Smart Water Application Technologies™ (SWAT)

Turf and Landscape Irrigation Systems Smart Controllers

SOIL MOISTURE SENSOR-BASED CONTROLLERS

Phase 1: Laboratory Screening Tests

7th Draft Testing Protocol (October 2008)

Developed by

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TABLE OF CONTENTS

FOREWORD ii

INTRODUCTION iii

Phase 1: Laboratory Screening Tests 1

1.0 Introduction 1

2.0 Scope 1

3.0 Normative References 2

4.0 Terms and Definitions 2

5.0 Symbols and Abbreviations 4

6.0 Test Specimen Selection 5

7.0 Test Method and Representation 5

7.1 Soil Containment Box 5

7.1.1 Sensor Installation 5

7.2 Sensor Testing 6

7.2.1 Testing Procedure: (Fine Texture) 6

7.2.2 Testing Procedure (Medium Texture) 7

7.2.3 Testing Procedure (Coarse Texture) 7

7.3 Temperature Response Test 7

7.3.1 Test at a Temperature of 15°C 7

7.3.2 Test at a Temperature of 35°C 8

7.3.3 Test at a Temperature of -5.0°C 8

7.4 Testing procedure for Salinity Levels 8

7.4.1 Test at a Water Conductivity of 2.5 dS/m 8

7.4.2 Test at a Water Conductivity of 5.0 dS/m 8

7.5 Test for Sensor Reading Variability 8

7.5.1 Test for Sensor Reading Variability (Medium Texture) 8

7.5.2 Test for Sensor Reading Variability (Coarse Texture) 8

7.6 Multiple Cycle Test 8

7.6.1 Medium Texture Test 9

8.0 Results 9

9.0 Appendix 9

10.0 Bibliography 10

FOREWORD

The Irrigation Association has established a Smart Water Application Technologies™, or SWAT, committee to oversee the development of product testing protocols. This committee is assisted by a Technical Working Group (TWG) and project leaders. The protocol development process involves a drafting of the document followed by a public review and comments period. If required, the document is redrafted and a second review process is initiated. Ultimately the SWAT committee votes on the acceptability of the last protocol. All protocols will be reviewed for possible revision every three years. The development of this testing protocol represents the first attempt by the Irrigation Association to develop product testing protocols. The actual product testing began in 2004 when the first climatologically based commercial controller was tested using the 5th Draft Testing Protocol dated May 3, 2004. The documents have no known predecessors.

This protocol was developed to test products designed and sold for use with residential and similar scale light commercial and institutional properties. This protocol may not be suitable for testing products used in larger more demanding irrigation systems as used at parks, golf courses, etc.

This testing protocol consists of the following parts under the general title of "Turf and Landscape Irrigation System Smart Controllers":

Climatologically Based Controllers

Additional protocols address the following parts under the general title of "Turf and Landscape Irrigation System Smart Controllers."

Soil Moisture Sensor Based Controllers
- Phase 1: Laboratory Screening Tests
- Phase 2: Operational Test on a Virtual Landscape

INTRODUCTION

This protocol is designed to test the efficacy of a soil moisture sensor-based controller suitable for use with residential and light commercial irrigation systems. Conditions unique to this controller application are as follows:

- The system must function without human intervention. [1]
- The system must provide high levels of irrigation adequacy and scheduling efficiency.
- The system must function over a wide range of field conditions including:
    1. Climate
    2. Plant materials
    3. Topography
    4. Soils
    5. Water quality and quantity
- The system must be adjustable to reflect the homeowner's preferences relative to vegetative quality.

It is recognized that controlling the irrigation of turf and landscape is a combination of scientific theory and subjective judgments. The attempt in developing this protocol is to use only generally recognized theory and to avoid judgments involving the art of irrigation. The protocol then recognizes that only the theory of irrigation is controllable by the skill of the controller manufacturer. The protocol will measure the ability of the controllers to provide adequate and efficient irrigation while minimizing potential run-off. The sensors provide feedback on root zone moisture status to the controller. The controller interprets the feedback and sets irrigation schedules accordingly. Soil moisture sensors are an important component of some sensor-based irrigation system controllers. With a standard time-based system controller, they act to provide closed-loop control feedback. They may also find application by closing the loop or giving feedback to climate-based system controllers. The objective of this protocol is to evaluate how well current commercial technology has integrated the scientific data into a practical system that meets the agronomic needs of the turf and landscape vegetation.

In general there are a least two types of standards. The first is a standard that defines the details of how a performance test is to be conducted and what data will be recorded. This SWAT testing protocol is that type of test. It does not result in a pass or fail evaluation. The second type of standard defines performance limits that must be met to quantify the capabilities of the product. The performance standards in this case are established by related considerations and organizations.

In order to realize the full potential of the smart controller concept the following issues must be addressed:

- The quality of the input data must be verified by a certified professional
- The controller must be set up and programmed by individuals familiar with the technology
- The irrigation system must be properly designed and maintained

[1]The protocol recognizes that the root zone environment can change dramatically as for example, water tables drop and irrigation water becomes more saline. With the current state of the art, soil moisture sensors are not automatically compensated for this root zone environmental change. In this case a periodic manual change in the threshold sensor settings is anticipated.

The Phase 1: Laboratory Screening Tests are estimated to take approximately 6-8 months.

The Phase 2: Operational Test on a Virtual Landscape takes at least one month or longer until the required climatic conditions of 0.40 in. of gross rainfall and a minimum of 2.50 in. of ETo.

Soil moisture sensors, by their nature, operate in a responsive mode. The specifics of the mode are defined by the sensor laboratory results (Phase 1) and site considerations including soil classification, planting materials, and water quality. As a result then for a specific sensor, the operating mode can be different for different zones. In any case, the manufacturer must specify the mode(s) before the Phase 2 test evaluation can be conducted. Representative modes include the following:

a) when the soil moisture sensor reaches a lower threshold value then;
    1) a fixed runtime application is made **or**
    2) a variable runtime application is made with irrigation terminated when an upper threshold setting is reached.
b) Irrigations are scheduled on a time framed basis (e.g. daily) for a given runtime. If the soil moisture sensor shows readings above a wetter threshold value, the irrigation is aborted. If the soil moisture is below the threshold value, the irrigation proceeds for a runtime sufficient to reach at least the threshold value.

While not a part of this protocol, the dynamics of these control concepts need to be anticipated and dealt with. Specifically, the dynamics of the response time required for surface-applied water (rainfall or irrigation) to be reflected in the sensor reading is not scientifically characterized. This probably means, for example, that the soil moisture sensor will not function satisfactorily as an instantly responding rain switch. While an intuitive judgment characterizing their performance on coarse soils and shallow root zones is probably satisfactory, the same judgment on fine soils and deeper root zones would be misleading. This suggests that yesterday's moisture status readings that have reached at least near equilibrium conditions are a better basis for making today's irrigation decisions than to attempt a real time-based program. Because of the fundamental dynamic of root zones, moisture gradients are always present. Perhaps the best temporal judgment is to read the sensor at the same time each day for purposes of scheduling the next day's irrigation events.

Turf and Landscape Irrigation Systems Smart Controllers – Soil Moisture Sensor Based Controllers

Phase 1: Laboratory Screening Tests

1.0 Introduction

Phase 1 of the protocol is a series of laboratory tests that characterize the performance of the sensor when it is subjected to the following conditions:

- Fine-, medium-, and coarse-textured soils
- Ambient temperatures of -5°C, 15°C, 25°C and 35°C.
- Water conductivity values of 0 ds/m, 2.5 ds/m, and 5.0 ds/m.
- Base soil conductivity using saturated paste testing method: clay soils 1.0-2.0 dS/m and all other soils <1.0 dS/m.

This range of individual variables and parameters, if tested for at all possible combinations, leads to a prohibitively large number of tests. Standard conditions are defined as a medium soil at 25°C using water of conductivity 0 dS/m. An important requirement of the sensors is their ability to maintain a stable calibration when subjected to repeated wet/dry cycles with moisture content values ranging from field capacity to permanent wilt point, with temperatures ranging from 15°C to 35°C and soil EC extractions ranging from 0 to 5.0 dS/m.

Performance of individual sensors in this test provides an indication of the general capability of sensors available for sale. It is recognized that for a given sensor in an individual zone, an initial adjustment can be made to reflect the desired vegetative quality requirements and other unpredictable conditions such as product variability inherent in the manufacturing process and soil variablity.

2.0 Scope

This testing protocol standard is being established to verify the testing response accuracy of commercially available soil moisture sensors. This protocol characterizes the ability of the sensor to provide reliable results when comparing an individual unit's performance during multiple wetting cycles. This protocol also tests the sensors over the range of conditions encountered in typical field installations. This includes a range of soil types, a range of soil temperatures (including freezing conditions) and a range of irrigation water salinity levels.

Phase 1 focuses on the performance of the soil moisture sensor independent of how it is used in controlling irrigation. The objective of Phase 1 is to determine whether the sensor is sufficiently stable in its response to varying environmental conditions to be able to support a virtual irrigation system that neither wastes water nor stresses plants. Stability can be measured by statistical analysis of sensor responses over prescribed ranges in the following variables:

a) soil water content
b) soil temperature
c) soil textural classifications

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d) water electrical conductivity
e) repeated wet/dry cycles
f) freeze/thaw cycles

The protocol recognizes the availability of soil moisture sensors capable of estimating the "absolute soil moisture content" and those providing "relative soil moisture content." Both sensor concepts will be held to the same standard of providing repeatable results under a range of controlled conditions.

The protocol determines the testing response of the sensors under essentially static laboratory conditions. The impact of such real world conditions as compaction, roots, and soil fauna have not been addressed.

It is recognized that this protocol is not designed to establish criteria for usefulness of the sensors as scientific instruments to gather research data. The purpose of the protocol is to determine the efficacy of soil moisture sensors to measure and monitor changes in soil moisture as required to automatically control irrigation events in urban landscapes.

3.0 Normative References

Soil Science Society of America "Glossary of Soil Science Terms"

Soil Textural Classifications: Soil textural classifications will correspond to the U.S. Department of Agriculture definitions.

4.0 Terms and Definitions

For the purpose of this testing protocol, the following terms and definitions apply.

4.1 Absolute Soil Moisture Sensor
A soil moisture sensor that is sensitive to soil moisture changes only and not affected by soil type, water conductivity, or temperature. Using moisture retention curves the sensor can then be used to set limits on root zone tension at values known to provide quality turf with efficient water use.

4.2 Available Water
The portion of water in a soil that can be readily absorbed by plant roots

4.3 Bulk Density, Soil
The mass (weight) of dry soil per unit bulk volume, kg/L

4.4 De-ionized Water
Conductivity is 0 dS/m

4.5 Evapotranspiration (ET)
Water transpired by vegetation plus that evaporated from the soil

4.6 Field Capacity
The percentage of water remaining in the soil 2 or 3 days after the soil has been saturated and free drainage has practically ceased. The percentage may be expressed in terms of weight or volume.

4.7 Gravimetric Moisture Content
The mass of water per unit mass of dry soil. It is measured as the water lost from the soil upon oven drying to constant mass at 105°C (usually attained after 48 hours of drying in an oven at 105°C). It is normally expressed as a decimal or percentage value, but the ideal SI units are kg per kg or other consistent mass units.

4.8 Mass Water Content
The water content expressed as the weight of water in the soil divided by the oven-dried weight of soil

4.9 Mass Water Percentage
The mass water content times 100

4.10 Oven-dried Soil
Soil placed in an oven and dried at 105°C for 48 hours

4.11 Permanent Wilting Point (PWP)
Permanent wilting point or permanent wilting percentage (PWP) is defined as the soil wetness at which a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours.

4.12 Relative Soil Moisture Sensor
A sensor that is sensitive to soil moisture changes and other factors including, for example, soil texture, water conductivity and temperature. This sensor must be calibrated "in situ" by an iterative process of adjusting water applications and making observations on plant quality. Related factors such as water conductivity changes during fertilization could change threshold stress and require a change of threshold setting values by the operator.

4.13 Saturated Paste Extraction
Soils will be tested for electrical conductance utilizing a saturated paste methodology.

4.14 Siemens
The SI unit of electrical conductance. It is the inverse of electrical resistance or impedance (ohms).

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4.15 Smart Controllers

Smart controllers estimate or measure depletion of available plant soil moisture in order to operate an irrigation system, replenishing water as needed while minimizing excess water use. A properly programmed smart controller requires initial site specific set-up and will make irrigation schedule adjustments, including run times and required cycles throughout the irrigation season without human intervention.

4.16 Soil Texture

The relative proportions of the various soil size separates. For example, a fine-textured soil has a large percentage of silt and clay (protocol will use the USDA classification system).

4.17 Soil Water Potential, (Pressure, Head)

The amount of work that must be done per unit of a specified quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a specified source to a specified destination.

-If the specified quantity is volume, the potential is referred to as pressure (Pa).
-If the specified quantity is weight, the potential is referred to as head (m).
-If the specified quantity is mass, the potential is expressed in J kg.

4.18 Volumetric Water Content

The ratio of the volume of water in a soil to the total bulk volume of the soil, in decimal form

4.19 Volumetric Water Percentage

Volume water ratio multiplied by 100

4.20 Water Salinity Level

An electrical conductance measurement characterizing the level of soluble salts that can interfere with the growth of some crops

5.0 Symbols and Abbreviations

dS - deci-Siemens
Note: SI (metric units) will be used in the protocol as defined by American Society of Agricultural Engineers Standard ASAE EP 285.7.

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6.0 Test Specimen Selection

6.1 Sampling Test

A representative of the testing agency shall select test specimens for each test at random from a sample of at least 20 units supplied by the manufacturer. The number of specimens selected for each test are listed in Table 1 with methods described in section 7.0.

Table 1

Clause	Subject of Test	Number of Test Specimen
7.2.1	Testing response in a fine-textured soil [1]	3
7.2.2	Testing response in a medium-textured soil [1]	3
7.2.3	Testing response in a coarse-textured soil [1]	3
7.3.1	Testing response at 15°C [1]	2
7.3.2	Testing response at 35°C [1]	2
7.3.3	Test for freezing susceptibility -5° [1]	2
7.4.1	Testing response when wetted with water with a conductivity of 2.5 dS/m on a fine-textured soil	2
7.4.2	Calibration when wetted with water with a conductivity of 5.0 dS/m on a fine-textured soil	2
7.5.1	Calibration when wetted with water with a conductivity of 2.5 dS/m on a medium-textured soil	2
7.5.2	Calibration when wetted with water with a conductivity of 2.5 dS/m on a coarse-textured soil	2
7.6.1	Verification of performance when the sensor is subjected to standard [1] conditions for a total of six wet/dry cycles.	2

[1] Standard conditions are defined as (a) using a medium-textured soil, (b) testing at 25˚C, and (c) water with conductivity of 0 dS/m, except as may be required to meet the specification in a specific clause.

7.0 Test Method and Representation

7.1 Soil Containment Box

Preparation of the soil containment box [Ref. CIT Drawing No. 1000-8 (12/2005) copy in the appendix] and installation of the sensor. Note: this containment box is meant to be used with sensors of limited volumetric range. Other configurations may be required for sensors with larger volumetric range.

7.1.1 Sensor Installation

Use a standardized box sitting on a flat surface capable of containing a fixed weight and volume of the representative soil type. The box shall be wet and drain the soil through a perforated bottom. The box shall allow for the determination of the net weight of water required to bring the soil sample to field capacity. The volume of soil shall be sufficient to permit the sensor to function without being materially affected by the box dimensions. The soil shall be oven dried and screened for ease of packing around the sensor. The soil shall be placed and tamped so as to result in the representative bulk density (range 1.2 to 1.4 kg/L). The sensor will be located in the

center of the box at a cover depth of approximately 3.0 in. or as per manufacturer's recommendation. Sensor reading and temperature measuring device output wiring shall be arranged so as not to interfere with the procedure for weighing the box. The weight of all components, except for the soil and water shall be known.

The box is designed to represent a section of turf grass root zone with a maximum depth of 6-7 inches. The actual depth of placement will be recorded. The sensor will be located at the depth recommended by the manufacturer. It is recognized that the combined effects of surface drying and drainage below the root zone will result in a moisture gradient within the box. This is meant to simulate a representative environment in which the sensor is designed to function

7.2 Sensor Testing

Test for the sensor's ability to provide a consistent response between drying cycles and between individual sensors. Repeat the test for a range of textural classifications. Note: The sensor is to be installed and conditioned to the site as per the manufacturer's written standard requirements.

7.2.1 Testing Procedure: (Fine Texture)

Assemble three soil containment boxes complete with moisture and temperature sensors including provision for electrical hookup to registering and/or recording devices. Predetermine the weight and volume of the soil moisture sensing device. Place the oven-dried fine-textured soil in the box and tamp to achieve the design bulk density. Include in this process the installation of the soil moisture sensor in the location recommended by the manufacturer. Obtain the weight of the box plus soil, and the volume of the tamped soil and calculate the actual bulk density. Place the box in the environmental chamber set at 25°C. By a process of adding a known amount of de-ionized (DI) water, fill the box until the soil is completely saturated. Note: water is introduced from the bottom up to avoid trapping air in the soil mass. Allow the box to drain until all free drainage ceases. Measure the amount of drainage water and calculate the net amount of water stored in the box. Alternatively the box can be weighed before and after being saturated and drained to determine the net amount of water retained. In both methods the box will be covered to be sure the water loss is from drainage only. Read and record the soil temperature and sensor reading and weigh the box. This initiates the test run. Remove the box cover and let the soil dry in the environmental chamber taking periodic readings of temperature, sensor output, and box weights[2]. In any case, a minimum of one to two readings per day are required as the soil dries out over the total period of the test. Plot the results for each sensor from the three boxes; obtain a regression curve on each sensor.

Repeat the test by re-wetting the soils and taking readings as previously defined. The analyst will plot the results and develop best-fit function response curve. The required range of moisture content over which the sensor is to be tested is shown

[2] Initial test runs with a sandy loam in Fresno suggests that the drying process will take 15-18 days.

in Table 3. This range is defined by the practical limits as needed to support the controller in its attempt to effectively manage root zone stored moisture.

Table 2: Particle Size Analysis

Soil		Particle Size, %		
Texture	Classification [1]	Sand	Silt	Clay
Fine	Clay	45	10	45
Medium	Sandy loam	70	15	15
Coarse	Loamy sand	85	85	10

[1] Reference USDA soil classification system

Table 3: Test Soils Texture Field Capacity and Permanent Wilting Point

Soil Texture	Field Capacity, (FC), %	Permanent Wilting Point, (PWP), %
Fine	40	25
Medium	25	9
Coarse	16	8

A minimum of 10 discreet data points uniformly spread across the drying curve within the specified range and 2 data points beyond each limit is required.

7.2.2 Testing Procedure (Medium Texture)

Repeat Clause 7.2.1 except:

- Use a medium-textured soil

7.2.3 Testing Procedure (Coarse Texture)

Repeat Clause 7.2.1 except:

- Use a coarse-textured soil

7.3 Temperature Response Test

Test for the sensor's ability to provide a constant response curve between individual sensors in a medium-textured soil at 15°C and 35°C and after being frozen at - 5.0°C for 7 days in saturated soil**.** **Note:** Test 7.2.1 provides a test run at 25°C.

7.3.1 Test at a Temperature of 15°C

Repeat Clause 7.2 except:

- Set the environment chamber at 15°C
- Conduct a single wetting run only

7.3.2 Test at a Temperature of 35°C

Repeat Clause 7.2 except:

- Set the environmental chamber at 35°C
- Conduct a single wetting run only

7.3.3 Test at a Temperature of -5.0°C

Use the box prepared for 7.3.2

- Re-saturate the box and let it stand until drainage ceases
- Hold the box at - 5.0°C for 7 days
- Remove the box and conduct a single wetting run (7.2.2)

7.4 Testing procedure for Salinity Levels

Test for the sensor's ability to provide a consistent response curve between individual sensors when water of elevated salinity levels of 2.5 and 5.0 dS/m are used on a fine-textured soil at 25°C.

Note: Testing to Clause 7.2.1 gives comparable results with a water conductivity of 0 dS/m.

7.4.1 Test at a Water Conductivity of 2.5 dS/m

Repeat Clause 7.2.1 except:

- Wet the soil with water with a conductivity of 2.5 dS/m
- Conduct a single wetting run only

7.4.2 Test at a Water Conductivity of 5.0 dS/m

Repeat Clause 7.2.1 except:

- Wet the soil with water with a conductivity of 5.0 dS/m
- Conduct a single wetting run only

7.5 Test for Sensor Reading Variability

Test for the sensor's ability to provide a consistent testing response curve between individual sensors when water of an elevated salinity level of 2.5 dS/m is used to wet soils of a range of textural classifications.

7.5.1 Test for Sensor Reading Variability (Medium Texture)

Repeat clause 7.4.1 except:

- Use a medium-textured soil only

7.5.2 Test for Sensor Reading Variability (Coarse Texture)

Repeat clause 7.4.1 except:

- Use a coarse-textured soil only

7.6 Multiple Cycle Test

Verification of performance when the sensor is subjected to standard conditions for a total of six wet/dry cycles. Wet point will be field capacity. Dry point will be defined by the manufacturer that would be used in Phase 2 testing to encompass the portion of the curve that would indicate adequacy for plant needs.

7.6.1 Medium Texture Test

Repeat clause 7.2.1 except:

- Use a medium-textured soil only
- Re-run the wet/dry cycling six times to develop and compare six separate results.

8.0 Results

In order for the sensor to support the controller, its testing response must be stable for the root zone condition existing on site. This protocol is an attempt to reasonably frame the range of conditions anticipated in locations where the concept of "soil moisture sensor-based controller" can be expected to apply. For each of the tests defined as clauses in Table 1, the "Client's Report" will show 95% confidence limits based on standard deviation for the best-fit response curve used. These results on individual sensors will be reported in a tabular format. This data correlates sensor reading with volumetric water content of the test.

8.1 A correlation will be made for Clauses 7.2.1, 7.2.2 and 7.2.3 both individually and in combination. This deals with soils of a range of textures.

8.2 A correlation will be made for Clauses 7.2.1, 7.3.1, 7.3.2 and 7.3.3 both individually and in combination. This deals with soil temperature.

8.3 A correlation will be made for Clauses 7.2.1, 7.4.1 and 7.4.2 both individually and in combination. This analysis deals with a fine textured soil subjected to a range of water conductivities.

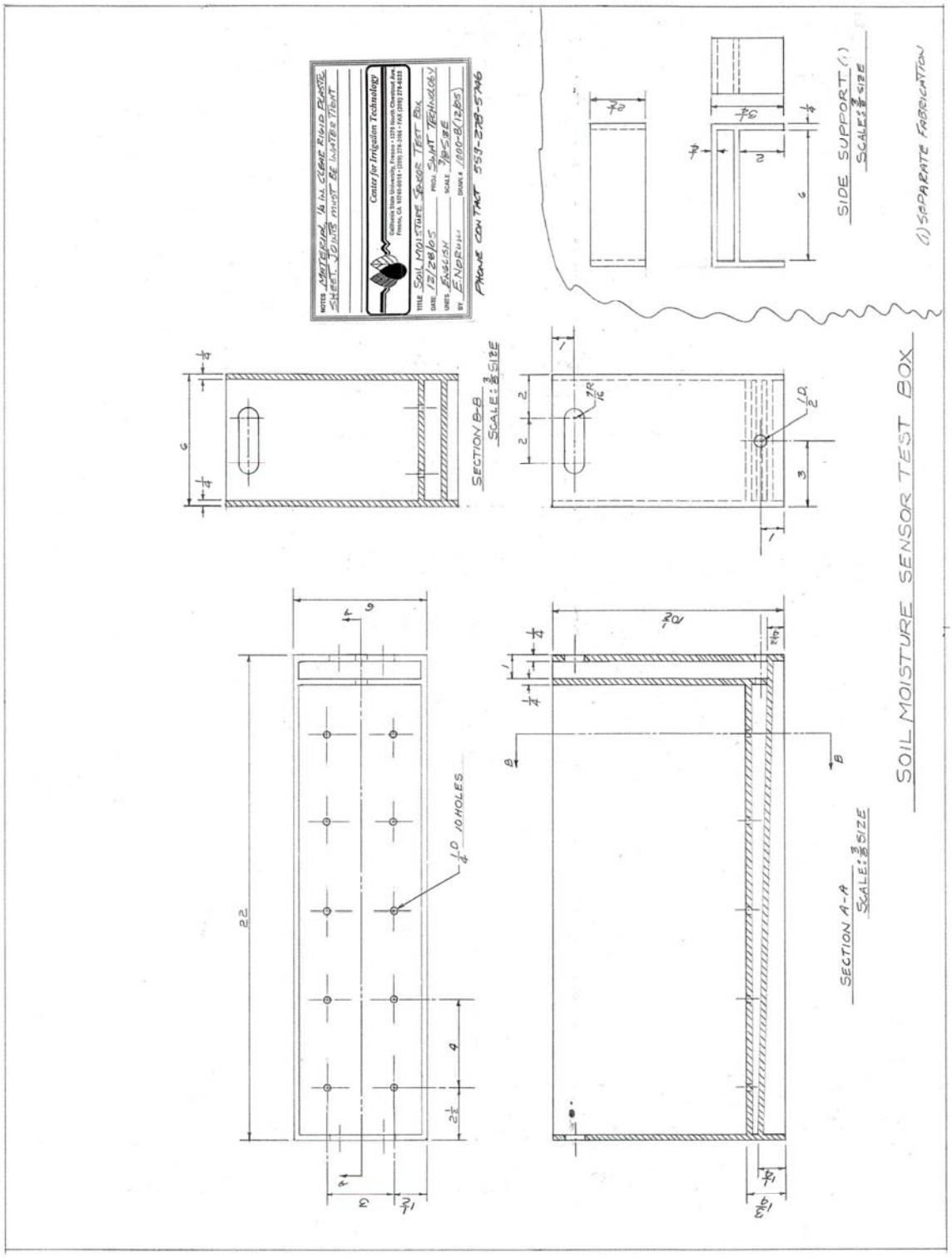
8.4 A correlation will be made for Clauses 7.2.1, 7.5.1and 7.5.2 both individually and in combination. This analysis deals with a medium textured soil subjected to a range of water conductivities.

8.5 A correlation will be made for Clause 7.6.1 both individually and in combination. This analysis deals with medium-textured soils subjected to multiple wet/dry cycles.

In addition, a summary report of the Phase 1 testing results will be posted on www.irrigation.org. This report will verify that the sensor has completed the Phase 1 testing and give other descriptive information on the sensor's capabilities.

9.0 Appendix

- Copy of drawing No. 1000-8 (12/2005) Soil Containment box



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