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Soil Temperature and Moisture Profile (STAMP) System Instrument Handbook

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ARM
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Acronyms and Abbreviations

ABS	acrylonitrile butadiene styrene
ARM	Atmospheric Radiation Measurement
CLL	crop lower limit
DOE	U.S. Department of Energy
DQ Explorer	Data Quality Explorer
DQO	Data Quality Office
DQPR	Data Quality Problem Reports
DQR	Data Quality Report
EF	extended facility
OSU	Oklahoma State University
PVC	polyvinyl chloride
PWA	plant water availability
QC	quality control
RMSE	root-mean-square error
SGP	Southern Great Plains
STAMP	Soil Temperature and Moisture Profile
SWATS	Soil Water and Temperature System
UV	ultraviolet
VAC	Volts alternating current
VAP	value-added product
VDC	voltage, direct current

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Tables

1.0 General Overview

The soil temperature and moisture profile system (STAMP) provides vertical profiles of soil temperature, soil water content (soil-type specific and loam type), plant water availability, soil conductivity, and real dielectric permittivity as a function of depth below the ground surface at half hourly intervals, and precipitation at one-minute intervals. The profiles are measured directly by in situ probes at all extended facilities of the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Climate Research Facility Southern Great Plains (SGP) observatory. The profiles are derived from measurements of soil energy conductivity. Atmospheric scientists use the data in climate models to determine boundary conditions and to estimate the surface energy flux. The data are also useful to hydrologists, soil scientists, and agricultural scientists for determining the state of the soil.

The STAMP system replaced the Soil Water and Temperature System (SWATS) in early 2016.

2.0 Contacts

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3.0 Deployment Locations and History

Current health and status information for each STAMP instrument can be found at the DQ Explorer website http://dq.arm.gov/dq-explorer/cgi-bin/main/metrics or NCVweb at http://dq.arm.gov/ncvweb/ncvweb.cgi.

All SWATS were decommissioned when the STAMP system was installed, except at EF13, where the SWATS will be maintained for at least a year for comparison with the new STAMP system.

Table 1 identifies the location of the STAMP instrument systems and the depths at which sensors were installed at each extended facility:

Table 1. STAMP instrument system locations and sensor depths.

Extended Facility	Depths (cm)	Status
E9 Ashton, KS	5, 10, 20, 50, 100	Installed 26 Feb 2016
E11 Byron, OK	5, 10, 20, 50, 100	Installed 25 Feb 2016
E12 Pawhuska, OK	5, 10, 20, 50, 100	Installed 4 Mar 2016
E13 Lamont, OK	5, 10, 20, 50, 75/100	Installed 22 Feb 2016
E15 Ringwood, OK	5, 10, 20, 50, 100	Installed 1 Mar 2016
E21 Okmulgee, OK	5, 10, 20, 50, 100	Installed Mar 2016
E31 Anthony, KS	5, 10, 20, 50, 80	Installed 3 Mar 2016
E32 Medford, OK	5, 10, 20, 50, 100	Installed 25 Feb 2016
E33 Newkirk, OK	5, 10, 20, 50, 100	Installed 23 Feb 2016
E34 Maple City, KS	5, 10, 20, 50, 100	Installed 26 Feb 2016
E35 Tryon, OK	5, 10, 20, 50, 100	Installed 2 Mar 2016
E36 Marshall, OK	5, 10, 20, 50, 100	Installed 29 Feb 2016
E37 Waukomis, OK	5, 10, 20, 50, 100	Installed 29 Feb 2016
E38 Omega, OK	5, 10, 20, 50, 100	Installed 1 Mar 2016
E39 Morrison, OK	5, 10, 20, 50, 100	Installed 24 Feb 2016
E40 Pawnee, OK	5, 10, 20, 50, 100	Installed 24 Feb 2016
E41 Pecham, OK	5, 10, 20, 50, 100	Installed 19 Apr 2016

4.0 Near-Real-Time Data Plots

See the Data plots in DQ Explorer at http://dq.arm.gov/dq-explorer/cgi-bin/main/metrics.

In DQ Explorer, select ‘ARM site: SGP’ and ‘Data Streams: stamp’ or ‘Data Streams: stamppcp’ and the EF (number, as “xx” below) of interest.

On NCVweb, select ‘sgp’ then ‘sgpstampexx.b1’ or ‘sgpstamppcpexx.b1’.

In Plot Browser, select ‘Search Site - SGP’ and ‘Datastream - sgpstamp’ or ‘Datastream - sgpstamppcp’.

5.0 Data Description and Examples

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

The STAMP system is designed to provide temperature and soil moisture measurements, as well as plant water availability for plant root use. The measurements are given below, with some description, units of measure, and uncertainty. Measurements are made in three soil profiles (west, south, east) at generally 5, 10, 20, 50, and 100 cm depths (lowest depth varies from this at three extended facilities; see Table 1).

Soil Temperature: Soil temperature is the temperature of the sensor/soil water system. Soil temperature is reported in units of degrees Celsius (C).

Soil Moisture: Soil moisture is reported as the volumetric percentage (%) of soil water contained in a given volume of soil, or in other words, 100 times units of cubic meters of water per cubic meter (m^3/m^3) of the soil/water system. The measurement is reported in two ways, as soil-type-specific water content and as the equivalent soil water content for the loam soil type.

Plant Water Availability: The equivalent depth of water in a soil section that is available for plant root use. Since HydraProbes were installed at each SGP extended facility (EF) at five depths, with a few exceptions where the soil was shallower than 100 cm, there are five sections of soil considered for this measurement. The amount of water in each section depends on the soil moisture and the height of the section. For a typical deployment, the section heights, from most shallow to deepest, are 7.5 cm, 7.5 cm, 20 cm, 40 cm, and 50 cm. Although these were chosen somewhat arbitrarily, they function to provide an idea of where the greatest and least amount of water is stored in the total soil water column.

Total Plant Water Availability: The equivalent depth of water in the soil column that is available for plant root use. Most of the EF deployments of the STAMP have the deepest installed HydraProbe at 100 cm, although there are a few exceptions. So the total soil column considered is 125 cm.

Table 2. STAMP measurements and uncertainties.

Data File Variable	Units	Uncertainty
soil_specific_water_content_west soil_specific_water_content_south soil_specific_water_content_east	% (100 x m^3/m^3)	3%
plant_water_availability_west plant_water_availability_south plant_water_availability_east	mm	1%
total_plant_water_availability_west total_plant_water_availability_south total_plant_water_availability_east	mm	1%
soil_temperature_west soil_temperature_south soil_temperature_east	^oC	0.3 ^oC
loam_soil_water_content_west loam_soil_water_content_south loam_soil_water_content_east	% (100 x m^3/m^3)	3%

Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = \left(B^2 + \sigma^2\right)^{1/2}.$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval we use the Student's t distribution: tn; 0.025 ≈ 2, assuming the RMSE was computed for a reasonably large ensemble. Then the uncertainty is calculated as twice the RMSE.

The uncertainties shown in Table 2 and 3 were determined by the manufacturer of the HydraProbe.

5.1.2 Secondary/Underlying Variables

Soil Conductivity: The soil electrical conductivity (in Siemens/m) is an indication of dissolved salts, dissolved solids, fertilizer, and soil pH in the soil. The measurement used is not temperature corrected.

Real Dielectric Permittivity: The dielectric permittivity is a measure of how much electric field (more correctly, flux) is generated per unit charge in the soil, as a result of the electrical signal that is produced by the HydraProbe. The measurement used is not temperature corrected.

Table 3. STAMP secondary measurements and uncertainties.

Data File Variable	Units	Uncertainty
soil_conductivity_west soil_conductivity_south soil_conductivity_east	Siemens/m	2%
real_dielectric_permittivity_west real_dielectric_permittivity_south real_dielectric_permittivity_east	unitless	1.5%
precip	mm	1 %

Note that precip is actually part of a separate datastream: sgpstamppcpExx.b1.

5.1.3 Diagnostic Variables

battery_voltage (VDC) is the only diagnostic variable.

5.1.4 Data Quality Flags

Data quality flags are used to alert users of bad or questionable data.

-9999 in the datastream means either that a particular sensor depth was not installed or the data for that sensor is reporting missing. 9999 normally indicates an offscale value (beyond the capability of the data logger to measure).

netCDF files contain the following flags:

Flag=0: value is within the specified range
Flag=1: value is missing (recorded as '-9999')
Flag=2: value is less than acceptable minimum
Flag=4: value is greater than acceptable maximum
Flag=8: failed delta check (value differs too greatly from previous value)

For example, the quality control (QC) variable 'qc_precip' is actually a diagnostic variable equal to the sum of the data quality flags for the variable 'precip.' (There are QC variables for all variables.)

qc_precip = 5

To interpret the QC variable, convert the number to base 2. For example, 5 = 4x1 + 0x2 + 1x1 = 101 [base2].

qc_precip = 4 + 1

This means that the QC variable contains the maximum and missing flags.

precip = '-9999' > acceptable minimum value

Table 4. STAMP variable acceptable minimums and maximums.

Variable	Acceptable Minimum	Acceptable Maximum
soil_specific_water_content	0 %	100 %
loam_soil_water_content	0 %	100 %
plant_water_availability	-200 mm	400 mm
total_plant_water_availability	-800 mm	1200 mm
soil_temperature	-40 ^{o}C	50 ^{o}C
soil_conductivity	0 S/m	2 S/m
real_dielectric_permittivity	0	650
battery_voltage	0 V	15 V
precip	0 mm	10 mm

5.1.5 Dimension Variables

Time: a complete file will contain observations for each half hour of the day (dimension 'time' equals 48) for all variables except precip, which contains observations for each minute (dimension 'time' equals 1440).

Depth: depth (cm) below the surface of the ground (sensor altitude is equal to the value of 'alt' minus the value of 'depth').

5.2 Annotated Examples

See plots in DQ Explorer at http://dq.arm.gov/dq-explorer/cgi-bin/main/metrics.

5.3 User Notes and Known Problems

Soil and Physical Characteristics of the ARM Extended Facilities with SWATS

The range of soil textures (called “types” for the STAMP system) is summarized on a soil texture triangle in Figure 1. At a couple of extended facilities the same soil type is found at all five depths, but often the soil type varies significantly with depth. Table 5 shows the soil type for each HydraProbe depth at each extended facility, as determined from Oklahoma State University soil texture measurement.

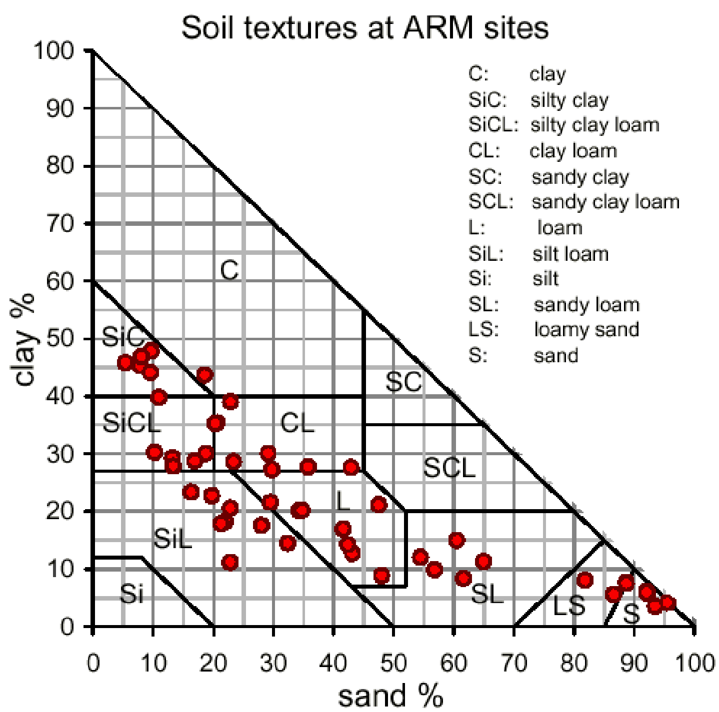

Figure 1. Soil texture triangle illustrating range of soil textures at the ARM STAMP sites.

Table 5. Soil types and HydraProbe depths for SGP EF STAMP sites.

Extended Facility	Depths (cm)	Soil Type
E9 Ashton, KS	5, 10, 20, 50, 100	L, L, L, CL, CL
E11 Byron, OK	5, 10, 20, 50, 100	L, L, L, CL, CL
E12 Pawhuska, OK	5, 10, 20, 50, 100	SL, SL, SL, SL, SL
E13 Lamont, OK	5, 10, 20, 50, 75/100	SiL, SiL, C, CL, CL
E15 Ringwood, OK	5, 10, 20, 50, 100	SL, S, S, S, S
E21 Okmulgee, OK	5, 10, 20, 50, 100	SiCL, SiC, SiC, SiC, SiC
E31 Anthony, KS	5, 10, 20, 50, 80	SiL, SiL, SiL, SiL, SiL

Extended Facility	Depths (cm)	Soil Type
E32 Medford, OK	5, 10, 20, 50, 100	SiCL, SiL, SiCL, SiC, SiC
E33 Newkirk, OK	5, 10, 20, 50, 100	SiL, SiL, SiCL, SiC, SiC
E34 Maple City, KS	5, 10, 20, 50, 100	SiCL, SiCL, SiCL, SiC, SiC
E35 Tryon, OK	5, 10, 20, 50, 100	CL, CL, C, CL, CL
E36 Marshall, OK	5, 10, 20, 50, 100	SL, SL, CL, SCL, SCL
E37 Waukomis, OK	5, 10, 20, 50, 100	SiL, SiL, SiL, SiCL, SiCL
E38 Omega, OK	5, 10, 20, 50, 100	SiL, SiL, SiL, CL, CL
E39 Morrison, OK	5, 10, 20, 50, 100	SiL, SiL, SiCL, SiCL, SiC
E40 Pawnee, OK	5, 10, 20, 50, 100	SiL, L, C, SiC, SiCL
E41 Pecham, OK	5, 10, 20, 50, 100	SiL, SiL, SiL, SiCL, SiCL

5.4 Frequently Asked Questions

Q: How reliable have the HydraProbes been?

A: After more than one year of use, the HydraProbes have proven to be very reliable. However, they have been found to be somewhat sensitive to lightning energy that travels through wet layers of soil, particularly at the deeper depths. Therefore, several have already been replaced.

Q: At what ARM facilities are the STAMP systems installed?

A: They are installed at all SGP extended facilities.

Q: Will the STAMP system be deployed at other ARM facilities?

A: There are no plans to install STAMP systems at other ARM facilities.

6.0 Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results:

- DQ Explorer http://dq.arm.gov/dq-explorer/cgi-bin/main.
- NCVWEB at https://plot.dmf.arm.gov/ncvweb/ncvweb.cgi for interactive data plotting.

The tables and graphs shown at these two areas provide the same information used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

For DQ Explorer, select 'site: SGP' and 'Data Stream: stamp', and then for 'Facility', the desired extended facility.

6.2 Data Reviews by Instrument Mentor

Mentor notes on data quality control procedures:

- QC frequency: Once per week
- QC type: Graphical plots, data quality metric tables
- Inputs: Netcdf data
- Outputs: Data Quality Problem Reports (DQPRs), and Data Quality Reports (DQRs) issued to the site scientist team.

The instrument mentor inspects STAMP data from all sites approximately once per week, using in particular the plots and metrics from DQ Explorer, plots from NCVWEB, and data assessments from the Data Quality Office (DQO). The mentor reports data deficiencies via DQPRs and DQRs to the SGP site scientist team and continually works with SGP Site Operations to issue work orders to fix any problems noted.

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQO and most Site Scientist techniques for checking have been incorporated within DQ Explorer and can be viewed there.

The DQO produces weekly assessment summaries for all STAMP systems; these are only available to the STAMP instrument mentor.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Facility are met through the analysis and processing of existing data products into “value-added” products or VAPs. No VAPs have been created for the STAMP system. The VAP Archive can be viewed at https://engineering.arm.gov/datagrid/DataGrid.html?conf=class.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The STAMP system consists of several components that enable the system to collect, store, and transmit data automatically. All of the components, with the exception of the sensors, are installed in a weatherproof enclosure located above the soil surface. The components of the system include the following:

- Sensors
  - Stevens Water Monitoring Systems, Inc. Hydraprobe

  - Texas Electronics, Inc. Model TR-525M Metric Heated Rain Gauge
- Data logger
  - Manages measurement and control functions
  - Campbell Scientific, Inc. Model CR800.
- Multiplexer
  - Allows the connection of up to 32 sensors
  - Campbell Scientific, Inc. Model AM16/32B.
- Power supply
  - Provides electrical power for the data logger and telecommunications equipment
  - Campbell Scientific, Inc. Model PS12.
- Communications equipment
  - Allows communication with external devices
  - Via serial port on the Campbell Scientific, Inc. Model CR800.

7.1.2 System Configuration and Measurement Methods

Sensors: At a typical extended facility, HydraProbes are installed at five depths in the soil profile: 5, 10, 20, 50, and 100 cm below the soil surface. Three profiles are installed at each extended facility for replication and redundancy of measurements, resulting in a total of 15 HydraProbes at each site. The three sensor profiles are located approximately 1 m apart. At a few EFs, rock or shallow soil prohibits installation at the greater depths.

Installation: At each of the EFs, most of the installation work was performed manually to minimize disturbance of the soil and vegetation at the site, and to minimize safety hazards. The holes for the HydraProbes were dug using a powered auger. Then the HydraProbes were placed in the soil in the sides of the holes with as little disturbance as possible, to provide a relatively undisturbed profile of soil in which measurements are made. The electronics enclosure containing the electronic measurement equipment is mounted on poles in concrete foundations, placed in the ground surface in such a way and at a reasonable distance from the HydraProbes so as to minimize the influence of the equipment on the HydraProbe measurements.

The measurement methodology is described in Section 7.2., Theory of Operation.

7.1.3 Specifications

See Section 7.1.1, List of Components, and Tables 2, 3, and 4 for some details on the HydraProbes and rain gauges. The factory specifications are below:

TR-525M Metric Heated Rain Gauge

Resolution	0.1 mm Metric

Accuracy	1.0% up to 2"/hr (50 mm/hr)
Collector Diameter	9.66" (245 mm) with knife-edge
Funnel Depth	7.2" (183 mm)
Splash out Protection	>2" (50 mm)
Operating Temp	32 to 125°F (0 to 50°C)
Storage Temp	-40 to 160°F (-40 to 70°C)
Humidity Limits	0 to 100%
Weight	2.5 lbs. (1.2 kg) 6 lbs. (2.7 kg) shipping
Height	12" (305 mm)
Cable	25', 24-gauge 2-conductor
Switch	Momentary potted reed switch
Switch Rating	30 VDC @ 2 A, 115 VAC @ 1 A
Switch Closure Time	135 ms
Bounce Setting Time	0.75 ms
Pivot	Hardened SS Jewel & Pivot
Bucket	Black ABS injection molded
Level	Integral Bubble Level
Power	120 VAC
Current	1.65 A
Starting Temperature	45°F (7.2°C)
Minimum Temperature	-65°F (-54°C)

HydraProbe

Measurement	**Accuracy**	**Range**
Real dielectric permittivity (isolated)	± 1.5% or 0.2 whichever is typically greater	1 to 80 where 1 = air, 80 = distilled water
Soil moisture for inorganic & mineral soil	± 0.01 WFV for most soils ± 0.03 max for fine textured soils	From completely dry to fully saturated
Bulk electrical conductivity	± 2.0% or 0.02 S/m whichever is typically greater	0.01 to 1.5 S/m
Temperature	± 0.3°C	-10°C to +55°C
Inter-sensor variability	< ± 0.012 WFV (θ m^3 m^{-3})	n/a

Electrical

	SDI-12
Power supply	9-20 VDC
Power consumption	<1 mA idle / 10 mA active for 2 seconds during duty cycle
Cable	3-wire: power, ground, data
Max. cable length	60 m (197 ft)

Baud Rate	1200
Communication protocol	SDI-12 Standard v. 1.2
Addressing	Serial; allows multiple sensors to be connected to any SDI-12 data logger via a single cable

Environmental

Operating temperature range	• In soils: freezing to +55°C (for soil moisture only) • Standard temperature probe range: -10°C to +55°C
Storage temperature range	-40°C to +55°C
Water resistance	Tolerates continuous full immersion
Cable	18 gauge (22 gauge for RS-485 and analog versions), UV resistant, direct burial
Vibration and shock resistance	Excellent; potted components in PVC housing and 304 grade stainless steel tines

Physical

Length	4.9” (124 mm)
Diameter	1.6” (42 mm)
Weight	7 oz. (200 g)
Cable weight	0.86 oz/ft (80g/m)
Sensing volume (cylindrical region)	Length: 2.2” (5.7 cm) Diameter: 1.2” (3.0 cm)

7.2 Theory of Operation

The HydraProbe soil temperature and moisture sensor measures soil temperature, and bulk electrical conductivity and real dielectric permittivity, based on the reflectance of an electrical signal transmitted through the soil between the center and three perimeter tines. An internal microprocessor calculates the soil moisture based on the loam soil texture calibration. The Campbell CR800 program calculates soil moisture and plant water availability based on the physically measured soil-specific texture at each measurement depth (see Section 7.3.2, Soil Analyses, for more details on the soil texture determinations) and calibration coefficients determined by Stevens Water Monitoring Systems, Inc.

7.3 Procedures

7.3.1 Sensor Calibration

The sensors are factory calibrated by Stevens Water Monitoring Systems, Inc. to yield accurate soil temperature for any soil texture, and volumetric soil moisture for the loam soil texture. Calibration coefficients are also provided for the calculation of volumetric soil moisture for soil-specific textures. Two soil-specific texture calibration equations are used, depending on whether the soil is sand, silt, or clay, as opposed to other soil textures.

Sand, Silt, Clay

$$\Theta = 100(A + B\varepsilon_R + C\varepsilon_R^2 + D\varepsilon_R^3) \qquad [1]$$

Other Soil Textures

$$\Theta = 100(A(\varepsilon_R)^{0.5} + B) \qquad [2]$$

where Θ is soil moisture in %, ε_R is the real dielectric permittivity , and A, B, C, and, D are coefficients.

Plant Water Availability (PWA, often called Plant Available Water) per soil section is estimated from the soil moisture, the standard wilting point for each soil texture (also called the crop lower limit) and the following equation:

$$PWA = SS(\Theta - CLL)/10$$

where PWA is plant water availability in mm, Θ is soil moisture in %, CLL is crop lower limit in %, and SS is the height of the soil section in cm.

This estimation is performed in the Campbell CR800 program for each soil section, and for the total depth of soil measurements to 125 cm.

7.3.2 Soil Analyses

Physical analyses for the soils at each of the ARM EFs were performed by the Oklahoma State University (OSU) Biosystems and Agricultural Engineering Department. At each site, a trench was dug 0.5 m deep to visually characterize the soil profile and to identify different soil layers. Multiple soil samples were collected from each distinct soil layer and returned to the laboratory for analysis. The samples were analyzed to determine: a) the particle-size distribution; b) sand, silt, and clay fractions; c) textural classification; d) organic-matter content (in the near-surface layer only); and e) the soil-water retention curve.

The soil textural classifications allow calculations of soil-specific soil moisture and estimates of plant water availability to be determined based on soil texture, using the HydraProbe measurements.

7.4 History

Installations of the STAMP occurred in late 2015 and early 2016. The period of measurements thus far have shown the STAMP to be very reliable, although the microprocessor in the HydraProbe seems to be somewhat sensitive to failure from nearby lightning ground strikes.

7.5 Operation and Maintenance

7.5.1 User Manual

The STAMP User Manual consists of this handbook, the Preventative Maintenance Checks document, and the STAMP wiring document.

7.5.2 Routine and Corrective Maintenance Documentation

See the STAMP Preventative Maintenance Checks document in Appendix A and the STAMP wiring document in Appendix B.

Corrective Maintenance is performed when there are problems with the measurements or transmission of data. Normal corrective maintenance includes activities such as tightening loose leads, replacing broken leads, replacing failed HydraProbes, unclogging the rain gauge tubing, modifying the CR800 program, and calibrating the rain gauge.

Bi-weekly tip test checks are performed on the precipitation gauge and a calibration is performed every six months using a calibration device purchased from the precipitation gauge vendor.

7.5.3 Software Documentation

ARM netCDF file header descriptions may be found in NCVWEB by choosing SGP, sgpstampe9.b1 (all measurements other than precipitation) or sgpstamppcpe9.b1 (precipitation), Submit DataStream, File Header.

All STAMP CR800 programs are maintained by both the mentor and by SGP Site Operations.

8.0 Citable References

Stevens Water Monitoring Systems, Inc. HyraProbe website, http://www.stevenswater.com/products/sensors/soil/hydraprobe/

Stevens Water Monitoring Systems, Inc., "HydraProbe User's Manual," web page https://www.fondriest.com/pdf/stevens_hydra_manual.pdf

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White, B. (Cropfacts Pty Ltd for Birchip Cropping Group Inc.(BCG)), "BCG Soil Test Interpretation Workshop Notes," website http://www.bcg.org.au/cb_pages/HealthySoils.php

Better Soils Module 2, Soil & Nutrition: Crops, 2.1 Soil Holding Capacity, web page http://www.soilwater.com.au/bettersoils/module2/2_1.htm#wilting%20point

Appendix A

STAMP Preventative Maintenance Checks

1) Test battery voltage:
a) remove charging power (whether AC supply or DC supply) to the PS12LA.
b) measure the battery voltage
c) re-connect charging power

2) Check for reasonable values in the measurements:
a) soil water content range 0 to 100 %
b) soil temperature range -40 to +50 deg C
c) PWA range -200 to 400 mm
d) soil conductivity range 0 to 2 S/m
e) real dielectric permittivity range 0 to 650 (unitless)
f) check for general consistency between the measurements

3) -9999 values in the measurements may indicate:
a) a failed soil probe
b) a non-functioning multiplexer channel
c) loose or broken lead connections on the multiplexer or data logger
d) broken or chewed soil probe cable

4) Physical checks:
a) check for loose or broken leads on the CR800 data logger
b) check for loose or broken leads on the multiplexer
c) check for secured ground lead to enclosure
d) check condition of enclosure for cracks, condensation, outside deterioration
e) check that HydraProbe cables don't protrude above ground from the end of the conduit
f) check that conduits are secure to the bottom of the enclosure
g) check if the precipitation gauge funnel is blocked by debris or ice/snow

g1) if precipitation gauge funnel is blocked by ice/snow, one or both of the heaters may not be operating
g2) disconnect the precipitation gauge lead from P1 on the logger to prevent the recording of precipitation tips
g3) remove the funnel
g4) remove any blockage in the funnel
g5) if ice/snow had blocked the funnel, check by hand feel that both heaters in the precipitation

gauge are working
g6) if a heater is not working, replace the precipitation gauge (or just possibly the funnel if the funnel heater is not working)
g7) remove any significant amount of soil or debris in the precipitation gauge tipping bucket
g8) check that the precipitation heater and signal leads are properly connected
g9) check that the precipitation gauge is draining properly
g10) replace the precipitation gauge funnel
g11) replace the precipitation gauge lead to P1 on the logger
g12) perform tip test (after setting flag 7 high, to prevent recording of the tips

h) Every six months, use the vendor calibration device to perform a calibration check. Record the result and adjust the precipitation tipping bucket, if needed, so that the precipitation gauge passed the check.

Appendix B

STAMP Wiring

Multiplexer AM16/32B (use 2x32 mode)

Connection	Wire Color	Contact on CR800
RES	Yellow	C2
CLK	Green	C1
G	Black	G
12V	Red	12V
Comm H	White	C3
Comm L	Red	SW12V
Comm G	Black	G

Hydra Probe II:

1H	Blue	(SDI-12 digital output)
1L	Red	
G	Black	

(H/L/G for all 15 HydraProbes in channels 1-15)

Precipitation Gauge

	Clear	P1
	Black	G
	Shield	enclosure ground

PS12 Battery

12V	Red	12V on Input Connector
G	Black	G on Input Connector

RS232 Serial Port - Site Communications

CS I/O Serial Port - Keypad

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