CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Soil moisture[4] is a critical land surface parameter affecting a wide variety of economically and environmentally important processes. From agricultural monitoring, to weather prediction, to drought and flood forecasting, the value of soil moisture metrics is undeniable. At the same time, the means and methods of monitoring soil moisture are undergoing rapid growth and innovation with the advent of new in situ and proximal sensors, new data telemetry methods, and new remote sensing technologies to provide broad and accurate soil moisture estimates. Many nations have established soil moisture sensing networks, including the United States, which has a prolific but uncoordinated collection of monitoring networks at the national, state, and local levels. There is currently no national strategy for the development, deployment, and maintenance of soil moisture monitoring networks. The absence of a coherent strategy leads to a host of problems including many states lacking adequate monitoring, multiple data sets which are not standardized or directly comparable, and no clear plan for how best to target investments to improve the overall monitoring infrastructure. Because of these deficiencies, the United States has not yet capitalized on the transformative potential of nationwide, coordinated in situ soil moisture observations for applications such as improved drought monitoring, water resource management, and fire danger ratings.

In 2013, NOAA's National Integrated Drought Information System (NIDIS) and its partners began an initiative to work towards a coordinated national soil moisture network. The first meeting to discuss this effort with a group of Federal, state, and academic experts was held in November 2013 in Kansas

[4] Soil moisture is shorthand for soil water content, which has units of $m^3\ m^{-3}$ and is represented by the symbol θ.

City, Missouri. The key findings from that meeting[5] included the need for improved metadata, calibration, and validation of soil moisture data, as well as the importance of data integration. The conclusion and recommendations from the meeting included: 1) convening a working group to discuss issues of scale and spatial distribution for monitoring via in situ networks, remote sensing platforms, and modeling efforts; 2) developing a nationwide product from existing soil moisture data to demonstrate the potential usefulness of a coordinated effort; and 3) piloting a soil moisture monitoring system for a small number of regions that would integrate all available soil moisture data types and assess how the data would be used.

As a result of the 2013 workshop, NIDIS funded a series of workshops and a pilot project to advance this goal. The pilot project served as the first proof of concept for a coordinated national soil moisture network by demonstrating that in situ soil moisture data could be integrated in real time from a variety of sources and made accessible both by a web service and a webpage at a common location. This project was led by the U.S. Geological Survey (USGS) and Texas A&M University (Quiring et al., 2016).

In order to continue the progress and discussion on how to better coordinate soil moisture monitoring and perform data assimilation and communication across the federal landscape, and with states and other interests, a second workshop on a National Coordinated Soil Moisture Monitoring Network (NCSMMN) was held in May 2016 in Boulder, CO.[6] The discussion at this 2016 workshop focused on three core elements of a coordinated and integrated national soil moisture network. These included: 1) improving collaboration through incentives and partnerships; 2) developing a consistent methodology for data collection and installation of in situ sensors including metadata standards; and 3) developing a national multi-platform soil moisture gridded product that could serve as a first-order data and information source as well as a platform for the development of derivative or secondary soil moisture products. A third NCSMMN workshop was held in Stillwater, OK, in May 2017 in conjunction with the Marena, OK, In Situ Sensor Testbed (MOISST) workshop. Participants discussed the outcomes of the NIDIS data integration pilot project and refined the vision for the NCSMMN. Desired features for a national gridded soil moisture product were identified, including the need for both surface and root zone soil moisture products and the need for soil moisture data both as absolute values as well as percentiles.

The efforts of creating and formalizing a national coordinated soil moisture network increased significantly in 2018 as a result of some important efforts. Following the 4th NCSMMN meeting in Lincoln, Nebraska in June 2018 (held again in conjunction with the MOISST workshop), an Executive Committee was formed for the network. The NCSMMN Executive Committee (EC) included leaders from Federal agencies and academic institutions, and was charged with clearly defining the goals and framework to bring the NCSMMN concept to fruition (Clayton et al., 2019). Early efforts included a successful project that demonstrated the feasibility of merging soil moisture datasets within the Southern Great Plains, and a NIDIS-funded project by Dr. Trent Ford and Dr. Steven Quiring which showed promise for the generation of a single soil moisture platform of widely available data, including in situ, remotely sensed and modeled data (Zhao et al., 2020). However, there are still challenges that need to be addressed to fully realize the value of the diversity of soil moisture resources available in the United States.

The importance of soil moisture data and a coordinated network garnered further attention of Congress in 2018, in response to the lack of early warning for the 2017 Northern Plains drought and the significant impact it had on the region. The NIDIS Reauthorization Act of 2018 (P.L. 115-423)[7] calls for NIDIS to develop a strategy for a national coordinated soil moisture monitoring network no later than 1 year after the date of enactment of the Reauthorization Act. In addition, the Agriculture Improvement Act of 2018 (P.L. 115-334)[8] (i.e., the "Farm Bill") calls for the U.S. Department of Agriculture (USDA) and NOAA to coordinate with

[5] *https://www.drought.gov/documents/developing-coordinated-national-soil-moisture-network.*

[6] *https://www.drought.gov/documents/national-soil-moisture-network-workshop-2016-progress-made-future-directions*

[7] *https://www.congress.gov/115/plaws/publ423/PLAW-115publ423.pdf*

[8] *https://www.congress.gov/115/plaws/publ334/PLAW-115publ334.pdf*

the National Drought Mitigation Center (NDMC) to enhance the collection of data (including soil moisture) to improve the accuracy of the U.S. Drought Monitor.

Challenges are common in soil moisture monitoring, and it is important to understand the goal or purpose of a soil moisture network. Very often soil moisture sensors are added to existing networks to enhance their monitoring capability. Or, in the development of a sensor network, a variety of parameters are identified for observation, but siting logistics require a compromise on the different criteria necessary to accurately assess each parameter. A few networks have been developed to specifically monitor soil moisture, including the USDA Soil Climate Analysis Network (SCAN) (Schaefer et al., 2007). However, even if the parameter of interest is ideal, the purpose or use of the network can still impact its applicability for various uses. For instance, the need to monitor soil moisture within an agricultural domain (in-field) requires redeployment during planting and harvesting periods, which results in a discontinuous data record that is not as valuable for long-term research analysis. Also, a soil moisture station for irrigation scheduling is not as valuable for regional monitoring, due to the anthropogenic influence. Remote sensing calibration and validation studies need a different type of network deployment at different depths. Table 1.1 (*below*) lists some of the considerations for network deployment based on the network's primary purpose.

Attempting to satisfy all of these requirements can be difficult, but it is the belief of the community that we are still capable of developing a coordinated soil moisture strategy to address the majority of these considerations, offering a path forward for improved soil moisture monitoring.

The infusion of support from Congress and rising awareness of soil moisture's critical importance in drought prediction and other applications has led the NCSMMN to develop the coordinated strategy that is laid out in this document. The goal of this document is to identify a roadmap forward and the resources needed for implementing the coordinated network; specifically, a network that will provide coordinated, high-quality, nationwide soil moisture information for the public good.

This strategy document was developed as a collaborative effort organized by the NCSMMN EC under the sponsorship of NIDIS and with broad community engagement (see Report Contributors, *page 5*). The document includes: a summary of current networks and remote sensing resources, a discussion on network design considerations, guidance for installation and quality assurance/control, and the implementation strategy for the proposed National Coordinated Soil Moisture Monitoring Network.

Table 1.1: Considerations for network deployment

Purpose of Network	Latency	Duration	Distribution	Depths
Weather Monitoring	X		X	X
Climate Monitoring		X	X	
Agricultural Monitoring	X			X
Forest/Ecological Monitoring	X	X	X	X
Remote Sensing and Model Validation			X	X
Flood Forecasting	X	X	X	X