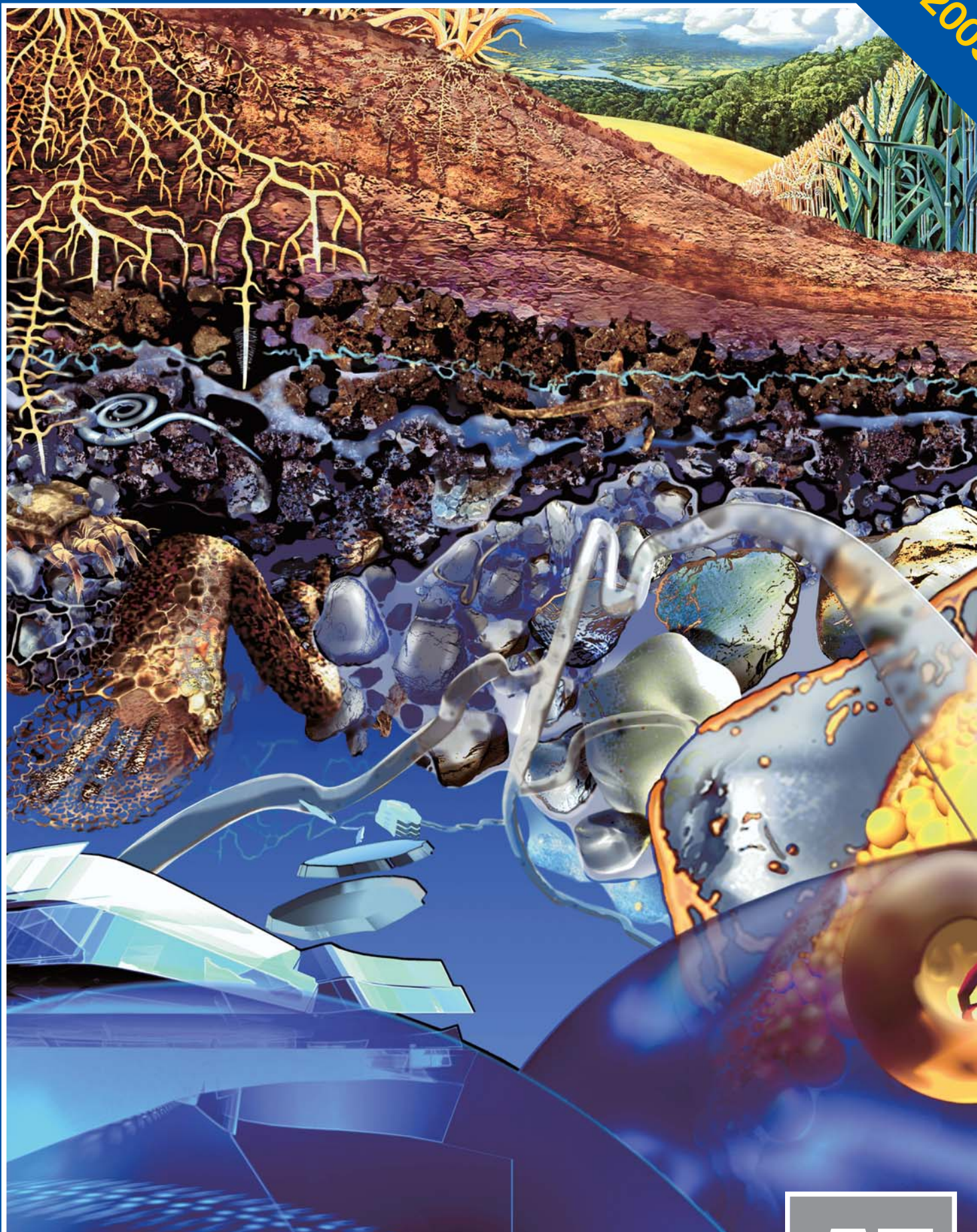


2005



# ***Soil and Plant Water Measurement***

**AT**

*Delta-T  
Devices*



# ThetaProbe type ML2x

- $\pm 1\%$  accuracy
- Easy data logger connection (DC in DC out)
- Excellent temperature and salinity stability
- Dual purpose: either hand-held for spot readings or left in-situ for data logging

The ThetaProbe type ML2x measures volumetric soil moisture content to within 1%. The ML2x has decisive advantages over other technologies, offering precision and reliability at an affordable price

## Simple to use

With the ThetaProbe type ML2x it's easy to make reliable, accurate soil moisture measurements. Simply insert the probe into the soil, connect to your data logger or meter, provide 5-15V DC at 20mA, and within seconds you can be measuring soil moisture.

## Calibration

After a single two-point gravimetric calibration, ThetaProbes will meet their full 1% accuracy specification for your specific soil (or other medium).

For convenience, many users simply apply one of the two standard calibrations supplied by Delta-T. With these "generalised" mineral or organic calibrations, 5% accuracy can be achieved.

The ML2x has a predictable saline response (which declines as salinity increases); it can be used even in very saline soils - up to 2000 mS.m<sup>-1</sup>.

Please see the table on page 8 for further information on accuracy and calibration.

## Applications

Typical application areas include irrigation, hydrology, civil engineering, soil water profiling, pollution monitoring, remote sensing validation and forestry.

Wherever a vertical soil moisture profile is required, Profile Probes should be considered (see PR2 data sheet), however, it should be noted that ThetaProbe accuracy is  $\pm 1\%$ , compared to the Profile Probe's  $\pm 3\%$ .

## Horticulture and agriculture

ThetaProbes can be used in a wide range of soils, composting and other growing media. Because they are so compact, ThetaProbes can be inserted into plant pots, or may be positioned horizontally in a seed tray (they require a minimum 50mm depth of compost).

**Composting** The ML2x can be placed in composting material where it can tolerate temperatures up to +70°C. The accuracy between 40 and 70°C is  $\pm 2\%$ , but media density and contaminant levels may affect the accuracy attainable (and the lifespan of the probe).

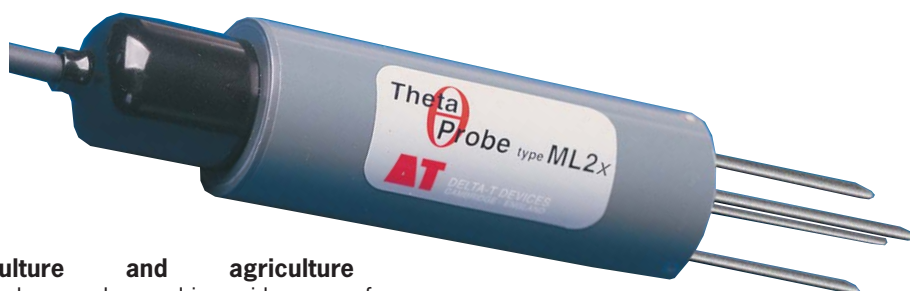
**Irrigation** Accuracy, ease of use and speed of response make the ThetaProbe well suited to irrigation applications. Readings can be used to optimise irrigation scheduling, or ThetaProbes can be installed as part of an automatic irrigation system.

**Environmental monitoring** Long term studies of global climate and local environments require the monitoring of land-atmosphere interactions, and soil water is increasingly seen as one of the critical components.

New low cost logging options for 2005

**DL6 and GP1 Data Loggers**

See separate data sheets for details.



Most automatic weather stations (including all Delta-T systems) can be expanded to include one or more ThetaProbes - as easily as adding, say, another temperature sensor.

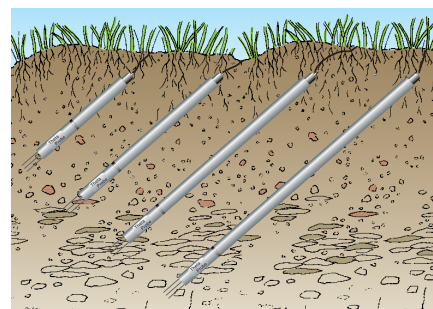
## Data logging and readout

Most types of data logger can provide the 5 - 15V DC required to power the ThetaProbe, and will accept its 0 - 1V DC output signal. Up to 60 ThetaProbes can be controlled and logged using the **Delta-T Data Logger**.

The **Moisture Meter type HH2** connects to a ThetaProbe to provide a portable system for instantaneous readout of soil moisture (see pages 4 and 5).

## Improved rod design

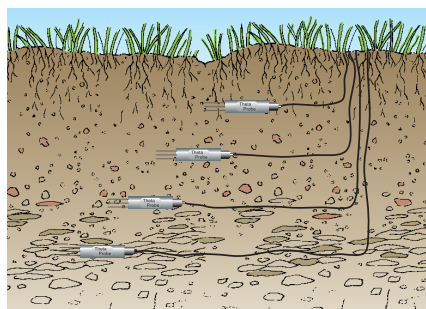
Since early 2003, ThetaProbes have been fitted with an improved design of rod that greatly reduces the chance of breakage. A low cost conversion kit is available to allow the new rods to be fitted into older ThetaProbes.



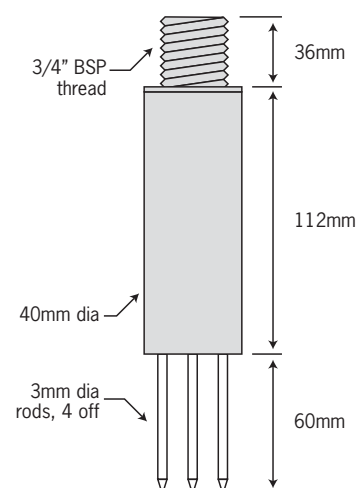
## Installation

ThetaProbes are robust, buriable and maintenance free. They can be placed in the soil by inserting them into augered holes or alternatively by positioning them in the wall of a trench (which is then carefully back-filled).

Optional Extension Tubes assist convenient placement and removal when burying at depth. Access holes should be angled to minimise water "tracking".

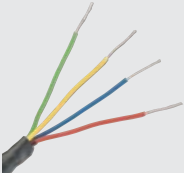

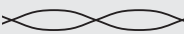







## ThetaProbe Dimensions



## Outstanding performance for demanding applications

What do you gain when you choose the ThetaProbe?

Feature	Description	Advantage
<b>DC in, DC out</b> 	Requires 5 to 15V DC at 20mA. Provides 0 to ~1V DC output. Compatible with HH2 Moisture Meter and most data loggers.	<ul style="list-style-type: none"> <li><b>Dual purpose:</b> <ul style="list-style-type: none"> <li>- for burial and data logging</li> <li>- for hand-held use</li> </ul> </li> <li><b>Long cable runs possible</b></li> <li><b>Easy to include in large-scale logging set ups</b></li> </ul>
<b>100MHz signal</b> 	With frequencies below ~30MHz, salinity effects can be a problem. With frequencies above ~250MHz, measuring bound-water in clay soils is a problem. 100MHz is an excellent compromise.	<ul style="list-style-type: none"> <li><b>Performs well in most soil types, including clays</b></li> <li><b>Usable in saline soils - up to 2000 mS.m<sup>-1</sup></b></li> </ul>
<b>Standing wave measurement</b> 	Simple, elegant circuit responds precisely to the dielectric properties of soil.	<ul style="list-style-type: none"> <li><b>±1% accuracy</b></li> <li><b>Precision measurements at moderate cost</b></li> </ul>
<b>4-Rod arrangement</b> 	3 rods are arranged in a circle around a central rod. This creates a defined cylindrical zone of measurement, 60mm long x 26.5mm diameter (300mm <sup>3</sup> ).	<ul style="list-style-type: none"> <li><b>Holds soil closer to central rod when drying and cracking (2 and 3 rod sensors, and particularly flat pcb devices, don't do this)</b></li> <li><b>Measurements can be made close to the soil surface</b></li> </ul>
<b>Replacement rods</b> 	Made of 3mm diameter, resilient, 304 austenitic stainless steel, with sharpened tips. Rods have threaded ends that screw into ThetaProbe body.	<ul style="list-style-type: none"> <li><b>Withstand repeated insertion in soil. Can be replaced at low cost if bent or damaged</b></li> <li><b>Highly resistant to corrosion</b></li> <li><b>Narrow rods with sharp tips minimise errors due to soil compaction as rods are inserted</b></li> </ul>
<b>Cylindrical shape</b> 	The ThetaProbe casing is a 40mm diameter tube, with threaded end. Extension tubes (500 and 1000 mm) screw onto this thread.	<ul style="list-style-type: none"> <li><b>Easy to insert and remove in augered holes</b></li> <li><b>Rapid attachment of extension tubes</b></li> </ul>
<b>Compact size</b> 	Case is robust and sealed to IP68 standard. Overall length of probe is 207mm.	<ul style="list-style-type: none"> <li><b>Handy size for portable use</b></li> <li><b>Rugged, waterproof and buriable to 5m</b></li> </ul>
<b>Delta-T support</b> 	Thousands of ThetaProbes are in use all over the world. The latest ML2x includes improvements suggested by customer feedback.	<ul style="list-style-type: none"> <li><b>World-wide availability</b></li> <li><b>Reassurance of quality</b></li> <li><b>Advice on complete systems</b></li> </ul>

For technical specifications - see table across pages 8 and 9.

## Comparison with other techniques

**TDR** ThetaProbes have some clear advantages over TDR systems. In general terms ThetaProbes are more stable, less troubled by salinity, easier to log, use less power, have simpler cabling requirements and can be used to make spot readings on the move (as well as buried for long term logging).

**Neutron Probes** have many drawbacks when compared with ThetaProbes: they create licensing and safety problems, they cannot measure the top 25cm of soil, they cannot be data logged and the overall cost of ownership is high. (Profile Probes are in many respects an even better alternative to neutron probes - see PR2 data sheet).

## Further information

Latest developments are announced on our web site, [www.delta-t.co.uk](http://www.delta-t.co.uk).

The ThetaProbe has been jointly developed with the Macaulay Land Use Research Institute (MLURI), as originally described in *ThetaProbe ML2: Principles of Operation and Applications* J.D. Miller & G.J. Gaskin.

**Patents** UK patent 2300485B, US patent 5804976. Patent applied for: EUR 96303190.1

## Ordering information

ThetaProbes are available with 3 alternative cable terminations, as follows:

<b>ML2x/w</b>	ThetaProbe (bare wires) (5m cable). Cable terminates with bare wires suitable for direct connection to terminal blocks
<b>ML2x/d</b>	ThetaProbe (D socket) (5m cable). Fitted with 25-way D socket, suitable for use with HH2 Moisture Meter
<b>ML2x/t</b>	ThetaProbe (IP68 plug) (5m cable). Fitted with latching IP68 connecting plug. Suitable for connecting to HH2 Moisture Meters when fitted with C-HH2-T connector
<b>TK3-BASIC</b>	ThetaKit v3 - Portable soil moisture measuring kit. Includes ThetaProbe ML2x/d-02 (2m cable), pack of 4 x spare stainless steel rods, Moisture Meter HH2, Insertion Kit ML-INK1, users manuals and carrying case.
<b>Extension Tubes</b> The ML2x/t should be used whenever it is intended to use Extension Tubes with an HH2 Moisture Meter (the ML2x/d is NOT suitable for use with Extension Tubes).	
<b>ML/EX50</b>	50cm Extension Tube for ThetaProbe, type ML/EX50
<b>ML/EX100</b>	100cm Extension Tube for ThetaProbe, type ML/EX100
<b>Spare Rods</b>	Pack of spare stainless steel rods for ThetaProbe, type ML-RODS. 12 rods per set. NB: Rods are available in original style or in stronger new style. Conversion kits available. Please enquire before ordering.
<b>Additional cable</b>	
<b>ML-CAB</b>	Additional cable fitted to ThetaProbe. Available in multiples of 5m only. Max. recommended length 100m.

# Moisture Meter type HH2

- Holds multiple user-defined soil types
- Includes PC data collection software

The Moisture Meter type HH2 is a versatile readout unit for use with Delta-T soil moisture sensors: the Profile Probe, ThetaProbe, Equitensiometer and WET Sensor

## Simple, versatile operation

The HH2 offers impressive functionality in a compact, hand-held unit, designed for field use. Readings are displayed on the LCD and can be stored to memory for later download to a PC. Up to 2100 time-stamped readings can be stored.

The unit can be operated with one hand, for convenience in the field. Each time-stamped reading includes a unique sample number, a plot identification number (A to Z), and a sensor location number (1 to 255).

Data is transferred to a PC using the RS-232 cable provided with each unit. The HH2Read Windows PC software provides a data import wizard for direct download into Excel or other PC spreadsheet packages, or into irrigation scheduling programs. Data can also be downloaded in comma-separated ASCII data file (.CSV) format.

## Use with WET Sensors

The HH2 can display and store the 3 outputs from a WET sensor. See page 7 for details. Older versions of the HH2 have to be upgraded before they can be used with a WET sensor (see box).

## Ordering information

**Moisture Meter type HH2** with integral 25-pin D-connector, battery, user manual, PC Software and RS232 cable.

If the HH2 is intended for use with a single ThetaProbe it can be ordered as part of a convenient kit - see page opposite.

The WET Sensor can also be ordered as part of a similar kit - see page 7 for details.

**HH2 Moisture Meter Factory Upgrade type HH2-UPGD3** includes installation of latest firmware, HH2-READ PC Software, and current User Manual.



## Upgrading HH2 Moisture Meters

Newly purchased HH2 Moisture Meters can be used with all current Delta-T soil moisture sensors and with most older sensor types. If you already have an HH2, the PROM firmware and PC software can be upgraded to work with new types of sensor. Information about upgrading can be found at [www.delta-t.co.uk](http://www.delta-t.co.uk)

## Using the HH2 with ThetaProbes and Profile Probes

**ThetaProbes** When used with ThetaProbes, the HH2 displays and stores single point soil moisture measurements. This creates a compact system for obtaining soil moisture readings on the move, and is best suited to surface measurements.

**Profile Probes** When used with Profile Probes, the HH2 reads and stores the soil moisture content at either 4 or 6 depths simultaneously and can calculate the water deficit at each depth. The HH2 auto-detects the number of sensors present in each Profile Probe.

This combination of Profile Probe and Moisture Meter provides a portable, low cost system for quickly collecting soil moisture profile data. Readings can be taken wherever access tubes have been installed.

\*\*\*\*\*

### User-defined soil types

Standard, generalised calibrations for mineral and organic soils are supplied with the HH2. These are suitable for use with the ThetaProbe or the Profile Probe. The software also permits up to 5 extra user-defined soil calibrations to be characterised and stored for later use.

The active soil type can be switched at any time during the collection of data, and can be specified separately for each sensor position on a single profile probe. The unconverted millivolt readings can be stored alongside the soil moisture readings.

### Water deficit reading

This reading indicates the amount of water needed (in mm) to restore the plot to field capacity, across a user-defined rooting depth. The HH2 automatically calculates the water deficit, based on data from a ThetaProbe or the individual sensors of a PR2 within that depth.

Field capacity (or "refill point") is user-defined. The HH2 User Manual contains tables of standard soil classifications and their equivalent field capacity values.

## Moisture Meter type HH2 Specifications

<b>Soil moisture range</b>	Zero to saturation. 0 – 1.5V on voltage range
<b>Accuracy/Resolution</b>	± (0.13% of mV reading +1.0 mV). 1 mV resolution
<b>Connection</b>	1 x male 25-pin connector, used for RS232 communications and sensor connection
<b>Sealing/environment</b>	IP54 (Splashproof). Operating temp range 0°C – 40°C
<b>Shock</b>	Maintains functional specification after 1m drop onto concrete
<b>EMC testing</b>	Fully complies with European EMC regulations. Tested to comply with EN 61326 class B
<b>Size/weight</b>	150 x 80 x 40mm, 450g
<b>Battery life</b>	Typically : 6500 readings for ThetaProbe type ML2x; 4500 readings for Profile Probe type PR2/6

## Comparison of memory capacities

Device	Memory capacity	
	Minimum	Typical
ThetaProbe	227	2186
Profile Probe (PR2/6)	166	782
Profile Probe (PR2/4)	221	1042
W.E.T Sensor	204	1272

Minimum = all reading options changed for each reading

## HH2 Output options

Measurement	Theta Probe	Profile Probe	WET	Equitensiometer
Soil moisture content (m <sup>3</sup> .m <sup>-3</sup> or % Vol)	✓	✓	✓	
Water deficit (mm)	✓	✓	✓*	
Unconverted mV output	✓	✓		✓
Temperature			✓	
Pore Water Conductivity (EC <sub>p</sub> ) mS.m <sup>-1</sup> , mS.cm <sup>-1</sup> or μS.cm <sup>-1</sup> **			✓	
Soil Permittivity (ε <sub>b</sub> )			✓	
Soil bulk conductivity (EC <sub>b</sub> ) mS.m <sup>-1</sup> , mS.cm <sup>-1</sup> or μS.cm <sup>-1</sup> **			✓	

\* But not a typical application for the WET Sensor

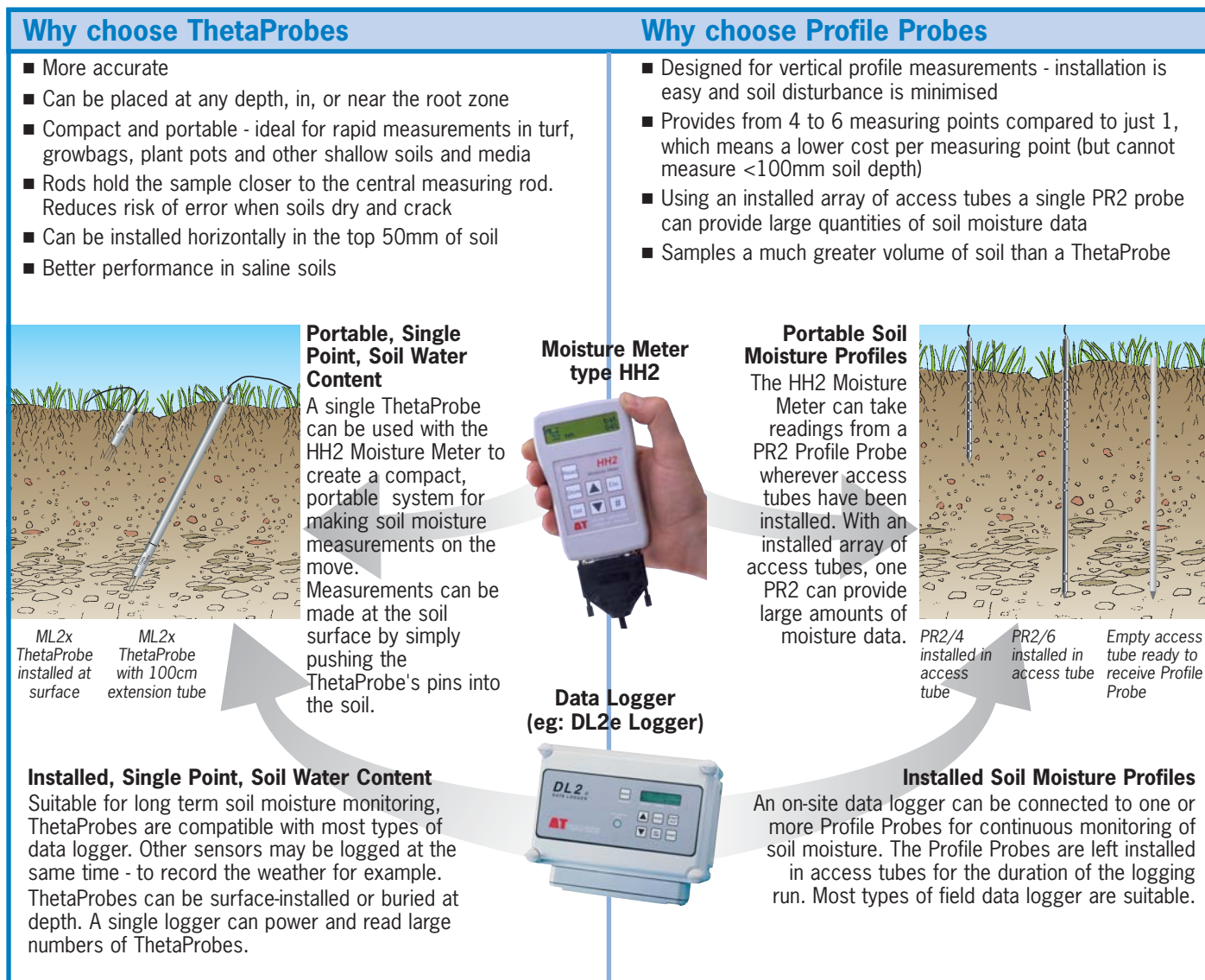
\*\* Selectable



# Multi-Purpose Technologies

## Making the best system choice

Soil types, environmental conditions and data collection requirements vary enormously, so how can you choose the system best suited to your application? The diagrams below explain some of the possibilities, but Delta-T and our local representatives are always willing to discuss specific applications in detail.



## New low cost data logging options – We now offer the DL6 Soil Moisture Data Logger and the GP1 Logger/Irrigation Monitor.

Please see separate data sheets for details.

### ThetaKit type TK3-BASIC

This portable kit contains all the items needed to make rapid spot readings of soil moisture content with a ThetaProbe. The kit includes:

- **ThetaProbe type ML2x/d** - with 2m cable length
- **Spare ThetaProbe rods** - pack of 4
- **Moisture Meter type HH2** - with spare battery
- **Insertion Kit type ML-INK1** - for use in hard soils
- **Carrying Case type HHCC1** - to hold all items in kit. Case dimensions 340(w) x 85(d) x 280(h) mm. (Height includes handle).

See page 3 for ordering information



### DL2e Basic Data Logger

The DL2e is a simple to use, field data logger, capable of logging a wide range of sensors. Suitably configured, it is compatible with all Delta-T soil moisture sensors. The DL2e accepts 15 input channels, expandable to 60, and the memory capacity is 64k, upgradable to 128k readings.



Separate data sheet available.

# Soil Water Potential (matric potential)

- Loggable, water-filled, pressure transducer tensiometers
- Maintenance-free, wide range Equitensiometers

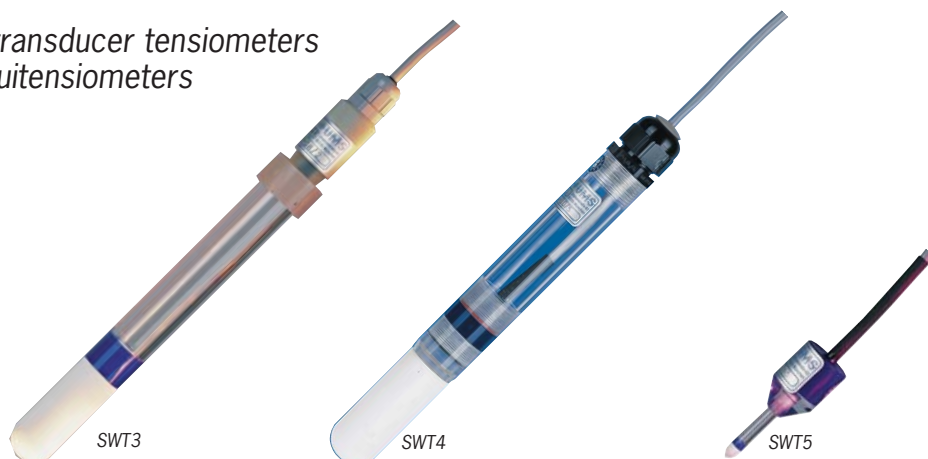
## Tensiometers types SWT3, SWT4, SWT4R and SWT5

These precision, water-filled, ceramic cup tensiometers have good accuracy ( $\pm 0.2$  kPa) over the range +100 to -85 kPa.

SWT tensiometers require refilling and degassing after dry periods and must be protected from frost. The SWT4R refillable version can be filled and emptied in-situ and gives best performance. The SWT5 is a miniature version for plant pots, for example.

The tensiometers require a stabilised 10.6V DC, 1.3mA power source. A DL2e Data Logger, with a TVB1 Voltage Regulator can power and log up to 30 tensiometers (or 60 with special cable arrangements).

For operation in drier soils ( $> -85$  kPa), or in remote or inaccessible sites the Equitensiometer EQ2 should be considered.



## Ordering information for water-filled Tensiometers

Description	Notes	Range of shaft lengths	Ceramic cup dims.	Measurement range
<b>Tensiometer, general purpose, type SWT3</b>	Lowest cost. Water-filled shaft and cup. Not frost resistant. More prone to thermal effects than other models, standard shaft 300 or 1500mm.	50 - 2000mm (in 100mm increments)	50mm x 20mm dia	+10 to -70 kPa
<b>Tensiometer, superior types SWT4 and SWT4R refillable version</b>	Water-filled cup only. Improved frost resistance. "R" versions are refillable in-situ. Standard shafts 30 and 1500mm.	50 - 2000mm (in 100mm increments)	50mm x 20mm dia	+100 to -85 kPa
<b>Tensiometer, miniature, type SWT5</b>	Compact - minimal soil disturbance. Can be used in plant pots. Water filled shaft and cup. Not frost resistant. Standard shaft length 70mm.	20 - 200mm (in 10mm increments)	5mm x 5mm dia	+100 to -85 kPa

- All SWTs are fitted with cable and male connector approx 1.5m from the pressure sensor. An SWTCC connecting cable must be ordered with each SWT. SWTCC cables are fitted with a female connector and bare wire tails and come in lengths of 5, 10, 20 and 50m. Lengths of up to 100m can be achieved with the SWTEC-20 extension cable (20m length).
- The SWT4, SWT4R and SWT5 require calibration and refill service kits. Please enquire for further details.

## Equitensiometer type EQ2

The Equitensiometer type EQ2 provides a new technique for measuring soil water potential (matric potential). The EQ2 makes clever use of the ThetaProbe (see page 2), to obtain readings without the familiar problems of water-filled tensiometers. The ThetaProbe pins are embedded into a specially formulated porous matric material\*.

The Equitensiometer is compatible with most data loggers, including all Delta-T Loggers and the HH2 Moisture Meter.

Being maintenance free, (i.e. no refilling, degassing or topping up required) and low power, the EQ2 can be conveniently used at remote sites. It is not harmed by frost, nor by long term burial. The EQ2 achieves best accuracy over the range -100 to -1000 kPa. This makes it well suited to plant water stress studies - even in very dry soils. However, the EQ2 should not be seen as a rapid response, high accuracy device covering the full range of water potentials, as such a sensor does not yet exist. EQ2 equilibration time is typically several days (see page 8 for further specs).

Extension Tubes can be used to position EQ2s at depth (see ThetaProbe p.2 for details).

## Ordering information

**Equitensiometer:** soil matric potential sensor. (Supplied with calibration certificate).

**Type EQ2/w-05** (5m cable). Cable terminates in bare wires suitable for connection to data logger terminal blocks.

**Type EQ2/d-05** (5m cable). Fitted with D socket suitable for use with HH2 unit.

## Low cost matric potential sensors

### Watermark Sensors type WMSM



These granular matrix sensors have a range of 0 to -200 kPa. They are a good choice when many replicates are required - as in irrigation monitoring for example. They are more durable in soil than gypsum block sensors.

### Ordering Information

Watermark Sensor type WMSM (5m cable).

### Gypsum Block Sensors type GYP1



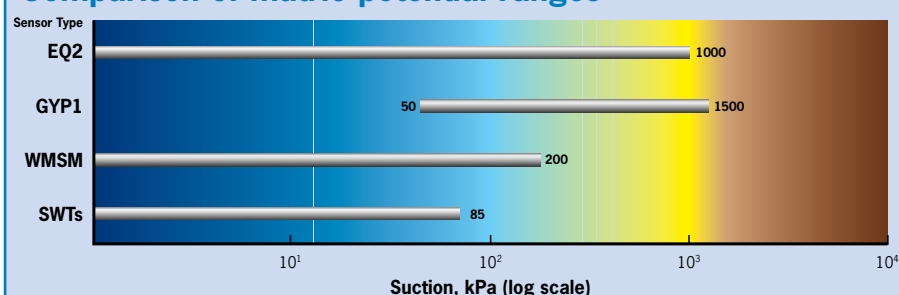
Gypsum Block Sensors measure from -50 to -1500 kPa. They have a relatively short operating life. They are better suited to dry soils than wet soils.

### Ordering information

Gypsum Soil Moisture Blocks type GYP1 set of 5 blocks, each fitted with 3.5m cable.

**It is important to note** that although both of the above electrical resistance sensors are inexpensive, the overall cost is increased by the need to include an AC excitation current and a device to read the AC output. A suitably specified DL2e Data Logger can perform both functions.

## Comparison of matric potential ranges



## Specifications

For all products on this page, please see Comparative Specifications page 8.

\* Developed by Dr Liu. Patent application no. 19629745.1

# WET Sensor type WET-2 Multi-parameter soil sensor

- Moisture and nutrient content in the root zone

The WET Sensor measures three vital soil properties:  
Water content, Electrical conductivity (EC) and Temperature

## Applications

The WET Sensor has applications in precision horticulture and soil science research and is usable in both soils and growing substrates. It is unique in its ability to measure pore water conductivity (EC<sub>p</sub>), which is the EC of the water that is available to the plant.

## Readout and data storage

Readout and data storage are handled by the HH2 Moisture Meter. The HH2 is able to display the 3 outputs produced by the WET Sensor and store them until downloaded to a PC. Standard calibrations for Mineral, Organic, Clay, or Sand media can be selected. In addition, user-defined custom

calibrations can be entered for soils and other substrates.

User-selectable options allow pore water and/or bulk conductivity to be displayed, and also the permittivity. The HH2 provides user-selectable temperature compensation.

## Horticultural Media Calibrations

The WET sensor is particularly valuable in greenhouse or protected environment applications, for fertigation monitoring. Special WET-GH-1 substrate calibrations can be ordered, as a set, for a variety of horticultural media including coir, peat-based potting mixes and greenhouse "mineral" soils.



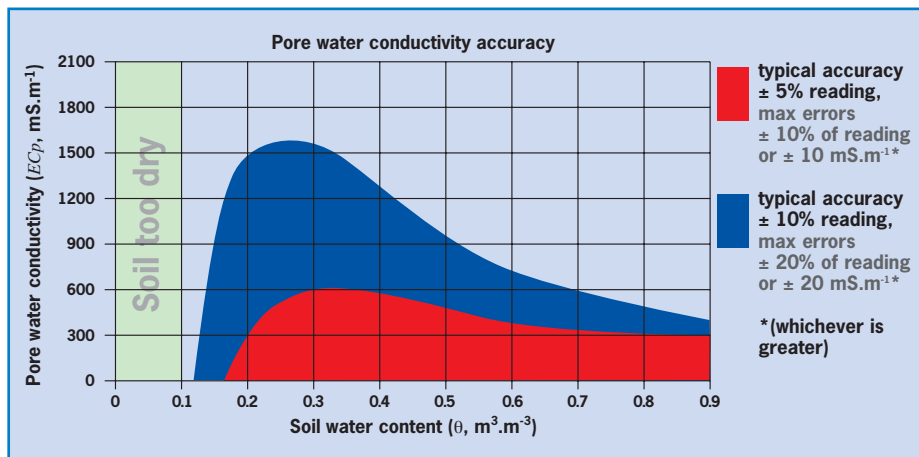
## WET Sensor Kit

The WET Sensor can be ordered as part of a complete kit that includes an HH2 Moisture Meter and carry case. See Ordering Section for details.

WET Sensor Specifications						
Probe Output:	Range	Accuracy	Resolution	Units	Environmental	Sensor sealed to IP67. Operating temperature 0 to 50°C.
• Bulk conductivity, EC <sub>b</sub>	0 - 200	± 10	1.0	mS.m <sup>-1</sup>	Frequency	20 MHz.
• Temperature, °C	-5 - 50	± 1.0	0.1	°C	Calibration	Individual sensor calibrations supplied.
• Permittivity, ε [1]	1 - 80	± 2.5	0.1	(no units)	Power	Typically 38mA for 2.5 seconds. 6 - 10 Volts.
Calculated parameters					Response time	5s reading (1 min temp equilibration)
• Volumetric Soil Moisture, θ	0 - 1	± 0.03 [2]	0.001	m <sup>3</sup> .m <sup>-3</sup>	Dimensions & weight	Probe housing: 55 x 45 x 10mm. Rods: 68mm long x 3mm dia. Wt. 75g
• Pore water conductivity, EC <sub>p</sub>	Depends on water content and conductivity, see graph		1.0	mS.m <sup>-1</sup>		

Notes: [1] Permittivity is a measure of the dielectric properties of materials (soil).

[2] Soil Moisture accuracy specs refer to errors after applying a soil-specific calibration, within 10°C of calibration temperature



Delta-T gratefully acknowledges the partner organisations that have enabled the development of the WET Sensor:

### Institute of Agricultural and Environmental Engineering (IMAG-BV)

P O Box 43, 6700 AA Wageningen, The Netherlands.  
Tel: +31.317.476654 Fax: +31.317.425670 Website: www.imag.wag-ur.nl  
Designers of the WET Sensor and the integrated circuit which enables accurate measurement of the permittivity and conductivity of the bulk soil or media.



### Saint-Gobain Cultilène B.V.

Hoekenidsehof 1, 2665 JZ, Postbus 4, 2665 ZG Bleiswijk, The Netherlands.  
Tel: +31.10.5294294 Fax: +31.10.5294299 Website: www.cultilene.nl  
Sponsors of research into horticultural media applications and suppliers of horticultural media calibrations. Exclusive suppliers of mineral wool media calibrations to customers in the Netherlands.



### Applied Plant Research

Division Glasshouse Horticulture, (Praktijkonderzoek Plant & Omgeving B.V.)  
(former Research Station for Floriculture & Glasshouse Vegetables), P O Box 8, 2670 AA Naaldwijk, The Netherlands.  
Tel: +31.174.636700 Fax: +31.174.636835 Website: www.ppo.dlo.nl  
Developers of the WET calibrations for horticultural media. © 2001



## Ordering Information

### WET Sensor Kit type WET-2-K1

Comprises WET-2/d WET Sensor, HH2 Moisture Meter, spare battery, user manuals and carrying case. (Supplied with sensor calibrations suitable for a variety of standard soil types).

**WET Sensor Kit type WET-2-K4** As WET-2-K1, plus WET-GH-1\* (substrate calibrations upgrade).

**WET Sensor type WET-2/d** Combined water content, electrical conductivity and temperature probe. Includes sensor calibration on 3.5" disk. 2m cable, with 25-way D-connector. (For use with HH2 only).

**Moisture Meter type HH2** See page 4 for Moisture Meter ordering information.









(NB: the HH2 can only be configured for use with a single WET Sensor. Swapping between different WET Sensors requires the use of a PC and takes a few minutes. We recommend that an HH2 is dedicated to each WET Sensor.)

### \*WET Substrate Calibrations Upgrade

**type WET-GH-1** Upgrade of HH2 Moisture Meter with WET substrate calibrations suitable for a variety of horticultural media. NB calibrations are factory installed into the HH2 at Delta-T premises (they are not installed into the WET Sensor itself).



# Soil Water Measurement *specifications and comparisons*

	Accuracy & range	Calibration	Response & stabilisation time	Environmental	Input and output
<b>Soil Water Content</b>					
<b>ThetaProbe</b> type ML2x 	$\pm 0.01 \text{ m}^3.\text{m}^3$ (1%): 0 to 40°C $\pm 0.02 \text{ m}^3.\text{m}^3$ (2%): 40 to 70°C $\pm 0.05 \text{ m}^3.\text{m}^3$ (5%): 0 to 70°C Accuracy figures apply over the range 0.05 to 0.6 $\text{m}^3.\text{m}^3$ Full reading range is 0 to 1 $\text{m}^3.\text{m}^3$ Salinity errors from 0.0 to 250 $\text{mS.m}^{-1}$ , < -0.0001 $\text{m}^3.\text{m}^3$ change per $\text{mS.m}^{-1}$ . Minimal change beyond 250 $\text{mS.m}^{-1}$ . Can be calibrated up to 2000 $\text{mS.m}^{-1}$ .	After calibration to a specific soil type. Using "generalised" soil calibrations supplied.	Response: <0.5s to 99% of change. 1s warm-up is advised. Full accuracy achieved within 5s.	Operates over -10 to +70°C without damage. Buriable up to 2m deep in soil or water. For use at greater depth contact Delta-T. Readings in frozen soils are not meaningful.	Requires 5 to 15V DC at 20mA (typical). Minimum >5.5V with 100m cable Voltage output 0 to ~1V DC for 0 to 0.6 $\text{m}^3.\text{m}^3$ , almost linear. Compatible with most data loggers.
<b>SM200 Soil Moisture Sensor</b>  <a href="#">See separate SM200 data sheet.</a>	$\pm 0.03 \text{ m}^3.\text{m}^3$ (3%). Accuracy specified over the range 0 to 0.5 $\text{m}^3.\text{m}^3$ , 0 to 60°C. Salinity errors up to $\pm 0.035 \text{ m}^3.\text{m}^3$ , over the range 0 to $\pm 0.4 \text{ m}^3.\text{m}^3$ , 50 to 500 $\text{mS.m}^{-1}$ (0.5 to 5 dS.m <sup>-1</sup> ). Accuracy figures apply after calibration to a specific soil type.		0.2 second warm-up (minimum). 1 second warm-up recommended.	Operating range: -20 to +60°C. Readings in frozen soil are not meaningful.	Requires 5 to 14V DC at 12mA (typical). Voltage output 0 to 1.0V for 0 to 60% nominal.
<b>Profile Probe</b> types PR2/4 & PR2/6  <a href="#">See separate PR2 data sheet.</a>	Measurement: volumetric soil moisture content $\Theta_v$ ( $\text{m}^3.\text{m}^3$ or % vol) $0.0 \text{ to } 0.4 \text{ m}^3.\text{m}^3 \pm 0.04 \text{ m}^3.\text{m}^3$ , 0 to 40°C, Typical, after calibration to a specific soil type $0.0 \text{ to } 0.4 \text{ m}^3.\text{m}^3 \pm 0.06 \text{ m}^3.\text{m}^3$ , 0 to 40°C, Typical, using the generalised soil calibrations in 'normal' soils Accuracy figures apply from 0 to 0.4 $\text{m}^3.\text{m}^3$ . Full range is from 0.0 to >0.6 $\text{m}^3.\text{m}^3$ . 100m is the maximum cable length for stated performance accuracy. Longer cables can be used and compensated for. Accuracy when installed in the field will depend on soil type, soil homogeneity and the care taken over installation. The quoted accuracy figures were obtained under uniform and controlled conditions. Salinity errors are included in above accuracy figures (50 to 400 $\text{mS.m}^{-1}$ , 0.5 to 4 dS.m <sup>-1</sup> , pore water conductivity).		Full accuracy achieved within 1 second. Minimum 1 second power-up recommended for full accuracy. (0.5 second minimum.)	0 to 40°C for full accuracy specification, -20 to +60°C full operating range. IP67 rated when installed in access tube.	Minimum supply voltage 5.5V DC with 2m cable, 7.5V with 100m. Maximum: 15V DC. Consumption: PR2/4 : < 80 mA, PR2/6 : < 120 mA 4 (PR2/4) or 6 (PR2/6) analogue voltage outputs: 0 to 1.0V DC corresponding to 0 to 0.6 $\text{m}^3.\text{m}^3$ (mineral calibration).
<b>Soil Water Potential - Water-filled tensiometers</b>					
<b>Tensiometers</b> types SWT3, 4, 4R & 5 	$\pm 0.2 \text{ kPa}$ over operating range. Range: SWT3 +10 to -75 kPa SWT4 +100 to -85 kPa SWT5 +100 to -85 kPa	Recalibration every 2 years recommended for full accuracy. Special kit and pump required for refill and recalibration of SWT4 and 5. None needed for SWT3. Refilling required after dry periods. SWT4R can be refilled and emptied in-situ.	0.1s to 99% of change. Warm-up time 10s. Rapid pressure equilibration, approx. 60 kPa/h, installation dependent.	Operates over 0 to +50°C without damage. Storage without water -20°C to +70°C. SWT3 and SWT5 cannot be used in frozen soil. The SWT4 can remain installed if measuring at a frost free depth.	Requires precision 10.6V DC input at 1.3mA. See "Installed Use" column. Outputs 1mV /kPa.
<b>Soil Water Potential - Porous matrix tensiometers</b>					
<b>Equitensiometer</b> type EQ2 	$\pm 10 \text{ kPa}$ from 0 to -100 kPa. $\pm 10\%$ of reading from -100 to -1000 kPa. Hysteresis effects may add $\pm 20 \text{ kPa}$ to errors. For temp range 0-40°C.	Calibration normally stable for 2 years. Unsuitable for use in saline soils. User can check calibration but unit must be returned to Delta-T for recalibration.	Electrical response: <0.5s to 99% of change. 1s warm-up is advised. Pressure equil. 6 kPa/h.	Operates over -10 to +70°C without damage. Buriable up to 5m deep in soil or water. Readings in frozen soils are not meaningful.	Requires 5 to 15V DC at 20mA (typically). Minimum > 5.5V with 100m cable. Output range approx. 150 to 550mV, non-linear, for 0 to -1000 kPa.
<b>Watermark Sensor</b> type WMSM 	WMSM: 0 to -200kPa range.	Individual in-soil calibration improves performance.	Not quoted.	Operates over 0 to +80°C. Lifespan depends on soil acidity and water flow.	Requires AC excitation and device to read AC output.
<b>Gypsum Block</b> type GYP1 	GYP1: -50 to -1500 kPa range. WMSM & GYP1: Accuracy not quoted: data is "trend only".				
<b>Pore Water Conductivity</b>					
<b>WET Sensor</b> 	<b>Soil Moisture:</b> $\pm 0.03 \text{ m}^3.\text{m}^3$ (3%) over range 0.0 to 1.0 $\text{m}^3.\text{m}^3$ <b>Pore Water Conductivity:</b> see graph on preceding page. <b>Temperature:</b> $\pm 1.0^\circ\text{C}$ , -5 to 50°C.	Individual sensor calibrations supplied. Generalised calibrations for Mineral, Organic, Sand and Clay soils supplied as standard. Calibrations for key greenhouse substrates available as an option.	Not continuous measurement. Reading takes ~5s.	Operates over 0 to 50°C. Sensor sealed to IP68 (1m), connector to IP65.	Sensor is powered by the HH2. Outputs RS232 serial data (requires special conversion software).



Dimensions, sampling volume and cabling*	Portable use	Installed use (logging)	Comments
Rods 60mm x 3mm diameter. Overall length 207mm, diameter 40mm. Sampling volume: approx 60mm x 30mm diameter. Standard cable length 5m.	ThetaProbes are well suited to portable applications, using the HH2 Moisture Meter to display and store soil moisture readings or water deficit readings.	ThetaProbes are low power and easy to log. Sensors can be pushed into the soil surface, buried at depth or used with extension tubes in augered holes.	<b>Versatile, high accuracy sensor, recognised as the "gold standard" for the precise determination of soil moisture content.</b>
Rods 51mm long. Overall length 138mm, diameter 40mm. Sampling volume: approx 55mm x 70mm diameter. Polyurethane braided cable with industrial M8 IP68 connector. Standard and extension lengths available.	The SM200 can be used with an HH2 Moisture Meter for readout and data storage.	The SM200 is low power and easy to log. Sensors are buriable with extension rods in augered holes.  For high accuracy solutions at low cost, use GP1 or DL6 data loggers.	<b>Scientific grade sensor. Suited to research and irrigation applications. A cost-effective option where ML2x accuracy is not required.</b>
PR2/6: sensing depths 10, 20, 30, 40, 60, 100 cm PR2/4: sensing depths 10, 20, 30, 40 cm (nominal) Sampling volume: ~95% sensitivity within a cylinder of radius 100mm. Construction: 25.4mm polycarbonate rod with stainless steel rings. PR2/4 length: 750mm, weight: 0.6kg. PR2/6 length: 1350mm, weight: 0.9kg. Access tube diameter: 28mm. Cable: standard and extension cables – with M12, IP68 industrial connector.	A Profile Probe connected to an HH2 Moisture Meter can easily be inserted into pre-installed access tubes for rapid spot measurements of the soil moisture profile.  The whole reading operation takes typically less than a minute at each location.	For continuous monitoring of soil moisture the PR2 is left installed in an access tube. PR2s are compatible with many types of data logger, including Delta-T Loggers. (Readings can also be made with an HH2 Moisture Meter, if desired).	<b>Provides rapid and convenient moisture readings in a vertical soil profile. Used in access tubes for easy insertion and removal. Can be left installed for data logging, or used with hand-held Moisture Meter for multi-site, portable readings.</b>
Shaft lengths from 20mm to 2000mm are available. See table on page 6. Connecting cables 5, 10, 20 or 50m ordered separately.	Not possible, due to time taken for sensor to equilibrate to changes in soil water potential.	The tensiometers require a stabilised 10.6V DC, 1.3mA power source. A DL2e Logger (see page 5), fitted with a TVB1 Voltage Regulator can power and log up to 30 tensiometers (or 60 with special cable conns).	<b>Precision, trusted range of sensors. Accurate in wetter soils - well suited to irrigation scheduling and the study of water uptake and water movement. Require maintenance.</b>
Length 215mm, 40mm diameter. Standard cable length 5m.	Not possible, due to time taken for sensor to equilibrate to changes in soil water potential.	Well suited to unattended logging - no maintenance is required and the sensor can be left buried long term. Compatible with most data loggers.	<b>For measurement of matric potential. Zero maintenance, Best accuracy in dry soils. Can be left installed in frozen soils.</b>
WMSM: 80mm length, 23mm diameter. Standard cable length 5m.	Not possible, due to time taken for sensor to equilibrate to changes in soil water potential.	Resistance sensors requiring AC current and a device to read the AC output. A suitably specified DL2e Logger can perform both functions.	<b>WMSM for irrigated and other wet soils. Low cost - suited to large installations.</b>
GYP1: 36mm length, 24mm diameter. Standard cable length 3.0m.			<b>GYP1 Very low cost sensor, suited to drier soils. Relatively short lifespan.</b>
Probe length ~65mm, diameter 3mm. Sampling volume: approx 60 x 45 x 12mm. Standard cable length 2.5m.	Designed to be used with an HH2 for convenient portable operation.	Not suitable for data logging.	<b>Measures pore water conductivity, moisture content and temperature directly in the soil or substrate.</b>

## Evapotranspiration Software type ET2

- *FAO Penman-Monteith and other Penman methods*
- *Daily or hourly P-M results*

**ETo and crop water requirements** All the above methods calculate potential ET: the maximum evaporative load for a non water-stressed crop. ETo is a vital input to the calculation of crop water needs, in conjunction with other crop factors.

The Penman-Monteith (time-step) version offers a choice of surfaces: various grasses, bare soil, upland, conifers and water. The four essential meteorological parameters are air temperature, relative humidity, solar radiation and wind speed. Other parameters such as net radiation, soil heat flux and air pressure may be used if available.

**Input data files** All data files in ASCII characters, and "rectangular" format are compatible, including weather data files from the DL2e Data Logger. A wide variety of data units can be accepted, e.g. for solar radiation: sunshine duration, kW/m<sup>2</sup>, or MJ/m<sup>2</sup>.

**ETo output file** The program creates a standard ASCII file of ETo with a summary of all input data parameters. There is a free choice of the synoptic hour. The output file can be viewed on-screen and then exported to spreadsheets etc.

**Further information** There is a demonstration version of ET2 on our website.

## Delta-T Automatic Weather Stations

These are well suited to evapotranspiration studies. They are able to operate at remote and exposed sites using batteries or solar power. Systems are based on the DL2e data logger. Additional sensors to measure, for example, soil moisture and sap flow can be included. This versatile logger can be expanded to over 60 channels.



\* For all sensors, except for the WET Sensor, cables can be extended, to a maximum length of 100m (SM200 up to 55m for best accuracy). Please contact Delta-T if cable length is a problem.

# Sap Flow Sensors and Systems

- Dynagages for stems and trunks 2 to 125 mm diameter
- TDP (Granier) Probes for stems and trunks 70 to > 200 mm diameter

The latest technology for measuring the sap flow and hence the water consumption of plants and trees. Proven methods for measuring sap flow in greenhouses, nurseries and natural environments

## Why measure sap flow?

Measuring sap flow directly is a key technique in understanding and regulating plant water relations. Fields of study include irrigation, agronomy, commercial growing, crop science, hydrology, tree water use, water stress, calculating water balances in forestry and in phytoremediation.

## Dynagages or TDP Probes?

The choice is mainly determined by the diameter of the stem or trunk. In the middle region of diameters either method can be used.

**Dynagages:** Microsensors are used for the tiniest stems (2 to 5 mm in diameter). Stem and Trunk gauges are used for medium sized stems and branches up to 125 mm in diameter. One gauge is used per stem. A reasonably straight portion of stem is needed on which to mount the gauge.

**TDP (Granier) Probes:** are for use with stems or trunks ranging from 70 mm to over 200 mm in diameter. For the smaller trunks, one probe per tree is required. Sap velocity can vary around the circumference of a tree, so two probes are advisable for trees greater than 125 mm diameter, and four probes for trees greater than 200 mm. However, for uniform trees in a closed canopy, only one probe per tree is needed.

TDP Probes are installed in holes drilled



**Dynagages for 2 to 125 mm**

- Measure absolute mass flow - no calibration required
- Strap-on sensor collar, non-invasive, harmless, conform to plant size
- Reliable and proven method
- Constant heat energy balance
- Re-usable, portable

into the sapwood; the choice of probe length is determined by the thickness of the sapwood.



**TDP probes for 70 to >200 mm**

- Measure sap velocity, hence volume or mass flow
- Dual stainless steel teflon coated needles
- Granier method - empirical thermal dissipation technique
- Easily inserted and removed for re-use

SF1 Dynagage Sap Flow sensors: output in grams/hour sap flow						
Gauge Class	Example product	Stem dia. range (mm)	Height mm	Heater voltage	Power (typ) W	Range covered (nominal dia.)
Microsensor	D\SGA3	2.7 - 4.0	35	2.3	0.05	2, 3, 5
Stem Gauge	D\SGA13	12 - 16	70	4.0	0.15	9, 10, 13, 16, 19, 25
Trunk Gauge	D\SGB50	45 - 65	305	6.0	1.4	35, 50, 70, 100
Logger inputs (per gauge): 3 channels DIF (<1mV full scale), 1 channel DIF (for heater voltage, <10V full scale) Cable: 1.5m standard (8 wires, with connector). Extensions: 7.6m, 15m, 22.8m, 30.5m available						
SV1 TDP Sap Velocity sensors: output in cm/hour sap velocity						
Probe Type	Needle length/dia	Trunk dia. range (mm)	Vertical spacing	Heater voltage	Power (typ) W	Sapwood thickness
D\TDP-30	30/1.2 mm	70 - 200	40 mm	3.0	0.2	30 - 70 mm
D\TDP-50	50/1.65 mm	100 - 300	40 mm	5.0	0.35	50 - 100 mm
D\TDP-80	80/1.65 mm	Over 180	40 mm	7.5	0.5	>80 mm
Logger inputs (per probe): 1 channel DIF (<1mV full scale), 1 channel DIF (for heater voltage, up to 10V full scale) Cable: 3.0m standard (5 or 6 wires, with connector). Extensions: 7.6m, 15m, 22.8m available						
D\AVRD:	<b>Dual Adjustable Voltage Regulator type D\AVRD</b> Dynagages and TDP probes have heaters which require a continuous source of power and an adjustable voltage level to control the heater power during the initial set-up. The D\AVRD has two independently adjustable voltage outlets suitable for all probe types. Each channel outputs 1.5V to 10V (max. current 3A) and can cope with a recommended 4-8 sensors of a similar type (or voltage requirement).					
For larger sizes of Dynagage and longer length TDP probes, please enquire.						

## Measurement principles

Both types of sensor use a constant heat input but they derive their results in different ways. They are not heat pulse methods.

**Dynagages** consist of a heater element which is strapped round the stem of the plant and insulated from the ambient conditions. The plants are heated typically only 1° to 5°C. Thermocouples built in to the gauge measure the heat carried away by the sap flow, which can be converted into real-time sap flow (in g/h or kg/h). This is an absolute measurement and does not require calibration. The principles of the heat balance method have been scientifically proven over many years and references exist for many major crops and tree species.

**TDP probes** feature improved needles used with the Granier technique (ref.1). Each probe has two thermocouple needles which are inserted into the sapwood, the upper one containing an electric heater. The needles measure the temperature difference (dT) between the heated needle and the sapwood ambient temperature below. The dT variable and the maximum dTm at zero flow provide a direct and calibrated conversion to sap velocity.





DL2e sap flow system. DAVRD Voltage Regulator is mounted on enclosure door.

#### Dynagages or TDP Probes have been used on...

Cotton, corn, maize, sorghum, soybean, sugarcane, sunflower, sweet potato, tomato.

Coffee, grape vine, kiwi fruit, ligustrum, mesquite, potato, rose, hibiscus.

Almond, apple, avocado, cypress, fir, eucalyptus, ficus, kumquat, mangosteen, oak, orange, pecan, pine, poplar, red cedar, tangerine.

## Sap Flow systems building

Dynagages and TDP sensors can be used with the Delta-T DL2e Data Logger. It records "raw" data which can be converted to sap flow subsequently using spreadsheets.

Systems comprise:

- The necessary sap flow sensors and extension cables
- DAVRD Voltage Regulator(s)
- Any other meteorological or soil sensors required (typically soil moisture, soil temperature, rain etc)
- The DL2e and communications system
- Mast or pole mounted enclosures
- Batteries, solar power modules or mains power systems

## Ordering Information

Please contact Delta-T or your local Delta-T distributor to discuss your TDP and Dynagage requirements. A quotation for a suitable system will then be issued.

*In use, sap flow systems require a continuous power supply. For remote sites Delta-T can provide customised solar power charging systems.*



Dynagage 5mm Microsensor type D/SGA5

**References** ref.1 Granier, André (1985). Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Ann.Sci.For.,1985,42 (2), 193-200.  
TDP Probes are licenced under patents by INRA. All rights reserved.

# Porometer type AP4

- Direct readout of conductance or resistance
- Simple absolute calibration in the field
- Minimises leaf stress during measurement

*The AP4 Porometer measures the rate of water diffusion through leaf surfaces and calculates stomatal conductance*

Stomatal aperture is the dominant factor in the diffusion conductance of leaf surfaces, which controls both the water loss from plant leaves and the uptake of CO<sub>2</sub> for photosynthesis. Measurements of diffusion conductance are therefore important indicators of plant water status and provide a valuable insight into plant growth and plant adaptation to environmental variables.

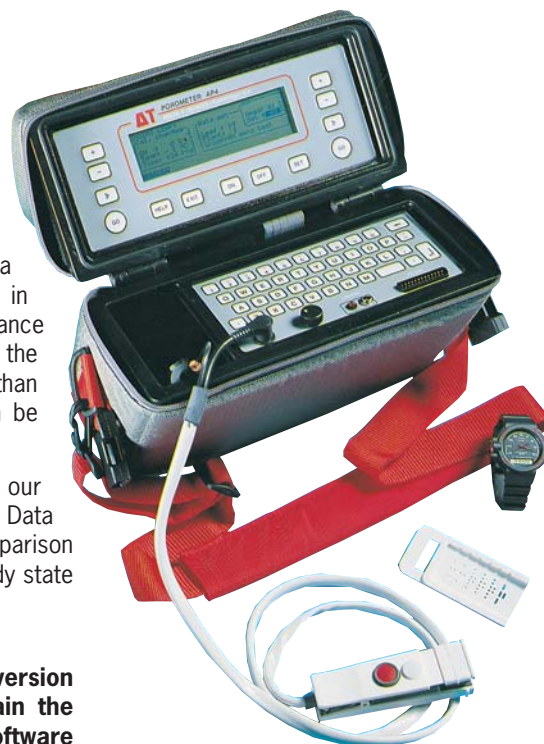
The AP4 measures diffusion conductance by comparing the precise rate of humidification within a small cuvette to readings obtained with a calibration plate.

Quoted accuracy figures for steady state porometers and gas analysis systems are based on time-consuming laboratory set-ups and calibrations which bear little comparison to field conditions. The AP4 features simple

direct calibration in the field against a tested physical standard, whereas in the steady state system, performance depends on the absolute accuracy of the RH measurement: an error of more than  $\pm 18\%$  in the diffusion reading can be caused by a  $\pm 3\%$  RH error.

Further details are available on our website or in a 4 page Porometer Data Sheet, which also includes a comparison between dynamic diffusion and steady state porometers.

**Customers running the DOS version of AP4 software can now obtain the new AP4 Retrieve Windows Software free of charge as a download from [www.delta-t.co.uk](http://www.delta-t.co.uk).**



## Ordering Information

**Details regarding ordering information, accessories, consumables and spares for our instruments can be found in our price lists, available on request, and also on our web site at [www.delta-t.co.uk](http://www.delta-t.co.uk).**

### UK customers

**SALES AND TECHNICAL ENQUIRIES:** should be made directly to Delta-T in Burwell.

**PRICES:** are available on request, and a detailed quotation can be provided if required.

**PAYMENT:** for new customers, we usually ask for payment in advance. Account facilities are available for customers placing regular orders: details may be obtained from our Finance Department.

### Customers outside the UK

**OVERSEAS REPRESENTATION:** Delta-T has an extensive network of representatives to serve customers outside the UK. In these countries, all sales and technical enquiries should be directed to our representatives: details are available.

**DIRECT SUPPLY:** if there is no Delta-T representative in your country, we will supply you directly from the UK. Export sales account for more than three quarters of our business and we have many years' experience of dealing with enquiries from overseas clients.

**PRICES:** are available on request from Delta-T or your local representative. Detailed quotations can also be provided when needed, including costs for freight, insurance and documentation.

**PAYMENT:** our normal terms are payment in advance of shipment, or by irrevocable documentary credit. Account facilities may be available for customers placing regular orders: details of these facilities and documentary credit conditions may be obtained from our Finance Department.

**GUARANTEE AND SERVICE:** Delta-T guarantees its products against defects in manufacture or materials for a period of 12 months from the date of delivery. Full details of the guarantee, terms and conditions of sale, and arrangements for servicing and recalibration are available on request.

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## Cover Illustration - Living Soil

In the left foreground, films of water can be seen tightly bound to the surfaces of clay particles made of crystals of quartz rock. To the right, at lower magnification, clays, silt and sand grains combine into soil crumbs, held together by gels and gums produced by soil bacteria (shown in yellow) and by a mesh of fungus threads and plant roots. This crumb structure allows water, air and roots to pass through the pore spaces.

On the left, a decomposing root is being consumed by bacteria and fungi, which themselves supply a protein-rich diet to protozoans, nematodes and mites, these excrete N and P salts, which then become available for plant growth.

The pale blue line that crosses the image just below the soil profile indicates the level of water-filled pores.

*Cover illustration by Glynn Gorick, Cambridge, UK.  
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Information on the full range of Delta-T products can be found on the Internet:

**[www.delta-t.co.uk](http://www.delta-t.co.uk)**

If you have any questions, require advice on an application, or need a quotation, we will be pleased to help and can be contacted by e-mail:

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