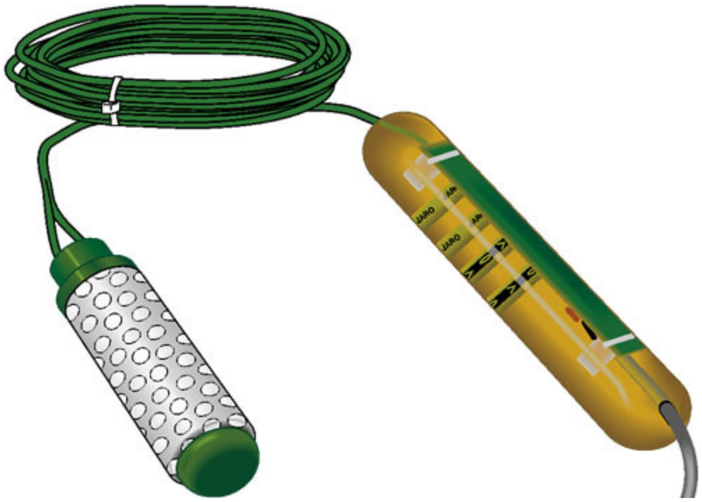
INSTRUCTION MANUAL

Models 253-L and 257-L (Watermark 200) Soil Matric Potential Sensors

Revision: 3/09



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PLEASE READ FIRST

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. (CSI) primarily for the US market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area: 1 in^2 (square inch) = 645 mm^2

Length: 1 in. (inch) = 25.4 mm
1 ft (foot) = 304.8 mm
1 yard = 0.914 m
1 mile = 1.609 km

Mass: 1 oz. (ounce) = 28.35 g
1 lb (pound weight) = 0.454 kg

Pressure: 1 psi (lb/in2) = 68.95 mb

Volume: 1 US gallon = 3.785 litres

In addition, part ordering numbers may vary. For example, the CABLE5CBL is a CSI part number and known as a FIN5COND at Campbell Scientific Canada (CSC). CSC Technical Support will be pleased to assist with any questions.

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Models 253-L and 257-L (Watermark 200) Soil Matric Potential Sensors

1. General Description

The Watermark 200 (CSI sensor Models 253-L and 257-L) soil matric potential sensor provides a convenient method of estimating water potential of wetter soils in the range of 0 to 200 kPa with a Campbell Scientific datalogger. Supported dataloggers include the CR1000, CR3000, CR800 Series, CR10(X), CR23X, CR510, 21X and CR7. The CR200 series datalogger is not compatible because it cannot provide AC excitation to the sensor.

This manual refers to Model 253-L and Model 257-L as the 253 and 257 respectively.

The difference between the 253 and the 257 is that there is a capacitor circuit and completion resistor installed in the 257 cable (Figure 1-1) to allow for direct connection to a datalogger, while the 253 does not have any added circuitry. For applications requiring many sensors on an analog multiplexer, the 253 is used and one or more completion resistors are connected to the datalogger wiring panel. A capacitor circuit is not required for the 253 on a multiplexer because the electrical connection between the sensor and the datalogger is interrupted when the multiplexer is deactivated. Any potential difference between the datalogger earth ground and the electrodes in the sensor is thus eliminated.

The Watermark block estimates matric potential. For applications that require high accuracy, call a Campbell Scientific applications engineer for information on precision matric potential measurement systems.

The Watermark 200 consists of two concentric electrodes embedded in a reference granular matrix material. The granular matrix material is surrounded by a synthetic membrane for protection against deterioration. An internal gypsum tablet buffers against the salinity levels found in irrigated soils.

If cultivation practices allow, the sensor can be left in the soil all year, eliminating the need to remove the sensor during the winter months.

NOTE The black outer jacket of the cable is Santoprene® rubber. This compound was chosen for its resistance to temperature extremes, moisture, and UV degradation. However, this jacket will support combustion in air. It is rated as slow burning when tested according to U.L. 94 H.B. and will pass FMVSS302. Local fire codes may preclude its use inside buildings.

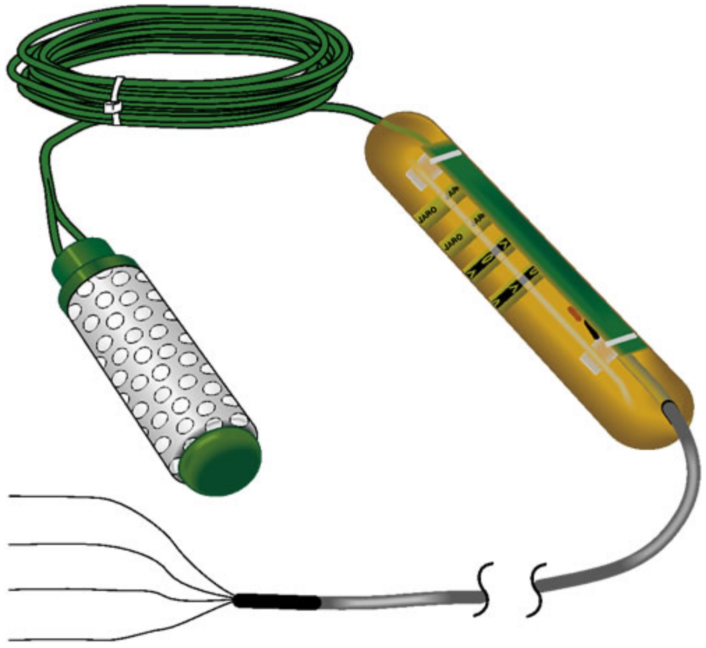

FIGURE 1-1. 257 Soil Matric Potential Sensor with capacitor circuit and completion resistor installed in cable. Model 253 is the same, except that it does not have completion circuitry in the cable.

2. Specifications

Range:	0 to 200 kPa
Dimensions:	8.26 cm (3.25”) long with a 1.91 cm (0.75”) diameter
Weight:	363 g (0.8 lbs)

3. Installation and Removal

Placement of the sensor is important. To acquire representative measurements, avoid high spots, slope changes, or depressions where water puddles. Typically, the sensor should be located in the root system of the crop.

1. Soak the sensors overnight in irrigation water. Always install a wet sensor. If time permits, allow the sensor to dry for 1 to 2 days after soaking, and repeat the soak/dry cycle twice to improve sensor response

2. Make a sensor access hole to the depth required with a 22 mm (7/8”) diameter rod. Fill the hole with water and push the sensor to the bottom of the hole. Very coarse or gravelly soils may require an oversized hole (25 to 32 mm) to prevent abrasion damage to the sensor membrane. In this case, you will need to “grout in” the sensor with a slurry made from the sample soil to get a snug fit in the soil.

Snug fit in the soil is most important. Lack of a snug fit is the premier problem with sensor effectiveness. In gravelly soils, and with deeper sensors, sometimes it is hard to get the sensor in without damaging the membrane. The ideal method of making the access hole is to have a “stepped” tool that makes an oversized hole for the upper portion and an exact size hole for the lower portion. In either case, the hole needs to be carefully backfilled and tamped down to prevent air pockets which could allow water to channel down to the sensor.

A length of ½” class 315 PVC pipe fits snugly over the sensor collar and can be used to push in the sensor.

You can leave the PVC in place with the wires threaded through the pipe and the open end taped shut (duct tape is adequate). This practice also makes it easy to remove sensors used in annual crops. When doing this, solvent weld the PVC pipe to the sensor collar. Use PVC/ABS cement on the stainless steel sensors with the green top. Use clear PVC cement only on the PVC sensors with the gray top.

3. When removing sensors prior to harvest in annual crops, do so just after the last irrigation when the soil is moist. Do not pull the sensor out by the wires. Careful removal prevents sensor and membrane damage.

4. When sensors are removed for winter storage, clean, dry, and place them in a plastic bag.

4. Wiring

4.1 General Wiring

4.1.1 257 Wiring

The 257 wiring diagram is illustrated in Figure 4-1. The red lead is inserted into any single-ended analog channel, the black lead into any excitation channel, and the white lead to any Analog Ground (CR10(X), CR510) or Ground (CR1000, CR3000, CR800 series, CR23X, 21X, CR7).

Installed in the cable is a capacitor circuit that stops galvanic action due to the differences in potential between the datalogger earth ground and the electrodes in the block. Such a difference in potential would cause electrical current flow and lead to rapid deterioration of the sensor block.

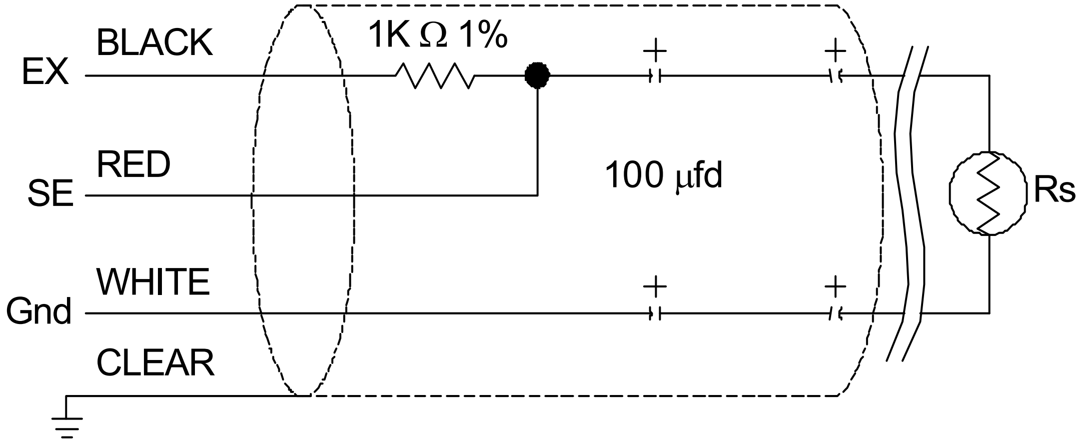

FIGURE 4-1. 257 Schematic

4.1.2 253 Wiring

An example of wiring for the 253 is illustrated in Figure 4-2. The 253 is for use with analog multiplexers including models AM32, AM416, and AM16/32 series. Sensor leads are connected to channels on the multiplexer and the common channels of the multiplexer are connected to the datalogger wiring panel. The sensor has two green leads. One of the green leads has a ridged strip while the other is smooth. Campbell Scientific connects a white lead to the ridged green lead, a black lead to the smooth green lead, and adds clear shield wire that is not connected to the sensor. The white lead connects to the high end of a multiplexer channel, the black lead to the low end of the multiplexer channel, and the clear lead to a multiplexer ground channel. A 1000 ohm resistor at the datalogger wiring panel is used to complete the half bridge circuitry.

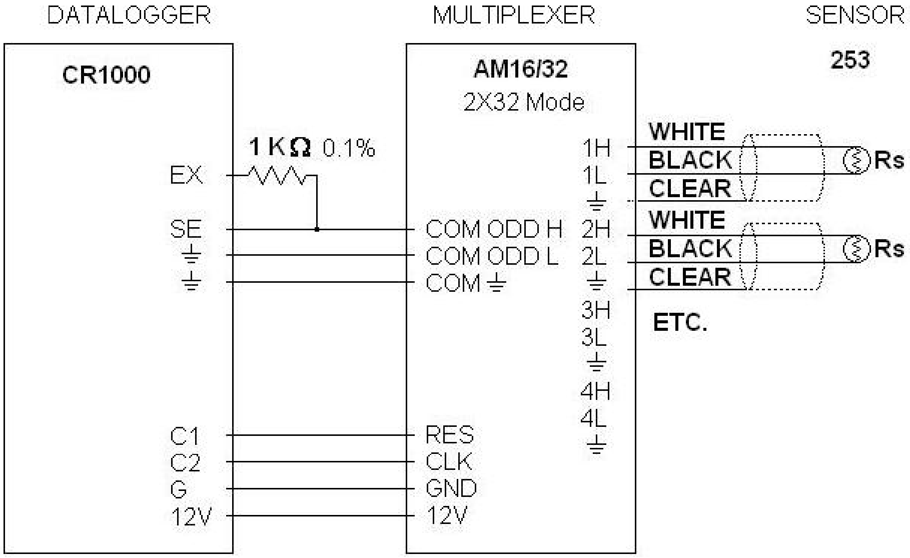

FIGURE 4-2. 253 Wiring Example

4.2 Wiring For Example Programs

The example programs in section 6 include programming for one or more 107 soil temperature probes which are needed for temperature correction of the resistance readings taken with the 253 and 257. Wiring for that probe is included in the following tables.

4.2.1 Wiring for 257 Example Programs

TABLE 4-1. Wiring for Programming Example #1

Sensor	**Wire**	**Function**	**Channel**
107	Black	Excitation	EX1
	Red	Positive Signal	SE1 (1H)
	Purple	Negative Signal	Ground
	Clear	Shield	Ground
257	Black	Excitation	EX2
	Red	Positive Signal	SE2 (1L)
	White	Negative Signal	Ground
	Clear	Shield	Ground

TABLE 4-2. Wiring for Programming Example #2

Sensor	**Wire**	**Function**	**Channel**
107	Black	Excitation	E1
	Red	Positive Signal	SE1 (1H)
	Purple	Negative Signal	AG
	Clear	Shield	G
257	Black	Excitation	E2
	Red	Positive Signal	SE2 (1L)
	White	Negative Signal	AG
	Clear	Shield	G

4.2.2 Wiring for 253 Example Programs

TABLE 4-3. Wiring for Programming Example #3

CR1000	AM16/32	Sensor	Wire	Function
12V	12V			
G	GND			
C1	RES			
C2	CLK			
VX1 or EX1	COM ODD H			
SE1 (1H)	COM ODD L			
Ground	COM GROUND			
SE2 (1L)	COM EVEN H			
Ground	COM EVEN L			
1000 ohm resistor from SE2 to EX2				
	1H	107	Black	Excitation
	1L		Red	Positive Signal
	GROUND		Purple	Negative Signal
	GROUND		Clear	Shield
	2H	253	White	Positive Signal
	2L		Black	Negative Signal
	GROUND		Clear	Shield
	Continue wiring sensors to multiplexer with 107 probes attaching to odd numbered channels and 253 sensors to even numbered channels. AM16/32 in 4x16 mode.			

TABLE 4-4. Wiring for Programming Example #4

CR10X	AM16/32	Sensor	Wire	Function
12V	12V			
G	GND			
C1	RES			
C2	CLK			
E1	COM ODD H			
SE1 (1H)	COM ODD L			
AG	COM GROUND			
SE2 (1L)	COM EVEN H			
AG	COM EVEN L			
1000 ohm resistor from SE2 to E2				
	1H	107	Black	Excitation
	1L		Red	Positive Signal
	GROUND		Purple	Negative Signal
	GROUND		Clear	Shield
	2H	253	White	Positive Signal
	2L		Black	Negative Signal
	GROUND		Clear	Shield
	Continue wiring sensors to multiplexer with 107 probes attaching to odd numbered channels and 253 sensors to even numbered channels. AM16/32 in 4x16 mode.			

5. Description of Measurement

The 253 and 257 sensors are measured with an AC Half Bridge measurement followed by a sensor resistance calculation.

This section will distinguish between CRBasic dataloggers and Edlog dataloggers. CRBasic dataloggers refer to the CR1000, CR3000, and CR800 series. Edlog dataloggers include the 21X, CR10(X), CR510, CR23X, and CR7.

5.1 CRBasic Dataloggers

5.1.1 BRHalf instruction

CRBasic dataloggers use the BRHalf instruction with the RevEx argument set to True to excite and measure the 253 and 257. The result of the BRHalf instruction is the ratio of the measured voltage divided by the excitation voltage.

Table 5-1 shows the excitation and voltage ranges used with the CRBasic dataloggers.

TABLE 5-1. Excitation and Voltage Ranges for CRBasic Dataloggers

Datalogger	mV excitation	Full Scale Range
CR800 Series	250	± 250 mV
CR1000	250	± 250 mV
CR3000	200	± 200 mV

5.1.2 Resistance Calculation

Sensor resistance is calculated with a CRBasic expression. If the result of the BRHalf instruction is assigned to a variable called kOhms, then the resistance would be determined with the expression:

kOhms = 1 * (kOhms/(1-kOhms))

where the 1 represents the value of the reference resistor in k-Ohms and can be omitted from the expression if desired. This expression is the equivalent of the Edlog instruction 59 described in section 5.2.2.

5.2 Edlog Dataloggers

5.2.1 Program Instruction 5

Edlog dataloggers use instruction 5, AC Half Bridge, to excite and measure the 253 and 257. Recommended excitation voltages and input ranges for Edlog dataloggers are listed in Table 5-2.

TABLE 5-2. Excitation and Voltage Ranges for Edlog Dataloggers

Datalogger	mV excitation	Range Code	Full Scale Range
21X	500	14	± 500 mV
CR10(X)	250	14	± 250 mV
CR510	250	14	± 250 mV
CR23X	200	13	± 200 mV
CR7	500	16	± 500 mV

5.2.2 Program Instruction 59

Instruction 59, Bridge Transform, is used to output sensor resistance (R_s). The instruction takes the AC Half Bridge output (V_s/V_x) and computes the sensor resistance as follows:

$$R_s = R_1\left(\frac{X}{(1-X)}\right)$$

Where X = V_s/V_x (output from Instruction 5).

A multiplier of 1, which represents the value of the reference resistor in kΩ, should be used to output sensor resistance (R_s) in terms of kΩ.

5.3 Calculate Soil Water Potential

The datalogger can calculate soil water potential (kPa) from the sensor resistance (Rs) and soil temperature (Ts). See Table 5-3.

The need for a precise soil temperature measurement should not be ignored. Soil temperatures vary widely where placement is shallow and solar radiation impinges on the soil surface. A soil temperature measurement may be needed in such situations, particularly in research applications. Many applications, however, require deep placement (12 to 25 cm) in soils shaded by a crop canopy. A common practice for deep or shaded sensors is to assume the air temperature at sunrise will be close to what the soil temperature will be for the day.

5.3.1 Linear Relationship

For applications where soil water potential is in the range of 0 to 200 kPa, water potential and temperature responses of the 257 can be assumed to be linear (measurements beyond 125 kPa have not been verified, but work in practice).

The following equation normalizes the resistance measurement to 21 ºC.

$$R_{21} = \frac{R_s}{1-\left(0.018 * dT\right)}$$

where

R_{21} = resistance at 21 ºC

R_s = the measured resistance

$dT = T_s - 21$

T_s = soil temperature

Water potential is then calculated from R_{21} with the relationship,

$$SWP = 7.407 * R_{21} - 3.704$$

where SWP is soil water potential in kPa

5.3.2 Non-Linear Relationship

For more precise work, calibration and temperature compensation in the range of 10 to 100 kPa has been refined by Thompson and Armstrong (1987), as defined in the non-linear equation,

$$SWP = \frac{R_s}{0.01306[1.062(34.21 - T_s + 0.01060 T_s^{\,2}) - R_s]}$$

where SWP is soil water potential in kPa

TABLE 5-3. Comparison of Estimated Soil Water Potential and R_s at 21 °C

kPa (Non-Linear Equation)	kPa (Linear Equation)	(R_s) kOhms
	3.7	1.00
9	11	2.00
14	18	3.00
20	26	4.00
27	33	5.00
35	41	6.00
45	48	7.00
56	56	8.00
69	63	9.00
85	70	10.00
105	78	11.00
	85	12.00
	92	13.00
	99	14.00
	107	15.00
	115	16.00
	122	17.00
	129	18.00
	144	20.00
	159	22.00
	174	24.00
	188	26.00
	199	27.50

5.3.3 Soil Water Matric Potential in Other Units

To report measurement results in other units multiply the result from the linear or non-linear equation by the appropriate conversion constant from table 5-4.

TABLE 5-4. Conversion of Matric Potential to Other Units

Desired Unit	Multiply Result By
kPa	1.0
MPa	0.001
Bar	0.01

6. Example Programs

This section is for users who write their own datalogger programs. A datalogger program to measure the 253 or 257 can be created using Campbell Scientific's Short Cut Program Builder software (SCWin). You do not need to read this section to use Short Cut.

NOTE Short Cut requires that you add a soil temperature sensor before adding a 253 or 257 sensor. This is needed because there is a temperature correction factor in the equations that convert sensor resistance. In these examples, a 107-L temperature probe is used to measure soil temperature.

These examples show programs written for the CR1000 and the CR10X dataloggers. With minor changes to excitation and voltage ranges, the code in the CR1000 examples will work with all compatible CRBasic dataloggers (see Table 5-1). The code in the CR10X examples will work with all Edlog dataloggers as long as the correct excitation and voltage range is chosen for the P5 instruction (see Table 5-2).

6.1 257 Program Examples

6.1.1 Program Example #1 — CR1000 with one 107 and one 257

The following example demonstrates the programming used to measure the resistance (kΩ) of one 257 sensor with the CR1000 datalogger. A 107 temperature probe is measured first for temperature correction of the 257 reading. The linear equation is used and the non-linear equation is included in the program notes. To use the non-linear equation, remove the linear equation from the program and uncomment the non-linear equation. Voltage range codes for other CRBasic dataloggers are shown in Table 5-1. Sensor wiring for this example is shown in Table 4-1.

```
'CR1000

Public T107_C, kOhms, WP_kPa

Units T107_C=Deg C
Units kOhms=kOhms
Units WP_kPa=kPa

DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Average(1,T107_C,FP2,False)
  Sample(1,WP_kPa,FP2)
EndTable

BeginProg
  Scan(1,Sec,1,0)
    '107 Temperature Sensor measurement T107_C:
    Therm107(T107_C,1,1,1,0,_60Hz,1.0,0.0)
    '257 Soil matric potential Sensor measurements:
    BrHalf(kOhms,1,mV250,2,Vx2,1,250,True,0,250,1,0)
```

```
    kOhms=kOhms/(1-kOhms)
    'Equation for linear (0 to 200 kPa) relationship
    WP_kPa=7.407*kOhms/(1-0.018*(T107_C-21))-3.704
    'For non-linear (10 to 100 kPa) relationship, use the following equation:
    'WP_kPa=kOhms/(0.01306*(1.062*(34.21-T107_C+0.01060*T107_C^2)-kOhms))
    CallTable(Hourly)  'Call Data Table and Store Data
  NextScan
EndProg
```

6.1.2 Program Example #2 — CR10X with One 107 and One 257

The following example demonstrates the programming used to measure the resistance (kΩ) of one 257 sensor with the CR10X datalogger. A 107 temperature probe is measured first for temperature correction of the 257 reading. The linear relationship between sensor resistance and water potential in the 0 to 200 kPa range is used. For Edlog programming of the non-linear relationship, see program example #4. Voltage range codes for other Edlog dataloggers are shown in Table 5-2. Sensor wiring for this example is shown in table 4-2

```
;{CR10X}

*Table 1 Program
  01:  1.0000        Execution Interval (seconds)

;Measure soil temperature with 107 sensor
1:  Temp (107) (P11)
  1:   1             Reps
  2:   1             SE Channel
  3:   1             Excite all reps w/E1
  4:   1             Loc [ Tsoil_C   ]
  5:   1.0           Multiplier
  6:   0.0           Offset

;Measure 257 block resistance
2:  AC Half Bridge (P5)
  1:   1             Reps
  2:   14            250 mV Fast Range
  3:   2             SE Channel
  4:   2             Excite all reps w/Exchan 2
  5:   250           mV Excitation
  6:   2             Loc [ kOhms   ]
  7:   1             Multiplier
  8:   0             Offset

;Convert Half Bridge reading to kOhms
3:  BR Transform Rf[X/(1-X)] (P59)
  1:   1             Reps
  2:   2             Loc [ kOhms   ]
  3:   1             Multiplier (Rf)
```

```
;Calculate dT = T -21
4:  Z=X+F (P34)
   1:   1              X Loc [ Tsoil_C   ]
   2:   -21            F
   3:   4              Z Loc [ CorFactr  ]

;Calculate (0.018 * dT)
5:  Z=X*F (P37)
   1:   4              X Loc [ CorFactr  ]
   2:   0.018          F
   3:   4              Z Loc [ CorFactr  ]

;Calculate (1 - (0.018 * dT))
6:  Z=X+F (P34)
   1:   4              X Loc [ CorFactr  ]
   2:   -1             F
   3:   4              Z Loc [ CorFactr  ]

7:  Z=X*F (P37)
   1:   4              X Loc [ CorFactr  ]
   2:   -1             F
   3:   4              Z Loc [ CorFactr  ]

;Apply Temperature correction and sensor
;Calibration to kOhm measurements.

;Temperature correct kOhms
8:  Z=X/Y (P38)
   1:   2              X Loc [ kOhms     ]
   2:   4              Y Loc [ CorFactr  ]
   3:   3              Z Loc [ WP_kPa    ]

;Apply calibration slope and offset
9:  Z=X*F (P37)
   1:   3              X Loc [ WP_kPa    ]
   2:   7.407          F
   3:   3              Z Loc [ WP_kPa    ]

10:  Z=X+F (P34)
   1:   3              X Loc [ WP_kPa    ]
   2:   -3.704         F
   3:   3              Z Loc [ WP_kPa    ]

;Send measurements to final storage hourly
11:  If time is (P92)
   1:   0              Minutes (Seconds --) into a
   2:   60             Interval (same units as above)
   3:   10             Set Output Flag High (Flag 0)

12:  Set Active Storage Area (P80)
   1:   1              Final Storage Area 1
   2:   60             Array ID
```

```
13:  Real Time (P77)
  1:   1220           Year,Day,Hour/Minute (midnight = 2400)

14:  Average (P71)
  1:   1              Reps
  2:   1              Loc [ Tsoil_C   ]

15:  Sample (P70)
  1:   1              Reps
  2:   3              Loc [ WP_kPa    ]
```

6.2 253 Program Examples

6.2.1 Program Example #3 — Five 107 Temperature Probes and Five 253's on AM16/32 and CR1000

The following example demonstrates the programming used to measure five 107 temperature probes and five 253 sensors on an AM16/32 multiplexer (4x16 mode) with the CR1000 datalogger. In this example, a 107 temperature probe is buried at the same depth as a corresponding 253 sensor. The linear equation is used and the non-linear equation is included in the program notes. To use the non-linear equation, remove the linear equation from the program and uncomment the non-linear equation. Voltage range codes for other CRBasic dataloggers are shown in Table 5-1. Sensor wiring is shown in Table 4-3.

```
'CR1000
Public T107_C(5), WP_kPa(5), kOhms(5)
Dim i

Units T107_C()=Deg C
Units kOhms=kOhms
Units WP_kPa=kPa

DataTable(Hourly,true,-1)
  DataInterval(0,60,Min,10)
  Average(5, T107_C, FP2, 0)
  Sample(5, WP_kPa, FP2)
  Sample(5, kOhms, FP2)
EndTable

BeginProg
  Scan(60,Sec, 3, 0)
    PortSet(1,1) 'Turn AM16/32 Multiplexer On
    Delay(0,150,mSec)
    i = 1
    SubScan (0,uSec,5)
      PulsePort(2,10000)
      'Soil temperature measurement
      Therm107(T107_C(i),1,1,VX1,0,250,1,0)
      '253 Soil Moisture Sensor measurements
      BrHalf(kOhms(i),1,mV250,2,VX2,1,250,true,0,250,1,0)
      'Convert resistance ratios to kOhms
```

```
      kOhms(i) = kOhms(i)/(1-kOhms(i))
      i = i+1
    NextSubScan
    PortSet(1,0) 'Turn AM16/32 Multiplexer Off
    'Convert kOhms to water potential
    For i = 1 To 5
      'For linear equation (0 - 200 kPa) use this equation:
      WP_kPa(i)=(0.07407*(kOhms(i)/1-(0.018*(T107_C-21)))-0.03704)*100
      'For non-linear equation (10 - 100 kPa) uncomment and use this equation:
      'WP_kPa(i) = kOhms(i)/(0.01306*(1.062*(34.21-T107_C(i)+0.0106*T107_C(i)^2))-kOhms(i))
    Next i
    CallTable Hourly 'Call Data Table and Store Data
  NextScan
EndProg
```

6.2.2 Program Example #4 — Five 107 Temperature Probes and Five 253's on AM16/32 and CR10X Using Non-Linear Equation

The following example demonstrates the programming used to measure five 107 temperature probes and five 253 sensors on a AM16/32 multiplexer (4x16 mode) with the CR10X datalogger. In this example, a 107 temperature probe is buried at the same depth as a corresponding 253 sensor. The non-linear relationship between sensor resistance and water potential in the 10 to 100 kPa range is used. For Edlog programming of the linear relationship, see program example #2. Voltage range codes for other Edlog dataloggers are shown in Table 5-2. Sensor wiring is shown in Table 4-4.

```
;{CR10X}
  01:  30.0000        Execution Interval (seconds)

;Turn on AM16/32
1:  Do (P86)
  1:   41             Set Port 1 High

;Loop to measure five 107 probes and five 253's
2:  Beginning of Loop (P87)
  1:   0              Delay
  2:   5              Loop Count

;Advance to next multiplexer channel
    3:  Do (P86)
      1: 72      Pulse Port 2

;10 msec delay to allow switch to settle
    4:  Excitation with Delay (P22)
      1:    1             Ex Channel
      2:    0             Delay W/Ex (0.01 sec units)
      3:    1             Delay After Ex (0.01 sec units)
      4:    0             mV Excitation
```

```
;Measure soil temperature
    5:  Temp (107) (P11)
      1:  1              Reps
      2:  1              SE Channel
      3:  1              Excite all reps w/E1, 60Hz, 10ms delay
      4:  1         --   Loc [ T107_C_1  ]
      5:  1.0            Multiplier
      6:  0.0            Offset

;Measure 253 sensor
    6:  AC Half Bridge (P5)
      1:  1              Reps
      2:  14             250 mV Fast Range
      3:  2              SE Channel
      4:  2              Excite all reps w/Exchan 2
      5:  250            mV Excitation
      6:  11        --   Loc [ kOhms_1   ]
      7:  1              Multiplier
      8:  0              Offset

;Convert Half Bridge reading to resistance (k-Ohm)
    7:  BR Transform Rf[X/(1-X)] (P59)
      1:  1              Reps
      2:  11        --   Loc [ kOhms_1   ]
      3:  1              Multiplier (Rf)

;Apply nonlinear equation from 5.3.2
    8:  Z=X*Y (P36)
      1:  1         --   X Loc [ T107_C_1  ]
      2:  1         --   Y Loc [ T107_C_1  ]
      3:  6         --   Z Loc [ WP_kPa_1  ]

    9:  Z=X*F (P37)
      1:  6         --   X Loc [ WP_kPa_1  ]
      2:  0.0106         F
      3:  6         --   Z Loc [ WP_kPa_1  ]

    10:  Z=F x 10^n (P30)
      1:  34.21          F
      2:  0              n, Exponent of 10
      3:  16             Z Loc [ Const_1   ]

    11:  Z=X-Y (P35)
      1:  16             X Loc [ Const_1   ]
      2:  1         --   Y Loc [ T107_C_1  ]
      3:  16             Z Loc [ Const_1   ]

    12:  Z=X+Y (P33)
      1:  6         --   X Loc [ WP_kPa_1  ]
      2:  16             Y Loc [ Const_1   ]
      3:  6         --   Z Loc [ WP_kPa_1  ]
```

```
    13:  Z=X*F (P37)
      1:   6          --   X Loc [ WP_kPa_1  ]
      2:   1.062           F
      3:   6          --   Z Loc [ WP_kPa_1  ]

    14:  Z=X-Y (P35)
      1:   6          --   X Loc [ WP_kPa_1  ]
      2:   11         --   Y Loc [ kOhms_1   ]
      3:   6          --   Z Loc [ WP_kPa_1  ]

    15:  Z=F x 10^n (P30)
      1:   1.306           F
      2:   -2              n, Exponent of 10
      3:   17              Z Loc [ Const_2   ]

    16:  Z=X*Y (P36)
      1:   6          --   X Loc [ WP_kPa_1  ]
      2:   17              Y Loc [ Const_2   ]
      3:   6          --   Z Loc [ WP_kPa_1  ]

    17:  Z=X/Y (P38)
      1:   11         --   X Loc [ kOhms_1   ]
      2:   6          --   Y Loc [ WP_kPa_1  ]
      3:   6          --   Z Loc [ WP_kPa_1  ]

;End of measurement and processing loop
18:  End (P95)

;Turn off multiplexer
19:  Do (P86)
  1:   51             Set Port 1 Low

;Output hourly data
20:  If time is (P92)
  1:   0              Minutes (Seconds --) into a
  2:   60             Interval (same units as above)
  3:   10             Set Output Flag High (Flag 0)

21:  Set Active Storage Area (P80)
  1:   1              Final Storage Area 1
  2:   60             Array ID

22:  Real Time (P77)
  1:   1220           Year,Day,Hour/Minute (midnight = 2400)

23:  Average (P71)
  1:   5              Reps
  2:   1              Loc [ T107_C_1  ]

24:  Sample (P70)
  1:   10             Reps
  2:   6              Loc [ WP_kPa_1  ]
```

7. Interpreting Results

As a general guide, 253 and 257 measurements indicate soil matric potential as follows:

0 to 10 kPa =	Saturated soil
10 to 20 kPa =	Soil is adequately wet (except coarse sands, which are beginning to lose water).
20 to 60 kPa =	Usual range for irrigation (except heavy clay).
60 to 100 kPa =	Usual range for irrigation for heavy clay soils.
100 to 200 kPa =	Soil is becoming dangerously dry for maximum production.

8. Troubleshooting

To test the sensor, submerge it in water. Measurements should be from -3 to +3 kPa. Let the sensor dry for 30 to 48 hours. You should see the reading increase from 0 to 15,000 + kPa. Put the sensor back in the water. The reading should run right back down to zero in 1 to 2 minutes. If the sensor passes these tests, consider the following:

1. Sensor may not have a snug fit in the soil. This usually happens when an oversized access hole has been used and the backfilling of the area around the sensor is not complete.

2. Sensor is not in an active portion of the root system, or the irrigation is not reaching the sensor area. This can happen if the sensor is sitting on top of a rock or below a hard pan which may impede water movement. Re-installing the sensor usually solves this problem.

3. When the soil dries out to the point where you are seeing readings higher than 80 kPa, the contact between soil and sensor can be lost because the soil may start to shrink away from the sensor. An irrigation which only results in a partial rewetting of the soil will not fully rewet the sensor, which can result in continued high readings from the 257. Full rewetting of the soil and sensor usually restores soil to sensor contact. This is most often seen in the heavier soils and during peak crop water demand when irrigation may not be fully adequate. The plotting of readings on a chart is most useful in getting a good picture of this sort of behavior.

9. Reference

Thompson, S.J. and C.F. Armstrong, Calibration of the Watermark Model 200 Soil matric potential Sensor, Applied Engineering in Agriculture, Vol. 3, No. 2, pp. 186-189, 1987.

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