User Manual for the

SM150T

Soil Moisture Sensor

Delta-T Devices Ltd

Notices

Copyright

Patents

The SM150T is protected under international law by the following patents:-

USA: Patent US7944220
Europe: Patent EP1836483
Australia: Patent AU2005315407
China: Patent CN101080631

EMC Compliance

See page 38.

Design changes

Delta-T Devices Ltd reserves the right to change the designs and specifications of its products at any time without prior notice.

User Manual Version: SM150T-UM-0.f Nov 2016

Delta-T Devices Ltd
130 Low Road, Burwell
Cambridge CB25 0EJ
UK

Tel: **+44 1638 742922**
Fax: **+44 1638 743155**
email: **sales@delta-t.co.uk**
web: **www.delta-t.co.uk**

Contents

Introduction

Description

The *SM150T* measures soil moisture content and temperature.
Its sealed plastic body is attached to two sensing rods which insert directly into the soil for taking readings.
A waterproof plug connects to a choice of signal cables.
Both extension cables and extension tubes can be used.

The soil moisture output signal is a differential analogue DC voltage. This is converted to soil moisture by a data logger or meter using the supplied general soil calibrations.
It can also be calibrated for specific soils.

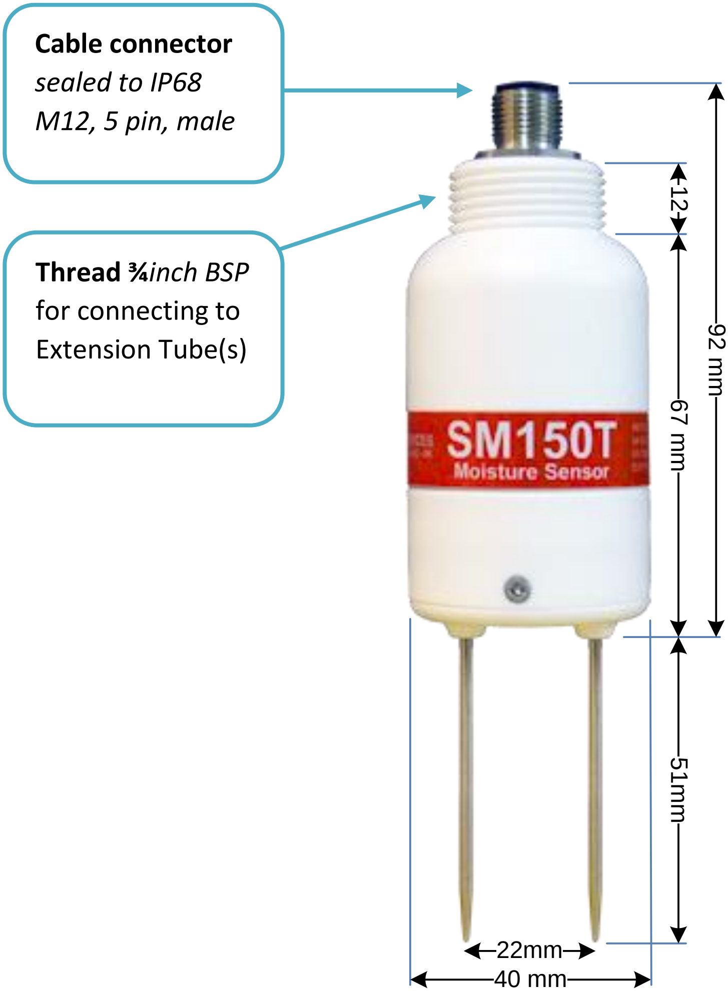
Features

- Soil moisture accurate to ± 3%
- Soil temperature to ± 0.5 °C over 0-40 °C
- Low salinity sensitivity
- Excellent stability
- Minimal soil disturbance
- Easy installation at depth in augured holes
- Waterproof connector to IP68
- Rugged, weather-proof and can be buried.
- Good electrical immunity
- Choice of cabling system options
- Cable connector, cylindrical profile and extension tube design simplifies removal for servicing
- Dedicated HH150 meter kit for simple readings[1]
- HH2 meter[1], GP1, GP2, DL6 and DL2e logger compatible

See also ***Specifications*** on page 33

[1] Does not read temperature

Dimensions



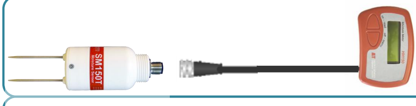
Cable connector
sealed to IP68
M12, 5 pin, male
Thread *¾inch BSP*
for connecting to
Extension Tube(s)
SM150T
Moisture Sensor
12
67 mm
92 mm
51mm
22mm
40 mm

Parts list

Your shipment may include the following:

SM150T soil moisture sensor

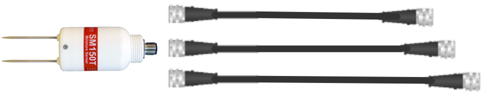
HH150 +SM150T Kit



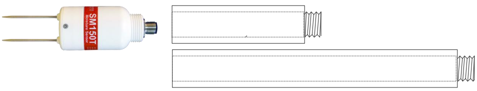
HH150 includes 1m cable,
Connects to SM150T

SMCS/d-HH2 0.9m cable
Connects SM150 to HH2

SMSC/lw-05 5m cable
200mm flying leads
Connect to data logger



Logger extension cables
EXT/5W-05 5m
EXT/5W-10 10m
EXT/5W-25 25m



Extension tubes
ML/EX50 50cm
ML/EX100 100cm

SM-AUG-100 Spiral Auger 1.2m

Care and Safety

- The rods of the SM150T are sharp in order to ease insertion. Care must be taken and handling precautions followed.

To prevent personal injury and damage to the probe always store and transport the SM150 in this protective tube

CAUTION

SHARP PINS

- Avoid touching the rods or exposing them to other sources of static charge, particularly when powered up.
Keep the SM150T in its protective tube when not in use.

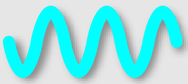
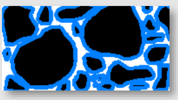
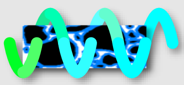
- Take care when attaching cables to ensure that the connectors are clean, undamaged and properly aligned *before* pushing the parts together.

- Do not pull the SM150T out of the soil by its cable.

- If you feel strong resistance when inserting the SM150T into soil, it is likely you have encountered a stone. Stop pushing and re-insert at a new location.

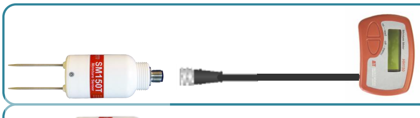
- Do not touch the pins, particularly when the sensor is attached to a cable. An electrostatic discharge from your body can typically cause a temporary -10mV offset in sensor readings for up to one hour. At worse it may permanently damage the sensor.

How the SM150T works

	When power is applied to the *SM150T*...
	...it creates a 100MHz waveform (similar to FM radio).
	The waveform is applied to a pair of stainless steel rods which transmit an electromagnetic field into the soil.
	The water content of the soil surrounding the rods...
ε	...dominates its **permittivity**. (A measure of a material's response to polarisation in an electromagnetic field. Water has a permittivity ≈ 81, compared to soil ≈ 4 and air ≈ 1)
	The permittivity of the soil has a strong influence on the applied field…
Vout	…which is detected by the SM150T, resulting in a stable voltage output that…
Soil Moisture 22 %	...acts as a simple, sensitive measure of **soil moisture content**.

Operation

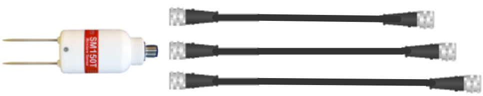
Cable Connections



HH150 includes 1m cable,
Connects to SM150T

SMCS/d-HH2 0.9m cable
Connects SM150 to HH2

SMSC/lw-05 5m cable
200mm flying leads
Connect to data logger



Logger extension cables
EXT/5W-05 5m
EXT/5W-10 10m
EXT/5W-25 25m

See also **Logger connections and configuration** page 14

- Take care when attaching cables to ensure that the connectors are clean, undamaged and properly aligned **before** pushing the parts together.
- Screw together firmly to ensure the connection is water-tight.
- Extension cables* can be joined up to a recommended maximum of 100m (for GP1 or GP2 data loggers) – see **Specifications** on page 33.

*Note: for full accuracy, do not use extension cables with the HH150
** Note The HH150 meter does not record temperature.

Installation

Surface installation and spot measurements

Clear away any stones. Pre-form holes in very hard soils before insertion.

- Push the SM150T into the soil until the rods are fully inserted. Ensure good soil contact.
- If you feel strong resistance when inserting the SM150T, you have probably hit a stone. Stop, and re-insert at a new location.

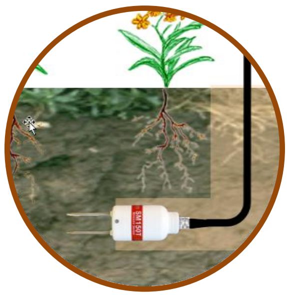
Note: The SM150T is not suitable for soil surface temperature measurements. For soil temperature near the surface dig a trench and install horizontally as shown below.
Cover both SM150T and the first 30cm of cable with at least 5cm of soil.

Installing at depth

- Make a 45mm diameter hole, preferably at about 10° to the vertical using the **SM-AUG-100** auger.
- Connect an extension tube e.g. **ML/EX50**
- Push the SM150T into the soil until rods are fully inserted. Ensure good soil contact.

Alternatively

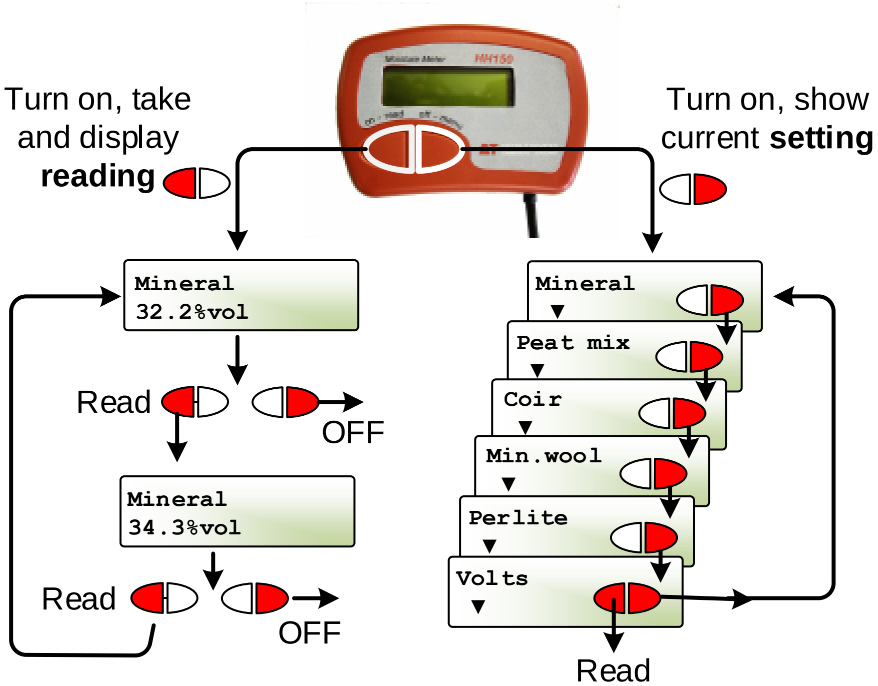
- Dig a trench, and install horizontally.



HH150 Meter

- Connect the SM150T to the HH150 meter.
- With the meter OFF, press the right **Off – menu** button. This wakes and allows you to set the meter to display readings - as % volumetric water content of either Mineral, Peat Mix, Coir, Mineral Wool or Perlite soils, or to show the sensor output in Volts.
- Press the left **on – read** button to take a reading.

Repeat as required. You may wish to write down the readings.



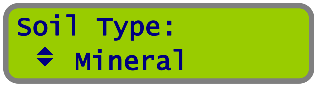
Note: The HH150 meter does not record temperature.

HH2 Meter

This assumes you have version 2.8 or later for both the PC software HH2Read and the HH2 firmware (see foot of page).

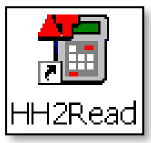
- Connect the SM150T to the HH2 meter.
- Press **Esc** to turn the meter on, and if necessary press again until the HH2 displays the start-up screen.
- Set the meter to read from an SM150T:
  - Press **Set** and scroll down to the **Device** option.
  - Press **Set** again and scroll down to select SM150T.
  - Press **Set** to confirm this choice.

- Make sure the HH2 is correctly configured for your soil type:
  - At the start-up screen, press **Set** and scroll down to the **Soil Type** option.
  - Press **Set** again and scroll down to the appropriate soil type (use **Mineral** for sand, silt or clay soils or **Organic** for peaty soils)
  - Press **Set** to confirm this choice.



- Choose the units in which you want to display the readings.
  - At the start-up screen, press **Set** and scroll down to the **Display** option.
  - Press **Set** again and scroll down to select units.
  - Press **Set** to confirm this choice.
- Press **Read** to take a reading.
- Press **Store** to save or **Esc** to discard the reading.

- Remove the SM150T from the soil and move to a new location...
- If you have saved data, connect your HH2 to a PC and run ***HH2Read*** to retrieve the readings.



For an upgrade contact Delta-T.
See also: **HH2 User Manual v4.2** or later

Note: The HH2 does not read temperature

Logger connections and configuration

GP1 Logger

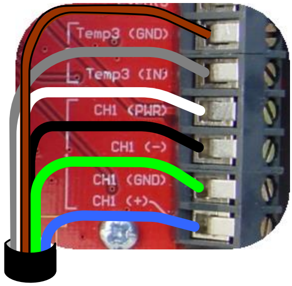
Two SM150Ts can connect to each GP1.
Each soil moisture sensor is wired as a differential, powered sensor.

Requirements

GP1 logger (with v1.48 firmware or later)
PC running DeltaLINK (version 3.6 or later)
SM150T with SMSC/lw-05 cable

Channel 1 and 2 wiring

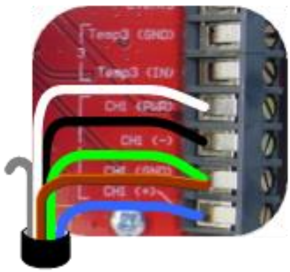
SM150T wire		*Colour*	*GP1 terminal*
Power 0V		brown	**CH1/2 (GND)**
Power V+		white	**CH1/2 (PWR)**
Signal HI		blue	**CH1/2 (+)**
Signal LO		black	**CH1/2 (-)**
Cable shield		green	**CH1/2 (GND)**
Temperature +		grey	**Temp3 (IN)**



Using the DeltaLINK2 logger software, configure channel 1 or 2 as soil moisture sensor type **SM150T** channel 3 or 4 as **SM150T Temperature**.

Two more SM150T sensors can be added, to Temp3 and/or Temp4 channels to measure soil moisture -if temperature readings are not required:

Power 0V		brown	**CH1/2 (GND)**
Power V+		white	**CH1/2 (PWR)**
Signal HI		blue	**CH1/2 (+)**
Signal LO		black	**CH1/2 (-)**
Cable shield		green	**CH1/2 (GND)**



See also **GP1 Quick Start Guide** v4 or later and the ***DeltaLINK*** on-line Help.

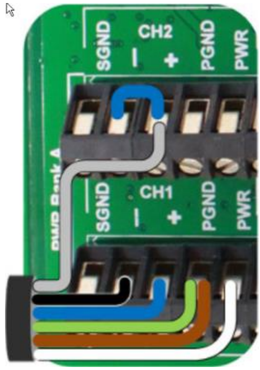
[2] You need the PC logger software DeltaLINK version 3.6 or later. A free upgrade can be obtained from www.delta-t.co.uk or from the **Software and Manuals DVD**.

GP2 Logger Controller

Up to 6 SM150Ts can connect to a GP2.
Up to 12 can be connected if not using the temperature sensor.
If using more than 9 you need expansion lid **GP2-G5-LID**

These details illustrate connection to Channels 1 and 2:

SM150T wire		*Colour*	*GP2 terminal*
Power 0V		brown	**CH1 (PGND)**
Power V+		white	**CH1 (PWR)**
Soil Moisture Signal HI		blue	**CH1 (+)**
Soil Moisture Signal LO		black	**CH1 (-)**
Cable shield		green	**CH1 (PGND)**
Thermopile HI		grey	**CH2(+) and CH2(-)** ***Fit wire link***



For configuration details see the ***DeltaLINK*** software sensor **Info Panel** and **Help** or the **GP2 User Manual.**

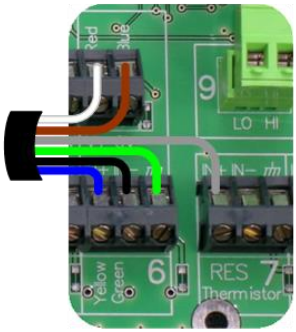
Configure each soil moisture channel as sensor type **SM150T** and configure the temperature channel as sensor type **SM150T Temperature**.

DL6 Logger

6 SM150Ts can be connected to a DL6.
Each soil moisture sensor is wired as a differential, powered sensor.
A DL6 logger can only read one SM150T temperature sensor.

These details illustrate connection to channels 6 & 7:

SM150T wiring		*Colour*	*DL6 terminal*
Power 0V		brown	**0V**
Power V+		white	**V+**
Signal HI		blue	**IN+**
Signal LO		black	**IN-**
Temperature +		grey	**RES IN+**
Cable shield		green	⏚



In DeltaLINK[3] configure channel 1 - 6 as Moisture Probe **SM150T** and channel 7 as **SM150T Temperature**.

See also the **DL6 Quick Start Guide** and the ***DeltaLINK*** online Help.

---

[3] You need the PC logger software DeltaLINK version 3.6 or later obtainable online at www.delta-t.co.uk or from the **Software and Manuals DVD**

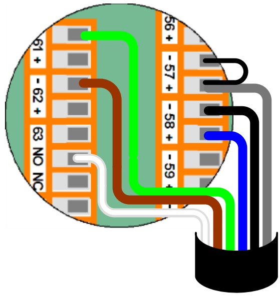
DL2e Logger

Up to 60 SM150Ts can be connected to a DL2e logger (if not using the temperature sensor channel).
Up to 30 SM150Ts can be connected if also reading the temperature sensors.

Each moisture sensor is connected as a differential, powered sensor.

These details illustrate connection to channels 57 and 58 using a **LAC1** input card configured in 15-channel mode, and warm-up channel 63:

SM150T wiring		*Colour*	*DL2e terminal*
Power 0V		brown	**CH62- or 61-**
Power V+		white	**CH63 NO**
Signal HI		blue	**CH58+**
Signal LO		black	**CH58-**
Temperature +		grey	**CH57+ and CH57-**
Cable shield		green	**CH61- or 62-**



Note: If using channel 58 ensure the **LAC1** card ribbon is attached to the connector block opposite terminal groups 46-60.
See page 3 of **DL2e Quick Start Guide.**

Configure the chosen DL2e logger channels by selecting the appropriate mineral or organic soils listed in the Ls2Win[4] sensor library.

See also the **DL2e User Manual** and the ***Ls2Win*** online help

[4] You need a PC running Ls2Win version 1.0 SR10 or later. A free upgrade can be obtained from www.delta-t.co.uk or from the **Software and manuals DVD**.

Other Data Loggers

Connection

SM150T wiring Description	*Wire colour*		*Logger connection* Differential connection is preferred
Power 0V (Power return and thermistor return)		brown	**Power ground/OV** Power return OV
Power V+ (Power supply voltage)		white	Sensor Power/V+ 5-14 VDC, 18 mA, for 0.5 to 1s
Signal HI (Volumetric water measurement signal)		blue	Differential in+/IN+ Or Signal Input (on single ended loggers) 0-1V ≈ 0 to 60% vol nominal ±3.0% (±3% vol over 0 to 70% vol and 0-60°C) (±5% vol over 100 to 1000mS.m^{-1} and 0-60% vol) 0-1.5V ≈0 to 100%vol (Reduced accuracy especially at 100%) See look-up tables and polynomials
Signal LO (Volumetric water content return)		black	**Differential in-/IN-** Or 0V (On single-ended loggers)
Temperature + (Thermistor connection)		grey	**Resitance measurement channel** **10 K thermistor, ±0.5ºC over 0-40°C** (5.8kΩ to 28kΩ - See Resistance Lookup table)
Cable shield (Noise shield)		green	**Low noise 0v (sensor 0v)** (Can use power 0V if sensor 0V not available)

- The SM150T soil moisture output is best connected as a differential, powered sensor.
- Configure the logger to convert the SM150T readings from milliVolts into soil moisture units by using either :-
  Polynomial conversion below (or on page 28) or
  Linearisation table conversion on page 29[5]

Note: Output signals in the range 0 to 1.0 volts from the SM150T, corresponding to ~0 to 60% water content in mineral soils – see **Linearisation table conversion** on page 29.

Note: The SM150T has been optimised for warm-up of 0.5 to 1 second duration. It is recommended that the sensor is not powered continuously.

- The temperature sensor output should be read as a resistance and the logger configured with a look-up table to covert the measured resistance to temperature.

See **SM300 Temperature Measurement** on page 50

and **Resistance to Temperature Lookup Table** on page 53.

Logging Advice

Allow 20 minutes for the temperature readings to stabilise after installation

Do not log faster than 1 minute to avoid SM300 self-heating, which could affect the accuracy of temperature readings.

[5] Tables are only available for mineral and organic soils (and temperature).

Use of polynomial equation to calculates soil moisture

To convert the SM150T output to soil moisture

1) Convert Volts V to $\sqrt{\varepsilon}$ using the following equation

$$\sqrt{\varepsilon} = 1 + 14.4396\,V - 31.2587V^2 + 49.0575V^3 - 36.5575V^4 + 10.7117V^5$$

Where V is the SM150T soil moisture output converted from milliVolts to Volts.

2) Convert the $\sqrt{\varepsilon}$ value to soil moisture θ using $\theta = (\sqrt{\varepsilon} - a_0)/a_1$

Where a0 and a1 are constants:-

	a_0	a_1
Mineral	**1.6**	**8.4**
Organic	**1.3**	**7.7**
Peat mix	**1.16**	**7.09**
Coir	1.16	7.41
Min. wool	1.04	**7.58**
Perlite	1.06	6.53

For temperature measurement see page 50

Logger Grounding

Sub-optimal grounding of a DC power supply and its cabling to a logger can cause currents in the screen of the cable connected to a soil moisture sensor, and so cause corrosion at the M12 connector of the SM150T. In addition, if used in an electrically noisy environment - such as a farm or greenhouse - then the presence of a ground loop can permit AC signals to inject noise and so disrupt readings.

To minimise sensor cable-screen currents that can result from the DC power supply unit and its cabling to the logger, earth the logger using a 1m long copper-clad earth stake.

Figure 1 Showing the use of a 1m long copper-clad earth rod connected to a GP1 logger earth

Ungrounded system

In the example shown in Figure 2 both the logger and the power supply are not grounded, so a current loop can exist between the sensor and the mains power source, allowing noise to be injected into readings, and increasing the risk of galvanic corrosion to the M12 connector on the SM150T.

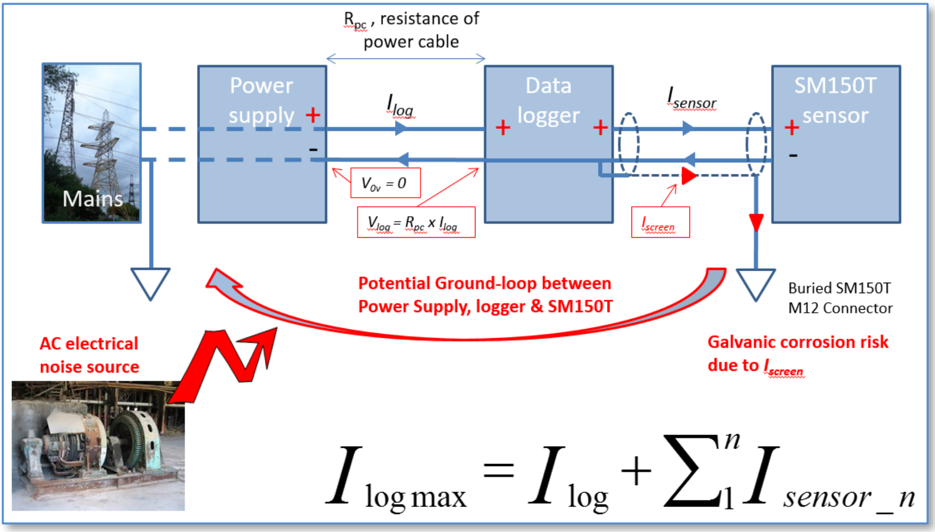


Figure 2 This diagrams shows that if the logger is not well grounded then a potential ground loop can exist between the sensor and the power supply and/or mains power. There is also the risk of galvanic corrosion to buried M12 connectors on the sensor and cable.

Fully grounded system

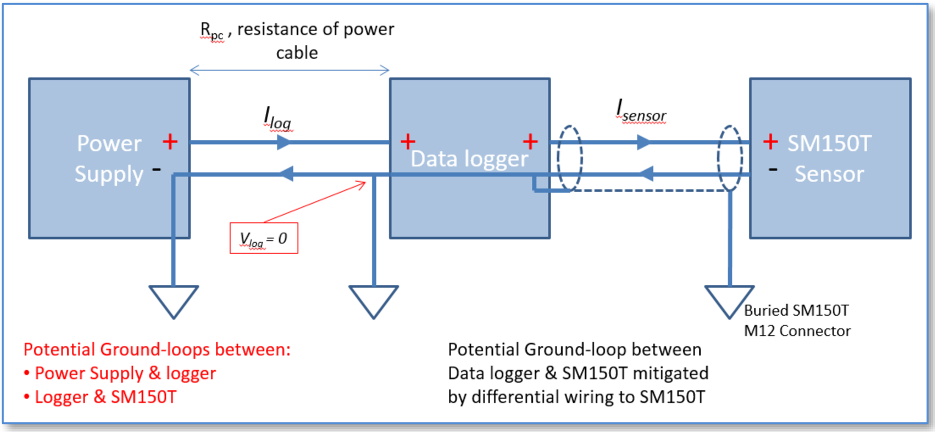


Figure 3 This diagram shows the logger, power supply and sensor all grounded. This minimises the possibility of galvanic corrosion of the SM150T connector. It also minimises the possibility of nearby AC-powered machinery injecting noise into the readings. The impact of the potential ground loop between logger and sensor is mitigated by the differential wiring of the SM150T.

Logger grounded

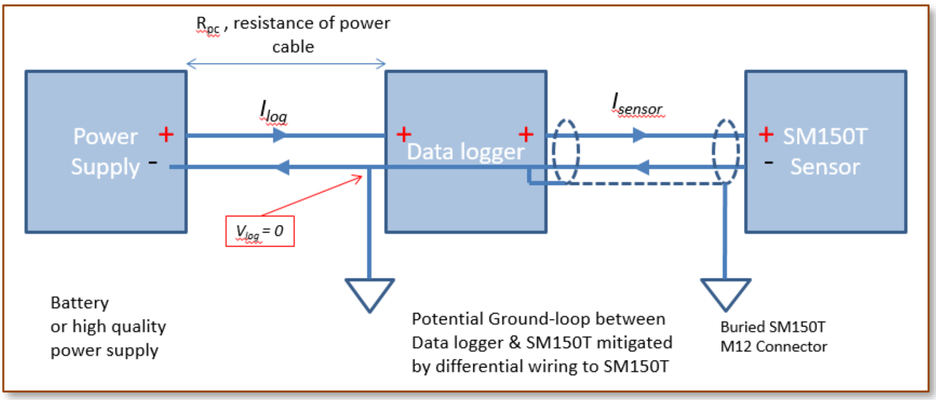


Figure 4 This diagram shows a battery or high quality power supply with no leakage current to ground. The logger is grounded. The potential ground loop between logger and sensor is mitigated by the differential wiring of the SM150T. This is the best arrangement.

Calibration

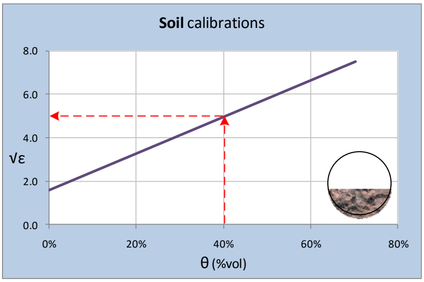
The SM150T is provided with general calibrations for **mineral** and **organic** soils which can be used to convert the output from the sensor directly into soil moisture when used with Delta-T loggers and moisture meters. This section explains how these calibrations work, how to adapt them for other soils and how to provide calibrations for other data loggers.

The SM150T measures volumetric soil moisture θ, by detecting the dielectric properties of the damp soil – the permittivity, ε, or more conveniently the **refractive index**, which is closely equivalent to $\sqrt{\varepsilon}$.

The SM150T response is best understood in these stages:

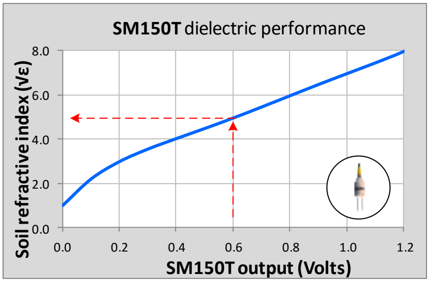
1. Soil calibration

$\theta \rightarrow \sqrt{\varepsilon}$



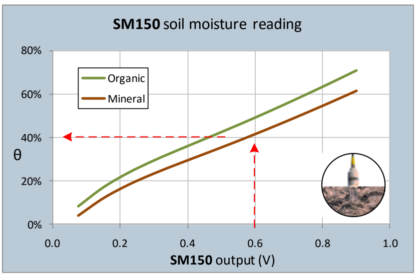
2. Sensor calibration

$V \rightarrow \sqrt{\varepsilon}$



3. Soil moisture reading

$V \rightarrow \theta$



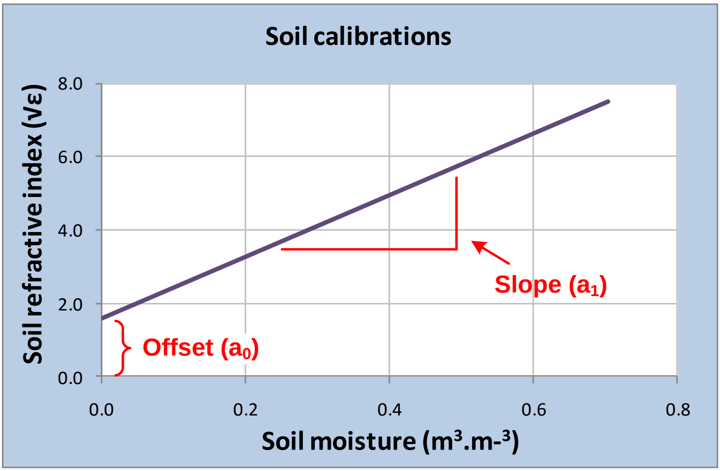
Soil calibration

Damp soil is essentially a mixture of soil particles, air and water, and together these components determine its dielectric properties, including the refractive index $\sqrt{\varepsilon}$. The refractive index of the mixture is approximated simply by adding the contributions from the individual components [ref 4.].

For a particular soil, the contribution from the soil particles can be assumed to be constant, so the refractive index measured by the SM150T is only affected by changes to the water content, θ. This relationship simplifies to:

$$\sqrt{\varepsilon} = a_0 + a_1 \cdot \theta$$

where the coefficients a_0 and a_1 conveniently parameterise the dielectric properties of soils.



Note that:

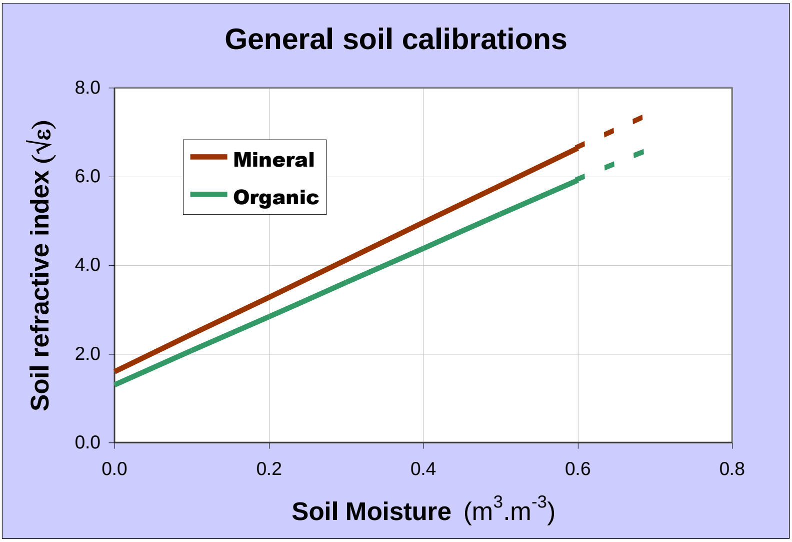
$a_0 = \sqrt{\varepsilon_{dry\_soil}}$ is usually between 1.3 to 2.3

a_1 corresponds approximately to $\sqrt{\varepsilon_{water}} - 1$ and usually takes a value about 8.0. Real soil values for a_0 and a_1 can vary significantly from these guidelines when they are affected by other factors – in particular, bound water in clay may result in higher values of a_1.

General soil calibrations

Most soils can be characterised simply by choosing one of the two general calibrations we supply, one for mineral soils (predominantly sand, silt and clay) and one for organic soils (with a high organic matter content).

	a_0	a_1
Mineral soils	**1.6**	**8.4**
Organic soils	**1.3**	**7.7**



These values have been used to generate the polynomial conversions and linearisation tables in the **Soil moisture reading** section.

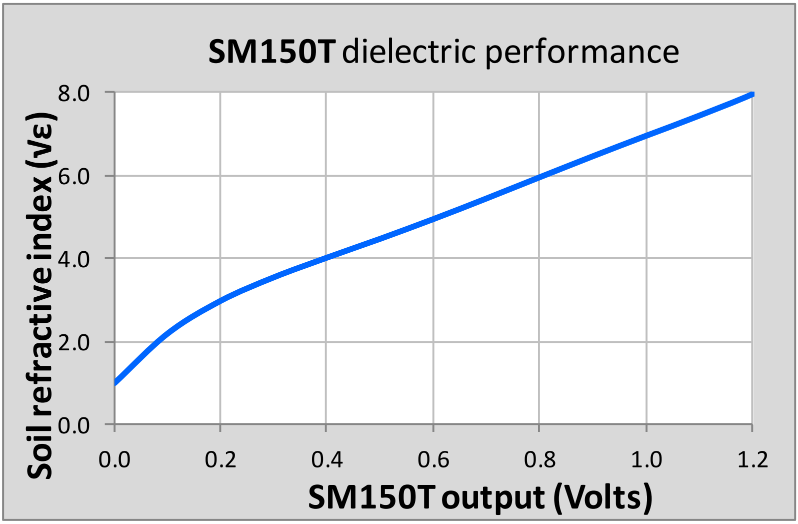
Soil-specific calibration

Instead of adopting these general calibrations, you may wish to determine specific calibration values of a_0 and a_1 for your soil. This procedure is fairly straightforward if you can get access to standard laboratory equipment and is described in detail in Appendix 1 on page 42.

Soil specific calibration can significantly improve the accuracy of individual readings - but make less of an improvement to readings where installation and sampling errors are high.

Sensor calibration

Each SM150T is individually adjusted to provide consistent dielectric performance:



This response can be approximated either by a polynomial (below) or by a linearisation table (see next page):

Polynomial (for use over the full range of SM150T readings)

$$\sqrt{\epsilon} = 1.0 + 14.4396V - 31.2587V^2 + 49.0575V^3 - 36.5575V^4 + 10.7117V^5$$

where V is the SM150T output in Volts

Linearisation table
(for use over the full range of SM150T readings)

V	√ε	*V*	√ε	*V*	√ε	*V*	√ε	*V*	√ε
0.000	1.000	0.300	3.576	0.600	5.101	0.900	6.778	1.200	8.924
0.075	1.942	0.375	3.964	0.675	5.503	0.975	7.232	1.275	9.743
0.150	2.620	0.450	4.337	0.750	5.917	1.050	7.720	1.350	10.808
0.225	3.144	0.525	4.713	0.825	6.342	1.125	8.270	1.425	12.242

Soil moisture reading

Polynomial conversion

Combining the **Soil calibrations** and **Sensor calibration** steps, the conversion equation becomes:

$$\theta = \frac{[1.0 + 14.4396V - 31.2587V^2 + 49.0575V^3 - 36.5575V^4 + 10.7117V^5] - a_0}{a_1}$$

where a_0 and a_1 are the calibration coefficients

For a generalised **mineral** soil this becomes:

$$\theta_{mineral} = -0.0714 + 1.7190V - 3.7213V^2 + 5.8402V^3 - 4.3521V^4 + 1.2752V^5$$

And for a generalised **organic** soil:

$$\theta_{organic} = -0.0390 + 1.8753V - 4.0596V^2 + 6.3711V^3 - 4.7477V^4 + 1.3911V^5$$

Linearisation table conversion

The conversion from SM150T reading (Volts) to soil moisture θ ($m^3.m^{-3}$ or %vol) can be accomplished by a look-up table.

The following table lists the values used for the DL2e data logger:

Soil moisture %vol	Mineral soil Volts	Organic soil Volts	Soil moisture %vol	Mineral soil Volts	Organic soil Volts
-4	-2.090	-2.090	52	0.758	0.638
0	0.046	0.022	56	0.818	0.695
4	0.076	0.046	60	0.876	0.750
8	0.110	0.074	64	0.933	0.805
12	0.149	0.105	68	0.987	0.859
16	0.195	0.140	72	1.039	0.910
20	0.248	0.180	76	1.087	0.962
24	0.308	0.226	80	1.130	1.010
28	0.373	0.279	84	1.170	1.056
32	0.440	0.336	88	1.206	1.099
36	0.507	0.397	92	1.238	1.138
40	0.573	0.458	96	1.267	1.174
44	0.636	0.520	100	1.294	1.207
48	0.699	0.580	104	2.090	2.090

Troubleshooting

Always try to identify which part of the measurement system is the source of the difficulty. For the *SM150T* this may fall into one of the following areas:

The measurement device

What equipment is being used to read the probe output?

- An HH150 or HH2 Moisture Meter.
  Note these meters do not make temeprature measurments.
- A data logger such as the GP1, GP2, DL6 or DL2e.

Check Versions

Check you have the correct versions:

HH2 Meter: Firmware version 2.8 or later and PC software HH2Read version 2.8 or later.

GP1, GP2 & DL6 Loggers: DeltaLINK version 3.6 or later is required.
DL2e Logger: Ls2Win 1.0 SR10 or later is required.

Consult the user manuals or the on-line help for these devices and their related software.
Try alternative types of equipment if you have them available.

Check that you are using an appropriate soil calibration and the correct conversion method – see **Calibration** section.

The SM150T itself

Try to isolate the problem into one of the following areas

- The SM150T or the connecting cable

Then try to narrow down the area further

- Mechanical problems faults, or damage
- Electrical or electronic problems or faults

Functional check

Air reading

Hold the SM150T in air and away from other objects and take a reading using an HH150 or HH2 meter or voltmeter or a logger with no more than 5m of cable.

Warning: Do not touch the pins

A typical electrostatic discharge from your body can create a temporary -10mV offset in sensor readings lasting an hour.

In air an SM150T gives an output of 0 ±4mV.
Note: the HH150 reports under-range if the reading is less than zero.

Mid range reading – dip rod tips in water

If you wish to take a quick reading to check the sensor is working you can dip the sensor into water.

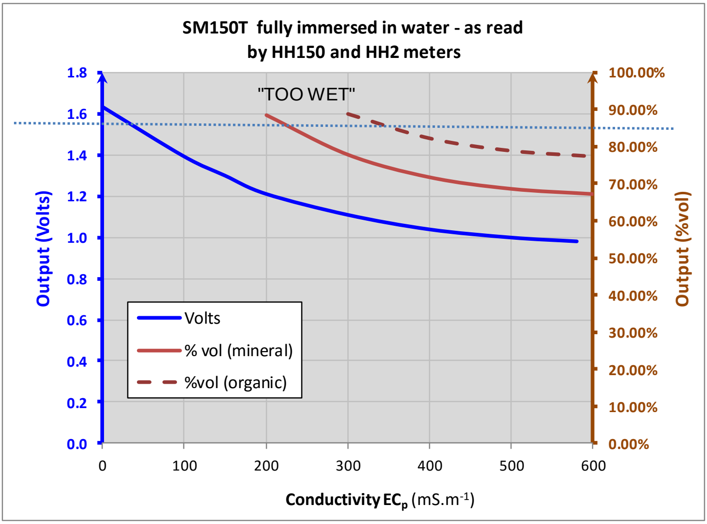
With the pins half-immersed in tap water an HH2 set to read an SM150T with soil type set to Organic should give a reading in the range 80 to 100%vol.

Water reading

Fully immerse the pins in water and measure the output in volts.

In the UK the sensor will typically read about 1.5 volts in tap water (because the salinity is typically 50mS.m-1).
The "water reading" will depend on the salinity of your local water.

Note: HH150T meter indicates "TOO WET" above 1.5V or 85% vol.



Soil moisture readings are not correct when no soil is present i.e. at 100% vol.

SM150T tables and polynomial constants are optimised at 220 mS.m^{-1} for soil moisture values below 70%vol

Graph: showing the effect of salinity on SM150T sensor output when fully immersed in water with no soil present.

Technical Reference

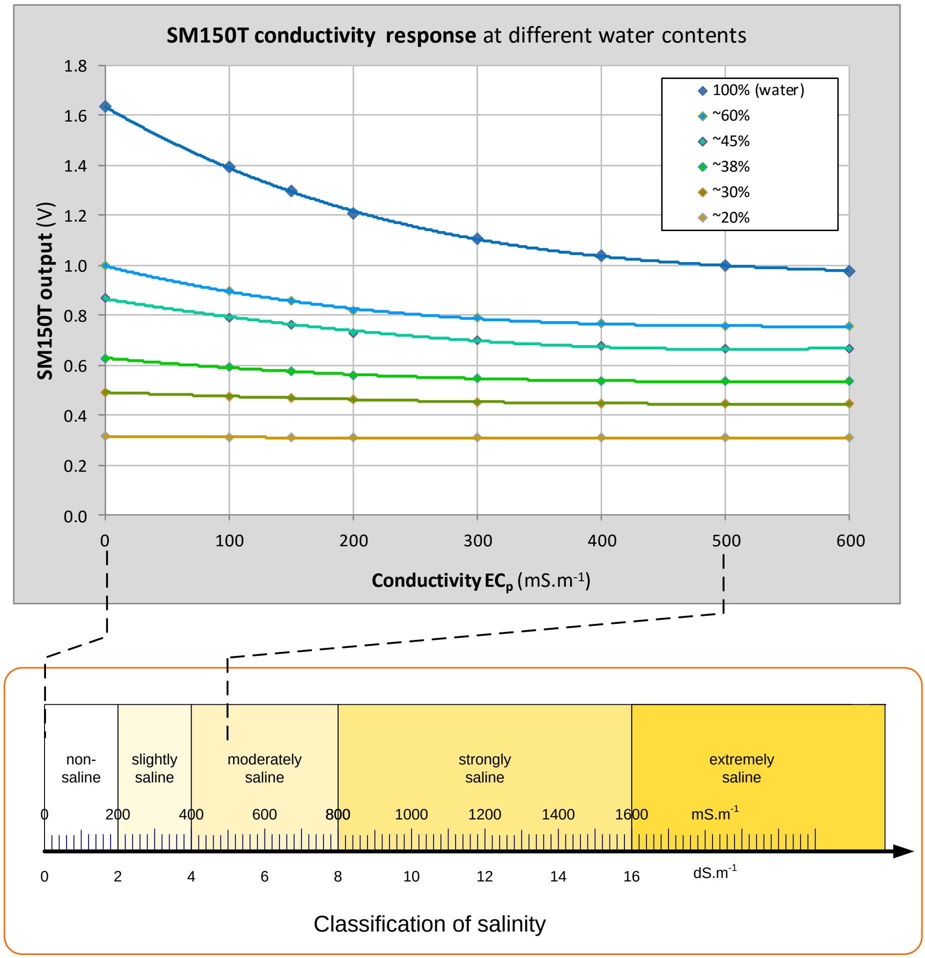
Specifications

Volumetric water content	
Accuracy	±3.0% vol over 0 to 70% vol and 0-60 °C
Measurement range	0 to 100% vol with reduced accuracy[6]
Salinity error (see p.34)	±5% vol over 100 to 1000 mS.m^{-1} and 0-60% vol
Output Signal	0-1 V differential ≈ 0 to 60% vol nominal
Output compatible with	GP1, GP2, DL6, DL2e, HH2, HH150
Temperature	*SM150T must be fully buried to accurately measure soil temperature*
Sensor accuracy	±0.5 °C over 0-40 °C *not including logger or cabling error*
Output	Resistance:[7] 5.8 kΩ to 28 kΩ
Output compatible with	GP1, GP2, DL6[8], DL2e
Cabling error contribution (to temperature readings)	Negligible for GP1, GP2, DL6 (any cable length) Negligible for DL2e (with 5m cable)[9]
Maximum cable length	100 m (GP1, GP2 & DL6 data loggers) 100 m (DL2e: water content measurement) 25 m (DL2e: temperature measurement)
Power requirement	5-14 VDC, 1 8mA for 0.5 to 1 s
Operating range	-20 to +60 °C
Environment	IP68
Sample volume	55 x 70 mm diameter
Dimensions	143 x 40 mm diameter
Weight	77 gm (without cable)

6 In water (no soil present) the reading may not be 100% vol. It depends on a0 and a1 but can still be used as a quick check that the unit is working. See page 24.
7 See Appendix 2 on page 49.
8 Note: The DL6 has only one temperature channel. The DL6 error contribution to SM150T temperature measurement is negligible compared to the accuracy of the SM150T temperature sensor itself. The two only become comparable below -15C.
9 DL2e logger users can apply a correction in the Ls2Win logging software (for cable lengths >5m)

Conductivity response

This chart shows how salinity affects the output of the soil moisture sensor at various soil moisture levels.

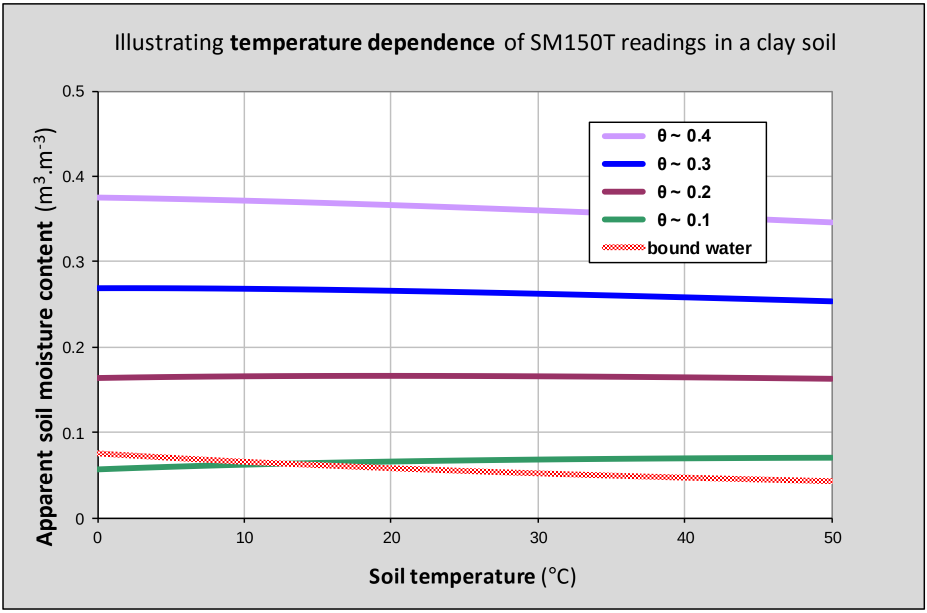


Temperature response of soil moisture readings

The effect of temperature on the SM150T soil moisture readings in any particular soil will depend on a combination of effects:

- The SM150T soil moisture electronics has very low temperature sensitivity, and makes a negligible contribution to the overall sensitivity.
- The refractive index of water ($\sqrt{\varepsilon}$, see **Calibration** section) reduces as the temperature increases. This produces a negative temperature response particularly in soils or substrates with high water content.
- Water that is bound to the surface of soil particles has a much lower refractive index than free water. The percentage of bound water decreases with temperature and this produces a positive temperature response particularly in clay soils at lower water contents.

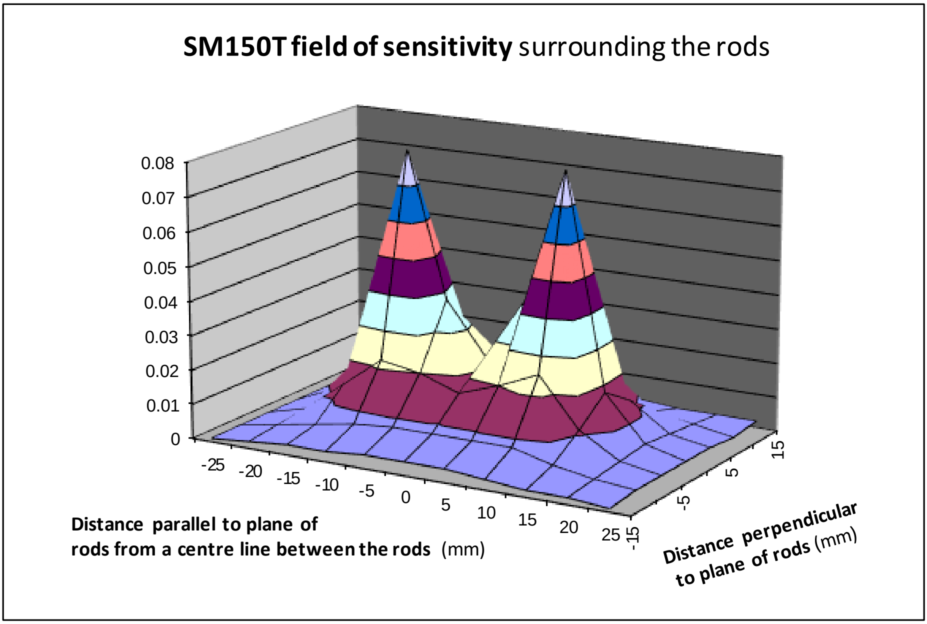
The last two effects partially offset each other, but in soil conditions where one or the other effect dominates, the SM150T will appear to have a significant temperature response. This illustration is based on the model in reference 7, see page 41.



Note: ice has a quite different refractive index from water, so SM150T soil moisture readings cannot be interpreted reliably when inserted into soil below 0°C.

Sampling Volume

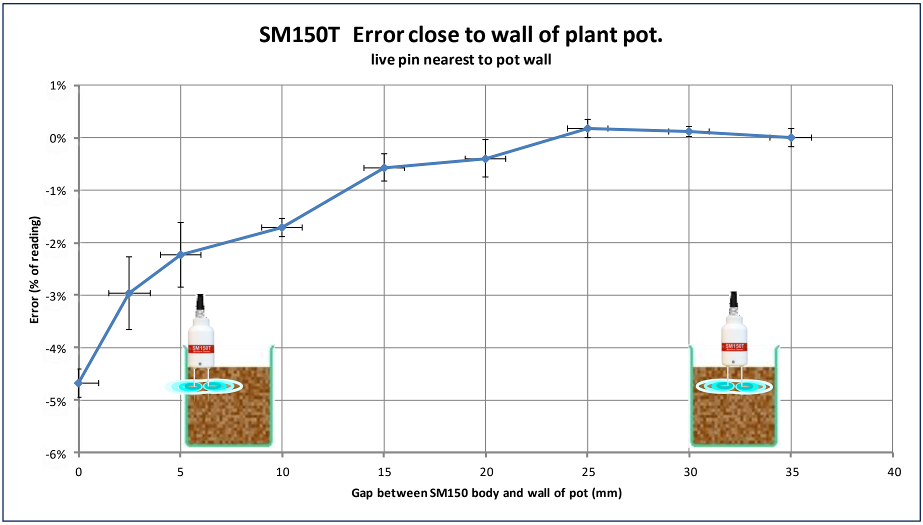
The SM150T is most sensitive to signals very close to the two rods, but a small proportion of the signal reaches up to 50mm from the rods.



Minimum soil sample size: Full accuracy requires a soil volume of one litre but the additional error from taking a reading in a 0.5 litre sample is negligible

SM150Ts may interact if they are placed too close together – they should be separated by at least 100mm.

If the SM150T is inserted too close to the wall of a plant pot the sensing field can “see” outside the pot. This behaviour is shown in the graph below.



For best results keep a gap of at least 25mm (1 inch) between the body of the sensor and the wall of the plant pot.

Electromagnetic Compatibility (EMC)

General information

SM150T is a Class A product, intended for operation in non-residential environments.
Only use cables and accessories authorised by Delta-T (sensor cables from other sources for example may adversely affect product performance and affect quality of results).
If possible route cables along the soil surface or bury them – this also reduces possible trip hazard and animal damage.
Do not modify the product or its supplied accessories.
See also **SM150T EMC Guidance** on the Software and Manuals DVD

Regulatory information

Europe

This device conforms to the essential requirements of the EMC directive 2004/108/EC, based on the following test standards:

EN61326-1:2006 Electrical requirement for measurement, control and laboratory use. EMC requirements: Group 1, Class A equipment – (emissions section only).

EN61326-1:2006 Electrical requirement for measurement, control and laboratory use. EMC requirements: Basic Immunity (immunity section only).

FCC compliance (USA)

This device conforms to Part 18 of FCC rules – Industrial, Scientific & Medical Equipment.

Note: with reference to FCC Part 18.115 Elimination and investigation of harmful interference.

(a) The operator of the ISM equipment that causes harmful interference to radio services shall promptly take appropriate measures to correct the problem.

Definitions

Volumetric Soil Moisture Content is defined as

$$\theta_V = \frac{V_W}{V_S}$$

where V_w is the volume of water contained in the sample

and V_s is the total volume of the soil sample.

The preferred units for this ratio are **m^3.m^{-3}**, though **%vol** is frequently used.

Soil Moisture Content varies from approx. 0.02 m^3.m^{-3} for sandy soils at the permanent wilting point, through approx. 0.4 m^3.m^{-3} for clay soils at their field capacity, up to values as high as 0.85 m^3.m^{-3} in saturated peat soils.

Gravimetric Soil Moisture Content is defined as

$$\theta_G = \frac{M_W}{M_S} g.g^{-}$$

*where M_W is the mass of water in the sample, and M_S is the total mass of the **dry** sample.*

To convert from volumetric to gravimetric water content, use the equation

$$\theta_G = \theta_V \times \frac{\rho_W}{\rho_S}$$

where ρ_W is the density of water (= 1g.cm^{-3}),

and ρ_S is the bulk density of the sample ($\frac{M_S}{V_S}$).

Organic and Mineral soil definitions:

The general calibrations have been optimised to cover a wide range of soil types, based on the following definitions:

Soil type	optimised around organic content:	use for organic contents:	bulk density range: (g.cm^{-3})	use for bulk densities: (g.cm^{-3})
Mineral	~ 1 %C*	< 7 %C	1.25 - 1.5	> 1.0
Organic	~ 40 %C	> 7 %C	0.2 - 0.7	< 1.0

** Note: %C denotes "percentage Carbon" and is a measure of organic content*

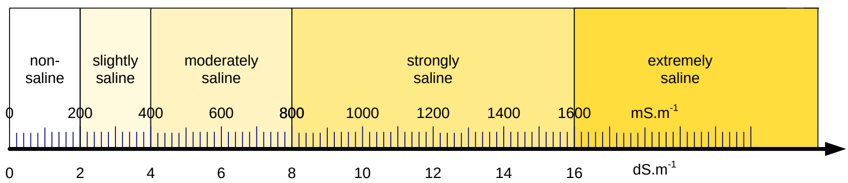
Salinity

The preferred SI units for ionic conductivity are **mS.m^{-1}** (where S is Siemens, the unit of electric conductance. Dimensionally it is equivalent to the inverse of resistance i.e. Ohm^{-1}).

The following conversions apply:

$$1\ \text{mS.m}^{-1} = 0.01\ \text{dS.m}^{-1}$$
$$= 0.01\ \text{mS.cm}^{-1}$$
$$= 10\ \mu\text{S.cm}^{-1}$$

Soil salinity can be classified using the following descriptive categories:



Classification of salinity

References

1. Gaskin, G.J. and J.D. Miller, 1996
Measurement of soil water content using a simplified impedance measuring technique.
J. Agr. Engng Res ***63***, *153-160*

2. Topp, G.C., J. L. Davis and A. P Annan 1980
Electromagnetic determination of soil water content.
Water Resour. Res ***16****(3) 574-582*

3. Whalley, W.R. 1993
Considerations on the use of time-domain reflectometry (TDR) for measuring soil moisture content.
Journal of Soil Sci. ***44***, *1-9*

4. White, I., J.H. Knight, S.J. Zegelin, and Topp, G.C. 1994
Comments on 'Considerations on the use of time-domain reflectometry (TDR) for measuring soil water content' by W R Whalley
Journal of Soil Sci. ***45***, *503-508*

5. Roth, C.H., M.A. Malicki, and R. Plagge, 1992
Empirical evaluation of the relationship between soil dielectric constant and volumetric water content as the basis for calibrating soil moisture measurements.
Journal of Soil Sci. ***43***, *1-13*

6. Knight, J.H. 1992
Sensitivity of Time Domain Reflectometry measurements to lateral variations in soil water content.
Water Resour. Res., ***28***, *2345-2352*

7. Or, D. and J.M. Wraith 1999
Temperature effects on soil bulk dielectric permittivity measured by time domain reflectometry: A physical model.
Water Resour Res., ***35***, *371-383*

Appendix 1

Soil-specific Calibration

This note provides details of 2 techniques for generating soil-specific calibrations:

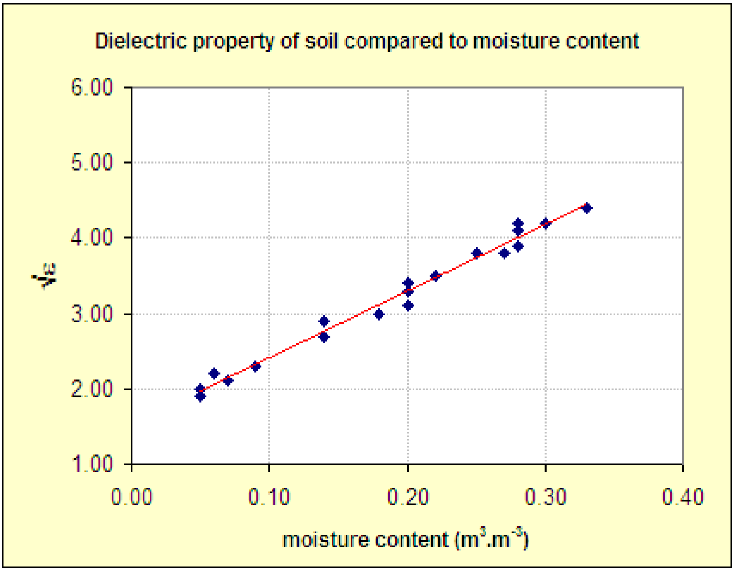
Laboratory calibration for substrates* and non-clay soils

Laboratory calibration for clay soils

* We use the term substrate to refer to any artificial growing medium.

Underlying principle

Soil moisture content (θ) is proportional to the refractive index of the soil (√ε) as measured by the *SM150T* (see **Calibration** section).



The goal of calibration is to generate two coefficients (a_0, a_1) which can be used in a linear equation to convert probe readings into soil moisture:

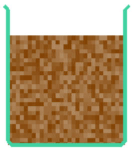
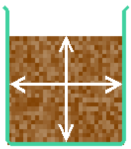
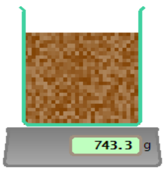
$$\sqrt{\varepsilon} = a_0 + a_1 \times \theta$$

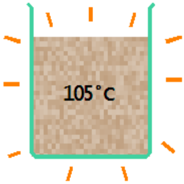
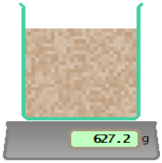
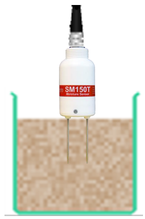
Laboratory calibration for non-clay soils

This is the easiest technique, but it's not suitable for soils that shrink or become very hard when dry.

Equipment you will need:

- SM150T and meter
- Soil corer (if doing a calibration for a cohesive soil rather than sand or a substrate)
- Heat-resistant beaker (≥ 0.5 litre)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven (for mineral soils or substrates)

Process	*Notes and example*
	Collect a damp sample of the soil or substrate. This sample needs to be unchanged from its in-situ density, to be ≥ 0.5 litre, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. For cohesive soils this is most easily done with a soil-corer. Sandy soils can be poured into the beaker, but you should take the subsequent measurements immediately, as the water will quickly begin to drain to the bottom of the beaker. Compressible soils and composts often require measurement of the in-situ density and then need to be carefully reconstituted at that density within the beaker.
	Measure the volume occupied by the sample. ***L_s = 463.5ml***
	Weigh the sample, including the beaker. ***W_w = 743.3g***

	Insert SM150T into the sample and record its output in Volts. ***V_w* = 0.350*V***
	Dry the sample thoroughly. With mineral soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity). For organic soils and composts it's usual to air-dry the sample to avoid burning off any volatile factions.
	Weigh the dry sample in the beaker. ***W_0* = 627.2*g***
	Re-insert the SM150T into the dry sample and record this reading. ***V_0* = 0.051*V***
Calculate ***a_0***	For the SM150T, In the dry soil $V = V_0 = 0.051$ Volts Substitute this into the equation $\sqrt{\epsilon} = 1.0 + 14.4396V - 31.2587V^2 + 49.0575V^3 - 36.5575V^4 + 10.7117V^5$ gives $\sqrt{\epsilon} = 1.66$ Since $\theta_0 = 0$, this is the value needed for a_0 **a_0 = 1.66**
Calculate ***θ_w***	The water content of the wet soil, θ_w, can be calculated from the weight of water lost during drying, ($W_w - W_0$) and its volume, L_s: $\theta_w = (W_w - W_0)/L_s = (743.3 - 627.2)/463.5 = 0.25$ **θ_w = 0.25**

Calculate ***a*₁**	In the wet soil $V = V_w$ = 0.350 Volts and substituting gives $\sqrt{\varepsilon_w} = 3.79$ Finally $a_1 = \left(\sqrt{\varepsilon_w} - \sqrt{\varepsilon_0}\right) / \left(\theta_w - \theta_0\right) = (3.79 - 1.66)/(0.25 - 0) = 8.51$ **a_1 = 8.51**
Result	**a_0 = 1.66** **a_1 = 8.51**

In this example this soil is now calibrated.

You can now use these two numbers in place of the standard mineral or organic calibration factors to convert SM150T readings into volumetric water content θ using:

$$\sqrt{\varepsilon} = a_0 + a_1 \times \theta$$

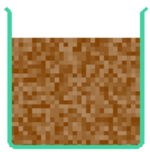
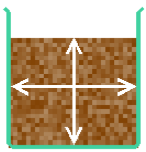
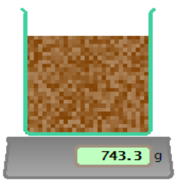
See also page Underlying principle on page 42

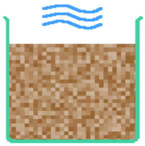
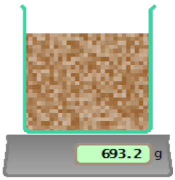
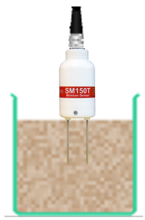
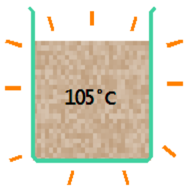
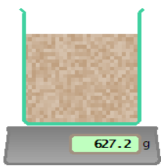
Laboratory calibration for clay soils

This technique is adapted to avoid the near-impossibility of inserting the SM150T into completely dry clay soil. It requires taking measurements at 2 significantly different, but still damp, moisture levels.

Equipment you will need:

- SM150T and meter
- Soil corer
- Heat-resistant beaker (≥ 500ml)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven

Process	*Notes and example*
	Collect a wet sample of the clay soil: 25 to 30% water content would be ideal. This sample needs to be unchanged from its in-situ density, to be ≥ 500ml, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. This is most easily done with soil-corer.
	Measure the volume occupied by the sample. **$L_s = 463.5ml$**
	Weigh the wet sample, including the beaker. **$W_w = 743.3g$**

	Insert SM150T into the wet sample and record its output in Volts. **V_w = 0.349V**
	Dry the sample until still moist, ~15% water content. Gentle warming can be used to accelerate the process, but take care not to over-dry in places, and allow time for the water content to equilibrate throughout the sample before taking a reading.
	Reweigh. **W_m = 693.2g**
	Re-measure with the SM150T. **V_m = 0.180V**
	Dry the sample thoroughly. With clay soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity).
	Weigh the dry sample in the beaker. **W_0 = 627.2g**
Calculations	Substituting in the SM150T equation $$\sqrt{\epsilon} = 1.0 + 14.4396V - 31.2587V^2 + 49.0575V^3 - 36.5575V^4 + 10.7117V^5$$

	provides two dielectric values, $\sqrt{\varepsilon_w}$ and $\sqrt{\varepsilon_m}$, at two known water contents, θ_w and θ_m
For the wet soil	Substituting Vw = 0.349 gives $\sqrt{\varepsilon_w} = 3.83 = a_0 + a_1.\theta$ for $\theta_w = \frac{(743.3-627.2)}{463.5} = 0.25$
For the moist soil	Substituting Vm = 0.180 gives $\sqrt{\varepsilon_m} = 2.84 = a_0 + a_1.\theta$ for $\theta_m = \frac{(693.2-627.2)}{463.5} = 0.14$
Calculate a_1	Then $a_1 = \frac{\sqrt{\varepsilon_w} - \sqrt{\varepsilon_m}}{\theta_w - \theta_m} = 9.0$ **a_1 = 9.00**
Calculate a_0	and $a_0 = \sqrt{\varepsilon_w} - (a_1.\theta_w) = 1.58$ **a_0 = 1.58**
Result	**a_1 = 9.00** **a_0 = 1.58**

In this example this soil is now calibrated.

You can now use these two numbers in place of the standard mineral or organic calibration factors to convert SM150T readings into volumetric water content θ using:

$$\sqrt{\varepsilon} = a_0 + a_1 \times \theta$$

See also page Underlying principle on page 42

Appendix 2:

The SM150 Temperature Sensor

Soil moisture content is used with the measurement of soil temperature in several major application areas including the following:

Global warming and climate studies

Soils contain more than four times as much carbon as the CO2 in the atmosphere, and each year they release about ten times as much carbon through soil respiration as the combined release through burning fossil fuels. Soil respiration rates are particularly sensitive to changes in both temperature and the moisture content of the soil.
Soils also have a significant interaction with climate as they store and release heat – soil temperature provides a measure of the energy partitioning, which in turn is strongly influenced by the effect of soil moisture on thermal conductivity.

Civil engineering

Most civil engineering projects depend critically on the mechanical properties of soils. Those properties are effected by many different parameters, but moisture content and temperature are the two variables that are most likely to change over time, so may be measured together in order to assess their impact.

Soil contamination and hydrogeology

Soil moisture is the main determinant for the movement of contaminants and solutes through soils, but temperature also has a significant influence so they are often measured together.

Agriculture

Temperature may be measured alongside soil water content for studies of evapotranspiration, soil water balance and irrigation. Soil strength and seedling emergence depend on soil moisture and temperature, and both need to be taken into account when deciding when to sow.

SM150T Temperature Measurement

The SM150T Temperature sensor uses a thermistor with a 10K resistance at 25 ˚C. However:

A. This sensor has a different response curve from the more widely used 10K3A1B type. The response curve is given in the Resistance to Temperature Lookup Table on page 53

B. The Thermistor circuit shares the Power 0V wire. If the thermistor is measured when the SM150T is powered, the measured resistance measurement may need to be corrected for 18 mA SM150T supply current.

Allow 20 minutes for the temperature reading to stabilise after installation. Do not log at frequencies under 1 minute - in order to prevent thermal self-heating errors.

GP1, GP2 and DL6 loggers

The 'SM150T Temperature' sensor type in DeltaLINK performs the supply current correction.

DL2e Logger

The linearization table for the 'S3T' sensor code ('SM150T Temperature') provides supply current correction for the **SMSC/lw-05** 5m logger cable ONLY.

Extension cables and other cable lengths

Create your own custom sensor type(s) and linearization tables as described in ***Ls2Win*** Help topic, How to… 'Add or modify a sensor type in the sensor library'.
Enter corrected resistance values (R) for each linearization table point:

R = R5 + (0.059 x Lex) kΩ (See footnote[10])

Or R = R5 + (0.9 x Rc – 0.297) kΩ

where

R5 = value supplied in the table for the 'SM150T Temp, 5m' sensor type.

Lex = length of extension cable, excluding the 5m of **SMSC/lw-05** cable.

Rc = total cable resistance, including resistance of **SMSC/lw-05** cable, if fitted.

Other loggers

If your logger can be programmed so that the soil moisture and temperature readings can be taken sequentially (i.e. the sensor is not powered during the temperature reading), then the temperature can be obtained directly from the response curve on page 50.

Otherwise, correct the resistance reading before applying the response curve.

You need to know the resistance of the Power 0V wire in the SM150T cable (Rc) and establish whether your logger uses voltage or current excitation for resistance measurement.

---

[10] *Note: This equation only applies to Delta-T SM150T cables*

Voltage Excited

You need to know the excitation voltage (Vref), reference resistance (Rref).

The correct resistance is given by the equation:

$R = a0 + a1 * Rmeas$

Where:

$a0 = – Ic.Rc.Rref / Vref$

$a1 = 1 – Ic.Rc / Vref$

Ic = 18 mA (SM150T sensor supply current)

For Delta-T **EXT/5W-xx** series cables:

Rc = 0.066 Ω.m-1

For the **SMSC/lw-05** 5m logger cable

Rc = 0.33 Ω

Current Excited

You need to know the excitation current (Iex).

The corrected resistance is given by the equation (using terms defined above):

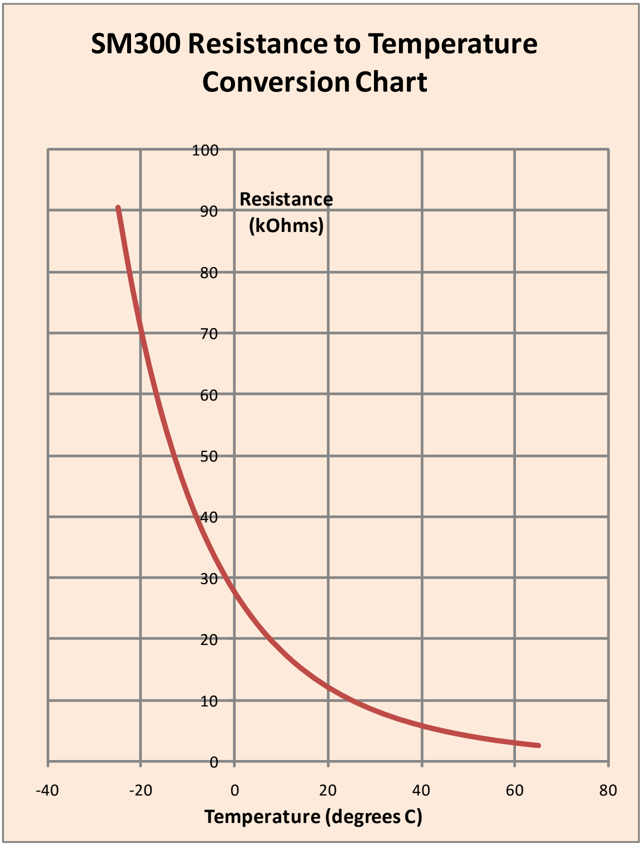
$R = Rmeas – Ic.Rc/Iex$

Effect of Temperature on Water Permittivity

See **Temperature response of soil moisture readings** on page 35

Resistance to Temperature Lookup Table

Temperature degrees C	Resistance Kohms
-25	90.538
-22	77.683
-19	66.854
-16	57.713
-13	49.968
-10	43.379
-7	37.759
-4	32.957
-1	28.844
2	25.299
5	22.244
8	19.608
11	17.321
14	15.334
17	13.606
20	12.098
23	10.780
26	9.623
29	8.611
32	7.720
35	6.935
38	6.241
41	5.627
44	5.080
47	4.595
50	4.162
53	3.775
56	3.430
59	3.121
62	2.843
65	2.593



Note: This table has been optimised for use as a look-up table.
To minimise linear interpolation errors the data points fall either side of the manufacturers' specified sensor response curve. This helps optimise the overall accuracy of readings.

Technical Support

Terms and Conditions of Sale

Our Conditions of Sale (ref: COND: 1/07) set out Delta-T's legal obligations on these matters. The following paragraphs summarise Delta T's position but reference should always be made to the exact terms of our Conditions of Sale, which will prevail over the following explanation.

Delta-T warrants that the goods will be free from defects arising out of the materials used or poor workmanship for a period of two years from the date of delivery.

Delta-T shall be under no liability in respect of any defect arising from fair wear and tear, and the warranty does not cover damage through misuse or inexpert servicing, or other circumstances beyond their control.

If the buyer experiences problems with the goods they shall notify Delta-T (or Delta-T's local distributor) as soon as they become aware of such problem.

Delta-T may rectify the problem by replacing faulty parts free of charge, or by repairing the goods free of charge at Delta-T's premises in the UK during the warranty period.

If Delta-T requires that goods under warranty be returned to them from overseas for repair, Delta-T shall not be liable for the cost of carriage or for customs clearance in respect of such goods. However, Delta-T requires that such returns are discussed with them in advance and may at their discretion waive these charges.

Delta-T shall not be liable to supply products free of charge or repair any goods where the products or goods in question have been discontinued or have become obsolete, although Delta-T will endeavour to remedy the buyer's problem.

Delta-T shall not be liable to the buyer for any consequential loss, damage or compensation whatsoever (whether caused by the negligence of the Delta-T, their employees or distributors or otherwise) which arise from the supply of the goods and/or services, or their use or resale by the buyer.

Delta-T shall not be liable to the buyer by reason of any delay or failure to perform their obligations in relation to the goods and/or services if the delay or failure was due to any cause beyond the Delta-T's reasonable control.

Extended Warranty

All Delta-T Devices products have a two year (24 month) warranty as standard, but the ML3, SM150T and SM300 soil moisture sensors benefit from a 5 year warranty (60 months from date of delivery). Simply register the product(s) with us via and we will add 3 more years to the standard warranty, extending it to the full 5 years duration. To qualify, products must be registered within 12 weeks of delivery.
All SM150s, SM150Ts, SM300s and ML3s sold since 1 January 2016 are eligible.

Visit the Support Section of our website www.delta-t.co.uk to register your sensor for an extended 5 year warranty.

Service, Repairs and Spares

Users in countries that have a Delta-T distributor or technical representative should contact them in the first instance.

Spare parts for our own instruments can be supplied and can normally be despatched within a few working days of receiving an order.

Spare parts and accessories for products not manufactured by Delta-T may have to be obtained from our supplier, and a certain amount of additional delay is inevitable.

No goods or equipment should be returned to Delta-T without first obtaining the return authorisation from Delta-T or our distributor.

On receipt of the goods at Delta-T you will be given a reference number. Always refer to this reference number in any subsequent correspondence. The goods will be inspected and you will be informed of the likely cost and delay.

We normally expect to complete repairs within one or two weeks of receiving the equipment. However, if the equipment has to be forwarded to our original supplier for specialist repairs or recalibration, additional delays of a few weeks may be expected. For contact details see below.

Technical Support

Users in countries that have a Delta-T distributor or technical representative should contact them in the first instance.

Technical Support is available on Delta-T products and systems. Your initial enquiry will be acknowledged immediately with a reference number. Make sure to quote the reference number subsequently so that we can easily trace any earlier correspondence.

In your enquiry, always quote instrument serial numbers, software version numbers, and the approximate date and source of purchase where these are relevant.

Contact details:

Technical Support
Delta-T Devices Ltd
130 Low Road
Burwell
Cambridge CB25 0EJ
England (UK)

Tel: +44 1638 742922
Fax: +44 1638 743155
E-mail: tech.support@delta-t.co.uk
sales@delta-t.co.uk
Web: www.delta-t.co.uk

Index

Technical Support
Delta-T Devices Ltd
130 Low Road
Burwell
Cambridge CB25 0EJ
England (UK)

Tel: +44 1638 742922
Fax: +44 1638 743155
E-mail: tech.support@delta-t.co.uk
sales@delta-t.co.uk
Web: www.delta-t.co.uk