Using the LI-300 and LI-350

Soil Moisture Sensors

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Notice

This manual contains operation and maintenance information for the LI-300 and LI-350 soil moisture sensors. Read the operating instructions before using the sensors.

The information contained in this document is subject to change without notice.

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For ReaCH (Regulation (EC) n.1907/2006) related questions, information is available on the European Chemicals Agency maintained website for the Waste Framework Directive SCIP database.

You can search by product name (for this product "LI-300"), or request an "SCIP number" from the email above.

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Standard Terms and Conditions

Section 1.
Introduction to the LI-300 and LI-350

Welcome, and thank you for your purchase of the LI-300 or LI-350 Soil Moisture Sensors. If you have just taken delivery of the product, check the packaging list to be sure you have received everything you ordered.

The LI-300 and LI-350 Soil Moisture Sensors feature stainless steel electrodes (tines) and circuitry that is enclosed in a water-tight housing and potting compound. The cable is equipped with a ferrite bead to minimize electrical interference. Cables terminate with bare leads or an M12 connector (see *Table 1-1* on the next page).

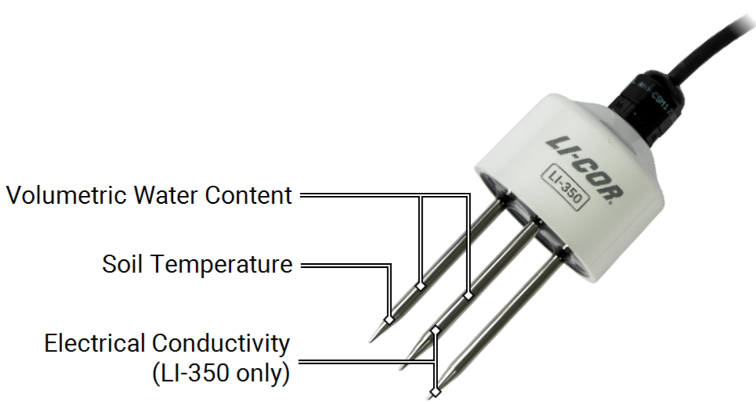


Figure 1-1. Components of the soil moisture sensor. Both the LI-300 and LI-350 have a soil temperature thermistor inside one tine. The cable includes a ferrite bead on the terminal end. The ferrite bead is required to prevent electrical interference.

The LI-300 and LI-350 measure numerous soil parameters, reporting soil volumetric water content (VWC), soil temperature, and soil electrical conductivity (LI-350 only). The LI-300 provides analog output, whereas the LI-350 is an SDI-12 device, reporting data using the SDI-12 protocol. Both sensors are available with a variety of cable lengths.

Table 1-1. LI-300 and LI-350 cable length, termination, and output options.

Name	Cable Length	Custom Cable Lengths	Termination	Output
LI-300-BL	5 m (LI-300-BL-5)	10 m, 25 m, 40 m	Bare Leads	Analog
LI-350-BL	5 m (LI-350-BL-5)	10 m, 15 m, 25 m, 50 m, 75 m	Bare Leads	SDI-12
LI-350-M12	1 m (LI-350-M12-1) 5 m (LI-350-M12-5)		M12 Connector	SDI-12

Warning: *Puncture hazard. Tips of the tines are sharp and may cause a puncture injury. Handle probes with care and keep a protective foam cover in place when the probe is not being installed or in use.*

LI-300 performance characteristics

The LI-300 provides measurement data as analog signals. It requires a power supply of 3.05 to 15 VDC, with current consumption of < 10 mA for < 12 ms while active and 1.3 mA while passive. Additional performance characteristics are given in *LI-300 specifications* on page 8-2.

LI-350 performance characteristics

The LI-350 provides measurement data as a digital signal using the SDI-12 protocol. It requires a power supply of 4 to 15 VDC, with current consumption of < 10 mA for < 12 ms while active and 500 µA while passive. Additional performance characteristics are given in *LI-350 specifications* on page 8-2.

Section 2.
Installing the LI-300 and LI-350

To ensure that you collect valid soil measurements, use great care when installing soil moisture sensors. Scrutinize data for unexpected readings, and check installations regularly and correct any issues that may introduce uncertainty into the data.

Another common error is the soil type setting not matching the soil being measured. This is less severe than a poor installation, typically, but recorded measurements still are difficult to correct.

Both of these issues are easy to solve by installing the probe carefully and configuring it correctly. We address installation concerns in this section and configuration concerns later in *Configuring the LI-350 (SDI-12)* on page 4-1.

Installation considerations

⚠ ***Warning:*** *Puncture hazard. Tips of the tines are sharp and may cause a puncture injury. Handle probes with care and keep a protective foam cover in place when the probe is not being installed or in use.*

The LI-300 and LI-350 can be installed on the soil surface or buried in a pit. For surface installations, be sure to press the tines fully in the soil. The ideal installation is in a pit with the tines fully inserted into the side of the pit and soil back-filled with the same bulk density. Do not compact the soil or create voids.

Caution: Do not touch the tines with bare hands and do not allow them to come into contact with oils or other non-conductive residues. Oily deposits can affect the measurement accuracy. Clean the tines with mild detergent and rinse with water until clean.

The pitfalls of a poor installation (things to avoid)

Whether it is installed on the surface or in a pit, the entire length of the tines must be in contact undisturbed soil in order to make accurate measurements. Any portion a tine that is exposed to open air, air pockets, or pooled water can induce errors in the measurement. *Figure 2-1* below shows common problems with poor installations.

- Press the tines into undisturbed soil.
- Do not touch the tines; oils from skin will affect measurements. Clean tines with mild detergent and water if touched.
- If a tine makes contact with a rock or root during insertion, install the probe in a different location. Do not push, as the rock may move, creating a void around the tine, or worse, the tine may bend.
- If the probe shifts after insertion, voids will be created around the tines. Install the probe in a different location.

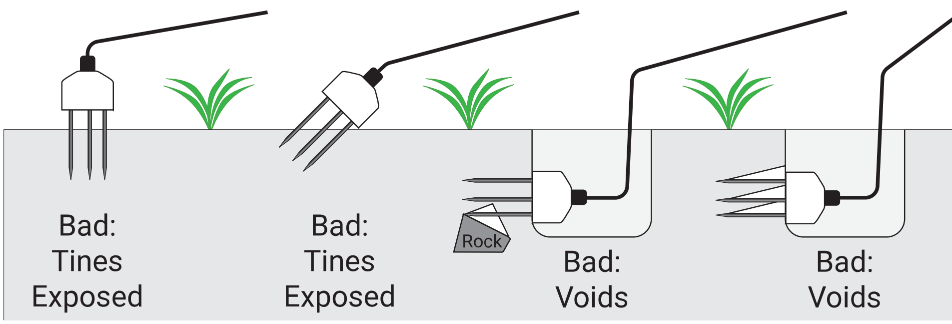


Figure 2-1. Poor installations, such as those shown, give poor quality data.

The potential of a proper installation (good, better, and best)

For the best results, follow these guidelines when installing a probe. See *Figure 2-2* on the facing page.

- Be sure that the full length of each tine is in contact with undisturbed soil.
- Surface installation is good, but burying the probe in an excavation is better. An installation depth >3 cm is best.
- If installed in an excavation, back-fill the pit with soil of the same bulk density as before excavating. Be sure the probe does not move while back-filling the pit.

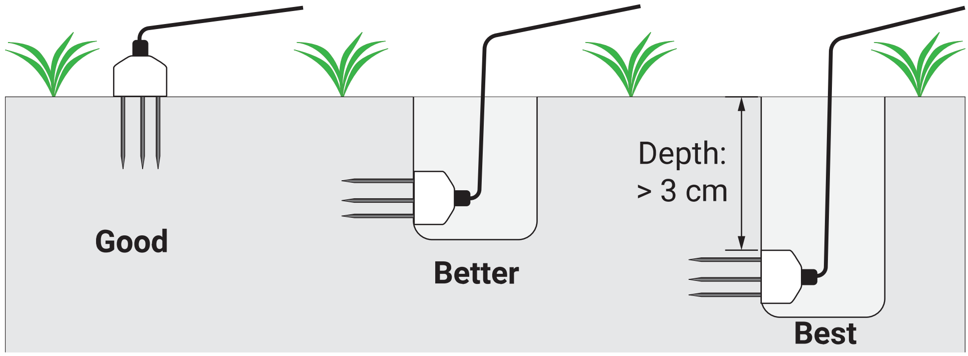
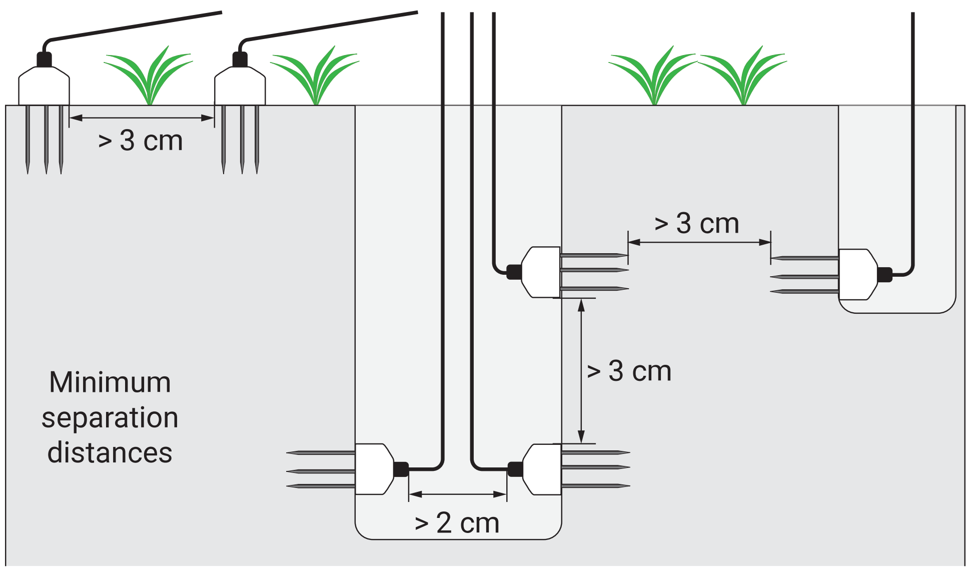


Figure 2-2. A proper installation gives the best data.

Sensor separation distances

Soil probes are sensitive to a volume that surrounds each probe. If they are too close one another, sensors may cause interference with each other. To avoid this type of interference, maintain a minimum separation of 3 cm between the tips of tines and the edges of probes. Maintain at least 2 cm between cable glands.

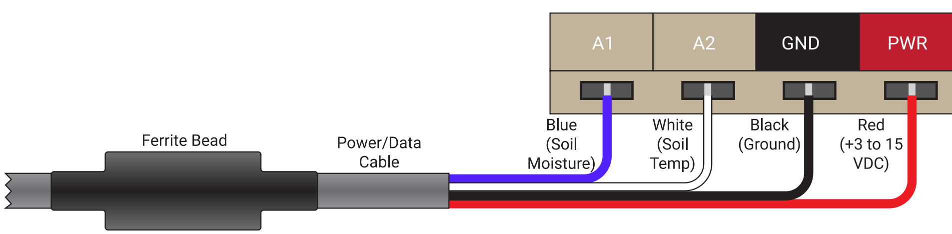


Section 3.
Configuring the LI-300 (analog)

The LI-300 provides data as analog signals. It features a single default configuration that is suitable for most soil types. You simply need to connect the leads to a suitable data logging device and scale the data logger channels to associate the voltages with soil moisture values. All LI-300 probes have the same response.

Connecting the LI-300 to an analog data acquisition device

The LI-300 provides data as analog voltage. It features a four-wire cable with assignments given in *Table 3-1* on the next page. The power supply voltage should be slightly above 3 volts. If you are using a long cable, expect the voltage to drop due to the cable length. In cases like this, be sure the power supply voltage is high enough to account for attenuation that results from the long cable.



Data are logged on two channels. One channel reports soil moisture (blue wire, voltage range of +0.5 to +2.5 V). The other channel reports soil temperature (white wire, voltage range of +0 to +2.5 V). See *Table 3-1* on the next page for wire colors and functions.

Table 3-1. Wire assignments for the LI-300.

Color	Function
Black	Ground
Red	Power (+3.05 to 15 VDC)
Blue	VWC Soil Moisture Signal (+0.5 to 2.5 V)
White	Soil Temperature Signal (+0 to 2.5 V)

Computing VWC and soil temperature

Analog voltages representing VWC and soil temperatures are non-linear. Voltages for both signals can be converted using the appropriate equation. Conversions can be carried out on the data logger or after the voltages are recorded. Use the following polynomials and equations.

VWC

The analog VWC signal covers the full range of soil moisture across the range of 0.5 to 2.5 volts. 0.5 V is the reading in air; 2.5 V is the reading in water. The signal is converted to VWC by applying equation 3-1 with the appropriate coefficients in *Table 3-2* below.

Table 3-2. VWC parameters for mineral soil and soil-less media for the LI-300.

Parameter	Mineral	Soil-less
a_4	0.462950	0.224644
a_3	-2.464058	-1.141152
a_2	4.602823	2.033601
a_1	-3.238826	-1.136964
a_0	0.746572	0.184659

The VWC equation is

$$VWC = a_4 V_{cal}^4 + a_3 V_{cal}^3 + a_2 V_{cal}^2 + a_1 V_{cal} + a_0 \qquad 3\text{-}1$$

Soil temperature

The soil temperature signal covers a temperature range of –40 to 60 °C across a voltage range or 0 to 2.5 V. The signal is converted by applying the following equation and coefficients.

$$T = V\left(\frac{4.095}{2.5} \times 27\right) - 40 \qquad 3\text{-}2$$

Section 4.
Configuring the LI-350 (SDI-12)

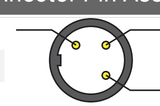
This section describes how to apply new settings on the LI-350 using a terminal program and SDI-12-to-USB adapter.

Connecting the LI-350 to an SDI-12 data acquisition device

The LI-350 provides a digital output using the SDI-12 protocol. LI-350 sensors that feature the M12 connector are designed for use with some compatible LI-COR products. For these sensors, all functions are exposed in the device interface. Normally, you won't need to configure the connectorized LI-350 beyond applying some settings in the host device. Never-the-less, see *Table 4-1* below for wire assignments.

LI-350 sensors that feature bare leads can be configured using a datalogger or an SDI-12-to-USB adapter.

Table 4-1. Wire assignments for the LI-350.

Color	Function	M12 Connector Pin Assignments
Black	Ground	1: Power  4: Ground
Red	Power (4 to 15 VDC)	
White	Data	3: Data
Bare	Connects to ground	

SDI-12 translator tutorial

The following items are required to complete this tutorial:

- **LI-350 soil moisture sensor** (SDI-12; bare leads).
- **SDI-12-to-USB Translator** (e.g., vegetronix.com translator or Dr. John Liu adapter liudresllc.com).
- **Personal Computer** (Windows 10/11).
- **Terminal Emulator** (e.g., Tera Term).

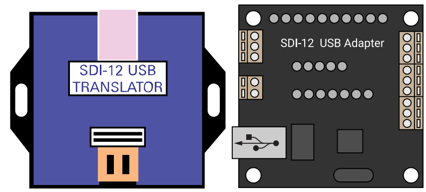


Figure 4-1. SDI-12-to-USB translators allows communication with the soil moisture sensor.

You will connect the wires from the soil moisture sensor to the data and ground connectors on the translator. Depending on the translator, you may need to power the sensor from an external power supply (see *Figure 4-2* below).

Connecting to a computer with an SDI-12 translator

Connect the soil moisture sensor to the SDI-12 translator and power supply, and then connect the USB cable to your computer. The computer will establish a COM port, which may be indicated in the notifications or found in the Device Manager.

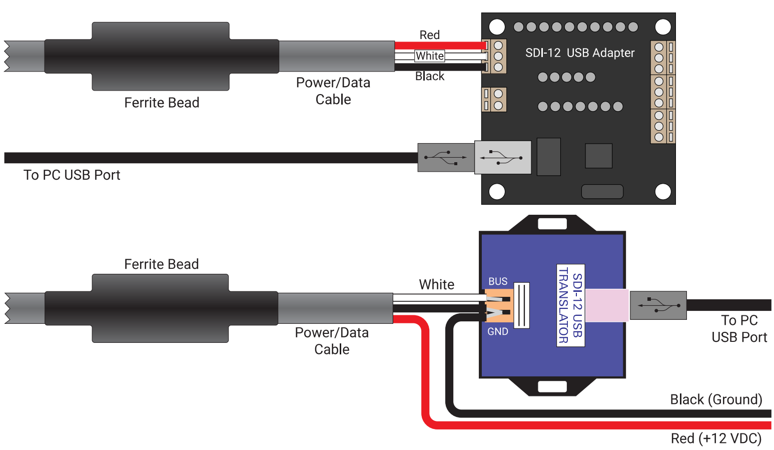


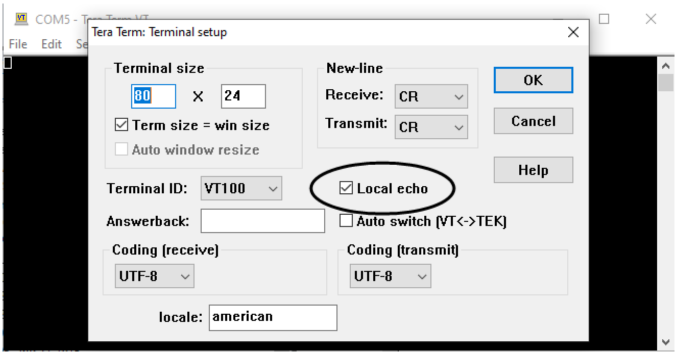
Figure 4-2. The Liu SDI-12 Adapter (top) can power the soil probe via the USB power. With the Vegetronix SDI-12 Translator (bottom), the soil probe must be powered externally. In either case, data from the probe can be read in a terminal program.

To connect to the SDI-12 translator:

1. Launch a terminal program, such as Tera Term.
2. Select **Serial** as the connection type, select the port for the USB translator, and then click **OK**.

   In the default configuration, Tera Term will pass your keystrokes directly to the COM port - you will not see what you have typed. Change the setting under **Setup > Terminal**, and check **Local Echo** and your keystrokes will appear in the terminal, along with replies from the sensor. This is a matter of convenience - so you can see what you are sending to the device.

Note: The **New-line Receive** and **Transmit** settings must be CR.



Communicating with a command-line interface

This section presents a variety of commands and replies that you can use to configure and view data from the device. This is a practical tutorial; you won't do this when the LI-350 is deployed. You will do this to observe the configuration and familiarize yourself with the data structure. Normally, communication with the probe (including data logging) will be carried out by a data logger.

Vegetronix translator only: Use transparent mode

If using the Vegetronix translator, queries must be sent in transparent mode. This is accomplished by preceding the command with a capital `T` and a space. So, instead of `?!`, you'll send `T ?!`.

Get the address

To request the address of the sensor connected to the SDI-12 bus, enter the following. Remember the `T` if using the Vegetronix translator.

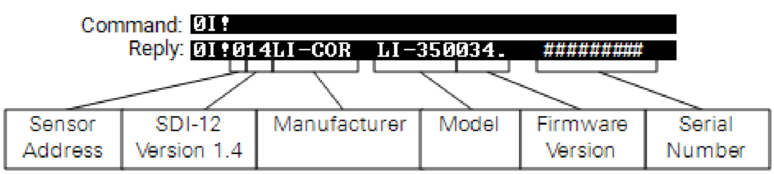
- **Command:** `?!`
- **Reply:**`0`

The number in the reply (`0` in this case) is the connected sensor's address. Replies are presented in the same line as the command.

Device information

Each probe is configured with an address of 0 by default. The first time you connect to a probe, it should be the only device attached to the SDI-12 array. After connecting initially, you can set the address and then power up the remaining SDI-12 devices.

- **Command:** `0I!` (the address (`0`), the capital letter `I` for information, and an exclamation point). Remember the `T` if using the Vegetronix translator.
- **Reply:** `014LI-COR LI-350034. #########` (identifying information for the sensor, including the device address, manufacturer, model, firmware version, and serial number)



Change the address

LI-350s can be addressed with alphanumeric characters (0 to 9, A to Z, and a to z). To change a sensor's address, the command starts with the current address followed by a capital A for address, and then the new address.

- **Command:** `0A1!` (the address (`0`), capital letter `A` for address, the number `1`, which is the new address, and the exclamation point)
- **Reply:** `1` (the new address)

Query the soil type setting

Mineral soil is the default soil setting. To see the current soil type setting, enter the following the command.

- **Command:** `0XST!` (the address (`0`), the command `XST`, and the exclamation point `!`)
- **Reply:** `Mineral_Soil` (the soil type)

Change the soil type setting

To change the soil type setting, enter the command, with the new soil type.

- **Command:** `0XSTM!` (the sensors address (`0`), the command `XST`, and the exclamation point `!`), where `M` represents the new soil type (mineral, in this case).
- **Reply:** `Mineral_Soil` (the soil type)

Soil type options are `M` for mineral soil, `SL` for soil-less media, `C1` for custom 1, and `C2` for custom 2. Custom soil types require custom calibration coefficients to be loaded, as described in *Custom calibrations for the LI-350* on page 5-1.

Get new data

Enter the `M` command to instruct the LI-350 to perform a new measurement.

- **Command:** `0M!` (address (`0`), the command `M`, ending with `!`).
- **Reply:** `00003`

Display the new data

Enter the following to report the new data.

- **Command:** `0D0!` (address (`0`), the command `D0` for data group 0, ending with `!`.
- **Reply:** The data (#, ####, ##.##, #) Sensor Address, Calibrated Counts (Moisture; signed 32-bit integer), Soil Temperature (°C), Electrical Conductivity (µS/cm).

To read the latest data, do both *Get new data* above and *Display the new data* above.

Basic SDI-12 commands

With the letter `a` as a proxy for sensor address, you can send the following commands to the LI-350. Remember the `T` if using the Vegetronix translator. Refer to the documentation for your adapter for more details.

Sensor information commands

Table 4-2. Basic commands can query the sensor and set some basic settings, such as soil type.

Command	Description	Expected Response
`aI!`	Identify sensor	LI-COR LI-350 + SW_Version.Serial_Number
`aXST!`	Query soil type	Returns current soil type - String
`aXST<char>!`	Set soil type `M` - Mineral_Soil `SL` - Soilless_Media `C1` - Custom1 `C2` - Custom2	Returns soil type stored in memory after update - String

Report data commands

Table 4-3. Summary of commands that report data.

Command	Description	Expected Response
`aM!`	Retrieve new data	a0003!
`aD0!`	Report the data	Address <ASCII> Soil Moisture - Calibrated Counts <int32> Temperature - °C <float> EC - µS/cm (temperature corrected) <int32>
`aM1!`	Retrieve new data (group 1)	a0005!
`aD0!`	Report the data	Address <ASCII> VWC - m^3/m^3 <float> EC - µS/cm (temperature corrected) <int32> Temperature - °C <float> Temperature - °F <float> EC - µS/cm (no temperature correction) <int32>
`aM2!`	Retrieve new data (group 2)	a0009!
`aD0!`	Report the data	Address <ASCII> VWC - m^3/m^3 <float> Temperature - °C <float> EC - µS/cm (temperature corrected) <int32> Raw Counts <int32>
`aD1!`	Report the data	Address <ASCII> Calibrated Counts <int32> Soil Moisture Zero <int32> Soil Moisture Span <float> EC - µS/cm (no temperature correction) <int32> EC Span <float>
`aM3!`	Retrieve new data (group 3)	a0006!

Table 4-3. Summary of commands that report data. (...continued)

Command	Description	Expected Response
`aD0!`	Report the data	Address <ASCII> VWC - m^3/m^3 - Mineral Soil <float> VWC - m^3/m^3 - Soil-less Media <float> Temperature - °C <float> EC - µS/cm (temperature corrected) <int32> Dielectric Permittivity - unitless <float> Calibrated Counts <int32>

Extended SDI-12 Commands

Additional commands allow you to adjust the calibration of the sensor. These should be used with caution, as some of these command will adjust the sensor response.

Endmember calibration commands

Table 4-4. Commands related to air and water calibrations (endmembers).

Command	Description	Expected Response
`aXMA!`	Perform an air calibration	ACK (NOTE: this changes the sensor response!)
`aXMW!`	Perform a water calibration	ACK (NOTE: this changes the sensor response!)
`aXSA!`	Query air calibration value	Current air calibration value - Int
`aXSA<(int)>!`	Set air calibration value	Air calibration stored in memory after update - Int
`aXSW!`	Query water calibration value	Current water calibration value - Int
`aXSW<(int)>!`	Set water calibration value	Water calibration stored in memory after update - Int

Electrical conductivity correction commands

Table 4-5. Commands related to electrical conductivity correction.

Command	Description	Expected Response
aXCA!	Query A electrical conductivity correction	Current A factor for correction SMS += $A \times (EC)^2$
aXCA<(float)>!	Set A electrical conductivity correction	Value stored in memory after update - Float
aXCB!	Query B electrical conductivity correction	Current B factor for correction SMS += $B \times (EC)$
aXCB<(float)>!	Set B electrical conductivity correction	Value stored in memory after update - Float

Electrical conductivity commands

Table 4-6. Commands related to electrical conductivity calibration coefficients.

Command	Description	Expected Response
aXEA!	Query coefficient of electrical conductivity EC_3 factor	Current electrical conductivity A factor - Float
aXEA<(float)>!	Set coefficient of electrical conductivity EC_3 squared factor	Electrical conductivity A factor stored in memory after update - Float
aXEB!	Query coefficient of electrical conductivity EC_2 factor	Current electrical conductivity B factor - Float
aXEB<(float)>!	Set coefficient of electrical conductivity EC_2 factor	Electrical conductivity B stored in memory after update - Float
aXEC!	Query coefficient of electrical conductivity EC_1 factor	Current electrical conductivity C factor - Float
aXEC<(float)>!	Set coefficient of electrical conductivity EC_1 factor	Electrical conductivity C stored in memory after update - Float
aXES!	Query electrical conductivity span	Current value of electrical conductivity span - Scientific Notation
aXES<float>!	Set electrical conductivity span	Electrical conductivity span stored in memory after update - Scientific Notation
aXEK!	Query electrical conductivity span	Current value of electrical conductivity span - Scientific Notation
aXEK<float>!	Known electrical conductivity, Calculate span; Calculates the EC span using a user-provided EC value at 25 °C. Value is normalized using measured temperature	Electrical conductivity span stored in memory after update - Scientific Notation

Volumetric water content commands

Table 4-7. Commands related to volumetric water content calculations. VWC coefficients can only be changed when using a custom soil type.

Command	Description	Expected Response
aXVA!	Query coefficient of soil a_4 factor	Current volumetric water content a_4 factor - Float
aXVA<(float)>!	Set coefficient of soil a_4 factor	Volumetric water content a_4 stored in memory after update - Float
aXVB!	Query coefficient of soil a_3 factor	Current volumetric water content a_3 factor - Float
aXVB<(float)>!	Set coefficient of soil a_3 factor	Volumetric water content a_3 stored in memory after update - float
aXVC!	Query coefficient of soil a_2 factor	Current volumetric water content a_2 factor - Float
aXVC<(float)>!	Set coefficient of soil a_2 factor	Volumetric water content a_2 stored in memory after update - Float
aXVD!	Query coefficient of soil a_1 factor	Current volumetric water content a_1 factor - Float
aXVD<(float)>!	Set coefficient of soil a_1 factor	Volumetric water content a_1 stored in memory after update - Float
aXVE!	Query coefficient of soil offset	Current volumetric water content offset - Float
aXVE<(float)>!	Set coefficient of soil offset	Volumetric water content offset stored in memory after update - Float

Dielectric permittivity commands

Table 4-8. Commands related to dielectric permittivity calculations.

Command	Description	Expected Response
aXDA!	Query coefficient of dielectric permittivity E_3 factor	Current value of coefficient - Scientific Notation
aXDA<float>!	Set coefficient of dielectric permittivity E_3 factor	Set coefficient value stored in memory - Scientific Notation
aXDB!	Query coefficient of dielectric permittivity E_2 factor	Current value of coefficient - Scientific Notation
aXDB<float>!	Set coefficient of dielectric permittivity E_2 factor	Set coefficient value stored in memory - Scientific Notation
aXDC!	Query coefficient of dielectric permittivity E_1 factor	Current value of coefficient - Scientific Notation
aXDC<float>!	Set coefficient of dielectric permittivity E_1 factor	Set coefficient value stored in memory - Scientific Notation

Table 4-8. Commands related to dielectric permittivity calculations. (...continued)

Command	Description	Expected Response
`aXDD!`	Query coefficient of dielectric permittivity E_0 factor	Current value of coefficient - Scientific Notation
`aXDD<float>!`	Set coefficient of dielectric permittivity E_0 factor	Set coefficient value stored in memory - Scientific Notation

Note: Coefficients have a resolution of eight digits. V commands can only be edited if the device is configured for Custom 1 (C1) or Custom 2 (C1) soil types.

Responses may include the following error codes.

Code	Reply	Description
00	-	No error
01	UNKNOWN_CMD	Unknown command
02	INVALID_INPUT	Invalid input
03	EEPROM_WRITE_FAIL	Write failure
04	INPUT_OUTSIDE_BOUNDS	Value is outside allowed bounds
	CANNOT_OVERRIDE_PRESETS	Some presets cannot be changed
99	UNKNOWN_ERROR	Unknown error

The SDI-12 implementation follows the specifications at https://www.sdi-12.org/current_specification/SDI-12_version-1_4-Jan-30-2021.pdf.

Section 5.
Custom calibrations for the LI-350

The LI-350 is calibrated at the factory to read accurately in mineral soil and soil-less media (such as coconut coir, peat, or potting soil). You can improve the accuracy of the sensor by developing a calibration curve that describes the sensor response in soils with a different composition. Below we provide the steps for a user calibration for the LI-350.

Equipment

The user calibration requires some equipment. Gather everything before you start.

- Trowel or shovel to collect a bulk sample of soil.
- Container for samples (e.g., large resealable plastic bags).
- 2-mm sieve to break up clumps.
- Calibration container with volume sufficient to surround the soil moisture sensor and the volume-of-influence around the probe with sampled soil. A piece of PVC pipe with diameter >20 cm (8 inches) and height >26 cm (10 inches) and an end cap is a suitable container. Weigh the clean, dry container and record the clean dry weight.
- Drying oven with suitable drying pans.
- Large scale (capacity >10 kg; resolution >0.1 g).
- Small scale (resolution >0.01 g).
- Soil moisture sensors to be calibrated.

Tips for success

If it is your first time, acquaint yourself with the entire process before you start. Allow several days to compete the full protocol. The adage applies: Plan your work;

work your plan.

- Measure samples promptly after collection. Samples may change in storage.
- If samples must be stored, keep them closed in a refrigerator or on ice in a cooler.

Custom calibration procedure

The multi-point custom calibration procedure can provide more accurate measurements in situations where soils are dramatically different from the default soil types provided with the probe. You can apply the custom calibration to each sensor to record calibrated measurements, or you can record raw counts from the LI-350 and apply the custom calibration later on a datalogger or with a spreadsheet.

Regardless of the when you apply the custom calibration, you'll use the following procedure to develop new coefficients. The steps for applying the coefficients to a custom calibration (C1 or C2) in the sensor are in *Applying a custom calibration* on page 5-7. The steps for post-processing to convert raw counts are in *Converting calibrated counts with a custom calibration* on page 5-9. A detailed procedure for custom calibrations follows:

1 Collect a bulk sample of at least four liters of soil.

Samples must represent the soil that will be measured and should be taken from the same depth and general area where the probe will be deployed.

2 Sieve and air dry the soil bulk sample.

Press the soil through a 2-mm sieve to break up clumps and separate rocks and other large particles. Allow the soil to dry in ambient air. Spread the bulk sample in a thin layer in a well-ventilated space to speed up the drying.

3 Determine the mass of and volume of the bulk sample.

A Put the bulk sample into a container and pack it to the same density as in the field.

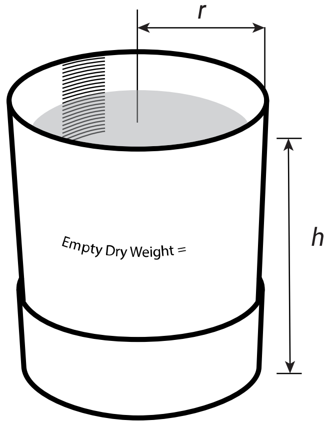
You may need to add the soil in layers, packing each layer before adding the next. Add or remove soil and record the height in the container (h).

B Record the mass of the bulk sample (M_{bs}).

You can either weigh the container with soil and then subtract the container tare weight from the combined weight, or you can place the empty dry container on the balance and tare the balance before adding the bulk sample.

C Compute initial volume of the bulk sample (V_{bs_1}).

Use $V_{bs_1} = \pi \times r^2 \times h$, where r is the radius of the vessel and h is the height of the soil in the container, then record the volume of the bulk sample.



4 Determine the volumetric water content of the air-dried bulk sample.

A Collect a small subsample from the bulk sample.

B Measure the <u>m</u>ass of the <u>s</u>ub-<u>s</u>ample, <u>a</u>ir-dried (M_{ssa}) using the small scale with fine resolution.

C Dry the sub-sample.

Spread the sub-sample in a thin layer on a drying sheet and dry at 60 to 70 °C for 48 hours.

D When drying is complete, obtain the <u>m</u>ass of the <u>s</u>ub-<u>s</u>ample, <u>o</u>ven-dried (M_{sso}):

You can either weigh the sub-sample container with the subsample and then subtract the container tare weight from the combined weight, or place the empty dry container on the balance and tare the balance before adding the sub-sample.

E Calculate dry <u>v</u>olumetric <u>w</u>ater <u>c</u>ontent the <u>a</u>ir-<u>d</u>ried bulk sample (VWC_{ad}).

$$VWC_{ad} = \frac{M_{ssa} - M_{sso}}{M_{sso}} \tag{5-1}$$

5 Calculate the dry mass of the bulk sample.

The mass of the bulk sample must be corrected for the initial H_2O present:

$$M_{bsd} = M_{bs} - (M_{bs} \times VWC_{ad}) \tag{5-2}$$

yielding the <u>m</u>ass of <u>b</u>ulk <u>s</u>ample, <u>d</u>ry (M_{bsd}) that will be used for the calibration calculations.

6 Check and set the zero (in air) and full-scale (in water) calibrations (optional).

Although sensors are calibrated at the factory and sensor-to-sensor variation is low, you may improve performance by setting the zero and full-scale readings.

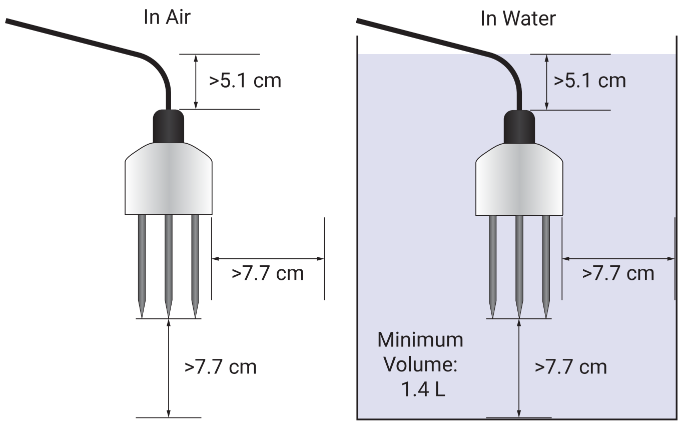


Figure 5-1. The probe should be far from interfering elements during calibration. While in water, use a volume that is greater than 1.4 L and be sure the tines are at least 7.7 cm (3 inches) from the container walls.

A While the probe is in air, perform the in-air calibration:

Command: `aXMA!` (use the address of your sensor if different from `0`)

Reply: `ACK`

B While the probe is in DI water, perform the in-water calibration:

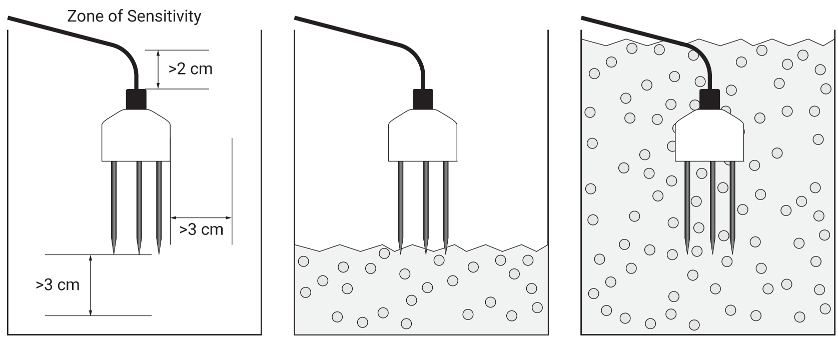
Command: `aXMW!`

Reply: `ACK`

7 Record the first coefficient.

A Insert the probe into the bulk sample.

Remove soil, insert the probe, and repack the soil around the probe. For best results, add layers of soil and pack each layer before adding more. Pack the soil to match the bulk density before collection.



B Record the raw counts reported by each sensor in the air-dried bulk sample.

- **Command:** `aM3!` (the measure command).
- **Reply:** `ACK`
- **Command:** `aD0!` (report measurement group 3).
- **Reply:** The data (e.g., 0-0.007+0.038+22.96+0+3.05+2928)

The final value in this group is calibrated counts. If using multiple sensors, compute the average of responses at each wetness level. If these values show an appreciable difference from sensor to sensor, that is a clue that there may be a problem with the setup, such as air pockets or voids near tines, for example. Try to determine why you have unexplained variation, then consider redoing the procedure.

8 Develop the rest of the coefficients.

With the starting mass of dry media known, the calibration consists of a series of steps where the probes to calibrate are inserted into the soil and a measurement of raw counts made and recorded.

A Place the bulk sample in container for mixing.

B Add a known mass of water.

200 grams of water is a good starting place, but you may need to use more or less. The objective is to assess sensor response to 6 to 8 evenly spaced VWC levels between dry and fully saturated. Choose a mass that accomplishes this.

C Mix the water with the soil, breaking up clumps and kneading to a uniform consistency.

D Pack the moistened bulk sample into the calibration container and record the volume, if different from before (V_{bs_2}).

This new volume is the volume term used to compute VWC at this moisture level. If volume has not changed, use the same value as before.

E For each addition of water, compute the new mass of H_2O and a new VWC_g.

$$M_{H2O_2} = M_{bsw_2} - M_{bsd} \qquad \text{5-3}$$

M_{bsw_2} is the mass of the bulk sample after the first wetting. M_{bsd} is mass of the bulk sample after drying. M_{H2O_2} is the mass of water in the sample after the first wetting.

$$VWC_{g_2} = \frac{M_{H2O_2}}{V_{bs_2}} \qquad \text{5-4}$$

V_{bs_2} is the volume of bulk sample after the first wetting. VWC_{g_2} is the gravimetric volumetric water content (m^3/m^3).

F Install the sensor in the moistened bulk sample.

G Record the raw counts reported by each sensor for this sample.

H Repeat these steps until the soil is saturated, creating a calibration curve with 6 to 8 steps.

Table 5-1. Example of a data table showing sensor response (raw counts) to incremental wetness levels.

Water Added	VWC_{g*}	Sensor 1	Sensor 2	Sensor 3	Avg. Response
None (dry)		e.g. 986			
e.g. 200 g		e.g. 1620			
e.g. 400 g		e.g., 3585			
e.g. 600 g		e.g. 4654			
e.g. 800 g		e.g. 5479			
e.g. 1000 g		e.g. 7278			
e.g. 1200 g		e.g. 11225			
e.g. 1400 g		e.g. 15670			

9 Generate a calibration function for the soil type using the average sensor response and VWC_{g*}.

You can plot the data in a spreadsheet or with your favorite statistics program. The calibration function will be a fourth-order polynomial, but lower order polynomials may work too. Use your judgment to determine which fits the data best.

The highest-order polynomial leads to VWC = 1 in water. You many not be interested in such wet conditions, and are willing to accept large errors in the full-saturation range, a lower-order polynomial can give better accuracy in dry soils. This could be useful if, for example, you are interested in high accuracy in the 0 to 50% VWC range, but less concerned with VWC from 50% to 100%.

Furthermore, you can remove some unrealistic data points from the fit and improve the accuracy of readings in a narrower range of VWCs.

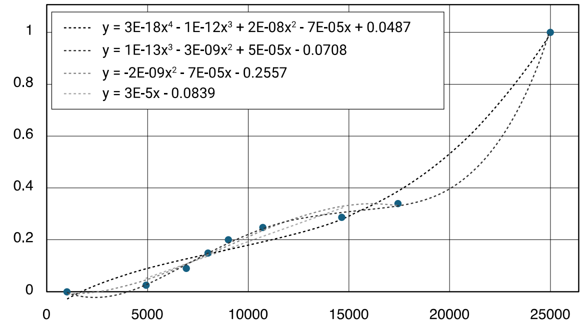


Figure 5-2. An example of calibration data from a test sensor. Both the 4th- and 3rd-order polynomials use the full range of test data. The 2nd-order polynomial eliminates the full range value and the linear fit eliminates the two highest and one lowest value. Example coefficients are in Table 5-2 below.

The calibration for a soil type can be determined by a regression of the sensor response and the calculated gravimetric VWC. The coefficients are new values used in equation 7-2. The LI-350 sensor supports coefficients for up to 4th order polynomial, however a lower order curve may be appropriate, in which case the coefficients for the higher order components can be set to 0.

Applying a custom calibration

After following the procedure to develop custom calibration parameters, you'll load them for one of the custom calibrations (C1 or C2). Be sure you have the coefficients with resolution of eight digits.

Note: Values for VWC coefficients, when displayed as a reply to a user-entered command, are in scientific notation and typically rounded to 5 decimal places. The value you write to them is NOT rounded and is written to memory in “float type” precision. This means the value you write to the sensor is properly being saved but when reported back to you will be rounded.

Table 5-2. Coefficients to be applied, depending on which curve is preferred from *Figure 5-2* above. Your coefficients, which will be different, should have a resolution of 8 digits.

Parameter	4th Order	3rd Order	2nd Order	Linear
a4	3.18259e-17	0	0	0

Table 5-2. Coefficients to be applied, depending on which curve is preferred from Figure 5-2 above. Your coefficients, which will be different, should have a resolution of 8 digits. (...continued)

Parameter	4th Order	3rd Order	2nd Order	Linear
a3	-1.12441e-12	1e-13	0	0
a2	2.00235e-08	-3e-9	-2e-9	0
a1	-7.60457e-05	5e-5	-7e-5	3e-5
a0	0.048707	-0.0708	-0.2557	-0.0839

Here's how:

1 Configure the probe for a custom calibration.

If using a terminal emulator, connect to the probe and use local echo mode so you can see your text entries. Assuming an address of `0`, enter the following:

- **Command:** `aXSTC1!` to configure C1 (or `C2` for C2)
- **Reply:** `0Custom1`

2 Send the new parameter.

The following command will load the new value for parameter <a4>, using a made up value in place of a4. Use scientific notation for simplicity and eight digits for accuracy.

- **Command:** `aXVA2.23259E-17!`
- **Reply:** The new value.

3 Check the new value (optional).

- **Command:** `aXVA!`
- **Reply:** The value for <new parameter>.

4 Repeat this with the other parameters.

Send the commands `aXVB<a3>!`, `aXVC<a2>!`, `aXVD<a1>!`, `aXVE<a0>!` with the new parameters. After all new parameters are loaded, the new calibration is available as the custom calibration (C1 or C2).

> **Note:** Values for VWC coefficients, when displayed as a reply to a user-entered command, are in scientific notation and typically rounded to 5 decimal places. The value you write to them is NOT rounded and is written to memory in “float type” precision. This means the value you write to the sensor is properly being saved but when reported back to you will be rounded.

5 Test the calibration (optional).

To confirm the performance of the calibration, it is a good idea to check the zero and full-range readings. For additional assurance, you can check one or more readings with different soil moisture levels.

Converting calibrated counts with a custom calibration

In this example, you'll configure the LI-350 to record calibrated counts. Calibrated counts are normalized to the zero and full range readings. These data are used to apply a custom calibration after the data are logged. You can apply the calibration via a spreadsheet, programmed datalogger, or a computer program. In the following section, we show the steps for creating the custom calibration function and the steps for processing the data in a spreadsheet.

If you record raw counts instead of calibrated counts, you can apply the calibration to the data, along with the sensor-specific zero and span that normalizes readings from sensor to sensor. You'll use whichever function you choose (three of the four options are likely a poor choice) and the polynomial values in the equation to convert counts to measurements.

G3 =(A$3*(F3^4))+(B$3*(F3^3))+(C$3*(F3^2))+(D$3*(F3))+E$3

	A	B	C	D	E	F	G	H	I	J
1		Calibration Polynomial				Calibrated Counts	Results			
2	a4	a3	a2	a1	a0	Vcal	VWCg			
3	3.18E-17	-1.12E-12	2.00E-08	-7.60E-05	4.80E-02	10	0.05			
4						5500	0.08			
5						6578	0.15			
6						7584	0.24			
7						8354	0.31			
8						9612	0.44			
9						10585	0.55			
10						12563	0.82			

Figure 5-3. Vcal is the actual sensor response (Vraw) from zero (Z) and full range values.

Section 6.
Maintenance and troubleshooting

The LI-300 and LI-350 are not user-serviceable. The devices will not require maintenance beyond cleaning and changes to the configuration and calibration settings.

Cleaning the sensor

Oils from skin can be deposited while handling, and this may affect the measurement accuracy. If the tines are dirty (soil from a prior installation or oil from any source, including hands), clean them with a mild detergent, water, and a soft cloth. Rinse the sensor with tap or deionized water after cleaning.

Caution: Do not touch the tines with bare hands and do not allow them to come into contact with oils or other non-conductive residues. Oily deposits can affect the measurement accuracy. Clean the tines with mild detergent and rinse with water until clean.

⚠ ***Warning:*** *Puncture hazard. Tips of the tines are sharp and may cause a puncture injury. Handle probes with care and keep a protective foam cover in place when the probe is not being installed or in use.*

Troubleshooting

If your sensor is not performing as expected, review these troubleshooting steps.

Readings unreasonable (too low or negative)

Low or negative readings may result from an improper setting or a poor installation.

- **Wrong soil type setting?**
  Check the soil type setting and be sure it is suitable for the soil being measured.
- **Air gaps around tines?**
  If part of a tine is in air or an air gap, or if it is within a few cm of the soil surface, the measurements may include the effects of the air, leading to low or negative readings. Air gaps can form if large solid objects in the soil become dislodged by a tine during installation or if the sensor is not inserted fully. Check the installation to confirm that there are no air gaps and that the tines are too close to the surface.
- **Something besides soil in the measurement volume?**
  Roots and rocks in the volume of sensitivity around the sensor can affect the measurement. You can install the sensor in a different place, collect a larger sample size, or take other steps to ensure that the data collected represents your measurement goals.
- **If using a custom calibration, are the coefficients correct?**
  Double check your work developing coefficients and verify that the coefficients that are loaded correctly on the sensor.

Readings unreasonable (too high)

Unreasonable high readings may result from an improper setting or soil compaction.

- **Wrong soil type setting?**
  Check the soil type setting and be sure it is suitable for the soil being measured.
- **Soil expressively compacted?**
  Hard packed soil can lead to high readings. Be sure the soil being measured is representative of the site. Do not install the sensor on walking paths, roadways, or soils that have become artificially compacted.
- **If using a custom calibration, are the coefficients correct?**
  Double check your work developing coefficients and verify that the coefficients that are loaded correctly on the sensor.

Reported values are 0, NAN, 99, change erratically, or do not change

Issues described below will be indicated by the SDI-12 performance (LI-350 only). If measurements are not recorded or are incorrect, check the following.

- **Device address and program address incorrect?**
  Check either the device address and the address expected by the program. If they are not the same, change one so they match. All SDI-12 sensors must have a unique address. Double check device addresses to be sure there are not conflicts.
- **Sensor not powered?**
  Be sure the power wire is connected to the power supply. Check the power supply voltage with a voltmeter to be sure it is providing enough power.
- **Data wire not connected?**
  Check the data wire to be sure it is connected to the correct channel.

Section 7.
Summary of measurement principles

The LI-300 and LI-350 use established principles of dielectric permittivity to compute volumetric water content and electrical conductivity of the soil medium.

Normalized output

Measurements from each soil moisture sensor are standardized to real moisture scenarios using the end-points of water content: dry (zero) and immersed in DI water (maximum). The calibration function incorporates a zero (offset) adjustment and a slope (span) adjustment in the following form:

$$V_{cal} = (V_{raw} - Z)\,S \tag{7-1}$$

where V_{raw} is the initial sensor output, Z and S are factory parameters unique to each sensor. The calibrated sensor output is then used to calculate volumetric water content:

$$VWC = a_4 V_{meas}^4 + a_3 V_{meas}^3 + a_2 V_{meas}^2 + a_1 V_{meas} + a_0 \tag{7-2}$$

where VWC is volumetric water content (m^3/m^3) and a_4 through a_0 are soil-type specific calibration parameters. For mineral soils, values are in *Table 7-1* below.

Table 7-1. VWC parameters for mineral soil and soil-less media for both the LI-350 and LI-300. The factory calibration also provides parameters for a soil-less media.

	LI-350 (SDI-12)		LI-300 (Analog)	
Parameter	Mineral	Soil-less	Mineral	Soil-less
a_4	2.23259e-17	7.70525e-18	0.462950	0.224644
a_3	-9.79441e-13	-3.10523e-13	-2.464058	-1.141152
a_2	1.39235e-8	4.03550e-9	4.602823	2.033601

Table 7-1. VWC parameters for mineral soil and soil-less media for both the LI-350 and LI-300. The factory calibration also provides parameters for a soil-less media. (...continued)

	LI-350 (SDI-12)		LI-300 (Analog)	
Parameter	Mineral	Soil-less	Mineral	Soil-less
a_1	-4.60457e-5	1.07338e-5	-3.238826	-1.136964
a_0	3.18707e-2	-2.07032e-2	0.746572	0.184659

Z and *S* parameters can be computed on start-up from stored values of raw counts made in air and in water. Each sensor will then have V_{cal} = 1000 counts in air and 20000 counts in water. This gives a 19000 count range corresponding to a volumetric water content range of 0 to 1 m^3/m^3, or 190 counts per change of 0.01 m^3/m^3.

The LI-300 analog probe is zeroed and spanned at the factory to provide a calibrated output voltage range. The user must provide appropriate calibration coefficients for the soil type being measured to compute VWC (see *Table 7-1* on the previous page).

Factory calibration routine

The calibration requires measurement in air and water to calculate parameters *Z* and *S*, and then writing these values to memory (V_{air} and V_{water}, respectively). Upon start-up, *S* and *Z* are computed from those measurements:

$$Z = \frac{25V_{air} - V_{water}}{24} \tag{7-3}$$

$$S = \frac{1000}{V_{air} - Z} \tag{7-4}$$

Factory calibration setup

The calibration measurements are made in a manner that isolates the probe from any nearby influences on the measurement. Raw counts are stored to the device memory. The volume of influence of the VWC measurement extends beyond the edges of the sensor itself by a significant margin (*Figure 7-1* on the facing page). Thus, the measurements in air and water should be made in sufficient volume to account for this.

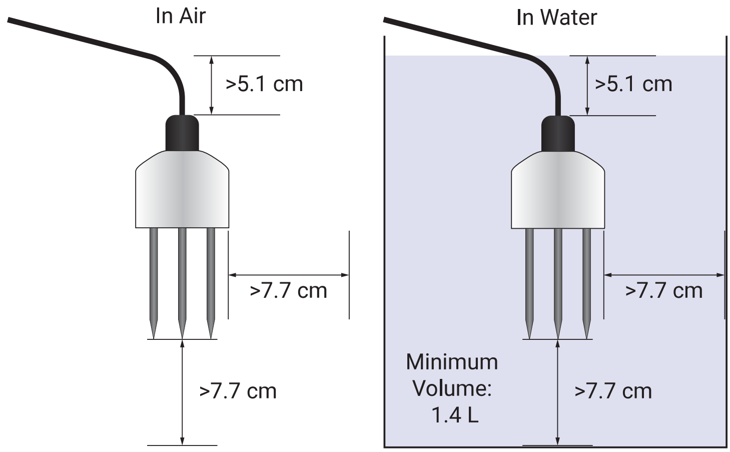


Figure 7-1. The volume of influence around the probe in all directions. During calibration and deployment, this volume should be free from interfering influences.

Testing indicates that the measurement influence extends 2 cm above the top of the cable gland and 3 cm beyond the tips of the tines (height ~ 16 cm), horizontally 3 cm beyond the edge of the probe housing (radius = ~ 5.25 cm), for a measurement volume ~ 1.4 L.

The probe responds quickly to H_2O, reaching within 0.1% of the final value within 20 seconds.

Temperature measurement

The LI-300 and LI-350 have a thermistor inside one tine. The thermistor responds quickly to temperature changes, but thermal mass of the tine limits the rate of temperature changes. Typically, the tine will reach equilibrium temperature within a few seconds. In the LI-350, voltage is converted to T (°C) internally. With the LI-300, you'll need to apply equation 3-2 to convert the voltage to temperature.

Dielectric permittivity

Dielectric permittivity is computed by the LI-350 and is available MX230x dataloggers. Dielectric permittivity is not computed on the analog probes (LI-300s), but some loggers can compute apparent dielectric permittivity (ϵ_a) using the Topp equation (Topp et al., 1980), which was published as a way to compute VWC from ϵ_a.

We have inverted the Topp equation to compute ϵ_a and then generated an equation for ϵ_a from the raw sensor output (V_{cal}). LI-350s do report this parameter for logging on MX230x HOBO loggers.

Due to the shape of the sensor response and the desire for the two ends to align with theory (ϵ_a of air = 1, ϵ_a of water = 80), a polynomial is used to compute ϵ_a from V_{cal}.

$$\epsilon = E_3 VWC^3 + E_2 VWC^2 + E_1 VWC + E_0 \tag{7-5}$$

Parameters for the LI-350 are given in *Table 7-2* below.

Table 7-2. Parameters used for dielectric permittivity in the LI-350.

Parameter	Value
E_3	-155.81260
E_2	247.67700
E_1	-12.69459
E_0	2.95259

Electrical conductivity

Electrical conductivity (EC) is computed with

$$I = \frac{V_L}{100+R_d} \tag{7-6}$$

where I is current through the solution, R_d is the microcontroller resistance (average value measured at 33.8 ohms) and V_L is ADC counts at the EC tine.

Calibration of the R value using a known resistance is not necessary. R_{sens} is computed from

$$R_{sens} = \frac{V_H - V_L}{\frac{V_L}{100+R_d}} \tag{7-7}$$

where R_{sens} in ohms is the resistance through the soil, V_H and V_L are the ADC counts from the two tines. Conductance is the reciprocal of resistance:

$$C_{sens} = \frac{V_L}{(V_H - V_L)(100+R_d)} \times 1E6 \tag{7-8}$$

where C_{sens} is conductance in microSiemens (µs). We include a cell constant (K) in units of cm^{-1} so that reported conductance is reported in units of µs/cm

$$C_{sens,cm} = C_{sens} K \tag{7-9}$$

A 3rd order polynomial is used to describe the EC measurement

$$EC = EC_3 C_{sens}^3 + EC_2 C_{sens}^2 + EC_1 C_{sens} \qquad 7\text{-}10$$

where EC is the conductivity computed at the measurement temperature.

Parameter	Value
EC_3	4.06958e-12
EC_2	8.87316e-07
EC_1	1.38449e-01

Finally, the value is be normalized to 25 °C with

$$EC_{\mu S,cm} = \frac{EC}{1+0.019\times(T_{meas}-25)} \qquad 7\text{-}11$$

where EC is from equation 7-10 and T_{meas} is the probe temperature in C.

References

1 Topp, G.C., Davis, J.L., and Annan, A.P. (1980). Electromagnetic Determination of Soil Water Content: Measurements in Coaxial Transmission Lines. Water Resources Research, [online] 16 (3), pp.574–582. https://doi.org/10.1029/WR016i003p00574.

Section 8.
Specifications

Specifications subject to change without notice.

General

General specifications apply to both the LI-300 and LI-350.

Volume of Influence: 1400 mL
Response Time in Water: < 20 seconds to 90%
Sensor Drift: < 0.01 °C per year
Weight (excluding cable): ~77 g (2.72 oz.)

Volumetric water content

Range: 0.0 to 1.0 $m^3\ m^{-3}$
Resolution: 0.001 $m^3\ m^{-3}$
Accuracy[a]:
±0.03 $m^3\ m^{-3}$ typical
±0.06 $m^3\ m^{-3}$ maximum

Dielectric permittivity[b]

Range: 1 (air) to 80 (water) dielectric permittivity units
Resolution: 0.002 dielectric permittivity units
Accuracy: ±1.0 dielectric permittivity units

Temperature

Range: –40 to 70 °C

[a]For factory calibration soils.

[b]Specifications exclude errors from the Topp (1980) approximation.

Resolution: 0.1 °C
Accuracy:
±0.5 °C from –40 to –20 °C
±0.3 °C from –20 to 70 °C

Electrical conductivity (bulk)

Range: 0 to 20000 $\mu S\ cm^{-1}$
Resolution: 1 $\mu S\ cm^{-1}$
Accuracy:
±5 % from 0 to 10000 $\mu S\ cm^{-1}$
±8 % from 10000 to 20000 $\mu S\ cm^{-1}$

LI-300 specifications

Power Requirements:
Input Voltage Range: 3.05[a] to 15 VDC
Average Idle Current Consumption (typical): 1.3 mA
Average Active Current Consumption: < 10 mA for < 12 ms
Power On Current Peak: 160 mA for 200 µs
Warmup Time (power on to valid DAC output): < 25.0 ms
Output Signals: Analog Voltage
VWC (Soil Moisture) Range: 0.5 to 2.5 V
Temperature Range: 0.0 to 2.5 V

LI-350 specifications

Power Requirements:
Input Voltage Range: 4.0[b] to 15 VDC
Average Idle Current Consumption (typical): 500 µA
Average Active Current Consumption: < 10 mA for < 12 ms
Power On Inrush Current Peak: 160 mA for 10 ms
Warmup time: < 50 ms
Output Signal Type: SDI-12
Digital I/O Signal Voltage Range: 3.6 to 5.0 V

[a]Does not include margin for cable voltage drop and power supply voltage dips.
[b]Can operate down to 3.05 V but the voltage levels of the SDI-12 bus will no longer be SDI-12 compliant.

Dimensions

Both LI-300 and LI-350 probes have the same external dimensions.

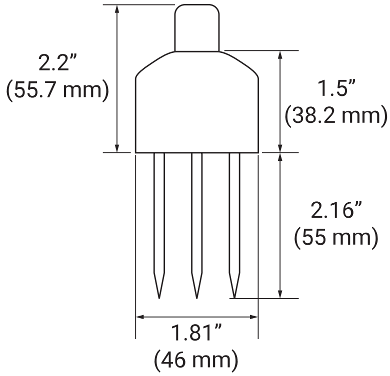


Figure 8-1. External dimensions of the LI-300 and LI-350.

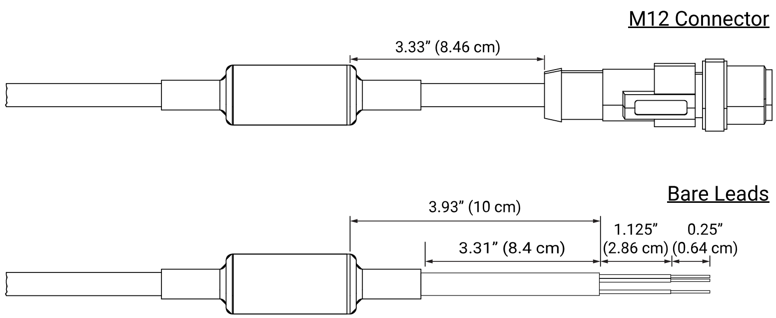


Figure 8-2. Cable termination dimensions for the M12 connector and bare leads.

Standard Terms and Conditions

1. General. LI-COR Inc. ("LI-COR") is delivering these goods and products ("Products") and/or performing services ("Services") subject to these Terms and Conditions of Sale ("Conditions"). Buyer will be deemed to have assented to these Conditions upon Buyer's placement of order. Notwithstanding the above, failure of LI-COR to object to provisions contained in any purchase order or other form or document from Buyer shall not be construed as a waiver of these Conditions nor an acceptance of any such provision.

2. Buyer's Use Only/No Resale. The purchase of Products only conveys to Buyer the non-transferable right for only Buyer to use the quantity of Products and components of Products purchased in compliance with the applicable intended use statement, limited use statement or limited label license, if any, in LI-COR catalogues or on the label or other documentation accompanying the Products (all such statements or licenses being incorporated herein by reference as if set forth herein in their entirety). Buyer has no right to resell the Products, or any portion of them to a third party outside Buyer's corporate organization, and any such purchase by a reseller for the purpose of resale is strictly prohibited unless LI-COR first accepts and approves a purchase order and acknowledges in writing that the Products may be resold by Buyer and the terms of such resale.

3. Prices/Taxes. All prices are quoted for delivery to Buyer when goods are loaded on the carrier at LI-COR premises in Lincoln, Nebraska, USA exclusive of shipping, insurance and installation charges, all of which are Buyer's sole responsibility. All prices are exclusive of all sales, use, excise, value added, withholding and other taxes, all customs, duties, documentation charges, and freights forwarder charges and charge of any nature now or hereafter claimed or imposed by any governmental authority upon the sale of the Products or performance of the Services. Any such charges will be added to the product invoice or subsequently invoiced to the Buyer. In the event LI-COR is required to pay any such tax, duty or charge, Buyer will promptly reimburse LI-COR.

4. Payment Terms. All payments shall be made in immediately available U.S. Dollars net thirty (30) days from the date of invoice for qualified accounts, without set-off, deduction or withholding of any kind, unless otherwise stated by LI-COR in writing and may be paid by check (drawn on a U.S. bank), wire transfer or major credit card. All open account invoicing must be pre-approved. Any amounts not paid when due will accrue interest at the rate of 1 1/2% per month, or the maximum amount allowed by law, if lower. In the event that any payment is more than thirty (30) days late, LI-COR shall have the right to suspend doing business with Buyer until all past due balances are made current. Buyer shall pay for all costs (including reasonable fees) incurred by LI-COR in connection with the collection of late payments. Each accepted purchase order is a separate, independent transaction, and Buyer has no right of set-off against other purchase orders or other transactions with LI-COR. Buyer hereby grants LI-COR a security interest in the Products or any deliverable in the amount of the unpaid balance of the purchase price until paid in full. LI-COR may file a financing statement for such security interest and Buyer shall sign any such statements or other documentation necessary to perfect LI-COR security interest.

5. Return Policy. Buyer may return non-consumable Products to LI- COR within forty-five (45) days of invoice date only with prior authorization by LI-COR. The Product(s) being returned new and unused condition and must be resalable as new. Any returned Product(s) are subject to payment of a fifteen percent (15%) re- stocking fee on all items returned. Buyer shall be responsible to make payment to LI-COR for any and all expenses related to de-installation of the Product(s), including but not limited to shipping, duties, and taxes. All payments subject to this provision shall be made to LI-COR within thirty (30) days of return, or de- installation, of the Product(s).

6. Delays In Performance. LI-COR shall not be liable for any delay in performance hereunder due to unforeseen circumstances or due to circumstances beyond its control including, but not limited to, acts of nature, acts of government, labor disputes, delays in transportation, delays in customs clearance and delays in delivery or inability to deliver by LI-COR suppliers.

7. Shipment and Packing. All Product prices exclude costs of shipping and handling and insurance, in accordance with delivery terms designated by LI-COR. Unless otherwise agreed in writing, such costs will be paid by the Buyer and will appear as a separate item on LI-COR invoice. LI-COR shall ship in accordance with LI-COR standard practices. Buyer may specify different shipping instructions, subject to agreement by LI-COR. Unless otherwise agreed to in writing by LI-COR, all products shall be packaged, if appropriate, for shipment and storage in accordance with standard commercial practices. All packing shall conform to carrier requirements.

8. Partial Shipments. LI-COR reserves right to make delivery in partial shipments ("Installments"). Any Products delivered in Installments may be invoiced individually and is payable subject to Section 4 of these Conditions. Additional shipping and handling charges for Installments may apply. Delay in delivery of any Installment shall not relieve Buyer of Buyer's obligation to accept remaining deliveries.

9. Title/Risk of Loss. All domestic shipments are made FOB per Uniform Commercial Code. All international shipments are made per INCOTERMS 2020 designated by LI-COR. Title to the Products and the risk of loss of or damage to the Products ordered by the Buyer will pass to Buyer at time of LI-COR delivery of Products to the carrier. The carrier shall be deemed Buyer's agent, and any claims for damages in shipment must be filed with the carrier. LI-COR is authorized to designate a carrier pursuant to LI-COR standard shipping practices unless otherwise specified in writing by Buyer.

10. Intellectual Property Rights. Title to and ownership of the documentation, and any improved, updated, modified or additional parts thereof, and all copyright, patent, trade secret, trademark and other intellectual property rights embodied in the Products, shall at all times remain the property of LI-COR or LI-COR licensors.

11. Acceptance. All sales are final and all Products shall automatically be deemed accepted upon delivery to Buyer when goods are loaded on the carrier at LI-COR premises in Lincoln, Nebraska, USA. Failure to provide written notice to LI-COR of any shortages, defects, or damages relating to the Products within fifteen (15) days after receipt shall conclusively deem that the Products conform to the terms set forth in these Conditions. Buyer may not return any Products to LI-COR except as provided for by LI-COR warranty or as provided herein.

12. Product Warranties. Unless otherwise specified by LI-COR:

a) LI-COR warrants that, for a period of twenty-four (24) months from the date of shipment of the Products from LI-COR (the "Warranty Period"), unless otherwise specified for individual Products (such as products with a specified shelf life) or extended by a Support Contract or Extended Warranty Contract (the "Extended Warranty"), the Products sold hereunder will be free from material defects in materials and workmanship and will conform to LI-COR published specifications in effect as of the date of manufacture. LI-COR SPECIFICALLY DISCLAIMS ANY INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES (INCLUDING LOSS OF USE OR LOST PROFITS) WHICH MAY RESULT FROM THE USE OF PRODUCTS PURCHASED HEREUNDER, AS FURTHER SET FORTH IN SECTION 13 OF THESE CONDITIONS OF SALE. This limited warranty extends only to Buyer as original purchaser unless otherwise agreed upon in writing by LI-COR.

b) The foregoing warranty/extended warranty coverage shall not apply if the defective Product (i) has been subjected to abuse, misuse, neglect, negligence, accident, improper testing, improper installation, improper storage, improper handling or use contrary to any instructions issued by LI-COR, (ii) has been repaired or altered by persons other than LI-COR, (iii) has been moved/relocated once originally installed unless LI-COR approved deinstall/reinstall procedures are followed; (iv) has not been installed, operated, repaired and maintained in accordance with the documentation or operated outside of the environmental specifications for the Product; (v) has failed due an Act of God, including but not limited to fire, flood, tornado, earthquake, hurricane or lightning or (vi) has been used with any devices, accessories or products not manufactured by or approved by LI-COR. In addition, the foregoing warranty shall not apply to Products (i) marked or identified as "sample," (ii) loaned or provided to Buyer at no cost, or (iii) which are sold "as is."

c) If during the Warranty/Extended Warranty Period: (i) LI-COR is notified promptly in writing upon discovery of any defect in the Product, including a detailed description of such alleged defect, (ii) such Product is returned, transportation charges prepaid, to LI-COR designated manufacturing facility subject to the prior approval of LI-COR with a valid Return Material Authorization ("RMA") number, and (iii) LI-COR inspections and tests determine that the Product is indeed defective and the Product has not been subjected to any of the conditions set forth above, then, as Buyer's sole remedy and LI-COR sole obligation under the foregoing warranty, LI-COR will, at LI-COR option, repair or replace without charge the defective Product. In no event will the Buyer itself nor will the Buyer allow any party other than LI-COR or a third party authorized in writing by LI-COR to perform any service on the Products.

d) Any Product that has either been repaired or replaced under this warranty shall have warranty coverage (parts only) for the longer of one (1) year or the remaining original warranty period. Replacement parts and/or replacement Products used in the repair or replacement of Products may be new or equivalent to new at LI-COR sole discretion.

e) EXCEPT FOR THE WARRANTIES SET FORTH IN THIS SECTION, LI-COR MAKES NO OTHER WARRANTIES, EXPRESS, IMPLIED OR STATUTORY, WITH RESPECT TO ANY SERVICES, PRODUCTS OR OTHER PRODUCTS PROVIDED IN CONNECTION WITH THESE CONDITIONS, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTY OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, NONINFRINGEMENT, OR ARISING FROM COURSE OF PERFORMANCE, DEALING, USAGE OR TRADE.

f) Notwithstanding anything herein to the contrary, LI-COR makes no warranty with respect to any third party products provided under these Conditions. Buyer's sole remedy with respect to such third party products shall be pursuant to the original manufacturer's or licensor's warranty, if any, to Buyer, to the extent permitted by the original manufacturer or licensor.

13. Limitation of Liability. IN NO EVENT SHALL LI-COR, ITS LICENSORS OR ITS SUPPLIERS BE LIABLE TO BUYER OR ANY THIRD PARTY FOR COSTS OFPROCUREMENT OF SUBSTITUTE PRODUCTS OR SERVICES, LOST PROFITS, DATA OR BUSINESS, OR FOR ANY INDIRECT, SPECIAL, INCIDENTAL, EXEMPLARY OR CONSEQUENTIAL DAMAGES OF ANY KIND ARISING OUT OF OR IN CONNECTION WITH THE USE OF THE PRODUCTS OR THESE CONDITIONS, HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY (WHETHER IN CONTRACT, TORT (INCLUDING NEGLIGENCE), STRICT LIABILITY, PRODUCTS LIABILITY OR OTHERWISE). LI-COR TOTAL AND CUMULATIVE LIABILITY ARISING OUT OF OR IN CONNECTION WITH ANY PRODUCTS PURCHASED BY BUYER OR SERVICES PERFORMED BY LI-COR ON BEHALF OF BUYER HEREUNDER SHALL IN NO EVENT EXCEED THE PURCHASE PRICE PAID BY BUYER FOR SUCH PRODUCTS OR SERVICES. THE LIMITATIONS SET FORTH IN THIS SECTION SHALL APPLY EVEN IF LI-COR OR ITS SUPPLIERS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, AND NOTWITHSTANDING ANY FAILURE OF ESSENTIAL PURPOSE OF ANY LIMITED REMEDY.

14. Severability. If any portion of these Conditions is held invalid, the parties agree that such invalidity shall not affect the validity of the remaining portions of these Conditions.

15. Export Control. Buyer acknowledges and agrees that the Products purchased under these Conditions or Services performed by LI-COR may be subject to restrictions and controls imposed by the United States Government and the regulations thereunder. BUYER WARRANTS THAT IT WILL NOT EXPORT OR RE-EXPORT ANY PRODUCTS PURCHASED OR DELIVERABLES FROM SERVICES PERFORMED BY LI-COR WITHOUT PRIOR WRITTEN NOTIFICATION AND APPROVAL OF LI- COR.

16. Assignment. Buyer shall not assign or transfer these Conditions or any rights or obligations under these Conditions, whether voluntary or by operation of law, without the prior written consent of LI-COR. LI-COR may freely assign these conditions. LI-COR or any successor may assign all or part of the right to payments under these Conditions. Any assignment or transfer of these Conditions made in contravention of the terms hereof shall be null and void. Subject to the foregoing, these Conditions shall be binding on and inure to the benefit of the parties' respective successors and permitted assigns.

17. Entire Agreement. These Conditions of Sale and Performance of Services take precedence over Buyer's additional or different terms and conditions, to which notice of objection is hereby given. Acceptance by Buyer is limited to LI-COR Conditions of Sale. Neither LI-COR commencement of performance nor delivery shall be deemed or construed as acceptance of Buyer's additional or different terms and conditions. These Conditions supersede all prior communications, transactions, and understandings, whether oral or written, and constitute the sole and entire agreement between the parties pertaining to the referenced quotation or purchase order, provided that: (1) these Conditions shall not, without LI- COR prior written consent, supersede any conflicting terms of: (a) prior written agreements duly executed by LI- COR, or (b) governmental purchase orders, terms of purchase, requests for quotation or acquisition regulations relative to governmental purchasers; and (2) to the extent not in conflict with any such prior or governmental terms, these Conditions shall supplement them. No modification, addition or deletion, or waiver of any of the terms and conditions of these Conditions shall be binding on either party unless made in a non-preprinted agreement clearly understood by both parties to be a modification or waiver, and signed by a duly authorized representative of each party.

18. Force Majeure. Shipping/delivery dates are approximate and may be delayed absent prompt receipt from Buyer of all necessary information. LI- COR shall not be responsible for any failure to perform or delay attributable in whole or in part to any cause beyond its reasonable control, including but not limited to Acts of God, government actions, war, civil disturbance, insurrection, sabotage, labor shortages or disputes, failure or delay in delivery by LI-COR suppliers or subcontractors, transportation difficulties, customs clearance, shortage of energy, raw materials or equipment, or Buyer's fault or negligence. In the event of any such delay the date of delivery shall, at the request of LI-COR, be deferred for a period equal to the time lost by reason of the delay.

19. Governing Law and Venue. These Conditions and performance by the parties hereunder shall be construed in accordance with the laws of the State of Nebraska, U.S.A., without regard to provisions on the conflicts of law.

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