Measurements of infiltration by accounting for the role of management practices

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June 6, 2007

EWRI

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Support

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Natural Resources Conservation Service
NRCS National Geospatial Development

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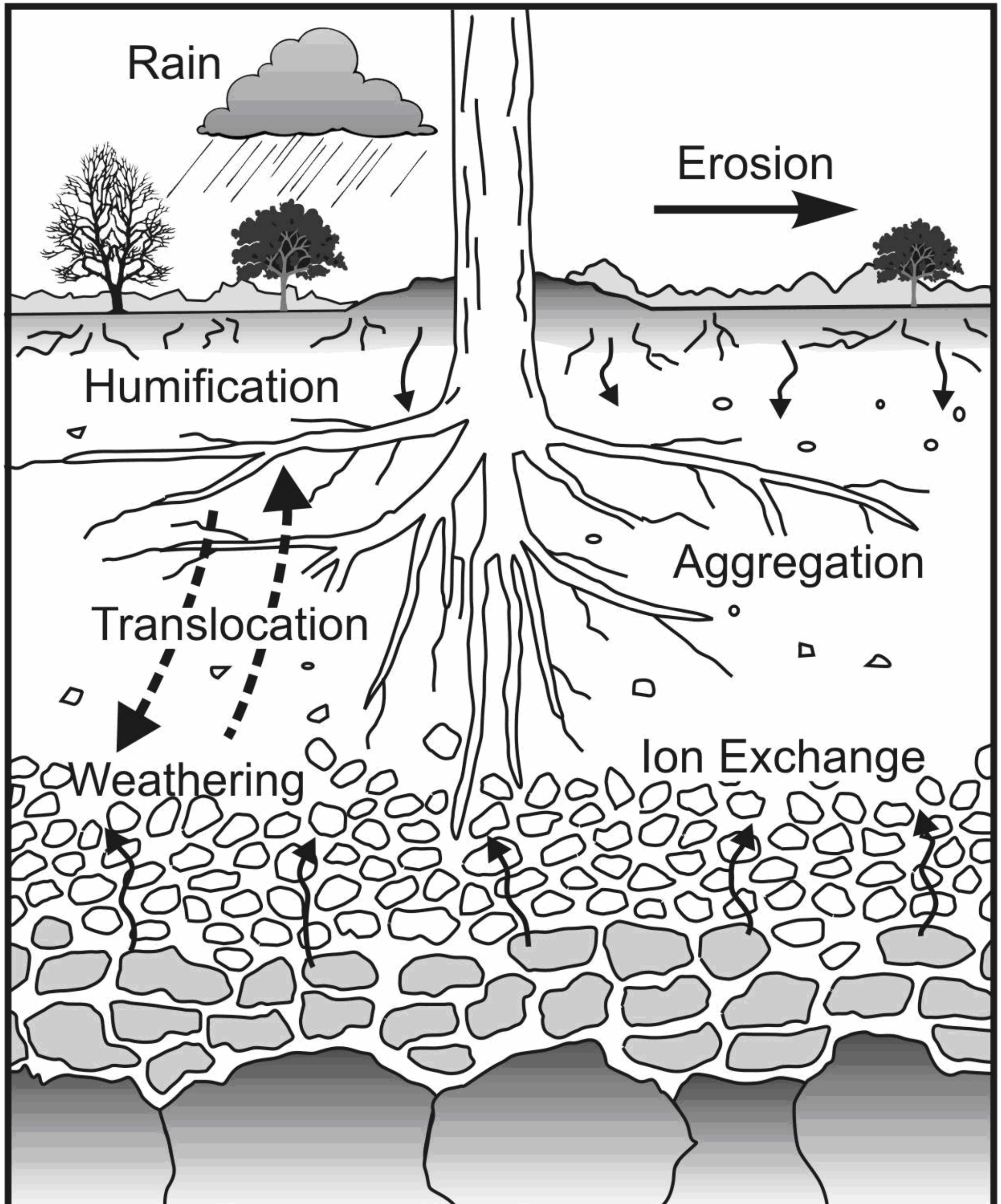
NRCS Iowa State Soil Scientist

Key Dynamic function K-sat

- Hydraulic conductivity can be defined as a measure of the ability of soil to transmit water. Under saturated conditions this parameter is usually denoted as K-sat or (Ks) and is assumed to be constant for a given space and time within a soil (Amoozegar and Wilson, 1999).

- The knowledge of K-sat for a specific soil is too important for instance in drainage design, the saturated hydraulic conductivity is used to compute the velocity in which water can move toward and into the drainlines below the water table (Amoozegar and Wilson, 1999).

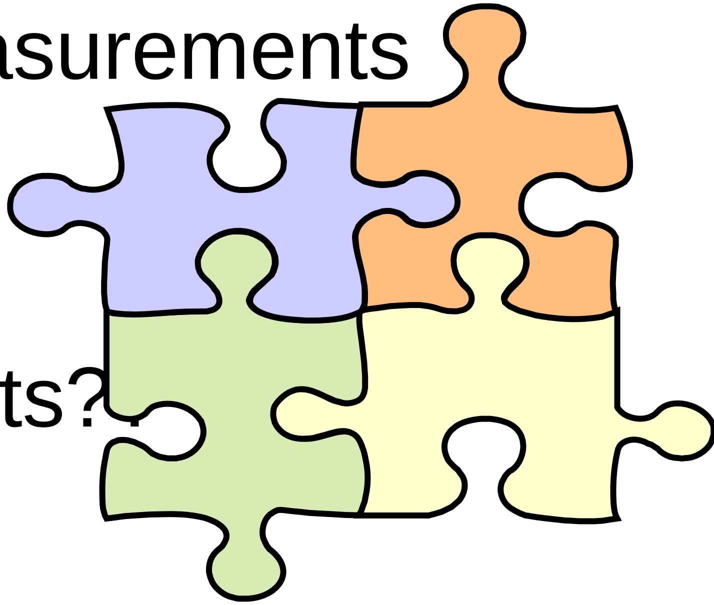
- Laboratory determined values rarely agree with field measurements, the differences often being on the order of 100 fold or more. Field methods generally are more reliable than laboratory methods due to the closer approximation to natural conditions (Scott, 2000).


Rain
Erosion
Humification
Aggregation
Translocation
Ion Exchange
Weathering

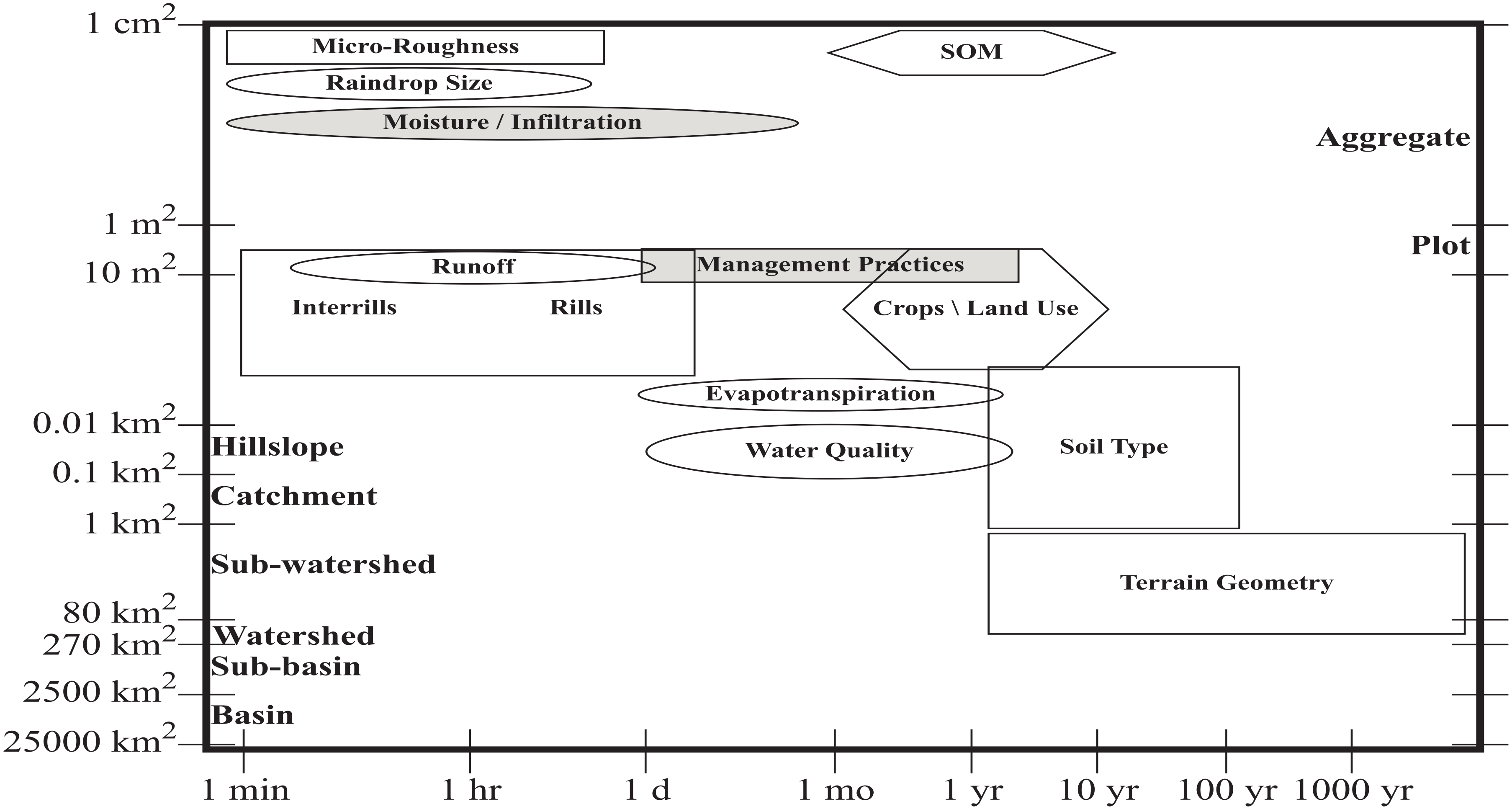
Key-challenges for K-sat

- K-sat measurements are typically point measurements. How can we do the integration of the point measurements over an area??

- Frequency of measurements??



Scales



After Papanicolaou (2006), Geomorphology

Key-questions towards the spatial/temporal integration

This collaborative investigation between UI and the Iowa State University (ISU) will examine the following research questions (Qs):

Q-1) Is the increase (decrease) in the hillslope gradient going to have an adverse (inverse) effect on the conductivity magnitude?

There are contradictory findings concerning the effects of slope gradient and landform geometry on infiltration rate. For example, Zaslansky and Sinai (1981) found that the infiltration rate decreased as the slope increased while Poesen (1986) reported an increase in infiltration as the slope increased.

Key-questions towards the spatial/temporal integration

Q-2) How slope, soil type and management practices collectively affect infiltration?

The effects of slope on infiltration rate for different soil types and land-use have not been thoroughly examined (Kidwell et al. 1997). More work is required to evaluate the cumulative effects of management practices and soil type on infiltration for different slopes. Furthermore, the role of soil microstructure on infiltration rate needs to be examined carefully as most of the studies thus far have focused only on the macroscopic properties of soil.

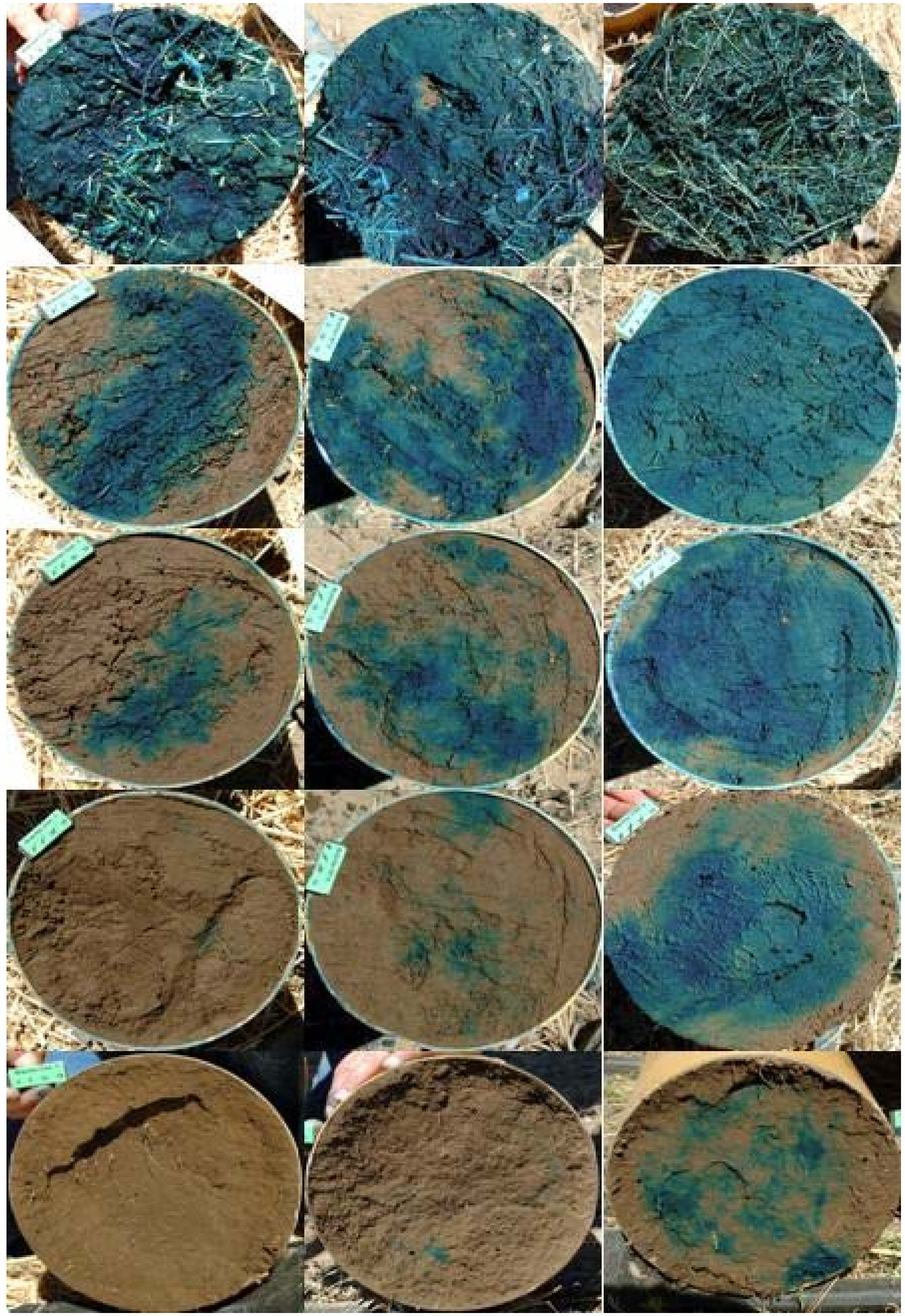
Surface

2 inch depth

4 inch depth

6 inch depth

10 inch depth



Shano very fine sandy loam.

Column 1:
conventional tillage

Column 2:
no-till

Column 3:
CRP

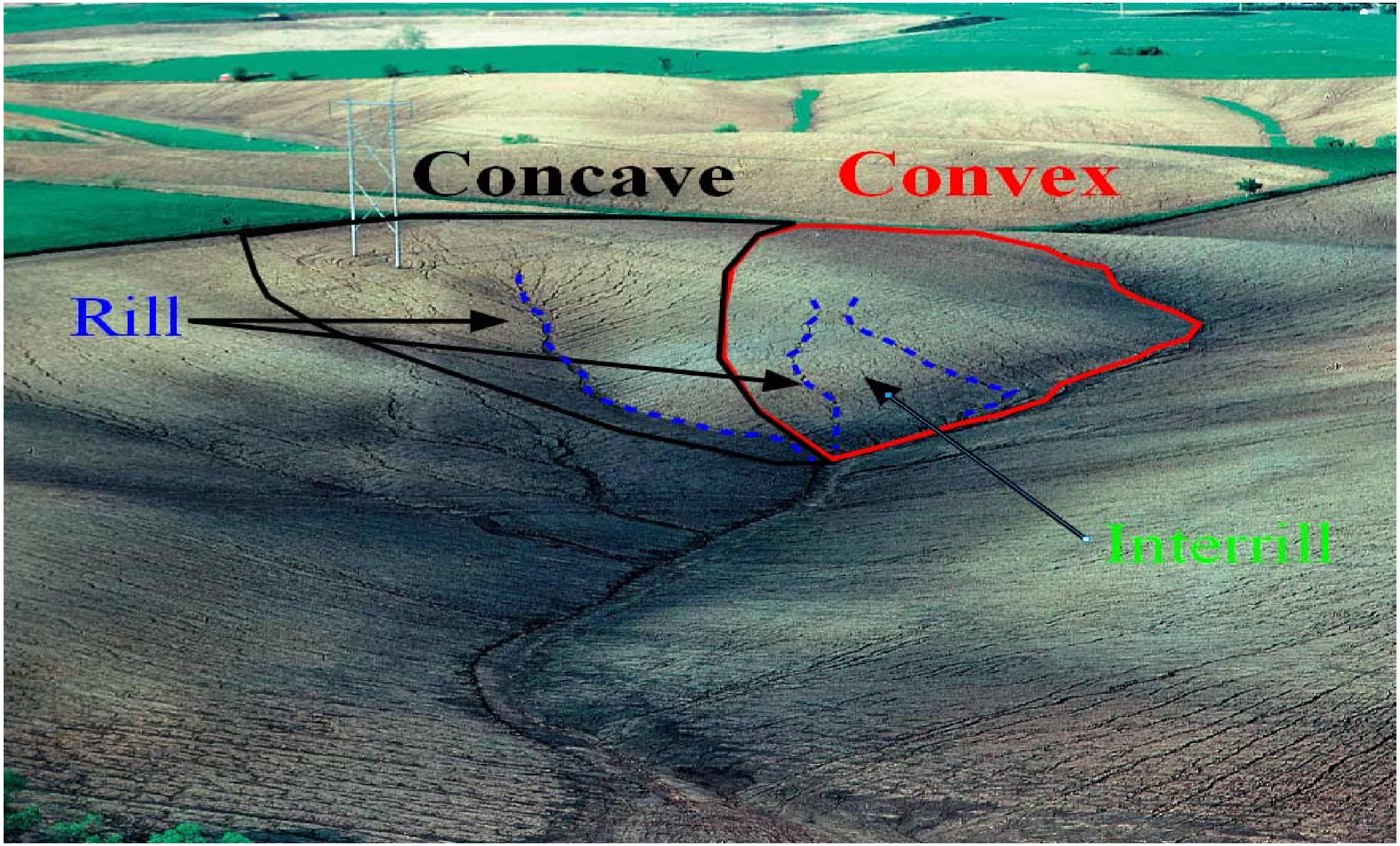
Key-questions towards the spatial/temporal integration es and Tasks

Q-3) Rainfall intensity and raindrop size relate to the rate of infiltration by affecting the porous microstructure of the soil. Do changes in rainfall intensity and therefore raindrop terminal velocity affect significantly the rate of infiltration? How significant these changes need to be in order to cause delay or acceleration of the infiltration process?

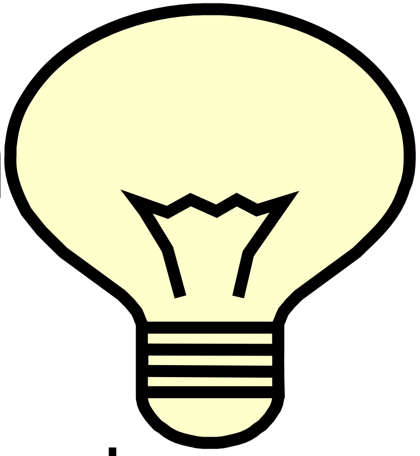
Conductivity relations that account for the changes in rainfall intensity and the kinetic energy of the raindrops need to be developed.

Key-questions towards the spatial/temporal integration

Q-4) There is still a need to define spatial variability of infiltration and runoff along a hillslope using new research methodologies and techniques.



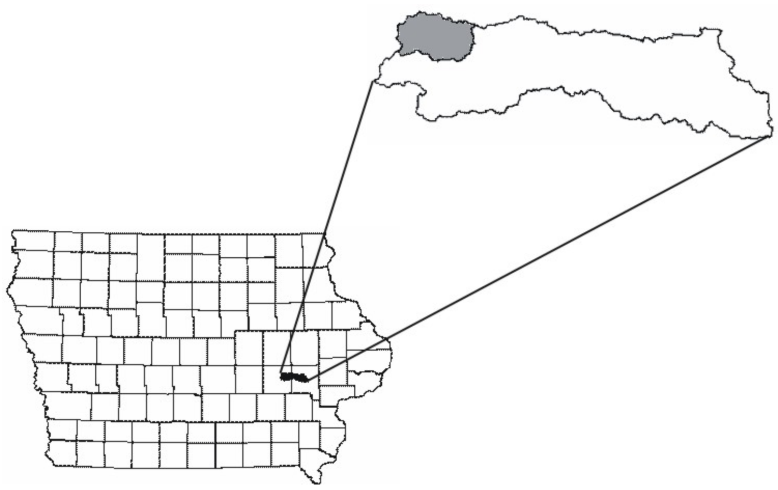
Hollistic approach

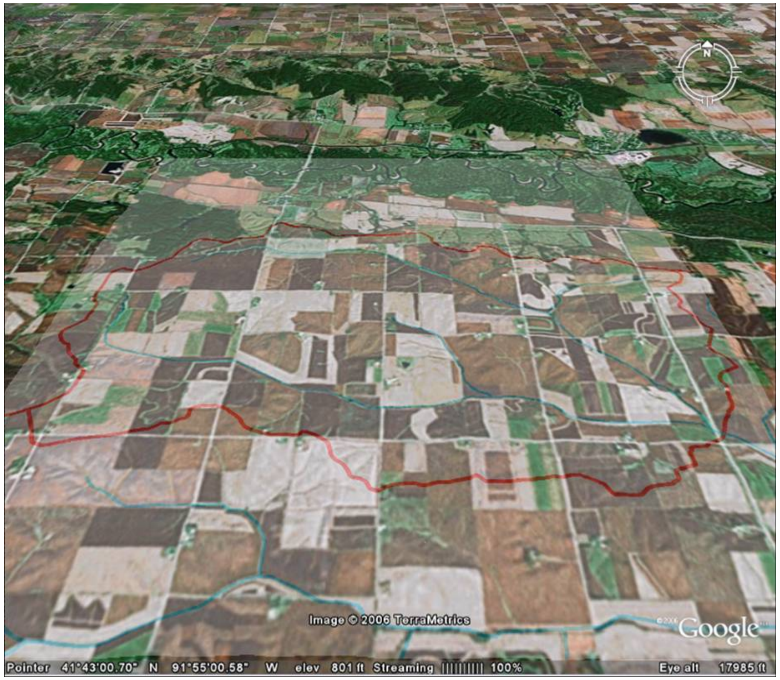


- Use geospatial tools and watershed models as a first step to identify the hotspots and address spatial/temporal variability.
- Perform continuous measurements using sensor technology at the hotspots to refine our existing understanding.
- Integration of point measurements.

Study Site

•South Amana catchment of Clear Creek watershed, IA
•The area of the catchment is approximately 6400 acres
•Primarily agricultural, with 60% of land cover being row crops and about 20% in pasture/hay





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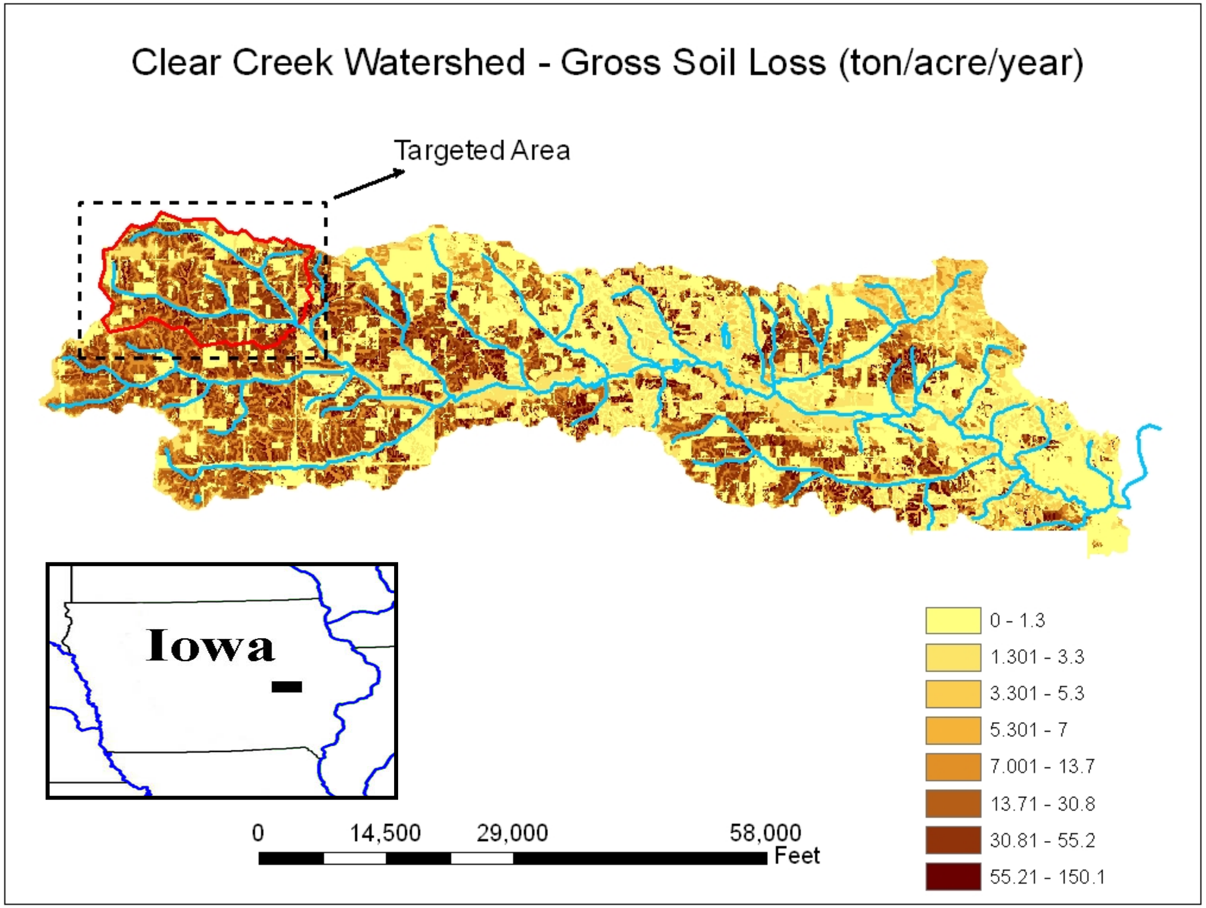
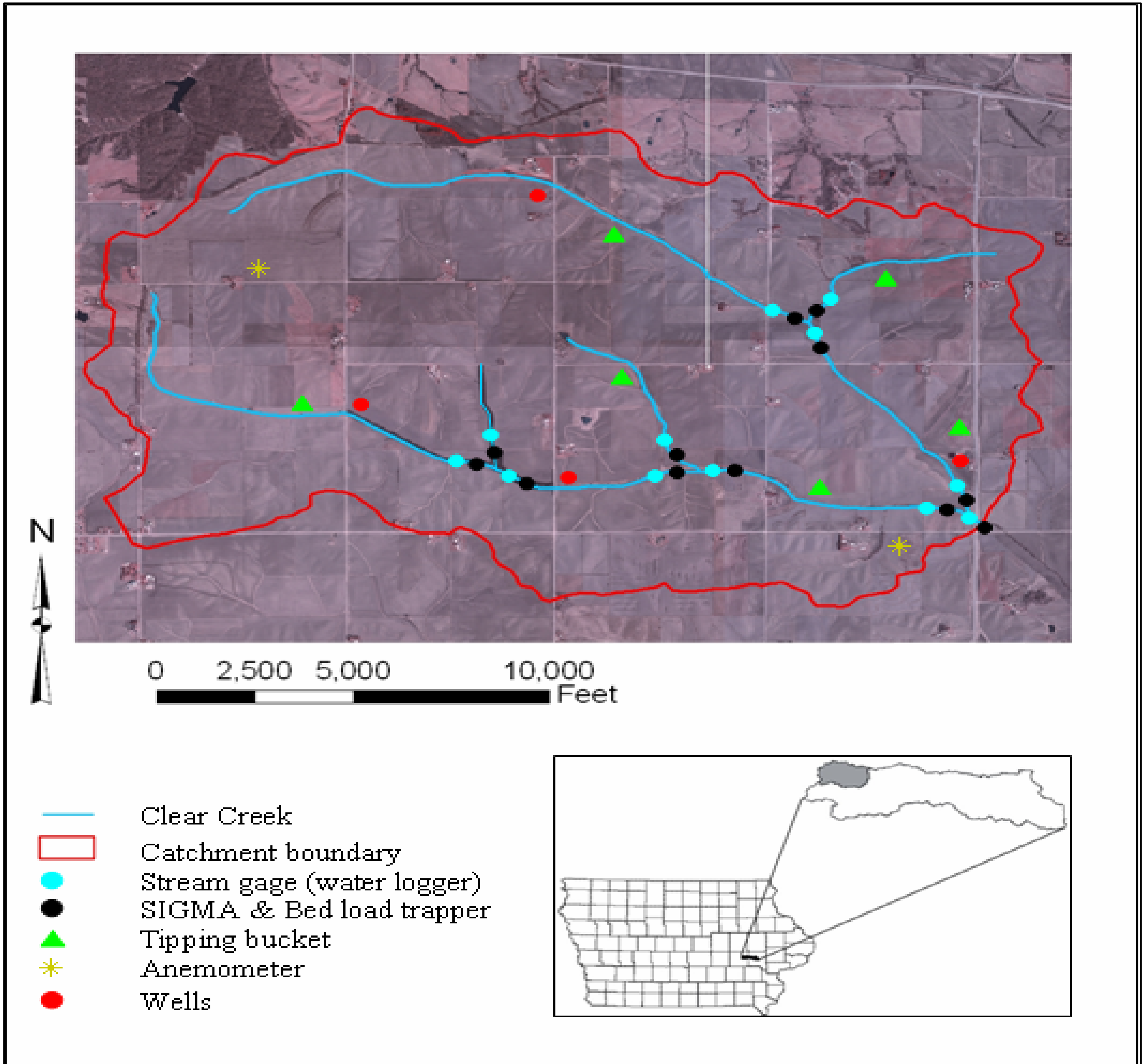
The Clear Creek Testbed, IA



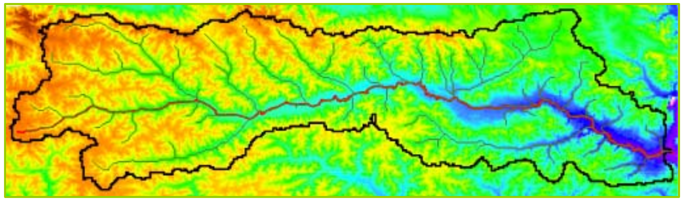

N
0
2,500
5,000
10,000
Feet
Clear Creek
Catchment boundary
Stream gage (water logger)
SIGMA & Bed load trapper
Tipping bucket
Anemometer
Wells

Clear Creek Digital Watershed

Data sources: third-party geo-physical measurements

DEM: National Elevation Dataset

Topography (10m and 30m resolution)



Hydrography: National Hydrography Dataset

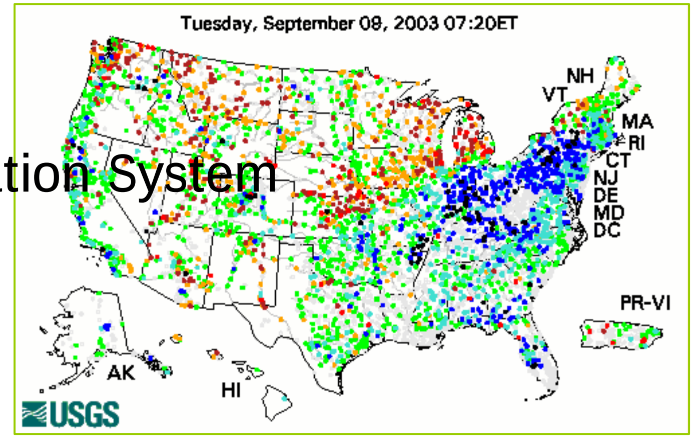
River networks for 8-digit HUC watersheds

Rainfall data: Iowa Environmental Mesonet & Nexrad NOAA

Rainfall estimates

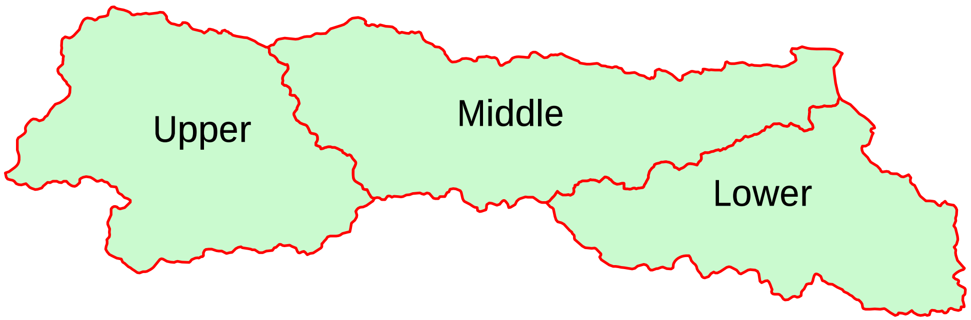
Stream data: National Water Information System

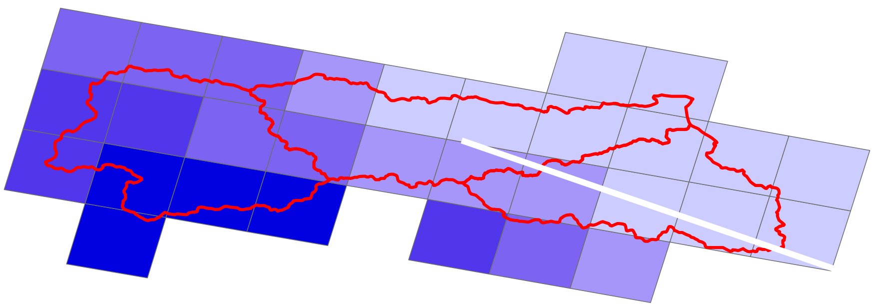
Discharges and stream gage locations

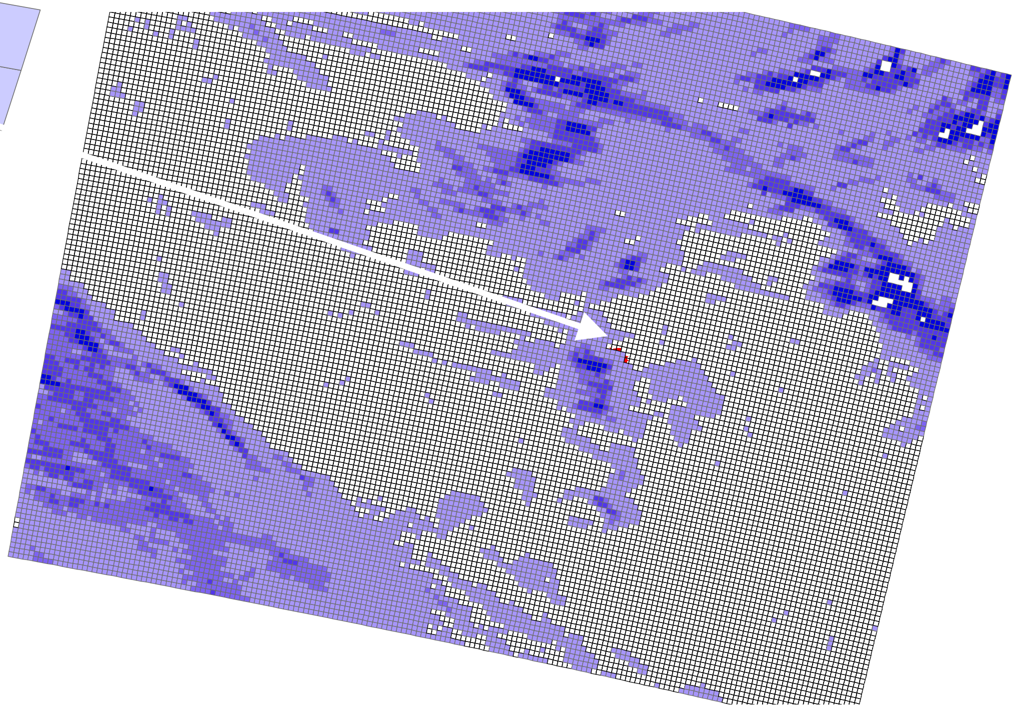


Clear Creek Digital Watershed

DW Application:
Rainfall from
NEXRAD







Data source 1: Iowa Mesonet (**daily**)

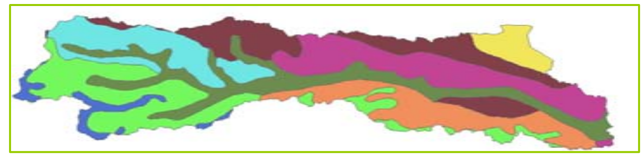
Data source 2: NOAA (**5 min)**

Clear Creek Digital Watershed

Data sources: third-party geo-bio-chemical measurements

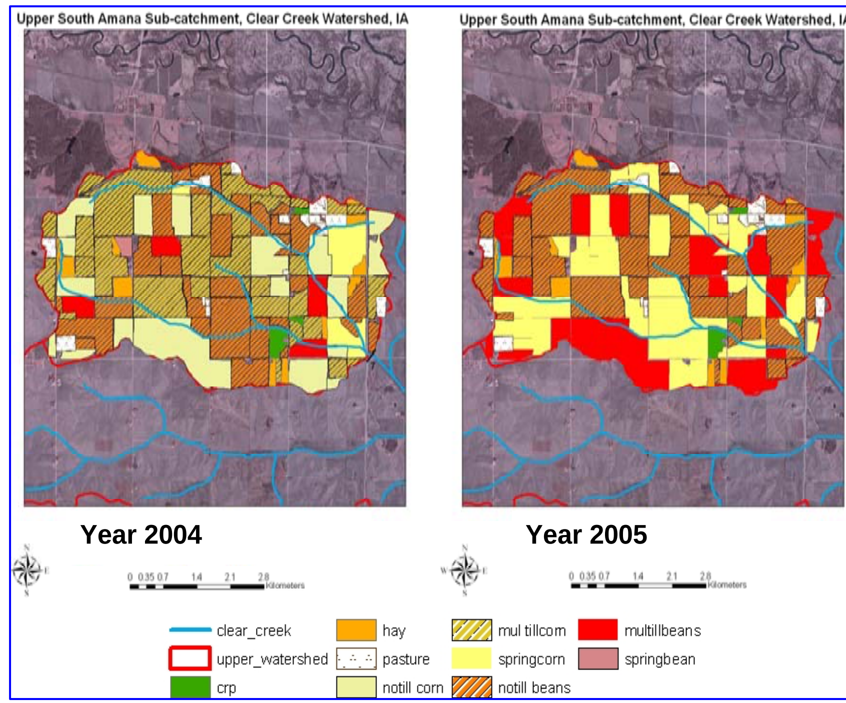
Soil type: STATSGO

- USDA-NRCS Soil Survey Division
- IDNR - Iowa Geological Survey (30-m grid)



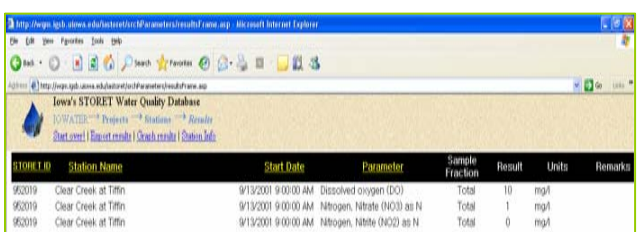
Land use/cover:

- National Land Cover Dataset
- USDA-NRCS office, Williamsburg (IA)



Water Quality:

- IowaStoret - DNR
- IowaWater



Iowa's STORET Water Quality Database

IOWATER → Projects → Stations → Results

Start over! | Export results | Graph results | Station Info

STORET ID	Station Name	Start Date	Parameter	Sample Fraction	Result	Units	Remarks
952019	Clear Creek at Tiffin	9/13/2001 9:00:00 AM	Dissolved oxygen (DO)	Total	10	mg/l	
952019	Clear Creek at Tiffin	9/13/2001 9:00:00 AM	Nitrogen, Nitrate (NO3) as N	Total	1	mg/l	
952019	Clear Creek at Tiffin	9/13/2001 9:00:00 AM	Nitrogen, Nitrite (NO2) as N	Total	0	mg/l	
952019	Clear Creek at Tiffin	9/13/2001 9:00:00 AM	pH	Total	8	None	

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Table : Crop Rotations in South Amana Catchment.

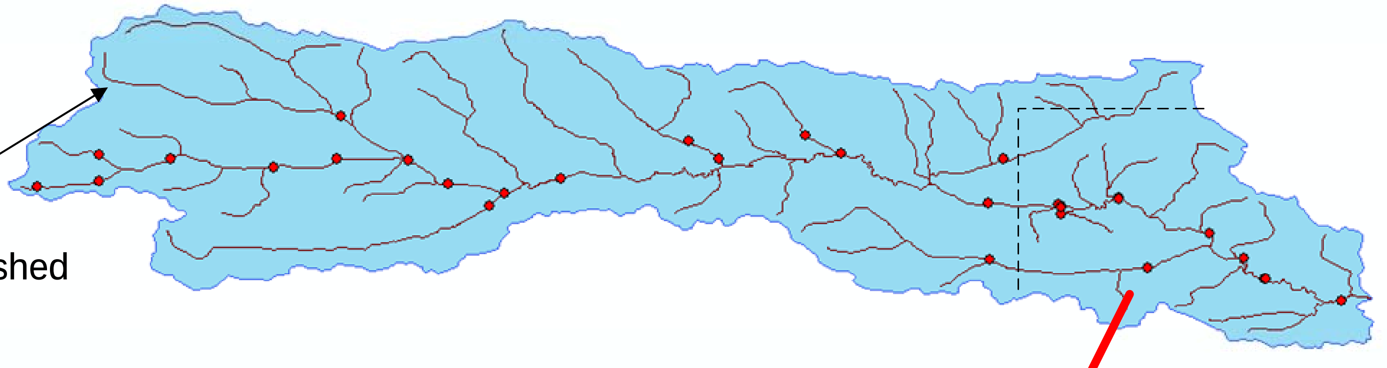
Rotation	Code	Areal Extent in Watershed
Fall Till Corn -> No-Till Bean	FTC-NTB	31.1 %
No-Till Bean -> Spring Till Corn	NTB-STC	25.1 %
No-Till Corn -> Fall Till Bean	NTC-FTB	22.8 %
Spring Till Corn -> No-Till Bean	STC-NTB	4.5 %
Fall Till Bean -> Spring Till Corn	FTB-STC	4.1 %

Clear Creek Digital Watershed

DW Application: Water Quality

Iowa Storet: **8** long-term stations and **24** newer stations (snap-shots)

Clear Creek Watershed



Station Name	*Station Number*
Clear Creek	**952024**
Clear Creek(down)	**952009**
Clear Creek(up)	**952008**
Clear Creek at Tiffin	**952019**
Clear Creek South Trib	948057
Clear Creek/Jasper Street(Tiffin)	**992002**

Measured Parameters

Dissolved oxygen (DO)	Temperature, water
Nitrogen, Nitrate (NO3)	Transparency
Nitrogen, Nitrite (NO2)	Water appearance
pH	Weather Comments
Phosphate	* *Precipitation*
Precipitation	* *Stream width measure*
Temperature, air	* *Flow*

* Not always available

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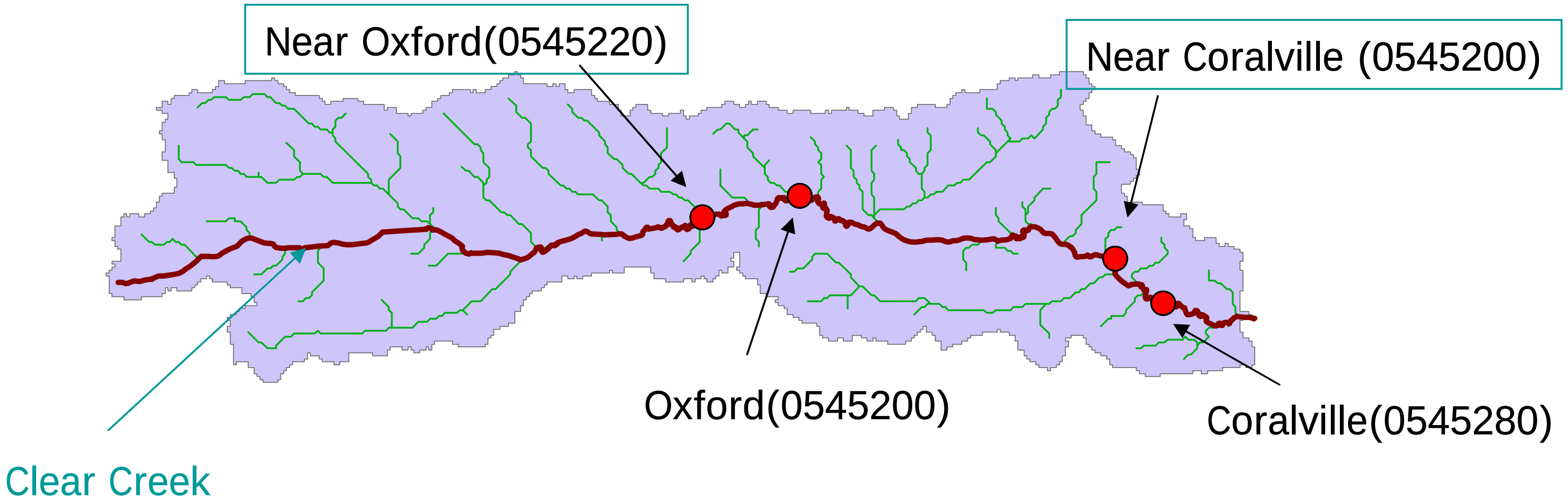
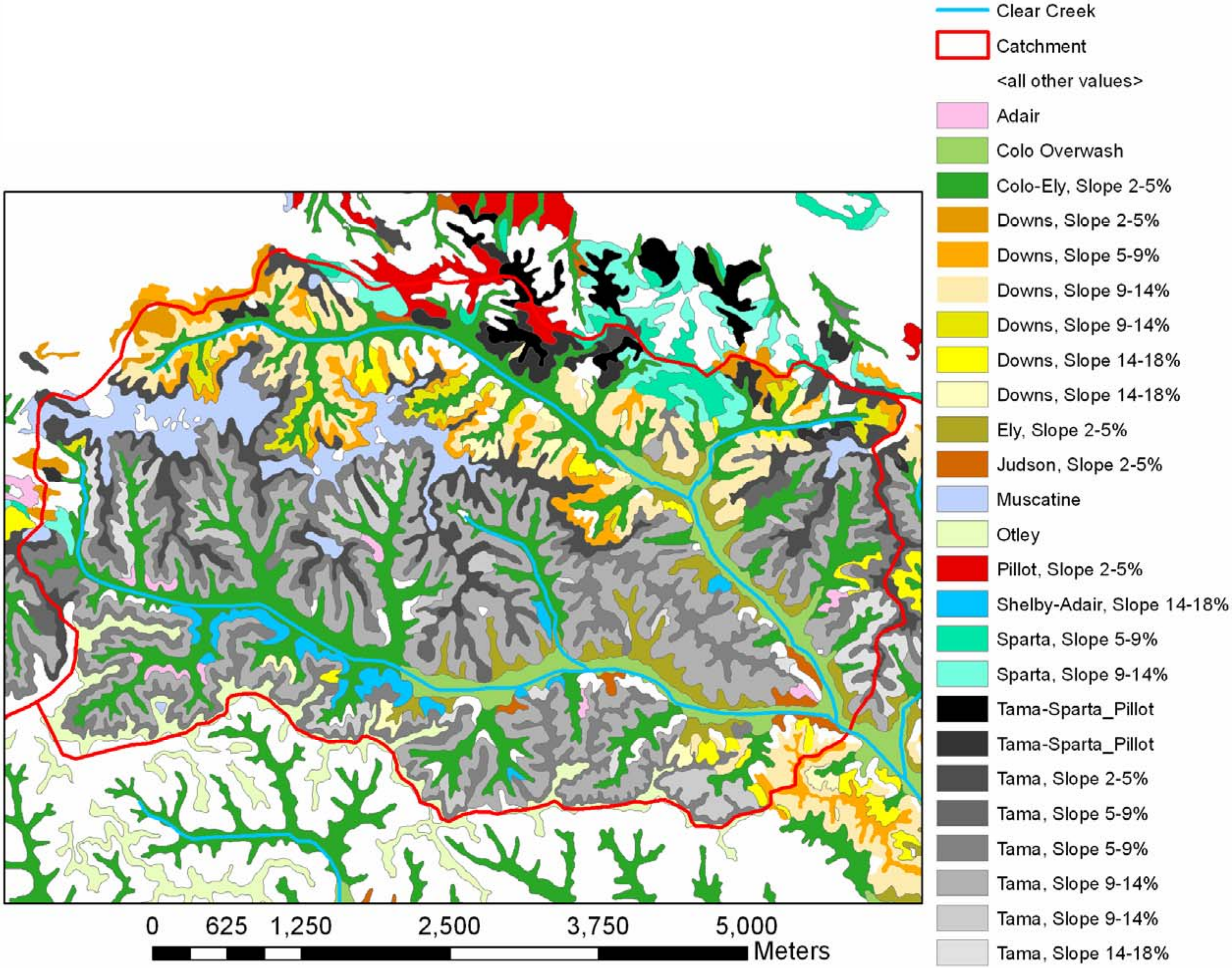
Clear Creek Digital Watershed

USGS Stream discharge network

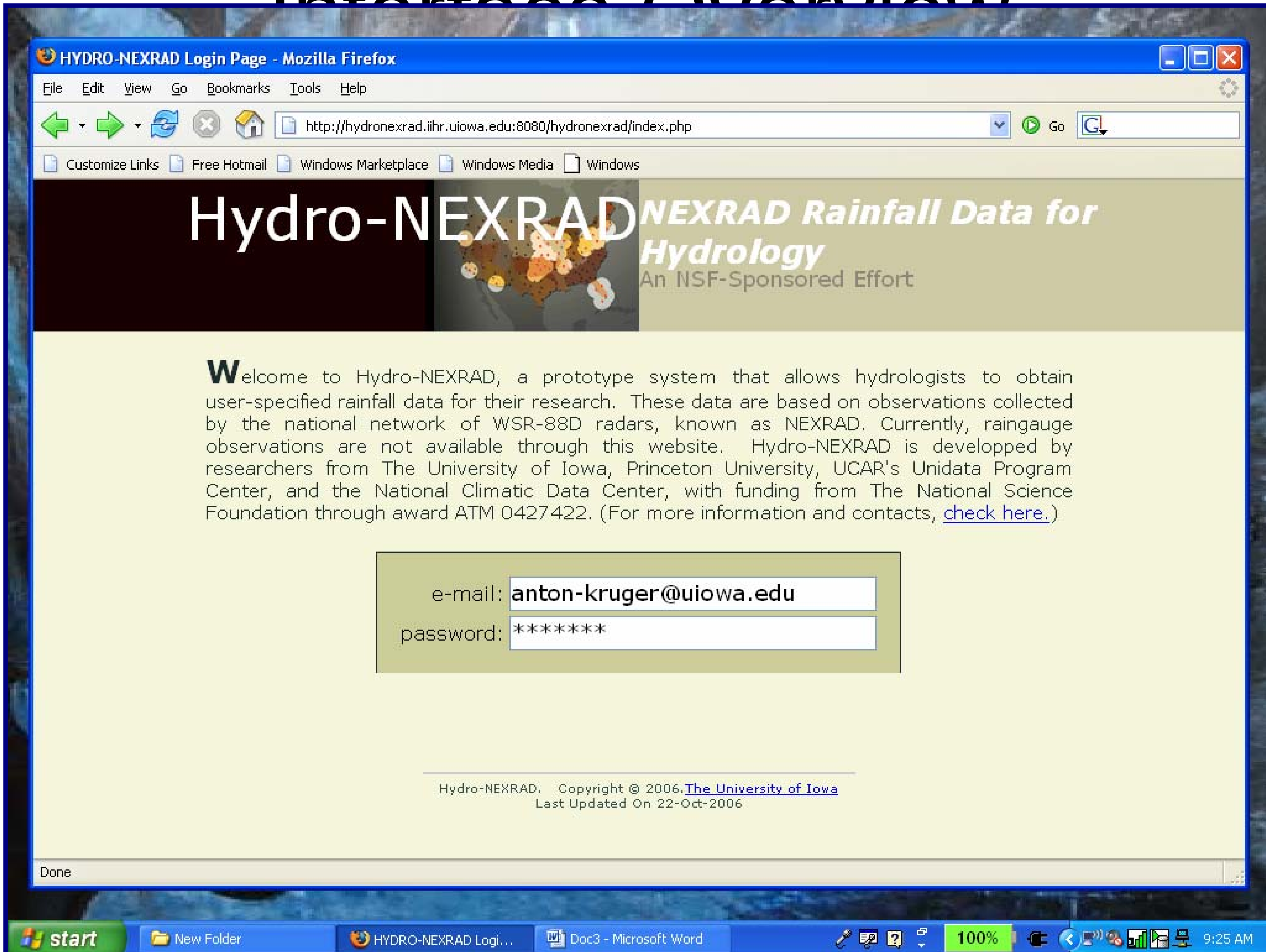


Instantaneous and daily discharges are acquired real-time from NWIS

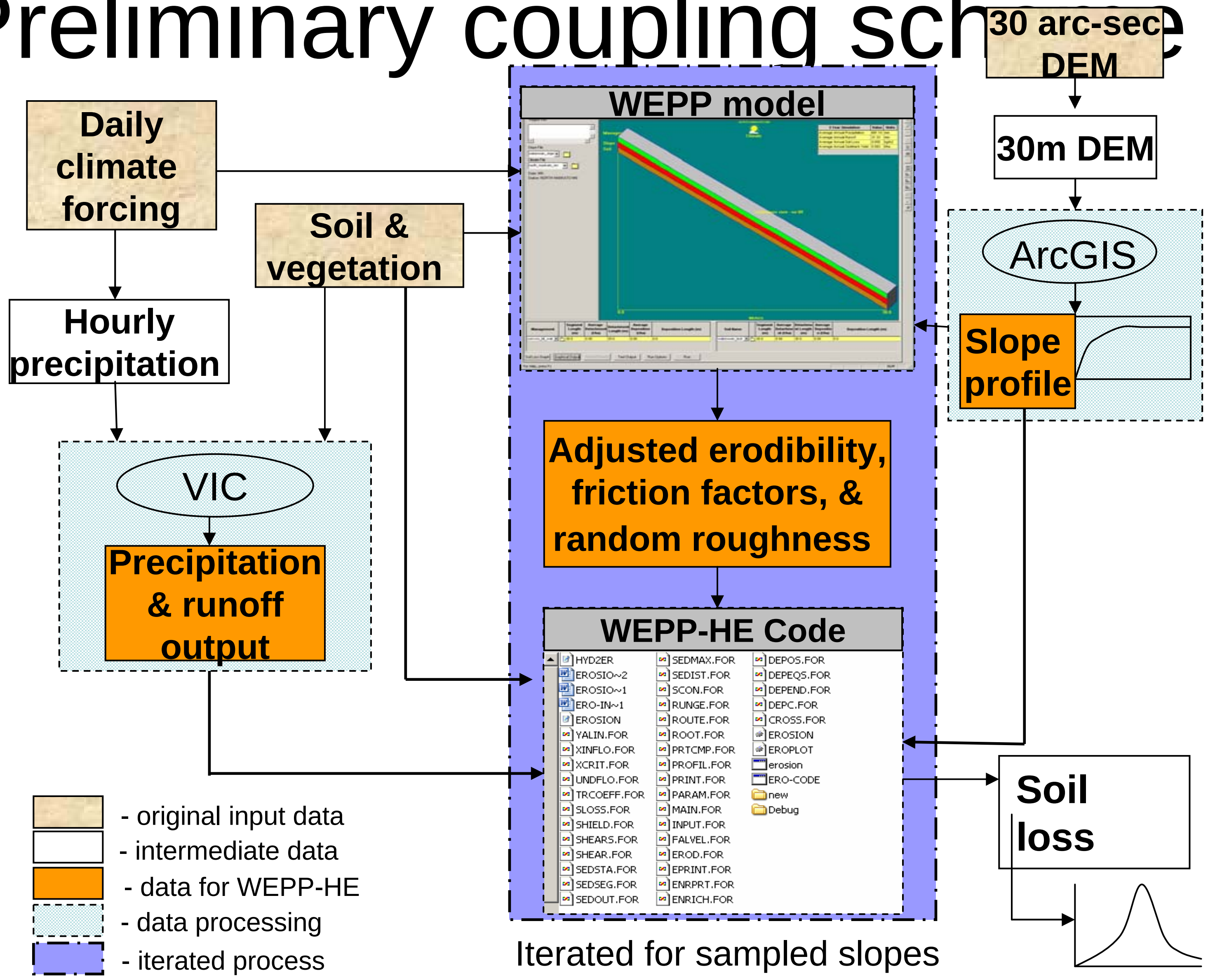
South Amana Soil Types – SoilView

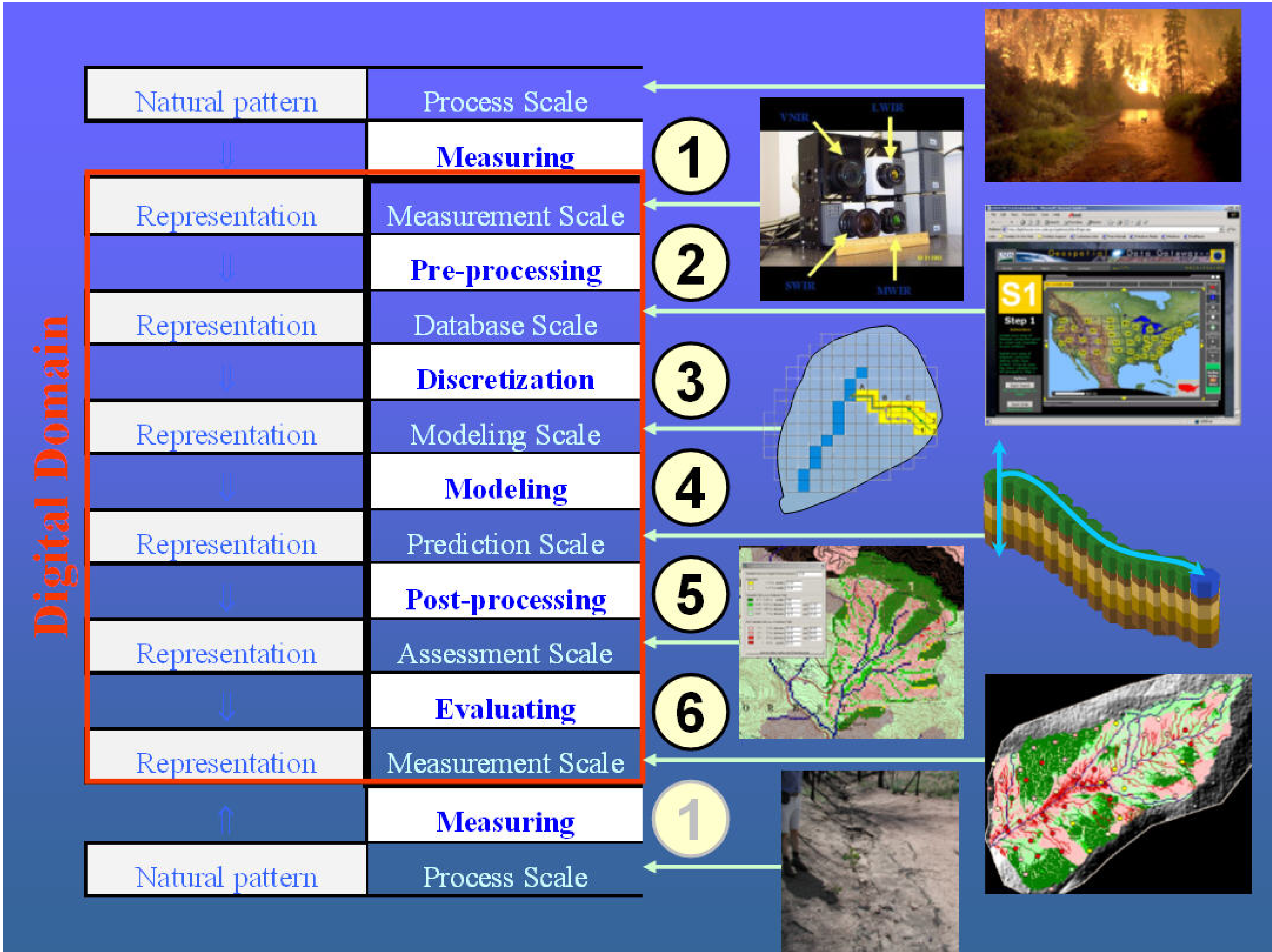


Interface Overview

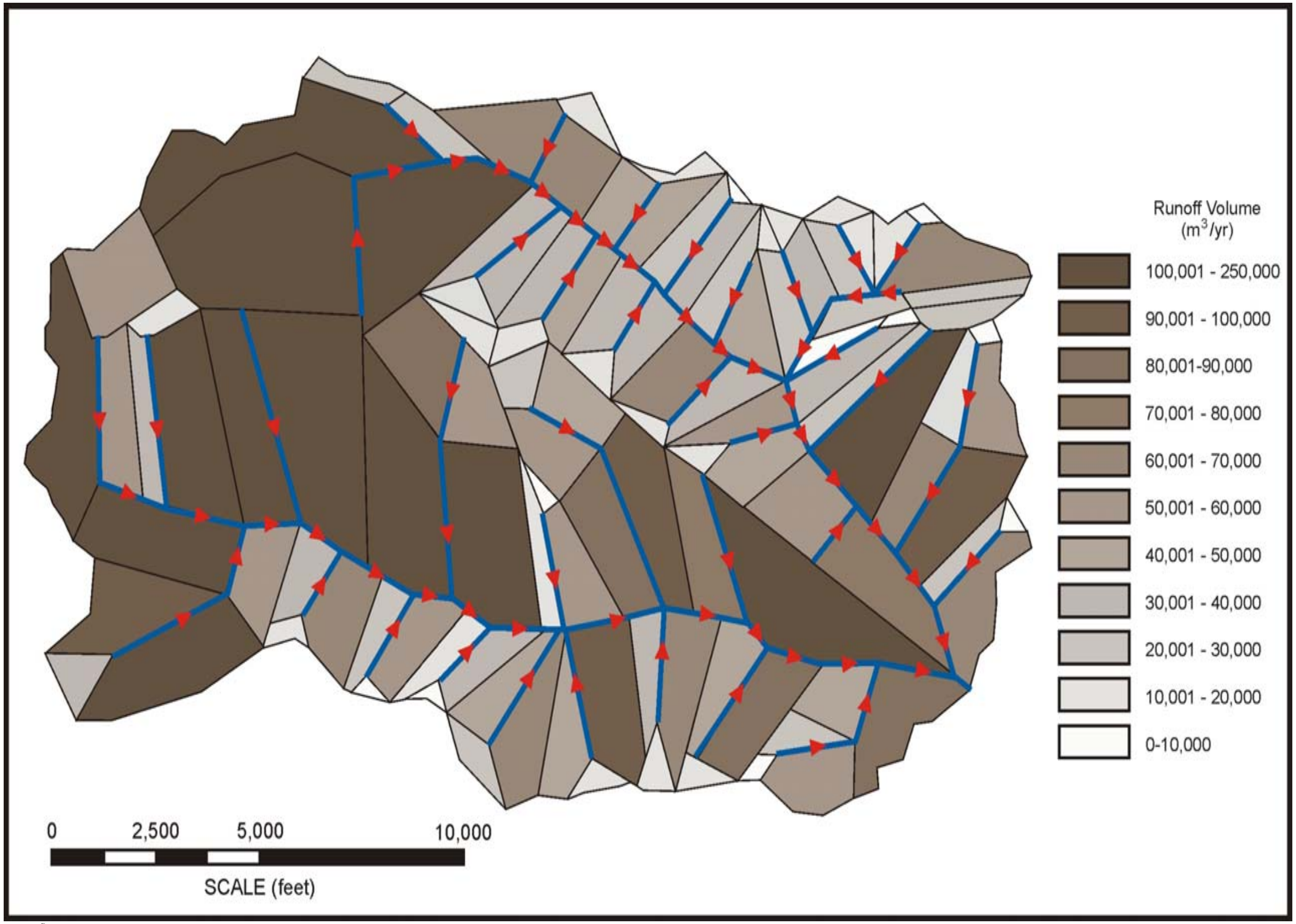


Preliminary coupling scheme




Digital Domain
Natural pattern
Process Scale
Measuring
1
Representation
Measurement Scale
Pre-processing
2
Representation
Database Scale
Discretization
3
Representation
Modeling Scale
Modeling
4
Representation
Prediction Scale
Post-processing
5
Representation
Assessment Scale
Evaluating
6
Representation
Measurement Scale
Measuring
1
Natural pattern
Process Scale
VNIR
LWIR
SWIR
MWIR
S1
Step 1

Hotspots



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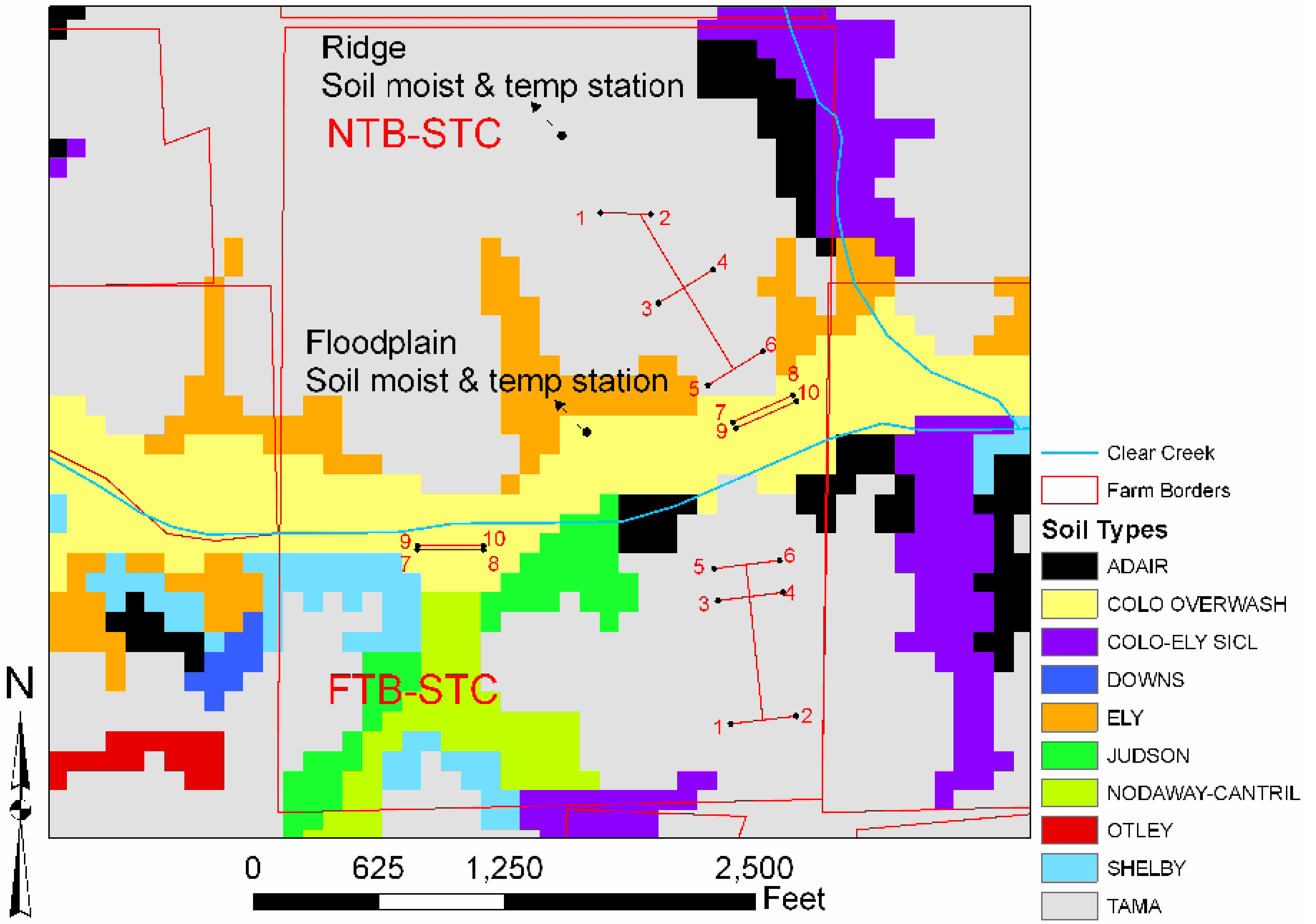
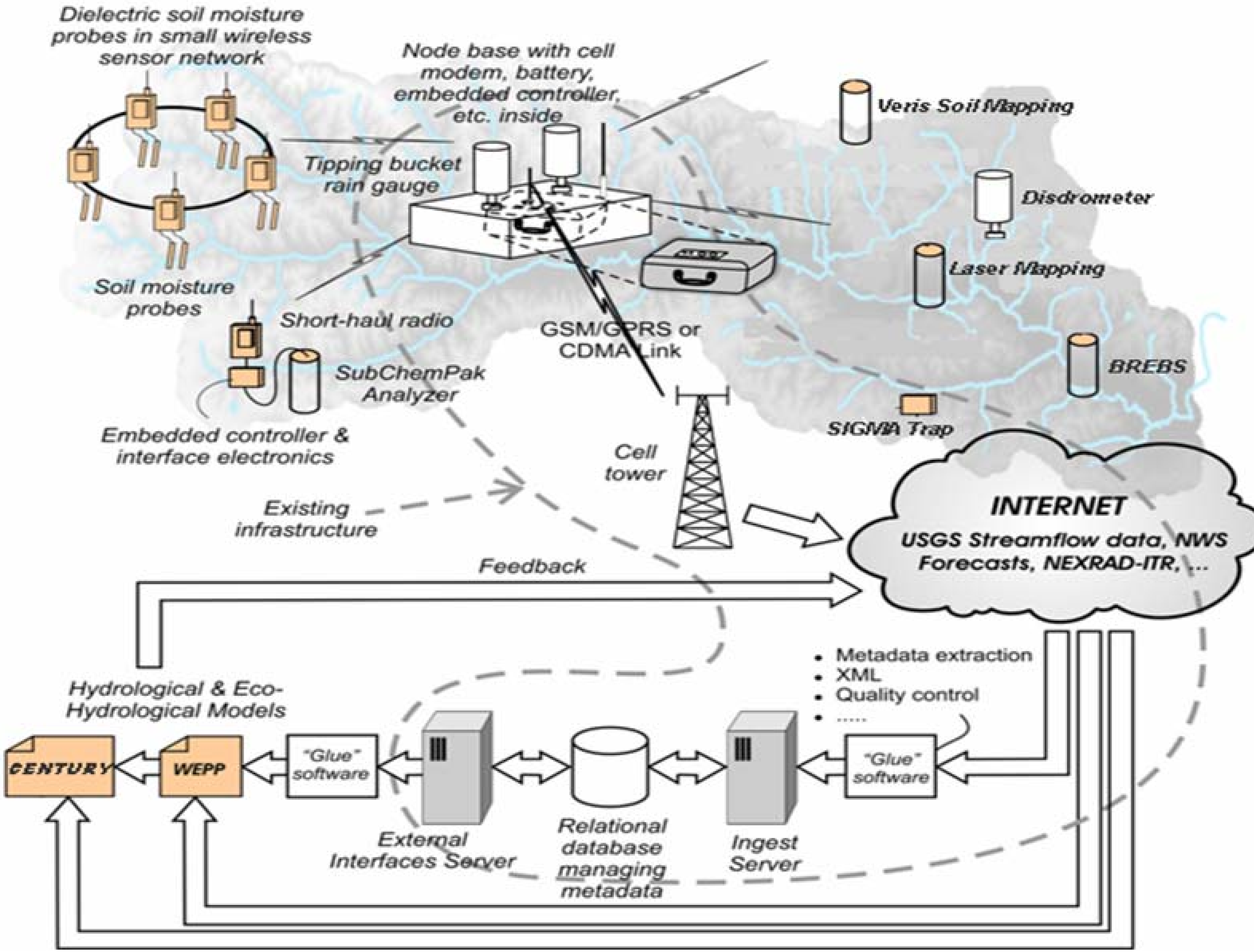
NTB-STC and FTB-STC Crop Rotations Sampling Locations



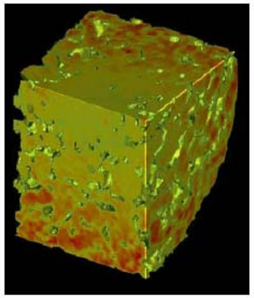


Dielectric soil moisture probes in small wireless sensor network
Node base with cell modem, battery, embedded controller, etc. inside
Veris Soil Mapping
Tipping bucket rain gauge
Disdrometer
Laser Mapping
Soil moisture probes
Short-haul radio
GSM/GPRS or CDMA Link
BREBS
SubChemPak Analyzer
SIGMA Trap
Embedded controller & interface electronics
Cell tower
Existing infrastructure
INTERNET
USGS Streamflow data, NWS Forecasts, NEXRAD-ITR, ...
Feedback
Metadata extraction
XML
Quality control
.....
Hydrological & Eco-Hydrological Models
CENTURY
WEPP
"Glue" software
External Interfaces Server
Relational database managing metadata
Ingest Server
"Glue" software

Clear Creek sensors

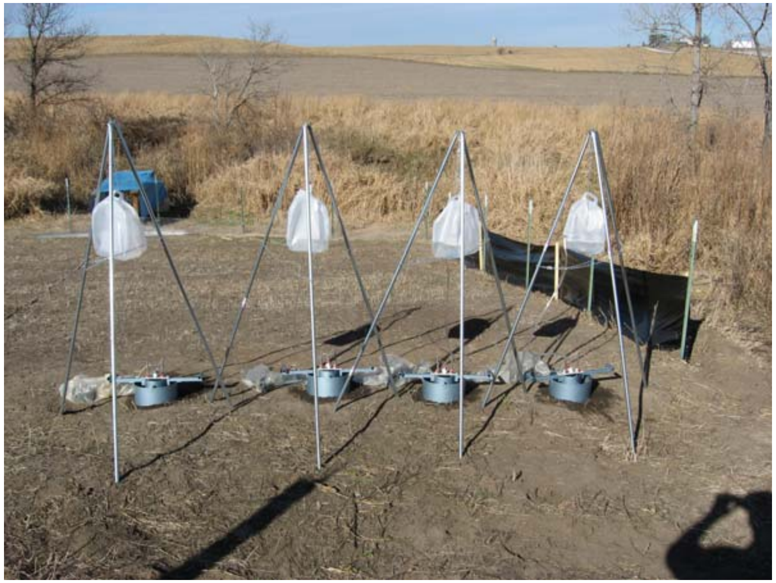
In-situ data collected with conventional and custom-built instruments & laboratory analysis (selection):

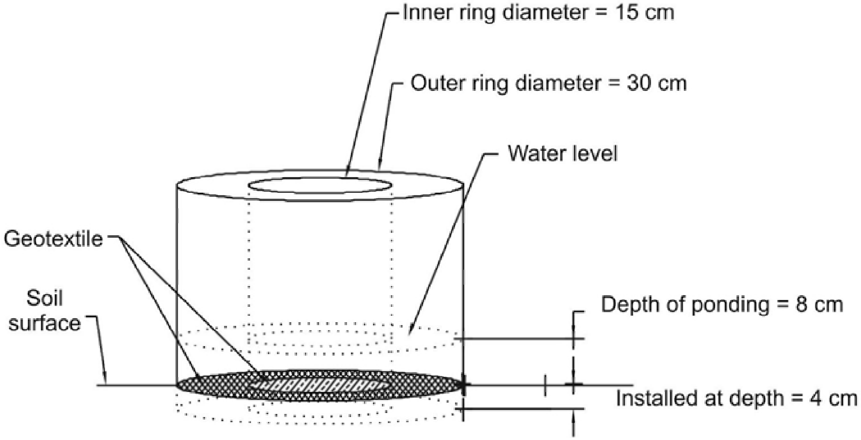
- Wireless sensor network for moisture and water quality data (Nitrates)
- Non-intrusive stream flow monitoring techniques (ADCP and LSPIV)
- Sources of sediment & pathways (stable isotope tracers & radionucleids)
- Rainfall (disdrometers, rain gages)
- Bed load and suspended sediment (ISCO, sedimeters)
- Permeability
- Hydraulic conductivity (via in-situ instrumentation and lab-based CT)
- Enrichment ratio
- Phosphorus (particulate and dissolved)

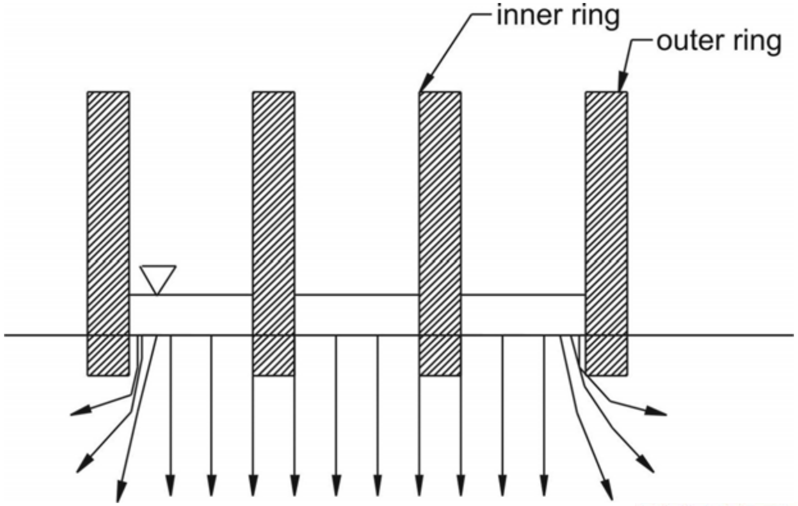


Ongoing Field Work

Double-ring infiltrometer







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Ongoing Field Work

Tensiometer & soil moisture probes

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Watershed Soil Characterization

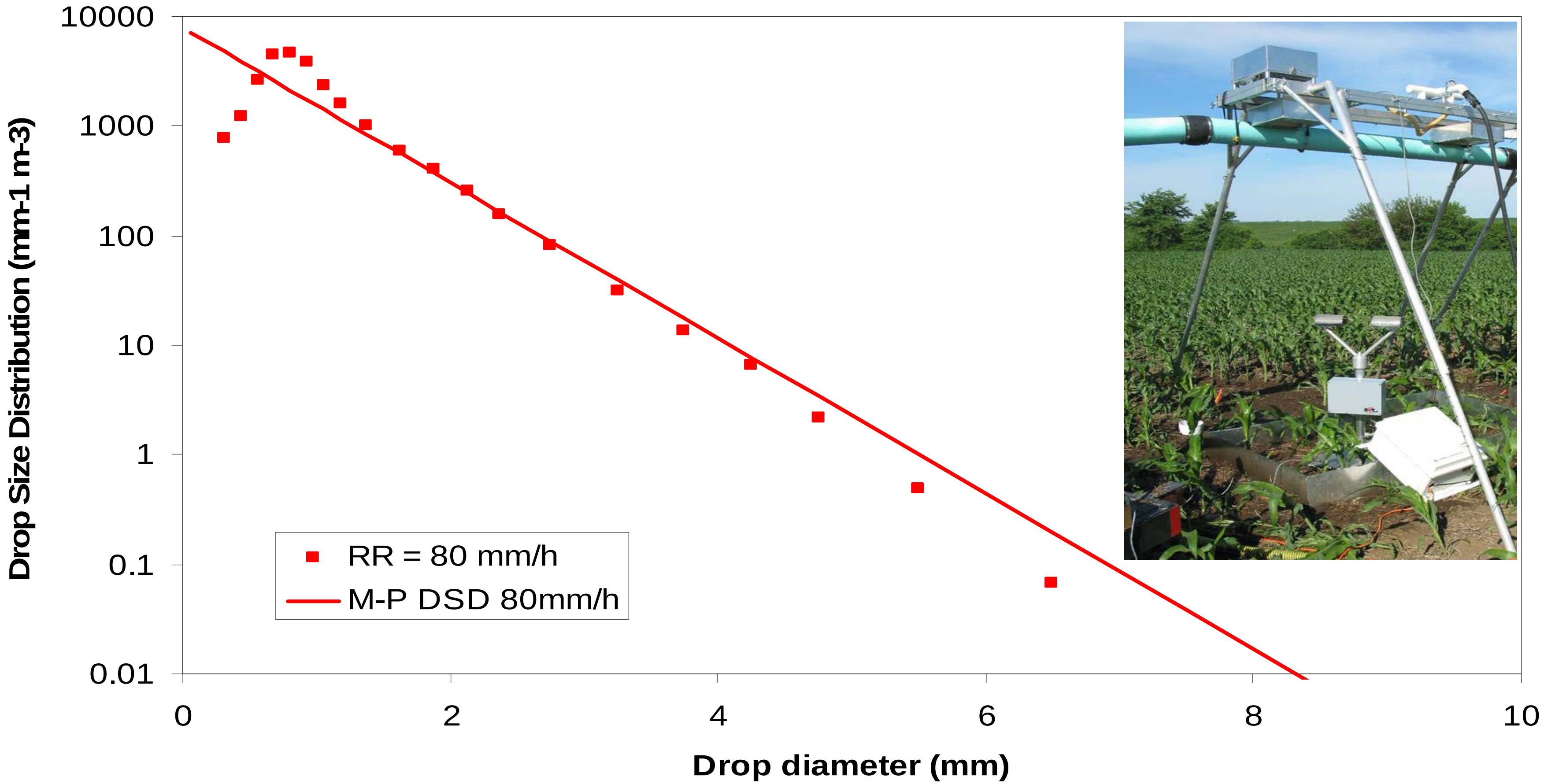
Property	Units	Corn	Soybean	CRP	Floodplain	Bank
Geological						
Silt	%	65.4	59.2	63.3	70.0	66.4
Clay	%	29.5	34.7	30.3	26.4	26.7
Sand	%	5.10	6.10	6.40	3.60	6.90
Water Content	%	21.5	20.0	25.36	16.1	18.35
Specific Gravity	---	2.56	2.73	2.46	2.54	2.50
Plastic Limit	%	26.70	27.00	24.20	32.35	24.36
Liquid Limit	%	36.34	38.07	38.59	47.00	37.68

Watershed Soil Characterization

Property	Units	Corn	Soybean	CRP	Floodplain	Bank
Chemical						
pH	---	7.70	7.75	6.05	6.45	6.95
Buffer pH	---	7.30	7.35	6.70	7.00	7.13
Exch. K	cmol/kg	0.749	0.639	0.431	1.154	0.248
Exch. Ca	cmol/kg	21.21	31.13	10.82	12.52	12.00
Exch. Mg	cmol/kg	3.63	3.26	2.18	3.36	2.98
Exch. Na	cmol/kg	0.07	0.10	0.05	0.03	0.04
Zn	g/kg	0.0021	0.004	0.0011	0.0052	0.0016
Fe	g/kg	0.070	0.098	0.116	0.140	0.088
Mn	g/kg	0.013	0.010	0.018	0.021	0.017

Watershed Soil Characterization

Property	Units	Corn	Soybean	CRP	Floodplain	Bank
Chemical						
Organic Matter	g/kg	43.55	54.85	53.85	74.70	30.52
Total C	g/kg	23.85	30.05	29.59	40.96	16.71
Total N	g/kg	2.061	1.964	2.672	3.496	1.638
NO_3-N	g/kg	0.0036	0.0022	0.0026	0.0027	0.0038
NH_4-N	g/kg	0.0013	0.0140	0.0040	0.0050	0.0080
CEC	cmol/kg	25.660	35.120	17.089	17.069	15.266
SAR	$\sqrt{}$(cmol/kg)	0.0191	0.0236	0.0205	0.0123	0.0135
Biological						
Photosynthetic Pathway	---	C4	C3	C3	---	---

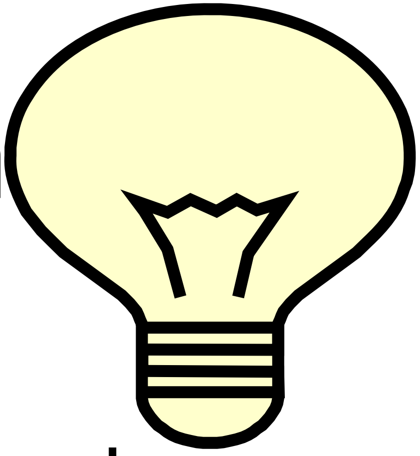


DSD Generated by the Rainfall Simulator

M-P=Marshall Palmer DSD

Fig. 3. Field measurements.

Hollistic approach



- Use geospatial tools and watershed models as a first step to identify the hotspots and address spatial/temporal variability.
- Perform continuous measurements using sensor technology at the hotspots to refine our existing understanding.
- Integration of point measurements using .

Ensembled averaging at the hillslope scale

$$\frac{\partial \langle h_r \rangle \langle c_{rl} \rangle}{\partial t} + \frac{\partial}{\partial x}\left[K_r(\langle r \rangle) \frac{\langle w_r \rangle^{1/2} \langle h_r \rangle^{3/2} \langle c_{rl} \rangle}{\left(\langle w_r \rangle + 2\langle h_r \rangle \right)^{1/2}} \right]$$

$$+ \frac{1}{2} \sum_i \sum_j \mathrm{cov}(r_i, r_j) \times \frac{\partial}{\partial x} \left\{ \frac{\partial^2}{\partial r_i \partial r_j} \left[K_r(r) \frac{\langle w_r \rangle^{1/2} \langle h_r \rangle^{3/2} \langle c_{rl} \rangle}{\left(\langle w_r \rangle + 2\langle h_r \rangle \right)^{1/2}} \right] \Bigg|_{r=\langle r \rangle} \right\}$$

$$= \langle D_{rl} \rangle + 2\rho_r \left(\frac{\pi}{2} \right)^{3/2} K_y(\langle r \rangle) \langle \bar{h}_o \rangle^{3/2} \langle c_{rl} \rangle + 2\rho_r \left(\frac{\pi}{2} \right)^{3/2}$$

$$\times \frac{1}{2} \sum_i \sum_j \mathrm{cov}(r_i, r_j) \frac{\partial^2}{\partial r_i \partial r_j} \left\{ K_y(r) \langle \bar{h}_o \rangle^{3/2} \langle c_{rl} \rangle \right\} \Bigg|_{r=\langle r \rangle}$$

Problem Statement and Background

A baseline effective conductivity, K_b, (mm/hr) is measured as function of the soil properties such as cation exchange capacity (CEC) and clay content (Onstad et al. 1984):

For clay content ≤ 40%

$$K_b = -0.265 + 0.0086\,(100\,sand)^{1.8} + 11.46\,CEC^{-0.75} \text{-------}(1a)$$

For clay content > 40%

$$K_b = 0.0066\,e^{(2.44/clay)} \text{--------}(1b)$$

where K_b is the baseline effective hydraulic conductivity, sand and clay are the fractions (%) of sand and clay, and CEC (meq/100g) is the cation exchange capacity of the soil.

Problem Statement and Background

If K_{bare} (mm/hr) denotes the effective conductivity for any given event, then K_{bare} is given by the following relation:

$$K_{bare} = K_b \left[CF + (1 - CF) e^{-C.E_e(1 - RR_t / 0.04)} \right] - - - - - - - - - -(2)$$

where K_b is the baseline hydraulic conductivity (mm/hr), CF is the crust factor which ranges from 0.2 to 1.0, C is the soil stability factor (m^2/J), Ea is the cumulative kinetic energy of the rainfall since the last tillage operation (J/m^2), and RR_t is the random roughness of soil surface (m).

Problem Statement and Background

Because the canopy cover and plant root density affect the path of flowing water in a hillslope, the effective conductivity of the bare area, K_{bare} , is corrected for the percentage of the plot that is covered by vegetation (Kidwell et al. 1997):

$$K_e = K_{bare} (1-scovef) + (c\ rain\ scovef) \text{ ----------- } (3)$$

where K_e denotes the effective conductivity of the covered area (mm/hr), c is a regression coefficient and rain is the storm rainfall amount (mm). This equation assumes that K_e for any given area can be conceptualized as the area-weighted average of K_{bare} and K_e in the covered area. For the fallow case, above eqn. reduces to $K_e = K_{bare}$

CN & K_{ef} Relationships

Hydrologic Soil Group	Formula
A	K_{ef} = 14.18
B	K_{ef} = 1.17 + 0.072 x %sand
C	K_{ef} = 0.50 + 0.032 x %sand
D	K_{ef} = 0.34

Table 1. Relationships for calculating curve number optimized Green and Ampt Effective Conductivity for fallow conditions, Kef (=1/2 Ksat)

K_e for the cropped conditions is related to the curve number by the equation

$$K_e = \frac{56.82 K_{ef}^{0.286}}{1 + 0.051 e^{0.062 CN}} - 2$$

where K_{ef} is the effective conductivity for fallow conditions and CN is curve number.

Outlook for the Holistic Approach

- **Advanced specialized cyber-tools and methods** (sensors, sensing networks, numerical and data models) are increasingly available, and sufficiently developed to aid **quantifiable understanding of the watershed processes** and their interactions with the bio-geo-chemical and socio-economical activities dependent on them.

- **Parallel advances** in high-performance computing, communication technologies, GIS along with innovative statistical, data-driven, and knowledge discovery models, **enable characterization of physical-biochemical habitat with increased spatial resolution over large-scale areas**.

- Collectively, these advances facilitate **adoption of a "information-centric" investigative and management approaches** enabling to understand and predict watershed ecosystem changes, protect the environment, and prevent natural and human disasters through knowledge-based adaptive management.

- The time is ripe for **WM and WS communities to coordinate and synergistically integrate their efforts** in a long-term, mutual-gain collaboration

Field Site and In-situ Instrumentation

Figure 6 (a) An Amoozemeter (side view).

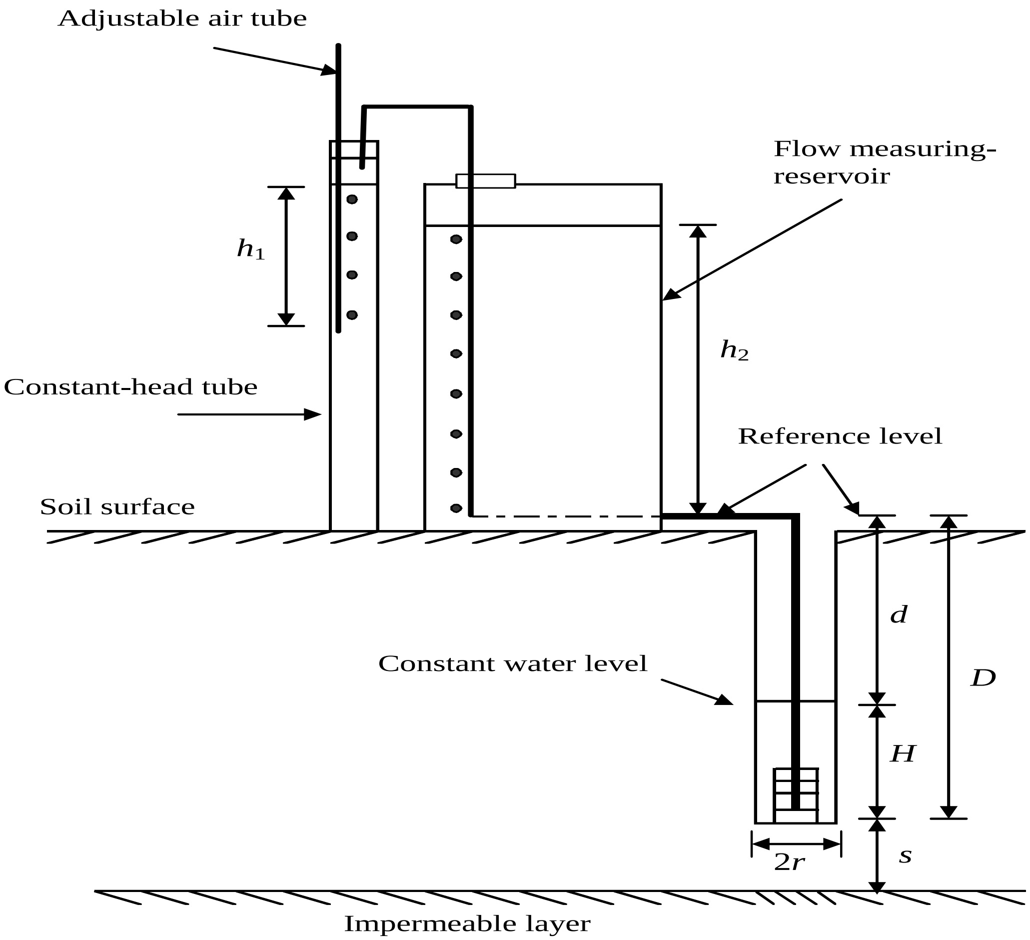
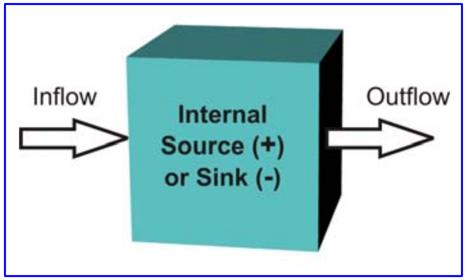


Figure 6 (b) The Amoozemeter method for determining K_{sat}

Water Cycle (including internal & external interactions)

Critical issues

- Watershed water balance



- Water pathways, residence times, vertical and horizontal fluxes over a variety of spatial-temporal scales
- Water cycle interaction and feedback with chemical reactions, microbial activity, food chains, ecological evolution, and human land and water choices