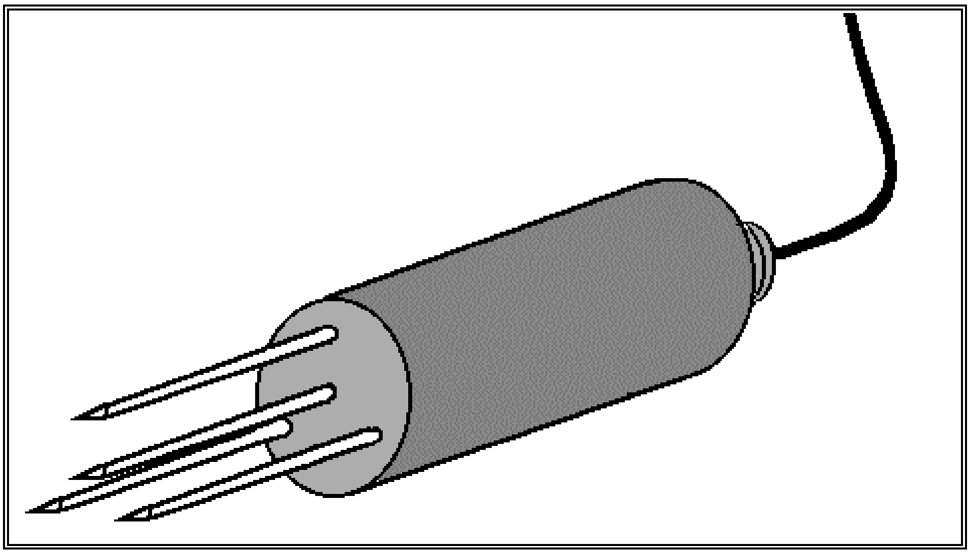
ThetaProbe

SOIL MOISTURE SENSOR



TYPE ML2

USER MANUAL

ML2-UM-1

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Patents

Patent applied for.

ThetaProbe has been jointly developed by The Macaulay Land Use Research Institute and Delta-T Devices and uses novel measurement techniques.

Patent Application Nos. 9609372.9 GB, 963703190.1 EUR and 08\706675 USA apply to this product.

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Introduction & description

ThetaProbe measures volumetric soil moisture content, θ_V, by the well established method of responding to changes in the apparent dielectric constant. These changes are converted into a dc voltage, virtually proportional to soil moisture content over a wide working range.

Volumetric soil moisture content is the ratio between the volume of water present and the total volume of the sample. This is a dimensionless parameter, expressed either as a percentage (%vol), or a ratio ($m^3.m^{-3}$). Thus 0 $m^3.m^{-3}$ corresponds to a completely dry soil, and pure water gives a reading of 1.0 $m^3.m^{-3}$. There are important differences between volumetric and gravimetric soil moisture contents. The section on Definitions gives details of the relationship between these two parameters and soil matric potential (as measured by Tensiometers).

Operating principles

ThetaProbe consists of a waterproof housing which contains the electronics, and, attached to it at one end, four sharpened, stainless steel rods that are inserted into the soil. The cable provides connection to a suitable power supply and an analogue output signal. It is an analogue device, continually producing an output signal and measuring soil properties in voltage difference terms.

ThetaProbe measures soil parameters by applying a 100 MHz signal via a specially designed transmission line whose impedance is changed as the impedance of the soil changes. This impedance has two components; the apparent dielectric constant and the ionic conductivity. The signal frequency has been chosen to minimise the effect of ionic conductivity, so that changes in the transmission line impedance are dependent almost solely on the soil's apparent dielectric constant. These changes cause a voltage standing wave to be produced which augments or reduces the voltage produced by the crystal oscillator, depending on the medium surrounding the measurement prongs. The difference between the voltage at the oscillator and that reflected by the rods is used by *ThetaProbe* to measure the apparent dielectric constant of the soil.

Each *ThetaProbe* is adjusted during manufacture to provide a consistent output when measuring media of known dielectric constant, making them readily interchangeable without system re-calibration.

Work published over many years by Whalley, White, Knight Zegelin and Topp and others, shows linear correlation between the square root of the dielectric constant, ($\sqrt{\varepsilon}$), and volumetric moisture content, (θ), and this has been documented for many soil types.

The output signal is 0-1V DC for a range of soil dielectric constant, ε, between 1 and 32, which represents 0.5 $m^3.m^{-3}$ volumetric soil moisture content for generalised mineral soils.

Essentially, installation is very simple - you just push the probe into the soil until the rods are fully covered, connect up the power supply and take readings from the analogue output. Optional extension tubes are available for monitoring a soil layer below the surface. However, it is quite possible to get sampling errors greater than 0.1 $m^3.m^{-3}$, and in extreme cases damage the probe if you don't pay due care and attention to the details of the installation of sensors when making measurements of soil water content.

You will need to consider each of the following factors when setting up a measurement:

Air pockets

The presence of air pockets around the rods will affect the reading in a similar fashion to soil compression (both reduce the value of soil moisture content measured). In particular, you need to be very careful when removing and re-inserting the probe into a previous location.

Insertion angle

If the probe is going to be left in situ, and measurements taken during and after rainfall, it is a good idea to insert it at an angle (say 20°), so that any water running down the side of the probe housing tends to be carried away from the rods. This is particularly important if the probe is being installed below the soil surface using a probe extension tube.

Holding the probe

If the *ThetaProbe* is inserted into moderately damp soil, particularly in a small container, then the presence of your hands around the case could cause a shift in reading of as much as 0.005 $m^3.m^{-3}$. Under most circumstances this will not be significant compared to other sampling errors, but for high accuracy readings you should take care not to handle the probe while taking a reading.

Soil sampling points

The soil water content measured by a *ThetaProbe* within one small locality can be affected by :

Variations in soil density and composition,

Stones close to the rods,

Roots (either nearby or pierced by the rods),

Earth worm holes (or even mole holes!),

Subsoil drainage,

Small scale variability in transpiration and evaporation losses.

It is important to take the degree of variability of these various parameters into account when deciding on the number of probes to use at any particular location. If the soil is known to be very heterogeneous, it will be necessary to take measurements from at least three closely-spaced locations.

Care and maintenance

ThetaProbe is sealed after calibration, requires no routine maintenance and utilises materials selected for successful field operation. No internal maintenance or repair can be performed by the user.

Removal of the cross- head sealing screws may damage the seal and will invalidate your guarantee.

ThetaProbe is a sensitive sensor, and particular consideration should be given to the measurement rods when planning your installation or use.

The measurement rods are assembled to the probe before calibration and should not be disturbed unnecessarily. All four rods may not be exactly parallel. This is acceptable, and no attempt to adjust them should be made while they are attached to the probe body, as it may break the rod or damage the case seal.

If the rods become excessively bent in use, they can be carefully unscrewed from the body and straightened. They have a right-handed thread. Replacements are available, if required. Ensure that they are fully tightened on re-assembly, but do not apply excessive force, as this will cause damage to the probe body seal. Disturbing the rod assembly should not affect calibration, but is not recommended unless the rods are badly bent. Pre-preparation of holes to accept *ThetaProbe* measuring rods is recommended in stony soils or other hard materials.

Burial, cable protection and Extension tubes.

The probe is designed to be permanently buried, if required. When used like this, optional extension tubes can be fitted to enable easier withdrawal, and to protect the cable from damage by animals, etc.

Extension tubes are lengths of the same tubing as is used to make the *ThetaProbe* cylindrical body. They have a female thread in one end and the same sized male thread in the other.

Two lengths are available. ML/EX50 is 50cms long and ML/EX100 is 100cms long. These can be screwed into each other to make longer lengths, as required.

Extension tubes allow *ThetaProbe* to be lowered into pre-augured holes down to the desired measurement depth, and to ease removal from the soil when the application requires burial.

The outside diameter of the extension tubes is 4cms, so an auger of approximately 5cms is recommended.

Extension tubes

Extension tubes can be easily added to the *ThetaProbe* by following these instructions:

Carefully remove the black plastic, thread protection cover from the *ThetaProbe*. This cover protects the extension tube mating thread when extension tubes are not needed. It can be removed by sliding it up the cable.

Pass the *ThetaProbe* cable through the hole in the extension tube, ensuring that the female thread in the extension tube is towards *ThetaProbe*. Screw the extension tube onto *ThetaProbe* and hand tighten only. Repeat this process for additional extension tubes to make up the length required.

Finally, thread the cable through the black plastic thread protection cover and slide the cover into place over the male thread on the end of the extension tube. This will minimise water ingress into the tube.

Wiring connections

ThetaProbe is supplied with a four core, screened cable which provides these connections:

Red	Power supply positive.
Blue	Power supply zero volts.
Yellow	Output signal HI, load resistance 10KΩ minimum.
Green	Output signal LO.
Braid	Cable screen. Not connected within probe.

The Blue and Green leads are connected internally.

The braid screen should be connected to an analogue earth on the logger or other measuring unit. If not using Delta-T equipment, please refer to the manufacturer's instructions.

Some *ThetaProbe* variants have or require a connector to be fitted to mate to appropriate Delta-T instrumentation. Connection details are given in the relevant instrumentation User Manual.

Electromagnetic Compatibility (EMC)

ThetaProbe has been assessed for compatibility under the European Union EMC Directive 89/336/EEC and conforms to the appropriate standards, provided the moisture measuring rods and probe body are completely immersed in the soil or other material being measured. The cable connecting the *ThetaProbe* to its associated instrumentation should also be routed along the surface of the soil.

If the probe is not installed in this way, some interference may be experienced on nearby radio equipment. Under most conditions, moving the equipment further from *ThetaProbe* (typically 1-2 metres) will stop the interference.

ThetaProbes installed near to each other will not malfunction due to interference.

Power Connections

ThetaProbe can be directly powered by Delta-T loggers using their internal batteries. However, if several probes are to be used, or if the logger has to supply significant power to other sensors or accessories, we recommend powering the logger and sensors from an external power supply.

Battery power consumed by a probe for a single measurement taken with a 5 second warm-up time is typically: 19mA * 5s ≅ 0.03mA.h

Delta-T loggers include a minimum of two relay controlled outputs to provide and control sensor power. Each relay (called a warm-up relay) is capable of switching 1A. This means that each relay can power 43 *ThetaProbes.*

Refer to your logger manual for exact connection details, or contact your local distributor or Delta-T Devices Ltd

Configuring the Warm-up Channel

Although the probe can be continuously powered and read, significant power can be saved by using the Delta-T logger warm-up relay facility to energise the sensor only just before and during a log.

For complete stability, a warm-up time of 5s is recommended, although good repeatability can be achieved using times down to 1s. Shorter times will significantly reduce the battery power consumption of the system.

Logger input channel configuration

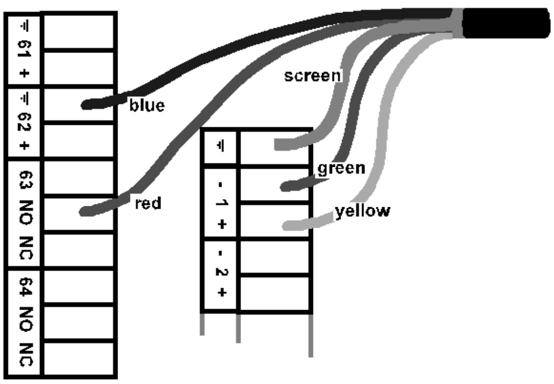
ThetaProbe has been designed to make its use with dataloggers straightforward, using only a single logger analogue input channel.

If you simply want to log the probe voltage directly, it can be treated as a differential voltage source of range 0-1.5VDC, and the logger should be configured accordingly. Use as a single -ended voltage source will will introduce measurement errors due to the sensor power return current and is not recommended. You can convert the data to soil moisture units after logging, using the information supplied in the **Calibration** section.

The **Calibration** section also describes how to program your datalogger to automatically convert probe output into soil moisture units before logging.

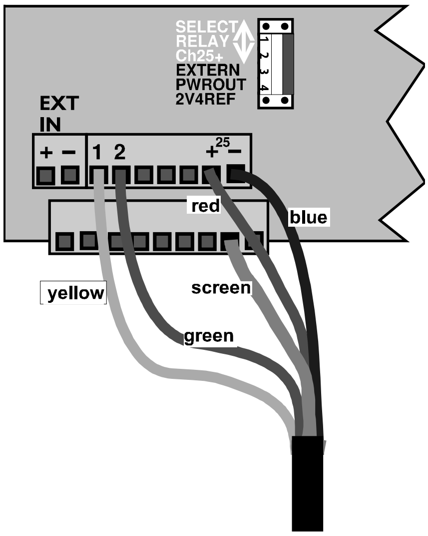
DL2e connections

This diagram shows the connections for a *ThetaProbe* connected to channel 1 of a DL2e in differential mode, and powered through the loggers internal power supply. Refer to the DL2e manual section on Relay Channels for details on this configuration, or for connection using an external power supply.

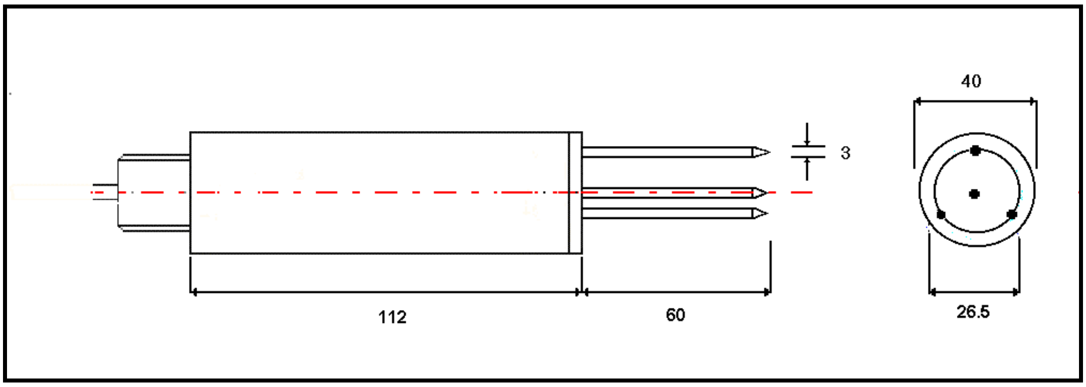


DL3000 connections

This diagram shows the connections to channel 1 of a DL3000 analogue input card, again making the connection in differential mode and using the loggers internal power supply. See the section on “Connecting sensors” in the DL3000 user manual for details on this and how to configure and connect to the logger when using an external power source



Mechanical and electrical specifications



(dimensions in mm)

Technical Specifications	
Type No.	ML2
Measurement parameter	Volumetric soil moisture content, θ_V, ($m^3.m^{-3}$ or %vol.).
Full range	0 - 1.0 $m^3.m^{-3}$
Accuracy	±0.02 $m^3.m^{-3}$ after calibration to a specific soil type, or, ±0.05 $m^3.m^{-3}$ using the supplied soil calibration, in all 'normal' soils, over range 0.05-0.6 $m^3.m^{-3}$ and 0-40°C ambient temperature when used with Delta-T loggers.
Soil conductivity range	Accuracy figures apply over a soil conductivity range of 0-100 $mS.m^{-1}$. Calibratable up to 2000 $mS.m^{-1}$.
Soil sampling volume	90% influence within cylinder of 2.5cm diam., 6cm long, (approx 30cm^3), surrounding central rod.
Environment	Will withstand burial in wide ranging soil types or water for long periods without malfunction or corrosion.
Stabilization time	1 to 5 sec. from power-up, depending on accuracy required.
Response time	Less than 0.5 sec. to 99% of change.
Duty cycle	100 % (Continuous operation possible).
Interface	Input requirements: 5-15V DC unregulated. Current consumption: 19mA typical, 23mA max. Output signal: approx. 0-1V DC for 0-0.5m^3m^{-3}
Case material	PVC
Rod material	Stainless steel
Cable length	Standard: 5m. Maximum length: 100m
Weight	350 gm approx. with 5m cable.

Use and calibration

ThetaProbe can be used to provide an instantaneous reading of soil conditions or, in conjunction with a datalogger, comprehensive moisture data over time.

The millivolt output from the probe, although requiring a non-linear conversion to soil moisture units for optimum accuracy, can provide reasonable results using a straightforward linear conversion.

To use the probe without a datalogger, you will need to provide it with 5-15VDC at about 20mA. Voltage readings can be taken with any general purpose voltmeter and the conversion to soil moisture units made using the information given in a later section.

This measurement method produces good, instantaneous results easily, but for optimum accuracy, automatic conversion to soil moisture units for known types of soil and, of course, permanent data records, *ThetaProbe* should be used with a datalogger.

Data conversion methods

Every *ThetaProbe* uses the same characteristic to convert from its mV output to the square root of the apparent dielectric constant,$\sqrt{\varepsilon}$, of the soil. However, the conversion from $\sqrt{\varepsilon}$ to percent moisture content depends on the soil type encountered. If you want to log data in soil moisture content units, you will have to provide the logger with information about how to convert the data.

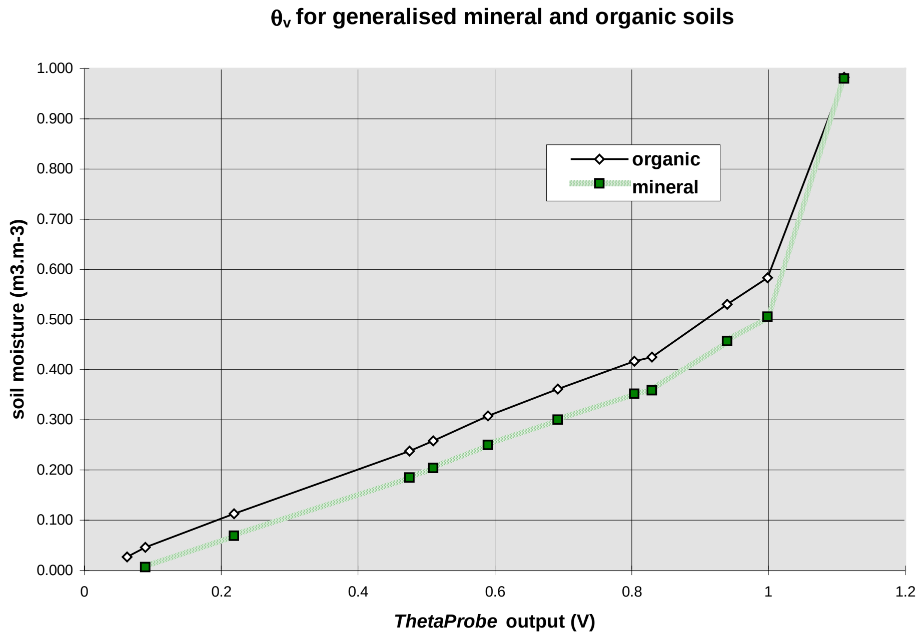
Three main methods of configuring dataloggers to *ThetaProbe* are recommended:

- Polynomial equation conversion.
- Linearisation table conversion.
- Slope and offset conversion.

Each method is described in the following section.

The need for calibration

The relationship beween *ThetaProbe* output and soil moisture content is a non-linear curve of this form:



These two curves are generalised examples for mineral and organic soils. The calibration curve for any specific soil would be slightly different from either of these because the *ThetaProbe* is actually sensing the dielectric constant, (ε) of the soil, and the relationship between the measured dielectric constant of a soil and its water content (θ) depends on the particular composition of the soil.

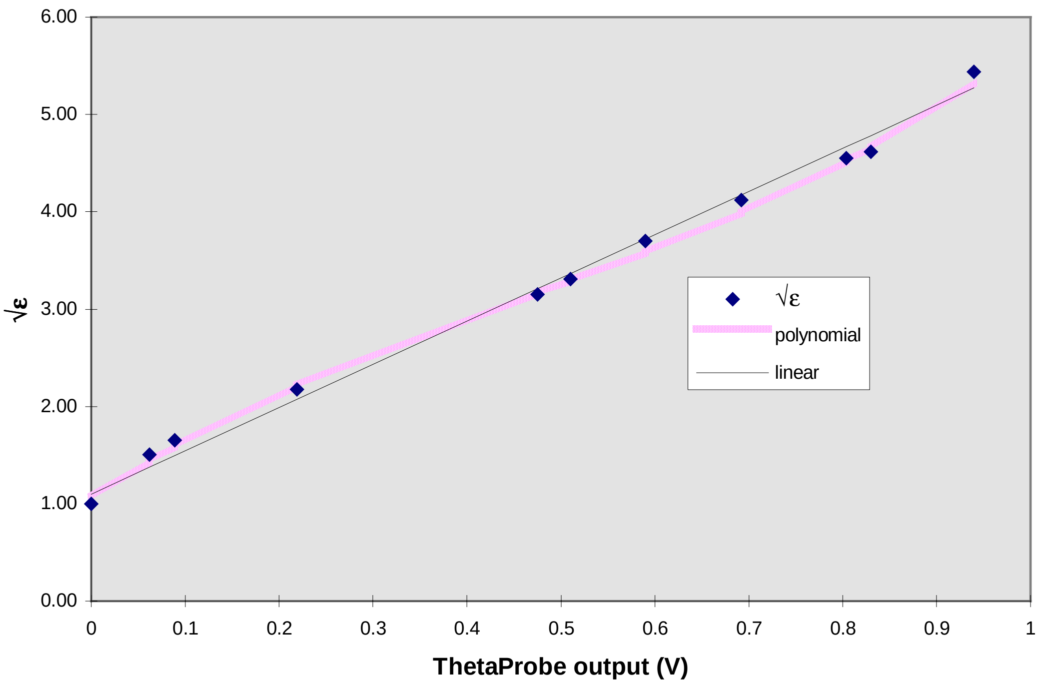
You will need to calibrate the *ThetaProbe* for your specific soil if you want to minimise the errors associated with converting the *ThetaProbe* output (V) to soil water content.

Repeatability of ML2 is $\pm 0.02\ m^3.m^{-3}$. Theoretically, if a **soil specific calibration** is performed with no additional errors, this will be the probe error in this situation. If using a **generalised calibration**, typical errors of $\pm 0.05\ m^3.m^{-3}$ should be expected. In practice, whether you need to do a soil-specific calibration will depend on what accuracy you need to work to and the size of your sampling errors (see section on "Achievable Accuracy").

Response to dielectric constant

Performing a soil-specific calibration is relatively straightforward, because all ML2 *ThetaProbe*s respond to dielectric constant in the same stable, uniform way, **so it is only necessary to do this once for one probe**.

The relationship beween *ThetaProbe* output, (V), and square root of dieletric constant, ($\sqrt{\varepsilon}$), is like this:



In the range 0 to 1 Volt (corresponding to a soil moisture range 0 to ~ 0.55 by volume), this relationship can be fitted very precisely by a 3rd order polynomial:

$$\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3 \qquad (R^2 = 0.998) \qquad \textbf{[1]}$$

or by the linear relationship:

$$\sqrt{\varepsilon} = 1.1 + 4.44V \qquad (R^2 = 0.99) \qquad \textbf{[2]}$$

Our experience of measurements on soils suggests that below 0.5 $m^3.m^{-3}$ there is no significant improvement to the overall accuracy to be achieved by using the 3rd order polynomial equation rather than the linear relationship.

For very high moisture contents ($\theta > 0.5$ $m^3.m^{-3}$), the polynomial equation should be used. This is usually only necessary for organic soils.

Soil-specific Calibration

Whalley, and White, Knight, Zeggelin and Topp have shown that there is a simple linear relationship beween the complex refractive index (which is equivalent to $\sqrt{\varepsilon}$), and volumetric water content, θ, of the form:

$$\sqrt{\varepsilon} = a_0 + a_1 \cdot \theta \qquad \textbf{[3]}$$

Since the relationship beween *ThetaProbe* output and $\sqrt{\boldsymbol{\varepsilon}}$ is already known, it is only necessary to determine the two coefficients $\boldsymbol{a_0}$ and $\boldsymbol{a_1}$. We suggest you use the following protocol:

Step 1

Collect a sample of damp soil, disturbing it as little as possible so that it is at the same density as in situ.

Insert the *ThetaProbe* into the sample and measure the probe output, $\boldsymbol{V_w}$. Use equation [1] or [2] to calculate $\sqrt{\varepsilon_w}$. Weigh the damp sample, ($\boldsymbol{W_w}$), and measure its volume ($\boldsymbol{L}$).

Step 2

Oven-dry the sample, insert the *ThetaProbe* into the dry soil ($\boldsymbol{\theta} \approx 0$), and measure the probe output, $\boldsymbol{V_0}$.

Weigh the dry sample, ($\boldsymbol{W_0}$). Use equation [1] or [2] to calculate $\sqrt{\varepsilon}_0$. This equals $\boldsymbol{a_0}$. It will usually have a value between 1.0 and 2.0.

Step 3

Calculate the volumetric water content θ_w of the original sample:

$$\theta_w = \frac{(W_w - W_0)}{L}$$

Step 4

Then $$a_1 = \frac{\sqrt{\varepsilon_w} - \sqrt{\varepsilon_0}}{\theta_w}. \qquad \textbf{[4]}$$

It will usually have a value between 7.6 and 8.6.

Step 5

By inverting equation [3], and substituting from equation [2], the water content determined from a calibrated *ThetaProbe* will then be:

$$\theta = \frac{[1.1 + 4.44V] - a_0}{a_1} \qquad \textbf{[5]}$$

The corresponding equation using the polynomial relationship is:

$$\theta = \frac{\left[1.07 + 6.4V - 6.4V^2 + 4.7V^3\right] - a_0}{a_1} \qquad \textbf{[6]}$$

Using this relationship (rather than the linear form) will enable the *ThetaProbe* to achieve full accuracy over the full specified range, particularly for wetter soils with $0.5 < \theta < 0.6$.

Example:

1. In a sample of moist soil, the *ThetaProbe* gives an output of 0.43 V. This sample weighs 1.18, and has a volume of 0.75 litres. From equation [1], $\sqrt{\varepsilon_w}$ **= 3.01**
2. After drying the sample of soil, the *ThetaProbe* gives an output of 0.11 V. From equation [1] again, we can calculate $\boldsymbol{a_0} = \sqrt{\varepsilon_0}$ **= 1.59**.
3. The dry sample now weighs 1.05 kg, so the volume of water in the moist sample was 0.13 litres. Volumetric water content of the sample θ_w **= 0.17 $m^3.m^{-3}$**.
4. By substituting in equation [4], $\boldsymbol{a_1}$ **= 8.35**

Finally, by inserting into equation [5], θ_V **= 0.53*V* - 0.059** $m^3.m^{-3}$

Generalised calibration

If it's not necessary to perform a soil-specific calibration, we suggest using the following parameters which have been derived from the measurements taken on a large number of mineral and organic soils:

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

These parameters have been used to generate the following Linearisation table and Slope and offset conversions:

Linearisation table conversion

Delta -T dataloggers are able to store a linear or non-linear conversion characteristic permanently in their software using a linearisation table. This enables almost instantaneous logger channel configuration. All that is required is to select a Sensor Type code number from a list displayed on your computer screen.

Linearisation tables for various soil types will come imbedded in future Delta-T software or will be available from Delta-T Devices.

For users of existing Delta-T dataloggers, you can add the necessary linearisation tables using the following data:

soil moisture θ_v, $m^3.m^{-3}$	**mV, organic soil**	**mV, mineral soil**	**soil moisture** θ_v, $m^3.m^{-3}$	**mV, organic soil**	**mV, mineral soil**
-0.05	-2090	-2090	0.55	970	1020
0	40	90	0.6	1010	1045
0.05	110	170	0.65	1025	1055
0.1	192	280	0.7	1045	1065
0.15	283	400	0.75	1060	1070
0.2	400	510	0.8	1070	1080
0.25	500	620	0.85	1080	1085
0.3	600	720	0.9	1090	1090
0.35	700	810	0.95	1100	1100
0.4	780	880	1.0	1110	1110
0.45	850	940	1.05	2090	2090
0.5	920	1000			

For details of how to do this, refer to your Datalogger User Manual.

Use of this feature will give improved accuracy and give indicative moisture readings at high moisture levels.

Note that non-linearity has been introduced at both ends of the table to avoid 'out of range' logged readings outside of the probes valid working range.

Slope and offset conversion.

Using linear - fit equations from experimental data, offset and slope parameters have been calculated that can be programmed into any data logger capable of accepting this conversion method. For details of how to do this, refer to your data logger documentation. Delta-T loggers can be programmed in this way if preferred, although linearisation tables are capable of achieving higher accuracy.

FOR DL2 AND DL2e LOGGERS, the 'Engineering Factor' used for slope conversion is the RECIPROCAL of the 'Slope' figures below.

This conversion method applies to a probe output range of 0-900mV, beyond which the output becomes excessively non-linear.

The parameters to convert from probe output in mV to organic and mineral % moisture content for soils are:

From probe mV to:	Slope	Offset
% moisture, Mineral soil	**0.050**	**-5.0**
% moisture, Organic soil	**0.055**	**-2.0**

Organic and Mineral definitions:

The generalised 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**
Mineral	**~ 1 %C**	**< 7 %C**	**1.25 - 1.5 $g.cm^{-3}$**	**> 1.0 $g.cm^{-3}$**
Organic	**~ 40 %C**	**> 7 %C**	**0.2 - 0.7 $g.cm^{-3}$**	**< 1.0 $g.cm^{-3}$**

Achievable accuracy

The errors associated with the *ThetaProbe* are shown in the Specifications table. They are the errors associated with the instrument itself, and don't take into account errors you may introduce when carrying out a calibration, and they assume you insert the probe perfectly into a perfectly uniform material. They assume an error budget like this:

Error category	**soil-specific calibration**	**generalised calibration**	**source of error**
ThetaProbe errors	± 0.02	± 0.02	repeatability beween ML2 probes
Calibration errors	± 0.00	± 0.04	typical error in values of a_0 and a_1
Overall error	**± 0.02**	**± 0.05**	(RSS value)

In practice, when determining the overall reading errors, sampling and insertion errors need to be considered. As described in the Installation section, these can be as large as 0.1 $m^3.m^{-3}$. With care and by taking appropriate numbers of samples (10 to 20 samples might be required for each reading), you may reduce this, but unless your soil is unusually homogeneous these errors are unlikely to be less than 0.04 $m^3.m^{-3}$.

Based on that, you might expect the errors associated with your readings to look like this example (values are $m^3.m^{-3}$):

Error category	**soil-specific calibration**	**generalised calibration**	**source of error**
ThetaProbe errors	± 0.02	± 0.02	repeatability beween ML2 probes
Calibration errors	± 0.02	± 0.04	errors in values of a_0 and a_1
Sampling errors	± 0.04	± 0.04	soil variability and insertion errors
Overall error	**± 0.05**	**± 0.06**	(RSS value)

If a linear, rather than Linearisation Table or polynomial conversion is used, the following additional error will apply, resulting in the overall error shown.

Linearity errors	± 0.015	± 0.015	if linear rather than polynomial conversion used (0 to 900mV)
Overall error	**~ ± 0.05**	**~ ± 0.06**	(RSS value)

Salinity

The output of the *ThetaProbe* is affected by the ionic conductivity of salts dissolved in the soil moisture. This effect is not major, and is limited to salinity levels below 500 $mS.m^{-1}$. The potential error is discussed below.

Units

The preferred units for ionic conductivity units are **$mS.m^{-1}$** (where S is Siemens, a measure of electric conductance).

The following conversions apply:

$1\ mS.m^{-1} = 0.01\ mS.cm^{-1}$

$= 0.001\ mmho.cm^{-1}$

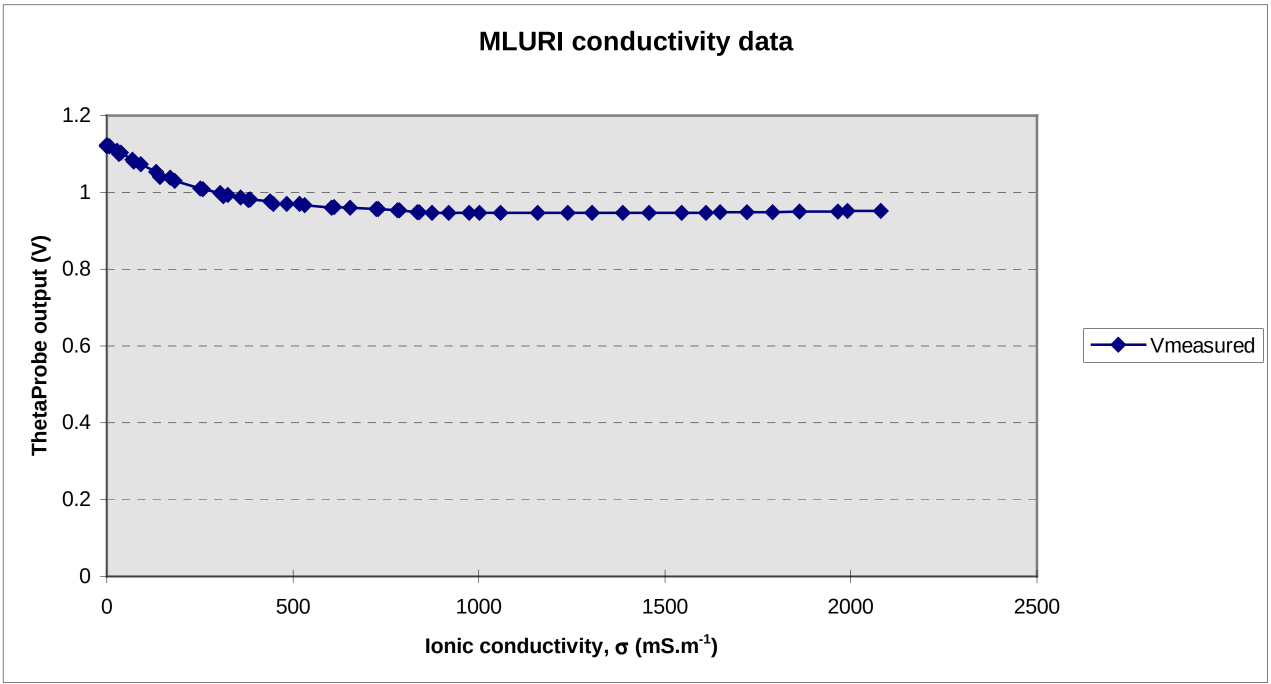
$= 10\ \mu S.cm^{-1}$

Soil salinity is also partitioned into the following descriptive categories:

non-saline	0 - 200	$mS.m^{-1}$
slightly saline	200 - 400	$mS.m^{-1}$
moderately saline	400 - 800	$mS.m^{-1}$
strongly saline	800 - 1600	$mS.m^{-1}$
extremely saline	> 1600	$mS.m^{-1}$

ThetaProbe response

The *ThetaProbe* has been tested extensively in saline conditions, both in fluids and soils (even up to 6000 $mS.m^{-1}$!). The response in water of varying salinity is as follows:



This response (in aqueous solutions) is accurately characterised by the following equation:

$$V_{(\sigma=\sigma')} = \frac{V_{(\sigma=0)}}{(1+b_0(1-e^{b_1 \cdot \sigma'}))}, \quad \text{where } b_0 \approx 0.175, \text{ and } b_1 \approx -0.0038, \text{ and } \boldsymbol{\sigma} \text{ is in } mS.m^{-1}. \qquad \textbf{[7]}$$

The response to changes in salinity for soils (at fractional volumetric water contents less than 0.6 $m^3.m^{-3}$) has been shown to be correspondingly less, but is difficult to quantify accurately. We believe from the data available that the response curve follows the same general shape, and that the values for $\boldsymbol{b}_0$ and $\boldsymbol{b}_1$ are similar.

Effect on the apparent soil moisture

There are two important simplifications to note as a result of the above response curve:

1. **You can ignore salinity effects for soils that are known to be moderately saline or strongly saline (i.e. $400 < \sigma < 1600$ mS.m^{-1}) provided you have performed a soil-specific calibration, except when a non-saline soil is irrigated with saline irrigation water.**
2. **Changes in salinity due solely to drying/wetting cycles do not significantly affect readings.**

The worst case situation occurs when a calibration is carried out on a non-saline soil sample (giving values for the coefficients $\boldsymbol{a}_0$ and $\boldsymbol{a}_1$, as in the previous section), but the actual measurement is made on a sample with significant salinity.

As an indication of the size of the possible errors, we will assume that equation [7] above is generally applicable to soils, and combine this with equations [2] and [3] to give:

$$V = \frac{a_0 + a_1.\theta - 1.1}{4.44\left[1 + b_0\left(1 - e^{b_1 \cdot \sigma}\right)\right]} \qquad \textbf{[8]}$$

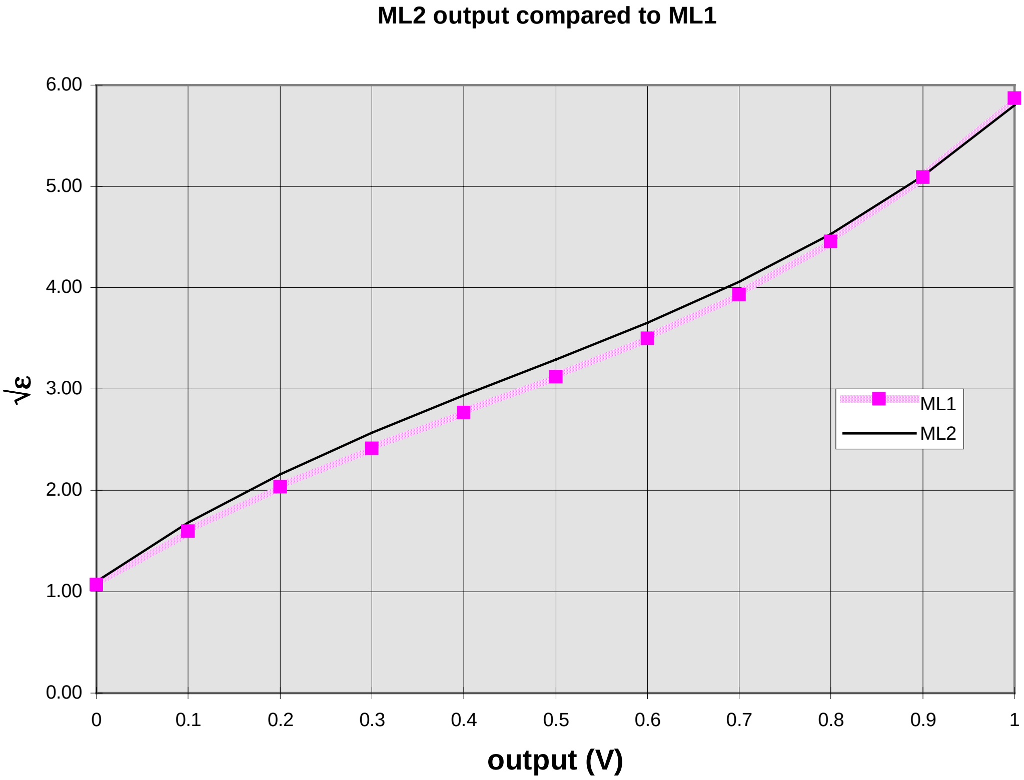
For example, suppose a calibration has determined that the coefficients for $\boldsymbol{a}_0$ and $\boldsymbol{a}_1$ should be **1.5** and **7.8**, and a reading of **0.71**Volts is obtained with the *ThetaProbe*. If it was assumed that the salinity was $\sigma' =$ **0.0** mS.m^{-1}, the soil moisture content calculated from equation [8] would be $\theta' =$ **0.35** m^3.m^{-3}. However, if the sample's salinity was in fact $\sigma'' =$ **100.0** mS.m^{-1}, the real moisture content would have been $\theta'' =$ **0.37** m^3.m^{-3}, resulting in an error of **0.02** m^3.m^{-3}.

Minimising errors due to salinity

Try to calibrate the *ThetaProbe* in a sample of soil which is towards the lower end of (but not below) the range of salinities that are likely to be encountered.

If you are using the ThetaProbe in situations where the salinity varies widely and includes non-saline conditions, you may need to measure the salinity and then apply a correction using equation [8].

Compatibility with ThetaProbe, type ML1



The ML2 performs very similarly to the previous version of the *ThetaProbe*, the ML1. This graph shows a comparison of their response to dielectric constant.

These differences beween the ML1 and ML2 result in very slightly different values of $\boldsymbol{a_0}$ and $\boldsymbol{a_1}$ when doing a soil-specific calibration (see below). When the differences in $\boldsymbol{a_0}$ and $\boldsymbol{a_1}$ are allowed for, the measurements of soil moisture can differ by up to 0.025 $m^3.m^{-3}$.

Adapting ML1 calibrations for ML2

If you've done a soil specific calibration with the ML1, and generated values of $\boldsymbol{a}_{0(ML1)}$ and $\boldsymbol{a}_{1(ML1)}$, those values <u>should</u> be unchanged when used with the ML2, because they describe the dielectric properties of the soil (see equation [3]), and are theoretically independent of the response of the *ThetaProbe*. However the changes to the nature of the curve (or linearisation) used to model the response of the *ThetaProbe* does have a slight effect on the calculated values of $\boldsymbol{a}_0$ and $\boldsymbol{a}_1$, and so you may choose to use slightly different values, $\boldsymbol{a}_{0(ML2)}$ and $\boldsymbol{a}_{1(ML2)}$, for the ML2.

• for maximum compatibility with ML1 readings, use:	mineral soils: no change. organic soils: $a_{0(ML2)} = a_{0(ML1)}$, $a_{1(ML2)} = a_{1(ML1)} - 0.1$
• for greatest accuracy	generate new values of $\boldsymbol{a}_0$ and $\boldsymbol{a}_1$ using the ML2 and following the procedure on page 11.

Mixed installations of ML1 and ML2 ThetaProbes

If you have a mixture of ML1 and ML2 *ThetaProbes* in an installation, obviously **the best choice is to use ML1 calibrations for the ML1 and ML2 calibrations for the ML2s**.

Sometimes that will be impractical, and you need to know whether it's possible to use both ML2 and ML1 with the same conversion. If you do, there will be an extra source of errors in the errors table, and the overall reading errors will typically increase by 0.01 $m^3.m^{-3}$, as in this rework of the example in the section on Acieveable Accuracy.

Error category	**soil-specific calibration**	**generalised calibration**	**source of error**
ThetaProbe errors	± 0.02	± 0.02	repeatability beween **ML2** probes
compatibility errors	± 0.025	± 0.025	max. differences beween **ML2** and **ML1** probes (non-random error)
Calibration errors	± 0.02	± 0.04	errors in values of $\boldsymbol{a_0}$ and $\boldsymbol{a_1}$
Sampling errors	± 0.04	± 0.04	soil variability and insertion errors
Overall error	**~ ± 0.06**	**~ ± 0.07**	(RSS value)

Using the ML2 with the ThetaMeter, type HH1

The *ThetaMeter* is optimised for use with the ML1 rather than the ML2. It is compatible with the ML2, and the mVolt readings will be accurate, but the mineral and organic conversions use the old ML1 values for slope and offset. The effect of this is to add approximately 0.01 $m^3.m^{-3}$ error to the readings, as in the example above. This can probably be ignored for the general purpose use for which the ThetaMeter was intended.

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 also frequently used.

The usefulness of this definition depends in part on the fact that the volume of the dry soil does not change as water is added. This is not true of shrink-swell soils, but for the most part is a reasonable approximation. Soil Moisture Content varies from approx. 0.02 $m^3.m^{-3}$ for sandy soils at the permanent wilting point, through approx. 0.5 $m^3.m^{-3}$ for clay soils at their field capacity, up to values as high as 0.85 $m^3.m^{-3}$ in peat bogs.

Soil water content is usually expressed volumetrically, because it is then possible to ignore the bulk density of the soil sample.

Volumetric versus Gravimetric soil water content

Gravimetric Soil Moisture Content is defined as

$$\theta_G = \frac{M_W}{M_S} \quad g.g^{-1}$$ 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

$$\theta_G = \theta_V * \frac{\rho_W}{\rho_S}$$ where ρ_W is the density of water (= 1),

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

Soil Water Content versus Soil Matric Potential

Studies of plant growth need to characterise the **availability** of water to the plant, and this is usually done using the water potential, Ψ, which measures the suction necessary to extract water from the soil, and has units of pressure, hPa. Components of this water potential are contributed by gravity, atmospheric pressure, osmosis, and the capillary action of the soil particles. This last component, called the Soil Matric Potential, Ψ_M, is highly dependent on the wetness of the soil, and varies from 0 hPa at field capacity, down to approximately -10^4 hPa at the permanent wilting point.

There is no generalised method of converting from soil water content to matric potential, though a number of expressions have been found which have been successfully applied to a restricted list of soil types.

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