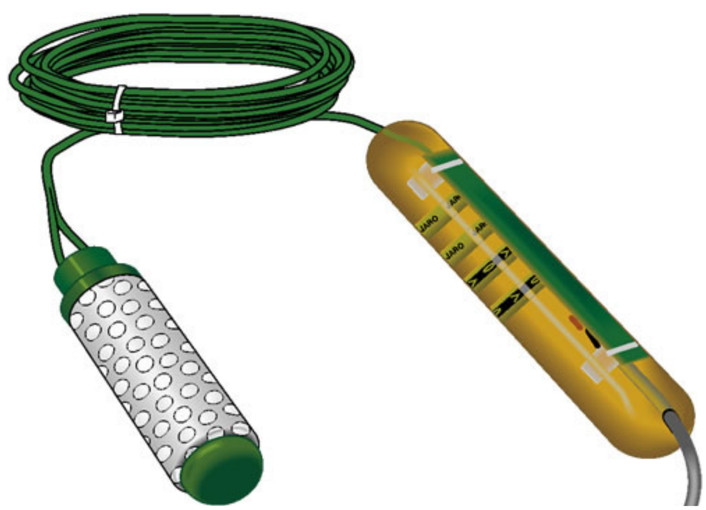
INSTRUCTION MANUAL

253-L and 257-L Soil Matric Potential Sensors

Revision: 9/13



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253-L and 257-L Soil Matric Potential Sensors

1. Introduction

The 253 and 257 soil matric potential sensors are solid-state, electrical-resistance sensing devices with a granular matrix that estimate soil water potential between 0 and –2 bars (typically wetter or irrigated soils).

The 253 needs to be connected to an AM16/32-series multiplexer, and is intended for applications where a larger number of sensors will be monitored. The 257 connects directly to our dataloggers.

Before using a 253 or 257, please study:

- Section 2, *Cautionary Statements*
- Section 3, *Initial Inspection*
- Section 4, *Quickstart*

2. Cautionary Statements

- The black outer jacket of the cable is Santoprene® rubber. 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.
- Avoid installing in depressions where water will puddle after a rain storm.
- Don't place the 253 or 257 in high spots or near changes in slope unless wanting to measure the variability created by such differences.
- When removing the sensor prior to harvest of annual crops, do so just after the last irrigation when the soil is moist.
- When removing a sensor, do not pull the sensor out by its wires.
- Careful removal prevents sensor and membrane damage.

3. Initial Inspection

- Upon receipt of a 253 or 257, inspect the packaging and contents for damage. File damage claims with the shipping company.
- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the correct product and cable length are received.

4. Quickstart

Please review Section 7, *Operation*, for wiring, CRBasic programming, Edlog programming, and interpretation of results.

4.1 Installation/Removal

NOTE 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 sensors in water for one hour then allow them to dry, ideally for 1 to 2 days.

2. Repeat Step 1 twice if time permits.

3. Make the sensor access holes to the required depth. Often, a 22 mm (7/8 in) diameter rod can be used to make the hole. However, if the soil is very coarse or gravelly, an oversized hole (25 to 32 mm) may be required to prevent abrasion damage to the sensor membrane. The ideal method of making an oversized 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.

4. If the hole is oversized (25 to 32 mm), mix a slurry of soil and water to a creamy consistency and place it into the sensor access hole.

5. Insert the sensors in the sensor access hole. A length of 1/2 inch class 315 PVC pipe fits snugly over the sensor collar and can be used to push in the sensor. The PVC can be left in place with the wires threaded through the pipe and the open end taped shut (duct tape is adequate). This practice also simplifies the removal of the sensors. When using PVC piping, 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.

6. Force the soil or slurry to envelope the sensors. This will ensure uniform soil contact.

NOTE Snug fit in the soil is extremely important. Lack of a snug fit is the premier problem with sensor effectiveness.

7. Carefully, back fill the hole, and tamp down to prevent air pockets which could allow water to channel down to the sensor.

8. When removing sensors prior to harvest in annual crops, do so just after the last irrigation when the soil is moist.

CAUTION Do not pull the sensor out by the wires. Careful removal prevents sensor and membrane damage.

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

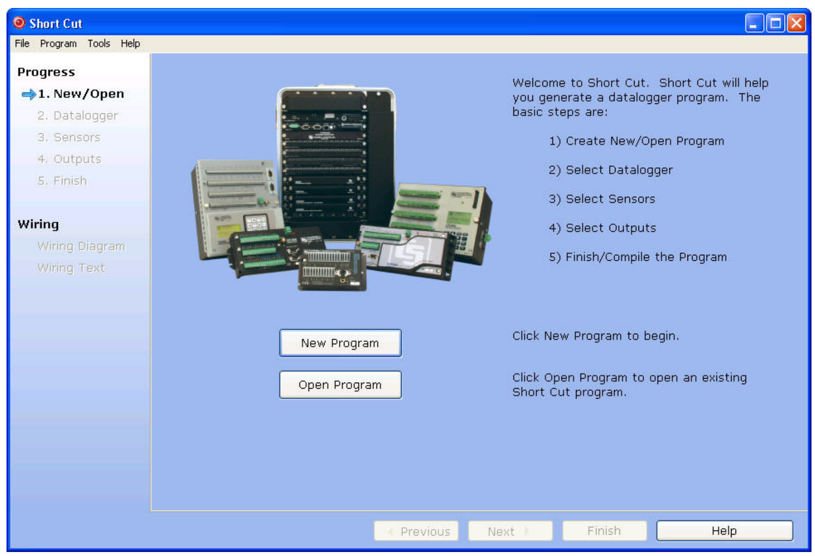
4.2 Use SCWin to Program Datalogger and Generate Wiring Diagram

The simplest method for programming the datalogger to measure the sensor is to use Campbell Scientific's SCWin Program Generator (Short Cut).

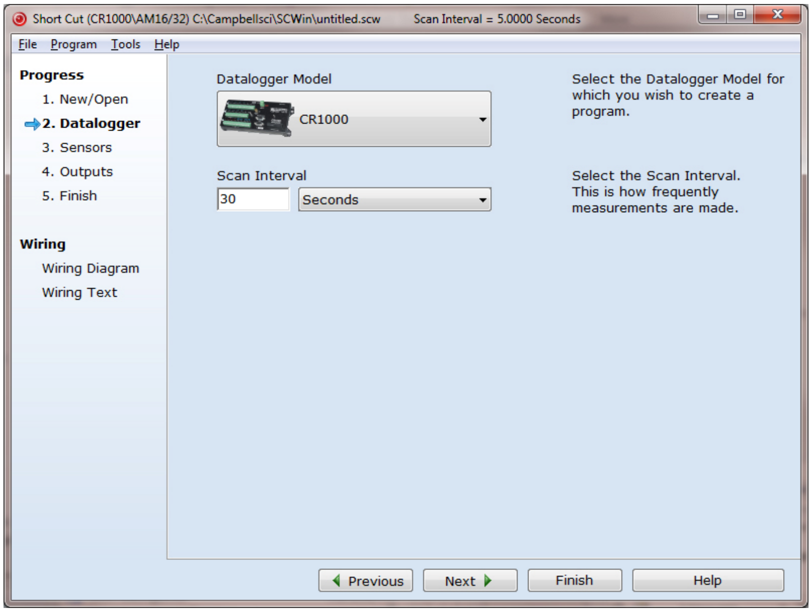
NOTE Short Cut requires the use of a soil temperature sensor before the 253 or 257 sensor is added. This is needed because there is a temperature correction factor in the equations that convert sensor resistance. In these Quickstart examples, a 107-L temperature probe is used to measure soil temperature.

4.2.1 257 SCWin Programming

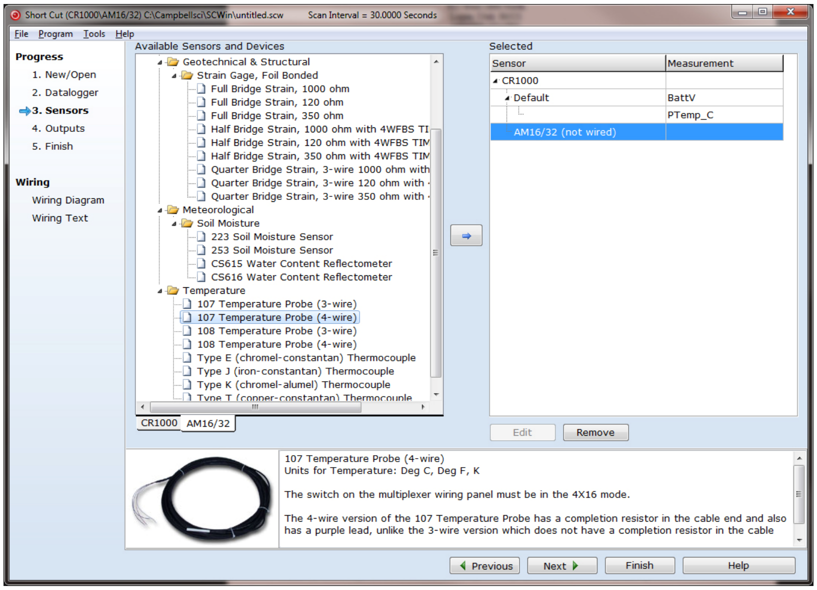
1. Open Short Cut and click on **New Program**.



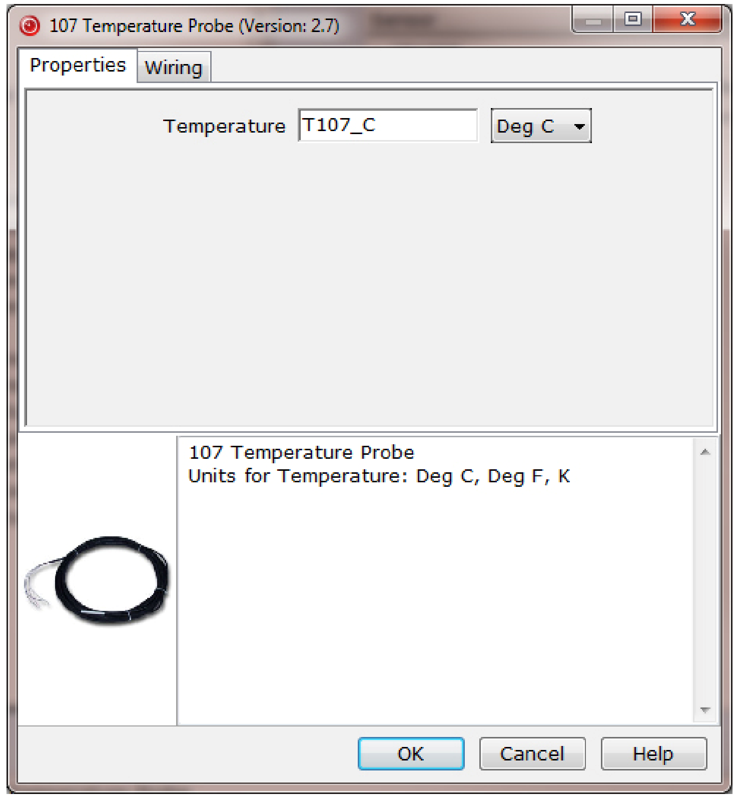
2. Select the datalogger and enter the scan interval, and then select **Next**.



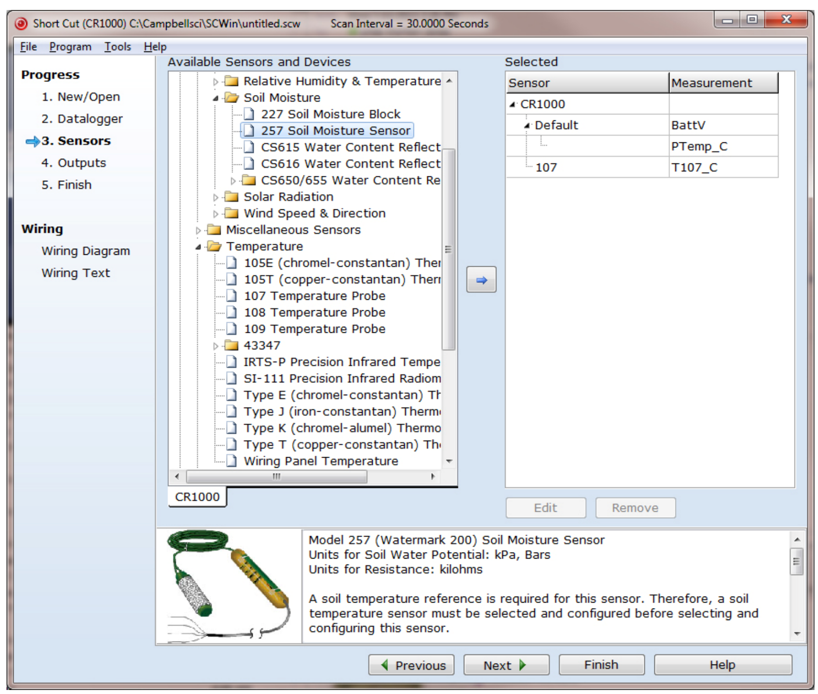
3. Select **107 Temperature Probe** and select the **right arrow** (in center of screen) to add it to the list of sensors to be measured.



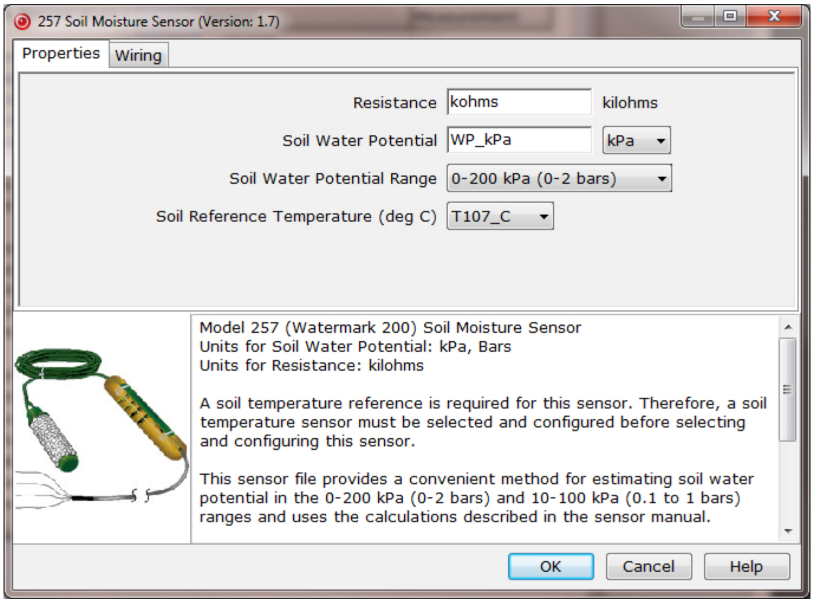
4. Select the 107's units and click on **OK**.



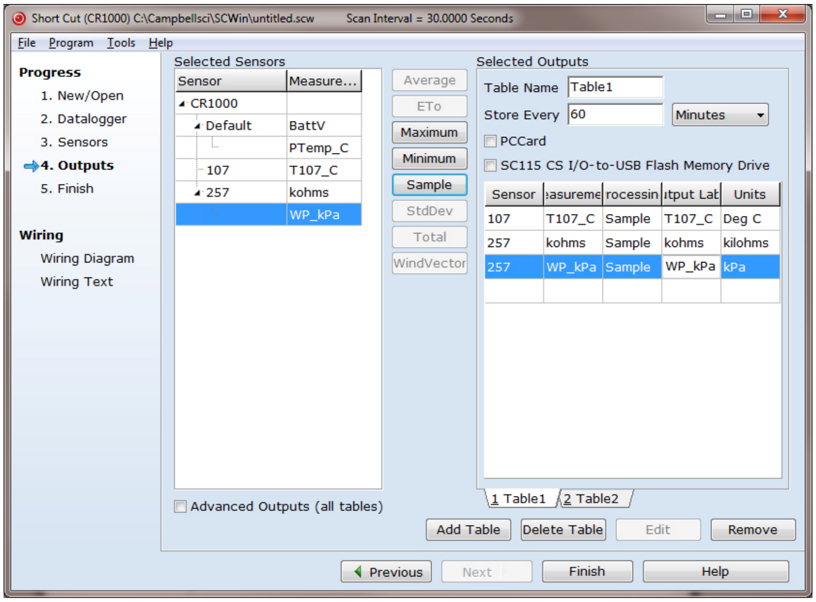
5. Select **257 Soil Moisture Sensor,** and select the **right arrow** (in center of screen) to add it to the list of sensors to be measured.



6. Select the resistance units, soil water units, soil water potential range, and soil reference temperature. After entering the information, click **OK**, and select **Next**.



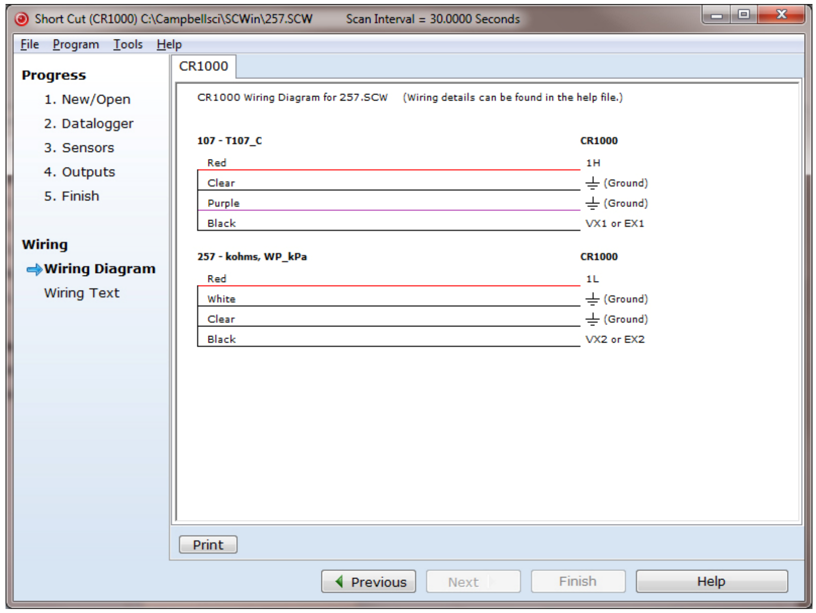
7. Choose the outputs and select **Finish**.



8. In the Save As window, enter an appropriate file name and select **Save**.

9. In the Confirm window, click **Yes** to download the program to the datalogger.

10. Click on **Wiring Diagram** and wire the 257 and 107 to the CR1000 according to the wiring diagram generated by Short Cut.

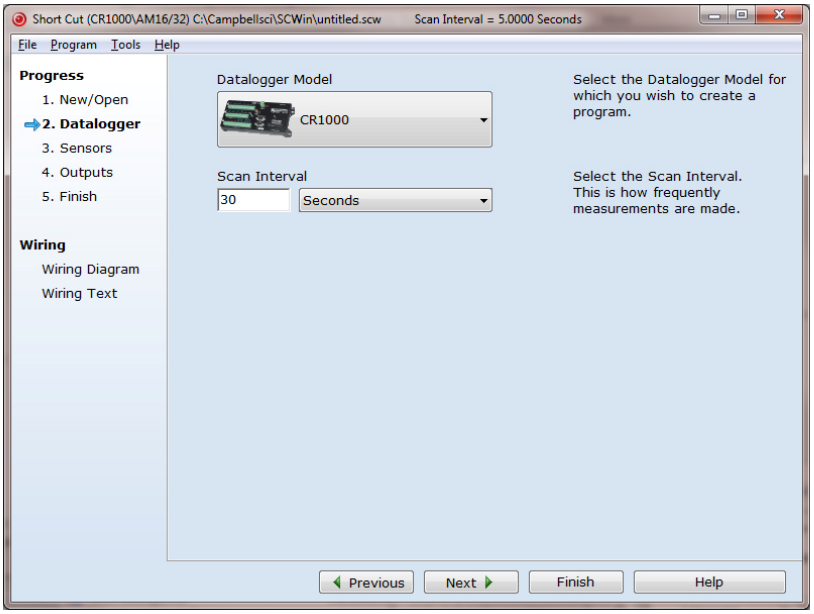


4.2.2 253 SCWin Programming

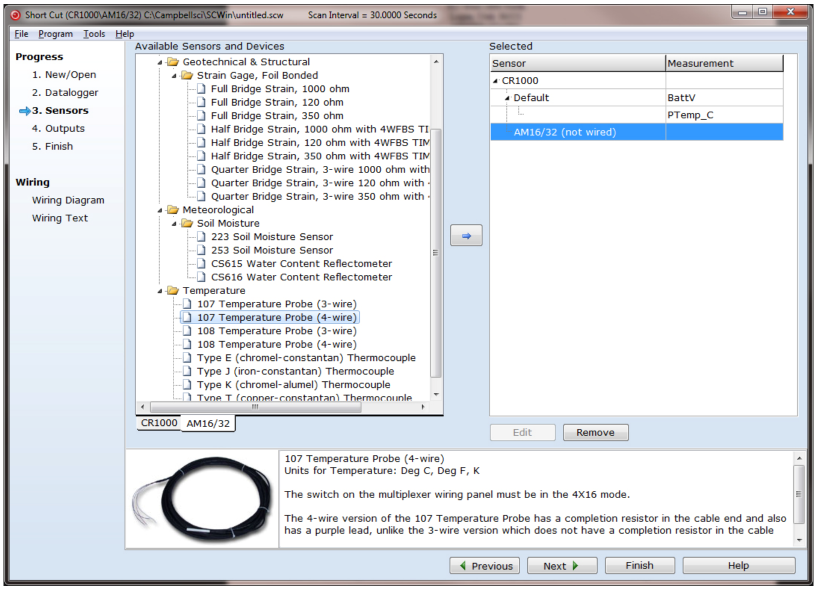
1. Open Short Cut and click **New Program**.

2. Select the datalogger and enter the scan interval, and select **Next**.

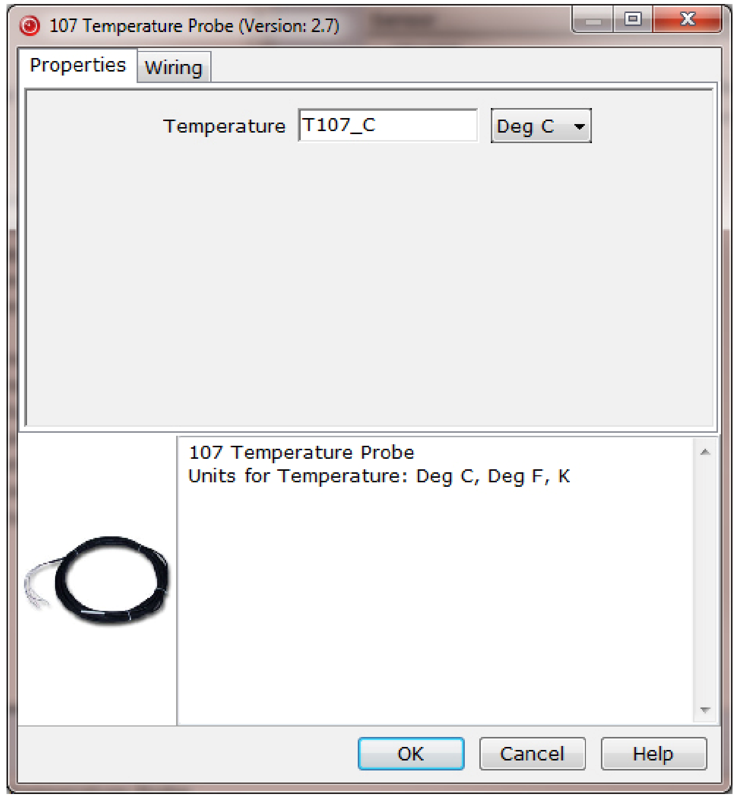
NOTE A scan rate of 30 seconds or longer is recommended when using a multiplexer.



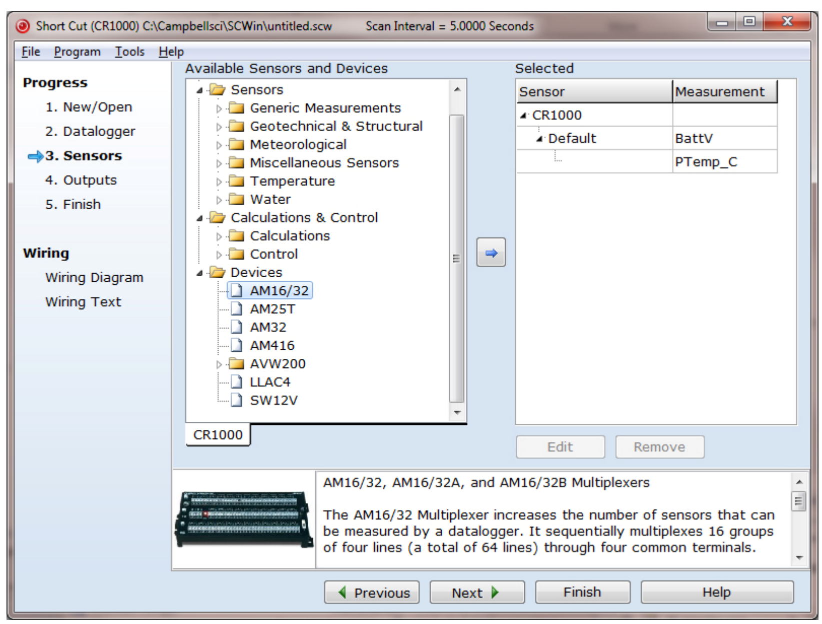
3. Select **107 Temperature Probe** and select the **right arrow** (in center of screen) to add it to the list of sensors to be measured.



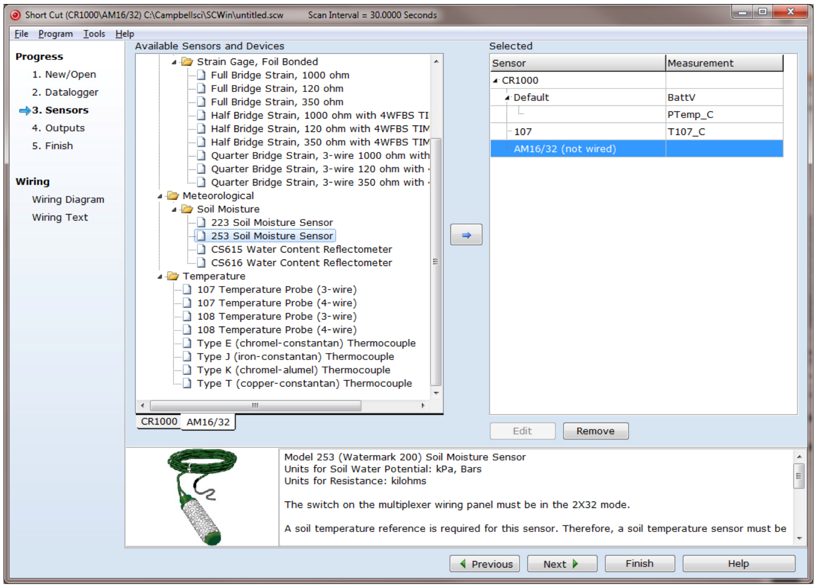
4. Select the 107's units and click **OK**.



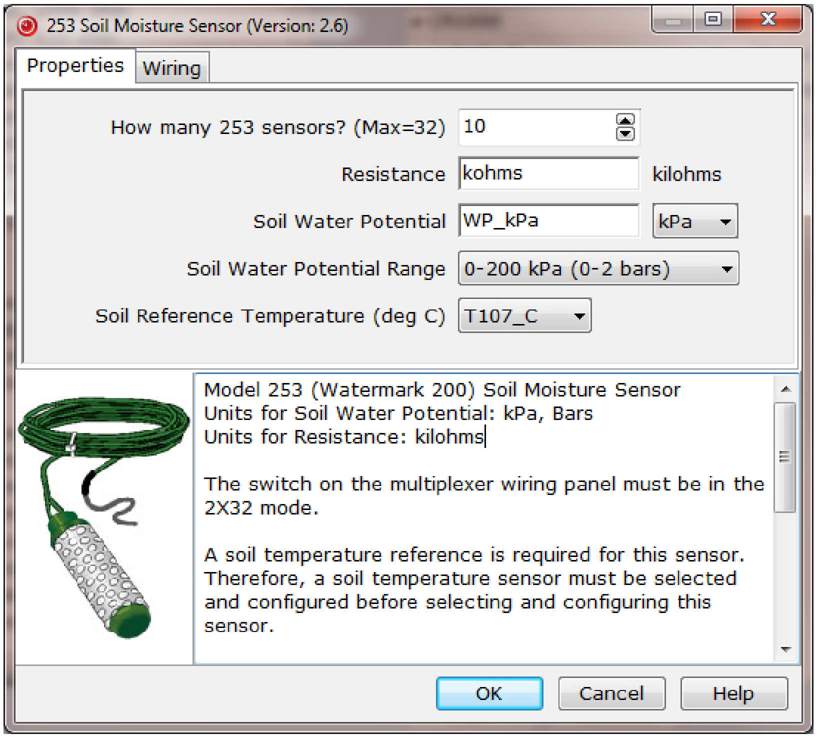
5. Under **Devices**, select **AM16/32,** and select the **right arrow** (in center of screen) to add it to the list.



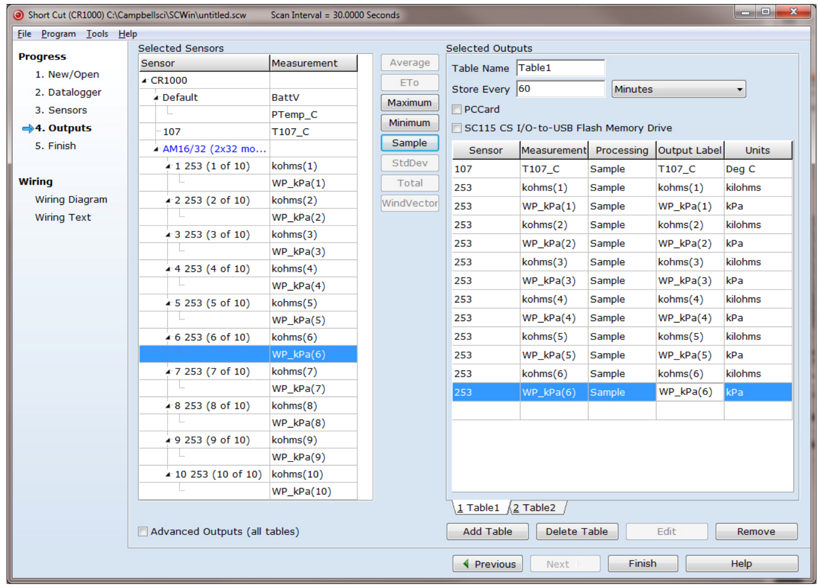
6. Select **253,** and select the **right arrow** (in center of screen) to add it to the list of sensors to be measured.



7. Select the number of sensors, resistance units, soil water potential units, soil water potential range, and soil reference temperature. After entering the information, click **OK**, and select **Next**.



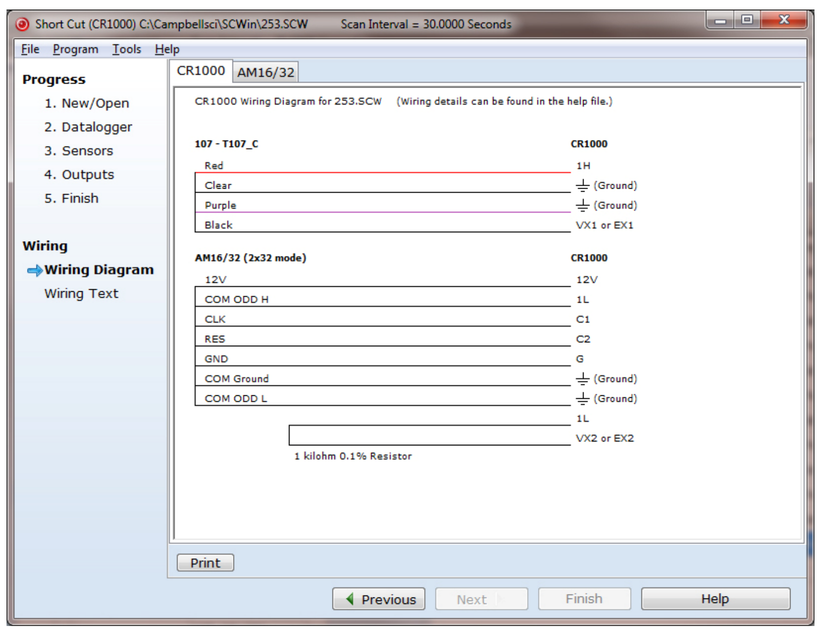
8. Choose the outputs and select **Finish**.



9. In the Save As window, enter an appropriate file name and select **Save**.

10. In the Confirm window, click **Yes** to download the program to the datalogger.

11. Click on **Wiring Diagram** and select the CR1000 tab. Wire the 107 and the AM16/32 to the CR1000 according to the wiring diagram generated by Short Cut.



12. Select the AM16/32 tab and wire the 253 sensors to the AM16/32 according to the wiring diagram generated by Short Cut.

5. Overview

The 253 and 257 soil matric potential sensors provide a convenient method of estimating water potential of wetter soils in the range of 0 to –200 kPa. The 253 is the Watermark 200 Soil Matric Potential Block modified for use with Campbell Scientific multiplexers and the 257 is the Watermark 200 Soil Matric Potential Block modified for use with Campbell Scientific dataloggers.

The –L option on the Model 257-L and 253-L indicates that the cable length is user specified. This manual refers to the sensors as the 257 and 253. The typical cable length for the 257 is 25 ft. The following two cable termination options are offered for the 257:

- Pigtails that connect directly to a Campbell Scientific datalogger (cable termination option –PT).
- Connector that attaches to a prewired enclosure (cable termination option –PW).

For 253 applications, most of the cable length used is between the datalogger and the multiplexer, which reduces overall cable costs and allows each cable attached to the 253 to be shorter. The cable length of each 253 only needs to cover the distance from the multiplexer to the point of measurement. Typical cable length for the 253 is 25 to 50 ft.

The difference between the 253 and the 257 is that there is a capacitor circuit and completion resistor installed in the 257 cable (FIGURE 5-1) 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 253 and 257 consist 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.

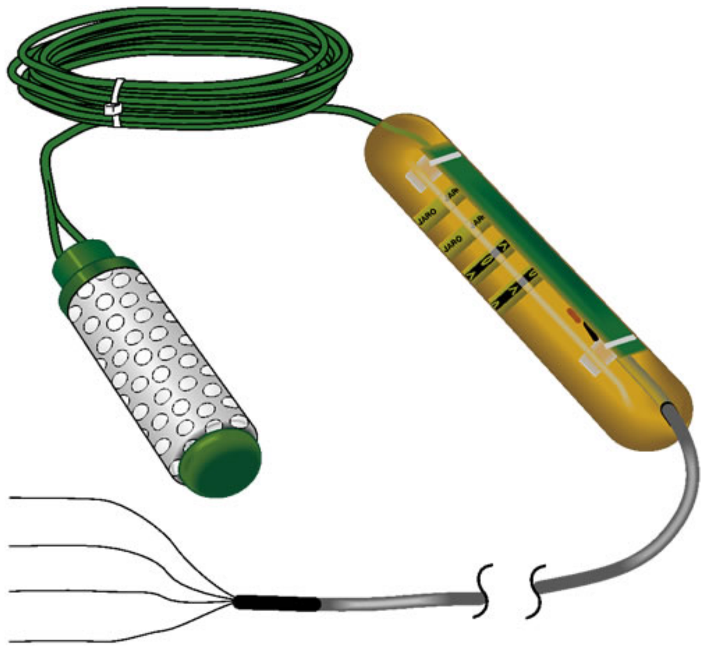


FIGURE 5-1. 257 Soil Matric Potential Sensor with capacitor circuit and completion resistor installed in cable. Model 253 is the same, except that it does not have completion circuitry in the cable.

6. Specifications

Features:

- Survives freeze-thaw cycles
- Rugged, long-lasting sensor
- Buffers salts in soil
- No maintenance required
- Compatible with most Campbell Scientific dataloggers
- The 257 contains blocking capacitors in its cable that minimizes galvanic degradation and measurement errors due to ground loops
- For the 253, the multiplexer connection prevents electrolysis from prematurely destroying the probe

Compatible Dataloggers:
CR800
CR850
CR1000
CR3000
CR5000
CR9000(X)
CR7
CR10(X)
21X
CR23X
CR500 (257 only)
CR510 (257 only)

Range:	0 to –200 kPa
Dimensions:	8.26 cm (3.25 in)
Diameter:	1.91 cm (0.75 in)
Weight:	363 g (0.8 lb)

7. Operation

7.1 Wiring

7.1.1 257 Wiring

The 257 wiring diagram is illustrated in FIGURE 7-1. The red lead is inserted into any single-ended analog channel, the black lead into any excitation channel, and the white lead to analog ground (CR10(X), CR510, CR500) or to ground (CR1000, CR800, CR850, CR3000, CR9000(X), CR5000, CR23X, CR7, 21X).

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.

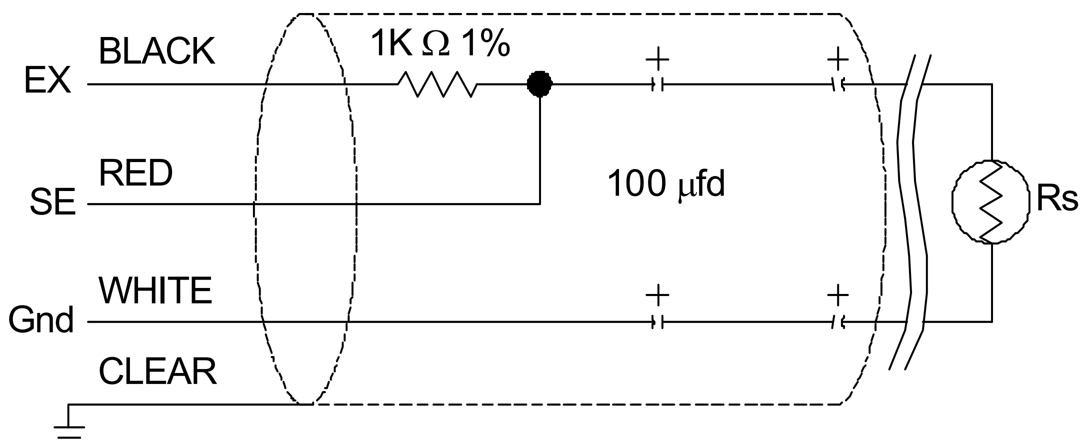


FIGURE 7-1. 257 schematic

7.1.2 253 Wiring

An example of wiring for the 253 is illustrated in FIGURE 7-2. 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.

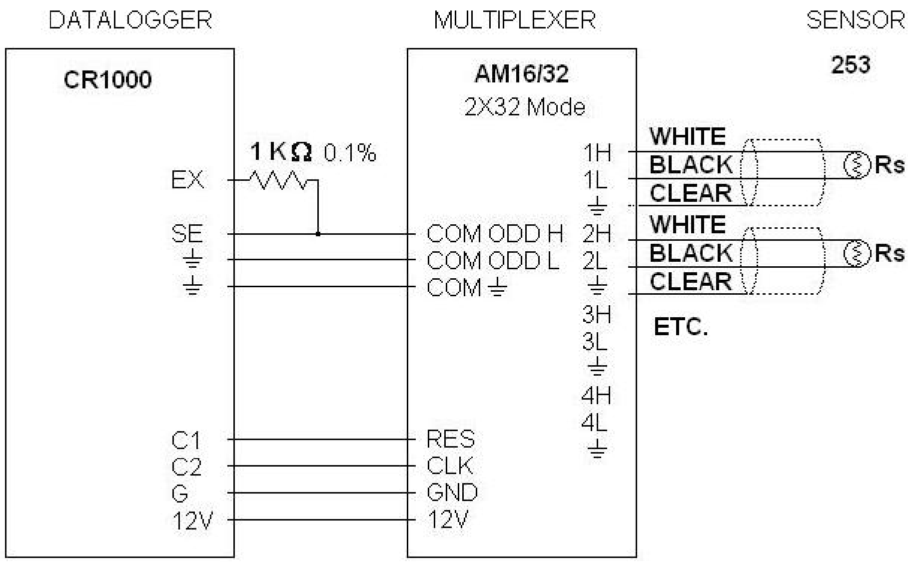


FIGURE 7-2. 253 wiring example

7.2 Programming

NOTE This section describes using CRBasic or Edlog to program the datalogger. See Section 4.2, *Use SCwin to Program Datalogger and Generate Wiring*, if using Short Cut.

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 CR800, CR850, CR1000, CR3000, CR5000, and CR9000(X). Edlog dataloggers are the CR10(X), CR510, CR500, CR23X, CR7, and 21X.

7.2.1 CRBasic Dataloggers

7.2.1.1 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 7-1 shows the excitation and voltage ranges used with the CRBasic dataloggers.

TABLE 7-1. 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
CR5000	200	± 200 mV
CR9000(X)	200	± 200 mV

7.2.1.2 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 kOhms and can be omitted from the expression if desired.

7.2.2 Edlog Dataloggers

7.2.2.1 Program Instruction 5

Edlog dataloggers use **Instruction 5**, **AC Half Bridge (P5)**, to excite and measure the 253 and 257. Recommended excitation voltages and input ranges for Edlog dataloggers are listed in TABLE 7-2.

TABLE 7-2. 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/CR500	250	14	± 250 mV
CR23X	200	13	± 200 mV
CR7	500	16	± 500 mV

7.2.2.2 Program Instruction 59

Instruction 59, **Bridge Transform (P59)**, 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.

7.2.3 Calculate Soil Water Potential

The datalogger can calculate soil water potential (kPa) from the sensor resistance (R_s) and soil temperature (T_s). See TABLE 7-3.

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.

7.2.3.1 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°C.

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

where

R_{21} = resistance at 21°C

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

7.2.3.2 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,

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

where SWP is soil water potential in kPa

TABLE 7-3. 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

7.2.3.3 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 7-4.

TABLE 7-4. Conversion of Matric Potential to Other Units

Desired Unit	Multiply Result By
kPa	1.0
MPa	0.001
Bar	0.01

7.3 Example Programs

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 7-1). 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 7-2).

7.3.1 257 Program Examples

7.3.1.1 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 7-1. Sensor wiring for this example is shown in TABLE 7-5.

TABLE 7-5. 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

```
'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
```

7.3.1.2 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 7-2. Sensor wiring for this example is shown in TABLE 7-6.

TABLE 7-6. 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

```
;{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    ]
```

7.3.2 253 Program Examples

7.3.2.1 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 7-1. Sensor wiring is shown in TABLE 7-7.

TABLE 7-7. 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.			

```
'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)=7.407*kOhms(i)/(1-0.018*(T107_C-21))-3.704
      '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
```

7.3.2.2 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 7-2. Sensor wiring is shown in TABLE 7-8.

TABLE 7-8. 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.			

```
;{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  ]
```

7.4 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. If the reading does not increase to 15,000 kPA, replace the sensor. If the reading increases as expected, 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 but it is still not functioning properly, 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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