User Manual for the

Tensiometer

types ***SWT5 & SWT5x***

SWT5-UM-2

Delta-T Devices Ltd

Notices

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CE conformity

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Design changes

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Within the EU: disposal through municipal waste prohibited - return electronic parts to your local distributor

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Introduction

1.1 Safety instructions and warnings

Electrical installations must comply with the safety and EMC requirements of the country in which the system is to be used.
Please note that any damage caused by handling errors are out of our control and therefore are not covered by guarantee.
Tensiometers are instruments for measuring the soil water tension, and soil water pressure and are designed for this purpose only.

Please pay attention to the following possible causes of risk:

- Lightning: Long cables act as antennas and might conduct surge voltage in case of lightning stroke – this might damage sensors and instruments.
- Frost: Tensiometers are filled with water and therefore are sensitive to frost! Protect Tensiometers from frost at any time. Never leave Tensiometers over night inside a cabin or car when freezing temperatures might occur!
  Tensiometers normally are not damaged when the cup is installed in a frost free soil horizon.
- Excess pressure: The maximum non destructive pressure is 300 kPa = 3 bar = 3000 hPa. Higher pressures - which might occur, for example, during insertion in wet clayey soils, whilst measuring shear force, or during refilling and reassembling - will destroy the pressure sensor!
- Electronic installation: Any electrical installations should only be done by qualified personnel.
- Ceramic cup: **Do not touch the cup with your fingers**. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.
- Do not twist the SWT5 shaft against the sensor body!

1.2 Unpacking

An SWT5 or SWT5x delivery includes:

- Tensiometer, calibrated and filled, with 4-pin plug M12/IP67 with plug cap
- This manual
- Rubber protection cap, half filled with water, for keeping the ceramic moist and clean

See also “Accessories” on page 41.

1.3 Foreword

Measuring systems must be reliable and durable and should require a minimum of maintenance to achieve target-oriented results and keep the servicing low. Moreover, the success of any technical system is directly depending on it being used correctly.
At the beginning of a measuring task or research project the target, all effective values and the surrounding conditions must be defined. This leads to the demands for the scientific and technical project management which describes all quality related processes and decides on the methods to be used, the technical and measurement tools, the verification of the results and the modeling.
The continuously optimized correlation of all segments and its quality assurance are finally decisive for the success of a project.
We wish you good success with your projects. Please do not hesitate to contact us for further support and information.

1.4 Guarantee

See **Terms and Conditions of Sale** on page 46.

1.5 Durability

The nominal lifespan for outdoor usage is 10 years, but protection against UV-radiation and frost as well as proper and careful usage substantially extends the lifespan.

1.6 SWT5 and SWT5x

1.6.1 Soils and soil water

All water movement in soil is directly dependant on the soil water tension, because water, both in soils and on the surface, will will move from a point of higher potential to a point of lower potential.

The majority of soil water flows take place in response to small water tensions. Only Tensiometers allow the direct and precise measurement of these small tensions.

Natural soils in the ground are heterogeneous. It is not just precipitation and evaporation that matter, but also the soil texture, particle size distribution, cracks, compaction, roots and cavities. All these heterogeneities cause the soil water tension to vary. It is prudent therefore to have multiple measuring points, particularly in soil horizons close to the surface.

1.6.2 Intended use

Tensiometers measure soil water tension – a measure of the soil matrix potential – which is the work the plant needs to do in order to extract water from a unit volume of the soil. These Tensiometers work from +100 kPa (water pressure/level) to -85 kPa (suction / soil water tension). The SWT5x operates to even lower tensions.

If the soil gets drier than -85 kPa, the Tensiometer runs dry and must be refilled as soon as the soil is sufficiently moist again (see Fig 6.1). Soil water and Tensiometer water have contact through the ceramic which is porous and permeable to water. A wetted porous ceramic creates an ideal pore/water interface. The soil water tension is directly conducted to the pressure transducer which offers a continuous signal. The atmospheric reference pressure is provided through a membrane on the cable, a unique patented method.

The SWT5 Miniature Tensiometer is specially designed for point measurements, e. g. in soil columns, pots or laboratory lysimeters, or when the measurement of a minimal span is desired.
With an active surface of only 0.5 cm^2 and a diameter of 5 mm the ceramic tip has all advantages of small dimensions: little soil disturbance, point measurement and fast response.

1.6.3 Typical applications

Typical applications of the SWT5 and SWT5x:

- Point measurements of water potential
- Miniature soil column studies, e. g. in combination with micro water samplers and soil temperature probes
- Determination of drying curves of water content vs tension, or water conductivity vs tension (pF/wc and K/Psi) in soil columns, soil cores or soil sampling rings
- Determination of leachate and capillary water movements
- Controlling irrigation
- Pot experiments
- Measurements in the upper soil horizons in the field
- Monitoring with data loggers
- Spot readings with the SWT-MR (INFIELD7)

For field applications it might be better to use SWT4 or SWT4R Tensiometers.

1.6.4 Extended measuring range of the SWT5x

The special version SWT5x is tested to reach a measuring range of -160 kPa (-1600 hPa) when delivered. To achieve this, the SWT5x requires an absolutely bubble-free filling.
You might notice that your SWT5x might even go down to -250 kPa before running empty, sometimes even to -450 kPa, but this is an exception and cannot be guaranteed.
The SWT5x is identical with the SWT5 but has a different ceramic. The extended measuring range is made possible by an effect called boiling retardation, which requires a special ceramic with smaller pores and an absolutely gas-free filling process.

- Do not allow the SWT5x ceramic to dry out by leaving it unprotected in air: by drying out the tension might reach the destructive pressure.
- Due to the finer pores of the ceramic the water conductivity is lower. Therefore the response of a SWT5x is slower than with a standard SWT5.
- When the shaft is touched it might warm up. This might cause a temporary change of the pressure.

1.6.5 Specific notes

- SWT5 and SWT5x are not suitable for dry soils and they are not frost resistant.
- When installed in the field provide sufficient protection.
- The less air that is inside the cup, and the better the soil's conductivity is, the faster the Tensiometer will respond to tension changes.
- It does not make sense to refill a Tensiometer while the soil is dryer than -90 kPa (-900 hPa) for the SWT5 or - 160 kPa (-1600 hPa) for the SWT5x.
- The use of a quartz clay slurry is only recommended in clayey soils and only if the drilled diameter is larger than the shaft diameter (5 mm). In coarse sand or gravel soil a fine grained slurry paste would act as a water reservoir which would lead to a slower response.
- The SWT5 can be installed in any position and orientation. Bubbles are easily detectable through the transparent shaft.
- Output signals are standardized.

1.7 Quick start

This is only a summary of following chapters. Please read the complete manual carefully before using the instrument!

SWT5 tensiometers are filled and degassed when supplied and are ready for installation. The procedure is the same for SWT5 and SWT5x.

In very soft soils the SWT5 can be inserted directly without drilling a hole. As the shaft is fragile, no force should be applied.

For hard soils a special auger kit for is available in the **SWT5-FRK2** field refill kit,
When the SWT5 auger is used, slurrying is unnecessary.

Installation procedure:

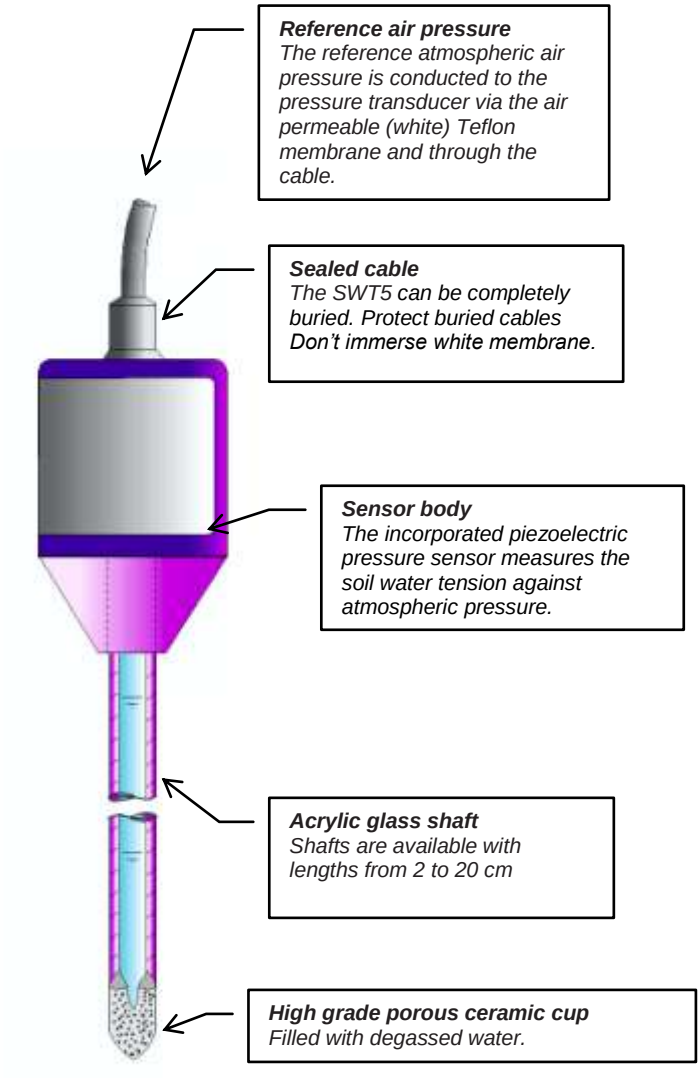
1. **Drill** a hole with the required diameter and depth.
Mark the installation depth on both auger and SWT5 shaft.

2. **Connect** the SWT5 to a readout device, for example a data logger for continuous measurements or the SWT-MR (INFIELD7) handheld device for spot readings.

- During the installation the Tensiometer reading must be controlled all the time. Especially in wet, clayey soils a high pressure might develop while inserting the SWT5.
  Avoid pressures of over 2 bar (200kPa, 2000 hPa).
  Note: 3 bar will destroy the pressure transducer. If necessary stop or slow down the insertion to allow the pressure to decrease.

3. Carefully **remove** the water-filled rubber bulb from the tip and **gently and steadily insert** the SWT5 down to the mark.

- Never turn the SWT5 inside the borehole as this might loosen the shaft.
- Put the protective cover on the plug whenever the plug is not connected. Dirt will reduce the water tightness of the plug. Remember to put the protective cover back on the plug after taking spot readings with the SWT-MR (INFIELD7).


Reference air pressure
The reference atmospheric air pressure is conducted to the pressure transducer via the air permeable (white) Teflon membrane and through the cable.
Sealed cable
The SWT5 can be completely buried. Protect buried cables Don't immerse white membrane.
Sensor body
The incorporated piezoelectric pressure sensor measures the soil water tension against atmospheric pressure.
Acrylic glass shaft
Shafts are available with lengths from 2 to 20 cm
High grade porous ceramic cup
Filled with degassed water.

2 Sensor Description

2.1 Parts

2.1.1 Body and shaft

The sensor body is made of transparent acrylic plastic and incorporates the pressure transducer and all electronic parts. The body is backfilled with resin to hermetically seal the electronics and make the body watertight.

2.1.2 Pressure sensor

The piezoelectric pressure sensor measures the soil water tension against the atmospheric pressure. Atmospheric pressure is conducted via a white air-permeable membrane on the cable, through the cable, to the reference side of the pressure sensor.

- The maximum permissible, i.e. non-destructive, pressure is ±3 bar (300 kPa, 3000 hPa). Higher pressure will damage the sensor and absolutely must be avoided! High pressures can appear for example when cup and sensor are reassembled, when inserted in wet, clayey soils, or in tri-axial vessels used for measuring shear forces.

2.1.3 Reference air pressure

The reference atmospheric air pressure is conducted to the pressure transducer via the air permeable (white) Teflon membrane in-line in the cable. The membrane does not absorb water. Water will not pass through the membrane into the cable, but condensed water inside the cable can leave the cable through the membrane.

- The white membrane on the cable must always be in contact with air during a measurement and should never be submersed under water.

2.1.4 The ceramic tip

To transfer the soil water tension as a negative pressure into the Tensiometer, a semi-permeable barrier is required. This must have good mechanical stability, be permeable to water and impermeable to gas (when wet).
The Tensiometer cup consists of a ceramic, sintered Al_2O_3. A special manufacturing process guarantees homogeneous porosity with good water conductivity and very high hardness. Compared to conventional porous ceramic the cup is much more durable.

The bubble point of a SWT5 cup is about 200 kPa (20 bar, 2,000 hPa), and for a SWT5x it is about 500 kPa (50 bar, 5,000 hPa).
If the soil gets dryer than these values, air can enter, the negative pressure inside the cup decreases, and the readings go down to 0 kPa. With these characteristics this material has outstanding suitability to work as the semi permeable diaphragm for Tensiometers.

- Ceramic cup: Do not touch the cup with your fingers. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.

- Do not allow the SWT5 ceramic to dry out by leaving it unprotected in air: By drying out the bubble point might be reached, the reading will go to 0 kPa and air can enter the cup, which will then require refilling.

2.2 Analog output signals

The pressure transducer offers the soil water tension as a linear output signal, with 1 mV corresponding to 1 kPa (10 hPa).

As the pressure transducer is a Wheatstone full bridge, it has to be connected correctly.
See also ***Connecting SWT5 and SWT5x*** on page 19.
Please also read the user manual for your display unit or data-logger before connection.

3 Installation

3.1 Advance planning

3.1.1 Selecting the measuring site

The installation spot should be representative of the soil horizon! In heterogeneous soils, several soil samples should be taken and classified before or during installation. If the column is refilled care should be taken to achieve the best possible homogenous distribution and uniform compaction. Bear in mind a possible shrinking of backfilled columns when SWT5s are installed.
On tillage sites (with plants) root spreading and growth during the measuring period should be considered. Fine roots might develop around the ceramic cup as it is a poor but assured water source. Avoid the root zone if possible or relocate the Tensiometer from time to time.

3.1.2 Number of Tensiometers per level

The lower the level the less the variations of water potentials are. In lower sandy or pebbly horizons one Tensiometer per depth is sufficient. Close to the surface about 3 Tensiometers per level are recommended.


Guiding principle: More heterogeneous sites and soil structures require a higher number of Tensiometers.

3.1.3 Extent of the site

A large number of well-spaced samples will help reduce sampling errors in heterogeneous soils.
To obtain a differential description of the soil water situation at least 2 Tensiometers are recommended per horizon, one in the upper and one in the lower level.
The maximum recommendable cable lengths for SWT5 and SWT5x are 20 meters.

- Accuracy: long cables cause a reduction of the accuracy.
- Lightning: cables act as antennas and should always be as short as possible.

3.1.4 Ideal conditions for installation

For the installation of Tensiometers, the ideal conditions are:

- Frost-free soil.
- Wet coarse clay or loess.
- Low gravel content.

3.1.5 Documentation

For every measuring spot you should:

- Measure out the position where the pressure sensor will be placed. (A must for installations below the ground surface).
- Take documenting photos before, during and after installation.
- Save a soil sample.
- Write down installation depth and angle with each sensor identification (serial number).
- Mark all connecting cables with the corresponding sensor identification, serial number or logger channel on each end. Clip-on numbered rings, available as an accessory.

3.1.6 Selecting the installation angle

An installation position would be ideal if the typical water flow is not disturbed by the Tensiometer. No preferential water flow along the shaft should be created.
If the ceramic cup is positioned higher than the sensor body the first bubble that appears inside the shaft will block the water exchange and stop the Tensiometer working.

3.2 Installation procedure

The following tools are required for installation in the field:

- An auger with diameter 5 mm, preferably the Tensiometer auger provided in the **SWT5-FRK2** field refill kit.
- Rule, spirit level, angle gauge, marker pen
- Note book and camera for documentation of site and soil profile
- Perhaps PE-plastic bags for taking soil samples from the site

1. Drill a hole with the required diameter and depth. Mark the installation depth on both auger and SWT5 shaft.
2. If the hole's diameter is larger than 5 mm mix a slurry of water and ground-up soil material.
3. Connect the SWT5 to a readout device, for example a data logger for continuous measurements or the SWT-MR (INFIELD7) handheld device for spot readings.

During the installation the Tensiometer reading has to be controlled all the time. Especially in wet, clayey soils a high pressure might develop while inserting the SWT5. A pressure of over 2 bar will destroy the pressure transducer. Stop or slow down the insertion to allow the pressure to be relieved.

4. If you use a slurry paste pour it into the hole.
5. Pull off the water filled rubber cap from the shaft. Do not turn the cap as this might unscrew the shaft.
6. Gently and steadily insert the SWT5 down to the mark while checking the reading.

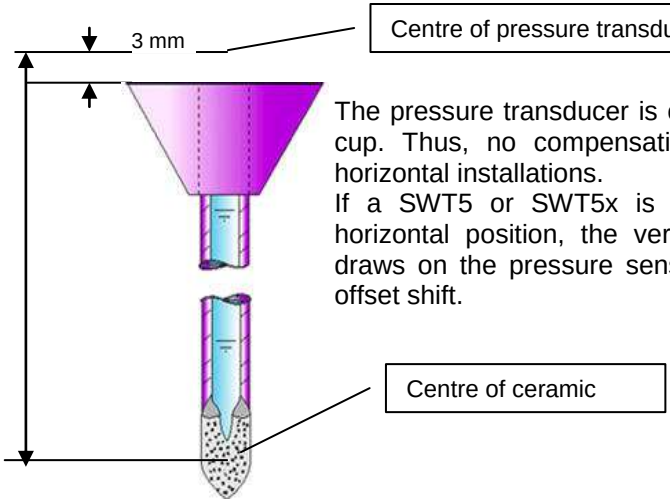
Never turn the SWT5 inside the borehole as this might loosen the shaft.

The less air there is inside the cup, and the better the soil's hydraulic conductivity is, the faster the Tensiometer will respond to tension changes.

7. Put the protective cover on the plug whenever the plug is not connected. Dirt will reduce the water tightness of the plug. Remember to put the protective cover back on the plug after taking spot readings with the SWT-MR (INFIELD7).

8. Connect the signal cables as described in the chapter "Connecting the SWT5 or SWT5x" on page 19.
9. Write down the serial number, position, installation angle and depth.
10. Protect the cables against rodent damage. Lead the cables through plastic pipes or protective cable trunking.

3.3 Offset correction for non horizontal installations



The pressure transducer is calibrated without a cup. Thus, no compensation is required for horizontal installations.
If a SWT5 or SWT5x is installed in a non horizontal position, the vertical water column draws on the pressure sensor and causes an offset shift.

Compensate the offset:

- by calculation,
- by entering the installation angle in the SWT-MR (Infield7) for spot readings,
- in the configuration of a data logger by setting an offset.

The deviation is largest for a vertical water column (at 0^{o}). The water column drawing on the pressure transducer is equal to the shaft length, ranging from 2 to 20 cm. The offset is shifted for 0.1 kPa per cm shaft length.

Example: A 5 cm vertical column of water below the pressure sensor will create an 0.5 kPa offset. This means that when the soil water tension is 0 kPa the sensor will indicate -0.5 kPa.

Table showing the offset correction when a 5 cm column of water is tilted at various angles:

Angle to vertical line	**0°**	**10°**	**15°**	**20°**	**25°**	**30°**
Offset correction in [kPa]	+0.5	+0.49	+0.48	+0.47	+0.45	+0.43

Angle to vertical line	**45°**	**60°**	**70°**	**75°**	**80°**	**90°**
Offset correction in [kPa]	+0.35	+0.25	+1.7	+1.3	+0.9	0

The offset is entered as + in your logger if you regard the soil water tension to be negative (0 ... -85 kPa).

3.4 Connecting SWT5 and SWT5x

3.4.1 Spot readings with the SWT-MR (Infield7)

SWT5 and SWT5x are fitted with a 4-pin plug. The plug can be connected directly to the handheld measuring device for taking spot readings of the soil water tension. This displays and stores the soil water tension readings.
Stored readings can be downloaded with the USB adapter and Windows PC software **SWT-MR-USB**, available as accessory.

Remember to put the protective cover back on the plug after taking spot readings with the SWT-MR.

3.4.2 Cables

Connecting and extension cables are required for connecting SWT5 and SWT5x to a data logger or other data acquisition device. Find cables in the chapter “Accessories”.

 Cover plugs with the supplied protective cover if not connected.

3.4.3 General requirements

The pressure transducer is a non-amplified bridge circuit which is calibrated for 10.6 VDC and requires a stabilized power supply.
Other supply voltages are possible, but the output signal range has to be recalculated.

In a full-bridge the signal must be measured differentially. This means do not measure only signal plus against common ground, but measure the voltage drop between signal minus against common ground and signal plus against common ground.

- The supply voltage has to be constant and stabilized.
- The supply voltage must not exceed 18 VDC.
- If the Tensiometer is not permanently powered the warm-up before a measurement should be no greater than 10 seconds. The 99% value is reached in 0.01 seconds, so a 1 s warm up is fine.
- If the Tensiometer is supplied with 10.6 VDC the output signal range is around 5.3 VDC. A data logger must have the capability to measure such a signal level, but many loggers cannot do this. In such cases use a TV batt (type TVB1 or TVB-M) power supply.

3.4.4 Connection to a data logger

The pressure transducer is a non-amplified bridge circuit which is calibrated for 10.6 VDC and requires a stabilized power supply.
Some logger types can measure bridge circuits directly, other loggers require certain measures as the signal minus and the supply minus do not have the same ground.
When supplied with just 10.6 V (supply minus = 0 V and supply plus = 10.6 V) the output signal range is between +3.2 V (min.) and +6.8 V (max.) related to power supply minus.
Other supply voltages are possible, but the output signal range has to be recalculated.

3.4.5 TVB1 and TVB-M Tensiometer power supplies

These power supplies are designed for Tensiometers **SWT3, SWT4, SWT4R** and **SWT5**. They offers a stabilized 10,6 V power supply, supplying -5 V and +5,6 V for powering up to 30 tensiometers.
These provide tensiometer output signals of <1V, which is suitable for many loggers,
The TVB1 fits inside a DL2e logger terminal compartment.
The TVB-M module has no environmental protection and can fit into an M-ENCL enclosure, and requires 7.5 – 16.0 V DC.

3.4.6 Delta-T Tensiometer loggers

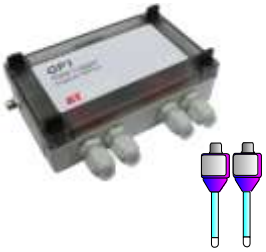
All **SWT** Tensiometers can be connected directly and without further power supply to the special Tensiometer logger **DL6-tens.**
Accessories are available for converting **GP1** and **DL2e** loggers to take Tensiometer readings.

DL6-tens Logger

The **DL6-tens** can take six SWT Tensiometers. This is a modified Delta-T DL6 6-channel logger with six 4-pin M12 sockets.
Each Tensiometer needs a **SWTEC-20** extension cable.

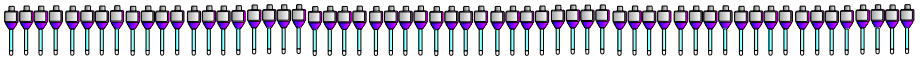
GP1 Logger

A **GP1** logger can take two SWT Tensiometers. Each tensiometer requires a **GP1-PBA1** adapter and connection cables type **SWTCC-XX .**
In addition 2 **SM200** soil moisture sensors, (or 10K thermistors), and a **WET** sensor may also be connected at the same time, along with two digital sensors such as rain gauges.
When fitting 5 or more sensors use the **GP1-LID2** expansion lid which has additional cable glands.



DL2e Logger

Up to 60 SWT tensiometers may be connected to a single **DL2e**.
Each group of 15 Tensiometers require one **LAC1** input card.
In addition, each group of 30 require one **TVB1** voltage regulator.



4 Service and maintenance

4.1 Refilling

To assure a rapid and reliable measurement of the soil water tension, the cup must be filled, bubble-free with degassed water. After dry periods or periods with a large number of wet and drying out successions, Tensiometers must be refilled.

Refilling is the easiest with the refilling tools included in the **SWT5-FRK2** Kit. A readout device, for example the SWT-MR, is always needed to control the signal.

4.1.1 When do Tensiometers need to be refilled?

Tensiometers need to be refilled if:

- the curve of the readings apparently gets flatter (for example a rain event has no sharp peak but is round),
- the maximum of -85 kPa is not reached anymore.

Refilling is only reasonable if the soil is moister than -90 kPa.

If the soil gets dryer than -85 kPa, the readings will remain constant at the vapor pressure of water (i. e. for example 92.7 kPa at 20°C and atmospheric pressure of 95 kPa). By diffusion and slight leakage the reading will slowly drop within months.

If the soil dries out and reaches the bubble point (-200 kPa for SWT5; -500 kPa for SWT5x), the tension will decrease rapidly as air will enter the cup.

4.1.2 Refilling SWT5 in lab and field

This chapter describes the refilling of SWT5 or SWT5x using the SWT5-FRK2 kit
The procedure has 5 steps:

1. Check the SWT5 Tensiometer
2. Degas cup and shaft
3. Degas sensor
4. Reassemble
5. Function test

The SWT5-FRK2 kit includes:

Check the SWT5

1. First, check if the SWT5 requires refilling: connect it to an SWT-MR (Infield7) or a voltmeter and power supply.

2. Wrap a dry paper towel (kitchen roll) around the cup to dry the ceramic surface.

With short shaft lengths cover the ceramic with a paper towel to avoid contamination.

3. Now wave the SWT5 tip around in the air. If the tension increases to -80 kPa within 10 seconds the T5 filling is OK.
If not then it needs to be refilled.

4. To disassemble the shaft hold the sensor body and turn off the shaft counter-clockwise.

The pressure sensor diaphragm is inside the small hole on the pressure sensor body (approx. ∅2 mm). It is very sensitive and must never be touched! It can be destroyed even by slightest contact! No contamination should get on the sealing and gasket.

Degas the cup

If the cup is completely dry just put the shaft in a beaker with deionised or distilled water over night.

Do not fill the shaft with water from inside the shaft! If water intrudes from both inside and outside then bubbles are trapped in the ceramic pores. But if the water only intrudes from the outside and soaks into the inside then any air bubbles are pushed out.

1. Take the syringe with the short rubber tube.
Pull up 10 ml of deionised or distilled water.

Take care to avoid bubbles.

2. Remove all air from the syringe.
Now block the tube with your finger and pull up the syringe. This creates vacuum inside the syringe and dissolved gas is released. Turn the still evacuated syringe to collect all bubbles. Hold the syringe upright, unblock the tube and remove all air. Repeat this procedure until no more bubbles appear.

3. Insert the ceramic cup into the tube as far as possible with the ceramic pointing inside.
The cup's tip should be close to the syringe nozzle.
Pull up the syringe just a little bit. Hold the syringe downwards and tap on it to loosen all bubbles.

Leave no air gaps inside the tube around the ceramic.

4. Take off the tube from the syringe. Leave the shaft inside the tube.
If necessary fill the tube with a few drops of water from the syringe.
Remove all air from the syringe.

6. Put the tube back on the syringe.

6. Now take the vacuum syringe with the 2 black spacers and the O-ring on the tube.
Pull up 10 ml water.

7. Degas the water as described above.

8. Now insert the threaded side of the T5 shaft completely into the tube.
Roll up the O-ring so the shaft is securely fixed: the O-ring should not be in the range of the thread but beyond the end of the thread.

Be careful to keep the parts clean so there will be no leaking when vacuum is applied

9. Now pull up the syringe until both spacers snap in.
Turn the syringe to collect all bubbles, but do not tap on the syringe!
Release the spacers and allow water to flow into the shaft.
Carefully remove the tube from the syringe nozzle and remove all air from the syringe (see 6).

There should be no air inside the tube before inserting the shaft again.

If there is air inside the tube inject some drops of water into the tube with the syringe. Reattach the syringe and pull it up until the spacers snap in. Leave the syringes on the shaft.

Degas the sensor body

1. Now take the syringe with the attached sensor body adapter. Pull up the syringe, but not so far that the spacers snap in.

2. Hold the syringe upwards and remove all air.

1. Insert the sensor body. If you rotate the sensor it will slip in easier.

2. Pull up the syringe a few times. Hold the syringe downwards so bubbles are collected inside the syringe.

3. Take off the tube and remove the air from the syringe.
Leave the sensor inside the adapter.

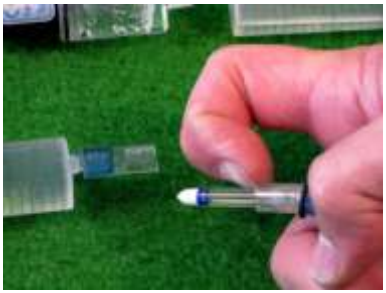
7. Squeeze the tube to remove any air inside while reattaching the syringe.

4. Pull up the syringe until the spacers snap in.
The Tensiometer water now is degassing.

Leave both syringe assemblies for at least 2 hours (the longer the better).

Reassembling

1. Take off the tubes from the shaft.



When removing the syringe from the sensor body take care to avoid damaging the pressure transducer!

The piston must not snap in as this might damage the pressure transducer!

2. Hold the syringe and the syringe piston securely. Bear in mind there is still vacuum inside. Press in the spacers and slowly release the piston.

3. Now remove the last remaining bubbles: draw up the syringe once more and release it slowly.
Now take off the syringe and remove the bubble inside.

4. Reattach the sensor body and draw up the syringe again. Tap on the sensor body to release any bubble.

Let the piston release slowly.

5. Now remove the sensor body.

6. Add one drop of water onto the shaft so a bulge of water overlaps the shaft ...

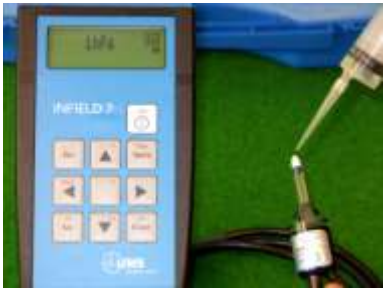
7. … and carefully screw in the shaft into the sensor body.

8. Continuously check the pressure with a meter: the pressure must not exceed 1 bar

You will clearly notice the point when the shaft hits the o-ring inside the sensor body.
From this point do only another quarter turn!

Check the SWT5

Zero offset:
Place the SWT5 horizontal on the table. Put a drop of water on the ceramic cup.
Now the potential is zero and the reading should be between
- 3 hPa and + 3 hPa
(= -0.3 kPa to +0.3 kPa).



Check the response:
Dry the ceramic surface with a clean tissue.
Then wave the cup in the air. The reading should rise to -80 kPa within 10 seconds.
If this is the case, the SWT5 is filled perfectly.

Find Maximum Measuring Range

To find out the maximum measuring range hold the ceramic tip in the airspace above the water surface inside the open water bottle.

When you raise the ceramic away from the water surface the air gets dryer and the suction rises.

Now hold the ceramic as close to the water surface - the tension reading should rise slowly. Depending on the filling quality the value will reach -85 to -450 kPa. Then, the value will rapidly drop to the vapour pressure (around -90 kPa depending on the altitude). Then, immediately put some water on the ceramic and cover the ceramic with the protective bulb half-filled with water. It should take one day for the Tensiometer to return to it's initial value.

4.2 Testing

4.2.1 Calibration

When delivered Tensiometers are calibrated with an offset of 0 kPa (when lying horizontally) and a linear response. The offset of the pressure transducer has a minimal drift over the years. Therefore, we recommend you check sensors once a year and re-calibrate them every two years.
Return the Tensiometers to us for recalibration, or contact us about available calibration accessories.

4.2.2 Check the Offset

If there is no pressure difference between the cup interior and the surrounding the signal should be 0 kPa.
There are two ways to check the offset.

1. Connect the Tensiometer to a readout device. Place the SWT5 in a beaker and fill the beaker with de-ionized water up to the centre of the sensor body (see 3.4.) Wait until the reading is stable. If there are bubbles inside the cup this might take a while.
Now the reading is the approximate offset. The value should be between +0.3 and -0.3 kPa.

2. To check the zero-point more precisely shaft and sensor body need to be disassembled.

- The pressure sensor diaphragm is inside the small hole on the pressure sensor body. It is very sensitive and must never be touched! It can be destroyed even by slightest contact! No contamination should get on the sealing and gasket.
- Before reassembling cup and sensor body carry out the degassing procedure (see chapter "Refilling").

After taking off the shaft shake the pressure sensor to remove water from the pressure transducer hole. The offset is acceptable when the reading is between -0.3 and +0.3 kPa.

Cleaning

Clean ceramic and sensor body only with a moist towel. If the ceramic is clogged it may be flushed it with Rehalon®.
If the pores are clogged with clay particles saturate the ceramic and then polish the ceramic surface with a wetted, waterproof sandpaper (grain size 150...240).

Storage

If the SWT5 or SWT5x is not be used for a year or more then empty shaft and sensor body to avoid algae growth. Store both in a dry place.

5 Protecting the measuring site

5.1 Theft and vandalism

The site should be protected against theft and vandalism as well as against any farming or field work. Therefore, the site should be fenced and signposts could give information about the purpose of the site.

5.2 Cable protection

Outdoors cables should be protected against rodents with plastic protection tubes.
Protection tubes are available. Contact us for further details.
In the lab the cables should be fixed so they are not accidentally pulled away and that there is no risk of stumbling.

5.3 Frost

Tensiometers are filled with water and are endangered by frost. SWT5 and SWT5x should only be use in frost-free surroundings.

- Do not store filled Tensiometer at temperatures below 0°C. Do not leave filled Tensiometers over night in your car, in a measuring hut, etc.
- Do not fill the Tensiometers with Ethanol, as this is corrosive for some materials (i. e. PMMA) and will destroy these.

6 Useful notes

6.1 Maximum measuring range and data interpretation

The measuring range of Tensiometers is limited by the boiling point of water. At a temperature of 20°C the boiling point is at 23 hPa over vacuum. So with 20°C and an atmospheric pressure of 950 hPa the Tensiometer cannot measure a tension below -927 hPa, even if the soils gets drier than that. The readings remain at a constant value (Fig. 6.1, between day 10 and 16).

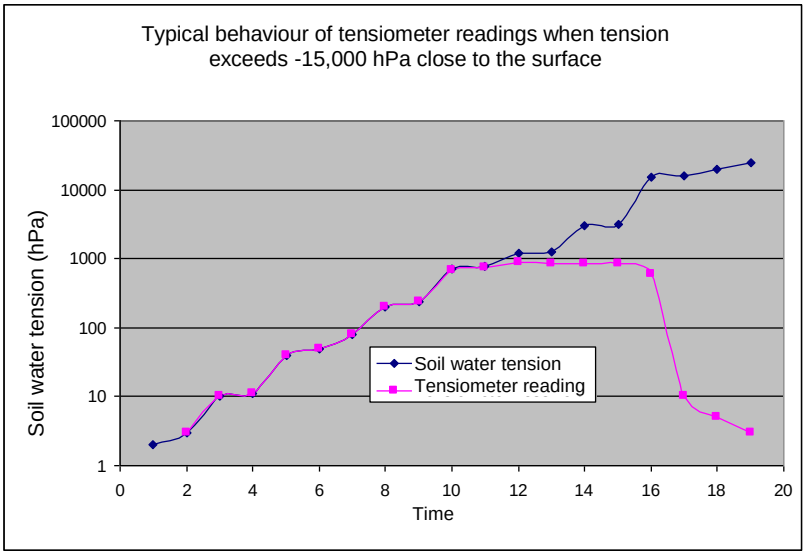


Fig. 6.1: Tensiometer readings with tensions to -15,000 hPa

If the soil dries to -15,000 hPa, the ceramic's bubble point is reached. The water in the ceramic cup will run out quickly and the reading of the air-filled cup will go to zero (Fig. 6.1, day 16 to 19).

If it rains before the soils reaches -15,000 hPa , the Tensiometer cup will suck up the soil water. However, the soil water includes dissolved gas which will degas as soon as soil dries again, increasing the tension. This will result in a poor response, the signal curve will get flatter and readings will only slowly adapt to the actual soil water tension. Depending on the size of the developed bubble, readings will undershoot the the maximum (Fig. 6.2, after day 20).

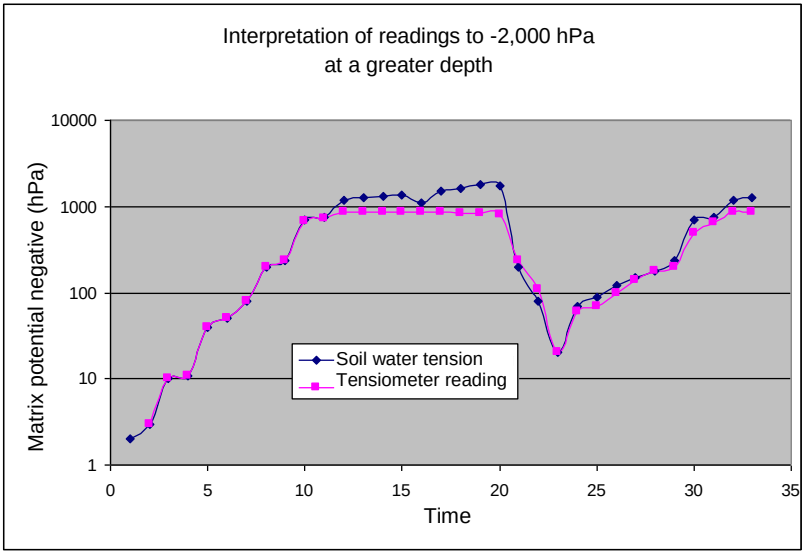


Fig. 6.2 Tensiometer readings with tensions to -2, 000hPa

Other problems that can be recognized by checking the data:
Soil water tension normally change only slowly. An erratic signal curve with many discontinuities could indicate, for example loose contacts, moisture in defective cables or plugs, poor power supply or a data logger malfunction.

6.2 Temperature influences

If the sensor does not need to be powered continuously then the warm-up voltage should be switched on for no longer than 10 seconds before a measurement. In this case, the self heating is negligible. Use a 1 second warm up for Delta-T loggers (Dl2e, DL6, DL6-tens & GP1).

The correlation of water tension to water content is temperature dependent. The influence is low at tensions of 0 to 10 kPa $\Rightarrow$ 0 … 0.6 kPa/K, but high for tensions over 100 kPa:

$$\Psi = \left(\frac{R \cdot T}{M}\right) \cdot \ln\left(\frac{P}{P_o}\right)$$

Ψ = Water tension R = Gas constant (8,31J/mol K)
M = Molecular weight p = Vapor pressure
p_o = Saturation vapor pressure at soil temperature
(from Scheffler/Straub, Grigull)

6.3 Vapor pressure influence

If the temperature of a soil with a constant water content rises from 20°C to 25°C the soil water tension is reduced for about 0.85 kPa due to the increased vapor pressure which opposes the water tension.

Temperature in °C	4	10	16	20	25	30	50	70
Pressure change per Kelvin in [hPa]	0.6	0.9	1.2	1.5	1.9	2.5	7.2	14

6.4 Osmotic effect

The ceramic has a pore size of r = 0.3 µm and therefore cannot block ions. Thus, an influence of osmosis on the measurements is negligible because ion concentration differences are equalized quickly. If the SWT5 cup is dipped into a saturated NaCl solution the reading will be 1 kPa for a short moment, then it will drop to 0 kPa again.

7 Troubleshooting

Please refer to the Delta-T website where you will find a regularly updated list of FAQs:
http://www.delta-t.co.uk/product-faq-table.html?product2005092818915

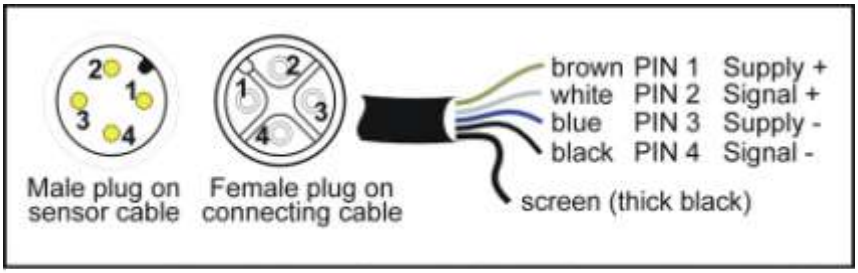
8 Appendix

8.1 Technical specifications

Material and dimensions	
Ceramic material	Al2O3 sinter
Bubble point T5	> 200 kPa
Bubble point T5x	> 500 kPa
Ceramic cup	Length 6 mm, ∅ 5 mm
Sensor body	PMMA, ∅ 20 mm
Shaft material	Impact-proof PMMA, ∅ 20 mm
Sensor cable	
Length	1.5 m
Plug	Male 4-pin, thread M12, IP67
Measuring range	
T5	-85 kPa ... +100 kPa
T5x	min. -160 kPa ... +100 kPa
Water tension	-85 kPa (-160 kPa) … 0 kPa (Tensiometer)
Water level	0 kPa … +100 kPa (Piezometer)
Output signal	
Pressure	160 mV = -160 kPa (T5x) 85 mV = -85 kPa (T5) 0 mV = 0 kPa -100 mV = 100 kPa (water level)
Accuracy	±0,5 kPa
Power supply	Power supply
Supply voltage V_{in}	typ. 10,6 VDC by TV-batt (recommended) 5 ... 15 VDC, stabilized
Current consumption	1,3 mA at 10,6 V (TV-batt)
Environmental (chemical)	
pH range	pH 3 ... pH 10
	Limited to substances that do not harm silicon, flour silicon, EPDM, PMMA and polyetherimid.

8.2 Wiring configuration

Configuration of SWT5 and SWT5x Tensiometer plug and the 4-wire connecting cables type SWTCC:



Pin and wiring configuration for connecting cable type

Signal	Wire	Pin	Function
V_{in}	brown	1	Supply plus
V-	blue	3	Supply minus
A-OUT+	white	2	Signal plus
A-OUT-	black	4	Signal minus

8.3 Accessories

8.3.1 Connecting and extension cables

Cables must be ordered additionally for each Tensiometer.

4-wire connecting cables **SWTCC-**xx... are fitted with a female plug M12/IP67 and 12 cm wire end sleeves.
Extension cables SWTEC-xx... have one each male and female plug M12/IP67. Plugs are supplied with protective covers.

Item	Delta-T no.
4-pin connection cables	
Length 1.5 m	**SWTCC-01**
Length 5 m	**SWTCC-05**
Length 10 m	**SWTCC-10**
Length 20 m	**SWTCC-20**
4-pin extension cable	
Length 5 m	**SWTEXT-05**
Length 10 m	**SWTEXT-10**
Length 20 m	**SWTEXT-20**

Additional items	
Clip-on cable markers, 30 sets of numbers 0 ... 9	Please contact Delta-T
Plastic protection tubes	Please contact Delta-T
Thermal insulation tubes	Please contact Delta-T

Plastic protection tubes for cables are available with several diameters, including dividable slotted tubes for easy re-fitting. Contact Delta-T for details.

8.3.2 Handheld measuring device

The SWT-MR manual readout unit is capable of taking and storing spot readings of soil water tension, soil temperature and filling status, depending on the type of Tensiometer used.
Includes an automatic offset correction for water column height and installation angle.
Suitable for all SWT Tensiometers. The unit comes with a small carrying case.

Item	Delta-T no,
SWT-MR manual readout	**SWT-MR**

A USB converter is available for data collection from the SWT-MR to a PC via PC or laptop. It includes Windows PC software TensioVIEW.

Item	Delta-T no,
USB PC adapter for SWT-MR	**SWT-MR-USB**

8.3.3 Tensiometer loggers

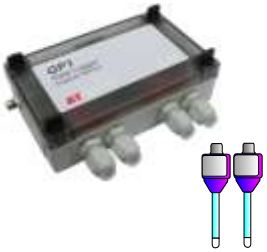
All **SWT** Tensiometers can be connected directly and without further power supply to the special Tensiometer logger **DL6-tens.**
Accessories are available for converting **GP1** and **DL2e** loggers to take Tensiometer readings.

DL6-tens Logger

The **DL6-tens** can take six SWT Tensiometers. This is a factory-modified Delta-T DL6 6-channel logger with six 4-pin M12 sockets. Each Tensiometer needs a **SWTEC-20** extension cable.

GP1 Logger

A **GP1** logger can take two SWT Tensiometers. Each tensiometer requires a **GP1-PBA1** adapter and connection cables type **SWTCC-XX .**
In addition 2 **SM200** soil moisture sensors, (or 10K thermistors), and a **WET** sensor may also be connected at the same time, along with two digital sensors such as rain gauges. When fitting 5 or more sensors use the **GP1-LID2** expansion lid which has additional cable glands.



DL2e Logger

Up to 60 SWT tensiometers may be connected to a single **DL2e**.
Each group of 15 Tensiometers require one **LAC1** input card and one **TVB1** voltage regulator.

Item	Delta-T no.
6-channel modified DL6 logger	**Contact Delta-T**
2-channel GP1 logger	**Contact Delta-T**
60 channel DL2e logger	**Contact Delta-T**

8.3.4 Voltage regulators

Tensiometer stablised power supply unit for SWT3, SWT4, SWT5, suited in DL2e-logger extension frame (left), or as an open module (right).
The regulated power supply itself can power up to 60 tensiometer. Each TVB1 logger frame has supply terminals for 15 Tensiometers. Contact Delta-T if you wish to fit more than 15 Tensiometers to one DL2e logger.

Item	Delta-T no.
TV-batt for DL2e logger	**TVB1**
TV-batt module only	**TVB-M**

8.3.5 SWT5-FRK2

Service kit for SWT5 and SWT5x (without a SWT5!), incl. refilling tools (syringes etc.), auger kit, connecting cable SWTCC-1.5, all in blue case 35 x 30 x 8 cm.

Item	Delta-T no.
SWT5 service kit	**SWT5-FRK2**

8.4 Units for soil water and matrix potentials

	pF	hPa	cm H_20	kPa = J/kg	MPa	bar	psi	%RH
	1	-10	9.8	-1	-0.001	-0.01	-0.1450	99.9993
	2.01	-100	98.1	-10	-0.01	-0.1	-1.4504	99.9926
Field capacity	2.53	-330	323.6	-33	-0.033	-0.33	-4.9145	99.9756
Standard Tensiometer range	2.93	-851	834.5	-85.1	-0.085	-0.85	-12.345	
	3	-1,000	980.7	-100	-0.1	-1	-14.504	99.9261
	4	-10,000	9,806.6	-1,000	-1.0	-10	-145.04	99.2638
Permanent wilting point	4.18	-15,000	14,709.9	-1,500	-1.5	-15	-219.52	98.8977
	5	-100,000	98,066.5	-10,000	-10	-100	-1,450.4	92.8772
Air dry, air humidity dependant	6	-1,000,000	980,665	-100,000	-100	-1,000	-14,504	47.7632
oven dry	7	-10,000,000	9,806,650	-1,000,000	-1,000	-10,000	-145,038	0.0618

9 Technical Support

9.1 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 twelve months 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.

9.2 Service 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.

9.3 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

Tech Support Team
Delta-T Devices Ltd
130 Low Road, Burwell,
Cambridge CB25 0EJ, U.K.

Tel: +44 (0) 1638 742922
Fax: +44 (0) 1638 743155
email: **tech.support@delta-t.co.uk**
email: **repairs@delta-t.co.uk**
web: **www.delta-t.co.uk**

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