Integrated Studies of *Landscape-Soil-Water Relationships*

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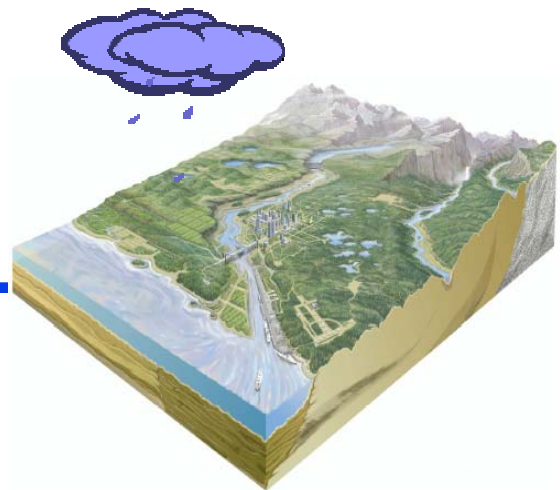
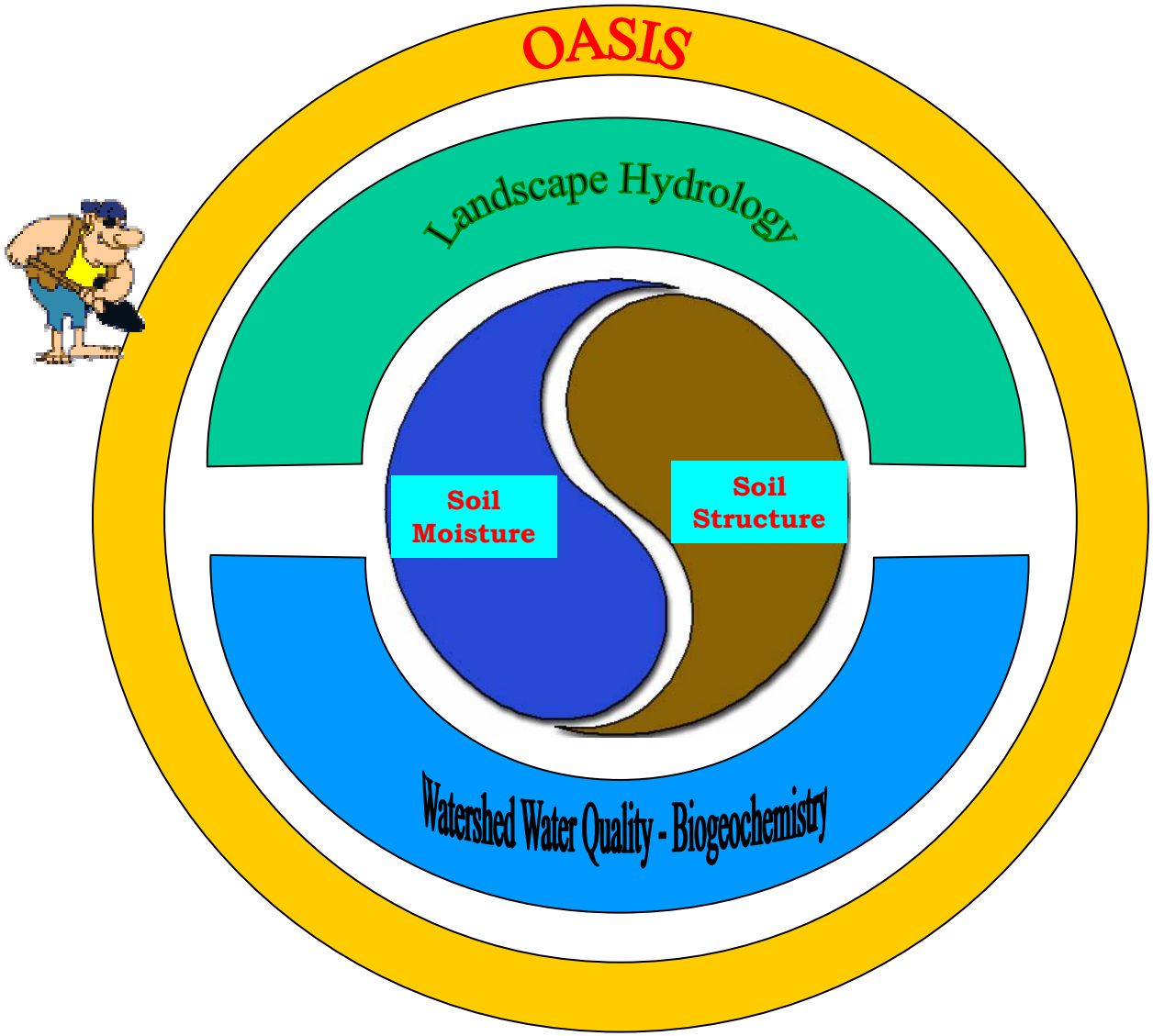
PENNSTATE

1855



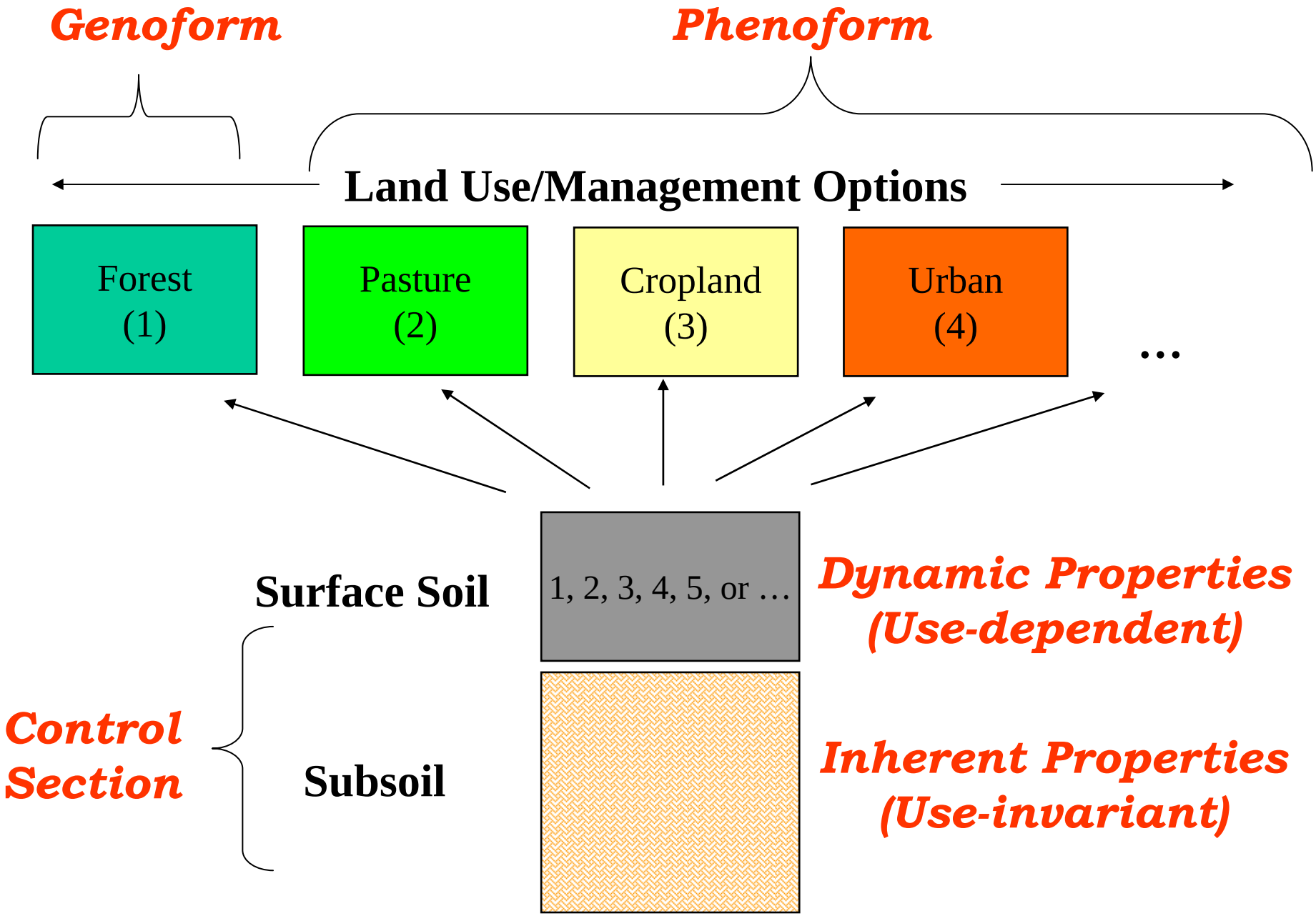

OASIS
Landscape Hydrology
Soil Moisture
Soil Structure
Watershed Water Quality - Biogeochemistry

Outlines

- **Land Use Impacts on Soil Properties**
- **Landscape Hydropedologic Studies**
  - ***Forest Catchment***
  - ***Agronomy Farm***
  - ***Wastewater Spray Irrigation***
- **Online Advanced Spatial Info System**

Modeling Soil Hydraulic Properties as a Function of Soil Morphology, Soil Structure, and Land Use

To develop a set of models (PTFs) for estimating soil hydraulic properties (such as infiltration rates, hydraulic conductivity, available water holding capacity, and others) based on land use, soil morphology, soil structure, and other available soil survey data.


Genoform
Phenoform
Land Use/Management Options
Forest
(1)
Pasture
(2)
Cropland
(3)
Urban
(4)
…
1, 2, 3, 4, 5, or …
Surface Soil
Dynamic Properties
(Use-dependent)
Control
Section
Subsoil
Inherent Properties
(Use-invariant)

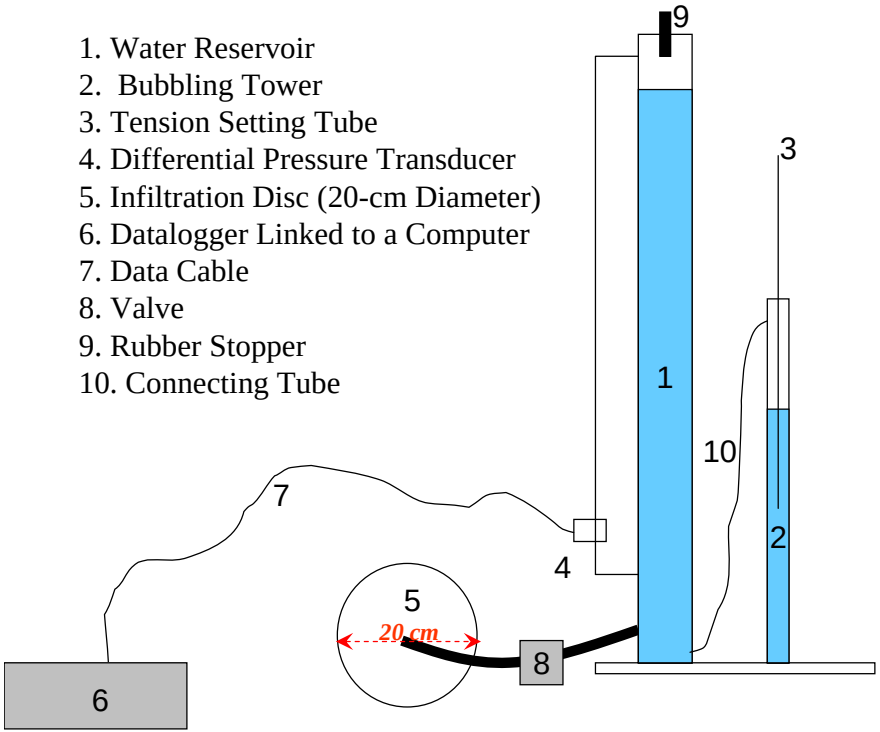
Materials and Methods

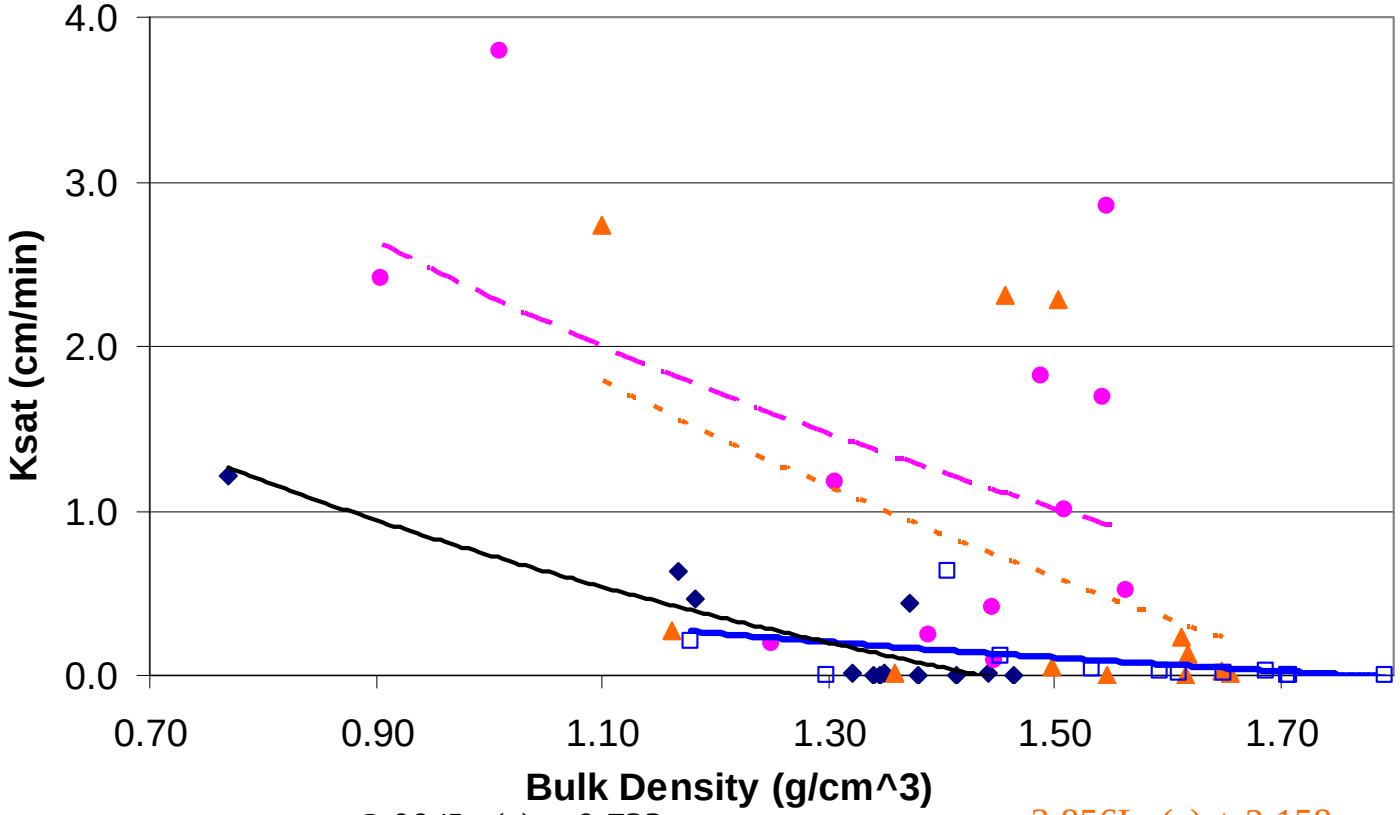
Four soil series, each under four different land uses (woodland, pasture, cropland, urban):

- Two series (*Glenelg* and *Joanna* series, both Typic Hapludults) are located in Chester County, PA, representing the Northern Piedmont MLRA 148;

- Two series (*Hagerstown* series, a Typic Hapludalf, and *Morrison* series, an Ultic Hapludalf) are located in Centre County, PA, representing the Northern Appalachian Ridges and Valleys MLRA 147.

Tension infiltrometers have been used for *in situ* infiltration measurements at each of the 16 sites. Apparent steady-state infiltration rates at the surface (A horizon) and subsurface (B and C horizons) were measured using a set of 4-5 tension infiltrometers simultaneously. Six different water supply tensions (12, 6, 3, 2, 1, and 0 cm) were used sequentially in each of the infiltrometers to enable the assessment of different soil pore sizes in influencing infiltration and the resulting soil hydraulic conductivities.





Glenelg $y = -2.004\mathrm{Ln}(x) + 0.733$ $R^2 = 0.8425$

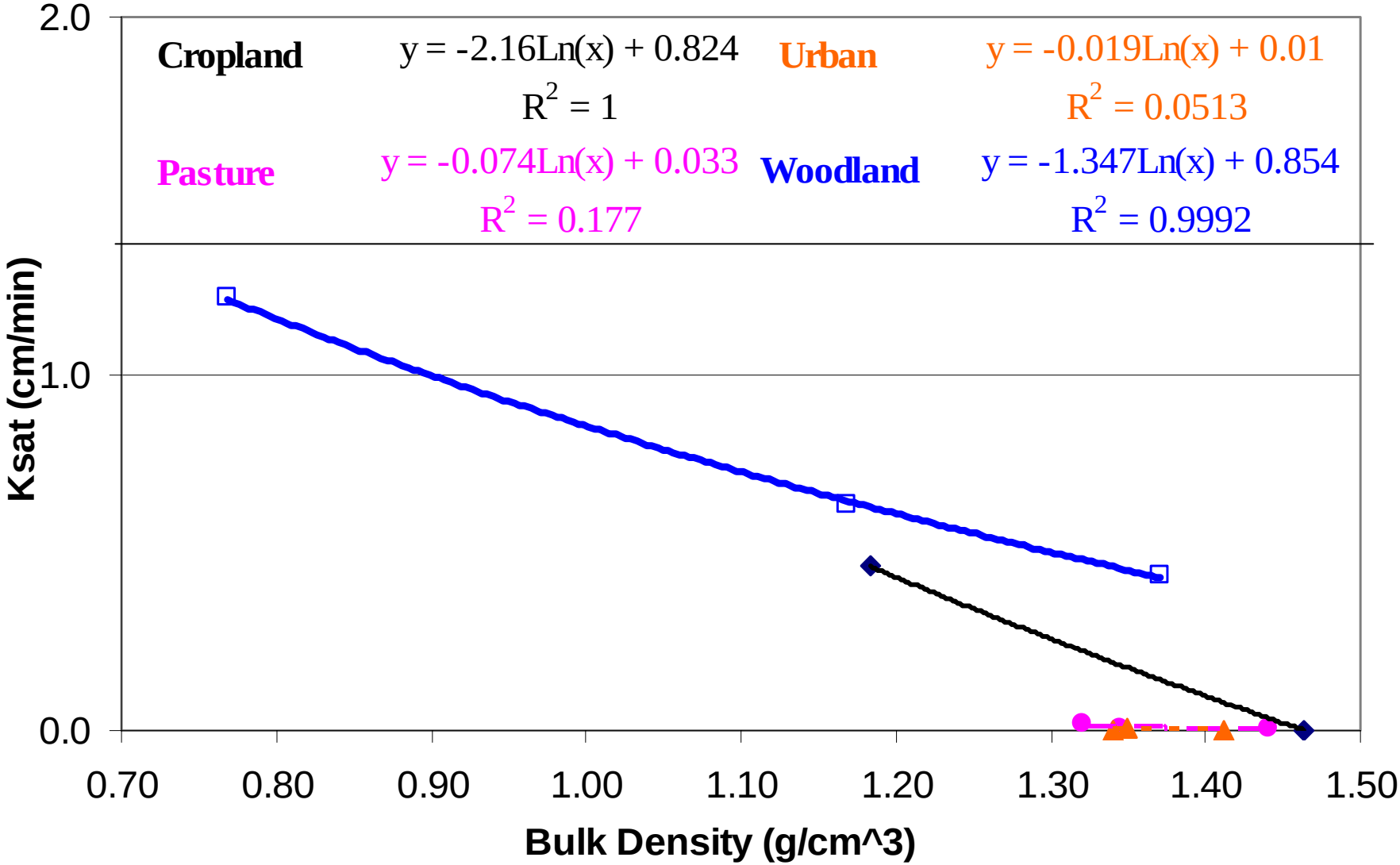
Joanna $y = -3.856\mathrm{Ln}(x) + 2.158$ $R^2 = 0.2366$

Hagerstown $y = -3.180\mathrm{Ln}(x) + 2.304$ $R^2 = 0.2225$

Morrison $y = -0.659\mathrm{Ln}(x) + 0.375$ $R^2 = 0.2104$

Highly compacted urban soil

Adjacent cropland soil of same series

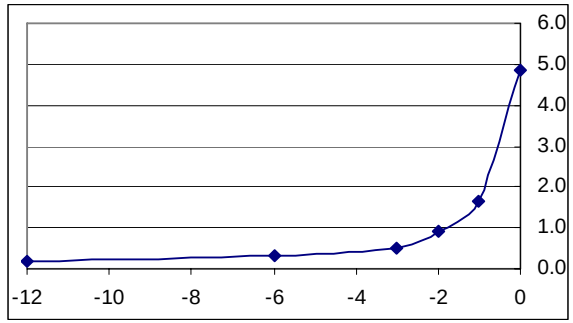


Saturated hydraulic conductivity vs. bulk density for the four land uses in the Glenelg.

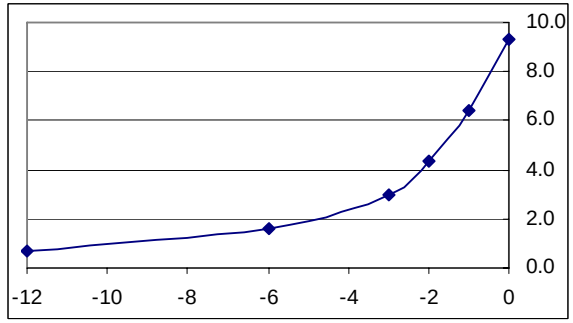
Glenelg Woodland
04-PA029-003

Location: Art Hershey Woods
Halfway up driveway into woods, from stake, 9.5’ at 80°

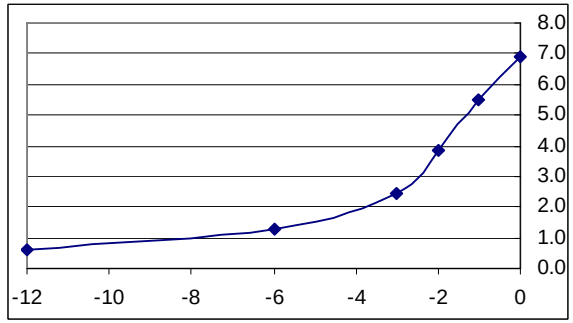
Surface (A)
Initial Moisture (m3/m3): 0.326
Structure: Medium, moderate, granular
Bulk Density (g/cm3): 0.77
Ksat (cm/min): 1.212
Macroporosity: Common, fine, Dendritic tubular
Root Density: Many, very fine-fine, throughout
Depth Measured (cm): Surface



B Horizon (Bt1)
Initial Moisture (m3/m3): 0.244
Structure: Medium, moderate, sub-angular blocky
Bulk Density (g/cm3): 1.17
Ksat (cm/min): 0.632
Macroporosity: Few, medium, Dendritic tubular
Root Density: Common, fine, throughout
Depth Measured (cm): 38



C Horizon (C1)
Initial Moisture (m^3/m^3): 0.148
Structure: Medium, moderate, sub-angular blocky
Bulk Density (g/cm^3): 1.37
Ksat (cm/min): 0.418
Macroporosity: None
Root Density: Common, very fine-fine, throughout
Depth Measured (cm): 93



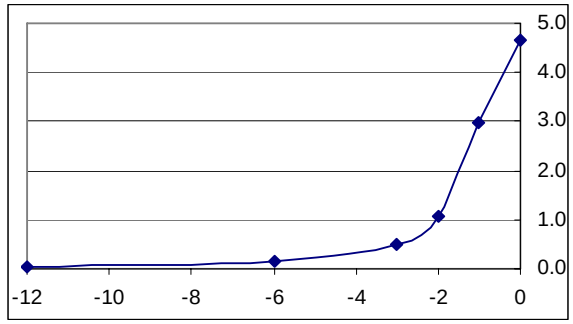
Glenelg Cropland

04-PA029-004

Location: Duane Hershey Farm
Stake at Telephone pole, 115' at 78°

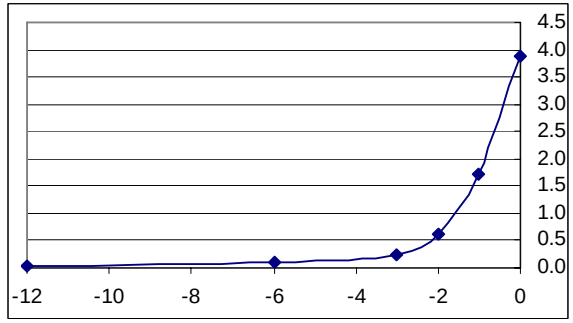
Surface (Ap)

Initial Moisture (m3/m3): 0.349
Structure: Medium, moderate, sub-angular blocky
Bulk Density (g/cm3): 1.18
Ksat (cm/min): 0.46
Macroporosity: Common, fine, tubular
Root Density: Many, fine, throughout
Depth Measured (cm): Surface



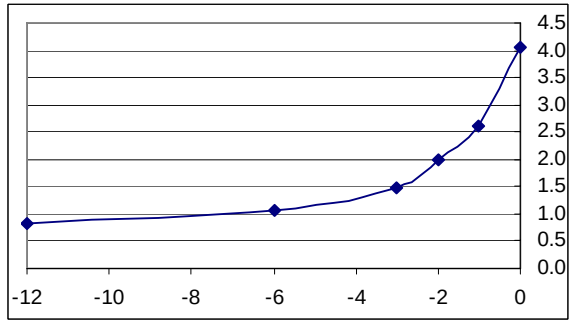
B Horizon (Bt2)

Initial Moisture (m3/m3): 0.281
Structure: Medium, moderate, sub-angular blocky
Bulk Density (g/cm3): 1.46
Ksat (cm/min): 0.001
Macroporosity: None
Root Density: None
Depth Measured (cm): 45



C Horizon (C1)

Initial Moisture (m^3/m^3): 0.234
Structure: Medium, weak, platy
Bulk Density (g/cm^3): 1.38
Ksat (cm/min): 0
Macroporosity: None
Root Density: None
Depth Measured (cm): 110

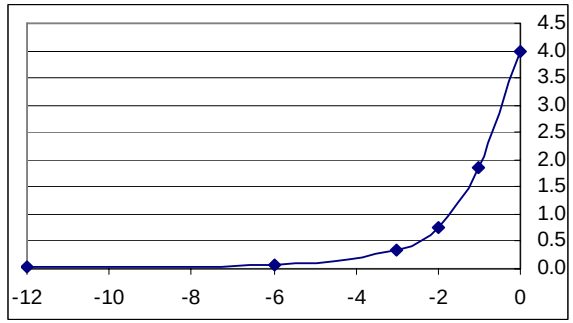


Glenelg Pasture
04-PA029-005

Location: Richard Breckbill Farm
Stake in fencerow, 25' at 62°

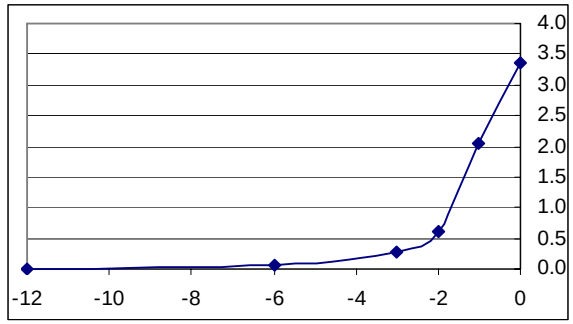
Surface (Ap)

Initial Moisture (m3/m3): 0.288
Structure: Medium, moderate, granular
Bulk Density (g/cm3): 1.32
Ksat (cm/min): 0.019
Macroporosity: Common, medium, tubular
Root Density: Many, fine-medium, throughout
Depth Measured (cm): Surface



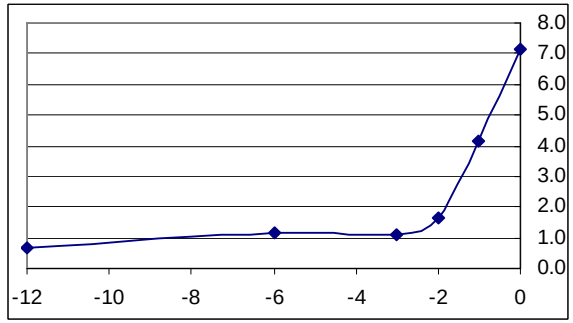
B Horizon (Bt)

Initial Moisture (m3/m3): 0.323
Structure: Moderate, medium, sub-angluar blocky
Bulk Density (g/cm3): 1.44
Ksat (cm/min): 0.008
Macroporosity: Few, fine, Dendritic tubular
Root Density: None
Depth Measured (cm): 43



C Horizon (C3)

Initial Moisture (m^3/m^3): 0.290
Structure: Thick, weak, platy
Bulk Density (g/cm^3): 1.35
Ksat (cm/min): 0.003
Macroporosity: None
Root Density: None
Depth Measured (cm): 110

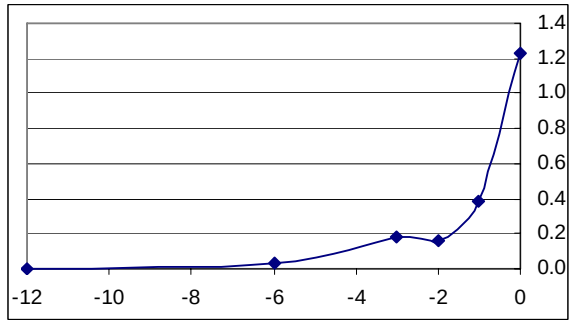


Glenelg Urban
04-PA029-006

Location: Lincoln University
Near Douglas statue, from manhole, 26’ at139°

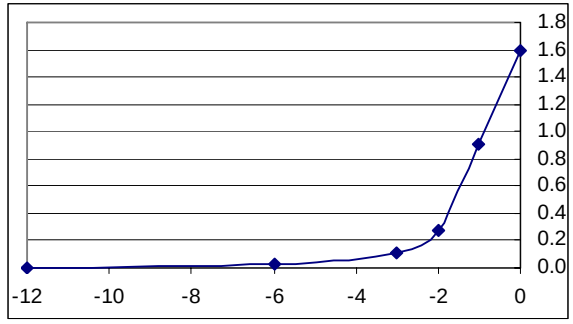
Surface (A/B)

Initial Moisture (m3/m3): 0.328
Structure: Thick, moderate, platy
Bulk Density (g/cm3): 1.34
Ksat (cm/min): 0.002
Macroporosity: Few, very fine, Dendritic tubular
Root Density: Common, very fine, throughout
Depth Measured (cm): Surface



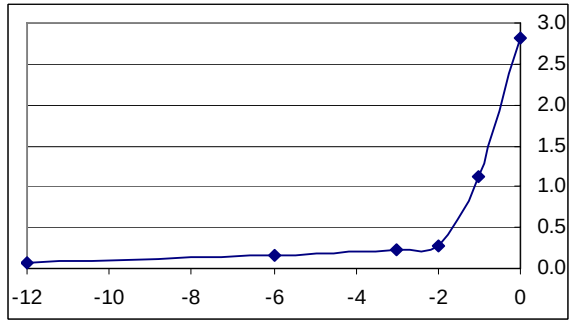
B Horizon (Bt1)

Initial Moisture (m3/m3): 0.335
Structure: Medium, moderate, sub-angular blocky
Bulk Density (g/cm3): 1.41
Ksat (cm/min): 0.003
Macroporosity: Common, medium, Dendritic tubular
Root Density: Few, very fine, in channels
Depth Measured (cm): 46



C Horizon (C)

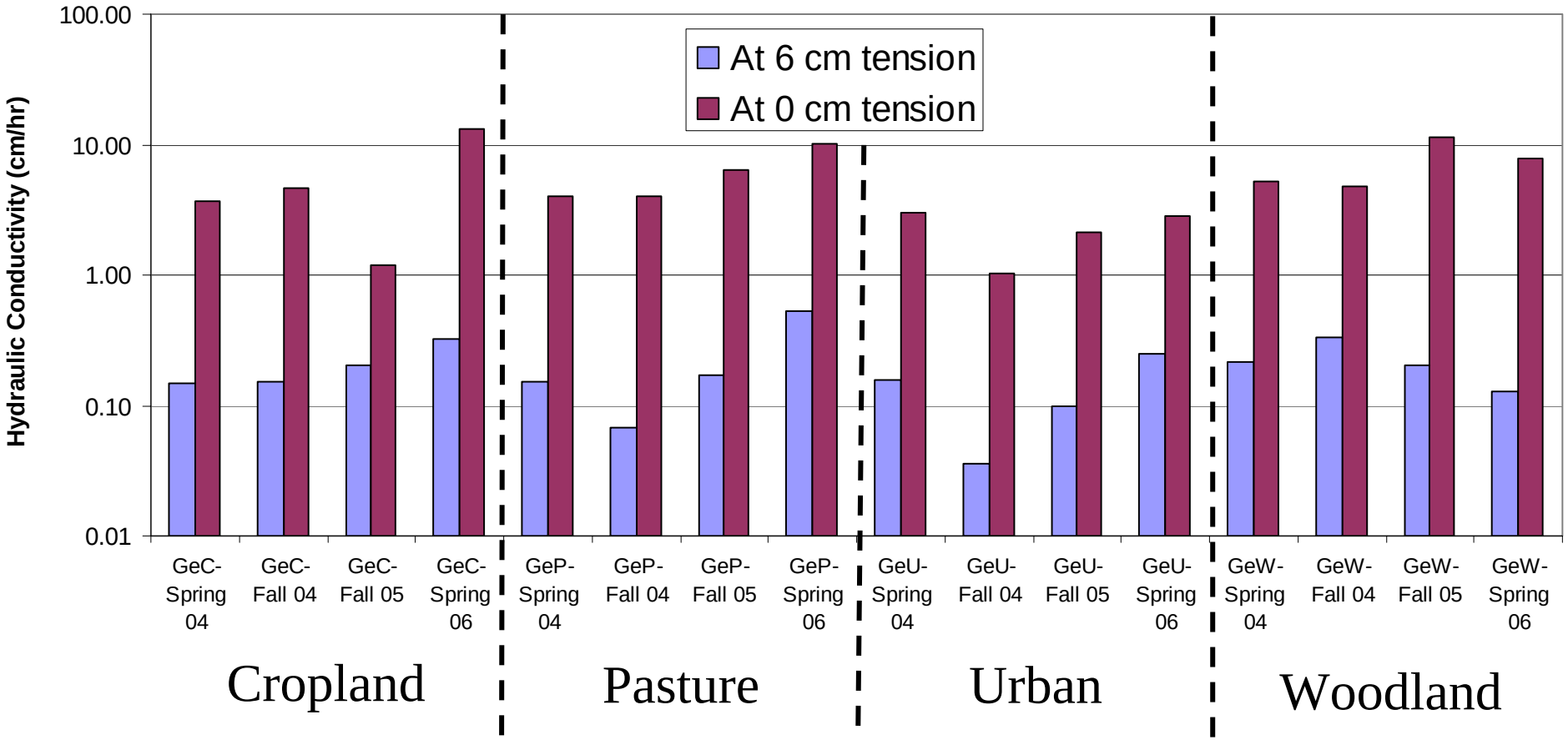
Initial Moisture (m^3/m^3): 0.300
Structure: Thick, strong, platy
Bulk Density (g/cm^3): 1.35
Ksat (cm/min): 0.007
Macroporosity: None
Root Density: None
Depth Measured (cm): 150



Repeated Measurements in Different Seasons …

Seasonal Changes of Surface Soil Hydraulic Conductivity

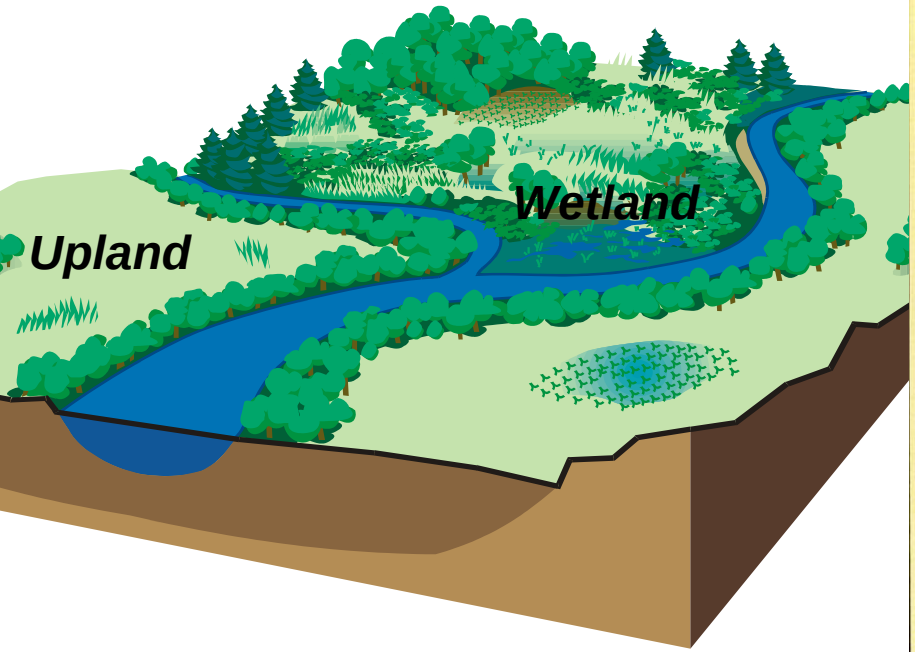
Glenelg

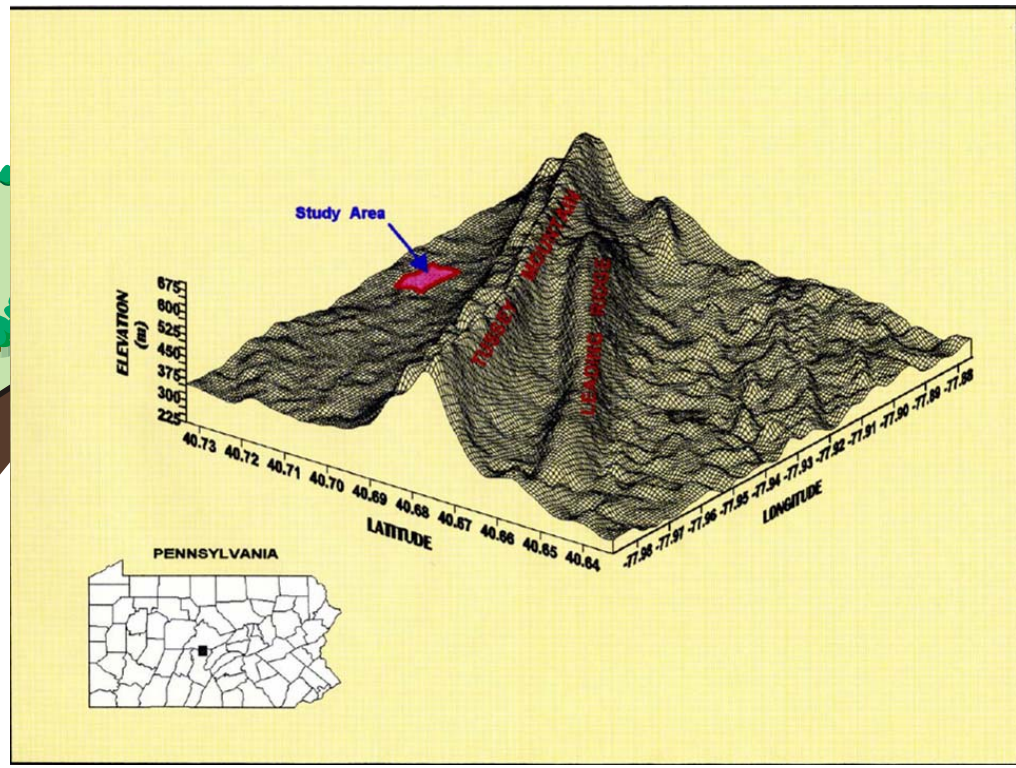


Where is the food, buddy!
Uhhh, at least he brought some water!

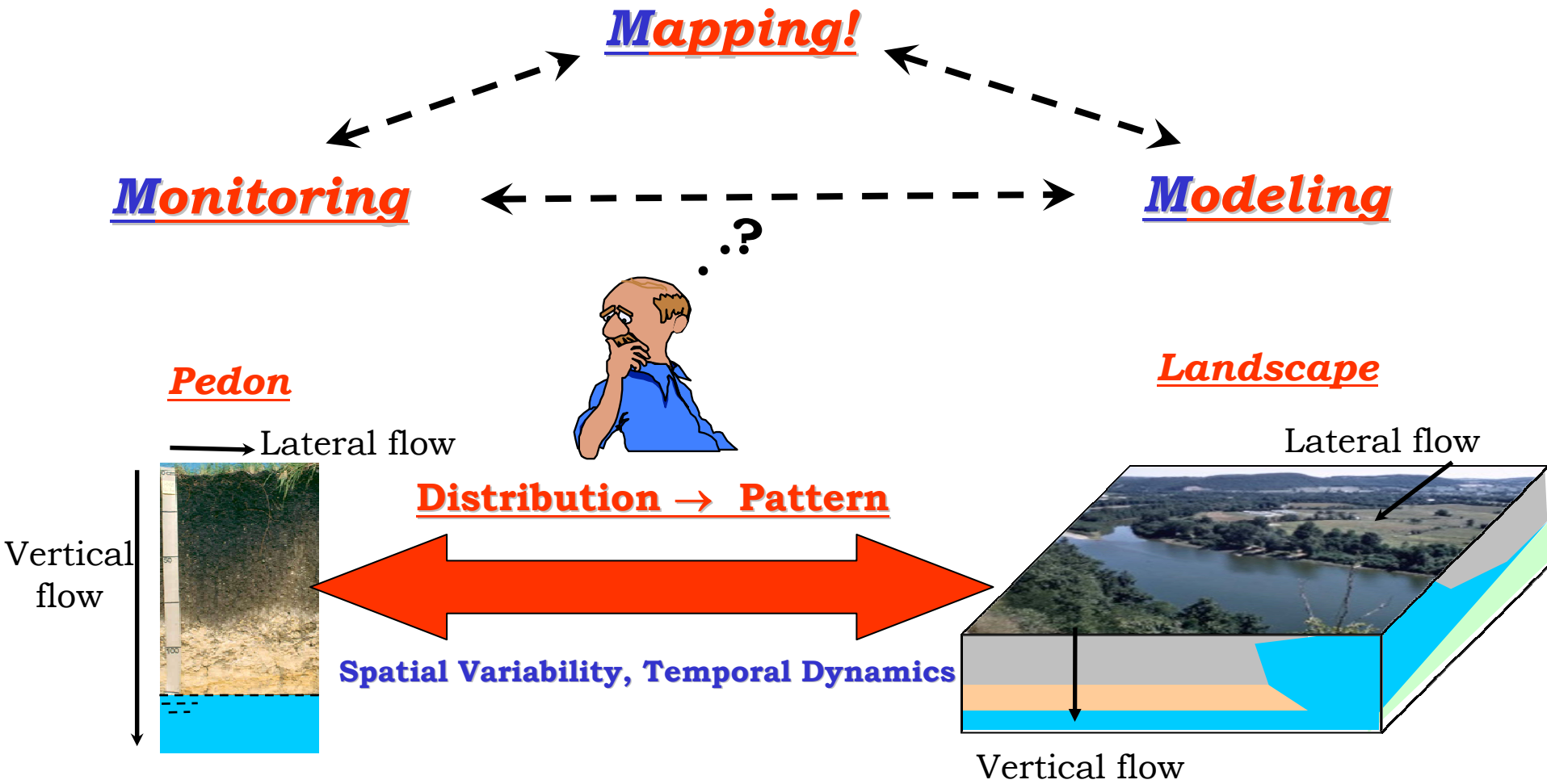
Landscape Hydropedologic Studies

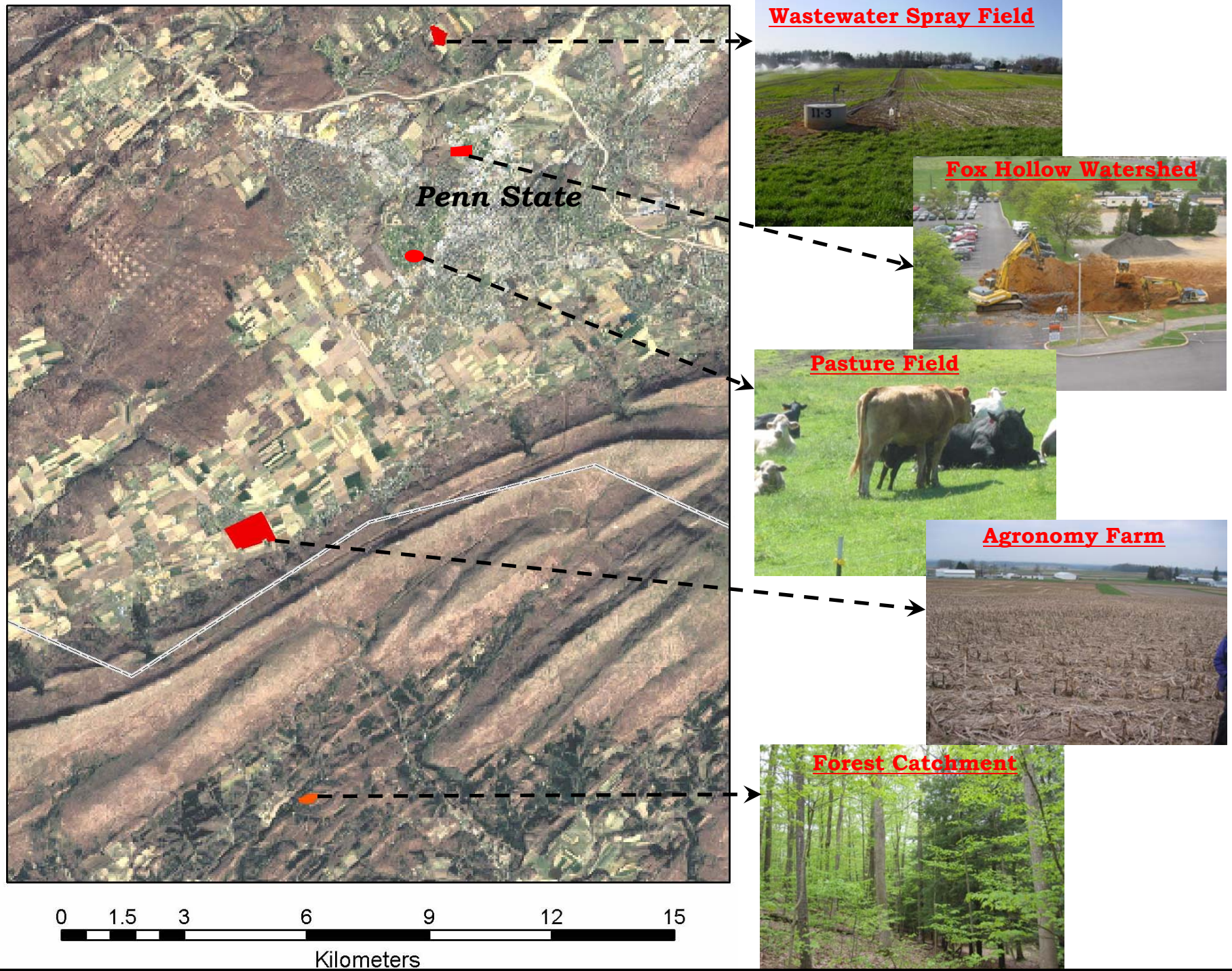
-- Spatial-Temporal Patterns of Soil Moisture and the Underlying Processes in Contrasting Landscapes



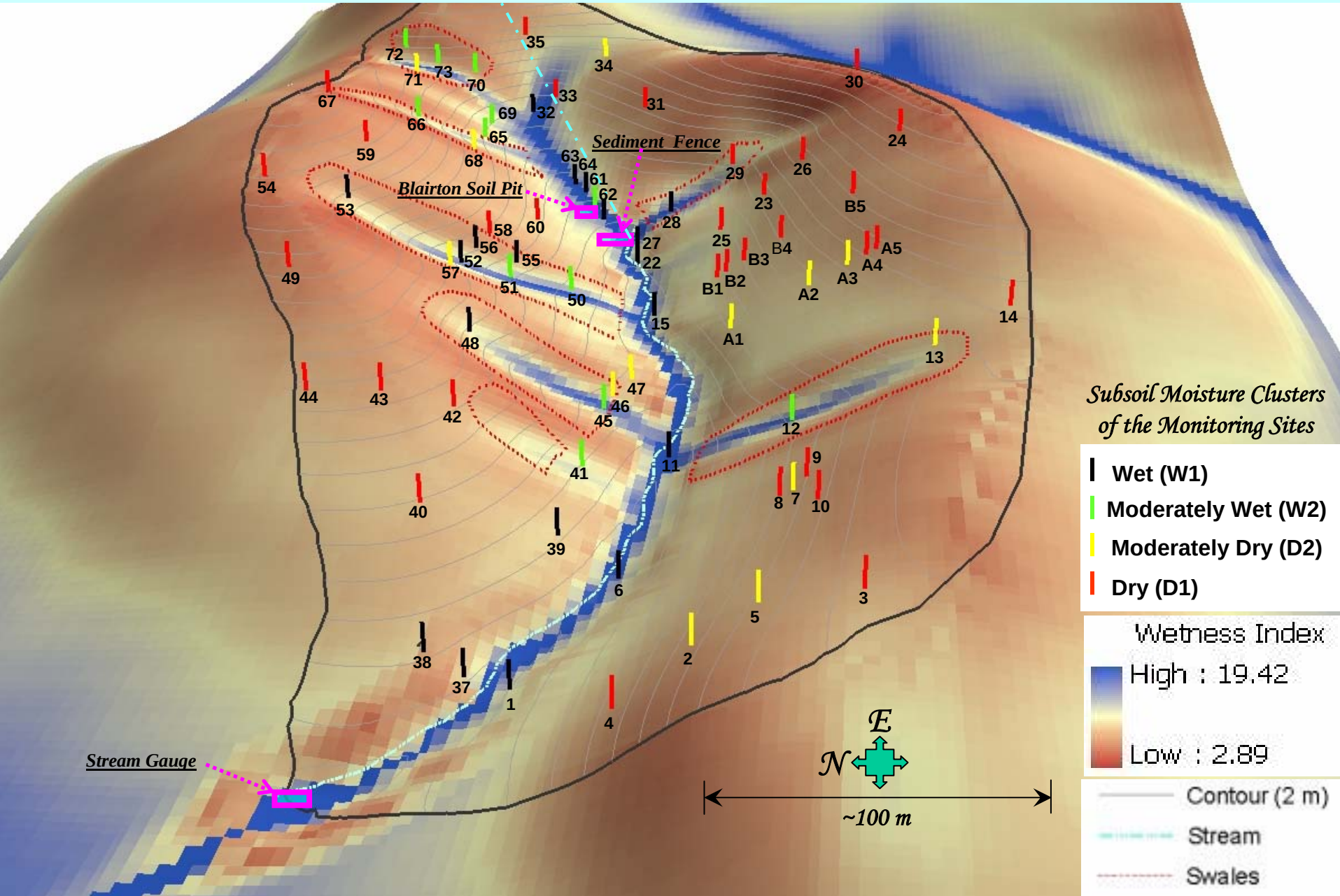


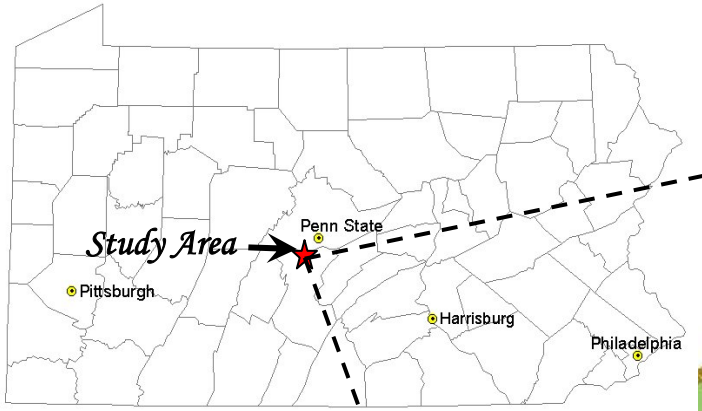
Hydropedologic Approach to Landscape Studies -- "3M" Cycle




Wastewater Spray Field
Fox Hollow Watershed
Penn State
Pasture Field
Agronomy Farm
Forest Catchment
0
1.5
3
6
9
12
15
Kilometers

A Hydropedologic Observatory: A Coupled Test Site for Hydrologic Observatory and Critical Zone Exploration

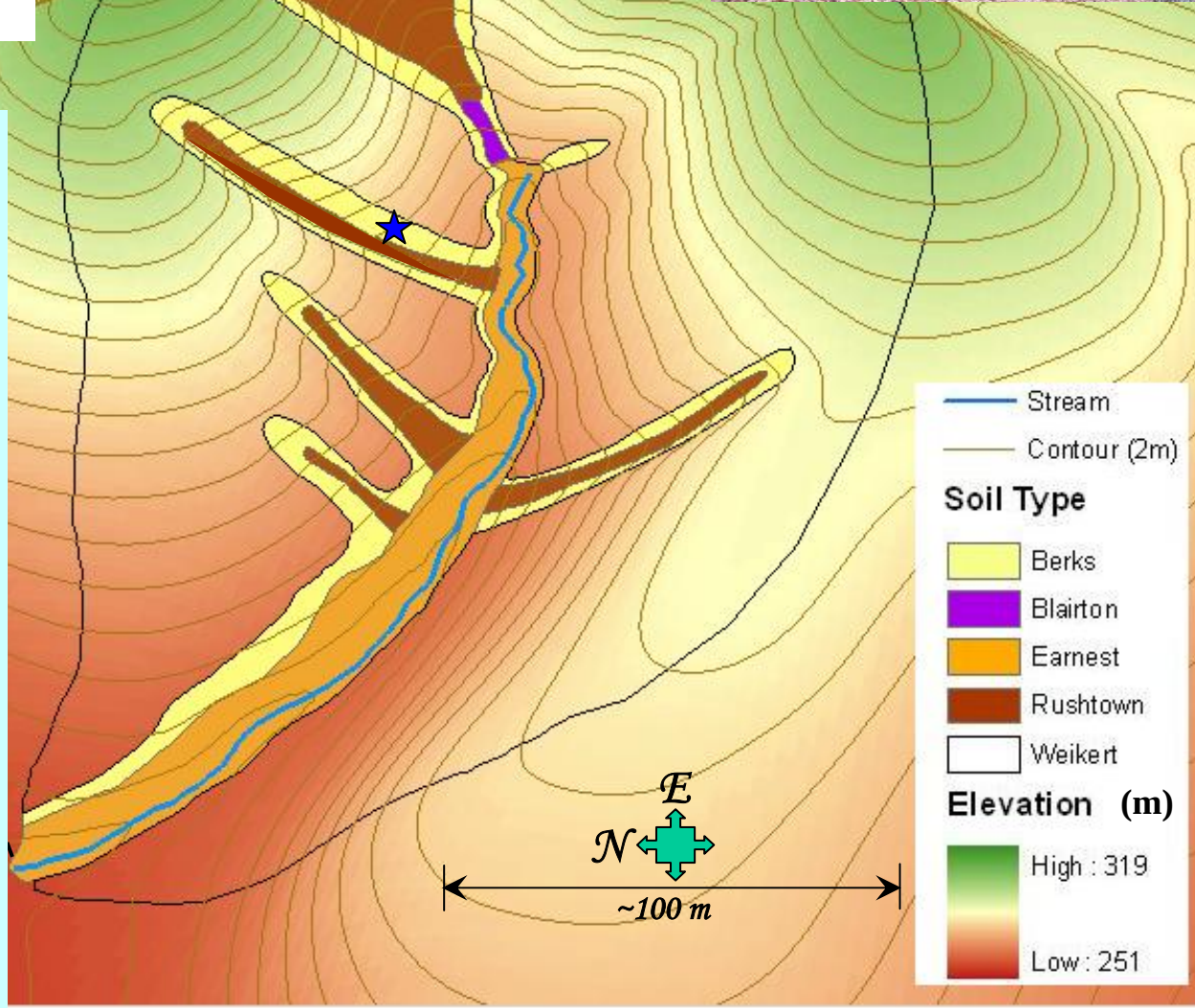


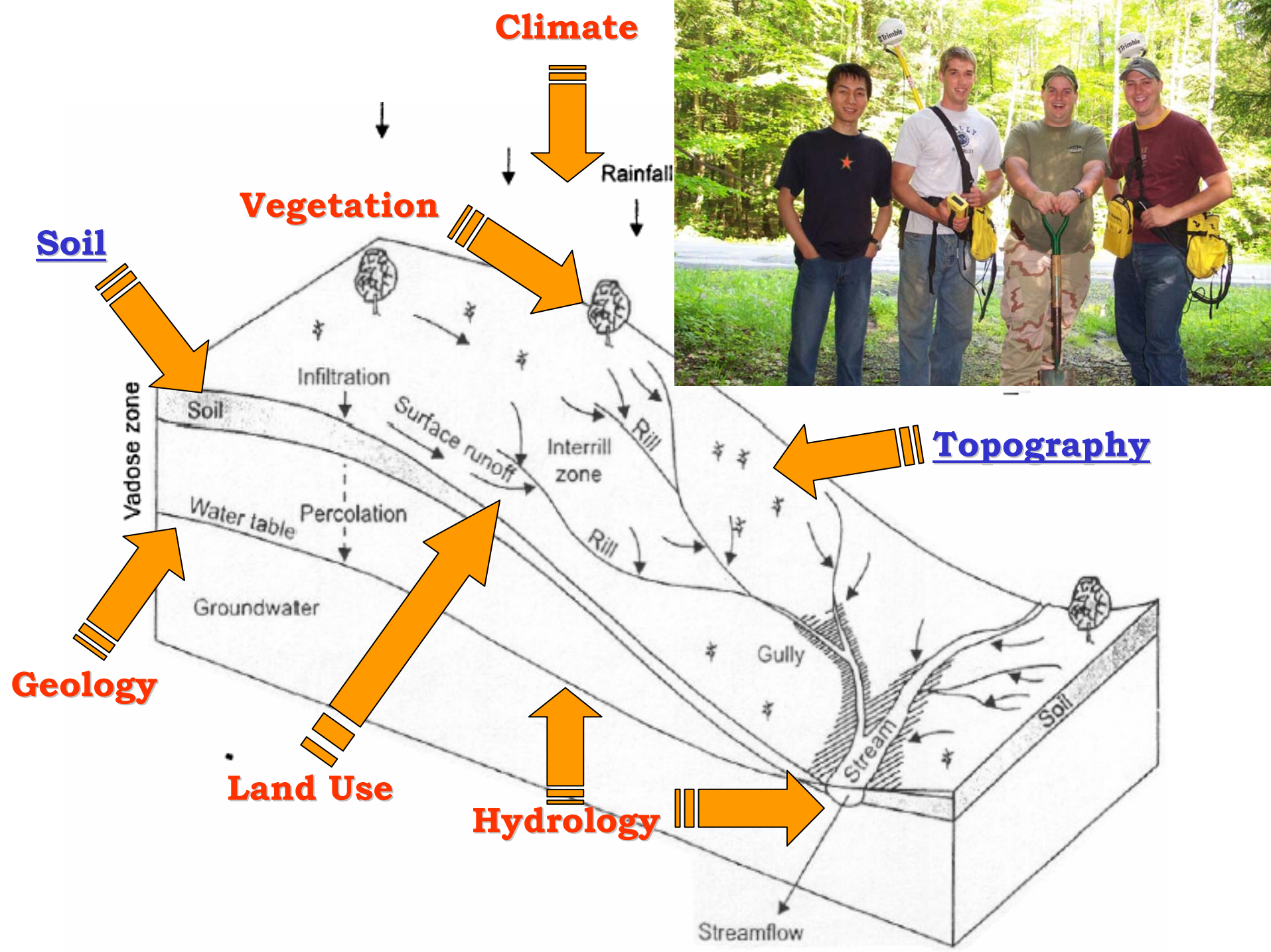


- **7.9 ha pristine forest catchment, V-shaped, 30 miles from PSU campus**

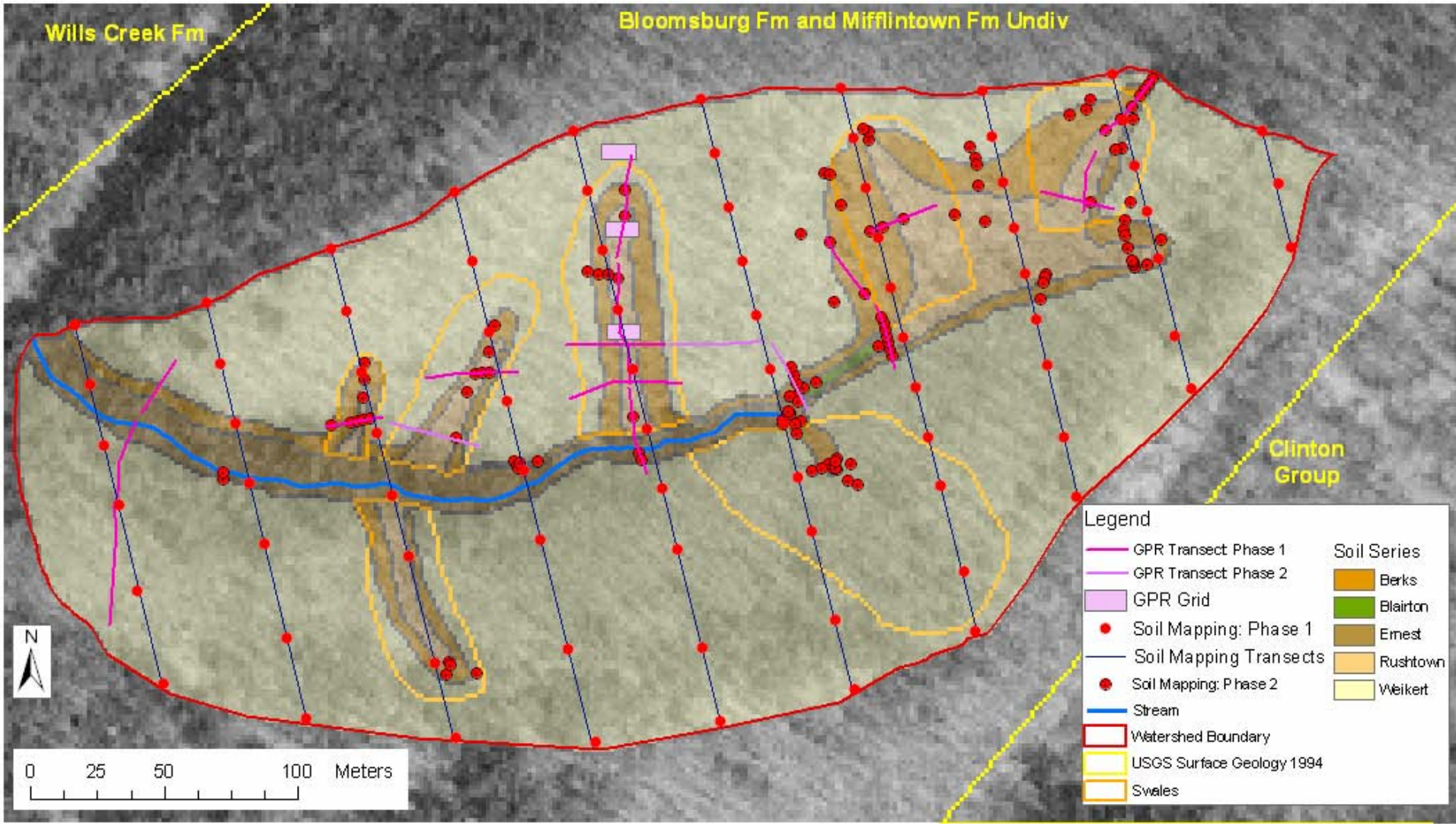
- **5 soil series (Weikert, Berks, Rushtown, Blairton, Ernest) were identified and mapped**

- **4 landforms: south-facing slope, north-facing slope, valley floor of a 1st-order headwater, swales**

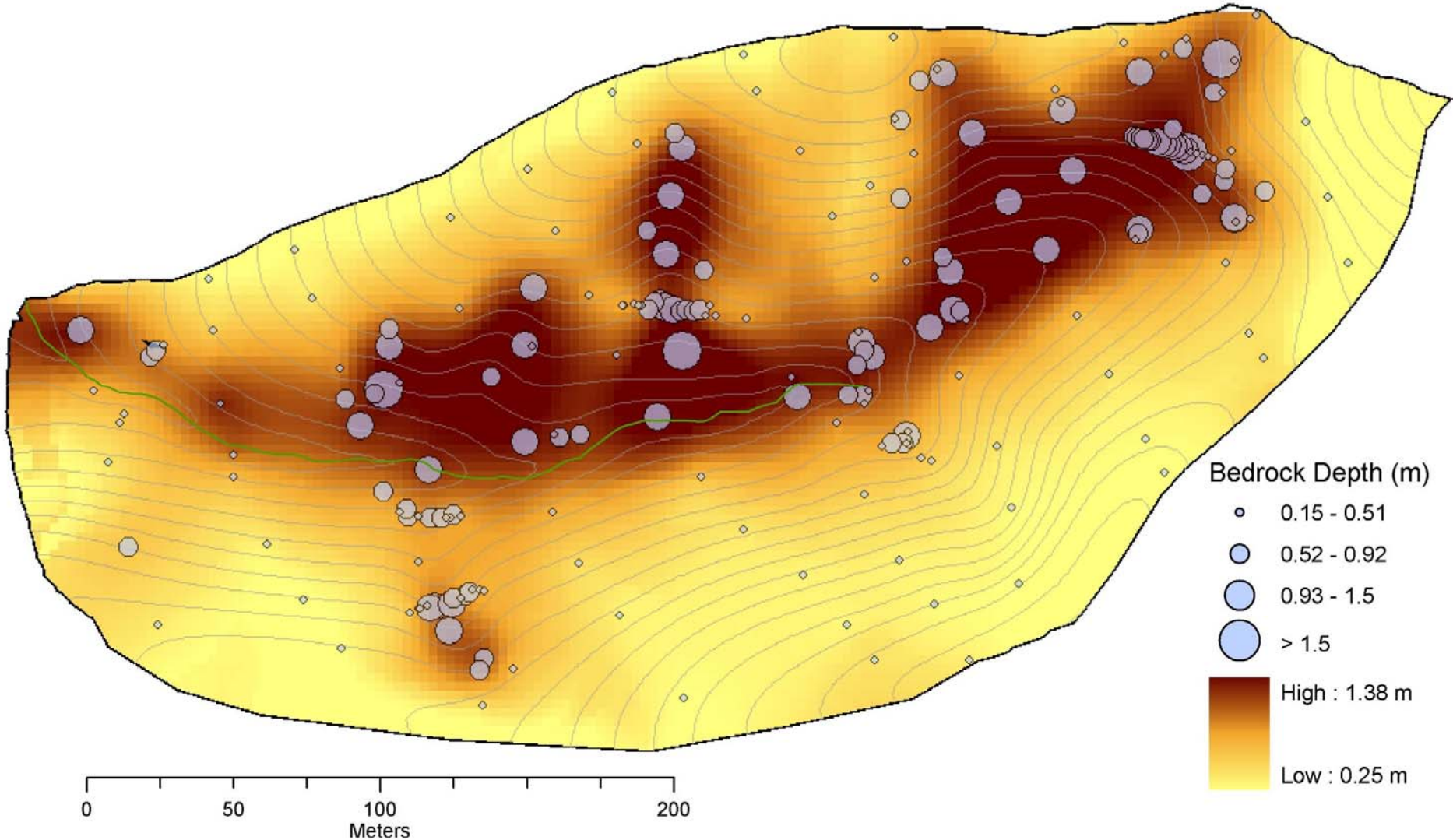



Climate
Rainfall
Vegetation
Soil
Topography
Geology
Land Use
Hydrology
Vadose zone
Soil
Infiltration
Surface runoff
Interrill zone
Rill
Rill
Water table
Percolation
Groundwater
Gully
Stream
Soil
Streamflow

Soil Survey and GPR Surveys at the Shale Hills Catchment



Map of Depth to Bedrock at the Shale Hills Catchment



Depth to bedrock ranges from <0.25 m on the ridge tops and upper side slopes to >2 m in the valley bottom and swales based on *in situ* 223 observations.

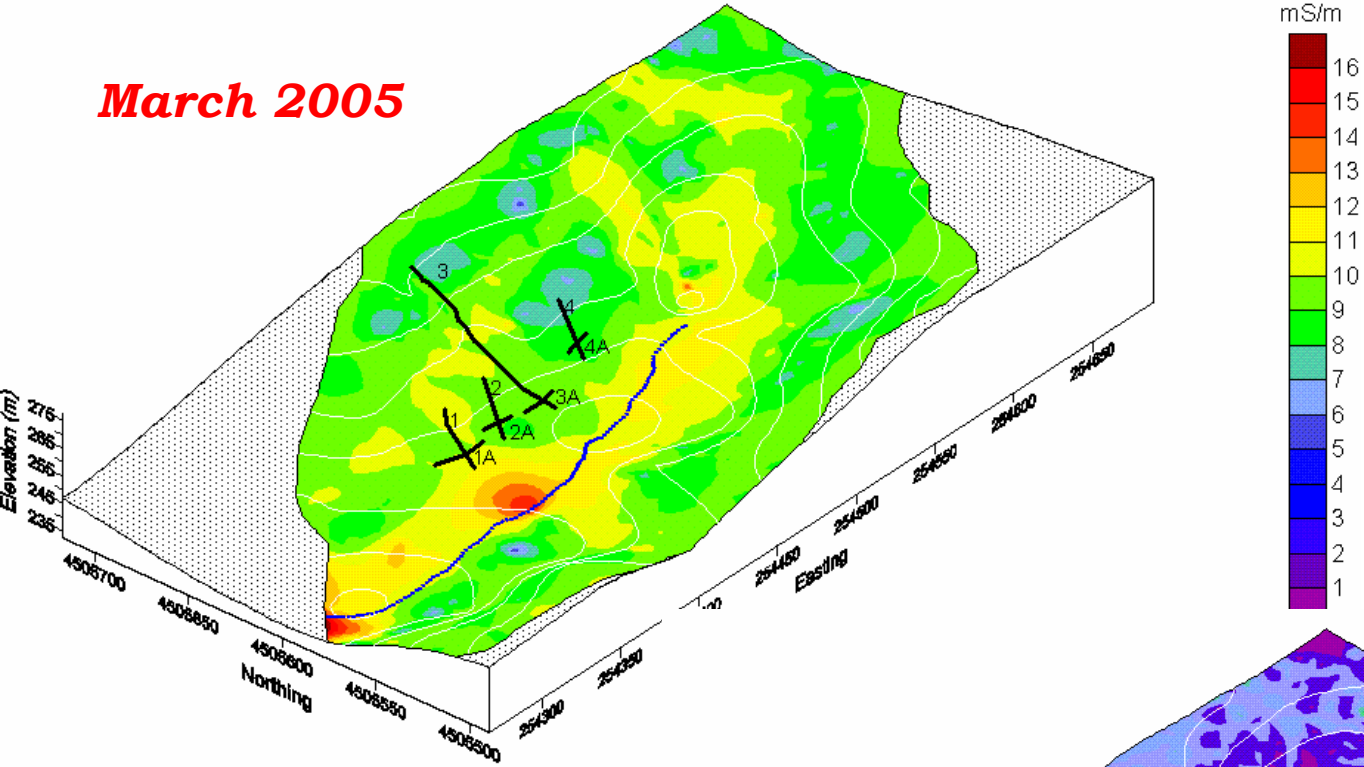
Integrated Use of Geophysical Tools in Hydropedologic Investigations

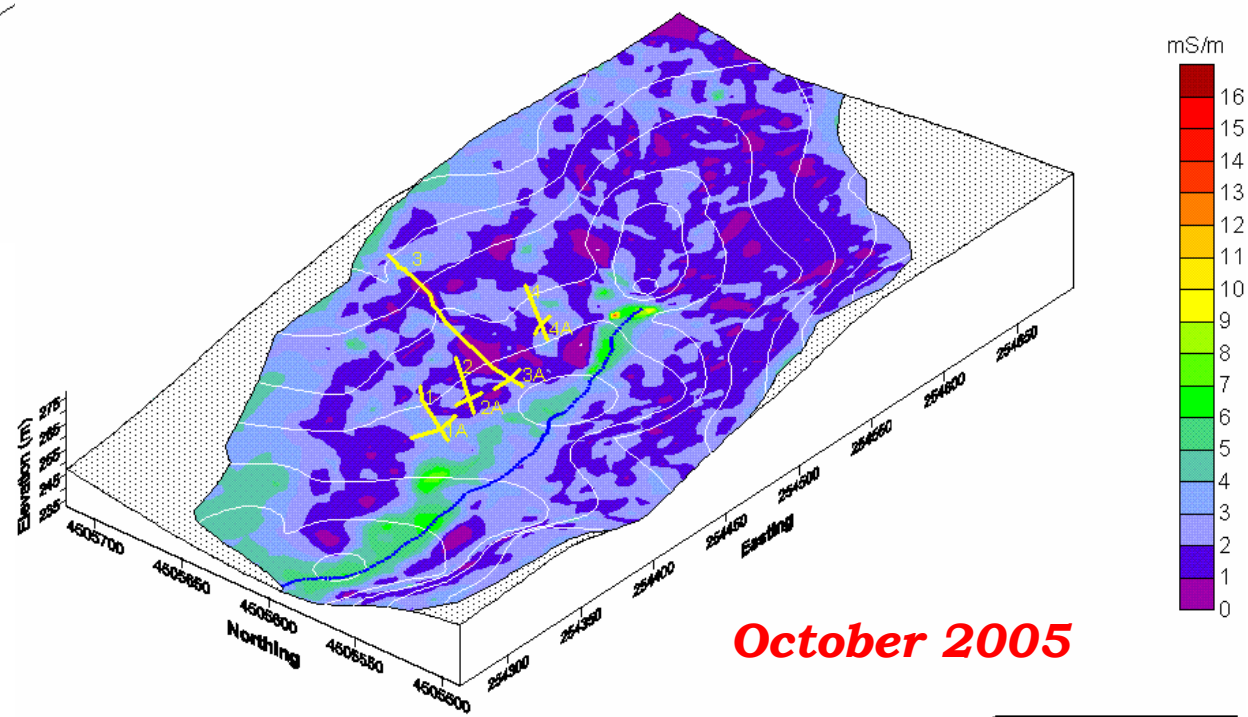
- **Investigate EMI as a potential noninvasive rapid reconnaissance tool for *mapping subsoil moisture distribution* in a pristine forest catchment**

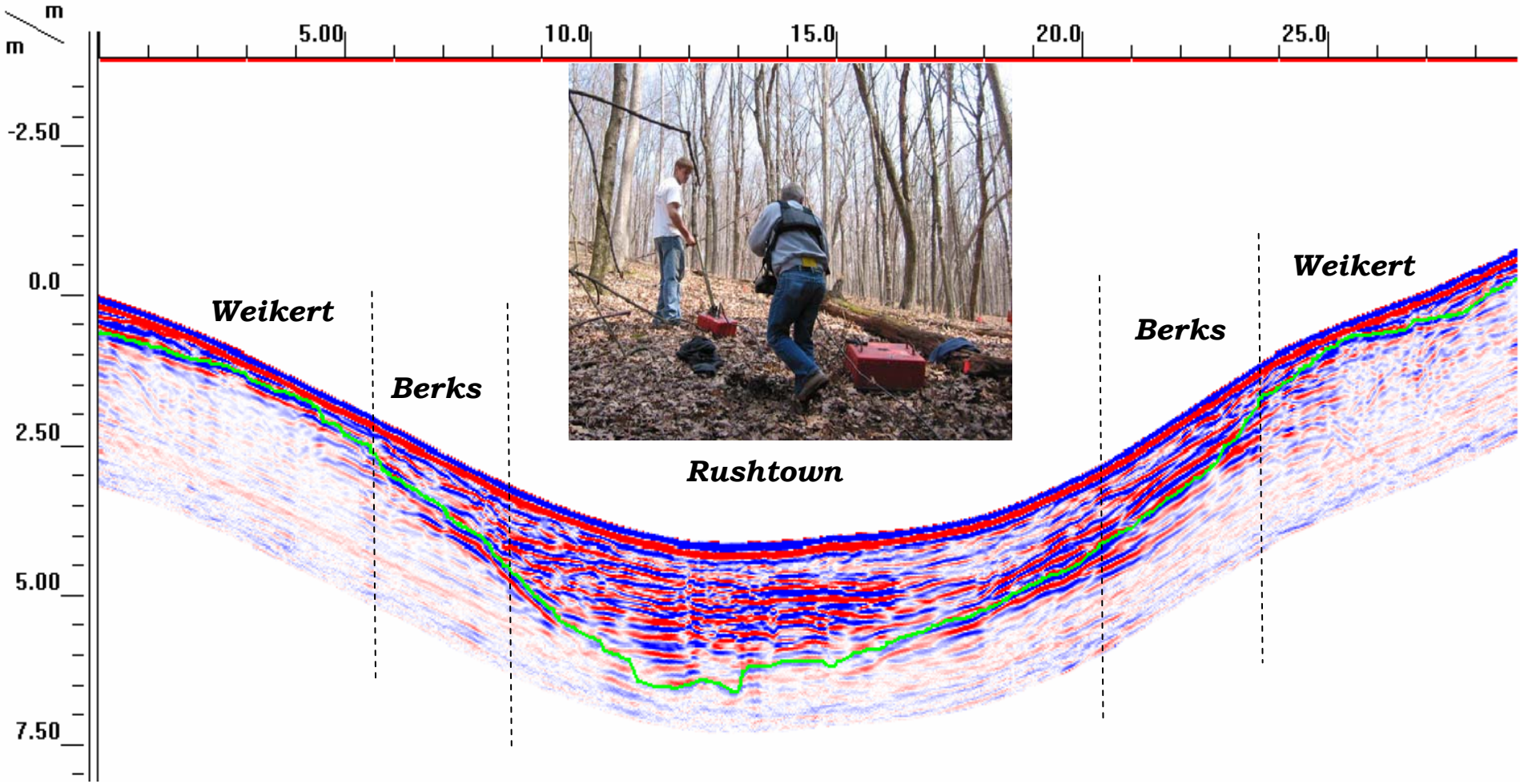
- **Investigate GPR as a potential noninvasive quick tool to provide continuous and high resolution data of *subsurface features including depth to bedrock* in the shale hills catchment**

- **Explore integrated use of geophysical tools for *identifying distinct soil-landscape components* and mapping soil variability across hillslope, especially *subsurface preferential flow pathways***

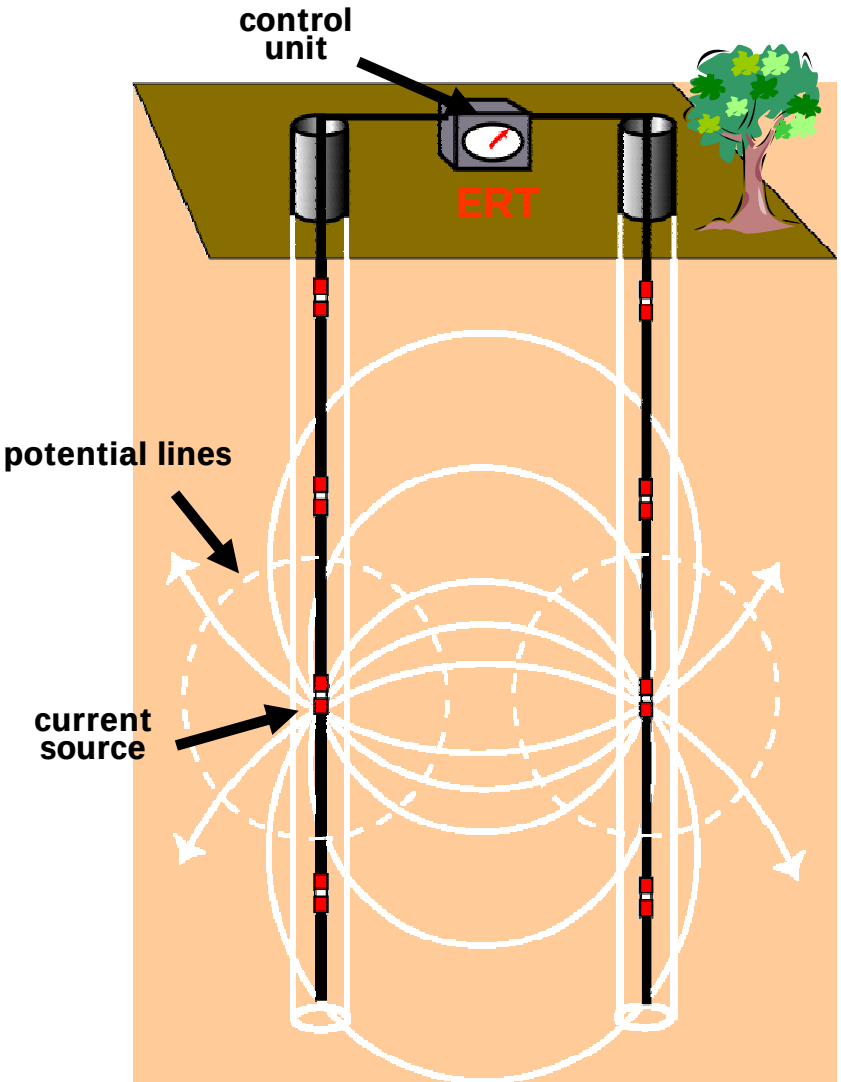
Examples of EMI Surveys

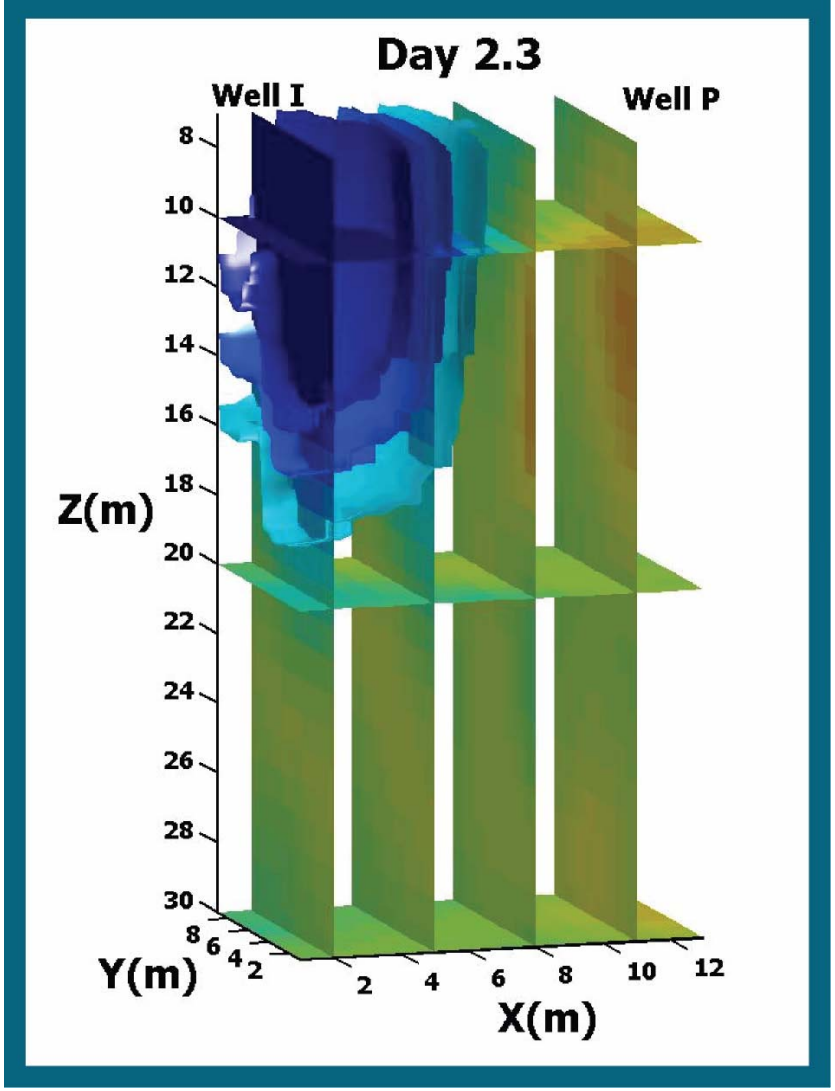




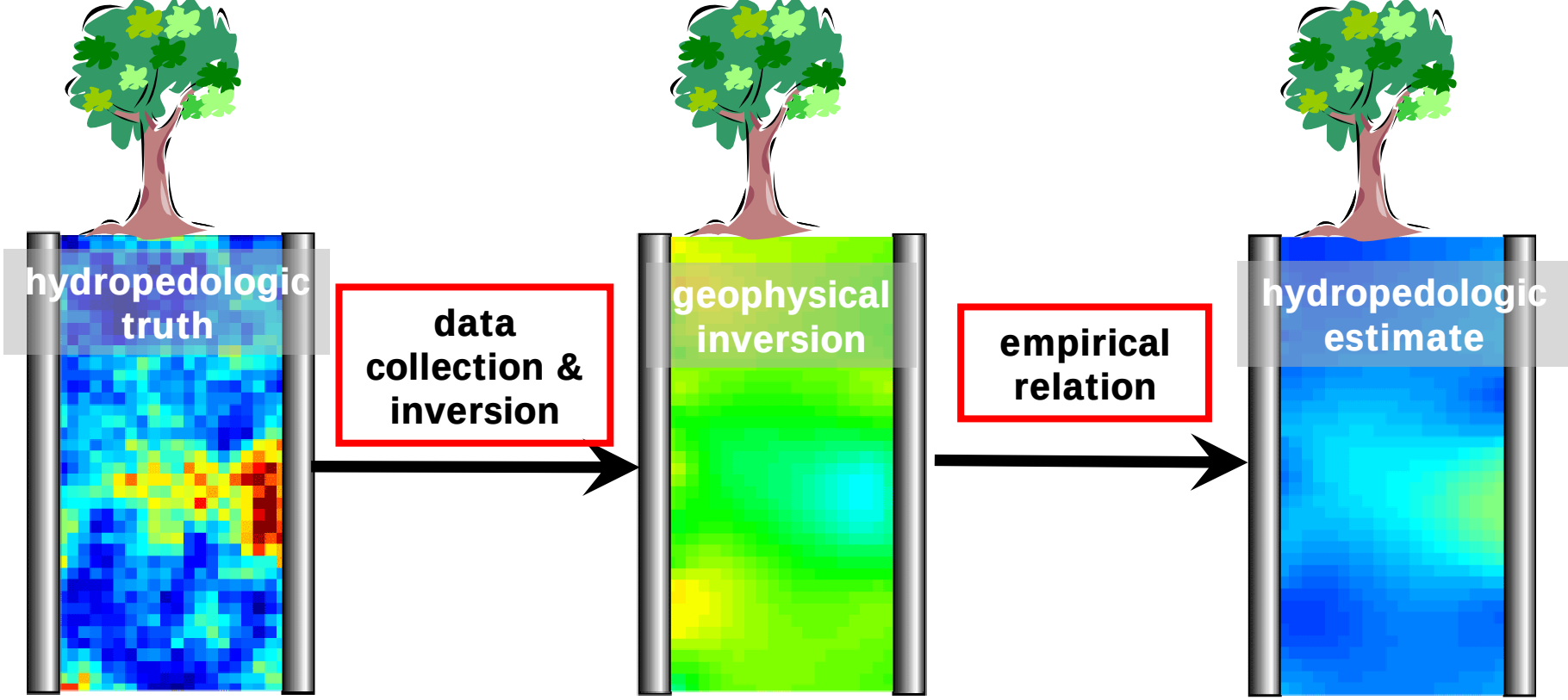


Ground-penetrating radar (GPR) image of a subsurface (a swale) in the Shale Hills Catchment. The green curve indicates an interpreted depth to bedrock. The dash lines separate 3 soil series along the hillslope.





An example of imaging tracer transport in the subsurface using ***electrical resistivity tomography (ERT)***. Cool colors on the right indicate an increase in electrical conductivity associated with the transport of a sodium-chloride tracer. From these spatially exhaustive data, the mass, center of mass, and spatial variance of the tracer plume can be estimated through time.

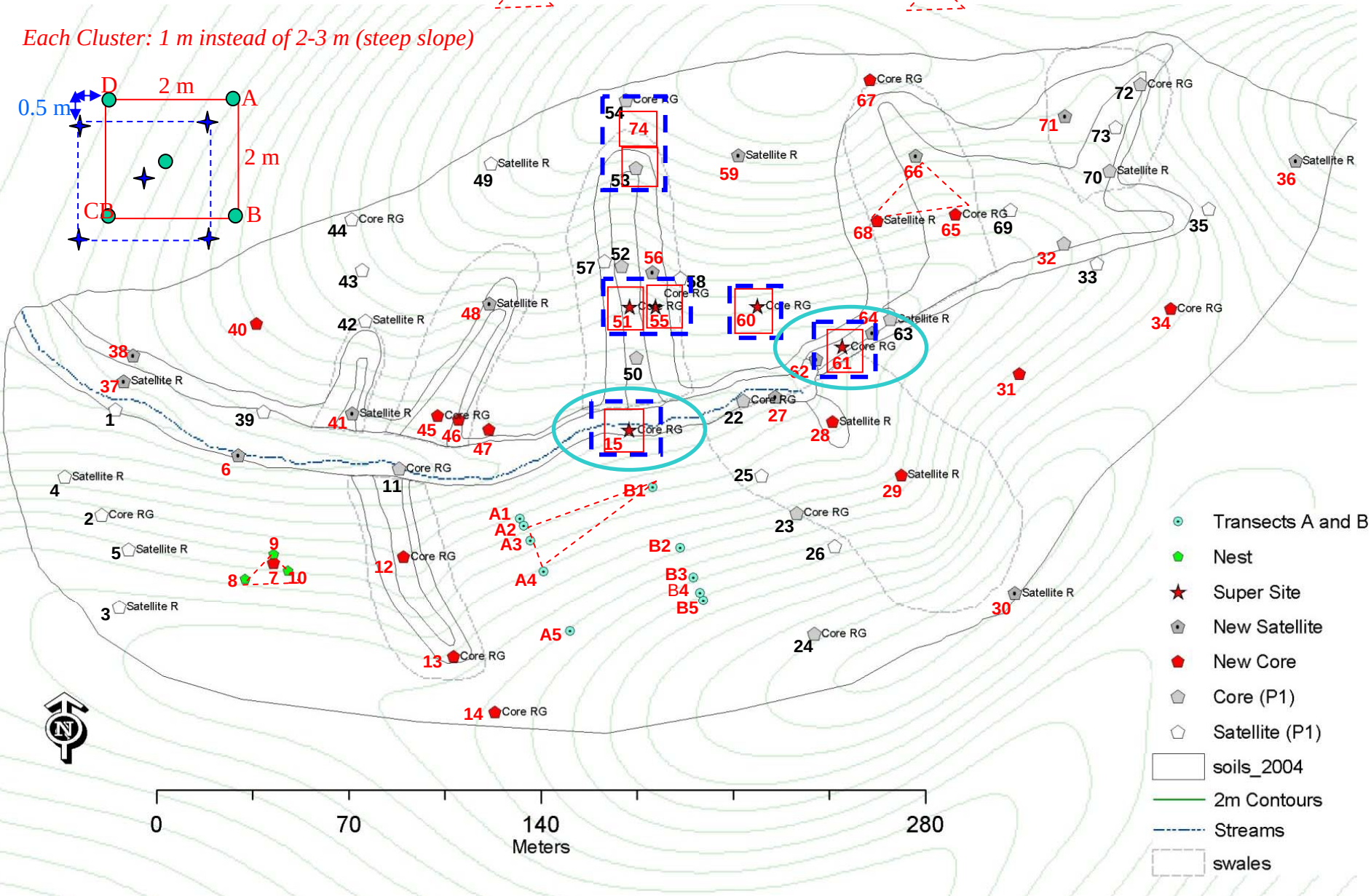


This is the **state of the practice**: Error is propagated through traditional estimation processes. Geophysicists generally apply empirical relations to convert the geophysical data back to the parameters of interest, which means that while we get good qualitative information about subsurface processes, the final images cannot be used quantitatively. One way to get around this is to insert hydropedologic insight to help constrain the geophysical inversion.

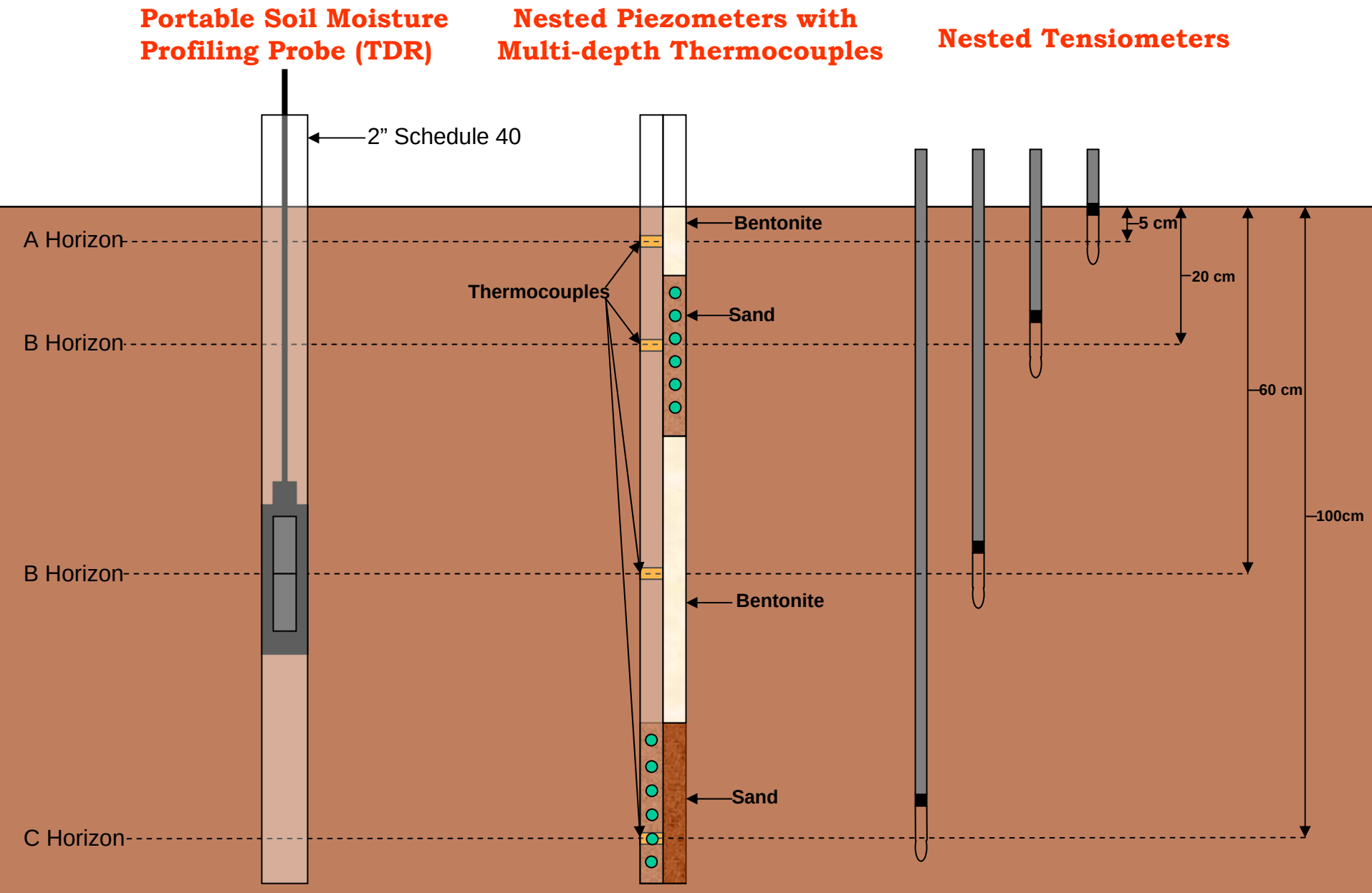
EMI and GPR are complimentary and their integrated use with standard soil survey are advantageous to hydropedologic studies.

Shale Hills Monitoring Design Map

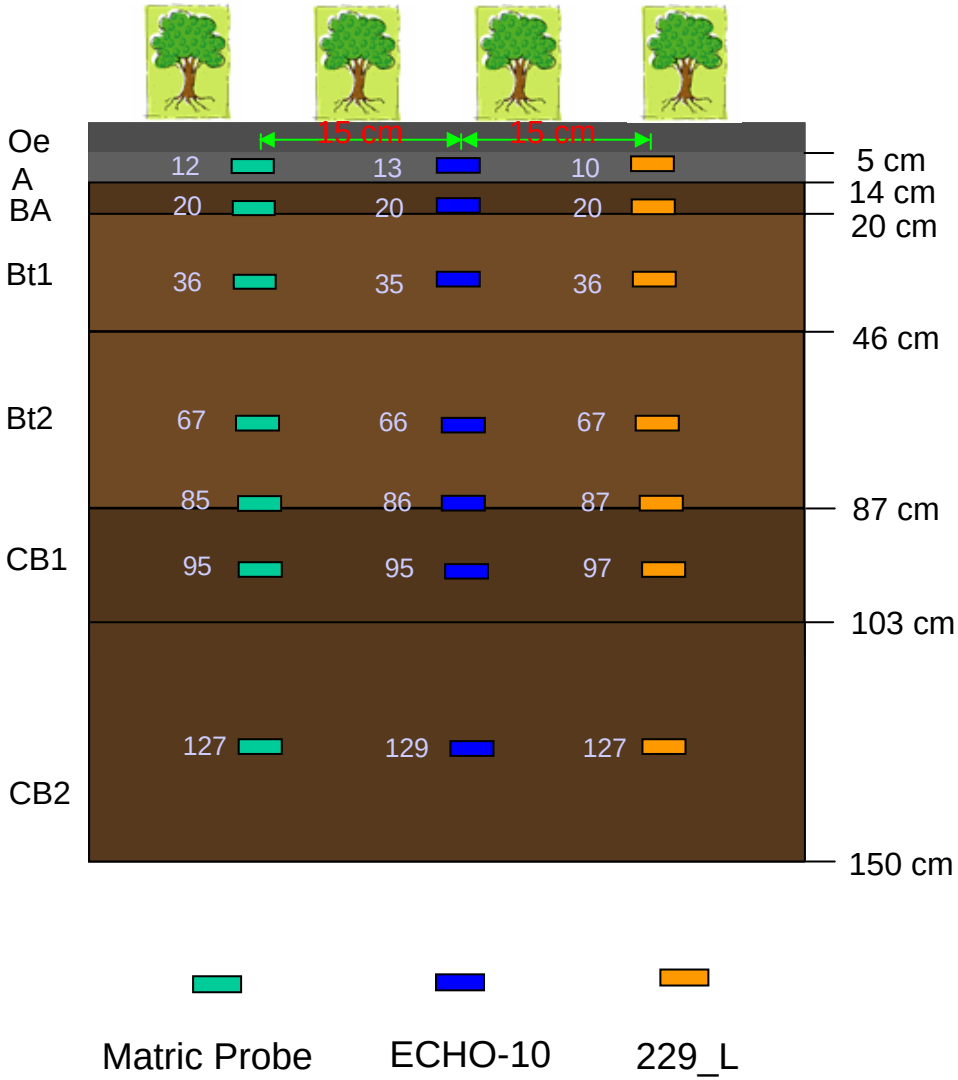
Clusters: **Dataloggers & Rain Gauges:**



Instrument Installation Scheme for the Shale Hills

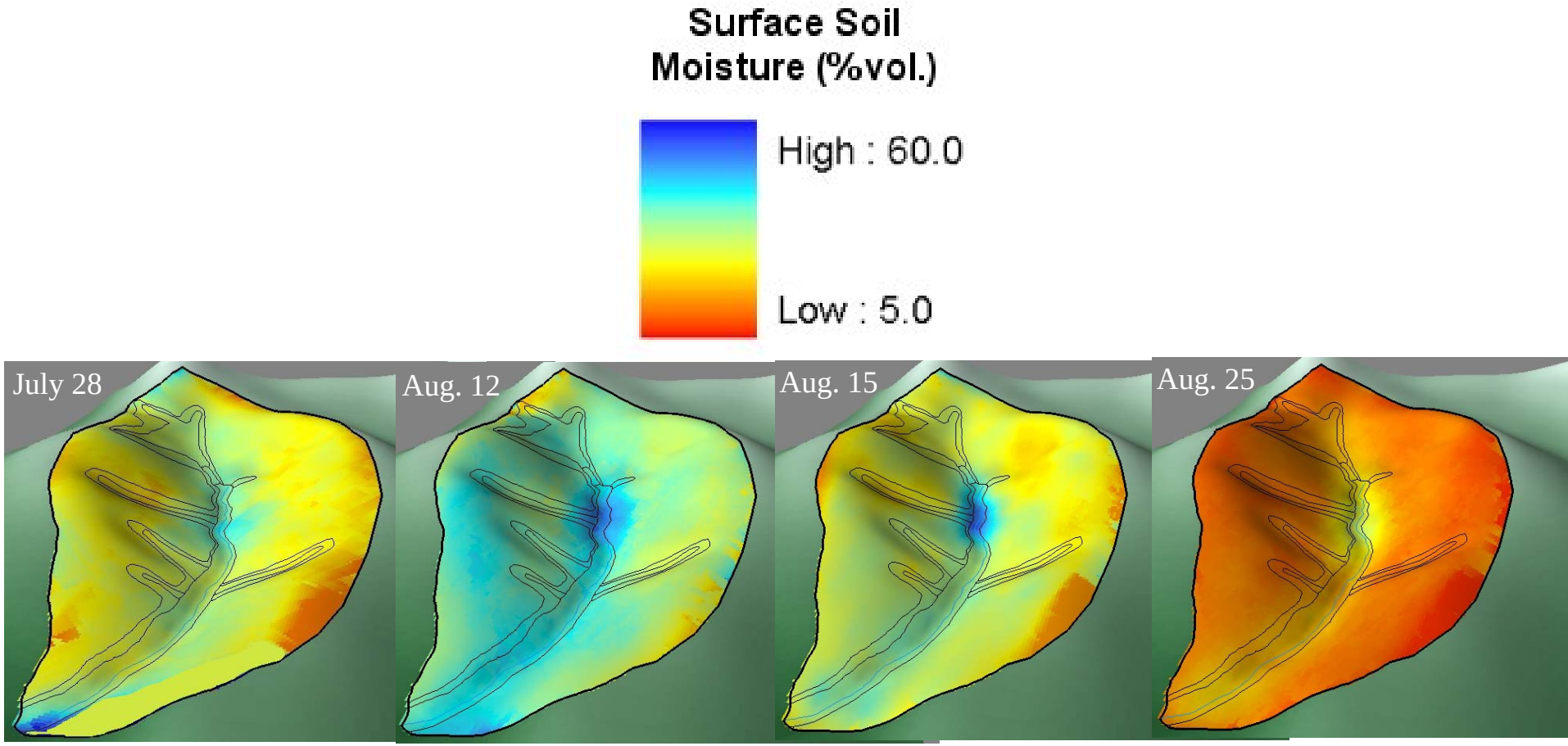


Site 61 (Blairton Soil)

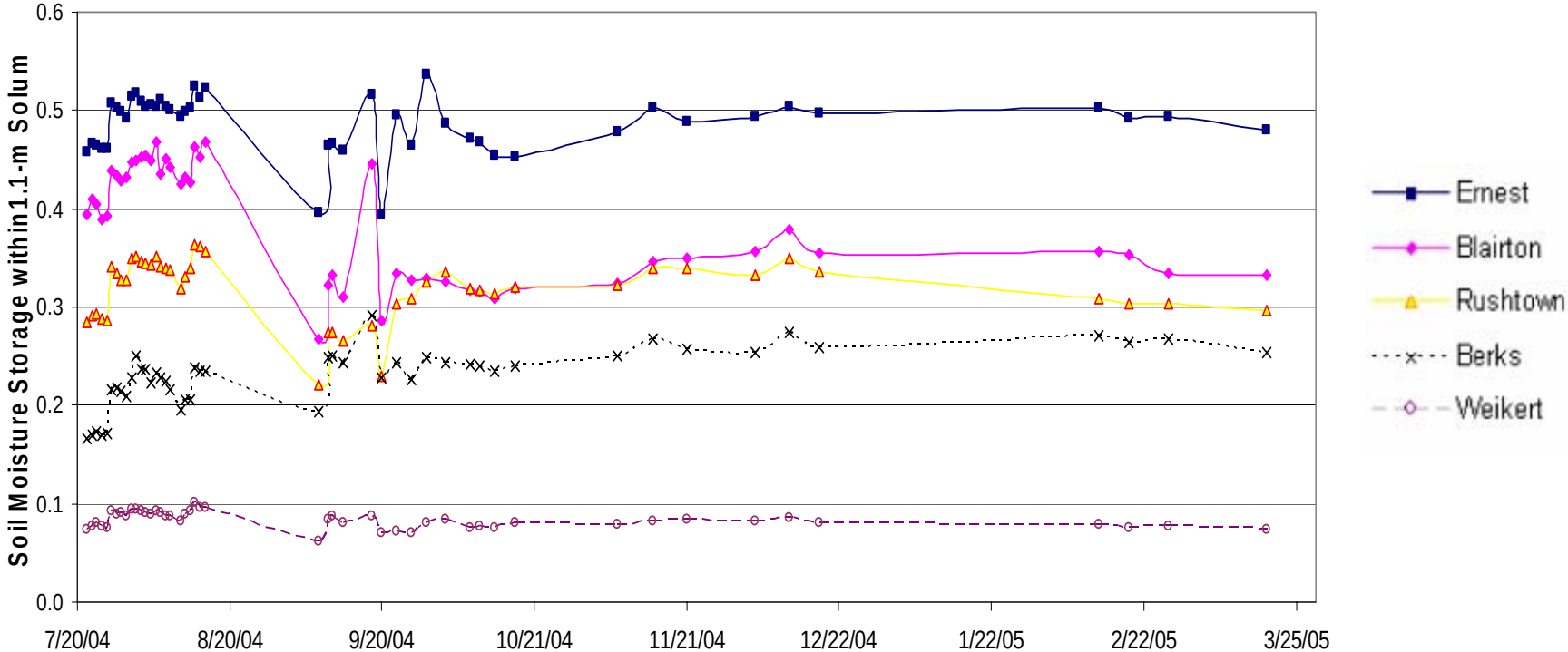


Gee, what these guys doing at my yard?!

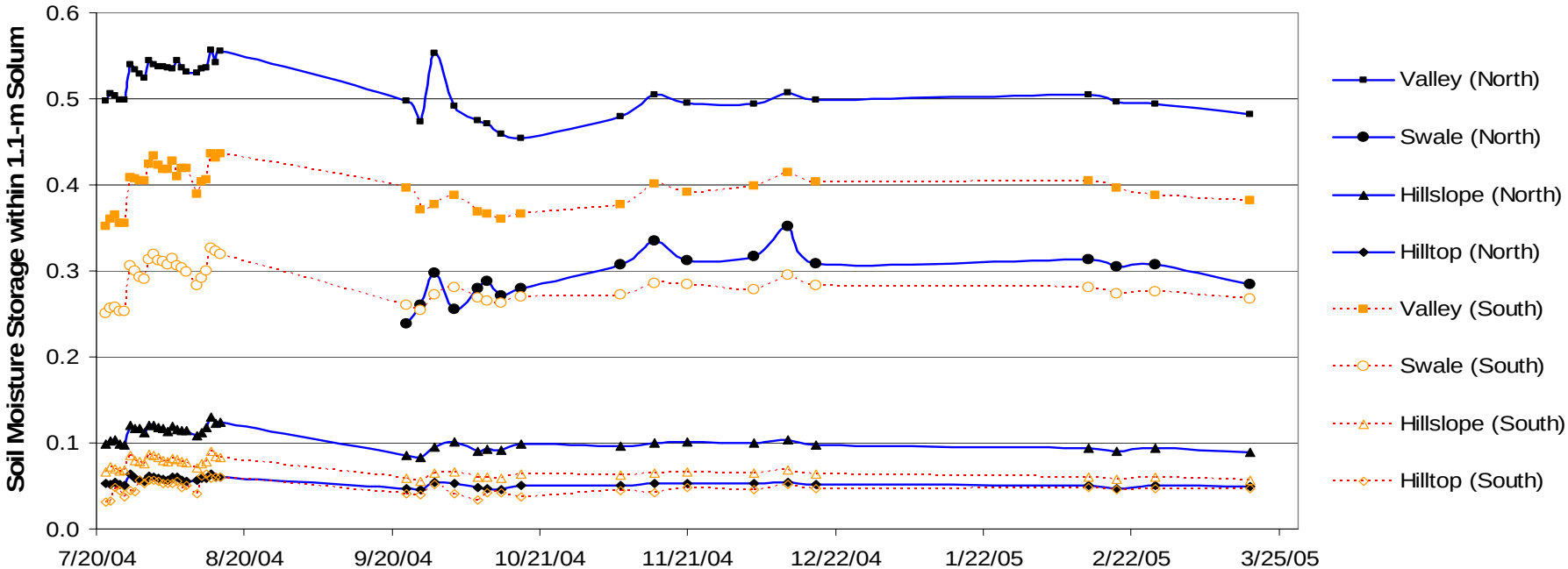
OCT 3 2005


Surface Soil
Moisture (%vol.)
High : 60.0
Low : 5.0
July 28
Aug. 12
Aug. 15
Aug. 25

A)


Soil Moisture Storage within 1.1-m Solum
0.6
0.5
0.4
0.3
0.2
0.1
0.0
7/20/04
8/20/04
9/20/04
10/21/04
11/21/04
12/22/04
1/22/05
2/22/05
3/25/05
Ernest
Blairton
Rushtown
Berks
Weikert

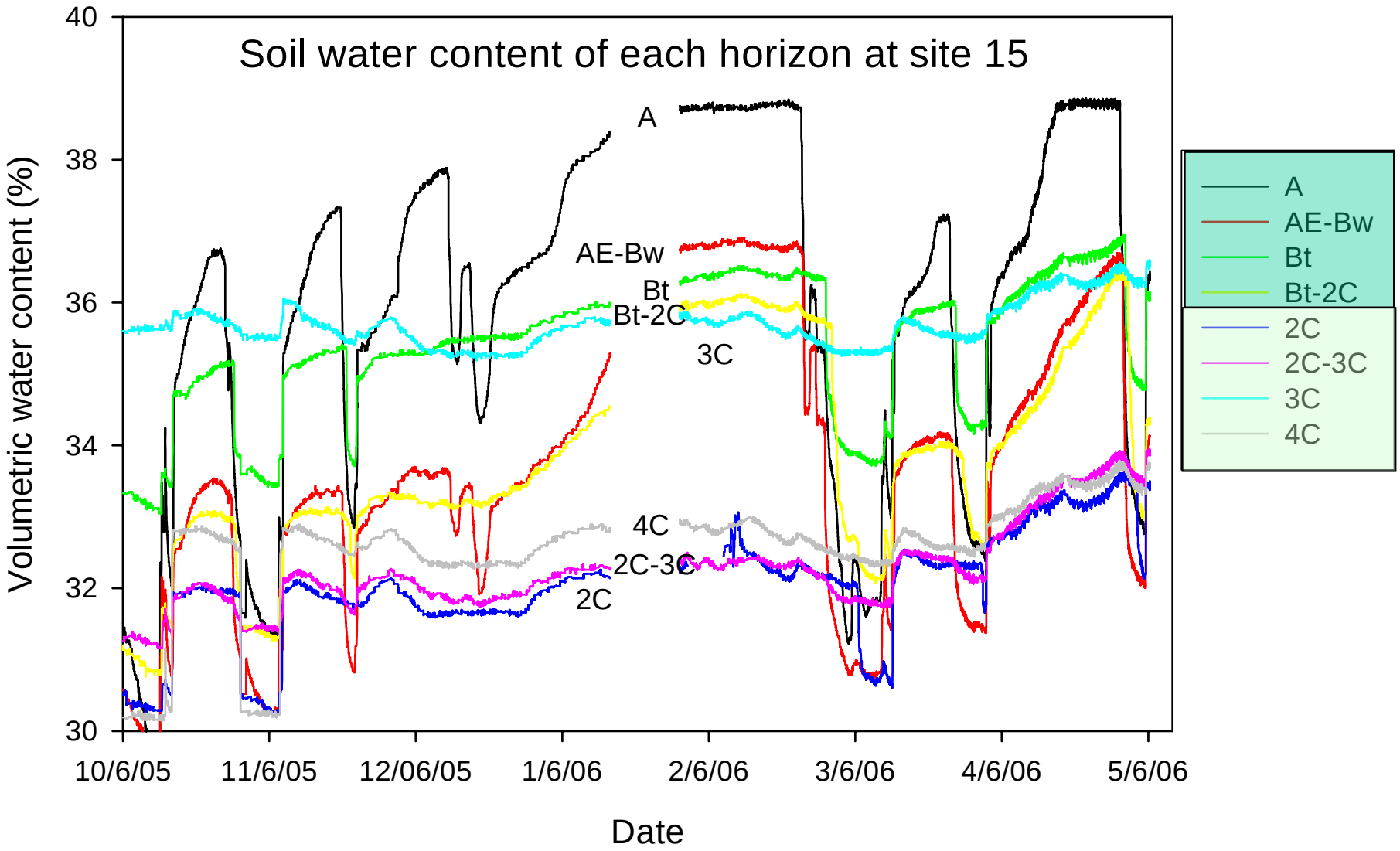
B)


Soil Moisture Storage within 1.1-m Solum
0.6
0.5
0.4
0.3
0.2
0.1
0.0
7/20/04
8/20/04
9/20/04
10/21/04
11/21/04
12/22/04
1/22/05
2/22/05
3/25/05
Valley (North)
Swale (North)
Hillslope (North)
Hilltop (North)
Valley (South)
Swale (South)
Hillslope (South)
Hilltop (South)

Soil properties of Site 15

Ernest
(Aquic Fragiudults)

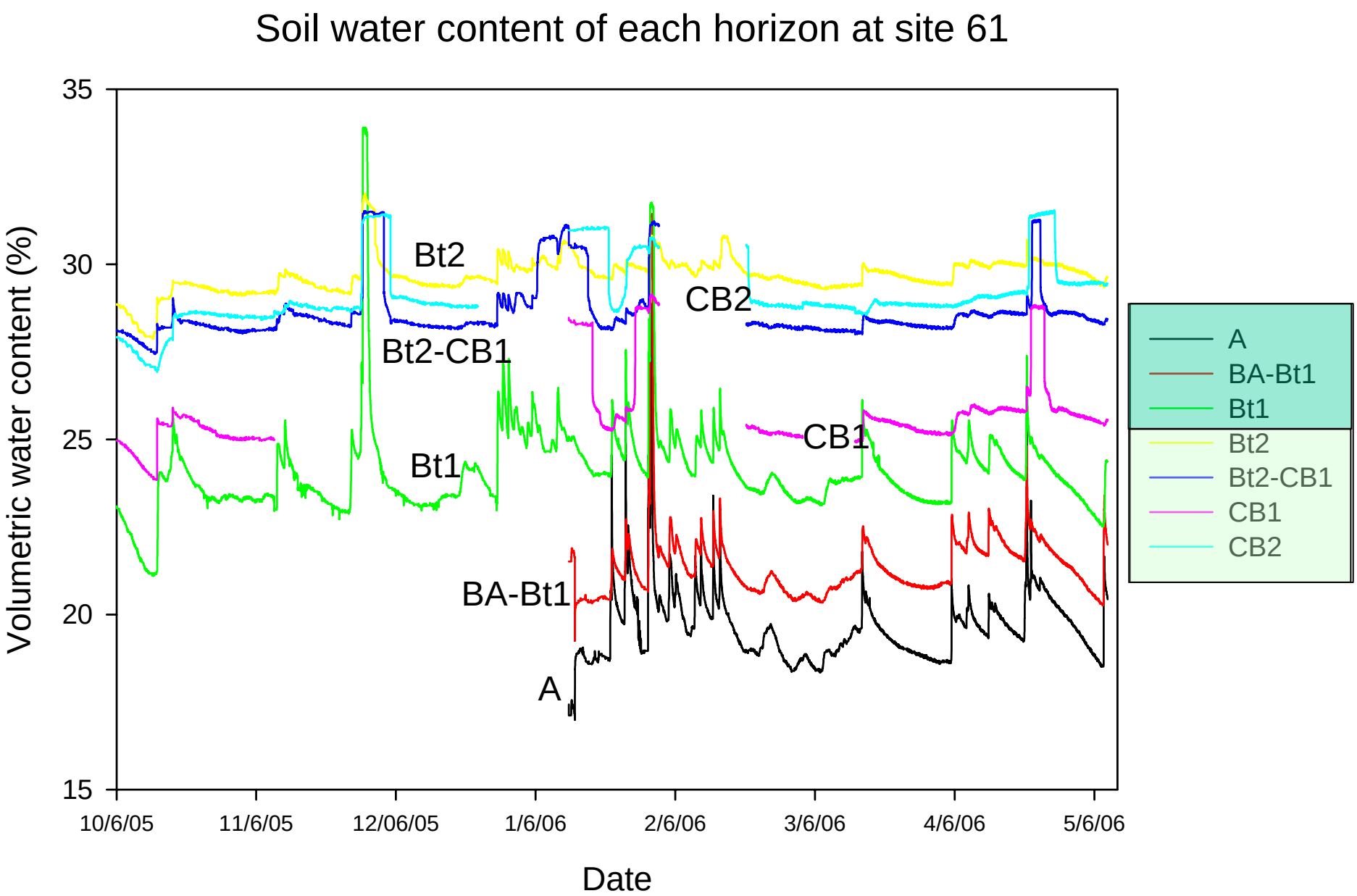
Horizon	Depth (m)	Texture	Bulk density (g/cm^3)	Total Porosity (%)	Ksat (cm/min)	
					Vertical	Horizontal
Oe	0-0.05					
A	0.05-0.15	Silt loam	0.856	0.677	0.237	0.459
AE	0.15-0.20	Silt loam	0.865	0.674	0.678	1.338
Bw	0.20-0.28	Silt clay loam	1.107	0.582	0.271	0.403
Bt	0.28-0.50	Silt clay	1.267	0.522	0.367	0.820
2C	0.50-0.83	Sandy loam	1.715	0.353	0.394	4.116
3C	0.83-0.91	Clay	1.560	0.411	0.000	0.001
4C	0.91-1.28	Sandy loam	1.673	0.369	0.060	0.186
5C	1.28-1.37	Clay	1.597	0.397	0.000	0.001

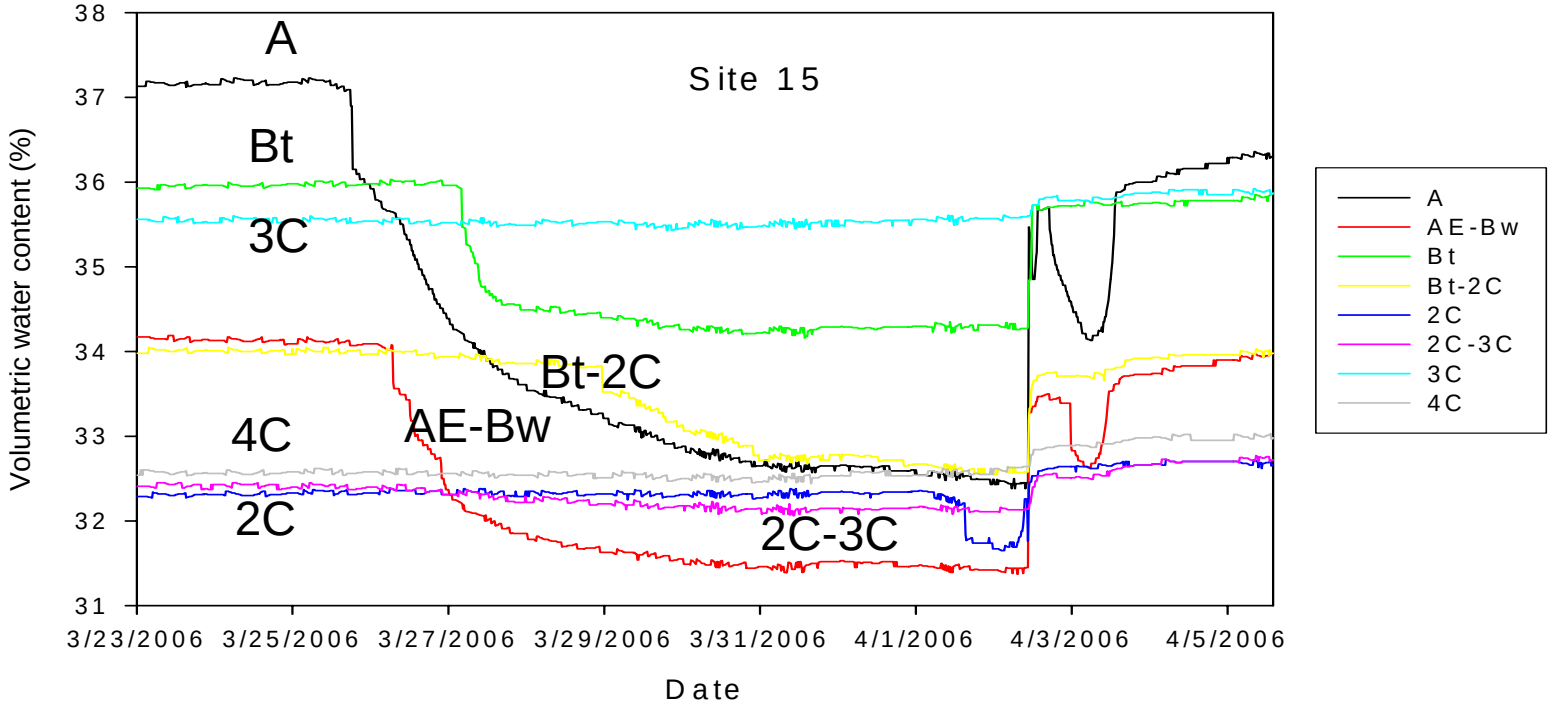

Soil water content of each horizon at site 15
Volumetric water content (%)
40
38
36
34
32
30
10/6/05
11/6/05
12/06/05
1/6/06
2/6/06
3/6/06
4/6/06
5/6/06
Date
A
AE-Bw
Bt
Bt-2C
3C
4C
2C-3C
2C
A
AE-Bw
Bt
Bt-2C
2C
2C-3C
3C
4C

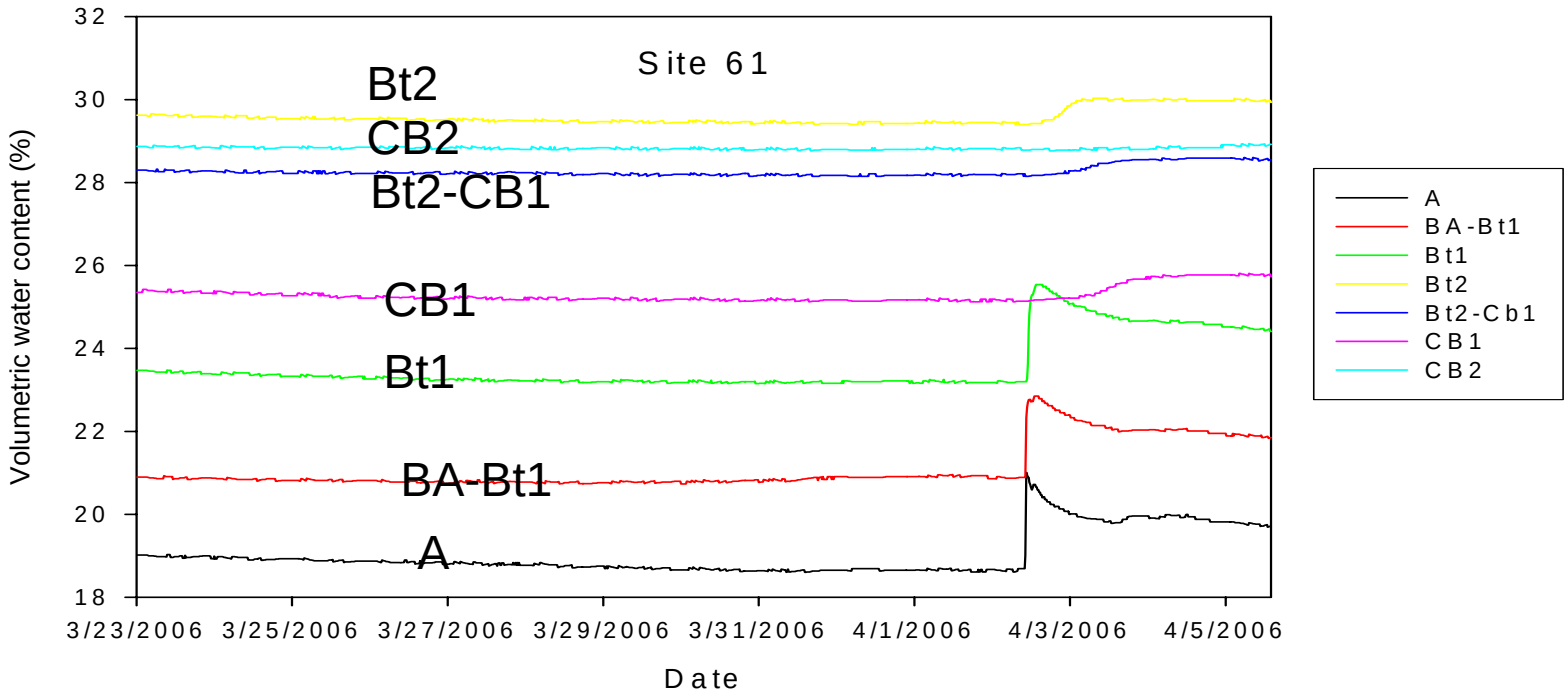
Soil properties of Site 61

Blairton
(Aquic Hapludults)

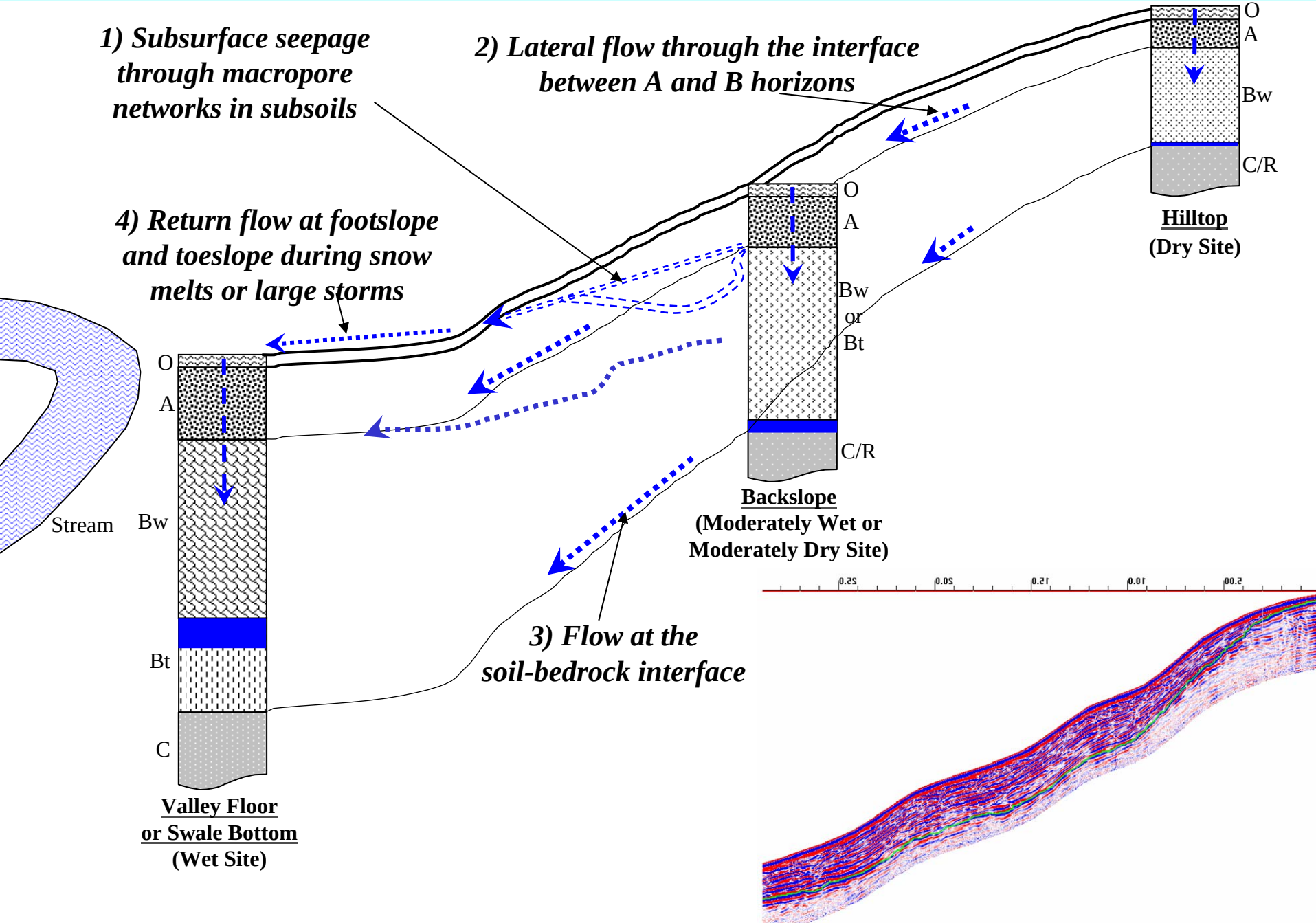
Horizon	Depth (m)	Texture	Bulk density (g/cm^3)	Total Porosity (%)	Ksat (cm/min)	
					Vertical	Horizontal
Oe	0-0.05		0.550	0.792	0.415	4.637
A	0.05-0.14	Silt loam	1.180	0.555	0.345	1.704
BA	0.14-0.20	Loam	1.299	0.510	0.020	0.128
Bt1	0.20-0.46	Clay loam	1.372	0.482	0.002	0.284
Bt2	0.46-0.87	Clay loam	1.662	0.373	0.018	0.649
CB1	0.87-1.03	Sandy clay loam	1.730	0.347	0.121	0.191
CB2	1.03-150+	Sandy clay loam	1.739	0.344	0.007	0.002


Soil water content of each horizon at site 61
Volumetric water content (%)
35
30
25
20
15
10/6/05
11/6/05
12/06/05
1/6/06
2/6/06
3/6/06
4/6/06
5/6/06
Date
Bt2
Bt2-CB1
Bt1
BA-Bt1
A
CB2
CB1
A
BA-Bt1
Bt1
Bt2
Bt2-CB1
CB1
CB2


Site 15
A
Bt
3C
Bt-2C
AE-Bw
4C
2C
2C-3C
Volumetric water content (%)
38
37
36
35
34
33
32
31
3/23/2006
3/25/2006
3/27/2006
3/29/2006
3/31/2006
4/1/2006
4/3/2006
4/5/2006
Date
A
AE-Bw
Bt
Bt-2C
2C
2C-3C
3C
4C

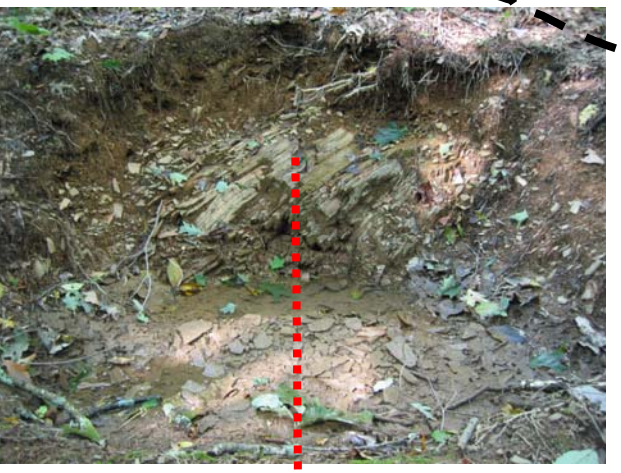

Site 61
Bt2
CB2
Bt2-CB1
CB1
Bt1
BA-Bt1
A
Volumetric water content (%)
32
30
28
26
24
22
20
18
3/23/2006
3/25/2006
3/27/2006
3/29/2006
3/31/2006
4/1/2006
4/3/2006
4/5/2006
Date
A
BA-Bt1
Bt1
Bt2
Bt2-Cb1
CB1
CB2

Four main flow paths downslope and the typical soil profiles along the hillslope



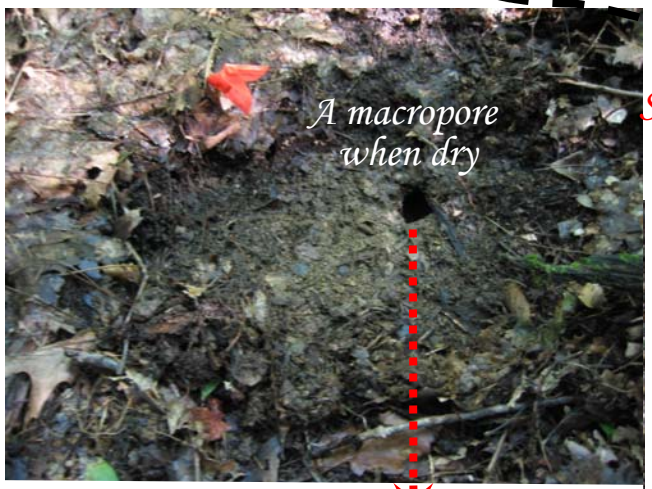
Hillslope Flow Pathway Observations

A) Upslope



Flow at the interface between the Weikert soil and the fractured shale

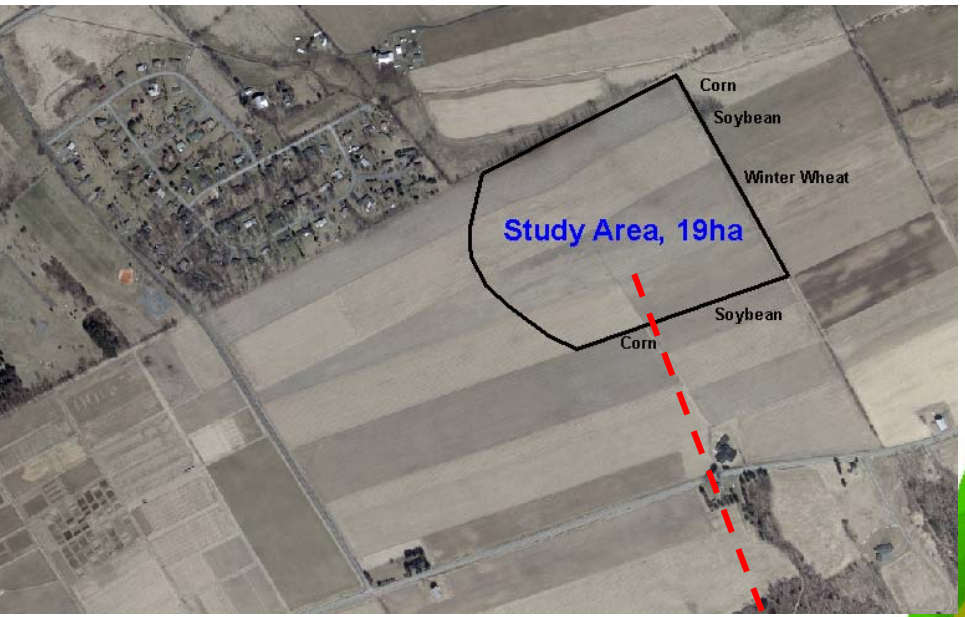
B) Midslope



C) Downslope

Surface runoff at footslope near the stream

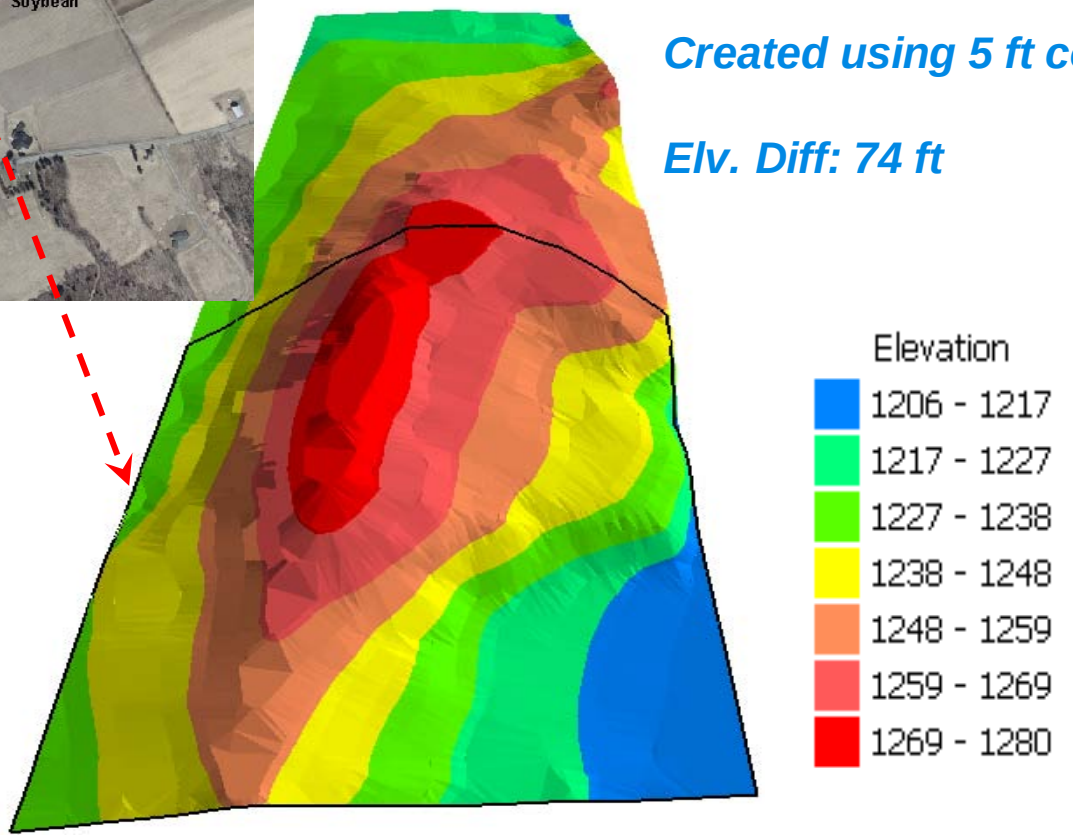
Penn State Agronomy Farm, Centre County, PA



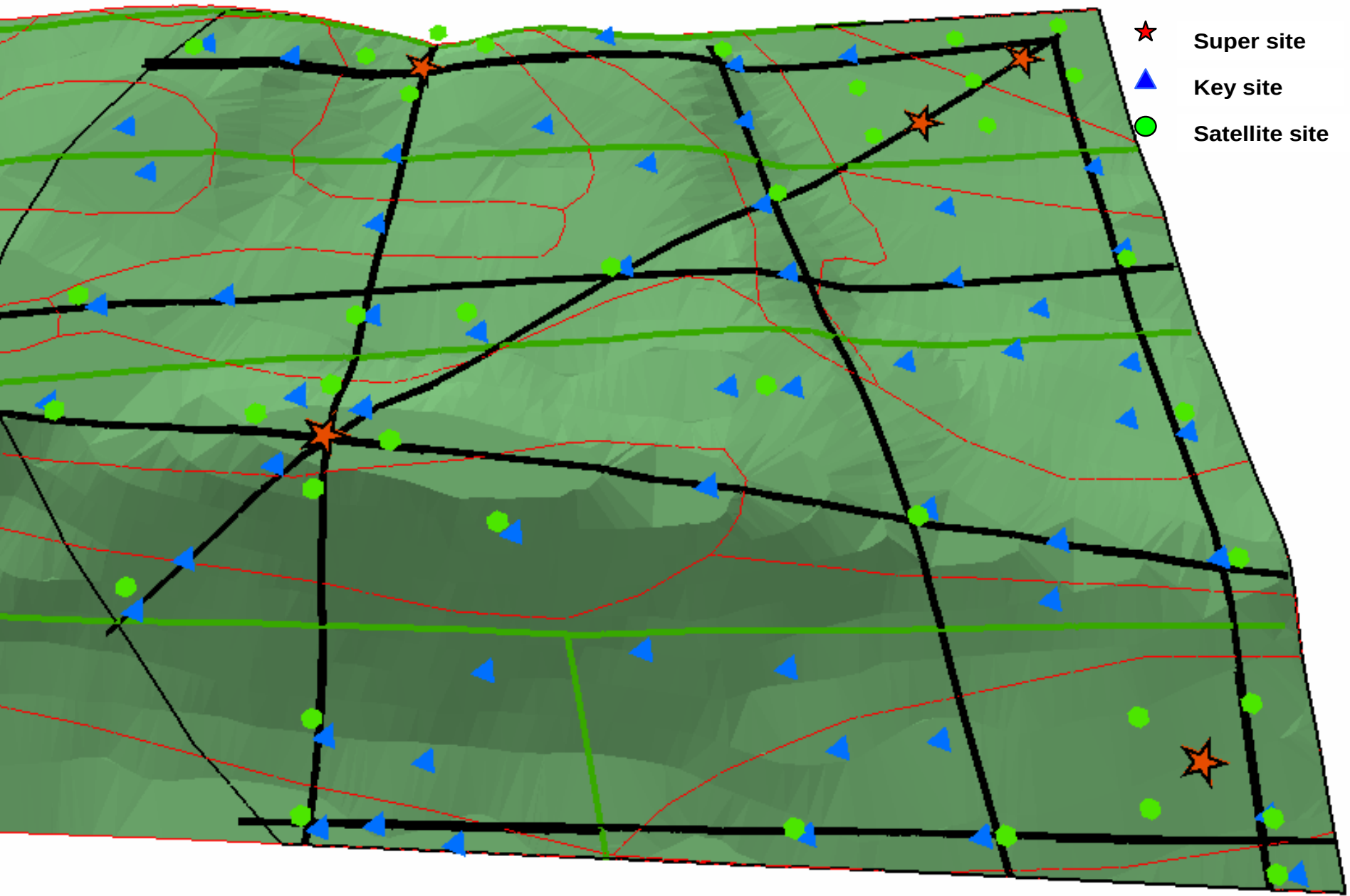
Surface Topography

Created using 5 ft contour

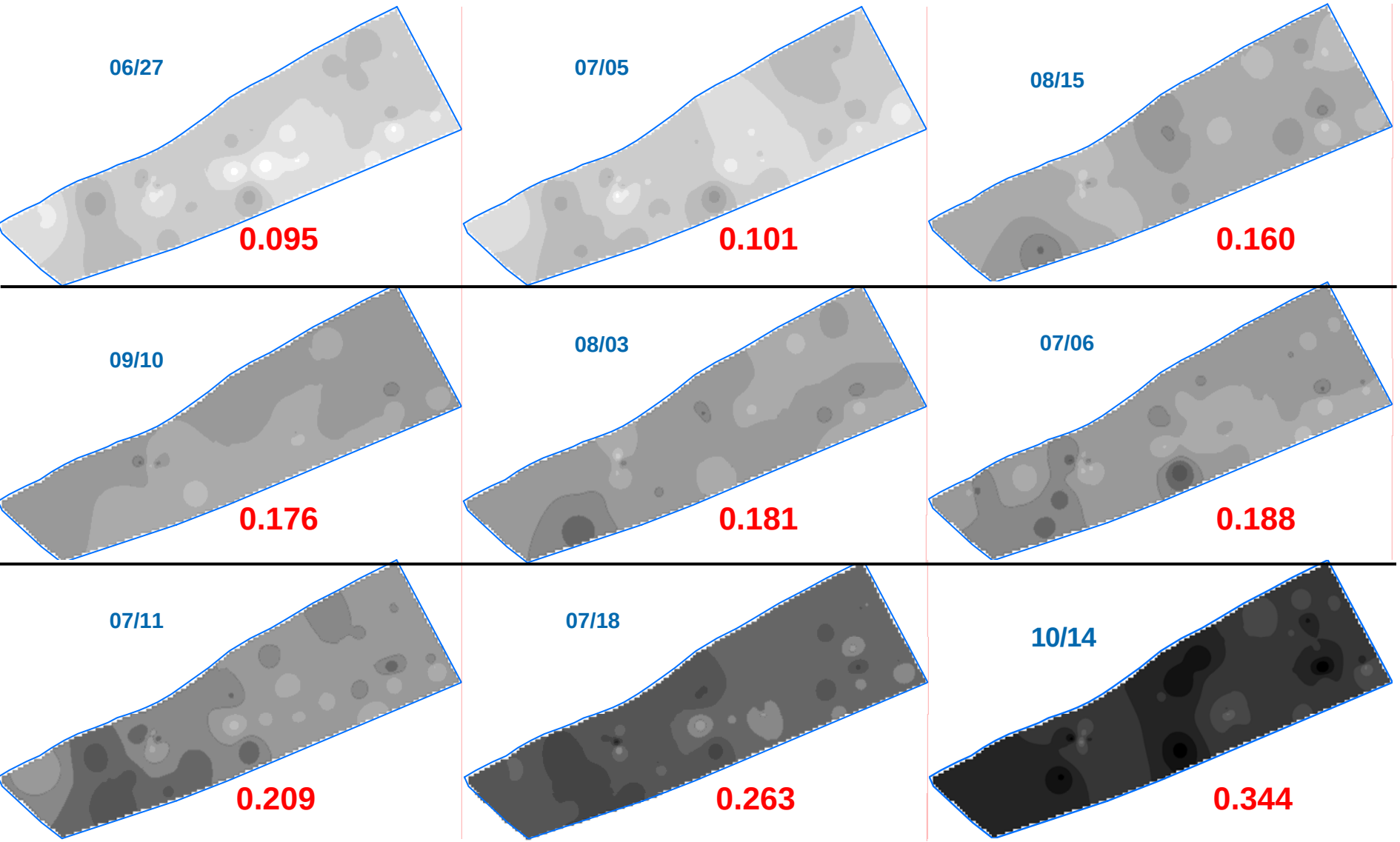
Elv. Diff: 74 ft



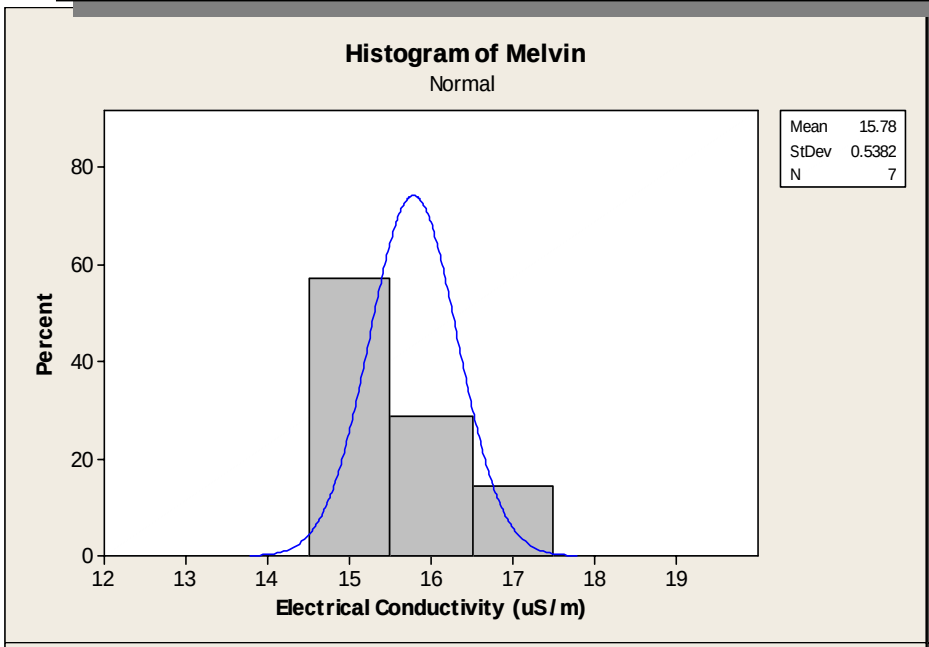
Monitoring Design

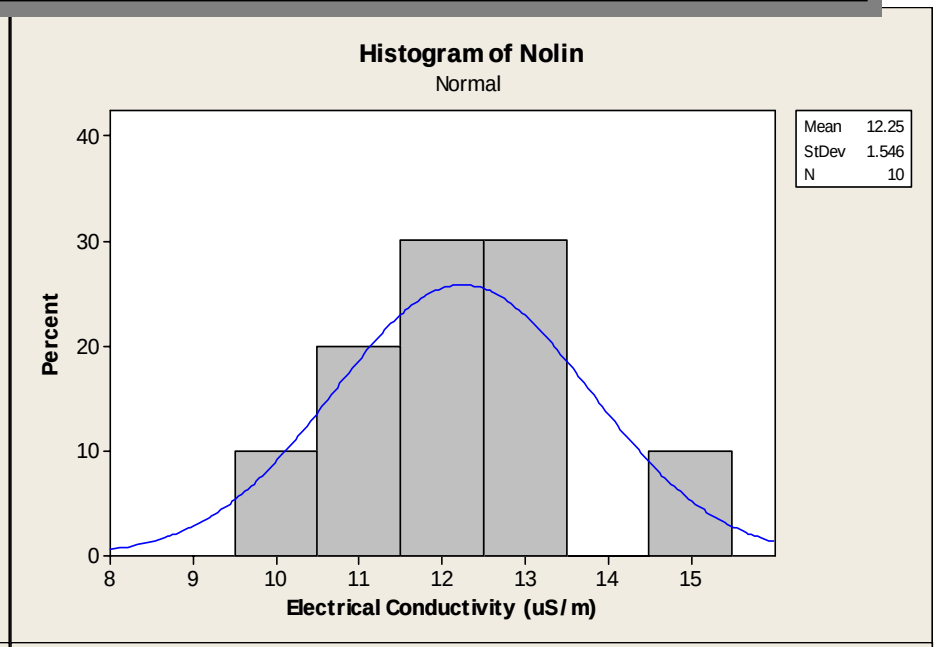


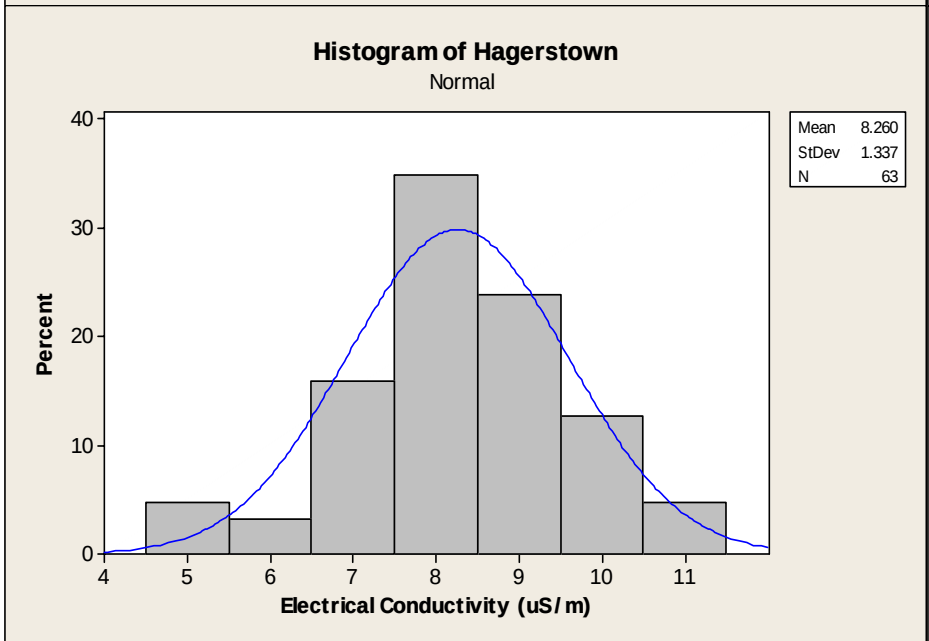
Soil Moisture Spatial Patterns in Crop Root Zone at Different Wetness Conditions

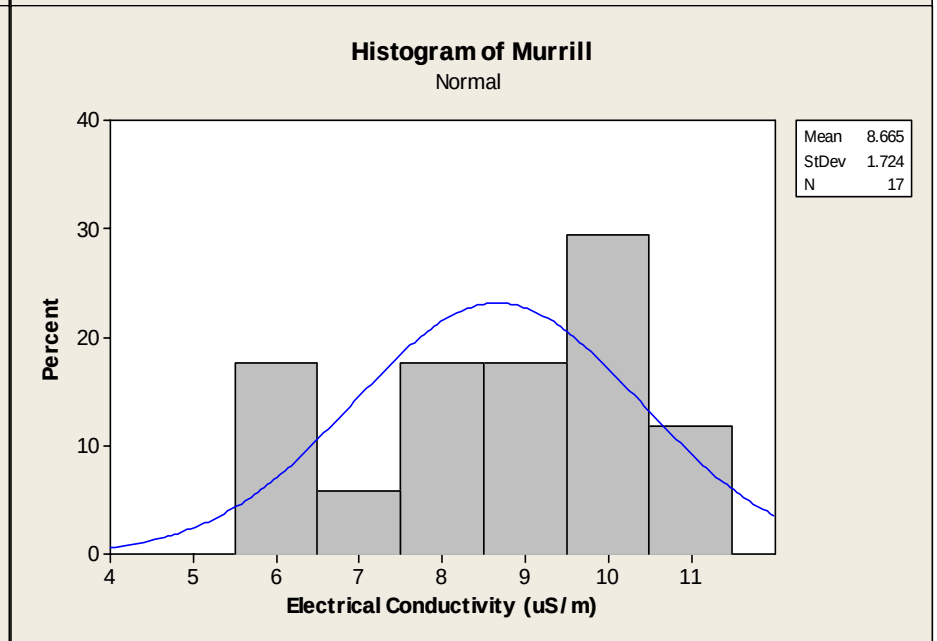


Soil Series vs. the Distribution of ECa Using EMI



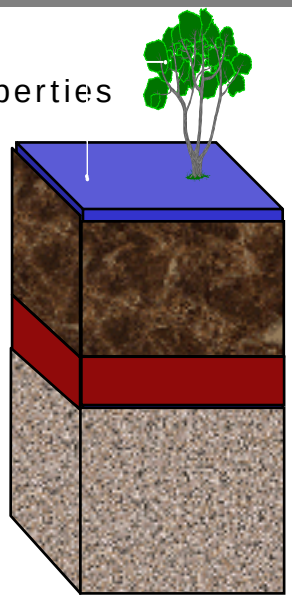




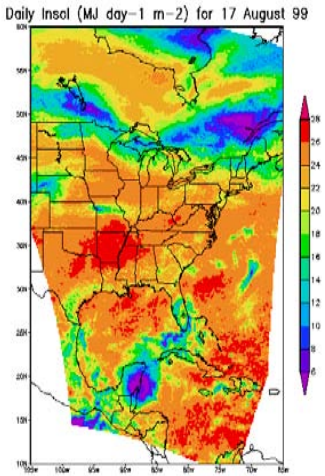


Precision Agricultural-Landscape Model (PALM)

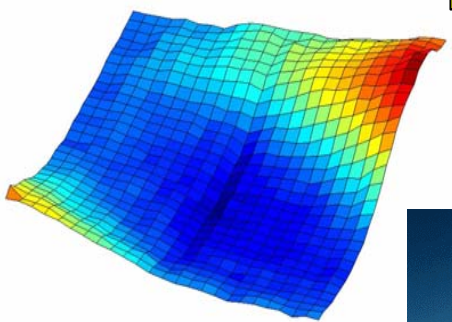
Soil Properties



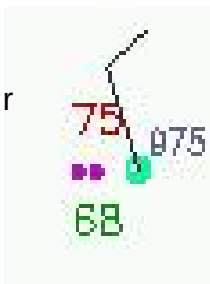
GOES Insolation

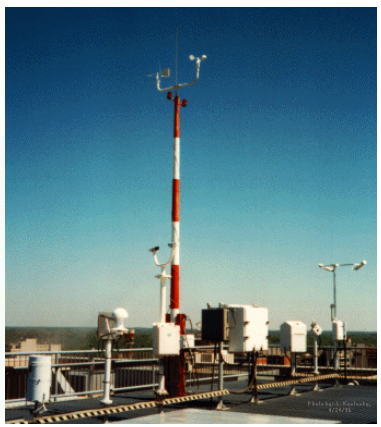


Topography



Hourly Weather



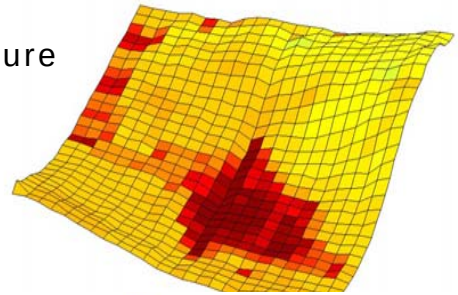


Inputs

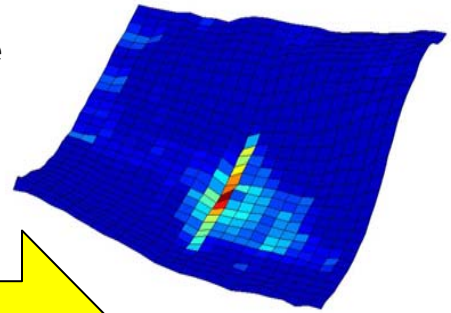
PALM

Outputs

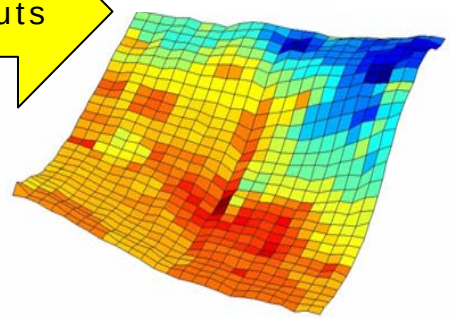
Soil Moisture



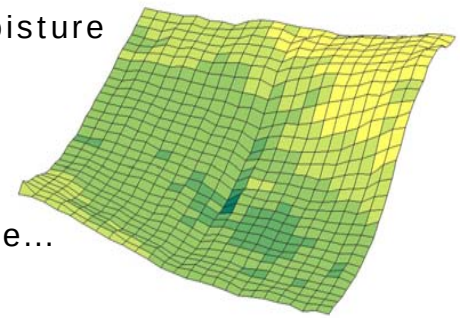
Drainage



Yield

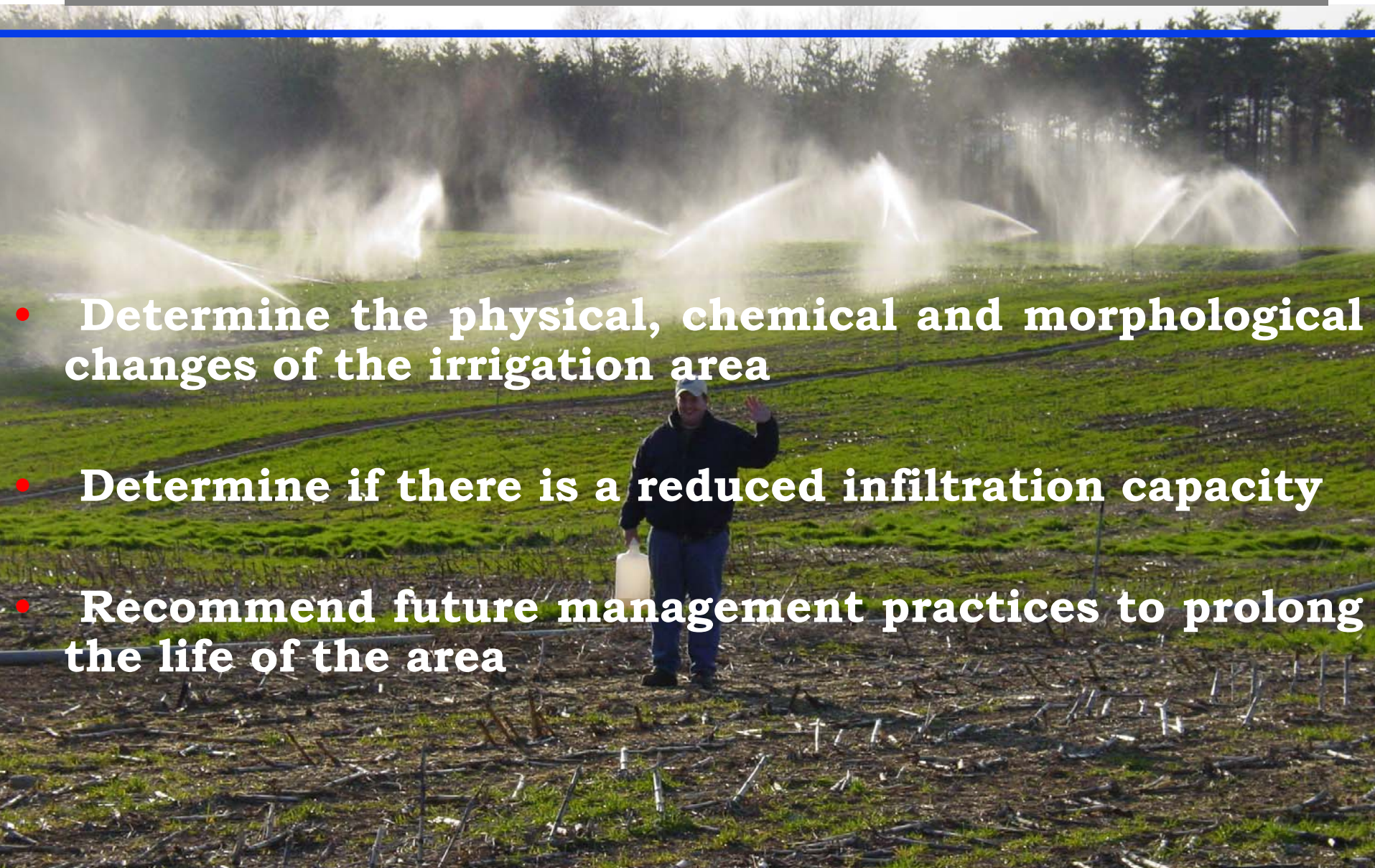


Grain Moisture



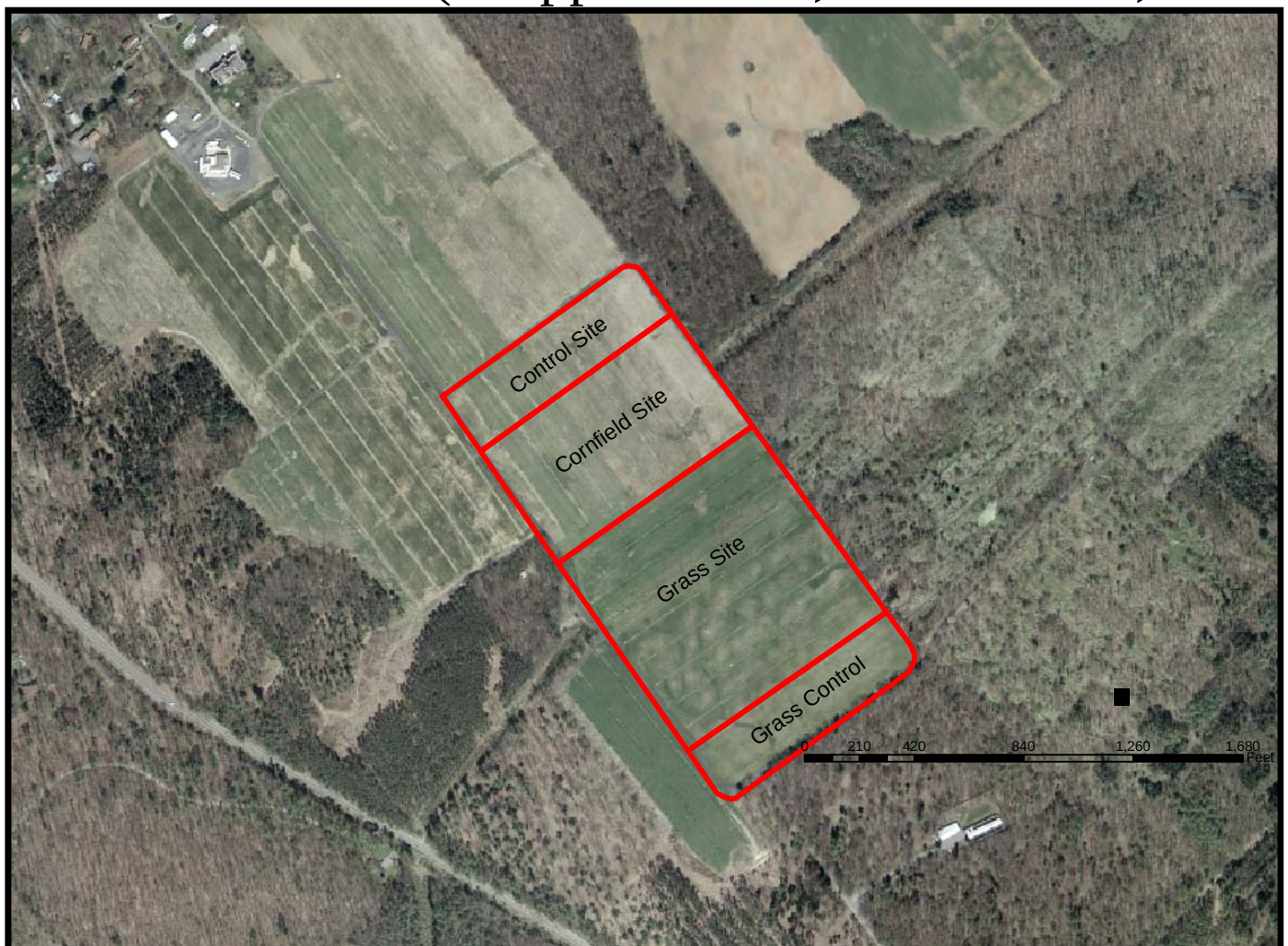
and more...

Determining Soil Changes after 40 years of Wastewater Irrigation



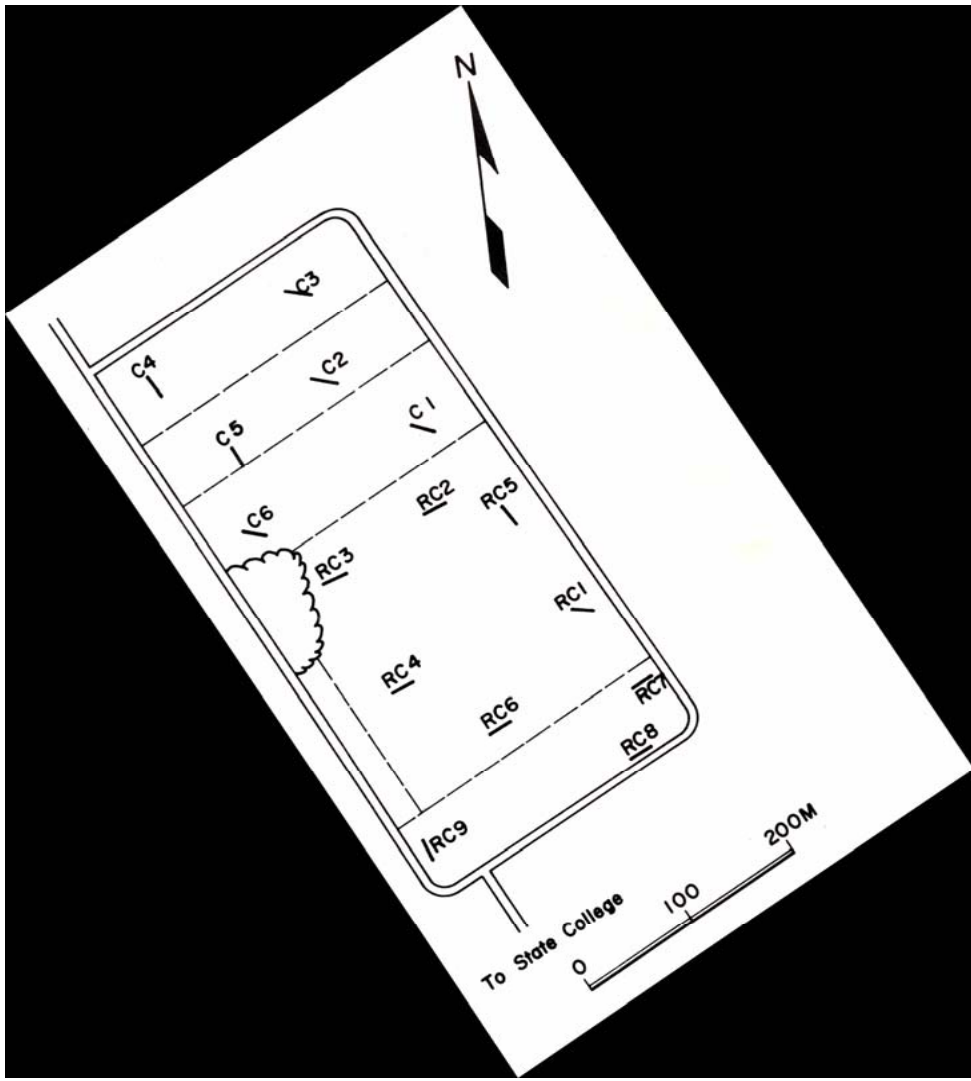
- Determine the physical, chemical and morphological changes of the irrigation area
- Determine if there is a reduced infiltration capacity
- Recommend future management practices to prolong the life of the area

- Penn State irrigates all of its wastewater since 1960's (40 years so far!)
- Approximately 2.5 million gallons/day, 365 days a year
- Permitted to add 102 inches/year. Similar to a tropical climate!
- 2 Sites (Toftrees and Astronomy Site)
- 3 Types of Land Cover (Cropped Fields, Grass Fields, Forested Areas)



Control Info: Simpson & Cunningham (1978)

- Performed 15 soil pit descriptions
- Developed a profile rating scale using several different morphologic properties
- Many pits showed redoximorphic features and there was also evidence of “vertical water channels”
- Estimated the life of the system to be 15 years when applying 91 inches of water annually.



Sample Location

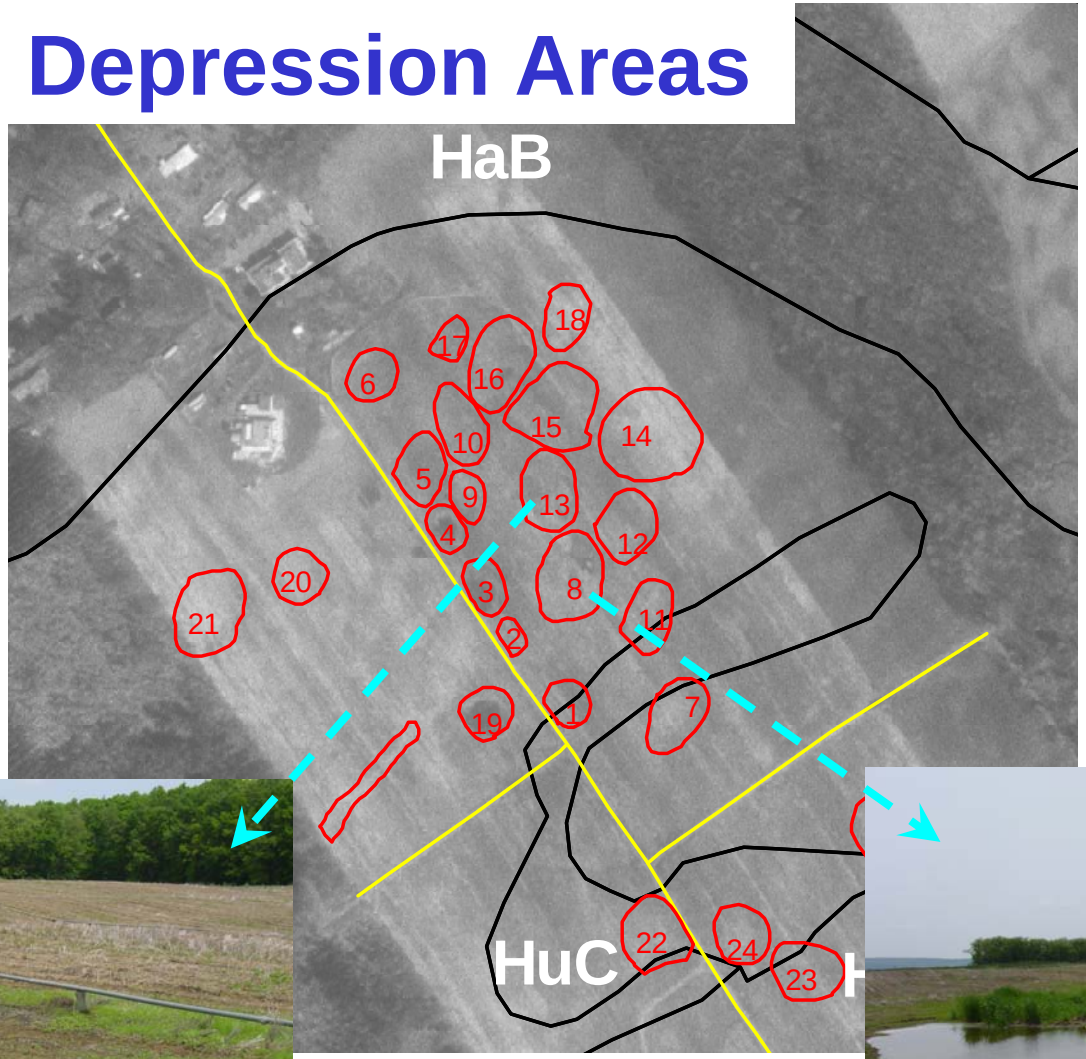
Original Control Area
(Irrigated for over 20 Years)

Original Irrigated Area
(Irrigated for over 40 Years)

- 60 1.2-m long soil core samples were taken by using a hydraulic giddings probe
  - Sample location was based on Landscape Position
    - Summit
    - Side slope
    - Depression
- 6 soil pits were also examined
  - Location based on
    - Previous Soil Pits
    - Landscape Position

Depression Mystery?!

Depression Areas



Depression #13

Depression #8

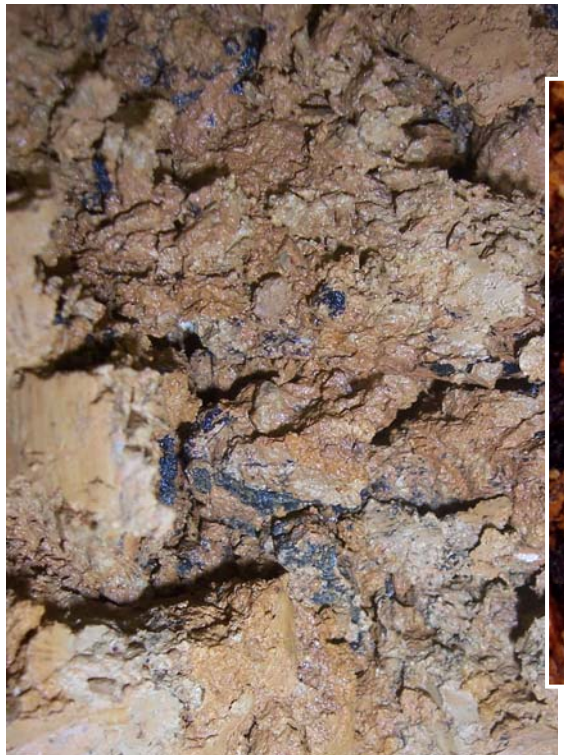
Top of the A

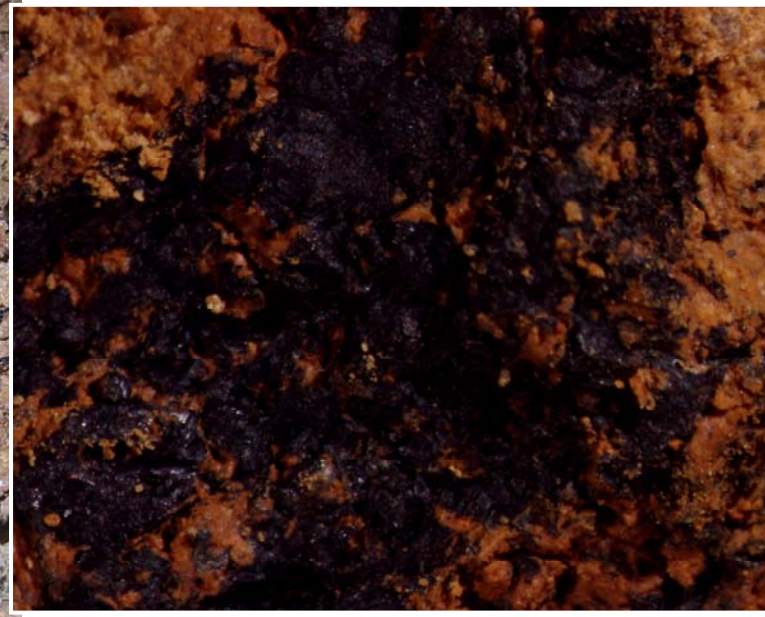
Middle A

Bottom A, with Buried A

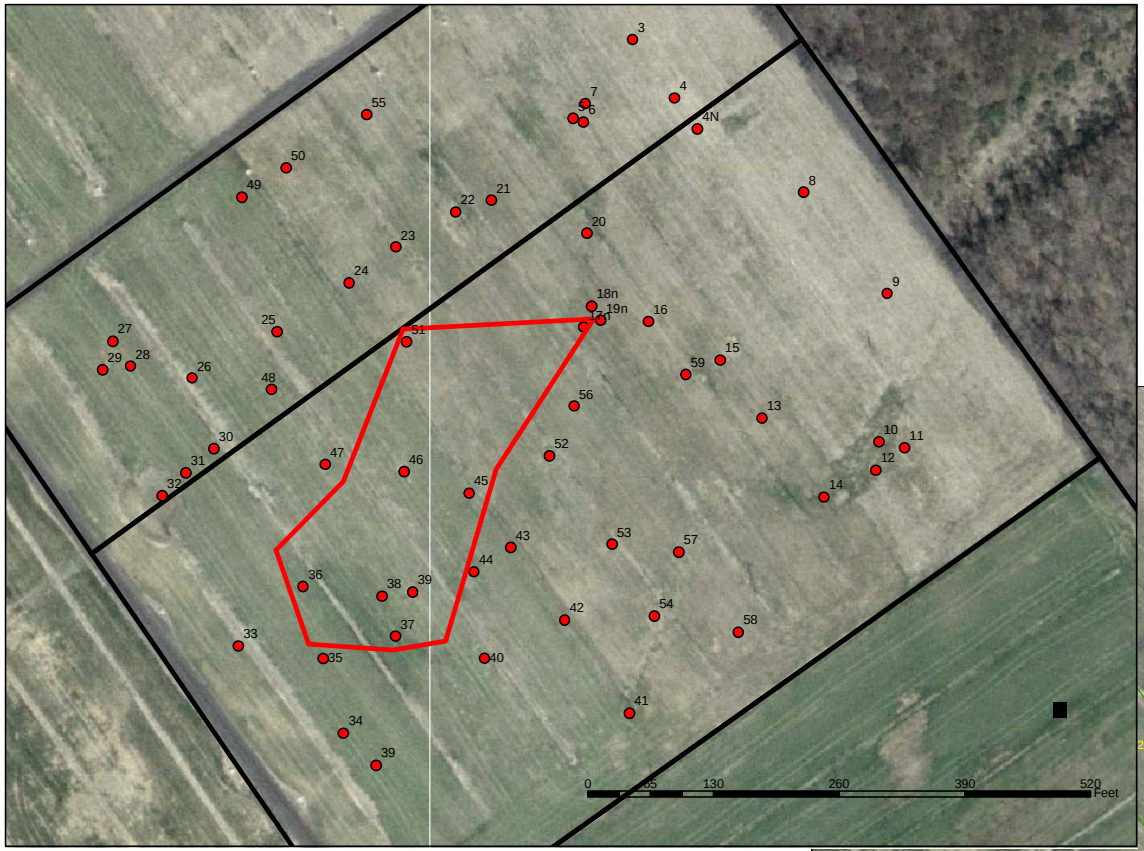
A Horizon:
Yellowish
Little Redox

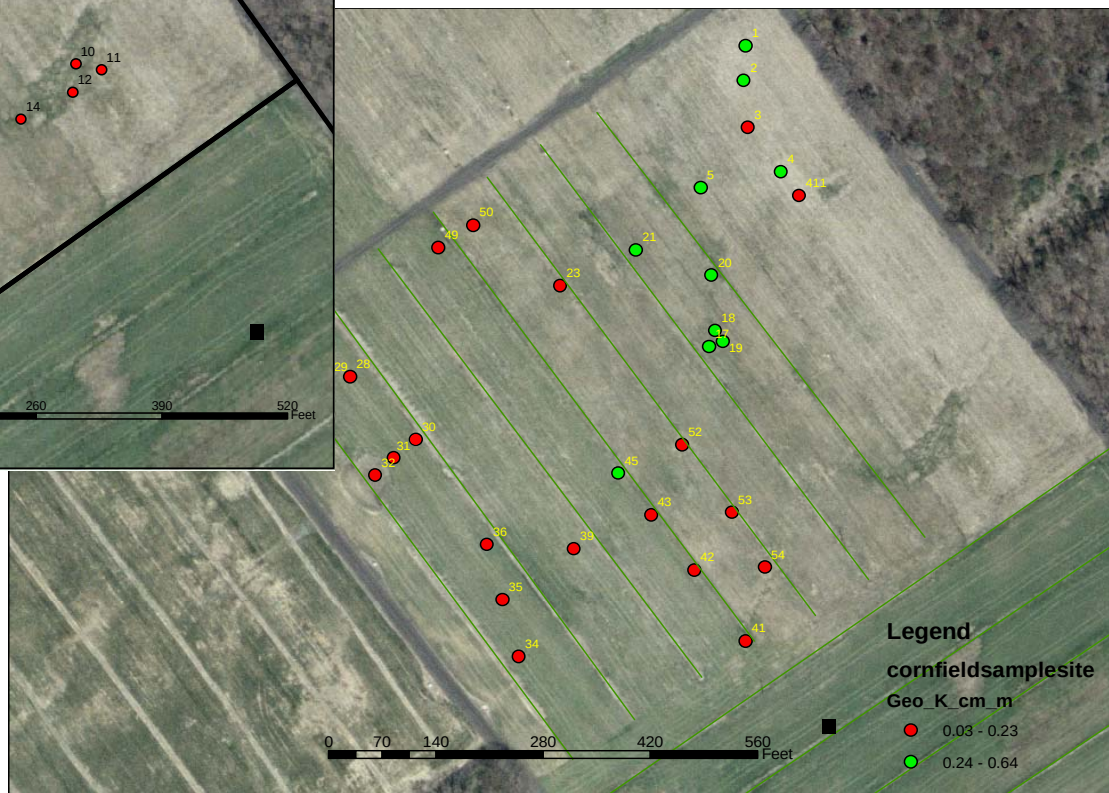
B Horizon:
Redox
Manganese





Is the Entire Field Showing Signs of Redoximorphic Features?



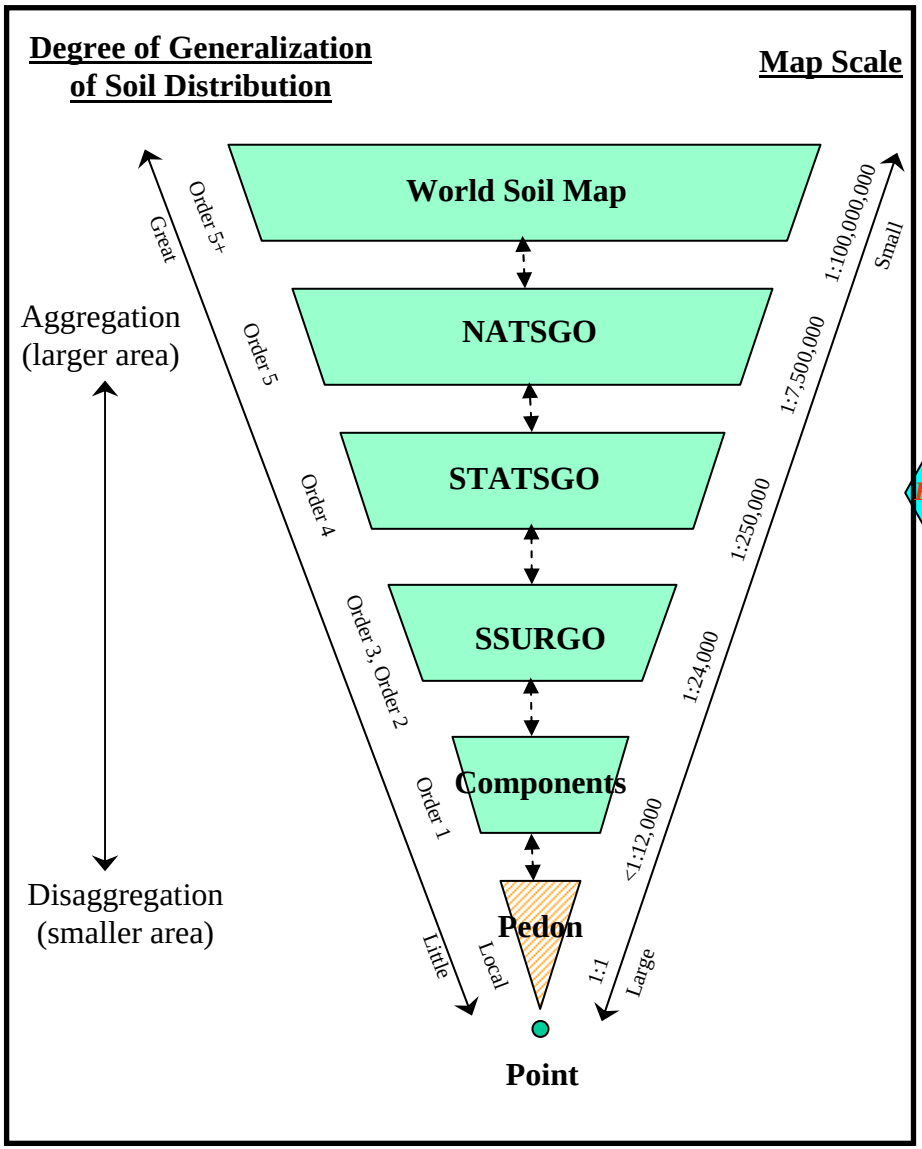


Some Preliminary Results

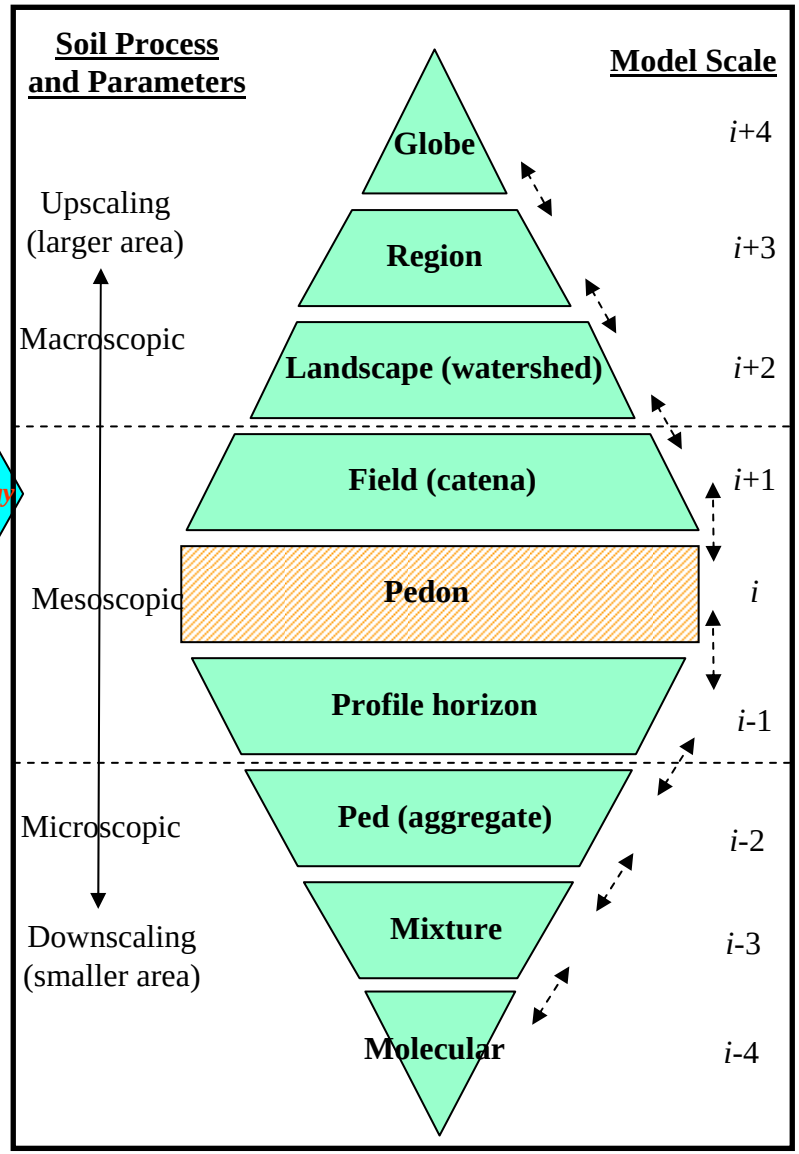
- The area is not as bad as predicted
- There are certain “wet spots”
- Local erosion is severe; overall site erosion probably not too bad
- Saturated hydraulic conductivity has been reduced, and bulk density increased
- Some of the problems may be attributed to the landscape hydrology of the area

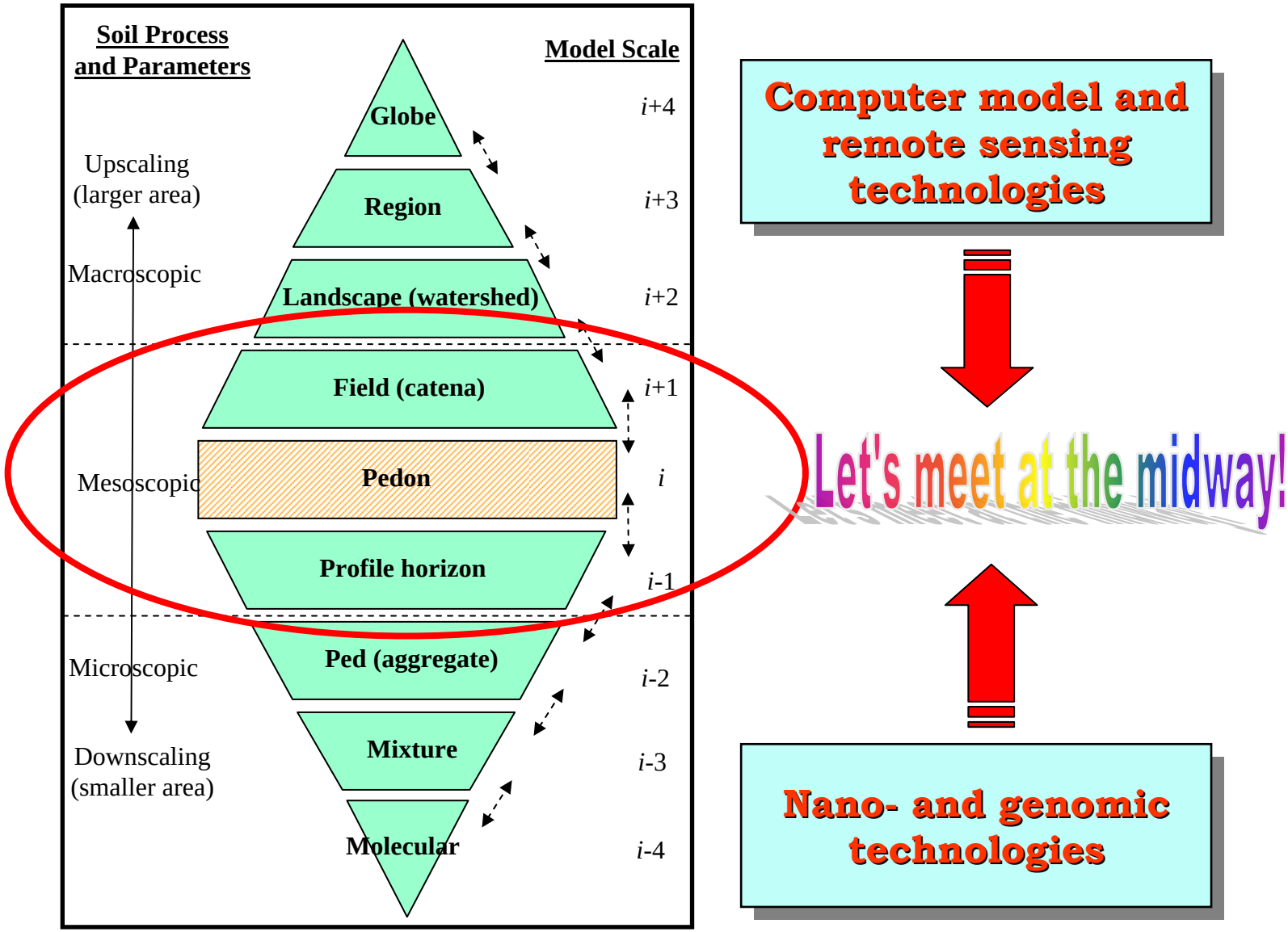
Two Hierarchical Frameworks for Multiscale Bridging in Hydropedology

A) ***Soil Mapping Hierarchy:***

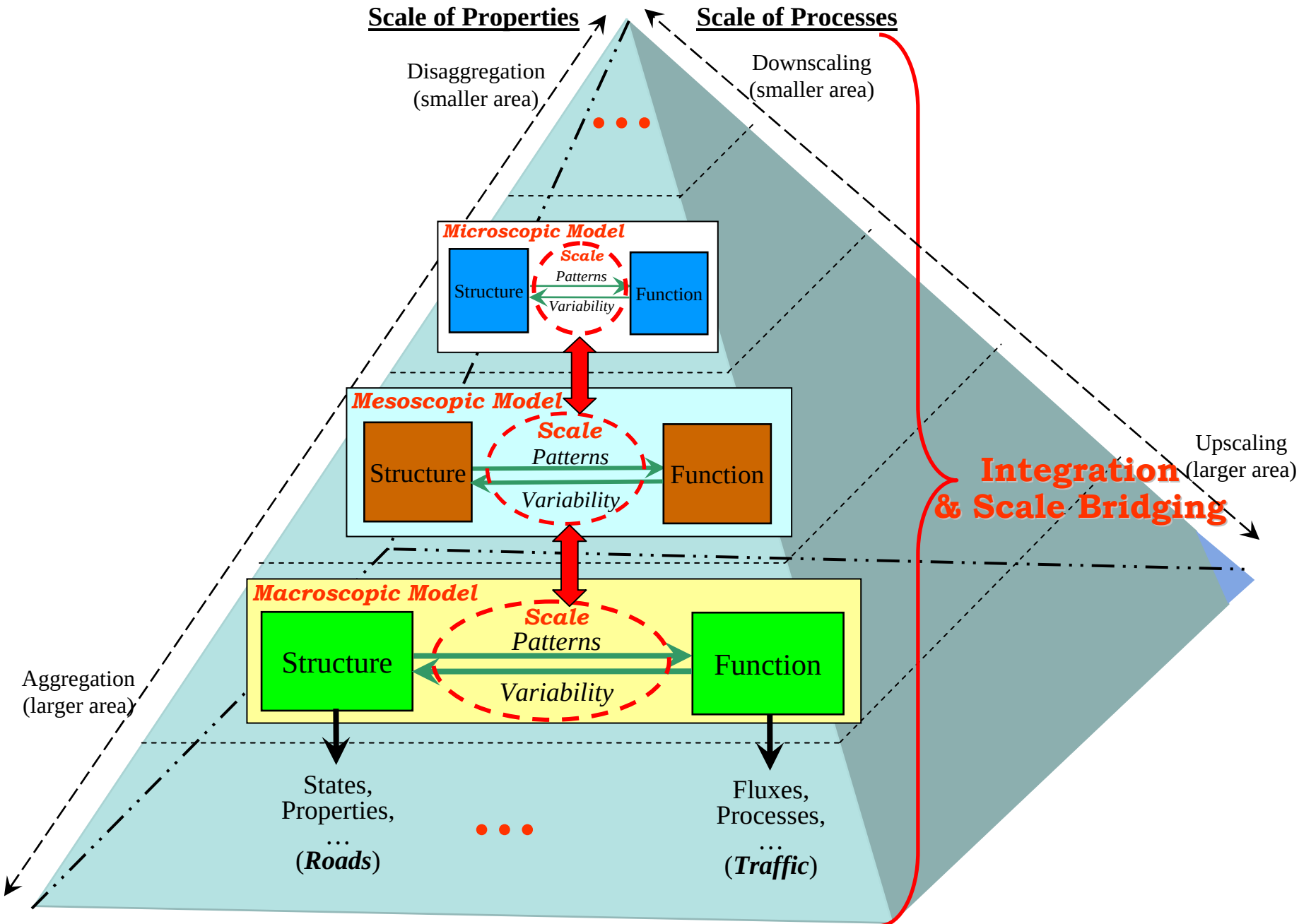


B) ***Soil Modeling Hierarchy:***



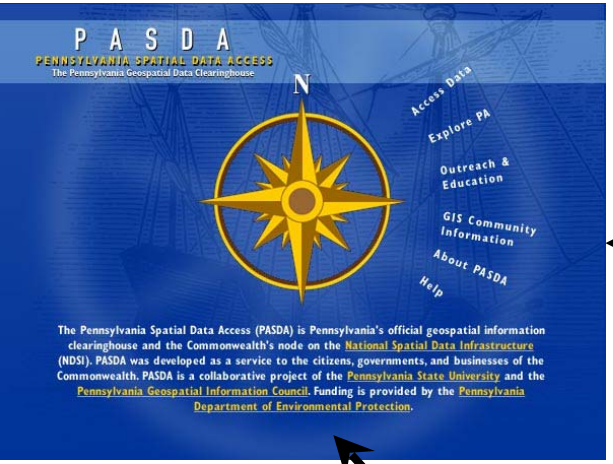

Soil Process and Parameters
Model Scale
Globe
Region
Landscape (watershed)
Field (catena)
Pedon
Profile horizon
Ped (aggregate)
Mixture
Molecular
i+4
i+3
i+2
i+1
i
i-1
i-2
i-3
i-4
Upscaling (larger area)
Macroscopic
Mesoscopic
Microscopic
Downscaling (smaller area)
Computer model and remote sensing technologies
Let's meet at the midway!
Nano- and genomic technologies

A Framework for Integrated Hydropedologic Studies

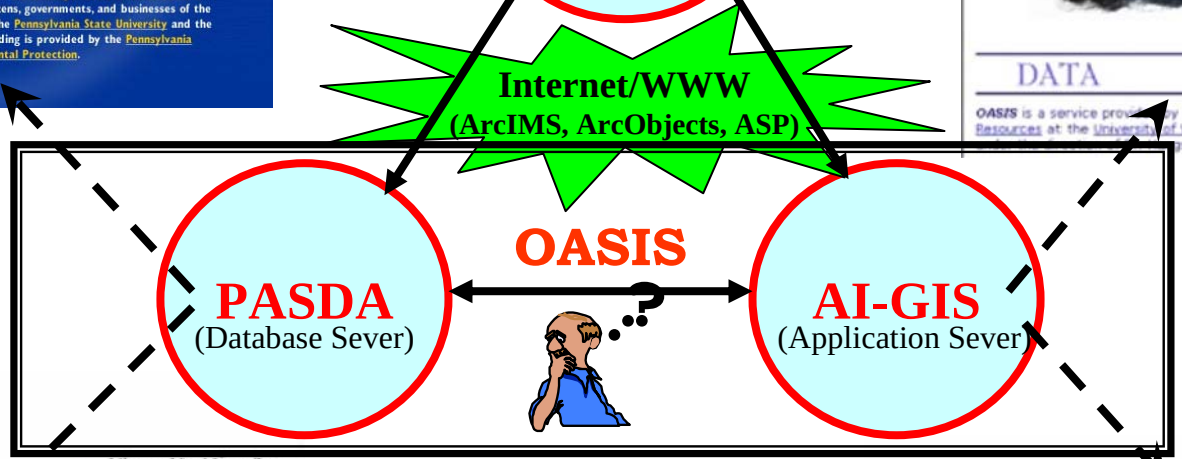


OASIS for Landscape-Soil-Water Information Delivery, Interpretation, and Modeling

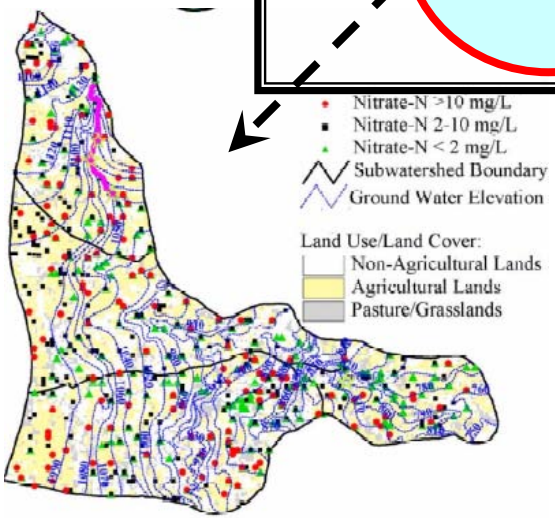
Example interface:



Example interface:

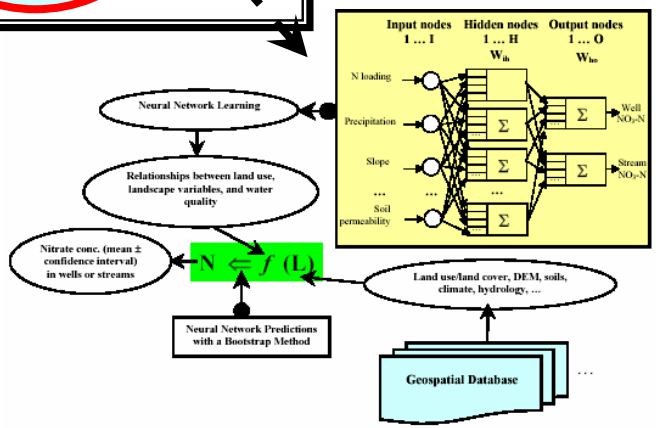


Example data:

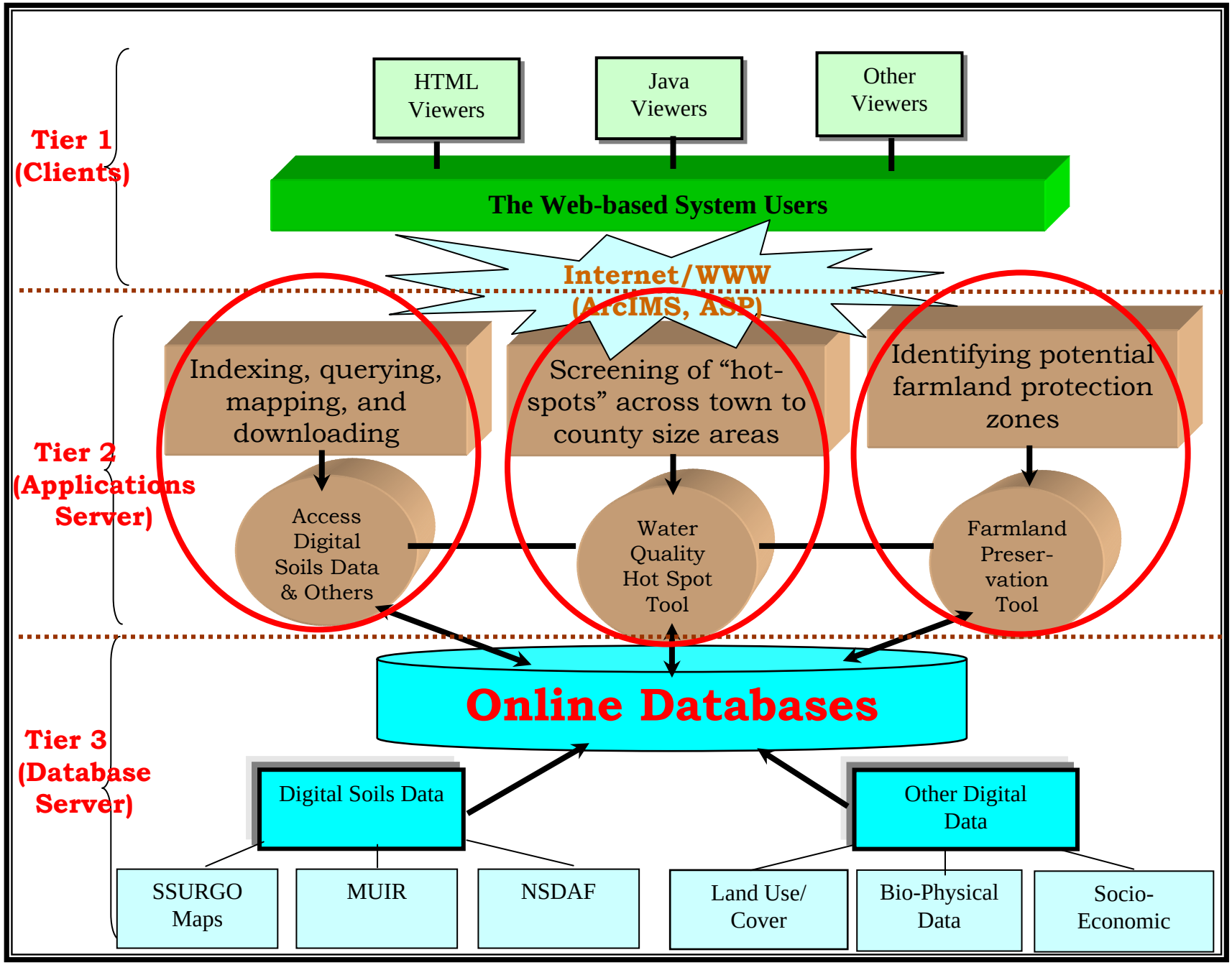


Nitrate concentration in ground water wells

Example tool:



Coupling neural network (shown in the inset) with geospatial database (shown in the lower right) for knowledge discovery and water quality prediction.

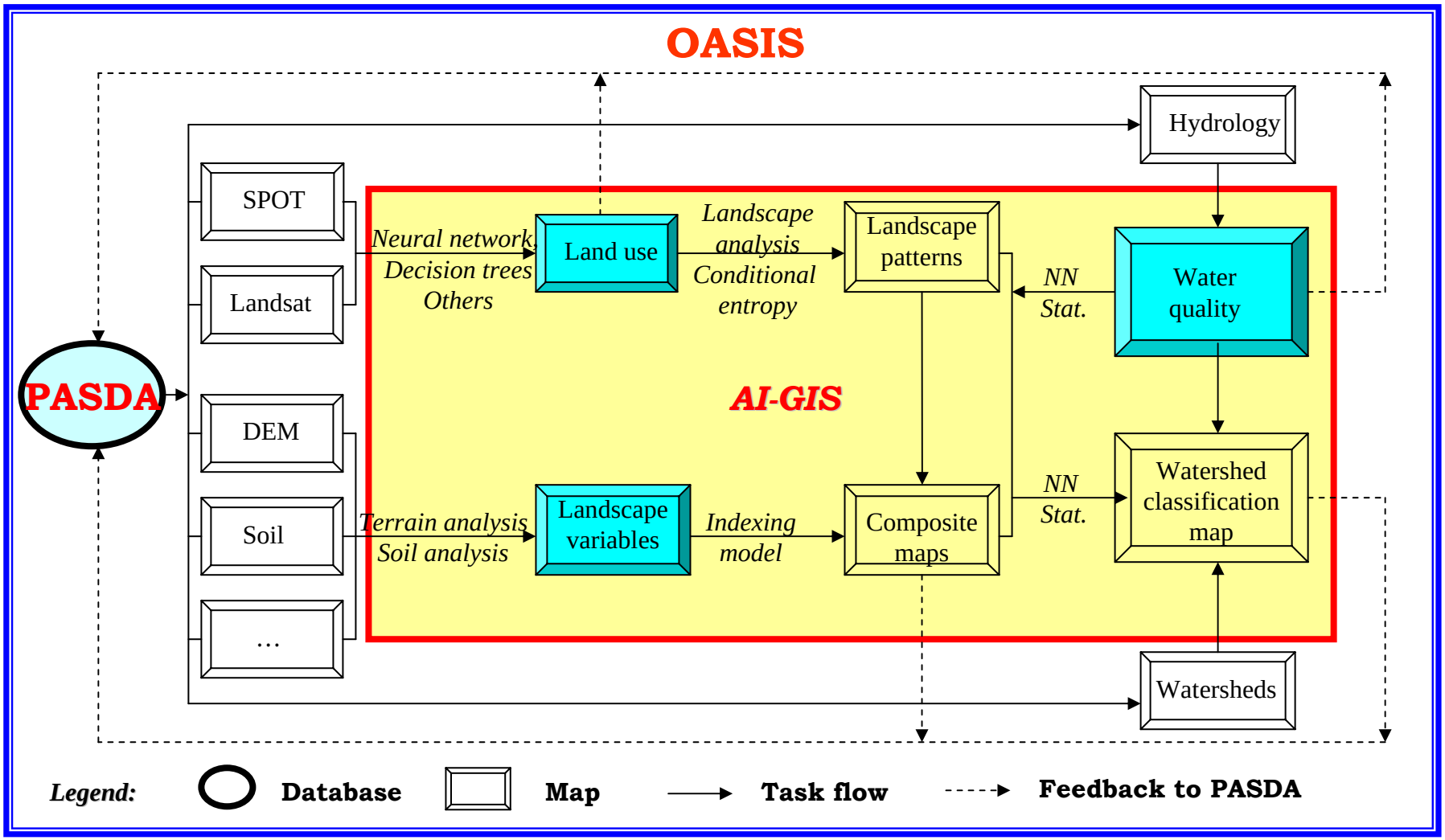

Tier 1 (Clients)
HTML Viewers
Java Viewers
Other Viewers
The Web-based System Users
Internet/WWW (ArcIMS, ASP)
Tier 2 (Applications Server)
Indexing, querying, mapping, and downloading
Screening of "hot-spots" across town to county size areas
Identifying potential farmland protection zones
Access Digital Soils Data & Others
Water Quality Hot Spot Tool
Farmland Preser-vation Tool
Tier 3 (Database Server)
Online Databases
Digital Soils Data
Other Digital Data
SSURGO Maps
MUIR
NSDAF
Land Use/ Cover
Bio-Physical Data
Socio-Economic

OASIS Vision

- Data mining & knowledge discovery
- Coupling environmental modeling with GIS
- Integrated multiscale landscape modeling

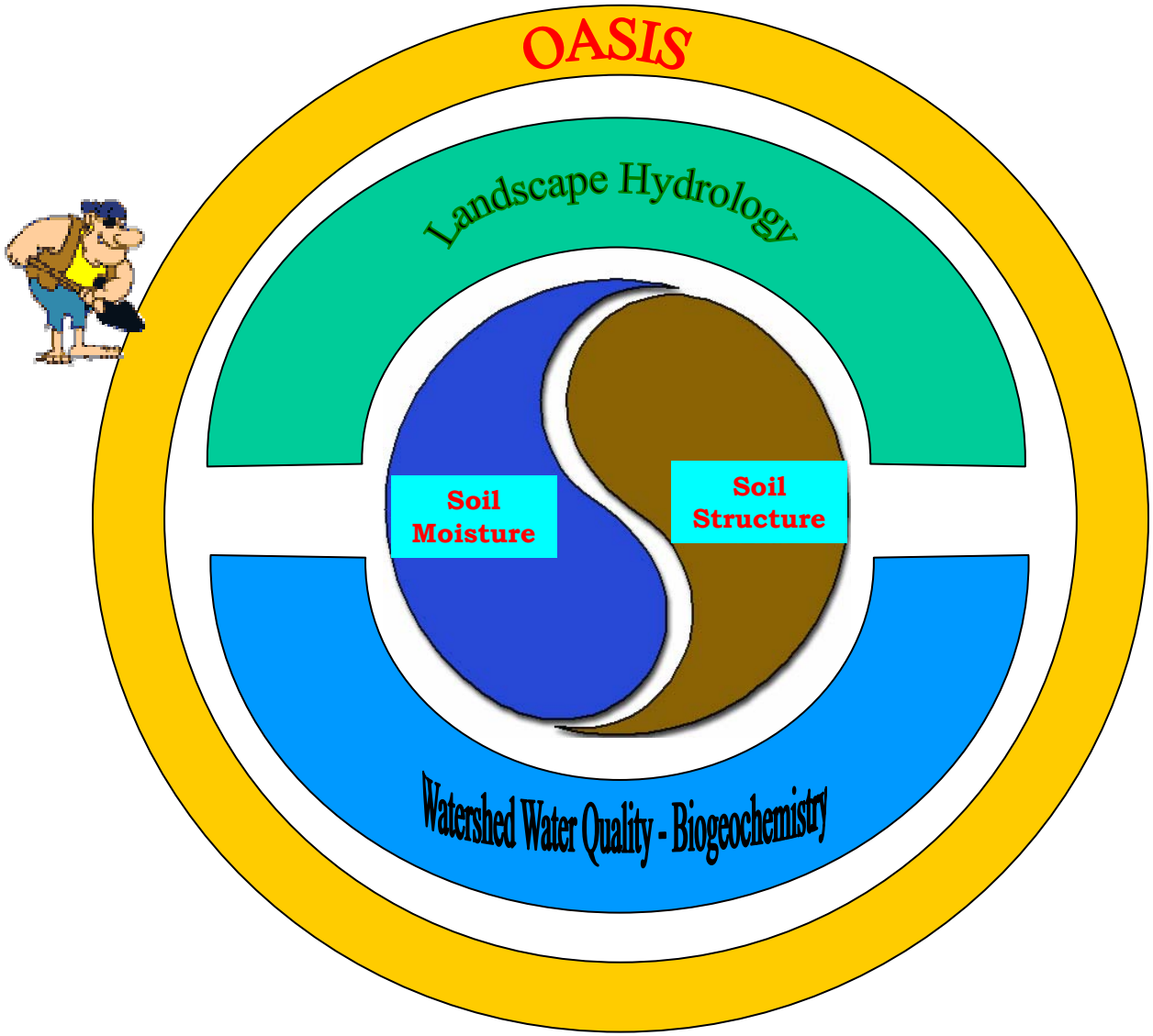
Visualization

"Data rich, information poor?" – The Need of Data Mining and Knowledge Discovery



Summary

- **Land Use Impacts on Soil Properties**
- **Landscape Hydropedologic Studies**
  - ***Forest Catchment***
  - ***Agronomy Farm***
  - ***Wastewater Spray Irrigation***
- **Online Advanced Spatial Info System**


OASIS
Landscape Hydrology
Soil Moisture
Soil Structure
Watershed Water Quality - Biogeochemistry

Hydropedology In Action?