CHAPTER 4

ENVIRONMENTAL CONSIDERATIONS FOR STATION SITING

Mike Cosh, Vinit Sehgal, Nandita Gaur

> **Learning Outcomes**
> Following appropriate methods for site selection can help maximize representativeness of long-term soil moisture measurements and support data quality.

The aspiration for siting an in situ sensor is that it provides representative information about moisture conditions in the general area around it. While the typically small support scale of an in situ sensor (of the orders of 10s of cm^3 of soil) makes it impossible to provide large-scale estimates, carefully considering the heterogeneity of the surrounding area as part of site selection (followed by field calibration) can allow the sensor to be representative of the general area surrounding it to a certain extent. In this chapter, we provide information on environmental factors that must be accounted for during site selection to make the measurements representative for the general area around to the maximum extent possible. This information must be used in combination with practical siting considerations described in Chapter 2 of this document and Chapter 4 of the NCSMMN Strategy Document (*A Strategy for the National Coordinated Soil Moisture Monitoring Network*, 2021).

CONSIDERATIONS FOR STATION SITING

Spatial representativeness of an in situ soil moisture measurement for the general area is mainly limited by the large spatial and temporal variability of soil moisture. One strategy to account for this variability and maximize representation is by utilizing upscaling methods prior to sensor siting. Upscaling methods typically require additional soil moisture measurements in a larger area before actually installing a station. Alternatively, biophysical factors, such as precipitation, soils, vegetation, and topography or a combination thereof that affect variability in soil moisture can be incorporated into the network design (Gaur and Mohanty, 2013, 2019). It should be noted that while the spatial dependence of soil moisture on these heterogeneous variables is strong, it is non-deterministic and can change with seasons and hydroclimates (Sehgal et al., 2021). Consequently, the spatial representativeness based on this method will change with seasons even if other landscape factors remain the same. Both methods of sensor siting are described below.

PROCESS OVERVIEW

Sensor siting is a multi-step and multi-scale process. Stations must first be regionally sited using either the upscaling or biophysical method approach, after which the exact soil profile where the sensors will be installed needs to be examined for representativeness. We refer to the latter as micro-site selection. A nested approach to site selection may be taken as well.

METHOD I: UPSCALING STRATEGIES BASED ON TIME STABILITY ANALYSIS

Crow et al. (2011) reviewed several upscaling strategies that can help determine ideal siting locations. Each strategy has its own data requirements. While this guidance document recommends referring to cited works for methodological details, provided here is a short overview of the resources necessary to conduct upscaling via a time stability exercise. Time stability is one of the very few upscaling exercises that work for upscaling point scale data measured with in situ sensors.

Time Stability Analysis Using Temporary Stations or Intensive Field Campaigns

Time stable locations (Vachaud et al., 1985; Vanderlinden et al., 2012) are locations within the landscape that continually represent the average moisture conditions of the entire landscape or a pre-determined region that needs to be represented. In other words, time stable areas are representative of average landscape-scale conditions regardless of season. To identify time stable locations, intensive soil moisture campaigns (Cosh et al., 2008, 2013) or the intensive installation of temporary soil moisture monitoring stations is required. Soil moisture must be measured at these sites repeatedly through different seasons for at least one calendar year to identify a site that reports the average of the entire area (Coopersmith et al., 2013). Once a time stable location is identified, it may be assumed to remain stable across years and assumed to report average values for that region (Cosh et al., 2006; Coopersmith et al., 2021). This site can then be used as the site to install long-term soil moisture sensors.

Method II: Using Maps of Biophysical Variables

Several qualitative factors need to be considered in the biophysical variables method, and, therefore, operators will often have to make several executive decisions while implementing this method. Documentation must include a justification of those decisions because qualitative factors may change with time in a region. The stepwise implementation of this method is described below. Note, however, since station siting depends primarily on stakeholder requirements, the first basis of site selection should be a physical variable that the stakeholder wants to monitor and measurement of this physical variable should be considered before any of the factors mentioned below. For example, if the stakeholder need is to measure a specific land-cover type (forest floors, pasture, cropland), then it should form the primary variable of interest in determining site locations.

Developing a Nested Siting Design

The dominant drivers of soil moisture variability change with scale (Figure 2). Hence, these factors can be used to nest the site design for a regional-scale network. Following this approach, a two-step siting plan followed by micro-site selection is recommended. One example of a nested-site design for validating remotely sensed soil moisture at 40-km is given in Caldwell et al. (2019).

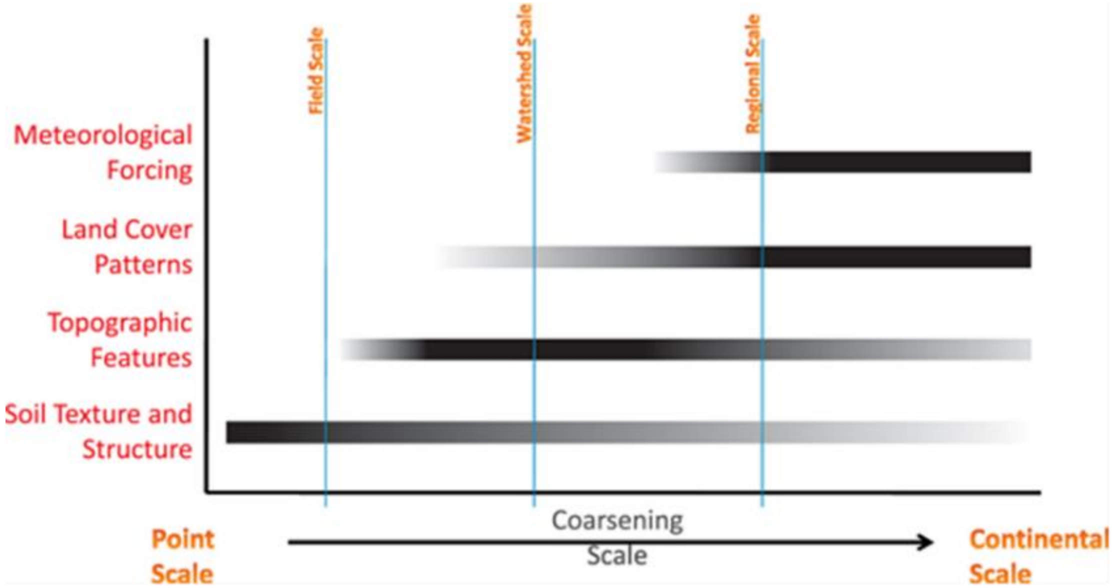

Figure 2. Dominant controls of soil moisture variability. Shades of gray indicate degree of control, with darkest gray being the strongest control. Figure Credit: Crow et al., 2012.

Step 1: Regional Siting of Stations

Meteorological forcings: The large-scale design of a network must be driven by variability in meteorological forcings (variables such as precipitation, temperature, relative humidity, wind speed, and more). Of these variables, precipitation is the single most important factor that changes the absolute value of soil moisture as a step function. Subsequent soil moisture dry downs depend non-linearly upon soils, topography, and vegetation. Hence, if there are predictable rainfall patterns expected in a region, soil moisture stations should be installed to first capture regional variability in precipitation to the best extent possible. In the absence of a comprehensive coverage of meteorological forcings, dominant ecoregions can be used as an indicator of the coexistence of soil, vegetation, and climate patterns which are observed to yield governing controls over the variability in the hydrologic state of soil moisture at a regional scale (Sehgal and Mohanty, 2024).

Step 2: Local Siting of Stations

A representative soil texture and structure should be considered the next most important variable for station siting, given that vegetation and topography are controlled for. While topography and vegetation aid movement and redistribution of water, soils exert a more intimate role on the actual capacity of the soil profile to hold water (Gaur and Mohanty, 2013, 2016). The capacity of the sub-surface to hold water and trigger runoff or infiltration and provide water for plants depends primarily on the type of soil (texture, structure, mineralogy and organic matter). Hence, one approach for regional representation could be to select uniform landscape locations and maintain uniform vegetation covers across the network while ensuring soil type representation of the region. This theory is also supported by some measurement evidence for near-surface soil moisture, wherein Gaur and Mohanty (2013) showed that near-surface soil moisture measured using theta probes in Little Washita, Oklahoma was most dominantly controlled by the soil at the support scale of in situ soil moisture measurements, when compared to topography and vegetation-based factors. Note that this study was conducted only during the growing season for grasslands and crops (soybean, corn, and wheat) and using only near-surface soil moisture data.

Controlling for vegetation type or terrain across all network stations may be more difficult for networks operating in forests or rangeland terrain.

Representative soils for the region can be identified by consulting available SSURGO soil survey maps from (NRCS) and selecting the soil series that is most spatially representative of the region. When possible, soil types should be ground-truthed (Metadata Guidance document). While locations with no slope to a mild slope that are easily accessible for most parts of the year may be desirable for installing sensors (Joshi et al., 2011), for regions that are dominated by sloping landscapes or with specific soils that 'live' on those sloping landscapes, installation on slopes would be preferred, unless soil moisture stations cannot be installed safely.

Note that multiple land-covers intersecting with the same soil series will create variability in moisture and impact site representativeness. Under such circumstances, stakeholder requirements and intended data application must take precedence in terms of desired land-cover. Otherwise, the spatially dominant land cover may be chosen for best representation, which can be followed by post-deployment activities (Chapter 6) to provide estimates on site representation to stakeholders. Table 3 can be used as a quick help guide to compare the two methods of macro-site (network scale) site selection.

Table 3. Comparison of resources required for the two methods of macro-site selection

Method based on upscaling	Method based on biophysical maps
A wait time of around 6 to 12 months is needed before site locations can be determined.	No wait time required.
Cost and resource-intensive upfront. It will require acquiring several additional soil moisture sensors and data loggers and access to the area surrounding the site.	No additional resources required upfront.
Provides quantified information on site representativeness and can provide data for field calibration of sensors upfront, thus reducing the need for post-deployment calibration, which satisfies a requirement for producing Tier I soil moisture data.	Provides qualitative information only. Post-deployment field-based calibration will be required to produce Tier I data.
Less uncertainty in final site representation but comes at higher upfront costs	Uncertainty rests in the reliability of maps and representation of measurements cannot be assess *a priori*.

MICRO-SITE SELECTION

Once a site is regionally located using either of the two methods, network operators must consult with a local soils expert for micro-site selection (Chapter 2). The soil profile must be examined to make sure that sensors are not installed in a locally disturbed area such as fill material from adjacent construction activities or an old, buried road. Identifying prior site disturbance can be carried out using a combination of activities. The easiest and most non-invasive activity is to contact the appropriate administrative or technical support staff for the area to ensure no utilities are buried at the location. This may include surveys for utility lines, cultural resources, and the like. A buried utility at the location or close to the site is indicative of disturbance to the surrounding soil. Contacting a utility locator is strongly recommended, in any case, to avoid disrupting local utilities.

The next activity involves selecting a suitable site around the station that is not likely to be disturbed and auguring to the depth of interest (e.g., 1m). The soil horizons (Figure 3) must be characterized as per NRCS recommendations[6] during auguring, and if any discrepancy such as unexpected soil textures, colors, or depth of layering is observed, the hole must be discarded and another location a reasonable distance away from the first one must be tested the same way. Unexpected soil texture, color, gravel, charcoal, or even trash may indicate fill material, buried pipes, or old roads, and consequently, any soil moisture measurements made at the location will not be spatially representative. This process must be repeated around the base station until an augured hole displays expected soil characteristics for the area (e.g., brown topsoil transitioning to red subsoil). This procedure is best conducted by someone trained in soil science.

Figure 3. Borehole for soil sensor installation with tape (left) and sensor inserted (right). Note that soil horizons that vary in soil color, texture, and structure. A soil scientist can help describe this profile. This information can be useful for stakeholders for interpreting soil moisture data measured in the soil profile. Image Credit: Matthew R. Levi, University of Georgia.

[6] Further information can be found at: https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soil/soil-survey