MPS-2

Dielectric Water Potential Sensor
Operator's Manual

Version 1

DECAGON DEVICES

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Contents

1. Introduction

Thank you for choosing the Dielectric Water Potential Sensor, model MPS-2 for measuring soil water potential and temperature. This manual is designed to help you understand the sensor's features, and how to use this device successfully.

In the engineering community, the term soil suction is commonly used instead of soil water potential. Soil water potential is simply the negative of soil suction and will be used throughout the remainder of this manual.

Specifications

Water Potential

Range: -5 to -500 kPa (pF 1.71 to pF 3.71)
Resolution: 0.1 kPa
Accuracy: ± 25% of reading from -5 kPa to -100 kPa*

Temperature

Range: -40 °C to +50 °C
Resolution: 0.1 °C
Accuracy: ± 1°C

General

Survival Environment: -40 to 60°C, 0 to 100% RH
Operating Temperature: 0 to 50°C (no water potential measurement below 0°C)
Power Requirements: 3.6 - 15 VDC, 0.03 mA quiescent, 10 mA max during 150 ms measurement

* See Measurement Range and Accuracy chapter for details on accuracy.

Dimensions: 9.6 cm (L) x 3.5 cm (W) x 1.5 cm (D)
Sensor Diameter: 3.2 cm
Dielectric Measurement Frequency: 70 MHz
Measurement Time: 150 ms (milliseconds)
Output: RS232 (TTL) with 3.6 volt levels or SDI-12 communication protocol
Connector Types: 3.5 mm (stereo) plug or stripped & tinned lead wires (3)
Cable Length: 5m standard; custom lengths available upon request
Data Logger Compatibility (not exclusive):
Decagon: Em50, Em50R, Em50G (rev 2.5+)
Campbell Scientific: Any logger with serial I/O including CR10X, CR23X, any CRBasic type logger (CR850, 1000, 3000, etc.)
Other: Any data acquisition system capable of 3.6-15V excitation and serial or SDI-12 communication
Handheld Reader Compatability: ProCheck (rev 1.29+)
Software Compatibility: ECH$_2$O Utility (rev 1.62+)
DataTrac 3(rev 3.3+)

Contact Information

To contact Decagon for customer support or questions:

E-mail: support@decagon.com
sales@decagon.com
Fax: (509) 332-5158
Telephone: 1-800-755-2751 (USA and Canada Only)
1-509-332-2756 International

Our Customer Support and Sales Representatives are available Monday thru Friday, 8am-5pm Pacific Time.

NOTE: With any correspondence please include your name, contact information, instrument serial number(s), and a description of your problem or question.

Warranty Information

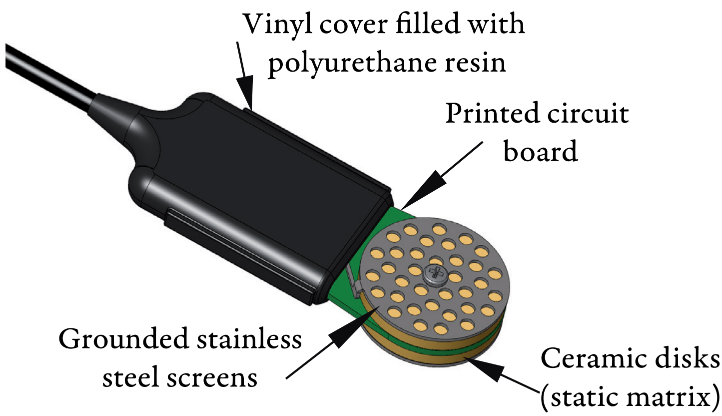
The Dielectric Water Potential Sensor has a 30-day satisfaction guarantee and a one-year warranty.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not to be considered a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts F.O.B. the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things of whatsoever kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, nonuse, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitutes Buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

2. About the MPS-2

The MPS-2 measures the water potential and temperature of soil and other porous materials. The MPS-2 has a low power requirement which makes it an ideal sensor for permanent burial in the soil and continuous reading with a datalogger or periodic reading with a handheld reader.



3. Theory

Water Potential Measurement

There are two basic parameters that describe the state of water in soil: one is soil water content, or the amount of water per unit of soil, and the other is soil water potential, or the energy state of water in the soil. Although water content is useful when trying to describe the water balance of a soil, i.e. how much water is moving in, out, or being stored, water potential is often preferred over water content because it shows how water will move in a soil or from the soil to the plant. In addition, water potential can be used to determine plant availability of water, determine soil stress, and schedule irrigation, among other things.

All soil water potential measurement techniques measure the potential energy of water in equilibrium with water in the soil. The Second Law of Thermodynamics states that connected systems with differing energy levels will move toward an equilibrium energy level. Thus, if an object comes into hydraulic contact with the soil, the water potential of the object will come into equilibrium with the soil water potential. Examples of instruments that make use of this principal are tensiometers, which measure the potential energy of a liquid water reservoir in equilibrium with the soil water (liquid equilibration), and psychrometers/dewpoint hygrometers, which measure the potential energy of water vapor in equilibrium with the soil water (vapor equilibration).

Another category of water potential sensors use a solid matrix equilibration technique to measure the water potential of the soil. This technique introduces a known material with a static matrix of pores into the soil and allows it to come into hydraulic equilibrium according to the Second Law of Thermodynamics noted above. Because the two are in equilibrium, measuring the water potential of the solid matrix will give the water potential of the soil. Historically, instruments have measured the thermal conductivity or electrical conductivity of the solid matrix to determine its water potential with varying degrees of success.

The MPS-2 uses the same principle, but instead measures the dielectric permittivity of a solid matrix - porous ceramic disks - to determine its water potential. The dielectric permittivity of air, the solid ceramic, and water are 1, 5, and 80 respectively. So, the dielectric permittivity of the porous ceramic disks is highly dependent on the amount of water that is present in the pore spaces of the ceramic. Thus, by measuring the dielectric permittivity of the ceramic disks, a wide range of water contents can be resolved.

Water content and water potential are related by a relationship unique to a given material, called the moisture characteristic curve. The ceramic used with the MPS-2 has a wide pore size distribution and is consistent between disks. So, if the water content of the ceramic is measured accurately, along with a measurement of actual water potential, then a calibration curve is generated that will give a standard calibration for the MPS-2 in terms of water potential. This calibration is not dependent on the type of soil into which the MPS-2 is installed.

The total soil water potential (Ψ_t) is made up of four water potential components:

$$\Psi_t = \Psi_p + \Psi_g + \Psi_o + \Psi_m$$

where the subscripts p, g, o, and m are pressure, gravitational, osmotic, and matric respectively. Of these four components, only Ψ_o

and Ψ_m are significant and often measured in soil. Ψ_o arises from dissolved salts in the soil, and only becomes important if a semi permeable barrier is present that prevents ionic movement (e.g. plant roots, cell membranes). Ψ_m arises from the attraction of water to the soil particles, and is the most important component of water potential in all but the most salt affected soils. The MPS-1 only measures the matric potential of the soil (Ψ_m). In highly salt affected soils, it may be necessary to quantify Ψ_o independently if measures of soil water potential relating to biological activity are being conducted.

Temperature Measurement

The MPS-2 uses a surface-mounted thermistor to take temperature readings. It is located underneath the sensor overmold, and will read the temperature of the sensor surface. The MPS-2 will output temperature in °C unless otherwise stated in your preferences file in either the DataTrac 3 or ECH$_2$O Utility programs. It is important to note that if the black plastic overmold of the sensor is in direct sunshine, the temperature measurement may read high. Exposure of the overmold to solar radiation will also drastically decrease the life expectancy of the sensor. We do not recommend that the sensor be installed with the overmold in the sun.

4. Measurement Range And Accuracy

Measurement Range

As described in the Theory chapter, the MPS-2 sensor measures the water content of porous ceramic disks and converts the measured water content to water potential using the moisture characteristic curve of the ceramic. It is important to the sensor design that the ceramics drain over a wide water potential range. The water potential at which a pore drains (the air entry potential or bubble pressure) is defined by the size of the pore so the ideal ceramic would have pores that range from very small to relatively large.

The MPS-2 ceramic has been specially designed to approach this ideal. Despite several decades of development, the MPS-2 ceramic still has a total pore volume that is weighted toward the larger pores that drain at wetter water potentials. This limits the effective measurement range of the MPS-2 to the range of -5 kPa (the air entry potential of the largest pores in the ceramic) to -500 kPa, with some limited sensitivity drier than -500 kPa (it can give meaningful qualitative information to air dry). However, if the output from the sensor is drier than -500 kPa, it should not be used for quantitative analysis because of potentially large errors in the magnitude of water potential. Also note that as the sensor dries past -500 kPa, the measured water potential becomes increasingly noisy due to very small changes in measured water content of the ceramic translating into very large changes in water potential. This phenomenon is most pronounced when the sensor is air dry. It is expected that the measured water potential of an air dry sensor can randomly oscillate throughout the range of -30,000 kPa to -100,000 kPa.

The air entry potential of the largest pores in the MPS-2 ceramic is about -5 kPa. However, the MPS-2 ceramic must have access to air for the large pores to begin draining and the response of the sensor to change. If the soil where the MPS-2 is placed has an air entry potential more negative (drier) than -5 kPa, air won't be able to reach the sensor until the air entry potential of the soil is reached. So, in this scenario, the wet end range of the MPS-2 will be limited by the air entry potential of the soil rather than the ceramic disks themselves. This is generally only an issue when using the MPS-2 sensor in poorly structured soils with high clay content.

Measurement Accuracy

The MPS-2 ceramic has excellent properties to produce good accuracy in the wet range. This results in accuracy of ± 25% of the measured water potential in the range of -5 kPa to -100 kPa. As the ceramic dries toward -500 kPa, the total pore volume that drains at a given water potential decreases substantially, creating lower and lower sensitivity as the ceramic dries. This lack of sensitivity creates larger uncertainty in the measurement accuracy. Our tests indicate the accuracy at -300 kPa has decreased to approximately ± 35% of the measured water potential, and at -500 kPa the accuracy is approximately ± 50%. Note that some of the variability in the sensor calibration data at water potentials drier than -100 kPa is likely due to the use of pressure plates to collect test data. Despite the well-documented problems with the pressure plate method (Campbell, 1988; Gee et. al, 2002; Bittelli and Fury, 2009; Frydman and Baker, 2009), we have not yet found a more convenient method to check accuracy drier than -100 kPa.

Calibration

Each MPS-2 sensor is calibrated air-dry and vacuum saturated at Decagon. This two-point calibration results in the accuracy stated above. Better accuracy can be achieved through user calibration of the sensor. However, if you plan to calibrate the sensors using the pressure plate method, please note the problems that are intrinsic to that method as described above.

The MPS-2 calibration is not affected by soil type because it only measures the water potential of the ceramic disks in equilibrium with the soil. The MPS-2 sensor will measure accurately in any soil type and other porous media as long as it is installed correctly with adequate hydraulic contact (to ensure timely water potential equilibrium between the sensor and the medium of interest).

Hysteresis

The amount of water that a soil holds at a given water potential will be greater if the material is dried to that water potential than if the material is wet up to that water potential; a phenomenon known as hysteresis. Because the MPS-2 essentially makes a dielectric measurement of water content and converts that to water potential, the MPS-2 measurements will have some hysteresis. In most situations, soil undergoes brief periods of wet up (precipitation or irrigation events) followed by longer dry down periods where water potential measurements are most useful. The calibration of the MPS-2 is performed on the drying leg of the hysteresis loop, so the measurements will be most accurate as the soil dries. MPS-2 measurements as the soil wets up will be slightly drier (more negative water potential) than the true water potential of the soil. Our wetting and drying tests show the magnitude of the error is about 10 kPa in the -20 kPa to -100 kPa range.

5. Connecting to a Logger

The MPS-2 sensor was designed to be used with Decagon's Em50, Em50R, Em50G data loggers or the ProCheck handheld reader. The standard sensor (with 3.5 mm stereo connector) quickly connects to and is easily configured within a Decagon logger or selected in ProCheck.

The MPS-2 sensor incorporates several features that also make it an excellent sensor for use with third party loggers. The sensor may be purchased with stripped and tinned wires (pigtail) for terminal connections.

Extending sensor cables

The MPS-2 sensor comes standard with a 5 meter cable. Our testing indicates that sensor cables can be extended up to 75meters (250 ft). Sensors may be purchased with custom cable lengths for an additional per-meter fee. This option eliminates the need for splicing the cable. If you do need to extend the cable, please be sure to adequately waterproof the cable splices as inadequately waterproofed cable splices are a major failure point. Visit www.decagon.com for detailed suggestions on waterproofing cable splices.

Connecting to Em50/Em50R/Em50G logger

The MPS-2 has been designed to work specifically with the Em50 data logger. Simply plug the 3.5mm "stereo plug" connector directly into one of the five sensor ports. The next step is to configure your logger port for the MPS-2 and set the measurement interval, this may be done using either ECH$_2$O Utility or DataTrac 3 (see respective manuals). Please check your software and firmware versions to ensure it will support the MPS-2. To update to the latest version, please visit Decagon's software download site:

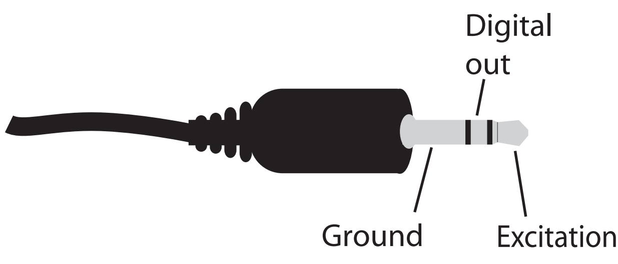
www.decagon.com/support

The following software/firmware supports the MPS-2 sensor:

ECH$_2$O Utility version1.62 or greater
DataTrac 3 version3.3 or greater
Em50's version 2.5 or greater
ProCheck readers version 1.29 or greater

To download data from a Decagon logger to your computer, you will need to use the ECH$_2$O Utility or DataTrac 3.

3.5mm Stereo Plug Wiring

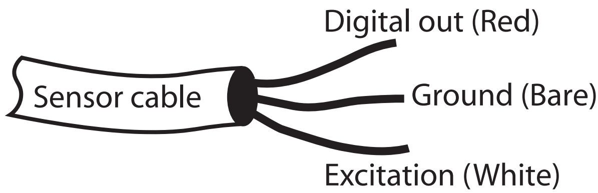


Connecting to a Non–Decagon Logger

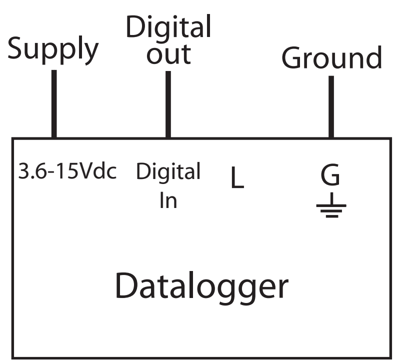
MPS-2 sensor may be purchased for use with non-Decagon data loggers. These sensors typically come pre-configured with stripped and tinned (pigtail) lead wires for use with screw terminals. Refer to your distinct logger manual for details on wiring. Our integrator's guide gives detailed instructions on connecting the MPS-2 sensor to non-Decagon loggers. Please visit www.decagon.com/

support for the complete integrator's guide.

Pigtail End Wiring



Connect the wires to the data logger as shown, with the supply wire (white) connected to the excitation, the digital out wire (red) to a digital input, the bare ground wire to ground as illustrated below.



NOTE: The acceptable range of excitation voltages is from 3.6 to 15 VDC. If you wish to read the MPS-2 with the Campbell Scientific Data Loggers, you will need to power the sensors off of the 12V or switched 12V port.

If your MPS-2 is equipped with the standard 3.5mm plug, and you wish to connect it to a non-Decagon data logger, you have two options. First, you can clip off the plug on the sensor cable, strip and tin the wires, and wire it directly into the data logger. This has the advantage of creating a direct connection with no chance of the sensor becoming un-plugged; however, it then cannot be easily used in the future with a Decagon readout unit or data logger. The other option is to obtain an adapter cable from Decagon. The 3-wire sensor adapter cable has a connector for the sensor jack on one end, and three wires on the other end for connection to a data logger (this type of wire is often referred to as a "pigtail adapter"). Both the stripped and tinned adapter cable wires have the same termination as seen above; the white wire is excitation, red is output, and the bare wire is ground.

6. Communication Non Decagon Loggers

The MPS-2 sensor can communicate using two different methods, Serial (TTL) and SDI-12. In this chapter we will briefly discuss the specifics of each of these communication methods. Please visit www.decagon.com/support for the complete integrator's guide, which gives more detailed explanations and instructions.

Serial Communication

When excitation voltage is applied, the MPS-2 makes a measurement. Within about 40 ms of excitation two measurement values are transmitted to the data logger as a serial stream of ASCII characters. The serial out is 1200 baud asynchronous with 8 data bits, no parity, and one stop bit. The voltage levels are 0-3.6V and the logic levels are TTL (active low). The power must be removed and reapplied for a new set of values to be transmitted.

The ASCII stream contains 2 numbers separated by spaces. The stream is terminated with the carriage return character. The first number is water potential output in kilopascals. The second number is the temperature in degrees Celsius.

SDI-12 Communication

The MPS-2 sensor can also communicate using the SDI-12 protocol, a three-wire interface where all sensors are powered (white wire), grounded (bare wire), and communicate (red wire) on shared wires (for more info, go to www.sdi-12.org). Below is a brief description of SDI-12 for communication. If you plan on using SDI-

12 for communication with the MPS-2, please see our integrator's guide at www.decagon.com/support for detailed instructions.

Sensor Bus

There are several benefits and drawbacks regarding the SDI-12 protocol. One benefit is that up to 62 sensors can be connected to the same 12 V supply and communication port on the data logger. This simplifies wiring because no multiplexer is necessary. The drawback to using multiple sensors on one bus is that a problem with a single sensor can bring down the entire array (through a short circuit, etc.). To avoid this problem, we recommend the user make an independent junction box with wire harnesses where all sensor wires are wired to wire lugs so sensors can be disconnected if a problem arises. A single three-wire bundle can be run from the junction box to the data logger.

Address

The SDI-12 protocol requires that all sensors have a unique address. MPS-2 sensors come from the factory with an SDI-12 address of 0. To add more than one SDI-12 sensor to a bus, the sensor address must be changed. Address options include {0...9, A...Z, a...z}. The best and easiest way to change an address is to use Decagon's ProCheck (if the option is not available on your ProCheck, please upgrade to the latest version of firmware). SDI-12 addressing can be accessed in the "CONFIG" menu by selecting "SDI-12 Address". Addresses may then be changed by simply pressing the up or down arrows until you see the desired address and pushing "Enter".

Power

The sensor can be powered using any voltage from 3.6 to 15 VDC, but 12 V is optimal. Although SDI-12 protocol allows the sensors to be continuously powered, you may connect the power (white wire) to a switching source. This can help reduce power use (although the MPS-2 sensors use very little power).

Reading

SDI-12 communication allows many parameters to be communicated at once. This allows you to see information such as the sensor model, SDI-12 version, temp, etc. Reading the MPS-2 sensor in SDI-12 mode requires function calls.

The water potential in kilopascals is the first number output by the sensor. The second number is temperature in Celsius.

The SDI-12 communication protocol is supported in Campbell Scientific data loggers like the CR10X, CR200, CR1000, CR3000, etc. Direct SDI-12 communication is supported in the "Terminal Emulator" mode under the "Tools" menu on the "Connect" screen. Detailed information on setting the address using CSI data loggers can be found on our website at http://www.decagon.com/support.

7. Installing the Sensors

Because it measures water potential, the MPS-2 is not as sensitive to air gaps or soil disturbance as water content sensors. It does, however, need good hydraulic contact with the surrounding soil. The preferred method for installing the sensor is to take some native soil, wet it, and pack it in a ball around the entire MPS-2, making sure that the moist soil is in contact will all surfaces of the ceramic. The sensor and moist soil are then packed into the soil at the desired depth.

In sandy soils, the soil may not adhere to the sensor even when wet. In this case the sensor can be packed into soil at the bottom of a hole dug to the desired installation depth. Again, care should be taken to pack the sandy soil around the sensor with good contact to all ceramic surfaces.

After installing the sensor and moist soil, the hole that was excavated to bury the sensor at depth should be back-filled with care taken to re-pack the soil back to its native bulk density. It is best to leave at least six inches of sensor cable beneath the soil before bringing the cable to the surface. The cable should never be bent in a tight radius as it leaves the sensor body. At least four inches of cable should exit the sensor body in a straight line before bending the cable.

8. Campbell Scientific Programs

Because the sensors uses digital rather than analog communication, they require special considerations when connecting to a Campbell Scientific data logger. Please visit our website at http://www.decagon.com/support to view sample Campbell Scientific programs

9. Handling and Care

The MPS-2 sensor measures the water potential of two engineered ceramic disks sandwiched between stainless steel screens and the MPS-2 circuit board. The ceramic disks are somewhat brittle, and can chip or crack if abused. The metal screens afford the disks some amount of protection, but sharp trauma on the disk edges or massive impact (such as dropping the sensor onto a hard surface) can cause the ceramic to break. One or two small chips on the edge of the disk will not affect the sensor accuracy significantly. However, a cracked ceramic will create a loss of accuracy.

For the MPS-2 to accurately measure water potential, the ceramic disks must readily take up water. If the ceramic is exposed to oils or other hydrophobic substances, then the ability of the disks to take up water from the soil can be compromised leading to slow equilibration times and/or loss of accuracy. It is recommended that exposure of the ceramic material to skin oils be minimized as much as is conveniently possible, and it is highly recommended that the disks not be handled with greasy hands, or otherwise exposed to synthetic oils or other hydrophobic compounds.

MPS-2 in Frozen Soils

The MPS-2 measures the dielectric permittivity of two ceramic disks to measure their water content and then derive their water potential. The dielectric permittivity of water in the ceramic disks is 80 compared to a dielectric permittivity of ~5 for the ceramic material, and 1 for air. When water freezes to ice, the dielectric permittivity drops to 5 at the frequency of the MPS-2 measurement meaning that the MPS-2 can no longer accurately measure the water in the ceramic. Under frozen soil conditions, the MPS-2 will not accurately measure the water potential of soil. However, under frozen soil conditions, the water potential of the soil can be measured simply by measuring the soil temperature accurately (Koopmans and Miller, 1966). For each 1° C decrease in temperature below 0° C, the water potential in the soil decreases by ~1200 kPa. Spaans and Baker (1996) showed that this relationship is valid in field soils for water potentials below about -50 kPa.

Rigorous testing indicates that the MPS-2 ceramic disks are unaffected by repeated freeze-thaw cycles. Several sensors were equilibrated in saturated soil, and then subjected to numerous freeze-thaw cycles in a temperature control chamber. The freezing rate of the soil containers was at least an order of magnitude faster than could be achieved in field soil under natural conditions. At several points during the test, and at the end of the test, the ceramic disks were evaluated for damage due to repeated rapid freezing with pore spaces full of water. None of the ceramic disks showed any signs of physical damage, and none of the sensors showed any significant change in output due to the freezing tests.

10. Troubleshooting

If you encounter problems with the MPS-2 sensor, they most likely will manifest themselves in the form of incorrect or erroneous readings. Before contacting Decagon about the sensor, do the following:

Data Logger

1. Check to make sure the connections to the data logger are both correct and secure.

2. Ensure that your data logger's batteries are not dead or weakened.

3. Check the configuration of your data logger in ECH$_2$O Utility or DataTrac to make sure you have selected MPS-2.

4. Ensure that you are using the most up to date software and firmware.

Sensors

1. Ensure that your sensors are installed according to the "Installation" section of this manual.

2. Check sensor cables for nicks or cuts that could cause a malfunction.

3. Check the ceramic disc to ensure that it is not damaged or contaminated.

References

Bittelli, M. And M. Flury (2009) Errors in Water Retention Curves Determined with Pressure Plates. Soil Science Society of America Journal 73: 1453-1460

Campbell, G. S. (1988) Soil water potential measurement: an overview. Irrigation Science 9:265-273.

Frydman, S. and R. Baker (2009) Theoretical Soil-Water Characteristic Curves Based on Adsorption, Caivitation, and a Double Porocity Model. International Journal of Geomechanics 9(6):250-257.

Gee, G. W., A. L. Ward, Z. F. Zhang, G. S. Campbell and J. Mathison (2002) The influence of hydraulic nonequilibrium on pressure plate data. Vadose Zone Journal 1:172-178.

Koopmans, R. W. R., and R. D. Miller 1966. Soil freezing and soil water characteristic curves, Soil Sci. Soc. Am. Proc., 30, 680–685, 1966.

Spaans, E. J. A., and J. M. Baker 1996. The soil freezing characteristic: Its measurement and similarity to the soil moisture characteristic, Soil Sci. Soc. Am. J., 60, 13– 19, 1996.

Appendix A

Declaration of Conformity

Application of Council Directive: 89/336/EE6

Standards to which conformity is declared:
EN61326 :1998 EN51022 : 1998

Manufacturer's Name:

Decagon Devices, Inc.
2365 NE Hopkins Court
Pullman, WA 99163 USA

Type of Equipment:
Dielectric Water Potential Sensor
Model Number: MPS-2

Year of First Manufacture: 2011

This is to certify that the dielectric water potential sensor, manufactured by Decagon Devices, Inc., a corporation based in Pullman, Washington, USA meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

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