

# Soil Moisture Measurement Methods

## Electrical Conductivity

Basis: Conductivity increases with Water Content (sometimes)

Advantage: Low cost

Disadvantage: Pure water is an Insulator and has no conductivity.

Measured conductivity is a function of Ion concentration and Ion mobility. Water increases Ion mobility. Changes in ion concentration and temperature cause very large errors in this method.

An improved approach is to measure the conductivity of an 'isolated' secondary medium such as gypsum to infer the water content of the soil. Accuracy and stability are still serious issues and the 'isolation' breaks down over time.

# Soil Moisture Measurement Methods

## Neutron Probe

**Basis:** Emitted Neutrons from isotope source lose energy only as they impact hydrogen atoms (water). Neutron detector response weakens as soil water content increases.

**Advantages:** Insensitive to temperature, soil EC, compaction, etc. Only responsive to soil water content (or other hydrogen-bearing constituents). Very large sampling volume.

**Disadvantages:** Very high cost. Requires license to operate. Cannot be installed permanently. Must be calibrated to the source of neutrons.



# Soil Moisture Measurement Methods

Specific Heat:  $\Delta T \sim k(\Delta J)$

**Basis:** Water has higher specific heat than soil minerals

**Advantage:** Insensitive to EC

**Disadvantages:** Measurement Sample Boundary, Measurement Sample Size, Power Consumption, Specific Heat Differentiation

# Soil Moisture Measurement Methods

## Tensiometer

**Basis:** Water concentration comes to equilibrium across a semi-permeable membrane.

**Advantage:** Immune to soil EC

**Disadvantages:** Frequent Maintenance, Vacuum break vulnerability



# Soil Moisture Measurement Methods

## Permittivity Measurement – Capacitor

Basis: Dielectric constant of water is ~30X that of other soil constituents.

Advantage: low cost

Disadvantages: EC losses in the soil confound the capacitance readings.

Dielectric constant of water is temperature dependent. Capacitive probes are 'surface' sensitive and thus subject to large air-gap errors.

Compensation is very difficult due to the requirement to separate temperature and EC errors.

# Soil Moisture Measurement Methods

## Permittivity Measurement – LC Resonance

$$\omega = 1/LC$$

Basis: Same as Capacitor method.

Advantage: Some configurations allow tube measurements at various depths. Higher frequency operation results in EM wave penetration of the soil, reducing air gap problem.

Disadvantages: High cost for tube insertion types. Sensitive to soil EC. Sensitive to Soil Temperature. Sensitive to air gap between plates and soil. Sensitive to Compaction. Separation of error-causing errors is very difficult.

# Soil Moisture Measurement Methods

## EM Wave Propagation Time – Analog TDR

$$c = \frac{1}{\sqrt{\mu\epsilon}}$$

Basis: Speed of light is inversely proportional to sq rt of permittivity. Soil permittivity is dominated by water content.

Advantage: High Accuracy. Large sampling volume. Well-understood standard for permittivity measurement.

Disadvantages: Very high cost. Waveform distortion errors from soil EC.

# Soil Moisture Measurement Methods

## EM Wave Propagation Time – Analog FDR

Basis: Speed of light is inversely proportional to sq rt of permittivity. Soil permittivity is dominated by water content. Frequency of fixed-length standing wave oscillation is dominated by water content.

Advantage: Large sampling volume. Lower cost than Analog TDR.

Disadvantages: Sensitive to Soil EC and compaction. More difficult to interpret than Analog TDR.



# Soil Moisture Measurement Methods

## EM Wave Propagation Time – Analog TDT

Basis: Same as Analog TDR

Advantage: Higher Signal to Noise Ratio than TDR.

Disadvantages: EC distortion of waveform causes large permittivity reading errors. Requires Excavation for Installation.



# Soil Moisture Measurement Methods

## EM Waveform Propagation Time – Digital TDT

Basis: Same as Analog TDR

Advantages: Stability far exceeds all other sensors – the stability standard for the industry. Lower cost than analog TDR. Low sensitivity to compaction. Deep waveform penetration provides High Sampling Volume and low air gap sensitivity. GHz operation reduces complex permittivity errors in clay soils. Linear. Highest Durability. Very Easy to Use.

Disadvantage: Excavation needed for Installation.

# Absolute vs. Relative

## Absolute:

The sensor provides a stable moisture reading when soil type, compaction, EC or temperature changes. The sensor is unresponsive to these variables over wide ranges.

## Relative:

The sensor reading increases and decreases with moisture content but also changes with EC, temperature, compaction, soil type, etc. Attempts to separate the effects of these variables from the output signal are deceptive. Relative sensors are unstable. They require calibration to the specific installation environment. As the environment changes the readings become unreliable.

# Calibration of Relative Sensors

Relative Sensors require calibration so that their readings can be correlated to absolute soil moisture or hydrostatic pressure. This calibration compensates for the specific EC, temperature, complex permittivity (soil type) and compaction of the soil around the sensor.

In some cases different models of sensors are sold that are factory calibrated for a near match to different soil conditions.

Neither approach works. Soil conditions change.

Ask for independent verification of manufacturers claims before buying sensors.

# Soil Moisture Measurement Methods

Sensor Type	Cost	Stability	Sampling Volume	Durability	Ease of Use	Score
Digital TDT	Medium/Low (8)	Excellent (10)	Good (9)	Exc. (10)	Good (10)	47
Analog FDR	High (2)	Good (8)	Good (6)	Exc. (10)	Good (8)	34
Analog TDT	Medium/Low (8)	Good (6)	Fair (3)	Good (5)	Good (8)	30
Analog TDR	Very High (-2)	Good (8)	Good (9)	Exc. (10)	Poor (2)	27
Capacitance	Low (9)	Poor (1)	Poor (2)	Good (5)	Good (7)	23
Tensiometer	Medium (7)	Good (6)	Good (6)	Poor (1)	Poor (2)	22
Gypsum Block	Low (10)	Fair (2)	Fair (2)	Poor (0)	Good (7)	21
Neutron Probe	Very High (-5)	Excellent (10)	Exc. (10)	Fair (3)	Poor (1)	19
Specific Heat	Medium/High (6)	Fair (5)	Poor (-5)	Fair (2)	Good (6)	14
LC Resonance	High (1)	Poor (1)	Fair (7)	Fair (3)	Poor (1)	13
Conductivity	Low (9)	Very Poor (-20)	Good (8)	Fair (2)	Poor (1)	0

# Closed-Loop Irrigation Concepts

-The Future of Irrigation

In Consideration of:

Cost

Stability

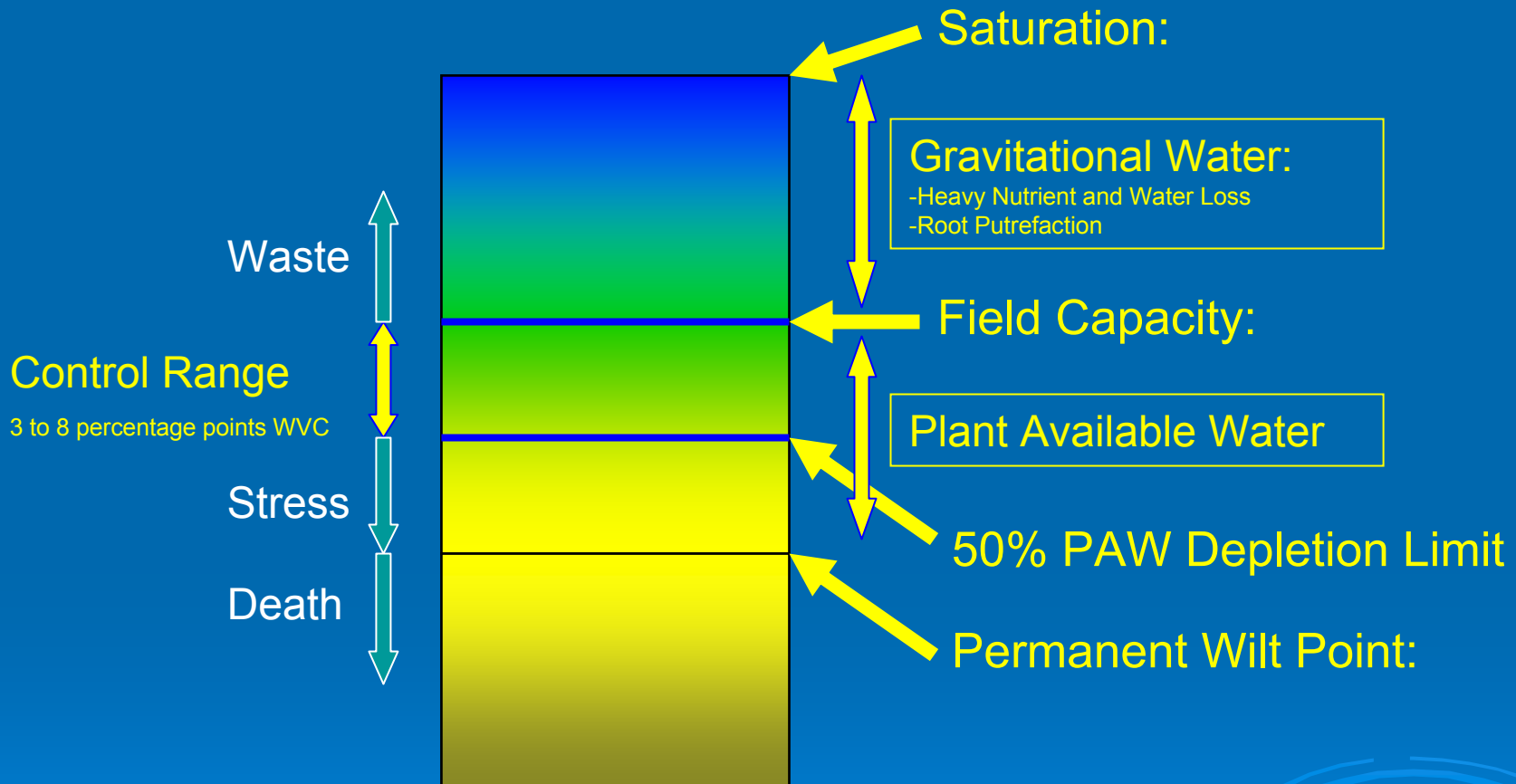
Durability

Ease of Use

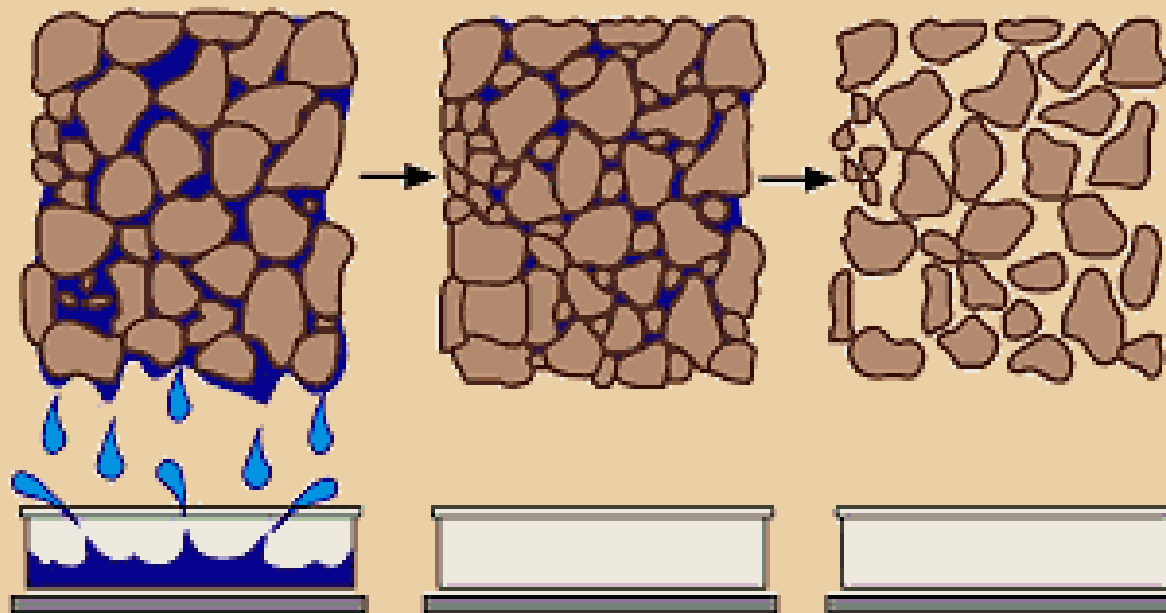
Maintenance



# The Limits of Effective Irrigation



# Available Water Capacity



## **Saturation**

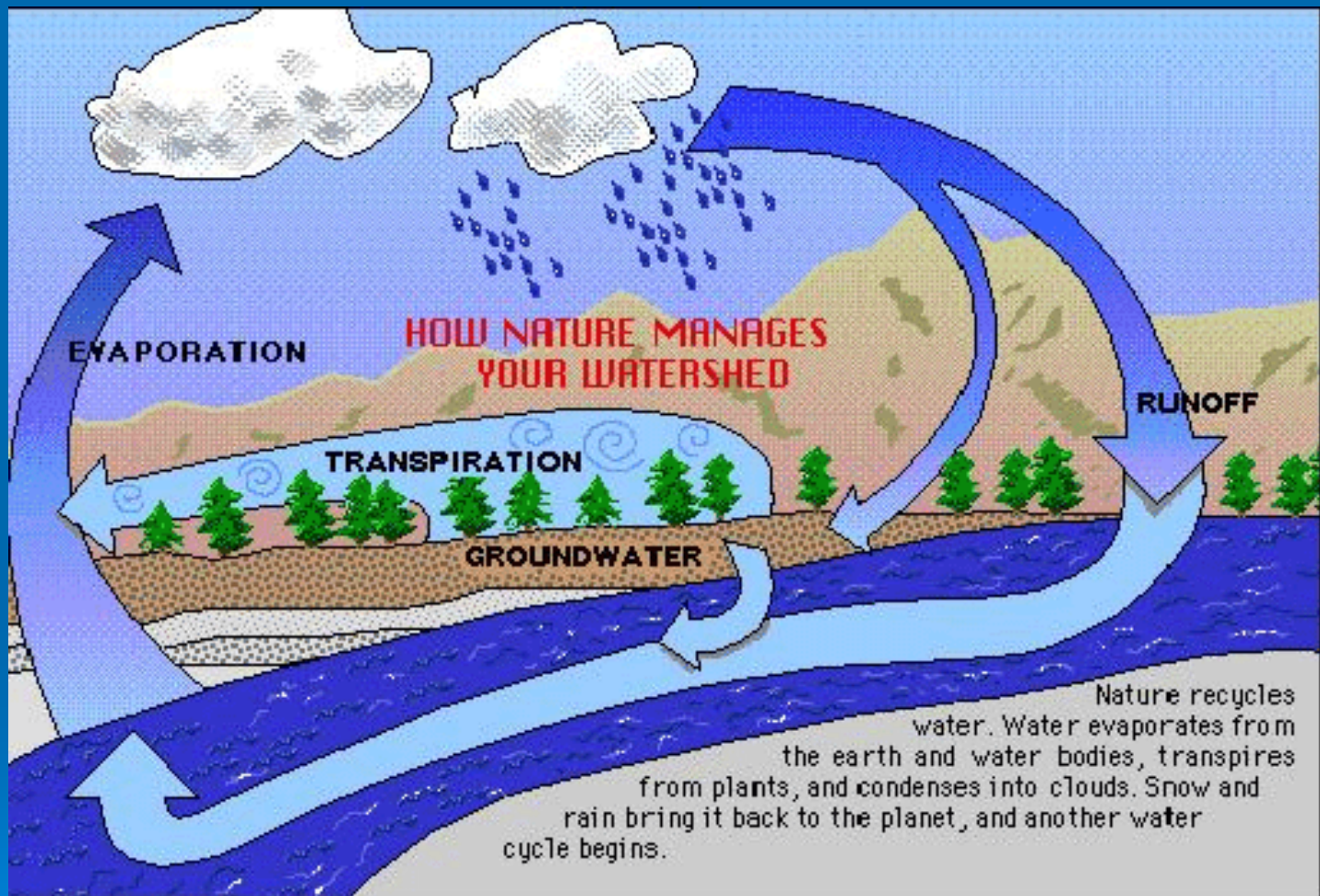
All pores are full of water. Gravitational water is lost

## **Field Capacity**

Available water for plant growth

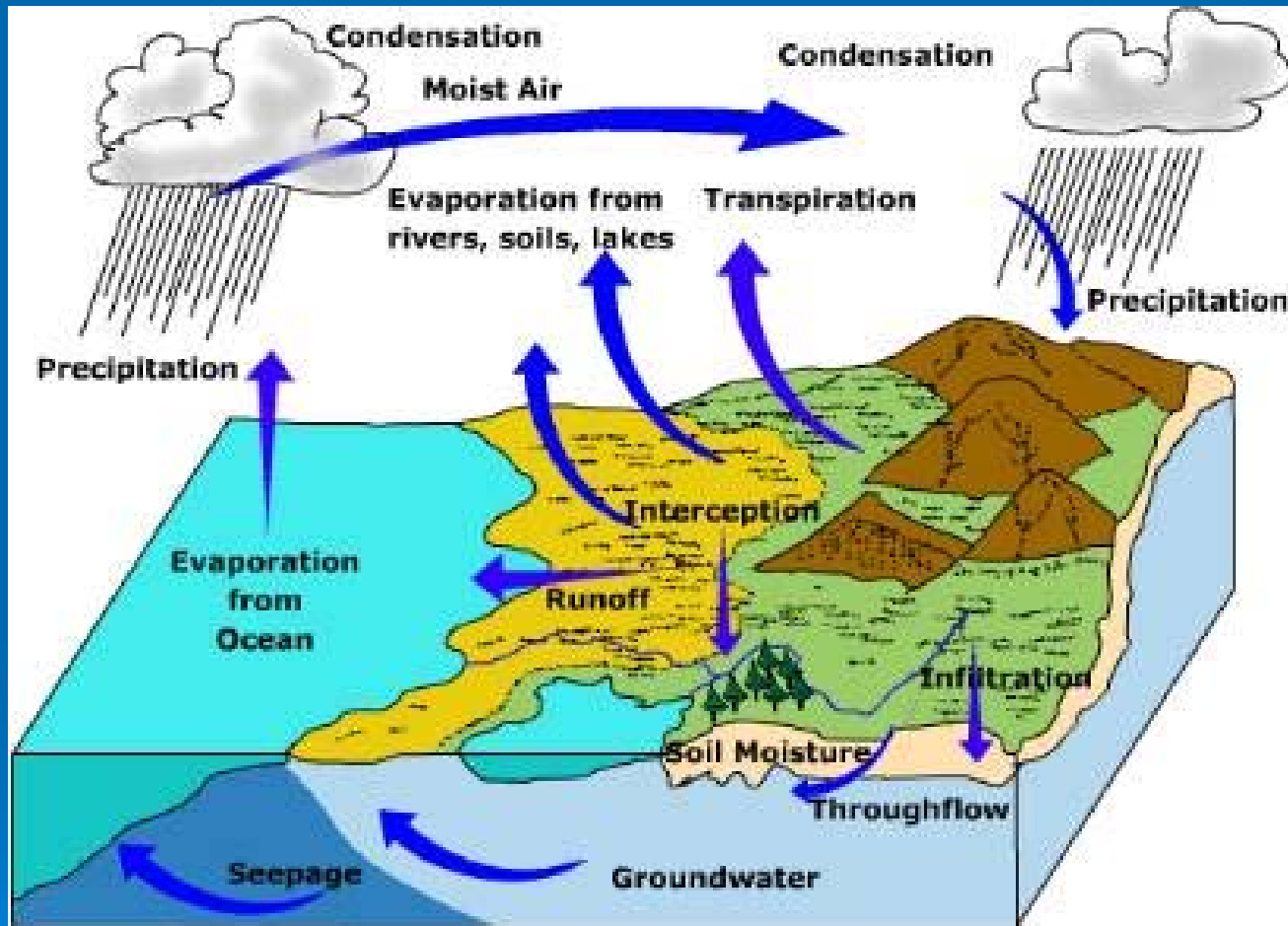
## **Wilting Point**

No more water is available to plants



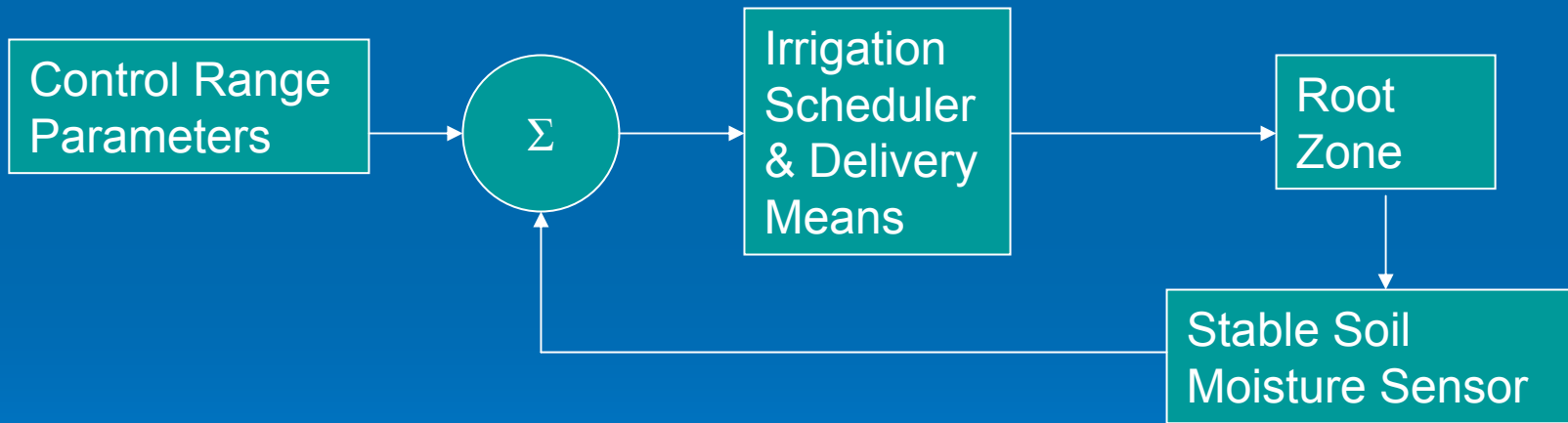
## ➤ **About Groundwater and the Water Cycle**

- Groundwater is an integral part of the earth's water cycle.
- The water (or hydrological) cycle is the continuous, repeating journey of water between the earth and the atmosphere. Heating of the ocean water by the sun keeps the cycle in motion. After water evaporates, it condenses to form clouds, then falls to the earth as precipitation (rain, snow, sleet, and hail).
- Some of the water evaporates again, some stays on the surface, becoming streams, rivers, lakes, etc., while a certain amount soaks, or infiltrates, into the ground, becoming groundwater.
- 
- The water moves downward through empty spaces or cracks in the soil, sand, or rocks until it reaches a layer of rock through which water cannot easily move. The water then fills the empty spaces and cracks above that layer, much like filling a bathtub. The top of this stored water, or aquifer, is called the water table and the water that fills the empty spaces and cracks is called ground water. The water table may be only a foot below the ground's surface or it may be hundreds of feet down.
- The world has a limited amount of water, and if not for this cycle, we would not have this continuous source of water to recharge our aquifers.
- Groundwater is used for drinking water, agriculture, commercial and industrial needs. Over time, groundwater also discharges to lakes, wetlands, streams, rivers, and the ocean. It helps keep streams cool and flowing during the hot, dry seasons; this is critical to wildlife habitat, especially for salmon.



# Closed-Loop Irrigation

## An Automatic Feedback Control System



# Basic System Requirement for Closed-Loop Control

## A Stable Sensor vs. Soil EC, Temperature and Time

The System's Ability to Maintain Moisture within Control Range is Limited by the Stability of the Sensor.

Unstable Sensor = Stressed Turf & Wasted Water

Stable Sensor = 100% Irrigation Adequacy and Efficiency

# Sensing Technologies

- Direct Conductivity (snake oil)
- Indirect Conductivity\* (response, mortality)
- Direct Capacitance\* (EC losses, surface sensitivity)
- Indirect LC Capacitance (EC losses, surface sensitivity)
- Specific Heat\* (power, sampling volume)
- Tensiometer (maintenance, range, durability)
- Analog Time Domain Reflectometer (EC distortion, reflection loss)
- Analog Time Domain Transmissometer\* (EC distortion)
- Wide Band Frequency Domain Reflectometer (EC absorption)
- Neutron Probe (regulations, cost, calibration)
- Digital TDR (cost, reflection loss, bulk, intimidation)
- Acclima Digital TDR\* (reflection loss)
- Acclima Digital TDT\* (excavation disruption)

\*Sensors with which Acclima has development experience.

# Technology Grouping

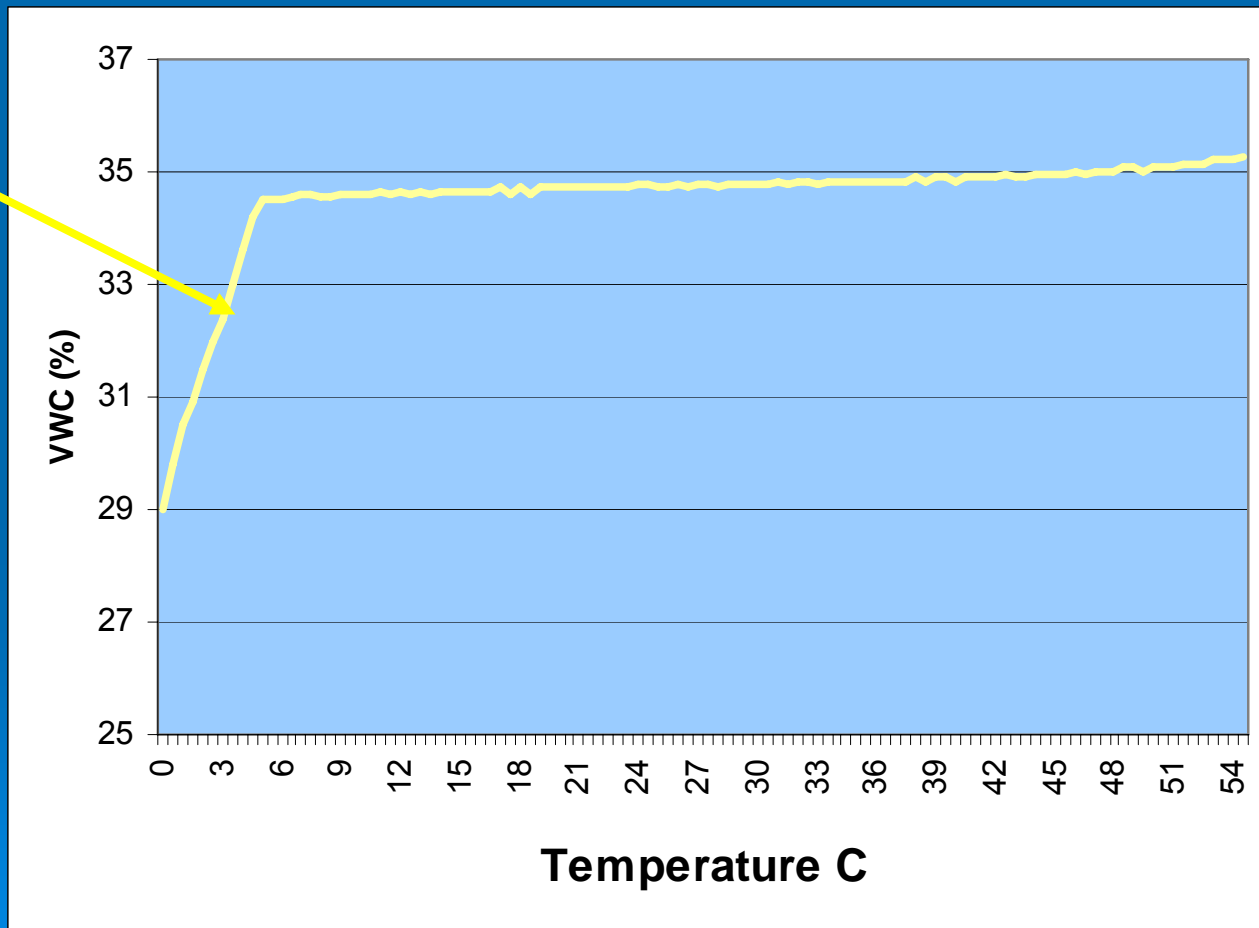
- Conductivity
- Capacitance Measurement
- Specific Heat
- Vacuum Tension
- Analog Propagation Time
- Nuclear Ballistic
- Digital Propagation Time

# Digital TDT/TDR Technology

- Water Content is Derived from the Details of a Propagated EM Wave
- High Resolution, Low Cost Digital Waveform Analysis (patented)
  - 12-bit A/D conversion with 5ps resolution (.06%VWC)
  - 200 GS/sec equivalent A/D conversion rate
  - Industry's Highest Performance Moisture Sensing Circuitry has ~\$6 materials cost incl. uP.
  - Inert, Indestructible Materials
- Demo

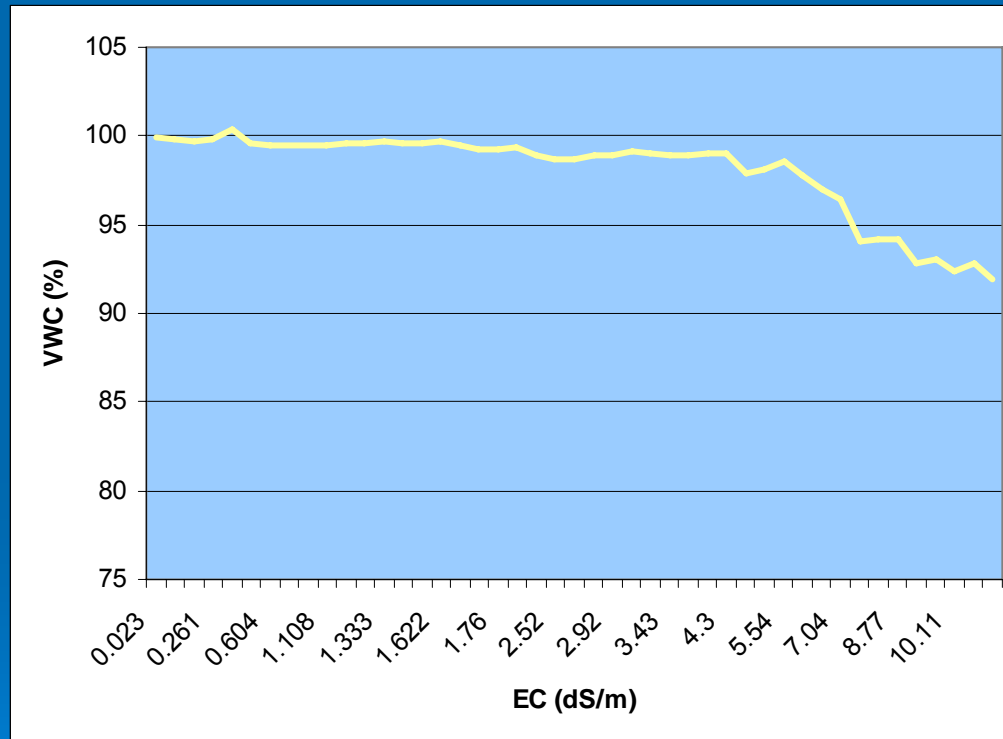
# Temperature Stability

Clay Soil – Frozen and Sealed with Embedded Sensor



# EC Stability

Measured in Distilled Water with Incrementally Added NaCl



# Acclima Sensor Family

- Digital TDT with 2-wire Interface
  - Operates on 24VAC using existing wiring
  - No need to install wiring to the controller
  - Includes single-zone valve switch
- Digital TDT with SDI-12 Interface
  - Designed for battery operation
  - Communicates over RS-232-like protocol
  - Easily modified to wireless operation
- Digital TDR (prototype)

# Market Implications

- Highest Performance SWAT:
  - Strong Approval from Regulators & Purveyors
  - Promotional Assistance from Researchers
- Automatic Parameter Setup (AAll)
  - Declining User Learning Curve
  - Easily Recoverable Operating Parameters
- Low Cost
  - Universally Affordable – Easily Rebated
  - Single Season Payback

# Closed-Loop Advantages

- In-Root-Zone Measurement & Control
- Measurement (not Inference) of Controlled Variable – SM Level Relative to Control Range
- Immediate and Continuous Knowledge of Static Moisture Level
- Calculable Site-Specific Parameters for Automatic Setup and Optimum Irrigation Control

# Relative to ET Systems...

- Lower Cost
- Higher Watering Efficiency
- No Maintenance
- Physics-Based Automatic Setup