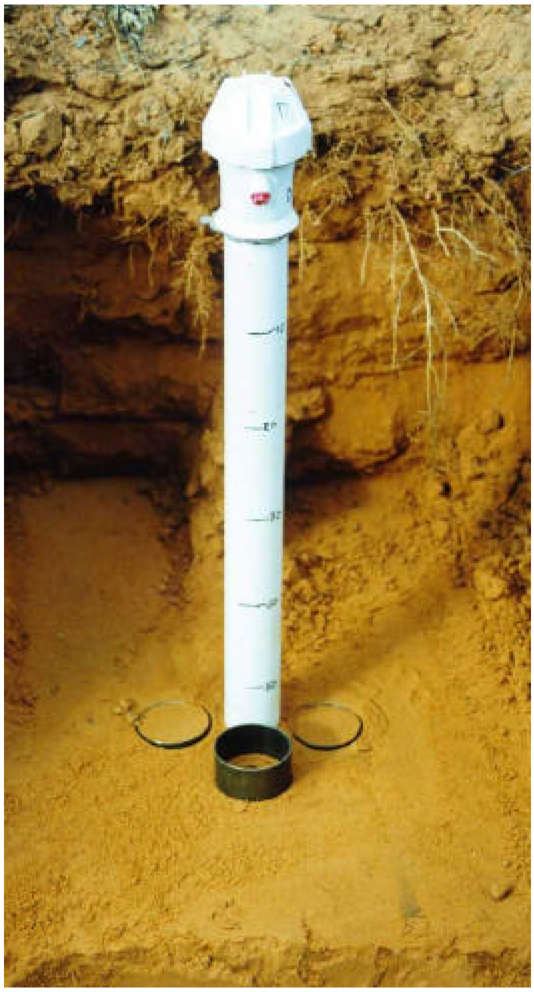
CALIBRATION

of

Sentek Pty Ltd Soil Moisture Sensors



Sentek sensor technologies

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Document Conventions

Before you start it is important that you understand the conventions used in this manual.

Conventions	**Type of Information**
Bold Text	Bold text is used to highlight • Names of products and companies, for example **Sentek** • An emphasised word, for example, '**Note'** or '**Warning**"
This font face	*This font face* is used for the names of tools, methods and miscellaneous items, for example *Sentek Soil Moisture Probes*

Text presented under the heading:

'Note:'	Is important information that should be considered before completing an action

1 Introduction

The purpose of this manual is to describe the methodology recommended by **Sentek Pty Ltd** for soil moisture instrument calibration of the **Sentek Pty Ltd** range of *soil moisture sensors*, herein referred to as *Sentek Soil Moisture Sensors*. These sensors form an integral part of the continuously logging, stand-alone, permanently sited probes, herein called *Sentek Continuous Probes*. Such probes include the EnviroSCAN® and a range of *Smart Probes*. The sensors are also a key part of the portable probes, herein called *Sentek Portable Probes*, which include the Diviner 2000®.

The basic principles of calibration are well documented in scientific literature, and the methodology described in this manual is based on gravimetric sampling, which is recognised as a standard calibration procedure worldwide. The aim of this manual, however, is to outline the procedure in a straightforward manner that can be readily adopted by the user.

Poor or unsuccessful calibration generally results from variations made from the recommended methodology. The intention of this manual is to help users avoid making some of the more common mistakes and to outline many of the pitfalls to be wary of.

A portion of this manual is also dedicated to some of the existing calibration equations that have been calculated for the EnviroSCAN® sensor by independent scientific studies. These cover a wide range of different soil types from around the world.

This manual is a dynamic document that should be regularly updated as new, revised or area-specific information becomes available.

2 What is Calibration?

Calibration of a measuring instrument is typically made by aligning the readings of that instrument against values determined by a method that is long established and accepted as a standard method for measuring the same value.

Calibration of the *Sentek Soil Moisture Sensors* is made by comparing Scaled Frequency readings from an access tube installed in the field or in a container in the laboratory with values of volumetric water content determined gravimetrically from immediately adjacent to the tube.

When these values are plotted on a graph, they form a relationship that is described by a mathematical equation. In this way the moisture levels sent from the sensor are directly related to real values determined in the soil.

3 Why Calibrate?

To convert *Sentek Soil Moisture Sensor* readings of a particular site into values that represent **absolute** volumetric soil water content a specific **calibration** must be performed for that site. The *Sentek Continuous Probes* and *Sentek Portable Probes* are precise measurement instruments. They do not however, automatically generate accurate **absolute** volumetric soil water content data for all soil types of the world. **Sentek Pty Ltd** provides **default calibration equations** for the *Sentek Soil Moisture Sensors* that convert the raw counts into **estimates** of soil water content.

For the typical irrigator that uses the *Sentek Soil Moisture Sensors* for irrigation scheduling purposes, calibration is an unimportant, time-consuming and relatively expensive procedure. Therefore, for such purposes, **Sentek Pty Ltd** recommends the use of their default calibration equations that have been calculated based on a range of different soil types, and which can be used to show **relative** soil water changes in all soil types.

Significant numbers of data sets collected from various soil types and crops around the world have shown that relative changes in volumetric soil water content based on the default calibration can be used to show the most important soil water trends in relation to optimum plant production (Alva and Fares, 1988 & 1999, Paltineanu and Starr 1997, Starr and Paltineanu 1998, Tomer and Anderson 1995). Irrigators mainly use relative data because they are interested in the relative changes in soil water dynamics for their daily irrigation management practices. Almost all of the economic gains recorded with the EnviroSCAN® in commercial agriculture to date have been made using the concept of "relative change" in soil water dynamics.

Obtaining absolute volumetric soil water content data is useful however, for scientific studies of the soil-plant-water-atmosphere continuum, and for other purposes where it is necessary to determine absolute values of soil water content. The use of tools such as the *Sentek Continuous Probes* and *Sentek Portable Probes* offers a non-destructive and less tedious method of measuring soil water content than traditional methods (Fares & Alva, 2000). For these purposes, calibration of the *Sentek Soil Moisture Sensors* at a site is essential.

It must be remembered that any site-specific calibration equation cannot be accurately extended to other sites to yield absolute soil water content, and is only representative of an area of the same soil properties that immediately surround that site. Due to the heterogeneous nature of soil no single calibration equation can yield absolute data for every situation. Different soils vary in a range of properties that influence the soil water storage, and therefore every site will require calibration to obtain absolute volumetric soil water content data.

Users of *Sentek Soil Moisture Sensors* should also be aware that the soil-water-plant-atmosphere continuum is dynamic and changes with time. Therefore a calibration equation will only hold true for a certain period of time after the calibration procedure has been performed. Day-to-day cultural activities on an irrigated property can have a significant impact on the soil and soil water storage capacity, and hence can influence the accuracy of the data produced by the calibration equation. Changes in bulk density due to compaction, for example, will have a direct influence on the volumetric soil water content, as will changes in organic matter content. For long-term projects, recalibration may be necessary after a period of time.

4 Site Selection

It is essential that the site chosen for calibration is representative of the total area over which the resultant calibration equation is to be applied. The aim of good site selection is to select an area that reflects changes in soil water content and crop water use trends across the study area or scheduling unit.

Factors such as soil, climate, plant variety, plant health, aspect, cultural management, irrigation system and topography should all be taken into account when locating a representative site.

Soil

Soil properties can be extremely variable, and there are many factors that need to be considered in combination when selecting a representative site for probe installation. Some of the major soil factors influencing the soil-water-plant-air relationship that should be considered are listed below.

Effective Soil Depth
The effective soil depth is the depth to which the majority of plant roots penetrate and effectively uptake water and nutrients. Effective soil depth can be one of the factors that vary most significantly across a property.

Texture
Texture influences many aspects of soil water behaviour and soil water storage capacity. In general terms, clay soils have a higher water storage capacity and lower permeability than sands.

Structure
The grade and stability of structure can have a significant impact on water entry into the soil. The spaces between soil structural units (peds) provide pathways for air and water. The stability of peds is also important in relation to crusting and water entry into wet soils.

Pans
Various different sorts of pans can form barriers to water and/or root penetration. Their influence is dependent upon the depth at which they form.

Porosity
Soil porosity influences the rate of water movement through the soil, and the balance between soil water storage and drainage. Destruction of connected macro-pores, for example, severely limits infiltration.

Coarse Fraction
The coarse fraction directly affects the capacity of a soil to store and supply water and nutrients. The water holding capacity of a soil is reduced in proportion to the volume of the rootzone occupied by the coarse fractions.

Salinity and Sodicity
Saline soils are likely to reduce plant health and vigour, in turn affecting crop water use. Dispersion of soil colloids due to sodicity can lead to poor infiltration and hydraulic conductivity.

Soil Water Characteristics
A range of different soil factors such as texture, structure, porosity, condition of surface soil, stoniness, organic matter content and presence of impermeable layers influence the infiltration rate, hydraulic conductivity and the water storage capacity.

Climate and Aspect

One of the most important factors influencing crop transpiration is the weather. Temperature, wind speed, humidity, solar radiation and rainfall all influence crop performance and transpiration rates. Weather factors may not always have a uniform impact across the property of concern. Some areas may be more wind-exposed, for example, or receive greater amounts of solar radiation, depending on their aspect.

Crop

Crop differences have an impact on crop water use and irrigation scheduling requirements. Changes in plant characteristics such as crop type, size, age, vigour, variety, rootstock, development stage, leaf area, nutrient and disease status and crop load can all affect crop water use.

Cultural Management

Cultural management can have a significant impact on soil water status and irrigation scheduling. Different cultural activities across a property such as cultivation, mulching, pruning, fertilising and spraying can impact on the crop water use and soil water storage capacity.

Irrigation System

Variations in irrigation system pressure and flow and water distribution uniformity cause differences in the application rates of water. Poor system performance can have a major impact on the success of soil moisture monitoring due to an over- or under-estimate of the soil moisture and watering requirements from placement of the monitoring device in “dry” or “wet” spots.

It is important that the calibration site is located in an area that is relatively uniform in terms of each of the factors listed above and is likely to respond in a similar manner under irrigation. It can be useful to create a series of maps (as shown in Figures 1-4) to help identify areas of uniform management requirements. Each of these maps can be overlaid to create an integrated picture of the land and irrigation requirements.

For further information on site selection refer to the Sentek Diviner 2000® Installation Guide Version 1.0.

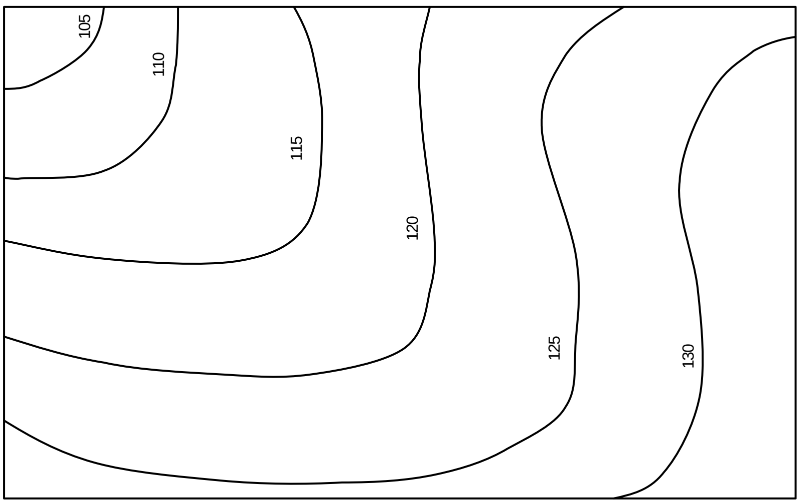


Figure 1. Example Contour Map

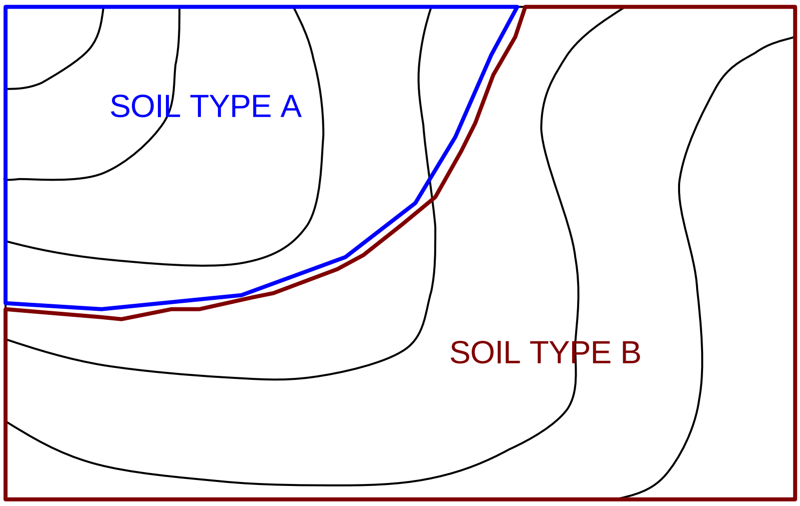


Figure 2. Example Soil Type Map

Figure 2 shows two predominant soil types, which may require quite different irrigation regimes.

Figures 3 & 4 show that placement of the probe site should take into account both physical characteristics and practical elements.

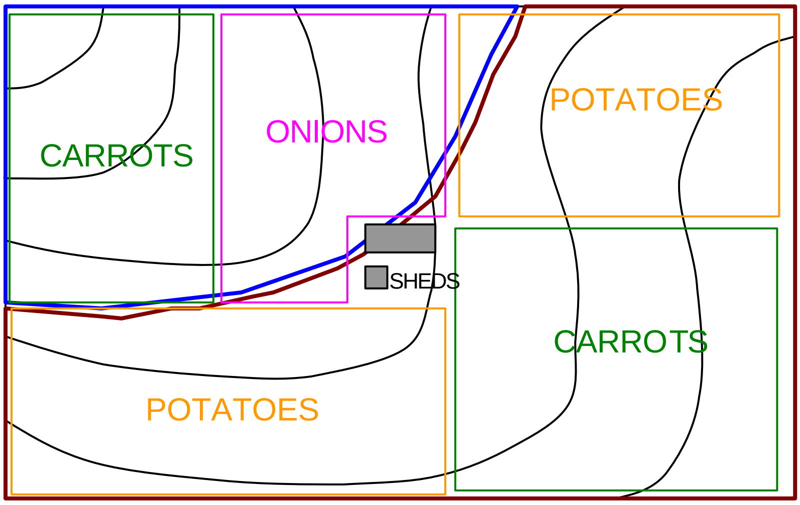


Figure 3. Example Planting Plan

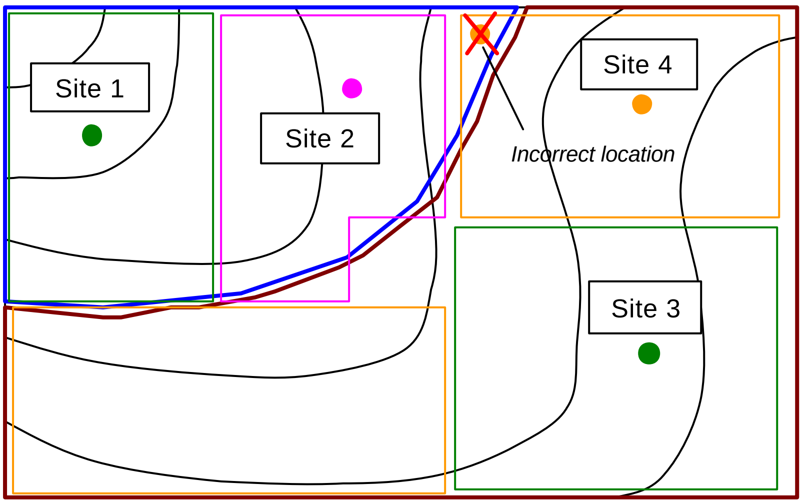


Figure 4. Example Probe Location

5 Calibration Procedure

5.1 Instructions for Calibrating Sentek Soil Moisture Sensors

The *Sentek Soil Moisture Sensors* are calibrated by comparing sensor readings (Scaled Frequencies) with actual soil water content values over a range of soil moisture contents. It is recommended that gravimetric sampling is the method used to determine soil water values independently. Gravimetric sampling, in conjunction with determination of bulk density, enables the volumetric soil water content to be derived.

The relationship between Scaled Frequencies and independently determined volumetric soil water content values provides a calibration curve. In fact this relationship can be a straight line or curve and is described mathematically by a calibration equation.

Calibrations can be performed either in the laboratory or in the field. Due to inherent soil variability, it is often difficult to gain the same accuracy with a field calibration as it is with a laboratory calibration. Both techniques are described in detail below.

5.2 Tools Required for a Field Calibration

Prior to undertaking a field calibration, it is worthwhile gathering all the necessary equipment. A list of some of the more useful equipment for performing field calibrations is provided below.

- ⇨ Access tubes
- ⇨ Cutting edges
- ⇨ Top cap assemblies
- ⇨ Expandable bungs
- ⇨ Sentek Pty Ltd Installation Toolkit No. 1
- ⇨ Additional tools for difficult soils, such as a 53 mm Regular Auger, 56 mm Regular Auger, Large Auger Cleaning Tool or an Open Centre Tungsten Tip 47 mm Auger
- ⇨ Sentek Pty Ltd Installation Toolkit No. 2
- ⇨ Sentek Continuous Probe or Sentek Portable Probe
- ⇨ Gloves
- ⇨ Safety Goggles
- ⇨ Plastic Ground Sheet
- ⇨ Laptop computer
- ⇨ Download cable
- ⇨ Notepad
- ⇨ Stopwatch
- ⇨ Portable scales (0-500 grams)
- ⇨ Metal sampling rings (minimum of three; see figure 6 for specification)
- ⇨ Sampling ring extension (see photo 4)
- ⇨ Rubber mallet
- ⇨ Sealable plastic bags
- ⇨ Alfoil trays
- ⇨ Permanent marking pen
- ⇨ Spades
- ⇨ Maddocks or picks
- ⇨ Spatulas
- ⇨ Backhoe or excavator (to be hired)
- ⇨ Sledgehammer
- ⇨ Fan forced drying oven
- ⇨ AC-DC converter

5.3 Gravimetric/ Volumetric Calibration Technique – Field Calibration

The following steps outline the recommended procedure for undertaking a field calibration.

Step 1

Install **Sentek Pty Ltd** approved *PVC access-tubes* in an appropriate site as outlined in Pages 4-6, using the appropriate method for the type of soil (refer to Diviner 2000® Installation Guide for further details on recommended installation procedure). Ensure there are no air gaps around the access tubes. A minimum of six (6) access tubes is required to perform a calibration. The aim of calibration is to obtain readings across a range of soil moisture contents – from wet, moist, to dry. A minimum of two tubes should be placed in wet soil, two in moist soil and two in dry soil. The replicates should be at least 2 metres apart and the different treatments at least 5 metres apart, but in the same general area.

Photo 1. Installing access tubes

Step 2

This is a time consuming but important step. Ensure that there is sufficient difference between calibration points for wet, moist and dry soil through good site preparation, i.e. wetting and drying procedures of the soil profile. The "wet" site may need artificial ponding with water to wet the soil around the access tube (ensuring **even** application of water). The "dry" site may need the establishment of a fast growing, deep-rooted crop to dry out the soil profile and/or the construction of some kind of shelter. Irrigation to the dry site should be avoided. Insufficient site preparation at this stage can lead to the derivation of an inaccurate calibration equation. It is recommended that the probes are installed prior to site preparation, and then sufficient time allowed for adequate wetting and drying. The approximate range of soil moisture contents can be checked with a *Sentek Soil Moisture Sensor* prior to calibration to ensure that there is sufficient difference in moisture content. The alternative is to stage calibration at different times of the season, i.e. reading and sampling the dry site in the "dry" season, and the wet site in the "wet" season, but this is a very time consuming process.

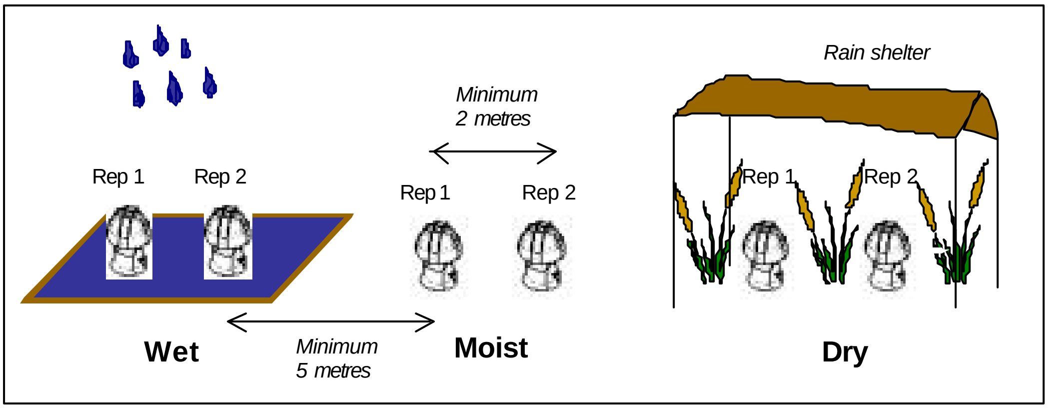


Figure 5. Layout of calibration access tubes

Step 3

For the *Sentek Continuous Probe*, collect a minimum of 3 raw count readings (preferably more) at each selected depth level (*i.e.* 3 readings at 10 cm/3.9”, 3 readings at 20 cm/7.8”, 3 readings at 30 cm/11.7” etc.). With the *EnviroSCAN*® sensors, this is conveniently done by setting the data collection time to 1 minute and leaving the probe in place for 10 minutes, giving 10 replicate readings. **Note time of recording, ensuring that the logger, computer and stopwatch times are synchronized.** For the *Sentek Portable Probe* take a minimum of 3 replicate swipes covering the full depth range. For the *Sentek Smart Probe*, plug the communication cable into the probe and record the raw counts shown in the Configuration Utility Software.

Step 4

Immediately after obtaining readings, dig a trench beside the tube to the depth of the deepest *Sentek Soil Moisture Sensor* or *Sentek Portable Probe* length, which is far enough from the access tube (approx. 30 cm/11”) to avoid disturbance of the soil being measured and sampled.

Note: Steps 4-7 should be carried out as soon as possible after obtaining moisture readings. This is critical, particularly in sandy soils with moisture contents above field capacity where soil moisture can change within minutes.

Photo 2. Digging trench

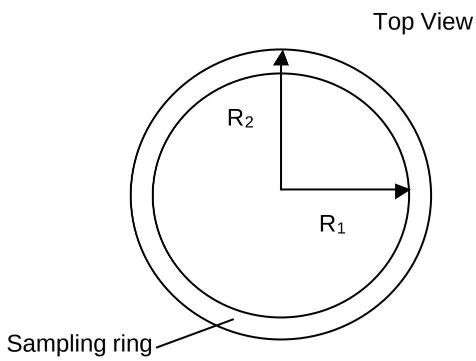
Step 5

Use three thin-walled metal rings to sample soil water and bulk density from each depth. Make sure that the area ratio of the cylinder is less than 0.1 (i.e. the ratio of the area of the cross section of metal to that of the soil within the cylinder, Figure 6). **Important:** This applies in particular to wet clay soils.

Label each sampling ring with a number using an engraver. Weigh each ring and record its weight and number.

Alternatively, label separate containers such as aluminium trays, which the soil can be put into after sampling, and record their weight (refer to Step 7).

Figure 6. Sampling ring dimensions



Area Outer Ring (A1) = $\pi (R_2^2 - R_1^2)$

Area Inner Ring (A2) = πR_1^2

Area Ratio = A1/A2

Sampling at different depth levels is achieved by building a series of soil platforms (Photo 3). To sample the 10 cm reading level, dig the first platform to the depth at which the top of the sampling ring should sit. For a 5 cm high sampling ring, dig the platform to 7.5 cm below the soil surface, such that the centre of the sampling ring is at a depth of 10 cm when pushed into the soil (Figure 8). Make sure that the soil above the sampling depth is removed without compressing the layer to be volume sampled. For the 20 cm reading level, dig the platform to a depth of 17.5 cm and incrementally thereafter.

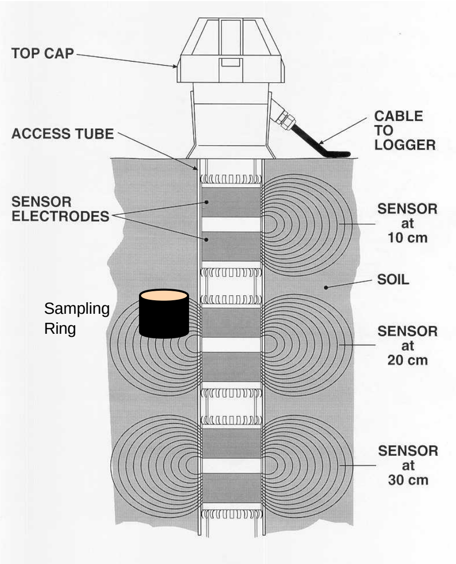


Figure 7. Vertical section of sampling ring placement within sphere of influence

Photo 3. Digging platform for sampling

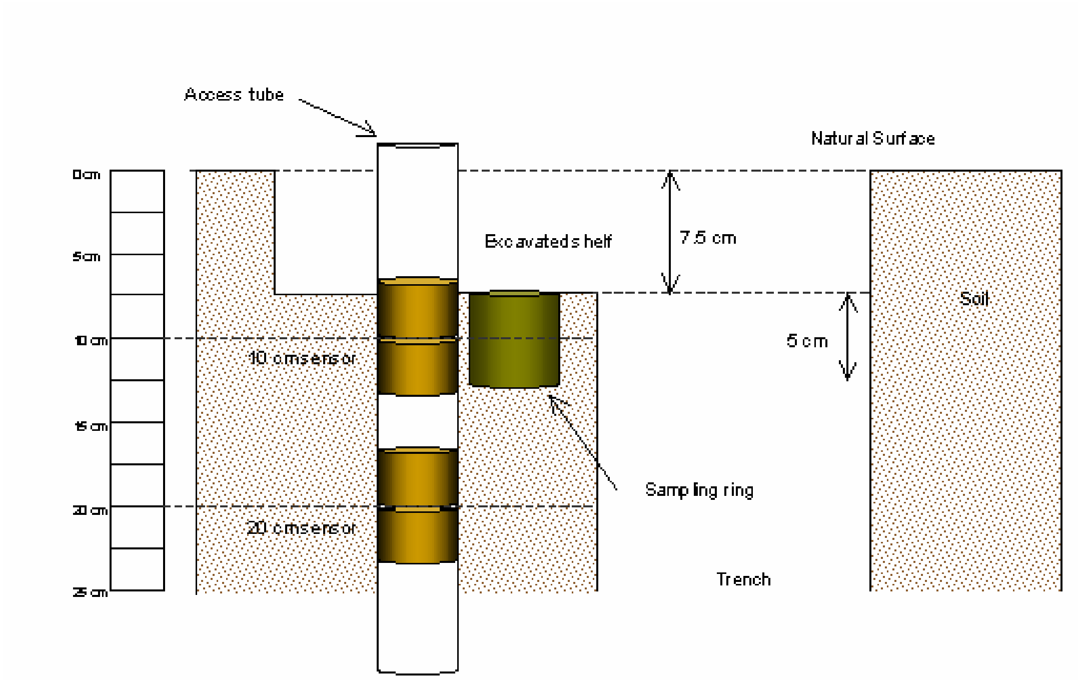


Figure 8. Side profile of excavated pit showing sampling depth

Take a minimum of 3 ring samples at each depth. Drive the rings in as close as possible to the access tube without touching it and stop driving when the centre of the ring matches the centre of the sphere of influence of the sensor field (Photo 7), which should be when the top of the sampling ring is level with the soil platform. Use a sampling ring tube extension when driving in the rings to avoid compacting the soil.

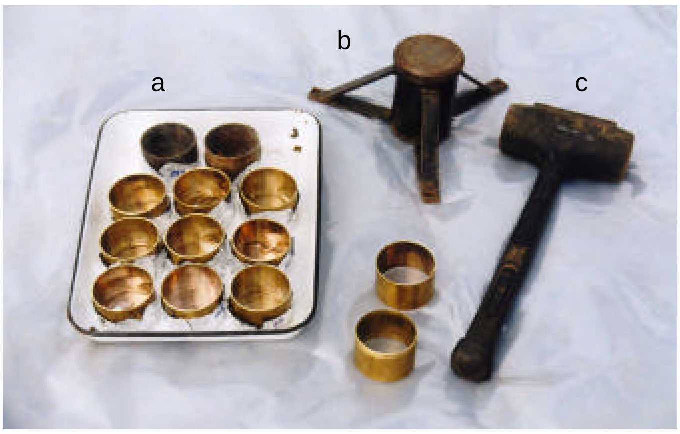


Photo 4. Sampling kit

a. Sampling rings
b. Sampling ring extension
c. Mallet

Photo 5. Placing ring extension on top of ring

Photo 6. Placing top on ring extension ready to hit with mallett

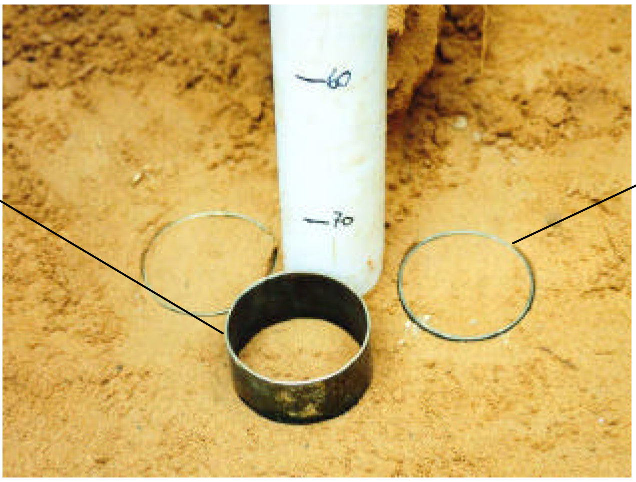


Photo 7. Ring placement around access tube

Step 6

Remove the soil samples with sufficient overburden to avoid soil from dropping out of the bottom of the ring. Trim each core with care using a spatula, without compressing the soil. Make a note if you lose soil out of the ring volume.

Photo 8. Removing sampling rings

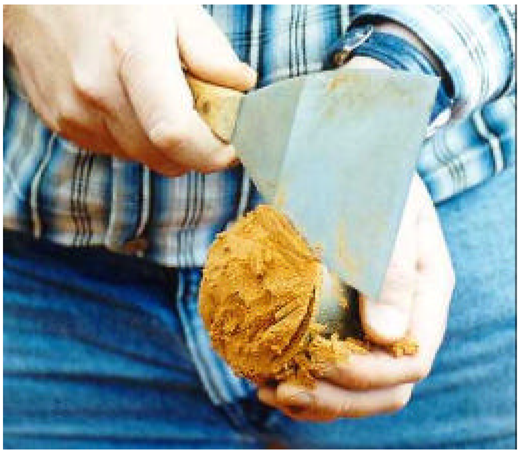


Photo 9. Trimming core

Step 7

If the soil can be easily removed from the sampling ring, place the soil from each ring into individual containers of known mass. If not, then place aluminium foil caps on the top and bottom of the ring. Clearly label each sample, and **as soon as possible**, weigh each of the samples to obtain the wet mass of the soil core (M_w). If the samples cannot be weighed immediately, store them in sealed plastic bags to minimize moisture loss. After weighing, dry the samples at 105^{o}C to constant weight. This may take several days. Reweigh to obtain the dry mass of the soil core (M_d).

NOTE: Ensure that the samples are clearly labelled such that they do not get mixed up during the drying procedure.

Photo 10. Weighing immediately after sampling

Step 8

Repeat Steps 4-7 for each of the other tubes.

Step 9

Perform the following calculations:

1. Determine the gravimetric water content (W) of each sample:

$$\mathbf{W = (M_w - M_d)/M_d}$$

   M_w = Wet Mass
   M_d = Dry Mass

2. Measure the volume (V) of the core sampler:

$$\mathbf{V =} \ p \ \mathbf{(ID/2)^2 h}$$

   ID = internal diameter of ring
   h = height of ring

3. Determine the bulk density (ρ) of each sample:

$$r \ \mathbf{= M_d/V}$$

4. Calculate the volumetric water content (θ) of each sample:

$$q \ \mathbf{= W}r$$

NOTE: It is important to keep every sample separate and not to average the results.

Step 10

Display the results in the following format:

	Tube 1			Tube 2		
Depth	θ Dry Rep 1	θ Dry Rep 2	θ Dry Rep 3	θ Dry Rep 1	θ Dry Rep 2	θ Dry Rep 3
10	3.61	4.19	5.51	1.44	1.39	1.42
20	4.00	4.42	5.79	3.78	3.91	3.15
30	6.30	5.27	7.93	4.21	4.63	3.96
40	7.22	6.76	8.67	5.14	6.02	5.82
50	8.41	8.73	8.70	6.93	7.25	7.43
60	9.13	9.22	9.61	8.22	8.79	7.68
70	11.5	10.4	10.7	9.81	9.39	8.89
80	11.9	11.1	12.1	11.5	12.2	9.45
90	12.2	13.3	14.4	13.2	14.3	13.7
100	13.8	14.7	14.7	14.0	15.6	14.2
Depth	θ Moist Rep 1	θ Moist Rep 2	θ Moist Rep 3	θ Moist Rep 1	θ Moist Rep 2	θ Moist Rep 3
10	22.4	24.5	21.2	18.0	17.5	20.0
20	23.5	25.0	24.4	17.6	16.6	19.5
30	24.6	25.1	24.9	17.6	16.8	20.1
40	24.8	25.9	25.3	19.4	17.8	21.0
50	26.1	26.4	25.9	21.1	18.3	21.0
60	28.2	27.4	26.7	21.5	20.6	21.4
70	28.3	27.9	27.3	23.7	21.7	22.5
80	28.2	28.3	27.9	24.1	23.3	23.6
90	29.7	28.5	28.4	26.3	25.1	25.6
100	30.8	29.4	30.5	28.0	26.9	27.2
Depth	θ Wet Rep 1	θ Wet Rep 2	θ Wet Rep 3	θ Wet Rep 1	θ Wet Rep 2	θ Wet Rep 3
10	32.0	31.6	33.8	35.3	37.1	37.3
20	32.4	32.7	32.7	34.3	36.2	35.9
30	33.6	33.0	32.9	36.4	36.4	36.0
40	35.2	34.9	34.8	36.1	36.6	37.1
50	36.9	37.2	37.0	38.4	37.3	37.6
60	38.4	38.7	38.9	39.7	38.9	38.6
70	41.9	39.9	40.2	39.6	39.0	39.2
80	42.4	41.1	41.7	40.4	41.2	40.7
90	44.6	43.8	45.1	42.6	42.4	41.8
100	46.6	46.7	47.2	43.8	44.7	44.2

Table 1. Volumetric water content

Step 11

⇨ Convert raw counts obtained from the *Sentek Soil Moisture Sensors* at each particular depth level into Scaled Frequencies (SF), where:

$$SF = (F_A - F_S) / (F_A - F_W)$$

F_A = raw count in the PVC access tube while suspended in air (Air Count);
F_W = raw count in the PVC access tube in a water bath or normalisation container (Water Count);
F_S = raw count in the PVC access tube in the soil at each particular depth level (Field Count).

⇨ Do not average the 3 Scaled Frequency readings per depth plane, but keep them separate as replicates and display in the following table format:

	Tube 1			Tube 2		
Depth	SF Dry Rep 1	SF Dry Rep 2	SF Dry Rep 3	SF Dry Rep 1	SF Dry Rep 2	SF Dry Rep 3
10	0.351	0.372	0.357	0.27	0.2714	0.274
20	0.394	0.394	0.443	0.394	0.371	0.341
30	0.445	0.444	0.451	0.378	0.382	0.371
40	0.463	0.455	0.556	0.428	0.413	0.437
50	0.451	0.516	0.559	0.466	0.474	0.438
60	0.456	0.458	0.506	0.496	0.500	0.495
70	0.561	0.563	0.518	0.522	0.552	0.532
80	0.622	0.566	0.564	0.592	0.566	0.533
90	0.594	0.526	0.567	0.563	0.600	0.562
100	0.568	0.534	0.573	0.578	0.567	0.592
Depth	SF Moist Rep 1	SF Moist Rep 2	SF Moist Rep 3	SF Moist Rep 1	SF Moist Rep 2	SF Moist Rep 3
10	0.706	0.712	0.716	0.690	0.605	0.629
20	0.750	0.726	0.711	0.692	0.693	0.658
30	0.742	0.731	0.756	0.653	0.642	0.676
40	0.757	0.787	0.771	0.657	0.646	0.679
50	0.770	0.743	0.788	0.689	0.652	0.667
60	0.801	0.785	0.756	0.704	0.683	0.694
70	0.749	0.771	0.743	0.742	0.721	0.737
80	0.801	0.774	0.740	0.757	0.737	0.751
90	0.798	0.796	0.785	0.772	0.758	0.754
100	0.795	0.834	0.806	0.771	0.778	0.793
Depth	SF Wet Rep 1	SF Wet Rep 2	SF Wet Rep 3	SF Wet Rep 1	SF Wet Rep 2	SF Wet Rep 3
10	0.826	0.797	0.881	0.858	0.875	0.873
20	0.876	0.819	0.849	0.865	0.871	0.841
30	0.848	0.812	0.831	0.845	0.855	0.852
40	0.834	0.852	0.860	0.872	0.887	0.866
50	0.879	0.842	0.880	0.863	0.853	0.865
60	0.893	0.896	0.878	0.884	0.879	0.987
70	0.901	0.887	0.909	0.904	0.884	0.994
80	0.938	0.901	0.902	0.895	0.909	0.963
90	0.946	0.949	0.950	0.926	0.908	0.923
100	0.967	0.938	0.957	0.979	0.959	0.936

Table 2. Scaled Frequency

⇨ Plot Scaled Frequency data on the Y-axis and plot volumetric water content on the X-axis in replicate pairs per depth level using a spreadsheet or graphics software program.

⇨ Fit the appropriate calibration curve to the data points. A similar graph to the default calibration equation shown in Figure 8 should be generated with corresponding A, B and C values.

⇨ Perform a regression analysis on the data (this is readily done in some graphical spreadsheet programs by adding a Trendline). The closer the R-square value is to 1, the better the fit of the curve. If a strong relationship cannot be established between the Scaled Frequency and Volumetric Soil Water Content, then all or part of the calibration procedure may need to be repeated, or the soil profile may need to be split into different textural layers. Refer to Section 7 for possible reasons why the calibration was not successful.

⇨ From the calibration equation derived, assign A, B and C coefficients to enter into the *Sentek Smart Probes*, *EnviroSCAN*® *software* or *Sentek Portable Probe* display unit. These must match the equation format $SF = A\theta^B + C$. If the derived calibration equation is linear, the B coefficient will be 1.

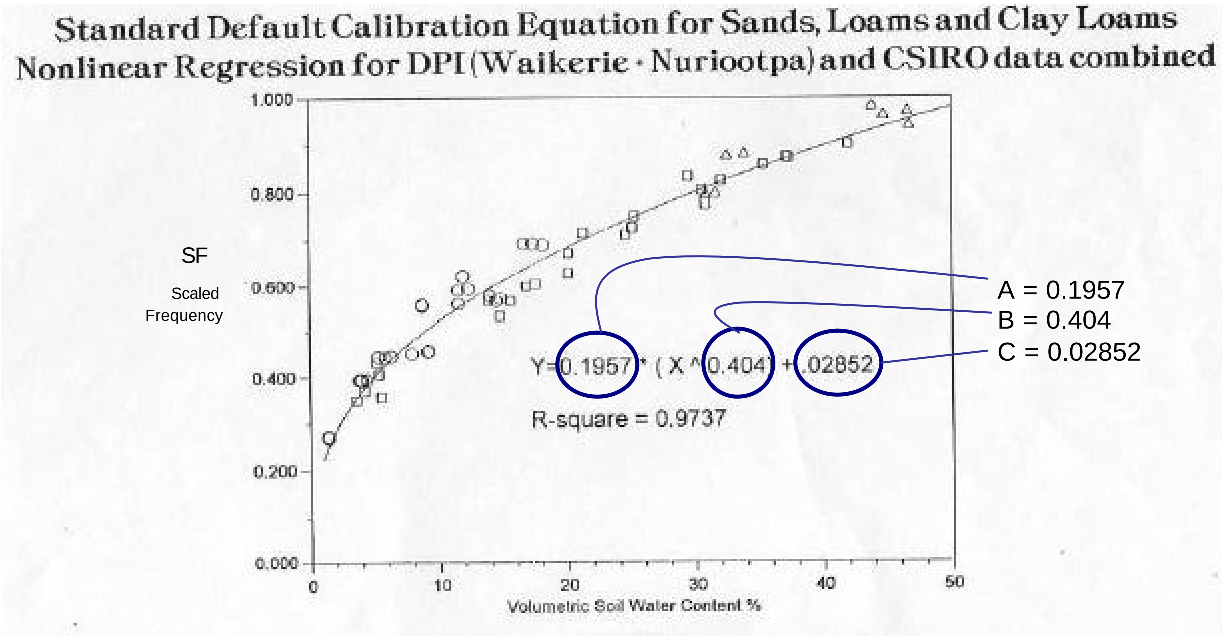


Figure 9. Default Sentek Calibration Curve

Note: *Calibration equations may not fit all points adequately on a single calibration for that profile. This is particularly relevant for soil profiles with different textural layers. In some cases you may need to generate separate calibration equations for individual soil layers at a particular depth level.*

5.4 Laboratory Calibration

The following steps provide a brief description of the recommended procedure for laboratory calibration (Paltineanu and Starr, 1997 and Greacen, 1981).

1. A container of minimum diameter 25 cm/9.8” and minimum height 10 cm/3.9” per sensor plus an additional 10 cm/3.9” is required in which to pack the soil to perform the calibration. For 5 sequential sensors at 10 cm/3.9” intervals the minimum container depth will be 60 cm/23.6”. The container needs to be robust.

2. Determine the required mass of soil to fill the volume of the container. The bulk density of the soil should match that of the soil in the field; therefore to calculate the required mass, multiply the bulk density of the soil by the container volume. Obtain soil from the site of interest and screen the required mass through a 5 mm/ 0.2” sieve.

3. Air-dry the soil and mix thoroughly on a plastic sheet.

4. Weigh out the mass of soil required for a 2 cm/0.79” soil depth that will be packed to the chosen density. Spread the soil uniformly in the container and pack down to a thickness of 2 cm/0.79”.

5. Repeat step 4 until the container is full.

6. Attach a rigid access tube guide to the top of the container to enable a proper installation of the access tube.

7. Install the access tube using the same methodology as recommended by **Sentek Pty Ltd** for standard field installations. Drill the access hole to the bottom of the container, but not through the bottom of the container.

8. Insert the *Sentek Continuous Probe* with sensors to the required depth, or swipe the *Sentek Portable Probe.*

9. Record at least 3 readings (preferably more) for each sensor depth level.

10. Use thin-walled metal rings to collect undisturbed soil cores by removing soil down to the required depth level in the same manner as described for the field calibration.

11. Obtain wet and dry oven weights to determine volumetric water content and bulk density.

12. Spread the soil in a thin layer on the plastic sheet and mist spray the soil with a measured volume of water. Mix the soil thoroughly and then apply further water and mix again.

13. Repeat steps 4-12 for at least 3 different soil moisture contents.

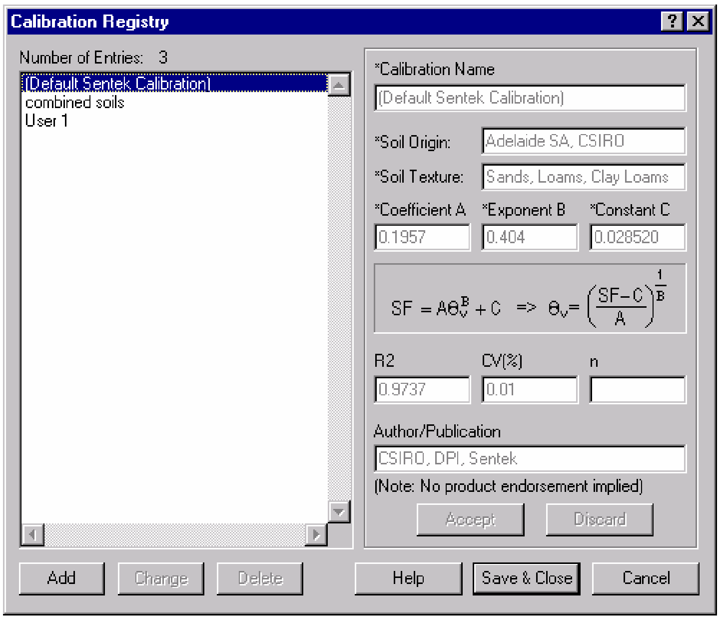
14. Tabulate the data as for the field calibration, and plot scaled frequency against volumetric water content to derive the calibration equation.

6 Inserting New Calibration Equations

6.1 EnviroSCANÒ Software

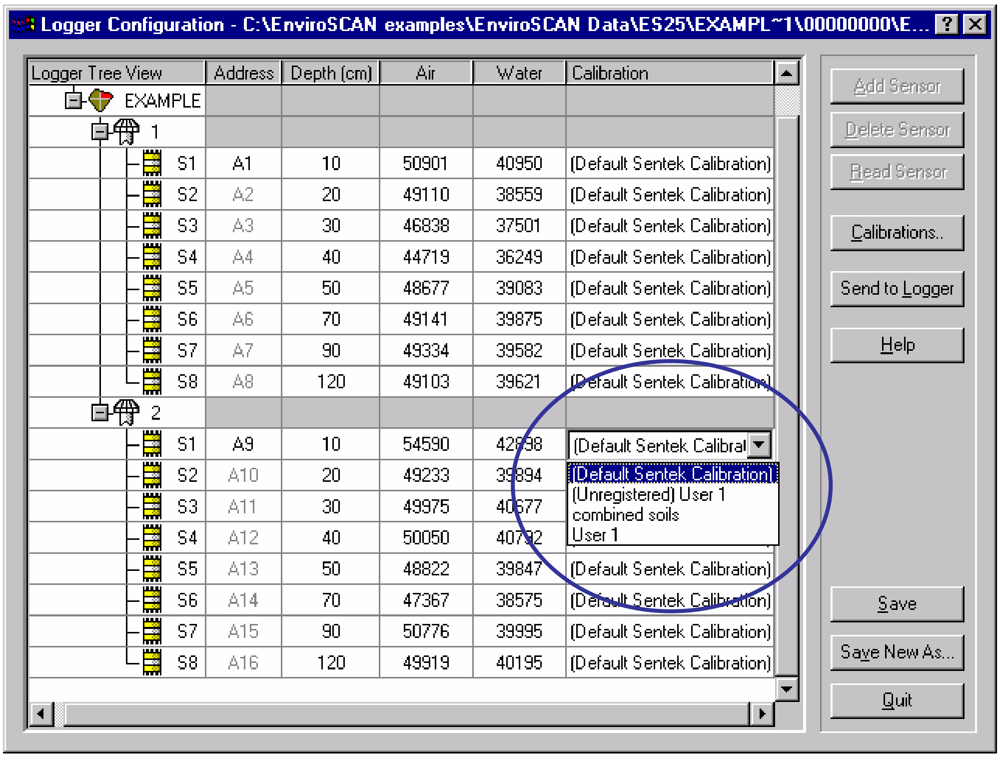
The EnviroSCAN® software enables users to insert their own calibration equations. Different calibration equations can be inserted for different sensor depths. Calibration equations are stored in the **Calibration Registry**.

The default **Sentek Pty Ltd** calibration is automatically assigned to all new sensors in the software. To assign a new calibration equation, users must open the **Calibration Registry** from the **logger configuration** dialog box.



To enter a new calibration equation, click on *Add*, and then enter the relevant details. It is important to complete as many details boxes as possible. The boxes marked with an asterisk (*) are mandatory. Click on *Accept*, and then *Save & Close* to save the changes and close the Calibration Registry dialog box.

Calibration equations are selected for each sensor by clicking on the calibration column in the **Logger Configuration Window**. A drop-down arrow appears and alternative calibrations that have been added to the Calibration Registry can be selected from the drop down list.

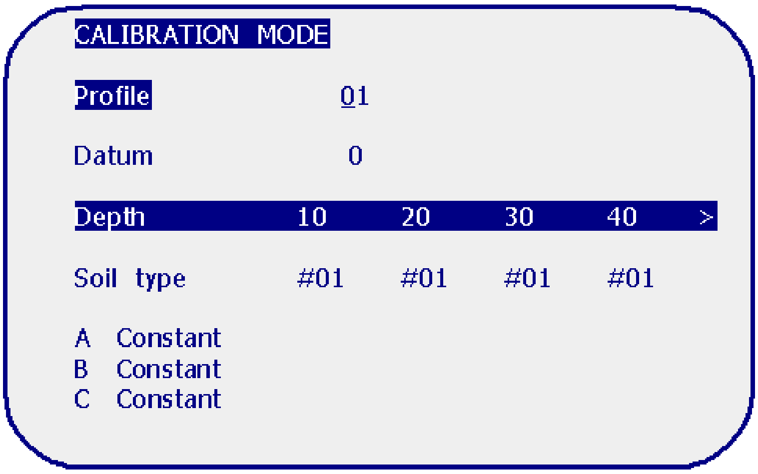


Further details are provided in the User Manual and help functions that accompany the software.

6.2 Sentek Portable Probe

Calibration equations can be changed or entered in the display unit of the *Sentek Portable Probe*. The default **Sentek Pty Ltd** calibration equation is built into the *Sentek Portable Probe* display unit and is labelled as the calibration equation for **soil type #01**.

To add a new calibration equation, enter the Calibration mode by pressing the CALIBRATE button on the display unit. The Calibration screen will appear. When the default soil type is selected, the A, B and C constants do not appear.



Up to 99 different calibration equations can be entered into the *Sentek Portable Probe* display unit. Each calibration equation is denoted as a soil type number between 01 and 99.

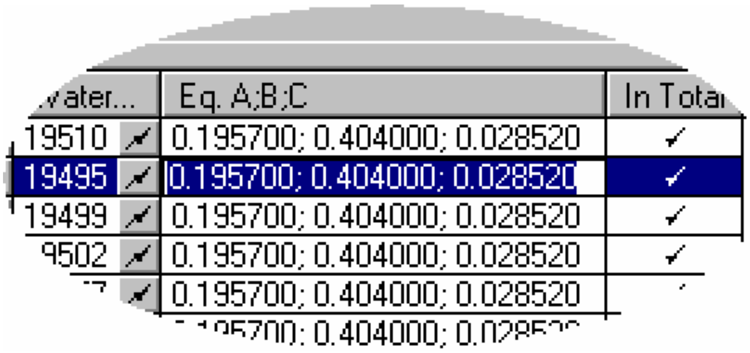
Use the arrow keys to select the Profile function and choose the appropriate profile number. Use the arrow keys to select Soil Type. Enter a soil type number between 01 and 99 using the numeric keypad. The ‘A Constant’ is selected. Use the numeric keypad to enter your customized ‘A’ value and press ENTER. The ‘B Constant’ is selected. Use the numeric keypad to enter your customized ‘B’ value and press ENTER. The ‘C constant’ is selected. Use the numeric keypad to enter you customized ‘C’ value and press ENTER.

If that soil type number is entered into the other depths or into other profiles, the ‘A’, ‘B’ and ‘C’ constants will be automatically entered into the Display Unit. Record the particular soil type (e.g. clay) for that particular soil type number for future reference. The Users Log Book is a convenient place to keep such records.

6.3 Sentek Smart Probes

The calibration coefficients for each sensor on the *Sentek Smart Probes* can be changed in the Configuration Software.

Click on the sensor coefficients cell. Type in the new A, B and C coefficients separated by semicolons. To accept the new coefficients press Enter or simply click outside the cell. The new coefficients will not be set in the probe’s configuration until you write the configuration to the probe.



7 Common Calibration Errors

Sentek Pty Ltd recognises and publicly acknowledges that if **absolute accuracy in total volumetric soil water content is required**, then a **site-specific calibration must be conducted** for the *Sentek Soil Water Sensors* in the same manner necessary for all instruments requiring volumetric soil water calibration. The results of the site-specific calibration can be used to replace the standard 'default' calibration equation provided in the software or firmware.

Sentek Pty Ltd cautions users on the risks of utilising inaccurate or misleading data obtained by inexperienced personnel conducting volumetric soil water calibration. The error in volumetric calibration based on gravimetric soil sampling and bulk density measurements can significantly exceed the error in the **Sentek Pty Ltd** instrumentation. This can result in inaccurate soil moisture determinations.

The fact that a highly accurate relationship between Scaled Frequency and volumetric water content can be derived is well documented (Fares and Alva, 1997, Mead et al 1995, Paltineanu and Starr, 1997). There are however, other issues to consider, such as the application of water in most commercial agricultural situations. The ability to deliver and distribute water with a high degree of accuracy is affected by issues of field uniformity, irrigation system operation and many other farm variables, which are far less accurate than the required scientific accuracy for calibration. In simple terms, the accuracy to measure water with *Sentek Soil Moisture Sensors*, as a farm management or research tool far exceeds the accuracy of the total farm management variables.

Sentek Pty Ltd actively encourages research organisations to conduct independent testing and to develop new data sets for a wider range of soils.

Some of the common errors to be wary of are listed below:

- Errors in soil sampling (i.e. sampling the wrong depth plane in relation to the sensor reading or sampling outside the sphere of influence of the sensor).

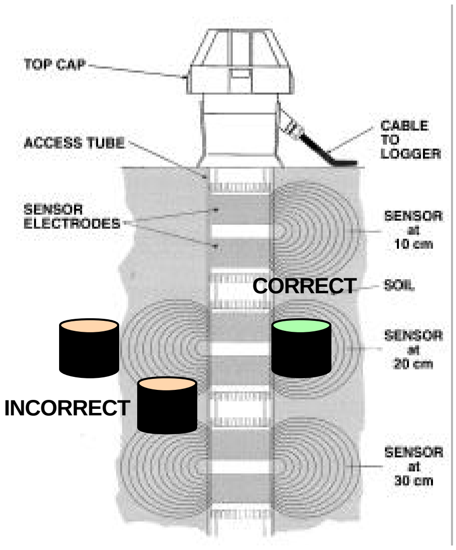


Figure 10. Positioning of sampling rings

Figure 10 shows:

A – sampling ring is beyond the effective sphere of influence for the sensor

B – sampling ring is at the incorrect depth level

C – sampling ring is immediately adjacent to the access tube and at the correct depth

- Too great a time gap between the sensor readings and soil sampling, especially in coarse sands with relatively high soil water contents, where changes in moisture content can occur in seconds to minutes, especially above field capacity (refer Figure 11).

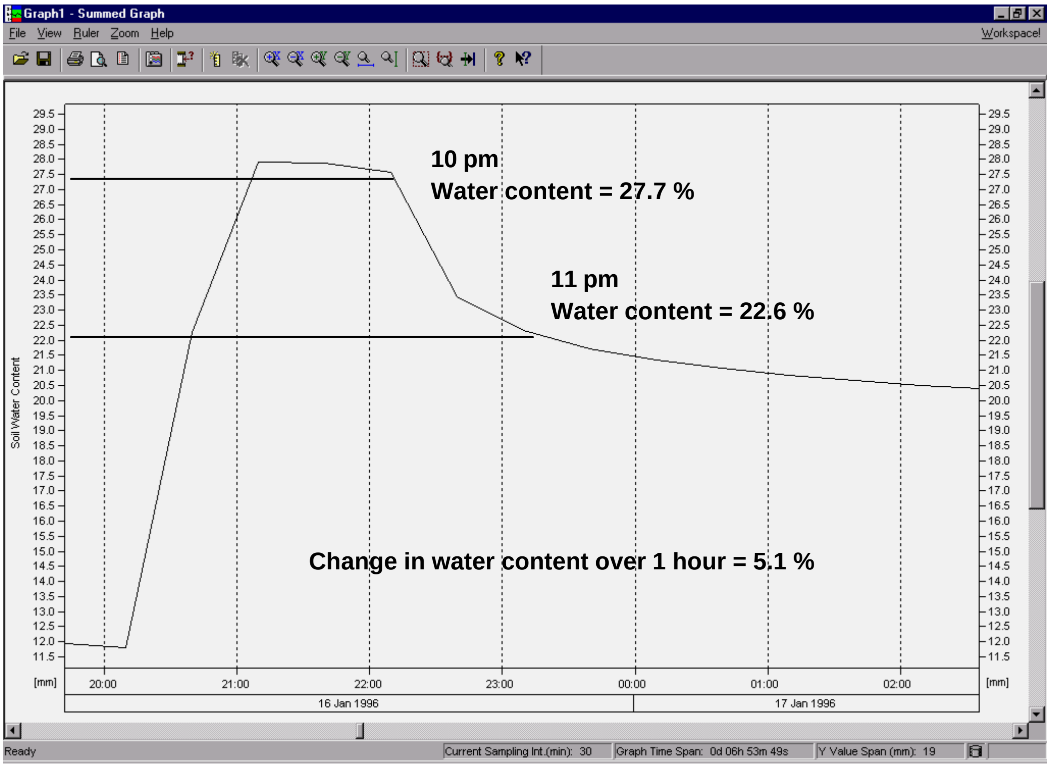


Figure 11. Change in soil water content over time in recently irrigated sandy soils

- Errors in volumetric measurement (e.g. weighing or bulk density calculations).
- Uneven wetting of the soil around the access tube.
- Using average bulk densities or bulk density approximation from historic field data instead of *in situ* measured, site specific bulk densities.
- Errors in the soil sampling drying process, i.e. insufficient drying temperature, insufficient drying time.
- Insufficient spread of moisture content between the wet, moist and dry sampling sites to yield data for a suitable calibration curve.
- Use of wrong air and water counts when calculating scaled frequency.
- Labelling errors.
- Incorrect set-up of scales, or poorly calibrated scales.
- Forgetting to weigh aluminium trays or sampling rings.

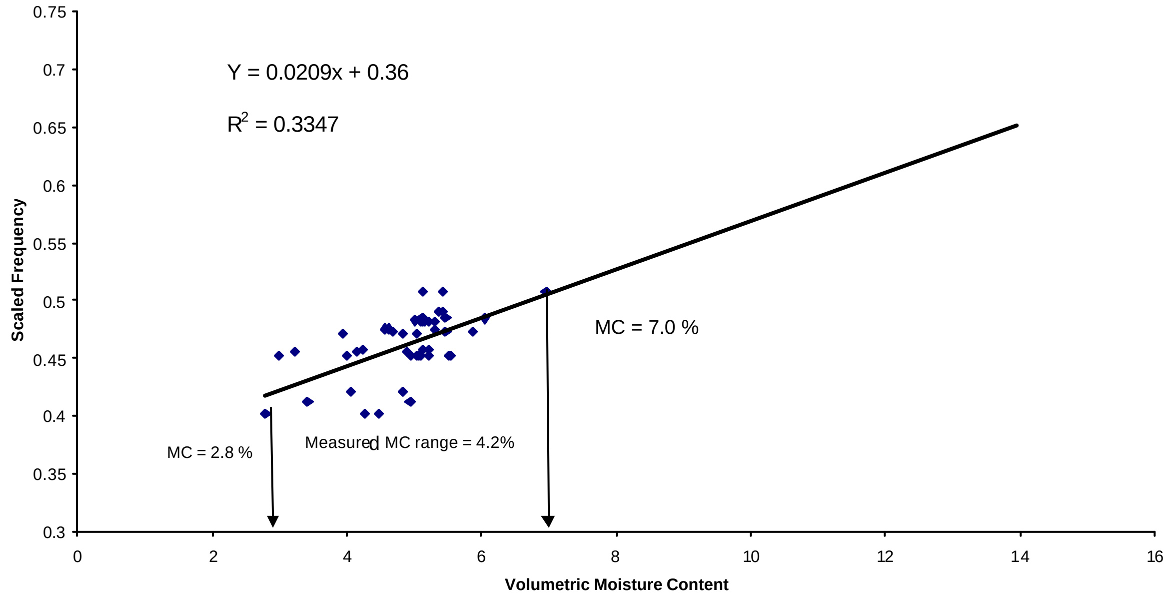


Figure 12. Poor scatter of points

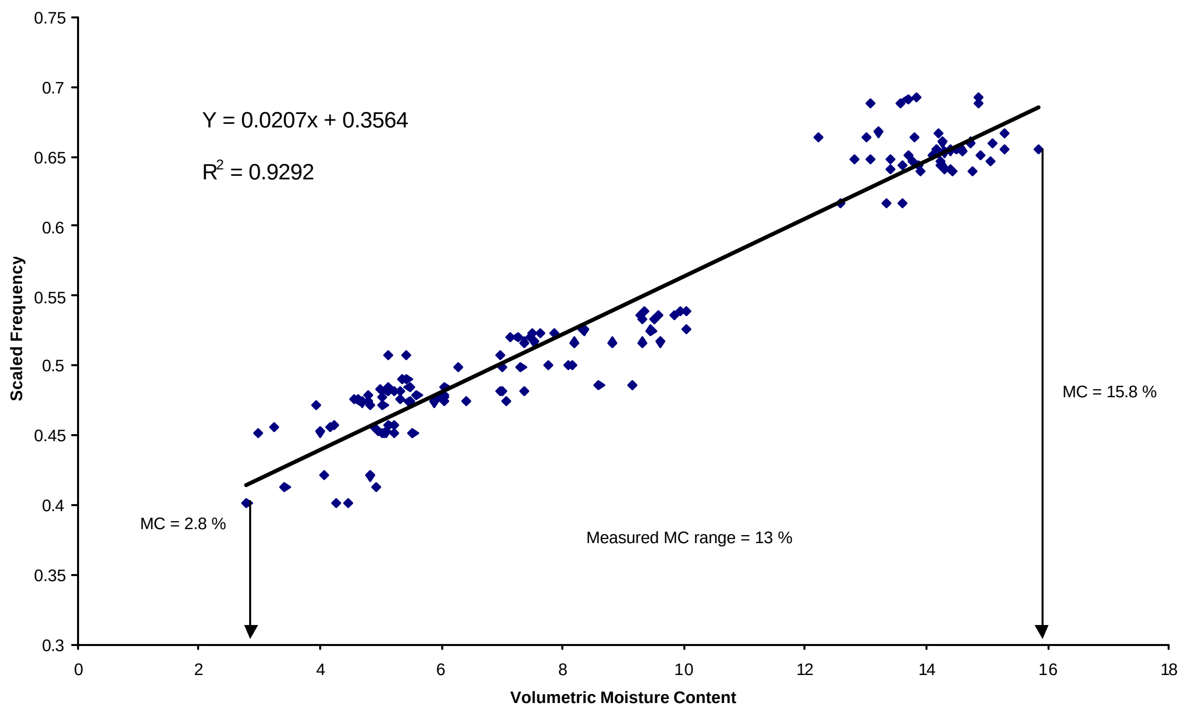


Figure 13. Good scatter of points

- Poor access tube installation (air gaps and soil compaction).

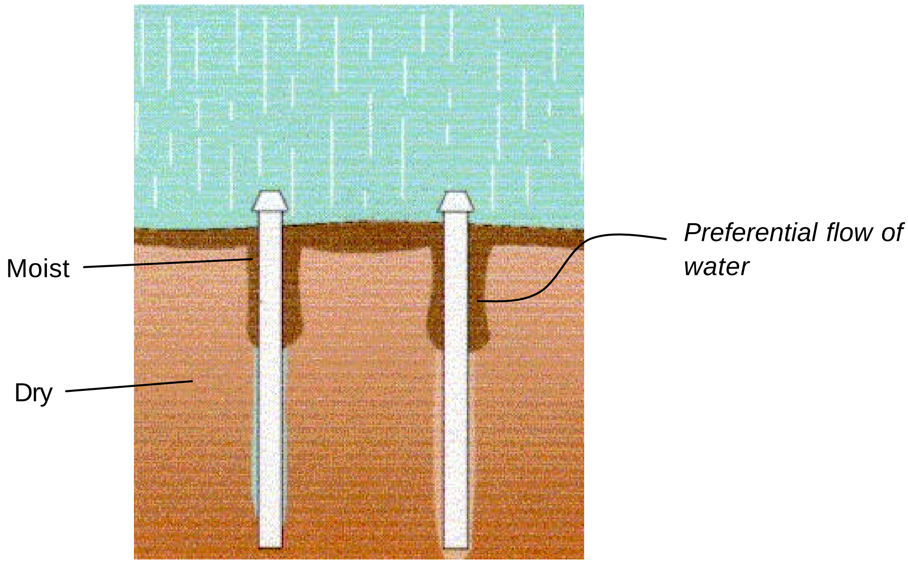


Figure 14. Results of poor access tube installation

- Errors in mathematical and statistical procedures.
- Excessive root growth in soil samples.
- Inaccurate data entry.
- Plotting Scaled Frequency or volumetric soil water content values on the wrong axis (Scaled Frequency must be on the Y–axis and Volumetric Water Content on the X-axis).
- Assigning the wrong A, B & C values. The equation must be of the format:

$$SF = A\theta_v^B + C$$

(Note: if the relationship is linear, the B value becomes 1)

It is a worthwhile exercise to insert some "dummy" scaled frequency data into the equation once it has been derived and solve for soil moisture. Match the derived data against the plotted graph. This acts as a double-check on both the equation and the A, B and C values.

8 Soil Water Dynamics

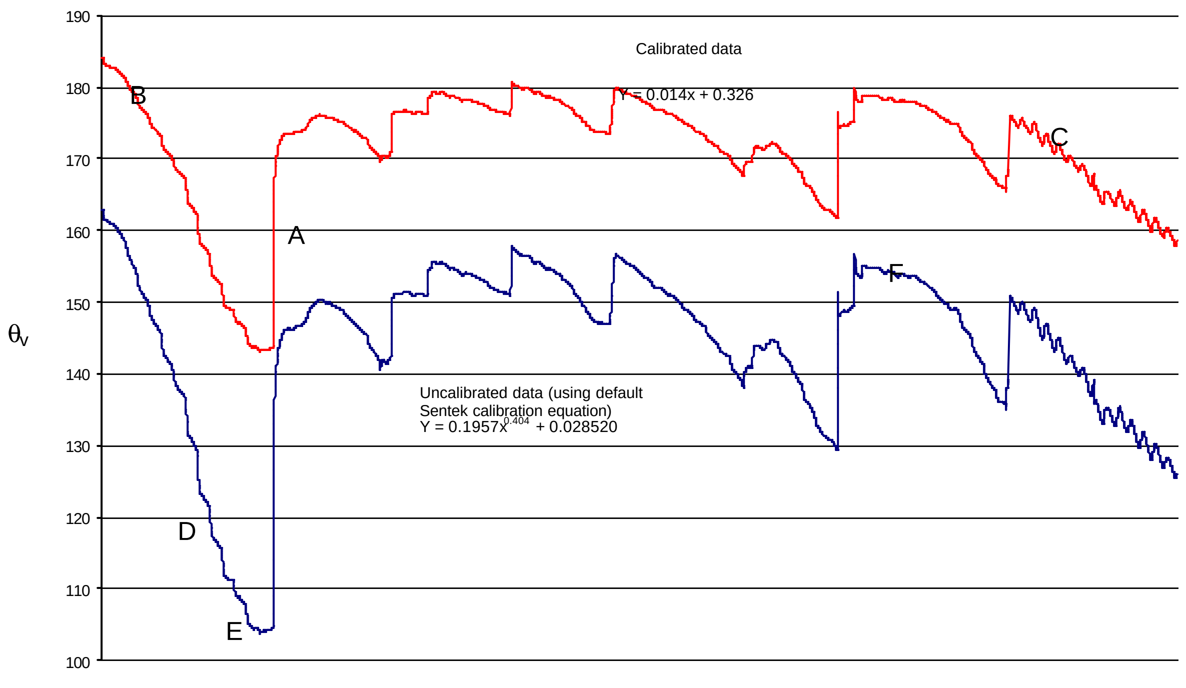
Sentek Pty Ltd recognises that the default calibrations do not yield absolute values of soil moisture, however experience has shown that the values obtained can be used to obtain a very clear picture of soil-water dynamics for most soil types around the world, particularly with continuous monitoring.

Relative changes in volumetric soil moisture content have been used to show the most important soil water trends with time. The dynamics of water fluctuations over time clearly show the relevant information that enables irrigators to manage their irrigation schedule. Even relatively minor changes in soil moisture can be distinguished and key indicators such as drainage and the onset of crop stress can be readily detected.

While the values obtained for soil moisture may differ between a calibrated and un-calibrated site, the overall picture of the soil water dynamics will be very similar. This is clearly shown in Figure 15, where data collected from a calibrated site is compared to the same data recalculated using the **Sentek Pty Ltd** default equation. The following are among some of the key issues that can be visualised on this graph:

A. Increases in soil moisture with irrigation
B. Decreasing soil moisture due to drainage and crop water use
C. Diurnal fluctuations
D. Water use during the day and no water use at night time
E. Onset of plant stress
F. Waterlogging

Figure 15. Relative changes with time versus actual soil moisture



If the site is not calibrated however, it is important to have an understanding of how well the derived soil moisture values relate to the actual soil moisture. This is because even very minor changes in soil moisture content can be zoomed into to appear as major changes on screen. Therefore as a minimum, it is suggested that when a probe site is first installed, small auger samples be taken at key times and by feeling the soil and making a visual assessment, approximating whether it is "wet", "moist" or "dry". The moisture content figures obtained by the *Sentek Soil Moisture Sensors* for the "wet", "moist" and "dry" soil should then be recorded. This will give a basic understanding of the likely range of soil moisture readings.

8.1 Key Signatures – Soil Water Dynamics

Some of the key "signatures" of soil-plant-water dynamics is shown in the figures below to outline the basic principles of using relative water for irrigation scheduling.

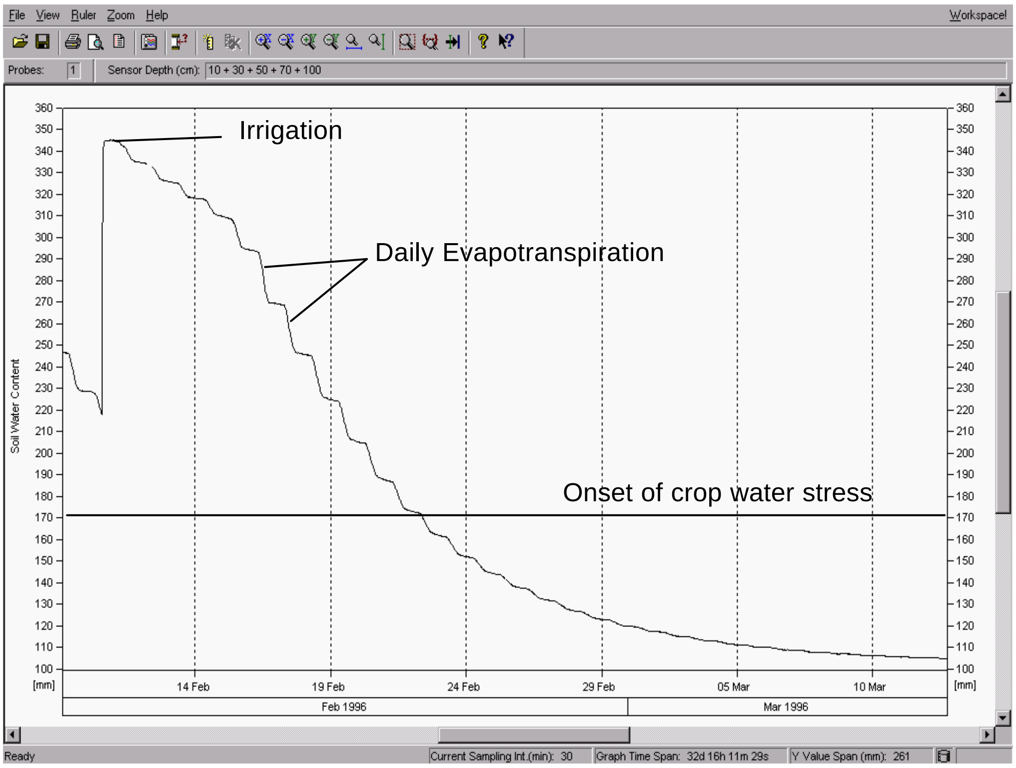


Figure 16. Pattern of crop water use

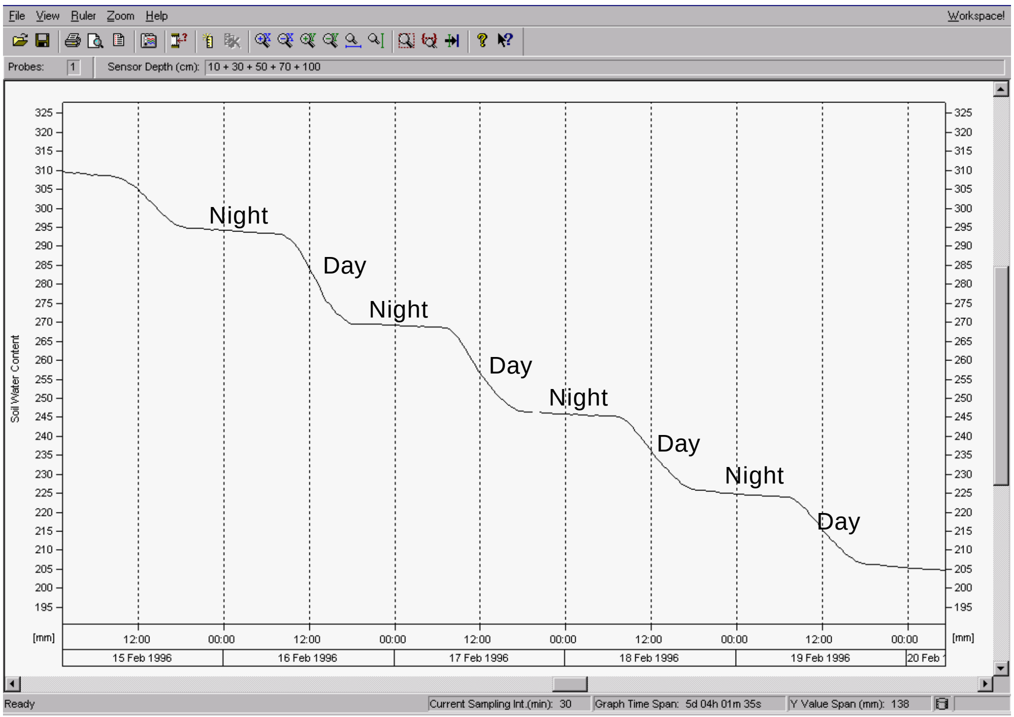


Figure 17. Dynamics of daily evapotranspiration

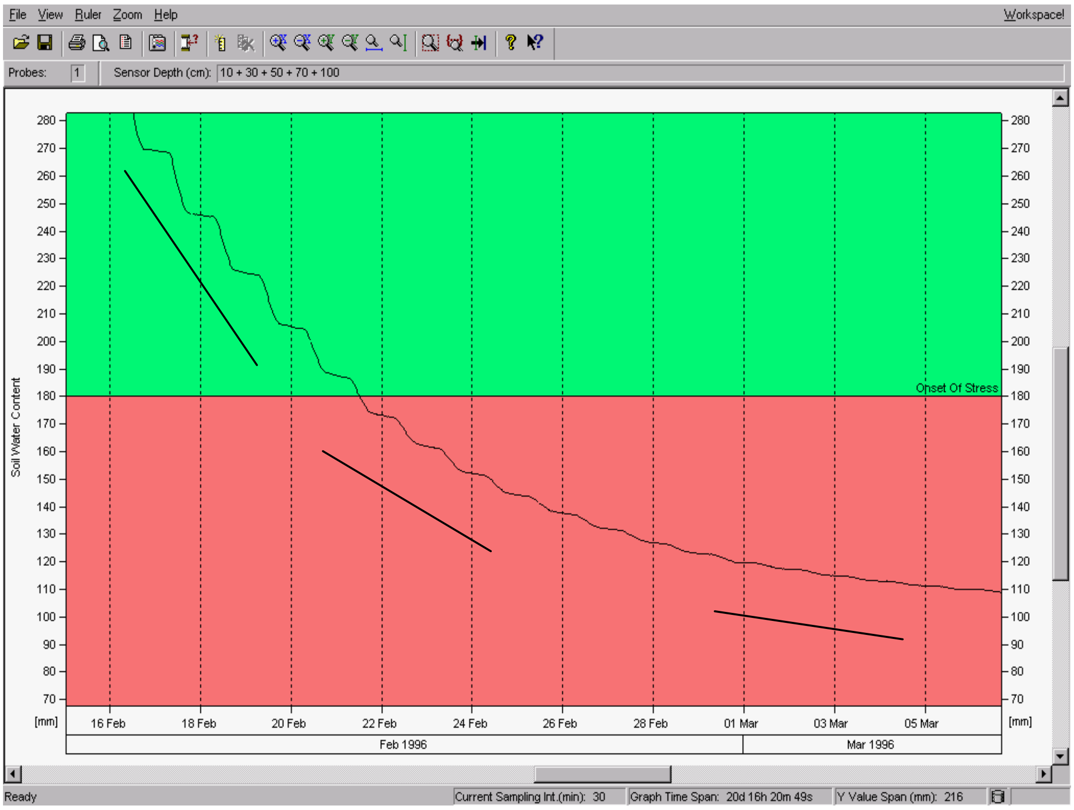


Figure 18. Detecting the onset of plant stress

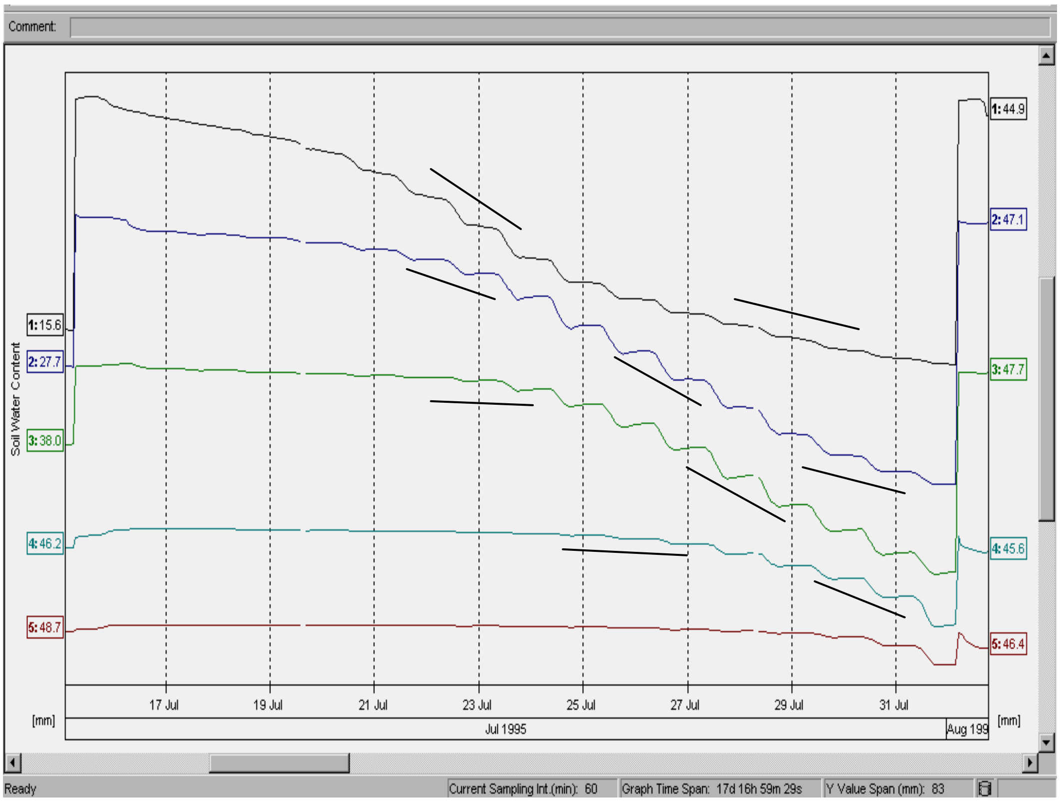


Figure 19. Differential rate of water uptake by roots

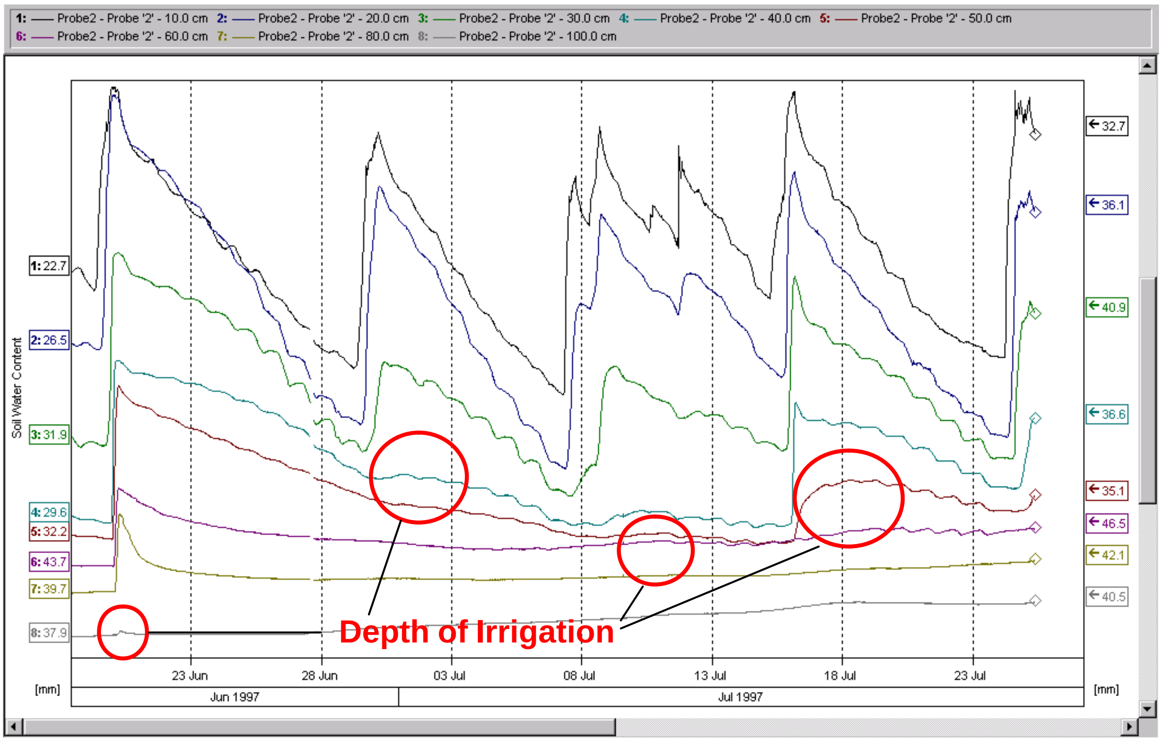


Figure 20. Detecting the depth of irrigation

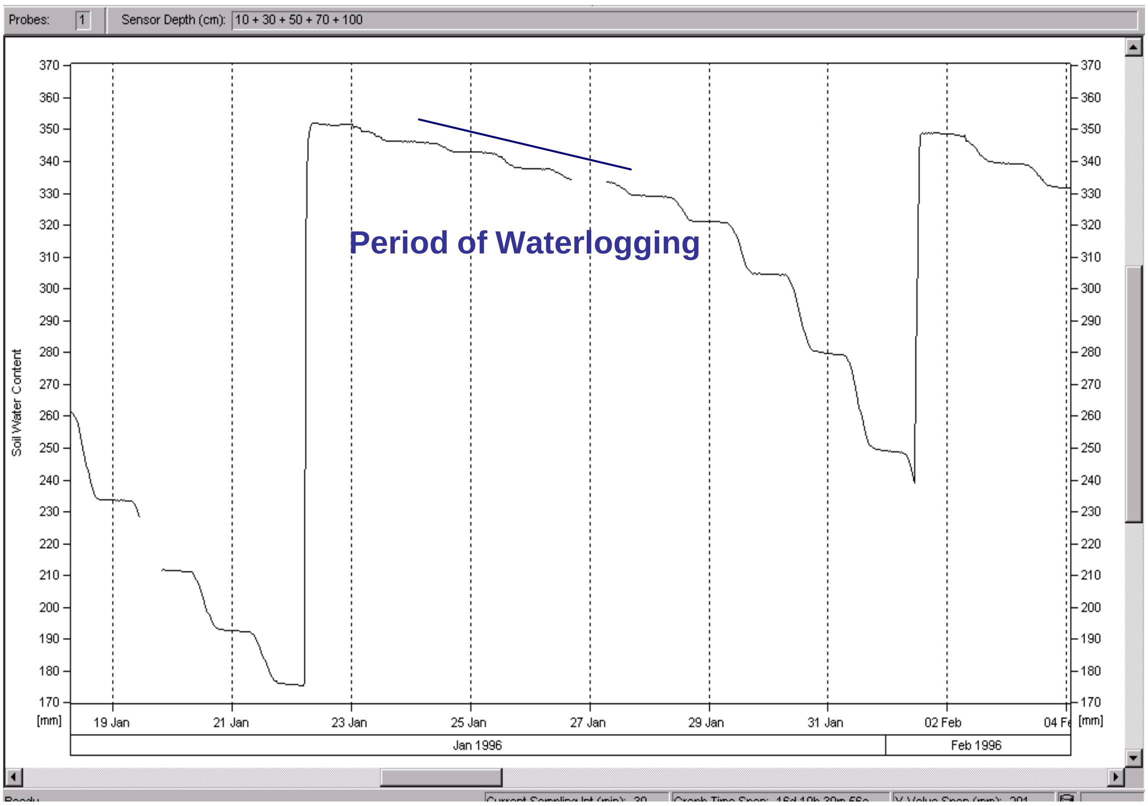


Figure 21. Effects of waterlogging

9 Appendices

Appendix I. Sentek Pty Ltd Default Calibrations

Appendix II. Summary of Existing Calibration Equations

Appendix III. Pro Forma for Performing New Calibrations

Appendix IV. Glossary of Terms

9.1 Appendix I - Sentek Pty Ltd Default Calibrations

9.1.1 EnviroSCAN®

Sentek Pty Ltd as the manufacturer of EnviroSCAN® provides a standard 'default' calibration equation derived from sands, loams and clay loams.

This standard default calibration equation is loaded in the software and has the following form:

$$y = A\,x^{B} + C$$

Where y = Scaled Frequency
x = volumetric soil water content in mm
A, B, C = calibration coefficients

The default coefficients are:

A = 0.19570
B = 0.40400
C = 0.02852

The Scaled Frequency is defined as:

$$y = \frac{(\text{Air Count} - \text{Field Count})}{(\text{Air Count} - \text{Water Count})}$$

Based on Australian data for samples of sands, loams and clay loams the standard default calibration equation provides an **R^2 value of 0.9737** for combined soil types.

9.1.2 Diviner 2000®

Sentek Pty Ltd as the manufacturer of Diviner 2000®, provides a standard 'default' calibration equation based on combined data from a sand, sandy loam and an organic potting soil. Although the Diviner 2000® uses identical sensor technology to the EnviroSCAN®, some minor structural differences between them necessitate the use of a different calibration equation.

This standard default calibration equation is built into the Diviner 2000® display unit and is labelled as the calibration equation for soil type #01. It has the following form:

$$y = A\,x^{B} + C$$

Where y = Scaled Frequency
x = volumetric soil water content in mm
A, B, C = calibration coefficients

The default coefficients are:

A = 0.2746
B = 0.3314
C = 0

The Scaled Frequency is defined as:

$$y = \frac{(\text{Air Count} - \text{Field Count})}{(\text{Air Count} - \text{Water Count})}$$

Based on Australian data for samples of sands, sandy loams and organic potting mix the standard default calibration equation provides an **R^2 value of 0.9985**.

Figure 22 summarises the different calibration curves that are currently available for the EnviroSCAN®.

9.2 Appendix II - Summary of Existing Calibration Equations

Table 3. EnviroSCAN Calibration Equations

Calibration Name	Soil Texture	Coefficient A	Exponent B	Constant C	R^2	Error	Origin	Author
Sentek Default (EnviroSCAN®)	*Sands, Loams, Clay Loams*	*0.1957*	*0.404*	*0.02852*	*0.9737*	*CV <0.01*	*Adelaide SA, CSIRO, Australia*	*CSIRO, Department of Primary Industries, Sentek Pty Ltd*
Heavy Cracking Clay, Warren (EnviroSCAN®)	*Uniformly textured, cracking clay*	*0.0254*	*1*	*-0.125 (10cm) -0.020 (20cm) -0.074 (30cm) -0.030 (40cm) -0.004 (50cm) 0.031 (60cm) 0.011 (70cm) 0.029 (80cm) 0.041 (100cm)*	*0.58*	*SE = 5.1*	*Warren NSW, Australia*	*Report available upon request from Sentek Pty Ltd.*
Heavy Cracking Clay, Trangie (EnviroSCAN®)	*Uniformly textured, brown cracking clay, 90cm to C horizon*	*0.0254*	*1*	*-0.105 (10cm) 0.00 (20cm) -0.054 (30cm) -0.010 (40cm) 0.016 (50cm) 0.051 (60cm) 0.031 (70cm) 0.049 (80cm) 0.061 (100cm)*	*0.58*	*SE = 5.1*	*Trangie NSW, Australia*	*Report available upon request from Sentek Pty Ltd.*
Heavy Cracking Clay, Emerald (EnviroSCAN®)	*Uniformly textured, dark cracking clay, 65 cm to C horizon*	*0.0254*	*1*	*0.085 (10cm) 0.190 (20cm) 0.136 (30cm) 0.180 (40cm) 0.206 (50cm) 0.241 (60cm) 0.221 (70cm) 0.239 (80cm) 0.251 (100cm)*	*0.58*	*SE = 5.1*	*Emerald QLD, Australia*	*Report available upon request from Sentek Pty Ltd.*

Calibration Name	Soil Texture	Coefficient A	Exponent B	Constant C	R^2	Error	Origin	Author
Heavy Cracking Clay, Narrabri (EnviroSCAN®)	*Uniformly textured, grey, cracking clay, >100 cm to C horizon*	*0.0254*	*1*	*-0.275 (10cm) -0.170 (20cm) -0.224 (30cm) -0.180 (40cm) -0.154 (50cm) -0.119 (60cm) -0.139 (70cm) -0.121 (80cm) -0.109 (100 cm)*	*0.58*	*SE = 5.1*	*Narrabri NSW, Australia*	*Report available upon request from Sentek Pty Ltd.*
Sandy Loam (1.3 g/cm³) (EnviroSCAN®)	*Sandy loam (59% sand, 22% silt, 19% clay)*	*0.013*	*1*	*0.326*			*United States Department of Agriculture, Water Management Research Laboratory, Fresno, California*	** Mead, R.M., Ayars, J.E. and Liu, J. "Evaluating the influence of soil texture, bulk density and soil water salinity on a capacitance probe calibration". Presented at the 1995 ASAE Summer Meeting, Paper No. 95-3264. ASAE , 2950 Niles Rd., St. Joseph, MI 49085-9659 USA.*
Sandy Loam (1.5 g/cm³) (EnviroSCAN®)	*Sandy loam (59% sand, 22% silt, 19% clay)*	*0.013*	*1*	*0.372*			*As above*	**As above*
Combined soils (EnviroSCAN®)	*Sand, Sandy Loam, Clay*	*0.014*	*1*	*0.326*			*As above*	**As above*
Mattaplex Silt Loam Ap horizon (1.24 – 1.58 g/cm³) (EnviroSCAN®)	*Silt loam (35% sand, 56 % silt, 9% clay)*	*0.5512*	*0.2582*	*-0.5272*	*0.992*	*RMSE = 0.0009*	*Beltsville Agricultural Research Centre, Beltsville, USA*	**Paltineanu, I.C. & Starr, J.L. (1997). Real-time soil water dynamics using mulitsensor capacitance probes: laboratory calibration. Soil Science Society of America Journal 61(6): 1576-1585.*

**The origin of the calibration equation is given for information purposes only and does not imply an endorsement, recommendation or exclusion by the USDA-ARS.*

Calibration Name	Soil Texture	Coefficient A	Exponent B	Constant C	R^2	Error	Origin	Author
Florida Sands	*Fine Sands*	*0.1659*	*0.4715*	*0*	*0.83*	*RMSE= 0.0085*	*Florida, USA*	**Morgan, K.T., Parsons, L.R., Wheaton, T.A., Pitts, D.J. and Obreza, T.A. " Field Calibration of a Capacitance Water Content Probe in Fine Sands". Soil Sci. Soc. Am. J. 63: 987-989 (1999).*

**The origin of the calibration equation is given for information purposes only and does not imply an endorsement, recommendation or exclusion by the authors.*

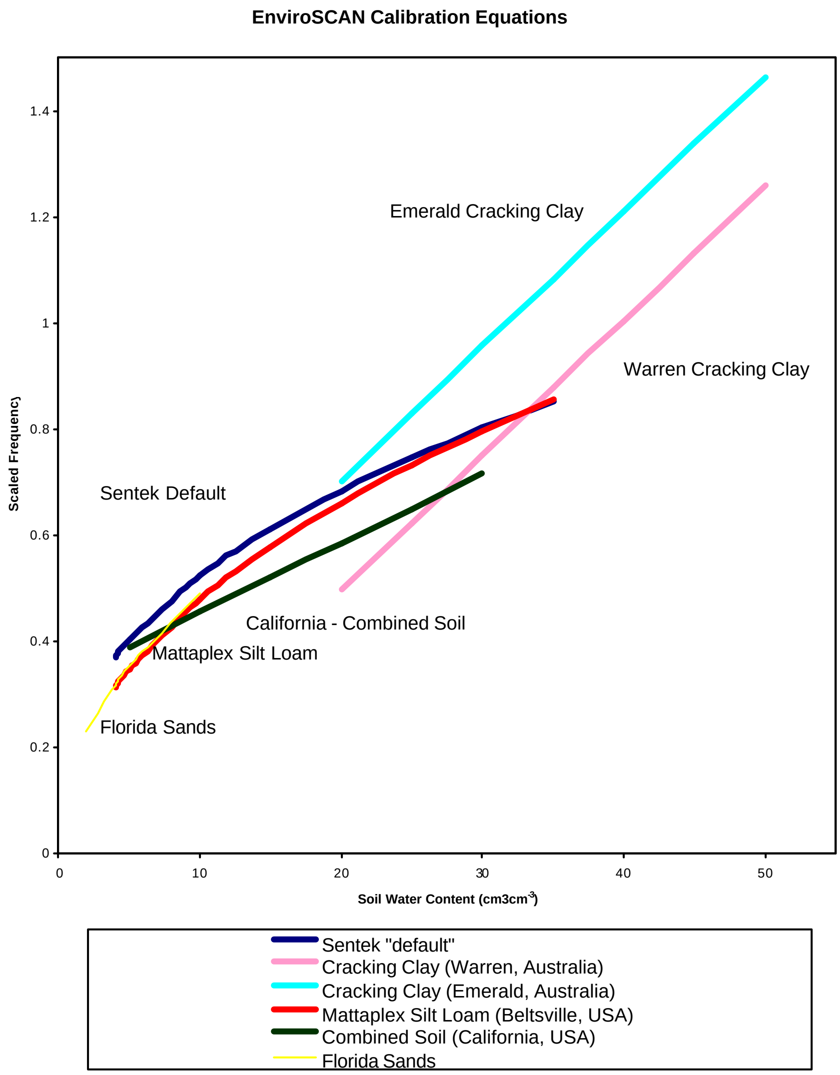


Figure 22. EnviroSCAN Calibration Equations

9.3 Appendix III - Pro Forma for New Calibrations

Sketch of Probe Layout

Insert sketch of the probe layout, i.e. probe depth, probe numbers and distances between probes. Include as much information as possible, including soil type, crop type, irrigation type etc.

Table 4. Volumetric Data Collection Template

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) (p(ID/2)^{2}h)	Bulk density (r) (Md/V)	MC (q) (Wr)
Wet Tube 1	1	10 cm										
	2	10 cm										
	3	10 cm										
Wet Tube 1	1	20 cm										
	2	20 cm										
	3	20 cm										
Wet Tube 1	1	30 cm										
	2	30 cm										
	3	30 cm										
Wet Tube 1	1	40 cm										
	2	40 cm										
	3	40 cm										
Wet Tube 1	1	50 cm										
	2	50 cm										
	3	50 cm										
Wet Tube 1	1	60 cm										
	2	60 cm										
	3	60 cm										
Wet Tube 1	1	70 cm										
	2	70 cm										
	3	70 cm										
Wet Tube 1	1	80 cm										
	2	80 cm										
	3	80 cm										
Wet Tube 1	1	90 cm										
	2	90 cm										
	3	90 cm										
Wet Tube 1	1	100 cm										
	2	100 cm										
	3	100 cm										

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) (p(ID/2)^{2}h)	Bulk density (r) (Md/V)	MC (q) (Wr)
Wet Tube 2	1	10 cm										
	2	10 cm										
	3	10 cm										
Wet Tube 2	1	20 cm										
	2	20 cm										
	3	20 cm										
Wet Tube 2	1	30 cm										
	2	30 cm										
	3	30 cm										
Wet Tube 2	1	40 cm										
	2	40 cm										
	3	40 cm										
Wet Tube 2	1	50 cm										
	2	50 cm										
	3	50 cm										
Wet Tube 2	1	60 cm										
	2	60 cm										
	3	60 cm										
Wet Tube 2	1	70 cm										
	2	70 cm										
	3	70 cm										
Wet Tube 2	1	80 cm										
	2	80 cm										
	3	80 cm										
Wet Tube 2	1	90 cm										
	2	90 cm										
	3	90 cm										
Wet Tube 2	1	100 cm										
	2	100 cm										
	3	100 cm										

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) (p(ID/2)^{2}h)	Bulk density (r) (Md/V)	MC (q) (Wr)
Moist Tube 1	1	10 cm										
	2	10 cm										
	3	10 cm										
Moist Tube 1	1	20 cm										
	2	20 cm										
	3	20 cm										
Moist Tube 1	1	30 cm										
	2	30 cm										
	3	30 cm										
Moist Tube 1	1	40 cm										
	2	40 cm										
	3	40 cm										
Moist Tube 1	1	50 cm										
	2	50 cm										
	3	50 cm										
Moist Tube 1	1	60 cm										
	2	60 cm										
	3	60 cm										
Moist Tube 1	1	70 cm										
	2	70 cm										
	3	70 cm										
Moist Tube 1	1	80 cm										
	2	80 cm										
	3	80 cm										
Moist Tube 1	1	90 cm										
	2	90 cm										
	3	90 cm										
Moist Tube 1	1	100 cm										
	2	100 cm										
	3	100 cm										

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) (p(ID/2)^{2}h)	Bulk density (r) (Md/V)	MC (q) (Wr)
Moist Tube 2	1	10 cm										
	2	10 cm										
	3	10 cm										
Moist Tube 2	1	20 cm										
	2	20 cm										
	3	20 cm										
Moist Tube 2	1	30 cm										
	2	30 cm										
	3	30 cm										
Moist Tube 2	1	40 cm										
	2	40 cm										
	3	40 cm										
Moist Tube 2	1	50 cm										
	2	50 cm										
	3	50 cm										
Moist Tube 2	1	60 cm										
	2	60 cm										
	3	60 cm										
Moist Tube 2	1	70 cm										
	2	70 cm										
	3	70 cm										
Moist Tube 2	1	80 cm										
	2	80 cm										
	3	80 cm										
Moist Tube 2	1	90 cm										
	2	90 cm										
	3	90 cm										
Moist Tube 2	1	100 cm										
	2	100 cm										
	3	100 cm										

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) (p(ID/2)^{2}h)	Bulk density (r) (Md/V)	MC (q) (Wr)
Dry Tube 1	1	10 cm										
	2	10 cm										
	3	10 cm										
Dry Tube 1	1	20 cm										
	2	20 cm										
	3	20 cm										
Dry Tube 1	1	30 cm										
	2	30 cm										
	3	30 cm										
Dry Tube 1	1	40 cm										
	2	40 cm										
	3	40 cm										
Dry Tube 1	1	50 cm										
	2	50 cm										
	3	50 cm										
Dry Tube 1	1	60 cm										
	2	60 cm										
	3	60 cm										
Dry Tube 1	1	70 cm										
	2	70 cm										
	3	70 cm										
Dry Tube 1	1	80 cm										
	2	80 cm										
	3	80 cm										
Dry Tube 1	1	90 cm										
	2	90 cm										
	3	90 cm										
Dry Tube 1	1	100 cm										
	2	100 cm										
	3	100 cm										

Treatment	Replicate	Depth	Sample No	Mw	Md	Container Weight	W (Mw-Md/Md)	Cylinder ID	Cylinder h	Cylinder Vol (V) ($\pi(ID/2)^2h$)	Bulk density (ρ) (Md/V)	MC (θ) ($W\rho$)
Dry Tube 2	1	10 cm										
	2	10 cm										
	3	10 cm										
Dry Tube 2	1	20 cm										
	2	20 cm										
	3	20 cm										
Dry Tube 2	1	30 cm										
	2	30 cm										
	3	30 cm										
Dry Tube 2	1	40 cm										
	2	40 cm										
	3	40 cm										
Dry Tube 2	1	50 cm										
	2	50 cm										
	3	50 cm										
Dry Tube 2	1	60 cm										
	2	60 cm										
	3	60 cm										
Dry Tube 2	1	70 cm										
	2	70 cm										
	3	70 cm										
Dry Tube 2	1	80 cm										
	2	80 cm										
	3	80 cm										
Dry Tube 2	1	90 cm										
	2	90 cm										
	3	90 cm										
Dry Tube 2	1	100 cm										
	2	100 cm										
	3	100 cm										

Table 5. Template for Plotting SF and Volumetric Water Content

Treatment	Replicate	Depth	SF	q
Wet Tube 1	1	10 cm		
	2	10 cm		
	3	10 cm		
Wet Tube 1	1	20 cm		
	2	20 cm		
	3	20 cm		
Wet Tube 1	1	30 cm		
	2	30 cm		
	3	30 cm		
Wet Tube 1	1	40 cm		
	2	40 cm		
	3	40 cm		
Wet Tube 1	1	50 cm		
	2	50 cm		
	3	50 cm		
Wet Tube 1	1	60 cm		
	2	60 cm		
	3	60 cm		
Wet Tube 1	1	70 cm		
	2	70 cm		
	3	70 cm		
Wet Tube 1	1	80 cm		
	2	80 cm		
	3	80 cm		
Wet Tube 1	1	90 cm		
	2	90 cm		
	3	90 cm		
Wet Tube 1	1	100 cm		
	2	100 cm		
	3	100 cm		

Treatment	**Replicate**	**Depth**	**SF**	q
Wet Tube 2	1	10 cm		
	2	10 cm		
	3	10 cm		
Wet Tube 2	1	20 cm		
	2	20 cm		
	3	20 cm		
Wet Tube 2	1	30 cm		
	2	30 cm		
	3	30 cm		
Wet Tube 2	1	40 cm		
	2	40 cm		
	3	40 cm		
Wet Tube 2	1	50 cm		
	2	50 cm		
	3	50 cm		
Wet Tube 2	1	60 cm		
	2	60 cm		
	3	60 cm		
Wet Tube 2	1	70 cm		
	2	70 cm		
	3	70 cm		
Wet Tube 2	1	80 cm		
	2	80 cm		
	3	80 cm		
Wet Tube 2	1	90 cm		
	2	90 cm		
	3	90 cm		
Wet Tube 2	1	100 cm		
	2	100 cm		
	3	100 cm		

Treatment	Replicate	Depth	SF	q
Moist Tube 1	1	10 cm		
	2	10 cm		
	3	10 cm		
Moist Tube 1	1	20 cm		
	2	20 cm		
	3	20 cm		
Moist Tube 1	1	30 cm		
	2	30 cm		
	3	30 cm		
Moist Tube 1	1	40 cm		
	2	40 cm		
	3	40 cm		
Moist Tube 1	1	50 cm		
	2	50 cm		
	3	50 cm		
Moist Tube 1	1	60 cm		
	2	60 cm		
	3	60 cm		
Moist Tube 1	1	70 cm		
	2	70 cm		
	3	70 cm		
Moist Tube 1	1	80 cm		
	2	80 cm		
	3	80 cm		
Moist Tube 1	1	90 cm		
	2	90 cm		
	3	90 cm		
Moist Tube 1	1	100 cm		
	2	100 cm		
	3	100 cm		

Treatment	Replicate	Depth	SF	q
Moist Tube 2	1	10 cm		
	2	10 cm		
	3	10 cm		
Moist Tube 2	1	20 cm		
	2	20 cm		
	3	20 cm		
Moist Tube 2	1	30 cm		
	2	30 cm		
	3	30 cm		
Moist Tube 2	1	40 cm		
	2	40 cm		
	3	40 cm		
Moist Tube 2	1	50 cm		
	2	50 cm		
	3	50 cm		
Moist Tube 2	1	60 cm		
	2	60 cm		
	3	60 cm		
Moist Tube 2	1	70 cm		
	2	70 cm		
	3	70 cm		
Moist Tube 2	1	80 cm		
	2	80 cm		
	3	80 cm		
Moist Tube 2	1	90 cm		
	2	90 cm		
	3	90 cm		
Moist Tube 2	1	100 cm		
	2	100 cm		
	3	100 cm		

Treatment	Replicate	Depth	SF	q
Dry Tube 1	1	10 cm		
	2	10 cm		
	3	10 cm		
Dry Tube 1	1	20 cm		
	2	20 cm		
	3	20 cm		
Dry Tube 1	1	30 cm		
	2	30 cm		
	3	30 cm		
Dry Tube 1	1	40 cm		
	2	40 cm		
	3	40 cm		
Dry Tube 1	1	50 cm		
	2	50 cm		
	3	50 cm		
Dry Tube 1	1	60 cm		
	2	60 cm		
	3	60 cm		
Dry Tube 1	1	70 cm		
	2	70 cm		
	3	70 cm		
Dry Tube 1	1	80 cm		
	2	80 cm		
	3	80 cm		
Dry Tube 1	1	90 cm		
	2	90 cm		
	3	90 cm		
Dry Tube 1	1	100 cm		
	2	100 cm		
	3	100 cm		

Treatment	Replicate	Depth	SF	q
Dry Tube 2	1	10 cm		
	2	10 cm		
	3	10 cm		
Dry Tube 2	1	20 cm		
	2	20 cm		
	3	20 cm		
Dry Tube 2	1	30 cm		
	2	30 cm		
	3	30 cm		
Dry Tube 2	1	40 cm		
	2	40 cm		
	3	40 cm		
Dry Tube 2	1	50 cm		
	2	50 cm		
	3	50 cm		
Dry Tube 2	1	60 cm		
	2	60 cm		
	3	60 cm		
Dry Tube 2	1	70 cm		
	2	70 cm		
	3	70 cm		
Dry Tube 2	1	80 cm		
	2	80 cm		
	3	80 cm		
Dry Tube 2	1	90 cm		
	2	90 cm		
	3	90 cm		
Dry Tube 2	1	100 cm		
	2	100 cm		
	3	100 cm		

9.4 Appendix IV - Glossary of Terms

Absolute moisture values
Absolute moisture values reflect accurate volumetric soil water content readings that have been derived by calibrating sensors for different depth levels for a specific site.

Access tube
The PVC tube, which is permanently installed in the ground, inside which the *Sentek Soil Moisture Sensors* are inserted.

Accuracy
Accuracy relates to the closeness of a measured value to its true scientific value.

Bulk density
The ratio of the mass of a given sample to its bulk volume.

Calibration
A calibration is an equation that is used to convert normalised, raw sensor data into moisture units. Moisture units describe volumetric soil water content.

Clay
Individual soil particles of size less than 0.002 mm.

Default Sentek Pty Ltd calibration equation
A calibration equation that is set as the default in the EnviroSCAN® software and *Sentek Portable Probe* instrumentation, designed to suit most soil types and to enable relative trends in soil moisture to be logged with time.

Distribution uniformity
A measure of the uniformity of the distribution pattern of a sprinkler system – generally measured by placing a series of cans in a grid pattern and measuring the volume of water emitted over a set period of time.

Diviner 2000Ò
A portable soil moisture monitoring system, comprising a data display unit and a portable probe.

EnviroSCANÒ
A semi-permanent soil moisture monitoring system, with sensors that measure the complex dielectric constant of the soil water medium.

Gravimetric sampling
Measurement of soil moisture content by determining the mass of water in relation to the soil mass.

Gravimetric soil water content
The amount of moisture stored in the soil as measured by mass before and after drying.

Irrigation scheduling
The practice of implementing a planned schedule of irrigation events, commonly in response to a measurement of soil moisture and/or plant health, taking into account cultural and environmental factors.

Normalisation
The process of obtaining measurements in water and air in order to enable comparison of raw count readings between different probes.

Pans
A pan is an indurated and/or cemented soil horizon that impedes root and/or water penetration.

Ped
A unit of soil structure such as a block, column, granulae, plate or prism, formed by natural processes.

Permeability	The potential of a soil to transmit water internally. It is independent of climate and drainage, and is controlled by the saturated hydraulic conductivity of the least permeable layer in the soil.
Porosity	The volume of pores in a soil sample divided by the bulk volume of the sample.
Precision	Precision relates to the variation of a set of readings of the same value from each other.
Probe	A probe is the hardware device that is inserted into the access tube, installed in the soil profile. The probe holds the sensor(s) that take the moisture readings.
Raw counts	Raw counts are the base units of data downloaded from the logger to the software.
Relative values	Reflect volumetric soil water content readings, which have been derived using an initial default calibration equation supplied by Sentek Pty Ltd and may not be accurate for a particular soil type.
Sand	Individual soil particles of size 0.02 mm to 2 mm.
Scaled frequency	Is a sensor reading in relation to air and water counts (readings). Scaled Frequency (SF) = [(Air Count) – (Soil Count)] / [(Air count) – (Water Count)]. All counts are taken within an access tube.
Silt	Individual soil particles of size 0.002 mm to 0.02 mm.
Soil Salinity	The amount of soluble salts in a soil. The conventional measure of soil salinity is the electrical conductivity of a saturation extract.
Soil Sodicity	A soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type.
Sphere of influence	The sphere of influence of the sensors is physically designed to represent a 10 cm vertical and 5 to 10 cm horizontal radius around the access tube.
Volumetric soil water content	The soil water content expressed as the volume of water per unit bulk volume of soil.

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