To what extent do states efficiently communicate high quality Soil Moisture data?

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Executive Summary

This report investigates the question, "To what extent do states communicate high-quality Soil Moisture data?" as well as the role the Interstate Council on Water Policy (ICWP) can play in supporting improved coordination.

Characterizing the extent that states efficiently communicate high quality Soil Moisture data requires both clarifying where communication is needed and defining what "high quality" Soil Moisture data is.

Communication is needed both between states and between states and their funding sources. Soil Moisture is a critical variable for agriculture, flood forecasting, drought preparedness, and fire management, yet current data systems are fragmented and inconsistent across states. In a rapidly expanding network, now it is very important to ensure that these networks are built with interoperability in mind, for the sake of both the Mesonets and users.

A high quality network of Soil Moisture data is characterized by spatial density, longevity of records, sensor type, and other aspects covered in The Soil Moisture Data Quality Guidance document provided by the National Coordinated Soil Moisture Network (NCSMMN) via NIDIS.

In terms of the role that the ICWP can play in supporting the communication of high-quality data, there are a few avenues to choose from, including funding support, budgeting standardization, fortifying communication lines, and joining current research initiatives.

Funding for Soil Moisture networks is volatile. When budgets are tight, sustaining existing stations is often a priority over adding new ones. Many rely heavily on the National Mesonet Program, which covers up to 42% of budgets for nearly half of the survey respondents. Formal ROI assessments may be useful in advocating for funding.

Despite the strong interest in standardization and interoperability, there are technical and personnel barriers that remain. Communication gaps also exist between states. Operation and Maintenance expenses are challenging to standardize. Soil Moisture is in its infancy compared to other hydrologic parameters.

Several initiatives are underway to address these issues, many of which are guided by the multi-agency community of the NCSMMN. Coordinating efforts of the NCSMMN include development of templates, coordinating meetings and webinars, and development of community resources. Of particular interest to the ICWP's work may be the upcoming white paper on Operations & Maintenance benchmarks and a NIDIS-funded study from Oklahoma State on the economic value of Soil Moisture monitoring. ICWP should monitor the progression of these projects.

This report recommends that ICWP support educational outreach, advocate for standardized O&M budgeting, and develop tools to help states justify long-term funding.

Why Coordinated Soil Moisture Monitoring Matters

Soil Moisture , or Soil Water Content, can be thought of as effective precipitation. The data provides valuable insights for agricultural monitoring, flood forecasting, drought early warning systems, and other applications (*The National Coordinated Soil Moisture Monitoring Network | Drought.Gov*).

Soil Moisture is a huge piece of the hydrologic puzzle, and without it, devastating events can be overlooked. For instance, insufficient Soil Moisture information played a role in missing the flood in the Upper Missouri River Basin. Two extreme snowpack events in 2011 and 2019 caused an air force base to get compromised — and the Infrastructure Investment and Jobs Act funded the Army Corps of Engineers to expand the state mesonets in the UMRB region to 540 stations by 2027 (*USACE Upper Missouri River Basin Soil Moisture and Plains Snow Monitoring Build-Out | Drought.Gov*).

But Soil Moisture is a complex metric. It varies extremely depending on location, soil type, sensor depth, and season. For example, as one Mesonet reports, there can be ten different soil types in an area of only a few acres.

This has complicated interoperability. It is difficult for users to implement data from highly varied networks, and in a challenging funding environment, networks can get picked off if seen as anomalies. Now, as networks are rapidly expanding, it is a crucial time to support the prioritization of Soil Moisture monitoring standardization.

Recent Legislation

Several bills introduced this year advocate for enhanced implementation of Soil Moisture data, highlighting applications such as forest resilience, precision agriculture, and improving flood forecasts:

1. H.R.1705, the Supporting Innovation in Agriculture Act of 2025 (2/27/25), establishes credit for investments in precision agriculture, which includes Soil Moisture monitoring.
2. S.613, the Improving Flood and Agricultural Forecasts Act of 2025 (3/12/25), authorizes appropriations totaling $304 million over the 2025-2029 period for the National Oceanic and Atmospheric Administration (NOAA). The goal is to maintain and expand the National Mesonet Program.
3. H.R.3816, the Weather Act Reauthorization Act of 2025 (06/06/2025), contains provisions for the National Mesonet Program and National Coordinated Soil Moisture Monitoring Network.
4. H.R.4075, the Fire Weather Development Act of 2025 (06/23/2025), advocates for establishment of a program to develop fire forecasting through improved monitoring of conditions like Soil Moisture.

Project Impetus

At this time, there are current gaps in understanding of Soil Moisture data sharing, flagged by the National Coordinated Soil Moisture Monitoring Network (NCSMMN), crucial to address by the ICWP.

According to the NCSMMN website, an absence of coordination of Soil Moisture data has led to several problems. This includes a lack of adequate spatial density (image 1), multiple non-standardized and non-interoperable datasets, and a lack of clarity on how investments improve infrastructure (*The National Coordinated Soil Moisture Monitoring Network | Drought.Gov*).

The engagement efforts by the ICWP include emphasizing interstate involvement, responsible communication in the collection of large data, securing federal support, promoting interagency cooperation, prioritization of enhancements and evaluation of the needs and drivers of resource challenges and opportunities. The ICWP does this through congressional appropriations, tracking federal legislation, nurturing positive working relationships and providing a national forum to share expertise. Therefore, the ICWP can play a role in partnering with the NCSMMN in coordinating Soil Moisture Data.

Advocating for a coordinated Soil Moisture monitoring network will fulfill ICWP's goals to improve water sustainability, water management and drought resiliency, as stated in the ICWP Principle Statement on Federal Support of Drought Planning and Resilience Activities.

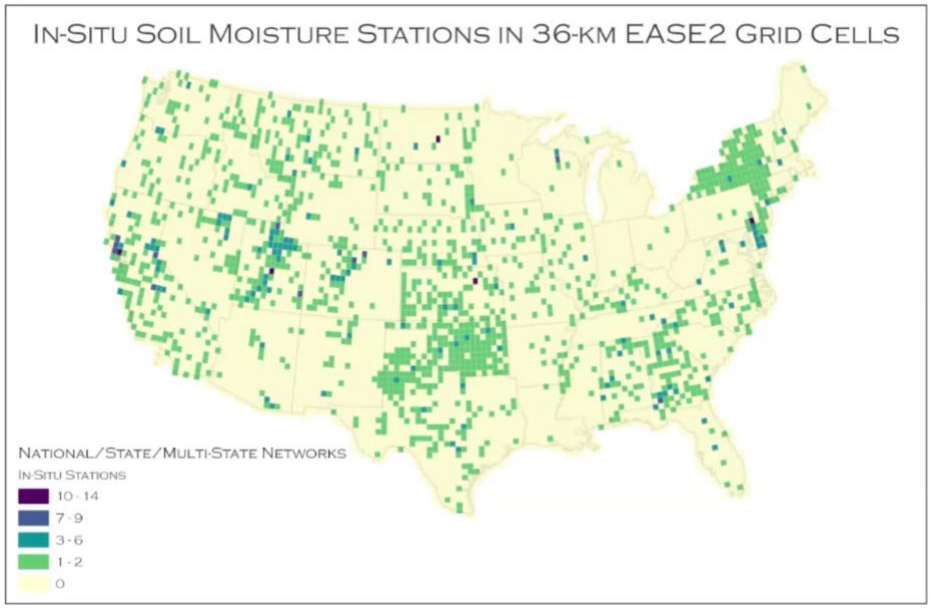

Image 1. Each cell represents 36 square kilometers. Ideally, there would be in situ stations represented in every cell. From Mike Cosh at the July 2025 National Soil Moisture Workshop.

Research Objectives

The main research objectives were threefold: to characterize the role economic drivers and ROIs play in the density or quality of a network, clarify the priority of Soil Moisture standardization and interoperability among agencies as recommended in the December 2024 NIDIS guidance for standardization, and identify opportunities for improving communication lines among States, or between States and users, in reference to the May 2021 NCSMMN recommendations.

Methodology

This research was structured using a four-pronged approach: (1) Hypothesize and Visualize, creating assumptions to map out ideal communication lines and standards of Soil Moisture data; (2) Outreach, to narrow issues in Soil Moisture data communication and implementation according to State interests; (3) Discussion, to lead collaborative brainstorming of tractable improvements in data interoperability or investment targeting; and (4) Report, to create a useful reference consolidating localized success stories, challenges, and action needed by ICWP advocates and member states themselves.

Assumptions

The original assumptions were the following:

1. Between Private Sector partners and States, there are differences in how Soil Moisture data is being prioritized and the extent of the ROI.

2. Private Sector partners and States would benefit from increased interoperability and standardization of Soil Moisture data.

3.States would benefit from taking more advantage of federal resources.

4. Stakeholders would benefit from increased *in situ* Soil Moisture data monitoring sites, especially on tribal lands or other underrepresented regions.

5. There are gaps in communication lines between member states and federal agencies.

6. There are budgeting gaps inhibiting improvements in monitoring infrastructure.

7. Compiled success stories and/or case studies of efficient Soil Moisture data sharing could bolster funding support for climate forecasting products.

Initial Interviews

Organizations reached out to during initial interviews:

University of Georgia Weather Network
Virginia Department of Environmental Quality
Oklahoma Climatological Survey
Kansas State University
OTT Hydromet

Topics discussed:

1. Drought variation and drought relief funding
2. Aligning Soil Moisture data with irrigation requirements
3. Sensor replacement methods
4. Challenges with instrument variation across states
5. Sensor installment depths
6. Preserving climatological integrity, value in long-term data sets
7. Plans to expand, increase spatial density
8. Budget distributions (federal, commodity grants, etc.)

Survey

Title: Soil Moisture Monitoring ICWP Survey

Open: June 13, 2025 — July 7, 2025

Target Audience: States and Universities acquiring and sharing Soil Moisture data

Response Rate: 31%

Responses: 15

Focus Group

Organizations represented:

NCSMMN
UGA Weather Network
Montana Climate Office
Illinois Department of Natural Resources

Topics discussed:

1. The priority to maintain or diversify funding sources.
2. Products of research that has helped fund network expansion.
3. What is necessary to be able to diversify funding, particularly with regards to the role a national forum can play.

Survey and Interview Findings

Economic Drivers

Takeaways

- **ROI is not widely assessed yet**, especially in states or regions that are still in early deployment stages.
- **Agriculture remains the dominant economic driver** for Soil Moisture data across many states.
- **Sustainable funding is a concern.** Networks are actively seeking to diversify their sources, with some grants (e.g. UMRB funds) nearing expiration. Creating products from funded research is a solution.
- **Political alignment with Soil Moisture ROIs can influence funding outcomes**.
- **Increased funding is likely to be directed toward network improvements**, particularly calibration and upgrades. This may not be in the best interest of building a coordinated, rather than highly varied, network.
- **Standardization is both desired and seen as achievable**, which may enhance economic justification and cross-state funding efforts.

Evidence & Examples:

- South Alabama: "Not currently at a point for ROI on Soil Moisture yet… We are just now getting to the point of installing sensors and testing deployment."
- **Political advocacy**: Senator Ted Cruz's office lobbied against NOAA's discontinuation of Soil Moisture monitoring in FY2024 (source: on behalf of Texas ag).
- **Funding reliance**:
    - 47% of respondents rely on an average of 42% of their funding from the National Mesonet Program.
- **Standardization needs**:
    - 60% of organizations want it, and 73% believe it's achievable (Image 3).

- **Use of new funding**: 73% would use additional funds for instrument calibration or upgrades (Image 2).
- **Cited funding sources**:
    - National Mesonet Program
    - NOAA
    - State Funds (e.g., MN Clean Water Funds)
    - NASA, USDA, EPA, FEMA, Synoptic
- **Focus group quote on funded research**:
  "Our Drought Dashboard is a direct product of funded research. We continue to develop tools on it... Our lead researcher created a synthetic streamflow model (75–80% reliability)… Used to characterize drought as primary assessment base."
- **Possible strings attached:** When federally funded, Mesonets must make their data public. This may compromise other opportunities for private funding.

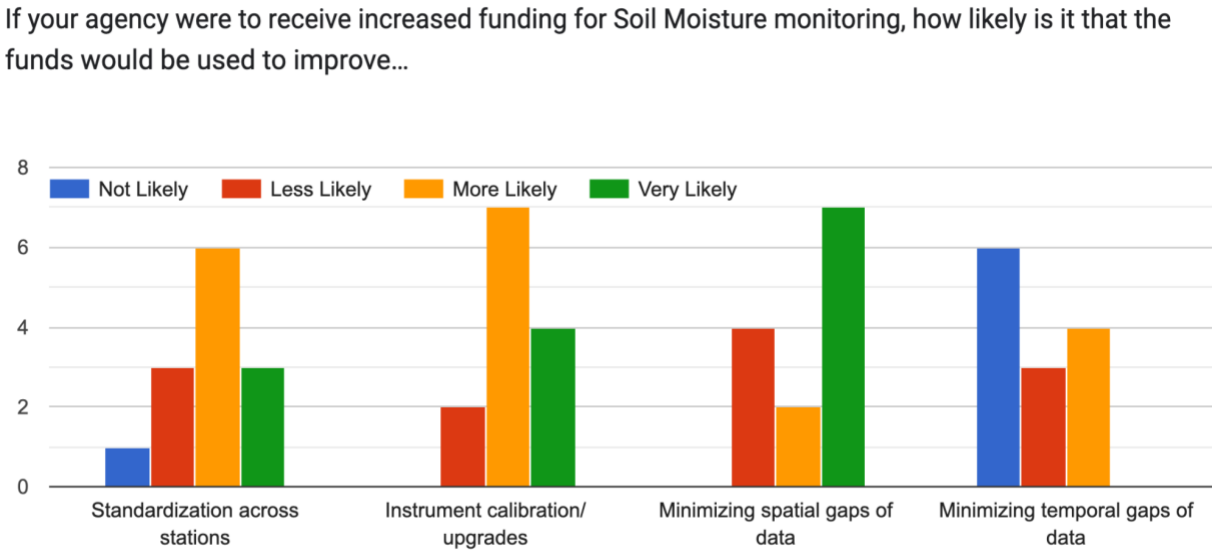

Image 2. Budgeting priorities in the event of an increase in funding, reported by ICWP survey respondents.

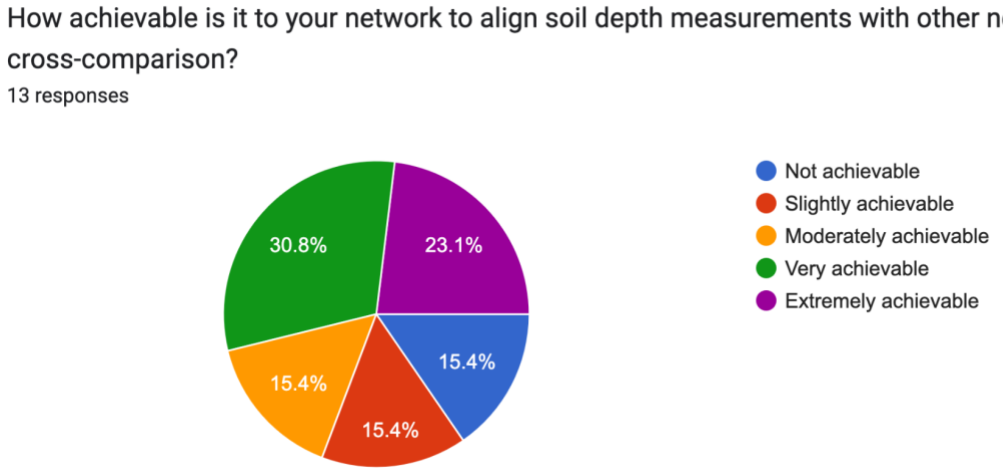

Image 3. Perceptions of achievability among ICWP survey respondents.

Barriers to Interoperability

Takeaways

- **Interoperability is hindered by inconsistent equipment, deployment, and metadata collection across networks.**
- **Lack of standardized soil metadata creates incompatibility, even when depths match.**
- **Inconsistent deployment reduces trust and incentives to collaborate across states.**
- **Limited staffing and funding constrain modernization and the pursuit of interoperability.**

Evidence & Examples

- **Soil metadata gaps**: UMRB recommends extensive metadata fields (soil type, texture, bulk density, etc.), which are often missing conductivity (*Soil Moisture Metadata Guidance | Drought.Gov*).
- **Prioritizing longevity**: All states in the Soil Moisture survey responded that it is important to maintain consistent instrumentation over the next 10-20 years (Image 4).

- **Interview quote on longevity:**

  "Our focus is really on climate and trying to capture data over a long period of time. The soil data we capture now, we don't want to change it in 10 years. We want it to be the same so we can have a huge database that actually looks at those changes over time."

- **Interview quote on metadata:**

  "We can have the same depths, but the data is still probably not comparable… Nebraska, for instance, has a lot of bare plot measurements, and we don't have any bare plot. We do everything over grass cover. There's just so many little metadata differences that make configurations impossible."

- **Interview quote on deployment inconsistency**:

  "The networks are always in a funding flux… [One State] closed down a bunch of stations a couple years ago. We don't want to match up with them if they are inconsistent over time."

- **Staffing constraints**:
  - 40% of survey respondents agreed and 26.7% strongly agreed that operational expense limitations are hindering network expansion and modernization.
  - Only 1 respondent disagreed that staff labor expenses were a barrier.

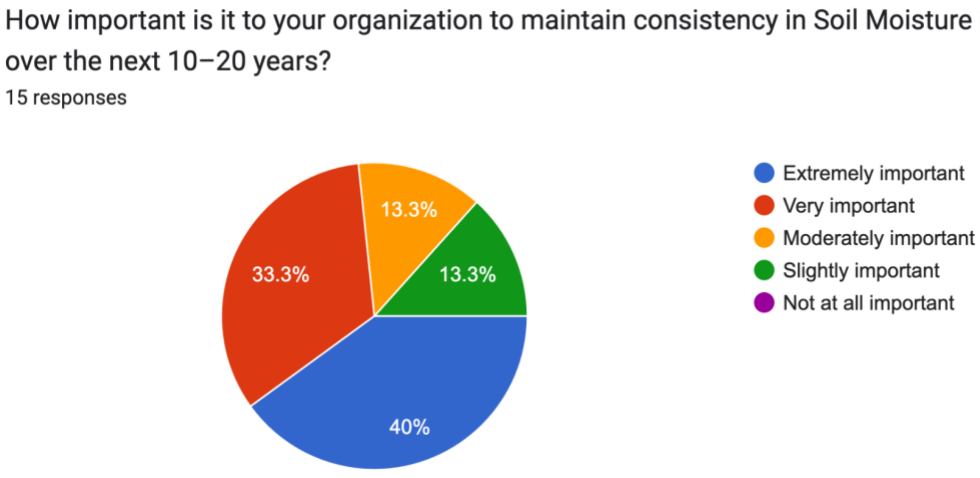

Image 4. Importance of maintaining consistent instrumentation among ICWP survey respondents.

Communication Breakdowns

Takeaways

- **Maintenance funding has been overlooked**, such as when allocating relief funds.
- Networks need support not just in hardware but in labor, documentation, and communication tools.
- The main communication breakdowns between states involve unnecessary competition, a need for a baseline of data interpretation (e.g. which depths are most useful to integrate), and a lack of standardization of operation and maintenance funding.
- **Networks don't typically acquire data from other networks.** They collect and manage their own data. The users of data are researchers, decision makers or resource managers.

Examples & Evidence

- Reported Issues: States should be advised against pouring relief funds entirely into new hardware after an emergency.
- 57% of states reported a lack of confidence that end users effectively understand and act upon Soil Moisture data they provide (Image 5).
- Interview quote on why maintenance is underfunded:

"It can be manageable to show the network needs to expand. What's harder to communicate is that we need the people to maintain them… Is there someone demonstrating the product? Do you have someone capable of your data management? That's a specific skillset to write the code, do the QC needed to make the data useful… Give people templates to cut down on needs and language to help communicate this to funders."

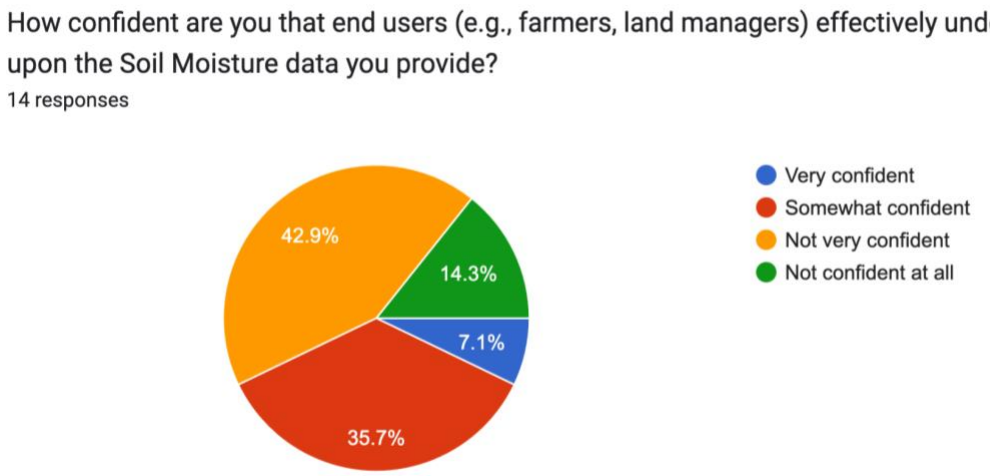

Image 5. Confidence in communication with end users.

Initiatives Underway

The National Coordinated Soil Moisture Monitoring Network (NCSMMN) is a multi-agency, national initiative to coordinate soil moisture data collection, analysis, and communication across networks, researchers, and data users. Their work, led by NOAA-NIDIS and the USDA-ARS, includes hosting workshops and webinars, supporting research and development of new technologies and approaches to data applications, and providing resources and templates to improve standardization of soil moisture data collection and quality. Two examples of ongoing projects specific to investigating economic costs and benefits of Soil Moisture networks include:

NCSMMN Operations and Maintenance (O&M) White Paper, *Expected June 2026*

- Led by Colorado State University, NOAA-NIDIS, and USDA-ARS
- Will share benchmarks for costs by Tier of data quality. It will also identify opportunities to reduce costs via network collaboration.
- Leverages a Colorado State University Survey of Mesonets, conducted in July/Aug 2025.
- NOAA-NIDIS hosted meeting of 30-35 network operators June 2, 2025 to discuss:
    a. What are the biggest challenges to sustaining O&M for your network?
    b. Where are you currently succeeding in your O&M approach? *(e.g., partnerships/division of labor, paying more up front for more durable equipment, etc.)*
    c. What are some of the largest costs associated with O&M for your network? *(e.g., data storage, physical equipment/sensors, skilled labor, etc.)*

Oklahoma State University Economic Value of Soil Moisture Study, *Expected Spring 2026*

- Funded by NOAA-NIDIS
- Will provide a literature review on the economic values of Soil Moisture data and applications.
    - E.g. drought forecasting, agriculture, rangeland management, water supply management

Call for Papers: Advances in Monitoring Soil Water Content, ***Submissions due Oct. 1 2025***

- The collection aims to present research on soil water science, including sensor technologies, data standardization, quality, and coordination of network deployments.
- Lead Editors are Todd Caldwell, Mike Cosh at USDA-ARS and Elise Osenga at University of Colorado, CIRES (More information found at Vadose Zone Journal page).

Another NIDIS-funded study (which was presented at the National Soil Moisture Workshop, the annual science meeting of the NCSMMN) showcased a promising method for measuring the ROI on Soil Moisture data.

An Ohio State Sensitivity Analysis presented by Jackie Beck at the National Soil Moisture Workshop tested how accurately soil moisture alone represents prior drought conditions in a network with few stations compared to a network with more stations.

The key finding of the Sensitivity analysis is that not all areas of the UMRB are equally well represented, and adding more stations will improve representation across the basin. They found this through calculating the positive impacts of an expanded upper Missouri river basin network:

- 98.35% of basin classification skill improved
- Reduced payment error from 29.6 to 6.9%
- From 2017 investment, it would have paid itself of by 3x

The methods for this study used USDM maps and payments as a standard against which drought maps generated using only soil moisture data were compared. IN other words, USDM maps and payments were assumed to be the ground-truth for accuracy. The study quantified how much accuracy of soil moisture as a drought indicator improved when there were fewer vs. More dense stations. The study found thtat there was a significant improvement in accuracy of soil moisture as an indicator of drought associated with an increase in monitoring stations. However, the USDM maps that are used to inform federal payouts are determined by a consensus-of-information approach, that includes many variables (wind speed, air temperature, citizen science reports, etc.). The soil moisture drought maps modeled in this study differ from actual USDM maps in that they used only one variable to represent drought.

Key Insights

1. There is a demand for educational programs.
2. The value of Soil Moisture data is difficult to quantify.
3. There is a strong preference for longevity of data.
4. Diversifying funding sources is key.
5. Operation and Maintenance costs lack standardization.

Recommendations

Questions to pursue:

- To what extent are resources for hydrologically applying Soil Moisture data distributed *fairly* among large states and tribes?
- What inventory is there of open source materials that could be shared?
- How are states diversifying funding?
- How many states are adequately accounting for O&M costs?
- Is there a way for Mesonets to standardize how they fund staff labor and operational expenses?
- Which states currently have plans to expand their networks and modernize their equipment, and what dollar value are their operational and maintenance budgets?
- What is included in the operational and maintenance budgets of States?

Next Steps:

- Advocacy for consistent, standardized funding.
- Continue researching use cases of Soil Moisture valuation.
- Collaboration with NIDIS/NCSMMN to advance soil moisture coordination).
- Create templates, communication tools to help justify funding, explaining that data infrastructure requires more than hardware.
    a. The NCSMMN core team is interested in finding use cases (e.g. “In one region, a decision to do X was made due to the availability of Soil Moisture data.”).
    b. Limitation: NOAA-NIDIS, as the host of the NCSMMN, is limited in its capacity to conduct work on behalf of the ICWP. Federal agencies need to ensure that they do not lobby for specific funding allocations.

Acknowledgements

Thank you to the State representatives for informing my outreach, contributing their expertise to my research, and enthusiastically engaging in the analysis of the survey results as well. I'd also like to thank the ICWP Board for the opportunity to embark on this work and for being open to my recommendations. I'm especially grateful to my mentor Christel Valentine, Marketing Director of Hydrology and Meteorology at OTT Hydromet, for her guidance and expertise that were invaluable in developing this report.

Appendices

Soil Moisture Survey Respondents
State Climate Office of North Carolina
University of Delaware Center for Environmental Monitoring and Analysis
Illinois Department of Natural Resources
Illinois Climate Network
Purdue University
MN Department of Agriculture
State of Alabama / University of Alabama in Huntsville
Oklahoma Mesonet
University of Utah
Georgia Water Planning & Policy Center
Kentucky Mesonet
Department of Environmental Protection
Metropolitan North Georgia Water Planning District
Kansas Mesonet
Montana Climate Office

Survey Questions asked:

1. What are the primary industries that use your data?
2. How does your agency evaluate the return on investment for Soil Moisture data? Please explain.
3. Please provide an estimate of the percentage of your network's annual budget that is currently supported by the Mesonet Program, Federal grants, Private or commodity group, or State funds. Please specify the federal grants or private sources.
4. To what extent do you agree with this statement: operational expense limitations are hindering network expansion and modernization.
5. To what extent do you agree with this statement: staff labor expense limitations are hindering network expansion and modernization.
6. To what extent is your budget for acquiring Soil Moisture data increasing in the next year?
7. If your agency were to receive increased funding for Soil Moisture monitoring, how likely is it that the funds would be used to improve…
8. How achievable is it to your network to align soil depth measurements with other networks for cross-comparison?
9. What depths are most beneficial to your stakeholders and why?
   To what extent would your agency benefit from a standardized Soil Moisture measurement depth at 100cm?
10. How often do installation and maintenance inconsistencies across states (e.g. sensor depth, soil type) affect your ability to integrate Soil Moisture data from other networks?
11. What other barriers do you face in integrating Soil Moisture data from multiple sources?
12. How important is it to your organization to maintain consistency in Soil Moisture instrumentation over the next 10–20 years?
13. How confident are you that end users (e.g., farmers, land managers) effectively understand and act upon the Soil Moisture data you provide?
14. How often does your agency utilize federal data or tools to supplement local Soil Moisture data? (e.g. SMAP, regional climate centers, NIDIS drought monitor)
15. How often does your agency collaborate with federal partners (e.g., NOAA, USDA, NRCS) to acquire or apply Soil Moisture data?
16. How would you rate the quality of communication between your agency and federal partners regarding Soil Moisture data priorities and needs?
17. How would you like to see communication lines improved across Soil Moisture data stakeholders?
18. Where do you see the most significant breakdowns in communication?

Bibliography

ICWP Soil Moisture Data Focus Group. 7 Jul. 2025.

Soil Moisture Metadata Guidance | Drought.Gov. 9 Dec. 2024, https://www.drought.gov/documents/soil-moisture-metadata-guidance.

The National Coordinated Soil Moisture Monitoring Network | Drought.Gov. https://www.drought.gov/drought-in-action/national-coordinated-soil-moisture-monitoring-network. Accessed 28 Jul. 2025.

USACE Upper Missouri River Basin Soil Moisture and Plains Snow Monitoring Build-Out | Drought.Gov. https://www.drought.gov/drought-research/usace-upper-missouri-river-basin-soil-moisture-and-plains-snow-monitoring-build. Accessed 28 Jul. 2025.