network. Some may be located in clearings in a forest, but unless the sensors are directly beneath the forest canopy, the resulting soil moisture values may not be representative of the forest landscape. Under-canopy stations face a combination of logistical challenges, including power, connectivity, and access for maintenance. In concert with the U.S. Forest Service as well as state forest managers, the NCSMMN should develop plans for implementing soil moisture monitoring stations for beneath forest

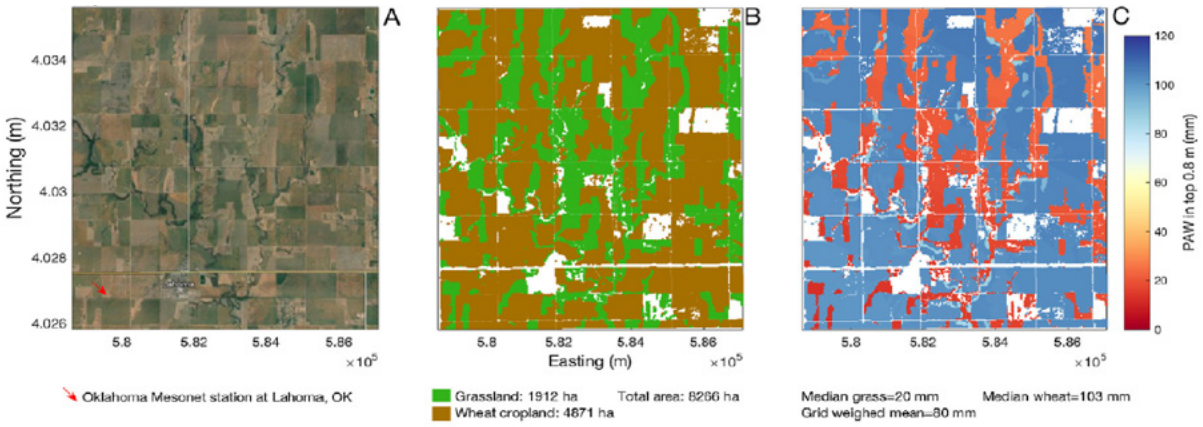

Figure 6.2: (*A*) Orthophoto, (*B*) grassland and winter wheat cropland area, and (*C*) estimated plant available water (PAW) in the top 0.8 m of the soil profile for a SMAP grid cell (FID: 153137, row: 329, column: 877) on 15 Oct 2011 near the Lahoma Oklahoma Mesonet station. Reproduced from Patrignani and Ochsner, 2018.

canopies. The data from such stations could have tremendous value for forest drought monitoring, fire danger rating, and water supply forecasts in forested regions.

The lack of long-term soil moisture monitoring stations in cropland is commonly overlooked and is surprising to many people. Long-term monitoring stations are not placed in cropland because normal agricultural operations such as tilling, planting, spraying, and harvesting all have potential to damage the monitoring equipment. Many soil moisture monitoring stations are adjacent to cropland, but research has proven that strong and temporally unstable differences exist between the soil moisture in cropland versus that in the adjacent uncultivated landscape (Han et al., 2012). For example, in the fall of 2011 the soil moisture under pasture and rangelands in northwestern Oklahoma was severely depleted while the soil moisture under adjacent winter wheat cropland, which had been fallow during the summer, was near field capacity (Figure 6.2c, *above*; Patrignani and Ochsner, 2018). Such contrasts between cropland and the adjacent uncultivated land cannot be represented by any of the existing in situ monitoring networks. There is a clear need for the NCSMMN to work with the USDA to develop and deploy long-term monitoring stations that are suitable for the unique challenges of cropland monitoring. This is particularly true because of the often-severe impacts of drought on crop production, and the large role of the Federal Government in crop insurance and disaster payments. It should also be noted that separate from long-term monitoring, there may also be a role for temporary, periodic monitoring efforts designed to inform model-based approaches.

6.3 DATA QUALITY STANDARDS AND ASSESSMENT

A frequent assumption within the applications and end-user scientific communities is that collecting in situ soil moisture data starts and ends with putting a sensor in the ground; whereas, it is widely understood within the mesonet community that putting sensors in the ground is somewhere in the middle of the never-ending process of in situ data collection. Landscape scouting, ancillary data set analysis (soil properties representation), dominant climate and weather patterns, as well as macro- and micro-topography are just some of the initial steps in the process, all before sensor installations. Other steps in the process include sensor selection, installation using best practices, calibration, maintenance, scaling studies, quality assurance, and data curation. Occasional reassessment of network function can help to refine and optimize the effort required to keep a large-scale network operating. Equipment replacement and recalibration are normal. These steps are all a part of a rigorous installation and maintenance protocol that the NCSMMN hopes to establish and evolve with changing technologies.

On the topic of sensor performance, as noted in Section 4.2.3, there are currently no common standards among sensor manufacturers pertaining to sensor performance and verification/evaluation, with each manufacturer using their own procedures. The NCSMMN will work to promote the adoption of

common standard testing criteria so sensors can be more easily compared.

Collecting high-quality soil moisture data can be a complicated and time-consuming process, but it is ultimately necessary if the value of soil moisture data is to be fully realized. Another assumption often made by data end-users is that all data in a data archive is of good quality, but it is too often the case that in situ sensors are not well calibrated and/or are not representative of the larger landscape. A related issue is that some networks have had soil moisture sensors added after siting and installation of the station has been completed with another set of observation variables as the focus. What is needed for the NCSMMN is a verifiable soil moisture dataset that can be used by operational decision makers to demonstrate that value that soil moisture information adds to their process.

Therefore, it is proposed that a protocol or set of criteria be established to assess and categorize the quality of in situ soil moisture networks. These criteria will have clear minimum threshold for quality control practices that lead to networks being categorized as producing high (versus moderate- or provisional-) quality soil moisture data. These categories will help guide data users as to their appropriateness for different applications. Meeting the high-quality standard will require items such as adequate metadata, calibration information, an appropriate site maintenance schedule, and post installation soil sampling to determine data accuracy and representativeness. To initiate this activity, it will be necessary to coordinate evaluations of networks against this set of criteria. Once established, regular reviews of network qualifications as well as evaluating new networks will need to be managed by dedicated personnel. A pilot study of this type could be initiated to demonstrate the process and form the initial set of NCSMMN sites.

To focus efforts on data quality and representativeness, one consideration is to provide financial compensation to contributing networks on a sliding scale, based upon the degree to which the network meets the agreed upon quality criteria. In initial discussions with mesonet operators, this idea was supported by many. Those quality criteria could be based on factors such as:

- Completeness of the soil moisture data;
- Accuracy of soil moisture data quantified by post-installation sampling;
- Data latency;
- Measurements of not only soil volumetric water content and soil temperature, but also other meteorological variables such as precipitation and potential evapotranspiration;
- Characterization and documentation of relevant soil properties for the site;
- Availability of site photos;
- Length of observational record; and
- Location in a relatively unmonitored region.

Other criteria for high quality are also worth considering. One example (discussed in 5.6.2) is whether the network has triplicate sensors rather than single ones. Triplicate installation provides redundancy that supports data quality and the identification of failure; however, this would mean less spatial distribution for the same capital outlay, and for many networks data gaps might be more of a priority to address. Thus, this type of consideration might be characterized as an eventual goal, rather than a near-term quality criterion.

The quality of a network (and of each individual station within a network) can change over time, so regular evaluation of network quality should be a part of the NCSMMN effort. Networks that do not meet the standards to be labeled as “high quality” can be accepted into the NCSMMN, but at a lower grade or status. Operators of such networks are encouraged to meet these standards to the degree possible. Another consideration is to make funding available for networks to improve and/or expand their soil moisture monitoring.

6.4 NATIONAL SOIL MOISTURE PRODUCTS FROM THE NCSMMN

6.4.1 The Value and Uses of NCSMMN Soil Moisture Products

The creation of near real-time, meaningful, and easy-to-understand soil moisture products from the NCSMMN is crucial to reduce societal risks from hazards such as drought, flood, and fire. These products will help contribute to better hazard early warning systems, improve characterization of

national water budgets and climate models, boost crop production and resilience, and benefit many additional user groups.

To promote utilization of NCSMMN data in different applications (e.g., drought or flood monitoring, planting guidance, water management), research needs to be conducted to determine the data accuracy and impact of the data. Decision-makers need to partner with soil and mesonet scientists to understand the metrics involved in the estimates of soil moisture and how to best use the data in the decision process. The uncertainties of soil moisture estimation have many nuances that cannot be evaluated with a single metric.

One of the key user groups are the authors for the U.S. Drought Monitor (USDM),[20] and an important early goal of the NCSMMN is creating products that will increase the availability and accuracy of soil moisture data to the authors as they determine drought status for this highly referenced national product. The Agriculture Improvement Act of 2018 calls for USDA and NOAA to coordinate with the director of the National Drought Mitigation Center (NDMC) to enhance the collection of data to improve the accuracy of the USDM. In addition, it states that USDA should, to the maximum extent practicable, develop standards to allow the integration of meteorological or climatological data into the USDM, and it specifically identifies in situ soil moisture monitoring.[21]

Another user group is the USDA National Agricultural Statistics Service (NASS), which conducts weekly national top and root zone soil moisture surveys and publishes weekly cropland soil moisture statistics at the state level in the Crop Progress and Condition Report,[22] and the Crop Weather Report. Currently, the assessment is conducted manually by visual observation and tactile sensing without instrumentation, and the assessments are qualitatively classified into four categories of very short, short, adequate, and surplus for both top and root-zone soil moisture. In the future, NASS could utilize NCSMMN soil moisture data to improve their soil moisture assessment, particularly if the data also incorporated crop type information. Another USDA agency, the Risk Management Agency (RMA), could use the soil moisture data and products to refine yield validation models, and it would also be useful in developing environmental models that would complement RMA's existing daily data stream of precipitation, temperature, and vapor pressure deficit data at an 800-meter spatial resolution.

Within NOAA, the River Forecast Centers (RFC) also utilize soil moisture data and would welcome additional products and sources of data. Soil moisture data has been incorporated as a qualitative check on their hydrologic models at the North Central RFC as a part of a recent NASA project. This effort could be expanded to other RFCs. In addition, soil moisture products that put the soil moisture state at a particular time in a historical perspective are helpful in messaging anticipated flood and/or drought threat. Finally, actual soil moisture data along with soil temperature at different depths can be used when the RFCs analyze the effects of frozen soils on runoff.

Two potential Federal user groups include the U.S. Forest Service (USFS) and the U.S. Environmental Protection Agency (EPA). The USFS is increasingly focused on soil moisture as an indicator of forest health and wildfire risk. And the EPA is interested in soil moisture data to enhance modelling of carbon stock changes in soils, and potentially nitrous oxide emissions as well, as part of the national Greenhouse Gas inventory.

Other user groups on the local and regional level include local NOAA National Weather Service Weather Forecast offices, local USDA offices, NIDIS' Regional Drought Early Warning Systems (DEWS), USDA Regional Climate Hubs, NOAA's Regional Climate Centers, the U.S. Army Corps of Engineers (USACE), the Department of Interior's Climate Adaptation Science Centers, state and local agencies, and others.

Finally, one emerging user group worth mentioning is the public health sector. Public health agencies and health researchers are increasingly recognizing the connections between human (and animal) health and soil disease vectors. There are many soil-borne diseases, and changes in soil moisture can have a direct relationship to disease outbreak

[20] *https://droughtmonitor.unl.edu/*

[21] *https://www.ers.usda.gov/agriculture-improvement-act-of-2018-highlights-and-implications/*

[22] *https://www.nass.usda.gov/Statistics_by_State/index.php*

for such diseases as valley fever, crop diseases, Toxoplasmosis, and Hantavirus (see for example: Coopersmith et al., 2017). Federal as well as state or local health agencies are therefore potential user groups.

The indisputable need for more accurate, abundant, and real-time soil moisture information has led the NCSMMN to prioritize making more soil moisture products that provide information for the needs described above available for stakeholders across the country. This may include developing new soil moisture products or operationalizing or increasing the visibility for high-quality products that already exist. While the focus is primarily on in situ observations, other data sources would also be utilized including remotely-sensed or modeled soil moisture estimates. The NCSMMN will also support the development of merged product(s) that combine multiple sources of data.

6.4.2 User-Specific Needs for National Soil Moisture Products

In order to determine user-specific needs for national soil moisture products, the NCSMMN has had discussions with several user groups, which have included the USDM authors, state-based mesonet operators, USDA Risk Management Agency, USDA National Agricultural Statistics Service, and NOAA River Forecast Centers.

The following list describes user needs identified thus far:

Accessibility of Products

- The suite of NCSMMN soil moisture products should be made available free online to all users. Many users also prefer some sort of interactive map/products as well, ideally with the option of creating a URL that automatically zooms into a specific area.
- Product(s) should be available in standard formats like CSV, txt, GeoTiff, machine readable, and common GIS formats. It would also be ideal if there are multiple layers of data that could be toggled on and off.
- Product(s) should be a form that can be pushed to users or that is accessible via automated downloading programs or scripts.

Format of Products

- There is a desire to have product(s) in the form of absolute values and their associated uncertainties, anomalies, and percentiles (with percentiles represented according to the same scheme used by the USDM).
- Products should be available in the form of time series for specific locations as well as gridded maps at the state and national levels.
- Soil moisture data is most helpful when it includes data from various depths, including both topsoil (top ~10cm) and root-zone (~10 cm to ~100cm) soil moisture.
- Due to inconsistency of density of in situ data, a product with point data should be made available. It might be helpful to have clickable points to bring up more information, like moisture availability at different depths. An example of how this could be displayed is from the South Dakota Mesonet[23] (see Figure 6.3, *next page*).
- It would be helpful to have a product expressing the soil moisture level in terms of crop water availability according to the scheme used by NASS (i.e., very short, short, adequate, and surplus).
- Soil temperature is a popular companion alongside soil moisture data for many users. For example, it is critical to see soil temperature data alongside soil moisture data for those concerned about the effect of frozen ground.

Frequency of Release

- Weekly or more frequent products and/or observations are needed for drought monitoring. For the USDM in particular, the cutoff time for data for inclusion in weekly map is 12z Tuesday, so products need to be available by early afternoon on Tuesday every week (though earlier products would be useful for first drafts).
- Other uses of soil moisture data require daily, or in some cases, hourly data.

[23] *https://climate.sdstate.edu/*

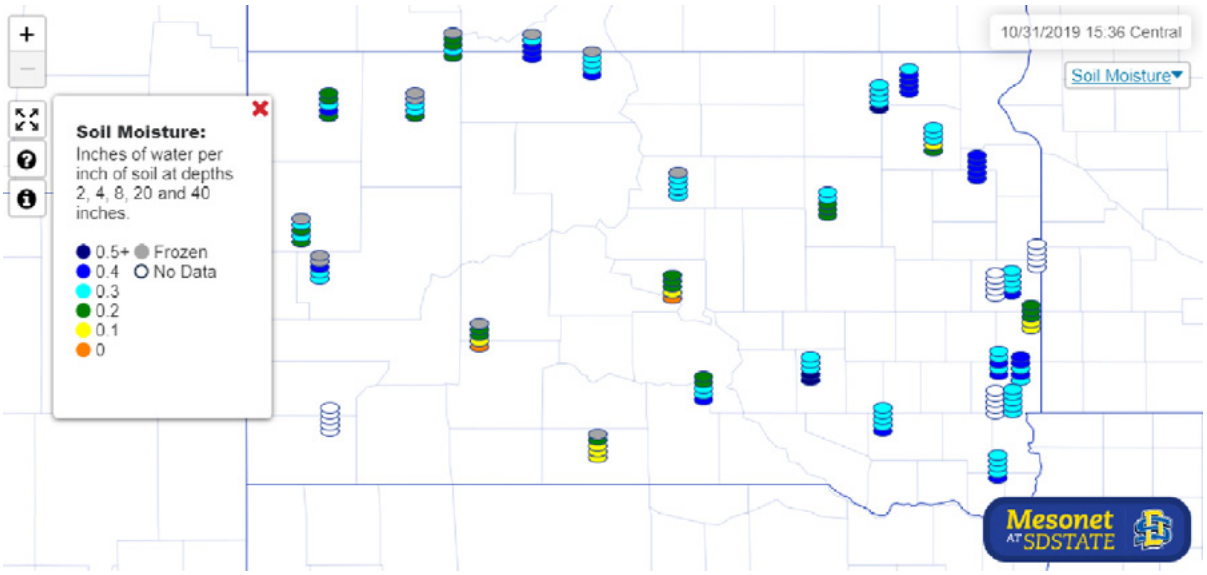

Figure 6.3: Example of displaying soil moisture data at various depths from the South Dakota Mesonet.

Spatial Coverage

- Preferred resolution for gridded data is at a maximum 4-km, but preferably 800-m spatial resolution.
- Since the USDM covers not only the contiguous United States but also Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, and the Pacific Islands, the USDM authors would like to see products covering these other areas as well.

6.4.3 Creating and Hosting a Suite of NCSMMN Soil Moisture Products

The NCSMMN aims to create a suite of real-time, meaningful, and easy-to-understand soil moisture products. The data sources within this suite of products will focus primarily on in situ observations and may be complemented by remotely sensed or modeled soil moisture estimates to produce merged products.

One of the first steps is to determine what entity will host the suite of NCSMMN national soil moisture products. One logical possibility is to have a NOAA program host this suite of products. Primarily, housing the suite of products within NOAA significantly increases the amount of data that is available for use in those products, due to the existing structure and agreements within NOAA's National Mesonet Program. NOAA programs have access to NOAA-only data within MADIS in addition to public domain data. While this NOAA-only data cannot be redistributed outside of NOAA, derivative data—such as an NCSMMN gridded product—could be. Other Federal agencies that could logically be involved or serve as the NCSMMN host include USDA, because it has a long history of soil moisture monitoring and the largest Federal monitoring networks, and USGS, because it is already tasked with monitoring surface water and groundwater. Soil water is the logical missing piece that is intrinsically linked to surface water and groundwater.

Another key step is to begin developing new soil moisture products, supporting the necessary research, and leveraging new collaborations through the NCSMMN effort. As discussed in section 6.2.2, it is recommended that aggregation of in situ data from monitoring networks be done through collaboration with the NOAA's National Mesonet Program and its existing database, MADIS. From there, the data will be used to develop a set of products, based on in situ soil moisture data. Necessary products include:

1. Standardized and combined daily, nationwide, multidepth (minimally surface and root zone) soil moisture observation set from all NCSMMN stations; this is product 1.
2. Daily, nationwide, soil moisture anomaly observation set based on product 1.

3. Daily, nationwide, soil moisture percentile observation set based on product 1.
4. Daily, nationwide, multidepth, gridded soil moisture data set at high resolution (4 km or better) derived from supplementing product 1 with digital soil maps, gridded precipitation data, and other beneficial supporting data layers in a geostatistical and/or machine learning-based mapping algorithm; this is product 4.
5. Additional products will be created that merge the in situ data with remotely-sensed soil moisture products and/or soil moisture estimates from land surface/hydrologic models.

Although preliminary research and demonstration projects have shown the feasibility of all these products, further research will be required to enable the creation of these products at the national scale and to rigorously quantify the uncertainty in those products. In particular, more research is needed: 1) to develop proven methods for standardizing data across differing sensor types and measurement depths; 2) to determine the best way to provide a historical context for soil moisture data with a short period of record; and 3) to develop effective methods for generating gridded soil moisture products from in situ observations at the national scale. Such research by Federal agency staff and university researchers should be supported through the NCSMMN effort.

As the necessary supporting research is completed, product development teams including personnel from one or more Federal agencies and university researchers could lead the work to create the operational systems and products. If the host agency is NOAA, it is important for the product development teams to have NOAA status in order to have full access to public domain, noncommercial only, and NOAA-only data within MADIS.

6.4.4 Research Needed to Enable Creation of NCSMMN Soil Moisture Products

Soil moisture measurement depths and sensor types vary between networks, which can impede interpretation of large-scale soil moisture conditions. Several approaches have been developed for extrapolating soil moisture data across depths, particularly from the surface to deeper depths, and perhaps the most successful approach has been the exponential filter. However, this method is effective mainly for extrapolating soil moisture values that have been normalized (i.e., from 0 to 1) and can have large biases when extrapolating absolute soil moisture values (Zhang et al., 2017). More research is needed to determine an effective approach for interpolating absolute soil moisture values across depths, accounting for temporal dynamics and soil property variation with depth. Similarly, normalized soil moisture data have been successfully combined for drought monitoring across networks using different sensor types (e.g. Krueger et al., 2019), but an accurate method to combine absolute soil moisture values across sensor types still needs to be developed. One possible approach is coordinated, post-installation soil sampling at each station to be included in the NCSMMN to quantify the accuracy of each network's soil moisture data and to facilitate correction/recalibration of absolute soil moisture values as needed. This approach has already been successfully applied to the OKM (Scott et al., 2013).

Based on user group feedback described in 6.4.2, the suite of NCSMMN national soil moisture products will strive to provide current soil moisture data in a historical context when possible (see products 2 and 3). However, not all in situ monitoring stations have a long period of record, and the accuracy and precision of anomalies and percentiles increase as the data record becomes longer. There is some evidence that seasonally standardized percentiles can be accurately characterized within 3–6 years of consistent data collection using bootstrapping methods (Ford et al., 2016). However, more research is needed to determine the best way to provide a historical context for soil moisture data with a short period of record, particularly as new networks and stations become available.

In addition to point-based soil moisture products, spatially interpolated gridded products will be created based on the in situ soil moisture measurements ingested from the various networks. Spatial interpolation of in situ soil moisture is challenging because there are many factors that may influence how soil moisture varies at regional scales (soil properties, topography, land use/landcover, climate, etc.). An automated regression kriging

methodology was recently developed for the Oklahoma Mesonet[24] to create daily gridded soil moisture maps at 800-m resolution for three depths across the State of Oklahoma (Ochsner et al., 2019). This method uses digital soil maps from USDA NRCS and gauge-corrected radar precipitation data from the National Weather Service with in situ soil moisture observations in a simple geostatistical framework. The resulting maps show detailed spatial patterns in soil moisture reflecting variations in landscape properties and meteorological forcings (Figure 6.4, *right*).

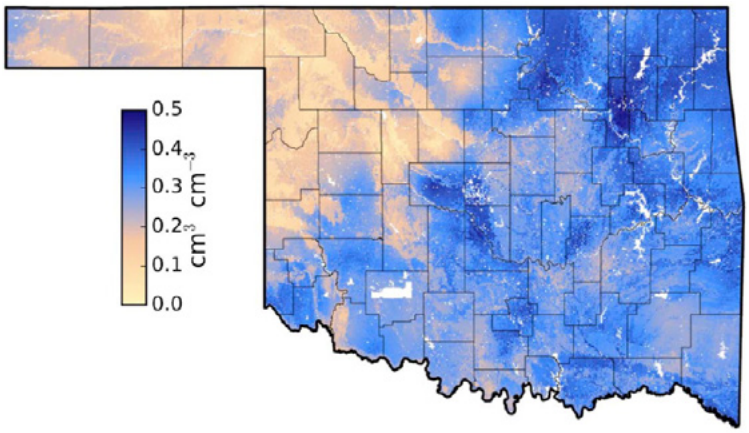

Figure 6.4: Map of volumetric water content for the 5-cm soil depth across Oklahoma at 12:00 a.m. CST, 9 March 2016. This map was produced using in situ soil moisture observations, digital soil maps, and radar-based precipitation data. Reproduced from Ochsner et al. (2019).

Work is ongoing to expand this approach to a national level as part of the National Soil Moisture Network, a first-generation, NIDIS-sponsored research effort to explore the feasibility of combining in situ, satellite, and modeled data into an operational product, currently found at *http://nationalsoilmoisture.com*. Percentiles based on in situ soil moisture observations are being interpolated at a 4 km spatial resolution across the contiguous United States (Zhao et al., 2020). The methodology has been tested in an operational environment and has been shown to outperform other methods for national-scale soil moisture interpolation. Fine resolution gridded soil moisture can be served in raster (GeoTiff, netCDF) format for direct ingestion to spatial analysis software used by U.S. Drought Monitor authors and for other uses.

A few additional key research needs include: 1) Developing an effective method to create gridded national data sets of absolute soil moisture values as required in many applications, not only percentiles; 2) Developing ways to account for the important effects of differing vegetation/land cover characteristics when producing these gridded data sets; and 3) Developing ways to upscale each of the NCSMMN stations so that the data are representative of the station's immediate surroundings and not only a single point. Thus, despite many promising developments, important research needs remain before the gridded products necessary to fulfill the NCSMMN vision can be fully created.

6.5 COMMUNICATION, COORDINATION, AND COLLABORATION

6.5.1 Collaboration and Coordination for NCSMMN Soil Moisture Products

There are several efforts within the NCSMMN that will require significant collaboration and coordination with agencies and other entities across the country. Many of these collaborations have been discussed throughout this chapter, including formalizing a financially supported collaboration between the NCSMMN partners at NOAA's National Mesonet Program and existing monitoring networks across the country. In addition, collaboration is needed with product developers for the existing and new soil moisture products that will be a part of the suite of NCSMMN products.

6.5.2 Citizen Science Collaboration

Another collaboration opportunity for the NCSMMN is to invite the participation of citizen science to the network. Citizen science is gaining in popularity across various disciplines as advances in both measurement technologies as well as web-based data platforms make engagement easier. In addition, the aforementioned Agriculture Improvement Act of 2018 and NIDIS Reauthorization of 2018 both include mandates for USDA and NOAA to engage and utilize data from citizen scientists. The NCSMMN

[24] *http://soilmoisture.okstate.edu/*

could explore ways to use data collected by citizen scientists as a means of filling in gaps from in situ data collected by state and Federal networks.

While it is desirable to include citizen scientists in an effort such as the NCSMMN, for the uninitiated citizenry, the path forward is not immediately obvious. Due to expense, it is unlikely that large numbers of citizens would invest in high-quality soil moisture monitoring equipment and the equipment needed to telemeter data into the NCSMMN portal. The utility of hand-collected data depends on: (a) if site metadata is available, (b) if the collection method is consistent with expected protocols, and (c) if data can be uploaded to a central portal via Web tools. A project to develop the protocols and Web tools to support an effort like this should be considered before commitment is made to include the use of citizens as a component of the formalized data-collection effort.

One possible approach would be to give participating citizen scientists the option to file either a quantitative or qualitative soil moisture report. Quantitative reports would likely be gravimetric measurements[25] of soil moisture, which is a sampling technique to obtain volumetric water content reading, for example for the top layer of soil. The NCSMMN could provide documentation which explains, as simply as possible, how to take a gravimetric sample. Qualitative reports can be provided by filling out a short form as is done with the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) Condition Monitoring[26] program where soils could be ranked on a scale from "severely dry" to "severely wet" based on anecdotal experiences. The volunteer would be asked to report local impacts of the dry/wet soils, and to give a brief written synopsis of the situation. A similar system has been developed by the Crowd Water[27] team which uses a phone application for people to enter soil moisture status among other parameters of interest. Qualitative reports such as this could provide useful ancillary information to the network, for example by extending the range of observations, or by providing confirmation of quantitative metrics.

In order to execute any citizen science efforts, a collaboration with CoCoRaHS would be a logical path forward. CoCoRaHS is a unique, nonprofit, community-based network of volunteers of all ages and backgrounds working together to measure and map precipitation (i.e., rain, hail and snow). Recently, CoCoRaHS also added the option for their observers to sign up to take soil moisture measurements as well.[28] CoCoRaHS already has the needed infrastructure in place for collecting both quantitative and qualitative soil moisture reports, and CoCoRaHS could easily share these reports directly with the NCSMMN.

NOAA's NWS Cooperative Observer Program (COOP) is another potential partner for expanding the network of community-based monitoring. In the COOP program, volunteers take daily weather observations at more than 8,000 set locations across the country, including both urban and more dispersed natural settings (public lands, agricultural areas, etc.). COOP data usually consist of daily maximum and minimum temperatures, snowfall, and 24-hour precipitation totals, but also can include additional hydrological or meteorological data such as evaporation or soil temperatures. It is worth investigating the possibility of soil moisture measurement being added to some of these locations. The opportunity to leverage COOP program expertise as part of the NCSMMN should be explored.

6.5.3 External Communication

There are several aspects of communication that need to be discussed for the NCSMMN including outward communication to increase awareness of NCSMMN efforts and products, communication regarding the information and uncertainties associated with the suite of NCSMMN soil moisture products, and internal communication among the NCSMMN community.

An important first step for NCSMMN communication is to establish a website for the effort, and this website can also serve as the home for the suite of NCSMMN soil moisture products. It will be important for stakeholders across the country to be able

[25] *https://www.globe.gov/documents/352961/353769/Soil+Moisture+-+Gravimetric+protocol/cbca34da-fcc7-4e5b-a8d9-eae745c7c17d*

[26] *https://www.cocorahs.org/maps/conditionmonitoring/about.html*

[27] *https://crowdwater.ch/en/app-2/*

[28] *https://www.cocorahs.org/Content.aspx?page=soilmoisture*

to easily find information about the NCSMMN, particularly for those who are interested in starting a monitoring network that might want to participate in a larger network and contribute data to the NCSMMN. It is crucial for these emerging networks to be aware of the NCSMMN and to know that the NCSMMN will be developing standards for monitoring that they can incorporate into their efforts, along with other technical assistance resources. As part of this effort, it will be important to clarify the identity and branding of the overall NCSMMN along with its various research component parts, including the proof-of-concept National Soil Moisture Network website (currently found at *http://nationalsoilmoisture.com*).

In order to increase the awareness of NCSMMN efforts across the country, it will also be important to do outreach to and collaborate with entities across the country that have a regional or local footprint. These partners may include NOAA NWS Weather Forecast Offices, local USDA offices, NIDIS' Regional Drought Early Warning Systems (DEWS), USDA Regional Climate Hubs, NOAA's Regional Climate Centers, the U.S. Army Corps of Engineers, the Department of Interior's Climate Adaptation Science Centers, state and local agencies, and others. These local or regional programs can tie local stakeholders interested in soil moisture data, monitoring, or other information into the larger NCSMMN efforts.

6.6 NETWORK MANAGEMENT

The existing management of the NCSMMN includes an ad hoc NCSMMN Executive Committee (EC), which was organized in 2018, and the broader community contributing to the NCSMMN that includes Federal, state, local, academic, private sector, and other partners. The entire NCSMMN community has been instrumental in bringing the NCSMMN to what it is today, and will continue to be instrumental in the future.

The current NCSMMN EC includes leaders from Federal agencies and academic institutions, and is the group that has been working with NIDIS to define the goals and develop a framework to bring the NCSMMN concept to fruition. This Strategy proposes to continue with a similar approach to managing the NCSMMN; however, with a more formalized structure in place. Work to develop such a management structure will be key to the implementation of the NCSMMN strategy, and should incorporate a means by which the broad range of Federal, state, local, academic, private sector, and other partners can continue to participate and provide ongoing consultation.

In terms of organizational "home," NIDIS will continue to shepherd progress toward the implementation of the NCSMMN strategy, per the NIDIS Reauthorization Act of 2018. As of December 2019, an NCSMMN Coordinator position has been created within NIDIS to provide organizing and management support to the NCSMMN, and to facilitate implementation of the NCSMMN Strategy. Ultimate residence of the NCSMMN management structure can adapt and migrate over time as needed to other appropriate agencies.

While a more formalized structure for the NCSMMN is being determined, meetings and webinars of the NCSMMN community will continue to be held, including the annual National Soil Moisture Workshop which grew from a series of annual workshops started in 2011. Associated communication efforts will include developing a web presence, developing brochures and other outreach materials, and creating an email listserv and/or newsletter to keep stakeholders up-to-date on activities that are happening, products that are being developed, and other NCSMMN news that might be of interest. Finally, because broad engagement is a priority of the NCSMMN, specific outreach will be conducted with both current and potential stakeholders across data provider, research, and user groups.

Much can be learned in managing such a network from similar, existing networks, and a key near-term task is to investigate models and best practices across the Federal Government. For example, the USGS hosts the National Ground Water Monitoring Network (NGWMN), which follows a three-tiered structure for network management. The NGWMN is a product of the Subcommittee on Ground Water (SOGW), which is part of the Federal Advisory Committee on Water Information. The NGWMN has a Program Board whose key role is to provide input to the USGS (the lead agency) and the SOGW on issues related to network growth, development, and operation from the perspective of data providers. The Program Board's duties and responsibilities are to provide input on the NGWMN Program's scope,

priorities and overall direction, evaluate funding proposals, and to communicate with current and potential data providers. More details about the board, and membership requirements, are laid out in the Structure and Operating Principles document. The NGWMN also has a USGS manager who oversees day-to-day operations of the NGWMN on a full-time basis. A network structure for the NCSMMN that utilizes governance protocols similar to the GWMN is worth considering, particularly given the fact that several elements of the NCSMMN will require formal decision-making, such as formalizing partnerships with data providers, funding research and product development, and ensuring general management and representation.

6.7 FUNDING FOR THE NATIONAL COORDINATED SOIL MOISTURE MONITORING NETWORK

Financial resources required for a robust NCSMMN will support a variety of activities. Of particular importance are: the integration of high-quality, in situ soil moisture data from existing and new monitoring networks, the evaluation and development of the suite of NCSMMN soil moisture products, and the sustained management of the NCSMMN.

While networks vary widely in size, quality, and capability, the typical high-quality, hydrometeorological station that reports soil moisture with relevant variables (soil temperature, precipitation, and atmospherics needed to calculate evapotranspiration) costs approximately $20,000 to $65,000 to install and $5,000 to $15,000 annual to operate. Expenses include personnel (engineer, technician, student help, IT professionals), travel, equipment and supplies, communications, and administrative overhead (i.e., indirect cost).

Often times, the original creation of a network is well funded, but over time operational funding may not keep pace. The remedy sought by many local and state networks is to find financial resources via fundraising, sponsorship, or sales of data records, necessitating an exclusivity of the data being collected. The biggest threat to any data provider's sustainability is to have their identity stripped from that data before it gets to the end user. NCSMMN's flexibility with contributors to permit them to retain their rights to ownership of their raw data, their right to restrict redistribution of data, and their right to demand attribution will be key to getting access to more data at lower cost. This model has precedent in the NMP, which has been a success story for data acquisition for NOAA. Many state mesonets are utilizing a business model that treats these data as a commodity to maintain network operations.

Soil moisture has applications from flash flood forecasting and fire weather, to agriculture and reservoir management. Consequently, there is a wide range of Federal agencies with a stake in having more accessible and accurate soil moisture data. Given the breadth of impact of this collective data, it is clear that inclusion of multiple agencies in some capacity would benefit the overall network and would enhance the ability to create diverse applications and respond to diverse stakeholders. Going forward, implementation of the NCSMMN strategy will need to consider these issues of inclusion.

6.8 RECOMMENDATIONS AND NEXT STEPS

Based on the discussion in this and previous chapters, there are several recommendations and next steps for moving forward the development of a coordinated NCSMMN. These recommendations include both organizational steps to solidify the NCSMMN program structure, as well as research and operational steps to advance soil moisture monitoring and data assimilation. The recommendations are listed in a roughly logical flow of activities, but many steps could and indeed should occur in parallel.

1. **Determine Home Agency and Management Structure for the NCSMMN.** NIDIS should work with the leadership of the participating Federal agencies to determine the ultimate management structure for the NCSMMN. In the interim, it is recommended that NIDIS continues as the near-term "home" for the NCSMMN. The reasons for this recommendation are threefold: this Strategy was called for in the 2018 NIDIS Reauthorization Act, NIDIS has a specific mandate for cross-agency collaboration, and as a part of NOAA, NIDIS is well-positioned to solidify partnerships with NOAA's National Mesonet Program. This Strategy further proposes reviewing models and best practices across the Federal Government

to inform the choice of a formalized management structure for the NCSMMN.

2. **Establish a Web Presence and Formalize Communication & Outreach Planning for the NCSMMN.** The success of the overall network depends in part upon partners and stakeholders being able to easily find information online about the network's efforts. Developing a visible, user-friendly website for the NCSMMN will be important for both communication and product delivery. The website can also serve as the host for the suite of products, as well as other resources such as technical assistance materials and standards documents, as they are developed. An Open Science Framework webpage[29] has been serving as a public repository for NCSMMN related documents; going forward, the NCSMMN will need to determine the most effective platform. In addition to a website, the NCSMMN will need to do broader communications planning, including developing appropriate branding, determining additional materials (e.g., newsletter) and channels (e.g., listserv) with which to engage stakeholders and the public, and developing plans for ongoing outreach.

   As a cornerstone engagement activity, the NCSMMN will continue to host the annual National Soil Moisture Workshop, which will bring together experts from across the United States to discuss the latest science and innovations in soil moisture monitoring. These meetings have been held since 2011 and initially were focused on in situ soil moisture monitoring but since have evolved to include remote sensing, modeling, and soil moisture applications. An annual meeting will be an important means to continue developing the NCSMMN, to communicate within the NCSMMN Community, and to make progress on implementing this Strategy. Going forward, this meeting should also include outreach to user groups, with the aim to build better collaboration between researchers, data providers, and users.

3. **Formalize Partnerships with the National Mesonet Program and Existing Monitoring Networks.** In order to obtain in situ soil moisture data from existing monitoring networks across the country, the NCSMMN should formalize a partnership with NOAA's NMP, which already has established partnerships with many mesonets throughout the country. In addition, MOUs will be needed with MADIS and with networks outside of the scope of NMP, including NRCS SCAN and SNOTEL, NOAA USCRN, and others. These partnerships should include financial compensation for networks contributing high-quality soil moisture data and options for technical assistance to networks on issues such as siting stations, soil characterization, data interpretation, sensor selection and calibration, installation, QA/QC, data management, and communication.

4. **Develop a Set of Criteria for High-Quality Data Sources.** Collecting high-quality soil moisture data can be a complicated and time-consuming process, but it is ultimately necessary if the value of soil moisture data is to be fully realized. What is needed for the NCSMMN is a verifiable soil moisture dataset that can be used by operational decision-makers, providing value in their decision-making process. Therefore, it is proposed that a set of criteria be established to qualify an in situ soil moisture network as producing high-quality versus moderate- or provisional-quality data. These criteria will be developed in coordination with the research, data provider, and user communities, and will include both standard metrics of data quality (e.g., random error rates), as well as other metrics of relevance, such as operational uptime and the existence of good metadata.

5. **Support Research Necessary to Develop or Improve NCSMMN Methodologies.** Although preliminary research and demonstration projects have shown the feasibility of the envisioned NCSMMN products, further research is required to enable the creation of these products at the national scale and to rigorously quantify the uncertainty in

[29] *https://osf.io/56gsj/*

those products. In particular, more research is needed: 1) to develop proven methods for standardizing data across differing sensor types and measurement depths; 2) to determine the best way to provide a historical context, i.e., anomalies and percentiles, for soil moisture data with a short period of record; and 3) to develop effective methods for generating gridded soil moisture products from in situ observations at the national scale.

6. **Increase In Situ Soil Moisture Monitoring Nationwide.** There is a clear need to increase the number of long-term, high-quality, in situ soil moisture monitoring stations across the United States. An initial milestone will be to meet the National Research Council (2009) goal of 3,000 monitoring stations across the continental United States. The NCSMMN will work with partners from across the country to optimize locations of new monitoring stations to meet Federal and state goals, following one or more of the approaches described in Chapter 4 and targeting spatial gaps in the existing in situ soil moisture monitoring infrastructure. In siting new locations, priority will also be given to increased monitoring in vegetation/land cover types that are underrepresented in the current monitoring infrastructure, especially forests, grazing land, and cropland.

7. **Explore Increasing Partnerships with the Private Sector.** The private sector operates a large number of weather and soil monitoring stations for a variety of purposes, such as irrigation scheduling, but the data from these stations are not readily available to the broader community. A concerted effort must be made to engage with the private sector not only to expand the impact of monitoring efforts from all sources, but also to provide feedback to the private sector with regards to methodologies and validation protocols, so that these efforts can benefit from the scientific advancements propagated by the NCSMMN community. Outreach can include engagement at meetings, joint presentations, and targeted workshops for private sector audiences.

8. **Engage with the Citizen Science Community.** One potential way to increase in situ soil moisture monitoring, and public support for such monitoring, is to invite the participation of citizen science. There are ideas to explore, including the quantitative and qualitative measurement methods by citizen scientists, and a pilot project should be considered to develop the protocols and web tools to support an effort like this. In order to execute any citizen science efforts, exploring collaborations with NOAA's COOP program and CoCoRaHS would be a logical path forward.

9. **Develop, Release, and Promote NCSMMN Products.** The primary aim of the NCSMMN effort is to provide coordinated, high-quality, nationwide soil moisture information for the public good. To date, there has been good progress on proof-of-concept and first-generation products, such as the National Soil Moisture Network (*http://nationalsoilmoisture.com*). A more comprehensive and fully developed platform will require developing, releasing, and promoting new, nationwide point-based and gridded soil moisture data products that meet the needs of diverse end user groups. These products, including absolute soil moisture values, anomalies, and percentiles, will be freely and publicly available in the form of maps and time series. They will be delivered in formats designed to maximize their public value for crucial applications such as drought and flood monitoring, fire danger ratings, and streamflow forecasting.

   While this recommendation is the most fundamental objective of the NCSMMN, its success will depend on most (if not all) of the preceding steps. Through efforts to: 1) develop a strong organizational home; 2) engage in communication and outreach; 3) establish partnerships and build out the network; 4) conduct needed research; and 5) develop and refine data collection, integration, and quality standards, the NCSMMN will be positioned to deliver transformative soil moisture products to the Nation.