Soil Water Measurement: Static and Dynamic Views

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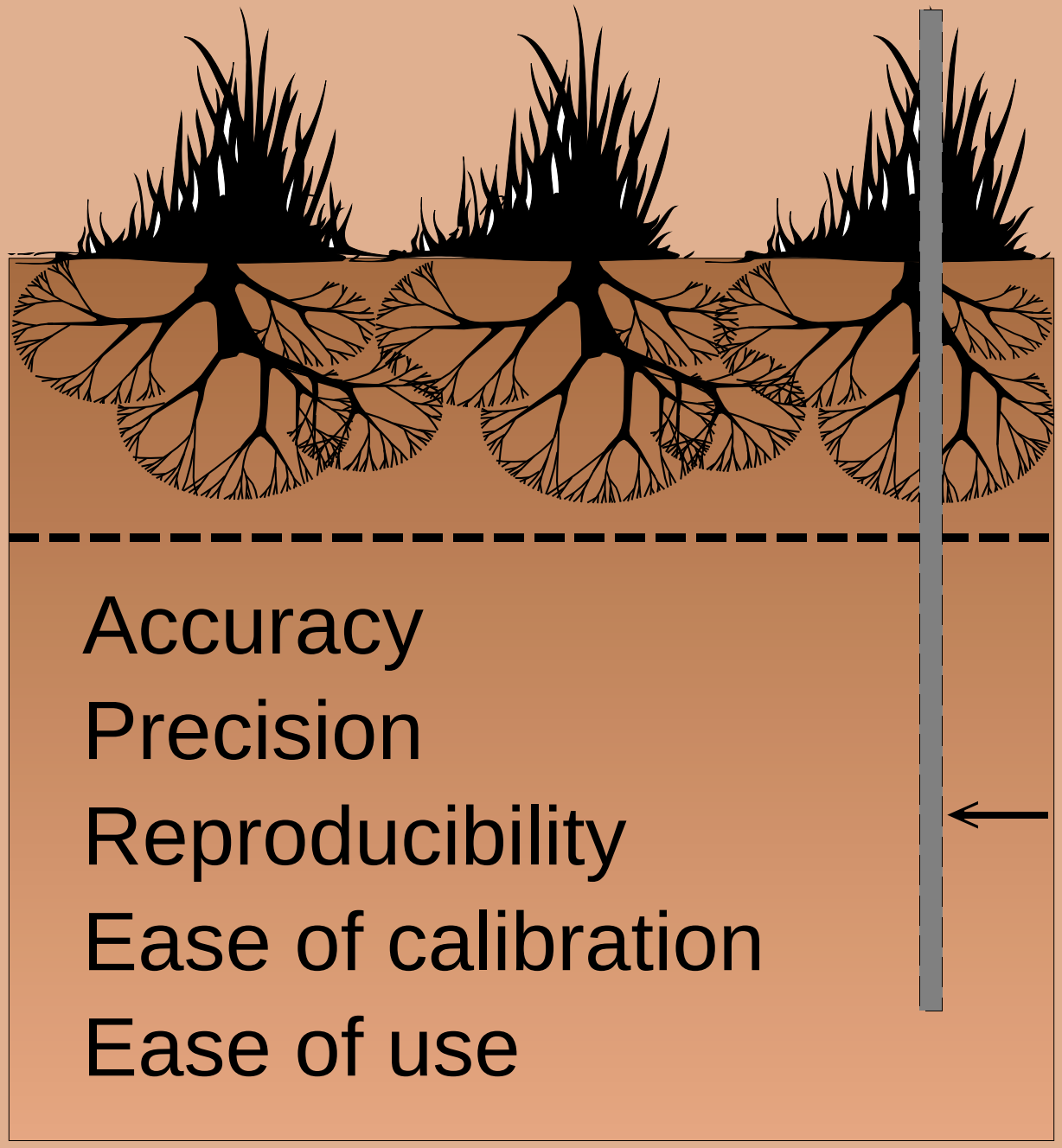
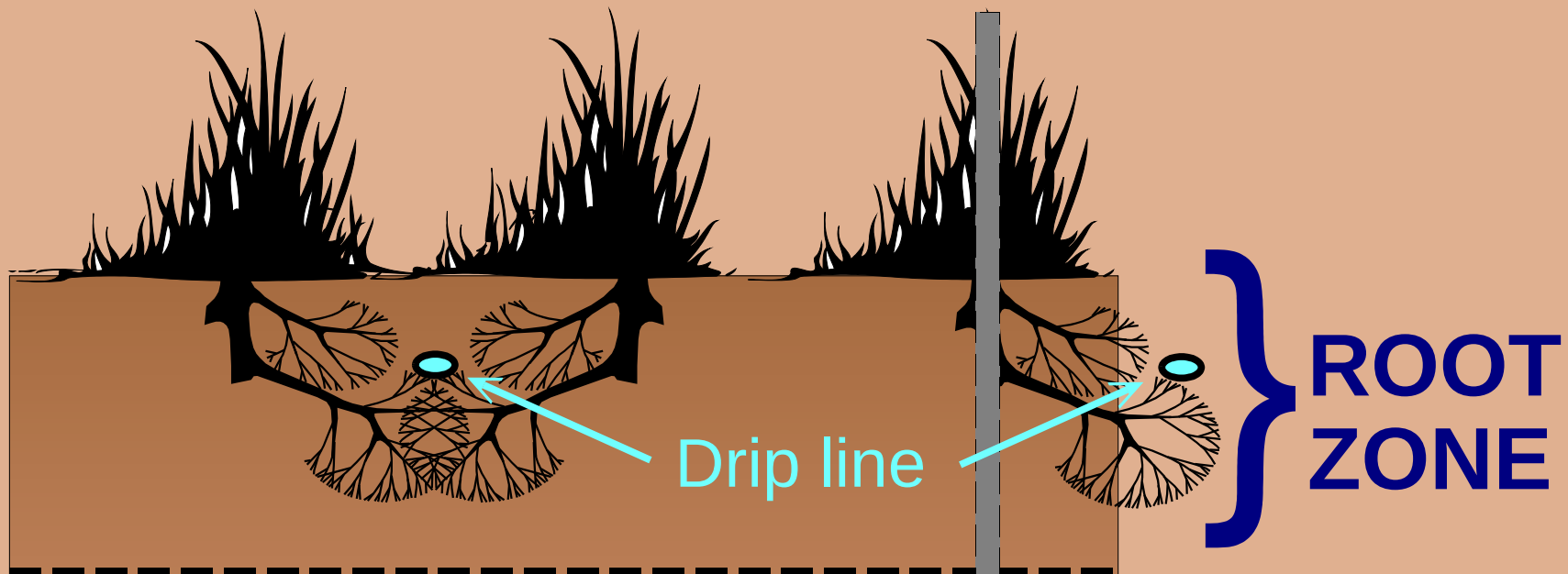
“A correct irrigation schedule requires that the amount of water (in the soil) and its use rate be known”. (Gear et al., 1977)

To schedule irrigation using soil moisture measurements, one must:

1. **Select a site for measurement**
2. **Choose a device for measurement**
3. **Set full and refill points for the soil**
4. **Establish some record keeping in order to**
   - **a. Know when irrigation will be needed.**
   - **b. Know when over-irrigation has occurred.**

(Campbell and Campbell, 1982)


ROOT ZONE
Accuracy
Precision
Reproducibility
Ease of calibration
Ease of use
Access tube for soil water measurement



Volume measured

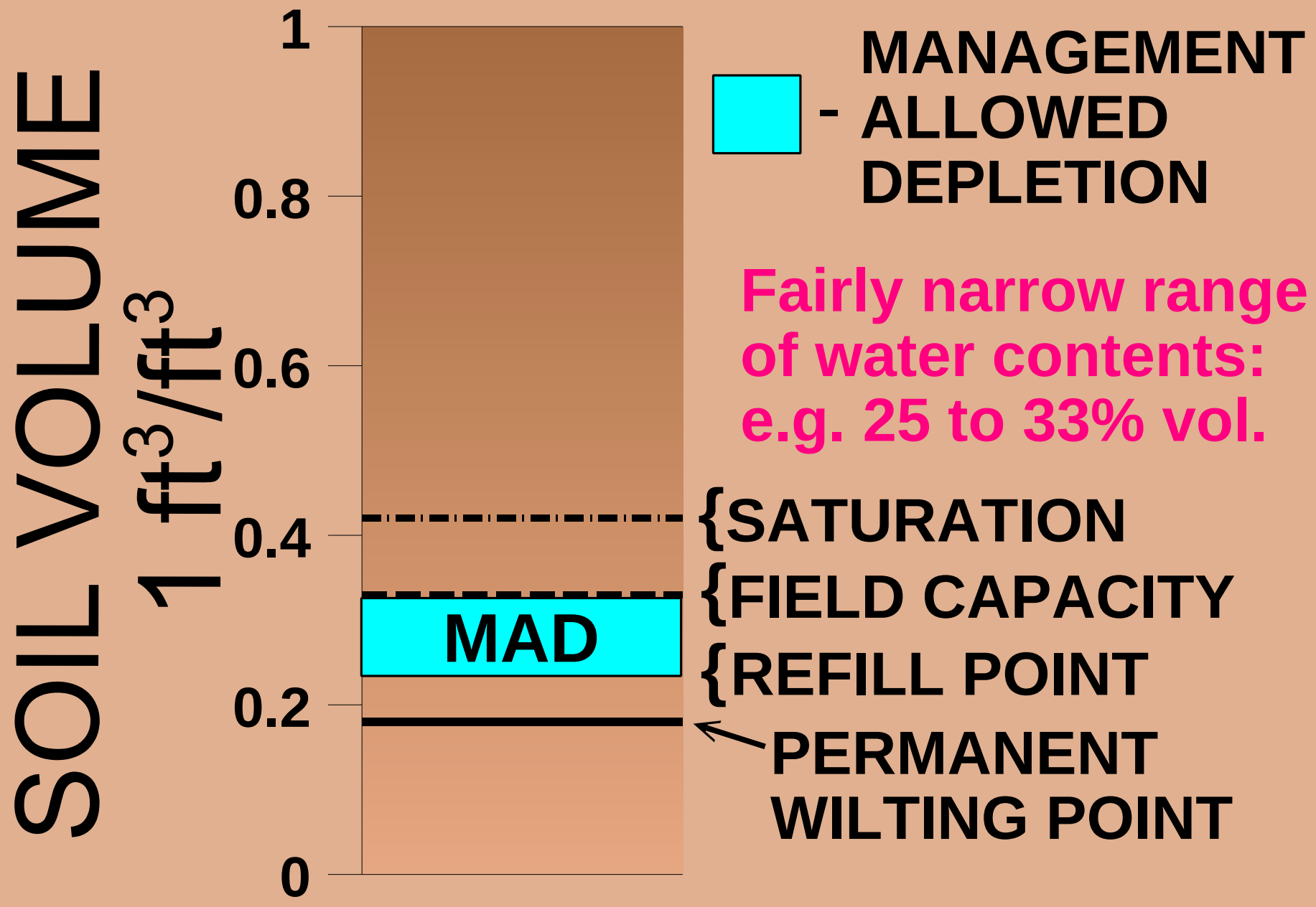
Adaptability/Automation

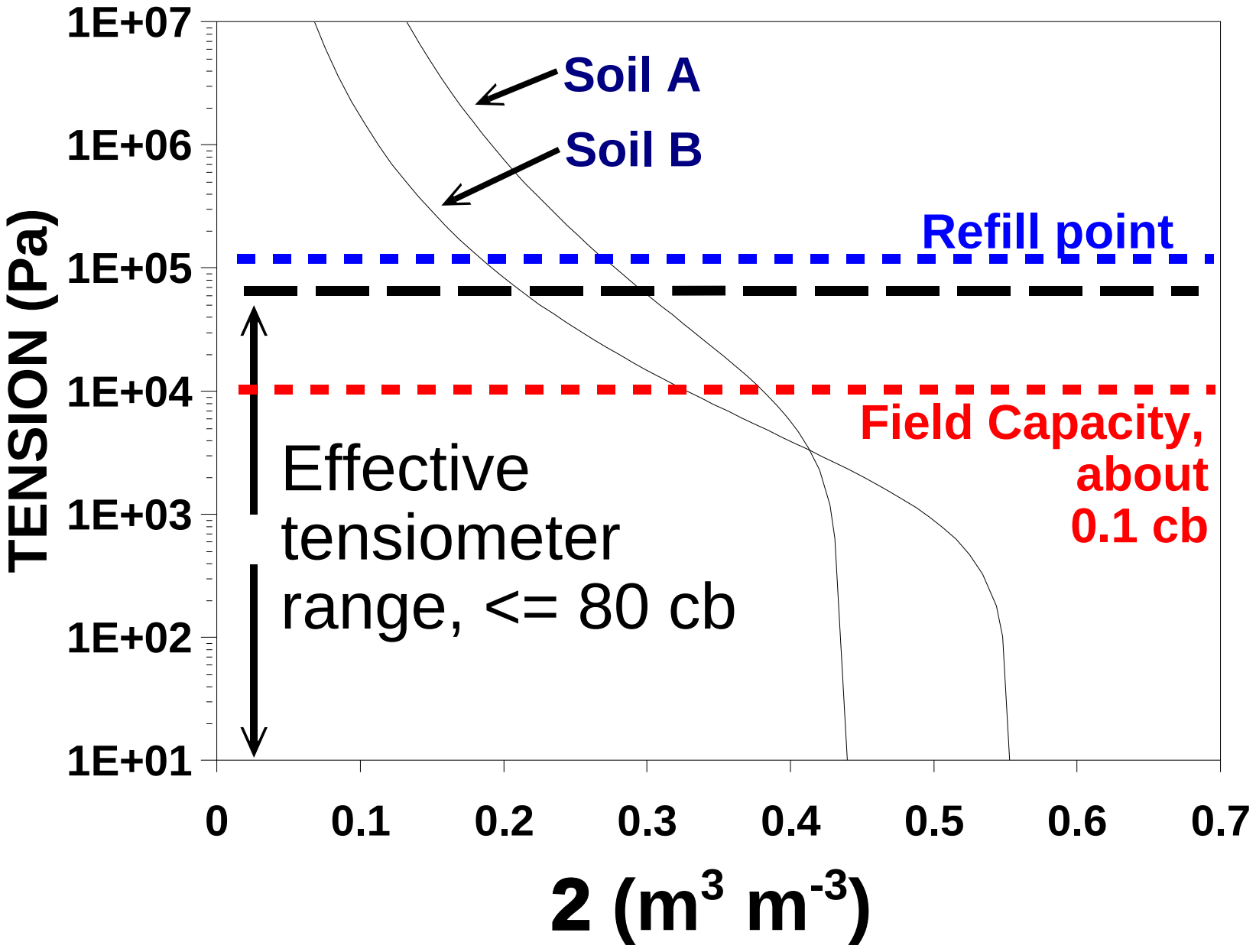
Cost - initial & per unit

Interferences

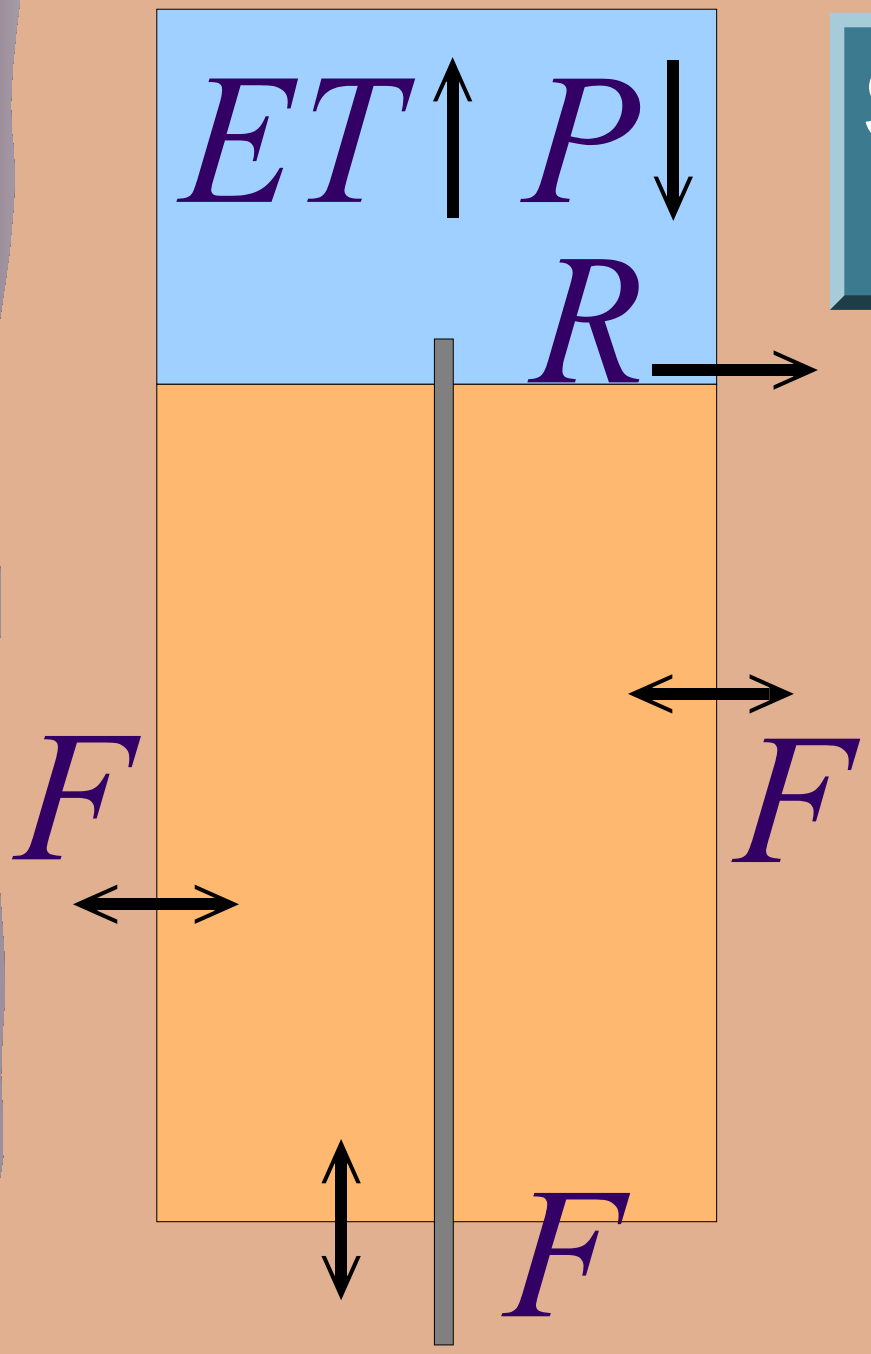
Labor requirement

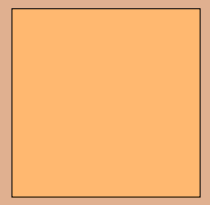
Access tube for soil water measurement


SOIL VOLUME
1 ft3/ft3
1
0.8
0.6
0.4
0.2
0
MAD
- MANAGEMENT ALLOWED DEPLETION
Fairly narrow range of water contents: e.g. 25 to 33% vol.
{SATURATION
{FIELD CAPACITY
{REFILL POINT
PERMANENT WILTING POINT


1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
TENSION (Pa)
Soil A
Soil B
Refill point
Field Capacity, about 0.1 cb
Effective tensiometer range, <= 80 cb
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2 (m3 m-3)

Soil Water Balance: Component Fluxes





= Control Volume

ΔS

Water Balance Errors, ET Centric

$$ET = \Delta S - P + R - F + \varepsilon_T$$

$$\varepsilon_T = \varepsilon(\Delta S, P, R, F)$$

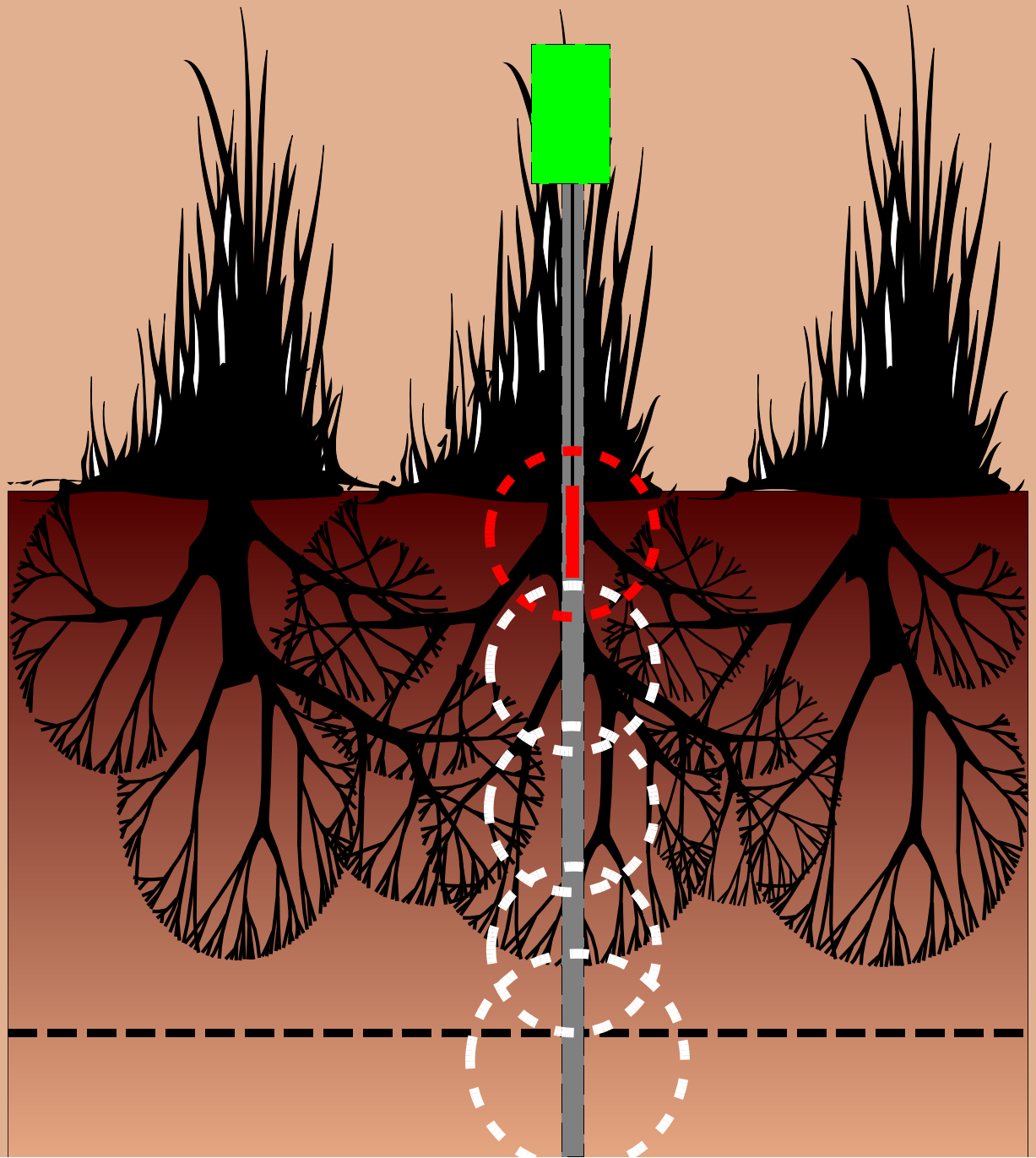
- **)** *S* – calibration curve errors (except intercept)
- *P* – rain gauge errors & spatial variability
- *R* – often uncontrolled/not measured
- *F* – often uncontrolled, difficult to estimate, related to depth of measurements

Water Balance Errors, Soil Water Centric

$$\Delta S = ET + P - R + F + \varepsilon_T$$

$$\varepsilon_{\Delta S} = \varepsilon(ET, P, R, F)$$

- ET – errors in weather data, ref. ET & Kc values
- *P* – rain gauge errors & spatial variability
- *R* – often uncontrolled/not measured
- *F* – often uncontrolled, difficult to estimate, related to depth of measurements



NEUTRON MOISTURE METER

ROOT ZONE

NEUTRON PROBE, Advantages

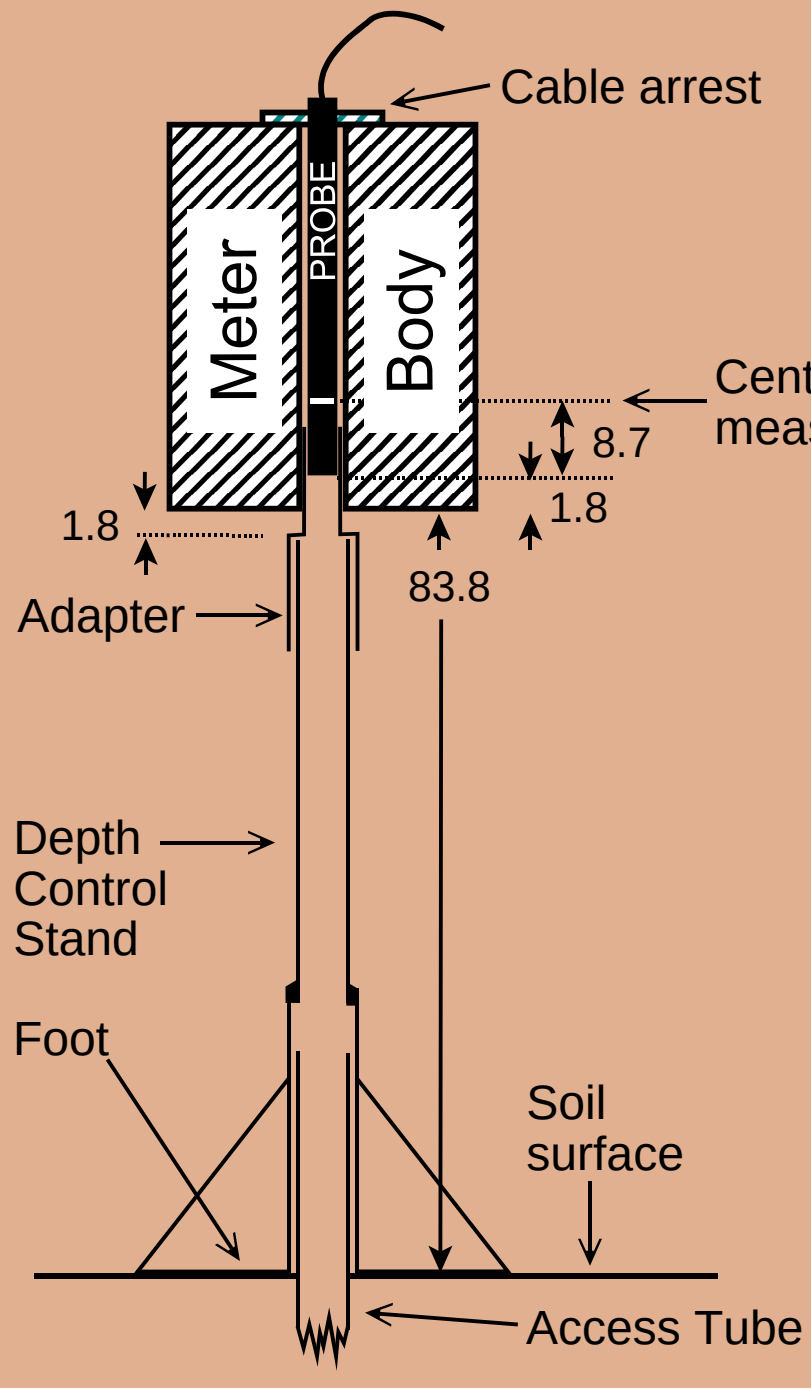
- A standard second only to gravimetric.
- Very accurate when calibrated (< 1% error).
- Covers root zones of any depth.
- Relatively simple, easy, and rapid.
- Safe.
- Nondestructive.
- Easy to use results in scheduling.

NEUTRON PROBE, Disadvantages

- Regulatory burden is considerable.
- Requires training for licensee and users.
- Requires doubly locked storage.
- Cannot be used or left unattended.
- Calibration is essential.

CPN model 503DR NMM on a depth control stand to elevate the NMM above the soil surface.

The stand fits over the top of the access tube.

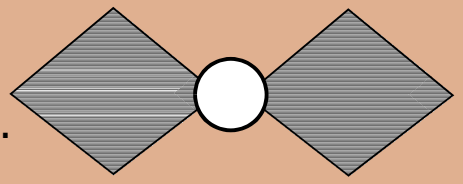


The depth control stand is 81.2-cm tall. The adapter is 7.6 - 7.1 = 0.5 cm thick above the top of the stand. There is 1.8 cm of space between the top of the adapter and the bottom of the meter.

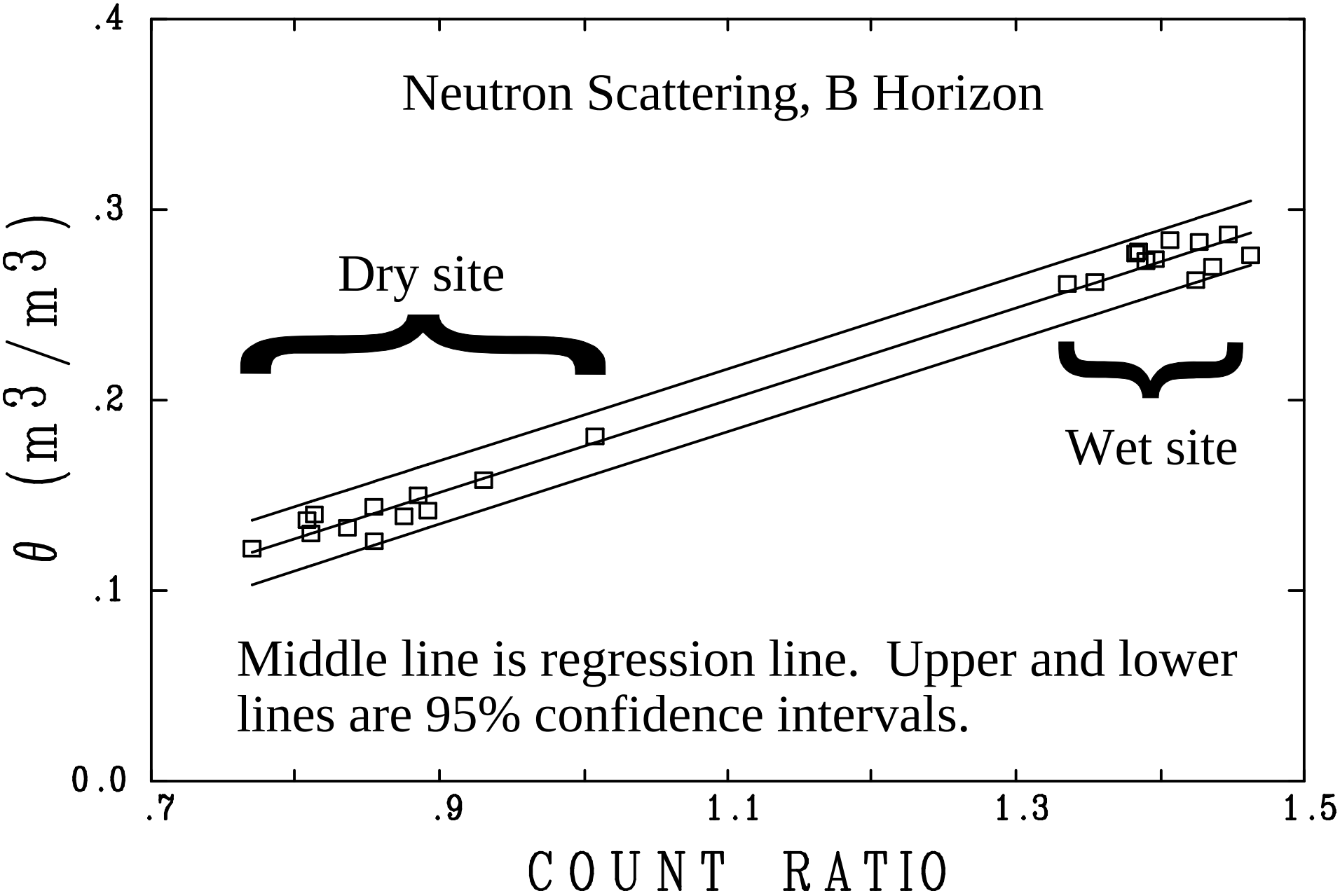
Dimensions in cm.
Drawing not to scale.

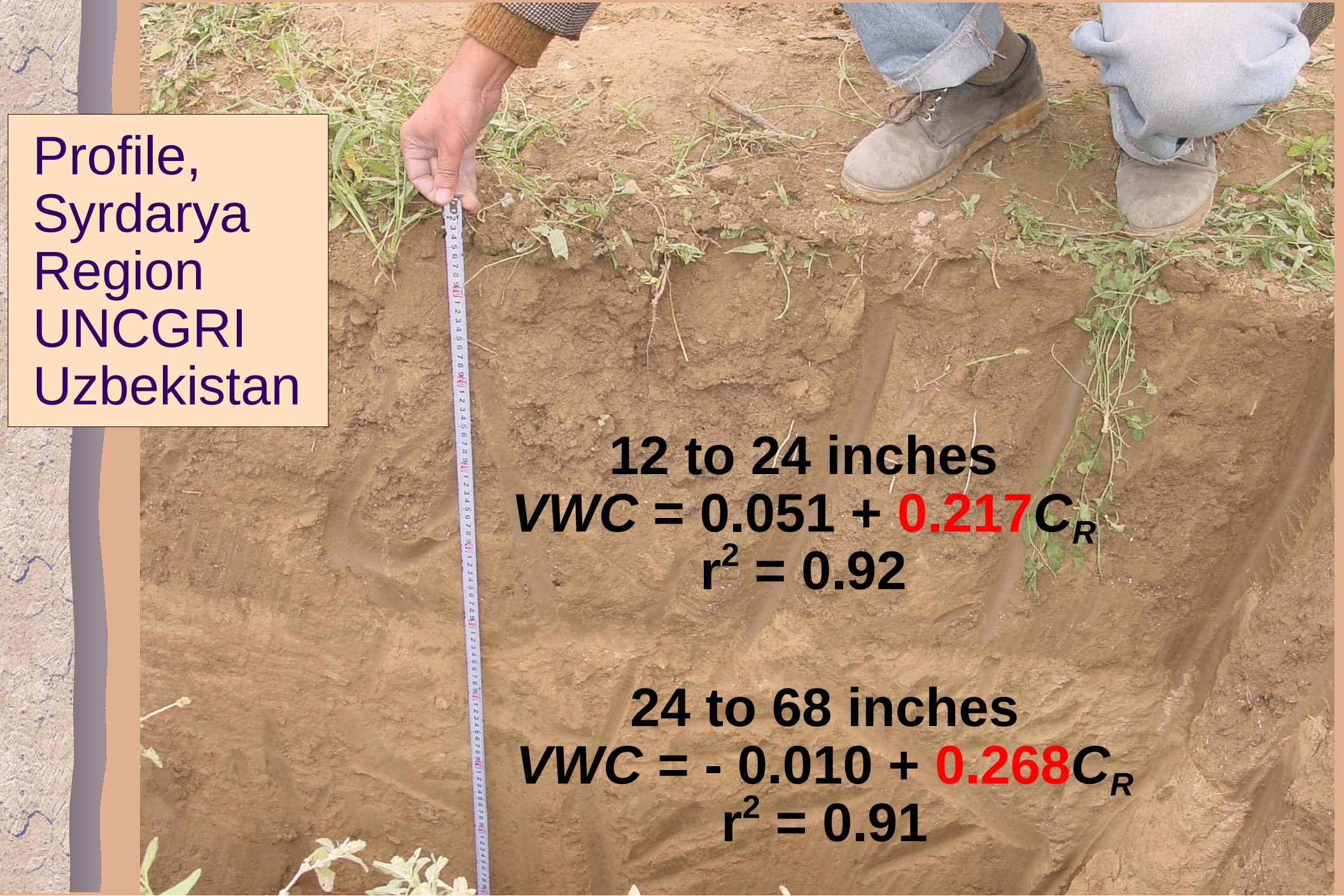
The bottom of the meter is 81.2 + 0.5 + 1.8 = 83.5 cm above the soil surface. The center of measurement is 8.7 + 1.8 = 10.5 cm above the bottom of the meter when the probe is locked in the shield; and it is >90 cm above the soil surface. To place the center of measurement at 10-cm depth, place a stop on the cable at 83.5 + 10.5 + 10 = 104.0 cm above the cable arrest at the top of the meter.

Bottom view of stand showing narrow foot for close plant spacing. In practice the points are rounded.



Wet site, Syrdarya Region UNCGRI Uzbekistan

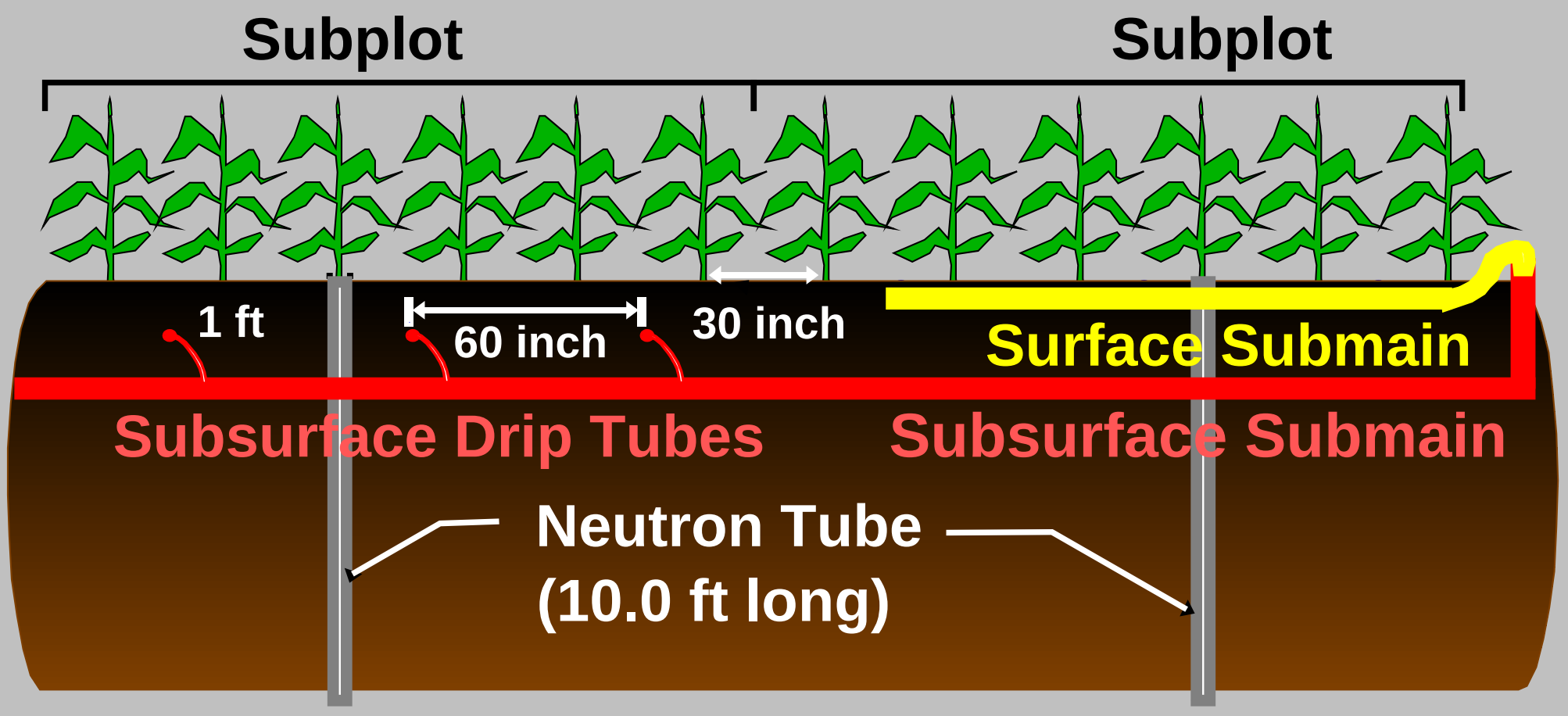

Neutron Scattering, B Horizon
Dry site
Wet site
Middle line is regression line. Upper and lower lines are 95% confidence intervals.
θ (m3/m3)
.4
.3
.2
.1
0.0
.7
.9
1.1
1.3
1.5
COUNT RATIO


Profile,
Syrdarya
Region
UNCGRI
Uzbekistan
12 to 24 inches
$VWC = 0.051 + 0.217C_R$
$r^2 = 0.92$
24 to 68 inches
$VWC = -0.010 + 0.268C_R$
$r^2 = 0.91$

Calibration in an Amarillo fine sandy loam using a depth control stand, four samples per depth at each tube, three tubes in the dry site and three in the wet site.

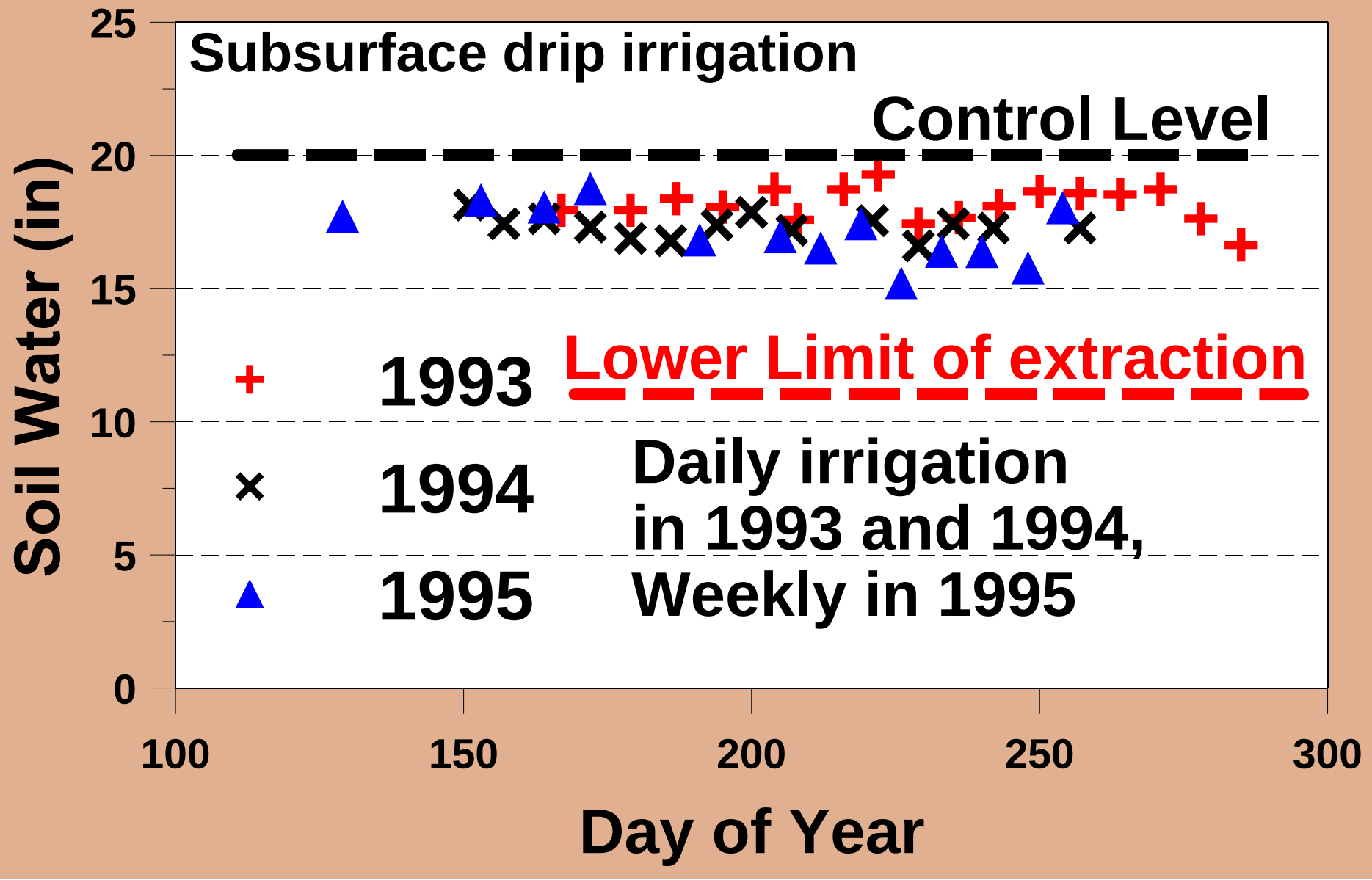
Depth (cm)	Regression Equation	RMSE $m^3\ m^{-3}$	r^2	N
10	$\theta_v = 0.014 + 0.217 C_R$	0.004	0.997	6
30 – 190	$\theta_v = -0.063 + 0.237 C_R$	0.007	0.988	44
30 – 90	$\theta_v = -0.066 + 0.242 C_R$	0.008	0.988	24
110 – 190	$\theta_v = -0.057 + 0.230 C_R$	0.006	0.992	20

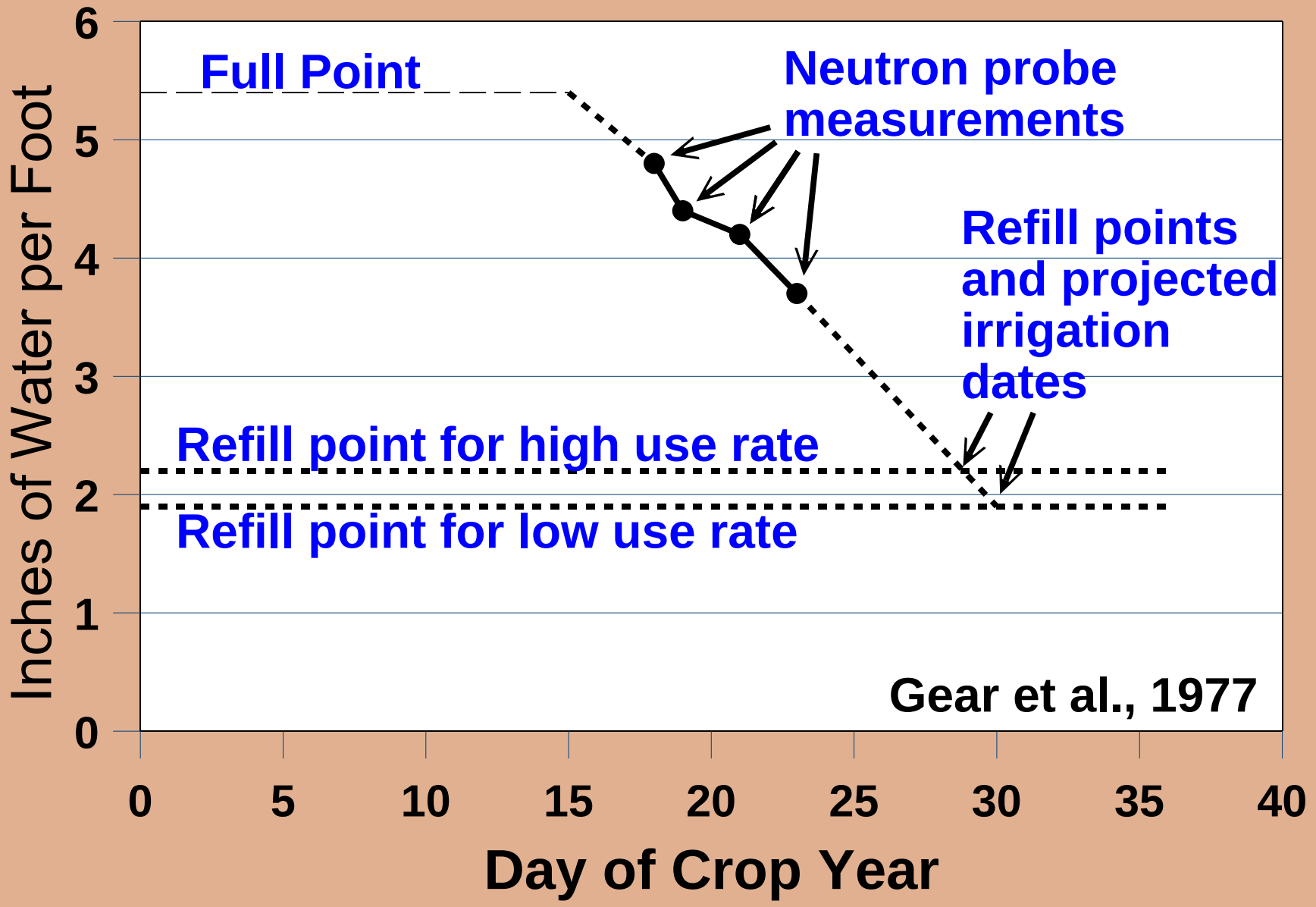
Drip Irrigation Systems



NOT TO SCALE

Soil Water — 5 ft Profile, weekly




Full Point
Neutron probe measurements
Refill points and projected irrigation dates
Refill point for high use rate
Refill point for low use rate
Gear et al., 1977
Inches of Water per Foot
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
Day of Crop Year

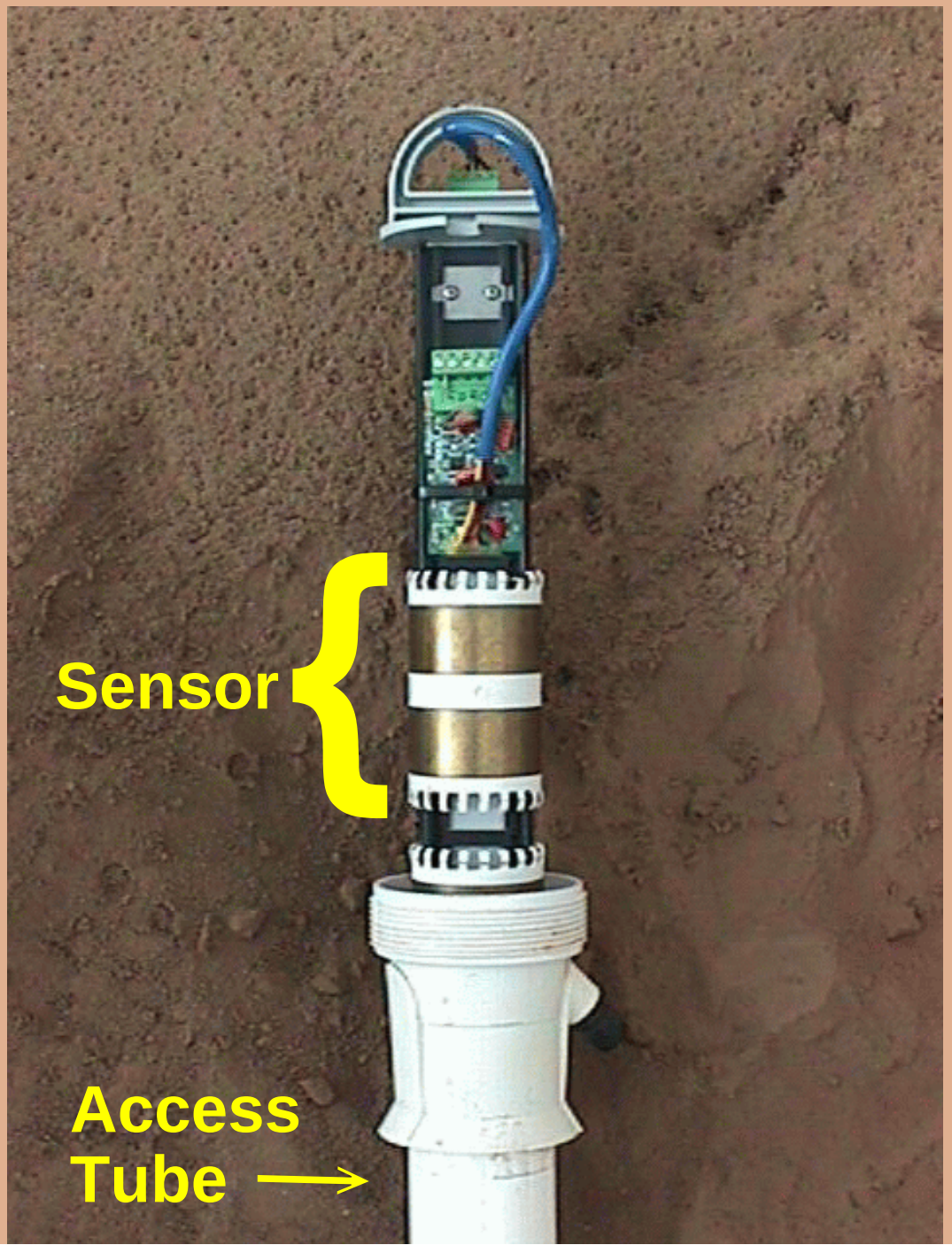
Capacitance/FD

Oscillator frequency ú as soil water content ü

Both probe and access tube types.

Example:
Sentek EnviroScan

The sensors are spaced vertically at 4 inches.



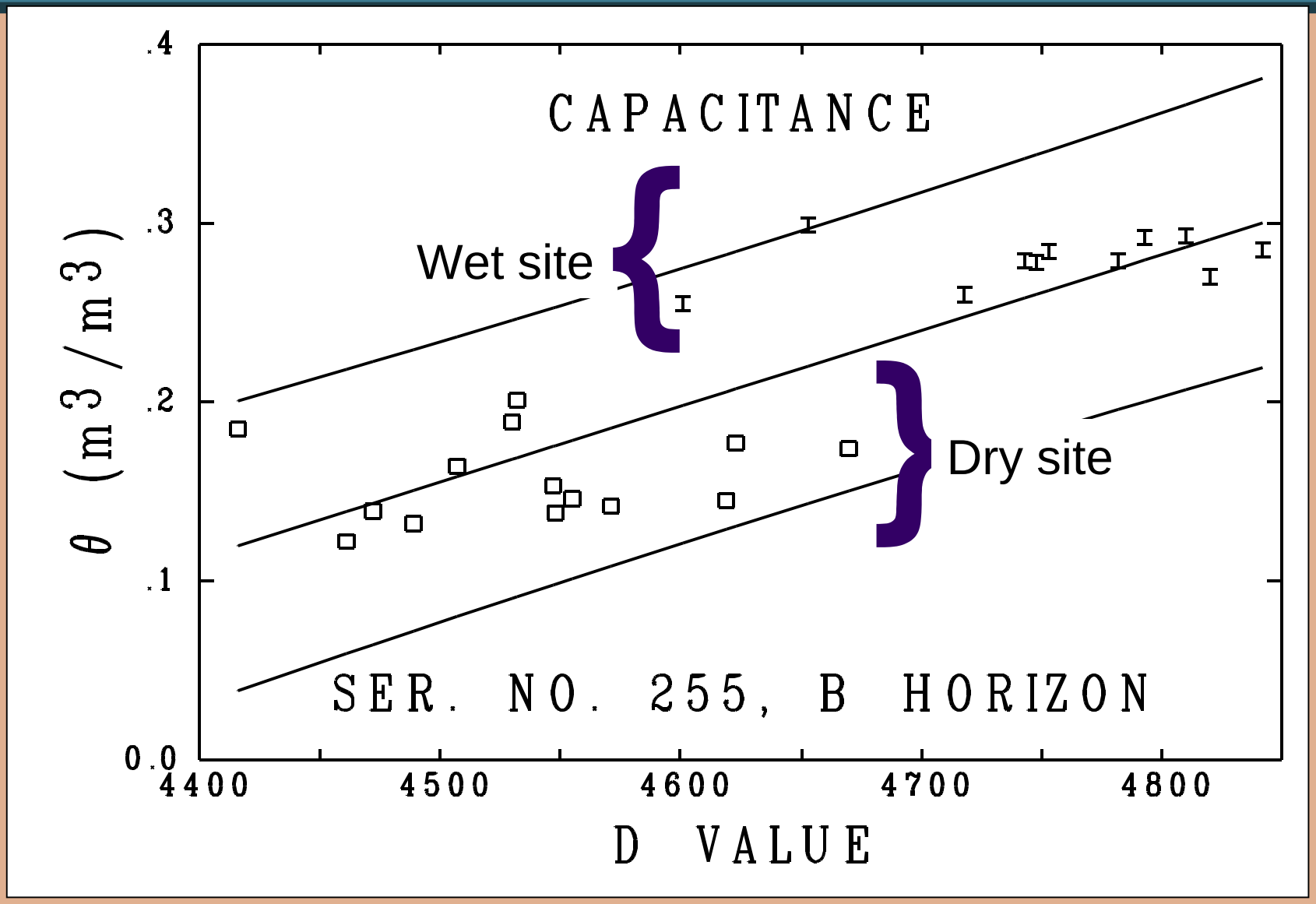
CAPACITANCE/FD, Advantages

- Often portable.
- Some are used with access tubes.
- Some can be used unattended and automated.
- Some can be multiplexed.
- May have lower initial cost than TDR or Neutron Probe (or not).

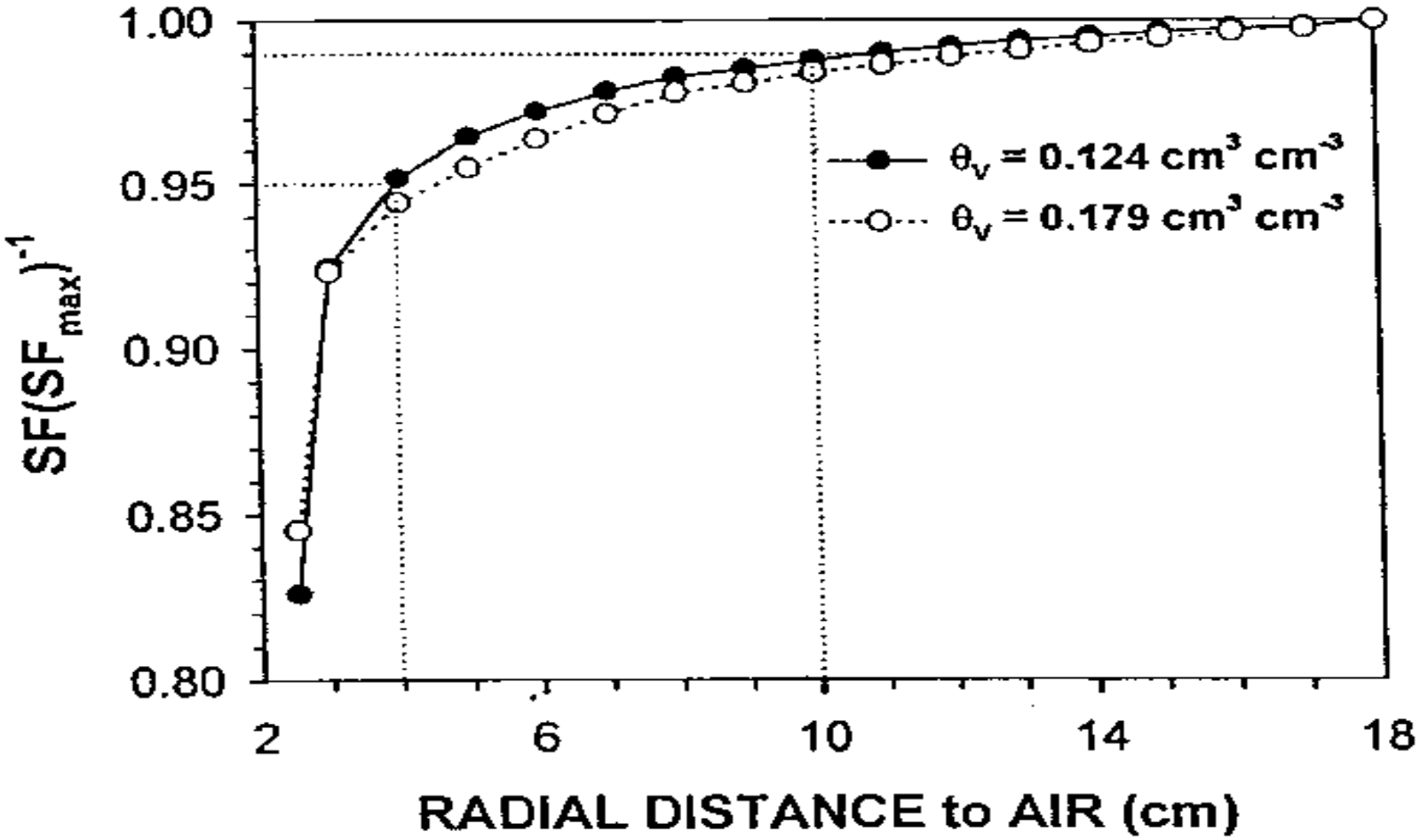
CAPACITANCE/FD, Disadvantages

- Reading is affected by clay content, bulk density, and soil salinity more than TDR or NP.
- Calibration required for different soil types and layers.
- More or less a point measurement.
- Installation is critical - good contact with soil required.

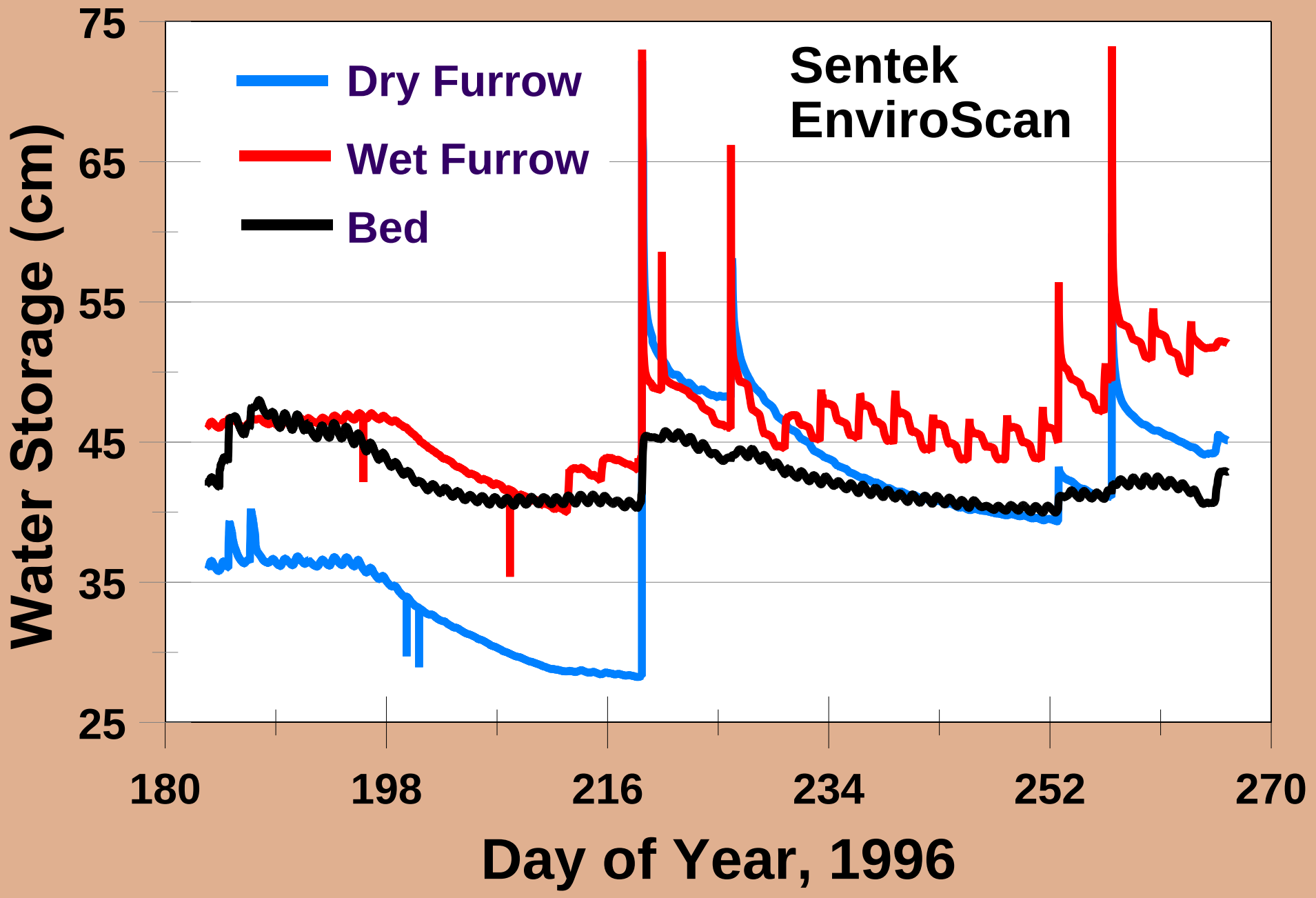
Troxler Sentry 200AP Calibration

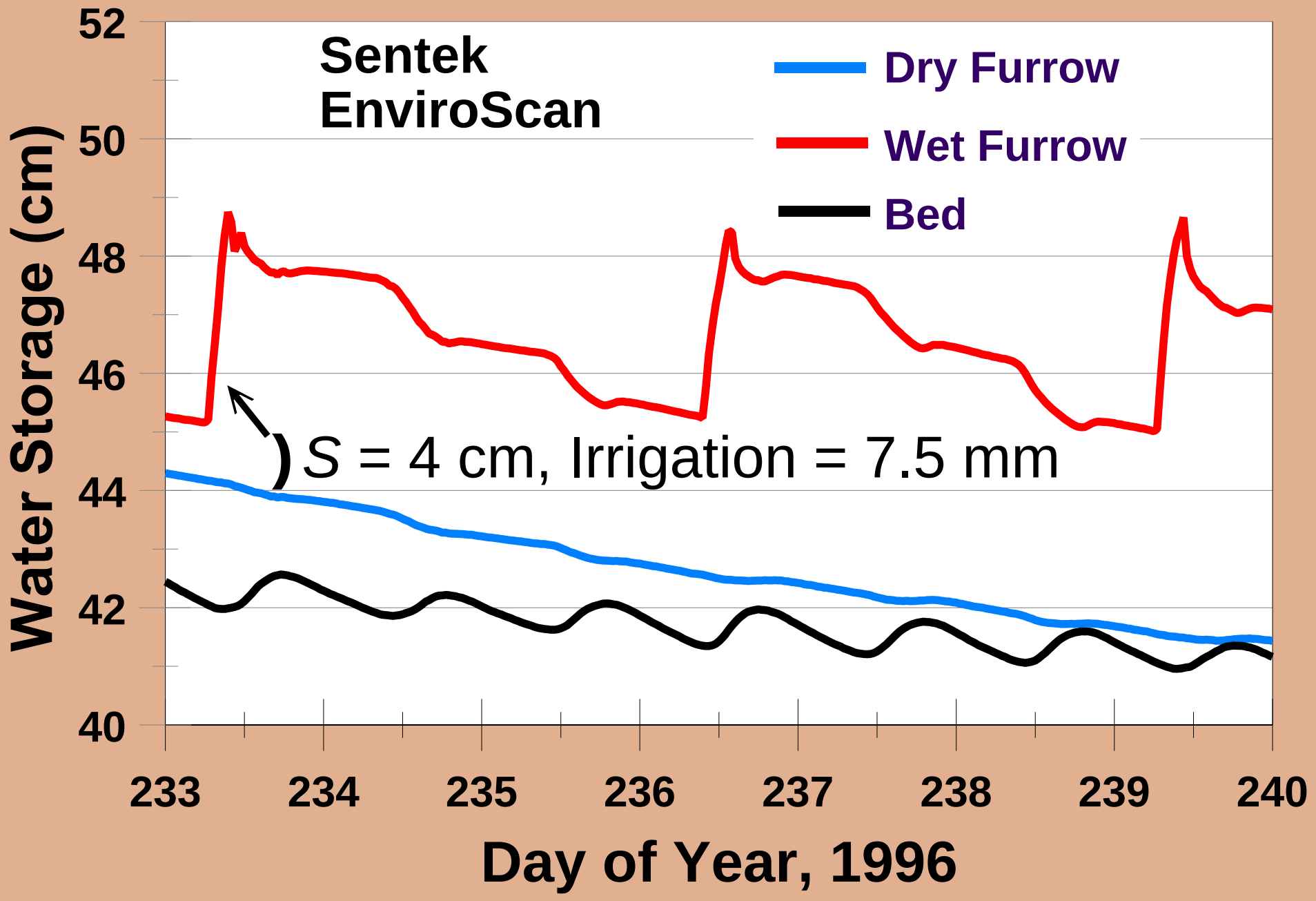


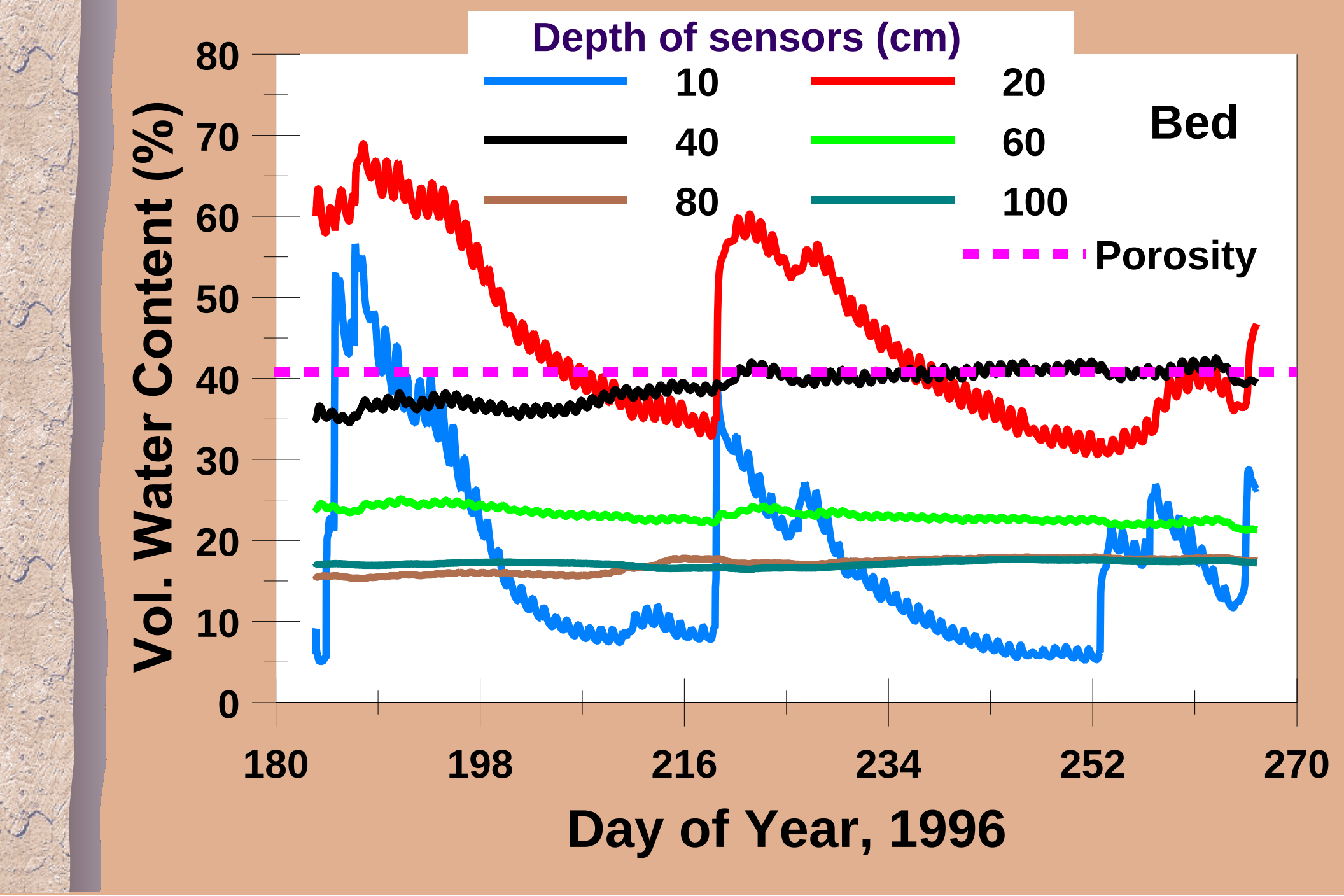
Capacitance meter radial sensitivity



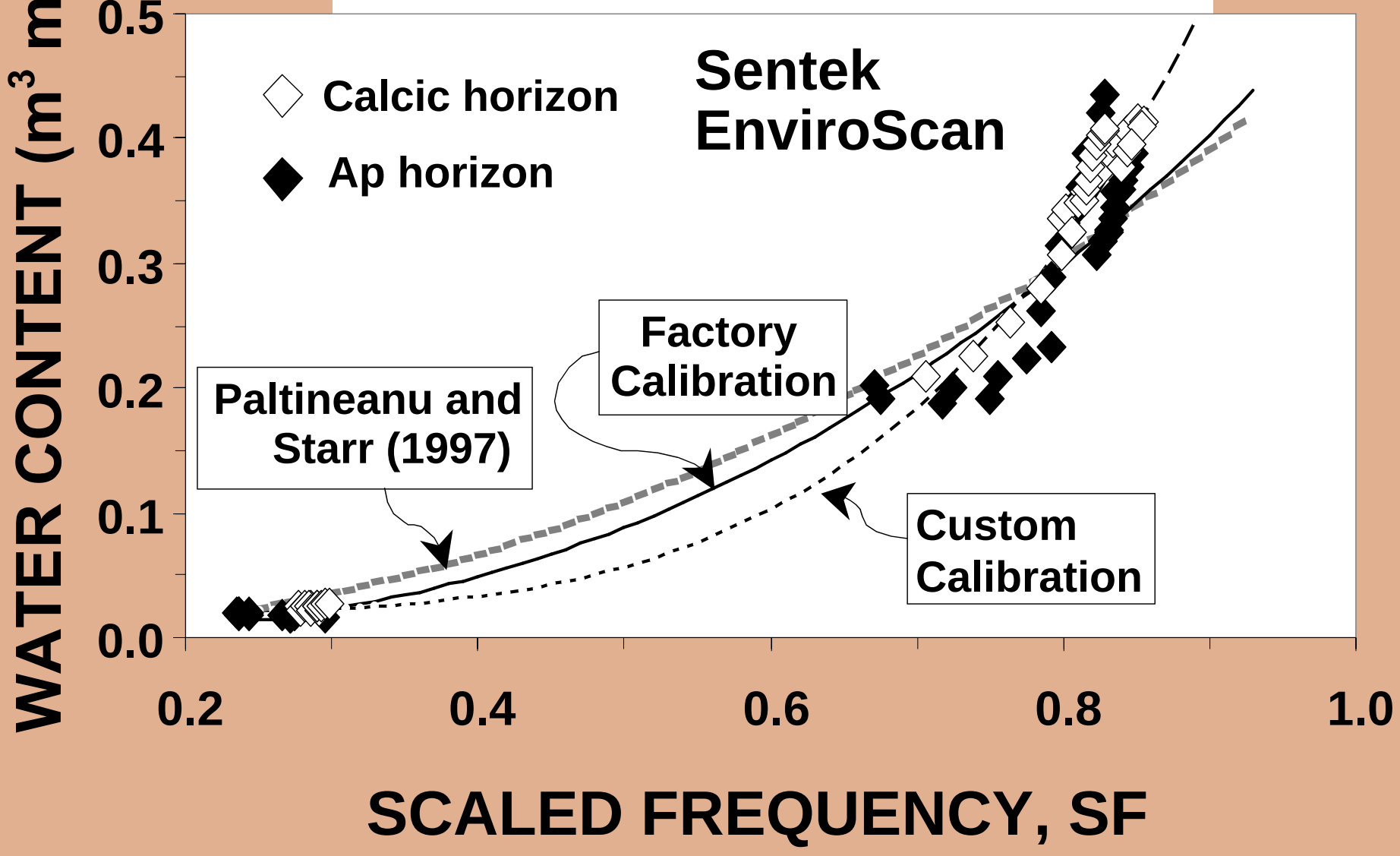
Paltineanu and Starr, 1997

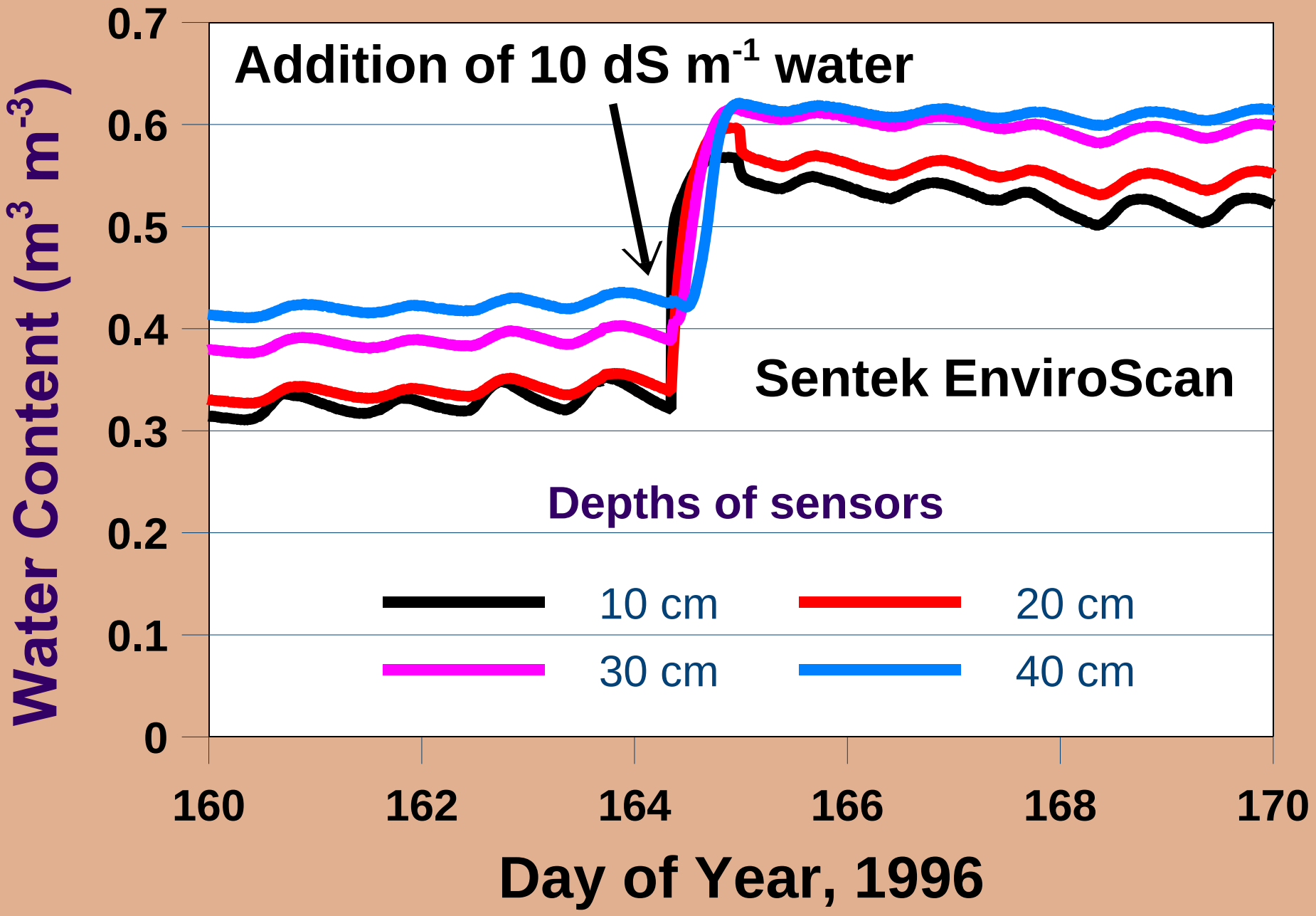

Sentek
EnviroScan
Dry Furrow
Wet Furrow
Bed
Water Storage (cm)
75
65
55
45
35
25
180
198
216
234
252
270
Day of Year, 1996


Sentek
EnviroScan
Dry Furrow
Wet Furrow
Bed
S = 4 cm, Irrigation = 7.5 mm
Water Storage (cm)
52
50
48
46
44
42
40
233
234
235
236
237
238
239
240
Day of Year, 1996


Depth of sensors (cm)
10
20
40
60
80
100
Bed
Porosity
Vol. Water Content (%)
0
10
20
30
40
50
60
70
80
180
198
216
234
252
270
Day of Year, 1996

$$2_v = 0.019 + 0.794\ SF^{4.39}$$
$$r^2 = 0.97,\ RMSE = 0.027\ m^3\ m^{-3}$$



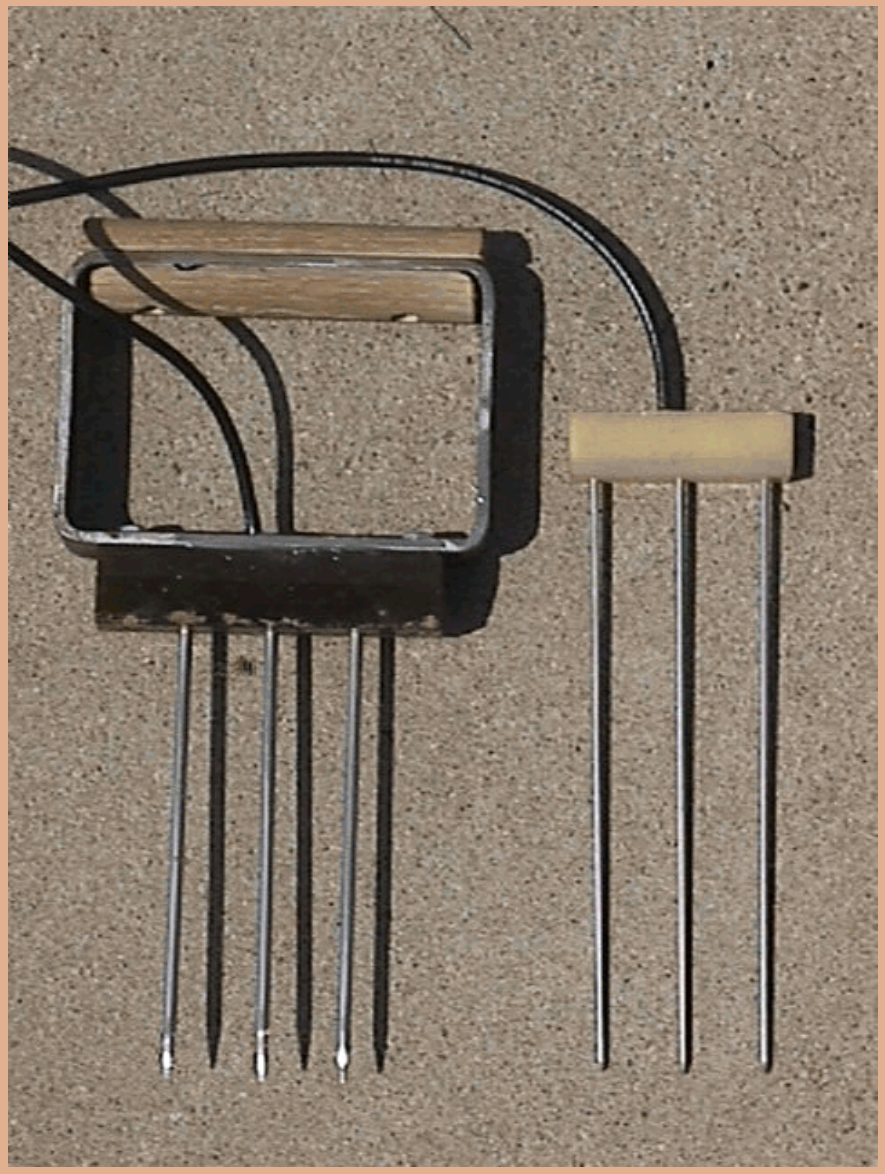

Addition of 10 dS m-1 water
Sentek EnviroScan
Depths of sensors
10 cm
20 cm
30 cm
40 cm
Water Content (m3 m-3)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
160
162
164
166
168
170
Day of Year, 1996

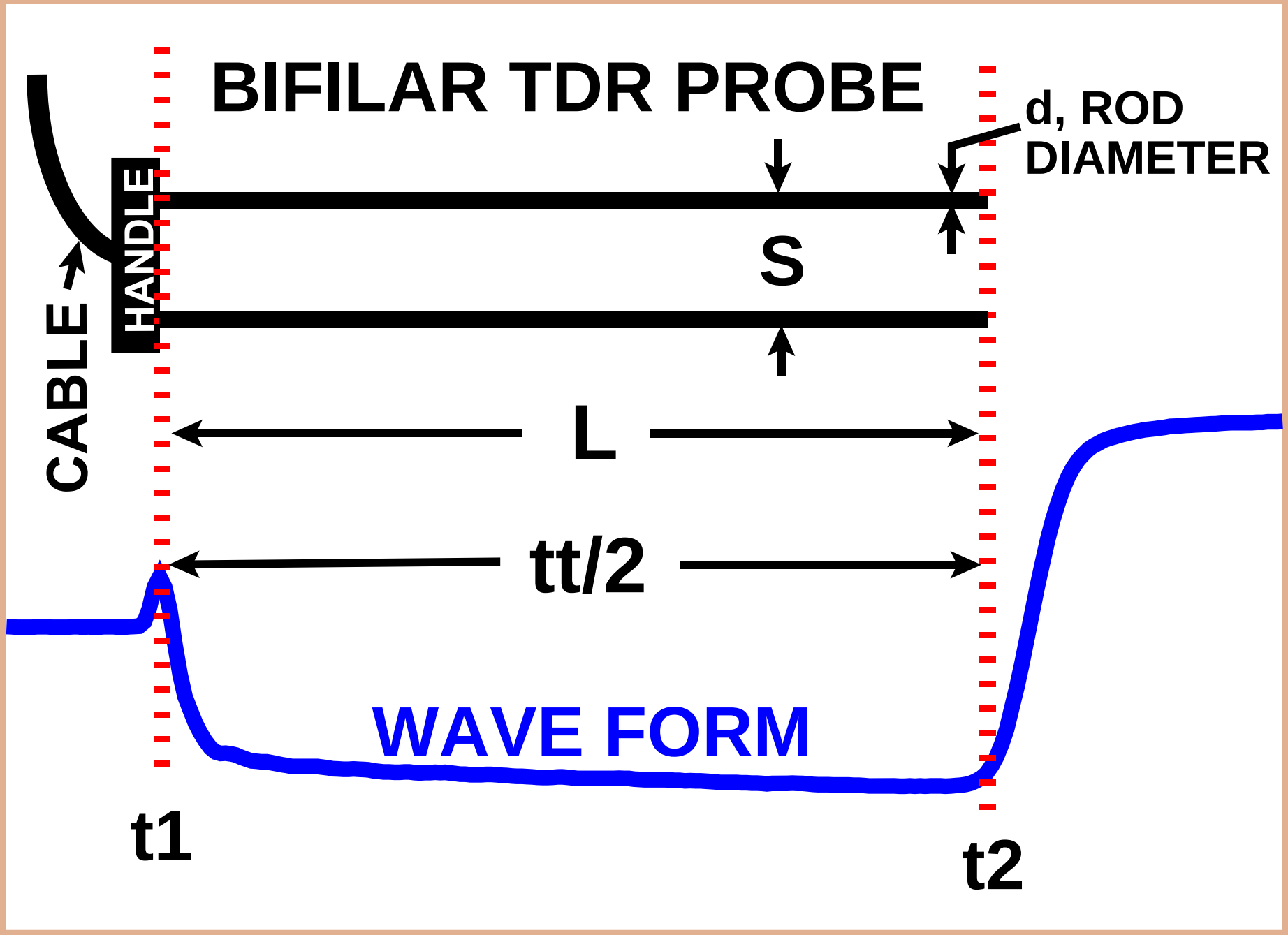
Sentek Diviner 2000

The TRIME System, FD

Time Domain Reflectometry, TDR

- Measures signal travel time in a probe.
- Accurate - data in ft^3/ft^3.




BIFILAR TDR PROBE
d, ROD DIAMETER
HANDLE
CABLE
S
L
tt/2
WAVE FORM
t1
t2

Time Domain Reflectometry

TDR Advantages

- Usually does not need calibration.
- Accurate and rapid.
- Nondestructive.
- May be automated.
- Portable systems available.
- Unattended use OK.
- Probes may be multiplexed.

TDR Disadvantages

- Measurement volume extends only about 1 inch beyond probe (mitigated by longer probe lengths and widths).
- Requires excellent probe to soil contact.
- Probe installation may disturb soil.
- Expensive
- Requires technical expertise

TENSIOMETERS Advantages

- Relatively inexpensive.
- Quickly read.
- Lengths from 6" to 6' are available - will cover profile.
- Some can be multiplexed.
- Some can be used for automatic irrigation control.

TENSIOMETERS Disadvantages

- Require excellent soil contact - do not work well with coarse sands or shrink-swell clays.
- Slow to respond.
- Maintenance requirement high.
- Work only in the wet range.
- Point measurement.

GRANULAR MATRIX Sensors

- Small cylinder of stable porous material, contains $CaSO_4$ wafer for buffering -2 wires.
- Read with AC bridge meter.

GRANULAR MATRIX Advantages

- Last longer than gypsum blocks.
- More reproducible.
- Calibration can be easier/more dependable.
- Can be multiplexed.
- Automatic irrigation control w/ up to 8 sensors is available.

GRANULAR MATRIX Disadvantages

- Sensors require calibration.
- Point measurement.
- Available automatic systems are limited.
- Sensitivity is in the 0.1 to 2 bar range.
- Do not work well in very coarse or shrink-swell soils.

Some comparisons :

The volume sampled by the NMM equals that of 24 cores, 5-cm in diameter and 30-cm in length.

Capacitance sensors in access tubes exhibit narrow radial and vertical sensitivity (good depth resolution, but small volume measured).

Time domain reflectometry (TDR) probes measure in a narrow band above and below the plane of the rods, but have flexibility in rod diameter, spacing, and length.

For more information, please visit:

http://www.cprl.ars.usda.gov/programs/