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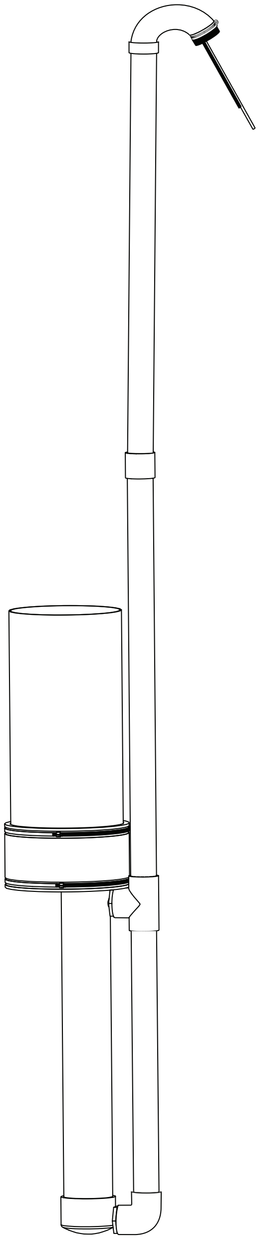


1. INTRODUCTION

Thank you for choosing the G3 Drain Gauge from METER Group. METER designed the G3 Drain Gauge for long-term monitoring of soil water drainage to observe soil water movement and chemical leaching accurately and affordably. The G3 Drain Gauge also has a collection system that allows for rapid sampling of drainage waters.

Verify all G3 Drain Gauge components are included and appear in good condition:

- G3 Drain Gauge
- HYDROS 21 sensor with sampling hose ring
- Diatomaceous earth (DE)
- Two sections of 1-m-long, 2-in-wide PVC tubing and slip coupling
- 2-in-wide schedule 40 PVC U-connector
- End cap with hose clamp
- Piston pump
- 1-L sample bottle
- 5-m sampling tube

2. OPERATION

Please read all instructions before operating the G3 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 G3 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

METER recommends referring to the Installing G3 Drain Gauge video (metergroup.wistia.com/medias/xwi9j6zbjh) prior to installation. The G3 installation is complex and requires two or three people. The goal is to install the G3 in such a way that the soil disturbance has minimal impact on the ability to measure deep drainage accurately.

Installation location determines soil drainage, so the location must match the objectives of the particular drainage study. For example, for an estimate of the average groundwater recharge from the study site, choose installation locations representative of the study site as a whole. Three main factors may affect study results:

- **Vegetation:** Once water has percolated into the soil, the main mechanism by which water is transported to the atmosphere is through vegetative transpiration. The G3 should be installed at a location with vegetative cover representative of the whole area of interest. It is also particularly critical that vegetation be reestablished above the G3 after installation.
- **Topography:** Typically, most accurate drainage results are measured at locations with a level surface, although installations on slopes can yield good results if the installation location is properly restored to natural conditions. Low areas where runoff collects can cause uncharacteristically high drainage rates.
- **Location Disturbance:** Disturb the location as little as possible during installation and reestablish natural conditions above the G3 after installation. In some cases, it may be necessary to install the G3 beneath an undisturbed core of soil. In all cases, allow time for roots to grow back into disturbed soil.

NOTE: NOTE: Tilled soil surface is considered already disturbed soil.

Follow the steps listed in Table 1 to set up the G3 and start collecting data. For a diagram of the drain gauge, refer to Section 3.2.

Table 1 Installation

Tools Needed	**Heavy machinery (backhoe or front-end loader) or shovel, as appropriate** **Sledgehammer** **4 × 4 wood boards (for stainless steel Divergence Control Tube [DCT])** **Flat blade (or other utensil)** **Diatomaceous earth (DE)** **Tarp** **Rope or strap, approximately twice the length of the intended installation depth** **Flat head screwdriver** **Cap, plug, or crimp for the end of the sampling tube** **PVC cement**
Preparation	**Select Location** Choose the desired location based on relevant details, including representative position for sensor installation, vegetation cover throughout the season, minimal interference, etc. **Determine Installation Depth** Decide installation depth (Section 2.1.1). **Select Location for DCT Soil** Select a separate location close enough to the installation location that soil properties are similar, but far enough away that excavation activities do not impact the installation location (e.g., 10 m apart). Both the amount of sample and its chemical composition need to be representative of deep drainage at the installation location. **Option 1: Collect Intact Soil Monolith** **NOTE: This option is only for a Stainless Steel DCT.** Excavate to the optimal level for the top of the DCT (Section 2.1.1). Place the DCT on the exposed soil in the excavated hole. Place one or more wood boards on top of the DCT to distribute the insertion force to avoid damaging the DCT. Press or pound the DCT into the soil a few inches using heavy equipment or a heavy sledgehammer, as appropriate. Remove the soil around the portion of the DCT that has been inserted. Alternate pounding and digging until the DCT is fully inserted into the soil. **NOTE: In some situations (e.g., stony soil), it may not be possible to push or pound the DCT into the soil to collect an intact monolith. In this case, a repacked monolith is the only option.** Dig a hole around the DCT large enough to access the bottom edge. Use a flat blade or other utensil to cut the soil at the bottom edge of the DCT, resulting in a flat soil face at the lower boundary of the DCT. Lift the DCT with intact monolith out of the hole.

Table 1 Installation (continued)

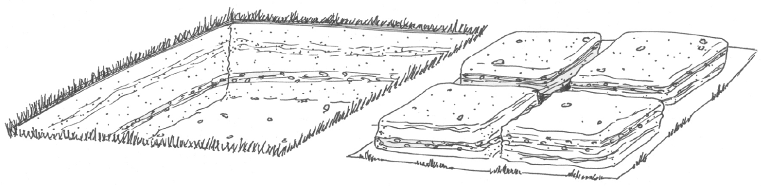
Preparation (continued)	**Option 2: Collect Repacked Soil Monolith** Carefully add each individual soil layer into the DCT as similarly as possible to the natural soil conditions in both bulk density and natural horizonation. Avoid large variations in bulk density between layers as these will retard flow and can cause flux divergence. **NOTE: This option can also be completed after the G3 has been installed into the hole.**
Installation	**Create Hole** Spread a tarp to hold the vegetation and soil to be removed from the site. Remove the surface vegetation and place it on the tarp. Preserve as much of the root mass as possible and organize the vegetation so it can be replaced as closely as possible to its original location.  **Initial Excavation for G3 Drain Gauge Installation** Make a vertical hole 41-cm (16-in) in diameter and approximately 63.5 cm (25 in) deep (the level of the junction between the DCT and the reservoir section). Select one of two methods to continue excavating the hole: • **Method #1 (nested offset holes).** At the floor of the 41-cm-diameter hole, make a 25.4-cm-diameter (10-in-diameter) vertical hole sharing an outer edge with the 41-cm-diameter hole. The 25.4-cm hole should be approximately 84 cm (33 in) deep to accommodate the reservoir section. The shelf formed between the two holes supports the weight of the G3 during installation and minimizes the amount of backfilling necessary. • **Method #2 (straight hole).** Continue the 41-cm hole for an additional 84 cm (33 in), to the depth of the bottom of the reservoir section. Total hole depth should be approximately 147 cm (58 in). This method is easier to accomplish in practice but requires more significant backfilling of soil. **Assemble Sensor** Cover the top of the DCT with a tarp (or something else to keep the soil in the DCT). Flip the DCT upside down, so the lower soil layer is at the top. **NOTE: Repacking a monolith creates good hydraulic contact, so a repacked monolith does not need the additional DE layer.**

Table 1 Installation (continued)

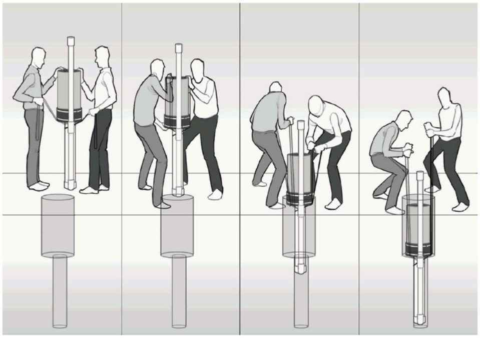
Installation (continued)	On the wick-reservoir assembly of the G3, loosen the screw on the hose clamp at the top of the rubber union sleeve until the hose clamp is visibly loose. **NOTE: If installing in saturated or near-saturated conditions, apply PVC cement to joints to prevent water infiltration.** **Insert G3 Drain Gauge** Loop the heavy rope or strap below the fitting connecting the reservoir section to the access tube immediately below the junction between the DCT and reservoir section. Lift the G3 and rotate it so the reservoir will be inserted into the hole first. ⚠ **CAUTION** **If using an intact monolith, do not lift the G3 Drain Gauge up using the bottom part of the reservoir as a lift point. This could result in a break around PVC fittings or the seal around the wick section.**  **Lower the G3 into the Installation Hole** Carefully lower the G3 into the installation hole with one person holding it level and guiding it into the hole while another person slowly lowers it into the hole using the rope or strap. ⚠ **CAUTION** **Do not drop the G3 into the hole or it could be permanently damaged** Carefully backfill soil into the hole around the reservoir section (especially if using method #2). **NOTE: Sufficient backfilling will prevent the G3 from settling over time.**

Table 1 Installation (continued)

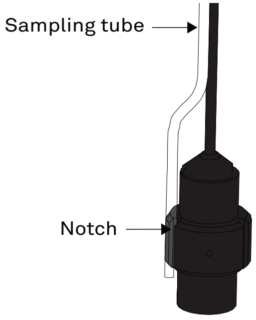
Installation (continued)	**Insert HYDROS 21 Sensor** Seat the end of the sampling tube all the way into the notch on the side of the HYDROS 21.  **Sampling Tube Seated into HYDROS 21 Adapter** Zip tie the sampling tube to the sensor cable to help keep it secure. Slowly lower the sensor down the access until it reaches the bottom of the access tube. **Sensor Assemble with Tube** Run the sampling tube and sensor cable through the U-connector. Run the sampling tube and sensor cable through the precut slit in the rubber end cap. Pull the sampling tube and sensor cable through the end cap until the end cap meets up with the end of the U-connector. Do not pull the tube or cable too tight to avoid pulling them back up the access tube. Connect the end cap with the end of the U-connector and tighten the hose clamp with a flat head screwdriver. Prime the G3 by adding 250 mL or more of water through the access tube. Connect the U-connector to the top of the access tube.

Table 1 Installation (continued)

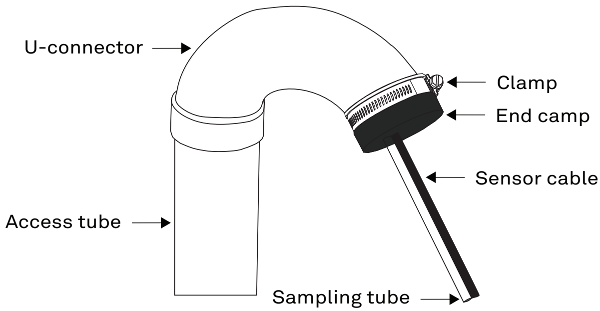
Installation (continued)	 **U-connector Assembly on Access Tube** Connect the sampling tube to the included piston pump. Remove all possible water from the access tube using the piston pump. Disconnect the sampling tube from the pump. Crimp or cap the end of the sampling tube to prevent debris from plugging the sampling tube between drainage sample collections. **Backfill the Hole** Backfill soil around the DCT. Try to achieve a similar bulk density as the surrounding soil. Carefully replace the soil and vegetation above the DCT. Repack the soil above the DCT to the same bulk density as the surrounding soil and recreate any layering that is present in the natural soil. Ensure the soil is level above the G3. Any mound or depression could significantly affect the infiltration of water. It may be desirable to water any disturbed vegetation to help it reestablish as soon as possible.

Table 1 Installation (continued)

Connecting	**Secure and Protect Cables** **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.** Install cables in conduit or plastic cladding when near the ground to avoid rodent damage. Gather and secure cables between the G3 and the data logger to the mounting mast in one or more places. **Connect to Data Logger** Plug the sensor into a data logger. **NOTE: The modified HYDROS 21 used with the G3 Drain Gauge will appear in METER data loggers as `CTD+DG`.** Use the data logger to make sure the sensor is reading properly. Verify that these readings are within expected ranges. For more instructions on connecting to data loggers, refer to Section 2.2.

2.1.1 DEPTH OF INSTALLATION

The depth of the G3 installation will depend on the depth of the root zone (Figure 1).

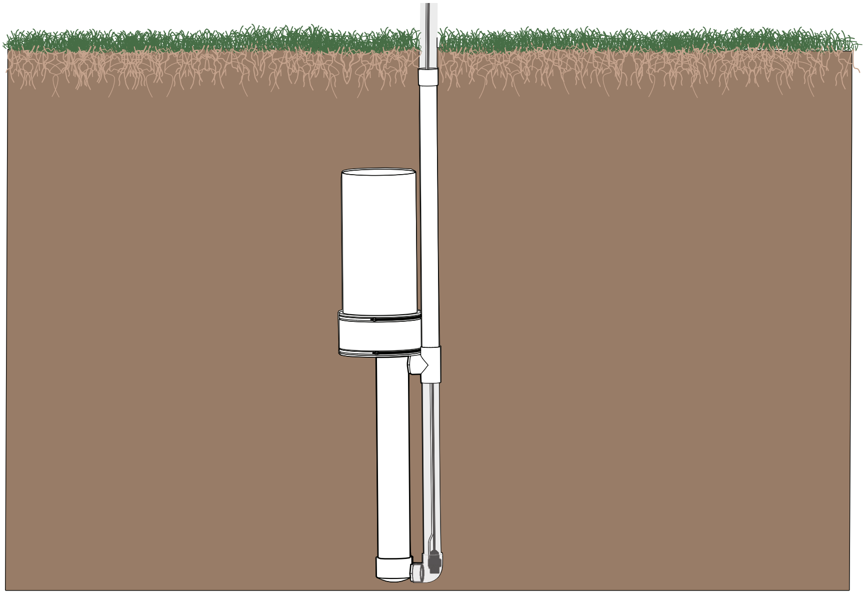


Figure 1 G3 Drain Gauge below root zone

In any soil profile, there is a zone of recharge and seasonal depletion extending to the bottom of the root zone. The objective of installation is to place the union between the DCT and the wick section below the root zone of the cover vegetation to intercept water that normally would be transpired from the soil by the vegetation. The installation depth will then vary from location to location, depending on the cover vegetation rooting depth.

Since root density decreases with depth, the bottom of the root zone may be difficult to locate. In annual crops, the bottom is typically around 1 m (3 ft), but it can be much deeper in perennials. There is a practical limit to how deep the G3 can be installed based on the tools and environment. With shallow-rooted crops, this is not an issue, but with deep-rooted plants, operators must strike a compromise between getting below all roots and installing the G3 at a practical depth. Even when roots go quite deep, the amount of water taken up by these roots may be small, so installing the G3 within the lower root zone helps minimize errors.

NOTE: If the union between the DCT and the wick section is in the root zone, the G3 Drain Gauge can intercept water that normally would be transpired from the soil by the vegetative cover, thus overestimating the amount of drainage.

The upper section of the DCT can be in the root zone as long as vegetation is reestablished above the G3 and normal root growth is present within the DCT. In some instances where the root zone is nonexistent or shallow (e.g., bare soil or turfgrass), the DCT may extend all the way to the surface. This has the advantage of preventing flow divergence or convergence; however, it can be difficult to reestablish natural surface conditions and surface vegetation.

Installation depth may also depend on the possibility of root incursion into the G3 wick section. One version of the G3 has a patch of Biobarrier™ root inhibitor fabric within the wick section. A version of the G3 without Biobarrier root inhibitor fabric is available. However, this drain gauge must be installed below the root zone to ensure roots do not grow into the wick and impede measurements.

2.1.2 ADDITIONAL REFERENCE SENSORS

It is often useful to install TEROS soil moisture sensors and an ATMOS 41 weather station to observe the precipitation and storage of water in the soil and quantify the water balance.

Some users also install TEROS sensors in the DCT to compare the soil moisture dynamics in the DCT to those in the undisturbed soil surrounding the G3 Drain Gauge. Install TEROS sensors as close to the center of the DCT as possible and do not touch any part of the DCT itself to avoid adverse effects on readings.

Contact Customer Support for more information on the TEROS and ATMOS sensors.

2.2 CONNECTING

The modified HYDROS 21 sensor within the G3 Drain Gauge works seamlessly with METER data loggers. The HYDROS 21 can also be used with other data loggers, such as those from Campbell Scientific, Inc. For extensive directions on how to integrate the sensors into third-party loggers, refer to the G3 Drain Gauge Integrator Guide (meter.ly/g3-lysimeter-support).

NOTE: The modified HYDROS 21 used with the G3 Drain Gauge will appear in METER data loggers as `CTD+DG`.

HYDROS 21 sensors require an excitation voltage in the range of 4.0 to 15.0 VDC and operate at a 4.0-VDC level for data communication. HYDROS 21 can be integrated using DDI Serial or SDI-12 protocol. See the G3 Drain Gauge Integrator Guide (meter.ly/g3-lysimeter-support) for details on interfacing with data acquisition systems.

HYDROS 21 sensors come with a 3.5-mm stereo plug connector (Figure 2) to facilitate easy connection with METER loggers. HYDROS 21 sensors may be ordered with stripped and tinned wires to facilitate connecting to some third-party loggers (Section 2.2.2).

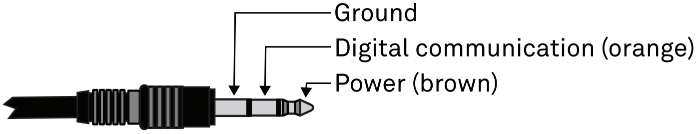


Figure 2 Stereo plug connector

TThe HYDROS 21 comes standard with a 10-, 20-, or 40-m cable. In some instances, the cable can be extended beyond 40 m by the user, but this is discouraged for a variety of reasons. Please contact Customer Supportfor more details before extending or splicing cables.

NOTE: The HYDROS 21 vents the pressure transducer through the cable to atmospheric pressure. Long cable lengths may cause a slow response to changes in atmospheric pressure; a maximum cable length of 40 m is recommended for optimal venting.

2.2.1 CONNECT TO METER DATA LOGGER

The G3 Drain Gauge works most efficiently with METER ZENTRA series data loggers. Check the G3 Drain Gauge Firmware Updater (meter.ly/g3-lysimeter-support) 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 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 G3. METER data loggers will automatically recognize G3 Drain Gauge sensors as CTD+DG.
3. Set the measurement interval.

   METER data loggers measure the G3 every minute and return the average of the 1-min data across the chosen measurement interval.

G3 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 A NON-METER DATA LOGGER

The G3 Drain Gauge 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 G3 Drain Gauge Integrator Guide (meter.ly/g3-lysimeter-support) also provides detailed instructions on connecting sensors to non-METER loggers.

G3 Drain Gauge 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 G3 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.

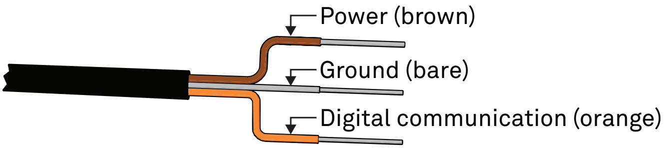


Figure 3 Pigtail wiring

NOTE: Some early G3 Drain Gauge units may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare and black wires are ground.

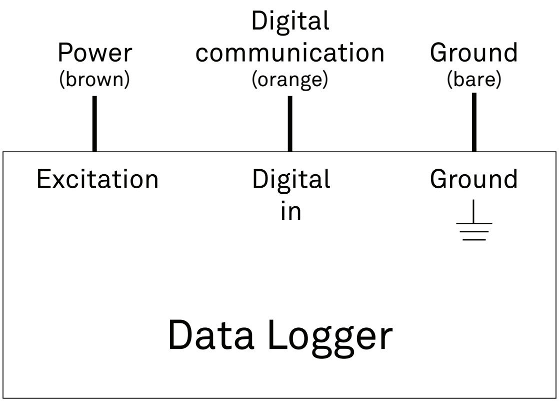


Figure 4 Wiring diagram

NOTE: The acceptable range of excitation voltages is from 3.6 to 15.0 VDC. To read G3 Drain Gauge 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 G3 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 and minimizes the 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 3: 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-lined heat shrink to ensure the sensor does not become disconnected during use.

2.3 COMMUNICATION

The HYDROS 21 within the G3 Drain Gauge communicates using two different methods:

- DDI Serial string
- SDI-12 communications protocol

To obtain detailed instructions, refer to the G3 Drain Gauge Integrator Guide.

The SDI-12 protocol requires that all sensors have a unique address. G3 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.

⚠ WARNING

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 TAKING DRAINAGE MEASUREMENTS

The G3 Drain Gauge accumulates a representative drainage sample in its reservoir. The HYDROS 21 sensor in the G3 will automatically measure water depth, temperature, and bulk electrical conductivity (EC) in the reservoir as determined in the initial setup with the data logger. For manual measurements for drainage volume and total drainage, the water in the reservoir section is easily removed by the sampling tube and pump. The removed water can be sent to a laboratory for chemical analysis of constituents of interest and their concentration can then be calculated.

If measuring remote, deep, or high-volume drainage sites, the reservoir may fill and the water level may come in contact with the wick. After this point, water may be pulled out of the reservoir due to capillary rise, which will result in an underestimation of drainage. The AutoPump was designed to drain the reservoir of the G3 when it becomes full (APPENDIX A).

The necessary equipment for taking volume measurements (sampling tubes, a piston pump, and a 1-L sample bottle) is shipped with the G3. This procedure is used to both collect samples and empty the reservoir.

1. Connect the longer sampling tube from the G3 to one of the connectors on the sample bottle cap.
2. Connect the shorter sampling tube from the other connector on the sample bottle to the inlet port of the piston pump.
3. Rotate the handle on the pump counterclockwise continuously.

   This creates a vacuum inside of the sample bottle, pulling the collected drainage water out of the sampling reservoir and into the sample bottle.

   Continue rotating the pump handle until water stops flowing into the sample bottle. More than one bottle may be needed.

   The reservoir should now be empty (except for the inaccessible 135 mL of “dead volume”).
4. Rinse the sample bottle, cap, and tubes using distilled water. Repeat three times to prevent cross contamination between samples and locations.

   The pump does not need to be rinsed since it does not come into contact with any of the sampled water.
5. Divide the total volume of collected water by 506.7 cm^2 (the cross-sectional surface area of the intake of the DCT). This should give an answer in units of cubic meters drainage per square meter of soil surface area, or more simply, centimeters of drainage.

   The calculated drainage can now be used to determine contaminant flux rates.

2.5 CALCULATING CONTAMINANT CONCENTRATION

The end of the G3 Drain Gauge sampling tube is situated slightly above the floor of the access tube. If all possible water is removed to the level of the end of the sampling tube, 135 mL of drainage water remains in the lowest portion of the access tube and in the lowest portion of the reservoir section. This drainage water mixes with any new soil solution that is collected by the G3. The chemical concentration of a sample that is subsequently removed for analysis then represents a weighted average of the chemical concentration of the remnant drainage water and the newly accumulated drainage water. For many applications, this is acceptable, but for some, only the chemical concentration of the newly accumulated drainage water is desired. This can be calculated by

$$C_{new} = \frac{[(C_{mix}(V_{mix} + V_{old})) - C_{old} \times V_{old})]}{V_{new}}$$ **Equation 1**

where C is constituent concentration, V is volume of drainage water, and the subscripts new, old, and mix indicate newly accumulated drainage water, drainage water remaining in the reservoir chamber after the previous extraction, and the mixture of the two types of drainage water, respectively.

If the concentration of a constituent of interest is measured, it can be multiplied by the drainage flux density to yield the flux density of the constituent through the soil.

EXAMPLE CALCULATION

The nitrate concentration of drainage water removed from a G3 just prior to fertilization of a corn crop was 30 mg/L. When the water was extracted a few weeks following application of urea, 500 mL of drainage water was extracted with a nitrate concentration of 45 mg/L.

The variables are therefore defined as follows:

C_{mix} = 45 mg/L

V_{new} = 500 mL

V_{old} = 135 mL

C_{old} = 30 mg/L

So,

$$C_{new} = \frac{[(45\ (0.500 + 0.135)) - (30 \times 0.135\ )]}{0.005} = 49.05 \text{ mg/L}$$

For this calculation to be valid, the reservoir must be fully emptied to the level of the bottom of the sampling tube during the evacuation previous to the analysis and during the evacuation used for the analysis.

3. SYSTEM

This section describes the G3 Drain Gauge system.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Drainage	
Range	0–61 mm bottom of wick 61–100 mm top of reservoir chambers
Resolution	0.2 mm
Accuracy	±1.4 mm
Water Depth	
Range	0–10,000 mm
Resolution	1 mm
Accuracy	±0.05% of full scale at 20 °C
NOTE: Depth measurement accuracy assumes no abrupt temperature variations.	
Temperature	
Range	−40 to +60 °C
Resolution	0.1 °C
Accuracy	±1 °C
NOTE: Ice formation within the G3 Drain Gauge will ruin the pressure transducer. Remove the HYDROS 21 sensor if the water temperature could drop below 0 °C (32 °F).	
Bulk Electrical Conductivity (EC)	
Range	0–120 dS/m
Resolution	0.001 dS/m
Accuracy	±0.01 dS/m or ±10%, whichever is greater
NOTE: The EC measurement is corrected to a standard temperature of 25 °C.	

COMMUNICATION SPECIFICATIONS

Output	
DDI Serial or 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

G3 Drain Gauge Dimensions	
Mass	20.0 kg (44.0 lb) with stainless steel DCT 14.0 kg (31.0 lb) with PVC DCT
DCT Dimensions	
Length	62.5 cm (24.6 in)
Inner Diameter	25.4 cm (10.0 in)
Outer Diameter	26.4 cm (10.4 in)
Width	3.3 cm (1.3 in)
Reservoir Dimensions	
Length	81.3 cm (32.0 in)
Outer Diameter	11.5 cm (4.5 in)
Access Tube Dimensions	
Length	180.0 cm (70.9 in) standard, custom lengths available
Outer Diameter	6.0 cm (2.4 in)
Material	Schedule 40 PVC
Sensor Dimensions	
Length	9.0 cm (3.5 in)
Diameter	3.4 cm (0.5 in)

Sampling Tube Dimensions	
Length	5.0 m (196.9 in) standard, custom lengths available
Outer Diameter	6.0 mm (0.5 in)
Material	Polyethylene

Operating Temperature Range	
Minimum	0 °C
Maximum	60 °C

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

Cable Length

10.0 m (standard)
20.0 m
40.0 m (maximum)

Cable Diameter

4.20 mm (0.165 in) with a minimum jacket of 0.76 mm (0.030 in)

Connector Type

Stereo plug connector or stripped and tinned wires

Connector Diameter

6 mm (0.24 in)

Conductor Gauge

22-AWG / 24-AWG drain wire

ELECTRICAL AND TIMING CHARACTERISTICS

Supply Voltage (power to ground)	
Minimum	4.0 V
Typical	NA
Maximum	15.0 V

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)	
Minimum	NA
Typical	3.6 V
Maximum	NA
Power Line Slew Rate	
Minimum	1.0 V/ms
Typical	NA
Maximum	NA
Current Drain (during measurement)	
Minimum	0.5 mA
Typical	4.0 mA
Maximum	8.0 mA
Current Drain (while asleep)	
Minimum	NA
Typical	0.3 mA
Maximum	NA
Power Up Time (DDI Serial)	
Minimum	NA
Typical	NA
Maximum	200 ms

Power Up Time (SDI-12)	
Minimum	NA
Typical	430 ms
Maximum	450 ms
Power Up Time (SDI-12, DDI Serial disabled)	
Minimum	NA
Typical	165 ms
Maximum	185 ms
Measurement Duration	
Minimum	NA
Typical	150 ms
Maximum	NA

COMPLIANCE

EM ISO/IEC 17050:2010 (CE Mark)
EN 55011:2016 / A1:2017 (GROUP 1, CLASS A) (RCM Mark)

3.2 COMPONENTS

The G3 Drain Gauge is considered a passive wick lysimeter, which allows direct measurement of the deep drainage component of the water balance. It intercepts and collects a representative sample of the water that moves below the root zone. The main components of the G3 Drain Gauge are the divergence control tube (DCT), reservoir, and sampling access tube (Section 3.2.1). The G3 Drain Gauge also includes a modified HYDROS 21 sensor for continuous water level measurements (Section 3.2.2).

3.2.1 DRAIN GAUGE

The DCT, filled with a soil profile monolith, collects water infiltrating down through the soil. A specially treated fiberglass wick maintains tension on the water at the bottom of the soil monolith. Without this tension, water would pile up at the outflow boundary and force the water in the soil above to move around the G3, rather than into it. The water follows the wick into the water reservoir.

The G3 can be ordered with or without Biobarrier™ root inhibitor fabric within the wick section of the DCT. This fabric has beads impregnated with triuralin, which prevents root tip cell division, thereby acting as a root elongation inhibitor with 20 or more years of effective lifetime. This fabric has been shown to effectively keep roots from penetrating the wick section. If the fabric is not used, other steps will need to be taken to ensure roots do not grow into the wick and impede measurements.

The water is stored in the reservoir until a sample can be removed. The reservoir can collect 61 mm (2.4 in) of drainage before the water level comes in contact with the wick.

NOTE: The G3 is a completely sealed system and does not have an overflow tube. It must be emptied periodically to prevent the water level from reaching the bottom of the wick, which reduces collection efficiencies (Section 2.4).

The G3 has an access tube for the sampling tube and the HYDROS 21 sensor cable to reach from the reservoir up to the surface. The access tube can be adjusted with the included PVC tube to the needed length at installation.

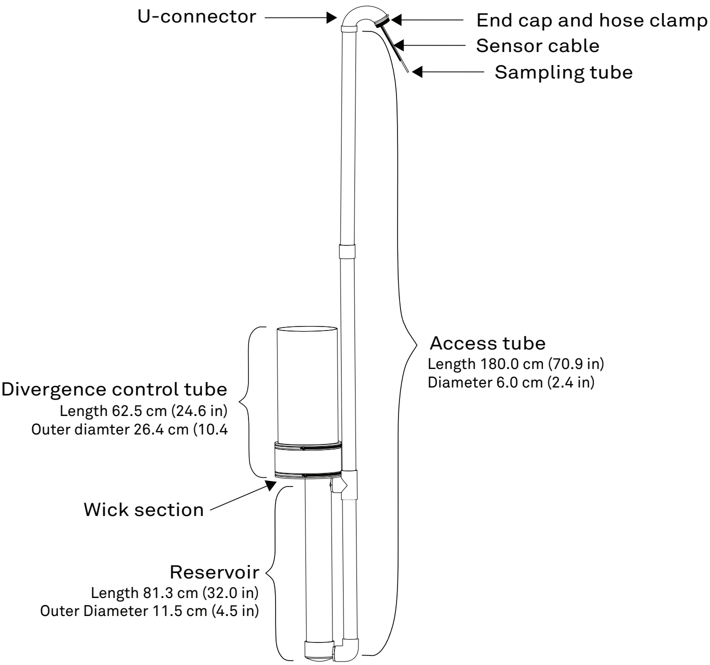


Figure 5 G3 Drain Gauge

3.2.2 SENSOR

The G3 Drain Gauge uses a modified METER HYDROS 21 sensor within the access tube to measure water level, temperature, and EC. The HYDROS 21 has a compact 3.4-cm-diameter body made of rugged Delrin® resin.

The HYDROS 21 uses a vented ceramic piezoresistive differential pressure transducer to measure the pressure from the water column to determine water depth. The reference port of the pressure transducer is vented through the cable to atmospheric pressure, so no reference barometric pressure is required. A porous Teflon® vent near the data logger end of the cable provides the reference. The Teflon keeps liquid water out of the cable but allows air to enter and leave. This vent must be kept open to the same atmospheric pressure that is applied to the water whose depth is being measured. Since the cable is conducting reference air between the sensor and the atmosphere, it is extremely important that the cable be protected from any damage that would allow water to enter.

A thermistor senses the temperature of the water. This temperature is used to adjust the EC measurements to their 25 °C value and provides the temperature output for the data stream. Stainless steel screws on the surface of the sensor form a four-electrode array to measure EC. The electronic circuitry is encapsulated in a marine-grade epoxy to protect the sensor in corrosive environments.

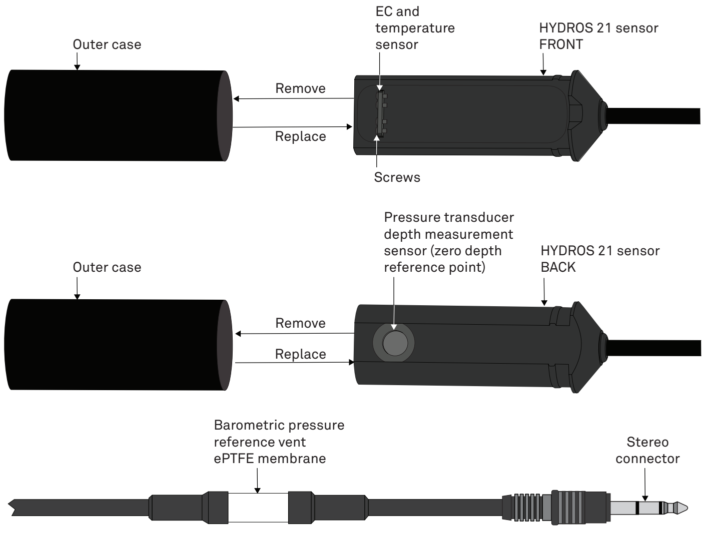


Figure 6 HYDROS 21 sensor

3.3 THEORY

This section explains the theory of the divergence and convergence of soil water, water balance, water depth, temperature, and electrical conductivity as implemented by the G3.

3.3.1 DIVERGENCE AND CONVERGENCE OF SOIL WATER

Water in the soil flows in response to differences in soil suction, which is the same as water potential, but with the opposite sign. The two components of soil suction that are important in water balance are the matric suction, which arises from the attraction between water and soil particle surfaces, and the gravitational suction, which arises from gravitational forces pulling on the soil water. Water always flows from low suction (high water potential) to high suction (low water potential). Suction in the soil generally ranges from 0 (saturation) to 100,000 kPa (air dry).

The suction at which there is no longer enough water in the soil to allow significant gravitational drainage is generally between 10 and 33 kPa. This range is known as field capacity. For water to enter a lysimeter, the suction at the intake must be equal to or greater than the suction in the surrounding soil. With traditional pan lysimeters, there is a zero-suction boundary, which means that water preferentially flows around the lysimeter intake (flux divergence) unless the soil suction is very close to zero (saturation). This results in significant underestimation of drainage rates with pan lysimeters.

The G3 uses a fiberglass wick to form a hanging water column which pulls continuous suction at the intake. In a perfect system, this suction would vary to match the matric suction of the surrounding soil allowing water to flow into the G3 in exactly the same manner as it flows through the soil. However, the wick system is only able to pull a constant suction. The suction at the top of the DCT is approximately 11 kPa (50-cm wick plus 60-cm soil column). If the soil is drier than 11 kPa, water preferentially diverges around the G3; if the soil is wetter than 11 kPa, water preferentially flows into the G3 (flux convergence). The chosen suction value of 11 kPa is an intermediate value between saturation and field capacity, which define the range of suctions where a significant amount of water drains through the soil. During very wet periods and during periods between 11 and 33 kPa of suction, the G3 may experience flux divergence. However, the overall integrated flux measurement should be close to the actual drainage.

In addition to the fiberglass wick, the G3 uses an innovative DCT that minimizes flux divergence and convergence and optimizes collection efficiency. Numerical and laboratory simulations performed by Gee et al. (2009) demonstrated the effectiveness of the DCT in preventing flux divergence and convergence around the collection point. Figure 7 shows the modeled collection efficiency of the passive wick lysimeters such as the G3 as a function of DCT height (60 cm) for six different flux rates in four different soils.

In coarse-textured or structured soils, the G3 achieves reasonable collection efficiency with the DCT even at low drainage flux rates. In nonstructured, fine-textured soils, the DCT only results in reasonable collection efficiencies at high drainage flux rates. However, the simulations were conducted with steady state drainage fluxes, which seldom (if ever) occur in nature. Typically, drainage occurs with pulsed infiltration events (e.g., rainfall, irrigation, snow melt), where relatively high drainage fluxes increase the overall integrated collection efficiency of the G3.

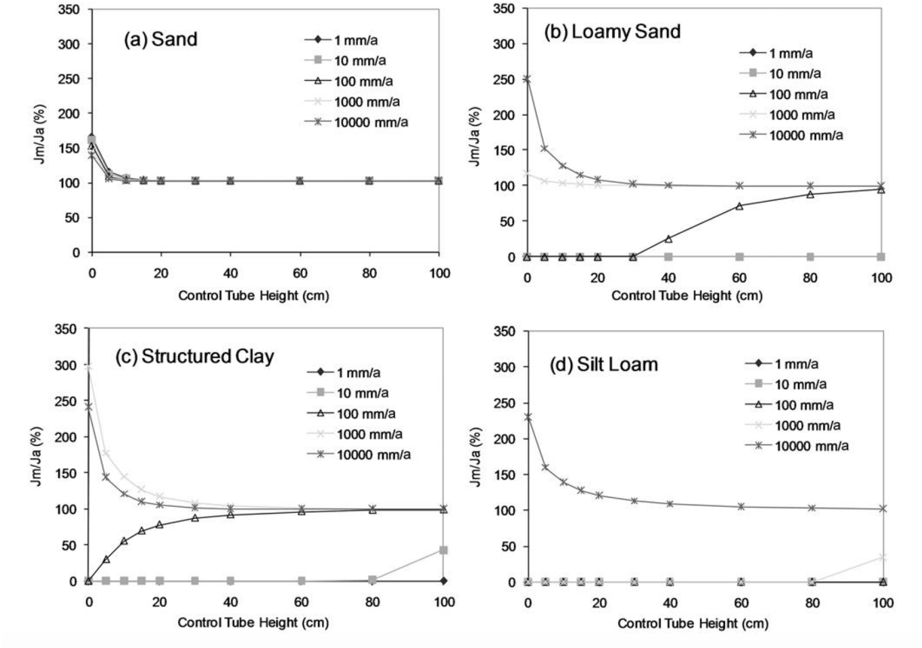


Figure 7 Simulated collection efficiency for passive wick lysimeters with 60-cm-long wicks in selected soils under a variety of steady state flux conditions and DCT heights (Gee et al. [2009]).

3.3.2 WATER BALANCE

The soil water balance is important in understanding groundwater recharge, plant water use, evapotranspiration, and the overall fate of water in the environment. An important component of the water balance is the water that drains from the bottom of the soil profile, often referred to as deep drainage or deep percolation. This is water that has gone sufficiently far below the root zone that it cannot be removed from the soil by transpiration or evaporation. The other components of the water balance can be measured, but the deep drainage typically has been computed as the residual after measuring and accounting for the other components. Because of uncertainties in the measurements of the other water balance components, deep drainage estimates were subject to large errors.

The G3 allows direct measurement of the deep drainage component of the water balance. It accomplishes this measurement by intercepting and collecting a representative sample of the water that moves below the root zone. Both the amount of sample and its chemical composition need to be representative of deep drainage in the area.

The soil water balance method is an approach that allows for calculation of one component of the water balance equation through measurement of the other components:

$$P + I - ET - D - \Delta S = 0 \qquad \textbf{Equation 2}$$

where ET is evapotranspiration, D is drainage measured by G3, P is precipitation (measured by a weather station such as ATMOS 41), and ΔS is the change in soil water storage (measured by soil moisture sensors such as TEROS 12).

3.3.3 WATER DEPTH

The HYDROS 21 sensor uses a ceramic peizoresistive differential pressure transducer to measure the pressure applied by the water column above the sensor. The HYDROS 21 uses a direct relationship between pressure and water depth to output water depth. The reference port of the pressure transducer is vented through the cable to atmospheric pressure, so the HYDROS 21 does not require a reference barometric pressure. A porous Teflon vent near the data logger end of the cable provides the reference. The Teflon keeps liquid water out of the cable but allows air to enter and leave.

Keep the vent open to the same atmospheric pressure that applies to the water and out of the water. Since the cable conducts reference air between the sensor and the atmosphere, it is extremely important to protect the cable from any damage that allows water to enter.

The HYDROS 21 measures the depth of water in the reservoir and converts the depth measurement to a cumulative drainage value based on the cross-sectional surface area of the soil (A_{soil}) and the reservoir ($A_{\text{reservoir}}$) (Section 2.4):

$$\text{Drainage (mm)} = \text{water depth (mm)} \times \frac{A_{\text{reservoir}}}{A_{soil}}$$

The cross-sectional surface area of the soil is 506.7 cm^2 and the cross-sectional surface area of the reservoir is 101.34 cm^2. So drainage is simply calculated as:

$$\text{Drainage (mm)} = \text{water depth (mm)} \times 0.2$$

3.3.4 TEMPERATURE

A thermistor near the EC sensor senses the temperature of the water. The HYDROS 21 uses the temperature to adjust the EC measurements to the 25 °C default value and provides the temperature output for the data stream.

3.3.5 ELECTRICAL CONDUCTIVITY

The HYDROS 21 uses EC to measure the concentration of salts in the water and for information about dissolved solids. The HYDROS 21 measures EC by applying an alternating electrical current to two electrodes, measuring the current flow through those electrodes, and then measuring voltage drop with a separate set of electrodes. The conductance is the ratio of current to voltage. The HYDROS 21 EC measurements are corrected to EC at 25 °C:

$$EC_{25} = \frac{EC_T}{[1+0.019(T-25)]} \quad \text{Equation 3}$$

where EC_{25} is the normalized EC at 25 °C, EC_T is the EC measured by the probe at temperature T, and T is the temperature at the time of measurement.

Conductivity is conductance multiplied by a cell constant (obtained by using conductivity standards).

NOTE: A four-electrode sensor gives unpredictable readings in air because there is no connection between the voltage and current electrodes.

4. SERVICE

This section contains calibration and maintenance guidelines for the G3 Drain Gauge. Troubleshooting solutions and customer support contact information are also provided.

4.1 CALIBRATION

METER factory calibrates the water depth and EC sensors to values stored internally in flash memory. The depth sensor is calibrated to known depths of water, and the EC sensor is calibrated using potassium chloride (KCl) solutions of known concentrations.

Table 2 relates EC at 25 °C for various concentrations of KCl, and these values can be used to verify the HYDROS 21 EC sensor performance. The value outputs from the HYDROS 21 are internally corrected to 25 °C.

Table 2 HYDROS 21 calibration values

Electrical Conductivity (mS/cm)	Concentration of KCl in Distilled Water (g/kg)
100	0.0446
200	0.0930
500	0.2456
1,000	0.5120
2,000	1.0673
5,000	2.8186
10,000	5.8758
20,000	12.2490

4.2 CLEANING

Maintaining the HYDROS 21 within the G3 Drain Gauge is essential for consistent sensor performance. Inspect and clean the HYDROS 21 frequently to prevent accumulation of microorganisms, plants, sedimentation, or other debris. Also inspect and clean the sampling tube as needed.

4.2.1 PRESSURE TRANSDUCER

The HYDROS 21 ceramic piezoresistive sensor must be protected from sediment and debris. If sediment or other debris build up on the pressure transducer, clean the membrane.

NOTE: Take care not to damage the pressure sensor.

Follow these steps to clean the HYDROS 21 pressure sensor:

1. Remove the outer cover.

   Figure 6 in Section 3.2.2 shows how to remove the cover.
2. Run water over the sensor housing and pressure sensor to remove debris.
3. If the sediment does not all come off with running water, soak the sensor in a mixture of water and dish soap for 1 h.
4. Use a Q-tip® cotton swab with very light pressure to wipe around the edges and over the pressure transducer to clean the sensing area.
5. Repeat step 2 and step 4.
6. Slide the outer cover back over the sensor.

4.2.2 ELECTRICAL CONDUCTIVITY SENSOR

The four-electrode conductivity measurement is less sensitive to sensor fouling than a two-electrode sensor, but contamination of the electrodes can still affect the measurement.

Follow these steps to clean the HYDROS 21 EC array:

1. Put on gloves.

   NOTE: Do not touch the screws without gloves or contact allow contact with any source of oil or other nonconducting residue.
2. Remove the outer cover.

   Figure 6 in Section 3.2.2 shows how to remove the cover.
3. Clean the screws using a mild detergent such as liquid dish soap and a nonabrasive sponge or cloth.

   NOTE: Avoid detergents that contain lotions or moisturizers.
4. Rinse the sensor and screws thoroughly with tap or distilled water.
5. Slide the outer cover back over the sensor.

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 3 Troubleshooting the G3 Drain Gauge

Problem	Possible Solutions
Sensor not responding	Ensure sensor is installed correctly. 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.

Table 3 Troubleshooting the G3 Drain Gauge (continued)

Problem	Possible Solutions
Sensor is not logging readings	Ensure the data logger batteries are not dead or weakened. Check configuration of the data logger in ZENTRA Utility to ensure the CTD+DG (not HYDROS 21) is selected. Ensure the most recent software and firmware are installed from metergroup.com.
Inaccurate pressure readings	Check pressure sensor to ensure it is clean and free of sediment or other debris (Section 4.2) Check for anything interfering with the opening of the vent.
Inaccurate EC readings	Check the four-electrode array and ensure it is clean and free of sediment or other debris (Section 4.2). Ensure stainless steel cover is on the bottom of the sensor housing. Contact Customer Support for a replacement if missing.
Cumulative drainage decreases over time	If the cumulative drainage is above 7 cm, the water is possibly being drawn up by the wick due to evaporative demand. Empty the reservoir more frequently. If the cumulative drainage is decreasing below 7 cm, it is possible that there is a crack in the reservoir. Contact Customer Support.

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.

REFERENCE

Gee, G. W. et al (2009). Passive wick fluxmeters: Design considerations and field applications. Water Resour. Res., 45, W04420, doi:10.1029/2008 WR007088.

APPENDIX A. AUTOPUMP INSTRUCTIONS

For remote or inaccessible installations of the G3 Drain Gauge, it may be necessary to use the AutoPump to ensure water is removed regularly from the water reservoir. The AutoPump is designed to sit on the surface near the G3 access tube.

The AutoPump sits between the data logger and the HYDROS 21 in the G3. From the perspective of the data logger, the AutoPump appears as a G3 sensor; from the perspective of the sensor, the AutoPump looks like a data logger. Use the following steps to set up the AutoPump with the G3 and data logger.

1. Slide the HYDROS 21 sensor cable through the cable gland on the lid of the AutoPump.
2. Connect the sensor cable connector to the sensor port inside the case. Leave enough slack in the cable to allow for easy opening of the case without putting stress on the connection.
3. Tighten cable gland and ensure it is tightly sealed to prevent water from leaking into the AutoPump.
4. Connect the AutoPump stereo plug connector from the case to the data logger.
5. Connect the sampling tube from the G3 to the In port on the back of the AutoPump.

   NOTE: For the older G3 Drain Gauge with the larger 0.5-in tubing, the tubing can either be replaced with a 6-mm polyurethane tubing or adapted down to the 6-mm connection using a reducer. Contact Customer Support to request replacement tubing.
6. Connect the 1-m length of 6-mm polyurethane tubing that came with the AutoPump to the Out port of the AutoPump.
7. Run the tubing from the AutoPump to the field away from the measurement area or connected into additional collection bottles on the surface.

   It is best to store additional collection bottles in a buried box to help keep sample temperatures down.

NOTE: In hot environments, it might be necessary to shade the AutoPump to prevent it from running at high temperatures. This can prematurely wear out the pump.

The pump is powered by a 12-V lead-acid battery connected via the 12-V power input jack. Each jack is labeled on the circuit board. The connectors on the AutoPump circuit board are provided in Table A.1.

Table A.1 AutoPump

Peripheral	ID	Circuit Board Connector
Drain Gauge	J1	Stereo Jack SJ-D-5
12-V power input	J5	Molex 39-29-5023, 2 CKT R/A HEAD-ER
Pump	P4	2PINRAHDR.15 2 position, 0.156 -in pitch, right angle header
Data logger	NA	Solder pads

A data logger connects to the AutoPump via the data logger solder pads on the AutoPump board. Since the AutoPump does not derive its power from the data logger, and since the Campbell data loggers do not read the DDI Serial string, a Campbell logger can connect to just the data and ground pads of the AutoPump.

The AutoPump takes an initial reading from the G3, so it always reports a value to the data logger. After that point, AutoPump attempts to read the sensor once every minute. The AutoPump stores the values from the startup string and interprets the pressure value to turn the pump on or off. The AutoPump is programmed with fixed upper and lower threshold limits. When the water level reaches the upper threshold (306 mm of water), the AutoPump turns on the pump; when the water level decreases to the lower threshold (20 mm of water), the AutoPump turns the pump off. The pushbutton on the circuit board toggles pump power and can be used to verify that the pump is operational and hooked up correctly.

The AutoPump is a Thomas Gardner SR10/50 peristaltic pump.

Table A.2 Autopump Specifications

AutoPump Dimensions	
Length	23.1 cm (9.1 in)
Width	17.3 cm (6.8 in)
Height	9.7 cm (3.8 in)
Weight	3.95 kg (8.7 lb)
Tube Dimensions	
Length	1.0 m (39.4 in) standard, custom lengths available
Outer Diameter	6.0 mm (0.5 in)
Material	Polyethylene
Operating Temperature Range	
Minimum	0 °C
Maximum	40 °C
Flow Rate	
Minimum	52 mL/min
Maximum	220 mL/min
Tubing Diameter	
6 mm	

This pump can pump air or water so it is safe to run it dry; however, the AutoPump minimizes the duration of time for which the pump runs dry to conserve battery life. While pumping, if the AutoPump misses a reading due to the sensor detaching or if it receives an error for the pressure, the AutoPump shuts off the pump.

In the event that a sensor is not attached, the AutoPump sends a response containing error values for the three readings (pressure, temperature, and EC) to the data logger. If the water level stops decreasing while pumping, the AutoPump turns off the pump; if at this point the water level is above the upper threshold, AutoPump does not turn the pump on again until after a reset (either via a power cycle or via pressing the PUMP button on the board). In all cases, the AutoPump continues to read the G3 regularly and provide the most recent reading to the data logger.

Upon receiving a power signal from the logger, the AutoPump relays the reading most recently received from the G3 using the DDI-Serial format (i.e., AutoPump sends the Startup String). The AutoPump also responds to SDI-12 commands: Measure and Concurrent commands require reading the sensor; Continuous and Verify Commands relay the values from the most recent periodic reading, with the exception of R3 which initiates a new read from the G3.

The AutoPump takes one reading from the sensor every minute. When it takes a reading, it turns off the pump if:

1. a sensor is not attached,
2. the G3 returns an error (CRC, invalid sensor type, pressure error value), or
3. the water level stops decreasing over time (i.e., either holds constant or increases).

If during the time that the pump is running the AutoPump detects four occurrences of the water level reading higher than the previous reading, the AutoPump determines that the pump is not making progress and turns off the pump. The AutoPump marks the pump as disabled and declines to turn it on again until the user resets the board or manually requests to turn on the pump via the pushbutton switch on the AutoPump. The Status LED and the Error LED flash in different patterns to reflect the current operational state of the pump and AutoPump. Refer to the Troubleshooting section for LED translations.

The depth of the water in the reservoir or volume of the removed sample can be used to calculate the total drainage since the last date the reservoir was emptied. Chemical analysis can also be performed on the sample. With the drainage rate and chemical concentration in the drainage water, the chemical flux through the soil can be calculated.

Table A.3 Troubleshooting the AutoPump and G3 Drain Gauge

Problem	Possible Solutions
AutoPump does not complete startup. LED stays constantly on and pump does not turn on and data logger cannot obtain readings. **LED FLASH CODE: Stays constantly on.**	Cycle power to the Autopump.
Water level reaches maximum threshold. **LED FLASH CODE: 3 s on and 2 s off. Pump turns on.**	Under normal conditions, pump stays on until water level reaches the minimum threshold.
No sensor attached. **LED FLASH CODE: LED blinks on, 5 s, then pumps turns off and does not come on, data logger reading contains all errors.**	Attach functional drain gauge.
Sensor returns Pressure Error. **LED FLASH CODE: LED blinks on, 5 s off. Pump turns off.** **Data logger reading contains pressure error.**	Check drain gauge. Pump should turn on again when water reaches the maximum threshold.
Water level stops decreasing before reaching minimum threshold. **LED FLASH CODE: Blink on, 5 s off, pump turns off after four measurements where water level previous water level.**	Use pushbutton to test pump operation. Check tube lengths and connections. Pump turns on again when water reaches the maximum threshold.
Water level stops decreasing above maximum threshold. **LED FLASH CODE: 1 s on, 1 s off. Pump turns off after four measurements where water level equals the previous water level. Pump does not come on again.**	Cycle power to the AutoPump or switch pump on/off via PUMP pushbutton.

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