



The Tully Rundown Experiment: Field instrumentation and associated measurements of the physical environment

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COOPERATIVE RESEARCH CENTRE for
SUSTAINABLE SUGAR PRODUCTION

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3. INTRODUCTION

Sugar yield decline within the Queensland sugar industry has been defined as the loss in productive capacity of soils as a result of growing sugarcane as a monoculture. It has been estimated to cost the sugar industry \$200 - \$400 million per year, and has in the past been largely associated with soil microbiological factors (Magarey 1996). The role soil chemical and physical factors may have in leading to a loss of productive capacity in a monoculture is at present not well understood, and the Rundown experiment near Tully in tropical north Queensland has been established to help address this lack of understanding (Bristow et al 1999).

The basic aim of the Rundown experiment is to analyse changes in soil properties with time in an attempt to establish critical factors which lead to a break down in the soils productive capacity, as expressed by a decline in crop yield. There is therefore a particular focus on developing an understanding of how the soil properties (physical, chemical and biological) change with time following introduction of sugarcane to a new site, where by 'new' we mean a site that has not previously grown sugarcane. In addition to studying the change in soil properties with time, attempts are also being made to address the likely impact of these changes on the soil water and nutrient balance, on associated issues such as soil acidification, and ultimately on the growth and yield of sugarcane. A measurement and modeling approach is being employed to help achieve these goals.

In this report we provide a brief overview of the instrumentation installed at the Rundown site. The instrumentation includes:

- a weather station (to measure atmospheric variables including precipitation, and to provide estimates of potential evapotranspiration)
- a TDR system (to measure soil water contents and electrical conductivity to provide insights into soil water storage and transport as well as nutrient movement)
- tensiometers (to measure the energy status of the soil water to provide insights into the storage and transport of soil water)
- piezometers (to measure ground water fluctuations to provide insight into potential water logging at the site)

Typical measurements from each of the above systems are also discussed.

4. SITE INFORMATION

4.1 Location

The Rundown experiment is situated on the Tully Tea Plantation road some 15 km from Tully. Its grid reference is 17° 53' south, 145° 50' east, and has an elevation of roughly 30 meters above mean sea level.

As far as we have been able to determine the site was under rainforest until 1962 when it was cleared for tea. Tea proved unsuccessful and was replaced with *Brachiaria humidicola* pasture in 1966. The site has been used for fattening beef cattle since then. We have not been able to determine if and when fertiliser was applied but it seems from the relatively high P and S levels we have measured that superphosphate may have been applied at some stage. We obtained access to the field site in late 1995.

4.2 Field Layout

The field site is rectangular in shape (143 x 218 m), with 14 treatments in 3 replicates giving a total of 42 plots. The plot size is 15 by 25 meters, with 3 meters between east-west borders and 5-10 meters between north-south borders. The site has small surface undulations and a gentle slope of 0.8 m from the NW corner, to the SE corner. The site has been surveyed to determine soil surface levels, referenced to a point in the NW corner. These measurements were taken at each piezometer location. All this information, as well as instrumentation locations are shown on the scale map in Figure 4-1. A photo showing some of the instrumentation is given in Figure 4-2. The first sugarcane crop (Q117) was planted in July 1996.

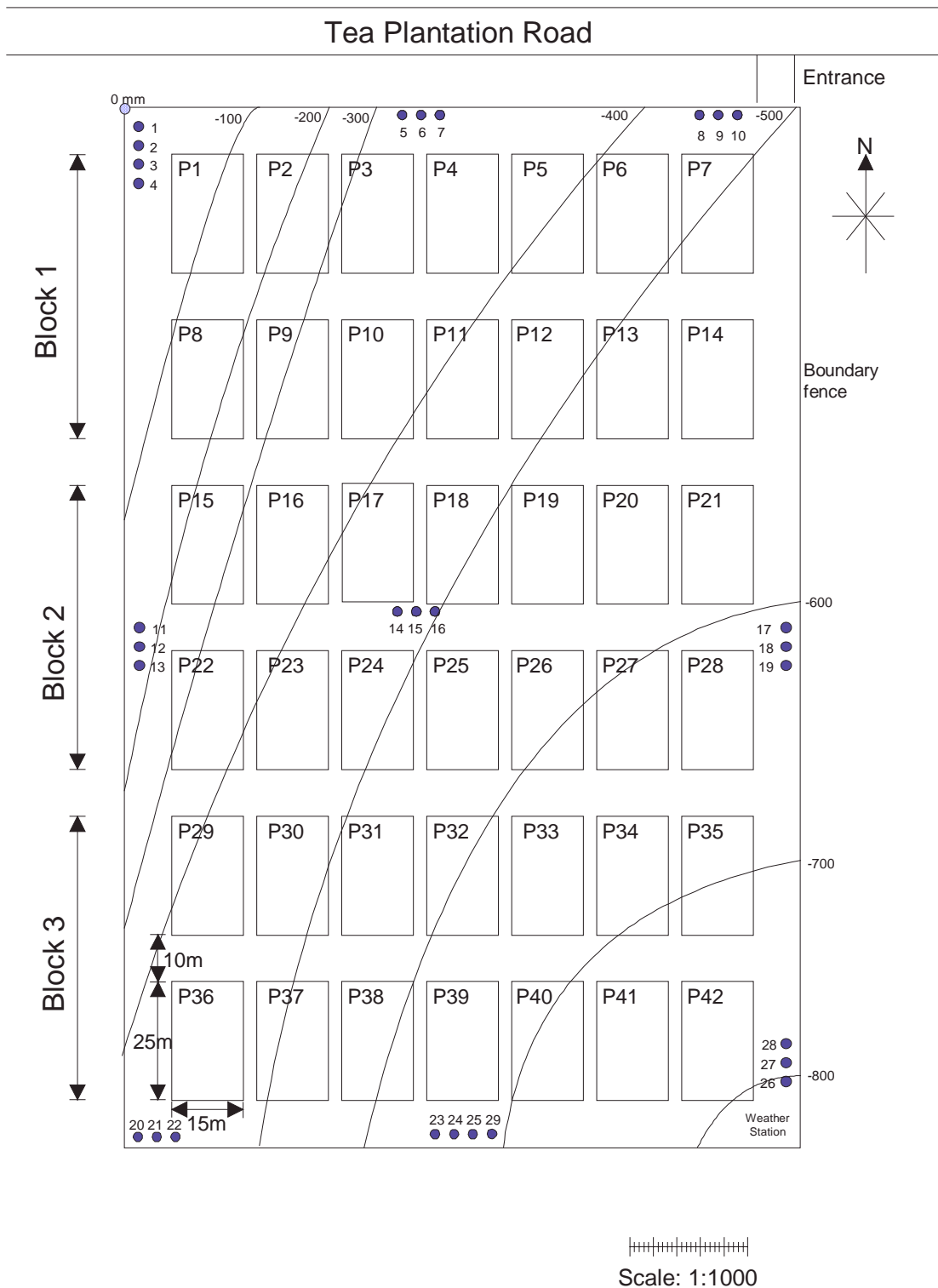


Figure 4-1: Field Layout of the Tully Rundown experiment with isolines showing changes in elevation from the top left hand corner in mm. Numbered points show piezometer locations and P=site plot number.

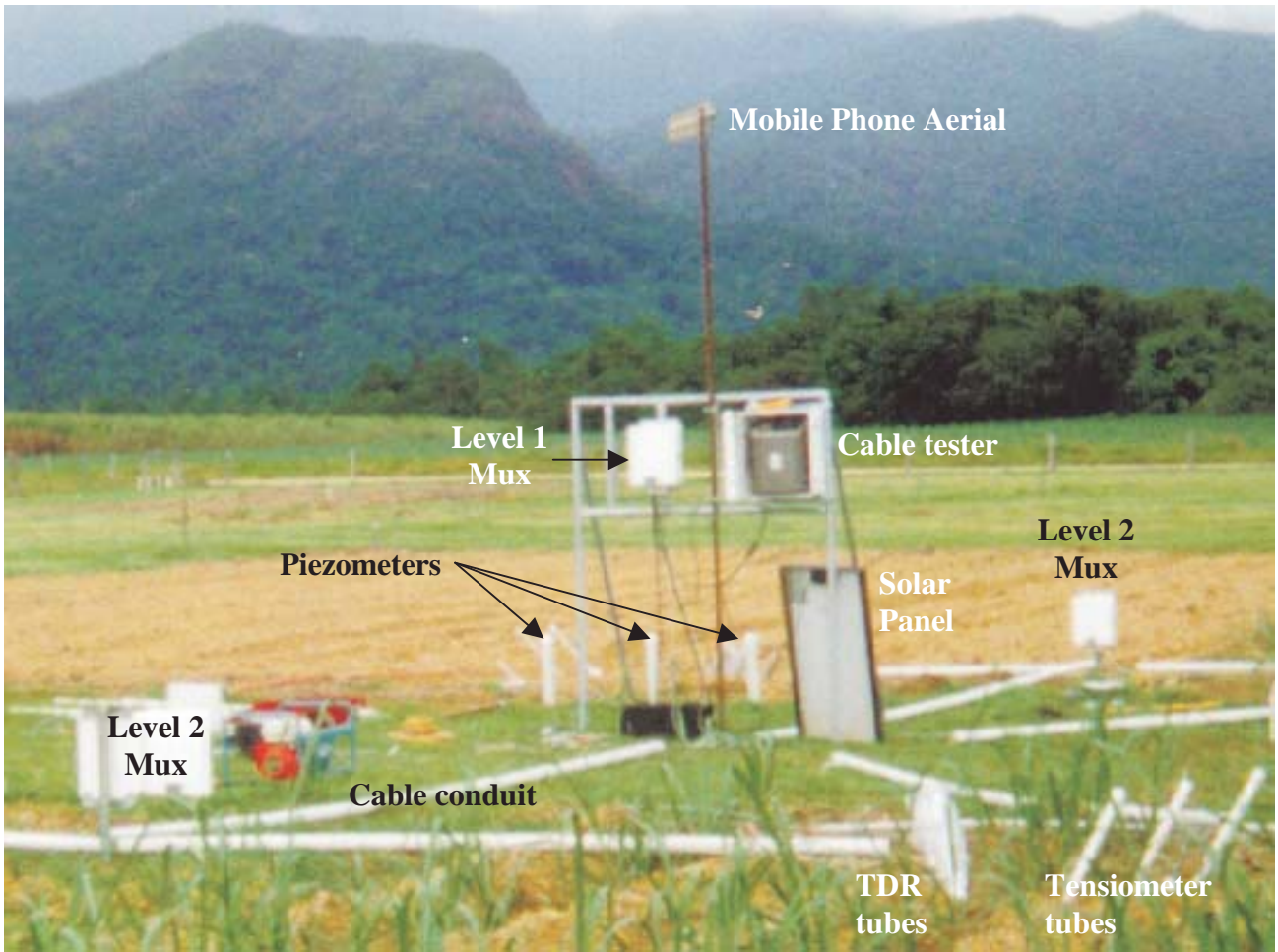


Figure 4-2: Instrumentation layout at the Tully Rundown site (Mux = multiplexer)

5. ENVIRONMENTAL MEASUREMENTS

5.1 General

An automated weather station (Campbell Scientific Australia, Townsville) (Figure 5-1) which is linked to CSIRO Davies Laboratory via analog mobile phone has been installed on site to provide continuous records of weather variables.

The environmental variables that are measured include:

- Air temperature
- Air humidity
- Solar radiation
- Wind speed
- Precipitation
- Soil Temperature

The weather station is located in the south-east corner of the field. A full 360 degree photographic panorama (Figure 5-2) was prepared for the site when installing the station. Regular updates of this will provide a record of changes in any nearby structures that may impact on the measurements.



Figure 5-1: Weather station

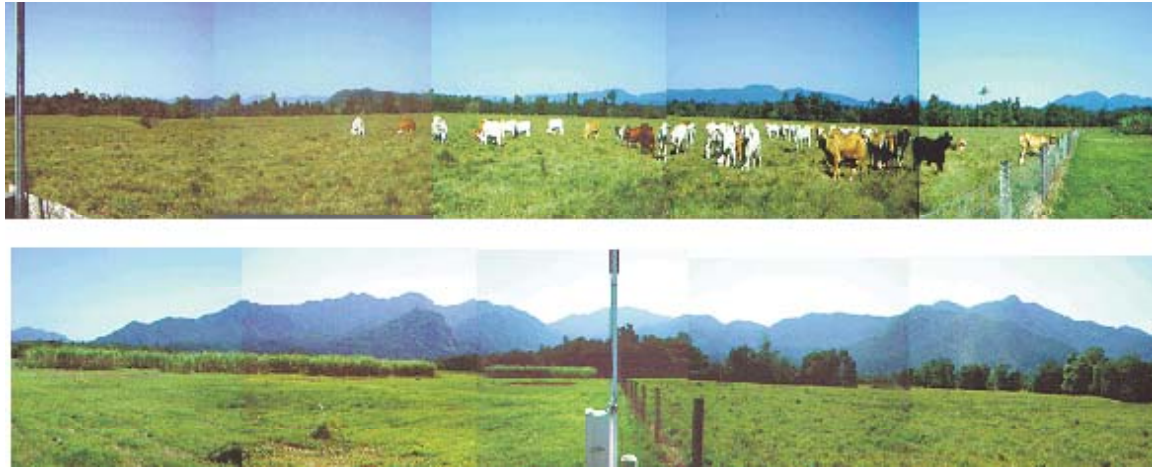


Figure 5-2: Initial 360° panorama of the Rundown site taken during installation of the weather station

5.2 Instruments and Data logger

The data logging (Campbell Scientific CR10; see Figure 5-3) and communications (Motorola) equipment is housed in a water tight, dust-tight, corrosion-resistant fibreglass enclosure (CS model name ENC 10/12) which has inside dimensions of 300 mm x 250 mm x 110 mm. The continuously high humidity environment in Tully requires that the cable entry port into the enclosure be sealed and extra desiccant be placed inside. The CR10's internal humidity is protected by internal desiccant and moisture sealing, but the above measures provide protection to the wiring panel, modem and phone system. Because the original door on the enclosure did not seal correctly the hinges were removed and the door bolted to the enclosure to ensure it remained waterproof. Over time the foam rubber was also eaten through by ants and was therefore replaced by a harder Nylal rubber, the same size as the original foam.

The weather station has a 10 mm diameter, 500 mm long grounding rod installed directly beneath the tripod to provide lightening protection. All components of the data logging system, including sensors and phone system, are referenced to this ground point through a 10 AWG wire connected to the enclosure.

Table 5-1 summarises the wiring for the weather station instruments.

The channels listed in

Table 5-1 are shown in Figure 5-3.

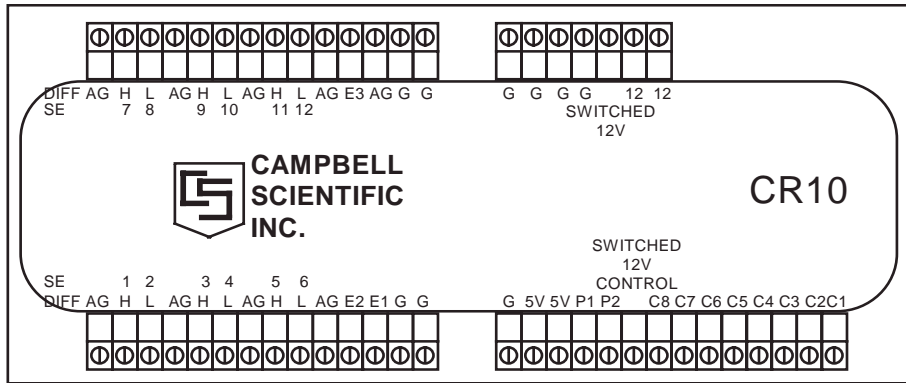


Figure 5-3: CR10 Datalogger

Table 5-1: Weather station probe wiring

PROBE	WIRE	CHANNEL
Anemometer	Black	P2
	White	G
	Clear	G
Temperature/RH	Red	+12V
	Yellow	E1
	Purple	AG
	Clear	G
	Green	SE2
	Black	E2
	Orange	SE1
Rain Gauge	Black	P1
	White	G
Soil Temperature	Black	E3
	Red	SE3
	Purple	AG
	Clear	G
Pyranometer	Red	SE5
	Black	SE6
	Clear	GND

5.2.1 Rainfall

The American Association of State Climatologists (AASC) recommends a gauge height of 1.0 m \pm 0.2 m above ground, while the World Meteorological Organisation (WMO) recommends a minimum height of 30 cm above ground level.

Rain at the site is measured using a Hydrological Services tipping bucket rain gauge model TB3 (Figure 5-4). This gauge has a 200 mm diameter receiver and each tip of the bucket records 0.2 mm of rainfall. The rain gauge is fitted with a 100 Ω resistor across the switch terminals to limit current flow, and hence extend switch life. The gauge was originally located roughly four meters from the weather station on a concrete base, but in December 1998 was mounted on a plate above the ground to avoid problems with surface ponding. During high rainfall events surface water can rise above the tipping bucket mechanism of the rain gauge and cause spurious tips. The ground surface around the rain gauge is sprayed regularly with herbicide to prevent excessive grass growth. The official recommendation by meteorological organisations is for maintenance of a short grass surface around the rain gauge but this is difficult in a remote locality.

The height of the orifice above the ground is an important consideration due to the increase of wind speed with the increase in height and can affect the amount of rain captured by the gauge. The mounting of the rain gauge on a concrete base is also generally not acceptable as solar radiation can cause the base to heat up, therefore increasing evaporation. This was taken into account when pouring the original concrete base that was made equal to the diameter of the gauge, therefore preventing direct exposure to the sun.



Figure 5-4: Tipping bucket rain gauge

5.2.2 Air Temperature/ Humidity

Air temperature and humidity are measured using a BetaTHERM 100KA61 thermistor and a Vaisala capacitive relative humidity sensor. These instruments are housed in a 12 plate Gill radiation shield, located 1.25 m above the ground behind the datalogger enclosure. This probe requires annual calibration checks and if required, re-calibration. The calibration can be checked in situ using humidity capsules (Vaisala Humidity checker, HME32) which are placed over the sensor. For more accurate calibration the probe needs to be calibrated in chambers using saturated salts of known humidity. Using either method the calibration of the sensor is set by adjusting the offset and gain potentiometers on the instrument. The accuracy of the temperature is largely determined by the interchangeability specification of the thermistor, which is $\pm 0.2^{\circ}\text{C}$. This is predominantly an offset error and can be minimised using a single point calibration.

More regular checks should be performed to check that the radiation shield is clear from debris and that the sensor screen is clean. The 1.25 m height is within both the AASC (1.5m \pm 1m) and WMO (1.25 - 2.00 m) standards.

5.2.3 Soil Temperature

Soil temperature is measured using a Fenwal Electronics UUT51J1 thermistor probe. This probe is designed to be buried or submerged in up to 60 m of water. It has been buried at a depth of 10 cm, between the weather station and adjacent fence. The cable is buried horizontally for 30 cm to minimise heat conduction along the cable. The 10 cm depth is consistent with the AASC recommendations, but the WMO recommends temperatures be measured at a series of depths.

5.2.4 Solar Radiation

Solar radiation is measured using a Li-Cor LI-200SZ Pyranometer. This sensor is made from a silicon photodiode, and is mounted on an elevated arm, on a level plate. The site is free from any obstruction to either direct or diffuse radiation. To meet with exposure standards it is required that any objects should be less than 10° above the horizontal plane of the sensor. The chosen site satisfies this requirement.

This radiation sensor was originally calibrated against an Eppley Precision Spectral Pyranometer under natural daylight conditions which gives the sensor an absolute error of ±5% maximum and ±3% typically. However, it also has a stability specification of ±2% change over a 1 year period. It is for this reason that the probe needs to be re-calibrated at least every two years. A secondary standard is usually used for the recalibration.

After the instrument had been installed for a year, the station was checked and the level of the pyranometer adjusted. The allen key bolts that were used to adjust the level were found to have corroded in position and these were drilled out and removed. Anodised bolts were used instead.

5.2.5 Wind Speed

Wind speed is measured using a R. M. Young wind sentry model 03101-5 which employs a three cup rotating design. The calibration for this sensor is provided by the manufacturer. To obtain wind speed measurements from a CR10 pulse count instruction (P3, Low level AC) we use the equation

$$speed = \frac{0.750}{execution\ time} cup\ pulses + 0.2$$

With an execution interval of 10 seconds a multiplier of 0.075 and an offset of 0.2 is used.

For anemometers, the standard height for BoM and WMO is 10 m above mean ground level. If this is not achievable, a power law formula is used

$$V_{10} = V_h \left(\frac{10}{h} \right)^{0.13}$$

where V_{10} is the standard ten meter exposure and V_h is the non standard height h . The AASC standard height is $3 \text{ m} \pm 0.1 \text{ m}$. This is the actual height of the instrument at our site.

5.2.6 General Maintenance

The weather station instruments need regular checking to ensure error free operation. Instruments such as the pyranometer and the humidity/temperature probe require annual or biannual checking of the calibration. Others, such as the tipping bucket rain gauge and the anemometer require that their moving parts be checked regularly to ensure that they move freely. The Gill radiation shield, which encloses the temperature and humidity probes needs to be cleaned to ensure the surface retains its original properties. This can be achieved by regularly dismantling the shield and cleaning each plate with a bleach solution such as diluted Exit Mould.

5.3 Communications

The weather station includes a Motorola Traveller-K cellular mobile phone. Although the analog phone service is scheduled to be phased out by the year 2001¹ a digital mobile phone was not possible due to the limited service area of the current digital network. The mobile phone is fitted with a 15 element 14 dB high gain antenna. This allows the phone to be used with reliable communications under most conditions. Due to the power consumed by the mobile phone it is only activated for short periods during each day, currently set at 15 minutes every 8 hours.

Figure 5-5 shows the wiring required for the communications system.

A separate controller is used to turn the phone on and off as required. This process is achieved by using the datalogger to control a relay which switches power to the mobile phone. The site has been evaluated for digital phone coverage and found that it is a fringing area for Telstra MobileNet, but not Optus or any of the other service providers. Plans will need to be made as this deadline becomes closer.

¹ It has been proposed that the analog system will be kept in regions not covered by the digital service, however no areas have been identified yet and so contingency plans need to be made

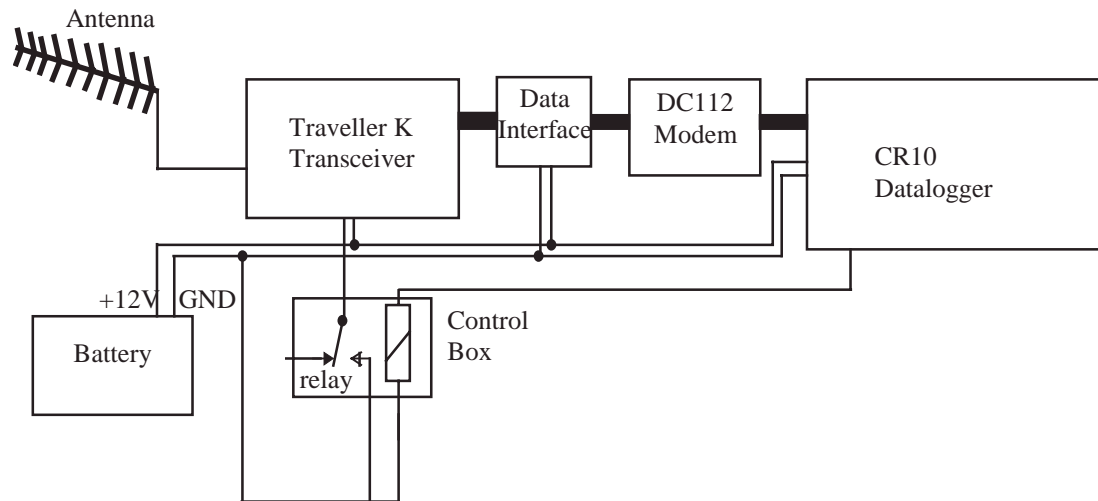


Figure 5-5: Communications System

5.4 Evapotranspiration calculations

Evapotranspiration (ET) is the loss of water from the soil by both evaporation and transpiration. The Penman-Monteith equation is used to estimate ET as

$$ET_o = \frac{\Delta(R_n - G)}{\lambda(\Delta - \gamma^*)} + \frac{\gamma^* M_w (e_a - e_d)}{R\theta r_v (\Delta + \gamma^*)}$$

where

- ET_o Potential evaporation (kg m⁻² s⁻¹)
- R_n Net radiation (kW m⁻²)
- G Soil heat flux density (kW m⁻²)
- M_w Molecular mass of water (0.018 kg mol⁻¹)
- R Gas constant (8.31 x 10⁻³ kJ mol⁻¹ K⁻¹)
- θ Kelvin temperature (293K)
- e_a-e_d Vapor pressure deficit of the air (kPa)
- λ Latent heat of vaporisation of water (2450 kJ kg⁻¹)
- r_v Canopy plus boundary layer resistance for vapor (s m⁻¹)
- Δ Slope of the saturation vapor pressure function (Pa °C⁻¹)
- γ* Apparent psychrometer constant (Pa °C⁻¹)

The use of the Penman-Monteith equation requires several assumptions to be made and weather station measurements to be converted to different forms. The implementation of this equation is described by Campbell (1995).

5.5 Power Usage

The weather station is designed to operate as a separate system from the TDR/Tensiometer system, and therefore requires a power supply that must be capable of supplying the station through periods of minimal charging. Power requirements were estimated using the sunlight information obtained from the Bureau of Meteorology for the South Johnstone Experimental Station², which is located approximately 30 km north of the site. The hours of bright sunshine, recorded using a paper marking technique, for the last 31 years³ are summarised in Table 5-2.

Table 5-2 - Hours of Sunshine at South Johnstone (1965-1996)

Month	Mean	Min.	Max.
January	6.5	3.4	9.1
February	5.4	2.5	9.5
March	5.5	1.7	8.8
April	5.4	2.5	7.4
May	4.5	2.5	6.3
June	5.6	2.8	8.5
July	5.6	2.9	8.3
August	6.4	2.8	9.2
September	7.4	4.7	9.9
October	8.2	5.2	10.8
November	8.2	5.1	10
December	7.4	3.8	9.4

The month of March in 1971 has the least amount of sunshine recorded, with only 1.7 hours. This figure is obtained from daily readings, averaged over the month. From this it can be assumed that there were periods in this month when there were several days in a row which were below this average. This must be taken into consideration when calculating the ultimate battery reserve required.

The equipment that requires power is listed in Table 5-3, together with the operating power, operating hours per day and the total power usage for the day.

² The South Johnstone experimental station is Bureau of Meteorology station number 032037 and is the closest station which records hours of bright sunshine.

³ The results are calculated using data collected from January 1965 to November 1996.

Table 5-3 - Power Usage (Ah = amp hour)

<i>Equipment</i>	<i>Operating Power</i>	<i>Hours/Day</i>	<i>Daily Amp-Hour Load</i>
CR10 datalogger-quiescent	0.006	21	0.01
CR10 datalogger-processing	0.156	1.5	0.02
CR10 datalogger-measurement	0.42	1.5	0.05
Phone - activated	4.38	1.0	0.37
Phone - online	10.056	0.2	0.17
Modem	0.54	0.2	0.01
Piezometers	0.18	24	0.36
Total			1.08

To adjust for loss is it normal to divide by a factor of 0.8, resulting in a total of 1.35 Ah. Using the worst case bright sunshine of 1.7 h day^{-1} , this results in a panel requirement of at least 0.8 A. The battery supply needs to be capable of sustaining the system through extended periods of negligible power from the solar panel. A value generally used for maximum confidence of system reliability is 5 days. It is also general to assume that over this period the battery capacity only drops by 50%. Using these values the battery needs to be 14 Ah or greater in capacity.

5.6 Event Record

Maintenance of an event record, which lists all pertinent events that occur at the weather station, helps in the identification of any problems that may arise. The event record should contain the date and time of any event, a short comment describing the event and the name of the operator who recorded the event.

6. TIME DOMAIN REFLECTOMETRY (TDR) SYSTEM

6.1 Introduction

The use of TDR for determination of volumetric water content (θ_v) and bulk electrical conductivity (EC) has rapidly attained widespread acceptance (Topp et al., 1980, Topp et al., 1985, Ledieu et al. 1986 and Zegelin et al., 1989). The factors behind this acceptance are mainly due to the automation and safety of the measurement which involves no ionising radiation. The use of an automated system, as described in this report, provides frequent, reliable data, which reduces the number of assumptions required during data analysis. Having the probe permanently installed in position results in highly reliable data, due to the probe having a fixed surrounding matrix, and no external stresses being applied to the probe. A further advantage is that the technique is non-destructive. With the installation technique described below, the TDR system also has the advantage of measuring an undisturbed profile, without the requirement of an installation pit, and the probes are easily removed if required.

2.1. Automated soil water content measurement

An automated soil water content measurement system has been installed at the site. This system consists of a Tektronix 1502B Cable tester, Campbell Scientific CR10 datalogger, three Campbell Scientific SDMX50 50Ω co-axial 8:1 multiplexers, and twenty Campbell Scientific three electrode TDR probes (Figure 6-1). The multiplexer system has been designed to minimise cable lengths and involves two levels of multiplexers. The first level multiplexer is located directly beside the cable tester. This multiplexer then has the two next level multiplexers, and six available channels. The second level multiplexers are each situated midway between two plots as shown in Figure 6-2. The probe arrangement is listed in Table 6-2, and shown in Figure 6-3.

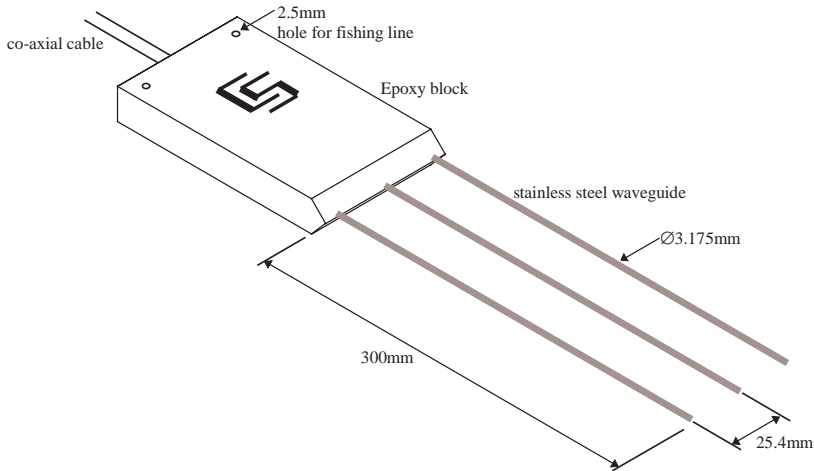


Figure 6-1: Schematic of TDR probe

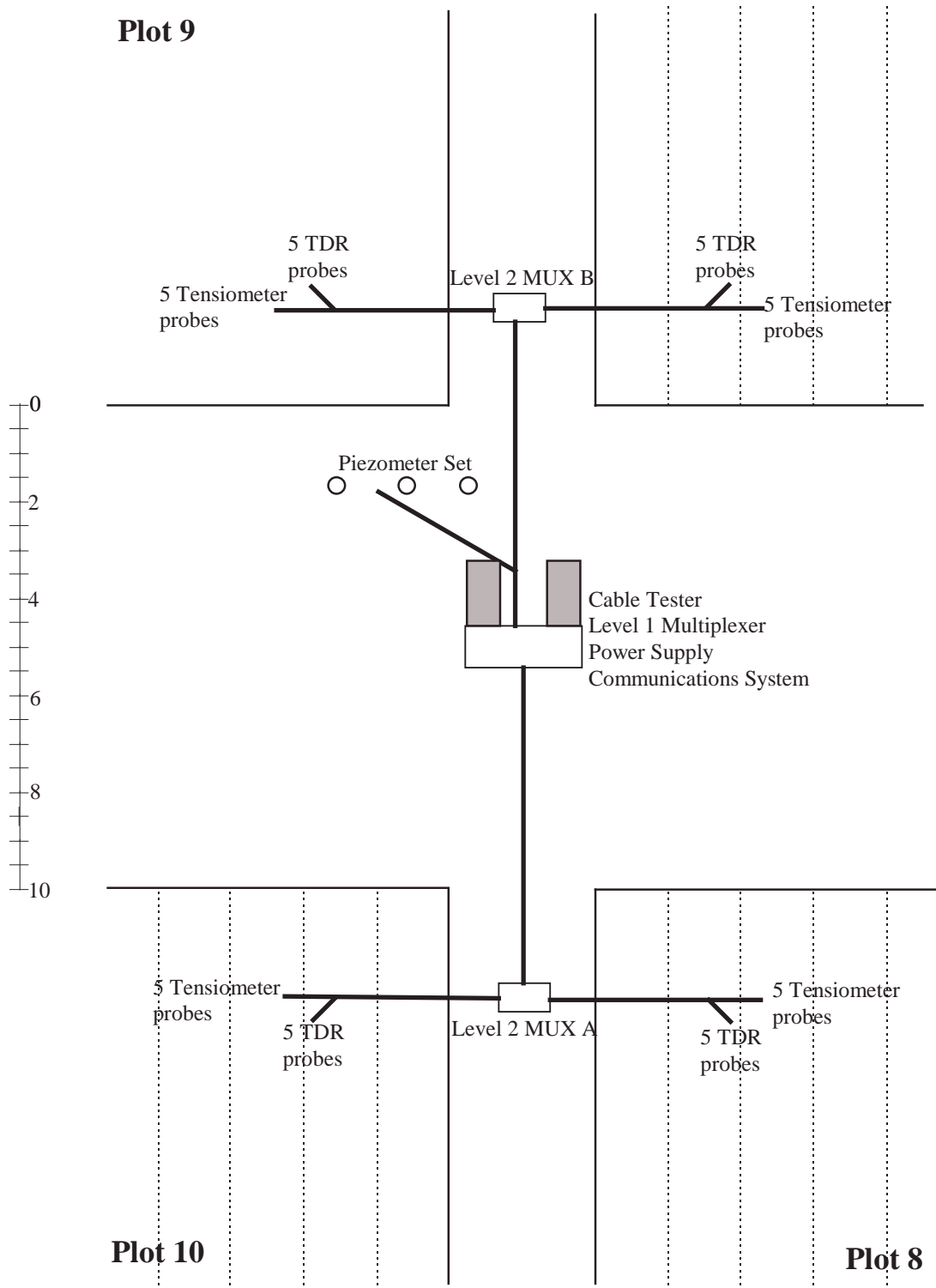


Figure 6-2: Field Layout showing different multiplexer levels

6.2 Installation

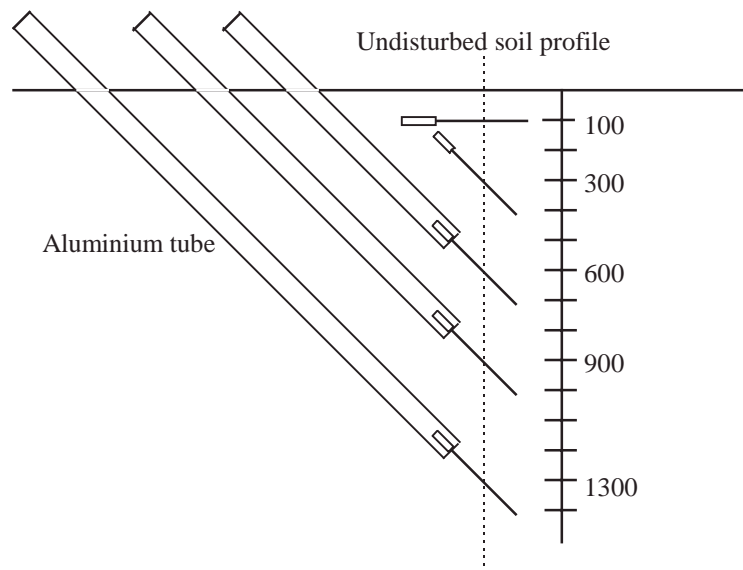


Figure 6-3: Schematic showing how probes are installed to provide measurements of a vertical profile

The installation technique for a set of probes is shown in Figure 6-3. Each set is located to measure an undisturbed soil profile, in the second row from the side of the plot, 3 meters from the front of the plot, as shown in Figure 6-2. Each of the three deep probes are housed in aluminium tube, 80 mm outside diameter, with a 3 mm wall. This was installed at an angle of 45° using a large drilling rig. This rig had the capability to push coring tubes down to the required depth at an adjustable angle and a sliding base that meant that the location of the hole could be adjusted. Although the probes integrates over a 300 mm length, the depth interval is 210 mm, due to the 45° angle. The depth quoted for each probe is the average depth. For example, the 60 cm probe measures from 49.5 cm to 70.5 cm.

The corer was made from 76.2 mm (3") pipe with a tip 79 mm in diameter. This corer compresses on the outside and resulted in a tight fit for the aluminium tube. The aluminium tube has two holes at the top so as to be able to remove the tube from the ground if required. If removal is required then a steel rod can be inserted through these two holes. The drilling rig can then be used in a reverse procedure to installing the tubes, or a large lever can be used. The probes have two holes drilled in the epoxy block and high tensile fishing line is threaded through these holes so the probes can be removed at the end of the experiment. This fishing line extends up to the end of the aluminium tube. It is not expected that the probes will be required to be removed during the experiment as they have no serviceable parts on these probes.

A waveguide spacer (Figure 6-4), is placed on the electrodes before insertion to ensure parallel insertion. This spacer is made from 1.5 mm thick Lexan. The holes in this material were made using a 3.175 mm drill, the same diameter as the waveguides, so as to provide a tight fit,

ensuring that it would not slip off when the probe was lowered down the tube. Once the probe was lowered into the tube it was not removed unless critical, so that the spacer would not slip off the waveguides. If this occurred it would have been difficult to either remove the waveguide⁴, or attempt to relocate the waveguides in the holes. A tool that fits over the top of the epoxy block with a gap allowing for the coaxial cable was used to push the probe into the ground. Water was poured down the access tubes several hours before the probes were installed to make insertion easier.

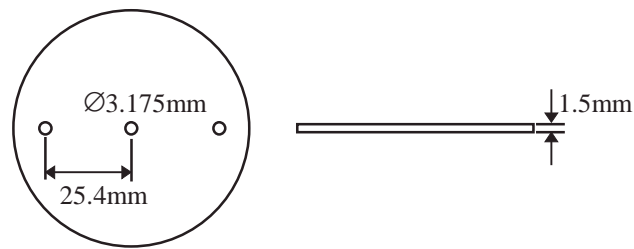


Figure 6-4: Schematic of waveguide spacer

Aluminium tubes were not used for the two near surface probes, at 10 cm and 30 cm. For the 30 cm probe a 45° face was made in the soil at the required depth and the probe was inserted normally, using the spacer and insertion tool as before. For the 10 cm probe a vertical face was made in the soil and the probe inserted horizontally. A small rectangular spacer was used for this probe as the full circle was not required. The probe was easily pushed in by hand, as the soil was loose due to the recent cultivation. The hole for these was then backfilled.

⁴ A tool was made for pulling out the waveguide spacers. This was required when several of the probes were pulled out at the end of the first growing season. This tool was essentially a self tapping wood screw welded on the end of a 6.2 mm steel rod, 2 meters in length, with a handle on the end.

The cable was run from the multiplexer, through 50 mm DWV PVC. A 50 to 100 mm joiner was used with a end cap which had five hose fittings screwed into it, to allow each individual cable to be covered in flexible conduit, down to either the top of the aluminium tube or into the ground. This is shown in Figure 6-5.

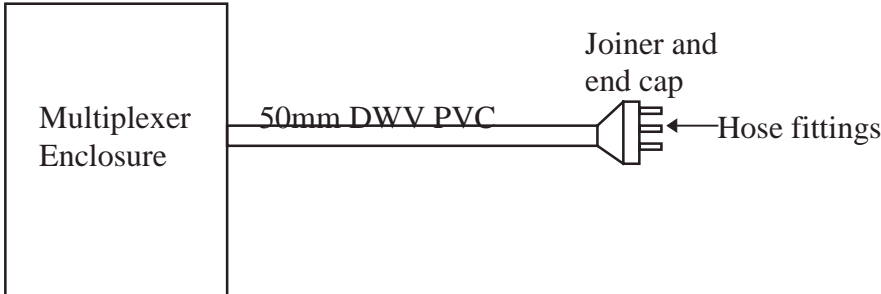


Figure 6-5: Cable conduit

A y-junction was placed before the joiner to allow the PVC to continue further into the plot, carrying the cables in a more secure way.

The cable from the front panel of the 1502B to the level one multiplexer, and the cable from the level one multiplexer to the level two multiplexers, is RG213/U coaxial cable, which although being more expensive than RG58 cable offers much better attenuation characteristics. These characteristics are summarised in Table 6-1.

Table 6-1 - Attenuation rates per 10 m lengths

Cable type	10MHz	100MHz	1000MHz
RG58	2dB	3.1dB	7.6dB
RG213	0.18dB	0.62dB	2.63dB

For the 10, 30, 60 and 90 cm probes in each plot the 6 m cable which comes connected to each probe is connected directly to a level two multiplexer. For the 130 cm probe in each plot, the cable is routed to the level one multiplexer using RG58 cable.

6.3 Data logging installation

The datalogger, cable tester, SDM1502 and mobile phone system are all mounted inside a CSI TDR enclosure. The TDR enclosure includes a mounting which allows the 1502B to swing out, enabling the screen to be easily viewed. A transient suppressor which blocks large voltage spikes is also included in the TDR enclosure, in between the 1502B and the level one multiplexer. The SDM1502 is a communications interface between the CR10 and the 1502B.

Each individual multiplexer is mounted inside an enclosure. The multiplexer and SDM1502 are synchronous addressable devices, requiring control by the datalogger. This is performed via control ports 1 to 3. The address is set via DIP switches in the device. The address assigned to the SDM1502 decides the addresses given to the multiplexer. The address of the level one multiplexer must be one greater than the SDM1502, while the level two multiplexer must be one more. For this system the SDM1502 address is set to 11 (Parameter 1, Instruction 100). Therefore, the level one multiplexer has the address 12 and the level two multiplexers have address 13.

Both the TDR enclosure and the level one multiplexer are mounted on a stand. The stand is made from 50 mm galvanised pipe, and stands approximately 1.8 m above ground. Vertical bars are used for U-bolts to hold the enclosures. The stand is located on four poles, buried 600 mm into the ground. Each pole has a 75 mm plate welded to it. A hole 80 mm in diameter was augured, the poles were placed in position and the holes were backfilled by repacking the removed soil. This provides a solid base for the instrumentation.

The communications system for the TDR is the same as that for the weather station except that the phone operates continuously. The aerial is mounted on a 3 m pole connected to the TDR stand.

The actual multiplexer channels for each probe are summarised in Table 6-2, and shown schematically in Figure 6-6.

Table 6-2: Multiplexer channel usage.

	10 cm	30 cm	60 cm	90 cm	130 cm
Plot 7	Mux 2,2. Ch 6	Mux 2,2. Ch 7	Mux 2,2. Ch 8	Mux 1. Ch 3	Mux 1, Ch 4
Plot 8	Mux 2,1. Ch 1	Mux 2,1. Ch 2	Mux 2,1. Ch 3	Mux 2,1. Ch 4	Mux 2,1, Ch 5
Plot 9	Mux 2,2. Ch 1	Mux 2,2. Ch 2	Mux 2,2. Ch 3	Mux 2,2. Ch 4	Mux 2.1, Ch 5
Plot 10	Mux 1. Ch 5	Mux 1. Ch 6	Mux 2,1. Ch 6	Mux 2,1. Ch 7	Mux 2.1, Ch 8

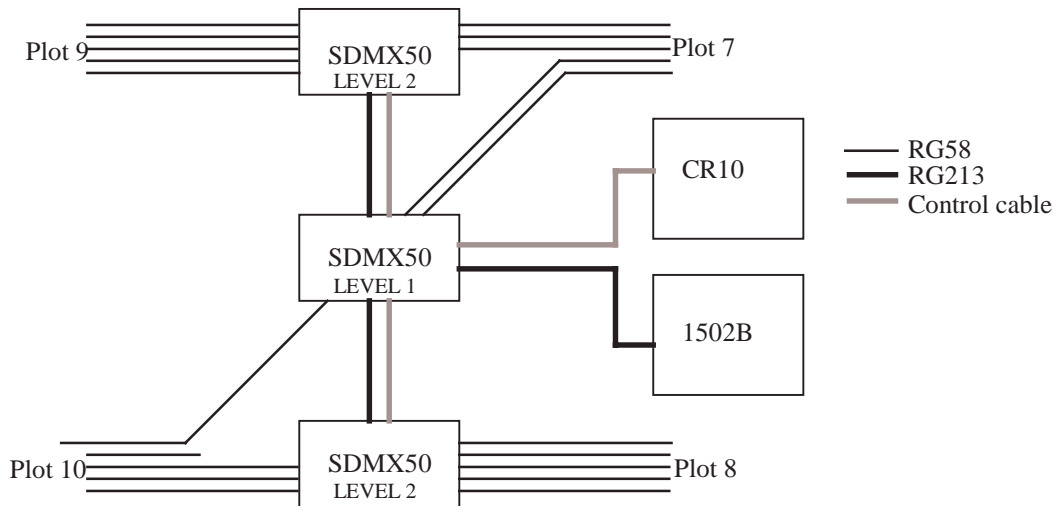


Figure 6-6: System design

The level two multiplexers, which are positioned in between two plots, were mounted on 1.2 m lengths of 50 mm galvanised pipe, with equal amounts above and below ground.

6.4 Calibration

6.4.1 Water Content Measurements

In a comprehensive analysis of the TDR method of determining water content, Topp et al. (1980) concluded that it was insensitive to variations in bulk density, temperature, salinity and the mineral composition of the soil. The impact of this conclusion was that a universal calibration equation could be applied to most soils. The calibration equation presented by Topp et al. (1980) is

$$\theta_v = -0.053 + 0.0292K_a - 0.00055K_a^2 + 0.0000043K_a^4$$

where K_a is the apparent dielectric constant.

Ledieu et al. (1986) in a similar analysis, presented a linear calibration equation

$$\theta_v = 0.1138\sqrt{K_a} - 0.1758$$

The two calibration equations are compared in Figure 6-8. Although Malicki et al. (1994) found that the dielectric constant was sensitive to bulk density, this has not yet been widely accepted.

A probe correction is required due to the fact that the waveguides are embedded a certain distance into the epoxy block. The TDR instruction 100, parameter 2, is used for this correction. The format of this parameter is 4XXX, where XXX is the correction value. For the CSI TDR probes installed at the site this value is 100. With the insertion of a Lexan spacer this correction needs to be altered. Consider the relationship

$$\sqrt{K_a} = \frac{L_a}{L} \text{ where } K_a \text{ is the apparent dielectric constant, } L_a \text{ the apparent probe length and } L$$

the physical probe length. If L_a can be determined for the Lexan, this value can be added to the probe correction. The dielectric constant of Lexan, being a polycarbonate, is 2.98 in the frequency range of interest. With a sheet thickness of 1.5 mm, L_a for this case would be approximately 2.5 mm. Therefore, the correction factor becomes 103.

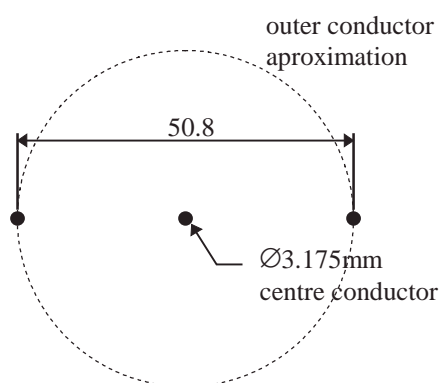


Figure 6-7: Co-axial conductor representation

6.4.2 EC measurements

The TDR probe is designed to represent a co-axial conductor. From the above diagram it can be seen that the outer two electrodes represent the shield (one of the references discusses the arrangement). The determination of the probe constant is discussed in the literature and can be calculated from electromagnetic wave theory or determined empirically. An empirical determination would involve placing the probe in multiple materials of known EC and regressing the instruction 100 output to the known EC value. To calculate the value,

$$K_p = \frac{Z_p}{120\pi L} \text{ with } Z_p = 60 \ln \frac{b}{d}$$

Here L is the probe length (m), b is the probe spacing (m) and d is the probe diameter (m). The units for the result are S/m (siemens/meter). These units can result in some small numbers

so you may wish to incorporate a scaling factor. For these probes, the probe spacing is 50.8 mm, the diameter is 3.175 mm, resulting in a probe impedance of 166Ω. With a probe length of 300 mm, the probe constant is 1.5, to obtain results in S m⁻¹.

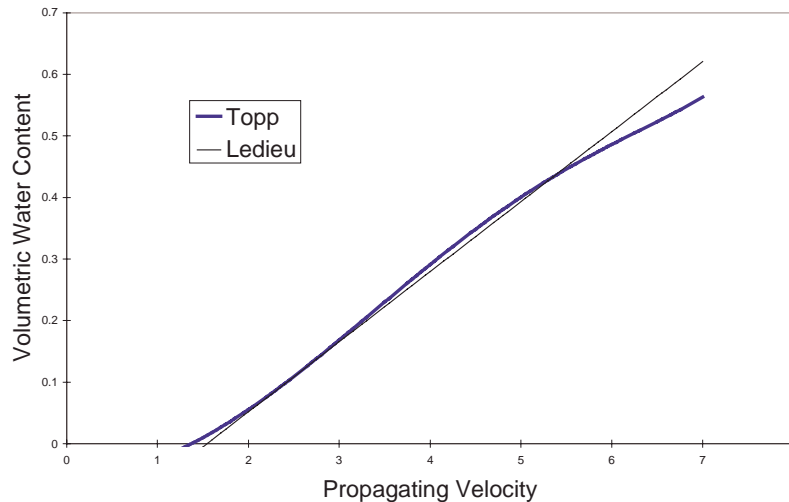


Figure 6-8: Comparison of calibration techniques

6.5 Program Operation

The program that controls the operation of the TDR system interacts with the operator through the use of flags. Depending on the status of the various flags the program will measure different parameters, or perform different operations. The list of the flags and their functions is shown in Table 6-3.

Table 6-3: Flag Operations

Flag #	setting	Operation
1	SET	Measure volumetric water content on all probes
2	SET	Measure electrical conductivity on all probes
3	SET	Store a waveform measurement on a single probe
8	CLEAR	Use Ledieu's calibration
8	SET	Use Topps calibration

The program performs a set of regular operations. Every hour the program sets flags 1 and 2, therefore measuring θ_v and σ . If the operator decides that a waveform is required to, for example check that the system is operation correctly, then flag 3 can be set, and the system will take the measurement once other pending tasks are cleared. For the water content measurements, the program will use one of the two calibration methods described earlier, depending on the status of flag 8.

For all TDR measurements the program uses the standard TDR extended options, except that the number of waveforms to collect before analysing is set to 128 (the maximum), which is high compared with the default of 4. It has been found that this greatly increases the precision

of the data. The trade-off for this increase in precision is that the measurement time increases from approximately 15 seconds for a waveform averaged 4 times, to 60 seconds for a waveform averaged 128 times. For the format of the output data see the sample measurement section.

When collecting the data via the mobile phone system it is advisable to use a small data block size, due to the poor reception strength. Although the phone system is quite powerful the site is located on the edge of the Tully reception area and so line noise occurs regularly. The TELCOM program, supplied with the CSI software PC208E, has good error checking protocols, however when it detects that garbage has been received it will attempt to get the data block resent. If after several retry attempts it is still unsuccessful the connection will be dropped. If the block size is reduced then less time will be wasted and fewer connections will be lost. The block size can be reduced by using the option /Bnn when using TELCOM from the command line. The /B denotes that it is to change the block size and nn is the block size to use (in number of locations to collect). The block size is in multiples of 27. A fairly reliable size is to use 54 locations. If a resend is required the program will drop back to 27 locations until several blocks are received correctly.

The power supply system for the TDR is designed to also power the tensiometer and soil thermal measurement. The power consumption of the three systems components are listed in Table 6-4. This table displays the operating power of each item, the hours per day that the item is operating, and the daily Amp-hour load for each item. The total Amp-hour load for the system is the sum of the individual components, and estimated at 9.4 Ah. Using a correction factor of 0.8, to allow for efficiency of the solar panel, and losses in the system, the total becomes 11.75 Ah. Using the worst case equivalent sun hours (ESH), discussed in the weather station section, of 1.7 hours, the solar array current requirements are calculated to be 6.9A, to operate the system without drawing from the battery reserve. The solar panel array chosen was two MSX-64 Solarex panels. These panels output 3.66 A each. The solar panels are mounted on the TDR stand, by using tie wire to connect to the top of the panel and the stand, and using a length of angle iron propped in between the bottom of the panel and the lower horizontal bar on the stand.

As discussed in the weather station section, the value of 1.7 is the worst case average for the month and there will be periods when the days will be less than this. To cope with this situation, an appropriate battery needs to be selected. The general rule used is that the battery should be sufficient to power the system for several days. As Tully often has extended periods of heavy rain we chose to make this five days and to set the maximum discharge as 50%. To meet these demands requires a battery capacity of more than 118 Ah.

Table 6-4: Power usage for TDR system

Equipment	Operating Power (W)	Hours/Day	Daily Amp-Hour Load
TDR CR10 datalogger			
quiescent	0.006	6	0.003
processing	0.156	12	0.156
measurement	0.42	6	0.21
1502B + peripherals	3.6	12	3.6
Thermal CR10 datalogger			0
quiescent	0.006	6	0.036
processing	0.156	12	0.156
measurement	0.42	6	0.21
Phone - activated	1.56	24	3.12
Phone - online	10.05	0.15	0.126
Modem	0.54	0.15	0.007
Tensiometer loggers x 3	0.90	24	1.8
Total			9.424

Output format

Array ID 1 - Status

Day, Hour/Minute, Battery voltage, internal temperature

Array ID 2 - Water content measurements

Day, Hour/Minute, Mux 1 Ch 3, Mux 1 Ch 4, Mux 1 Ch 5, Mux 1 Ch 6, Mux 2.1 Ch 1, Mux 2.1 Ch 2, Mux 2.1 Ch 3, Mux 2.1 Ch 4, Mux 2.1 Ch 5, Mux 2.1 Ch 6, Mux 2.1 Ch 7, Mux 2.1 Ch 8, Mux 2.2 Ch 1, Mux 2.2 Ch 2, Mux 2.2 Ch 3, Mux 2.2 Ch 4, Mux 2.2 Ch 5, Mux 2.2 Ch 6, Mux 2.2 Ch 7, Mux 2.2 Ch 8.

Array ID 3 - Electrical conductivity measurements

Day, Hour/Minute, Mux 1 Ch 3, Mux 1 Ch 4, Mux 1 Ch 5, Mux 1 Ch 6, Mux 2.1 Ch 1, Mux 2.1 Ch 2, Mux 2.1 Ch 3, Mux 2.1 Ch 4, Mux 2.1 Ch 5, Mux 2.1 Ch 6, Mux 2.1 Ch 7, Mux 2.1 Ch 8, Mux 2.2 Ch 1, Mux 2.2 Ch 2, Mux 2.2 Ch 3, Mux 2.2 Ch 4, Mux 2.2 Ch 5, Mux 2.2 Ch 6, Mux 2.2 Ch 7, Mux 2.2 Ch 8.

Array ID 4 - Waveform

Day, Hour/Minute, 251 Waveform points, distance to start of probe (m), distance per division, gain, offset, channel?

7. TENSIO METER SYSTEM

7.1 Introduction

The general operating principles of a tensiometer system are described in Goding et al. (1999). The system employed at the Rundown site consists of three loggers and 20 tensiometers. These are used to measure the soil matric potential profiles on the same four treatments as the TDR moisture contents are measured on. Each tensiometer probe corresponds to a TDR probe, being located at the same depth in the soil and separated by a horizontal distance of less than one meter. These measurements in combination will provide information on the water retention properties through the root profile.

7.2 Installation

The instruments are installed at an angle of 45 degrees (for the same reasons as the TDR), with each instrument housed in a section of PVC tubing. This PVC tube extends 400 mm above the soil surface. As the access tube has been well installed with careful sealing around the tube at the soil surface, it allows sensible measurements even when surface ponding occurs, as there is no preferential flow down the side of the tubes.

The tensiometer head is connected to a length of electrical conduit. The connection is made by using a female conduit connector, the same size as that used in the instrument. The purpose of this tube is twofold; firstly to provide access for the instrument, allowing it to be inserted and removed as required, and secondly, to provide the pressure vent to atmospheric pressure. The conduit connectors are fitted with an internal o-ring and teflon thread tape to provide a waterproof seal. The top of the tube is sealed with a PVC end cap fitted with a PVC hose connector. Over the connector is placed a flexible conduit that has been placed over the connector to carry the cable back to the main PVC tube, as for the TDR system.

As shown in Figure 7-1 the tensiometer does not perform a point measurement but rather averages over a depth range. This actual range depends on the length of the ceramic cup, multiplied by 0.71 as the cup has been installed on a 45° angle.

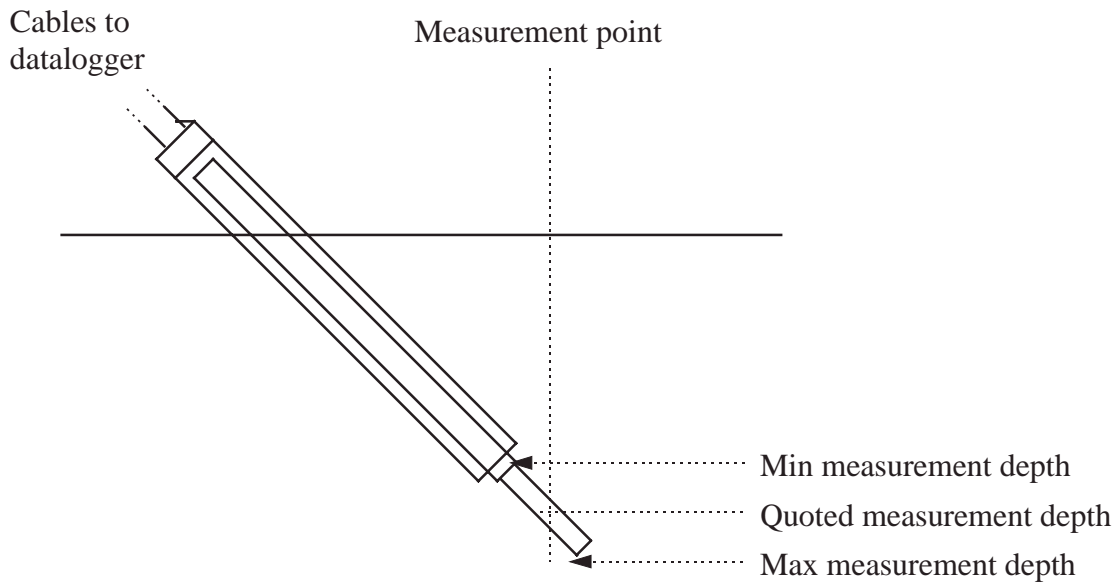


Figure 7-1: Tensiometer positioning showing measurement depths

Because each data logger is capable of measuring outputs from only seven tensiometers, three loggers are used to obtain measurements from the four plots. One logger is placed in the multiplexer box between plots 7 and 9 (logger 1 measures all of plot 7), while two are placed in between plots 8 and 10 (logger 2, measures all of plot 8, logger 3 measures all of plot 10). The bare plot, plot 9, is measured using the spare channel from each logger. Details of the tensiometers and logger usage are given in Table 7-1.

Table 7-1: Tensiometer depths and logger usage (p=plot)

Channel	Logger 1	Logger 2	Logger 3
1	p7, 10 cm	p8, 10 cm	p10, 10 cm
2	p7, 30 cm	p8, 30 cm	p10, 30 cm
3	p7, 60 cm	p8, 60 cm	p10, 60 cm
4	p7, 90 cm	p8, 90 cm	p10, 90 cm
5	p7, 130 cm	p8, 130 cm	p10, 130 cm
6	p9, 90 cm	p9, 30 cm	p9, 10 cm
7	p9, 130 cm	p9, 60 cm	Not Used

Each data loggers communication cable is permanently wired into the system, with the ports to connect to the computer for downloading located inside the TDR enclosure. This allows all weather access to the system as the TDR enclosure is covered by a galvanised sheet roof, providing both rain and sun protection. The multiplexer boxes have been sealed with silicon because of problems with both poor weatherproofing and ant invasions, so they are not readily accessible.

The tensiometers operate off the same power system as that for the TDR. The tensiometers are currently not connected to the mobile phone system so data can only be collected by down loading at the site.

7.3 Maintenance

The main points to remember from a maintenance point of view are that the o-rings need to be replaced on a regular basis or when perished and that the instrument needs to be recharged with de-aired water as required. One difficulty with the remote nature of the site is that it is often impractical to get measurements when the site undergoes rapid drying as the tensiometers quickly dry out and lose their connectivity with the soil. This requires that the tensiometers be recharged before reliable readings can be obtained following a dry period.

8. PIEZOMETER SYSTEM

A piezometer is an instrument used to measure the free water level in soils with perched or regional water tables. They consist of a tube with a sieve access at the base that allows water to enter and leave the tube. The position of the water level in the tube can be monitored, manually or automatically, to provide data on water table depths below the soil surface. Details of the piezometer system used at the Rundown site are given by Goding and Bristow (2000)

9. COMMUNICATIONS SYSTEM AND DATA MANAGEMENT

Most of the instrumentation at the site is connected to the phone system so that data collection can be automated as much as possible. This is achieved through the use of two mobile phones installed in the TDR and weather station systems. The aim is to have all instrumentation linked back to the laboratory so that data processing and quality control can be carried out regularly.

9.1 Error checking

One advantage of telecommunications is that it is possible to implement a strict automated error checking routine which would detect instrument failure when it occurs, rather than the associated delay when only checking instruments periodically. Note however that this does not eliminate the need for annual calibrations and regular maintenance of the instrumentation. An automated error checking routine as shown schematically in Figure 9-1 has the following features

- download data automatically and periodically
- sort down loaded data into appropriate files
- validate data - check ranges, rates of change, outliers, loss of sequence etc...
- allow visual inspection

The downloading and sorting of data automatically alleviates the workload associated with periodic visits when often months of data may be collected and sorted manually. The validation of the data can be automated to a large degree, where, for example the weather data is examined to find anomalies. Such inconsistencies in data would be:

- The rain gauge registers tips yet the solar flux indicates bright sunshine, and relative humidity is low
- The battery voltage is increasing yet the solar flux is low
- The soil temperature has greater daily fluctuations than the air temperature

Some examples of instrument or datalogger failure would be:

- Instrument exceeds expected maximum or minimums. For example Solar radiation exceeds solar constant or is less than zero, Anemometer is reading cyclonic wind speeds yet no cyclone is expected.

- Instrument output exceeds datalogger input limits. For example air temperature measures 6999 (off scale).
- Program signature changes indicating data logger failure or program modification.
- Battery voltage falls below 12V.

The above problems can be easily detected using the same software which down loads and sorts the data. For a more critical analysis a skilled human operator is required.

A computer program has been written to perform the above listed tasks and error checks. This program was written using QuickBASIC 4.5.

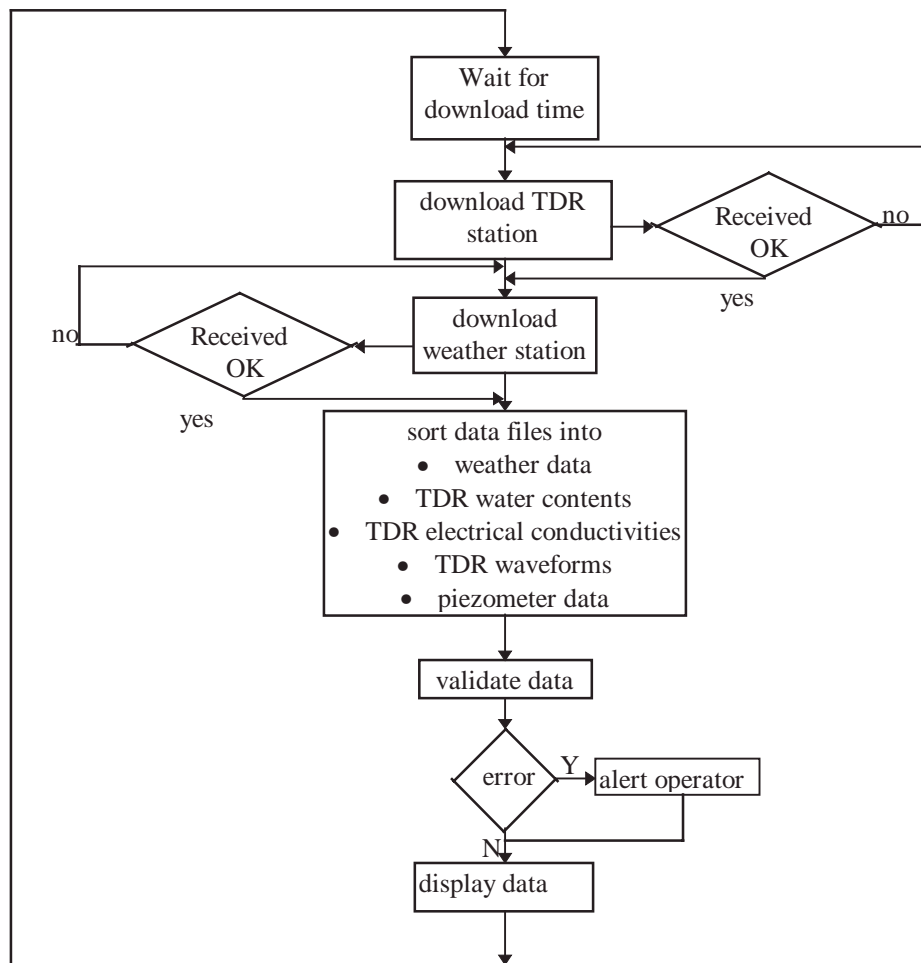


Figure 9-1: Schematic showing key features of an automatic downloading and error checking program

9.2 Data Organisation

The program organises the data into small, weekly data file. These can then be gathered together to form monthly, or yearly files. The organisation of the dates into separate files is shown in Table 9-1.

Table 9-1 - File organisation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

Add 1 to unshaded values during leap years

File A	File B	File C	File D	File E
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The naming convention for the files are

stnmmyyf.DAT

where

- stn is the station name. For the TDR station this is TDR and for the Weather station this is WTR.
- mm is the month, ie: 01 is January, 02 is February etc...
- yy is the year, ie: 97 is 1997, 98 is 1998 etc...
- f is the file extension listed in
- .

For example, a TDR weekly file, from days of year 32 to 38 inclusive, in year 1997 will have the filename TDR0297A.DAT.

10. EXAMPLE FIELD MEASUREMENTS

Example data from field instruments are given in the next several figures as a means of illustrating the data that obtained from the Rundown site.

Data from the weather station (rainfall and computed Penman-Monteith evapotranspiration) are shown in Figure 10-1 for June 98. There were two main rainfall events, 34 mm and 50 mm, with several 0.2 mm days, giving 86 mm of rain for the month. Total calculated potential evapotranspiration for the month was 71 mm. Rainfall from surrounding stations ranged from 48 to 157 mm for June 98. The measured ET at South Johnstone averaged 3.3 mm per day with a total of 99 mm for the month.

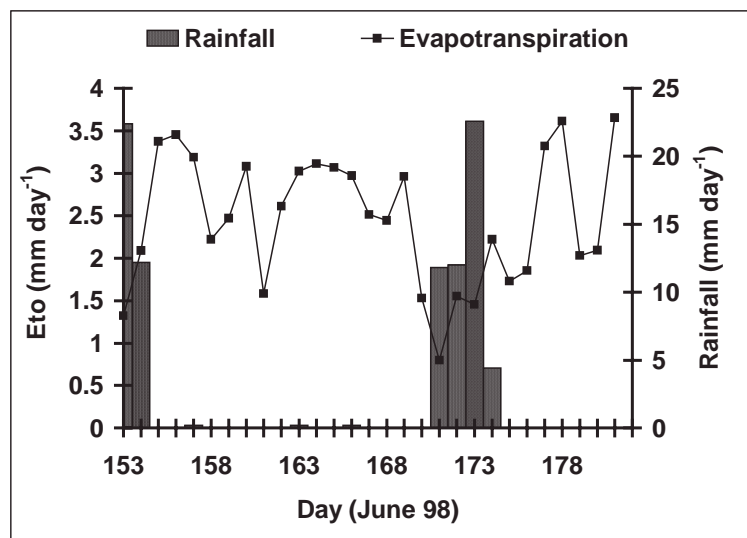


Figure 10-1: Rainfall and potential evapotranspiration at the Rundown site for June 98

Air and soil temperature are shown in Figure 10-2 as a function of time. They show the lag and diurnal variation typical of temperatures in this region.

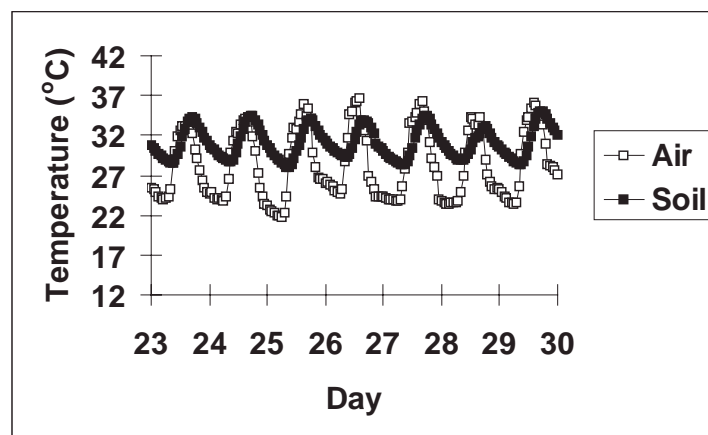


Figure 10-2: Air and soil temperature showing typical lags and diurnal variation

Evapotranspiration as a function of time is shown in Figure 10-3. Here one sees changes from day to day and variation within a day due to local variations in cloud cover and other climatic conditions.

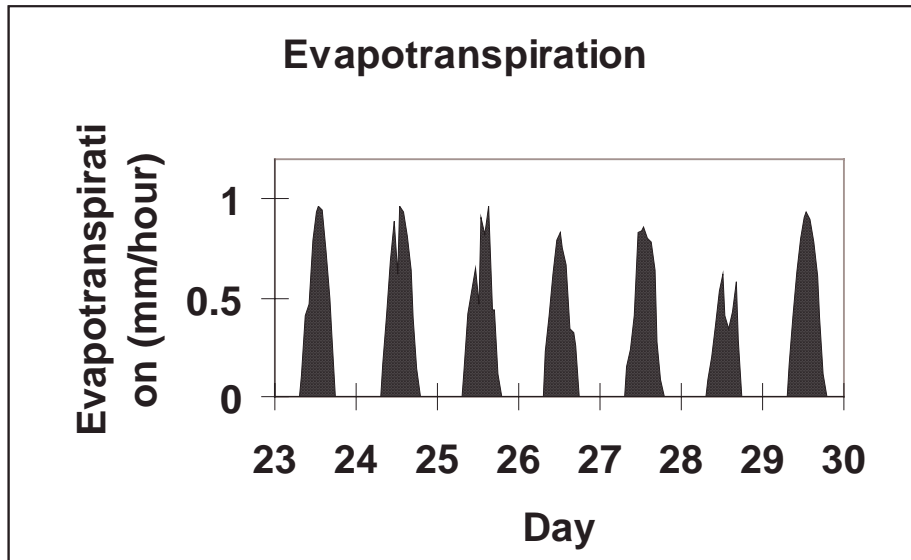


Figure 10-3: 'Potential' evapotranspiration as a function of time

Vapor pressure and relative humidity as a function of time are shown in Figure 10-4. We see a fairly stable vapor pressure and humidity that changes significantly through the day as would be expected. It is also interesting to note that the humidity reaches 100% by early morning on all days, indicating that the air temperature is cooling to dew point, and one would expect to see dew at the site.

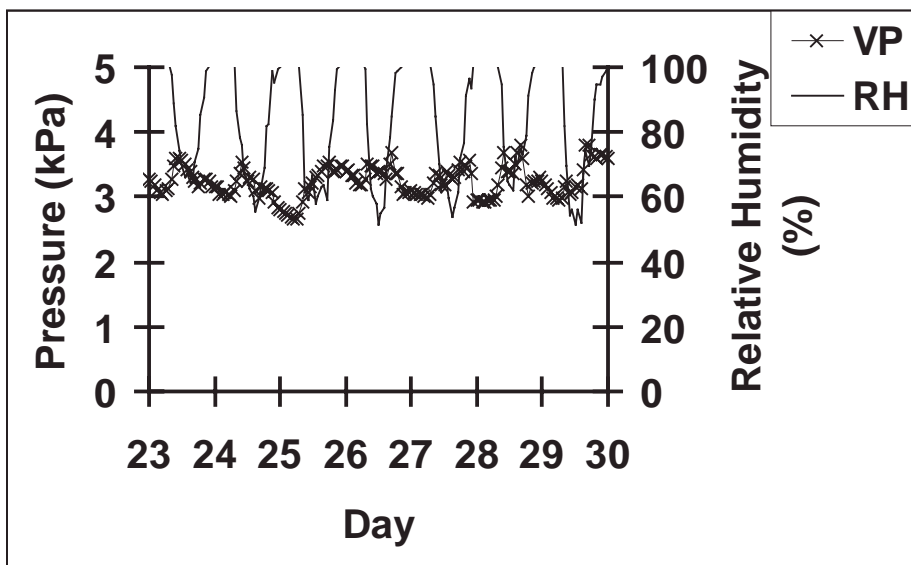


Figure 10-4: Vapor pressure and relative humidity

Solar radiation as a function of time is given in Figure 10-5 and again one sees the variation from day to day and within a day.

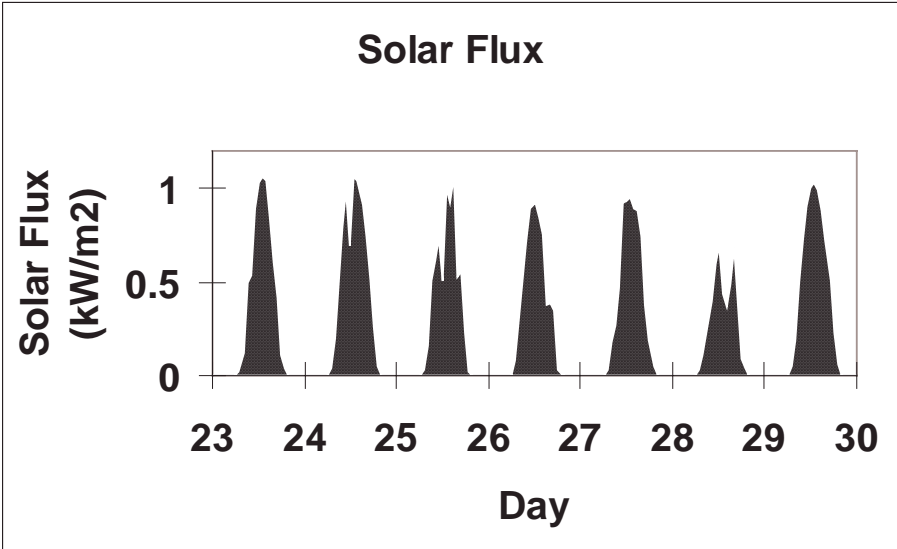


Figure 10-5: Solar radiation as a function of time

Wind speed as a function of time is shown in Figure 10-6. Wind speed seldom approached 5 m/s and showed the typical diurnal variation, with highest windspeed usually occurring early to late afternoon.

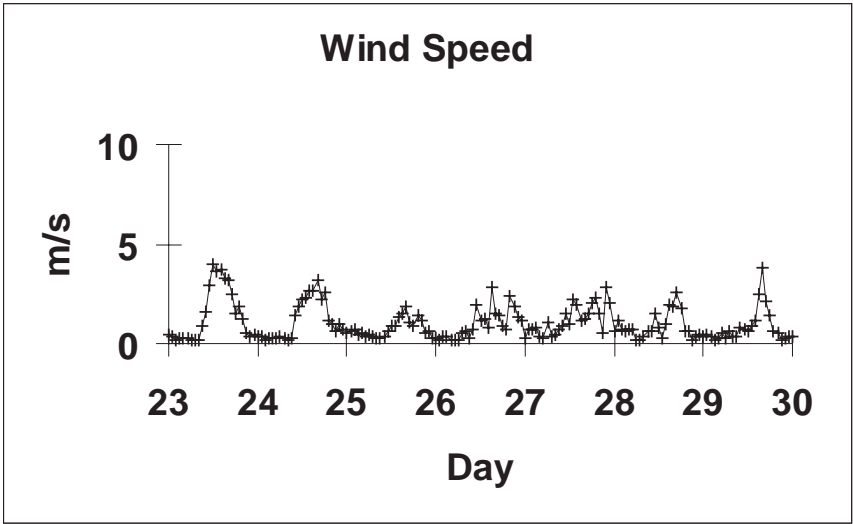


Figure 10-6: Wind speed as a function of time

Example soil water data obtained using the TDR system are given in Figure 10-7 for the bare plot and for the cane plot with residue retained (note there is no residue the first plant year). The data demonstrate typical diurnal fluctuations, a decrease during the drying period and wetting due to rainfall. Note there is some drying at 60 cm in the cropped plot suggesting some root uptake, but very little change in water content at this depth in the bare plot. Water contents at the 90 and 130 cm depths show essentially no change which is the case for most of the year. Based on the data presented it appears that it may be difficult to use water extraction patterns at this site as a means of determining root growth and activity, and other avenues to do this are going to have to be explored.

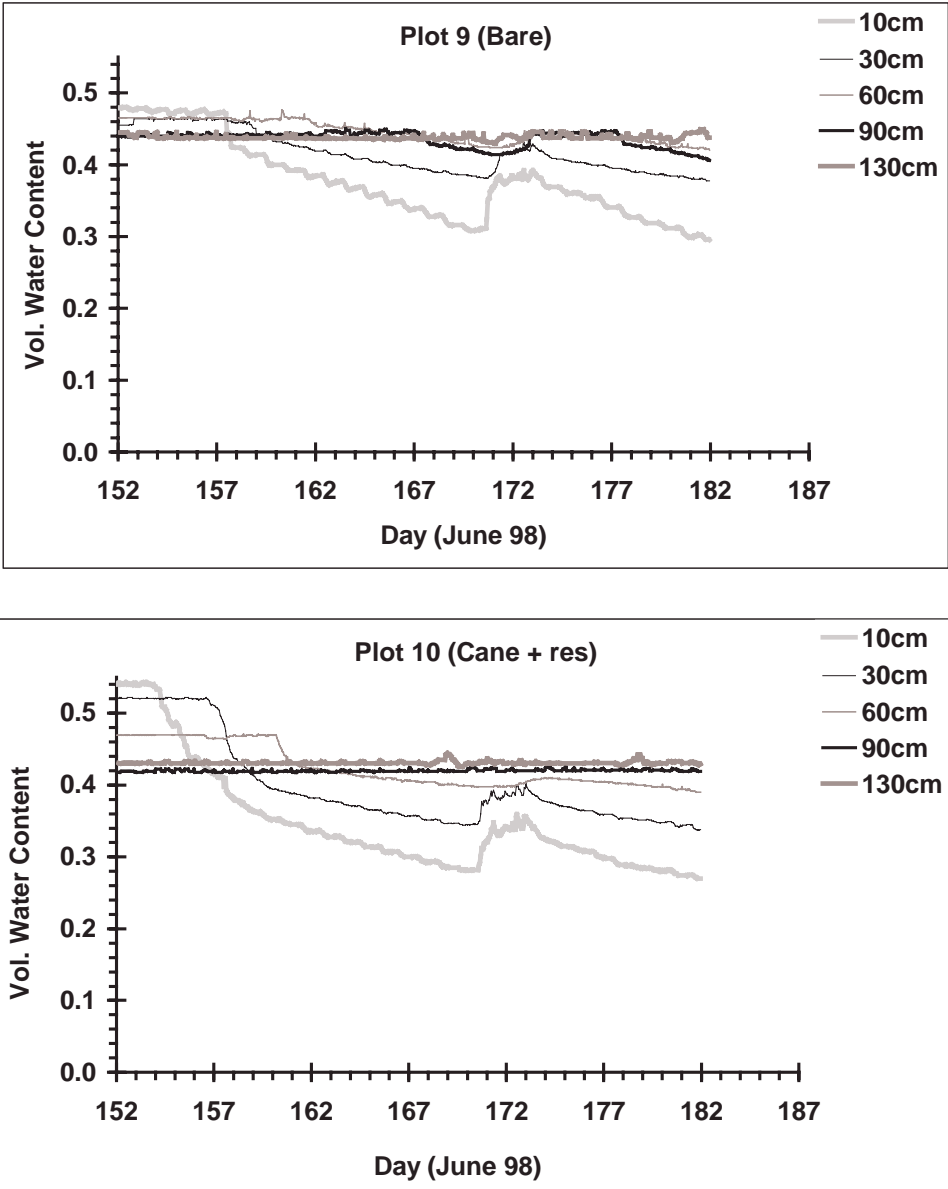


Figure 10-7: Soil water content measured using TDR for the Bare and residue retained treatments for June 98

Soil electrical conductivity as a function of time as demonstrated in Figure 10-8. Here we see changes in conductivity at the shallow depths as the soil dries, and then stabilisation in EC values.

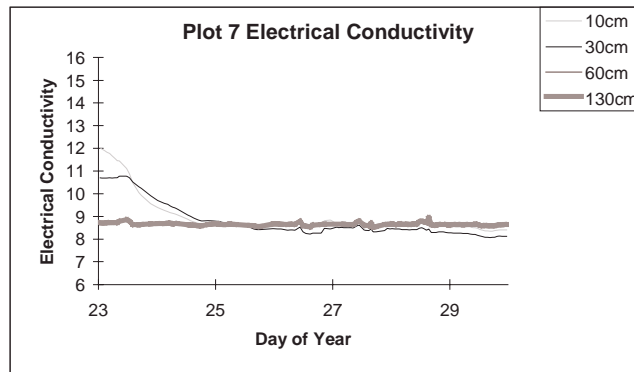


Figure 10-8: Soil electrical conductivity as a function of time

Water table depths as a function of time are demonstrated in Figure 10-9 for the four piezometers near the centre of the site. More detailed presentation and discussion of the groundwater system is given by Goding and Bristow (2000)

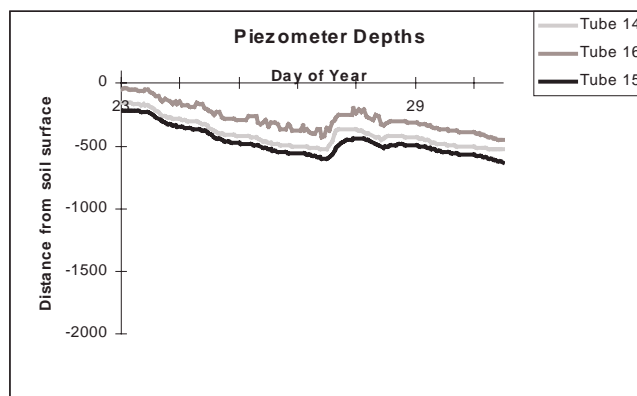


Figure 10-9: Water table depth as a function of time

The data presented above are typical of what can be obtained from monitoring systems such as those installed at the Rundown site. The data obtained play a critical role in helping with the analysis and interpretation of field experimental results, and in establishing initial conditions, boundary conditions, and test data for running simulation analyses. The key to much of this sort of work is identifying which data will be needed, and in obtaining sufficiently good quality data to add value to both the measurement and modeling components of the research work.

Although difficulties caused by waterlogging at the Rundown site and the early closure of the site due to restructuring of research programs meant that the original objectives of the Rundown experiment were not fully realised, the experiment did through the time it ran provide useful insights into aspects of sugarcane production in very wet environments. It was also very useful in highlighting the need for improved understanding of a wide range of issues associated with shallow fluctuating ground water systems.

11. ACKNOWLEDGMENTS

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