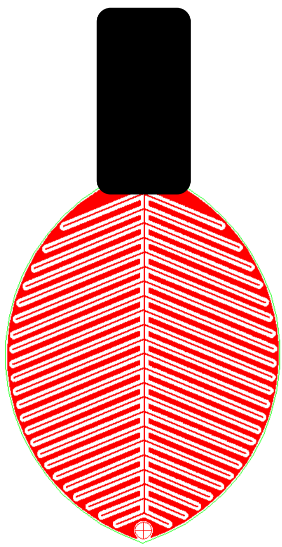
Dielectric Leaf Wetness Sensor

Operator's Manual



Version 3

DECAGON DEVICES

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Trademarks:
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Table of Contents

1. Introduction 1
Welcome 1
Contact Information 1
Warranty Information 1
Seller's Liability 1

2. The Dielectric Leaf Surface Wetness Sensor 3
About the Sensor 3
Specifications 3

3. Collecting Data 5
Installing the Sensor 5
Datalogger Requirements 5
Adapter Cable Wiring 6
Extending the Sensor Leads 7
UV Protection 7

4. Interpreting Data 8
Understanding Data from the Em50 9
Processed Data File 9
Unprocessed Data File 10
Data Trac File 11
Understanding Data from Other Dataloggers 11

5. LWS Theory 13
How the LWS Mimics a Real Leaf 13

Appendix A: Sample CSI Program . . . 15

Dielectric LWS CE Compliance 17

1. Introduction

Welcome

The Dielectric Leaf Surface Wetness Sensor (LWS) is an innovative new sensor that accurately and affordably measures the duration of leaf-surface wetness.

Contact Information

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(509) 332-5158
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Warranty Information

All Decagon products have 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. The Dielectric Leaf Surface Wetness Sensor

About the Sensor

The LWS measures leaf surface wetness by measuring the dielectric constant of the sensor's upper surface (see Chapter 5 for a more thorough explanation). It has a very low power requirement, which gives you the ability to make as many measurements as you want over a long period of time (such as a growing season) with minimal battery usage. This sensor also has very high resolution, which gives you the ability to detect very small amounts of water (or ice) on the sensor surface. Water on the sensor surface does not need to bridge electrical traces to be detected, as is common with resistance based surface wetness sensors. This means that the LWS does not need to be painted before use, which eliminates the need for individual sensor calibration.

Specifications

Measurement Time: 10 ms
Power: 2.5VDC @ 2mA, to 5VDC @ 7mA
Output: 320-1000 mV @ 3V excitation
Operating Environment: -20 to 60°C
Probe Dimensions: 11.2cm x 5.8cm x .075 cm
Cable Length: 5 m standard, extension cables are available
Connector Type: 3.5 mm plug or optional "pigtail" adapter (stripped and tinned lead wires)
Datalogger Compatibility (not exclusive):

Decagon: Em50, Em50R
Campbell Scientific: CR10, 10X, 21X, 23X, 1000, 3000, 5000

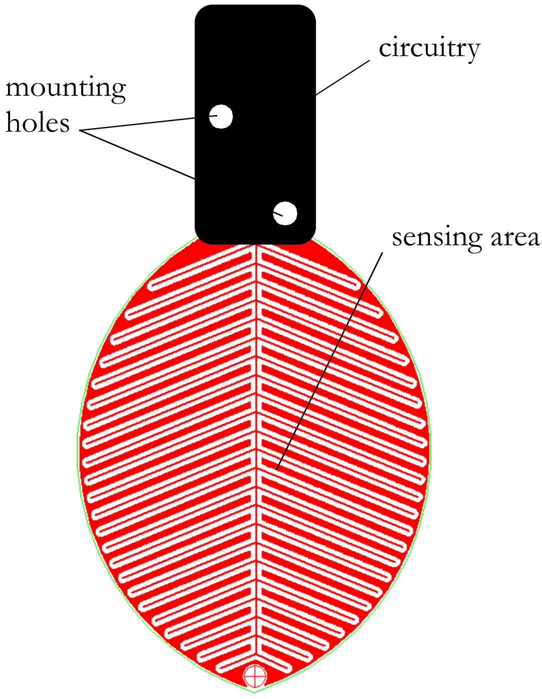

Figure 1: The LWS

3. Collecting Data

Installing the Sensor

The LWS is designed to be deployed either in the canopy or on weather station masts. There are two holes in the non-sensing portion of the sensor body for mounting. The holes can be used with either zip ties or with 4-40 bolts.

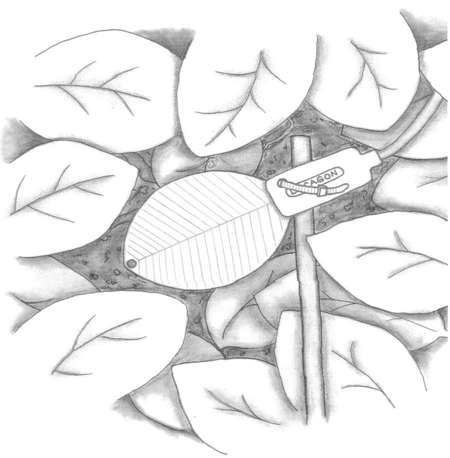

Figure 2: Top view of installed LWS in plant canopy

Datalogger Requirements

The LWS works with Decagon's 5-channel Em50 or Em50R dataloggers. It can also be adapted for use with other dataloggers, such as those from Campbell Scientific, Inc. (See Appendix A for a sample program.) The sensor requires an excitation voltage in the range of 2.5 to 5 volts. It produces an output voltage that depends on the dielectric constant of the medium surrounding the probe, and ranges between 10 to 50% of the excitation voltage. Any datalogger which can produce a 2.5 to 5V excitation with approximately 10 millisecond duration and read a volt-level signal with 12-bit or better resolution should be compatible with the LWS. The current requirement at 2.5V is around 2mA, and at 5V it is 7-8mA.

Important Note: *The LWS is intended only for use with dataloggers and readout devices which can provide short excitation pulses, leaving the probes turned off most of the time. Continuous excitation not only wastes battery power, but may, under certain circumstances, cause the probe to exceed government specified limits on electromagnetic emissions.*

Adapter Cable Wiring

If a non-Decagon datalogger is used, the stereo plug can be clipped off, and the lead wires can be directly connected to the chosen logger. The wiring configuration is shown below.

White = 2.5 to 5V excitation
Bare shield = ground
Red = sensor output (single ended)

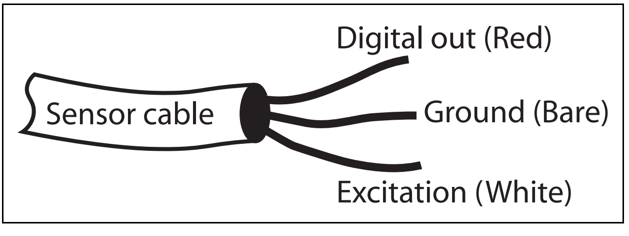

Figure 3: Sensor wiring diagram

Extending the Sensor Leads

Extension cables for the LWS are available from Decagon in 10 and 50 foot (3 and 15 meter) lengths. The leads can be extended up to 250 feet without signal attenuation. When using these extension cables in an unprotected environment, the junctions between cables must be waterproofed. This can be effectively accomplished by connecting the junction, applying silicone sealant to the junction, and shrinking appropriately sized heat-shrink tubing over the still-wet silicone sealant.

UV Protection

The LWS leaf wetness sensor is designed to withstand typical outdoor radiation and precipitation loads for greater than two years. If you are using the LWS in areas with non-typical (unusually high) radiation loads, we recommend additional applications of McNett UV Tech (available from http://www.mcnett.com) be reapplied every 45 days. McNett is the only tested and approved UV blocking system for Decagon's Leaf Wetness Sensor.

To apply McNett UV Tech:

1. Wipe sensor clean.
2. Spray sensor surface with McNett UV Tech.
3. Rub with soft cloth until dry.

4. Interpreting Data

Most leaf wetness applications (disease forecasting, etc.) don't require knowledge of the *amount* of water on the surface - only if there is *any* water on the surface. To make this determination, a sensor output threshold corresponding to the minimum wet state must be identified.

When read with the Em50 datalogger, the LWS outputs 445 raw counts when dry. When the sensor is totally wet, as in a heavy rain, the signal can range up to around 1400 counts. Varying amounts of water on the surface of the sensor cause a sensor output proportional to the amount of water on the sensor's surface.

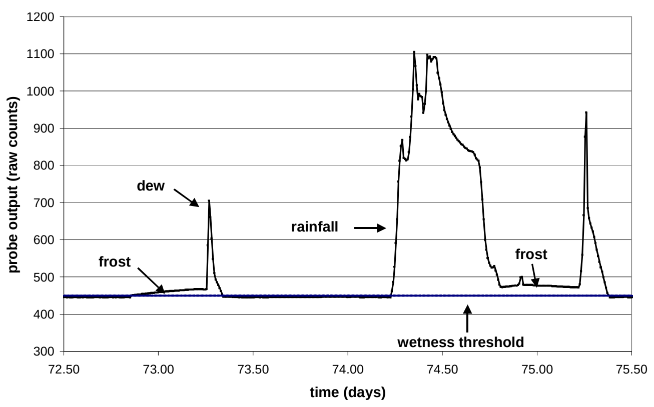

Figure 4: Sample raw output from the LWS

Because ice has a much lower dielectric constant than that of liquid water, the sensor output from frost will be much lower than that from a similar amount of rain or dew.

Note that over time, the accumulation of dust and bird droppings can cause the dry output to rise. We recommend that the sensors be cleaned using a moist cloth periodically, or when elevated dry output is detected.

Understanding Data from the Em50

With Decagon's Em50 and Em50R dataloggers, the user has multiple options for interpreting data. The sensors are factory calibrated to read 445 raw counts when dry. When an Em50 or Em50R port is configured to read a leaf wetness sensor, the logger reads the sensor every minute and compares the data to two pre-defined wetness thresholds of 450 and 460 raw counts. When the data are collected from the logger with ECH_2O Utility there are several options for the format of the data output.

Processed Data File

Processed Excel file or tab delimited text file

When a processed data file format is selected, three columns of data are output for each LWS port.

Column 1: The number of minutes that the LWS output was over 450 raw counts in the preceding wake interval. So, if a 30 minute wake interval has been chosen, then the number can range from 0 (the sensor was never wet during that 30 minute period) to 30 (the sensor was always wet during that 30 minute period). The numbers in this column can be summed to yield the cumulative wetness duration -in minutes- during the time period of interest.

Column 2: The number of minutes that the LWS output was over 460 raw counts in the preceding wake interval.

The data in this column follow the same format as those in column 1, only with the wetness threshold set slightly higher. Field tests of the LWS indicate that extreme dust buildup or bird droppings can cause the dry output of the sensor to climb above the 450 raw count threshold. If this occurs, the data in column 2 can be used until the sensor can be cleaned.

Column 3: The final reading (in raw counts) of the LWS during the wake interval. So, if again a 30 minute wake interval has been chosen, the number in column 3 is the output in raw counts from the LWS during the last minute of that 30 minute period. This data column is output in case an extreme contamination event occurs, forcing the dry output higher than 460 raw counts. In this case, the user can identify a new wetness threshold from the time series data, and calculate wetness duration from the new threshold until the sensor can be cleaned. See the section at the end of this chapter titled "Understanding Data from Other Dataloggers" for more information on this procedure. When using the data in this column, the user can only obtain a wetness reading every wake interval (typically 30 minutes or more), instead of the 1 minute wetness resolution available in column 1 and 2. Note that the conversion from Em50 raw counts to mV with 3000 mV excitation is mV = raw counts * 0.733.

Unprocessed Data File

Unprocessed Excel file

When an unprocessed Excel file format is downloaded, three columns of data are output for each LWS port.

Column 1: The cumulative number of minutes that the LWS output has been over 450 raw counts since the Em50 data were last erased or the accumulator has rolled over. Note that the accumulator has a maximum of 2048 minutes (1.42 days) of wetness. If the cumulative wetness duration exceeds this window (which will likely happen often), then the accumulator resets to zero and begins accumulating again.

Column 2: The cumulative number of minutes that the LWS output has been over 460 raw counts since the Em50 data were last erased or the accumulator has rolled over. Again, this accumulator rolls over to zero after 2048 minutes of wetness.

Column 3: The final reading (in raw counts) of the LWS during the wake interval. (See column 3 description under processed data files above).

Data Trac File

When the Data Trac file format (.dxd) is downloaded, a single 10 digit number is downloaded for each sensor. The .dxd format is easily imported into Decagon's convenient Data Trac graphing software. It also has the advantage that it can be converted with ECH_2O Utility to the other file formats listed above. See the manual for your Em50 datalogger for details on how to do this.

Understanding Data from Other Dataloggers

With non-Em50 dataloggers, the user will need to establish a wetness threshold for their system. The dry output of the LWS varies with excitation voltage (note that the acceptable excitation voltage range is 2.5 to 5V). The LWS dry output is easily determined from time series data such as those presented in Figure 4. A wetness threshold should be chosen that is slightly above the dry output, and subsequent readings should be compared to the dry output to determine surface wetness. When using a non-Em50 datalogger, it is important to collect data frequently enough to capture changes in the surface wetness. A sampling frequency of 15 minutes or less is often necessary to accurately capture leaf wetness duration.

5. LWS Theory

How the LWS Works

The LWS measures the dielectric constant of a zone approximately 1 cm from the upper surface of the sensor. The dielectric constant of water (80) and ice (5) are much higher than that of air (1), so the measured dielectric constant is strongly dependent on the presence of moisture or frost on the sensor surfaces. The sensor outputs a mV signal proportional to the dielectric of the measurement zone, and therefore proportional to the amount of water or ice on the sensor surface.

How the LWS Mimics a Real Leaf

The sensor has been specially designed to closely approximate the thermodynamic properties of a leaf. If the specific heat of a leaf is estimated at 3750 J kg^{-1} K^{-1}, the density is estimated to be 0.95 g/cm^3, and the thickness of a typical leaf is 0.4 mm, then the heat capacity of the leaf is 1425 J m^{-2} K^{-1}. This is closely approximated by the thin (0.65mm) fiberglass construction of the LWS, which has a heat capacity of 1480 J m^{-2} K^{-1}. By mimicking the thermodynamic properties of a real leaf, the LWS is able to more closely match the wetness state of the canopy.

The sensor has also been engineered to closely match the radiative properties of real leaves. Healthy leaves generally absorb solar radiation effectively in much of the visible portion of the spectrum, but selectively reject much of the energy in the near-infrared portion of the spectrum. The surface coating of the LWS absorbs well in the near-infrared region, but the white color reflects most of the visible radiation. Spectroradiometer measurements indicate that the overall radiation balance of the sensor closely matches that of a healthy leaf. During normal use, prolonged exposure to sunlight can cause some yellowing of the LWS. This is expected and will not affect the probe's function.

The surface coating of the LWS is hydrophobic—similar to a leaf with a hydrophobic cuticle. The sensor should match the wetness state of these types of leaves well, but may not match the wetness duration of leaves with plentiful leaf hairs or less waxy cuticles. It is impossible for any sensor to accurately mimic the properties of all leaves.

The LWS is engineered to be repeatable among units, so that relationships can be determined between the wetness state of the sensor, and the wetness state of various agricultural or natural plant canopies. Painting and individual sensor calibration is not necessary with the LWS.

Appendix A: Sample CSI Program

```
;{CR23X}
;
;Program to read Decagon's Dielectric Leaf Wetness ;Sen-
sor (LWS)
;
;Wiring: white to Ex1, red to 1H, shield to gnd
;
;This program separates LWS output into three bins
;bin 1 = output < 330mV - dry sensor
;bin 2 = 330mV < output < 337mV - wet sensor unless ;sen-
sor contaminated
;bin 3 = output > 337 mV - wet sensor even when contami-
nated
;The values output to final storage by the histogram
;command are the fraction of the OUTPUT INTERVAL that
;had sensor output in the preceding ranges
;
;Note that the wetness thresholds depend on excita- ;tion
applied.  If you are exciting with other than ;3000 mV,
you will need to determine a custom wetness ;threshold

*Table 1 Program
  01: 1         Execution Interval (seconds)

1:  Excite-Delay (SE) (P4)
 1: 1        Reps
 2: 20       Auto, 60 Hz Reject, Slow Range (OS>1.06)
 3: 1        SE Channel
 4: 1        Excite all reps w/Exchan 1
 5: 1        Delay (0.01 sec units)
 6: 3000     mV Excitation
 7: 1        Loc [ LWS_mV    ]
 8: 1.0      Multiplier
 9: 0.0      Offset


2:  If time is (P92)
 1: 0        Minutes (Seconds --) into a
 2: 60       Interval (same units as above)
```

```
 3: 10       Set Output Flag High (Flag 0)

3:  Real Time (P77)^14490
 1: 1110     Year,Day,Hour/Minute (midnight = 0000)

4:  Sample (P70)^21634
 1: 1        Reps
 2: 1        Loc [ LWS_mV    ]

5:  Histogram (P75)^15793
 1: 1        Reps
 2: 3        No. of Bins
 3: 0        Open Form
 4: 1        Bin Select Value Loc [ LWS_mV    ]
 5: 0        Frequency Distribution
 6: 330      Low Limit
 7: 337      High Limit

*Table 2 Program
  02: 0.0000    Execution Interval (seconds)

*Table 3 Subroutines

End Program
```

Dielectric Leaf Wetness Sensor CE Compliance

DECLARATION OF CONFORMITY

Application of Council Directive:	89/336/EE6
Standards to Which Conformity is Declared:	EN61326 : 1998 EN51022 : 1998
Equipment Type:	Leaf Wetness Sensor
Manufacturer's Name:	Decagon Devices, Inc. 2365 NE Hopkins Ct. Pullman, WA 99163 USA
Model Number:	LWS-1
Year of First Manufacture:	2006

This is to certify that the Dielectric Leaf Wetness 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

Index

C

Contact information 1

D

Data
- interpretation 8

Data Trac
- files 11

Datalogger
- data from non-Decagon loggers 11
- extending sensor leads 7
- requirements 5
- sample CSI program 15
- wiring configuration 6

Dielectric measurement 13

E

ECHO Utility
- processed data file 9
- Unprocessed data file 10

E-mail 1

F

Fax number 1
Features 4

I

Installation 5
Interpreting data 8

L

LWS
- operation of 3
- thermal properties 13

P

Processed data file
- in ECHO Utility 9

S

Specifications 3

T

Telephone number 1
Theory of operation 13
Thermal properties
- of LWS 13

U

Unprocessed data file
- in ECHO Utility 10

UV Protection 7

W

Warranty 1