MODEL 257 AND 257-L (WATERMARK 200)
SOIL MOISTURE SENSOR

REVISION: 6/96

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Logan, Utah 84321-1784

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CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N.
Logan, UT 84321-1784
USA
Phone (435) 753-2342
FAX (435) 750-9540
www.campbellsci.com

Campbell Scientific Canada Corp.
11564 -149th Street
Edmonton, Alberta T5M 1W7
CANADA
Phone (780) 454-2505
FAX (780) 454-2655

Campbell Scientific Ltd.
Campbell Park
80 Hathern Road
Shepshed, Loughborough
LE12 9GX, U.K.
Phone +44 (0) 1509 601141
FAX +44 (0) 1509 601091

MODEL 257 AND 257-L (WATERMARK 200) SOIL MOISTURE SENSOR

1. GENERAL

The Watermark 200 (CSI sensor Models 253, 253-L, 257, and 257-L) provides a convenient method of estimating water potential between 0 and 2 bars (wetter soils) with a Campbell Scientific CR10, 21X, or CR7 datalogger. CSI Models 253 and 253-L are for connection to the AM32 or AM416 Analog Multiplexers. Models 257 and 257-L connect directly to a datalogger.

The Watermark block estimates water potential. For applications requiring high accuracy, call a Campbell Scientific applications engineer for information on precision soil moisture measurement systems.

The Watermark consists of two concentric electrodes embedded in a reference matrix material. The 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.

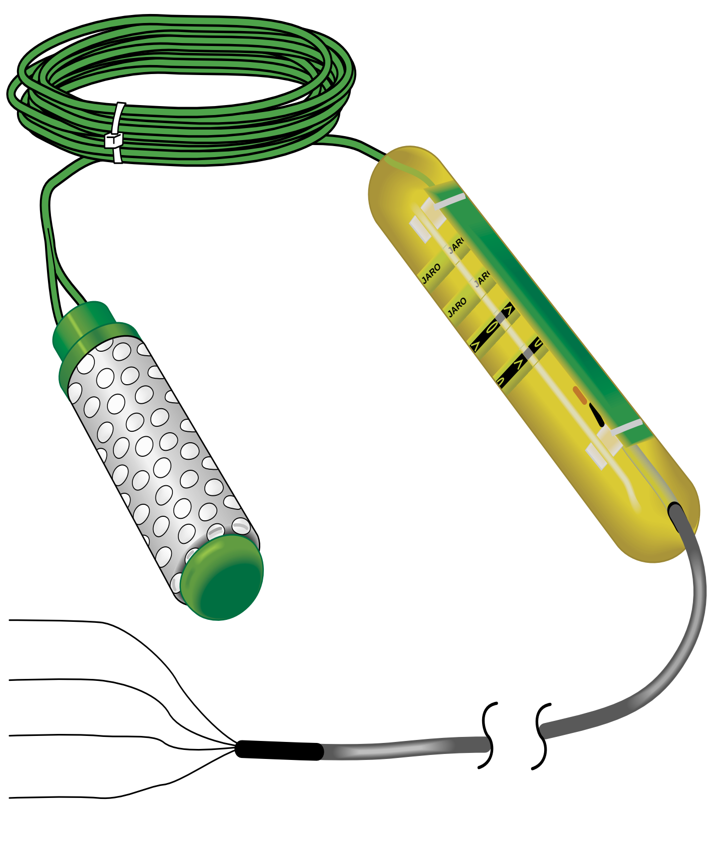

FIGURE 1.1 257 Soil Moisture Sensor

2. INSTALLATION AND REMOVAL

Placement of the Watermark is important. To acquire representative measurements, avoid high spots, slope changes, or depressions where water puddles. Typically, the sensor must 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 7/8" 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 (1 to 1-1/4") 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 in 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 1/2" 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.

3. WIRING

The 257 wiring diagram is illustrated in Figure 3.1. The red lead (Positive Signal) is inserted into any single ended analog channel ("HI or LO"), the black lead into any excitation channel, and the white lead (Negative Signal) to any Analog Ground (CR10) or Ground (21X and CR7).

Installed in the cable is a capacitor circuit which blocks galvanic action due to the differences in potential between the datalogger earth ground and the electrodes in the block. Such current flow would cause rapid block deterioration.

4. MEASUREMENT

Instruction 5, AC Half Bridge, is used to excite and measure the model 257. Recommended excitation voltages and input ranges are listed in Table 1.

TABLE 1. Excitation and Voltage Range

DATALOGGER	mV EX	RANGE CODE	FSR
21X	500	14	± 500 mV
CR10	250	14	± 250 mV
CR7	500	16	± 500 mV

NOTE: Do not use a slow integration time as sensor polarization errors will occur.

4.1 CALCULATE SENSOR RESISTANCE - INSTRUCTION 59

Instruction 59, Bridge Transform, is used to output sensor resistance (R_S). The instruction takes the AC Half Bridge output (Vs/Vx) and computes the sensor resistance as follows.

$$R_S = R1(X/(1-X))$$

where, X = Vs/Vx (Output from Instruction 5)

A multiplier of 1 should be used to output sensor resistance (Rs) in terms of kΩ.

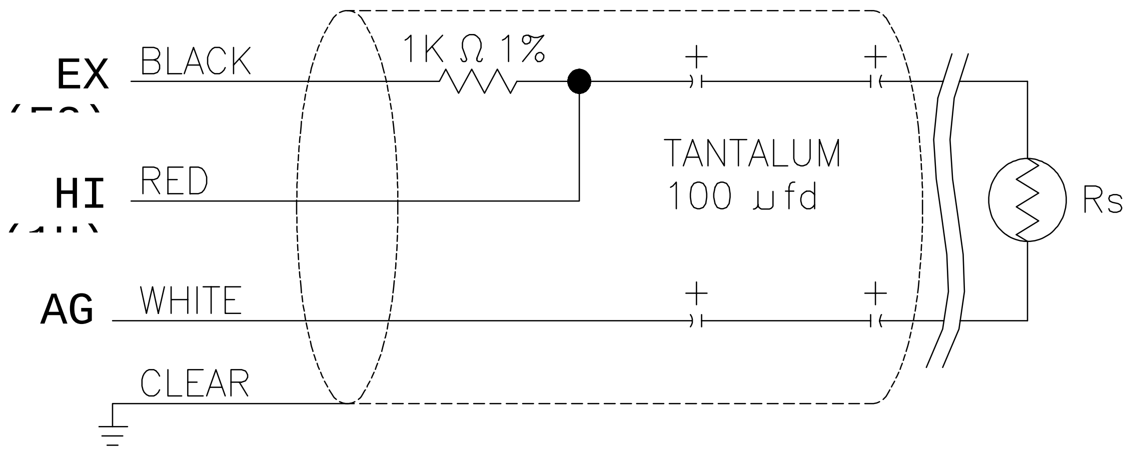

Figure 3.1. 257 Schematic

4.2 CALCULATE SOIL WATER POTENTIAL

The datalogger can calculate soil water potential (bars) from the sensor resistance (R_S) and soil temperature (T_S). See Table 2.

The need for a precise soil temperature measurement should not be over emphasized. 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 (5 to 10 inches) in soils shaded by a crop canopy. A common practice is to assume the air temperature at sunrise will be close to what the soil temperature will be for the day.

4.2.1 Linear Relationship

For applications in the range of 0 to 2 bars, the water potential and temperature responses of the Watermark can be assumed to be linear (measurements beyond 1.25 bars have not been verified, but work in practice).

The following equation normalizes the resistance measurement to 21°C.

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

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.

$$SWP = 0.07407 * R_{21} - 0.03704 \quad [2]$$

SWP = Soil Water Potential (bars)

4.2.2 Non-Linear Relationship

For more precise work, calibration and temperature compensation in the range of 0.1 to 1.00 bar has been refined by Thompson and Armstrong (1987), as defined in the non-linear equation,

$$SWP = \frac{R_s}{0.01306[1062(34.21 - T_s + 0.01060 T_s^2) - R_s]} * .01 \quad [3]$$

Table 2. Comparison of Estimated Soil Water Potential and Rs at 21°C

Bars (Non-Linear Equation)	Bars (Linear Equation)	(Rs)kOhms
	.037	1.00
.09	.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
1.05	.78	11.00
	.85	12.00
	.92	13.00
	.99	14.00
	1.07	15.00
	1.15	16.00
	1.22	17.00
	1.29	18.00
	1.44	20.00
	1.59	22.00
	1.74	24.00
	1.88	26.00
	1.99	27.50

5. PROGRAMMING (MEASURING BLOCK RESISTANCE)

The following examples demonstrate the programming used to measure the resistance (kohms) of one soil moisture block with the 21X or CR10 datalogger. Programs use wiring as shown in parantheses in Figure 3.1.

5.1 21X

```
XX:     P5      AC Half Bridge (Measure
                AC Conductivity)
  01:     1     Rep
  02:    14     500 mV Fast Range
  03:     1     In Channel
  04:     2     Excite All Reps w/Excite
                Channel 2
  05:   500     mV excitation
  06:     1     Location (Indexed Location
                to Store) [:kOhms#1]
  07:     1     Multiplier
  08:     0     Offset

XX:     P59     BR Transform Rf[X/(1-X)]
                (Compute Resistances)
  01:     1     Reps
  02:     1     Location [:kOhms#1]
  03:     1     Multiplier  (Rf/1000)
```

5.2 CR10

```
XX:     P5      AC Half Bridge  (Measure
                AC Conductivity)
  01:     1     Rep
  02:    14     250 mV Fast Range
  03:     1     In Channel
  04:     2     Excite All Reps w/
                Excitation Channel 2
  05:   250     mV Excitation
  06:     1     Location  (Indexed Location
                to Store) [:kOhms#1]
  07:     1     Multiplier
  08:     0     Offset

XX:     P59     BR Transform Rf[X/(1-X)]
                (Compute Resistances)
  01:     1     Reps
  02:     1     Location [:kOhms#1]
  03:     1     Multiplier  (Rf/1000)
```

6. PROGRAMMING (CALCULATING SOIL WATER POTENTIAL)

6.1 LINEAR RESISTANCE AND TEMPERATURE RELATIONSHIP (0 TO 2 BARS)

Calculate Temperature Correction Factor. See Equation [1] in Section 4.2.1...

...Calculate dT = T - 21

```
XX:     P34       Z=X+F
  01:     34      X Loc TmpDegC
  02:    -21      F
  03:     36      Z Loc [:CorrFactr]
```

...Calculate (0.018 * dT)

```
XX:     P37       Z=X*F
  01:     36      X Loc CorrFactr
  02:       .018  F
  03:     36      Z Loc [:CorrFactr]
```

...Calculate (1 - (0.018 * dT))

```
XX:     P34       Z=X+F
  01:     36      X Loc CorrFactr
  02:     -1      F
  03:     36      Z Loc [:CorrFactr]

XX:     P37       Z=X*F
  01:     36      X Loc CorrFactr
  02:     -1      F
  03:     36      Z Loc [:CorrFactr]
```

Apply Temperature Correction and Sensor Calibration to Ohm Measurements. See Equation [2] in Section 4.2.1...

...Temperature Correct Ohms:

```
XX:     P38       Z=X/Y
  01:      1      X Loc kOhms#1
  02:     36      Y Loc CorrFactr
  03:     41      Z Loc [:Bars#1    ]
```

...Apply Calibration Slope and Offset

```
XX:     P37       Z=X*F
  01:     41      X Loc Bars#1
  02:       .07407 F
  03:     41      Z Loc [:Bars#1    ]

XX:     P34       Z=X+F
  01:     41      X Loc Bars#1
  02:      -.03704 F
  03:     41      Z Loc [:Bars#1    ]
```

6.2 NON-LINEAR RESISTANCE AND TEMPERATURE RELATIONSHIP (0.1 TO 1 BAR)

The following instructions convert R_S to Soil Water Potential in bars. See Equation [3] in Section 4.2.2.

```
XX:    P36      Z=X*Y  SWP = Tsoil^2
  01:    34     X Loc Tsoil C
  02:    34     Y Loc Tsoil C
  03:    41     Z Loc [:Bars#1]
```

SWP = Tsoil^2 * 0.0106

```
XX:    P37      Z=X*F
  01:    41     X Loc Bars#1
  02:    0.0106 F
  03:    41     Z Loc [:Bars#1]
```

```
XX:    P30      Z=F
  01:    34.21  F
  02:    35     Z Loc [:Constant ]
```

SWP = 34.21-Ts

```
XX:    P35      Z=X-Y
  01:    35     X Loc Constant
  02:    34     Y Loc Tsoil C
  03:    35     Z Loc [:Constant ]
```

SWPcalc.=[(34.21-Ts)+(Ts^2*0.01060)]

```
XX:    P33      Z=X+Y
  01:    41     X Loc Bars#1
  02:     3     Y Loc Constant
  03:    41     Z Loc [:Bars#1]
```

SWP = 1.062[SWPcalc.]

```
XX:    P37      Z=X*F
  01:    41     X Loc Bars#1
  02:    1.062  F
  03:    41     Z Loc [:Bars#1]
```

SWP = SWPcalc.-Rs

```
XX:    P35      Z=X-Y
  01:    41     X Loc Bars#1
  02:     1     Y Loc kOhms#1
  03:    41     Z Loc [:Bars#1]
```

SWP = 0.01306*SWPcalc.

```
XX:    P37      Z=X*F
  01:    41     X Loc Bars#1
  02:    0.0130 F
  03:    41     Z Loc [:Bars#1]
```

SWP = Rs/SWPcalc.

```
XX:    P38      Z=X/Y
  01:     1     X Loc kOhms#1
  02:    41     Y Loc Bars#1
  03:    41     Z Loc [:Bars#1]
```

SWPbars = SWP(kPa) * 0.01

```
XX:    P37      Z=X*F
  01:    41     X Loc Bars#1
  02:    0.01   F
  03:    41     Z Loc [:Bars#1]
```

7. PROGRAMMING (COMPREHENSIVE)

Follow these steps to create a complete program:

Step 1. Set the execution interval according to need:

```
*          1    Table 1 Programs
  01:   3600    Sec. Execution Interval
```

Step 2. Make a temperature measurement to correct for temperature effects. Select from options 1 or 2.

Option 1. If a 107B Probe is part of your system, measure soil temperature:

```
XX:    P11      Temp 107 Probe
  01:     1     Rep
  02:     3     IN Chan
  03:     3     Excite all reps w/EXchan 3
  04:    34     Loc [:TempDegC ]
  05:     1     Mult
  06:     0     Offset
```

Option 2. If a 107B Probe is not available but a 107 Probe is part of your system, measure air temperature in the early morning (6:00 A.M.) and assume that will be the soil temperature for the day:

```
XX:    P92      If time is
  01:   360     minutes (seconds--) into a
  02:  1440     minute or second interval
  03:    30     Then Do
```

XX:	P11	Temp 107 Probe
01:	1	Rep
02:	3	IN Chan
03:	3	Excite all reps w/EXchan 3
04:	34	Loc [:TempDegC]
05:	1	Mult
06:	0	Offset

XX:	P95	End

Step 3. Make the resistance measurements. It may be appropriate to make measurements only once or twice a day. This example makes measurements twice a day at 6:00 AM and 6:00 PM:

XX:	P92	If time is
01:	360	minutes (seconds--) into a
02:	720	minute or second interval
03:	30	Then Do

> Insert one of the examples from Section 5 here.

Step 4. Calculate soil water potential using resistance and temperature:

> Insert one of the examples from Section 6 here.

Step 5. Output data to final storage after each measurement and calculation:

XX:	P86	Do
01:	10	Set high Flag 0 (output)

XX:	P77	Real Time
01:	0220	Day,Hour-Minute

XX:	P70	Sample kOhm Resistances
01:	1	Reps
02:	1	Loc

XX:	P70	Sample Deg C Temperature
01:	1	Reps
02:	34	Loc

XX:	P70	Sample Bar Potential
01:	1	Reps
02:	41	Loc

XX:	P95	End 6 am and 6 pm loop

8. INTERPRETING RESULTS

As a general guide, Watermark 200 measurements indicate soil moisture as follows:

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

9. TROUBLESHOOTING

To test the sensor, submerge it in water. Measurements should be from -.03 to .03 bars. Let the sensor dry for 30 to 48 hours. You should see the reading increase from 0 to 150+. 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 centibars, 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 Watermark. Full rewetting of the soil and sensor usually restores soil/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.

Reference

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

Parts of this manual were contributed by Irrometer Company, Inc., manufacturer of the Watermark 200.