A practical guide to using soil moisture sensors to control landscape irrigation

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Within the boundaries of the Northern Colorado Water Conservancy District are thirty municipalities of various populations. One thing that they do have in common is that lawn watering accounts for at least one-half of the water that each community needs to supply to its constituents. Approximately 50% of the residences and most commercial sites have automatic sprinkler systems. From past surveys, it has been determined that landscapes with automatic sprinkler systems are over-watered about 35-40% during the growing season. In contrast, those who still pull a hose around tend to over-water about 9%. For many years the "hose draggers" were perceived to be water "wasters". They would let water run on paved surfaces or for too long of a time and we would see water running in the gutters. However, with a new awareness of using water wisely, plus the increased cost of water and because so many people now have automatic sprinkler systems, the abuses of the past by "hose draggers" are not seen as frequently. They tend to water only when the lawn needs it, which is usually determined by visual observation.

Automatic sprinkler systems have the potential to save water **if** they are well designed, installed and maintained. People choose automatic sprinkler systems to avoid being bothered with the chore of lawn watering, but people tend to "set them and forget them". This method of watering accomplishes the task of keeping the lawn green, but over the growing season uses significantly more water than the grass requires. Another observation is that many people with automatic sprinkler systems have broken pipes, broken or missing sprinkler heads or sprinkler heads that are not correctly aligned. All of these problems contribute to water waste and are not often fixed because they are unnoticed when the lawn is being watered at night while they sleep.

Considerable amounts of time and effort have been invested to encourage people to be better water managers. But in reality it is a difficult and challenging task. Most urban dwellers have very little knowledge of plant materials and managing soils and water. Currently all irrigation controllers (timers) are programmed using minutes per watering zone, but lawn watering information made available to the public is given in inches of water. The great challenge for municipalities is teaching people how to make inches of water equal minutes of run time. And just to make it more complicated, the amount of water a lawn will need is always changing and every sprinkler system applies water at a different rate.

So there needs to be a better way for controlling sprinkler systems to conserve water and pulling a hose around the yard is not the solution that people will accept. They want a sprinkler system that is “set it and forget it”, will manage water correctly and keep the lawn green. A couple of possible solutions include changing how controllers function and are programmed or using soil moisture sensors to help manage the sprinkler system. New types of controllers are coming but are not yet available and finding the right sensor and gaining confidence in its ability to control the sprinkler system is challenging.

The basic concept of a soil moisture sensor system is to place a sensor in a representative part of the lawn and allowing the sensor to “sense” if there is sufficient moisture in the soil for the grass. If there is sufficient moisture, then the sensor will prevent the sprinkler system from activating and applying water. However, if it senses that the soil is dry, it allows irrigation to take place. The following information is to help explain, in simple terms, the different types of soil moisture sensors that are available and how they work. Also included is a short summary report of a comparative demonstration of soil moisture sensors controlling irrigation for turfgrass.

Soil Moisture Sensor Technology

Tensiometers measure the soil moisture tension or suction. This device is a plastic tube with a porous ceramic tip attached at one end and a vacuum gauge on the other end. The porous ceramic tip is installed into the soil at the depth where the majority of the active root system is located. The vacuum gauge measures the soil moisture tension or suction. It measures how much effort the roots must put forth to extract water from the soil and is measured in centibars. The higher the reading, the less moisture that is available and the harder roots must work to extract water. A lower reading indicates more available water. A tensiometer can be used to take manual readings or a special model can be installed to provide the capability for the tensiometer to be wired into the sprinkler system to provide control. Also the tensiometer needs routine maintenance to make sure enough liquid is in the tensiometer and that it hasn’t broken tension because the soil has separated away from the ceramic tip. In climates where the ground freezes, tensiometers must be removed and stored for the winter months and reinstalled the following year.

Electrical resistance blocks measure soil moisture tension with two electrodes imbedded in a porous material such as gypsum, or a sand-ceramic mixture. The block allows moisture to move in and out of it as the soil dries or becomes moist. The electrodes measure the resistance to electric current when electrical energy is applied. The more moisture in the block, the lower the resistance reading indicating more available moisture. The blocks use gypsum or similar material to be a buffer against salts (such as fertilizer) that would also affect resistance readings. The sensors using a granular matrix seem to work well and last for a longer time as compared to gypsum blocks.

Electrical conductivity probes measure soil moisture in the soil by how well a current of electricity is passed between two probes. In many ways the concept is similar to resistance blocks but the probes (electrodes) have direct contact with the soil and are not buffered as in resistance blocks. The more moisture in the soil the better the conductivity or the lower the electrical resistance. This method is very sensitive to the spacing of the probes as well as being influenced by soil type and salts that come primarily in the form of fertilizers.

Heat dissipation sensors measure soil moisture by measuring how much heat is dissipated in a ceramic medium. The heat dissipated is directly proportional to the amount of water contained within the ceramic's void spaces. The more water that is contained in the ceramic, the more heat is dissipated and the lower the sensor readings. This corresponds to a higher soil matric potential or in other words, more available water for the plant. The sensor works when water moves in or out of the ceramic due to capillary forces in the soil. The manufacturers claim this type of sensor is independent of soil type or salinity influences.

Dielectric sensors have been developed that will calculate the soil moisture content by measuring the dielectric constant of the soil. A dielectric is a material that does not readily conduct electricity. Dielectric sensors use two different methods to measure soil moisture without measuring electrical conductivity. **Capacitance** sensors use frequency-domain-reflectometry and **TDR** sensors use time-domain-reflectometry. Dielectric sensors are generally expensive and are used more in scientific research than to actually control a lawn sprinkler system.

> **Capacitance** sensors contain two electrodes separated by a dielectric. The electrodes are inserted into the soil or in an access tube in the soil and the soil becomes part of the dielectric. A very high oscillating frequency is applied to the electrodes, which results in a resonant frequency, the value of which depends upon the dielectric constant of the soil. The moisture content of the soil will change the dielectric constant of the soil, therefore more moisture in the soil will change the frequency. This change is converted into a soil moisture measurement.
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> **TDR** measures the time required for an electromagnetic pulse to travel a finite distance along a wave guide (steel rods or length of wire) and is dependent upon the dielectric properties of the material surrounding (the soil) the wave guide. As moisture increases in the soil, the time taken for the pulses to travel slows down. The signal is then converted into a soil moisture measurement. This technology is very complex and quite expensive, but seems to provide high accuracy.

The ***Neutron Probe*** has been around for many years and works by sending out neutrons from a probe (the radioactive source) that is lowered down a tube in preset increments. Neutrons emitted by the probe enter the soil and are thermalized by the hydrogen present in water. These thermalized neutrons enter the helium-3 detector and are registered as a count. As the instrument takes readings of how the neutrons are moving, a calibration is made that converts the neutron count into soil moisture content. The neutron probe needs to be calibrated for each type of soil but it has proven to be very reliable and accurate and is usually the benchmark by which other instruments are compared. However, it is not useful for controlling an irrigation system. It uses radioactive materials that many people don't want to be around and the required paper work to keep it licensed etc. is almost overwhelming and very costly. Again this type of sensor, while extremely accurate is not meant to directly control an irrigation system, but rather provide the manager with information upon which water management decisions can be made.

For more technical information and other technologies on soil moisture sensors try the Internet at www.mif.org/sensors/smi-article.html or www.sowacs.com/sensors/ or review the proceedings of the 1998 Irrigation Association Technical sessions of the International Irrigation Exposition at www.irrigation.org.

Lawn Watering using soil moisture sensors

FEATURES

Listed below are some important features when selecting a soil moisture sensor to control the sprinkler system:

Adjustable Moisture Level: the operator can set the sensitivity of how much moisture should be in the soil to meet the minimum needs of the grass.
Indicator Light: allows the operator to set the moisture level and receive immediate feedback from the sensor when current moisture level has been sensed. On some models the light comes on when water is needed and in other models the light remains on as long as there is adequate moisture.
Override position, will allow irrigation to take place even if the sensor would indicate that the soil is moist enough. This feature is useful when the site has just been fertilized or the system is being checked for correct operation
Sensor wire should be UL approved for direct bury in the soil. Use waterproof connectors. Bury the wires deep enough that they won't be damaged by equipment used to manage turf such as aerators.
Special tools when available, will make sensor installation into undisturbed soil easier and the sensor can take over control of the sprinkler system more quickly. Some sensors can only be placed in a hole where the soil has been disturbed. Take care to compact the soil around the sensor to have the same bulk density of the undisturbed soil.
Track record is important as well as service from the distributor after the sale. Choosing the soil moisture sensor system that will work best for your situation is perhaps the biggest challenge. There have been many companies come and go over the years, so finding one that has been

around for a while and appears to be stable will give you some confidence that their sensor and system must be working.

PLACEMENT

To begin, sensor placement is very critical for proper function of soil moisture sensors. The sensor should be placed in a “typical “ spot of the lawn. It shouldn’t be the wettest spot since it would inhibit the sprinklers from coming on and if it is in the driest spot, then the sprinklers would be allowed to water too frequently. Choosing the representative spot requires good site observations. The sensor should be in the middle of the sprinkler pattern. Usually the sprinkler zone with the soil moisture sensor will need to be wired into the controller as the last sprinkler zone. The sensors typically are installed or wired to interrupt the common wire going to each of the valves of the system to preempt irrigation.

INSTALLATION

How the sensor is actually placed in the soil takes care and planning. For the sensor to work the best, the soil around the sensor needs to be representative of the soil for the whole site. After an installation hole is dug, some sensors can be easily installed into undisturbed soil. This is the best because achieving the same bulk density of disturbed soil make take weeks or months of time. Otherwise the sensor will be placed in a situation where the disturbed soil will be replaced into the hole and tamped or compacted or watered in a way that will make it different than the surrounding soil. This difference will affect how well the sensor is sensing the soil moisture that is supposed to be representative.

For almost all soil moisture sensors, new wires will need to be installed from the sensor location to the irrigation controller. This effort may take substantial time, effort and expense to achieve. But this will be necessary if only one sensor will be used for the entire sprinkler system. Many times the cost of installing the additional wires will be more than the sensor and its controls. If a new sprinkler system is being installed, run additional wires from the field to the controller. The cost of doing this is minimal and allows flexibility for the future. Usually five correctly sized wires will be sufficient for even the more complicated sensors. Another option would be to place a sensor and its control at each zone in the system. This is a good alternative when valves are spaced far apart and each sensor is only for a particular zone. Installation is easier, but costs increase because of the total number of sensors being used.

Where the sensor is placed in the root zone is also critical. Ideally the sensor should be where the majority of feeder roots are growing. Typically the sensor will be about 4-6 inches deep for cool season turfgrass such as bluegrass or fescue grass and perhaps 10-12 inches deep for warm season grasses such as bermuda or buffalograss. Again it is very important to place the sensor properly to gain the best benefit for controlling irrigation. Another often overlooked aspect is to make quality water-proof wire connections. If more wire is needed than supplied by the manufacturer, make sure it is approved for underground burial.

PROGRAMMING

After the soil moisture sensor has been properly placed and installed, then a new approach to programming the controller will be required. Depending upon local ordinances or requirements there are several ways to approach programming.

Daily watering is programmed by selecting each day of the week for watering to occur. However the total run time should be split up among several start times. For example twenty minutes a day could be programmed to be four start times for five minutes each. That way if the sensor sensed that the soil was dry enough for irrigation to occur, then it would allow five minutes of watering to happen. Then, when the next cycle should begin, it “sensed” that it received adequate moisture from the first cycle, it would preempt the next three cycles from occurring. Schedule at least one hour of time between cycle starts so that the water can soak down towards the sensor. With this method, the watering should only occur when the sensor feels dry.

Programmed days uses the same approach as above, but irrigation can take place only on selected days. This method accommodates mowing schedules or ordinances that allows watering only on certain days or during certain hours. Again using multiple cycle starts will maximize the benefit of using soil moisture sensors by only applying the amount of water that the soil can hold to meet the needs of the grass.

TWEAKING

“Tweaking”, although not a very scientific term, describes the actions of observing and adjusting the controls to maximize the benefit of a soil moisture sensor system. This requires careful observation of how well the grass is doing as a whole and of the specific area where the sensor is located. After a period of time it might be determined that the sensor location is not as representative of the site as first thought. If the site overall looks dry, then either the other zones need additional run time for more water, or the sensor zone needs less run time. Balancing the run times for the various zones to be compatible with the sensor zone takes time and patience.

Once the sprinkler zones are balanced with the sensor zone, then further adjustment can be made to many of the systems. Most systems will have some type of control system that interfaces with the irrigation controller. This allows adjustment of the sensor sensitivity. If it is set for too wet then the sensor will allow more irrigation to take place than what the grass requires. If it is set for too dry, then the grass will become stressed. When this happens most people begin to lose confidence in the sensor thinking that it is not working correctly. The sensitivity needs adjustment and a period of time to determine if it is set properly.

Some sensors don’t have a sensitivity adjustment and then the only option is to dig it up and change its location in the root zone to better meet the needs of the grass.

Acceptance of the sensor-controlled irrigation system comes as the owner of the property is satisfied by the overall appearance of the turfgrass. When the owner is happy, then the sensor is doing its job. For most people, the sensor will allow less irrigation than what the owner would do on his own. But that is the goal of sensor-based irrigation-- to apply the right amount of water at the right time.

As a follow-up to see if the sensor is truly doing the job it is intended to do, there needs to be a way to measure how much water is being applied compared to what should be applied or has been in the past. Using past water records for similar periods of previous years will show if water is being conserved and money being saved. If current ET information is available, then knowing how much water should be applied in inches or gallons can be compared to current meter readings or site catchments. Without measuring and comparing, then there is no way to know if the soil moisture sensor system is working correctly and saving water.

The following case study describes an attempt to compare ET requirements for a bluegrass lawn and sensor-controlled irrigation on a small scaled demonstration area.

Case Study Using Soil Moisture Sensors to Control Lawn Watering

The demonstration site is located at the headquarters of the Northern Colorado Water Conservancy District in Loveland, Colorado. The site is situated in an urban commercial setting near roads and parking areas. In the summer of 1997 a demonstration site was constructed to allow soil moisture sensors to control sprinkler systems on turfgrass. Each plot is roughly 9’ x 9’ in size and has its own valve, heads and controller. The site has four plots with the native silty clay loam soil and four plots with fine sand. The sand was imported and is a minimum of three feet deep. A blend of Kentucky bluegrass was established in each plot and the grass is mowed twice weekly and fertilized as needed during the growing season. A nearby weather station is used to obtain ET information using the Penman-Monteith equation. See Figure 1.

Four different types of sensors were installed. A sensor of each type was placed in a plot of sandy soil and clay soil. Each controller was programmed to water daily with four start times of five minutes each. In the center of each plot was a recessed (flush with the soil surface) rain gauge to measure how much water was applied. The sprinkler system for each plot has an average precipitation rate of 1.80-2.00 inches per hour.

In this demonstration, four different soil moisture sensor systems were purchased and installed according to manufacturer’s specifications. The controllers were adjusted to do daily watering each evening. They were programmed to water four times each evening for five minutes per cycle, with at least one hour between cycles. The table shows what the adjusted ET for the grass was for each month and subtracting rainfall the net water need was determined. The readings in each column represent the amount of water in inches that was applied after subtracting rainfall. The goal was to set the sensors to apply water that would approximate ET or less and have acceptable quality. See Table 1.

The four sensors selected for the demonstration include

Aquatel by Automata, Inc a TDR sensor
Hydromanage by Systematic Irrigation Controls a conductivity sensor
SprinklerMaster by Sprinkler Master Inc. a conductivity sensor
Watermark by Irrometer Company, Inc. a resistance block

The Aquatel (**A**) sensor in clay soil was easiest to set. During the season it consistently watered less than ET, and though the quality of the lawn was not lush but it was acceptable. The same sensor in sand was much more difficult to tweak to optimum performance. The Aquatel sensor responded very quickly to soil moisture levels. The biggest problem encountered was the number of wires and a complicated wiring diagram needed to interface with the controller. Of all of the sensors used, it is the least "homeowner friendly" for cost and installation.

The Hydromanger (**H**) sensor quit working in mid June in the clay plot and the quality of the lawn deteriorated over the summer until finally the sensor was disabled and the controller applied water as it was programmed. In the sand the Hydromanager sensor worked intermittently. Judging from how the sensors work, the problem seems to exist in the electronics or the sensor control that interfaces with the sprinkler system controller.

The SprinklerMaster (**SM**) sensor quit working first in the sand and then in the clay after only a few weeks. The biggest problem observed was that the wire supplied with the sensor was speaker wire and not rated for underground burial. It was very easy to see through the clear insulation that water had penetrated the insulation and corroded the wire. It was the least expensive sensor purchased for installation and with proper wire it might work satisfactorily.

The Watermark (**WM**) sensor has proven to work quite well in both the clay and sandy soils, however because it does not have an indicator light on the sensor control next to the controller, it took most of the summer to tweak it to operate at acceptable levels. The Watermark sensor is also very slow to respond to changes as compared to all other sensors that would respond immediately.

Table 1
1998 Soil Moisture Sensor Comparison
Loveland Colorado May through September

Month	ET inches	Rain inches	Water Need inches	Clay A inches	Clay H inches	Clay SM inches	Clay WM inches	Sand A inches	Sand H inches	Sand SM inches	Sand WM inches
May	3.94	2.03	1.21	3.04	4.64	4.10	7.53	5.56	4.31	4.21	5.53
June	4.82	1.44	3.38	2.84	6.72	5.61	6.39	10.45	6.61	8.97	8.24
July	5.01	1.10	3.91	1.87	0.04	14.01	6.12	11.08	12.87	14.73	4.43
Aug	4.70	0.81	3.89	1.35	0.68	12.62	2.08	17.28	14.25	12.79	1.39
Sept.	4.18	1.70	2.48	2.20	12.04	9.50	3.78	3.02	8.35	9.39	3.29
Total	22.65	7.08	15.57	11.30	24.12	45.84	25.90	47.39	46.39	50.09	22.88

A= Aquatel Sensor by Automata   **SM** = SprinklerMaster system
H = Hydromanger by Systematic   **WM** = Watermark Sensor by Irrometer

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Soil Moisture Sensor Demonstration Site Layout

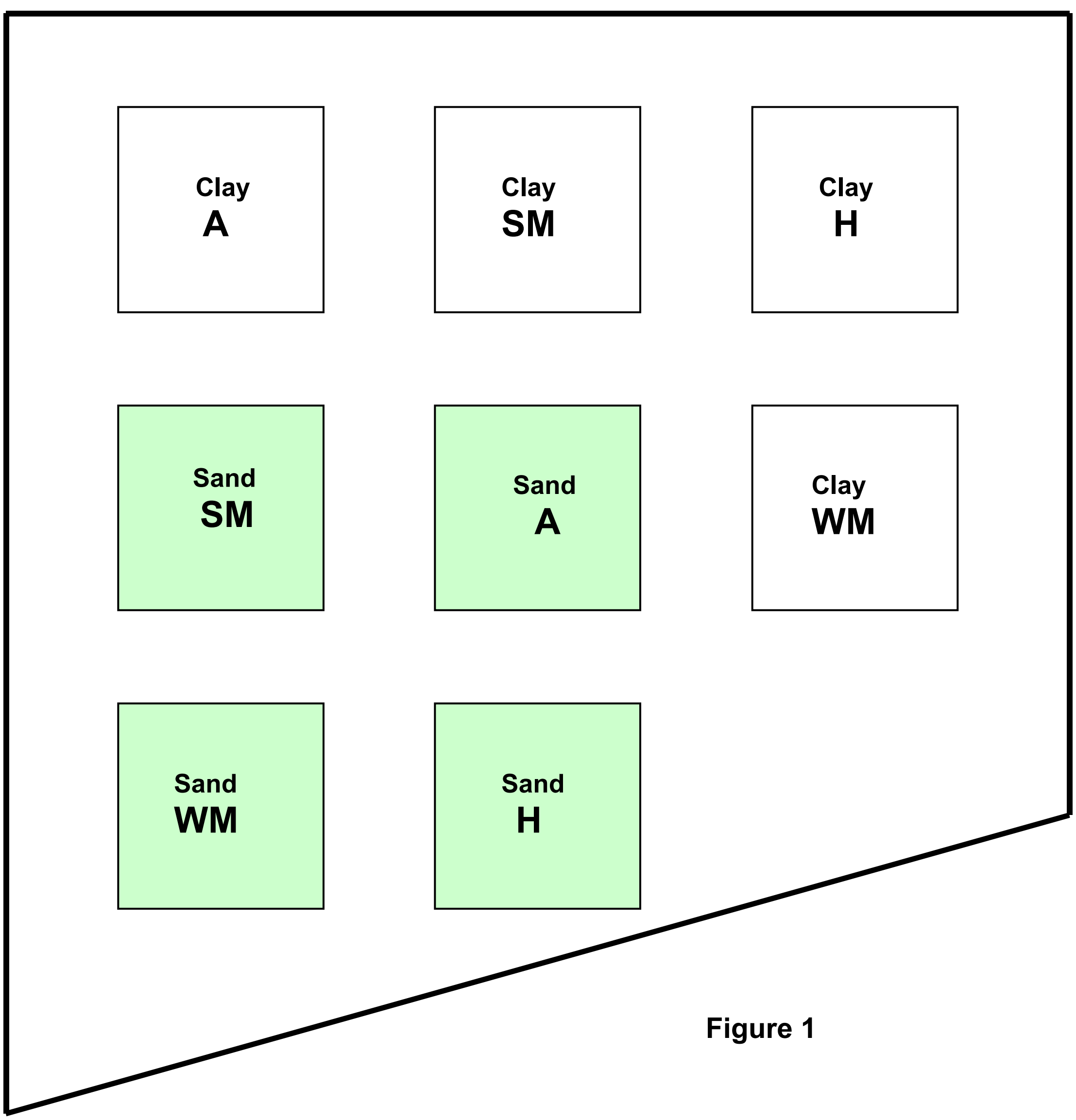

Figure 1

What's Next?

The District and the United States Bureau of Reclamation fund this project. It is intended that this study will continue for several years. Two new soil moisture sensor systems will be selected and installed. Primary consideration will be given to the cost of the system, ease of installation and user friendly features. The long term purpose of the study is to identify soil moisture sensor systems that will reliably control lawn sprinkler systems and provide practical information to end users as they adopt new technologies for managing and conserving water resources.

Listed below are the names of some manufacturers according to type of sensor. This listing is for reference and does not constitute an endorsement of a company or product

TENSIONMETERS:

Irrometer Company, Inc.
P.O. Box 2424
Riverside, CA 92516
(909) 689-1701

Forestry Suppliers, Inc.
205 West Rankin Street
Jackson, MS 39284
1-800-647-5368

RESISTANCE BLOCKS

Delmhorst Gysum Blocks
Ben Meadows Company
3589 Broad Street
Atlanta, GA 30341
1-800-241-6401

Waterguard
Viable Innovations Corporation
Boulder, CO
1-800-366-5325

Watermark
Irrometer Company, Inc.
P.O. Box 2424
Riverside, CA 92516
(909) 689-1701

CONDUCTIVITY PROBES

Waternomics Monitors
ETC Inc.
609 Noble Place NE
Alburquerque, NM 87107
(505) 341-9513

Water Guardian
Water Conservation Instruments
4900 Hawkins NE
Albuquerque, NM 87109

Sprinkler Master, Inc.
85 Chestnut Ridge, Rd.
Montvale, NJ 07645
1-800-728-3420

Hydromanager Interrogator
Systematic Irrigation Controls, Inc
P.O. Box 8051
Newport Beach, CA 92660
(714) 760-0411

HEAT DISSAPATION

Hydrovisor
Water Conservation Systems, Inc.
1935 W. Eleventh St. Suite L
Upland, CA 91786
1-800-821-1322

AGWATRONICS, Inc.
P.O. Box 2807
Merced, CA 95344
(209) 383-3215

Water Watcher
www.fishnet.net/~jackh/

CAPACITANCE TECHNOLOGY

Aquaterr Probe
Aquaterr Instruments, Inc
P.O. Box 459
Fremont, CA 94538
1-800-284-1201

Enviroscan
Sentek Ltd.
69 King William St.
Kent Town, SA 5067
Australia
(61)883630839

Flori
Netafim USA
5470 E. Home Ave.
Fresno, CA 93727
(209) 453-6800

ThetaProbe
Dynamax, Inc.
10808 Fallstone Suite 350
Houston, TX 77099
1-888-396-2628

Sentry 200-AP
Troxler Electronic Labs, Inc.
3008 Cornwallis Rd.
Research Triangle Park NC 27709
(919) 549-8661

TDR TECHNOLOGY

MoisturePoint & GroPoint
Environmental Sensors, Inc.
100-4243 Glanford Ave.
Victoria BC Canada V8Z 4B9
(604) 479-6588

Campbell Scientific, Inc
815 W. 1800 North
Logan, UT 84321
(435) 753-2342

VADOSE
Dynamax, Inc.
10808 Fallstone Suite 350
Houston, TX 77099
1-888-396-2628

AQUAFLEX
Streat Instruments
P.O. Box 2197
Walla Walla, WA 99362
(509) 529-2646

AQUA TEL
Automata, Inc
16216 Brooks Road
Grass Valley, CA 95945
1-800-994-0380

TRASE
Soilmoisture Equipment Co.
801 S. Kellogg Ave.
Goleta, CA 93117
1-888-964-0040

NEUTRON PROBE

Troxler Electronic Labs, Inc.
Research Triangle Park NC 27709
(919) 549-8661