

# Stable Soil Moisture Sensors Facilitate Highly Effective Closed-Loop Irrigation

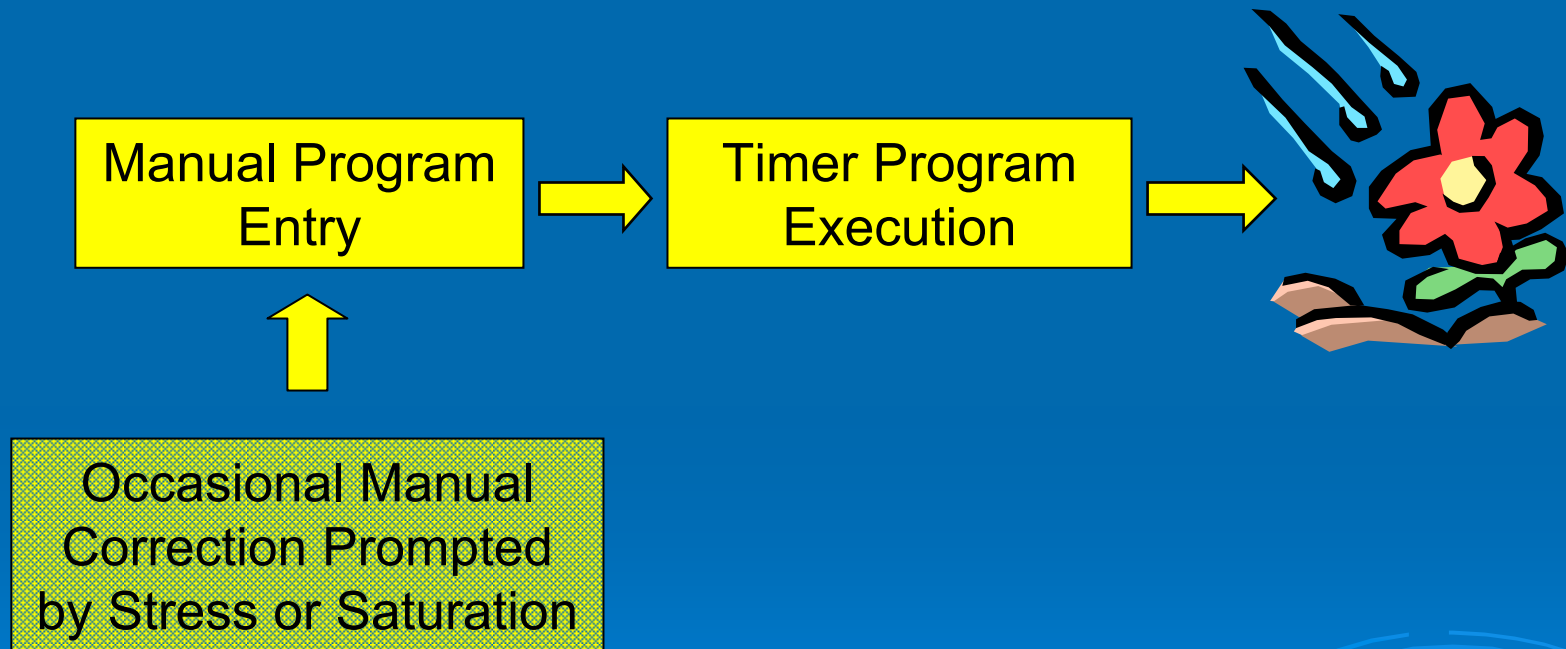
Acclima, Inc.



# Abstract

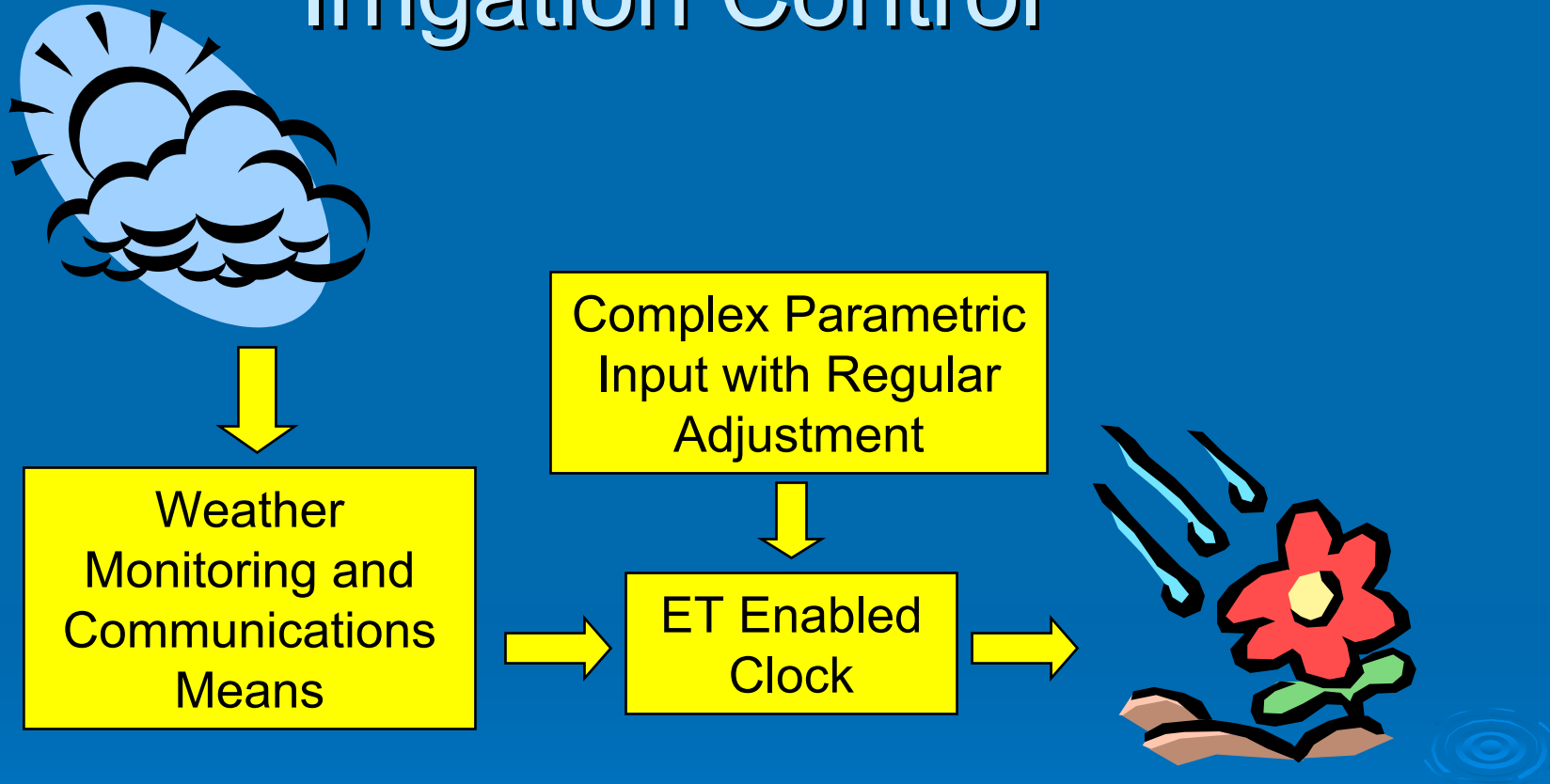
- Feedback control theory provides for accurate control over any measured variable, such as soil moisture, provided there is a monotonic relationship between a driving function (water application and evapo-transpiration) and the response variable (soil moisture), and provided that a transducer exists that can acquire stable readings of the controlled variable (soil moisture) as other variables such as temperature, compaction and soil EC change. Under such provisions, root zone moisture can be accurately controlled to remain between two limits such as field capacity and 50% available water depletion. Accuracy in holding soil moisture between these limits is limited by the ability of the soil moisture transducer to acquire stable soil water content readings as other variables change – particularly soil temperature and soil electrical conductivity. The instability of relative sensors has been the root cause of failures in attempts to control soil moisture in the past. A new soil moisture sensing technology based on digitizing and analyzing a soil-propagated step function provides stable, absolute volumetric water content readings over a wide range of soil temperature and electrical conductivity. These stable, absolute sensors have facilitated closed-loop irrigation control systems wherein root zone moisture is continuously held within the limits required for water conservation and turf quality. Inherent advantages over climatologically-based systems are localized closed-loop control, multiple independent microclimate control, accurate accounting of rainfall, soil chemistry monitoring for reclaimed water application control, and low cost.

# Conventional Clock-Based Irrigation Control



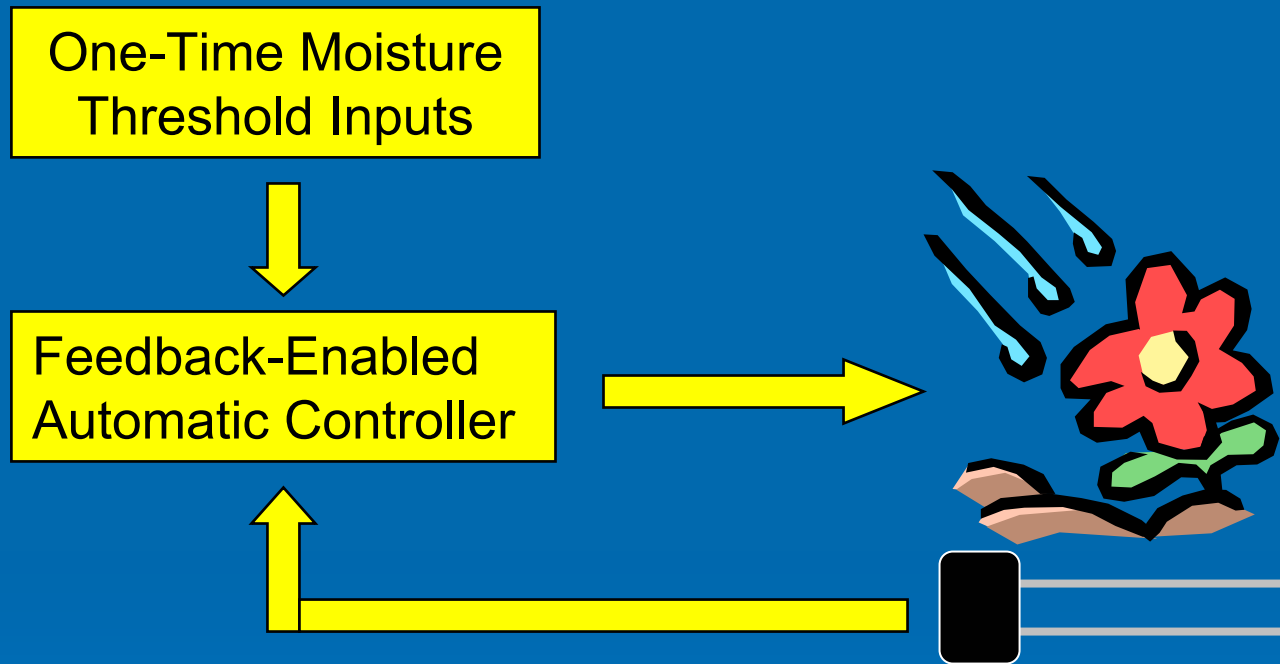
**Open Loop: No Automatic Feedback to Control Root Zone Moisture**

# Evapo-Transpiration-Based Irrigation Control



**Open Loop: No Automatic Feedback to Control Root Zone Moisture**

# Soil Moisture-Based Irrigation Control

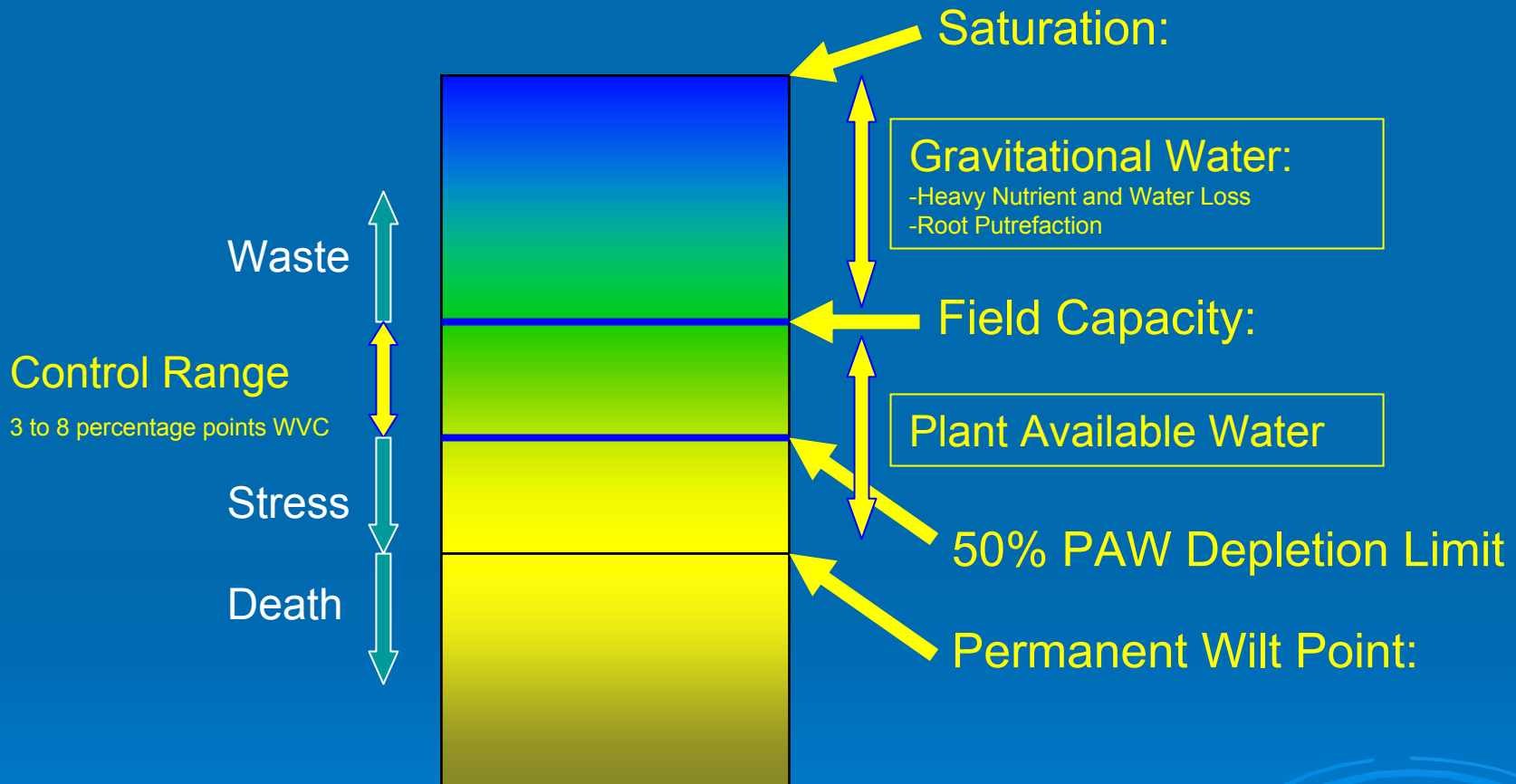


**Closed Loop: Automatic Feedback Maintains Proper Root Zone Moisture**

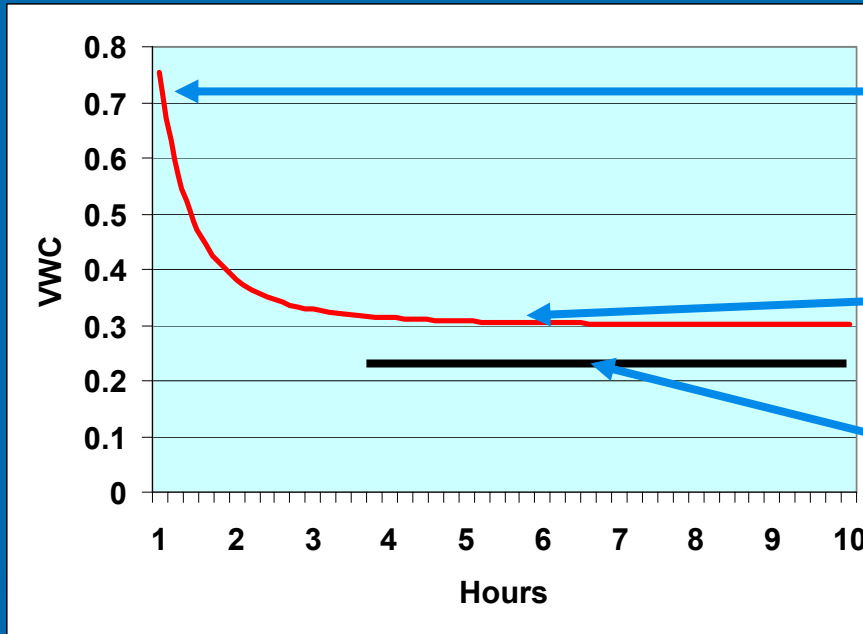
# Room Temperature Control Analogy

Conventional Timer	ET Controller	Closed-Loop System
No Thermostat	Thermostat Outside	Thermostat in Room that is being controlled

# Limits of Soil Water Content



# Setting the Limits

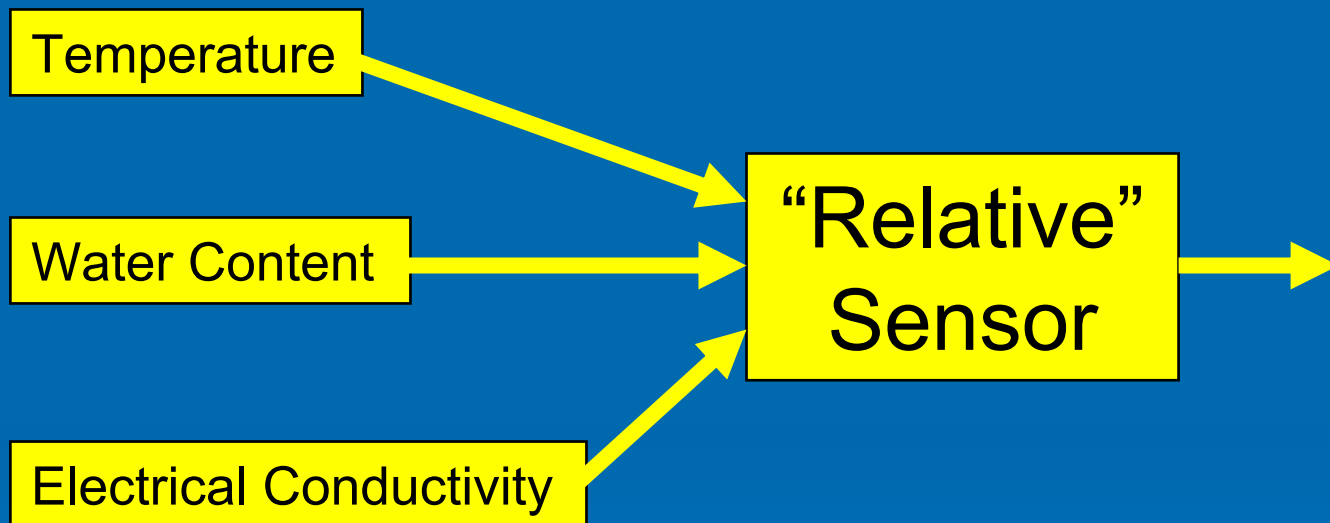


1. Saturate the soil around the Sensor the evening after installation.
2. Take a sensor reading at 5:00AM. This is Field Capacity.
3. Multiply Field Capacity by 0.75. This is the 50% PAW Depletion Limit.

Steps 2 and 3 are done automatically in Acclima's 2007 Controllers

# Instability (Relative Sensors)

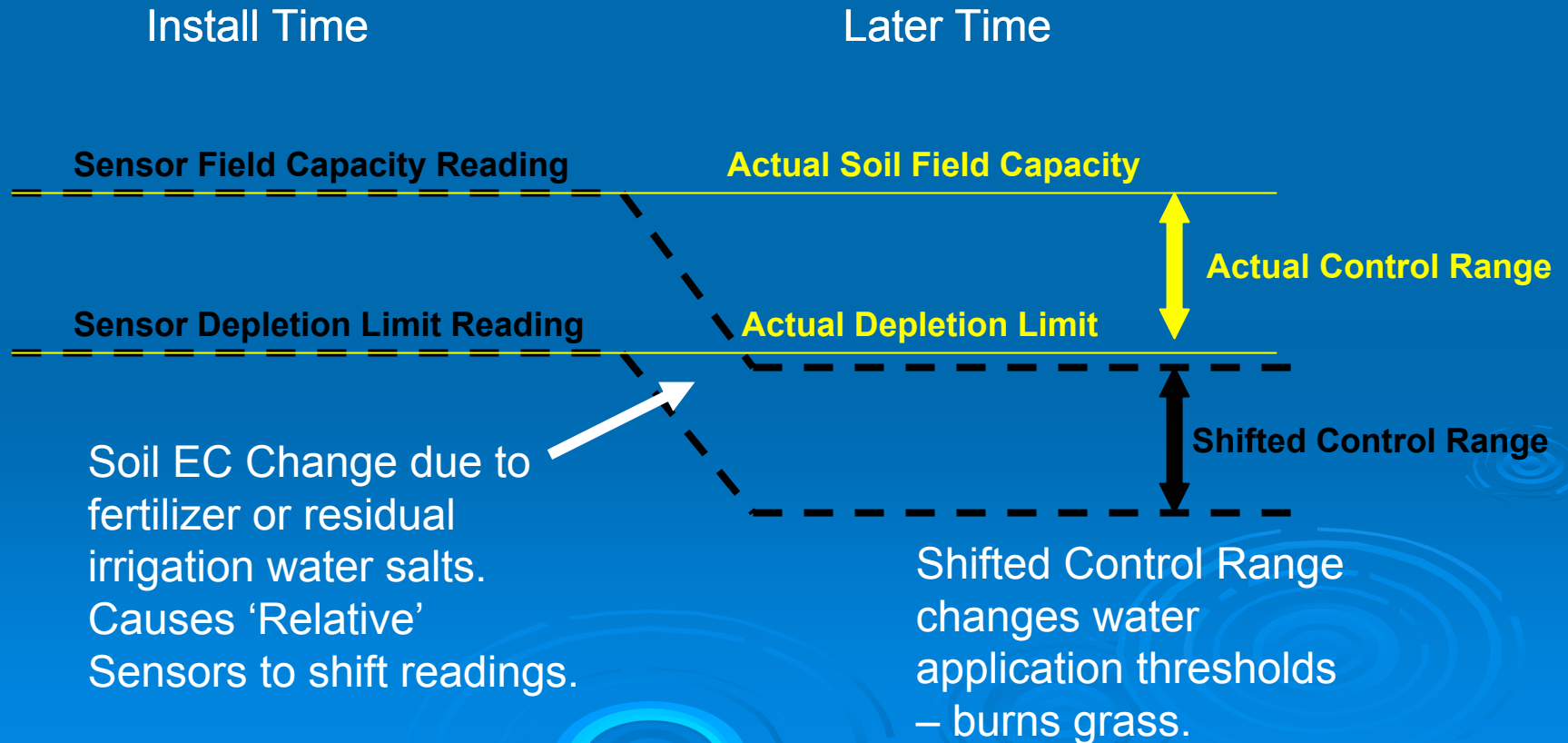
The #1 Problem Precluding Trouble-Free Closed Loop Control



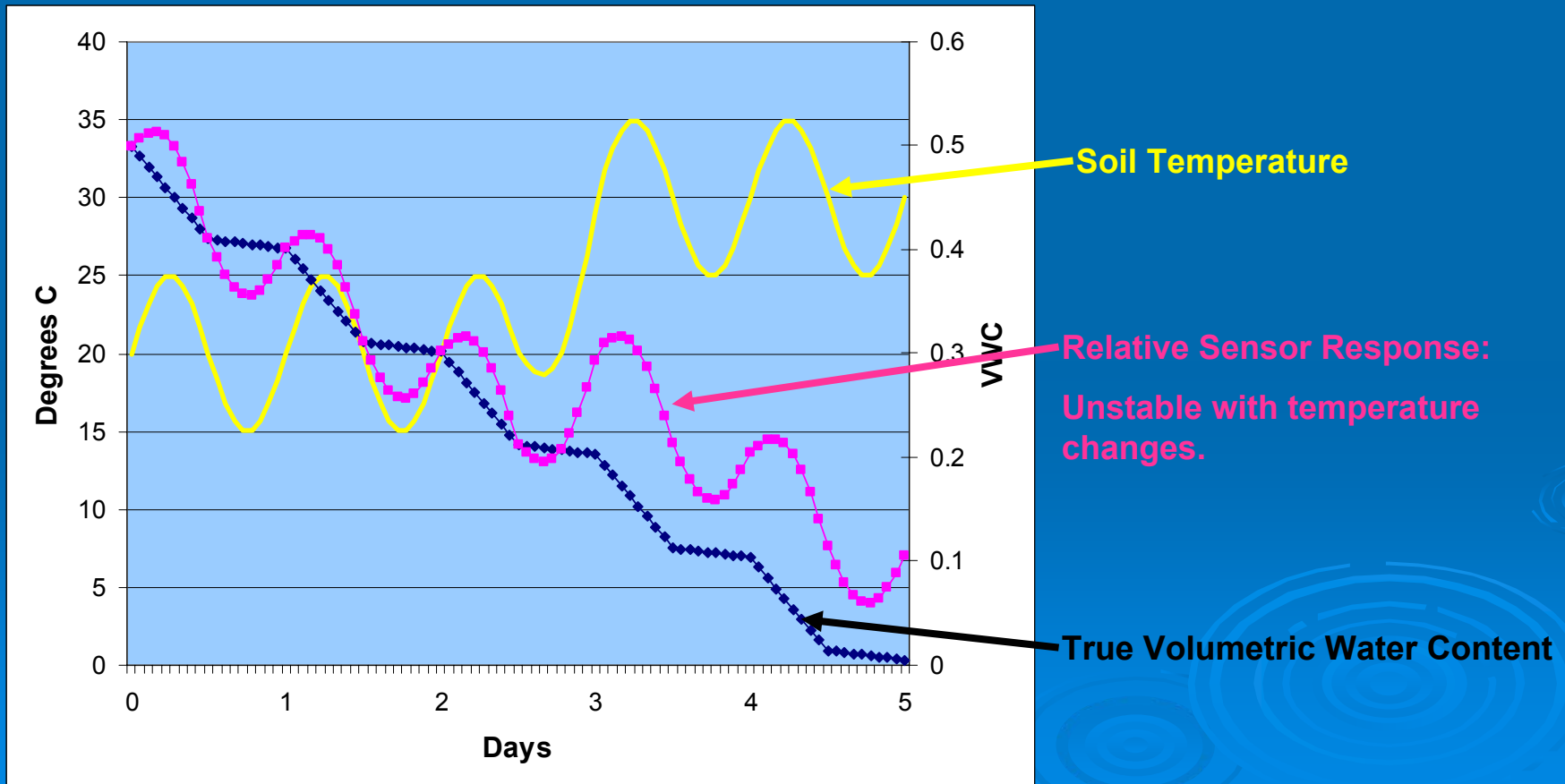
Sensor Output is a Complex Function of all Three Input Variables

# Impact of Sensor Instability - "Relative" Sensors

## Soil Electrical Conductivity Example



# Impact of Sensor Instability - "Relative" Sensors Soil Temperature Example



# Acclima Technology

## Digital Time Domain Transmissometry

Soil Permittivity Derived from Propagation Time.

$$\epsilon_r = \frac{t_{pd}^2}{l^2 \epsilon_0 \mu_0}$$

Volumetric Water Content Derived from Permittivity  
using modified Topp Equation

# Problems with tpd Determination

- Soil Chemistry Distorts Propagated Waveform
- Temperature Changes Impact Timing in Electronics



# Acclima Technology

## Overcoming EC and Temp. Induced Errors

- Waveform is digitized at 5ps intervals
- DSP algorithm finds first energy reception
- Accurate establishment of time delay
- Temperature Compensation
- Soil EC derived from waveform distortion



# Acclima Technology - Performance

- 5ps Timing Resolution - < 0.1% VWC resolution
- 0.1% typical Repeatability
- Permittivity Accurate to  $\pm 1\%$  of full scale (80)
- Soil EC Accurate to  $\pm 0.2$  dS/m
- VWC stable to  $\pm 1\%$  FS from 1 to 50 degrees C
- VWC stable to  $\pm 1\%$  FS from 0 to 5 dS/m

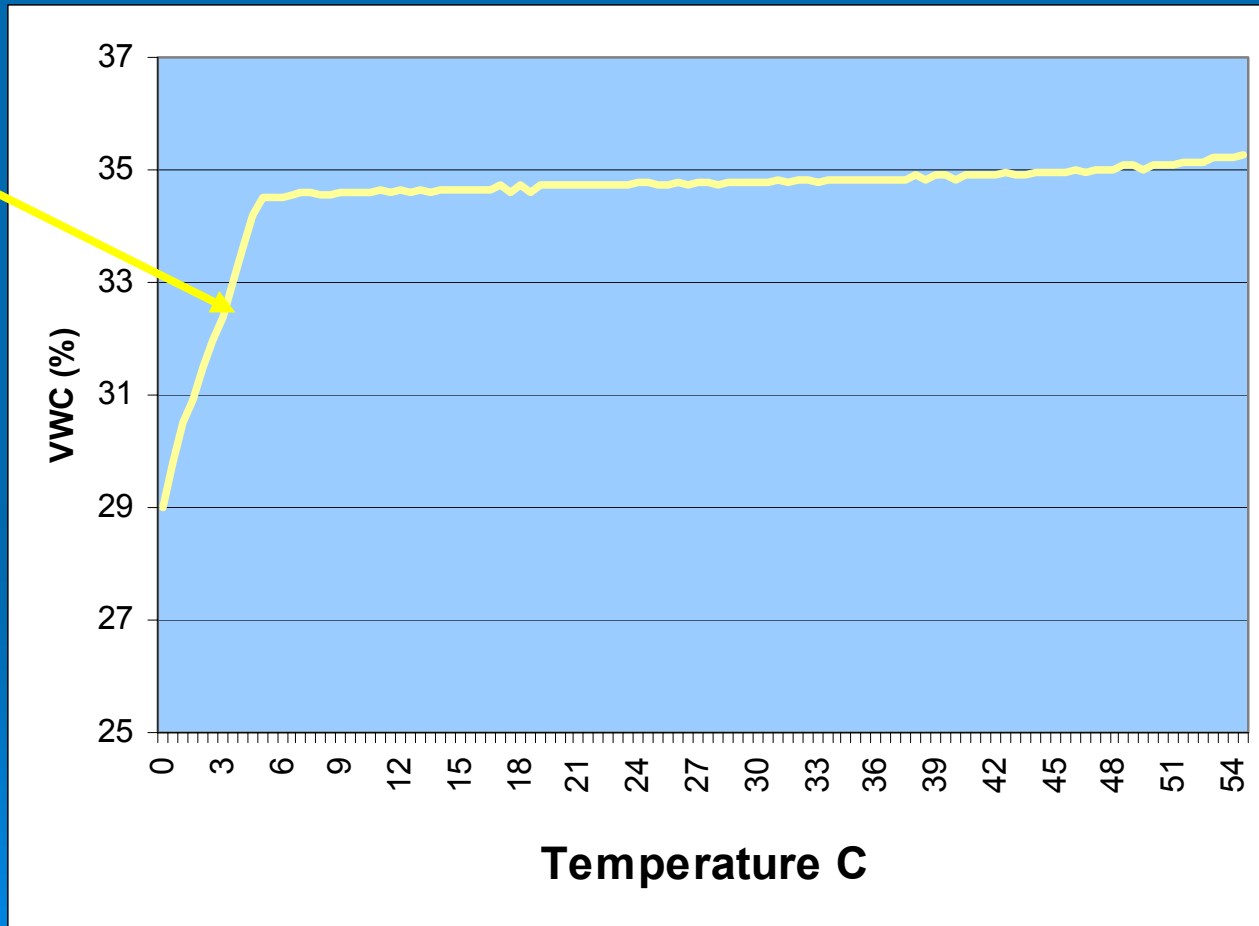
# Acclima Technology - Durability

- Type 316 Stainless Steel Transmission Line
- Water Impervious Epoxy Potting
- Robust Lightning Protection
- Power Surge Protection
- Isolated Transmission Line – Eliminates Galvanic Corrosion



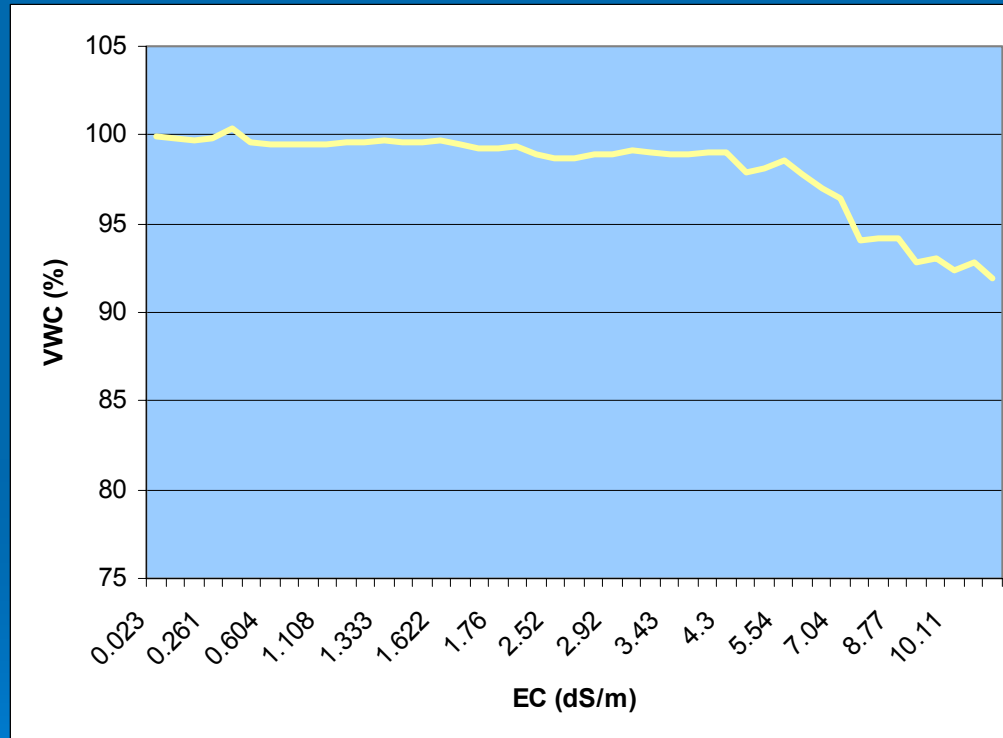
# Temperature Stability

Clay Soil – Frozen and Sealed with Embedded Sensor

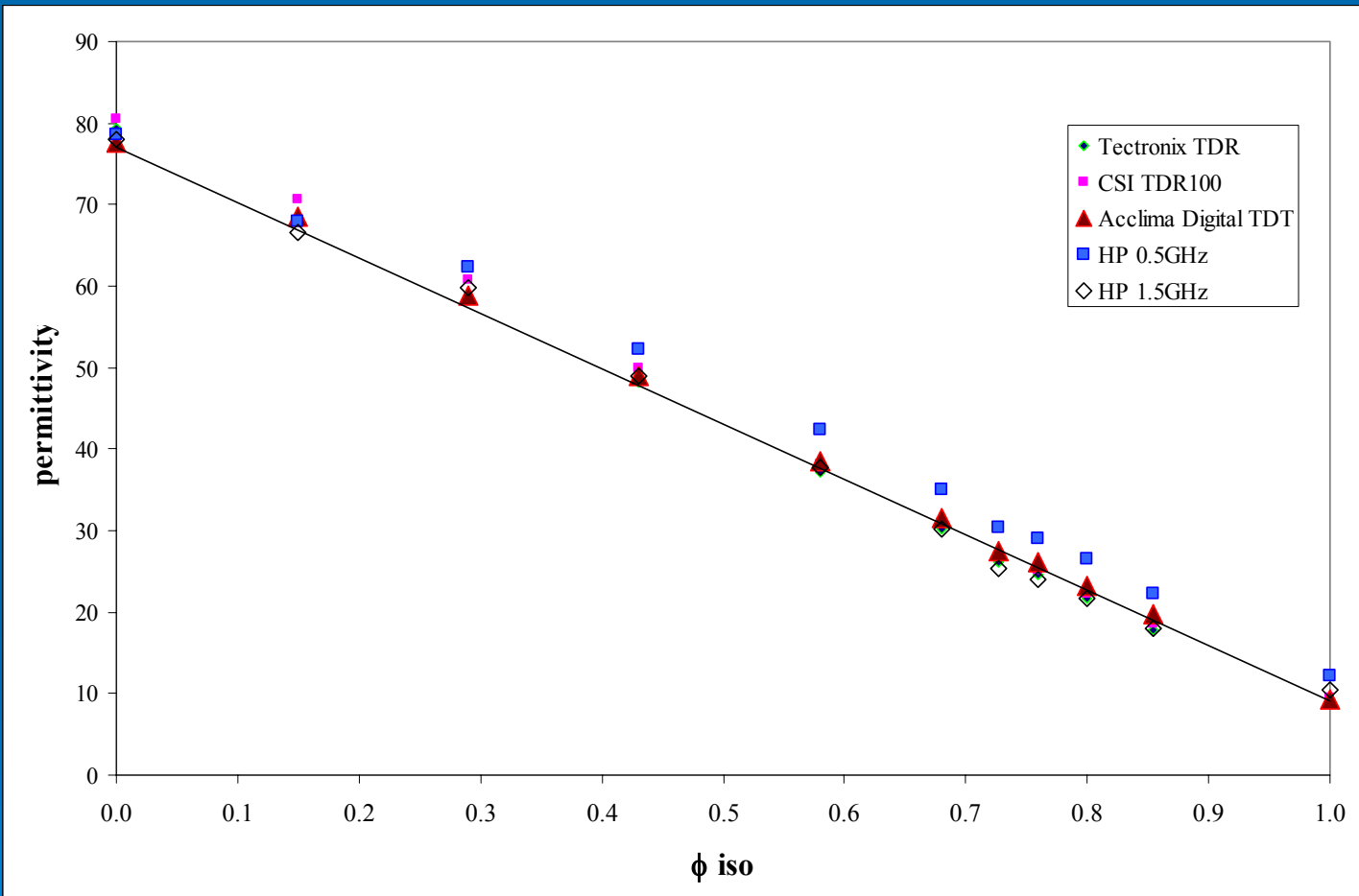


# EC Stability

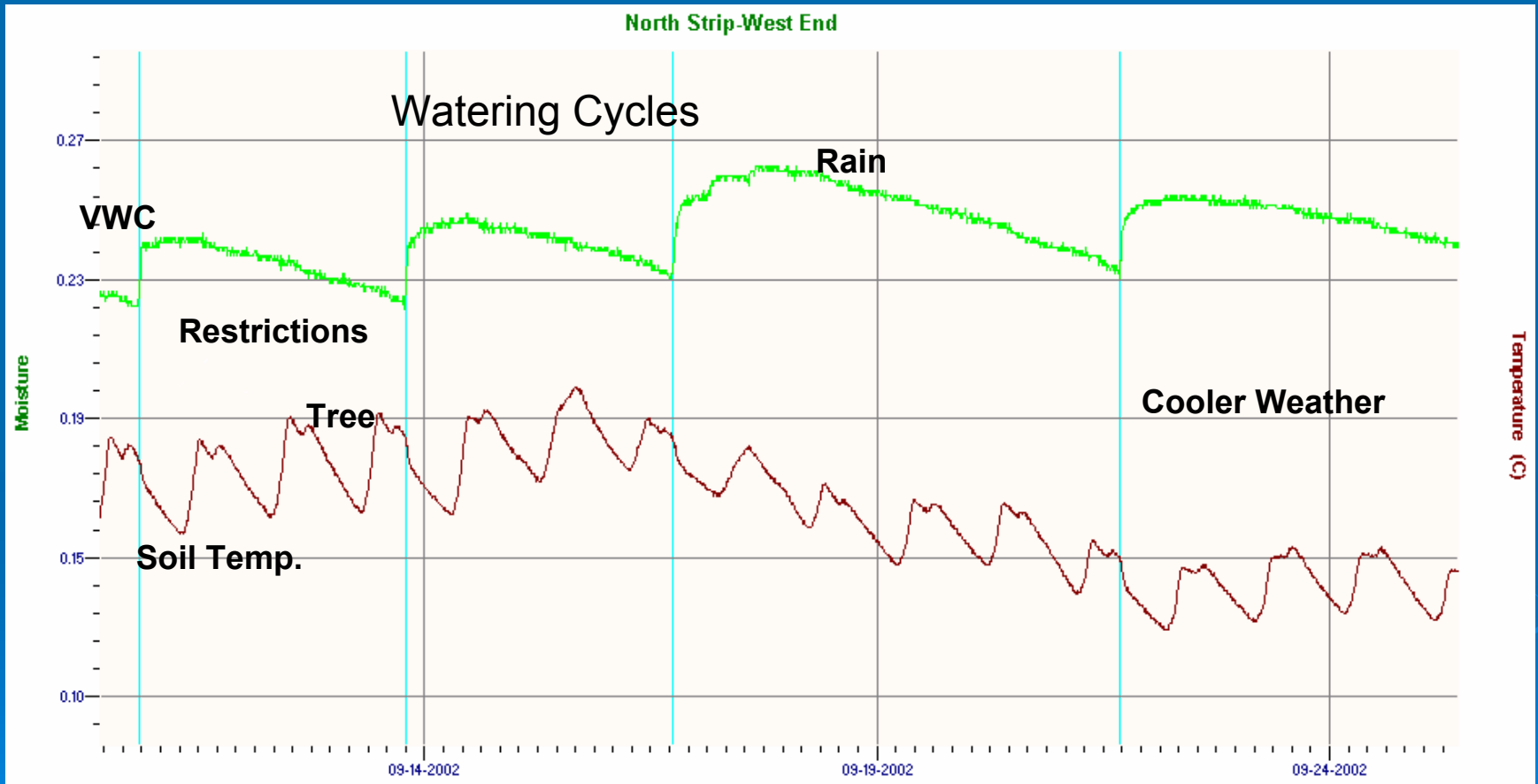
Measured in DI Water with Incrementally Added NaCl




# Permittivity Measurement




# Acclima at Work



# Advantages – Water Savings

- System Monitors ET in the Root Zone and Applies Just the Right Amount of Water to Hold Moisture in the Target Range
  - All Weather, Soil and Plant Characteristics are taken into Accurate Account in the Measurements
  - Upwards of 30% Water Savings can be Expected over a Well-Managed Clock-Based System
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# Advantages – Maintenance Savings

- Seasonal Clock Adjustments are Eliminated
  - System Automatically Accommodates Heavy Rains, Cool Periods, Hot Periods, Dry Winds without Need of Adjustment.
  - Initial Settings Remain Stable Year after Year
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# Advantages – Healthier Lawns

- Over-Watering Drives Oxygen out of the Soil and Putrefies Roots
- Over-Watering Leaches Nutrients and Pesticides from the Soil
- Over-Watering Develops Fungi in the Soil
- Over-Watering Weakens Drought Tolerance and Reinforces Over-Watering
- Under-Watering Stresses Lawns and Promotes Weed Growth

# Advantages – Environmental Issues

- Ground Water Contamination with Pesticides and Fertilizers is the Result of Over-Watering Crops and Turf.
- Significant Reductions in Fertilizer and Pesticide Applications are Possible with Closed-Loop Irrigation.



# Advantages over ET Systems

- Accurate Root Zone Moisture Control
- Accurately Accounts for Rainfall
- Provides for Multiple Independent Microclimate Control
- Controls Application of Reclaimed Water
- Low Cost

