TOIP Pty Ltd
Telemetry Over Internet Protocol

# User Manual

# MP02

# Single Level Soil Moisture Sensor

Version 2.5
June 2016

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# 1 MP02 Sensors

This manual is written for the MP02 soil moisture probe.

The MP02 returns soil moisture and soil temperature. It is idea for use in shallow rooted crops.

The sensor communicates using the SDI-12 protocol and can be sued with any SDI-12 compatible data logger or telemetry unit.

# 2 Specifications

| Unit | Parameter | Value |
|---|---|---|
| All | Dimensions | Length 140mm Width 29mm Depth 9mm |
| | Supply Voltage | 6 to 16V V DC 21mA |
| | Output | SDI-12 |
| | Measurement Time | 1 sec |
| Temperature | Range | -40 to + 85 °C |
| | Accuracy | -40 to +5 : +/- 1 °C<br>+5 to +60 : typ _+/- 0.2 °C, max +/- 0.4 °C |
| | Resolution | 0.01 °C |
| Soil Moisture | Range | 0 to 100 % |
| | Accuracy | Dependent on calibration for soil type |
| | Resolution | 0.04% |

# 3 Installation

The sensor may be installed horizontally or vertically in the soil.

Horizontal installation is preferred as there is then no impediment to water movement past the sensor. When installing horizontally, the sensor should be installed on edge.

Install the sensor as follows:

- Dig a hole in the soil to the required depth
- Remove any stones or debris from the hole
- Sieve the soil removed from the hole
- Place the sensor at the bottom of the hole
- Cover the sensor with the sieved soil
- Pour sufficient water into the hole to cover the sensor then allow the water to drain away
- As the soil will compact when it is wetted up, add more soil and then water. Repeat until the sensor is completely covered.

# 4 Wiring

The sensor should be wired according to the colour code shown in the table below – the bottom line shows the most recent colour code.

| **Power** | **SDI-12** | **Ground** |
|---|---|---|
| Red | White | Blue |
| Green | White | Brown |
| Red | Yellow | Brown |
| Blue | Green/Yellow | Brown |

# 5 SDI-12 Commands

The sensor can be configured using a variety of standard and extended SDI-12 commands.

| | | |
|---|---|---|
| aI! | | Return sensor information |
| aM! | aC! | Soil moisture level [%] |
| aM1! | aC1! | Soil moisture [%] and soil temperature [°C] |
| aM2! | aC2! | Soil temperature [°C] |

| | |
|---|---|
| aXCA! | Perform air calibration |
| aXCW! | Perform water calibration |
| aXCT! | Perform temperature calibration |
| aXSAnn! | Set the number of readings to be averaged when making a measurement |
| aXSTnn.nn! | Set scaling factor |
| aXSMt,dry,sat,max! | Set parameters for Min & Max during calibration<br>max. 7 digits for a, b; max. 5 digits for c, d; the decimal point may be at any position |
| aXSCn! | Set calibration method<br>n = 0 : min – max<br>n = 1 : Polynomial |
| aXSD! | Restore default settings |

| | |
|---|---|
| 1. Sensor address: | 0 |
| 2. Soil scaling coefficient: | 1 |
| 3. Temperature unit: | Celsius |
| 4. Temperature offset: | 0 |
| 5. Soil type: | 0 air/water calibration |
| 6. Polynomial coefficients: | a = 0; b = 0; c = 1; d = 0 |
| 7. Calibration method: | Min-max |

| | |
|---|---|
| aXGSt! | Select soil type for measurement |
| 0 | Air-Water calibration |
| 1 | Sand |
| 2 | Potting Soil |
| 3 | 50% mineral 50% organic |
| 4 to 9 | User Defined |
| aXSSt,a,b,c,d! | Set coefficients for soil type t using a polynomial equation of the form $SMcal = ax^3 + bx^2 + cx + d$ |
| aXGA! | Query number of samples set for averaging of the soil moisture value(how many times the sensor is read before |

| | |
|---|---|
| | taking the average and saving it) |
| aXGP! | Query number of samples set for gliding averaging of the soil moisture value (moving average based on last values) |
| aXGT! | Query soil type |
| aXGCT! | Query temperature calibration offset |

# 6 Driver Setup

This section shows the parameters to use when setting up a driver for the sensors in various telemetry systems and data loggers.

- Air Temperature:
  - Name MP02 SM
  - Manufacturer Tekbox
  - Type Soil Moisture
  - Engineering Unit Soil Vol %
  - Icon Soil Moisture
  - Technology SDI
  - Address S
  - Command M
  - Method 1
  - Index 0
  - Use CRC No (un-checked)
  - Measure Time 2 sec
  - Sensor Supply Time 2 sec
  - Sequential Measurement No (un-checked)
  - Sensor Always On No (un-checked)
  - Linear input value min 0 max 2.5
  - Linear output value min 0 max 2.5
  - Verifier min 0 max 100
  - Display scale min 0 max 60
  - Level Above Ground 0
- Soil Temperature:
  - Name MP02 ST
  - Manufacturer Tekbox
  - Type Soil Temperature
  - Engineering Unit Temperature $^{o}C$
  - Icon Temperature
  - Technology SDI
  - Address S
  - Command M
  - Method 1
  - Index 1
  - Use CRC No (un-checked)
  - Measure Time 2 sec

- Sensor Supply Time 2 sec
- Sequential Measurement No (un-checked)
- Sensor Always On No (un-checked)
- Linear input value min 0 max 2.5
- Linear output value min 0 max 2.5
- Verifier min -40 max 60
- Display scale min 0 max 40
- Level Above Ground 0

# 7 Configuring the Sensor

The sensor is configured using Extended SDI-12 commands.
By default the sensors are set to air-water calibration mode, wherein the values are scaled to read 0% with the sensor in air and 100% with the sensor in water. The mode should be changed to use the polynomial calibration mode and an appropriate soil type selected.

For many applications, soil type 3 will be suitable. If you require an accurate site specific calibration, you can select one of the custom soil types and set the coefficients of the polynomial to suit.

When setting a sensor for a specific soil you must:

- Set the calibration method to Polynomial
- Set the desired soil type
- Set the coefficients for the soil (these are 0 when the probe is set to its default settings and must be programmed before the soil can be used).

To set the calibration method: **<add>XSCn!**

e.g. To select Polynomial calibration (n=1)

0XSC1!
0X_OK

To display the current soil type <**add>XGT!**

e.g. To read the soil type

0XGT!
001.00

To Select a soil type: **<add>XGSt!**

e.g. To set soil type to 1 (Sand)

0XGS1!
0Now Soil Type:1

e.g. To set soil type to 3 (50:50 mineral organic)

0XGS3!
0Now Soil Type:3

Note:

- The display of the current soil type only shows the status of the soil calibration selection (i.e. air-water or polynomial). It does not show the actual soil selected

To set the parameters for a polynomial calibration **<add>XSSt,a,b,c,d!:**

| | | |
|---|---|---|
| add | = | SDI-12 address |
| t | = | soil type number |
| a, b, c, d | = | coefficients for calibration |

e.g. to set coefficients for soil type 3 with probe on address 0

0XSS3,0.00007,-0.1226,1.53233,-27.31!

0X_OK

2XSS3,0.00007,-0.1226,1.53233,-27.31!

# 8 Calibration

**Volumetric water content**, θ, is defined mathematically as:

$$\Theta = W_w / V_t$$

where

$V_w$ is the volume of water and
$V_T = V_{soil} + V_{void} = V_{soil} + V_{water} + V_{air}$
i.e. the total volume (that is soil volume + water volume + air space).

Soils consist of particles of minerals and organic matter with various sized voids which can be filled with either air or water. In oven dried soil, the voids are filled with air. As water is added it displaces the air. Once all voids are completely filled with water, the soil reaches saturation.

Water, air and soil all have vastly different dielectric properties (a measure of how easily the particles are polarised under the influence of an electric field). Air for instance, has a dielectric value of 1 and water 80. The dielectric values of soil will range from around 4 to over 100, with higher values seen in heavy clay soils and in saline soils. Dielectric sensors measure this change in dielectric properties and express it as an equivalent volumetric soil moisture value.

The MP02 provides several different calibration methods to convert the raw dielectric readings to a volumetric water content figure. The calibration method and variables used by each, are set using extended SDI-12 commands.

## *8.1 Factory Calibration*

The MP02 is normally shipped in air/water calibration mode, but can be set to one of 3 standard soil types and 6 user defined soil types.

**Air / Water Calibration**

- Air / water calibration is carried individually for each probe
- The probe is first suspended in air and the value recorded
- The probe is then placed in a bath of water and the value once again recorded
- The probe is set to return 0 for the air reading and 100 for the water reading

- Note that in soil, the readings will be much higher than the actual volumetric moisture content.

**Soil Specific Calibration**

- Two variations of soil specific calibrations are provided: Min-Max and Polynomial. The coefficients for each are stored against soil types 1 to 3
- The parameters have been based on measurements averaged over a large quantity of probes
- Thus although not an individual calibration, the high repeatability of the MP02,ensures the measurement results are typically within a range of ± 2% in an equivalent soil
- The parameters are as follows:

| Soil Type | Min/Max calibration | | | Polynomial calibration | | | |
|---|---|---|---|---|---|---|---|
| | dry | sat | max | a | b | c | d |
| Soil Type 1 - Sand | 26 | 75 | 40 | 0 | 0 | 0.85 | -21 |
| Soil Type 2 - Potting Soil | 15 | 100 | 72 | 0.00004 | 0.0004 | 0.3 | -4.7 |
| Soil Type 3 - 50% mineral / 50% organic | 21 | 92 | 65 | 0.00007 | -0.01226 | 1.53233 | -27.231 |

- Typically, Soil Type 3 is a good compromise in many soils.
- Users can over-rid the parameter for soil types 1 to 3 but can set them back again by using the command to Reset the probe to its default settings.
- Polynomial coefficients can be calculated using a tool which can be downloaded from the Tekbox website.

Refer to the MP02 calibration manual for more details.

## *8.2 Air-Water Calibration*

As the maximum water storage capacity largely depends on the soil type, the MP02 comes factory calibrated with a so called “air and water calibration”. This means that a measurement value of 0% corresponds with the sensor placed in air and a value of 100% corresponds with the sensor placed in water. This is a very basic calibration method, not taking into account any soil specific properties.

The dielectric constant of dry soil is higher than the dielectric constant of air consequently an air/water calibrated probe will show values above 0% when in dry soil dry soil. As an example:

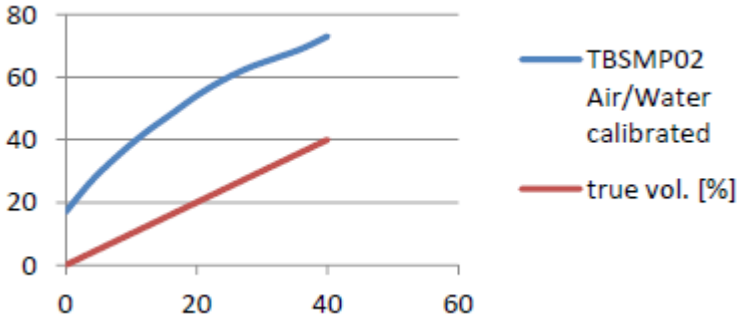
dry sand: 26%
dry volcanic scoria: 22%

dry potting soil: 15%

Nevertheless, for many purposes, when the focus is on observing trends rather than measurement of absolute values, an air/water calibration is sufficient.

The calibration is long term stable, but can be repeated at any time by placing the sensor in air and sending the extended SDI-12 command **aXCA!** for air calibration and then placing the sensor in water and sending the extended SDI-12 command **aXCW!** for water calibration.

The picture below shows the measurement response of an air/water calibrated probe in sand compared to the true, absolute volumetric value.




An Air-Water – calibrated MP02 will respond with 26% in dry sand and with 86% in fully saturated sand. The corresponding, true volumetric values would be 0% and 40% however.

A soil specific variant of the air/water calibration can be carried out by issuing the air calibration command when the probe is placed in dry soil and issuing the water calibration command, when the probe is placed in saturated soil. A measurement response of 0% would then indicate dry soil and 100% would indicate fully saturated soil.

## *8.3 Soil Specific Min-Max Calibration*

The Min-Max calibration process sets the probe to read from 0 to 100 over the range from air dry to saturation, in the soil under test. Prior to completing a Min-Max calibration, the probe must be given an Air-Water calibration.

A basic soil specific calibration can be carried out by taking a defined volume of soil, drying it, bedding the probe inside and using it as a 0% calibration reference. A minimum sample volume of 10 litres is recommended.

First record the measurement response of the probe in dry soil.

As a next step water in known amounts, and thoroughly mix it with the dry soil until it reaches saturation. Saturation is reached, once the water pools on the surface. Record the volume of water it took reach saturation as well as the reading from the probe.

Example calibration procedure, using sand with a probe set to SDI-12 address 0:

STEP 1. Set probe into air/water calibrated measurement mode: **0XGS0!**
Place probe into dry sand

- Issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+26.12
  - measurement response of the probe in dry sand is 26.12%

STEP 2 Assuming a sample volume of 10 litres, add 4 litres of water to raise the volumetric water content to 40%

- Place probe into saturated sand and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+74.70
  - measurement response of the probe in saturated sand is 74.7%

STEP 3 Store soil specific calibration values for MIN/MAX calibration method using following extended SDI-12 command:

**aXSMt,dry,sat,max!**

where:

**[a]** sensor address
**[t]** 1…9 = soil type
**[dry]** 4 digit number for value in dry (0.000 to 99.99)
**[sat]** 4 digit number for saturated value (0.000 to 99.99)
**[max]** the true volumetric value for the saturated soil

Given the measured values of sand, a probe address of 0 and assigning 1 as soil type, the extended SDI-12 command for a Min/Max calibration would look as follows:

**0XSM1,26.12,74.70,40.00!**

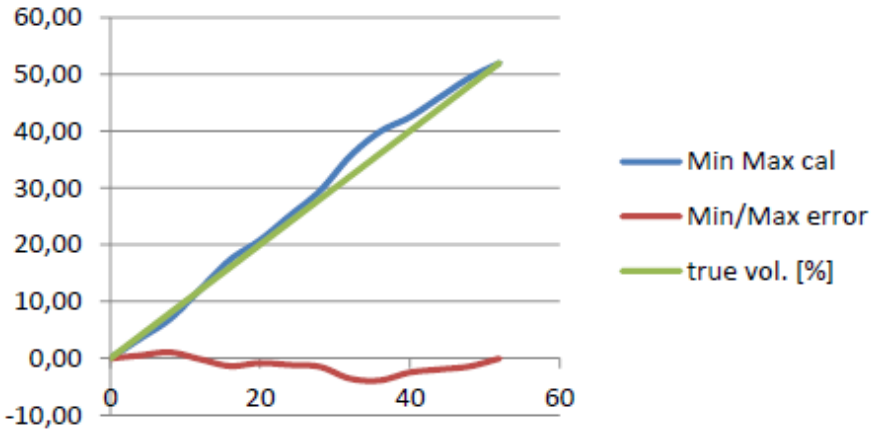
You can then select Soil Type 1 and this Min-Max calibration will be applied to the probe readings

**0XGS1!**,

- the probe will deliver values from 0% to 40% where 0% indicates dry soil and 40% is the volumetric soil moisture value of saturated sand.

As the relation between dielectric constant and volumetric soil moisture value is not perfectly linear, the measurement response has a certain deviation from the absolute volumetric soil moisture value.

The figure below shows the deviation of a Min/Max calibrated measurement response from the real volumetric value with the probe placed in sand. The brown curve shows the absolute measurement error, which is up to 3.8%.




The maximum error magnitude depends on the soil type. In soil types with mainly mineral content such as sand, the measurement response of the probe is close to linear and a Min/Max calibration results in a good approximation to the real volumetric soil moisture value which is accurate enough for most applications.

In case of soil types with high organic content and requirement for high accuracy, soil specific polynomial calibration is recommended.

## *8.4 Polynomial Calibration*

A polynomial calibration gives the lowest error.

Before carrying out the polynomial calibration, the probe must be set into air/water calibration mode.

Example calibration procedure for a probe on SDI-12 address 0, using organic potting soil:
STEP 1 : For probe set to address 0.

- Set probe into air/water calibrated measurement mode for soil 0: **0XGS0!**
- Prepare about 10 litres of dried potting soil. In case of this example we started with 8.4 litres of dried potting soil
- Place probe into dry potting soil and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: **0+15.07**
  - Measured value in dry potting soil is 15.07%

STEP 2 : Pour a defined quantity of water into the dried potting soil and stir it thoroughly. In this example we started by adding 0.35 litre of water (corresponding volumetric value = 4%)

- Place probe into the soil and issue Start Measurement Command: **0M!**
- Issue Read Data Command: **0D0!**
- Record response: 0+30.20
  - measurement value with 4% volumetric value is 30.2%
  - repeat the measurement a few times. If the measurement results differ more than 3%, the soil is not sufficiently stirred. Continue stirring the soil, until the measurement results become stable.

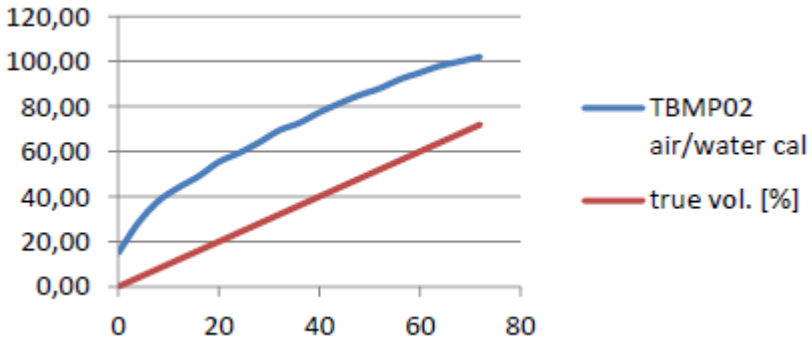
STEP 3 to n-1: add another defined quantity of water to the soil and stir it thoroughly

- Record the measurement response
- Continue this process, until the soil reaches saturation.

We derived the table below for potting soil:

| Water volume [l] | true vol. [%] | Measurement response |
|---|---|---|
| 0 | 0 | 15,00 |
| 0,35 | 4 | 28,33 |
| 0,7 | 8 | 38,00 |
| 1,05 | 12 | 44,00 |
| 1,4 | 16 | 49,00 |
| 1,75 | 20 | 55,33 |
| 2,1 | 24 | 59,33 |
| 2,45 | 28 | 64,00 |
| 2,8 | 32 | 69,33 |
| 3,15 | 36 | 72,67 |
| 3,5 | 40 | 77,33 |
| 3,85 | 44 | 81,33 |
| 4,2 | 48 | 85,00 |
| 4,55 | 52 | 88,00 |
| 4,9 | 56 | 92,00 |
| 5,25 | 60 | 95,00 |
| 5,6 | 64 | 98,00 |
| 5,95 | 68 | 100,00 |
| 6,3 | 72 | 102,00 |

The graph below shows the deviation of the measurement result to the true volumetric value before polynomial calibration.



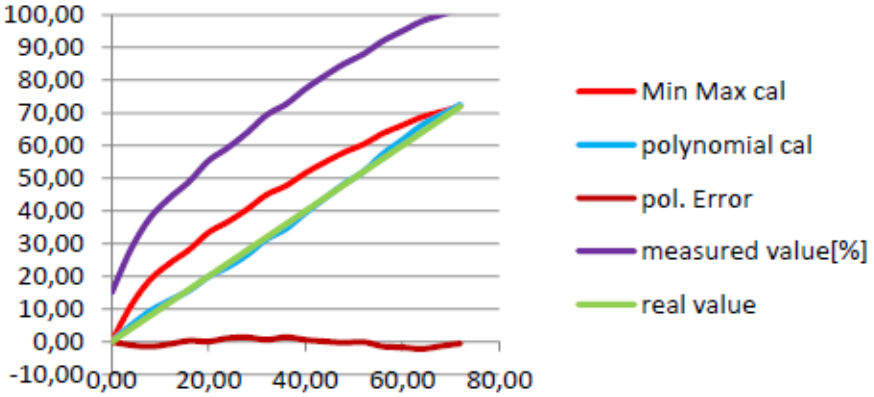

STEP n: Next we take table 1 and fit the values of the measurement response column to a 3rd order polynomial

$$ax^3+bx^2+cx+d$$

where x is the probe reading and the coefficients a, b, c, d are chosen to correctly convert the measurement response values into true volumetric value. In case of potting soil a = 0.00004, b = 0.0004, c = 0.3, d = -4.7

| air / water cal. measured value[%] | Polynomial calibrated result | Min/Max calibrated result | real Vol% | error |
|---|---|---|---|---|
| 15,00 | 0,02 | 0,00 | -0,02 | -0,02 |
| 28,33 | 5,03 | 11,03 | -1,03 | -1,03 |
| 38,00 | 9,47 | 19,03 | -1,47 | -1,47 |
| 44,00 | 12,68 | 24,00 | -0,68 | -0,68 |
| 49,00 | 15,67 | 28,14 | 0,33 | 0,33 |
| 55,33 | 19,90 | 33,38 | 0,10 | 0,10 |
| 59,33 | 22,86 | 36,89 | 1,14 | 1,14 |
| 64,00 | 26,62 | 40,55 | 1,38 | 1,38 |
| 69,33 | 31,35 | 44,97 | 0,65 | 0,65 |
| 72,67 | 34,56 | 47,72 | 1,44 | 1,44 |
| 77,33 | 39,39 | 51,59 | 0,61 | 0,61 |
| 81,33 | 43,87 | 54,90 | 0,13 | 0,13 |
| 85,00 | 48,26 | 57,93 | -0,25 | -0,25 |
| 88,00 | 52,06 | 60,41 | -0,06 | -0,06 |
| 92,00 | 57,43 | 63,72 | -1,43 | -1,43 |
| 95,00 | 61,71 | 66,21 | -1,71 | -1,71 |
| 98,00 | 66,19 | 68,69 | -2,19 | -2,19 |
| 100,00 | 69,30 | 70,34 | -1,30 | -1,30 |
| 102,00 | 72,51 | 72,00 | -0,51 | -0,51 |

| | |
|---|---|
| a | 0,00004 |
| b | 0,0004 |
| c | 0,3 |
| d | -4.7 |




The graph above shows that the polynomial calibrated results show good matching with the real volumetric soil value. The maximum error is 2.2%.

The graph also shows the error from the Min-Max calibration, which in this case is less accurate due to the non linear behaviour of potting soil.

Finally the polynomial coefficients need to be stored to the EEPROM of the probe using the extended SDI-12 command:

**aXSSt,a,b,c,d!**

where:

**[a]** the first “a” represents the sensor address
**[t]** represents a number in the range 1…9, which assigns a soil type. Consequently 9 soil specific sets of calibration values can be saved to the EEPROM of the probe
**[a]** represents coefficient a
**[b]** represents coefficient b
**[c]** represents coefficient c
**[d]** represents coefficient d maximum 8 digits per coefficient, the decimal point may be at any place

Given the measured values of potting soil, a probe address of 0, the required polynomial coefficients and assigning 2 as soil type, the extended SDI-12 command for the polynomial calibration looks as follows:

**0XSS2,0.00004,0.0004,0.3,-4.7!**

Set probe into polynomial calibrated measurement mode:

**0XSC1!**

Use the Soil Type Selection extended SDI-12 command to activate this soil type:

**0XGS2!**

- the probe will apply polynomial calibration and deliver measurement results with good accuracy.

Out of the three calibration methods offered by the MP02, the polynomial method delivers best accuracy with respect to true volumetric soil moisture value.

# 9 Maintenance

As the MP02 is a fully sealed sensor, it requires no ongoing maintenance. However you should still maintain a watch on the sensor data to check for any signs of mechanical damage to the sensor or cable.

6 Monthly:

- Review the data from the sensor and check that there are no spikes or dropouts
- Inspect the sensor cable to make sure it has not been damaged by machinery or chewed by animals (sheathing the cable in blind poly or conduit will help protect it from damage)
- Check that the connections from the cable to the data logger / telemetry unit are secure and free from water ingress.

# 10 Warranty

The sensors are covered by a one (1) year warranty.

Warranty is available on a return to base basis only. End users must pay for return shipment of faulty products either TOIP Pty Ltd or their local distributor. If the unit is assessed by TOIP Pty Ltd and found to be a warranty failure, it will be replaced free of charge. TOIP Pty Ltd will pay the return shipment to the owner.

The warranty does not cover mechanical damage, damage inflicted during installation or removal or damage caused by animals.

Prior to using the product, please ensure that you read, understand and accept the Warranty Statement. If you do not accept the conditions of the Warranty Statement, please return the probe for a refund.