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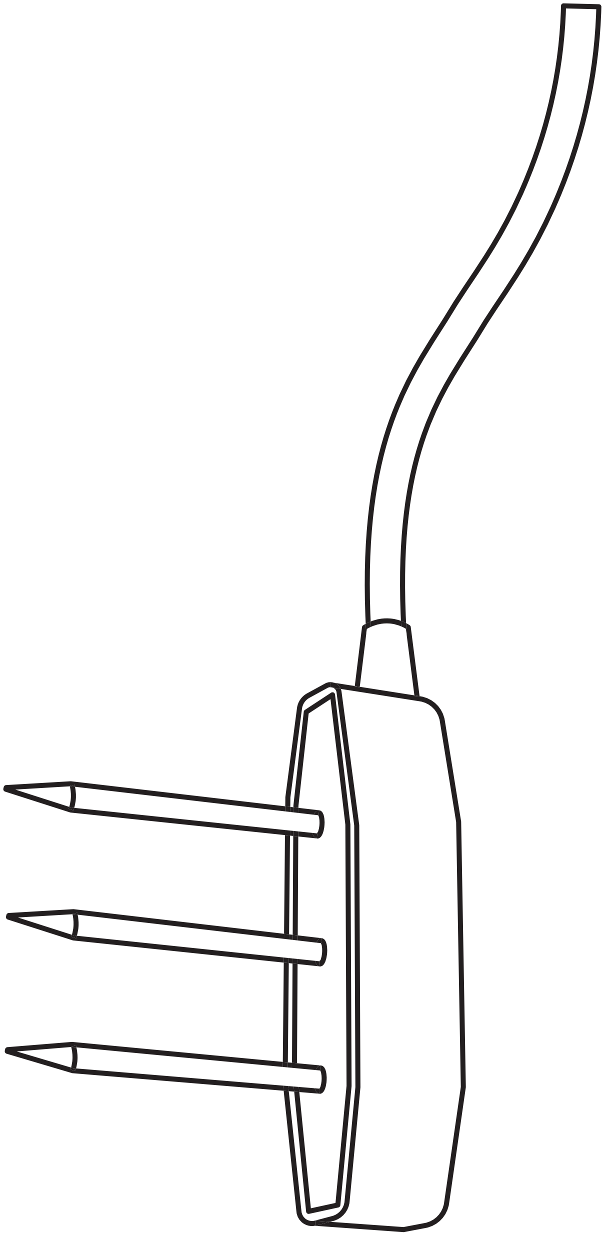


1. INTRODUCTION

Thank you for choosing METER Group soil sensors. This user manual provides SOLYX 14 complex dielectric sensor information for operation, maintenance, and theory.

The is designed to be a maintenance-free complex dielectric sensor for long-term, continuous field measurements of volumetric water content (VWC), temperature, and electrical conductivity (EC). The SOLYX 14 can be installed in minerals soils, many types of growing media, and other porous materials. Monitoring capabilities include volumetric water content (VWC), temperature in soil and soilless substrates, and EC. VWC and EC is determined using complex dielectric technology. The sensor uses a 70-MHz frequency, which minimizes textural and salinity effects, making the SOLYX 14 accurate in most mineral soils. A thermistor is used to measure temperature.

Prior to use, verify the SOLYX 14 arrived in good condition. Use this manual to learn about sensor features and for descriptions of how to use the sensor successfully. METER recommends testing the sensor with the data logging device and software before going to the field.

2. OPERATION

Please read all instructions before operating the SOLYX 14 to ensure it performs to its full potential.

⚠ PRECAUTION

METER sensors are built to the highest standards, but misuse, improper protection, or improper installation may damage the sensor and possibly void the manufacturer's warranty. Before integrating SOLYX 14 into a system, make sure to follow the recommended installation instructions and have the proper protections in place to safeguard sensors from damage. If installing sensors in a lighting-prone area with a grounded data logger, see the application note Lightning surge and grounding practices (meter.ly/lightning-surge-grounding-practices).

2.1 INSTALLATION

To begin collecting data, follow the steps listed below to set up and install the SOLYX 14. For more detailed installation information, consult the Soil Moisture Sensor Installation Best Practices video (meter.ly/soil-moisture-install-best-practice).

TOOLS NEEDED

The following tools are needed for installing the SOLYX 14:

- Auger or shovel
- Secure mounting location for data logger and cable
- TEROS Borehole Installation Tool (TBIT)
- Conduit to protect cables (recommended)

The TBIT is optional but recommended. See the METER Group TEROS Installation Borehole webpage for more information (meter.ly/borehole-install-tool)

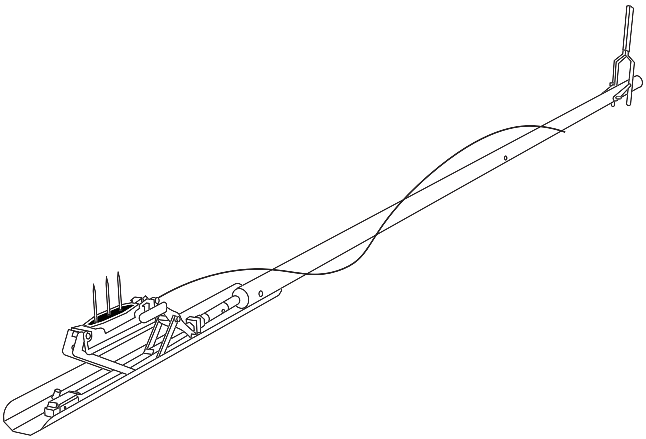


Figure 1 SOLYX 14 in TEROS Borehole Installation Tool

PREPARATION

1. Determine the best method for installing the SOLYX 14

   There are two methods: borehold and trench. These methods are described in Table 1.

2. Conduct system check.

   a. Plug the sensor into the data logger (Section 2.2) to make sure the sensor is functional.

   b. Verify all sensors read within expected ranges.

      The SOLYX 14 can be checked in a 6-L container of water to ensure it is reading an appropriate dielectric.

      Ensure the sensor is centered in the container of water and has equilibrated for 5 min before taking a reading.

      The SOLYX 14 should read a dielectric in DI water of approximately 78.

FIELD INSTALLATION STEPS

1. Auger or trench a hole to the desired sensor installation depth and direction according to the installation method desired (Table 1).

   Avoid interfering objects. Installations near large metal objects can affect the sensor function and distort readings.

   Large objects like roots or rocks could potentially bend the needles.

Table 1 Installation methods

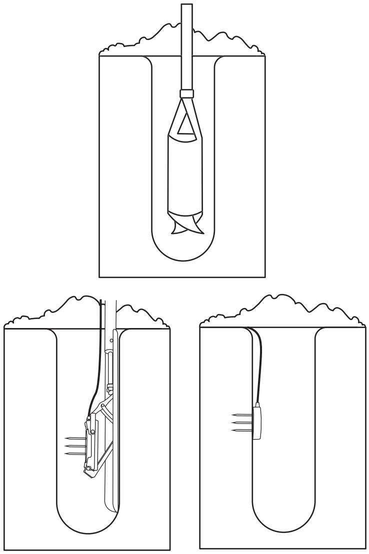
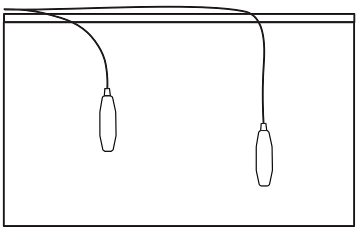
Borehole		Advantage	Disadvantage
This method uses the Borehole Installation Tool (Figure 1) that allows a profile of soil moisture sensors to be installed at different depths within a single borehole created with an auger A 10-cm (4-in) borehole is augered vertically at the measurement location. The Borehole Installation Tool is then used to install the sensors in the sidewall of the borehole. **NOTE: The borehole method requires specialized installation tool available from METER if installing at depths greater than 50 cm.**		Minimizes soil disturbance at the measurement site.	Requires a specialized installation tool that can be rented from METER.
Trench		**Advantage**	**Disadvantage**
The trench installation method is best for shallow installations (less than 40 cm). This requires digging a trench with a shovel, excavator, or other tool. The trench needs to be dug to the depth of the deepest installed sensor. For deep installations, this may require a large trench. The sensor is installed carefully by hand into the undisturbed soil of the trench sidewall. The trench is carefully backfilled to preserve the bulk density of the soil and to avoid dislodging the installed sensor.		Does not require specialized equipment.	Large soil disturbance created at measurement site. Potentially large excavation effort.

Table 2 contains brief descriptions for typical installation methods. Each has its own advantages and disadvantages. For more information about which installation method is best for specific applications, please see the Soil Moisture Sensor Installation Best Practices video (meter.ly/soil-moisture-install-best-practice) or contact Customer Support.

2. Determine sensor orientation.

   The SOLYX 14 sensor may be positioned in any direction. However, with the body in a vertical position (Figure 2 below), there is less restriction to water flow.

   A vertical position will also integrate more soil depth into the soil moisture measurement. Installing the sensor with the body in a horizontal position will provide measurements at a more discreet depth.

   See METER web article Measurement volume of METER volumetric water content sensors for more information on sensor measurement volume (meter.ly/webarticle-volumetric-water-content-sensors).

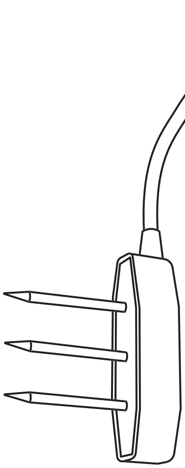


Figure 2 Sensor body vertical and needles horizontal

3. Insert the sensor.

   Avoid having any metal located near the sensor because it can interfere with VWC measurements.

   IMPORTANT: Minimize air gaps around the sensor. Air gaps around the sensor needles will result in low readings of soil moisture.

   a. Load the SOLYX 14 using the TBIT.

      NOTE: The TBIT provides a significant amount of mechanical advantage. See Table 1 for instruction on installing the SOLYX 14 without the TBIT.

   b. Lower the tool into the hole or trench with the back of the tool supported by the far wall of the hole/trench.

   c. Pull the tool lever to activate the jack and insert the sensor into the sidewall

The three tips of the SOLYX 14 sensor needles have a tapered shape for easy insertion in almost any kind of soil.

⚠ WARNING

WARNING: When installing sensors in rocky soils, use care to avoid bending sensor needles.

4. Protect the cables.

   Install cables in conduit or plastic cladding when near the ground to avoid rodent damage.

   NOTE: Improperly protected cables can lead to severed cables or disconnected sensors. Cabling issues can be caused by many factors such as rodent damage, driving over sensor cables, tripping over cables, not leaving enough cable slack during installation, or poor sensor wiring connections.

5. Secure and gather cables between the SOLYX 14 and the data logger to the mounting mast in one or more places.

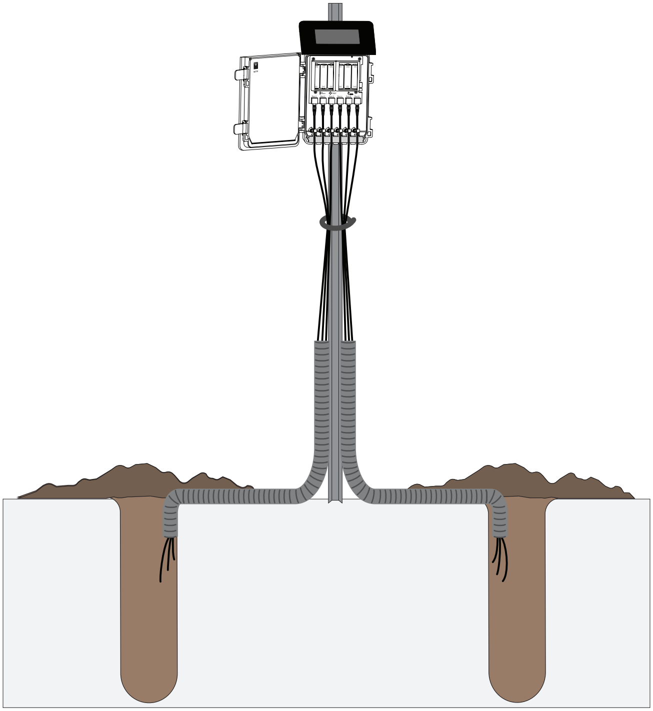


Figure 3 Protect, gather, and secure cables

6. Connect to Data Logger

   a. Plug the sensor into a data logger.

   b. Use the data logger to make sure the sensor is reading properly.

   For more specific instructions on connecting to data loggers, refer to Section 2.2.

   c. Verify that these readings are within expected ranges.

7. Backfill the hole.

   Return soil to the hole, packing the soil approximately back to its native bulk density.

2.2 CONNECTING

The SOLYX 14 works seamlessly with METER data loggers. The SOLYX 14 can also be used with other data loggers, such as those from Campbell Scientific, Inc. For extensive direction on how to integrate the sensors into third-party data loggers, refer to the SOLYX 14 Integrator Guide (meter.ly/solyx14-ig).

SOLYX 14 sensors require an excitation voltage in the range of 4 to 15 VDC and operate at a 3.6-VDC level for data communication. SOLYX 14 can be integrated using DDI serial or SDI-12 protocol. See the SOLYX 14 Integrator Guide (meter.ly/solyx14-ig) for details on interfacing with data acquisition systems.

SOLYX 14 sensors come with a 3.5-mm stereo plug connector to facilitate easy connection with METER data loggers. SOLYX 14 sensors may be ordered with stripped and tinned wires to facilitate connecting to some third-party loggers (Section 2.2.2).

2.2.1 CONNECT TO METER DATA LOGGER

The SOLYX 14 works most efficiently with METER ZENTRA series data loggers (meter.ly/data-loggers). Logger configuration may be done using either ZENTRA Utility Mobile or desktop application, or ZENTRA Cloud (web-based application for cell-enabled ZENTRA data loggers). Check that the firmware is up-to-date using ZENTRA Utility.

1. Plug the stereo plug connector into one of the sensor ports on the logger.
2. Use the appropriate software application to configure the chosen logger port for the SOLYX 14.

   METER data loggers will automatically recognize SOLYX 14 sensors.

3. Set the measurement interval.

   METER data loggers measure the SOLYX 14 once every minute and return the average of the 1-min data across the chosen measurement interval.

SOLYX 14 data can be downloaded from METER data loggers using either ZENTRA Utility or ZENTRA Cloud. Refer to the logger user manual for more information about these programs.

2.2.2 CONNECT TO NON-METER DATA LOGGER

The SOLYX 14 can be purchased for use with non-METER (third-party) data loggers. Refer to the third-party logger manual for details on logger communications, power, and ground ports. The SOLYX 14 Integrator Guide (meter.ly/solyx14-ig) also provides detailed instructions on connecting sensors to non-METER loggers.

SOLYX 14 sensors can be ordered with stripped and tinned (pigtail) connecting wires for use with screw terminals. Refer to the third-party logger manual for wiring details.

Connect the SOLYX 14 wires to the data logger illustrated in Figure 4 and Figure 5, with the power supply wire (brown) connected to the excitation, the digital out wire (orange) to a digital input, and the bare ground wire to ground.

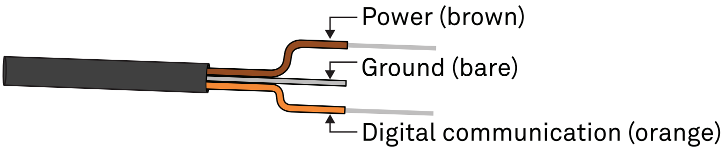


Figure 4 Pigtail wiring

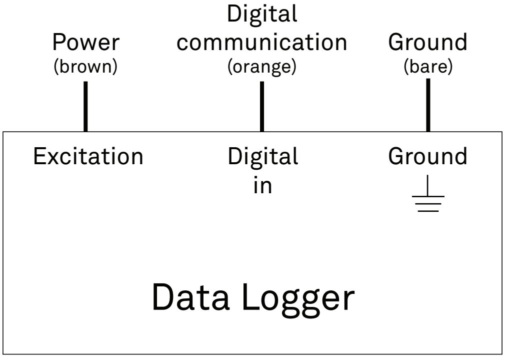


Figure 5 Wiring diagram

NOTE: The acceptable range of excitation voltages is from 4 to 15 VDC.

If the SOLYX 14 cable has a standard stereo plug connector and needs to be connected to a non-METER data logger, use one of the following two options:

Option 1

1. Clip off the 3.5-mm stereo plug connector on the sensor cable.
2. Strip and tin the wires.
3. Wire it directly into the data logger.

This option has the advantage of creating a direct connection with no chance of the sensor becoming unplugged. However, it then cannot be easily used in the future with a METER readout unit or data logger.

Option 2

Obtain an adapter cable from METER.

The adapter cable has a connector for the stereo plug connector on one end and three wires (or pigtail adapter) for connection to a data logger on the other end. The stripped and tinned adapter cable wires have the same termination as seen in Figure 5: the brown wire is excitation, the orange is output, and the bare wire is ground.

NOTE: Secure the stereo plug connector to the pigtail adapter connections to ensure the sensor does not become disconnected during use.

2.3 COMMUNICATION

The SOLYX 14 communicates using two different methods:

- DDI serial string
- SDI-12 communication protocol

To obtain detailed instructions, refer to the SOLYX 14 Integrator Guide (meter.ly/solyx14-ig).

The SDI-12 protocol requires that all sensors have a unique address. SOLYX 14 sensor factory default is an SDI-12 address of 0. To add more than one SDI-12 sensor to a bus, the sensor address can be changed using a ZSC Bluetooth® sensor interface and the ZENTRA Utility Mobile app as described below:

NOTE: The sensor SDI-12 address must be returned to 0 to work with ZENTRA loggers.

1. Using a mobile device, open the ZENTRA Utility Mobile app.
2. Connect the sensor to the ZSC.
3. Under Sensor Information, select the SDI Address dropdown.
4. Scroll through the options and select the desired SDI-12 address.

NOTE: Address options include 0-9, A-Z, and a-z.

Detailed information can also be found in the application note Setting SDI-12 addresses on METER digital sensors using Campbell Scientific data loggers and LoggerNet (meter.ly/article-SDI-12-use-Campbell).

When using the sensor as part of an SDI-12 bus, excite the sensors continuously to avoid issues with initial sensor startup interfering with the SDI-12 communications.

2.4 SENSOR CONSISTENCY TEST

SOLYX 14 can be tested for consistency using ZENTRA Utility Mobile (ZUM). The Sensor Consistency Test (SCT) is evaluating internal circuitry working correctly by checking specific values relative to an internal reference. To begin a SCT, open the ZUM app and select the **More** option and then **Sensor Tools** (Figure 6).

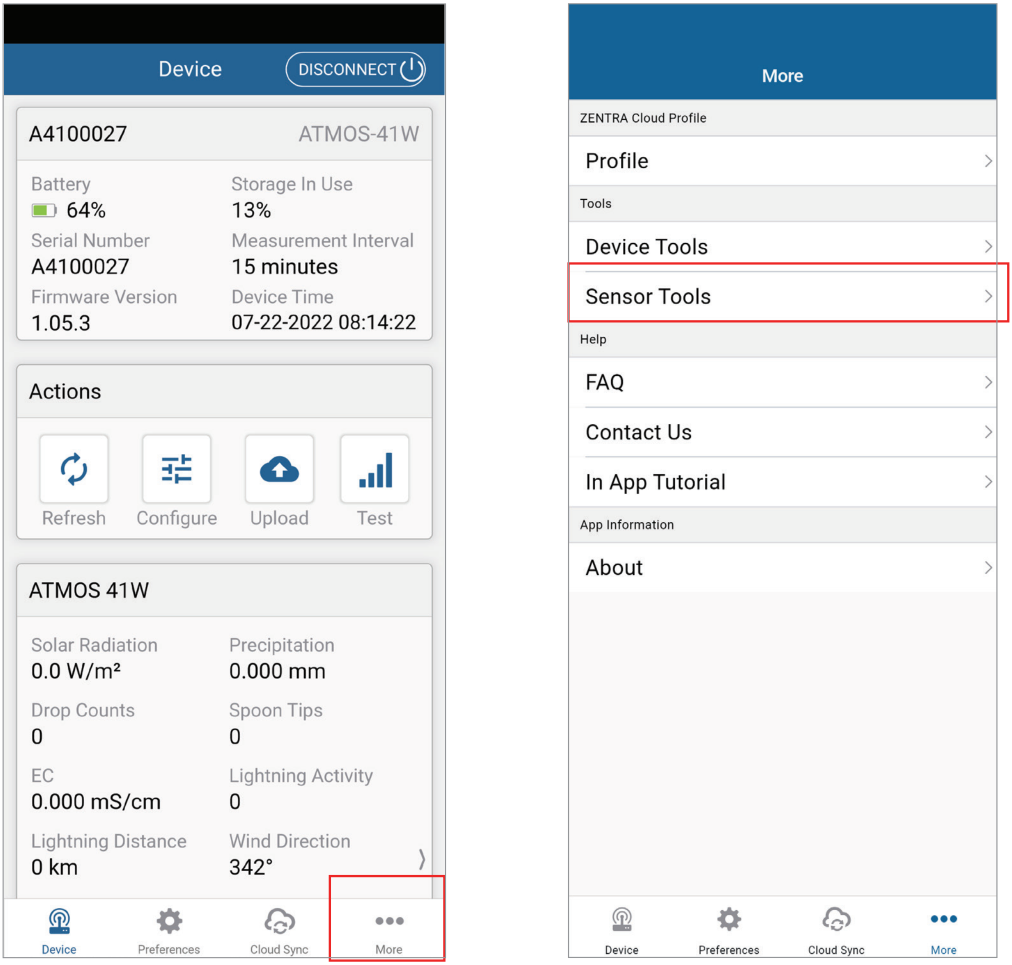


Figure 6 ZUM More and Sensor Tools options

In **Sensor Tools** , select the option for **Sensor Consistency Test** (Figure 7).

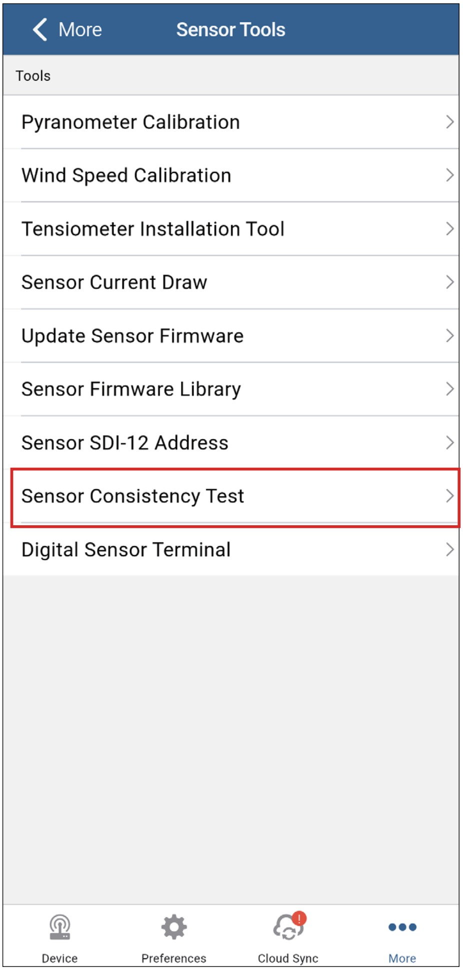


Figure 7 Sensor Consistency Test

The sensor consistency test will provide readings including a SCT value and sensor status. It will also show raw readings, dielectric permittivity, the temperature, and the EC (Figure 8).

If the SOLYX 14 sensor is working correctly it will highlight green and read **SCT Good!** (Figure 8).

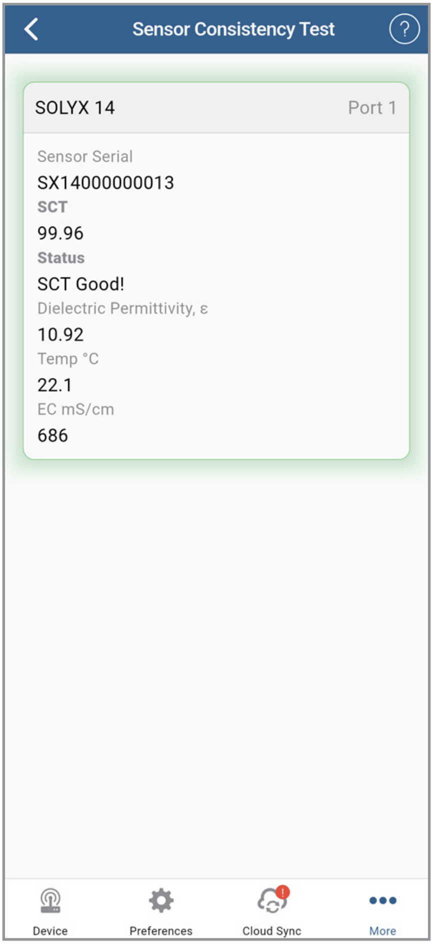


Figure 8 SCT Good

SCT Good status result means the SOLYX 14 is working properly and is ready for installation and/or continued use.

If the SOLYX 14 sensor readings are incorrect it will highlight red and read **SCT Bad, contact Meter SUPPORT**. The SCT will return bad if the value falls below 97.

Contact METER Customer Support if the SOLYX 14 fails the SCT.

3. SYSTEM

This section describes the specifications, components, and theory of the SOLYX 14 complex dielectric sensor.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Volumetric Water Content (VWC)	
Range	
Mineral soil calibration	0.00–0.72 m^3/m^3
Real dielectric permittivity (ε_r)	1 (air) to 80 (water)
NOTE: The VWC range is dependent on the media, the sensor is calibrated to. A custom calibration will accommodate the necessary ranges for most substrates.	
Resolution	0.001 m^3/m^3
Accuracy	
Generic calibration	±0.03 m^3/m^3 typical in mineral soils
Medium specific calibration	±0.01 m^3/m^3 in any porous medium
Real dielectric permittivity (ε_r)	± 1 ε_r (unitless)
Dielectric Measurement Frequency	
70 MHz	
Temperature	
Range	−40 to +60 °C
Resolution	0.1° C
Accuracy	±0.3 °C from 0 to +60 °C ±1 °C from −40 to 0 °C
NOTE: Temperature measurement for applicable sensor may not be accurate if sensor is not fully immersed in the medium of interest due to longer equilibration time.	
Bulk Electrical Conductivity (EC)	
Range	0–20 dS/m (bulk)
Resolution	0.001 dS/m
Accuracy	±(5% + 0.01 dS/m) from 0–10 dS/m ±8% from 10–20 dS/m

COMMUNICATION SPECIFICATIONS

Output

DDI -serial and SDI-12 communication protocol

Data Logger Compatibility

METER ZL6 data loggers and any data acquisition system capable of 4.0 to 15.0 VDC power and serial or SDI-12 communication.

PHYSICAL SPECIFICATIONS

Dimensions

Length	8.9 cm (3.50 in)
Width	2.5 cm (0.98 in)
Height	7.5 cm (2.96 in)

Needle Length

5.5 cm (2.17 in)

IP Rating

IP 65 and 67

Operating Temperature Range

Minimum	–40° C
Typical	N/A
Maximum	60° C

NOTE: Sensors may be used at higher temperatures under certain conditions; contact Customer Support for assistance.

Cable Length

5 m (standard) or up to 75 m (maximum custom cable length)

NOTE: Contact Customer Support if a custom cable length is needed.

Cable Diameter

0.54 ± 0.01 cm (0.212 ± 0.004 in) with minimum jacket of 0.076 cm (0.030 in)

Connector Types

3.5-mm stereo plug connector or stripped and tinned wires

Conductor Gauge

20-AWG / 22-AWG drain wire

ELECTRICAL AND TIMING CHARACTERISTICS

Supply Voltage (VCC) to GND	
Minimum	4.0 VDC continuous
Typical	N/A
Maximum	15.0 VDC continuous
Digital Input Voltage (logic high)	
Minimum	2.8 V
Typical	3.6 V
Maximum	5.0 V
Digital Input Voltage (logic low)	
Minimum	–0.3 V
Typical	0.0 V
Maximum	0.8 V
Digital Output Voltage (logic high)	
Mimimum	N/A
Typical	3.6 V
Maximum	N/A
Power Line Slew Rate	
Minimum	1.0 V/ms
Typical	N/A
Maximum	N/A
Required Supply Current	
Minimum	16.0 mA
Typical	N/A
Maximum	N/A
Current Drain (during measurement)	
Minimum	N/A
Typical	4.43 mA **NOTE: 372 ms ?M! command**
Maximum	N/A

Current Drain (while asleep)	
Minimum	N/A
Typical	0.03 mA
Maximum	0.06 mA
Power-up Time (DDI Serial)	
Minimum	N/A
Typical	100 ms
Maximum	350 ms
Power Up Time (SDI-12)	
Minimum	N/A
Typical	260 ms
Maximum	N/A
Power Up Time (SDI-12, DDI disabled)	
Minimum	N/A
Typical	170 ms
Maximum	N/A
Measurement Duration	
Minimum	N/A
Typical	50 ms
Maximum	N/A

COMPLIANCE

EM ISO/IEC 17050:2010 (CE Mark, DoC upon request)
2014/30/EU (EMC) via EN 61326-1:2013
2011/65/EU(RoHS) via EN 63000:2018
CISPR 11:2024 Group 2 Class A

COMPLIANCE STATEMENTS

This device complies with Canadian ICES-001 (Group 2 Class A).

This device has been tested and found to comply with the limits for Industrial, Scientific, and Medical (ISM) equipment pursuant to Part 18 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in commercial, industrial, or business environments.

This equipment generates, uses and can radiate radio frequency energy and may cause harmful interference to radio communications. If this device does cause harmful interference to radio or television reception, which can be determined by turning the device off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

1. Reorient or relocate the receiving antenna.
2. Increase the separation between the device and receiver.

Responsible Party: METER Group Inc, 2365 NE Hopkins Ct, Pullman, WA, 99163, USA, +1-509-332-2756

3.2 COMPONENTS

The SOLYX 14 sensor measures soil moisture, temperature, and EC of soil using stainless steel needles (Figure 9).

- SOLYX 14 sensors measure dielectric permittivity, soil moisture, and bulk electrical conductivity by applying the 70 MHz signal to Needle 2 and using Needle 1 and Needle 3 as the reference for the measurement.
- SOLYX 14 sensors measure temperature with an embedded thermistor.

These sensors have a low-power requirement, which makes them ideal for permanent burial in the soil and continuous reading with a data logger or periodic reading with a handheld reader.

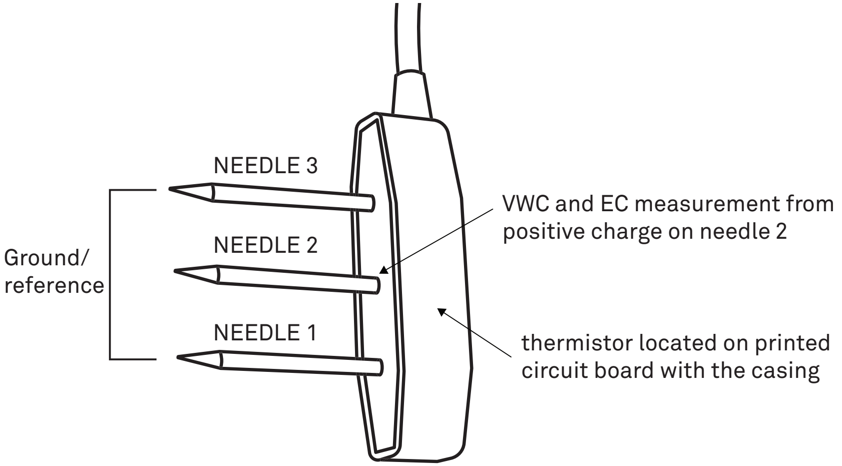


Figure 9 SOLYX 14 Sensor

The SOLYX 14 VWC measurement sensitivity is contained within a 800 cm^3 volume roughly depicted in Figure 10. Please see the application note Measurement volume of METER volumetric water content sensors (meter.ly/webarticle-volumetric-water-content-sensors) for testing protocol and more thorough analysis.

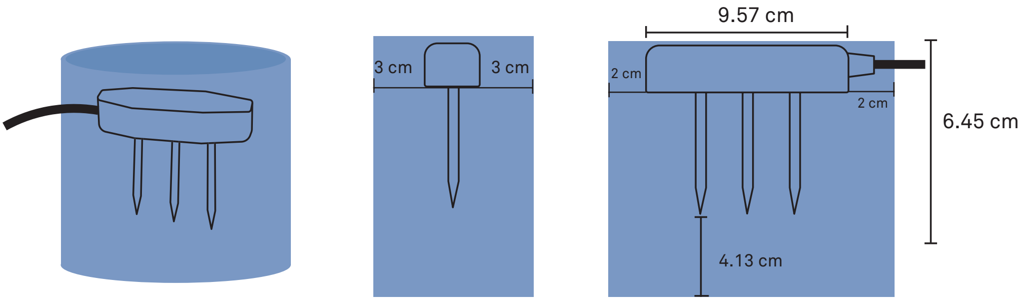


Figure 10 VWC volume of influence

NOTE: The SOLYX 14 provides instantaneous or near-instantaneous measurements; however because of the sensitivity of the measurement of the sensor head, the SOLYX 14 is not well suited for spot measurements of VWC.

3.3 THEORY

The following sections explain the theory of complex dielectric permittivity, volumetric water content, correcting electrical conductivity and dielectric for temperature, pore water electrical conductivity, and saturation extract (EC).

3.3.1 COMPLEX DIELECTRIC PERMITTIVITY

The metal electrodes of the SOLYX 14, surrounded by a material (i.e. soil) of relative permittivity, ε forms a capacitor, with capacitance:

$$C_s = C_0 \varepsilon$$ **Equation 1**

where C_0 [F] is a geometric factor determined by the shape of the electrodes ($C_0 = C_s$ in air). Likewise, if the material is electrically conductive, with conductivity σ [S/m], the sample will also display a conductance:

$$G_s = \frac{C_0}{\varepsilon_0} \sigma$$ **Equation 2**

At low frequency, sample capacitance and conductance can be regarded as elements in parallel. In this case, the total admittance is simply the sum of the two admittances:

$$Y_s = i\omega C_s + G_s$$ **Equation 3**

where ω is the angular frequency of the applied voltage and $i=\sqrt{-1}$. Capacitance and conductance are represented by real quantities (C_s and G_s), whereas the admittance of their parallel combination ($\boldsymbol{Y}_s$) is a complex number (bold fonts). From Equation 3, the current through the conductor is always in phase with the excitation source, while the current through the capacitor is $\pi/2$ out of phase (the corresponding phasors are orthogonal). This reflects the different nature of the polarization and conduction processes, whereby the energy is respectively conserved and dissipated.

Combining equations 1, 2, and 3, obtains:

$$\boldsymbol{Y}_s = i\omega C_o\left(\varepsilon - i\,\frac{\sigma}{\omega\varepsilon_o}\right)$$ **Equation 4**

It is then convenient to define a (relative) extended permittivity as:

$$\boldsymbol{\eta} = \varepsilon - i\,\frac{\sigma}{\omega\varepsilon_o}$$ **Equation 5**

and represent the system as a capacitor filled with a material of complex permittivity $\boldsymbol{\eta}$:

$$\boldsymbol{Y}_s = i\omega C_o\boldsymbol{\eta}$$ **Equation 6**

The complex permittivity $\boldsymbol{\eta}$ fully describes the electromagnetic behavior of materials, as it accounts for both polarization and conduction. In particular, it determines the admittance of electrodes surrounded by a sample. Hence, from measurements of $\boldsymbol{Y}_s$, $\boldsymbol{\eta}$ can be estimated using Equation 6, or more sophisticated models.

So far, the energy losses have been confined to transport of charges (conduction). This is an approximation, valid again at low frequencies. At high frequencies, polarization also gives rise to energy dissipation. This is because polarization, i.e. the rearrangement of molecules in response to an electric field, is not instantaneous. When the field changes very rapidly, the molecules don't have sufficient time to rearrange completely. With a twofold result:

i. the polarization over one cycle is partially diminished, and
ii. it is slightly delayed relative to the electric field.

This delay implies that the response is no longer in phase with the excitation: an orthogonal component arises, therefore the process must be described by a complex quantity. This is the complex dielectric permittivity:

$$\boldsymbol{\varepsilon} = \varepsilon' - i\varepsilon''$$ **Equation 7**

where ε' and ε'' (both frequency dependent) respectively account for the energy storage and losses arising from polarization. In presence of polarization losses, the real permittivity ε in Equation 5 must be replaced by the complex permittivity in Equation 7. The extended permittivity (which combines polarization and conduction) then becomes:

$$\boldsymbol{\eta} = \varepsilon' - i\left(\varepsilon'' + \frac{\sigma}{\omega\varepsilon_o}\right)$$ **Equation 8**

Substituting this expression in Equation 6, finds that the sample can be represented by a capacitance and a conductance in parallel (both real), of values:

$$C_s = C_o\,\varepsilon' \qquad \text{Equation 9}$$

$$G_s = \frac{C_o}{\varepsilon_o}\left(\sigma + \omega\varepsilon_o\varepsilon''\right) \qquad \text{Equation 10}$$

Note that the polarization losses ε'' are included in the conduction term G_s. Therefore, capacitance and conductance in the equivalent circuit should not be identified with the polarization and conduction processes, but rather as the conservative and dissipative components of the overall interaction of the material with an electromagnetic field. It also follows from Equation 10 that one has only access to the total dissipation, due to both conduction and polarization. As long as a single frequency is probed, the two individual contributions are indistinguishable. The term in parenthesis in Equation 10 is the high frequency conductivity. Since the d.c. value, σ, is of interest, some reasonable assumptions about ε'' are made to estimate σ from measured G_s. In particular, assume that ε'' in a porous medium is proportional to the value corresponding to pure water, the proportionality factor being the volume fraction of water. At 70 MHz, this value is typically small, and even a rough estimate of ε'' should yield sufficiently accurate measurements of σ.

The SOLYX 14 measures Y_s, converts it to η using Equation 6, then converts that to dielectric constant and conductivity using Equation 8 and the discussion following it.

Next is the description of the measurement of the sample admittance. The following figure shows the circuit the SOLYX 14 uses to make the measurement.

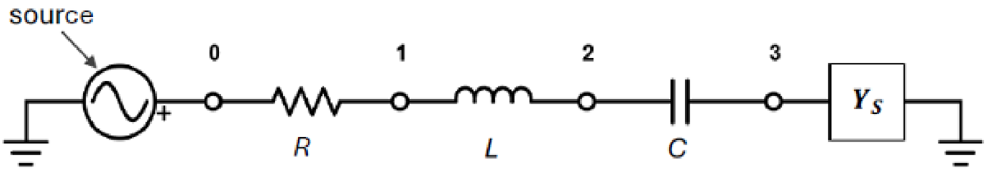


Figure 11 Measurement circuit for the SOLYX 14

R, L, and C are reference components in the SOLYX circuitry across which voltage differences are measured. Excite the circuit with a 70 MHz source, and measure the amplitudes of the voltages at nodes 0, 1, 2, and 3. Compute the amplitude ratios V_0/V_3, V_1/V_3, and V_2/V_3. These voltage ratios or gains, and the values of the reference components, provide the information needed to find Y_s. The solution is most readily explained graphically, rather than by equations. Figure 12 is a graph of the complex admittance plane.

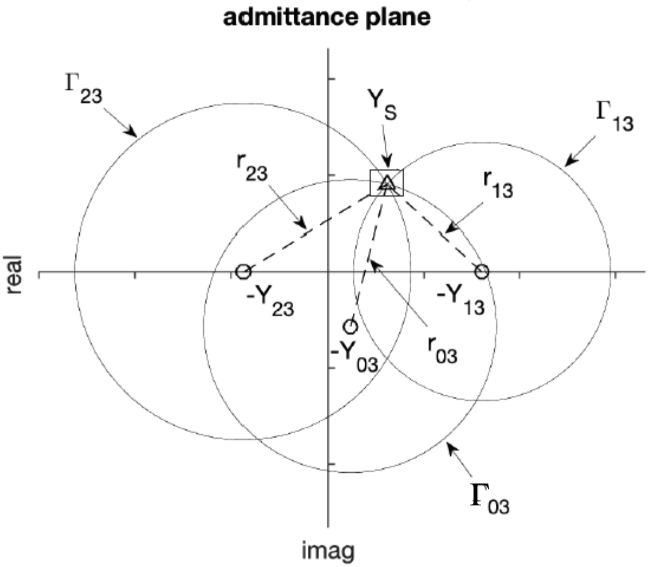


Figure 12   Complex admittance plane graph

The locations of the reference component admittances are shown as the circle centers, Y_{03}, Y_{13}, and Y_{23}. Y_{23}, on the left, is for the capacitor and Y_{13}, on the right, is for capacitor and inductor. Neither of those has any imaginary part. Y_{03} includes the resistor, so it has both real and imaginary parts. The radius of each circle is proportional to its gain or voltage ratio. The circles intersect at a common point, and that point is the sample admittance, Y_s, which is needed to find the dielectric and conductivity of the sample.

It should be clear that three circles are not needed to determine the intersection. Two circles would give the same answer. So why use three? The additional circle provides several advantages. First, it gives a self-consistency check. The probe is working correctly if with each combination of circles the sample admittance is the same. It can also provide reliable readings when a sample causes two of the circles to come together in ways that give uncertain results. Having all three results also improves the precision of the measurement by a factor of about 2, over having just two circles.

The SOLYX 14 solves for the three intersections, determines the self-consistency, and determines a weighting factor for each intersection based on the sensitivity of the computed admittance to the circle radius (from the voltage ratios). The sample admittance is then computed as a weighted average of the three intersections.

The technology used in the SOLYX 14 is called CDX. That comes from the circles and is short for **C**omplex **D**ielectric through Intersections.

3.3.2 CORRECTING ELECTRICAL CONDUCTIVITY AND DIELECTRIC FOR TEMPERATURE

The electrical conductivity of ionic solutions increases with temperature about 2% per degree C. Since bulk electrical conductivity is sampled over a range of temperatures, it is helpful to adjust the values back to a single temperature value. The one typically used is 25 °C. The SOLYX 14 sensor bulk EC measurements are corrected to EC at 25 °C using the equation:

$$\sigma_{25} = \frac{\sigma_T}{1 + 0.019(T - 25)}$$ **Equation 11**

where T is the temperature at the time of measurement.

The dielectric constant of water and solutions is also temperature dependent, and decreases with increasing temperature by around 0.5%/C. The temperature dependence of the dielectric of water in soil, however, is harder to predict, and depends on how tightly the water is bound. The value in soil can even be positive. Not correcting the dielectric constant for temperature often gives better water content than correcting it. For that reason, it is left uncorrected. If the user wants to correct it, however, Equation 11 is used with a constant of -0.005 instead of 0.019.

3.3.3 VOLUMETRIC WATER CONTENT

The primary job of the SOLYX 14 is the measurement of water content. Since water has a much larger dielectric constant than most other soil constituents, the dielectric measurement will be strongly influenced by the amount of water present in the soil. Other factors will, however, affect the reading. A commonly used dielectric mixing model used to predict bulk dielectric is

$$\varepsilon_b = \left[\theta\varepsilon_w^\beta + \phi\varepsilon_s^\beta + (1 - \theta - \phi)\varepsilon_a^\beta\right]^{\frac{1}{\beta}}$$ **Equation 12**

where θ is the volumetric water content (m^3/m^3), ϕ is the fraction of solids (m^3/m^3) (bulk density divided by particle density), β is an empirical constant, and the w, s, and a subscripts on epsilon are for water, soil (or solids) and air. Solving for volumetric water content gives

$$\theta = \frac{\varepsilon_b^\beta + \phi\left(\varepsilon_s^\beta - \varepsilon_a^\beta\right) - \varepsilon_a^\beta}{\varepsilon_w^\beta - \varepsilon_a^\beta}$$ **Equation 13**

This equation should make a couple of things clear. One is that dielectric sensors measure *volumetric*, not *gravimetric* water content (determined by oven drying). Another is that factors other than water content affect the reading, so there can't be a universal calibration equation relating water content to dielectric for soil. A few equations for typical soils and other media are provided below, but some media or soils may require their own calibration.

For soils, β is often set to 0.5. If it is assumed the dielectric of water is 81, of soil solids is 4 and air is 1, then Equation 13 simplifies to

$$\theta = \frac{\sqrt{\varepsilon_b} - \phi - 1}{8}$$

Equation 14

Here are some calibration equations that are recommended for the SOLYX 14:

For mineral soils the equation is the same form as Equation 14

$$\theta\left(\frac{m^3}{m^3}\right) = 0.0985\sqrt{\varepsilon_b} - 0.159$$

Equation 15

For potting soil it is a polynomial

Equation 16

$$\theta = 5.298 \times 10^{-6}\,\varepsilon^3 - 6.682 \times 10^{-4}\,\varepsilon^2 + 3.303 \times 10^{-2}\,\varepsilon - 3.825 \times 10^{-2}$$

3.3.4 PORE WATER ELECTRICAL CONDUCTIVITY

One of the most important things the SOLYX 14 can do is provide measurements of the quantities required to determine the electrical conductivity of the water in the soil pores. In the past this could only be determined by extracting water from the soil and measuring the EC in the laboratory. Pore water EC is a direct measure of the osmotic stress to which a growing plant is subjected, and therefore directly relates to plant performance. The SOLYX 14 sensor measures ε_b and σ_b simultaneously in the same soil volume. It is therefore well suited to this calculation.

METER uses the Hilhorst (2000) equation to compute pore water EC. It is

$$\sigma_P = \frac{\varepsilon_w \sigma_b}{\varepsilon_b - \varepsilon_{\sigma_b = 0}}$$

Equation 17

where $\varepsilon\sigma_b = 0$ is the permittivity of the soil when the conductivity goes to zero. Hilhorst recommended a value of 4.1 for mineral soil, but this is soil or substrate dependent. For substrates like rock wool or coir, a value around 2 works well. Since the denominator can be small, or even zero at low water content, causing predicted pore water values to become very large, this equation should not be used at low water content. Best results are obtained at water contents above 0.25 to 0.3 m^3/m^3.

3.3.5 SATURATION EXTRACT EC

The electrical conductivity of a saturated extract from the soil is often used to classify soils. If someone says a soil has an EC of 4, that would be its saturation extract EC. It is a measure of the amount of salt in the soil. It is determined by saturating a soil sample with distilled water, extracting some of the water, and measuring its EC. The pore water EC of a soil that has been saturated with distilled water is the same as the saturation extract EC. The saturation extract EC can be computed from the pore water EC using

$$\sigma_e = \sigma_P \left(\frac{\theta_s}{\theta} \right)$$

Equation 18

where θ_s is the saturation volumetric water content.

3.3.6 TEMPERATURE

The SOLYX 14 has an internal thermistor to measure its temperature. It is intended that the sensor head, with its thermistor, be buried in the soil. If the head sticks out, and especially if it is exposed to the sun, the internal thermistor will not be at the temperature of the soil or substrate and errors will occur.

4. SERVICE

This section describes the calibration and maintenance of the SOLYX 14. Troubleshooting solutions and customer service information are also provided.

4.1 CALIBRATION

The previous section provided a mineral soil and a potting soil calibration for SOLYX 14. The bulk dielectric permittivity, ε_b, is the raw sensor output when read with a METER or third-party data logger. The SOLYX 14 is not sensitive to variations in soil texture or EC because it is a true dielectric sensor (see theory Section 3.3). The generic calibration equation should result in reasonable absolute accuracy; ± 0.03 m^3/m^3 for most mineral soils. The potting soil equation should provide a good approximation for soilless growing media (i.e., potting soil, perlite, or peat moss). For added accuracy, customers are encouraged to perform soil-specific calibrations. For more information on how to calibrate sensors or to learn about METER calibration service (calibrations performed for a standard fee), see soil sensor calibration (meter.ly/how-to-cal-soil-sensors) or contact Customer Support.

4.2 CLEANING AND MAINTENANCE

SOLYX 14 may be returned to METER for maintenance in the following areas: system inspection, parts replacement, and instrument cleaning. Replacement parts can also be ordered from METER. Contact Customer Support for more information.

If the sensor needles become contaminated with oils from contact with skin or another source, it is necessary to clean the needles to ensure accurate EC readings in salty soils with bulk EC greater than 10 dS/m.

1. Clean each needle using a mild detergent such as liquid dish soap and a nonabrasive sponge or cloth.

   NOTE: Avoid detergents that contain lotions or moisturizers.

2. Rinse the sensor and needles thoroughly with tap or deionized (DI) water.

   NOTE: Do not touch the needles with an ungloved hand or bring them in contact with any source of oil or other nonconducting residue.

4.3 TROUBLESHOOTING

Table 2 lists common problems and their solutions. If the problem is not listed or these solutions do not solve the issue, contact Customer Support.

Table 2 Troubleshooting the SOLYX14

Problem	Possible Solutions
Cable or stereo plug connector failure	If a stereo plug connector is damaged or needs to be replaced contact, Customer Support for a replacement connector and splice kit. If a cable is damaged, follow these guidelines for wire splicing and sealing techniques (meter.ly/splice-kit-instructions).

Table 2 Troubleshooting the SOLYX14 (continued)

Problem	Possible Solutions
SOLYX14 not responding	Check power to the sensor. Check sensor cable and stereo plug connector integrity. Check data logger wiring to ensure brown is power supply, orange is digital out, and bare is ground. Check SDI-12 address is zero and reset to zero as needed. Sensor only works if address is zero.
Sensor reading too low (or slightly negative)	Check for air gaps around sensor needles. These could be produced below the surface of the substrate when the needle contacts a large piece of material and pushes it out of the way, or if the sensor is not inserted perfectly linearly. Ensure the calibration equation being used is appropriate for the media type. There are significant differences between substrate calibrations, so be sure to use the one specific to the substrate (example calibration equations Section 3.3.3).
Sensor reading too high	Check to make sure that the media was not packed excessively or insufficiently during sensor installation. Higher density can cause sensor reading to be elevated. Ensure the calibration equation being used is appropriate for the media type. There are significant differences between calibrations, so be sure to use the one most suitable to the substrate, or consider developing a substrate-specific calibration for the particular medium. Some substrates have an inherently high dielectric permittivity (soils of volcanic origin or high titanium, for instance). If the substrate has a dry dielectric permittivity above 6, a custom calibration may need to be performed. Soils with a saturated extract EC greater than 20 dS/m require substrate specific calibrations (Section 4.1).
Sensor is reading -9999	The SOLYX 14 has a built-in diagnosis tool to check proper operation (Section 2.4) called Sensor Consistency Test (SCT). This internal check ensures the measurement circuit is working properly. If the SCT check is out of range the sensor will trigger an error value -9999 instead of giving out an erroneous measurement. If the sensor is giving this value, contact Customer Support to evaluate if a replacement is needed.

4.4 CUSTOMER SUPPORT

NORTH AMERICA

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 7:00 am to 5:00 pm Pacific time.

Email: support.environment@metergroup.com
sales.environment@metergroup.com

Phone: +1.509.332.5600

Fax: +1.509.332.5158

Website: metergroup.com

EUROPE

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 8:00 to 17:00 Central European time.

Email: support.europe@metergroup.com
sales.europe@metergroup.com

Phone: +49 89 12 66 52 0

Fax: +49 89 12 66 52 20

Website: metergroup.com

If contacting METER by email, please include the following information:

Name	Email address
Address	Instrument serial number
Phone	Description of the problem

NOTE: For products purchased through a distributor, please contact the distributor directly for assistance.

4.5 TERMS AND CONDITIONS

By using METER instruments and documentation, you agree to abide by the METER Group, Inc. Terms and Conditions. Please refer to metergroup.com/terms-conditions for details.

REFERENCES

Hilhorst, M. A. (2000) A pore water conductivity sensor. Soil Sci. Soc. Am. Journal. Https://doi.org/10.2136/sssaj2000.6461922x

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