Layered Soil Salinity and Moisture Effects on Electromagnetic Induction Measurements (Sounding) in a Soil Profile

Hiruy Abdu - Biological and Irrigation Eng., USU
David Robinson – Geophysics, Stanford University
Scott Jones - Plants, Soils and Biomet., USU

WSSS , Park City June 19 2006

UtahState UNIVERSITY

Presentation Outline

- Motivation
  - Objective
- Electromagnetic Induction (EMI)
- Materials and Methods
  - Area of Study
  - Equipment
  - Profile Measurement
- Preliminary Results
- Application
- Summary

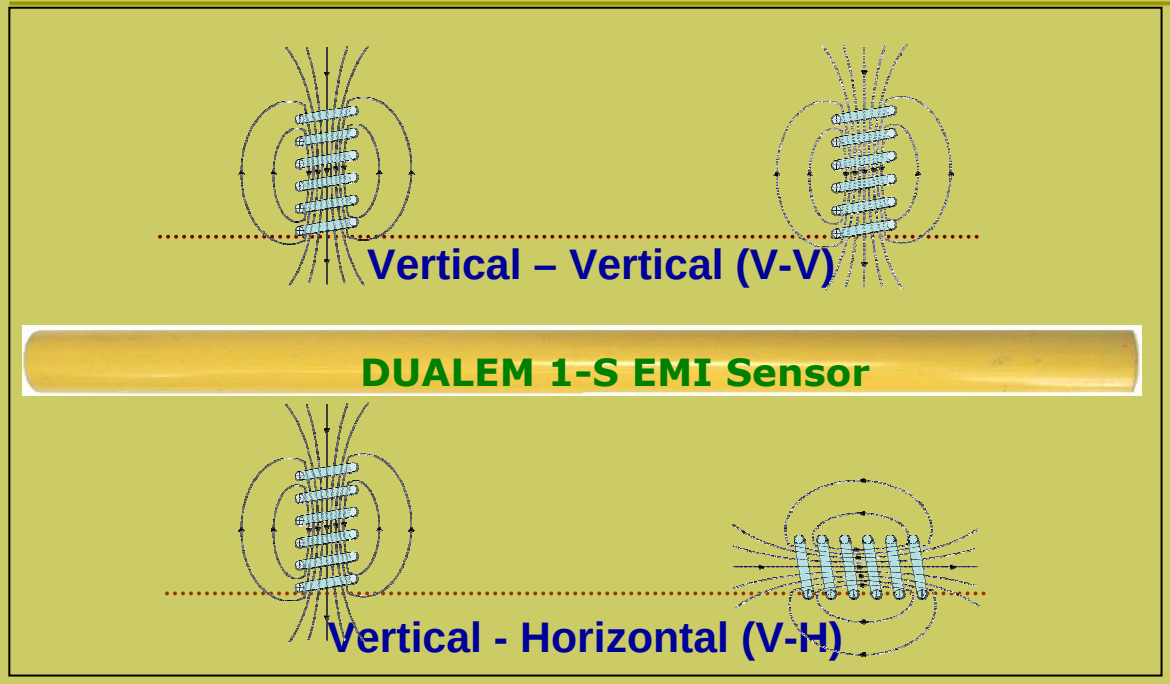
Motivation

- Modeling of subsurface processes is limited by the availability of time-sensitive high resolution maps of subsurface architecture.
- Knowledge of subsurface layering combined with EMI mapping can give a more thorough picture of the subsurface for hydrological modeling.

Objective

- Demonstrate the utility of EMI sounding for determination of layering in a soil profile.

Electromagnetic Induction (EMI)



EMI Sensor Characteristics

Operating frequency: 9 kHz

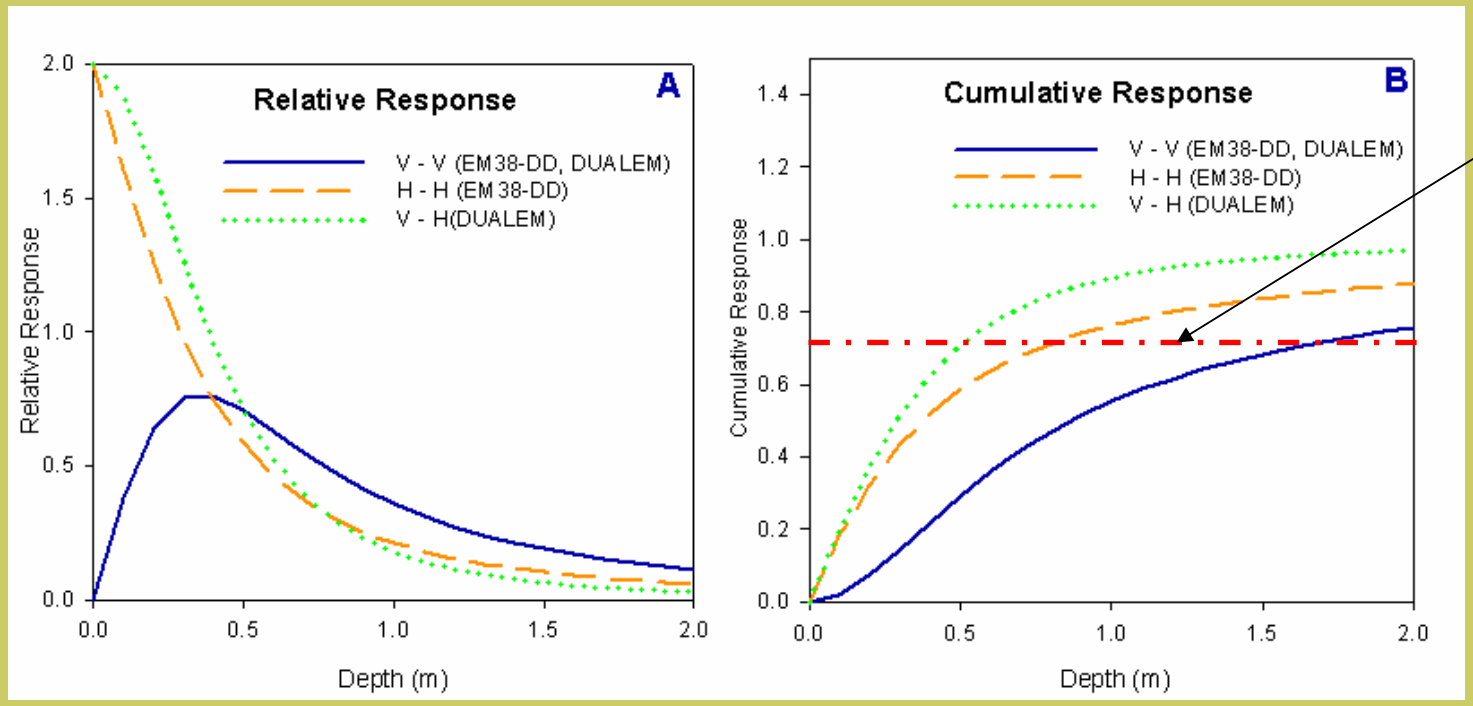
Depth Of Exploration (DOE): V-V 1.5 m

V-H 0.6 m

- Alternating current passing through the transmitter coil produces a primary magnetic field (Hp).
- The primary magnetic field induces small alternating currents creating a secondary magnetic field (Hs) which induces a small alternating current in the receiver coil.

$$EC_a = \frac{4}{2\pi f \mu_o s^2}\left(\frac{H_S}{H_P}\right)$$

Relative and Cumulative Response



$$\phi_{V-V}(z) = \frac{4z}{(4z^2+1)^{3/2}}$$

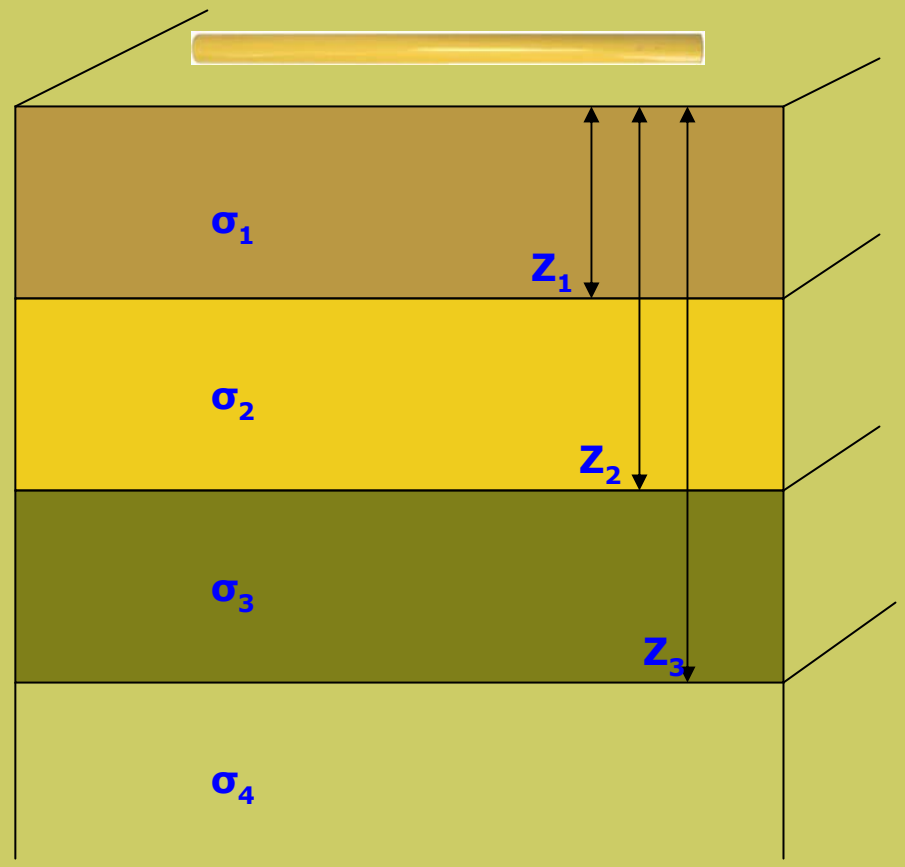
$$\phi_{V-H}(z) = \frac{2}{(4z^2+1)^{3/2}}$$

$$R_X(z) = \int_z^\infty \phi_X(z)\,dz$$

$$R_{V-V}(z) = \frac{1}{(4z^2+1)^{1/2}}$$

$$R_{V-H}(z) = 1 - \frac{2z}{(4z^2+1)^{1/2}}$$

Layered Earth System



$$EC_a = \sigma_1[1 - R(Z_1)] + \sigma_2[R(Z_1) - R(Z_2)] + \sigma_3[R(Z_2) - R(Z_3)] + \sigma_4[R(Z_3)]$$

$\sigma_{1,2,3}$ – bulk conductivities of layers 1,2,3,
σ_4 - bulk conductivity of uniform earth
$R(Z_{1,2,3})$ - cumulative response at $Z_{1,2,3}$

EMI Mapping

EMI instruments are gaining wider use due to:

- non-destructive nature
- rapid response
- ease of integration into a mobile platform

Factors influencing EC_a measurements include:

- soil salinity
- porosity
- clay content

water content
bulk density
mineralogy

Study Area

USU Greenville Farm, Logan, UT.

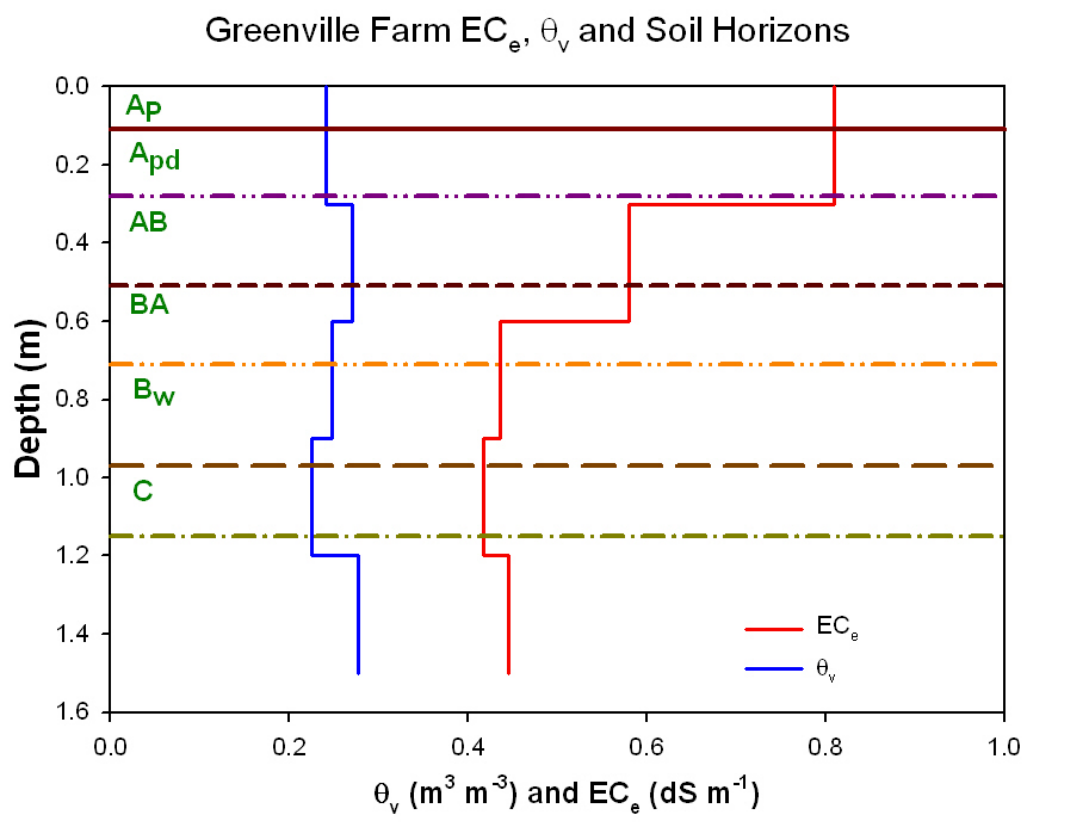
Soil : Millville Series

coarse-silty, carbonatic, mesic Typic Haploxeroll

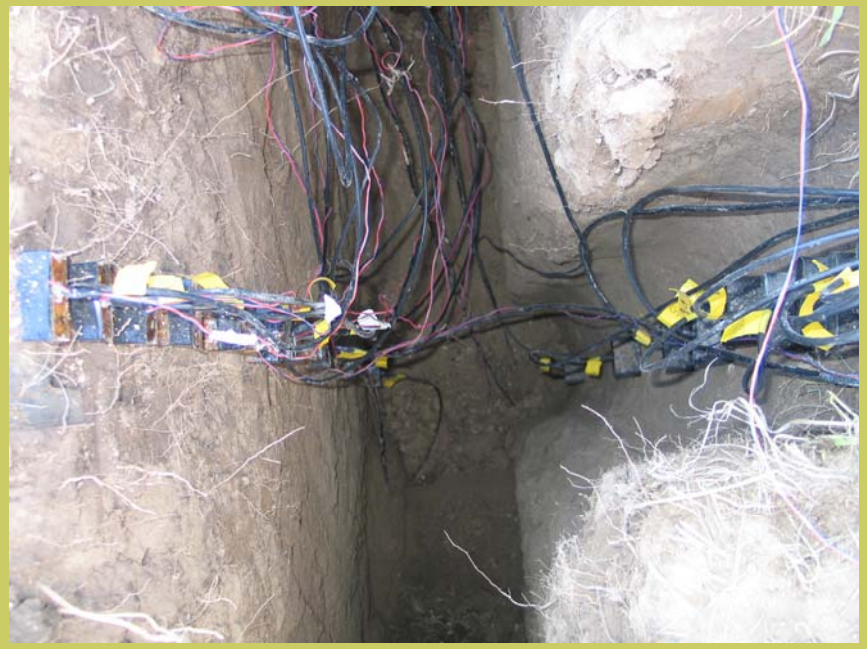
Mean annual Precip.: 422 mm

Mean annual temp. : 8.6°C

Large amount of $CaCO_3$ (>40%) disseminated throughout the soil



Profile TDR Setup



2 m deep profile

Two sets of 11 probes

Long (30 cm) probes in grass pasture

Short (15 cm) probes in bare soil

Probe Location:

Every 5 cm from 0.05 to 0.25 m

Every 10 cm from 0.25 to 0.45 m

Then at 0.65, 1, 1.5 and 2.0 m

We measured: θ_v, EC_a, Temperature

EMI Sounding/Directed Sampling

DUALEM-1S

connected to Allegro CX handheld computer

2 m away from TDR sensors

V-V and V-H measurements taken every 15 cm from ground up to 1.8 m

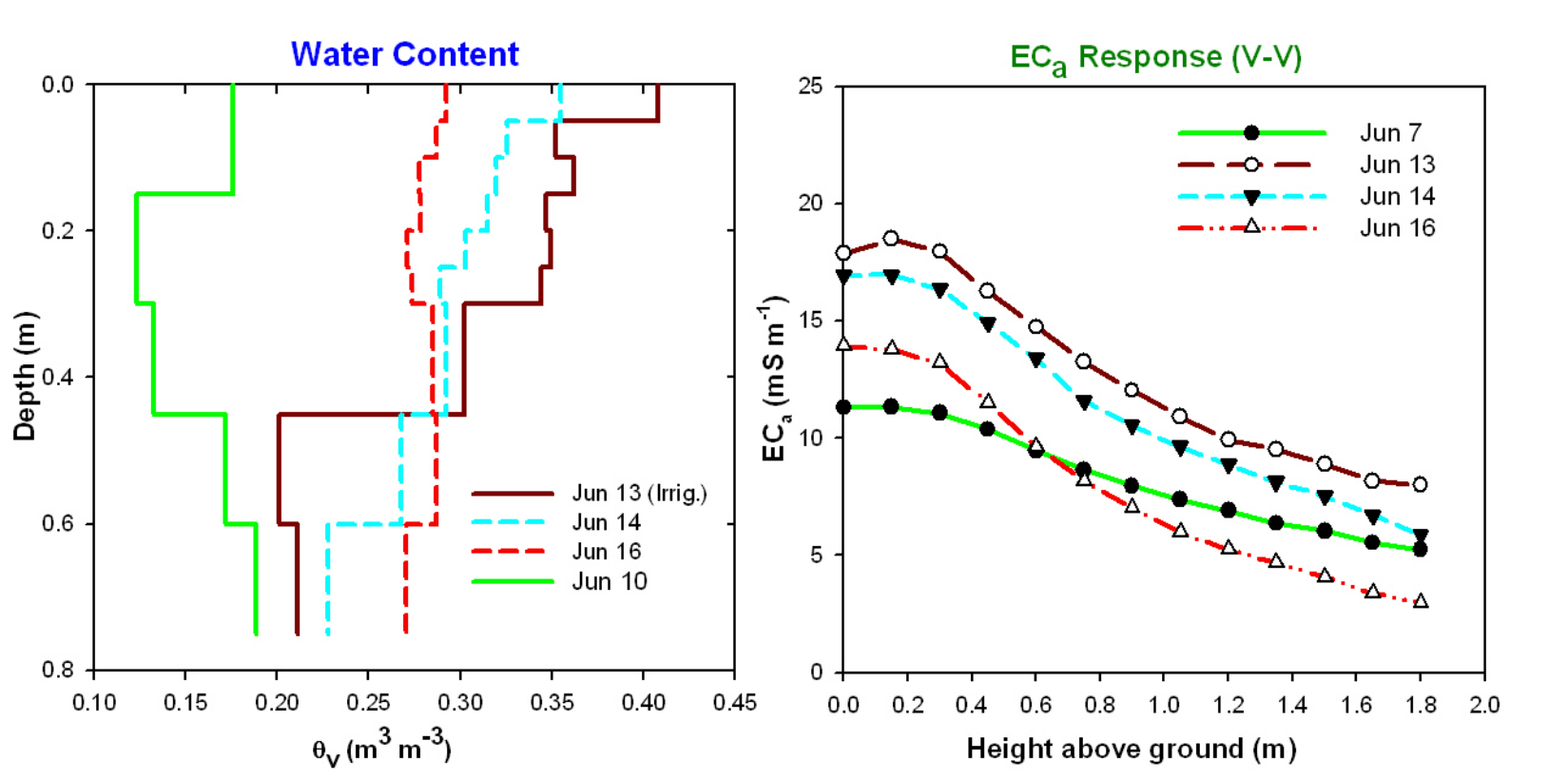
A background conductivity check at 2.1 m

A sprinkler system used to water the pasture - 5 cm of water applied

Measurements taken 30 minutes after application and every day

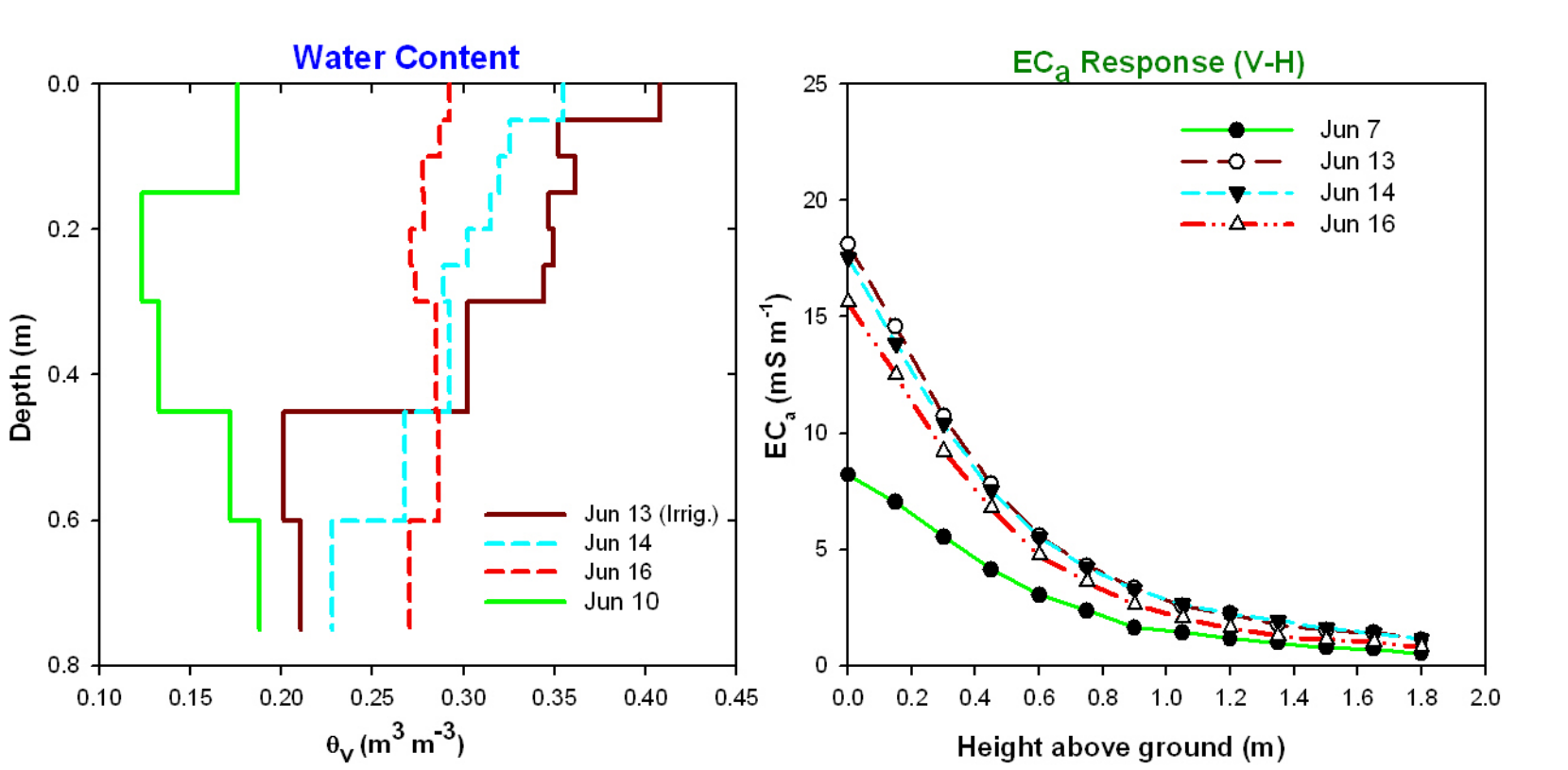
Soil samples taken(0-0.7m) for θ_v

V-V EC_a Response



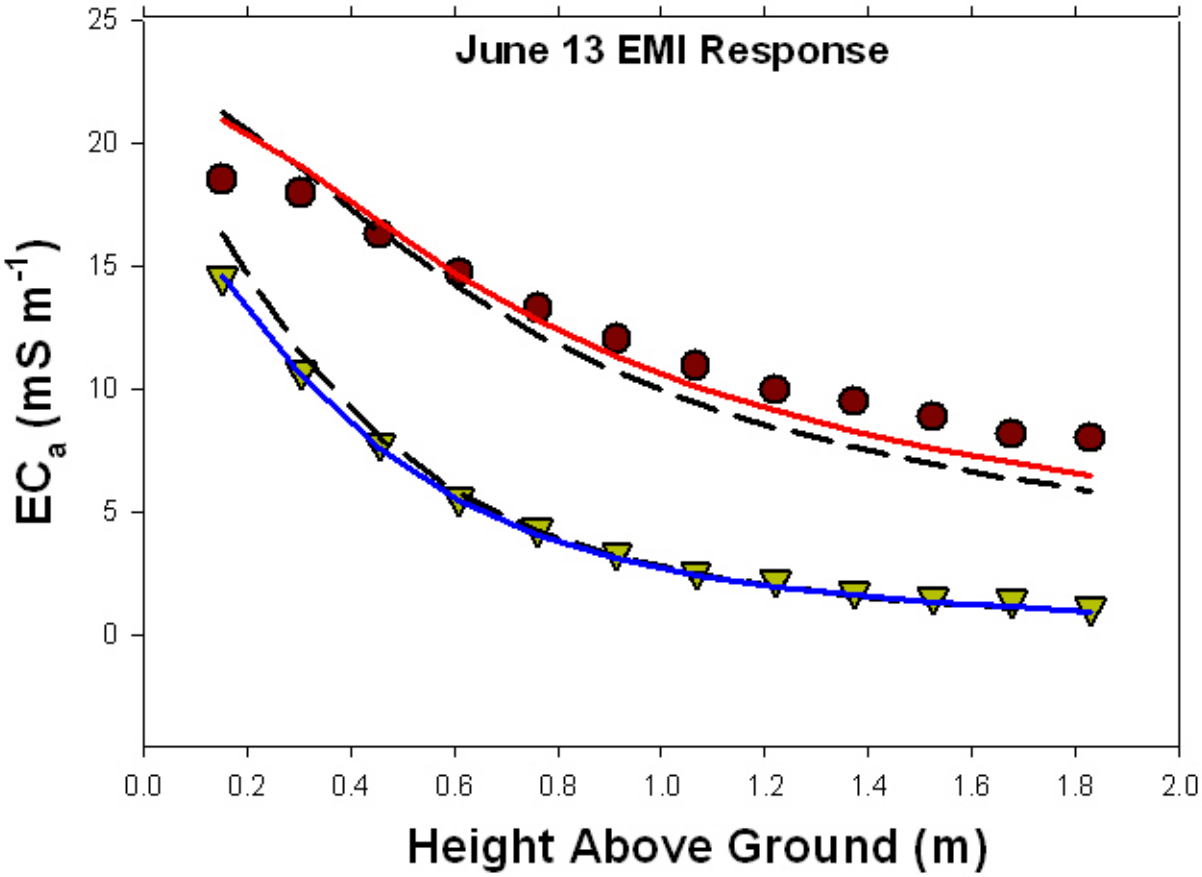
DOE = 1.5 m, V-V orientation perceives the overall trend

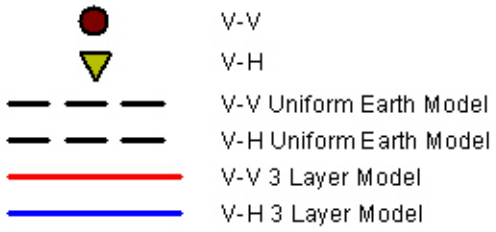
V-H EC_a Response



DOE = 0.5 m, V-H orientation focuses on the top layers

Layer Modeling





RMSE

	Uniform	3 Layer
V-V	0.51	0.36
V-H	0.18	**0.07**

Hydrology Application

Reynolds Creek Experimental Watershed 240 km^2 semi-arid mountainous watershed Located in southwestern Idaho.

Working on the 36 ha Reynolds Mountain East sub-watershed

Elevation Range: 2012 -2141 m

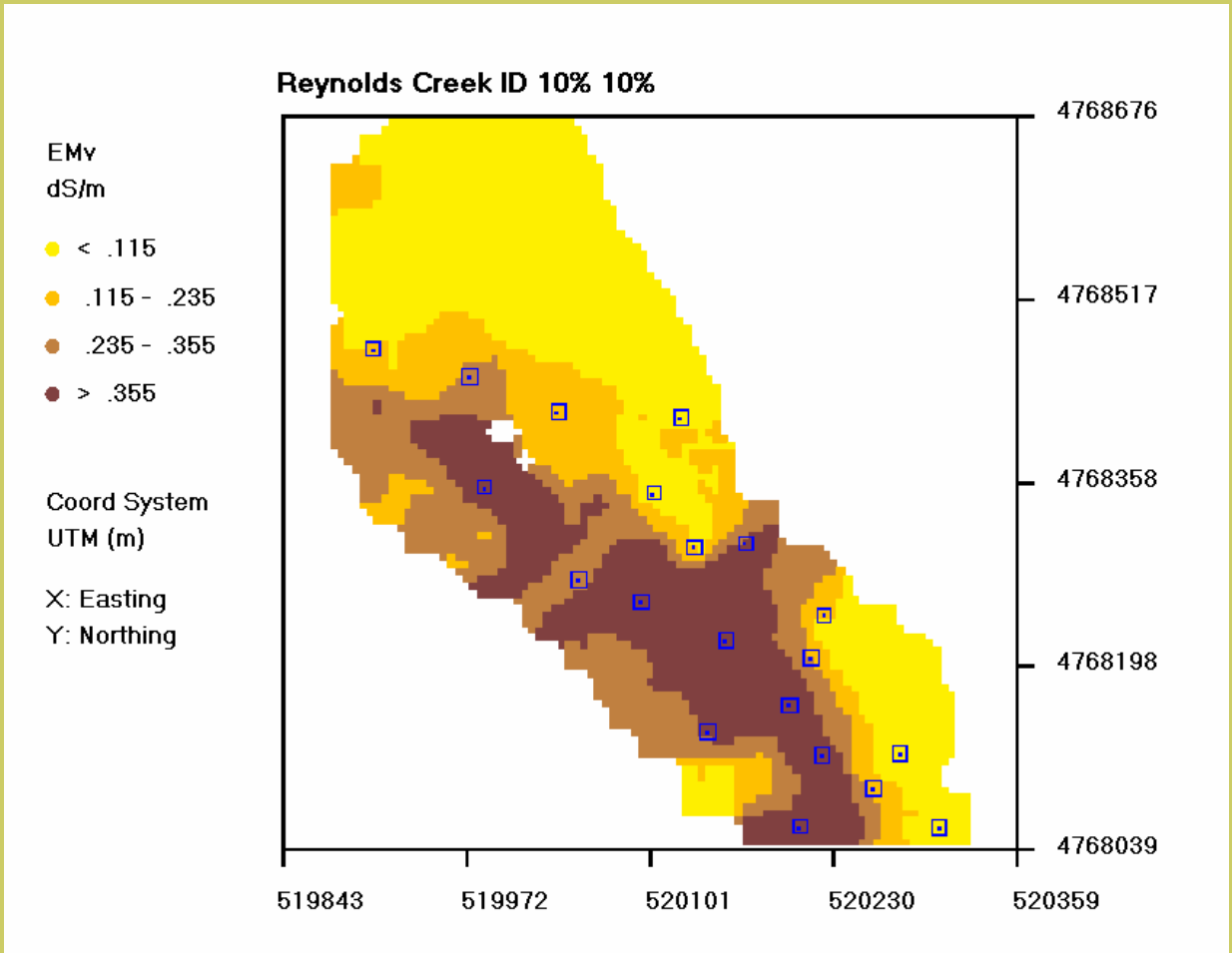
From, Seyfried et al. 2000

Data Analysis

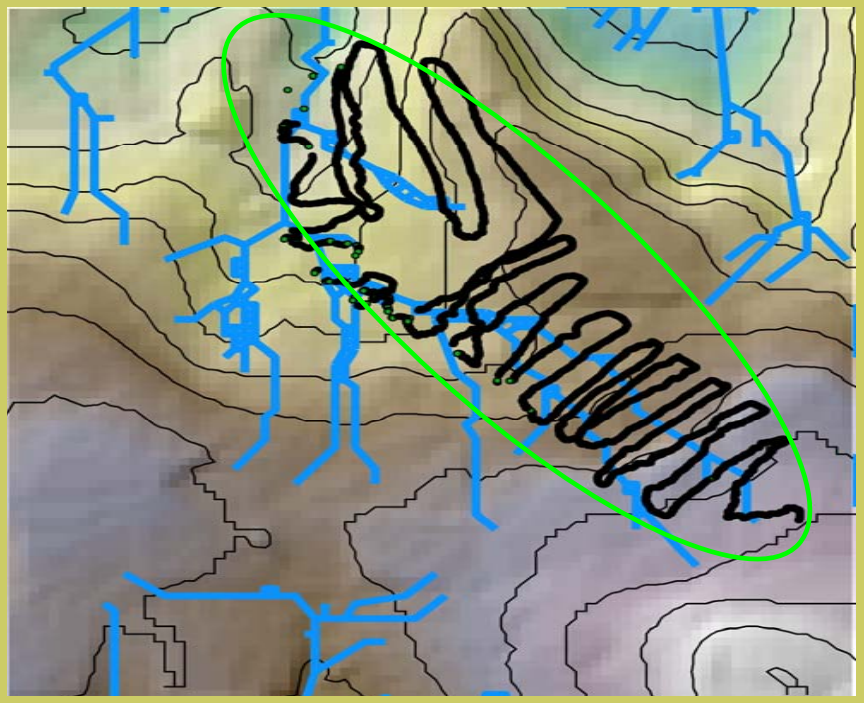
- An Electrical conductivity Statistical Analysis Package – ESAP – was used to obtain soil samples from 20 points.
- The 20 soil samples were analyzed in the lab for:
  - Volumetric moisture content
  - Particle size analysis (for clay content)
  - Electrical conductivity of the saturation paste extract (EC_e)
- ESAP was used to estimate the theoretical strength of correlation between EC_a and EC_e, clay percentage and soil moisture content.

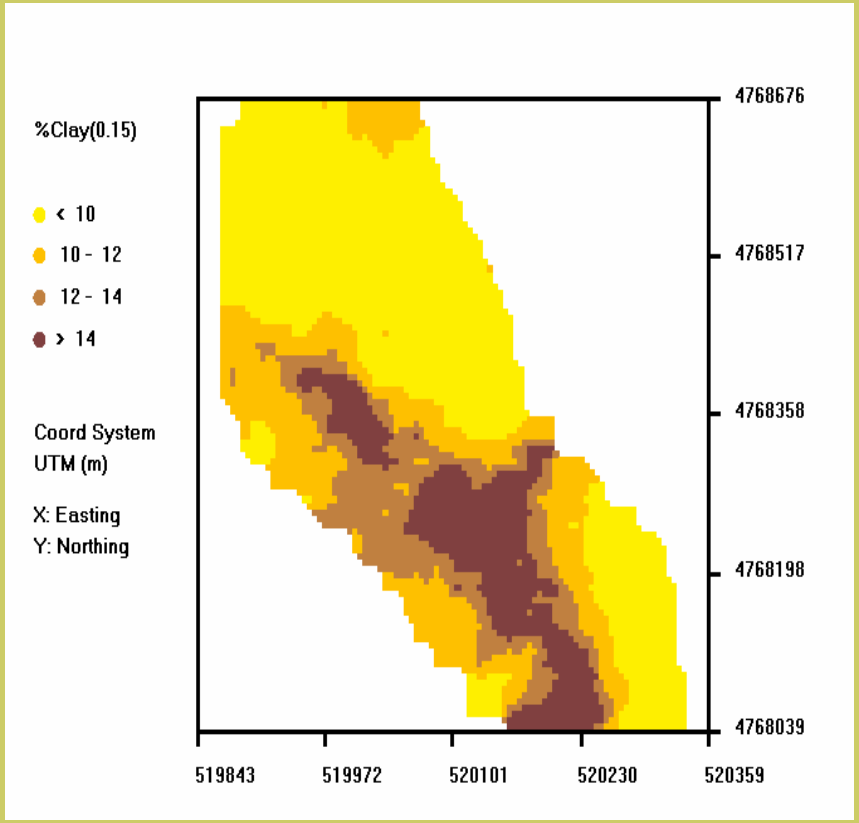
	EC_a	EC_e	Clay %
EC_e	0.92		
Clay %	**0.94**	0.83	
Vol H_20	0.54	0.55	0.23

Resulting ECa Map



Stream Network - Clay Percentage





Streamnet = con(flowacc >= 50,1)

Summary

- EMI vertical sounding is useful for subsurface layer characterization using directed sampling of water content, EC_e and texture.

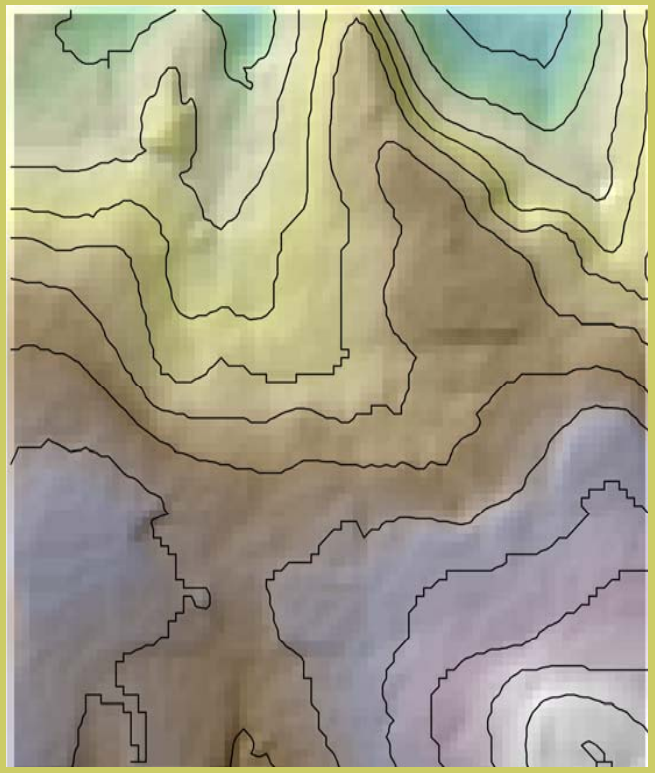
- EMI spatial mapping combined with vertical sounding and directed sampling provides a valuable tool for modeling watershed hydrological processes.

Future Work

- Use TDR setup to get continuous soil water content, EC_a and temperature information for better modeling of bulk layer conductivity.

- Combine automated sounding with EMI mapping for high resolution spatial subsurface characterization.

Terrain Analysis using GIS

- 10m-DEM
- Terrain Analysis using Hydrology tool in the Spatial Analyst toolbox in ArcGIS 9.1

DEM → Fill Sinks → Flow Direction → Flow accumulation → Identify Channel Networks