A Small-Scale Multifunctional Heat-Pulse Sensor for Soil Water Content and Electrical Conductivity

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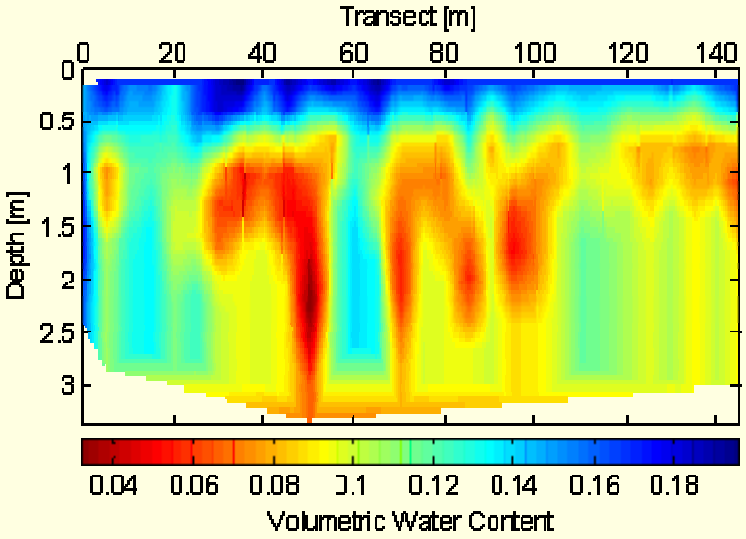
Rationale

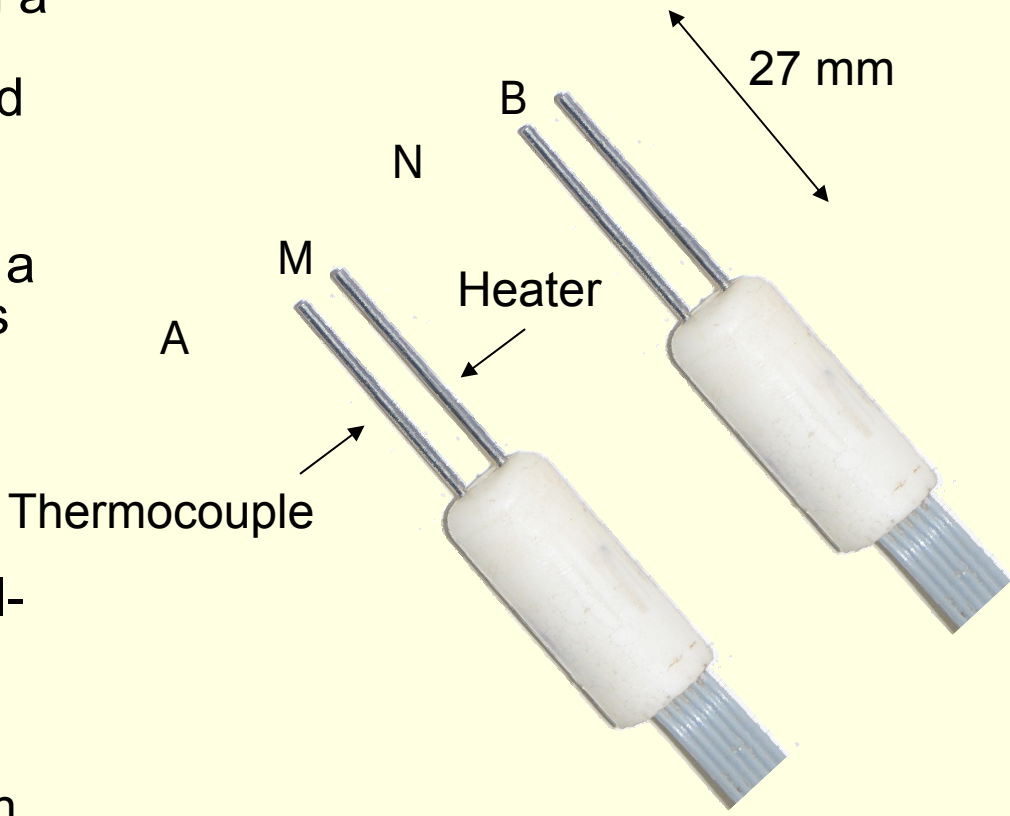
- Multifunctional sensor
  - Complex measurements
  - Integrated interpretation
- Water content and electrical conductivity
- Heterogeneity at a wide range of scales
- Sampling volume
- Heat-pulse method
- Direct current EC



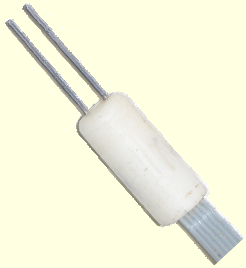
Objectives

- Sense water content using a physical property independent of salinity, and measure electrical conductivity
- Design, construct and test a sensor providing estimates of
  - water content
  - electrical conductivity

  at a comparable sampling volume by pairing two dual-probe heat-pulse (DPHP) sensors
  - dual-probe heat-pulse sensor (Ham and Benson, 2004)



Heat Pulse Theory



Knight and Kluitenberg (2004) model for predicting volumetric water content :

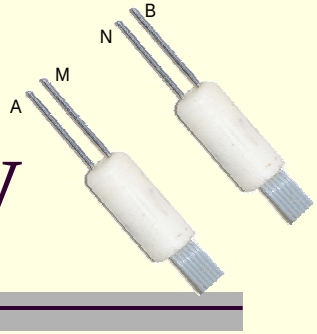
$$\rho c \approx \frac{q' t_0}{e \pi r^2 \Delta T}\left(1 - \frac{1}{24}\varepsilon^2 - \frac{1}{24}\varepsilon^3 - \frac{5}{128}\varepsilon^4 - \frac{7}{192}\varepsilon^5\right)$$

$$\varepsilon = t_0 / t_m$$

$$\theta_v = \frac{\rho c - \rho_b c_s}{\rho_w c_w}$$

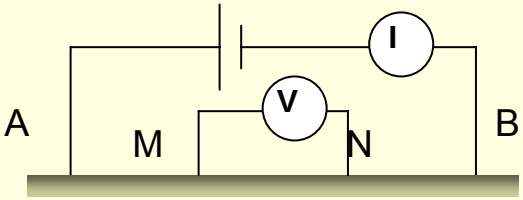
c = specific heat capacity
ρ = bulk density
q' = rate at which heat energy is released
t_0 = heater firing time
t_m = time to max temp
r = apparent probe spacing
ΔT = Change in Temp

Electrical Conductivity Theory



Measurement of the bulk electrical conductivity σ:

$$\sigma = \frac{I}{2\pi V}\left[\left(\frac{1}{r_{AM}} - \frac{1}{r_{AN}}\right) - \left(\frac{1}{r_{BM}} - \frac{1}{r_{BN}}\right)\right]^{-1}$$

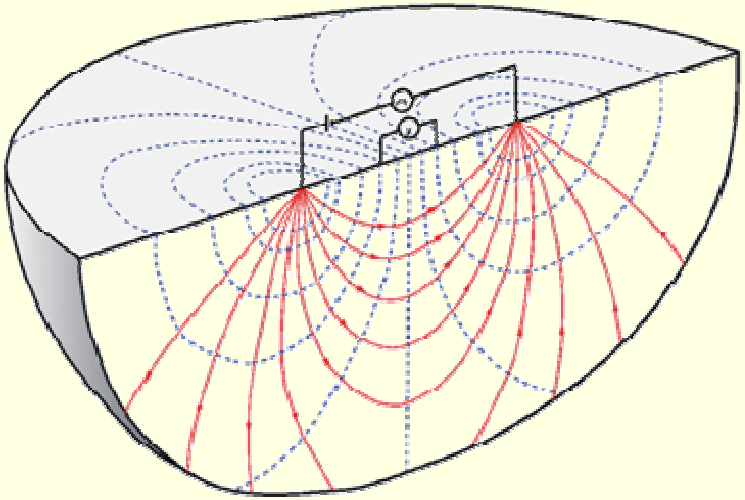


Prediction of the solution electrical conductivity σ_w:

Archie (1942)

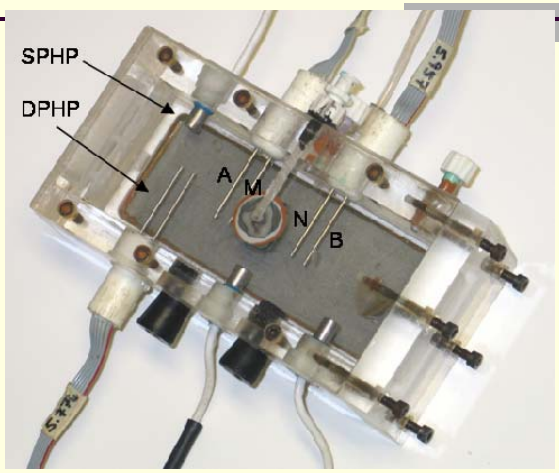
$$\sigma_w = a\Phi^{-m}S_w^{-n}\sigma$$

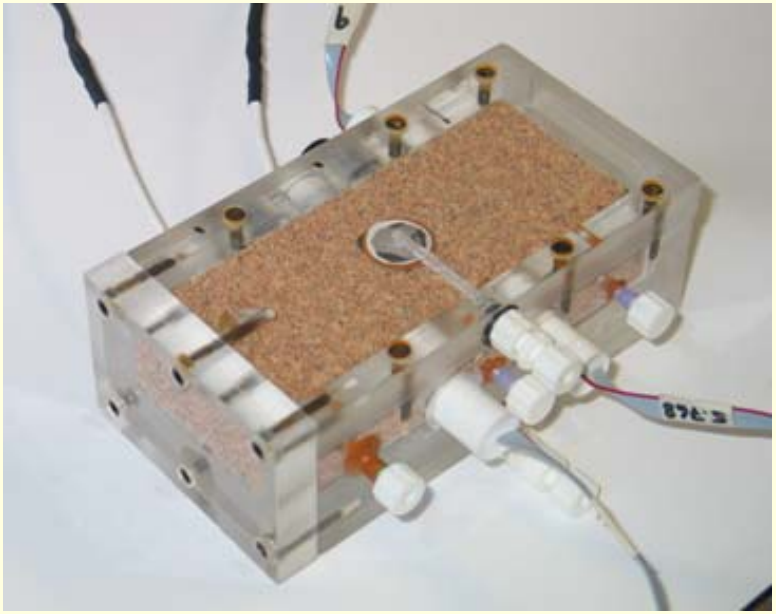
where: σ_w... pore water conductivity
S... saturation
Φ... porosity
a, m, n... parameters



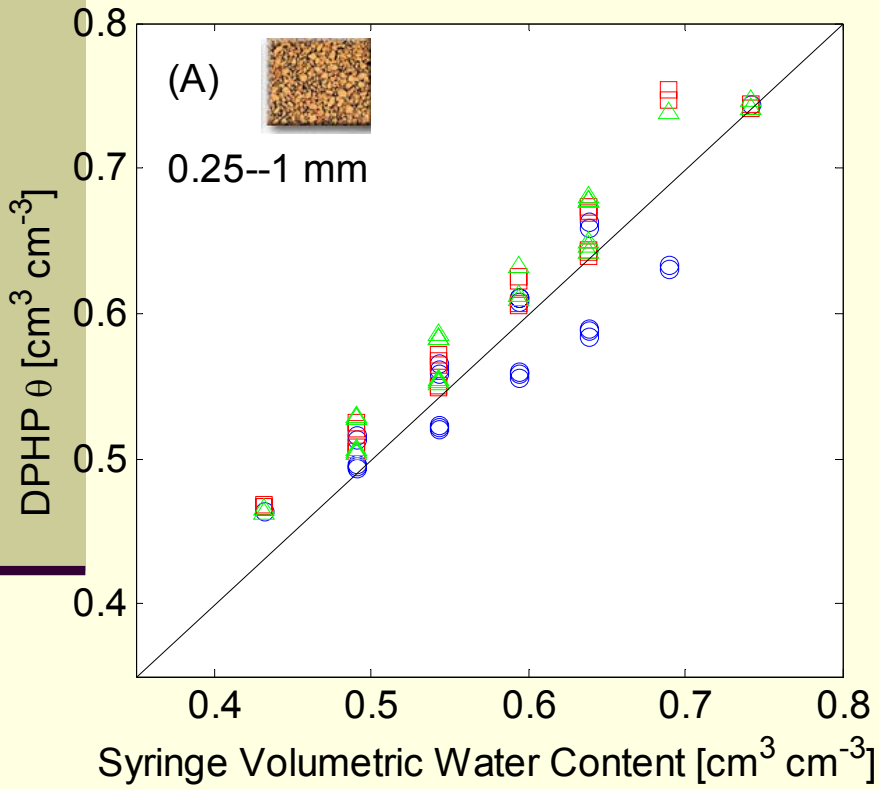
Implementation

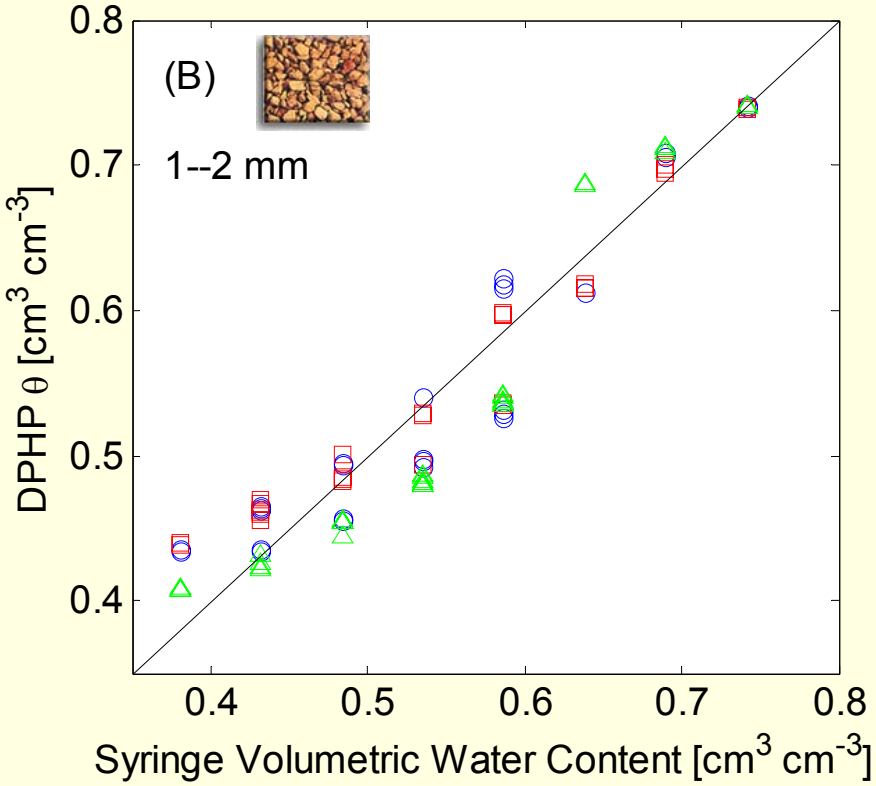
- Shallow sample cell (2cm tall)
- Water addition/removal capability
  - porous plate at the bottom
- DPHP and DPHP/4-electrode
- Aggregated clays
  - 0.25—1 mm
  - 1—2 mm





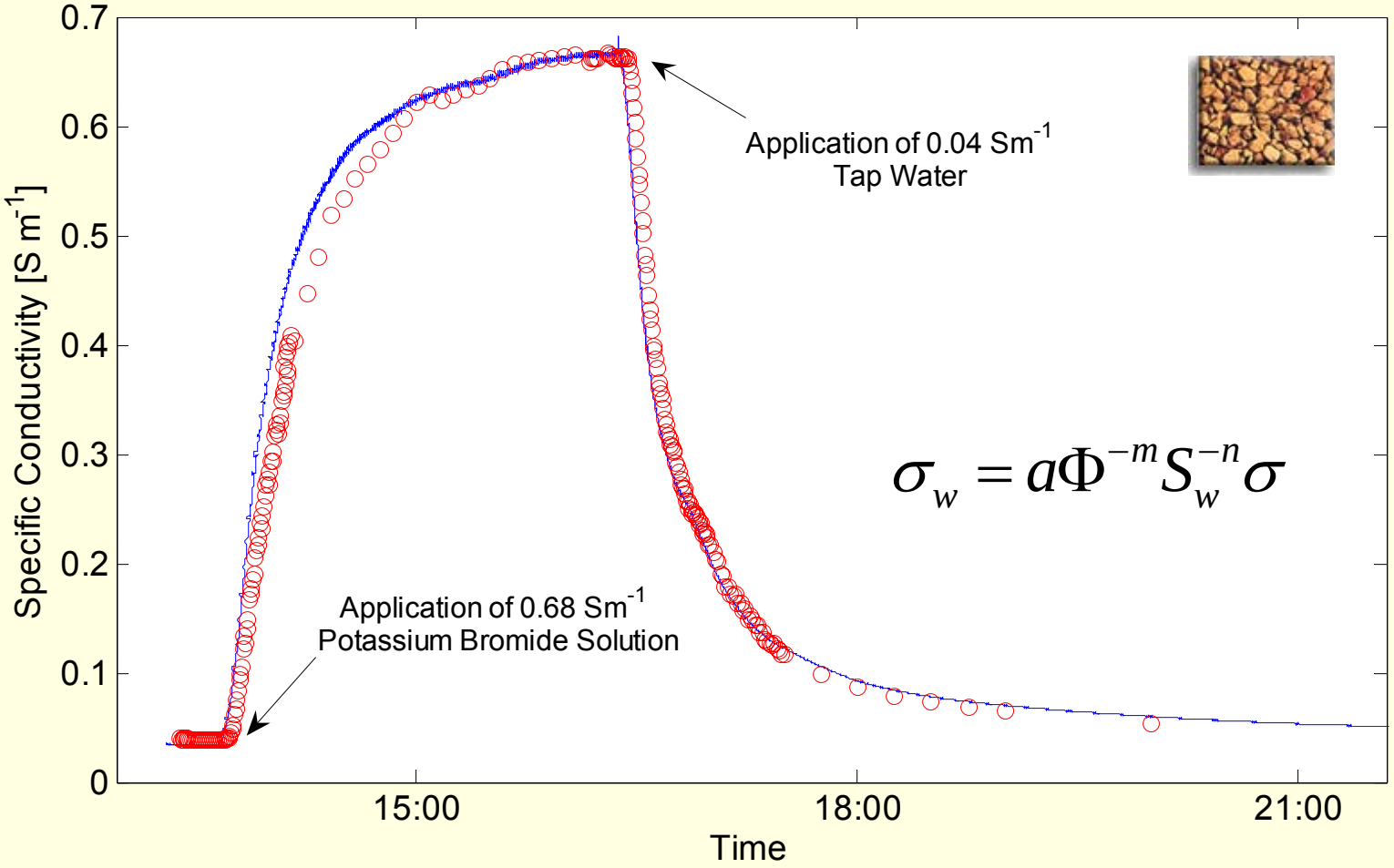
Water Content Prediction





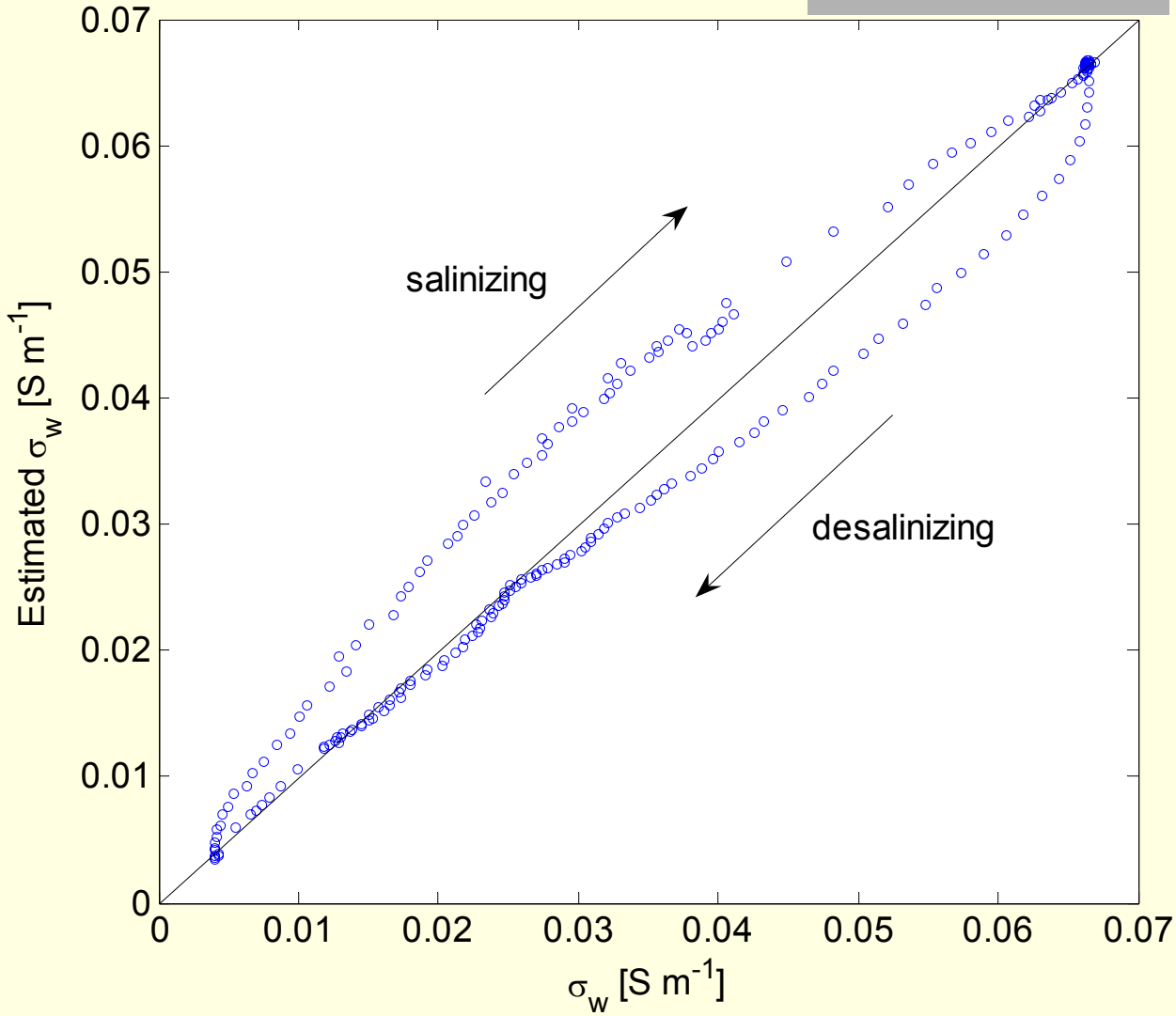
Change to cell water content!

Saturated measurements with a solute pulse

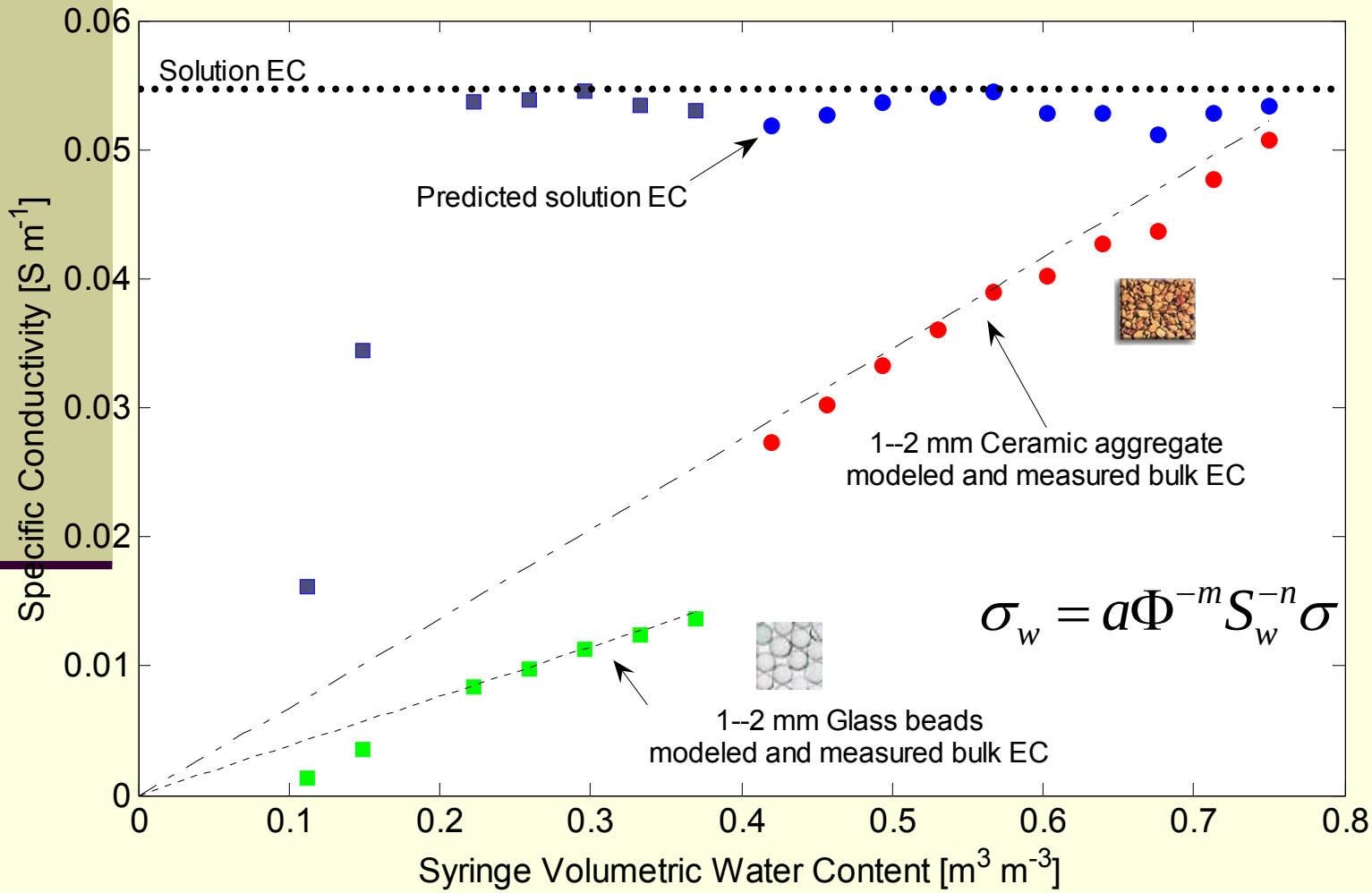


$$\sigma_w = a\Phi^{-m}S_w^{-n}\sigma$$

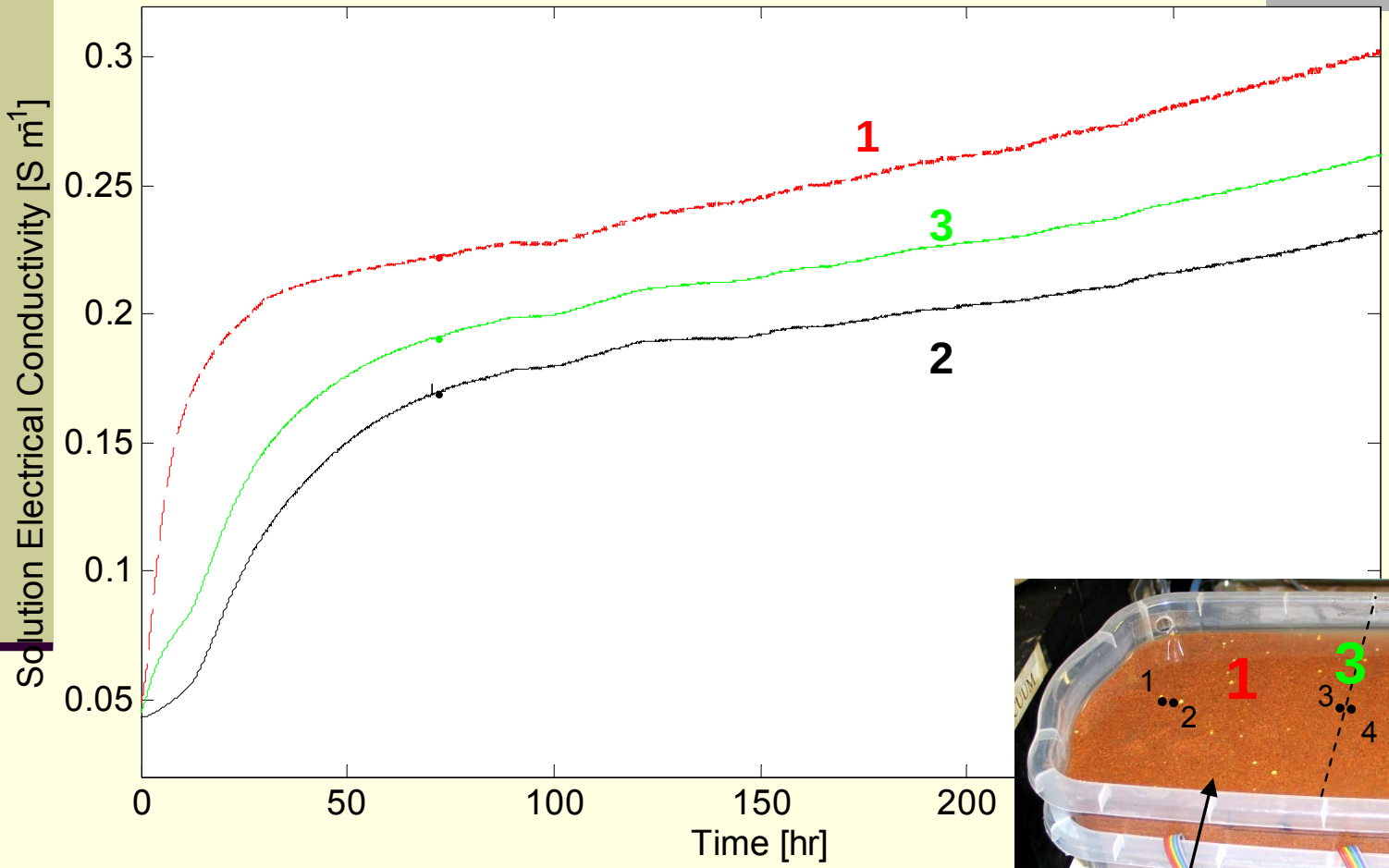
Saturated measurements with a solute pulse

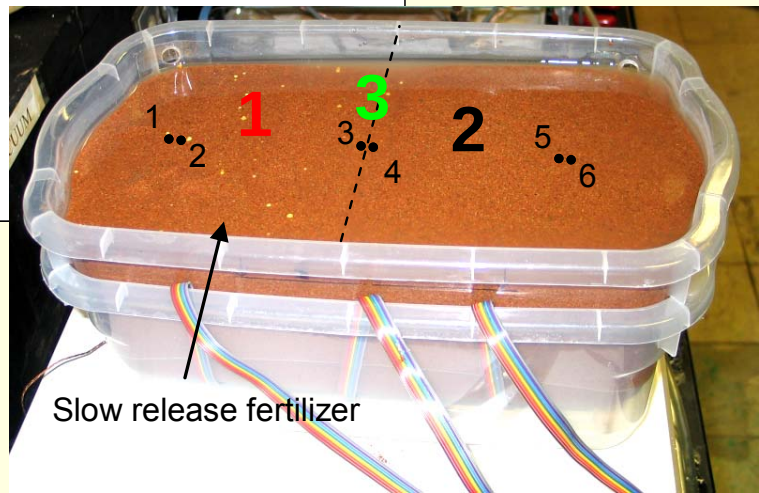


Unsaturated static measurement



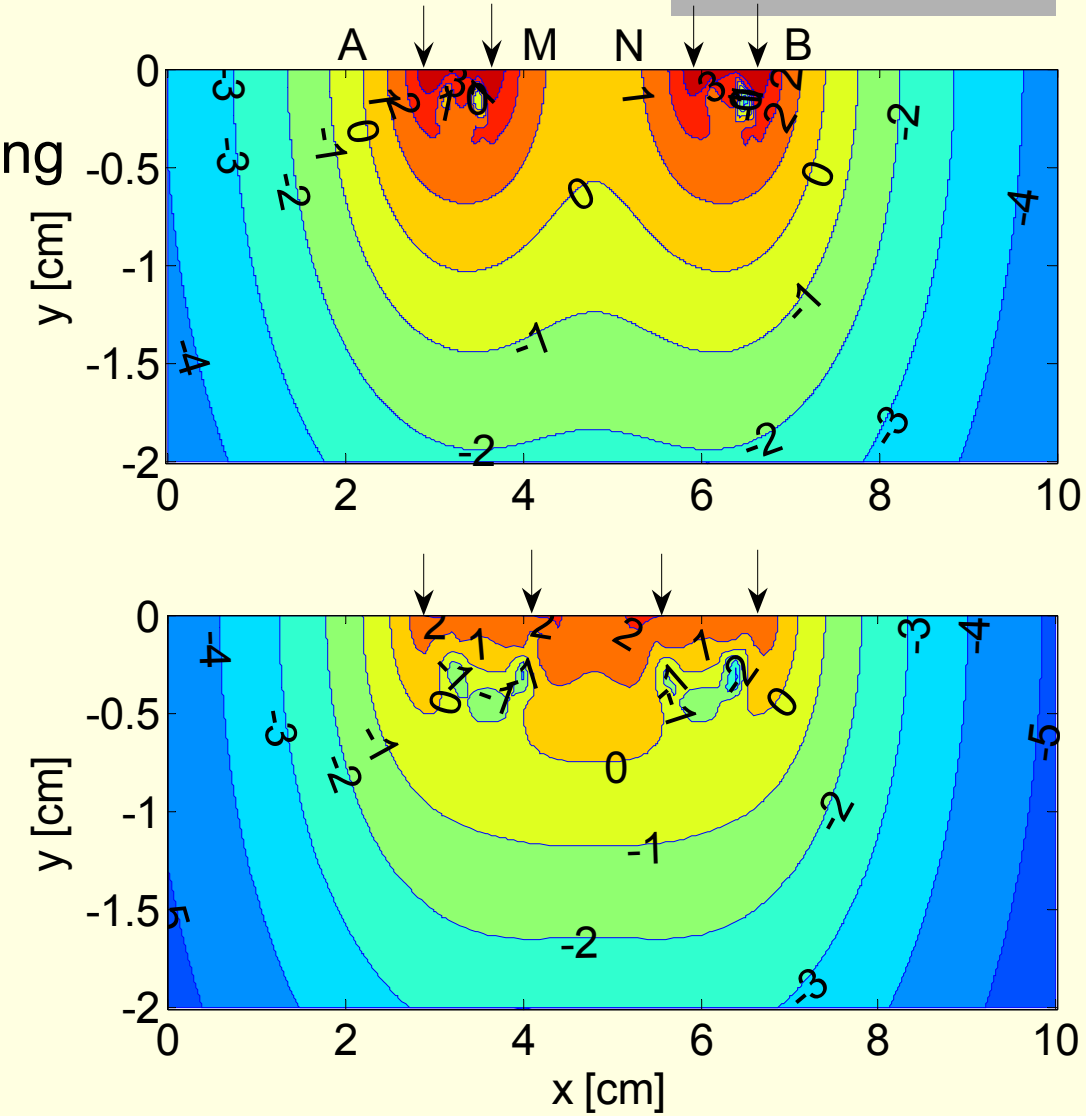
Nutrient monitoring





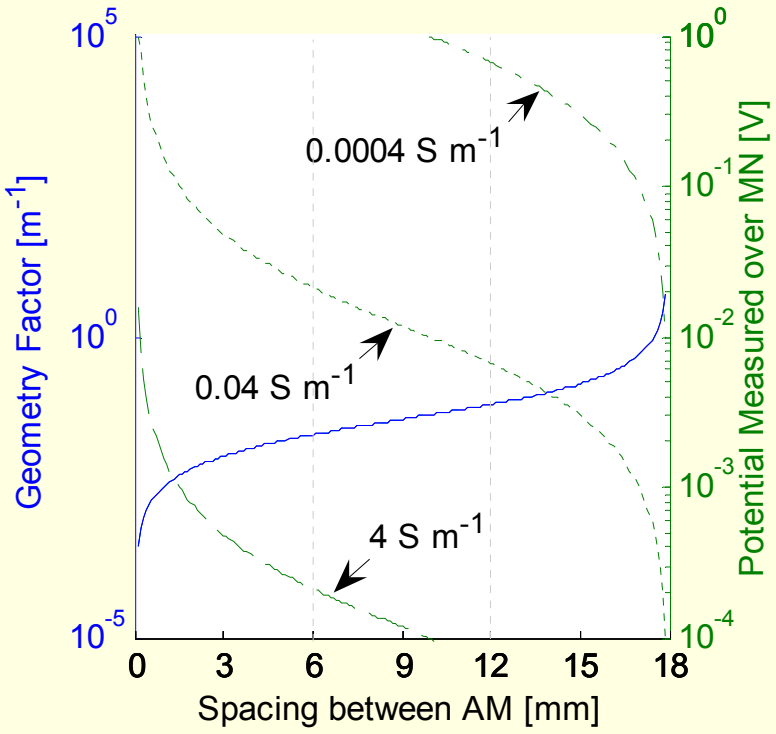
Sensitivity distribution

- Factors
  - Electrode spacing
  - Pair spacing
  - Depth
  - ???



Summary

- Integration of heat-pulse water content and 4-electrode electrical conductivity sensing
- In-situ predictions in comparable sampling volume
- Monitor fluxes of water and solutes

- Poster presentation: “Measuring Electrical Conductivity Using A Low-Power Data-Logging System” by Lewis et al.

Measurement Accuracy