Water, Climate & Food Security Conference for Students and Early Career Scientists

Prairie View A&M University, Thursday, 9 March 2023

Hydrology of Environmental & Agricultural Systems: Measurement & Simulation Across Scales

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Introduction to ARS

- The Agricultural Research Service (ARS) is the in-house research agency of the U.S. Department of Agriculture.
- ARS includes National Programs, Area Offices, and the Office of International Research Programs.
- ~750 research projects within 17 National Programs
- ~2000 scientists and post docs; ~6,000 other employees
- 90+ research locations, including overseas laboratories

- Mission (in my words):

***Feed the world & save the planet*.**

Our group's research scientists & areas of expertise

Dr. Dave Barnard Agro-ecology	• Physiological plant modeling • Ecosystem ecology & post-fire restoration • Snow hydrology & Water quality
Dr. Louise Comas Plant Physiology	• Plant stress and water use data • Plant growth and development under stress • Photosynthetic efficiency and acclimation to stress
Dr. Kendall DeJonge Agricultural Engineering	• Irrigation management & Deficit irrigation • Evapotranspiration & Infrared thermometry • Crop modeling
Dr. Sean Gleason Plant Physiology	• Water use efficiency & drought tolerance • Optimize water application and crop yield • Natural designs for success in water-limited habitats
Dr. Kyle Mankin, *Research Leader* Hydrological Processes	• Ephemeral Gully Erosion Model • Fire Effects on Hydrological Processes • Remote-sensing-based Evapotranspiration
Dr. Maysoon Mikha Soil Science	• soil fertility and microbial ecology • soil and crop management effects on soil quality/health • sustainable dryland cropping systems
Dr. Huihui Zhang Remote Sensing	• Infrared thermometry • Ground-based remote sensing • UAS-based remote sensing

Key Collaborators & Staff

- **ARS**: Rob Erskine, Nathan Lighthart, Lucretia Sherrod,
  Mike Murphy, Gale Dunn
- **USFS**: Chuck Rhoades; **US Army CoE**: Jeremy Giovando
- **CSU**: Olaf David, Holm Kipka, Mazdak Arabi, Anoop Valiya-Veettil*,
  Jeff Niemann, Stephanie Kampf, Aditi Bhaskar, Steven Fassnacht
- **Embrapa, Brazil**: Ricardo Figueiredo, Patricia Cruz
- **ETH, Switzerland**: Mike Schwank, Hannes Fluehler, Rainer Schulin
- **Inner Mongolia Ag. Univ., China**: Xiaohong Shi, Yong Wu

*Prairie View A&M

Systems Research Project

Spatial Modeling of Agricultural Watersheds:

Water and Nutrient Management and Targeted Conservation Effects at Field to Watershed Scales

Objective: Integrate field experiments with simulation models and decision support tools to address water and nutrient management on spatial scales from field to watershed scales.

The Agricultural Ecosytems Services (Ages) watershed model is a key component.

Introduction & Motivation

soil + water + … = food —> mammon

But it gets complicated, because …

we need to save the planet.

Altogether it's a global issue

of food security and ecosystem sustainability.

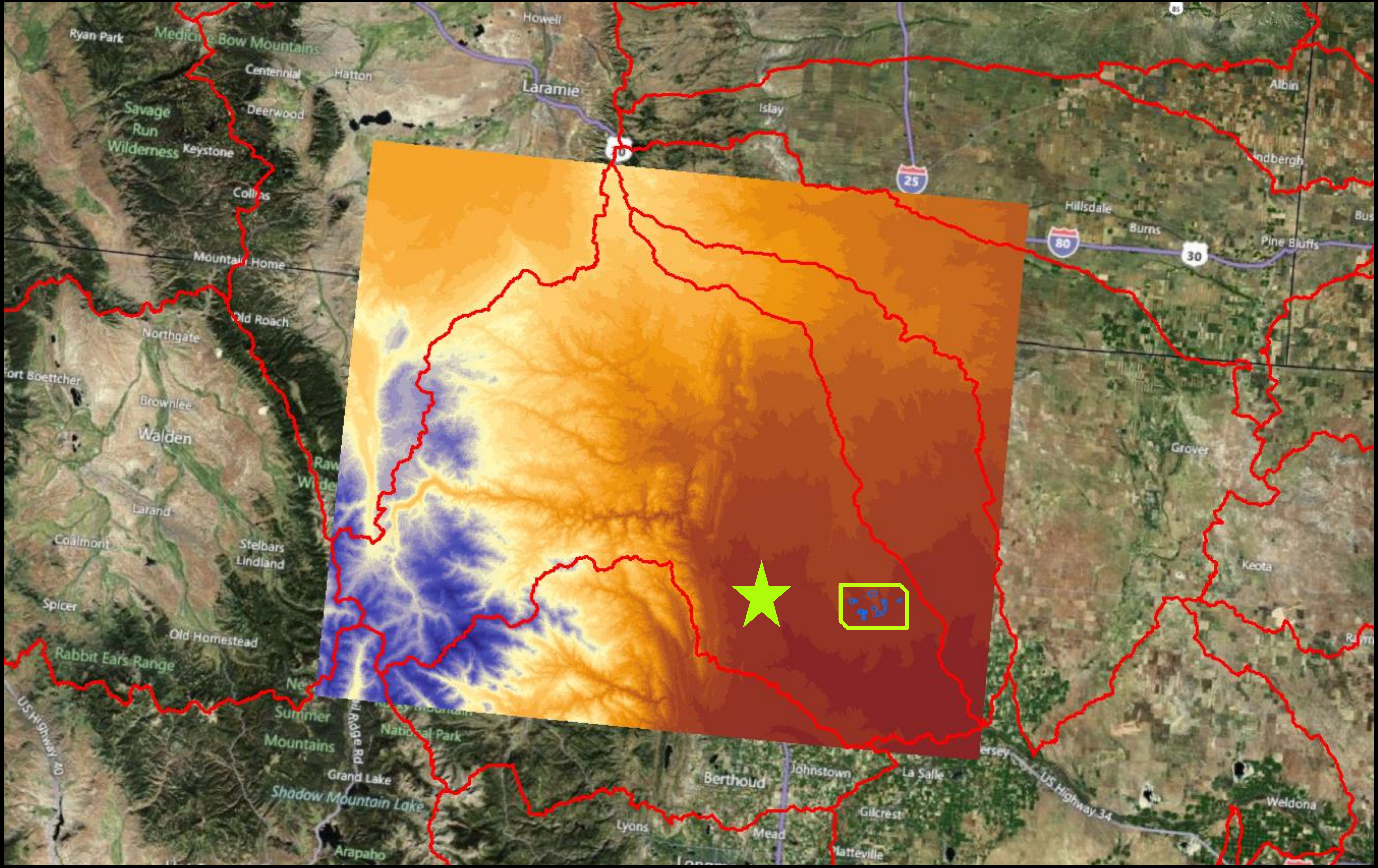
Technology to the rescue!?

Global Scale

Continental Scale

HUC 8-digit watersheds: http://water.usgs.gov/GIS/huc.html

Cache la Poudre Watershed Scale

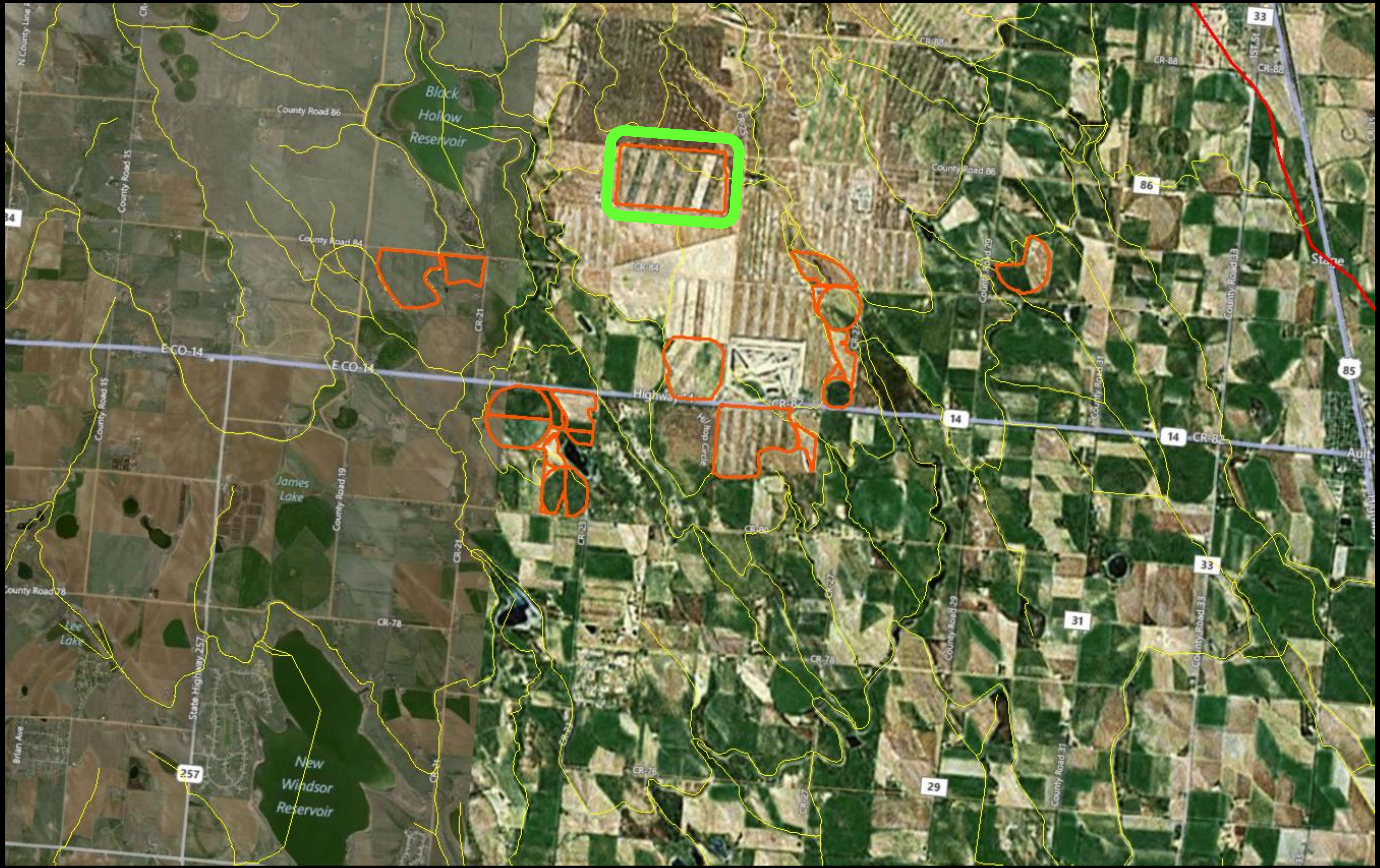


National Elevation Dataset: http://ned.usgs.gov

10 km

Farm Scale

(Drake Farm)

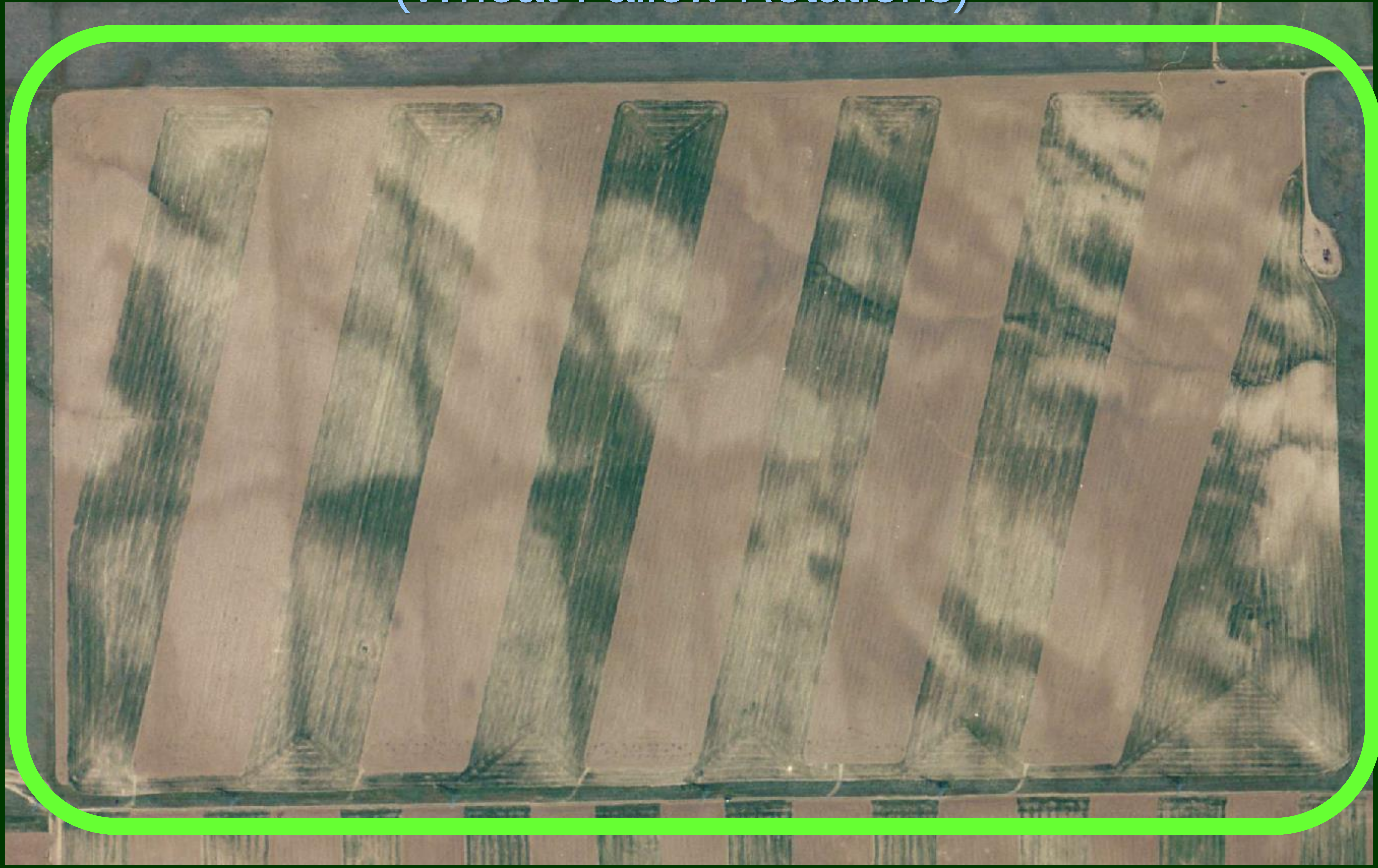


Flow line data: http://nhd.usgs.gov

1 km

Field Scale

(Wheat-Fallow Rotations)

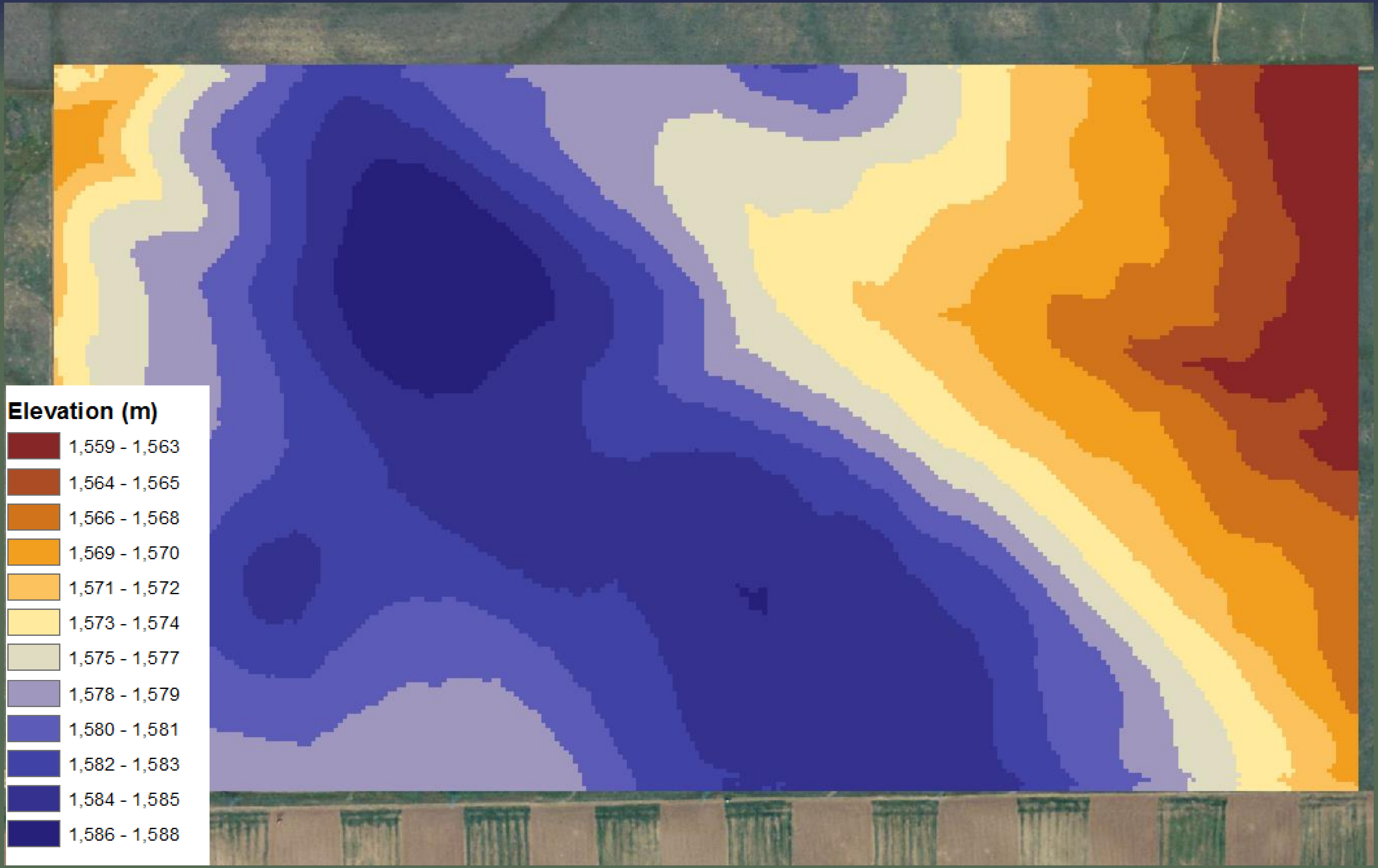


100 m

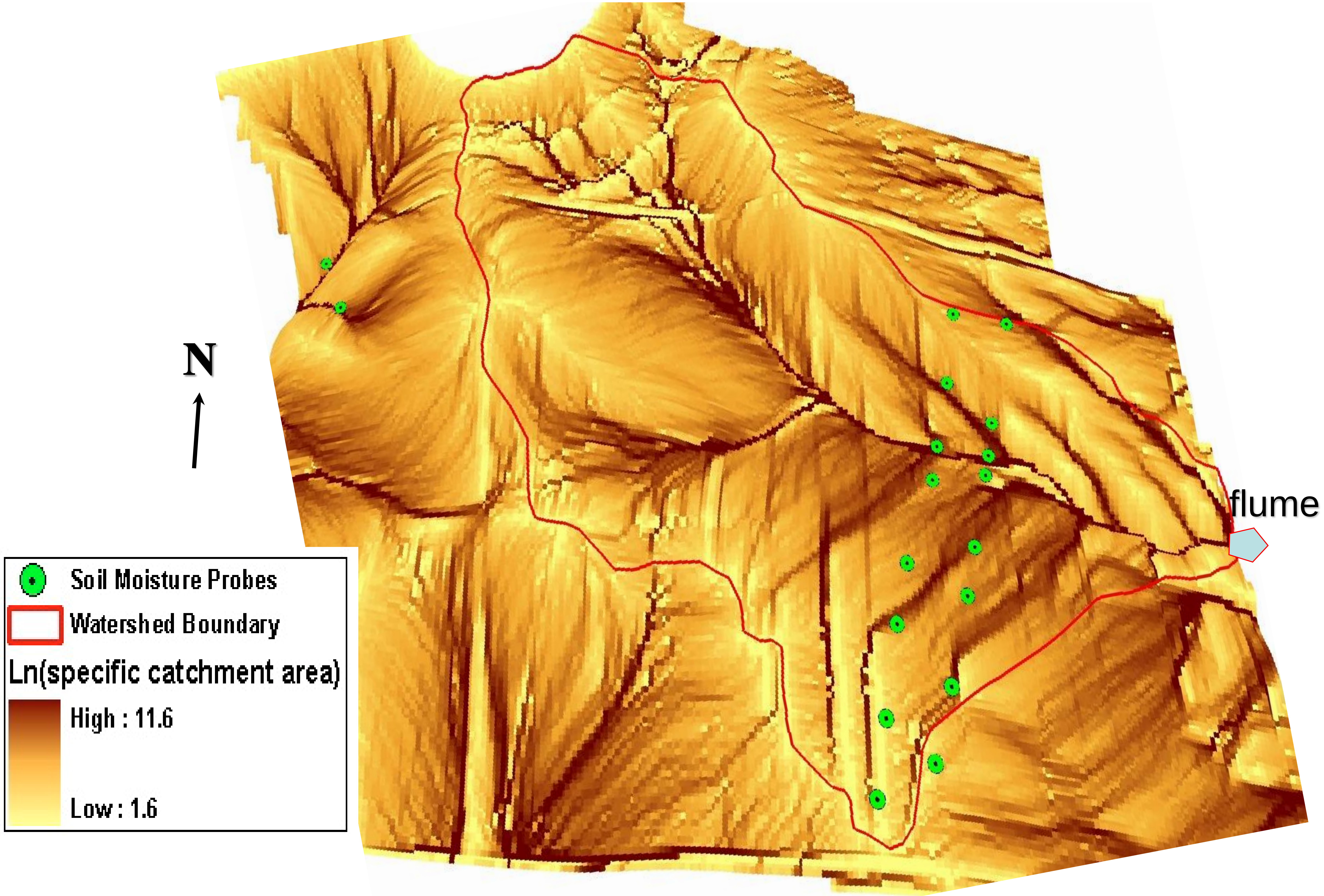
Long-term study: Colorado, USA

- Semi-arid climate $(P \approx 320\ mm/yr)$
- Small watershed (56 ha) in wheat field (110 ha)
- Measurements of water, soil C and erosion, plants, and air (meteorology)
- Models of hydrology and crop growth

Topographic Map (5-m grid cells)

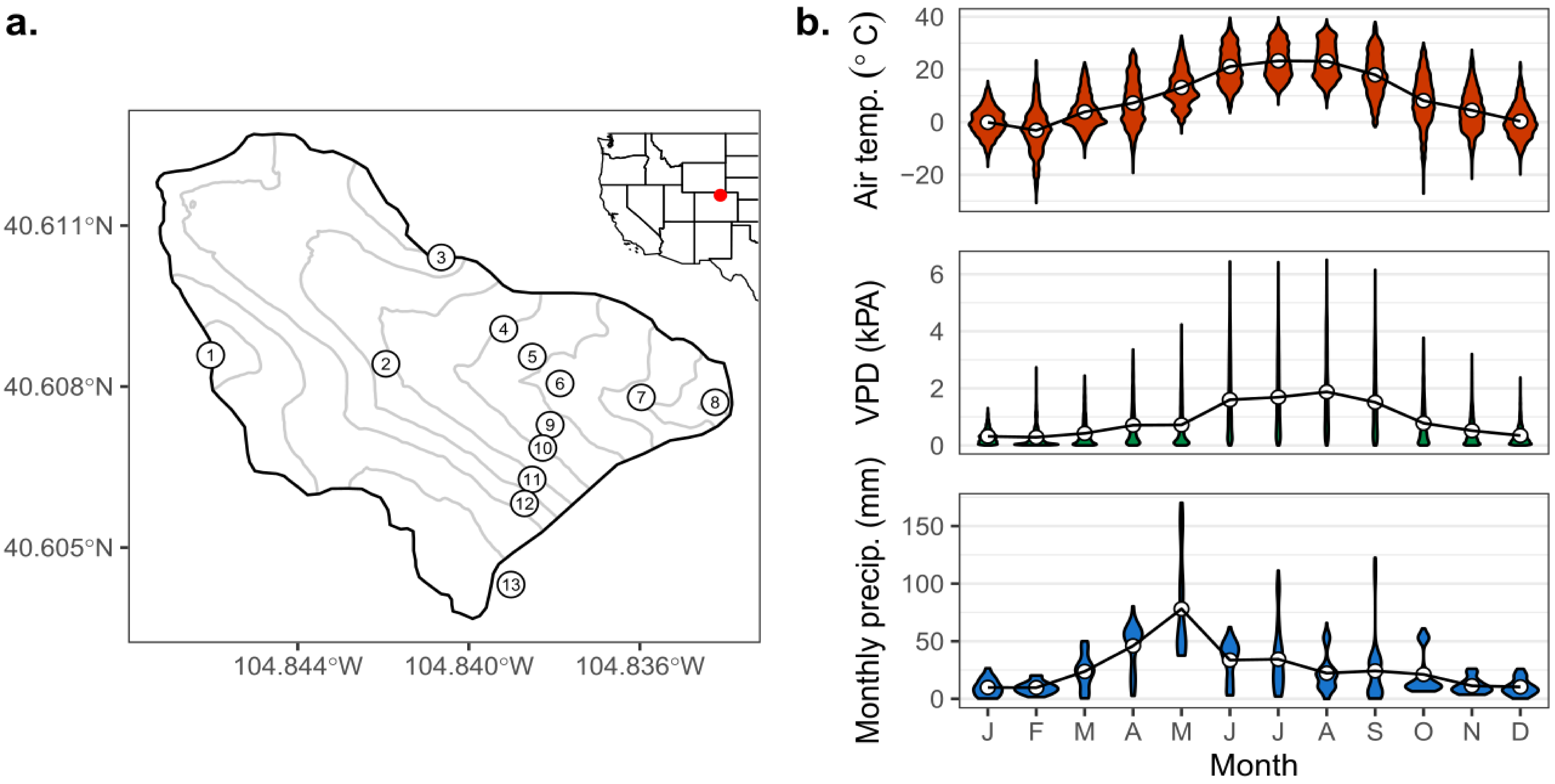


Watershed Perspective View

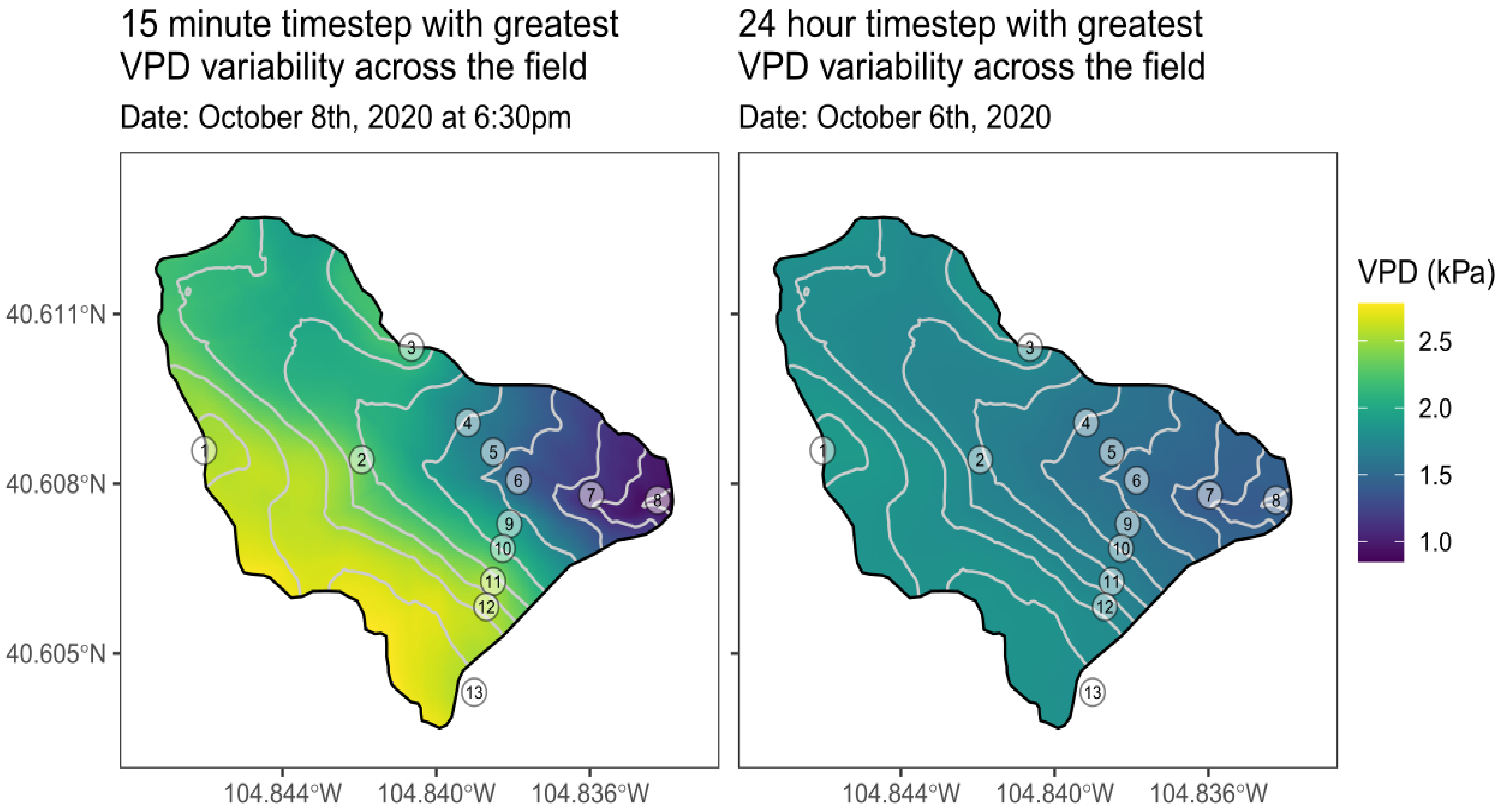


Air temperature (T) & relative humidity (RH) sensor network

Vapor Pressure Deficit, VPD = VPsaturated - VPactual = VPsat(T) * (1 - RH/100)

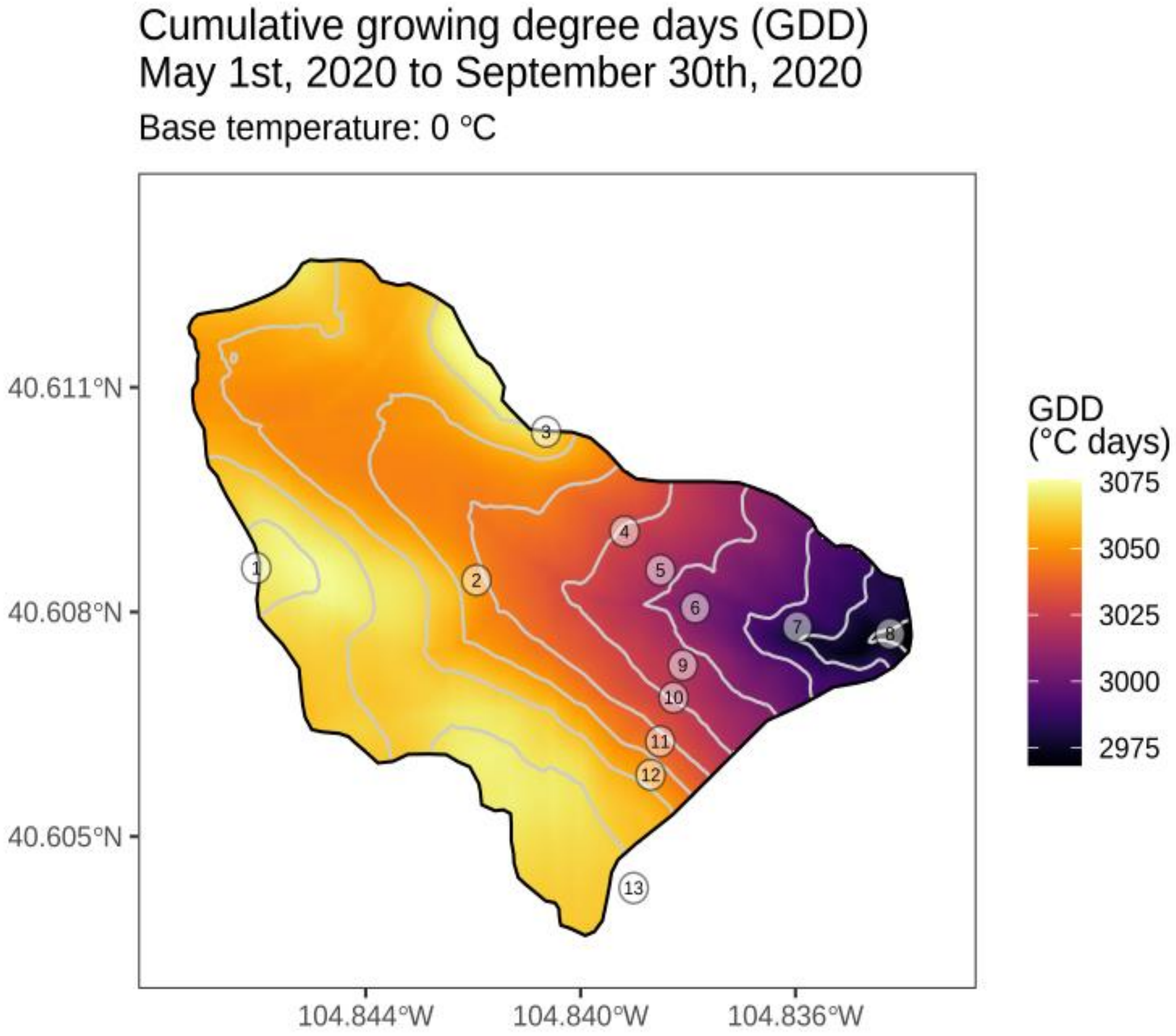


Spatial Patterns of Vapor Pressure Deficit

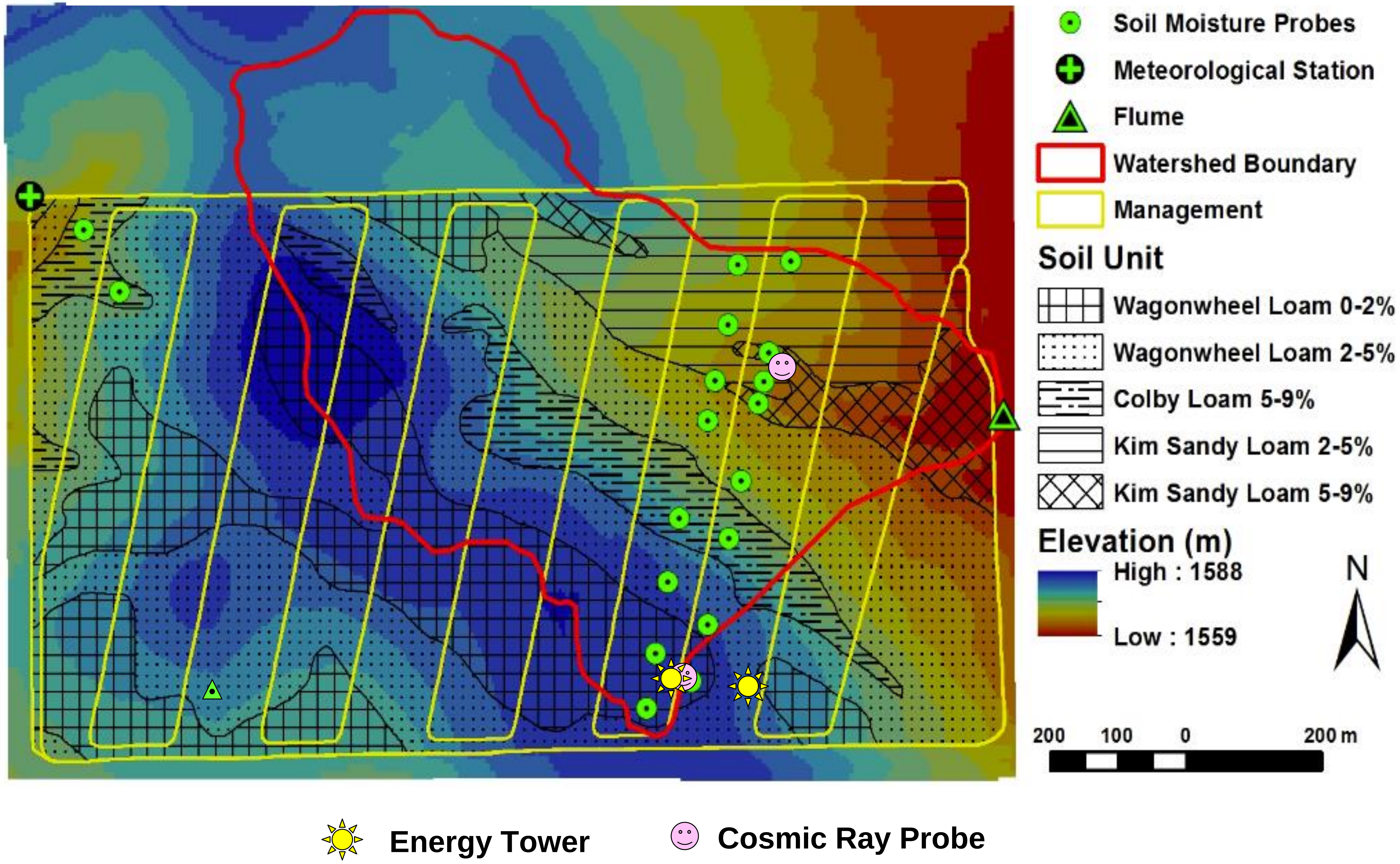


Spatial Patterns of Air Temperature

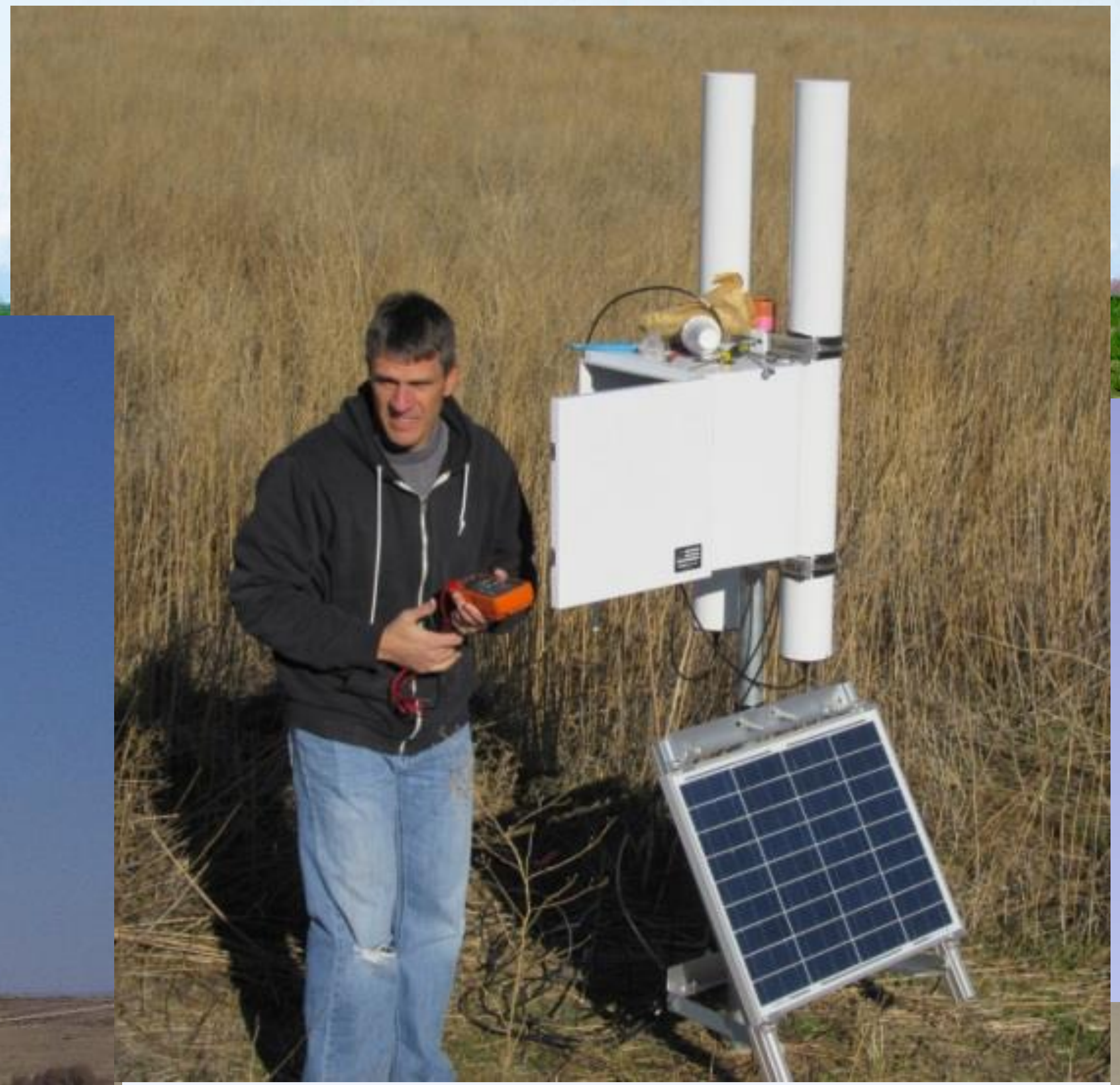
Thermal Time: $GDD = sum(T(t) - Tbase(t))$ [^{o}C day]

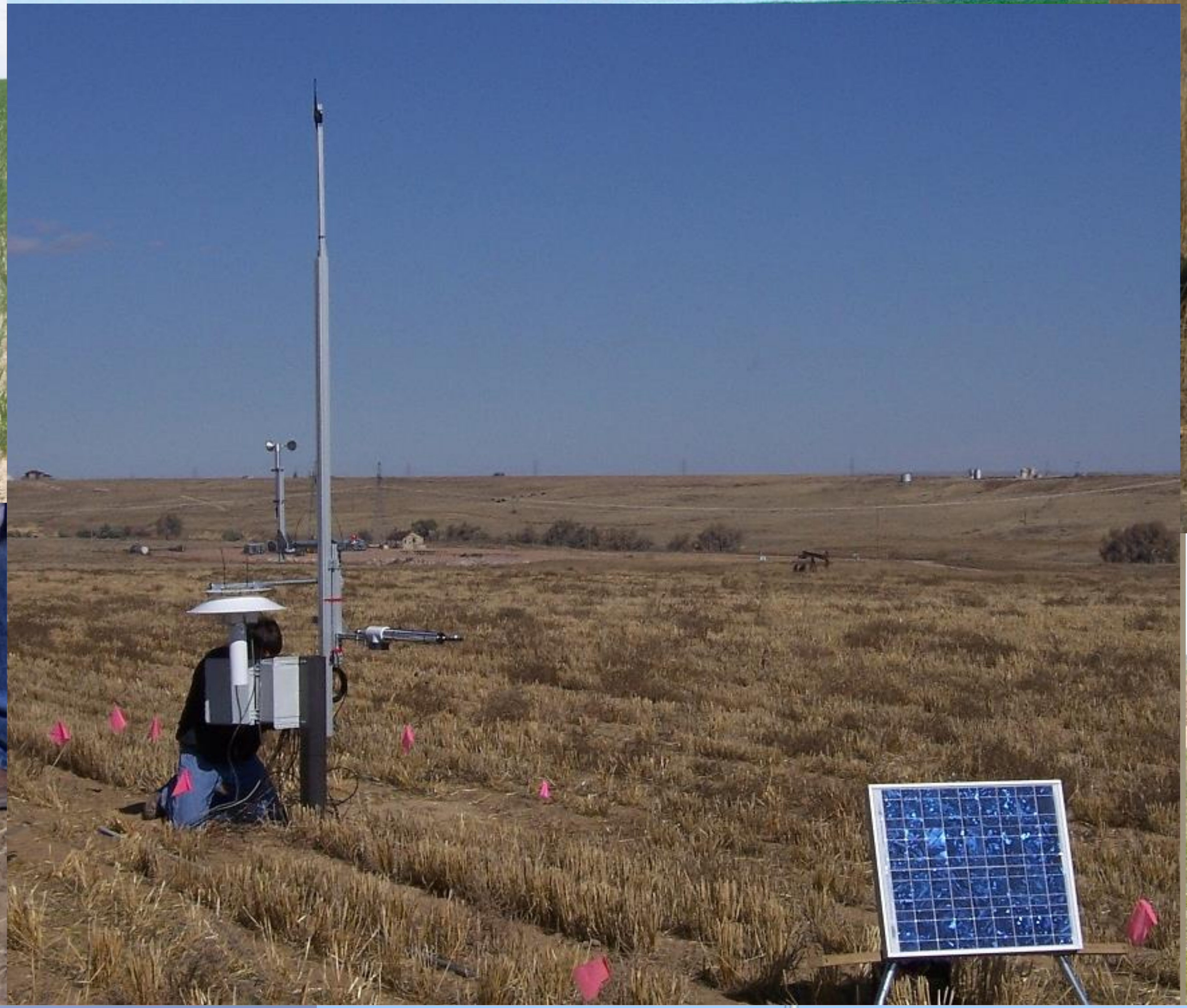


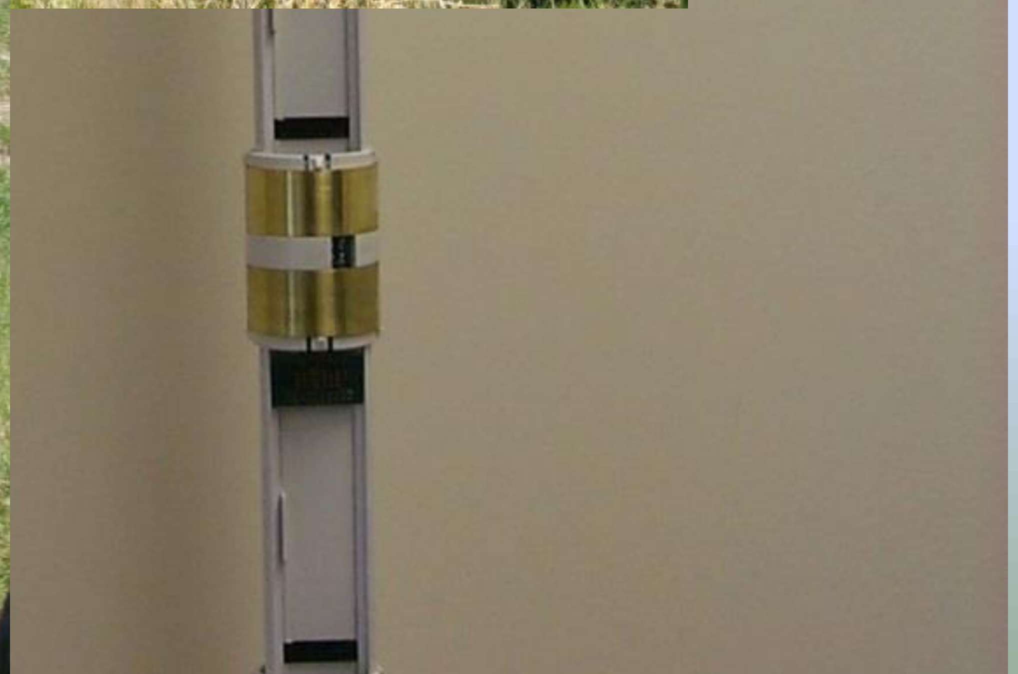
Long-term Instrumentation on the Scott Field, Drake Farm



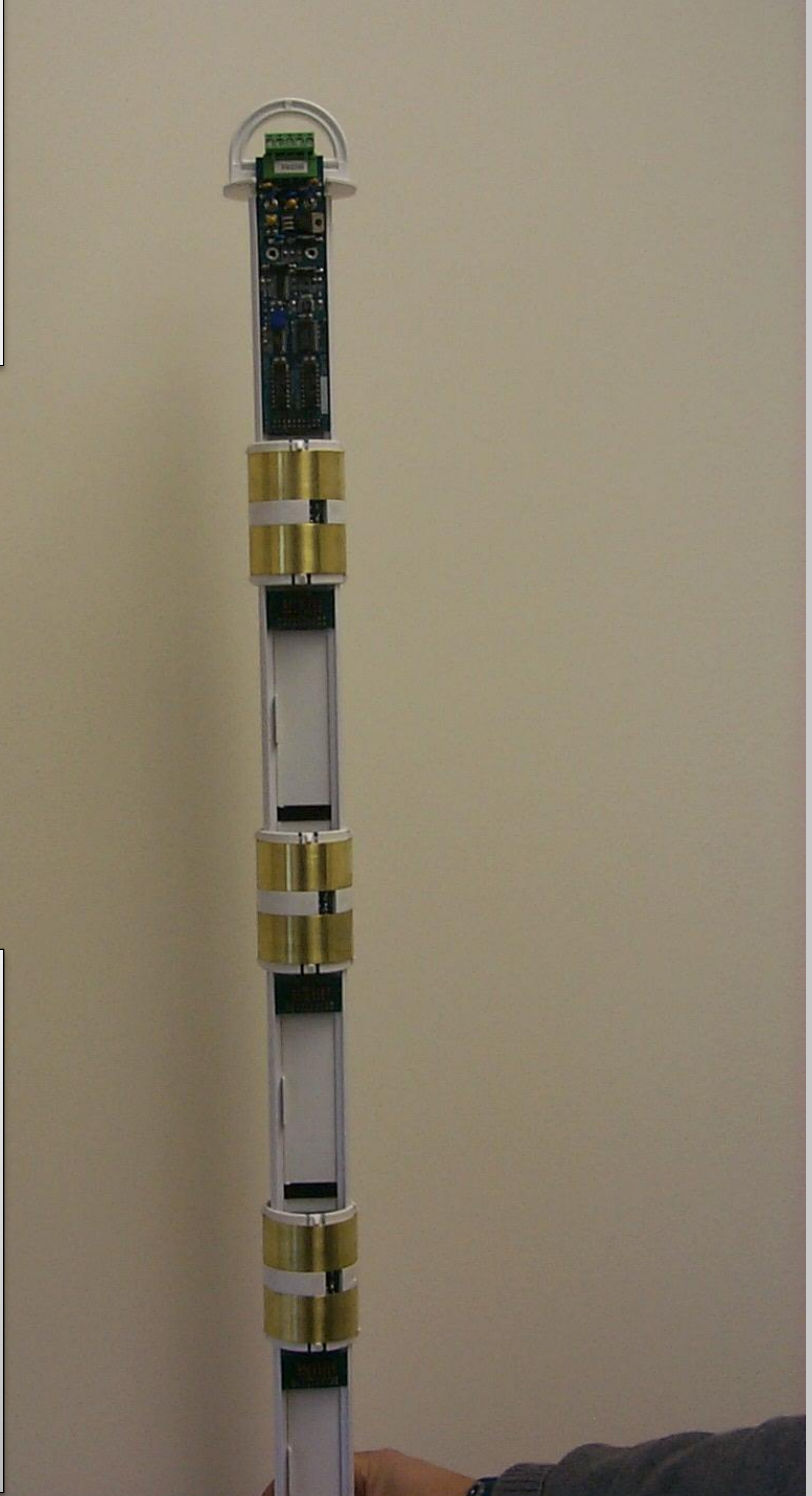
Instrumentation







Measuring Soil Moisture with Capacitance Sensors



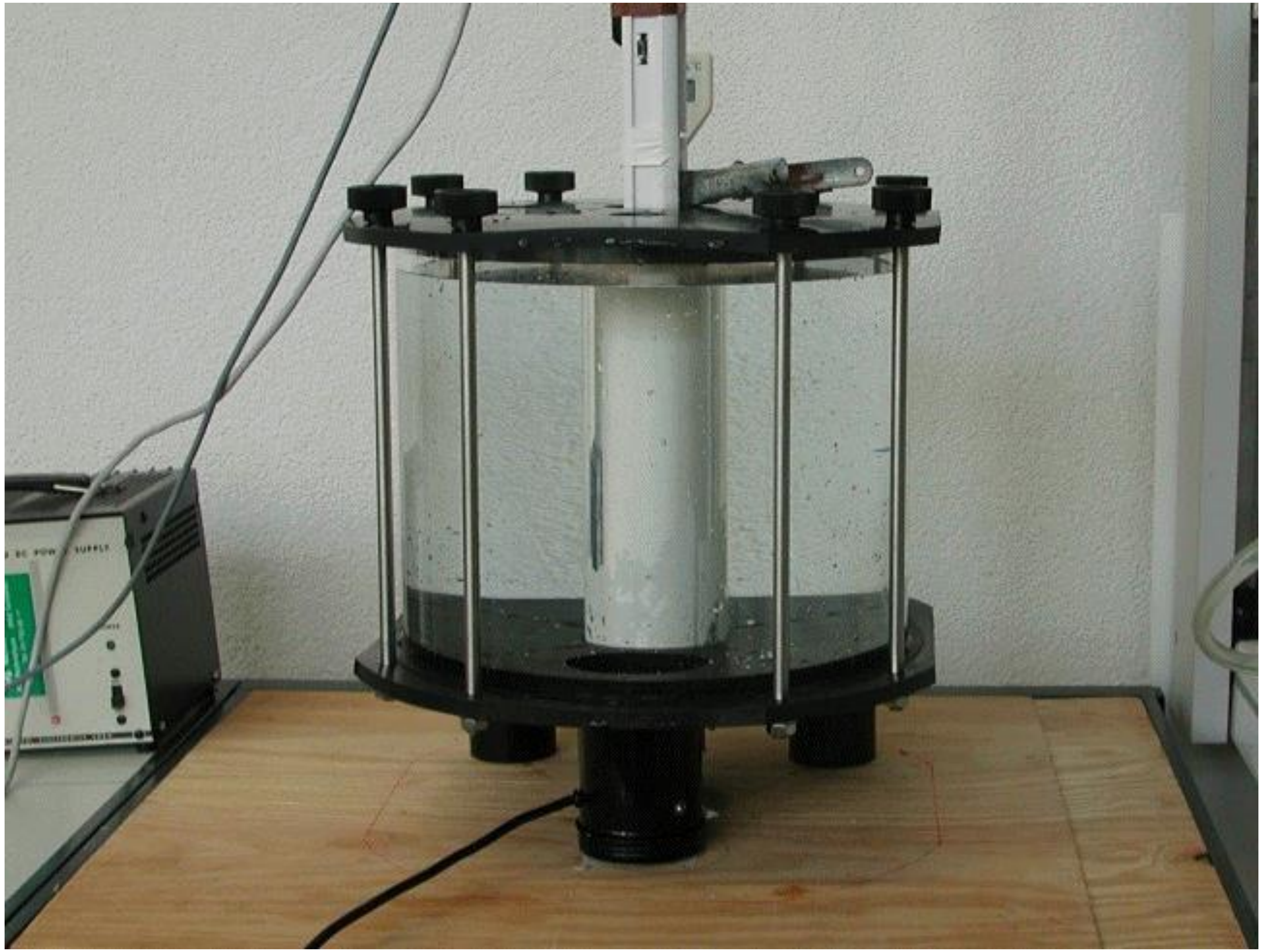
Schwank, M., T.R. Green, C. Mätzler, H. Benedickter, and H. Flühler. 2006. Laboratory characterization of a commercial capacitance sensor for estimating permittivity and inferring soil water content.
Vadose Zone J. 5:1048-1064.

Distance of Sensitivity

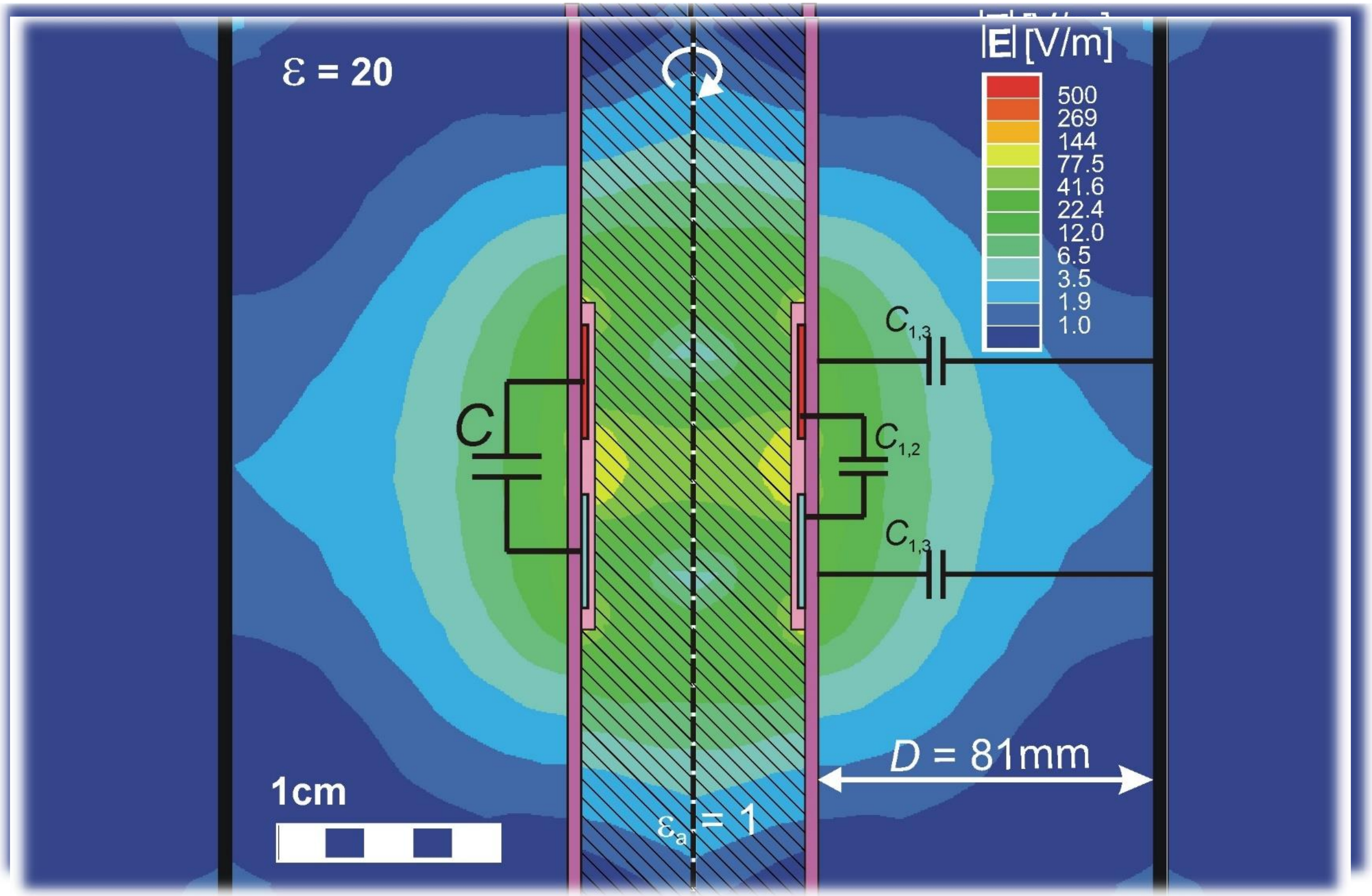
Rolled metal sheet is expanded stepwise.

Distance between access tube and metal disturbance:

D = 4 mm – 96 mm



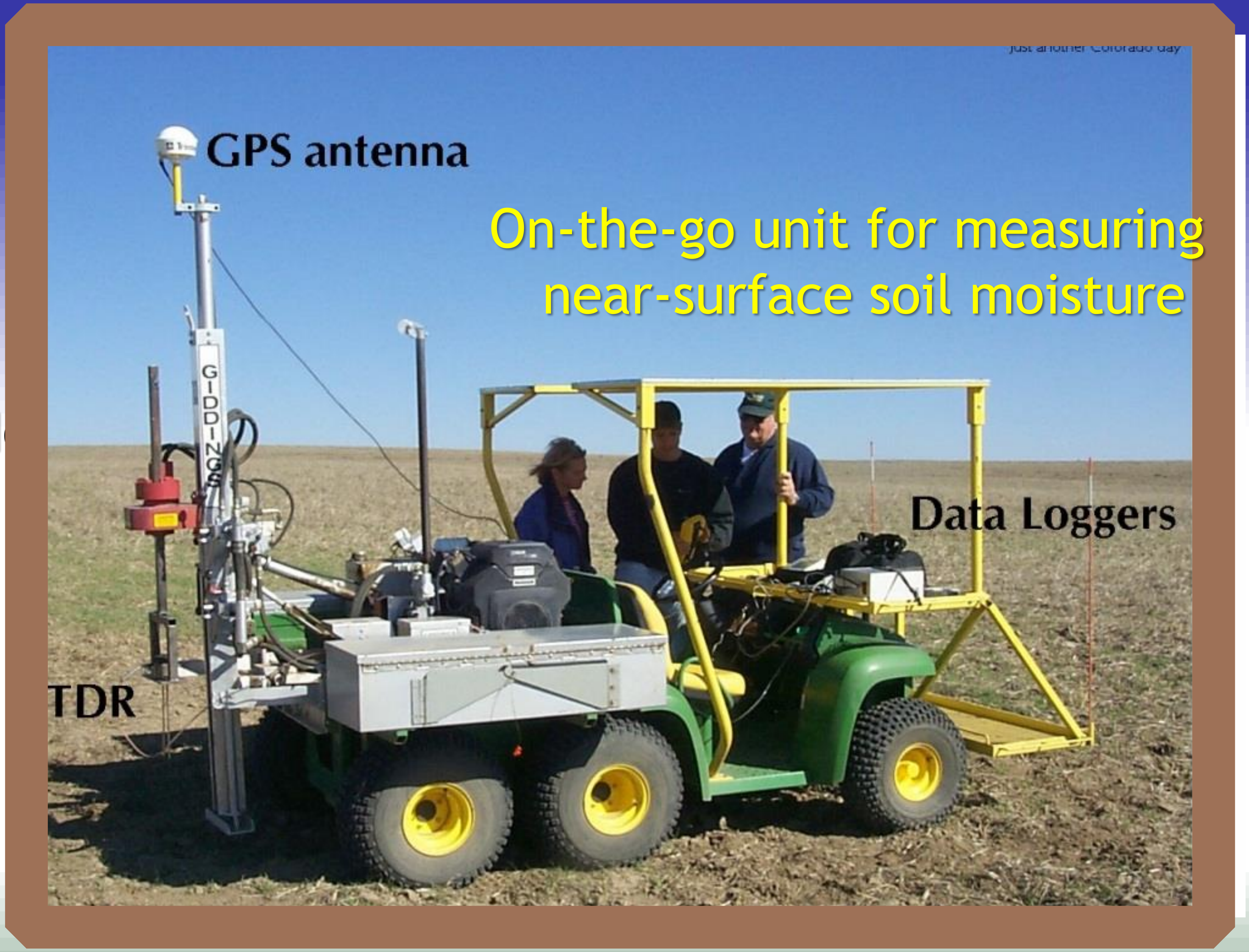
E-Field without metal sheet disturbance:



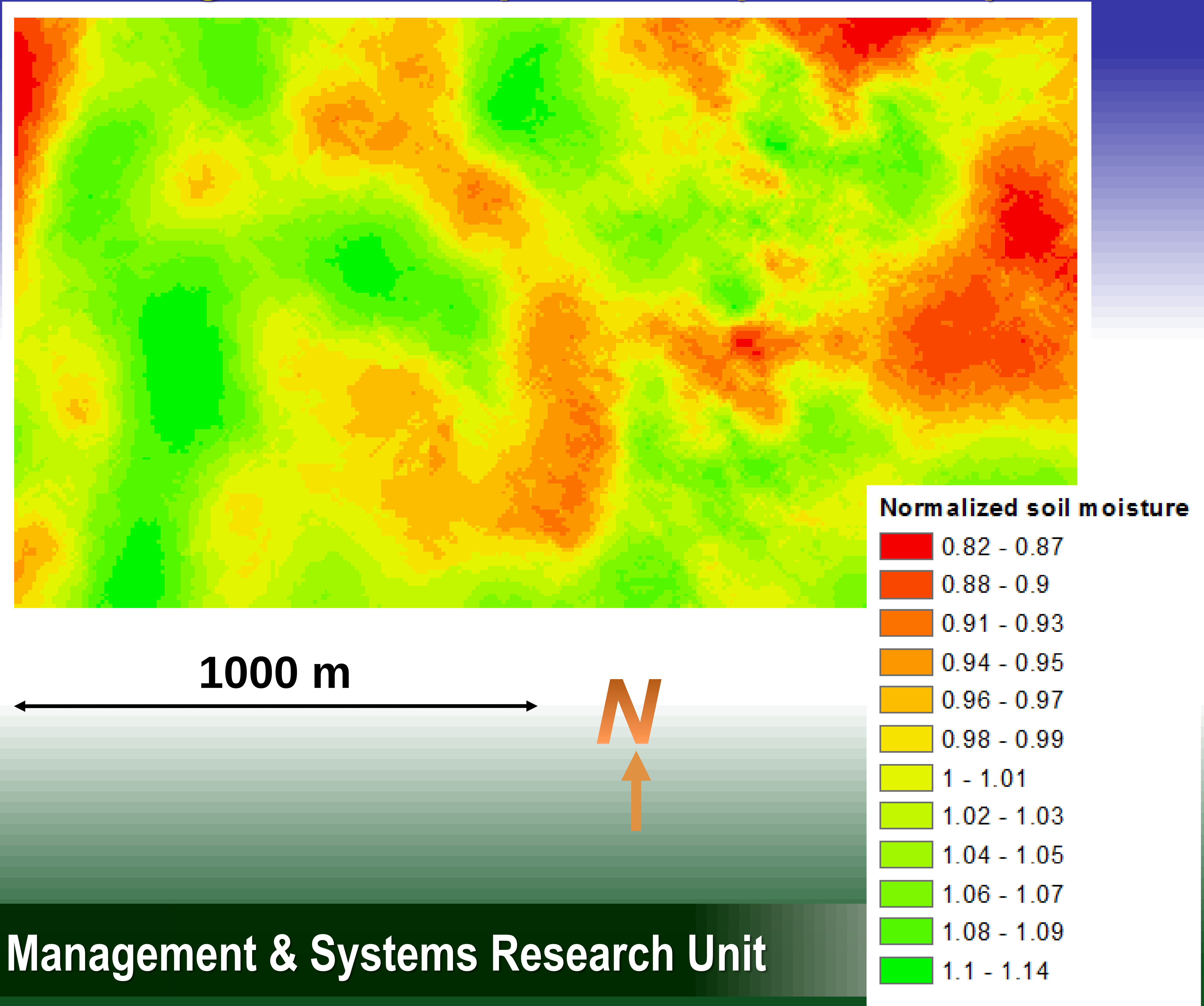
Electromagnetic Field Simulations

TDR (Time Domain Reflectometry) for Spatial Soil Moisture
Drake Farm, Severance, CO

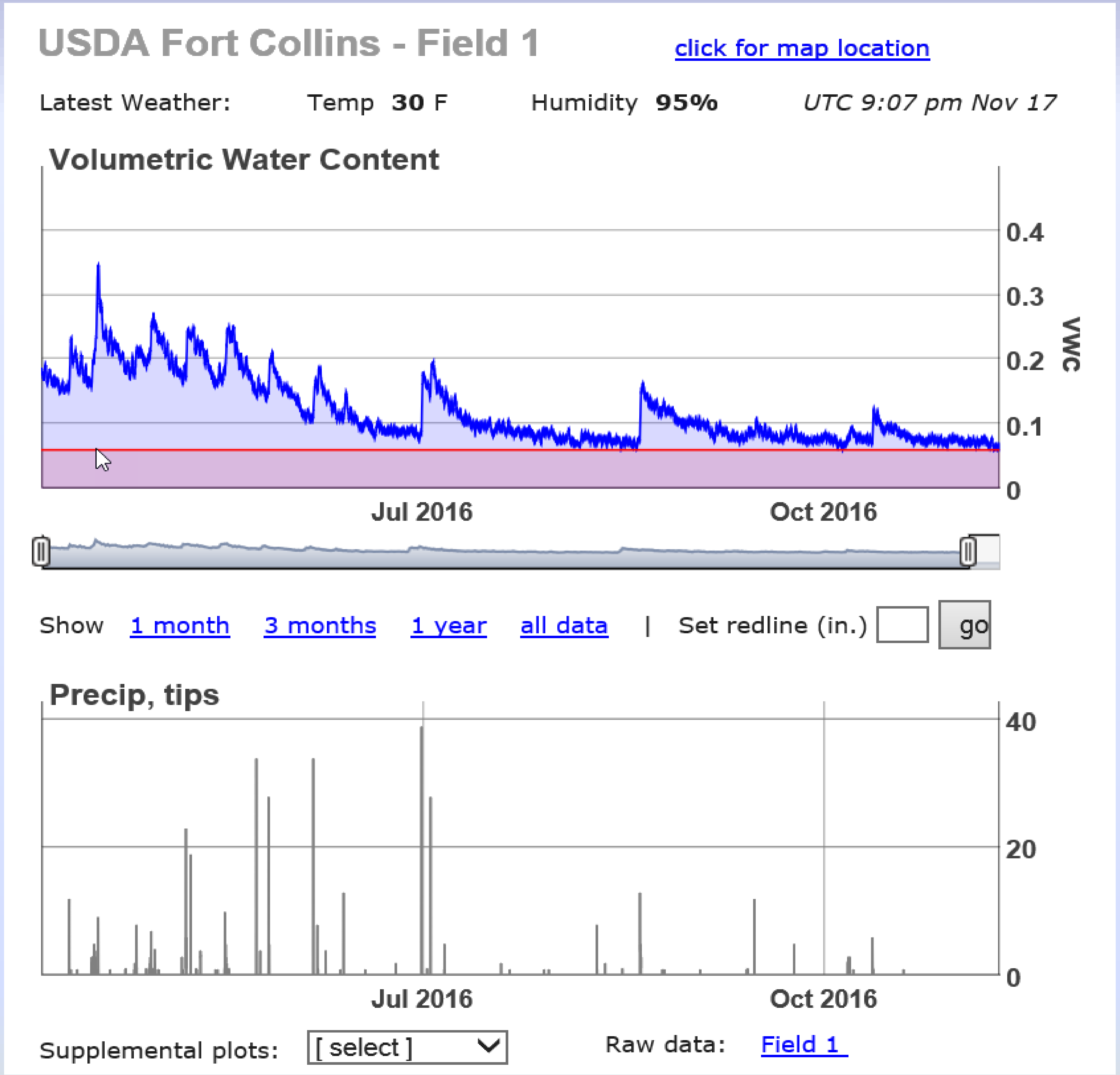
½ mil



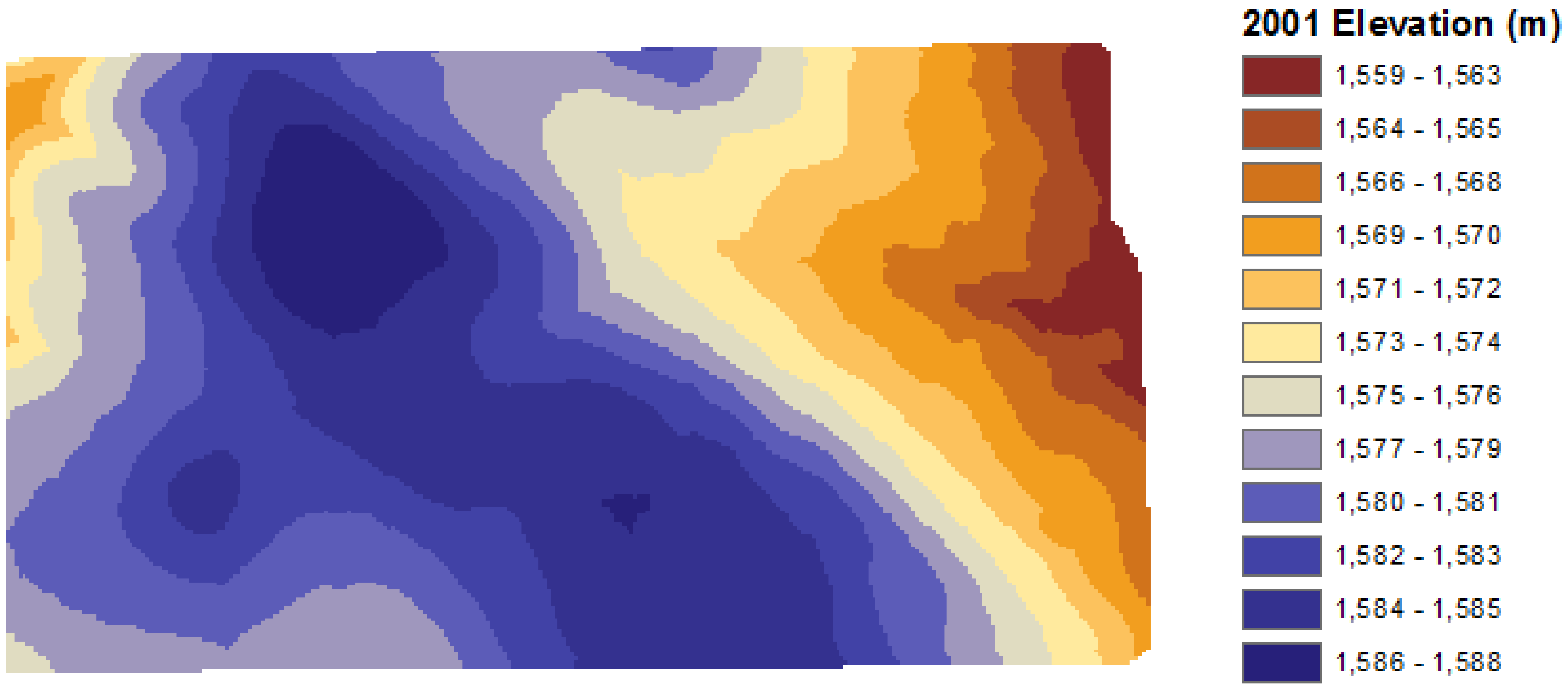
Normalized Soil Moisture (30 cm)
average of 18 sample dates (2001-2009)

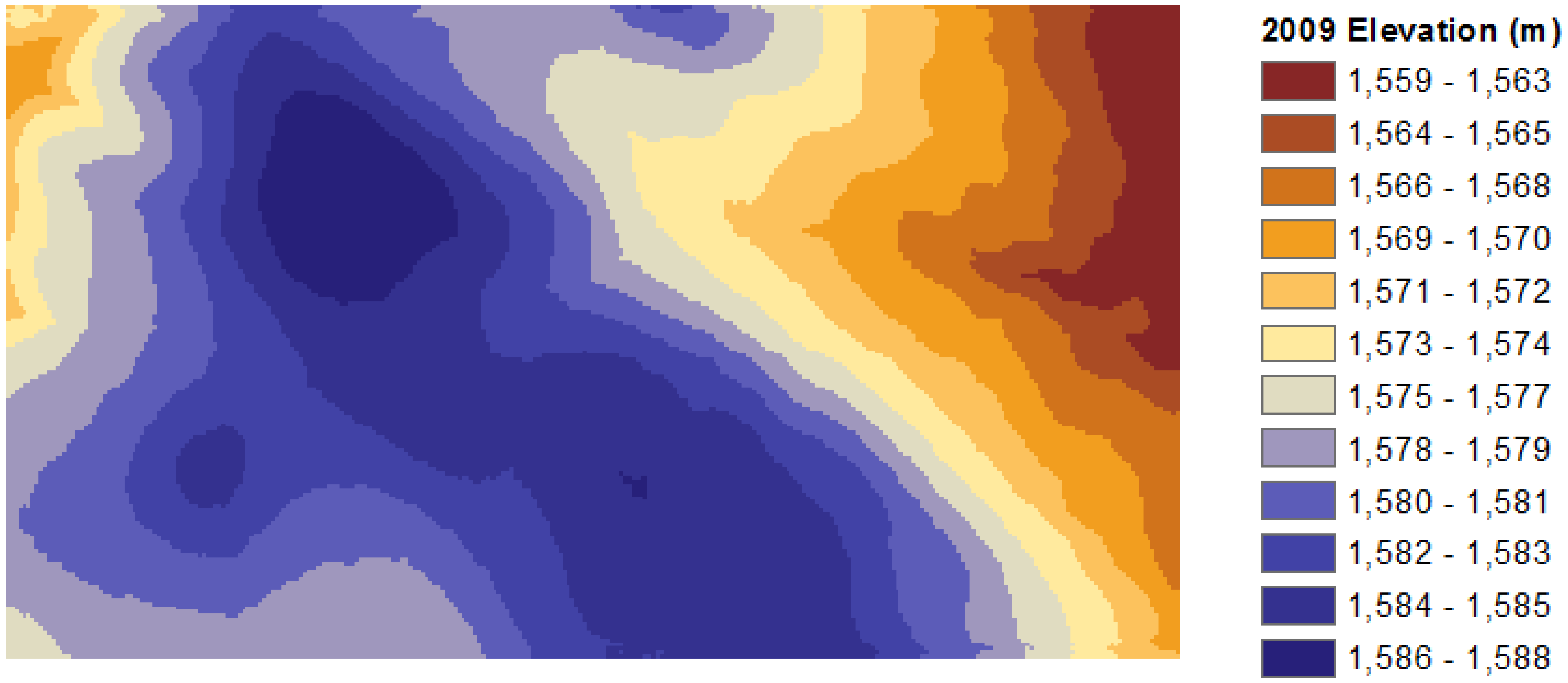


Cosmic Ray Neutron Sensor

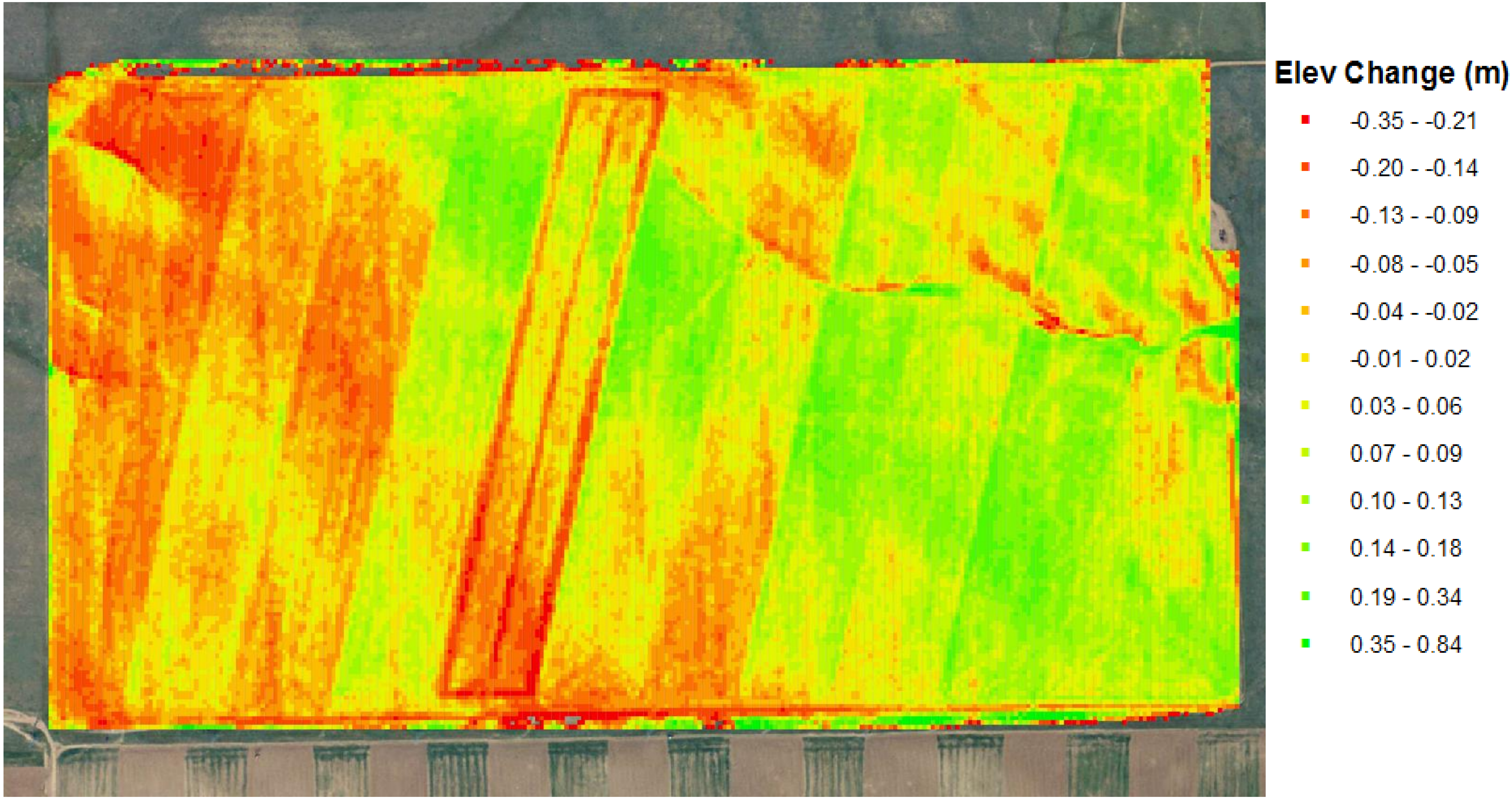



Summer convective rainfall in Colorado


2001 Elevation (m)
1,559 - 1,563
1,564 - 1,565
1,566 - 1,568
1,569 - 1,570
1,571 - 1,572
1,573 - 1,574
1,575 - 1,576
1,577 - 1,579
1,580 - 1,581
1,582 - 1,583
1,584 - 1,585
1,586 - 1,588


2009 Elevation (m)
1,559 - 1,563
1,564 - 1,565
1,566 - 1,568
1,569 - 1,570
1,571 - 1,572
1,573 - 1,574
1,575 - 1,577
1,578 - 1,579
1,580 - 1,581
1,582 - 1,583
1,584 - 1,585
1,586 - 1,588

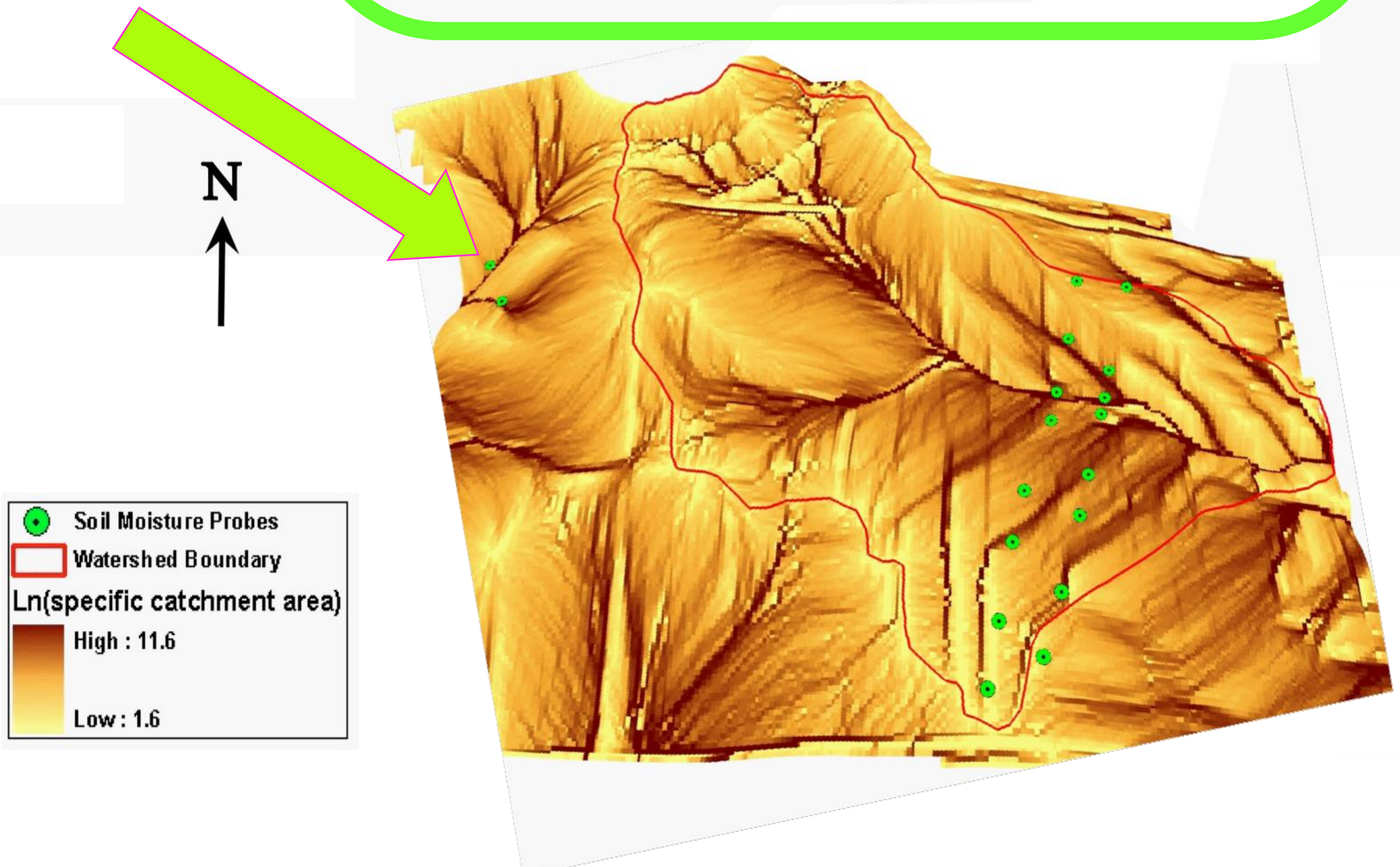
The Change: 2001 to 2009

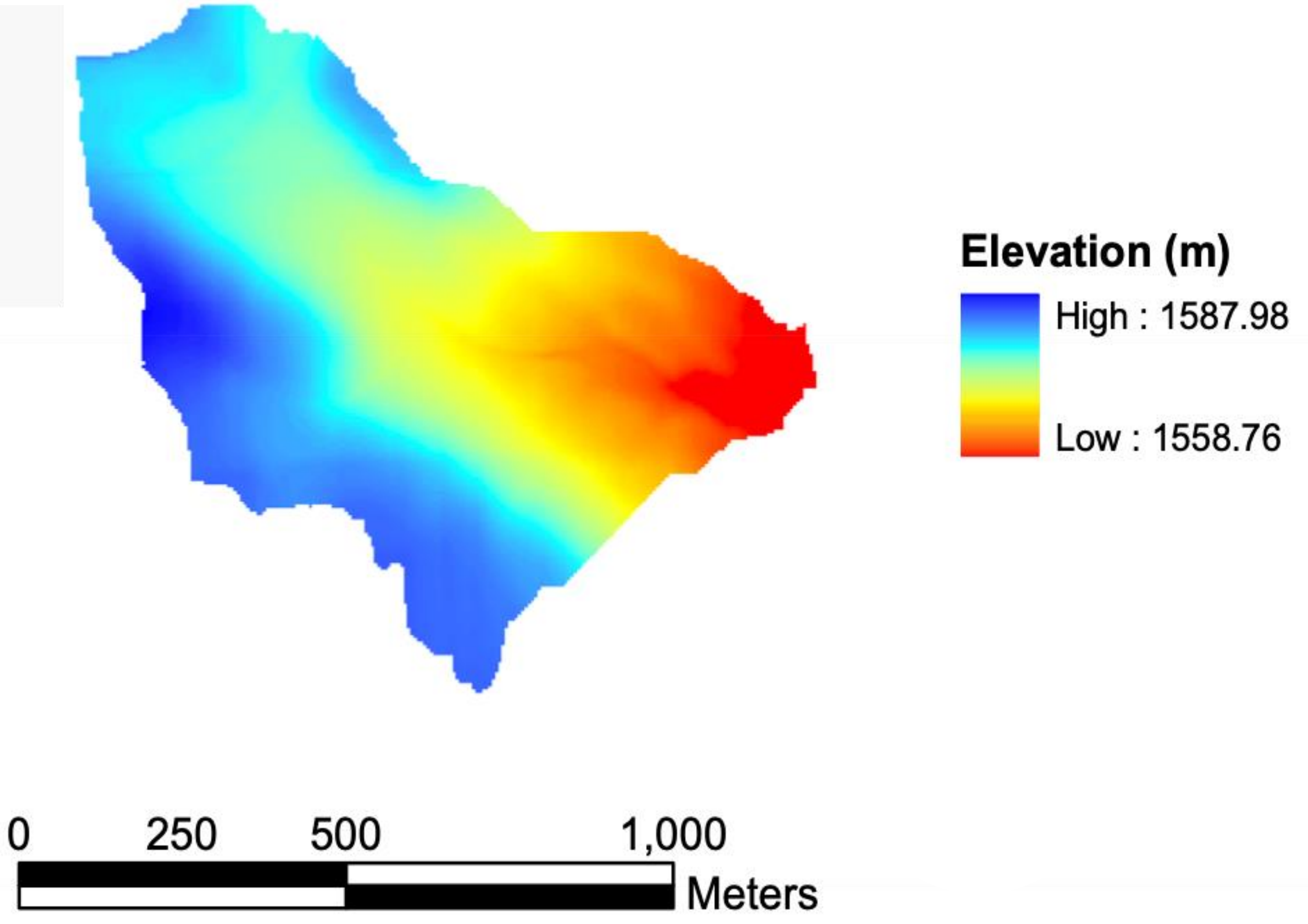


Soil Water Dynamics in a Small Watershed Context

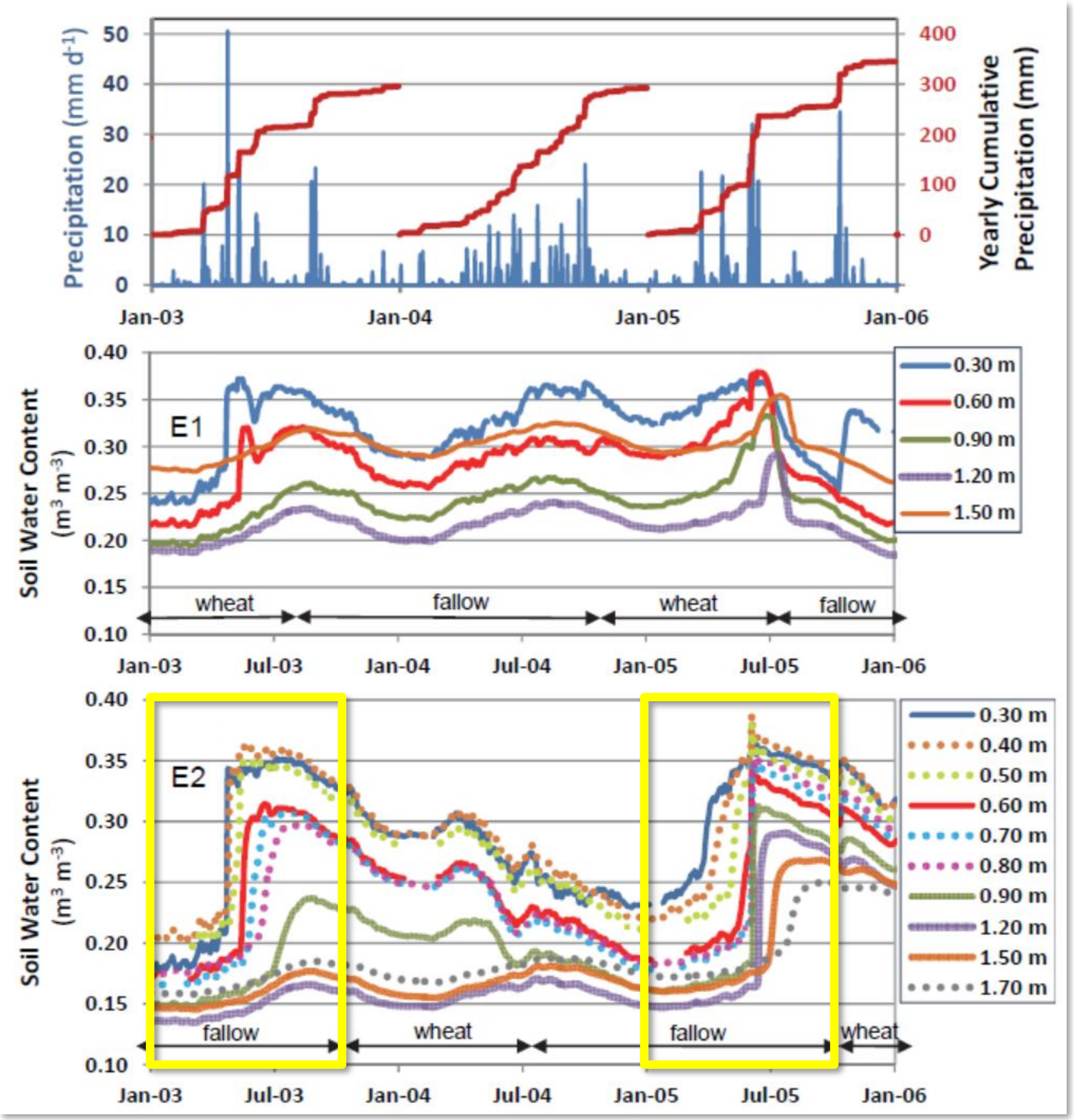
(Green & Erskine, 2011, *Water Resources Research*)

<u>Field-scale Watershed</u>
Location: 6 miles east of Fort Collins
Delineation Method: DEM
Area: 56 ha (140 acres)
Max Slope: 12%
Mean Slope: 4%
Relief: 29m (100 ft)
Elevation Data: 5m-spacing RTKGPS

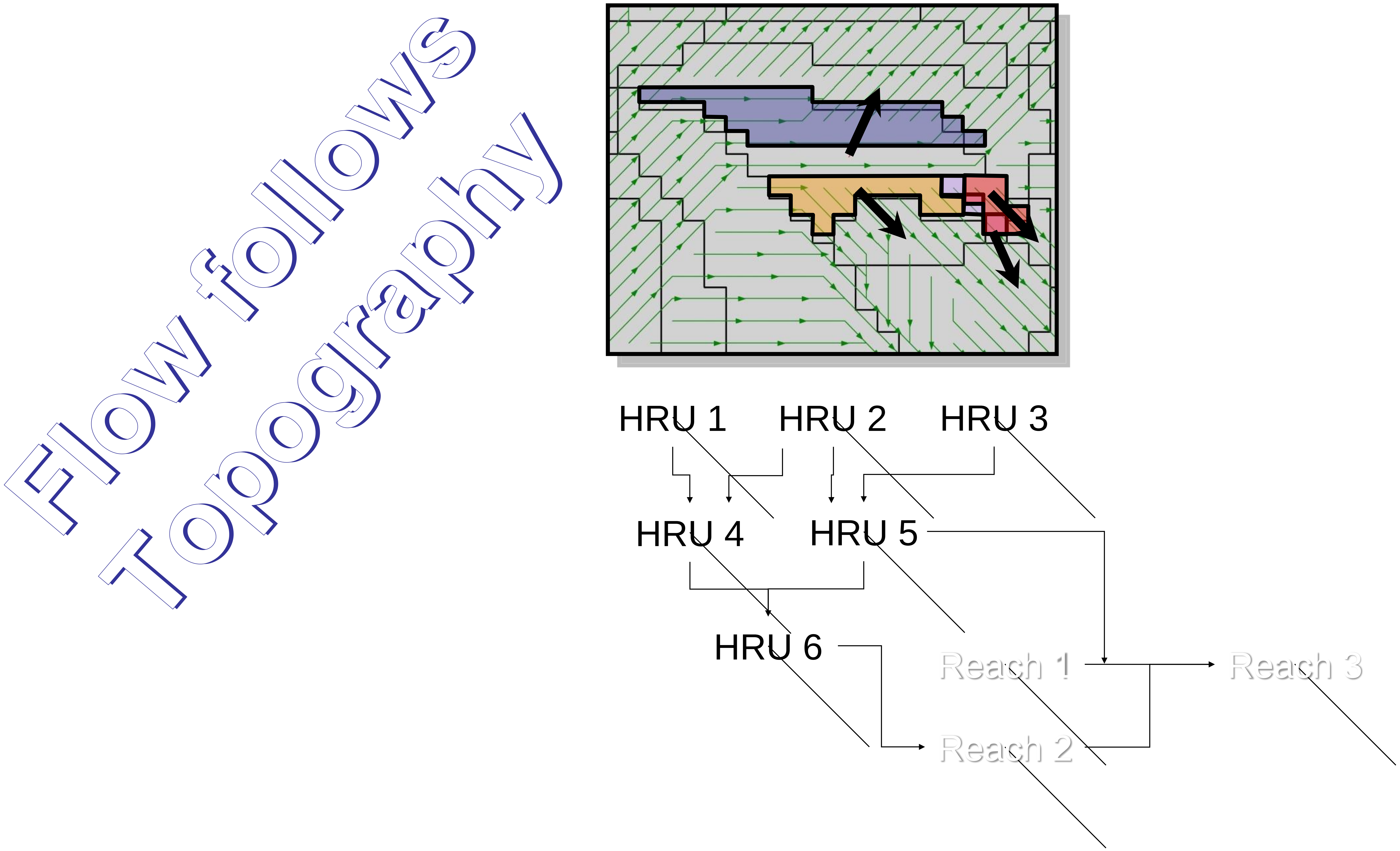




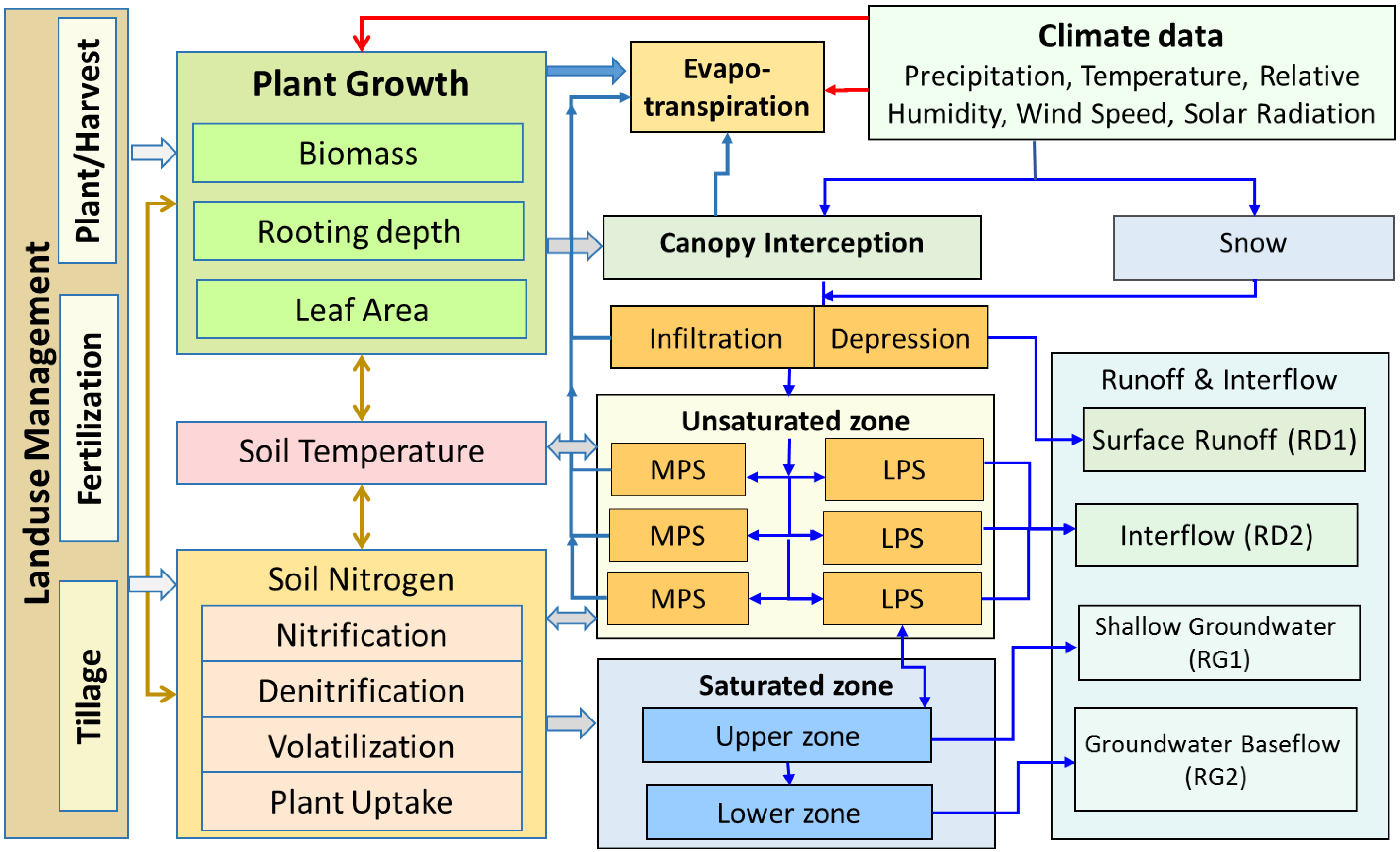
Measured dynamics of profile soil water content over time



Agricultural Ecosystem Services (Ages) watershed model



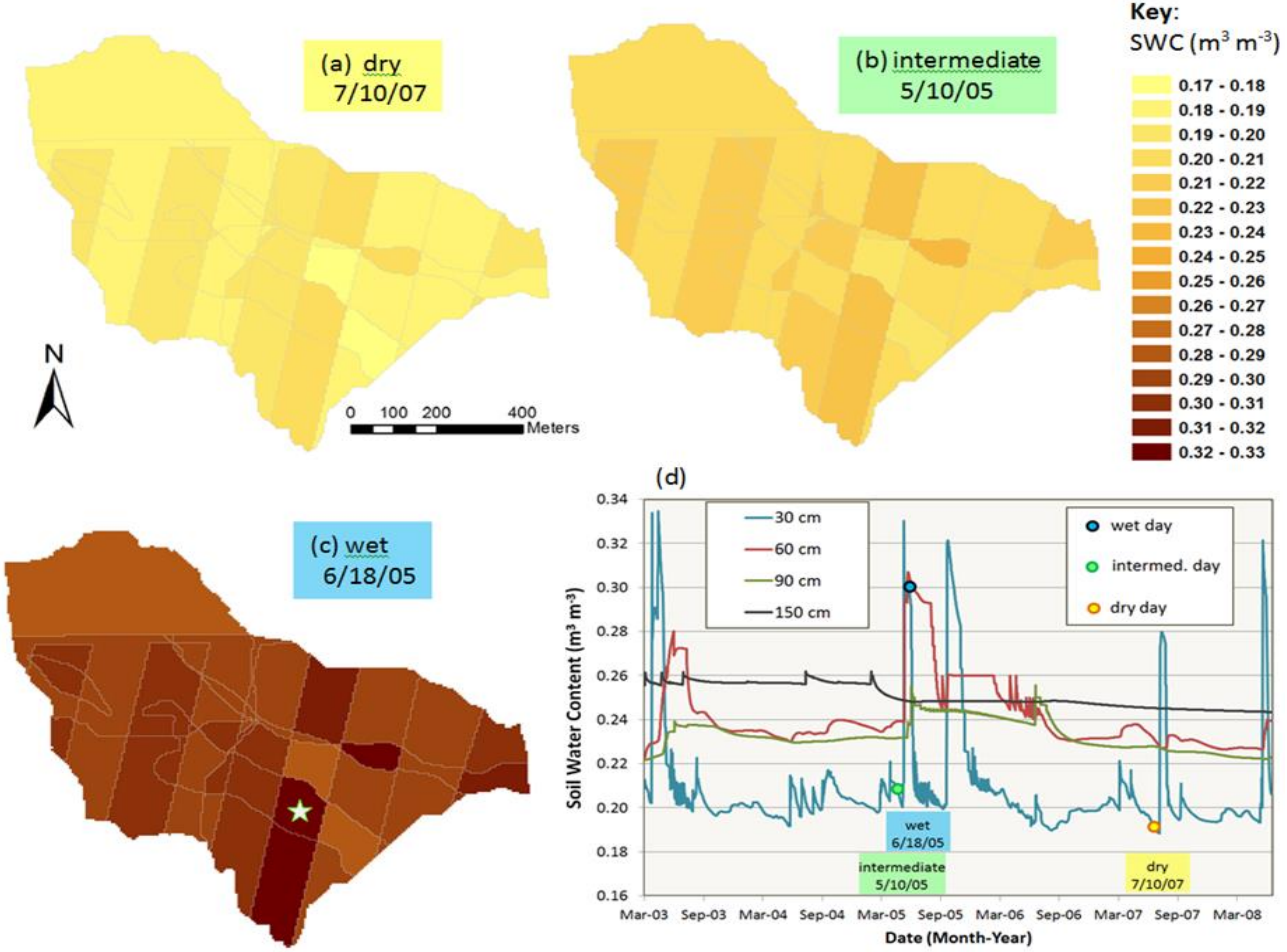
Agricultural Ecosystem Services (AgES) model processes in each HRU



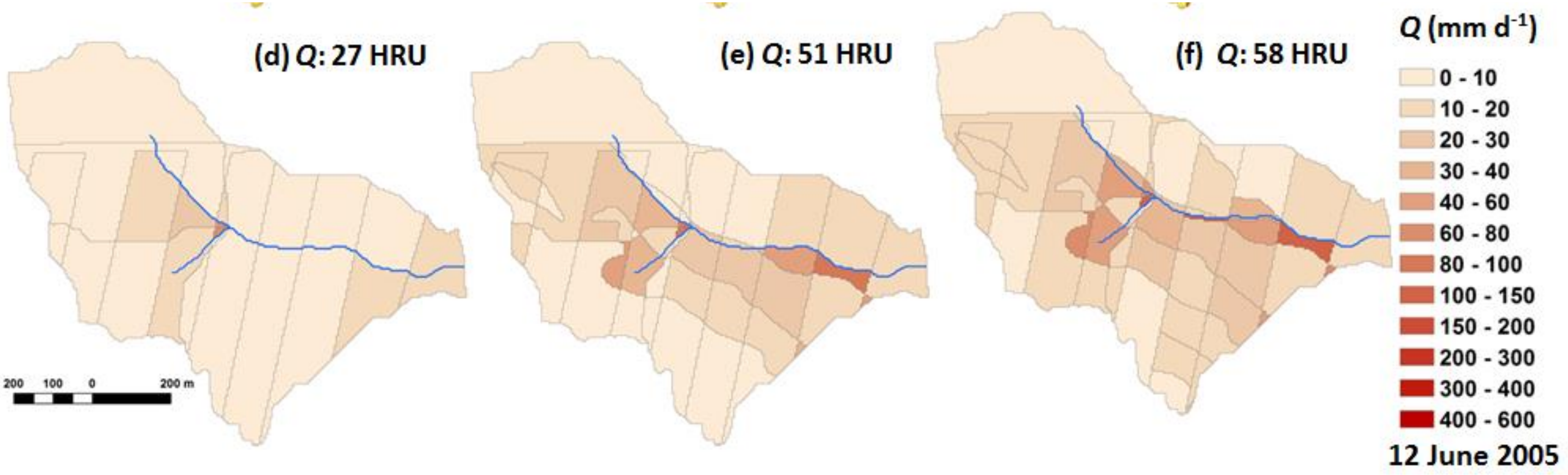
Simulated soil water at the measured depth of 25-35 cm

Each map (a-c) is a synoptic view during (a) relatively dry (mean SWC_{30} = 0.19 m^3m^{-3}), (b) intermediate (mean SWC_{30} = 0.21 m^3m^{-3}) and (c) wet (mean SWC_{30} = 0.30 m^3m^{-3}) conditions. SWC_{30} denotes SWC centered at 30 cm deep.

(d) Time series of simulated SWC at one HRU, shown with a star in (c).



Maps of daily surface runoff (Q) on 12 June 2005 at three different model resolutions

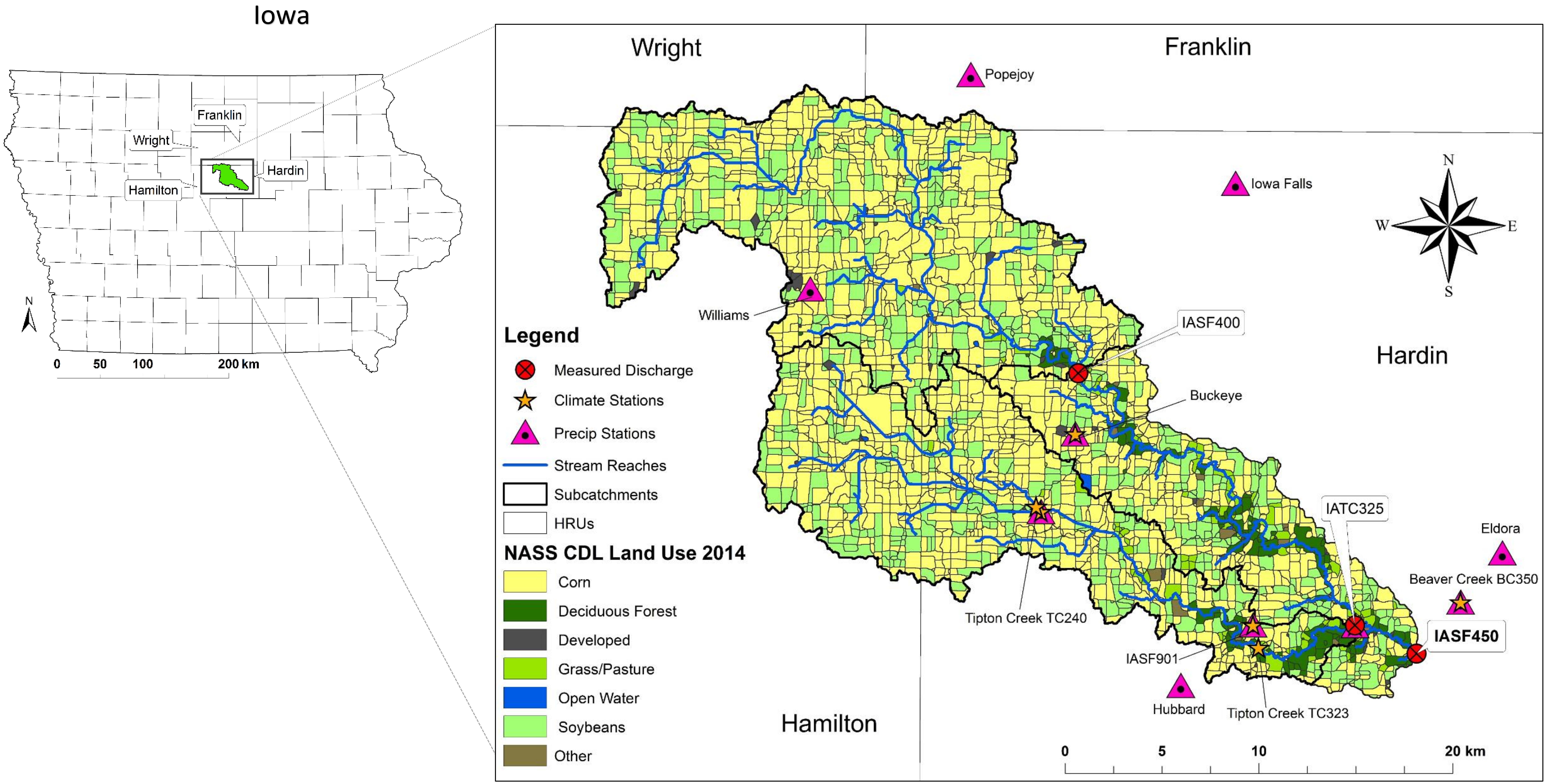


Blue lines are ephemeral channels.

Case Study:
South Fork Iowa River Watershed,

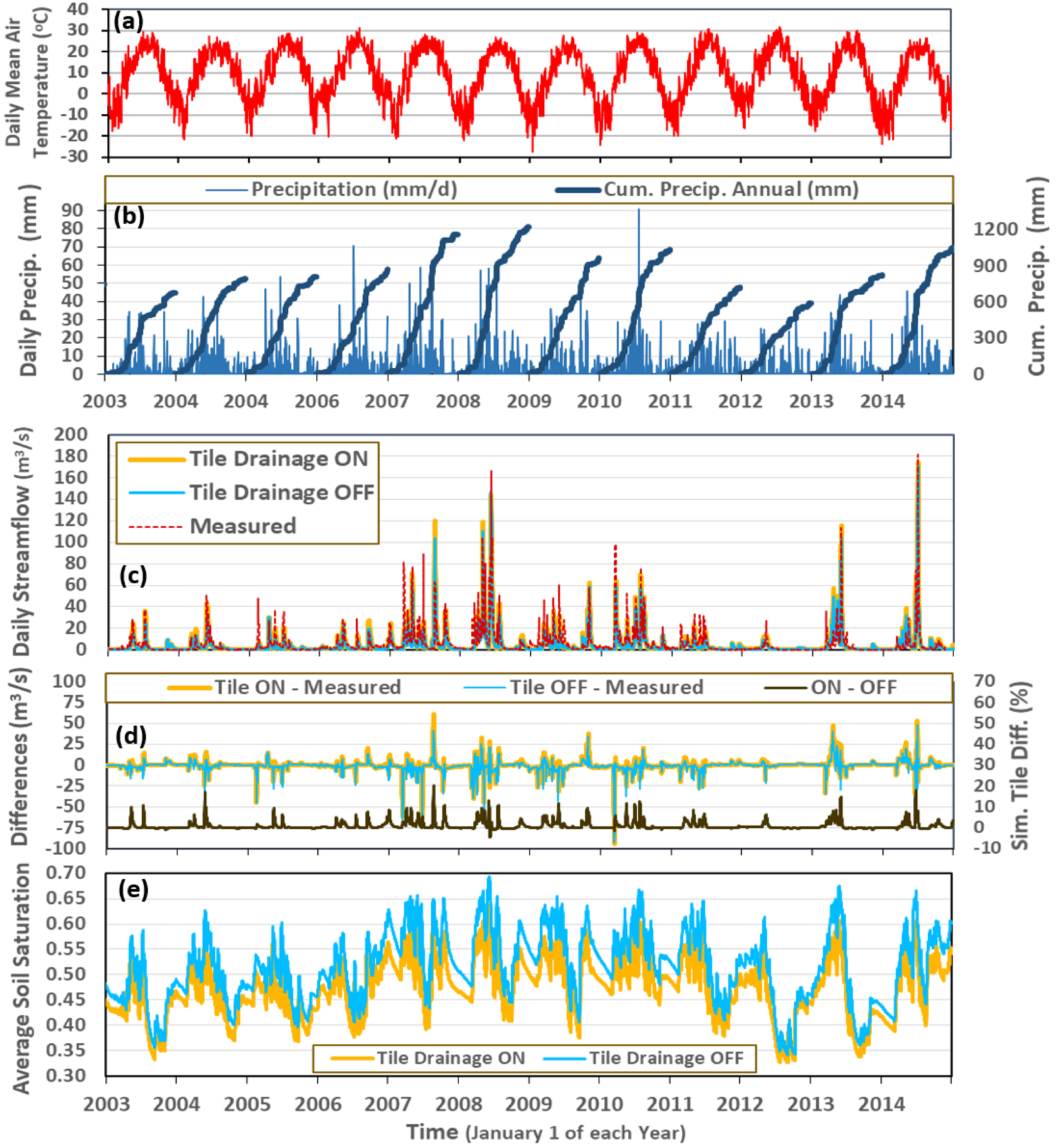
- Temperate Continental Climate
- Regional-scale watershed (~780 km^2)
- Primarily agricultural land use; intensive corn and corn-soybean rotations; swine manure
- Tile drainage common
- Simulate streamflow, nitrate concentrations and N loads
- Estimate fertilizer rates using adapted model

South Fork Iowa River Watershed: Land-use Map



South Fork Iowa River Watershed

Simulation Results

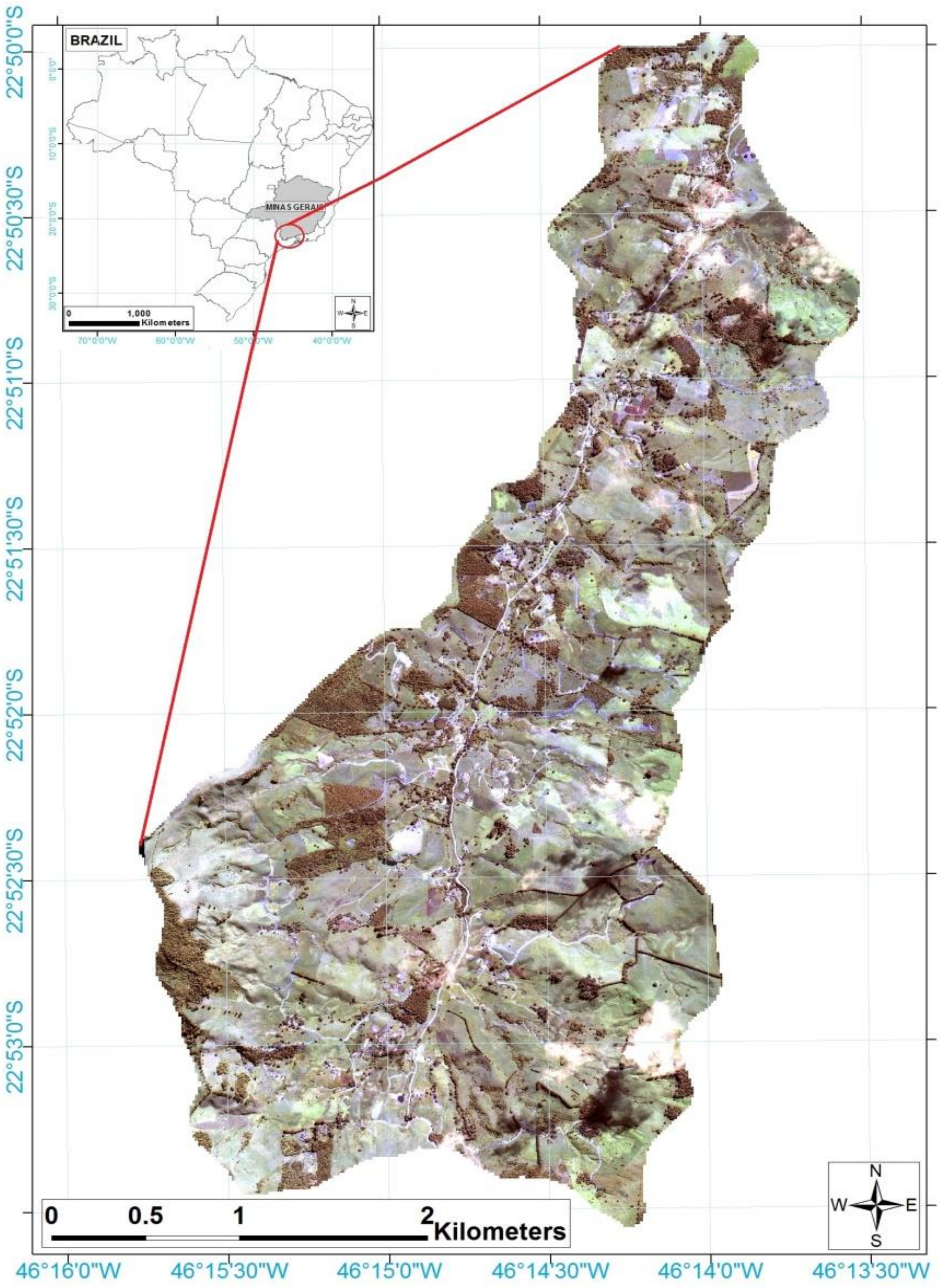


International Projects

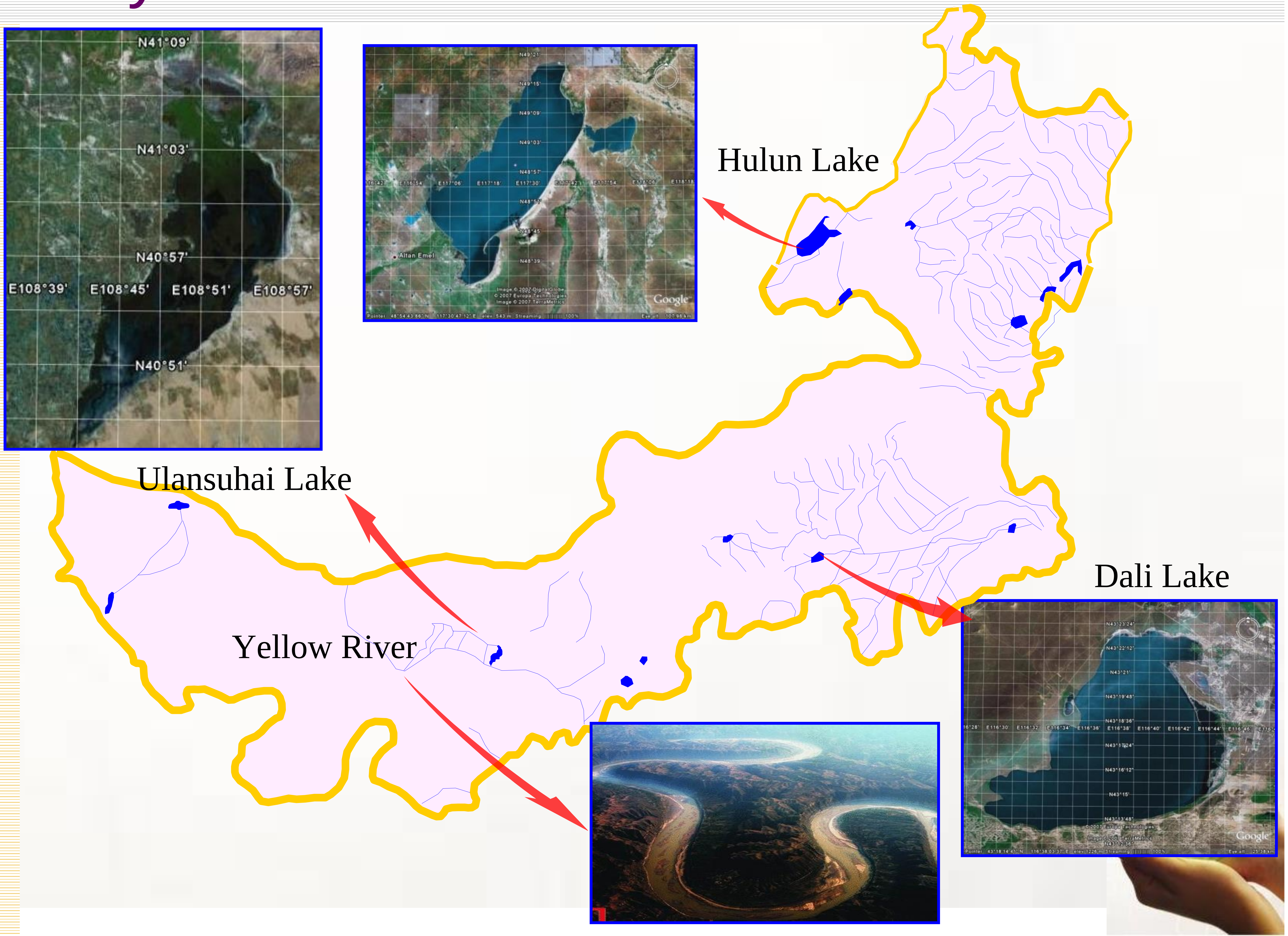
- Brazil: Headwaters of water supply for São Paulo
  Simulate streamflow and water quality responses to historical land use and projected reforestation.
- Inner Mongolia Agricultural University:
  Hetao Irrigation District
  Simulate streamflow and nutrient inflows to lakes experiencing declining water levels and eutrophication (algae and other ecosystem changes)

RIBEIRÃO DAS POSSES WATERSHED

- ✓ The 12-km^2 Ribeirão das Posses watershed is located in the south of Minas Gerais.
- ✓ Headwater catchment of the Jaguari River.
- ✓ Conservative Waters project has planted some small areas with vegetation native, in order to recover degraded areas and identify payments for ecosystem services.

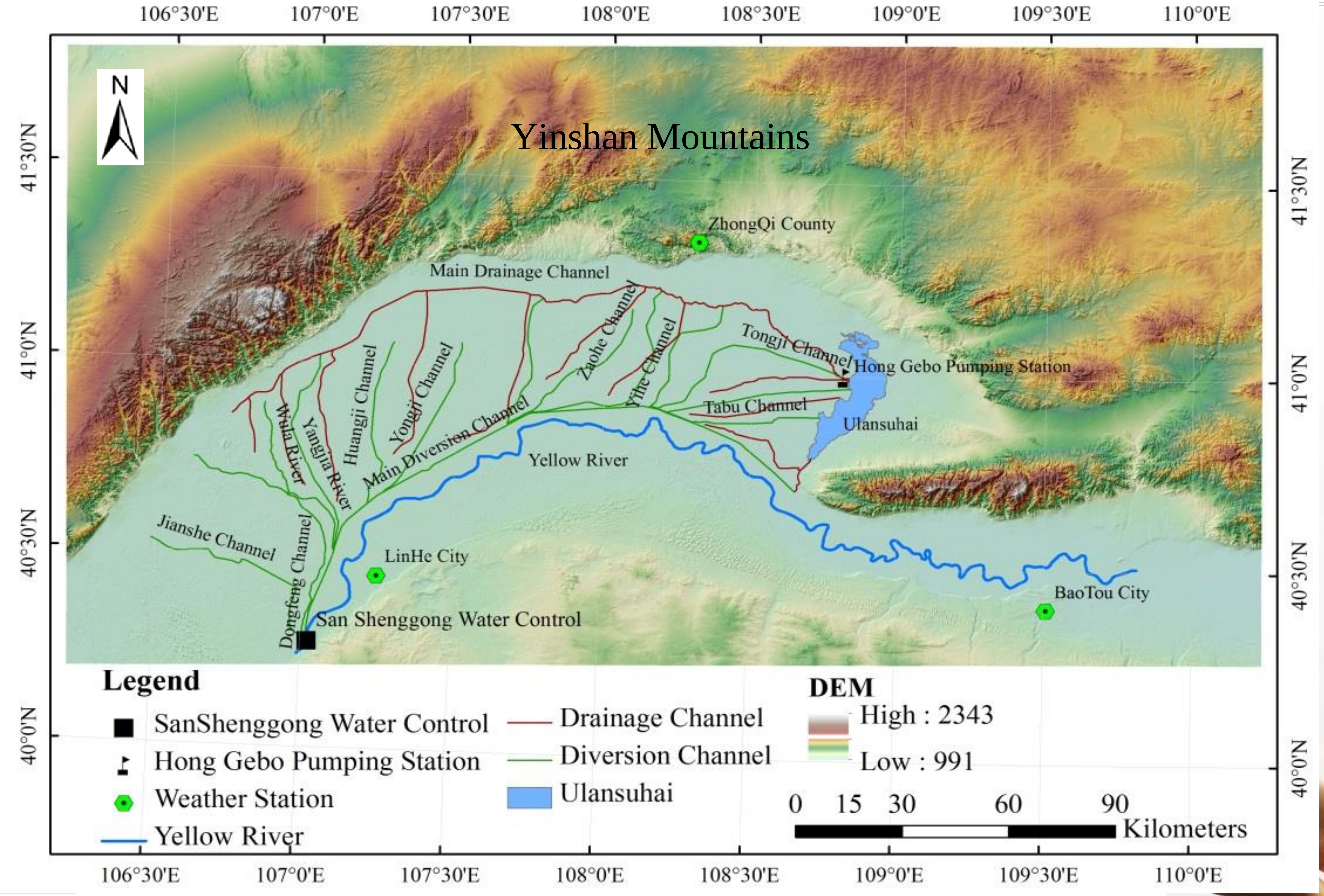


Study areas



Hulun Lake
Ulansuhai Lake
Yellow River
Dali Lake
N41°09'
N41°03'
N40°57'
N40°51'
E108°39'
E108°45'
E108°51'
E108°57'

Study area



106°30'E
107°0'E
107°30'E
108°0'E
108°30'E
109°0'E
109°30'E
110°0'E
41°30'N
41°0'N
40°30'N
40°0'N
N
Yinshan Mountains
ZhongQi County
Main Drainage Channel
Zaohe Channel
Yihe Channel
Tongji Channel
Hong Gebo Pumping Station
Tabu Channel
Ulansuhai
Huangji Channel
Yongji Channel
Main Diversion Channel
Wula River
Yangjia River
Yellow River
Jianshe Channel
Dongfeng Channel
LinHe City
San Shenggong Water Control
BaoTou City
Legend
SanShenggong Water Control
Hong Gebo Pumping Station
Weather Station
Yellow River
Drainage Channel
Diversion Channel
Ulansuhai
DEM
High : 2343
Low : 991
0 15 30 60 90
Kilometers

Conclusions

- Recent technological developments provide (semi)automated long-term measurements of spatial and temporal variables.
- Computer models are essential for process understanding and estimation over space and time.
- Key problems include agricultural water management, land use change, and projected climate change.
- International collaboration extends research to address issues around the globe.


Thoughts?