Applications of Soil Physics for Long-term Monitoring of Soil Water Content in Evapotranspiration Cover Systems in Montana; Case Studies and Equipment Evolution

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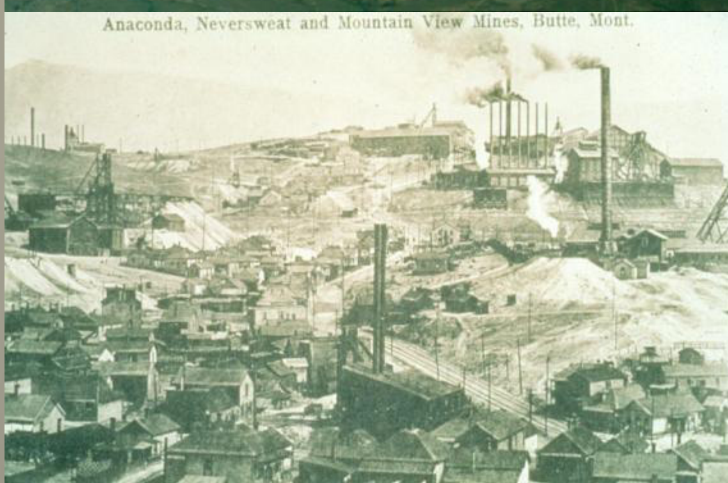
RECLAMATION RESEARCH GROUP

16th Annual BC/MEND Metal Leaching/ARD *Workshop—Soil, Geomembrane, and Non-traditional Material Covers*

Case Study 1—Butte/Anaconda, MT








Anaconda-Case Study #1

- Several thousand acre sulfide tailing impoundment
- Unvegetated, low pH, elevated metal levels
- Groundwater contamination observed
- Superfund site
- Cleanup goal: minimize groundwater inputs underneath tailings, control wind and water erosion, prevent human and ecological exposure
- Research project: evaluate *in-situ* treatment of acid-producing tailings followed by revegetation

Anaconda

- 1.5 acre test plot was constructed using lime, organic matter and fertilizer to chemically ameliorate tailings followed by reseeding
- Monitoring of soil chemistry, vegetation response, soil water content
- Soil water content monitored using datalogger and heat dissipation ceramic sensor
- Rainfall simulation to compare treated and untreated tailing surface


Opportunity Tailing
Ponds, Anaconda, MT

Anaconda results

- Evapotranspiration was increased from 20.2 cm/yr (unvegetated control plot) to 31.2 cm/yr (vegetated cover) corresponding with in increase in ET of 117,000 gallons/acre/year
- Percolation through the treated soil into the underlying untreated tailings decreased from 9.1 cm/yr to 4.4 cm/yr, or by 50,700 gallons/acre/year
- Rainfall simulation showed 91% infiltration on vegetated plots and 38% infiltration on unvegetated tailings.
- Soil pits suggest some upward flux of acidic water from tailings into treated, alkaline cover
- Overall, vegetation establishment increased infiltration and evapotranspiration while decreasing runoff and deep percolation.

Colstrip—Case Study 2

- Ash disposal pond with earthen soil cover
- Capillary barrier constructed of scoria
- Soil cover approximately 1m thick
- Cover constructed in 1996
- 1997—first growing season
- 13 year monitoring record of soil water content, vegetation conditions, soil chemistry
- 3 monitoring locations on pond

Case Study 2—Colstrip, MT

Colstrip Cap Characteristics

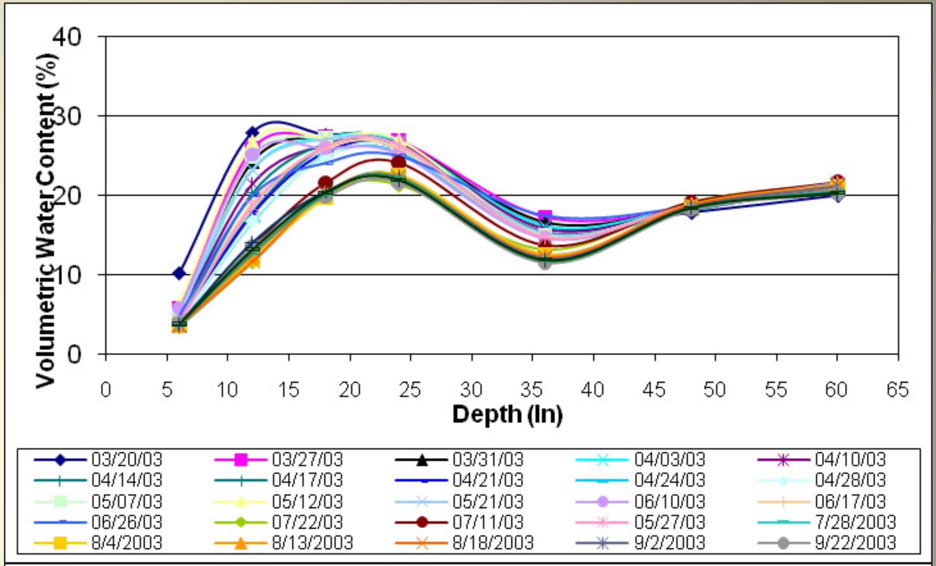
- 0-15 cm -- topsoil
- 15-75 cm -- subsoil
- 75-105 cm -- scoria (porcellanite)
- >105 cm -- ash

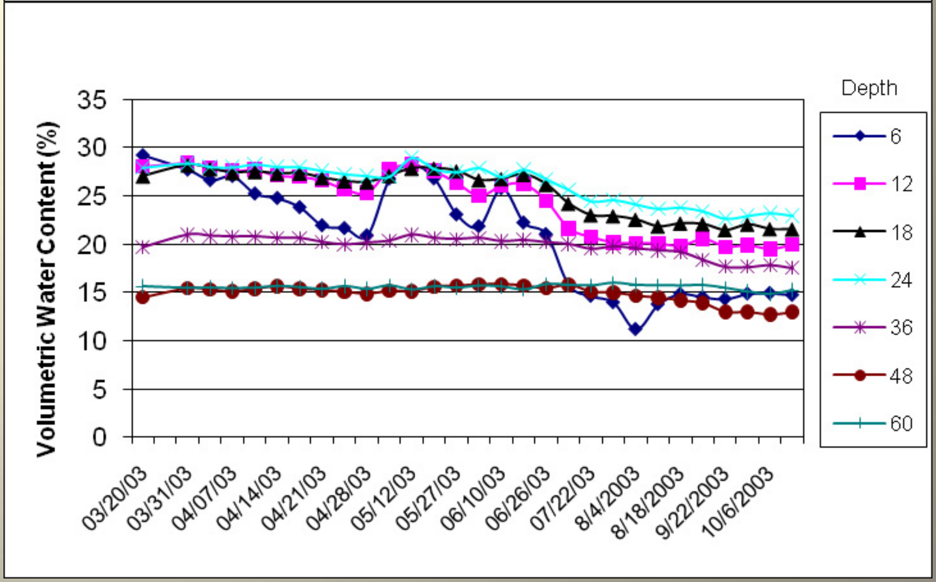
Equipment evolution—
Soil water content monitoring

Monitoring Equipment	Monitoring Period	Strengths	Weaknesses
Neutron Probe	1997-2004	Well known methodology, easy to measure at depth	Poor calibration, summer-only monitoring, labor intensive
TDR—Generation 1	2005-2008	Datalogger capability, extensive number of measurements over time	Interferences with high salinity, datalogger algorithm inaccuracies, too few sensors, telephone modem downloads
TDR—Generation 2	2009-	Data collection by datalogger, computer downloadable, improved software, electrical conductivity measurement, better calibration, more sensors	TBD

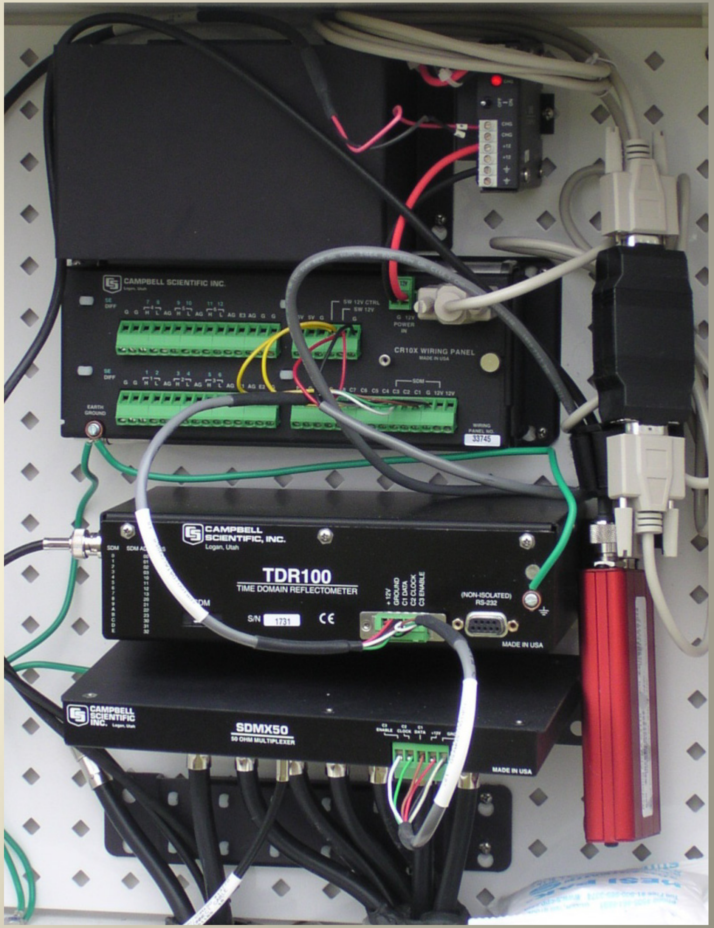
Neutron Probe Monitoring--2003

- 26 monitoring events during 2003 between March and October
- Data show the shallowest depths respond to precipitation events
- Entire soil profile down to ~1 meter depth dries during the growing season
- Deeper intervals in the ash remain at near constant water content
- No winter data, no annual water balance, qualitative interpretations

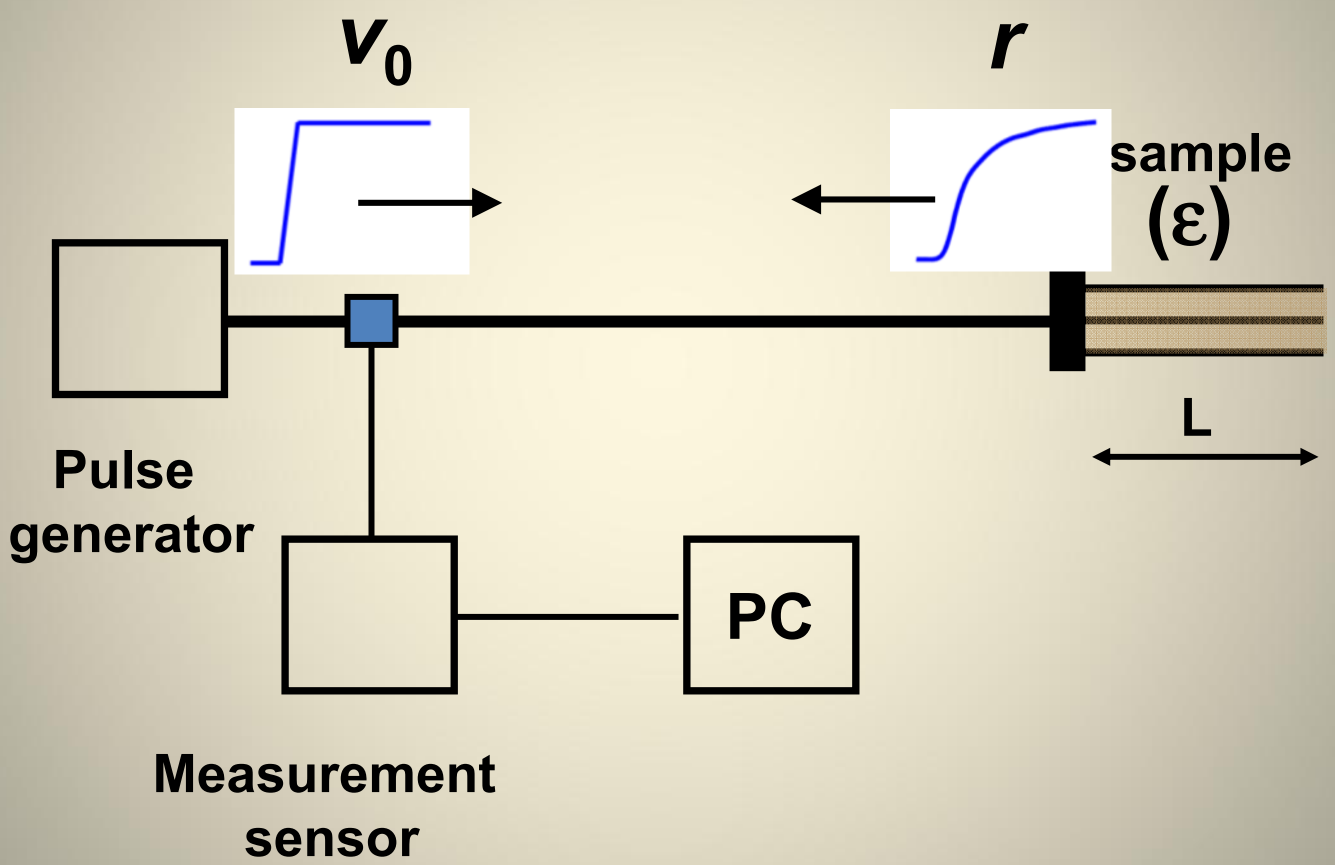




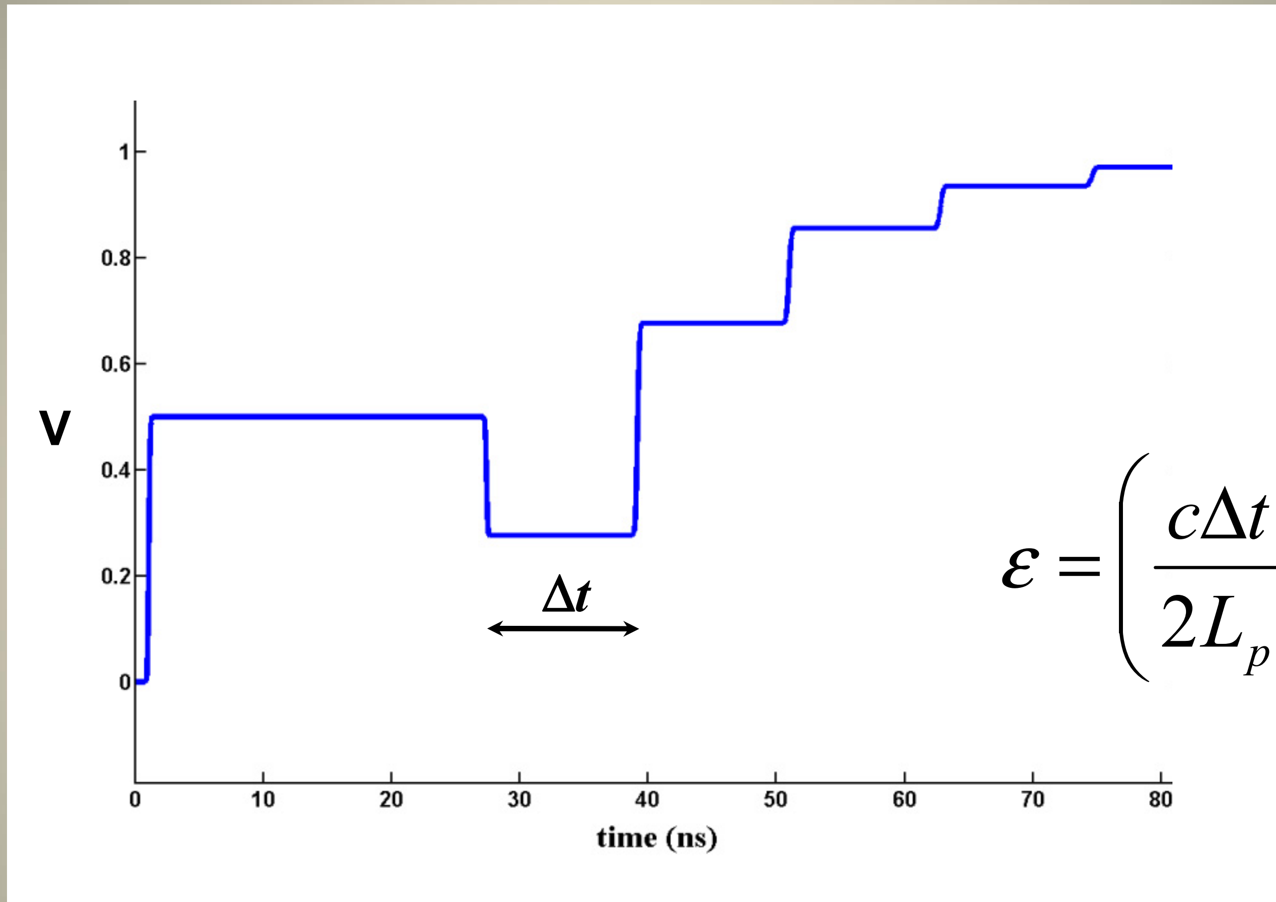
Time Domain Reflectometry (TDR)—How does it work?



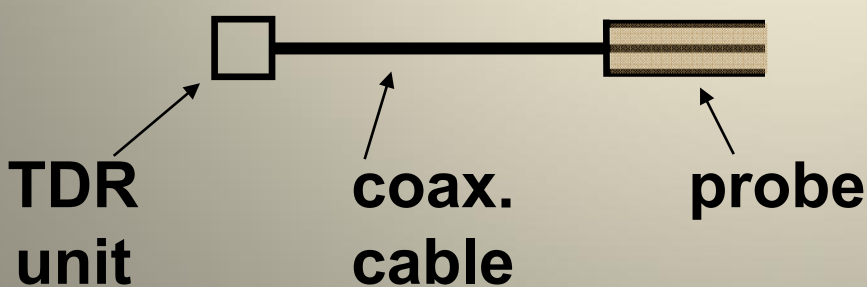
TDR apparatus



Travel Time Analysis (TTA)



$$\varepsilon = \left(\frac{c\Delta t}{2L_p} \right)^2$$



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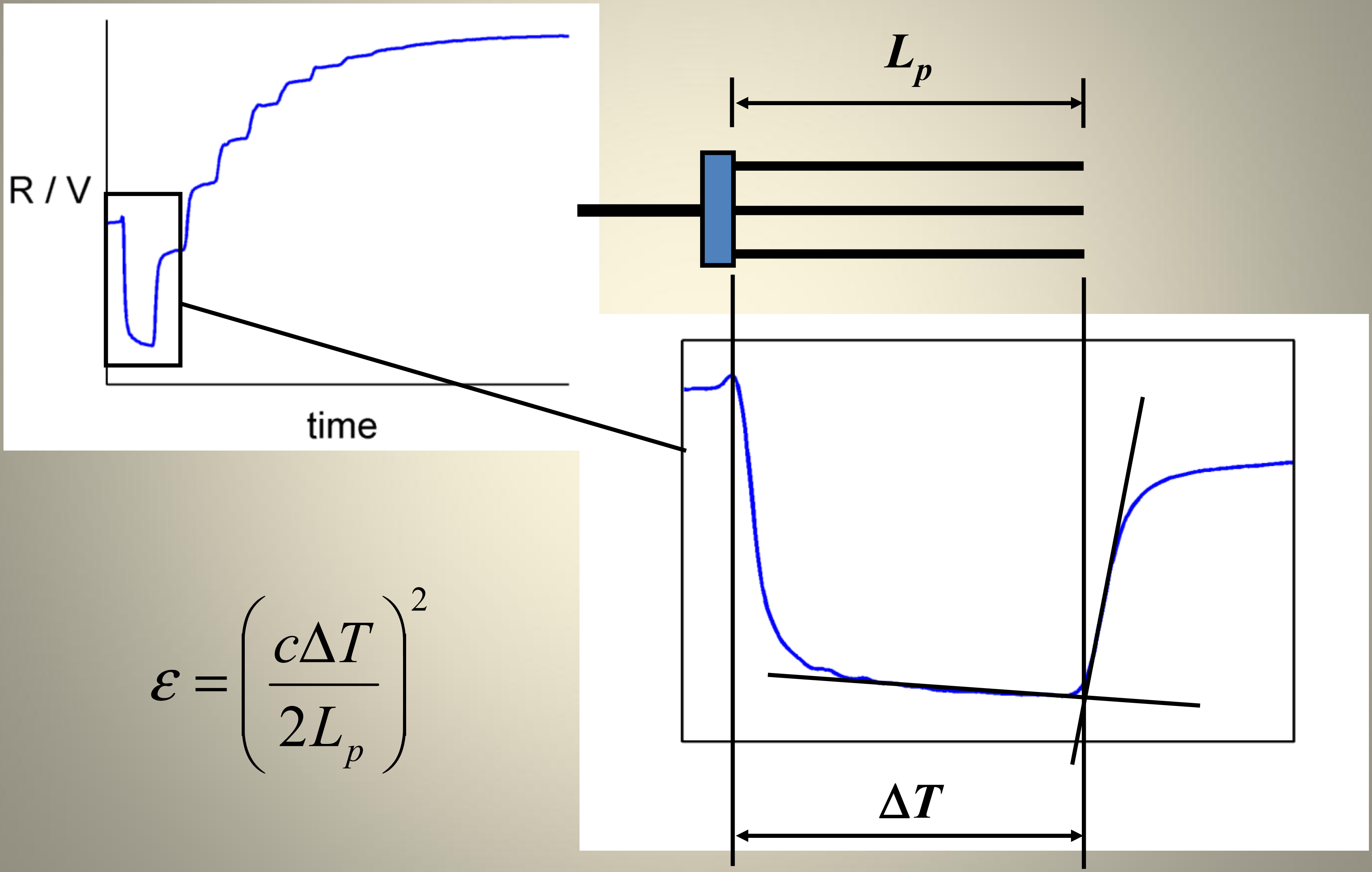
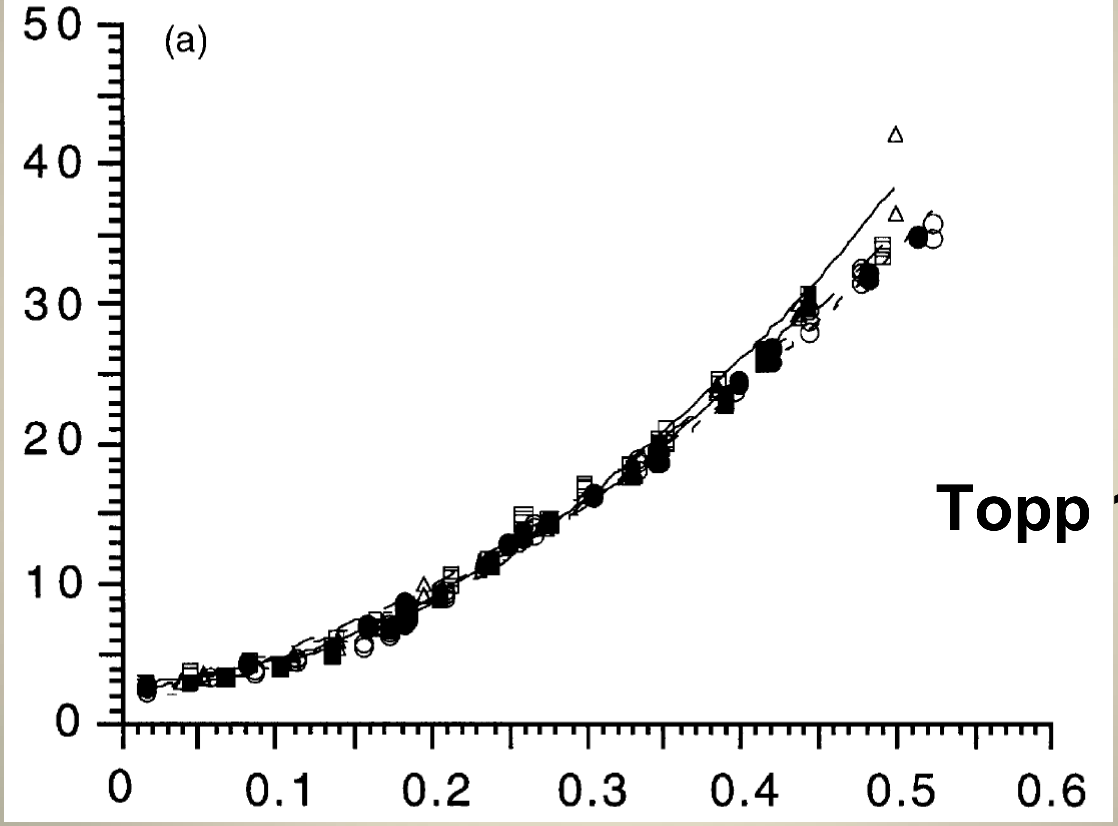


$$\varepsilon = \left(\frac{c \Delta T}{2 L_p} \right)^2$$

Dielectric permittivity versus Water Content

(low salinity - low clay content soil)

ε'

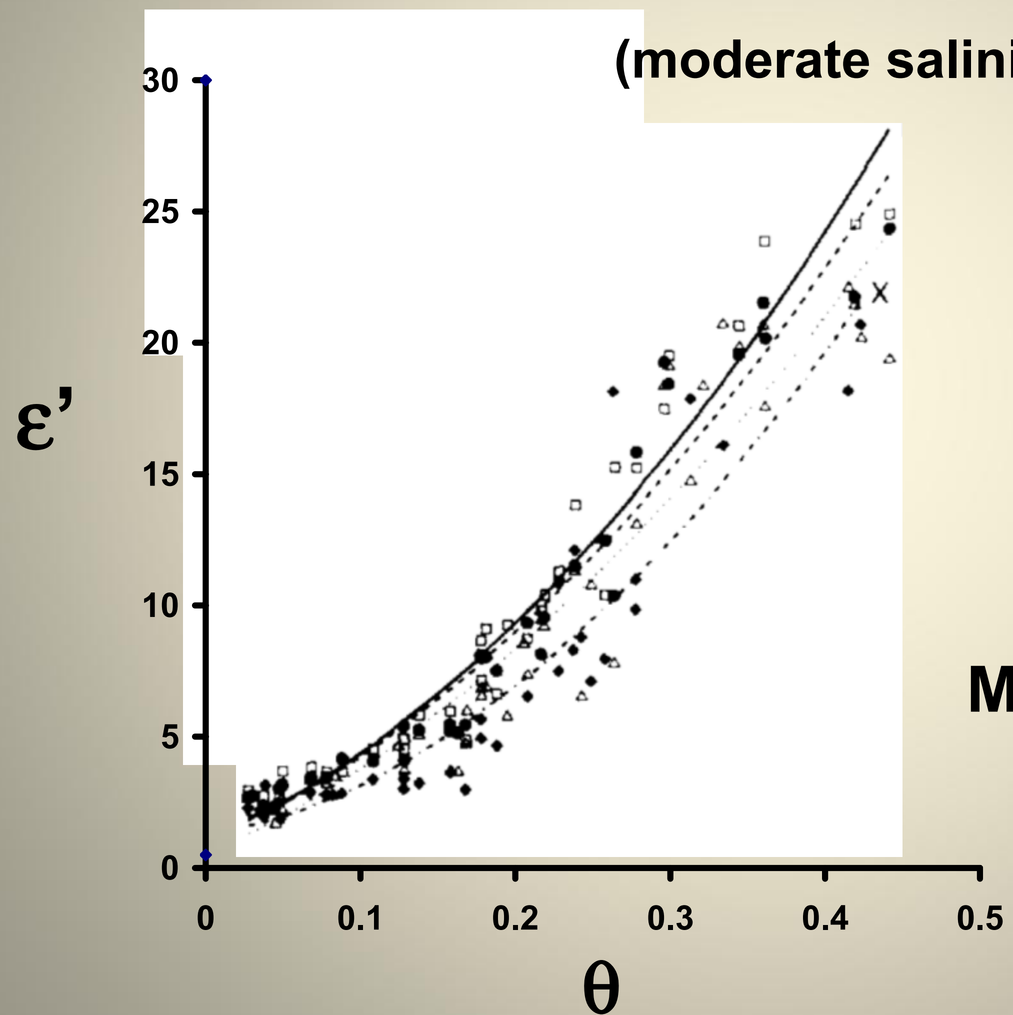


Topp 1980

water content

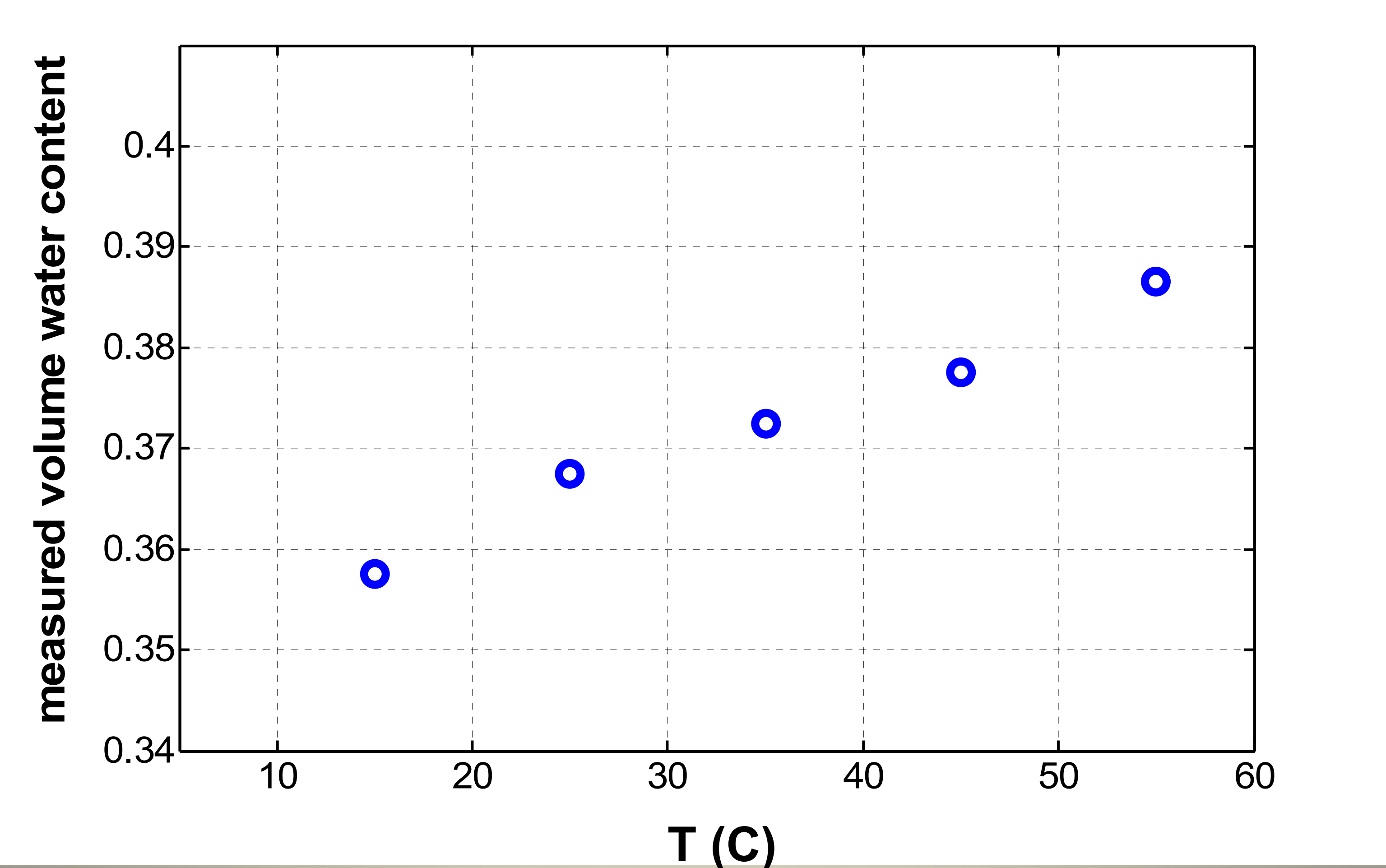
Dielectric permittivity versus Water Content

(moderate salinity and clay content soil)

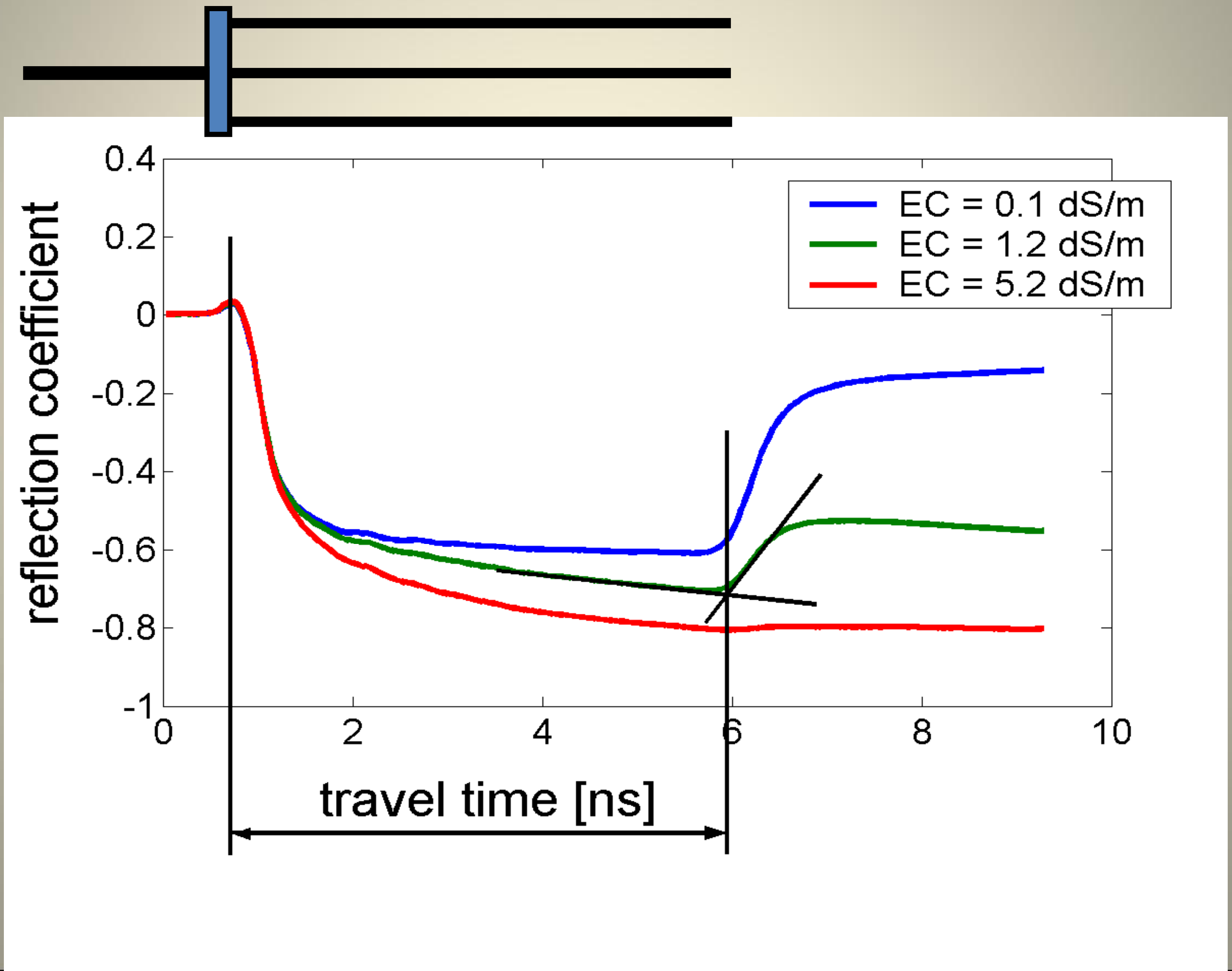


Malicki 1996

Temperature Effects on TDR



Salinity Effects on TDR



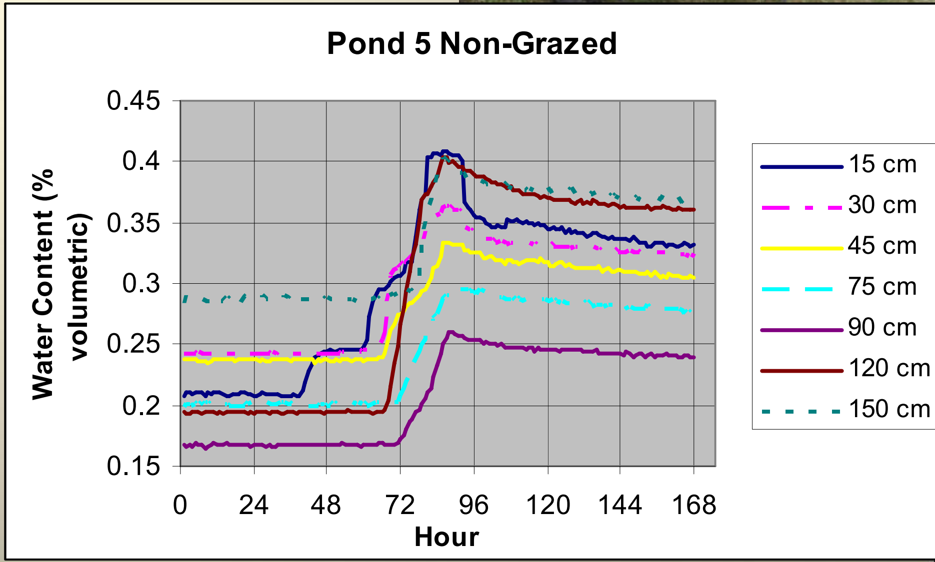
Limitations of the TDR technique

- The θ-ε relationship depends on texture
- Measurements may exhibit temperature effects
- TDR doesn't work well in saline soils
- In practice, TDR is an invasive technique
- Waveform analysis is often problematic

TDR installation--2005

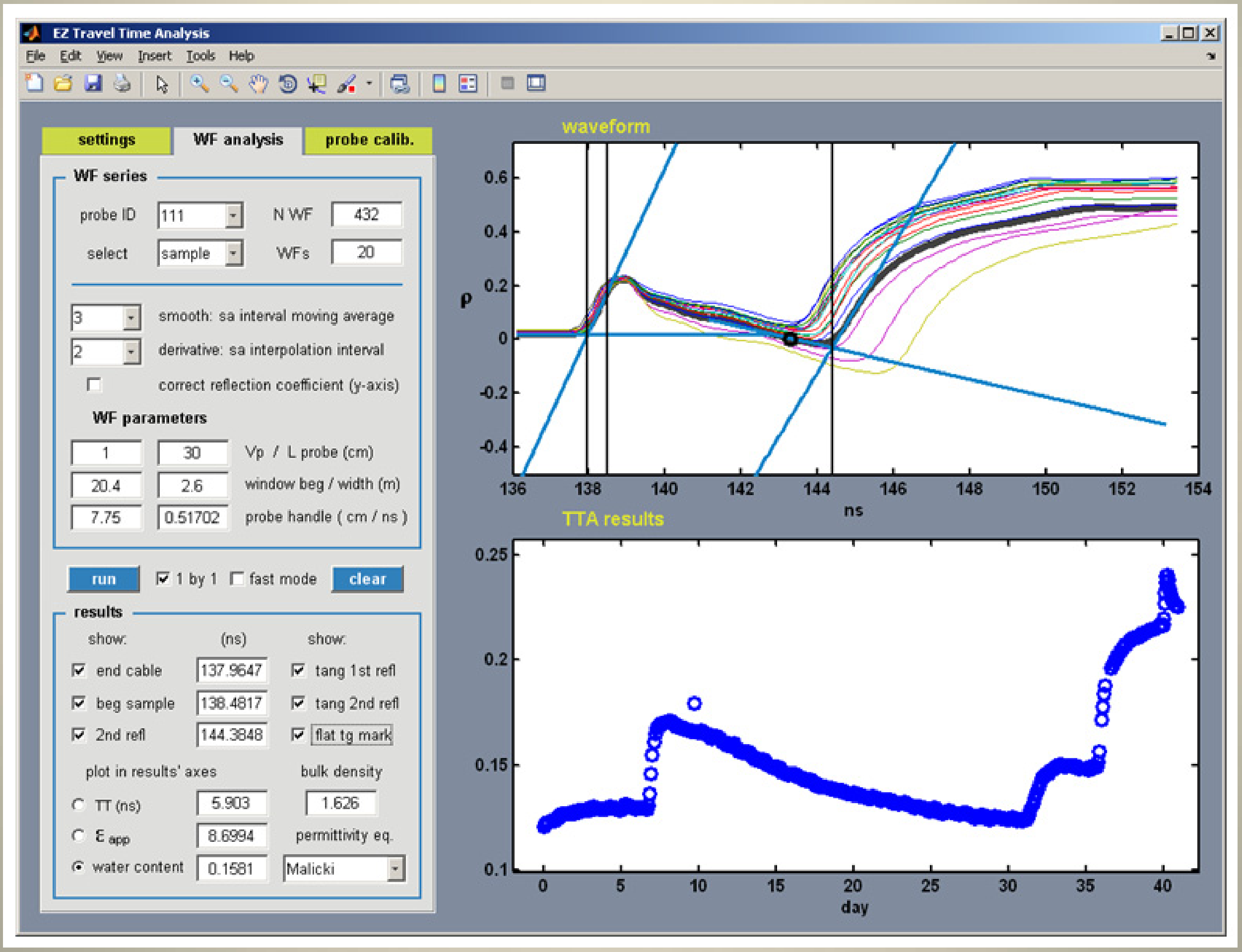
2006 observations

- Datalogger allowed collection of extensive record over 12 month period.
- Percolation through the soil cover was observed during periods of winter snowmelt.

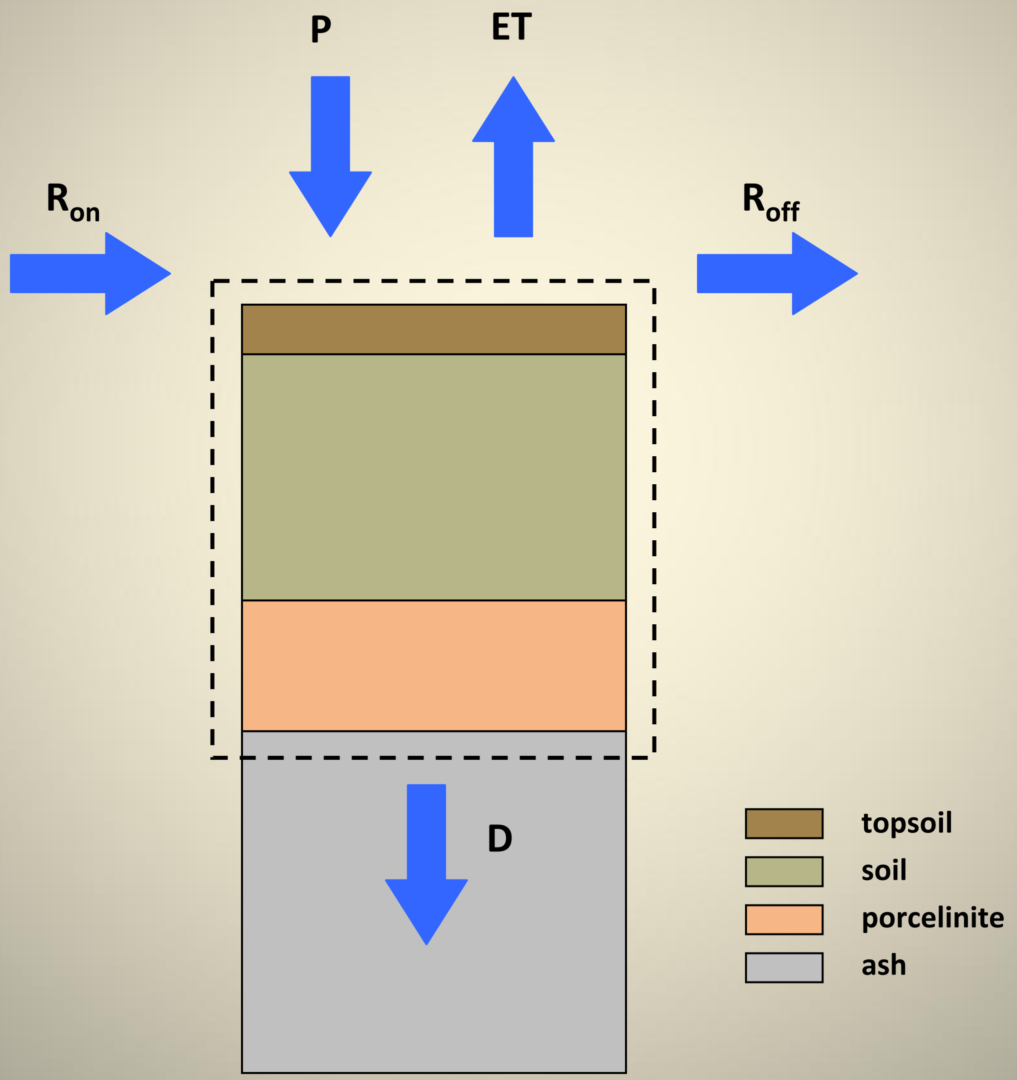


2007-2008 observations

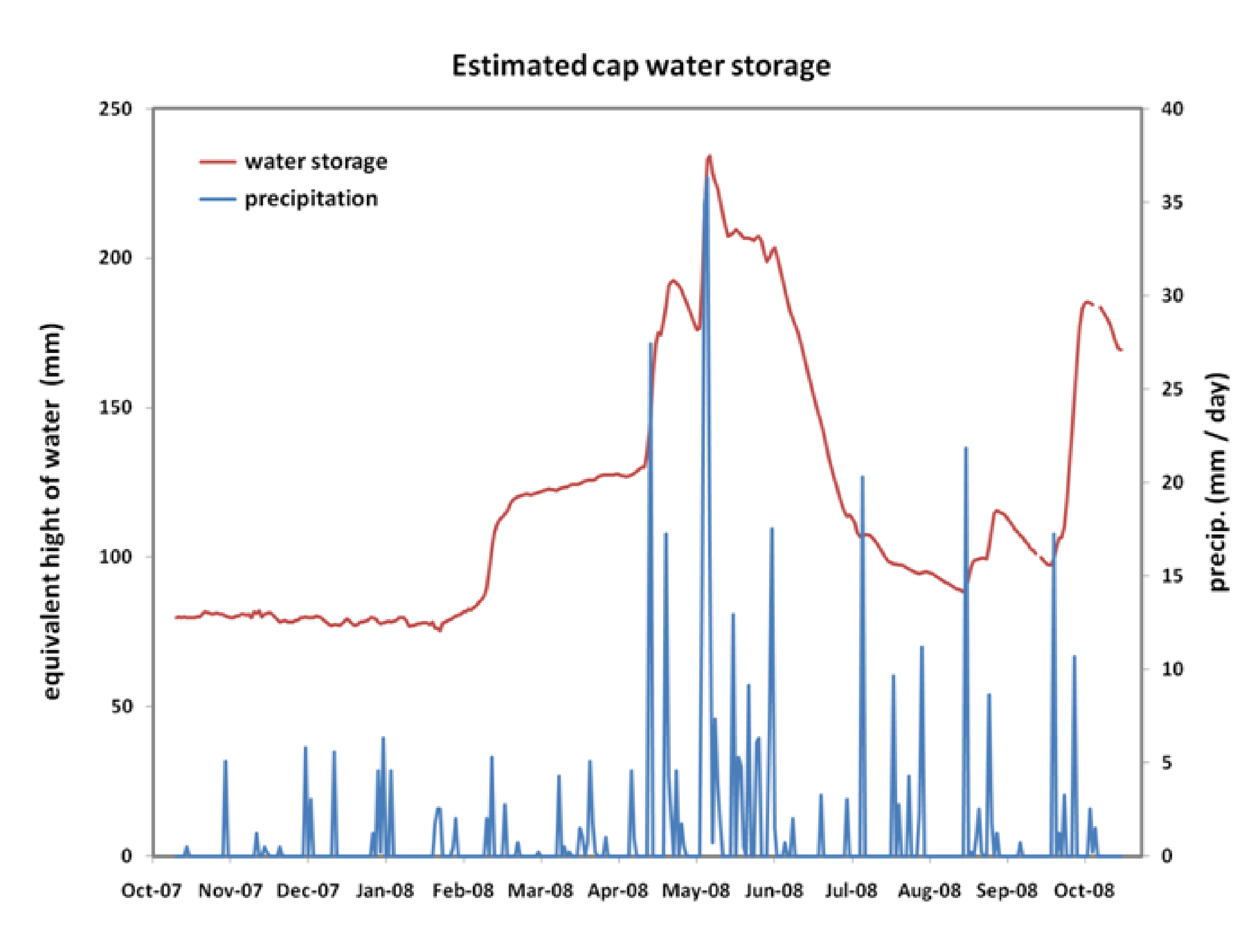
- 2 out of 3 stations not providing good data—interference with soil salinity
- Percolation observed during periods of prolonged intense rainfall (springtime)

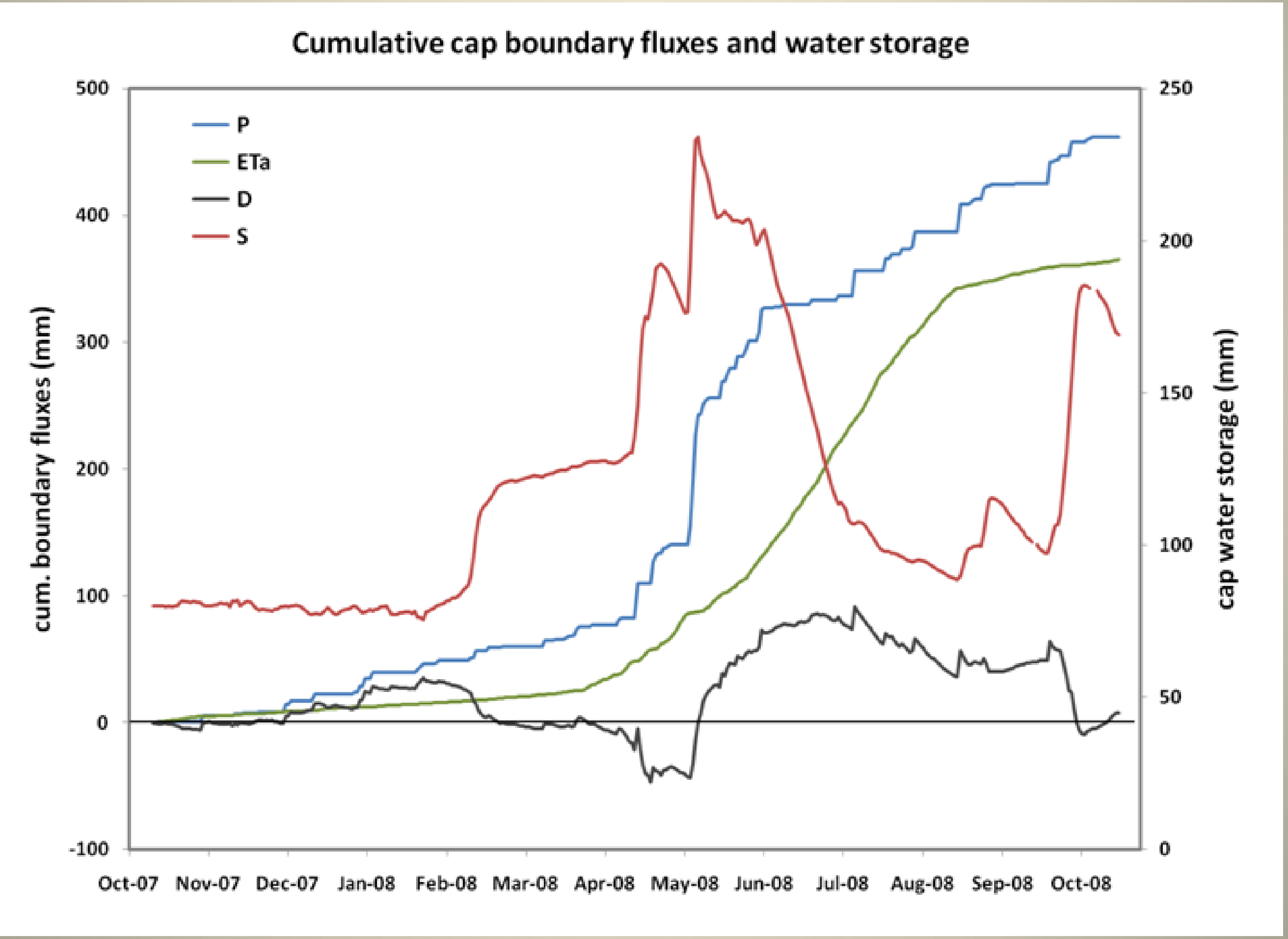

EZ Travel Time Analysis
File Edit View Insert Tools Help
settings
WF analysis
probe calib.
WF series
probe ID 111
N WF 432
select sample
WFs 20
smooth: sa interval moving average
derivative: sa interpolation interval
correct reflection coefficient (y-axis)
WF parameters
1 30 Vp / L probe (cm)
20.4 2.6 window beg / width (m)
7.75 0.51702 probe handle (cm / ns)
run
1 by 1
fast mode
clear
results
show:
(ns)
show:
end cable 137.9647
beg sample 138.4817
2nd refl 144.3848
tang 1st refl
tang 2nd refl
flat tg mark
plot in results' axes
bulk density
TT (ns) 5.903
1.626
ε app 8.6994
permittivity eq.
water content 0.1581
Malicki
waveform
ρ
ns
TTA results
day

Mass Balance Approach for Estimating Drainage



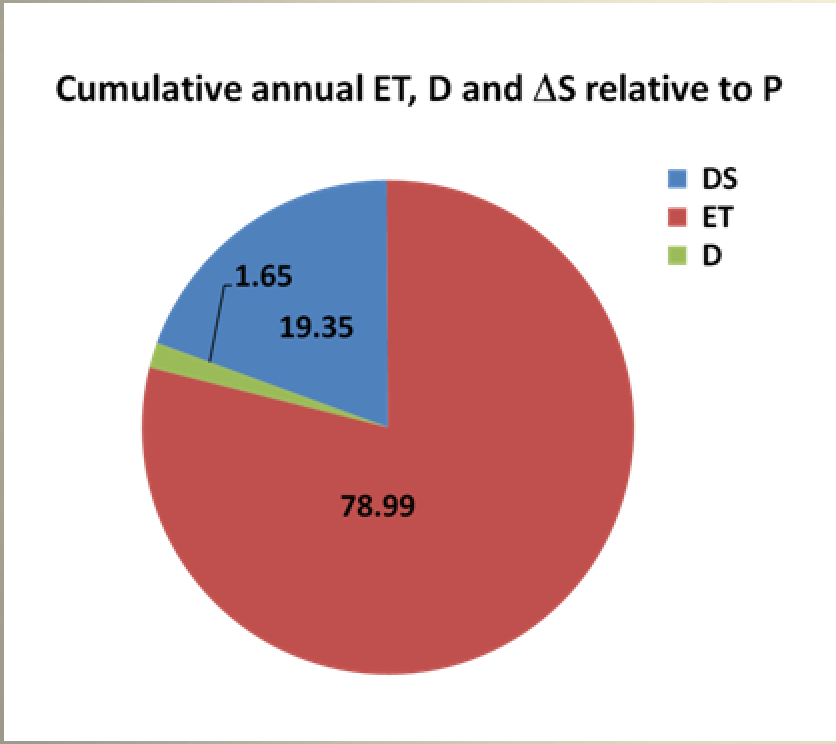
One year record of cap water storage



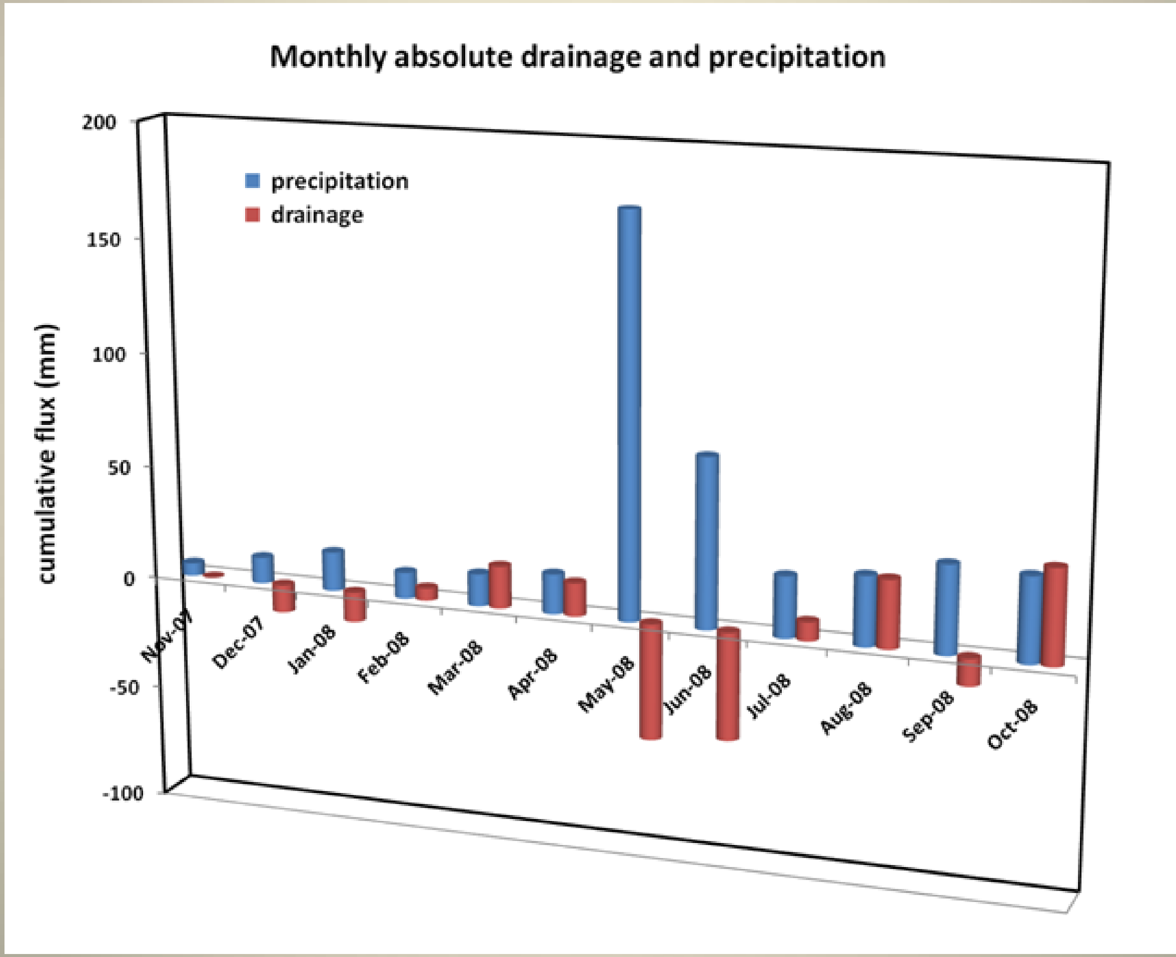


Cumulative cap boundary fluxes and water storage
P
ETa
D
S
cum. boundary fluxes (mm)
cap water storage (mm)
500
400
300
200
100
0
-100
250
200
150
100
50
0
Oct-07
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08

Distribution of 2008 Soil Cap Water

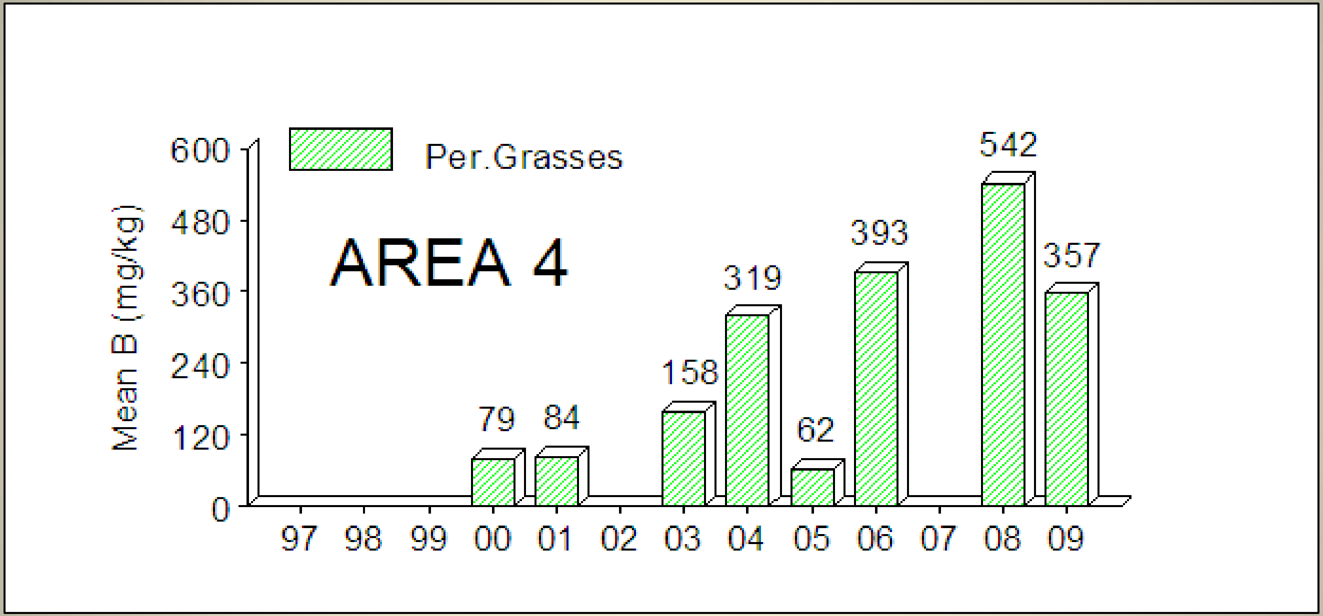


- Total precipitation in 2008 was 462mm
- 7.6 mm of water drained into the ash or 1.6% of total precipitation
- Most water was lost to evapotranspiration
- Water storage in the cap increase 19% over the year



Monthly absolute drainage and precipitation
precipitation
drainage
cumulative flux (mm)
200
150
100
50
0
-50
-100
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08

Vegetation accumulation of boron in perennial grasses



Summary of what we know about cap behavior up to 2008

- A vegetated 1 meter thick soil cover is capable of evapotranspiring >98% of precipitation at a semi-arid site in Montana
- Water passes both ways across the ash interface, upward and downward—through the capillary barrier
- Upward flux is desirable in meeting annual water balance, yet apparently carries a trace element signature of the ash
- The capillary barrier is not isolating soil water in the cap from the underlying ash
- Soil water storage capacity of the cap can be exceeded during mid-winter snowmelt and periods of prolonged precipitation
- Several difficulties have been encountered with the TDR setup

New questions have been formulated

- What is the actual performance of the soil cap and what portion of the water balance is caused by upward movement of ash water?
- What is the observed performance of the capillary barrier?
- Is the soil cap becoming saline by upward flux across the capillary barrier?
- Does some of the water crossing into the ash reach groundwater? How much?

Equipment evolution— Soil water content monitoring

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TDR—Generation 2	2009-	Data collection by datalogger, computer downloadable, improved software, electrical conductivity measurement, better calibration, more sensors	TBD

Moving Forward

- Major limitations of Generation 1 TDR—soil salinity, poor signal, inaccurate software, large surface disturbance required to install
- Major improvements of Generation 2

  -Better accuracy (texture and temp effects are minimized, as shorter probes operate at higher frequencies)

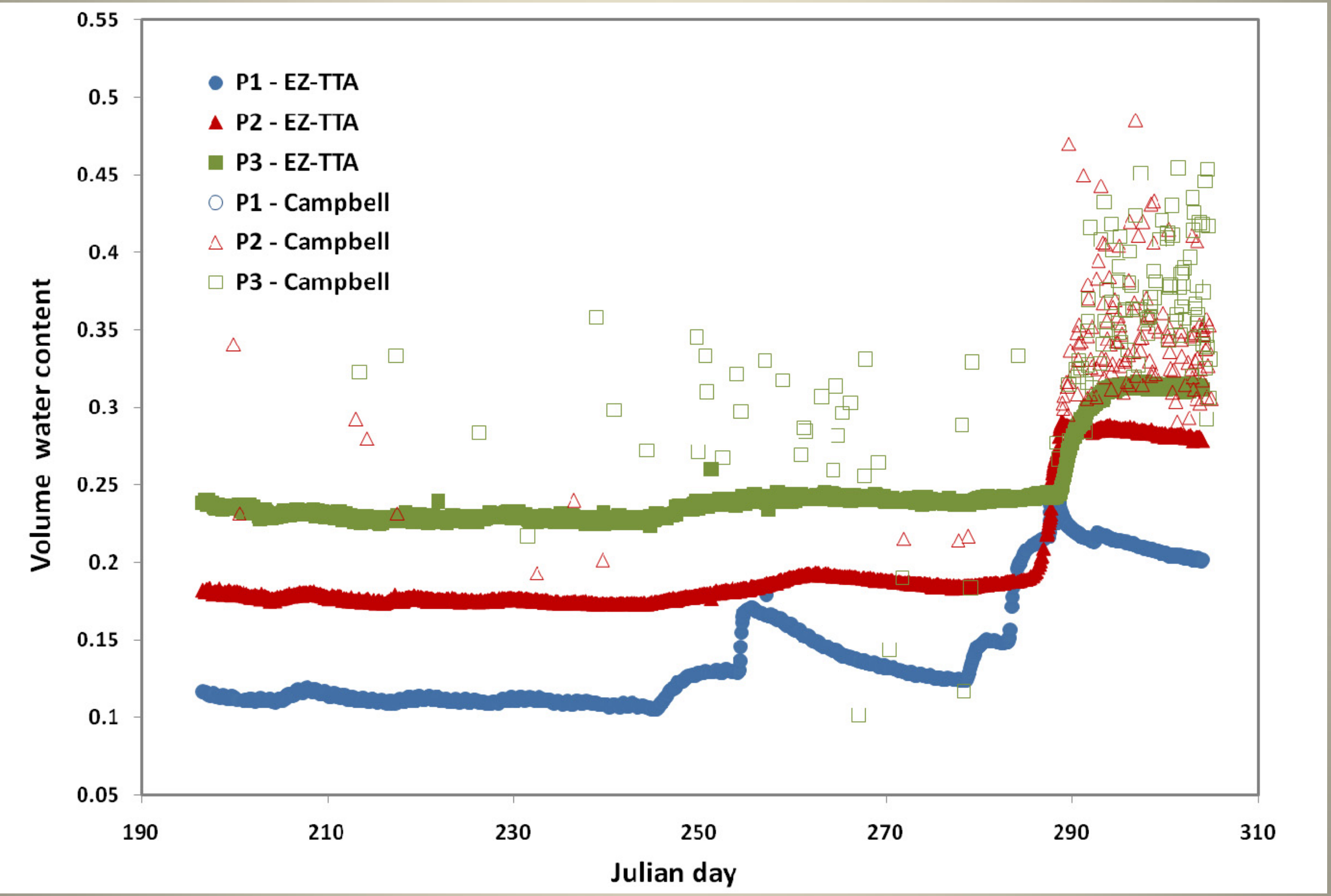
  -Improved TTA with new software

  -Withstand high salinity

  -Very precise EC measurements

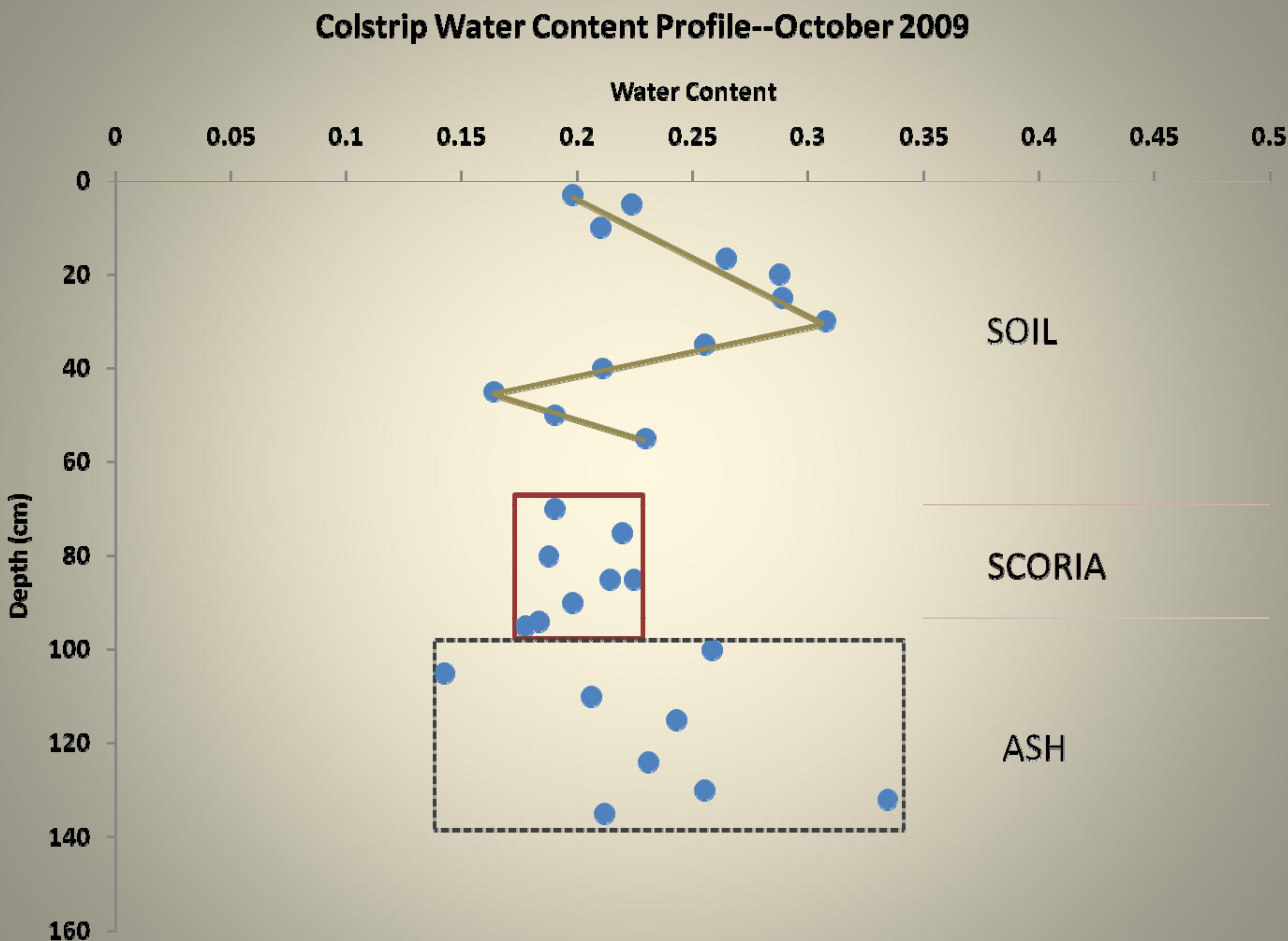
  -Smaller surface disturbance required to install

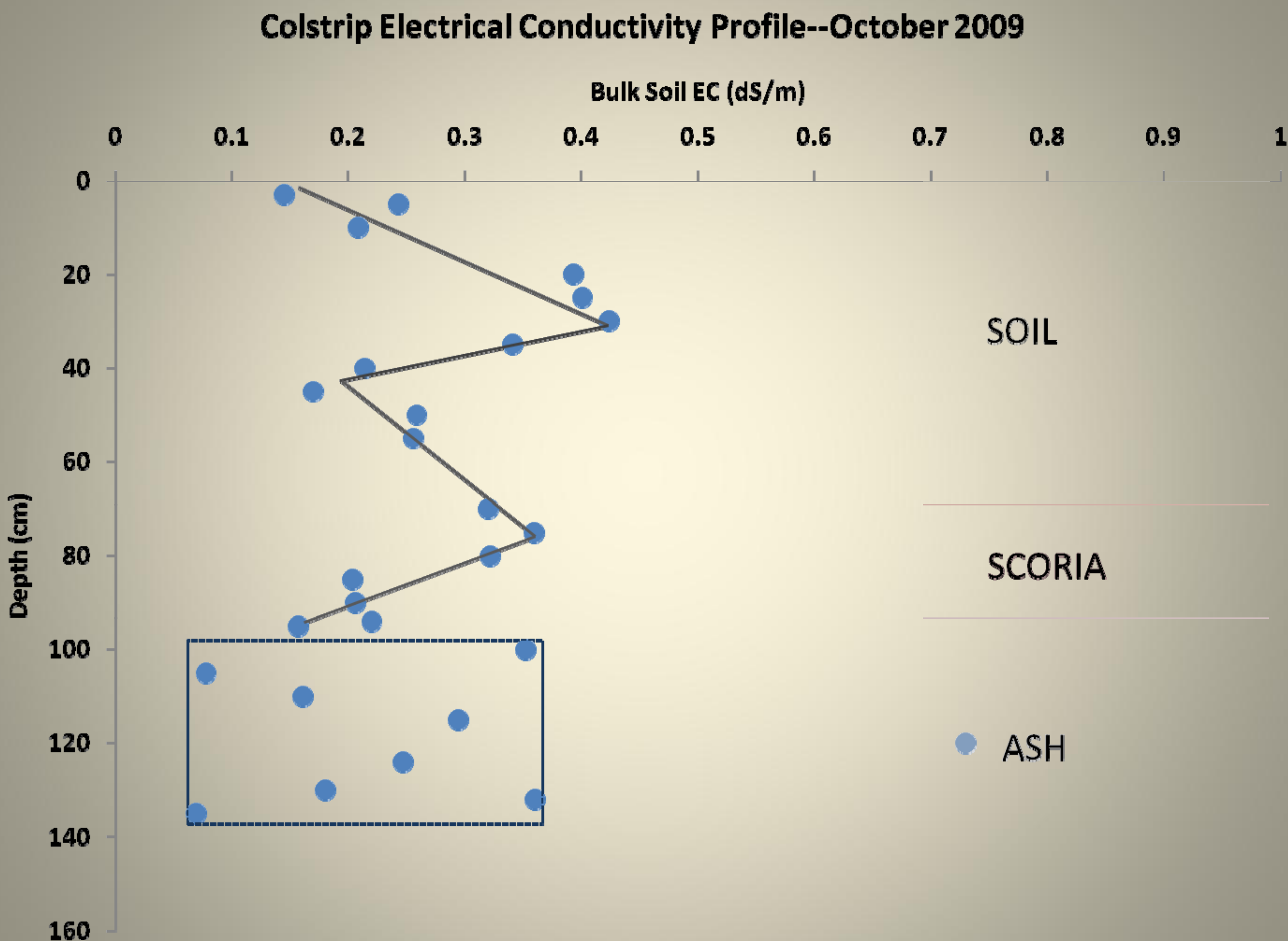
Comparison of TDR software packages



Improved Data Collection

- New TDR probes manufactured
- New installation methodology in drill hole
- Better soil characterization
- Greater density of probes


Colstrip Water Content Profile--October 2009
Water Content
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Depth (cm)
0
20
40
60
80
100
120
140
160
SOIL
SCORIA
ASH



Colstrip Electrical Conductivity Profile--October 2009
Bulk Soil EC (dS/m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Depth (cm)
0
20
40
60
80
100
120
140
160
SOIL
SCORIA
ASH

Ash-specific TDR calibration

- Topps equation was developed using agricultural soil.
- The applicability of Topps equation to ash or mine tailings is unknown.
- We plan to develop a TDR calibration specific to the ash.

Conclusions

- Long-term soil cap water content can be accurately monitored using TDR coupled with datalogger storage.
- Soil cover performance can be assessed by integration of soil hydraulic properties with field data.
- Equipment evolution has allowed for progressively better measurement and modeling of cap performance.
- Evapotranspiration covers in a semi-arid climate have dramatically reduced deep percolation, yet some limitations have been observed.

Questions?

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