METER

GS3

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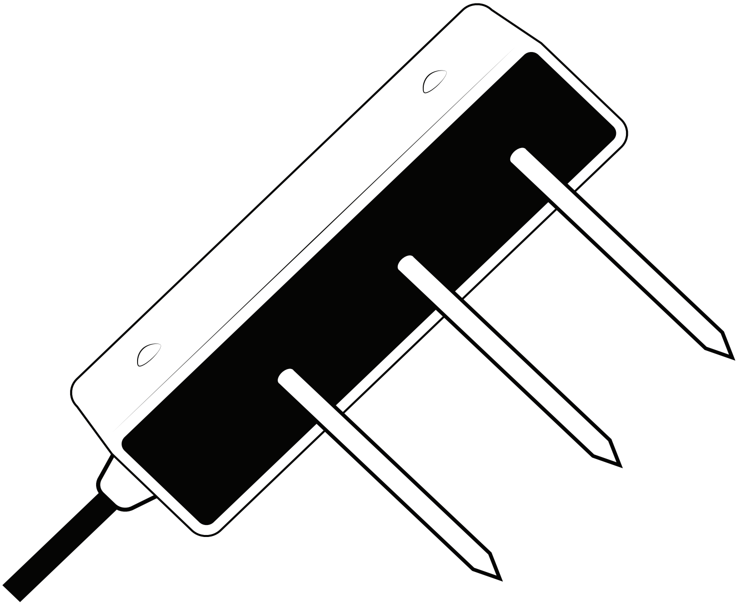

1. INTRODUCTION

Thank you for choosing the ECH$_2$O GS3 Volumetric Water Content (VWC), Electrical Conductivity (EC), and Temperature sensor from METER Group.

This manual guides the customer through the sensor features and describes how to use the sensor successfully. METER hopes the contents of this manual are useful in understanding the instrument and maximizing its benefit.

Prior to use, verify the GS3 arrived in good condition.

2. OPERATION

Please read all instructions before operating the GS3 to ensure it performs to its full potential.

⚠ PRECAUTIONS

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 GS3 into a system, make sure to follow the recommended installation instructions and have the proper protections in place to safeguard sensors from damage.

2.1 INSTALLATION

When selecting a site for installation, remember that the soil adjacent to the sensor surface has the strongest influence on the sensor reading and that the sensor measures the VWC of the soil. Therefore, any air gaps or excessive soil compaction around the sensor and in between the sensor needles can profoundly influence the readings.

- If installing sensors in a lightning-prone area with a grounded data logger, please read Lightning surge and grounding practices.
- Test the sensors with the data logging device and software before going to the field.

Do not install the sensor adjacent to large metal objects such as metal poles or stakes. This can attenuate the sensor's electromagnetic field and adversely affect readings. In addition, it is not recommended to install the GS3 sensor with the sensor body exposed at the surface, If the sensor body is in direct sunshine, the temperature measurement may read high.

Because the GS3 has gaps between its needles, it is also important to consider the particle size of the medium. It is possible to get sticks, bark, roots or other material stuck between the sensor needles, which will adversely affect readings. Finally, be careful when inserting the sensors into dense soil, as the needles can bend if excessive sideways force is used when pushing them in.

When installing the GS3, it is imperative to maximize contact between the sensor and soil (Figure 1). For most accurate results, the sensor should be inserted into undisturbed soil.

NOTE: Never pound the sensor into the soil! If there is difficulty inserting the sensor, loosen or wet the soil. This will result in inaccurate VWC measurements until the water added during installing redistributes into the surrounding soil.

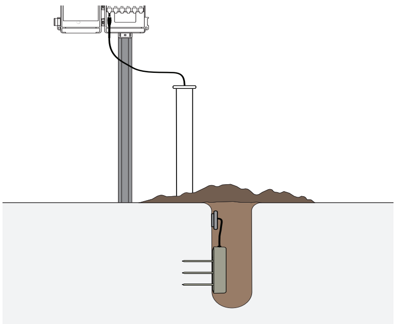

Figure 1 Example of GS3 proper installation

Use the following steps to install the GS3.

1. Excavate a hole or trench a few centimeters deeper than the depth at which the sensor is to be installed.
2. At the installation depth, shave off some soil from the vertical soil face exposing undisturbed soil.
3. Insert the sensor into the undisturbed soil face until the entire sensor is inserted. The tip of each needle has been sharpened to make it easier to push the sensor into the soil. Be careful with the sharp tips!
4. Backfill the trench taking care to pack the soil back to natural bulk density around the sensor body of the GS3.

View a visual demonstration on proper installation of the sensor in How to install soil moisture sensors.

The sensor can be oriented in any direction. However, orienting the flat side perpendicular to the surface of the soil will minimize effects on downward water movement.

The GS3 sensor makes EC measurements by exciting one needle on the sensor and measuring the current that moves from that screw to the adjacent grounded screw. The distance between the needles is an important part of the EC calculation. If GS3 sensors are placed close together (within 20 cm), it is possible for some of the current that leaves the excited screw to pass through the nearby sensor ground screw, thus producing an erroneous sensor reading.

This problem occurs regardless of which logging system is being used if the ground wires are connected at all times. If sensors must be close together (e.g., column experiments), consider a multiplexing option that would isolate the ground wires.

If installing sensors vertically at short depth intervals, do not bury them directly over the top of each other. Although at times the vertical distance may be less than 20 cm, the sensors can be staggered horizontally so they are not directly above each other, thus meeting the distance requirement.

2.2 REMOVING THE SENSOR

When removing the sensor from the soil, do not pull it out of the soil by the cable! Doing so may break internal connections and make the sensor unusable. If the sensor is buried, carefully dig down to the sensor, taking care not to damage the cable with the digging implement. After removing the media around the head, simply grab onto the sensor and remove it.

2.3 CONNECTING

The GS3 works seamlessly with METER data loggers. The GS3 can also be used with other data loggers, such as those from Campbell Scientific, Inc.

GS3 sensors require an excitation voltage in the range of 3.6 to 15 VDC. GS3 can be integrated using DDI serial or SDI-12 protocol. See the GS3 Integrator Guide for details on interfacing with data acquisition systems.

GS3 sensors come with a 3.5-mm stereo plug connector (Figure 2) to facilitate easy connection with METER loggers. GS3 sensors may be ordered with stripped and tinned wires to facilitate connecting to some third-party loggers (Section 2.3.2).

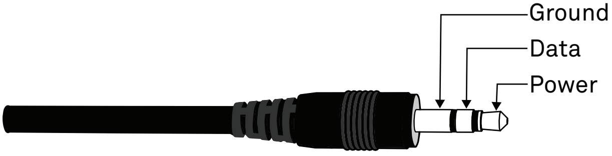

Figure 2 Stereo plug connector

The GS3 sensor comes standard with a 5-m cable. It may be purchased with custom cable lengths for an additional fee (on a per-meter basis). METER has successfully tested digital communication on cable lengths up to 1,000 m (3,200 ft). This option eliminates the need for splicing the cable (a possible failure point). However, the maximum recommended length is 75 m.

2.3.1 CONNECT TO METER DATA LOGGER

The GS3 sensor works most efficiently with METER ZENTRA series data loggers. Check the METER download webpage for the most recent data logger firmware. Logger configuration may be done using either ZENTRA Utility (desktop and mobile application) or ZENTRA Cloud (web-based application for cell-enabled ZENTRA data loggers).

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 GS3. METER data loggers will automatically recognize GS3 sensors.
3. Set the measurement interval.

METER data loggers measure the GS3 every minute and return the minute-average of the data across the chosen measurement interval.

GS3 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.

2.3.2 CONNECT TO NON-METER DATA LOGGER

The GS3 sensor 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 supply, and ground ports. The GS3 Integrator Guide also provides detailed instructions on connecting sensors to non-METER loggers.

GS3 sensors can be ordered with stripped and tinned (pigtail) wires for use with screw terminals. Refer to the third-party logger manual for details on wiring.

Connect the GS3 wires to the data logger as illustrated in Figure 3 and Figure 4, 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.

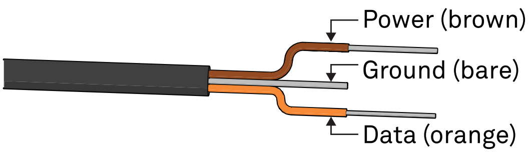

Figure 3 Pigtail wiring

NOTE: Some GS3 sensors may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare wire is ground.

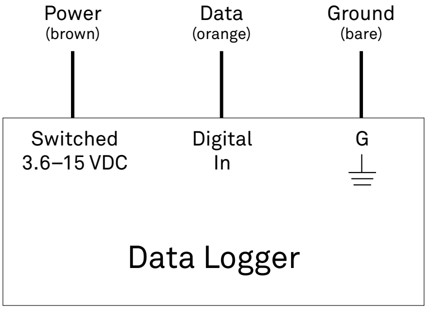

Figure 4 Wiring diagram

NOTE: The acceptable range of excitation voltages is from 3.6 to 15.0 VDC. To read GS3 sensors with Campbell Scientific data loggers, power the sensor from a switched 12-V port or a 12-V port if using a multiplexer.

If the GS3 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 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 in Figure 4: 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 using adhesive-line heat shrink to ensure the sensor does not become disconnected during use.

Because GS3 sensors use digital communication, they require special considerations when connecting to an SDI-12 data logger. Read SDI-12 example programs to view sample Campbell Scientific programs.

2.4 COMMUNICATION

The GS3 sensor communicates using two different methods, DDI serial and SDI-12. To obtain detailed instructions, refer to the GS3 Integrator Guide.

3. SYSTEM

This section describes the GS3 sensor.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Volumetric Water Content (VWC)		
Range		
	Mineral soil calibration	0.0–1.0 m^3/m^3
	Soilless media calibration	0.0–1.0 m^3/m^3
	Apparent dielectric permittivity (ε_a)	1 (air) to 80 (water)
Resolution		0.1 ε_a (unitless) from 1–20 <0.75 ε_a (unitless) from 20–80 0.002 m^3/m^3 from 0.0–0.4 m^3/m^3 0.001 m^3/m^3 for >0.4 m^3/m^3
Accuracy		
	Generic calibration	± 0.03 m^3/m^3 typical
	Medium-specific calibration	±0.01–0.02 m^3/m^3
	Apparent dielectric permittivity (ε_a)	1–40 (soil range), ±1 ε_a (unitless) 40–80, ±15% measurement
Dielectric Measurement Frequency		
70 MHz		
Temperature		
Range		−40 to +60 °C
Resolution		0.1 °C
Accuracy		±1 °C

NOTE: Temperature measurement may not be accurate if sensor is not fully immersed in the medium of interest, due to excessively long equilibration time.

Bulk Electrical Conductivity	
Range	0–25 dS/m (bulk)
Resolution	0.001 dS/m from 0–25 dS/m
Accuracy	±5% from 0–5 dS/m ±10% from 5–25 dS/m Custom calibration required 10–25 dS/m

COMMUNICATION SPECIFICATIONS

Output

DDI serial or SDI-12 communication protocol

Data Logger Compatibility

Data acquisition systems capable of 3.6- to 15.0-VDC power and serial or SDI-12 communication

PHYSICAL SPECIFICATIONS

Dimensions	
Length	9.3 cm (3.7 in)
Width	2.4 cm (0.9 in)
Height	6.5 cm (2.6 in)

Needle Length

5.5 cm (2.2 in)

Operating Temperature Range	
Minimum	–40 °C
Typical	NA
Maximum	+60 °C

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

Cable Length

5 m (standard)
75 m (maximum custom cable length)

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

Connector Types

3.5-mm stereo plug connector or stripped and tinned wires

ELECTRICAL AND TIMING CHARACTERISTICS

Supply Voltage (VCC to GND)	
Minimum	3.6 VDC
Typical	NA
Maximum	15.0 VDC
Digital Input Voltage (logic high)	
Minimum	2.8 V
Typical	3.0 V
Maximum	3.9 V
Digital Input Voltage (logic low)	
Minimum	–0.3 V
Typical	0.0 V
Maximum	0.8 V
Power Line Slew Rate	
Minimum	1.0 V/ms
Typical	NA
Maximum	NA
Current Drain (during measurement)	
Minimum	0.5 mA
Typical	3.0 mA
Maximum	30.0 mA
Current Drain (while asleep)	
Minimum	NA
Typical	0.03 mA
Maximum	NA
Power-Up Time (DDI serial)	
Minimum	NA
Typical	NA
Maximum	100 ms

Power-Up Time (SDI-12)	
Minimum	100 ms
Typical	150 ms
Maximum	200 ms
Measurement Duration	
Minimum	NA
Typical	150 ms
Maximum	200 ms

COMPLIANCE

EM ISO/IEC 17050:2010 (CE Mark)

3.2 ABOUT GS3

The GS3 is designed to measure the water content, EC, and temperature of soil (Figure 5).

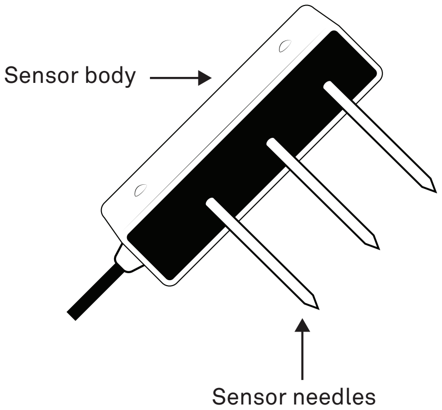

Figure 5 GS3 components

3.3 THEORY

The following sections explain the theory of VWC, temperature, and EC measured by GS3.

3.3.1 VOLUMETRIC WATER CONTENT

The GS3 sensor uses an electromagnetic field to measure the dielectric permittivity of the surrounding medium. The sensor supplies a 70 MHz oscillating wave to the sensor needles that charges according to the dielectric of the material. The stored charge is proportional to substrate dielectric and substrate volumetric water content. The GS3 microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor. The dielectric value is then converted to substrate water content by a calibration equation specific to the media you are working in.

3.3.2 TEMPERATURE

The GS3 uses a small thermistor to take temperature readings. It is located underneath the sensor overmold, next to one of the needles so it remains in thermal equilibrium with the medium, and reads the temperature of the needle surface.

The GS3 outputs temperature in degrees Celsius unless otherwise stated in the preferences file in the software programs. Do not install the sensor with the overmold in the sun. If the sensor body is in direct sunshine, the temperature measurement may read high. Exposure of the sensor head to direct UV radiation may also degrade the vinyl surface and cause it to discolor.

3.3.3 ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) is the ability of a substance to conduct electricity and can be used to infer the amount of charged molecules that are in solution. EC is measured by applying an alternating electrical current to two electrodes, and measuring the resistance between them. Bulk EC is derived by multiplying the inverse of the resistance (conductance) by the cell constant (the ratio of the distance between the electrodes to their area). GS3 bulk EC measurements are normalized to EC at 25 °C. METER factory calibrate the bulk EC measurement to be accurate within ±10% from 0 to 10 dS/m. This range is adequate for most greenhouse and nursery applications.

However, some special applications in highly saline substrates may require measurements with bulk EC greater than the specified range. The GS3 will measure up to 23 dS/m bulk EC, but user calibration is required above 10 dS/m. Additionally, EC measurements above 10 dS/m are very sensitive to contamination of the electrodes by skin oils, etc. Read Section 4.2 if measuring the EC of salty soils.

3.3.4 CONVERTING BULK EC TO PORE EC

For many applications, it is advantageous to know the EC of the solution contained in the soil pores (σ_p), which is a good indicator of the solute concentration in the soil. Researchers have traditionally obtained σ_p by extracting pore water from the soil and measuring σ_p directly. However, this is a time-consuming and labor-intensive process.

The GS3 measures the EC of the bulk soil surrounding the sensors (σ_b). METER has conducted a considerable amount of research to determine the relationship between σ_b and σ_p. Work by Hilhorst (2000) takes advantage of the linear relationship between the soil bulk dielectric permittivity (ε_b) and σ_b to allow accurate conversion from σ_b to σ_p if the ε_b is known. The GS3 measures ε_b and σ_b nearly simultaneously in the same soil volume, so it is well suited to this method.

Use Hilhorst (2000) to derive the pore water conductivity (Equation 1).

$$\sigma_p = \frac{\varepsilon_p \sigma_b}{\varepsilon_b - \varepsilon_{\sigma b=0}}$$

Equation 1

where:

σ_p = pore water EC (dS/m)
ε_p = real portion of the dielectric permittivity of the soil pore water (unitless)
σ_b = bulk EC (dS/m) measured directly by the GS3
ε_b = the real portion of the dielectric permittivity of the bulk soil (unitless)
$\varepsilon_{\sigma b=0}$ = the real portion of the dielectric permittivity of the soil when bulk EC is 0 (unitless)

ε_p can be calculated from soil moisture using a simple formula (Equation 2).

$$\varepsilon_p = 80.3 - 0.37\left(T_{soil} - 20\right)$$

Equation 2

where T_{soil} is the soil temperature (in degrees Celsius) measured by the GS3.

Convert raw VWC counts to bulk dielectric with the GS3 dielectric adjustment (Equation 3). Please note that this only applies to METER data loggers. The GS3 outputs dielectric directly with non-METER data loggers.

$$\varepsilon_b = \frac{\varepsilon_{raw}}{50}$$

Equation 3

Finally, $\varepsilon_{\sigma b=0}$ is an offset term loosely representing the dielectric of the dry soil. Hilhorst (2000) recommends using $\varepsilon_{\sigma b=0}$ = 4.1 as a generic offset. However, METER research in several agricultural soils, organic, and inorganic growth media indicates that $\varepsilon_{\sigma b=0}$ = 6 results in more accurate determinations of σ_p. Hilhorst (2000) offers a simple and easy method for determining for individual soil types, which will improve the accuracy of the calculation of σ_p in most cases.

METER testing indicates that the above method for calculating σ_p results in good accuracy (±20%) in moist soils and other growth media. In dry soils where VWC is less than about 0.10 m^3/m^3, the denominator of pore water conductivity equation becomes very small, leading to large potential errors. METER does not recommend this method to calculate σ_p in soils with VWC < 0.10 m^3/m^3.

3.3.5 PORE WATER VERSUS SOLUTION EC

Pore water EC can be calculated from bulk EC using the sensor-measured dielectric permittivity of the medium. However, pore water EC is not the same as solution EC. Pore water EC is the EC of the water in the pore space of the soil. One could measure this directly by squeezing the soil under high pressure to force water out of the soil matrix and test the collected water for EC.

Solution EC is the EC of pore water removed from a saturated paste. In this case, wet the soil with distilled water until the soil saturates, then place the soil on filter paper in a vacuum funnel and apply suction. An EC measurement on the removed sample water gives the solution EC.

Theoretically, the two are related by the bulk density. An example calculation illustrates this relationship. If a soil is at 0.1 m^3/m^3 VWC, has a pore water EC of 0.7 dS/m, and a bulk density of 1.5 Mg/m^3. Calculate the solution EC (dS/m) with Equation 4 and Equation 5.

$$\phi = 1 - \frac{\rho_b}{\rho_s} = 1 - \frac{1.5}{2.65} = 0.43$$

Equation 4

$$Solution\ EC = \frac{\sigma_p \theta + \sigma_d (\phi - \theta)}{\phi} = \frac{0.7(0.1) + 0}{0.43} = 0.162$$

Equation 5

In this example, ϕ is the porosity, ρ_b is bulk density, ρ_s is the density of the minerals (assumed to be 2.65 Mg/m^3), the subscript d is distilled water, and θ is VWC. It is assumed that the EC of the distilled water is 0 dS/m. In practice, solution EC calculated from this method and solution EC taken from a laboratory soil test may not correlate because wetting soil to a saturated paste is very imprecise.

4. SERVICE

This section contains calibration information, calibration frequencies, cleaning and maintenance guidelines, troubleshooting guidelines, customer support contact information, and terms and conditions.

4.1 CALIBRATION

METER software tools automatically apply factory calibrations to the sensor output data. However, this general calibration may not be applicable for all soil types. For added accuracy METER encourages customers to perform soil-specific calibrations.

There are two options for soil-specific calibration.

- Follow the step-by-step instructions for calibrating soil moisture sensors in the application note Calibrating ECH2O soil moisture probes.
- METER offers a service providing soil-specific calibrations.

This calibration service also applies to soilless materials, such as compost or potting materials. Contact Customer Support for more information.

4.1.1 DIELECTRIC PERMITTIVITY

In some specific cases, a calibration that gives dielectric permittivity (combined real and imaginary) for the GS3 is useful. The dielectric of the medium, ε_a is the standard factory calibrated output of the GS3 before applying a calibration.

4.1.2 MINERAL SOIL CALIBRATION

The calibration for mineral soils ranging from 0 to <5 dS/m is:

$$VWC = 5.89 \times 10^{-6}\,\varepsilon_a^3 - 7.62 \times 10^{-4}\,\varepsilon_a^2 + 3.67 \times 10^{-2}\,\varepsilon_a - 7.53 \times 10^{-2}$$ **Equation 6**

4.1.3 CALIBRATION IN SOILLESS MEDIA

The GS3 has been calibrated in media types including potting soil, perlite, and peat. The goal of these calibrations is to create a generic calibration equation that will work in all types of each substrate, with an accuracy of better than ±5% VWC. If more accuracy, you can perform a media-specific calibration to get the accuracy down to ±1 to 2%. It is interesting to note that the main difference between the calibrations is caused by the high air volume in the organic soils that lowers the starting (dry media) dielectric of the sensor. Contact Customer Support for more information.

The calibration for several potting soils, perlite, and peat moss at salinities ranging from 0 to <4 dS/m is given:

$$VWC = 0.118\sqrt{\varepsilon_a} - 0.117$$ **Equation 7**

4.2 CLEANING AND MAINTENANCE

Use the following steps to clean the sensor:

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 water.

Do not touch the needles without gloved hands and never contact the sensors with any source of oil or other nonconducting residue.

4.3 TROUBLESHOOTING

If problems with the GS3 are encountered, they most likely manifest themselves in the form of incorrect or erroneous readings. Review the information in Table 1 and the Troubleshooting METER soil moisture sensors video to identify the problem. Contact Customer Support for more information.

Table 1 Troubleshooting the GS3

Problem	Possible Solution
Sensor 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. **NOTE: Some GS3 sensors may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare wire is ground.**
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 bulk EC >10 dS/m require substrate-specific calibrations (Section 4.1).
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.

Table 1 Troubleshooting the GS3 (continued)

Problem	Possible Solution
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.

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@metergroup.de
sales@metergroup.de

Phone: +49 89 12 66 52 0

Fax: +49 89 12 66 52 20

Website: metergroup.de

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.

REFERENCE

Hilhorst, M.A. 2000. "A Pore Water Conductivity Sensor." Soil Science Society of America Journal 64, no. 6: 1922–1925.

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