INSTRUCTION MANUAL

Model 253 and 253-L (Watermark 200) Soil Moisture Sensor

Revision: 6/96

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MODEL 253 AND 253-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.

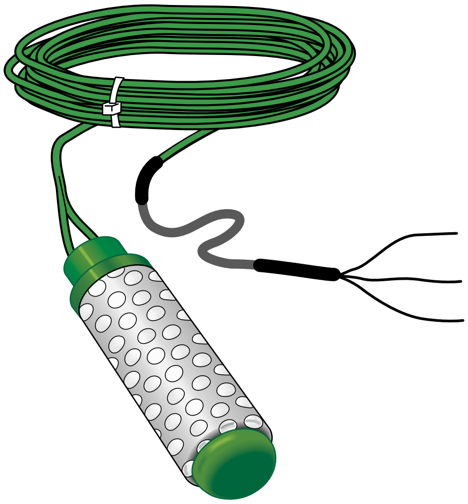

FIGURE 1.1 253 Soil Moisture Sensor

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.

> **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.

3. WIRING

The model 253 sensor is supplied with two green leads from Watermark. The leads from the Watermark electrode are connected directly to the H and L inputs on the AM32 or AM416. The lead coming from the center of the sensor is connected to H and the lead from the outer portion of the sensor to L. The wires can be differentiated by the grooved strip in one of the leads of the green wires. On the 253-L, Campbell Scientific splices a two conductor shielded cable to the two conductor green cable supplied from Watermark. The black conductor is connected to H, the white conductor to L, and the shield wire to G or ⏚. A 1kΩ resistor at the datalogger is used to complete the half bridge measurement.

4. MEASUREMENT

Instruction 5, AC Half Bridge, is used to excite and measure the model 253. 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

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 (R_S) in terms of kΩ.

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.

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

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.

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

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,

$$SWP = \frac{R_S}{0.01306[1.062(34.21 - T_S + 0.01060T_S^2) - R_S]} * .01$$

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

Bars (Non-Linear Equation)	Bars (Linear Equations)	(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 connections and programming used to measure the resistances (kohms) of 32 soil moisture blocks.

5.1 AM32 AND 21X

See Figure 5.1 for wiring diagram.

```
01:     P20          Set Port  (Enable AM32)
  01:      1         Set High
  02:      1         Port One

02:     P87          Beginning of Loop
  01:      0         Delay
  02:     32         Loop Count

03:     P22          Excitation with delay (clock)
  01:      1         Excitation Channel #1
  02:      1         Excite for 0.01 seconds
[3] 03:    0         0 second delay after excitation
  04:   5000         Excitation = 5000 mV

04:      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

05:     P95          End

06:     P20          Set Port (Reset AM32)
  01:      0         Set Low
  02:      1         Port Number

07:     P59          BR Transform Rf[X/(1-X)]
                     (Compute Resistances)
  01:     32         Reps
  02:      1         Location [:kOhms#1]
  03:      1         Multiplier  (Rf/1000)
```

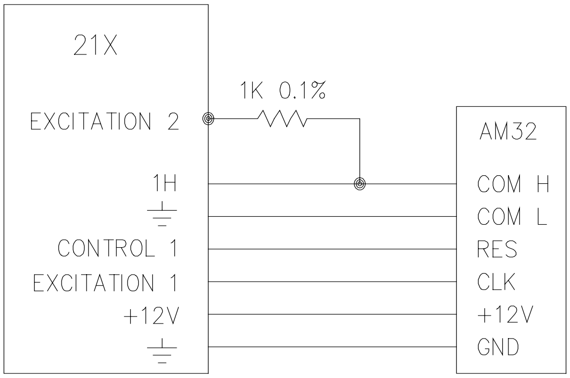

FIGURE 5.1

5.2 AM32 AND CR10

See Figure 5.2 for wiring diagram. This program can also be used with 21Xs with OSX PROMs although the clock pulse delay is 0.1 seconds (Figure 5.3).

```
01:      P86          Do
  01:     45          Set Port 5 high

02:      P87          Beginning of Loop
  01:      0          Delay
  02:     32          Loop Count

03:      P86          Do (Clock Pulse, 10 ms)
  01:     76          Pulse Port 6

04:       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

05:      P95          End

06:      P86          Do (Reset AM32)
  01:     55          Set Port 5 low

07:      P59          BR Transform Rf[X/(1-X)]
                      (Compute Resistances)
  01:     32          Reps
  02:      1          Location [:kOhms#1]
  03:      1          Multiplier  (Rf/1000)
```

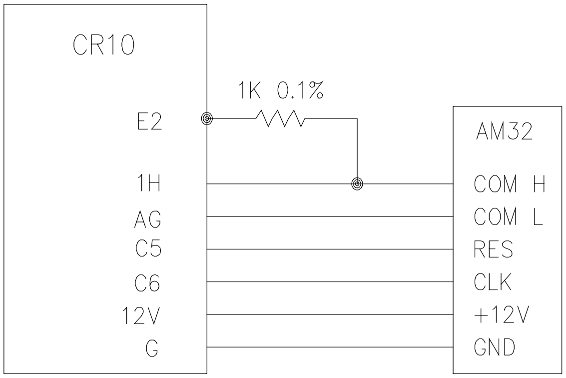

FIGURE 5.2

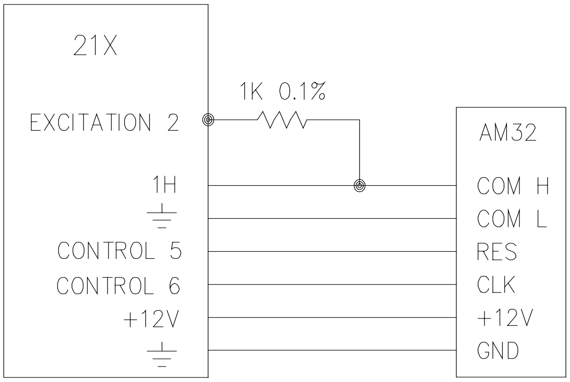

FIGURE 5.3

5.3 AM416 AND 21X

See Figure 5.4 for wiring diagram.

```
01:      P20          Port Set  (Enable AM416)
  01:      1          Set High
  02:      1          Port Number

02:      P87          Beginning of Loop
  01:      0          Delay
  02:     16          Loop Count

03:      P22          Excitation with delay (clock)
  01:      1          Excitation Channel #1
  02:      1          Excite for 0.01 seconds
  03:      0          0 second delay after excitation
  04:   5000          Excitation = 5000 mV

04:      P90          Step Loop Index
  01:      2          Step

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

06:      P95          End

07:      P20          Set Port  (Reset AM416)
  01:      0          Set Low
  02:      1          Port Number

08:      P59          BR Transform Rf[X/1(1-X)]
                      Compute Resistances
  01:     32          Reps
  02:      1          Location [:kOhms#1]
  03:      1          Multiplier  (Rf/1000)
```

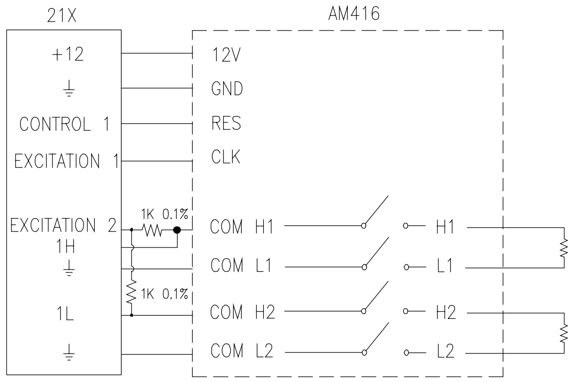

FIGURE 5.4

5.4 AM416 AND CR10

See Figure 5.5 for wiring diagram. This program can also be used with 21X with OSX PROMs although the clock pulse delay is 0.1 seconds (Figure 5.6).

```
01:      P86          Do Set Port (Enable AM416)
  01:     41          Set High Port 1

02:      P87          Beginning of Loop
  01:      0          Delay
  02:     16          Loop Count

03:      P86          Do (Clock Pulse, 10 ms)
  01:     72          Pulse Port 2

04:      P90          Step Loop Index
  01:      2          Step

05:       P5          AC Half Bridge  (Measure
                      AC Conductivity)
  01:      2          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

06:      P95          End

07:      P86          Do  (Reset AM416)
  01:     51          Set Low Port 1

08:      P59          BR Transform Rf[X/(1-X)]
  01:     32          Reps
  02:      1          Location [:kOhms#1]
  03:      1          Multiplier (Rf/1000)
```

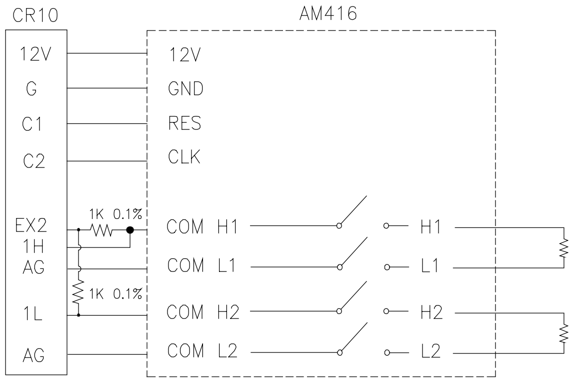

Figure 5.5

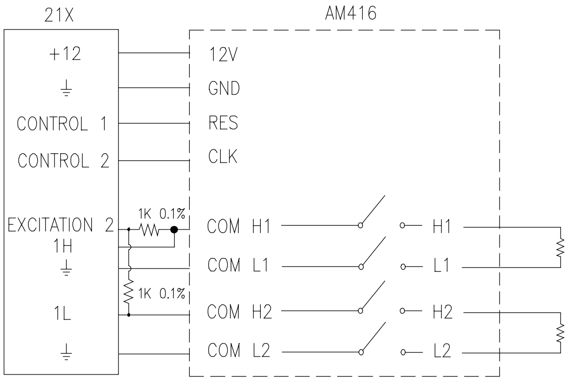

Figure 5.6

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

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

...Calculate (0.018 * dT)

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

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

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

07:      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...

```
08:      P87         Beginning of Loop
  01:      0         Delay
  02:     32         Loop Count
```

...Temperature Correct Ohms:

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

...Apply Calibration Slope and Offset

```
10:      P37         Z=X*F
  01:     41--       X Loc Bar#1
  02:        .07407  F
  03:     41--       Z Loc [:Bar#1    ]

11:      P34         Z=X+F
  01:     41--       X Loc Bar#1
  02:       -.03704  F
  03:     41--       Z Loc [:Bar#1    ]

12:      P95         End
```

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.*

```
08:      P87         Beginning of Loop
  01:      0         Delay
  02:     32         Loop Count

05:      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

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

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

SWP = 34.21-Ts

```
08:      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)]

```
09:      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.]

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

11:       P          35  Z=X-Y
```

SWP = SWPcalc.-Rs

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

SWP = 0.01306*SWPcalc.

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

SWP = Rs/SWPcalc.

```
13:      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

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

15:      P95         End Calculation Loop
```

7. PROGRAMMING (COMPREHENSIVE)

Follow these steps to create a complete program:

Step 1. Allocate at least 75 input locations in EDLOG.

Step 2. Set the execution interval according to need:

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

Step 3. 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:

```
01:      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:

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

03:      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

04:      P95          End
```

Step 4. 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:

```
05:      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 5. Calculate soil water potential using resistance and temperature:

Insert one of the examples from Section 6 here.

Step 6. Output data to final storage after each measurement and calculation:

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

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

08:      P70          Sample kOhm Resistances
  01:     32          Reps
  02:      1          Loc

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

10:      P70          Sample Bar Potential
  01:     32          Reps
  02:     41          Loc

11:      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.

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