**Project Title:**
*Using geophysics to identify land use and seasonal climate influences on groundwater recharge: implications for water resources and ecosystem sustainability*

**PIs:**
*Remke L. Van Dam – Department of Geological Sciences  
David W. Hyndman – Department of Geological Sciences*

**Date of Award:**

**Objective of the Study:**
To perform field surveys to obtain accurate information of the temporal and spatial characteristics of the vadose zone, including soil moisture distribution, depth to the water table, soil heterogeneity, water infiltration characteristics, frozen soil depths, and soil temperature changes.

**Key Findings:**

### Site description
Since mid-October 2006, fifteen 2-D Surface Electrical Resistivity Tomography (ERT) datasets have been collected at a research site south of the MSU campus. During site visits, electrical resistivity cables are laid out and connected to the 84 permanently installed electrodes used to collect apparent resistivity readings.

At the site, a managed ecotone separates a forest with mature ~25-30m tall deciduous trees from an open field that is covered with short wild grass (Figure 1). The forested area of the site is dense, and during the summer months the tree canopy insulates the forest floor from direct solar radiation. The canopy remained green until late October, 2006, and gradually turned yellow towards early November. By mid November all leaves had fallen off the trees. In contrast, the vegetation in the open area remained green and potentially active until first snowfall in early January, 2007. The unsaturated zone thickness at the site is about 15 meters. The subsurface is composed of one meter of organic-rich silty clay soils underlain by a thick layer of medium to fine grained glacial sands. Along the length of the electrode array, the ground surface is relatively flat with only about 80cm of elevation along the line from the forested area to open grassy area.

**ERT data – Seasonal variability**
Wenner and Dipole-Dipole data sets were inverted for differences in resistivity using the methods described in literature. Differences in seasonal vegetation dynamics strongly influence the resistivity changes observed through the study period. During the late Fall, when trees were active and weather conditions were favorable for high transpiration rates, water abstraction by deep root zones beneath the forest increased the resistivity in this region. In contrast, the open grassy area showed an increase in resistivity, due to ET, only from the shallow subsurface.
(Figures 2, 3a); no significant change was observed in the deeper zones below the open area. After leaves fell off the trees, the resistivity in the deeper root zone beneath the forest stabilized, and the areas closest to the surface became less resistive after precipitation events (Figure 3b).

Significant reductions in resistivity (increase in moisture content) were observed at the site from early December to the end of February of 2007. Despite the continued activity of the grasses throughout the early winter period, reduced solar radiation decreased the ET potential (Figure 2), which resulted in a slight wetting of near-surface zone in the open area (Figure 3c). Finally, onset of cold winter temperatures led to freezing of the soils near the surface under both land cover types as indicated by increases in resistivity (Figure 3d). Some redistribution of soil moisture beneath the forest was observed from early January to February, 2007 (Figure 5d).

**Conversion of resistivity to soil moisture**

In order to use the data from this pilot project for studies of groundwater recharge, carbon and nutrient fluxes, land use, and climate change it is important to translate the ERT data into quantitative soil moisture changes. To obtain data on changes in soil moisture content from the difference inversions of ERT data, we use 1) laboratory measurements of the soil water content-resistance relationships for different soils, 2) calibrations based on soil moisture monitoring probes, and 3) 1D modeling of vadose zone processes. The relationship between soil moisture and electrical resistivity is described by a well-defined power law (Figure 4a). Soil moisture probe data (Figure 4b) provide additional information for the conversion of electrical resistivity to soil moisture. We also use 1D infiltration models (HYDRUS) to simulate transient soil moisture and infiltration at the site in both forested and open grassy areas. Simulated moisture profiles for the different land cover types will then be used to quantitatively interpret the observed resistivity changes in terms of storage, ET, and recharge.

![Figure 2](image)

**Figure 2.** Weather data from October 2006 to February 2007 for the study site. Dates correspond to the data sets that have been collected. Color shadings correspond to the four resistivity difference inversions in Figure 3a-d.
Figure 3. Difference inversions of time-lapse Wenner resistivity data showing percent resistivity changes along a 124.5m long transect across a forest-grassland boundary. a) Soils beneath the forest (left) are losing soil moisture due to transpiration while surface soils in the open area are drying due to both transpiration and direct evaporation. b) Forest root water uptake ceased after leaves fell off the trees, and some wetting occurred after precipitation in both forested and open areas. c) Significant wetting was observed beneath the forest in the absence of any water use by the trees. d) Near surface resistivity increased in both the forested and the open areas in response to soil freezing.

Figure 4. a) Resistance vs. water content relationships developed for different soil types from the study site. b) Soil moisture observations at 80cm depth in the forest. Very low moisture contents are observed prior to the leaf off period in Mid November.
**Presentations:**
* Graduate student, Department of Geological Sciences
^ Undergraduate student, Department of Geological Sciences


**Publications (list works published or in review):**

**Grants Submitted as a result of this work:**

**Key points to include in CWS annual report:**
Our research demonstrates that seasonal and short duration variations in soil moisture can be effectively monitored and characterized. This has potential implications for studies of climate and land use changes, groundwater recharge, carbon and nutrient fluxes, and contaminant transport. In addition, we believe that the proposed method can be effectively used to evaluate changes in soil moisture across transitions in soil types, topographic features, and steep valleys with strong contrasts in incoming solar radiation. To our knowledge, no other method or current study is capable of continuous imaging and quantifying soil moisture variability at scales of meters to hundreds of meters across such a range of boundaries.

Based on the pilot data collected with financial support of the Center for Water Science, we have submitted a proposal to NSF Instrumentation and Facilities (EAR/IF) to request funds for permanent installation of ERT equipment at various sites in Michigan and New Mexico to conduct more high-resolution and continuous measurement of vadose zone soil moisture dynamics. Later this spring and summer we plan to submit research proposals to NSF hydrology, NASA ROSES, and DOE NICCR.