The Abdus Salam International Centre for Theoretical Physics

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College on Soil Physics - 30th Anniversary (1983-2013)

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Methods to Measure the Water Balance

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METHODS TO MEASURE THE WATER BALANCE

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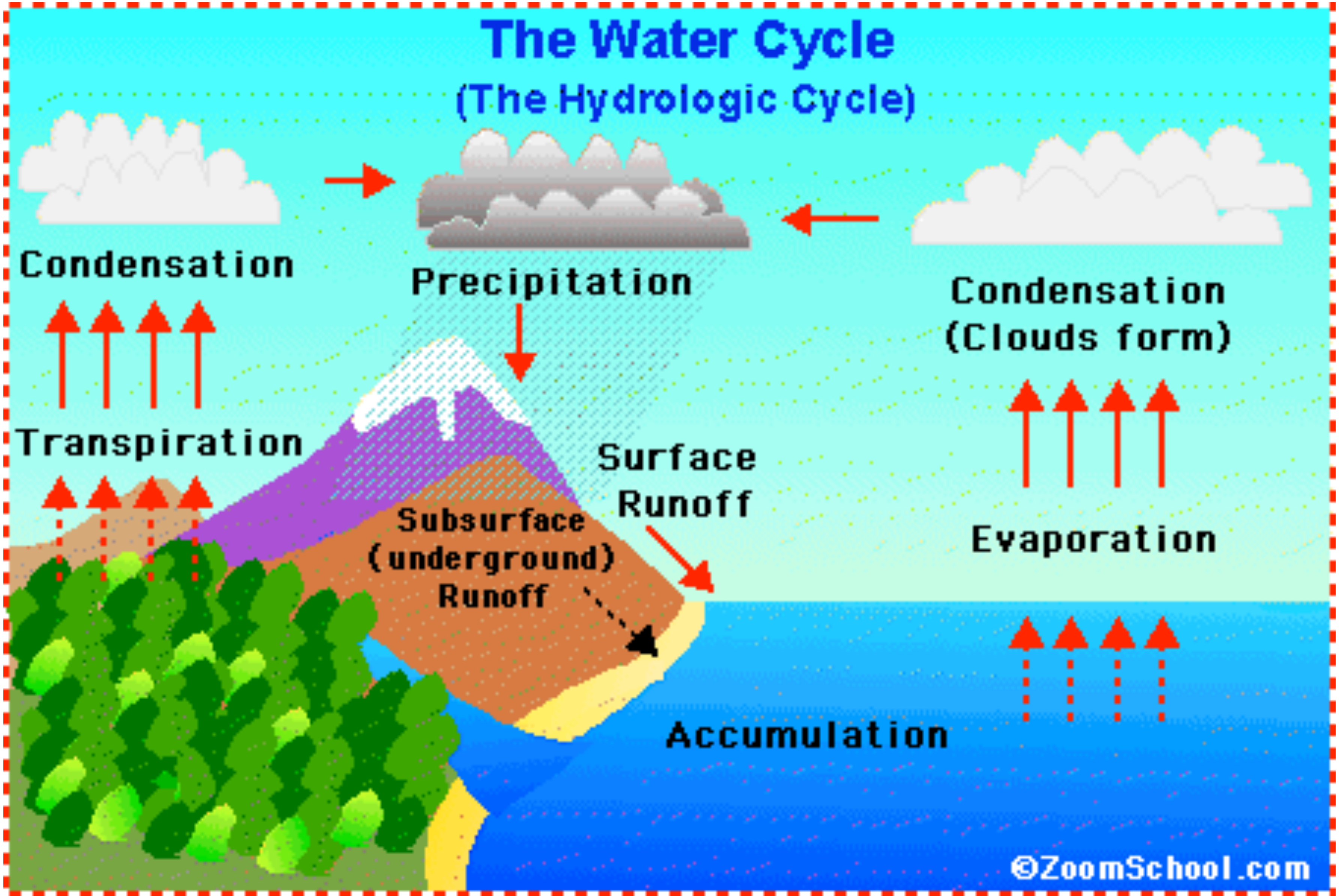

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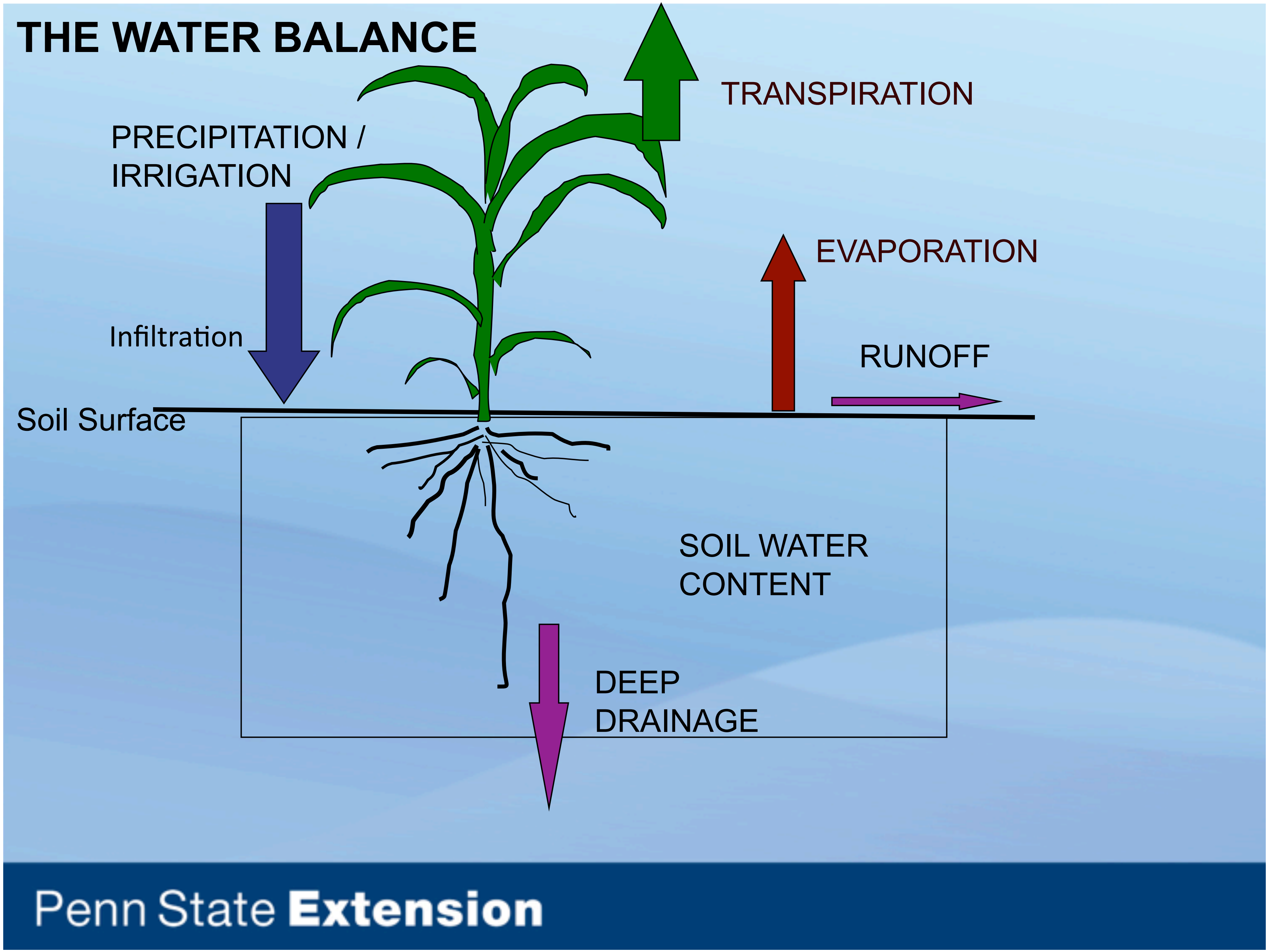
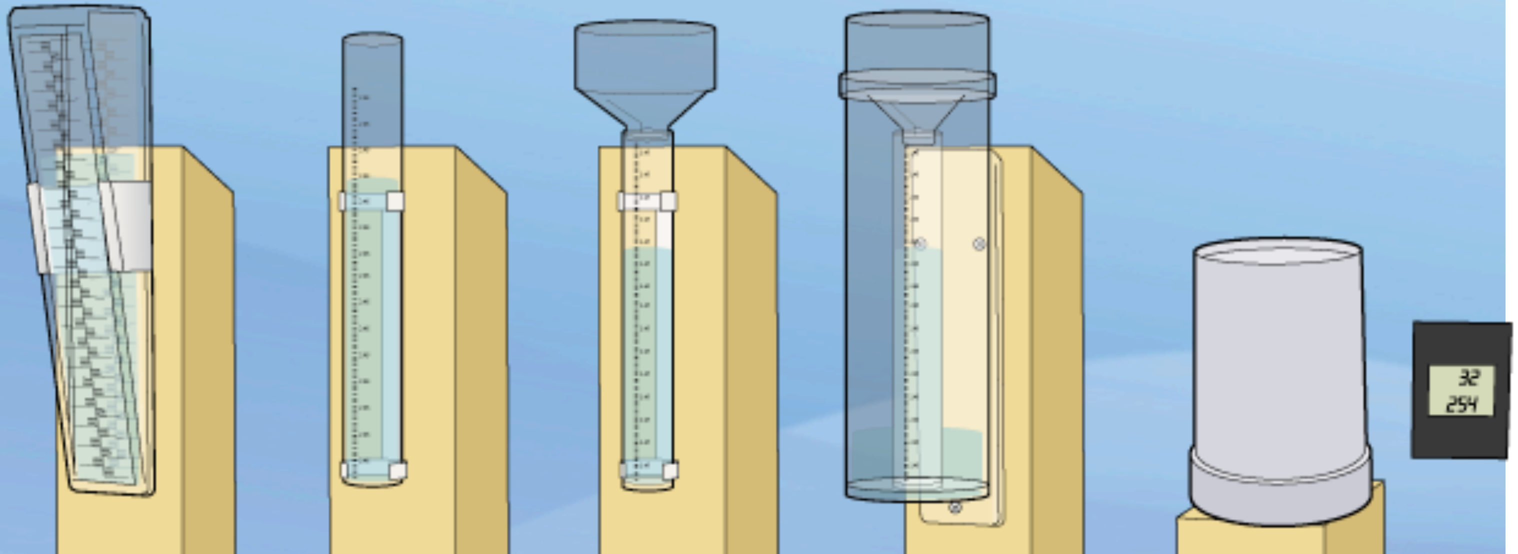

THE WATER BALANCE
TRANSPIRATION
PRECIPITATION /
IRRIGATION
EVAPORATION
Infiltration
RUNOFF
Soil Surface
SOIL WATER
CONTENT
DEEP
DRAINAGE
Penn State Extension

Water Balance Equation

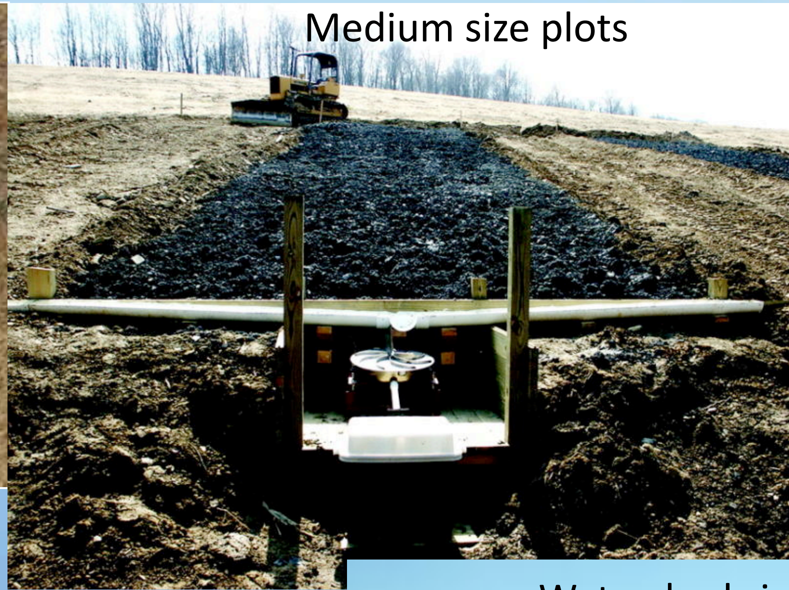
$P + I = E + T + D + R \pm \Delta S$

P = Precipitation
I = Irrigation
E = Evaporation
T = Transpiration
D = Deep drainage
R = Runoff (or Run-on)
ΔS = Soil moisture content change

MEASURING PRECIPITATION OR IRRIGATION



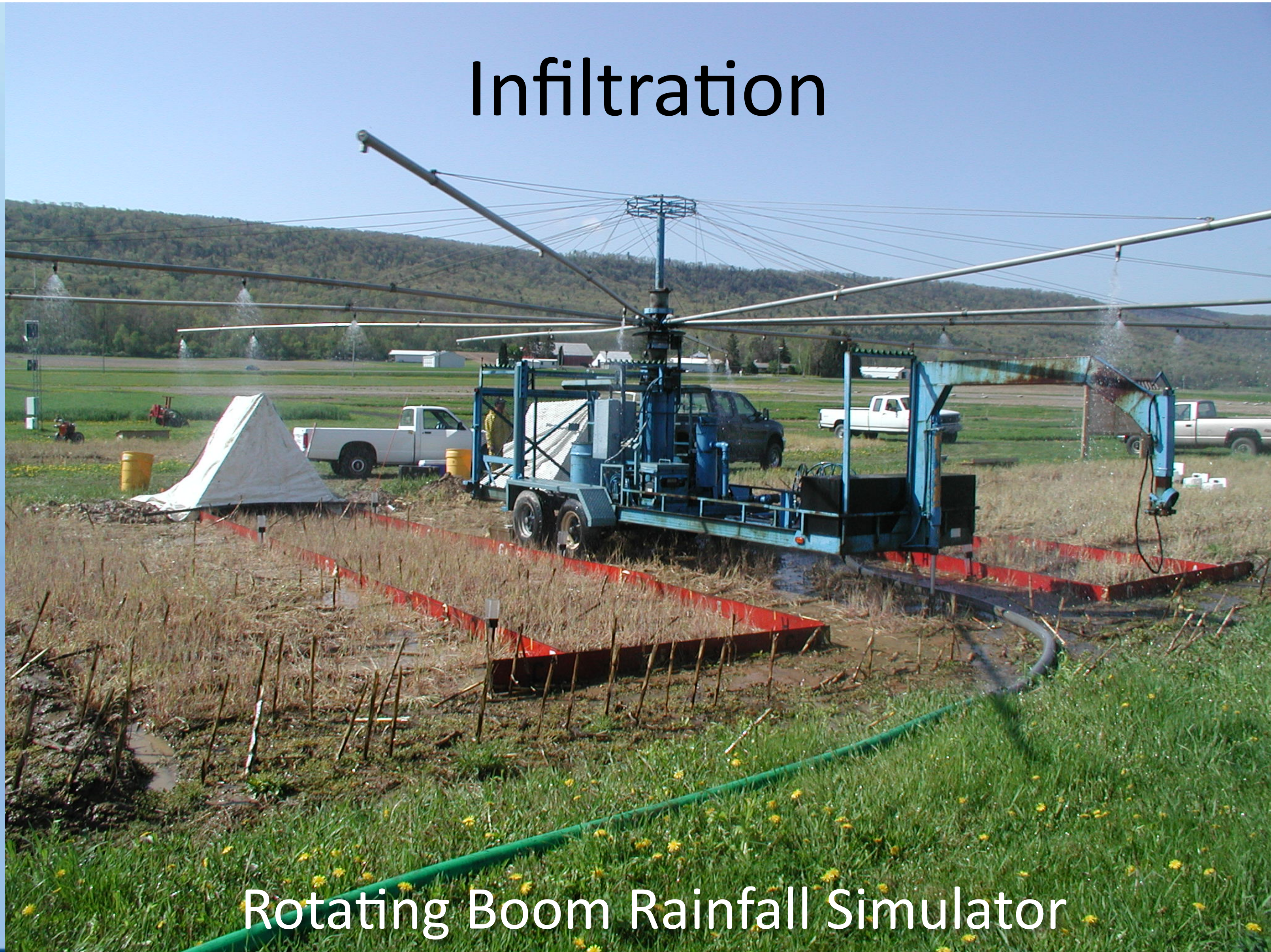
MEASURING RUNOFF



Infiltration

Double and Single Ring Infiltrometers

Infiltration



Rotating Boom Rainfall Simulator

Infiltration

Stationary Nozzle Rainfall Simulator

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MEASURING DEEP DRAINAGE

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Drainage: Pan lysimeter – zero tension

Measures only free water flow up

Can convert to depth (volume/ area of pan)

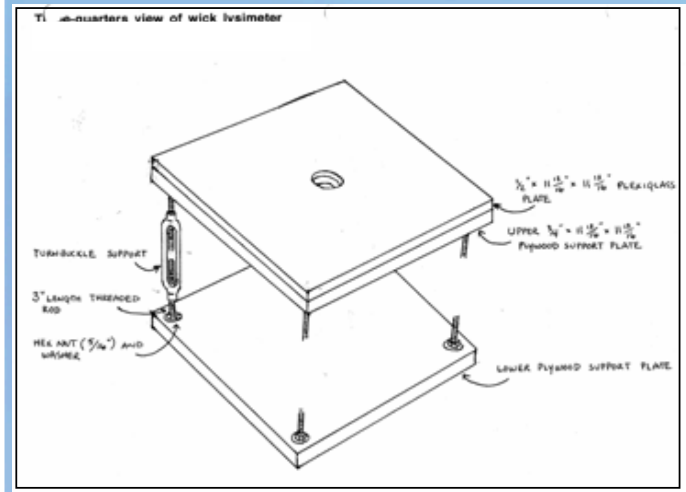
Used for water quality sampling and water balance measurements

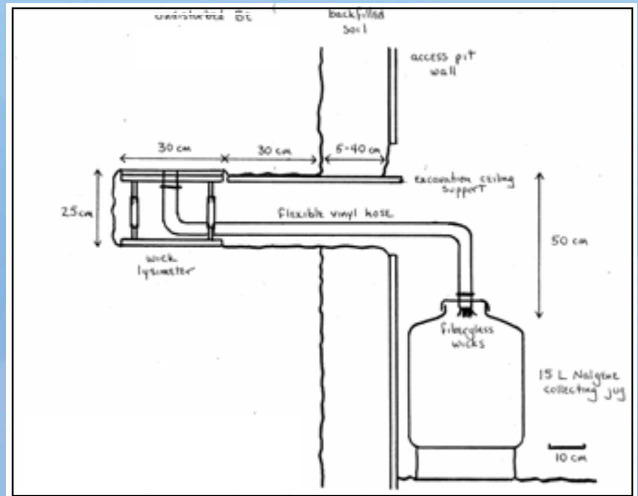
Drainage: Passive Wick Lysimeter - tension

Measures free water and matrix flow up to tension represented by height of wick

Can convert to depth (volume/ area of pan)

Used for water quality sampling and water balance measurements





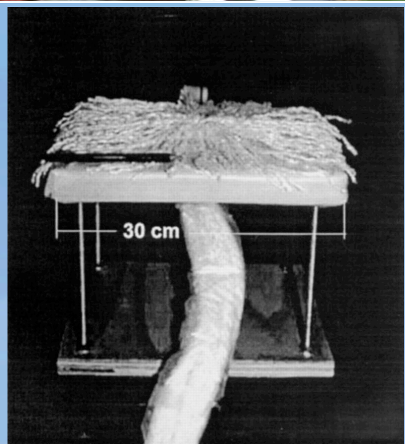
Courtesy of John Toth (2003)

Drainage – installing wick lysimeters




Drainage – installing wick lysimeter

Drainage: Installing wick lysimeter



Non-Pan Passive Wick Lysimeter

Affordable

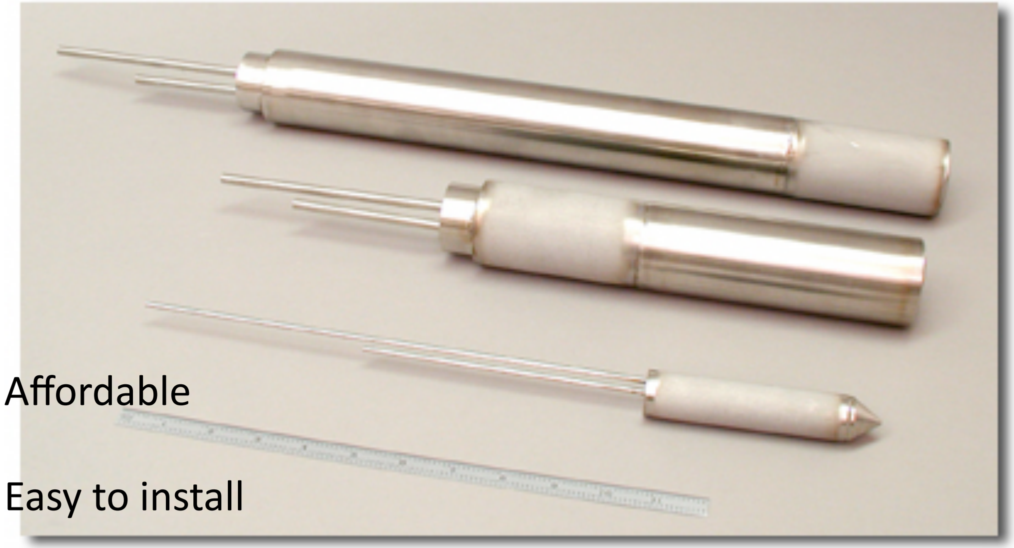
Easy to install

Measures free water and matrix flow up to tension represented by height of wick

Cannot convert to depth

Used for water quality sampling

Suction Lysimeter



Affordable

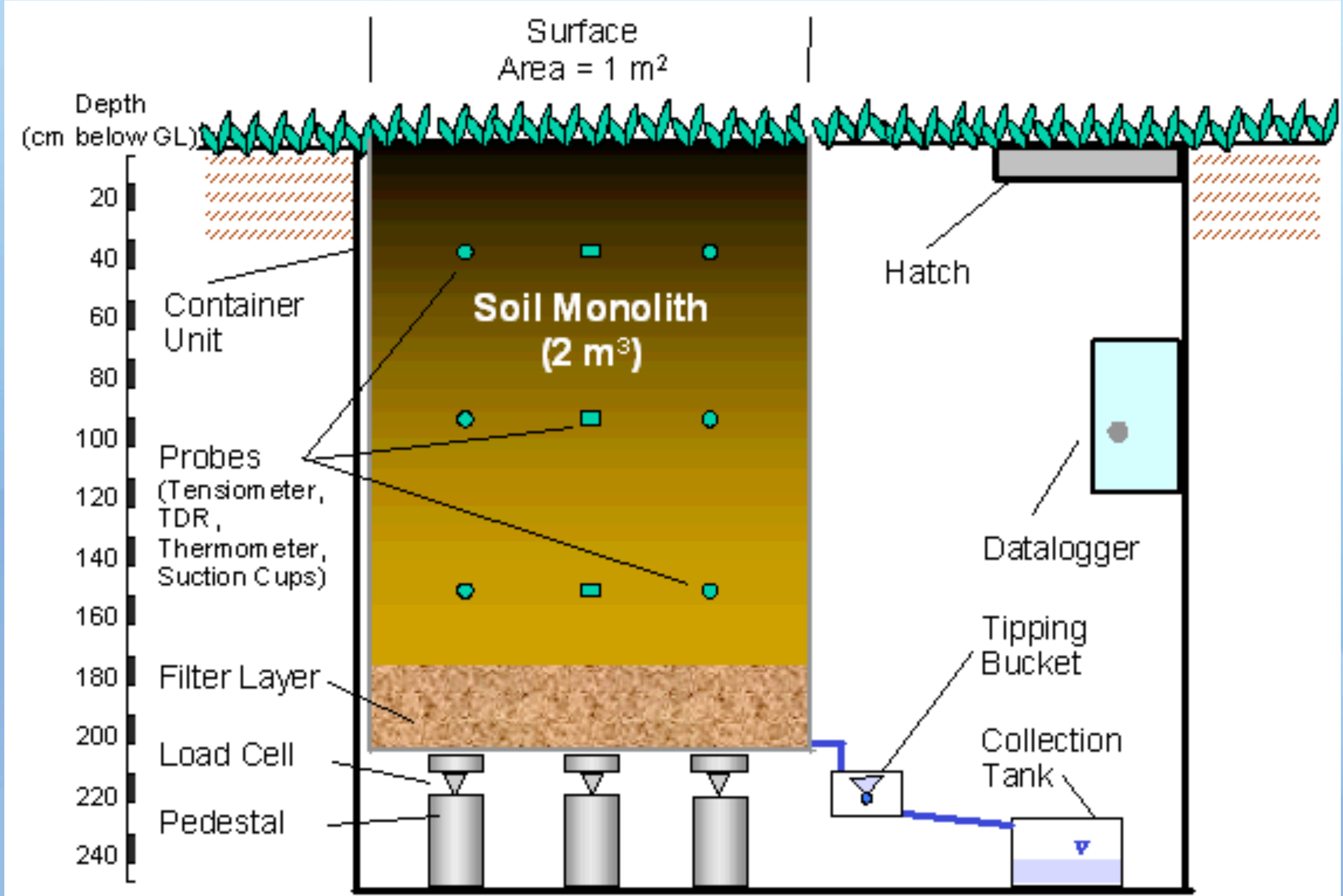
Easy to install

Measures free water and matrix flow up to tension represented by height of wick

Cannot convert to depth

Used for water quality sampling

ET: Weighing Monolith Lysimeter



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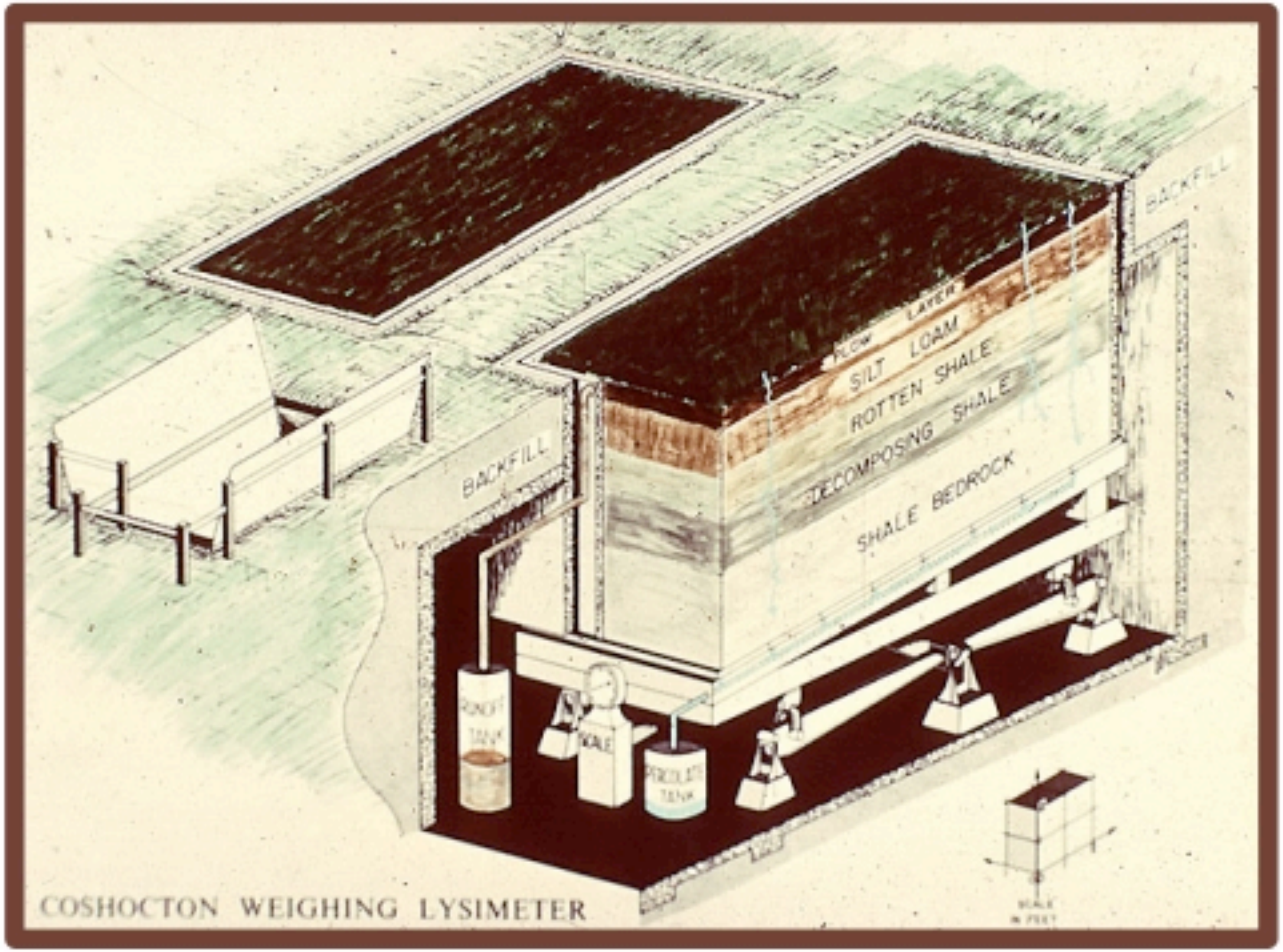

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Some large monolythic weighing lysimeters

Location	Area (m^2)	Depth (m)	Mass (Mg)	Soil type	Preserved vegetation
Coshocton, OH	8.1	2.1	59	Silt loam over rock	Sod
Dover, CO	7.3	1.2	22.7	Tight uniform silt	Prairie grass
Seattle, WA	10.8	1.2	28.9	Gravelling loamy sand	Douglas fir tree
Tucson, AZ	12.6	1.0	27.3	Fine gravelly sandy loam	Creosite bush
Bushland, TX	9.0	2.3	45.0	Clay loam	None
New South Wales, Australia	10.8	1.5	36.0	Topsoil over massive clay	Eucalypt
Richland, WA	2.25	1.7	6.0	Silty loam	Sagebrush and bunchgrass

Schneider and Howell. Large, monolythic, weighing lysimeters


SPEED
LIMIT
5

Gravimetric water content

$\Theta_m = M_w / M_d$

Θ_m = gravimetric water content (Mg Mg^{-1})
M_w = mass of water (Mg) lost on drying (usually 24 hrs at 105 ^oC)
M_d = mass of dry soil (Mg)

Standard method – all other methods are calibrated against this

For water balance calculations need *depth* or water lost

$\Theta_v = (M_w / \rho_w)/V_s$

Θ_v = Volumetric water content (m^3 m^{-3})
ρ_w = density of water (assumed to be 1.0 Mg m^{-3})
V_s = Volume of sample (m^{-3})

Volumetric water content

$\Theta_v = (\Theta_m/\rho_w) \times \rho_b = \Theta_m \times \rho_b$ (assuming density of water = 1.0 Mg m^{-3})

$\rho_b = M_d / V_s$ = dry bulk density of sample (Mg m^{-3})

Example

Θ_m = 0.14 Mg Mg^{-1}
P_b = 1.6 Mg m^{-3}
$\Theta_v = 0.14 \times 1.6 = 0.22$ m^3 m^{-3}

It is important that bulk density be determined on *same sample* as moisture content, b/c it is one of the *most spatially variable* soil properties

Calculation of water content of volume of soil

$W_{rz} = \Theta_{v1}\, d_1 + \Theta_{v2}\, d_2 + \Theta_{v3}\, d_3$

Θ_{vx} = Volumetric water content of layer *x* ($m^3\ m^{-3}$)

D_x = thickness of layer x (m)

How much water can a soil hold?

PAW = Plant Available Water = Water content at 'field capacity' – water content at 'wilting point'

Typical field capacity, wilting point, and PAW values (m^3 m^{-3}) for different soil textures

Soil texture	Field capacity	Wilting point	PAW
Coarse sand	0.06	0.02	0.04
Fine sand	0.10	0.04	0.06
Loamy sand	0.14	0.06	0.08
Sandy loam	0.20	0.08	0.12
Light sandy clay loam	0.23	0.10	0.13
Loam	0.27	0.12	0.15
Clay loam	0.28	0.13	0.15
Clay loam	0.32	0.14	0.18
Clay	0.40	0.25	0.15
Self-mulching clay	0.45	0.25	0.20

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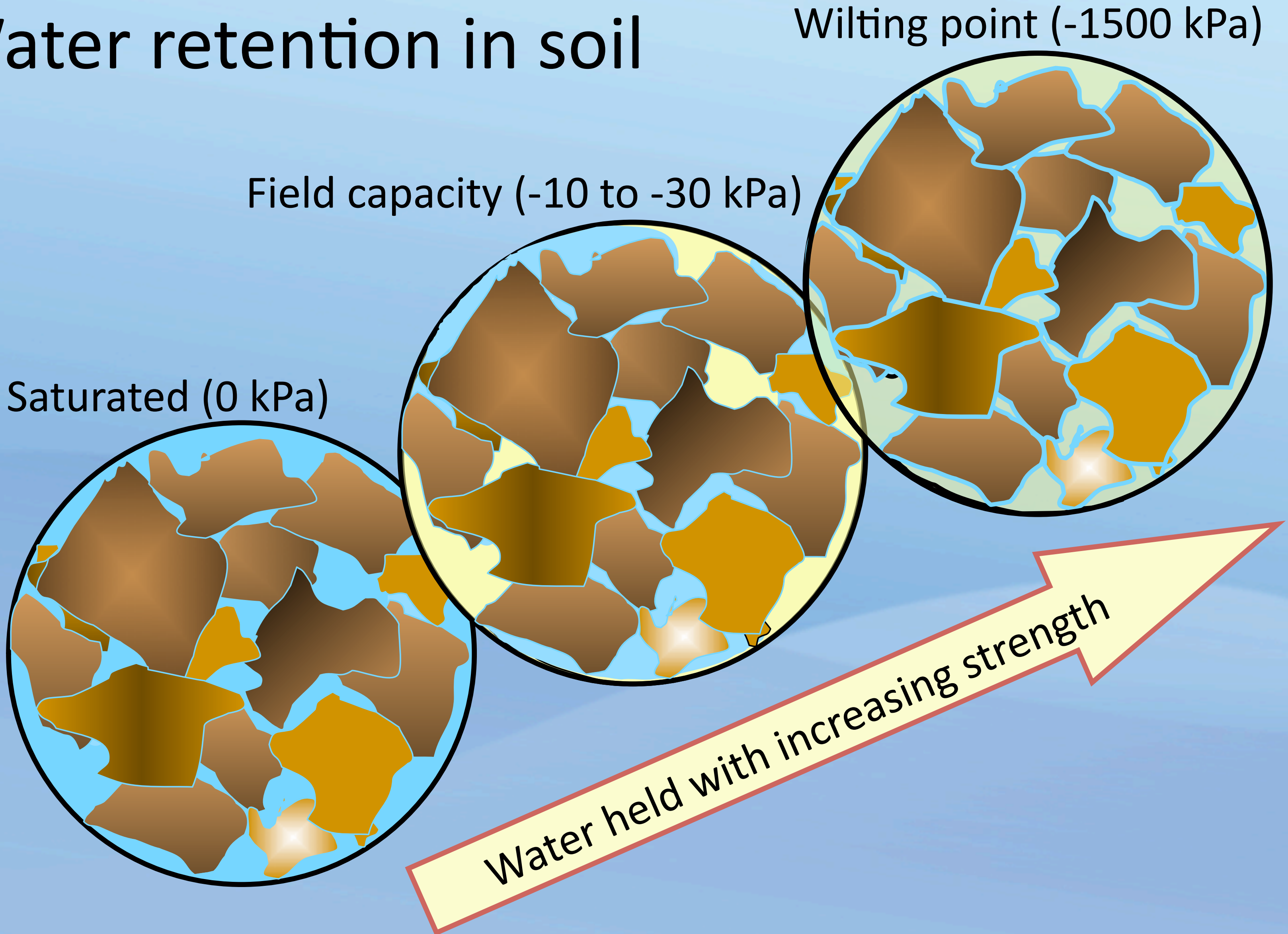
Water retention in soil



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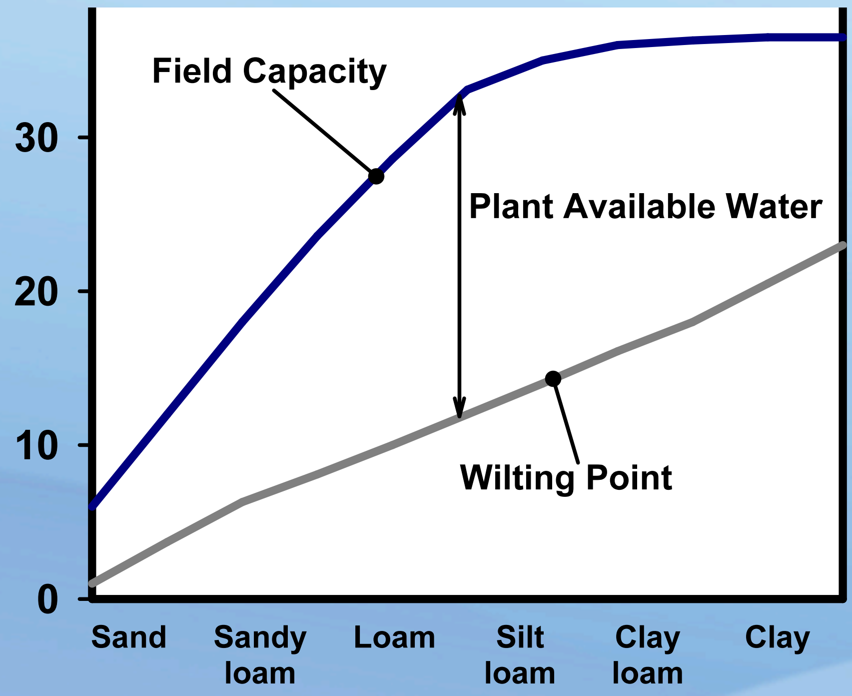
Plant available water



Unavailable water

From Brady and Weil. 1999. *The Nature and Properties of Soil*. Prentice Hall

Accuracy, precision, variability

Precision = *Variability of repeated measures in place (Standard Deviation) - measurement error*

Accuracy = *How close measured value is to actual water content*

Variability = *Real variability of water content in field*

Gravimetric moisture content: easily more accurate than 0.001 $Mg\ Mg^{-1}$

(accuracy of balance, water lost between sampling and weighing, inadequate drying time, reabsorption of water by sample)

Volumetric moisture content: easily more accurate than 0.01 $m^3\ m^{-3}$

(inexact trimming of sample, compression or dilation during sampling, errors in sampling volume)

Factors affecting field variation in soil moisture at different scales

< 1 m^2	0.1 ha	>10 ha
Gravel content Bulk density variation Water content variation Time since wetting Macropores/cracks Proximity to plant roots Microtopography (furrow, wheel track)	Landscape position Effects of ponding, runoff Proximity to irrigation Variation in soil texture Proximity to trees Type of plants	Aspect (N vs S facing) Soil type Soil substrate Land use (type of vegetation)

IAEA 2008. Field estimation of soil water content. Training Course Series 30

Surrogate measures used by different soil moisture sensors

Method	Measurement	Principle
Neutron moisture meter	Count of slow neutrons	Source releases fast neutrons, slowed down by collisions with H. Count of slow neutrons measure of Θ_v
Thermal sensors	Heat conductivity	Amount or rate of heat transmitted through soil affected by Θ_v
Time domain reflectometry	Travel time of electromagnetic pulse	Travel time of electromagnetic pulse along wave rods, is affected by bulk electrical permittivity of soil (BED). Θ_v affects BED.
Campbell FDR	Repetition time for a fast rise time electromagnetic pulse	Same as TDR
Capacitive sensors	Frequency of oscillating circuit	Oscillating current induced in circuit, part of capacitor arranged so that soil becomes part of dielectric field affecting electromagnetic field. Θ_v influences the frequency of oscillation to shift.
Conductivity sensors	Electrical conductivity of porous medium in contact with soil	Current between two electrodes in porous material is function of conductivity, a measure of soil water tension
Tensiometers	Matric and gravitational soil water components	Capillary forces retaining water in soil pores create negative pressure in water-filled tube connected to porous cup. This is a measure of soil water tension.

Characteristics of some types of soil water sensors

Technology	Sensed volume	Interferences
Neutron	30,000 cm^3 (wet soil) 28,000 cm^3 (dry soil)	Cl, B, Fe, C
TDR	Soil volume along probe rods, approx 10 mm to the side of plane of rods	Salt, EC, temperature
Capacitive, FDR	Highly variable – usually 20 mm from sensitive face or sensors	Salt, EC, clay type, clay%, temperature
Conductivity (e.g. gypsum)	Will equilibrate with small volume of soil (e.g. 500 cm^3 in wet, much smaller in dry soil)	Temperature, salts other than gypsum

Neutron Moisture Meter

Fast neutrons emitted from radioactive source (241Am/9Be) slowed down when they collide with particles having the same mass as a neutron (i.e., protons, H) building a “cloud” of “thermalized” (slowed-down) neutrons.

Since water is the main source of hydrogen in most soils, the density of slowed-down neutrons formed around the probe is nearly proportional to the volume fraction of water present in the soil.

Linear calibration of slow neutron count vs volumetric water content

Neutron Moisture Meter

Advantages	Disadvantages
Robust and accurate (±0.005 m^3m^{-3})	Safety hazard.
Little soil disturbance	Radioactive certification needed
Inexpensive per location	Requires soil-specific calibration
One probe allows for measuring at different soil depths	Heavy, cumbersome instrument
Large soil sensing volume (sphere of influence with 10-40 cm radius)	Takes relative long time for each reading
Not affected by salinity or air gaps	Readings close to the soil surface are difficult and not accurate
Stable soil-specific calibration	Manual readings; cannot be automated due to hazard
	Expensive to buy equipment

Dielectric Methods

Estimate soil water content by measuring the soil bulk permittivity (or dielectric constant), K*ab*,

K*ab* determines the velocity of an electromagnetic wave or pulse through the soil.

Dielectric constant of liquid water (K*aw* = 81) is much larger than that of the other soil constituents (e.g. K*as* = 2–5 for soil minerals and 1 for air).

Therefore, permittivity can be related to water content.

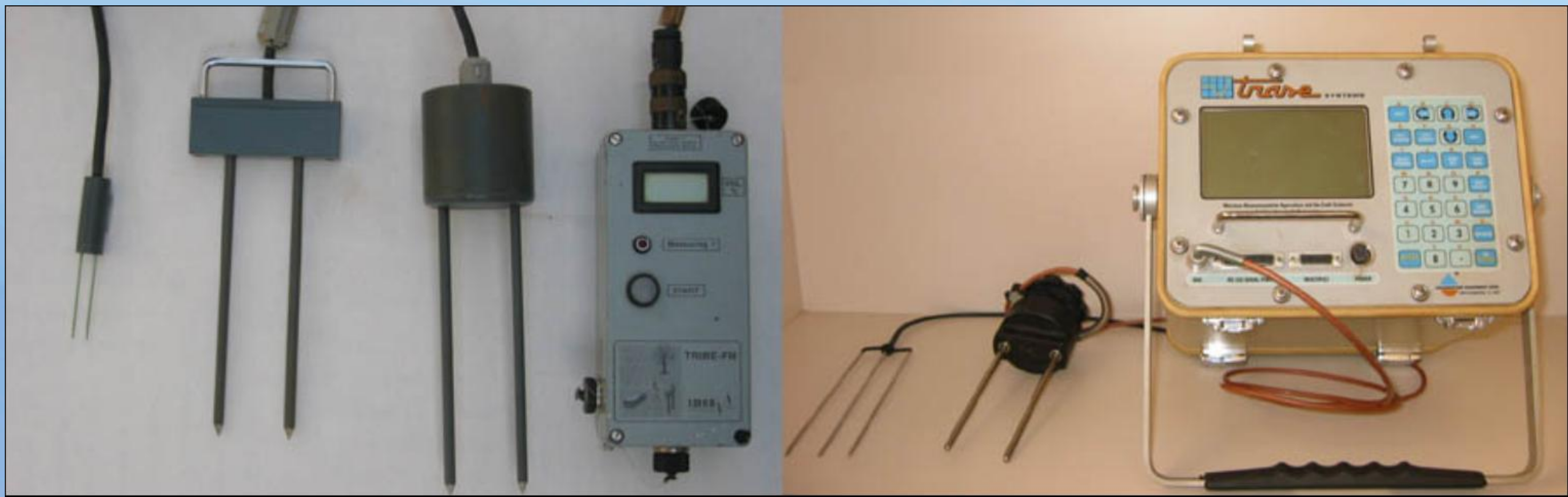
Dielectric Methods

Method	Principle
Time Domain Reflectometry	Time of electromagnetic signal to travel back and forth transmission line
Capacitance	Charge time of capacitor
Frequency Domain Reflectometry	Frequency of oscillation
Amplitude Domain Reflectometry	Amplitude of oscillation
Phase Transition	Sinusoidal wave shift
Time Domain Transmission	Time to travel trough transmission line

Dielectric methods

Advantages	Disadvantages
Easily automated	Equipment can be expensive due to complex electronics
Wide variety of probe configurations	Potentially limited applicability under highly saline conditions or in highly conductive heavy clay soils
Minimal soil disturbance except at installation (TDT/Phase Transition)	Soil-specific calibration
Relatively insensitive to normal salinity levels	Relatively small sensing volume (about 1.2 inch radius around length of waveguides)
Can provide simultaneous measurements of soil electrical conductivity/bulk density.	Sensitive to air pockets

Time Domain Reflectometer - TDR

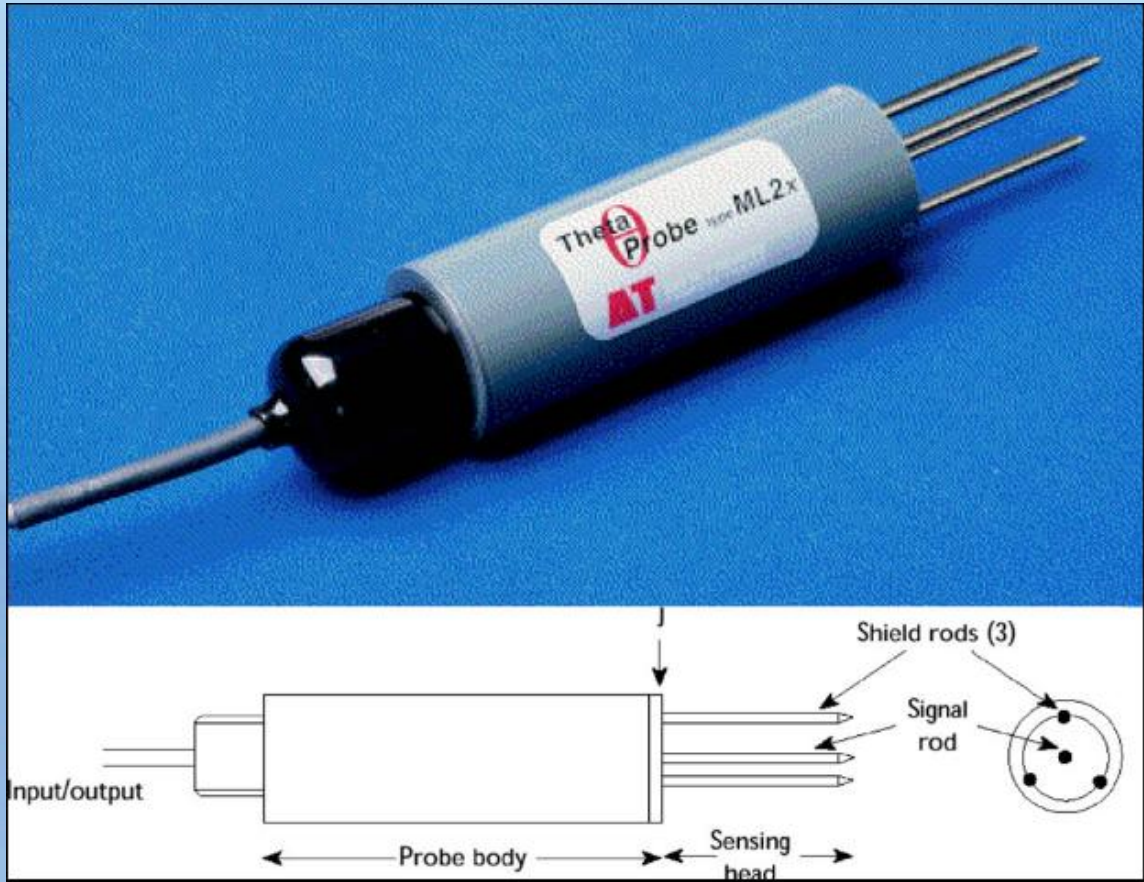


Time of electromagnetic signal to travel back and forth transmission line

Frequency Domain – Capacitance and FDR

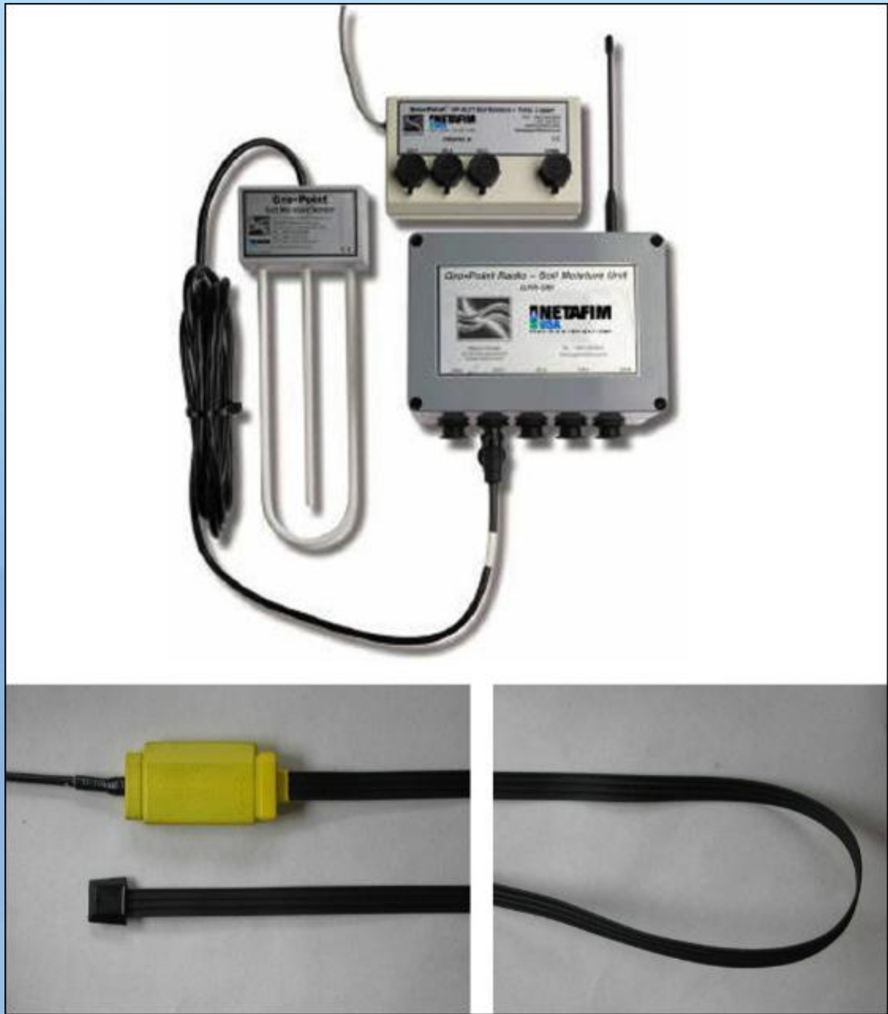
FD probes: a) Capacitance (plates imbibed in a silicon board);
b) Capacitance (rods); and c) FDR (rings). Charge time of capacitoror Frequency of oscillation

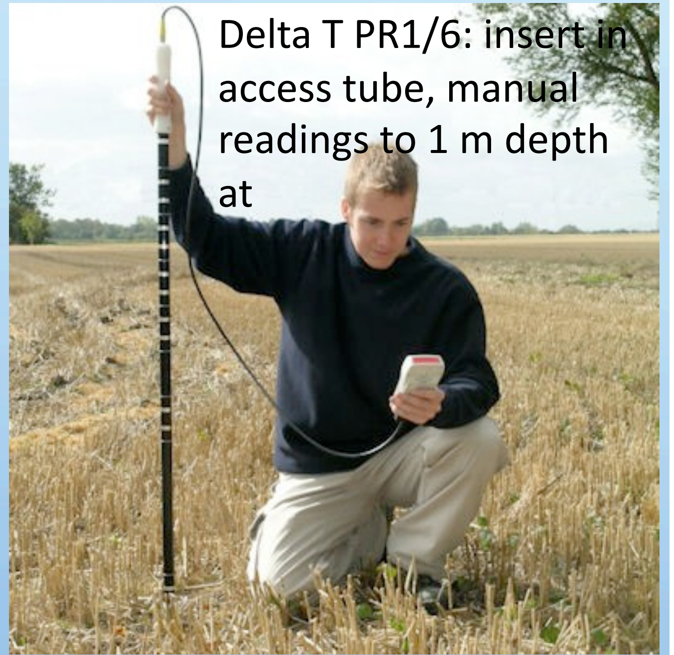
Amplitude Domain Reflectometry -ADR



Phase Transition

Time Domain Transmission



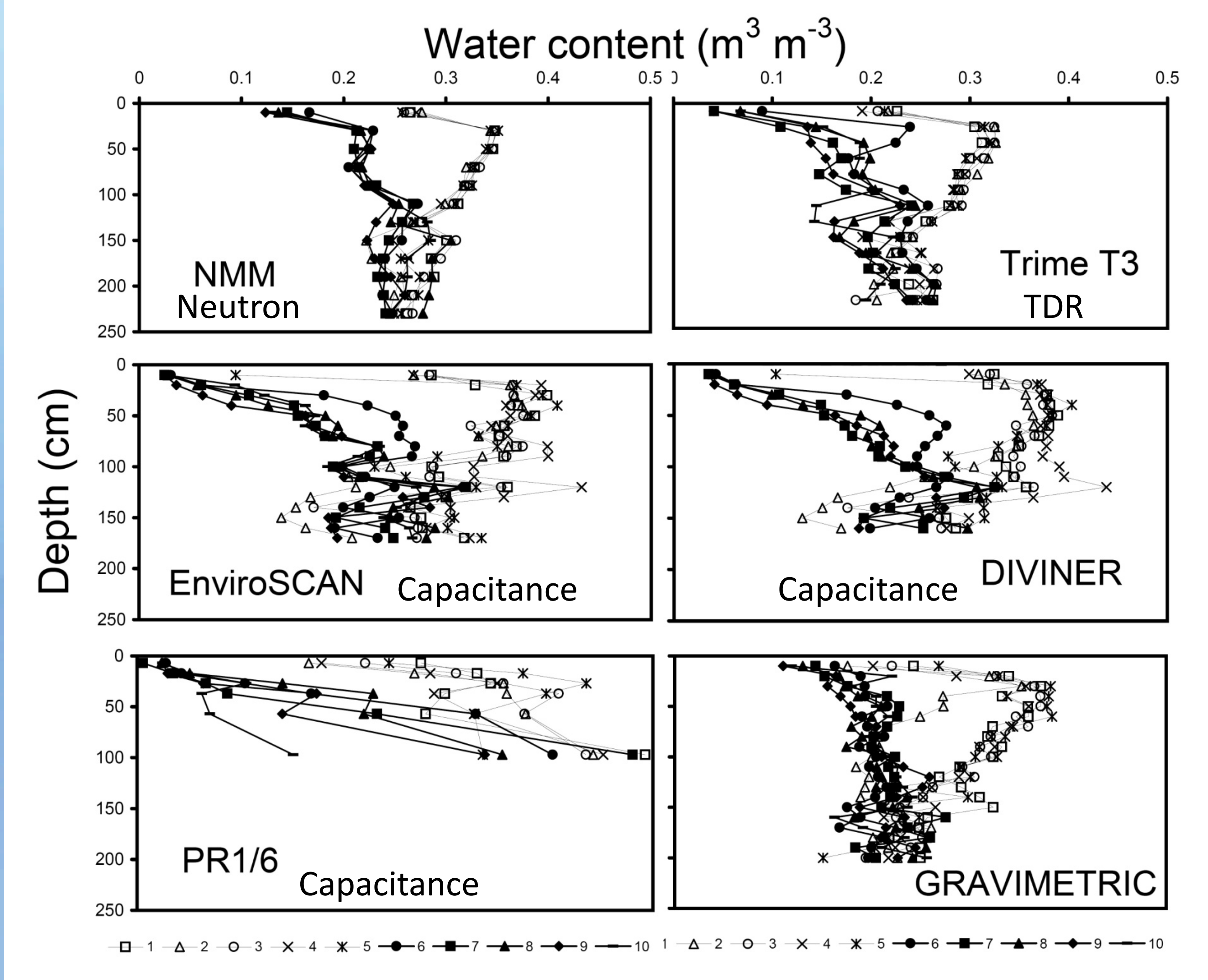


Delta T PR1/6: insert in access tube, manual readings to 1 m depth at

Sentek Diviner – insert in access tubes, manual readings, 10 cm intervals as sensor is pulled out of tube

Enviroscan: insert in access tube, automated, unattended

Trime FM3 : lower sensor in tube, take reading (manually at each desired depth)



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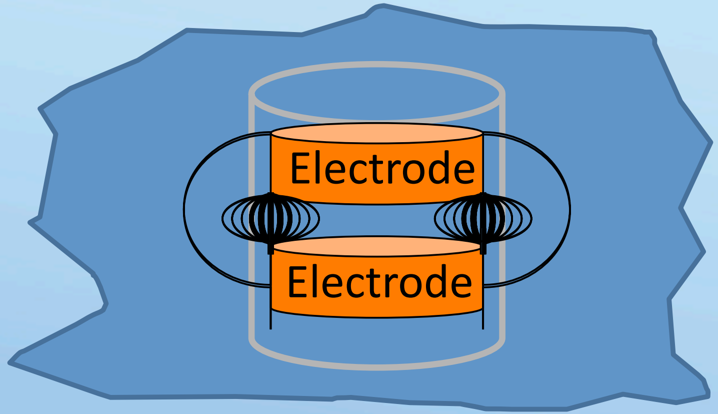
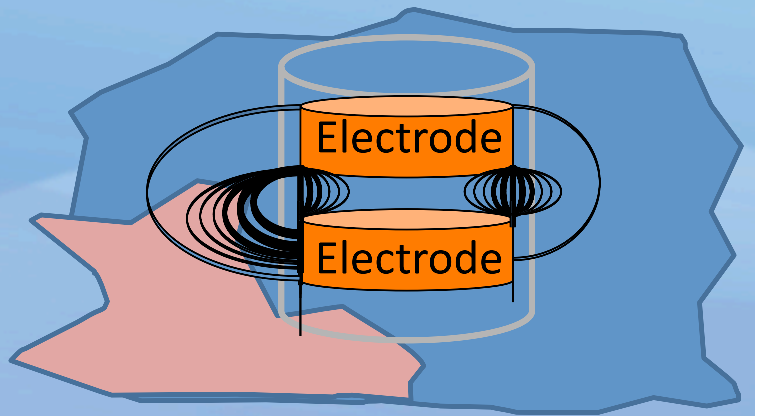
Evett et al. (2009)

EM Field Geometry



- Field in uniform medium – uniform geometry:
- Field in medium with more conductive (wetter) ped – *geometry changed*:



Evett et al. (2009)

Disadvantages of small measurement volume of equipment measuring permittivity

Evett et al. (2009)

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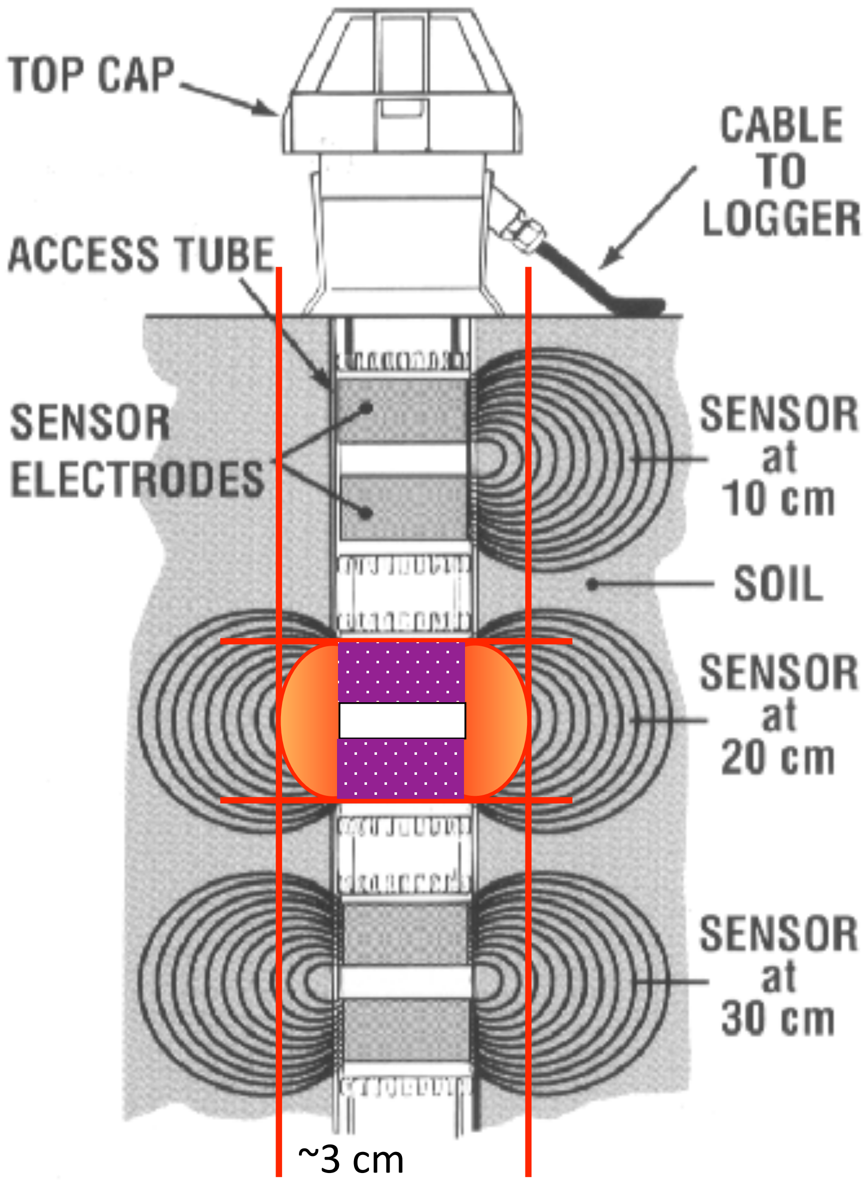
EnviroSCAN Probe Design



Need for field calibration

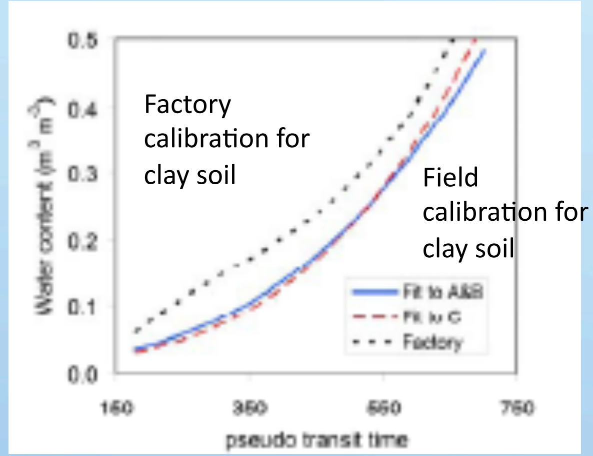
Factory calibration performed in

- Repacked, uniform soil,
- Uniform water content and temperature,
- No macropores
- Small clay content
- Low bulk electrical conductivity

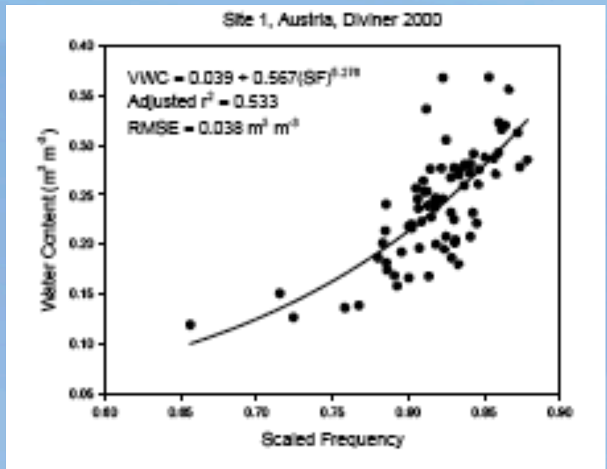
Factory calibration represent the best that can be expected from a given sensor

Calibration

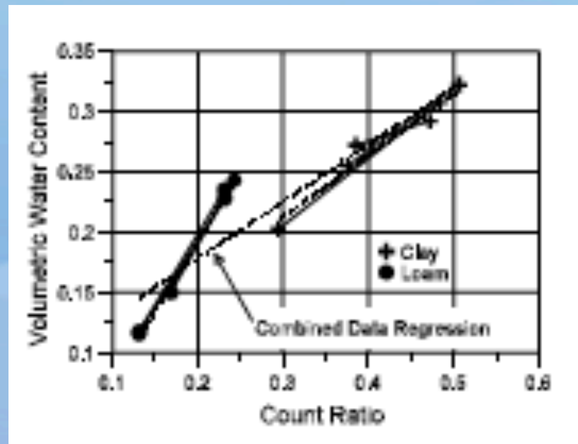
All equipment measuring surrogate properties needs to be calibrated
Factory calibrations are not sufficient
Calibration needs to be done in the field soil
Calibration needs to be done separately for each soil horizon



Capacitance Probe Calibration



Capacitance Probe Calibration



Neutron Moisture Meter Calibration

Evett et al., 2008

Calibration

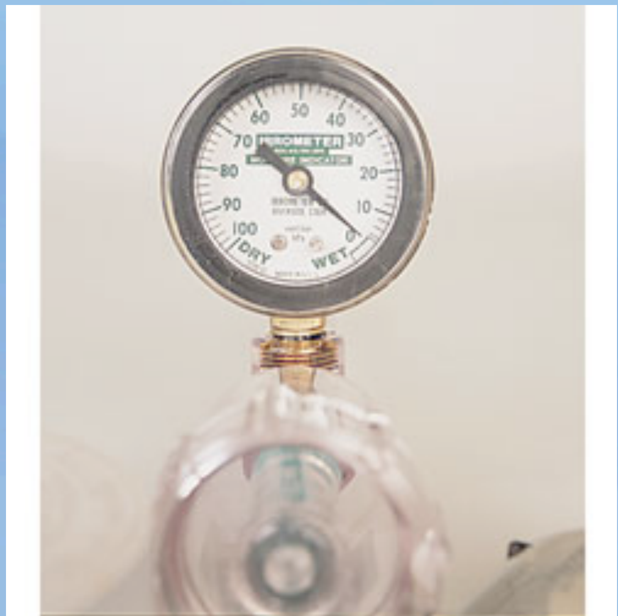
NMM has linear regression between count ratio and volumetric moisture content, so only dry and wet end calibration is needed

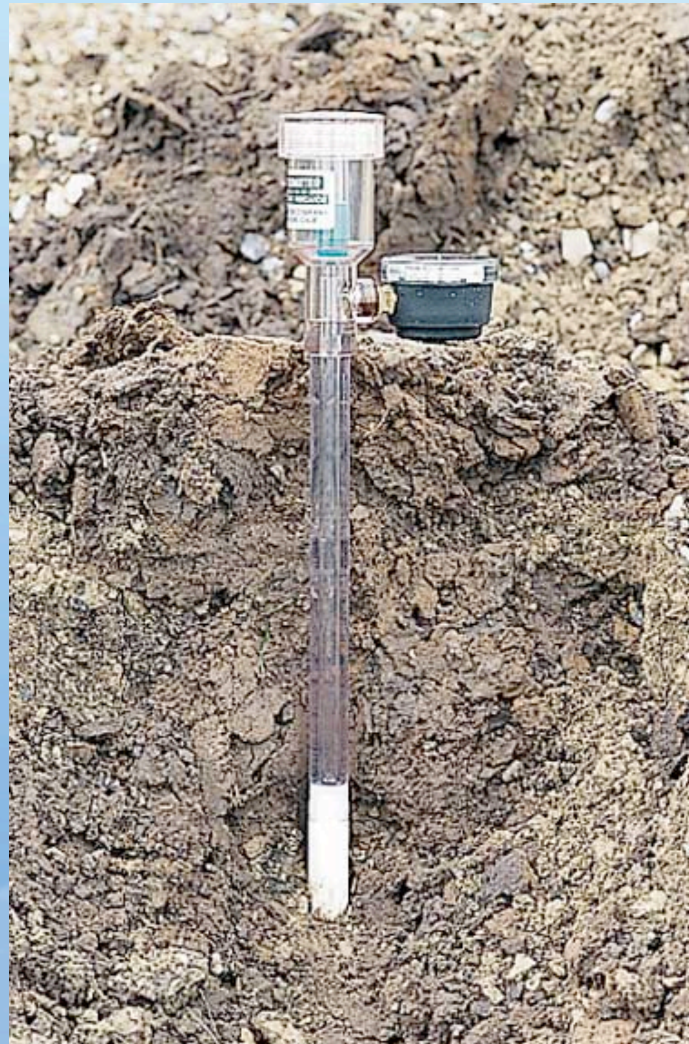
Select representative site, install 6 tubes – 3 in dry area, 3 in wet area (may need to build dikes and saturate entire root zone) – let drain to field capacity

TDR, capacitance, etc don't have a linear correlation so intermediate water content is needed.

Tensiometers

Measures matric + gravitational potential in soil
Degassed (boiled 10 min) water in tube – moves out ceramic cup when soil dries, water moves in when soil wets up – suction is shown on gauge





Info from Heng and Evett, 2008

Tensiometers

$\Psi_T = \Psi_m + \Psi_p + \Psi_o + \Psi_z$

where

Ψ_T = Total soil water potential
Ψ_m = Matric potential
Ψ_p = Pressure potential
Ψ_o = Osmotic potential
Ψ_z = Gravitational potential

Tensiometers do not measure Ψ_o - so overestimate PAW in saline or sodic soils

Small range 0 to -75 kPa (-0.75 bar) - 90% of PAW range of coarse, but only 30% of PAW range of silt loam - clay soils
Only work to -1.2 m depth
Need time to equilibrate in heavy soils
Not suited for cracking or very coarse soils
Regular maintenance needed

Electrical Resistance Sensors

Measures how well current is conducted – measure of soil water tension
Pair of electrodes embedded in porous body made of gypsum or saturated with gypsum

Each block must be calibrated – use pressure plate chamber

Gypsum block: Range -150 to -600 kPa (1.5-6 bar)
Granular matrix sensor: Range -10 to -150 kPa
Gypsum dissolves – changes calibration
GMS lasts longer
Gypsum block adapted to finer textured soils, and GMS to coarser soils.
Easily automated
Subject to hysterisis – not suited to measure water content

Conclusions

Many methods to measure components of the water balance have been developed

Selecting the appropriate method depends on objectives, resources available, and accuracy desired

Salesmen are overstating the capabilities of equipment

Much effort and energy can be wasted by not properly selecting and calibrating measurement equipment

References

- S.R. Evett, L.K. Heng, P. Moutonnet and M.L. Nguyen (eds.). 2008. Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation, and Sensor Technology. IAEA-TCS-30. International Atomic Energy Agency, Vienna, Austria. ISSN 1018–5518. Available at http://www-pub.iaea.org/mtcd/publications/PubDetails.asp?pubId=7801