

CHAPTER 1

INTRODUCTION

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The Data Quality Guidance Document provides guidelines for standardizing soil moisture data collection by mesonets and other long-term monitoring networks. It introduces a tiering system for categorizing soil moisture data into ‘Data Quality Tiers’ and provides aspirational goals to improve the quality of soil moisture data.

The approach described in this document for categorizing networks into three tiers parallels a [proposed tiering method](#) for meteorological networks more broadly, as described by the World Meteorological Organization's Global Climate Observing System (WMO GCOS)¹. However, this document differs from the WMO GCOS approach in that it is designed to specifically address challenges and needs associated with long-term soil moisture monitoring.

The document is designed to be used for self-assessment by monitoring networks and is intended to create greater transparency with respect to the quality of data for users of soil moisture data. This data quality guidance document is a companion to the “[Soil Moisture Metadata Guidance](#)” document (henceforth referred to as the Metadata Guidance document) and is part of a series of resources on long-term soil moisture monitoring that are being produced by the National Coordinated Soil Moisture Monitoring Network (NCSMMN) to standardize long-term soil moisture measurements.

BACKGROUND

The NCSMMN is led by the National Oceanic and Atmospheric Administration’s (NOAA’s) National Integrated Drought Information System (NIDIS). It is a collaborative effort among federal agencies, soil moisture scientists, mesonet operators, and others to plan for and support nationally coordinated soil moisture monitoring and data assimilation. As a key milestone of this effort, and in direct response to a Congressional requirement for a national soil moisture strategy, the NCSMMN community developed a “Strategy Document” in 2021. The “Strategy Document” provided a roadmap forward and delineated the resources and activities needed for implementing a coordinated national network; specifically, a network to provide coordinated, high-quality, nationwide soil moisture information for the public good. This Data Quality Guidance Document responds to two recommendations from the Strategy Document that are listed below.

1. Develop a set of criteria for high-quality soil moisture data sources.
2. Support research necessary to develop or improve NCSMMN methodologies.

¹ Proposal for formalization and standardization of tiered network approach across domains and observing system programs. 2022. <https://gcos.wmo.int>

Further resources on soil moisture and a full discussion of the objectives of the NCSMMN can be found in [A Strategy for the National Coordinated Soil Moisture Monitoring Network \(2021\)](#).

WHAT IS SOIL MOISTURE AND WHAT UNITS IS IT MEASURED IN?

Soil moisture is defined as the amount of water present in the soil. It is either measured gravimetrically (i.e., on a weight basis) or volumetrically (i.e., on a volume basis). Gravimetric soil moisture is the mass of water per unit mass of dry soil, which can be converted to volumetric soil moisture (referred to as Soil Water Content (SWC) in this report) by multiplying it by the soil bulk density and dividing by the density of water. In situ probes indirectly measure SWC, while gravimetric soil moisture can only be measured in the lab from mass loss by heating soils for 24 hours at 105 °C. Soil bulk density can be measured from volumetric soil cores or clods to determine dry soil mass in a fixed volume. These methods are detailed in several Natural Resources Conservation Service (NRCS) documents.

In relation to stakeholders, however, soil moisture is often useful in other units, such as plant available water², percentile³, and fraction available water⁴. In this document, the term “stakeholder” refers to users of soil moisture data, tools, or products. Fortunately, SWC as reported by in situ probes can easily be converted to all other units of soil moisture required by stakeholders, provided relevant soil properties are measured or estimated (as described in the [Metadata Guidance](#) document). Refer to Appendix D of this document for conversions between different units of soil moisture.

NEED FOR SOIL MOISTURE DATA QUALITY GUIDANCE

Soil moisture has been identified as a critical land surface variable for improving the quality of several hydrological applications that impact human life and enhance our understanding of the biosphere. Consequently, significant efforts are being made to expand soil moisture monitoring efforts. The combined benefits of these efforts, however, are limited since there is a large variability in how Soil Water Content (SWC) is measured and reported, which limits the utility of this important state variable for many applications. For stakeholders to seamlessly utilize soil moisture data collected by disparate monitoring agencies, it is essential to create a standardized method of measuring and reporting moisture data through a standardized guidance document. Factors that create variability in the measurement and reporting of SWC include:

1. Spatial and temporal representativeness of measured data
2. Accuracy of sensors and the volume of soil that the sensors measurement represents
3. Units in which SWC is reported

² Plant available water (PAW) is calculated as the difference between SWC at field capacity and SWC at wilting point for the entire root zone of the soil. PAW is typically expressed in units of length.

³ Soil moisture percentiles are reported in values ranging from 0-100 and provide an estimate of soil moisture conditions as compared to historical conditions for the region. More details can be found in Ford et al. (2016).

⁴ The *fraction* of plant available water (FAW) is a way to normalize SWC across different soils. FAW represents a normalized difference of SWC at a given time in relation to the difference between SWC at field capacity and SWC at wilting point for a specific soil depth. FAW typically ranges between 0 – 1.

4. Selection criteria for soil moisture sensors
5. Methods to produce useful data, and
6. Frequency of measurement, processing, and dissemination of data.

This document serves as an accessible guide for collecting, maintaining, and producing accurate and representative soil moisture data using in situ sensors. Key data applications by stakeholders considered in this document include agricultural monitoring, water resources, hydrologic and weather predictions, wildfire prediction, and drought and flood early warning.

SCOPE OF DOCUMENT

The scope of this document is restricted to recommendations for network operators of long-term monitoring networks that deploy in situ soil moisture sensors. The ‘Data Quality Tier’ system that the document introduces should be used for categorizing the quality of soil moisture data produced by such networks. These tiers are based on quality parameters that were identified through a literature review and through input from the soil moisture monitoring and applications communities.

Specifically, the document offers direction to network operators for:

- Planning and anticipating resource needs for a long-term monitoring program,
- Understanding and fulfilling diverse stakeholder data requirements,
- Site selection,
- Sensor selection,
- Laboratory and field-based sensor calibrations,
- Quality control and quality assurance protocols, and
- Self-assessment of network data quality according to standards herein.

Note: The Data Quality Tiers are aspirational, providing network operators a means to self-evaluate their data quality and develop long-term network goals. They also provide stakeholders a short-hand approach for assessing characteristics and utility of a data set for their desired application. There is no mandate or formal evaluation associated with these tiers. The document is simply providing guidance and best practices to improve soil moisture data collection.

PROCESS OVERVIEW

The Data Quality Guidance document has been compiled based on a review of existing literature, input from stakeholders of soil moisture data, surveys of existing soil moisture networks, and discussion with experts in soil moisture monitoring and measurement, which included scientists from: federal agencies, including the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and Agricultural Research Service (ARS), the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), the United States Department of Energy (DOE); as well as universities; operators of state mesonets; and other long-term environmental monitoring networks. A working group of

various experts and stakeholders met for six months and discussed each aspect of this report prior to its compilation. Contributors are listed at the end of the document.

DOCUMENT GUIDE

DOCUMENT STRUCTURE

The document is divided into nine chapters and five appendices. Chapters 2-8 provide detailed guidelines for establishing a soil moisture sensor network, from planning to reporting quality soil moisture data. Each chapter has an orange box that describes the learning outcome of that chapter. The appendices serve as checklists or handy reference guides for a quick overview of the entire document. The first and last chapter provide a general introduction and conclusion to this document.

The level of detail provided in chapters 2-8 of this document is recommended for those new to in situ soil moisture monitoring and/or those seeking clarification and background information on quality issues. Appendices A-E are designed to serve as a quick review checklist and are strongly recommended for those intending to apply the data quality principles in an actual operational setting. Note that using the appendices without any background in soil moisture monitoring runs the risk of missing key issues. See below for a list of the appendices.

- *Appendix A:* Checklist for planning a new station or network.
- *Appendix B:* Sensor calibration practices required for different tiers of soil moisture data quality at the time of sensor installation or at the time of upgrading the data quality tier of your stations/network.
- *Appendix C:* QA/QC activities.
- *Appendix D:* Guide for converting between different soil moisture units.
- *Appendix E:* Checklist for existing network operators for determining Tiers or upgrading stations to Tier I, II or III.

GETTING THE MOST OUT OF THIS DOCUMENT

This document will be most helpful if used in conjunction with other documents that have been created as part of the larger effort by the NCSMMN. This includes documents describing sensor installation, operations and maintenance, and data verification steps ([Caldwell et al., 2022](#)), data collection and data logger programming (Patrignani et al., 2022; <https://soilwater.github.io/mist/>), and metadata to ensure consistent reporting between data providers ([Metadata Guidance](#) document).