Predicting Soil Processes: Digital Soil Mapping as a platform for bridging scale discrepancies between measurements and predictions

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The Challenge

Mapping Business:

- Predict processes and properties with acceptable accuracy;
- Bridging scales, especially between field measurement data and predictions.

Bottom line:

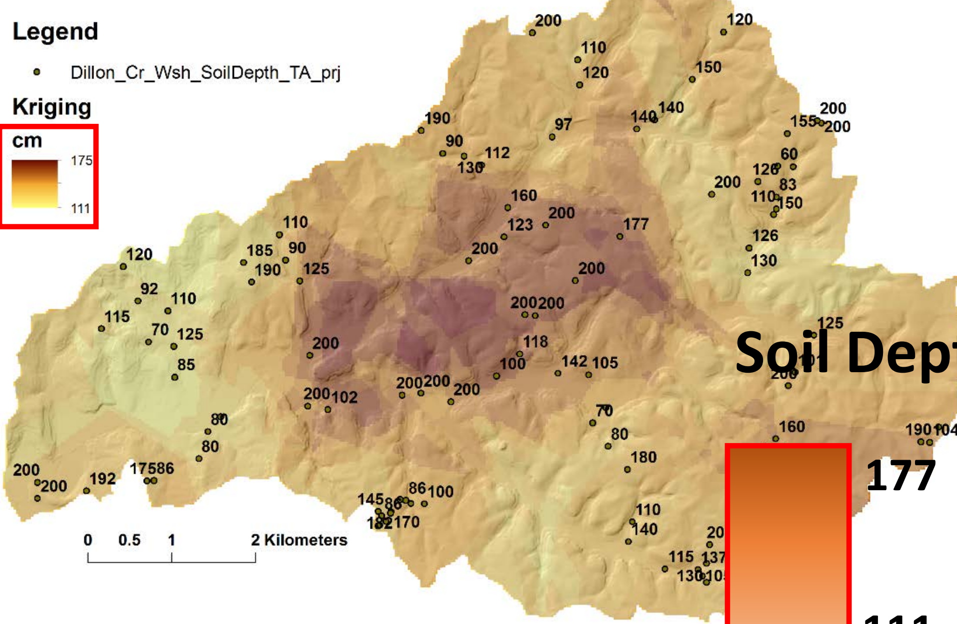
- Understanding processes and their spatial-temporal expression is essential.

The caveat:

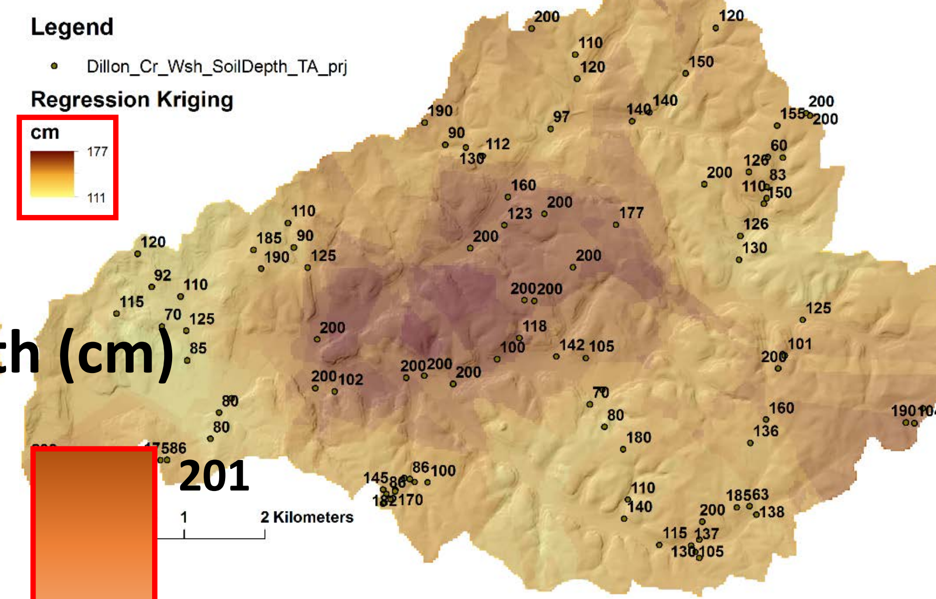
- Some prior knowledge required on the very same processes we are trying to predict (AKA “Catch 22”).

Soil Depth (cm)

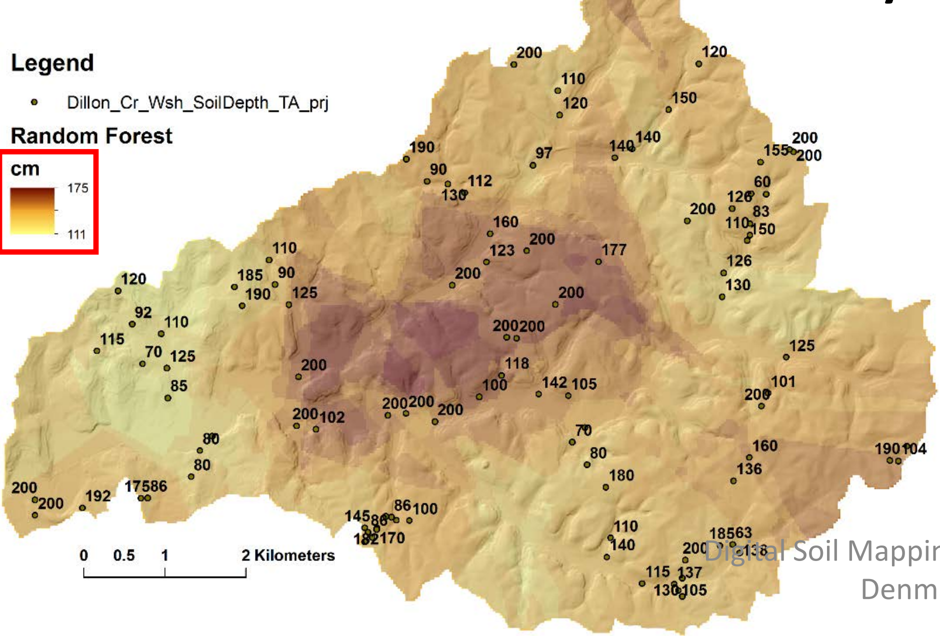
Kriging



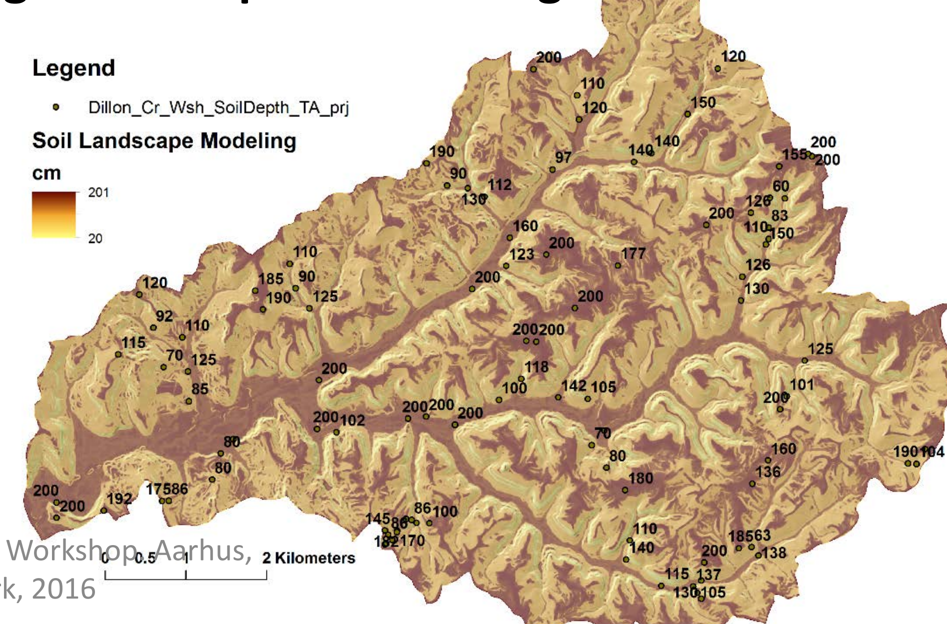
Regression Kriging



Random Forest



Fuzzy Logic with Expert Knowledge



Soil Saturated Hydraulic Conductivity

- **Definition**:

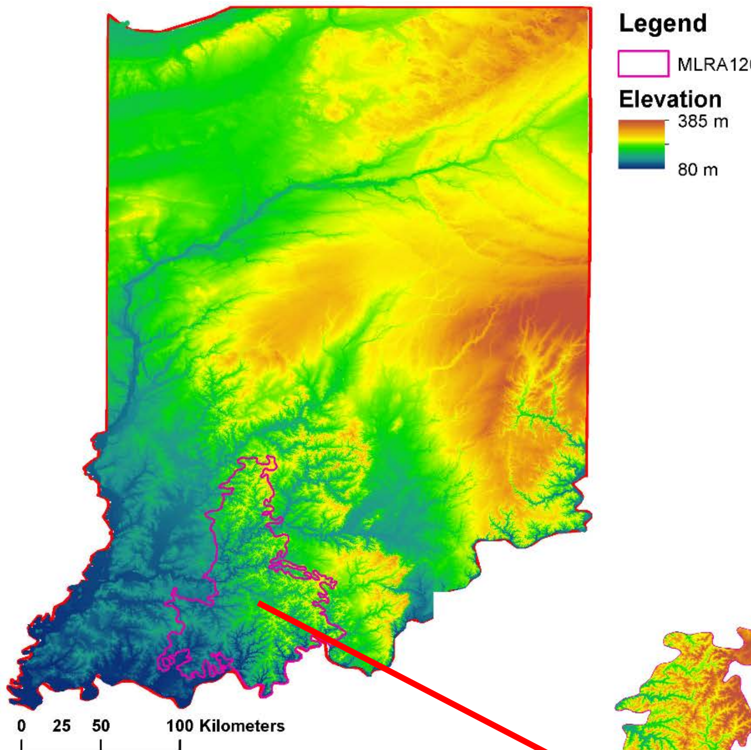
"quantitative measure of a *saturated soil's* ability to transmit water when subjected to a *hydraulic* gradient. It can be thought of as the ease with which pores of a *saturated soil* permit water movement.

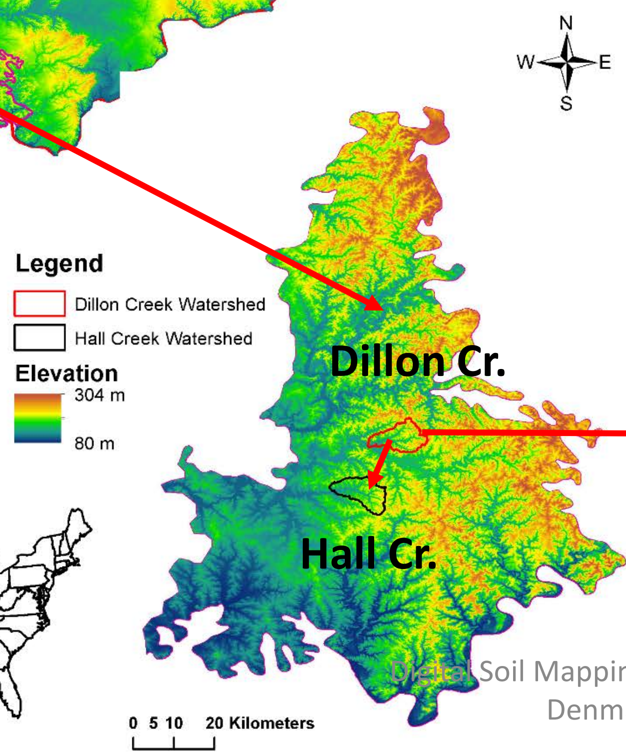
USDA-NRCS-Soil Survey Technical Note 6 at http://www.nrcs.usda.gov

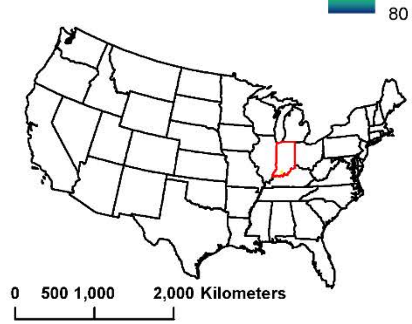
- **Why Ksat?:**
  - **Key input for most hydrological models;**
  - **Key property in more than 85% of soil interpretations;**
  - **Expensive to measure;**
  - **Highly variable;**

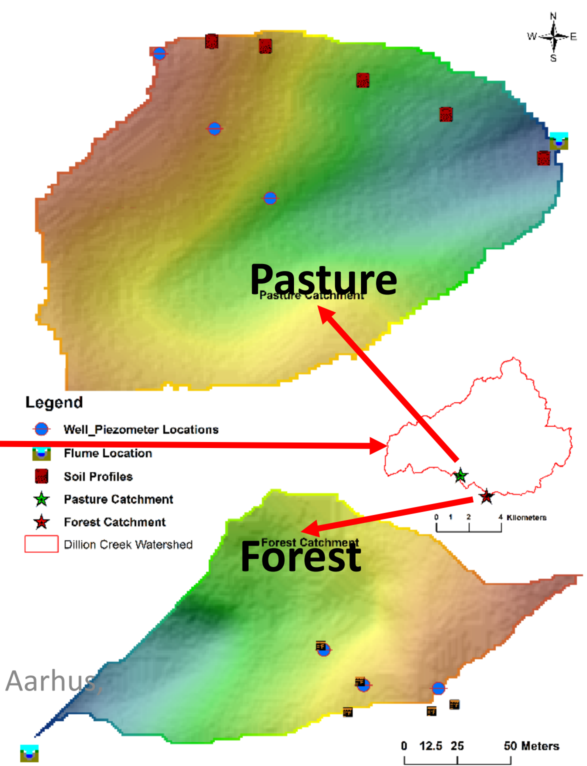
Study Site

There are two HUC-12 watersheds:
Dillon Creek where the small catchments are located;
Hall Creek with a USGS stream gage.
The majority of the soils in both watersheds formed in loess with varying thickness (few centimeters to several meters) over weathered sandstone, siltstone and shale.



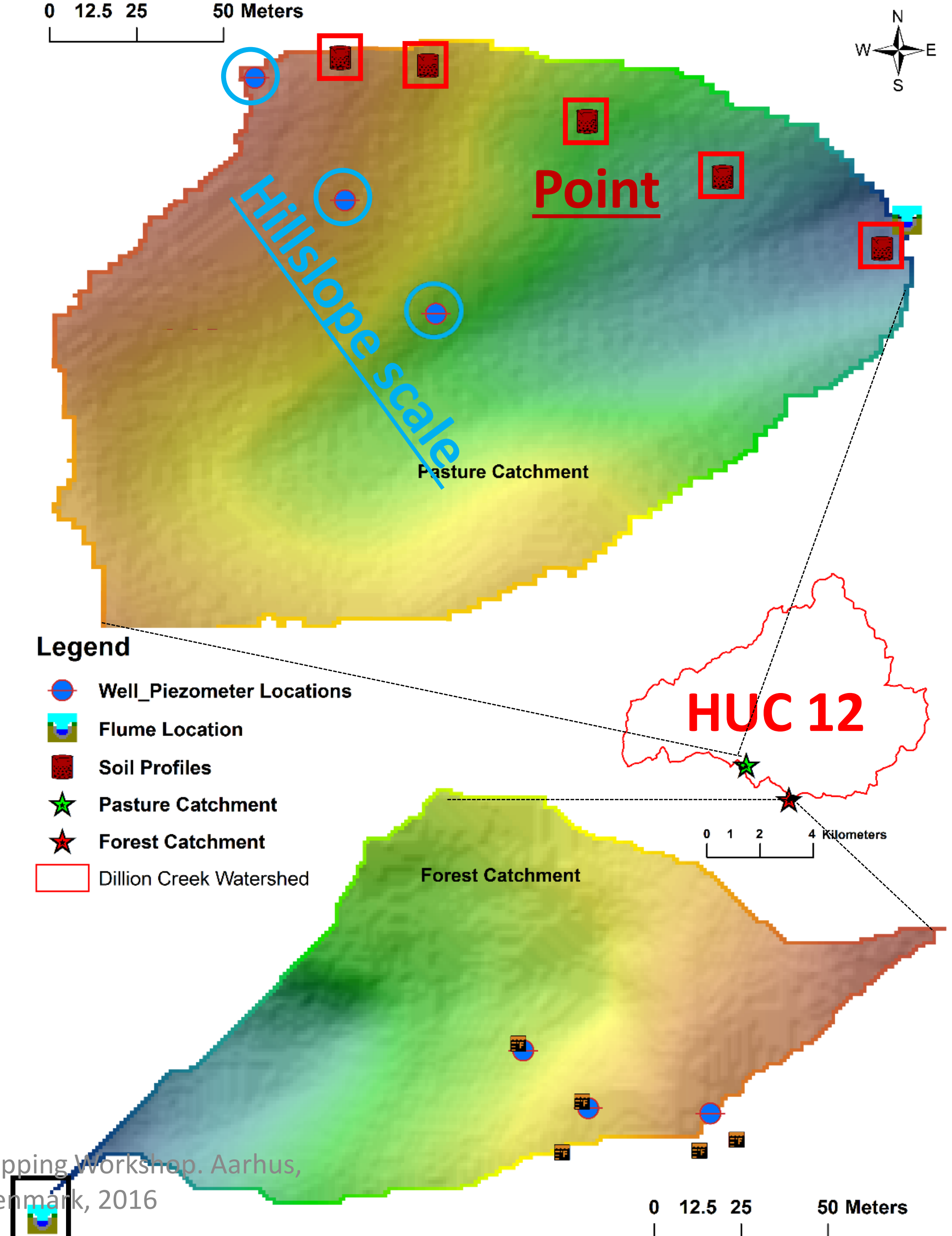






Objective

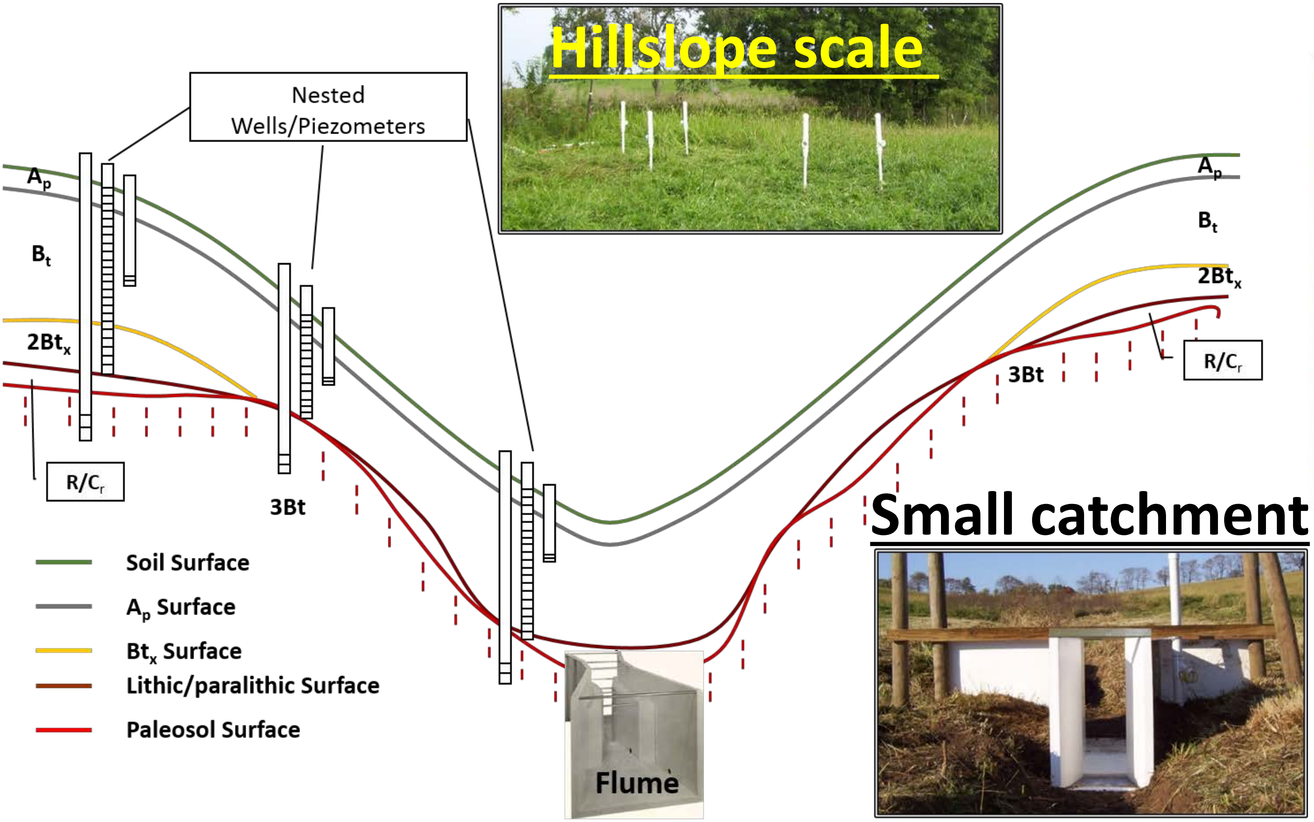
"Upscale soil hydrological properties measured at point / hillslope scale and small catchment to a HUC 12 watershed for stream flow predictions"



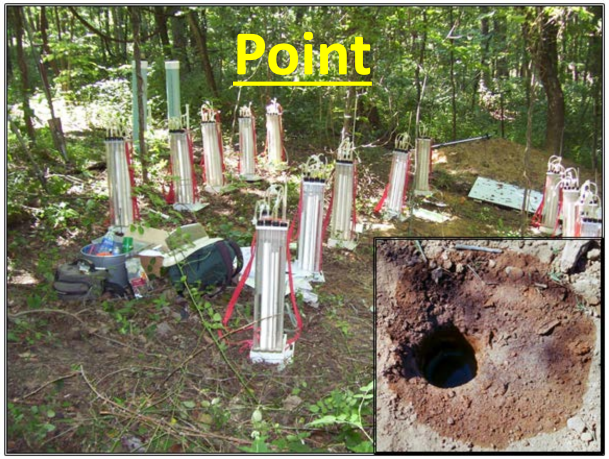
Small catchment

The Approach

Hillslope scale

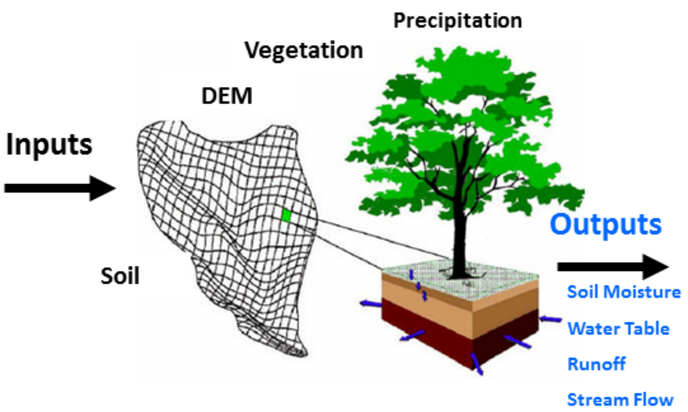


Point



Small catchment

Distributed Hydrological Soil Vegetation Model (DHSVM)



The **Input** for the DHSVM were lateral and vertical saturated hydraulic conductivity (K_{sat}), measured at:

(1) Point;
(2) Hillslope and;
(3) Small catchment scales.

Box Plot

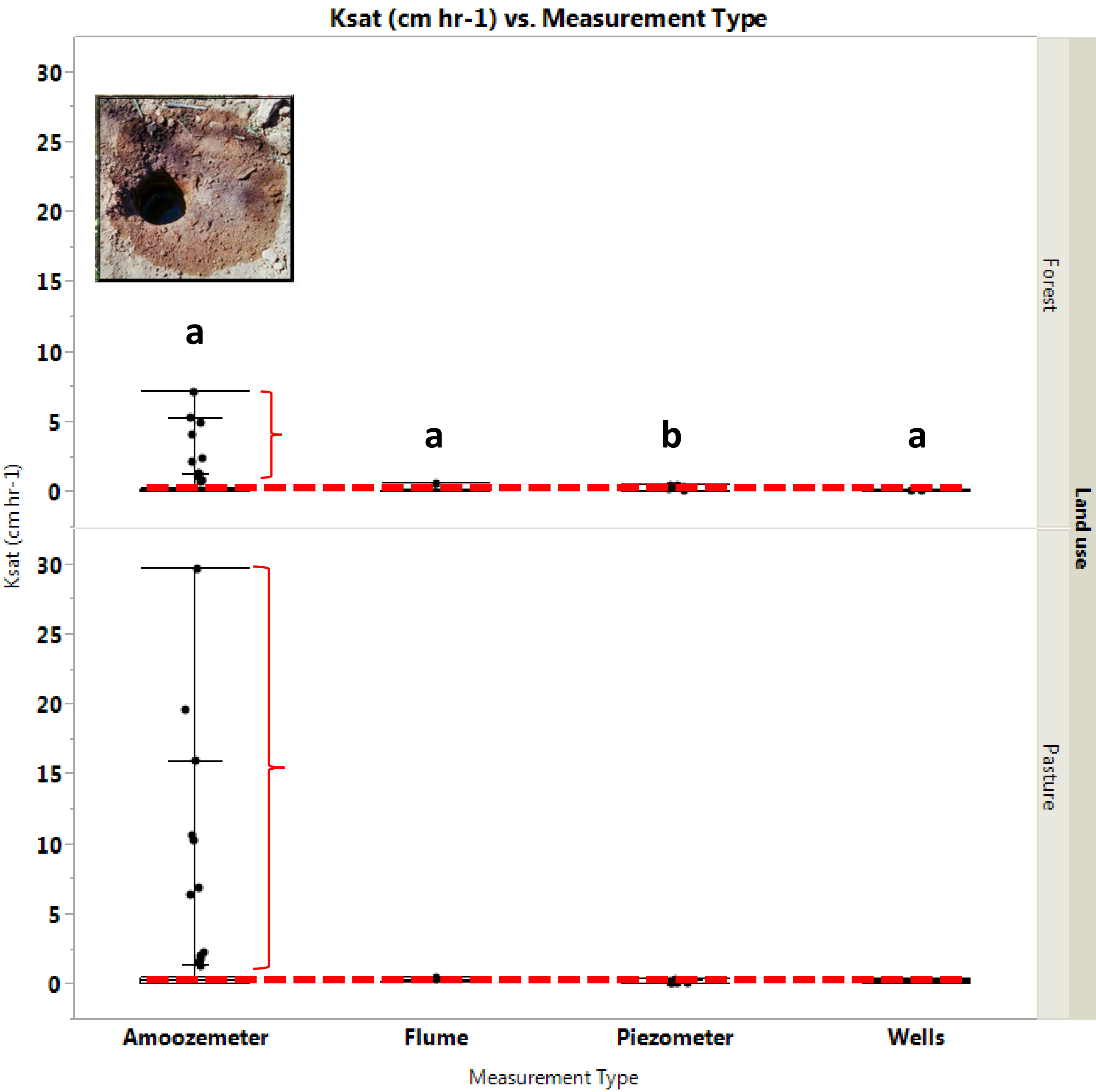
Key features :

(i) the lack of differences among measurement (piezometers);

(ii) a lack of significant trends between forest and pasture land uses

(iii) High CV (%)
- Amoozemeters 344
- Other methods 78.

(iv) the presence of a strong exponential decay of K_{sat} with soil depth R^2 = 086).



What Measurement method to use?

How to extrapolate to the large WSH?

DSM Approach – Knowledge Driven

Data mining from digital and analog sources to establish soil-landscape relationships → **Quantifying relationships between soils and their environment (Terrain Attributes)** → **Formalizing the relationships between soils and terrain attributes (Rules)** → **Creating raster based maps and predicted soil property maps**

Data mining from digital and analog sources to establish soil-landscape relationships

- County Soil Survey;
- OSD;
- SSURGO/Soil Data Mart;
- Soil Laboratory Characterization;
- Aerial Photography;
- Tacit Knowledge;
- Field data and observations;

Quantifying relationships between soils and their environment (Terrain Attributes)

- Block Diagrams;
- Soil Map Unit Descriptions (SMU)/OSDs;
- Soil Data Viewer;
- DEM-Terrain Attributes:
  - TWI; Slope; Curvature; Multi-Resolution Valley Bottom Flattens (MRVBF) & Ridgetop Flattens (MRRTF);
- Soil Knowledge Miner;
- Histograms.

Formalizing the relationships between soils and terrain attributes (Rules)

- Rules for terrain/soil relationships for each relevant terrain attribute:
- IF..THEN..EITHER/OR
- IF Slope < 10 THEN Soil A;
- IF TWI > 10 THEN Soil B;
- IF Slope < 10 AND >15 and
- TWI<5 AND >10 THEN Soil C.

Creating raster based maps and predicted soil property maps

- Assign a property value for each soil;
- Depth to Limiting Layer
- Available Water Holding Capacity; etc.
- Based on Fuzzy membership values predict the soil property (V_{ij}) at ij location;

$$V_{ij} = \frac{\sum_{k=1}^{n} S_{ij}^{k} \bullet V^{K}}{\sum_{k=1}^{n} S_{ij}^{k}}$$

S_{ij} – assigned property value;
S^{k}_{ij} – fuzzy membership value.

Terrain Attributes-Soil Relationships

Gilpin

MRRTF < 2.4

MRVBF < 2.9

Slope 12-18 %

Cuba

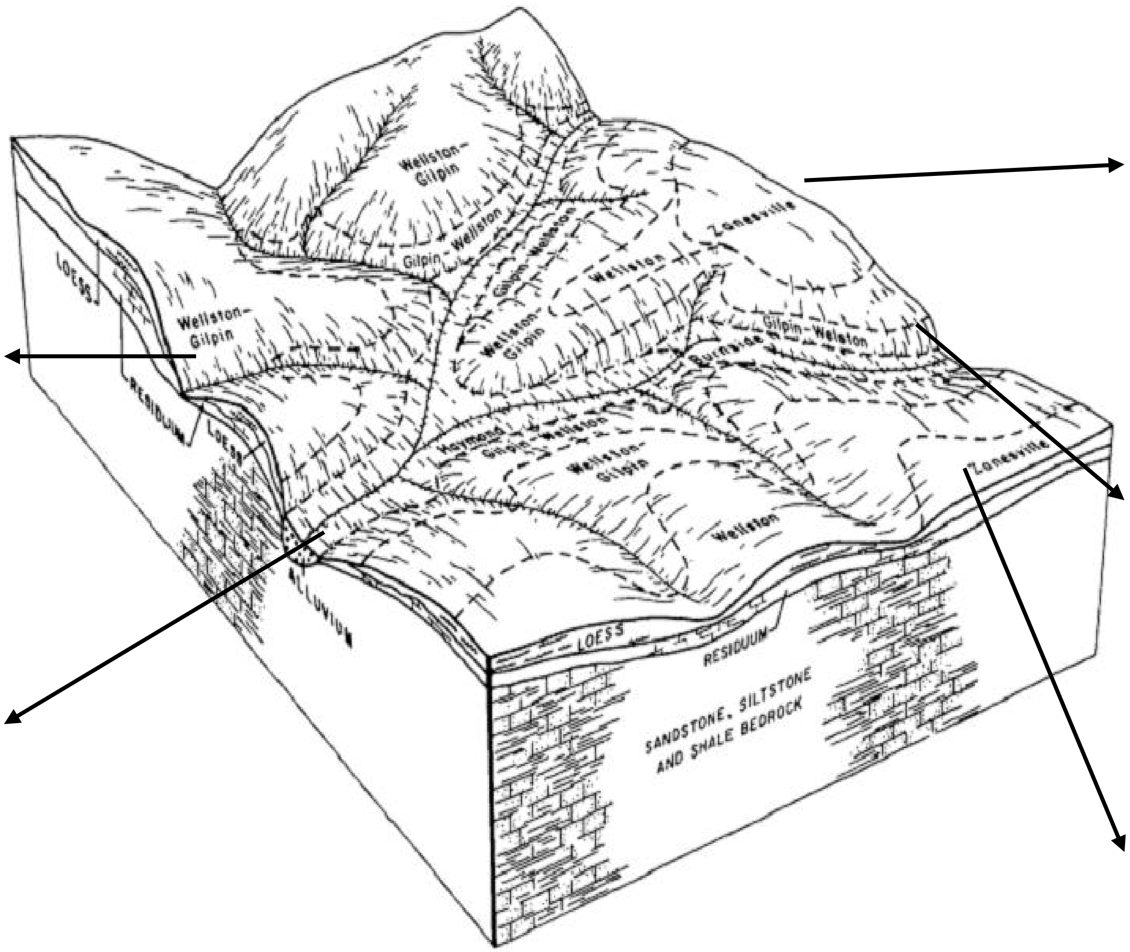
MRRTF < 2.4

MRVBF < 2.9

Slope 0-2 %

AACH >0.09

TWI <12



Zanesville

MRRTF > 2.4

MRVBF < 2.9

Slope 6-12 %

Gilpin-Berks complex

MRRTF < 2.4

MRVBF < 2.9

Slope 18-50 %

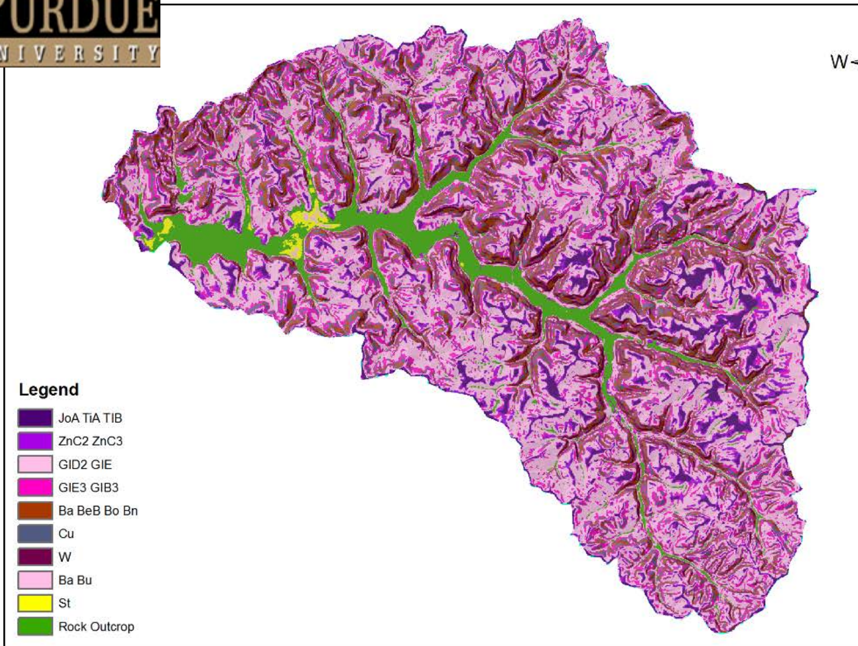
AACH 0.5-2.0

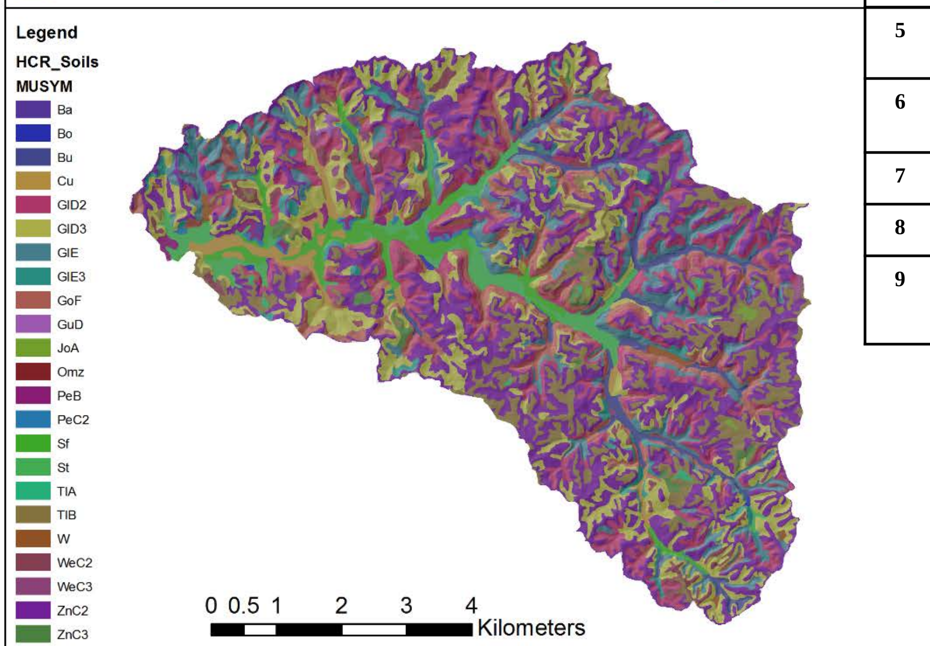
Tilsit

MRRTF > 2.4

MRVBF < 2.9

Slope < 2%





Terrain Attributes-Soil Relationships

No	Soil Series	MRRTF	MRVBF	Slope	AACHN	TWI
1	Tilsit/Bedford/Apallona/Johnsburg	> 2.4	< 2.9	< 2		
2	Tilsit/Bedford/Apallona	> 2.4	< 2.9	2-6		
3	Zanesville/Apallona/Wellston	> 2.4	< 2.9	6-12		
4	Gilpin/Wellston/Adyeville/Ebal	< 2.4	< 2.9	12-18		
5	Gilpin/Ebal/Berks	< 2.4	< 2.9	18-50	0.5-2.0	
6	Pekin/Bartle	< 2.4	> 2.0	2-12	0.5-2.0	
7	Cuba	< 2.4	> 2.9	0-2	> 0.09	< 12
8	Steff/Stendal/Burnside/Wakeland	< 2.4	0-1	0-2	<0.09	> 12
9	Rock Outcrops, Steep Slopes	< 2.4		> 50		

MRRTF- Multi Resolution Ridge Top Flatness
MRVBF-Multi Resolution Valley Bottom Flatness
AACHN-Altitude Above CHannel Network
TWI-Topographic Wetness Index

United States Department of Agriculture

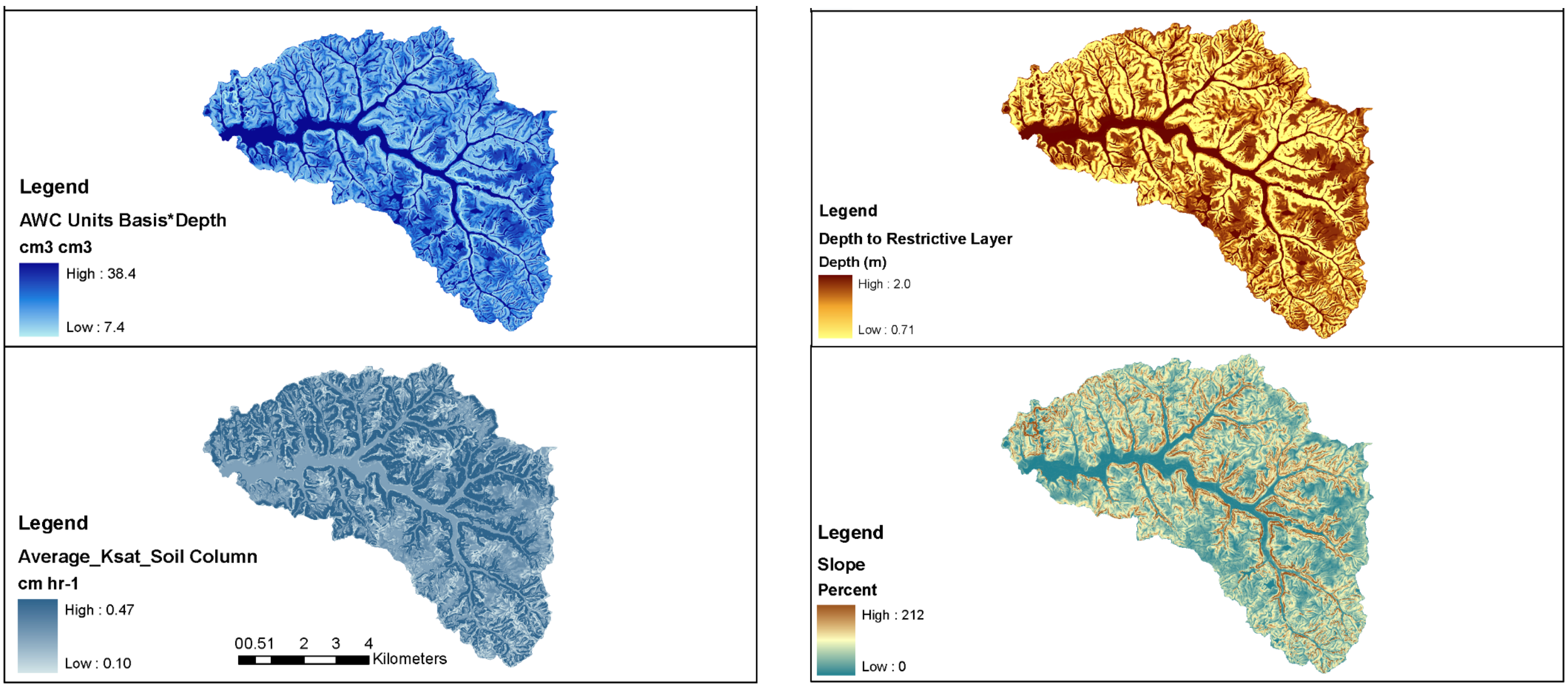
Soil Property Map for DHSVM Input

$$H_{ij} = \frac{\sum_{k=1}^{l} S_{ij,k} h_k}{\sum_{k=1}^{l} S_{ij,k}}$$

H_{ij}: the estimated soil property value at location (i, j);

S^k_{ij}: the fuzzy membership value for kth soil at location (i, j);

h_k: the representative property value for kth soil.



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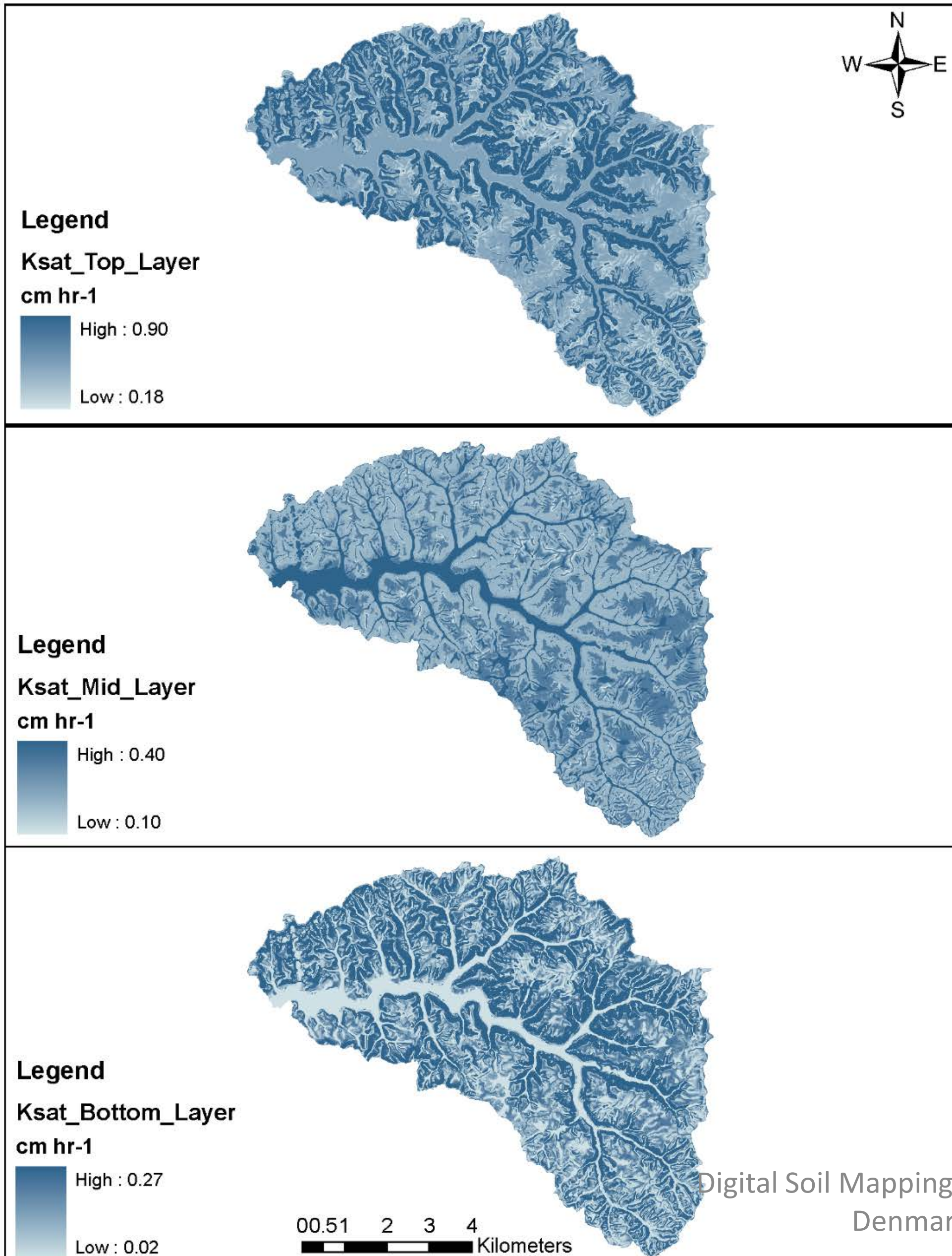
HUC 12 Watershed

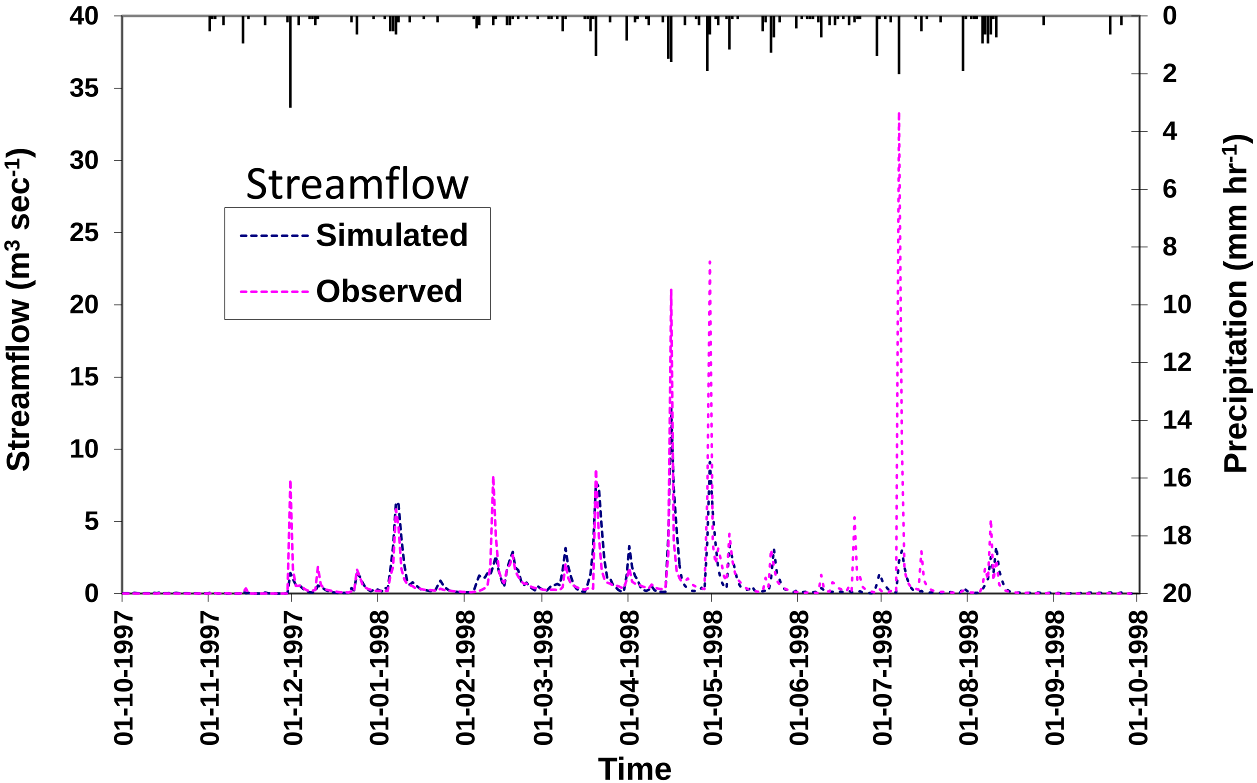


Assigning Other Hydraulic Soil Properties

All other hydraulic soil properties were assigned based on measurements conducted at soil pits in the study area located on summit, backslope and toe slope key hillslope position in small catchments.

Almost 75% of soils on the HUC-12 watershed were represented by the soils in the small pasture and forested catchments.

DHSVM Model Performance



Nash-Sutcliffe (N-S) model efficiency

$$N-S = 1.0 - \frac{\sum_{i=2}^{N}\left(O_i - S_i\right)^2}{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2}$$

O_i is observed daily streamflow;
S_i is simulated daily streamflow;
N is the number of days in the assessment period.

(Nash and Sutcliffe, 1970)

Nash-Sutcliffe model efficiency of 0.52 indicated overall a good performance of the model, however, it varied from 0.32 during dry season to 0.72 for winter season.

Concluding Remarks

- Despite these limitations, the overall good agreement between observed and simulated streamflows was achieved without any model calibration.
- Multiple K_{sat} measurement by different methods at small catchment scale combined with soil data and soil landscape knowledge is a valuable approach for upscaling soil hydraulic properties for streamflow predictions at larger watershed scale.
- However, the study area was dominated by forest and pasture. The relatively simple land use and homogenous soils facilitated the upscaling of K_{sat} measurements and other soil hydraulic properties.
- The approach needs to be evaluated for other more complicated and diverse soil systems with respect to soils and vegetation.