Field Measurement and Model Prediction of Saturated Hydraulic Conductivity at the Hillslope Scale under different Soil Series and Management Practices

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INTRODUCTION

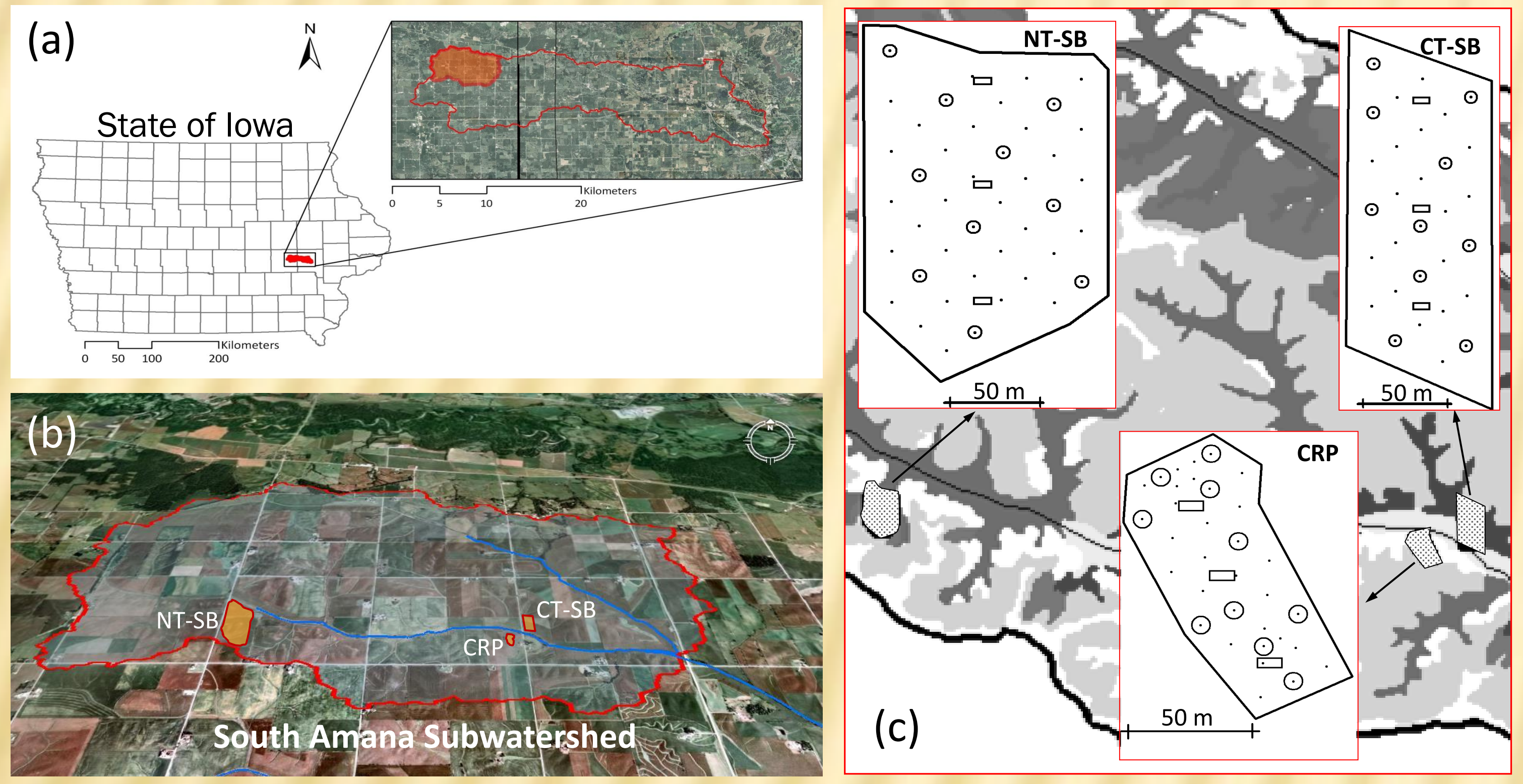
When infiltration rate reaches the steady state condition, it is defined as the saturated hydraulic conductivity, K_{sat}. K_{sat} is a key variable in the hydropedologic studies determining soil suitability for agricultural uses, water relationships for plant growth, and potentials for pesticide leaching. In addition, K_{sat} directly influences the amount of runoff and eroded surface soil that are delivered to local waterways, thereby affecting both in-field soil quality and in-stream water quality. Therefore, accurately measure and estimate of K_{sat} is of paramount importance when predicting hydrologically-driven processes or making catena assessments in landscapes.

OBJECTIVES

The main objective of the proposed research study is to introduce an innovative and versatile method to make adequate dynamic K_{sat} predictions at large scales (e.g., watershed, township, county, state, etc.). This method will involve in-situ measurements, and the use of watershed models and pedotransfer functions (PTFs) coupled with geospatial tools and satellite data. The proposed method will be complemented with field data for calibration and verification.

SITE DESCRIPTION

Heterogeneity of K_{sat} was investigated at the three fields in the South Amana Subwatershed (SAS), which is a subbasin of the Clear Creek Watershed. Three fields of different soil series, and management practices (tilled, no-till, CRP) were examined at SAS.



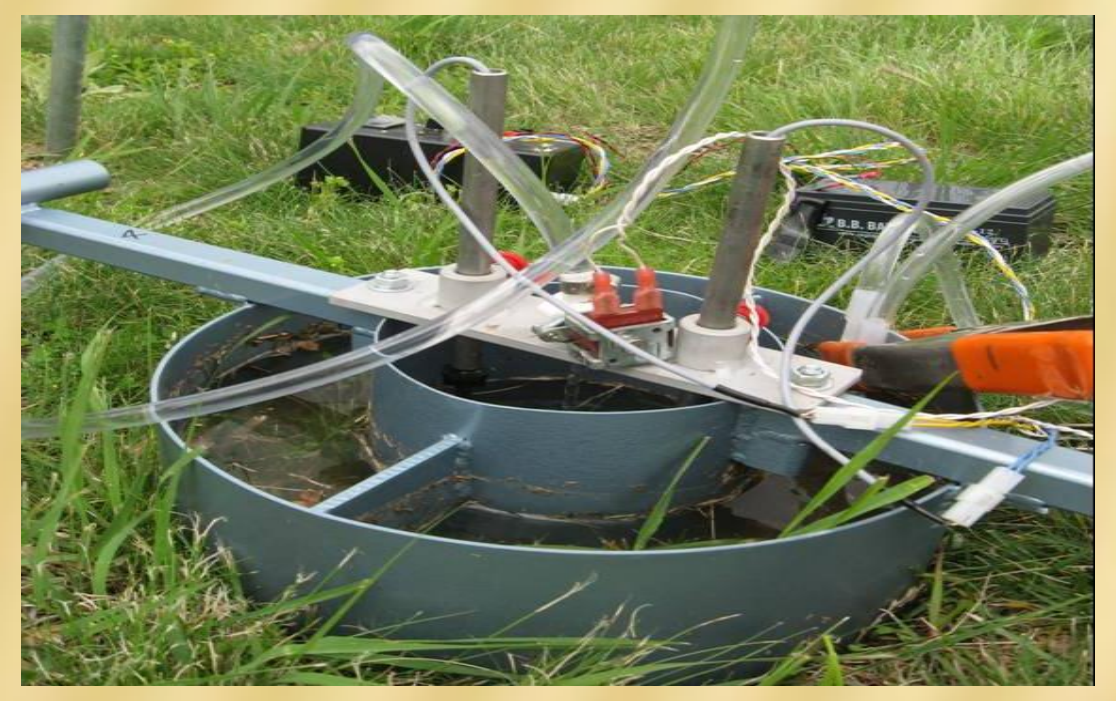
(a) Location of the South Amana Subwatershed (SAS); (b) the three sites of in-situ measurements in SAS; (c) the measurement points.

METHODOLOGY

The methodological steps needed to accomplish the study objectives include:

I. In-situ Measurements

The performance of field measurements using automated Double Ring Infiltrometers (DRIs) for model calibration.



Double ring infiltrometer (DRI)

Complete set of DRI

DRI field setup

Sample Collecting

Sampling location

Soil characterization

II-a. Selection of PTFs (Regression relations of K_{sat} with soil properties) and watershed models

Integration of the PTFs and watershed models with the geospatial tools to develop a physically-based, modeling framework within which different geographic, climatic, and land uses satellite data can be incorporated.

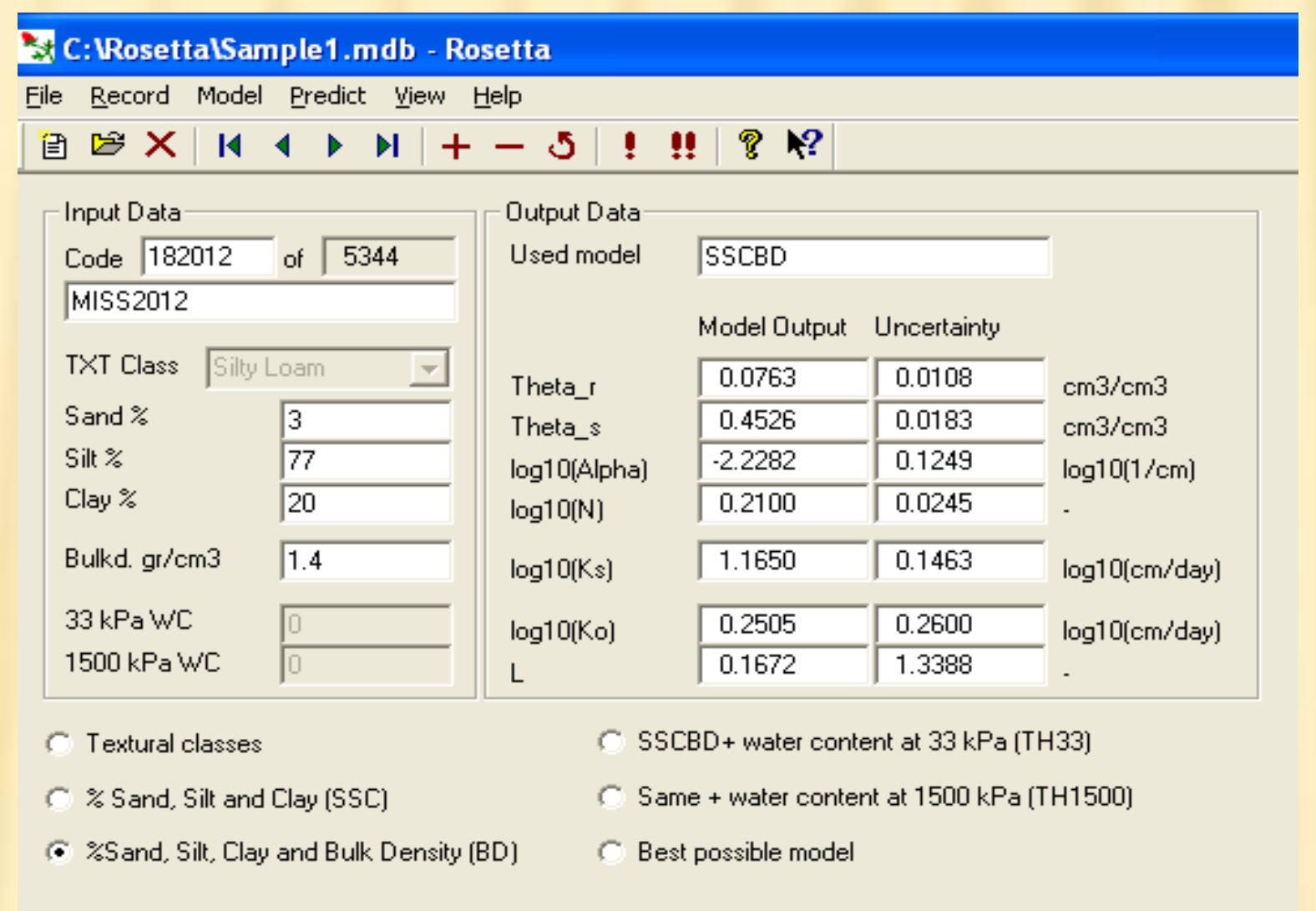
An example of PTFs: Cosby et al. (1984): $K_{sat} = 7.05556 \times 10^{-6} \times 10^{[-0.6 + 0.0126\,(\%Sand) - 0.0064\,(\%Clay)]}$

	Criterion*	HM	Min.	Max.	AIC	RMSE	GMER	GSDER	Total	Overall performance in %
PTFs	Cosby et al. (1984)	0.8	0.82	0.18	0.85	0.89	0.6	0.71	4.85	69
	Brakensiek et al. (1984)	0.87	0.98	0.42	0.54	0.68	0.36	0.71	4.56	65
	Saxton et al. (1986)	0.85	0.97	0.4	0.51	0.66	0.39	0.72	4.5	64
	Rawls and Brakensiek (1985)	0.32	0.72	0.23	0.96	0.95	0.89	0.86	4.93	70
	Jabro (1992)	0.73	0.94	0.08	0.21	0.15	0.1	0.65	2.86	41
	Dane and Puckett (1994)	0.51	0.68	0.37	0.93	0.93	0.83	0.78	5.03	72
	Campbell and Shiozawa (1994)	0.74	0.91	0.03	0.12	0.10	0.02	0.53	2.45	35
	Risse et al. (1995)	0.85	0.92	0.12	0.33	0.42	0.09	0.50	3.23	46
	Wosten et al. (1999)	0.83	0.91	0.42	0.66	0.81	0.61	0.55	4.79	68
	ROSETTA with BD - Schaap (1999)	**0.59**	**0.83**	**0.79**	**0.79**	**0.91**	**0.93**	**0.76**	**5.6**	**80**
	ROSETTA - Schaap (1999)	0.91	0.72	0.17	0.73	0.88	0.67	0.78	4.86	69
Watershed model	KINEROS (Smith et al., 1995)	0.67	0.53	0.18	0.88	0.88	0.58	0.69	4.41	63
	MIKE-SHE (Refsgaard and Storm, 1995)	0.86	0.89	0.40	0.56	0.67	0.78	0.69	4.85	69
	WEPP (Nearing et al., 1996)	**0.86**	**0.98**	**0.38**	**0.99**	**0.97**	**0.92**	**0.84**	**5.94**	**85**
	GSSHA (Downer and Ogden, 2002)	0.35	0.89	0.28	0.88	0.88	0.58	0.69	4.55	65

*HM = the harmonic mean, AIC = the Akaike Information Criterion, RMSE = the root mean square error, GMER = the geometric mean error ratio, GSDER = the geometric standard deviation of the error ratio.

II-b. Models: Rosetta and WEPP

Rosetta: Neural network analysis provides more accurate predictions when more input variables are used. Soil textures and bulk density are provided through the Soil Survey Geographic (SSURGO) Database.



Input Data
Code 182012 of 5344
MISS2012
TXT Class Silty Loam
Sand % 3
Silt % 77
Clay % 20
Bulkd. gr/cm3 1.4
33 kPa WC 0
1500 kPa WC 0

Output Data
Used model SSCBD

	Model Output	Uncertainty	
Theta_r	0.0763	0.0108	cm3/cm3
Theta_s	0.4526	0.0183	cm3/cm3
log10(Alpha)	-2.2282	0.1249	log10(1/cm)
log10(N)	0.2100	0.0245	-
log10(Ks)	1.1650	0.1463	log10(cm/day)
log10(Ko)	0.2505	0.2600	log10(cm/day)
L	0.1672	1.3388	-

○ Textural classes
○ % Sand, Silt and Clay (SSC)
● %Sand, Silt, Clay and Bulk Density (BD)
○ SSCBD+ water content at 33 kPa (TH33)
○ Same + water content at 1500 kPa (TH1500)
○ Best possible model

Interface of Rosetta (USDA)

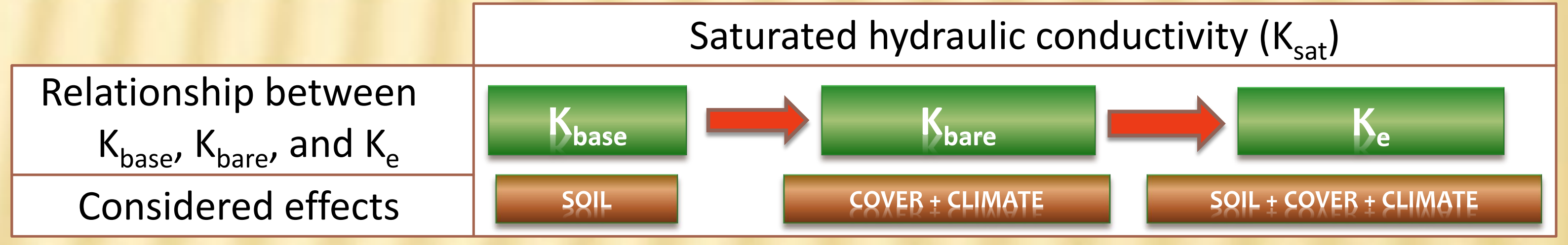
WEPP: Risse (1994) improved the accuracy of the prediction by considering the effect of dynamic natural parameters, such as field crust, rainfall depth and kinetic energy, and management practices. The climate data was collected from Iowa Environmental Mesonet (IEM).

$$K_{bare}=K_{base}\,[CF+(1-CF)e^{-C\cdot Ea(1-RRt/0.04)}]$$

K_{base}= baseline hydraulic conductivity, K_{bare}= K_{base} after adjustment for crusting and tillage, *CF*= crust factor, *C*= soil stability factor, E_a= cumulative rainfall kinetic energy since the last tillage, and *RRt*= random roughness

$$K_e=K_{bare}(1-scovef)+(0.0534+0.01179K_{base})(rain)(scovef)$$

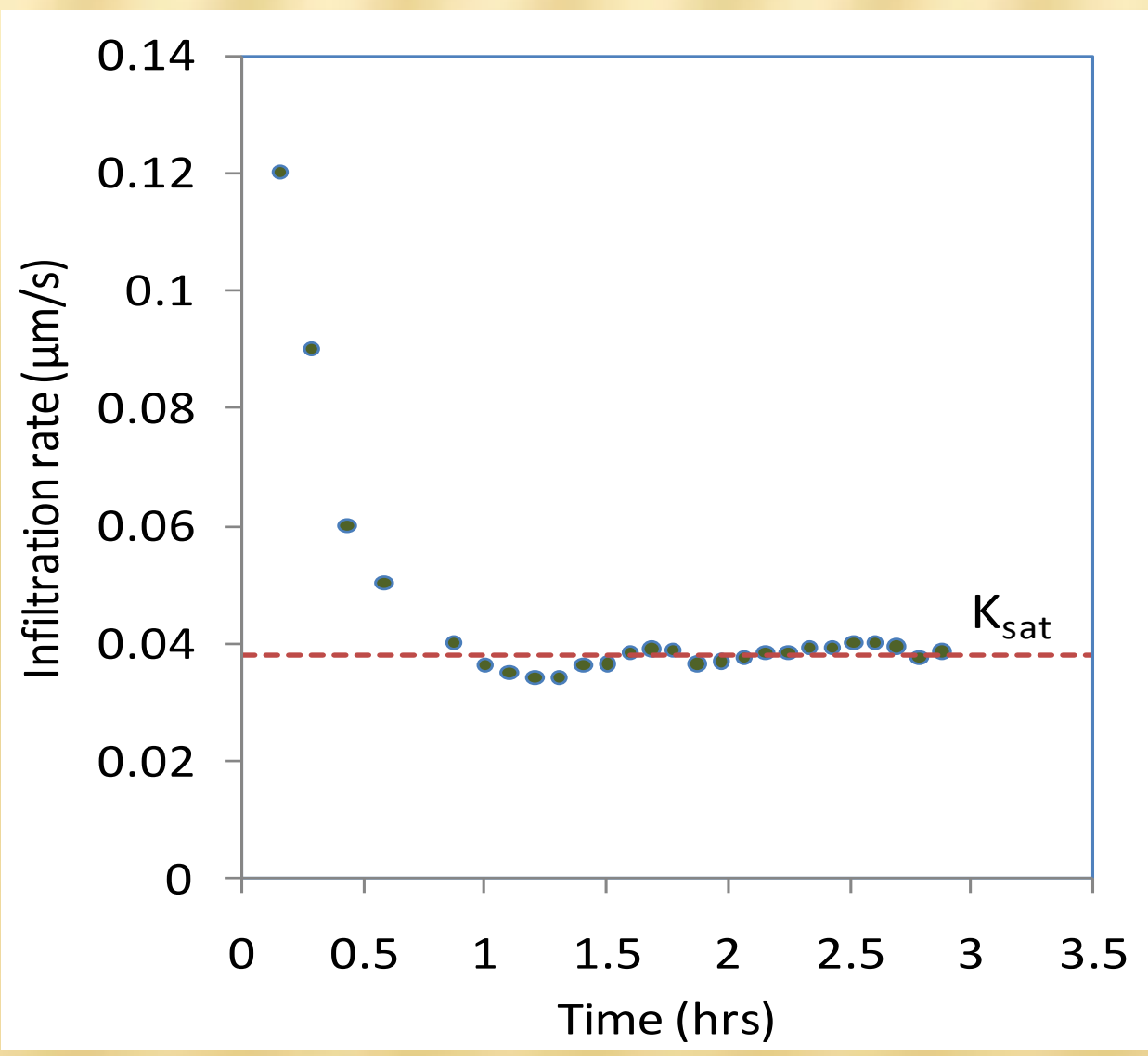
K_e= effective hydraulic conductivity in fill layer, *scovef*= total effective surface cover factor, *and rain*= storm rainfall amount.



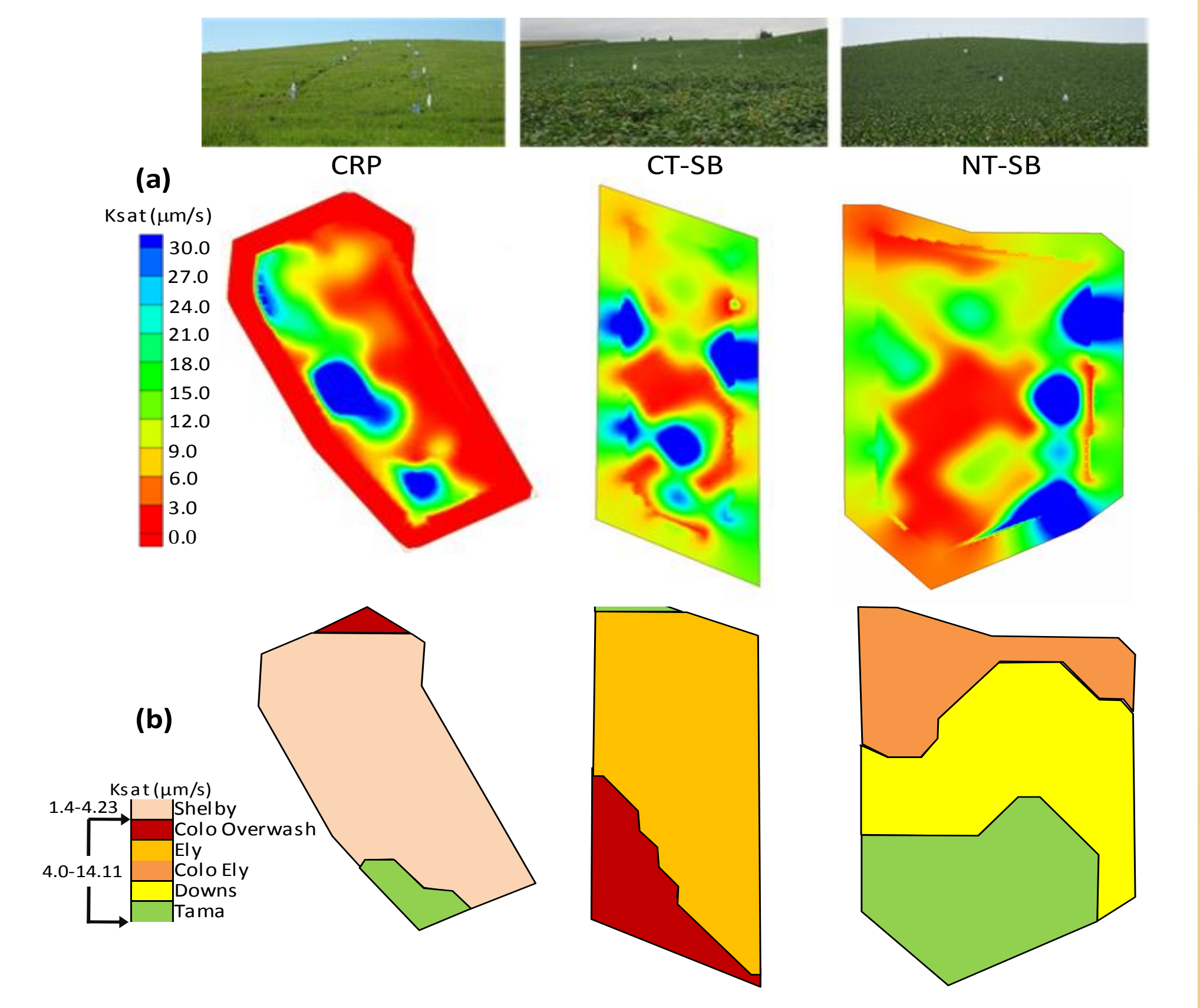
	Saturated hydraulic conductivity (K_{sat})		
Relationship between K_{base}, K_{bare}, and K_e	K_{base} →	K_{bare} →	K_e
Considered effects	SOIL	COVER + CLIMATE	SOIL + COVER + CLIMATE

RESULTS

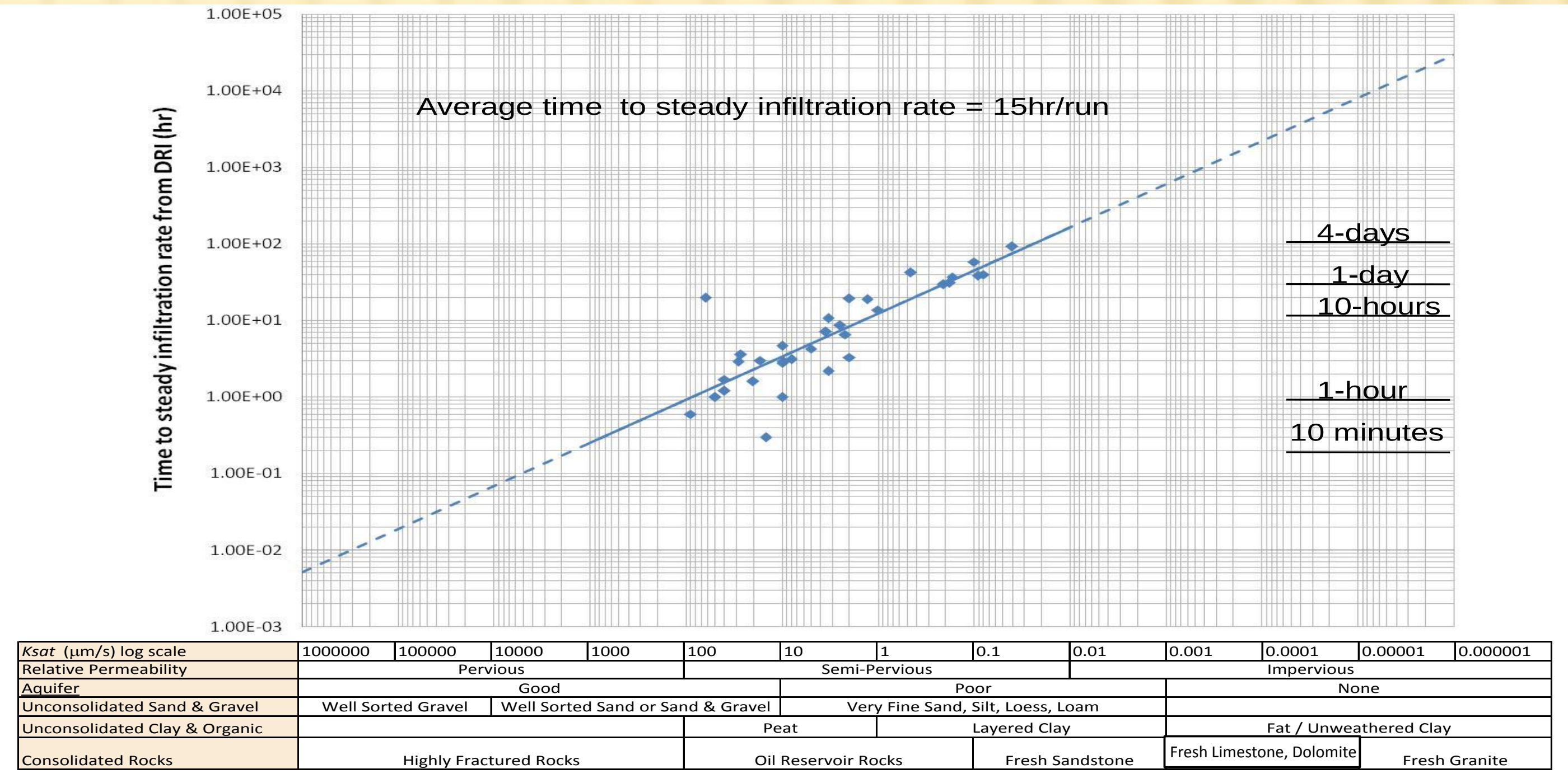
I. Field Work – SAS



(↑)Measured data of double ring infiltrometer. The soil reached the saturated condition about an hour after the measurement started.



Spatial variability of K_{sat} for the test fields at SAS obtained from: (a) ISPAD maps; (b) the DRI measurements

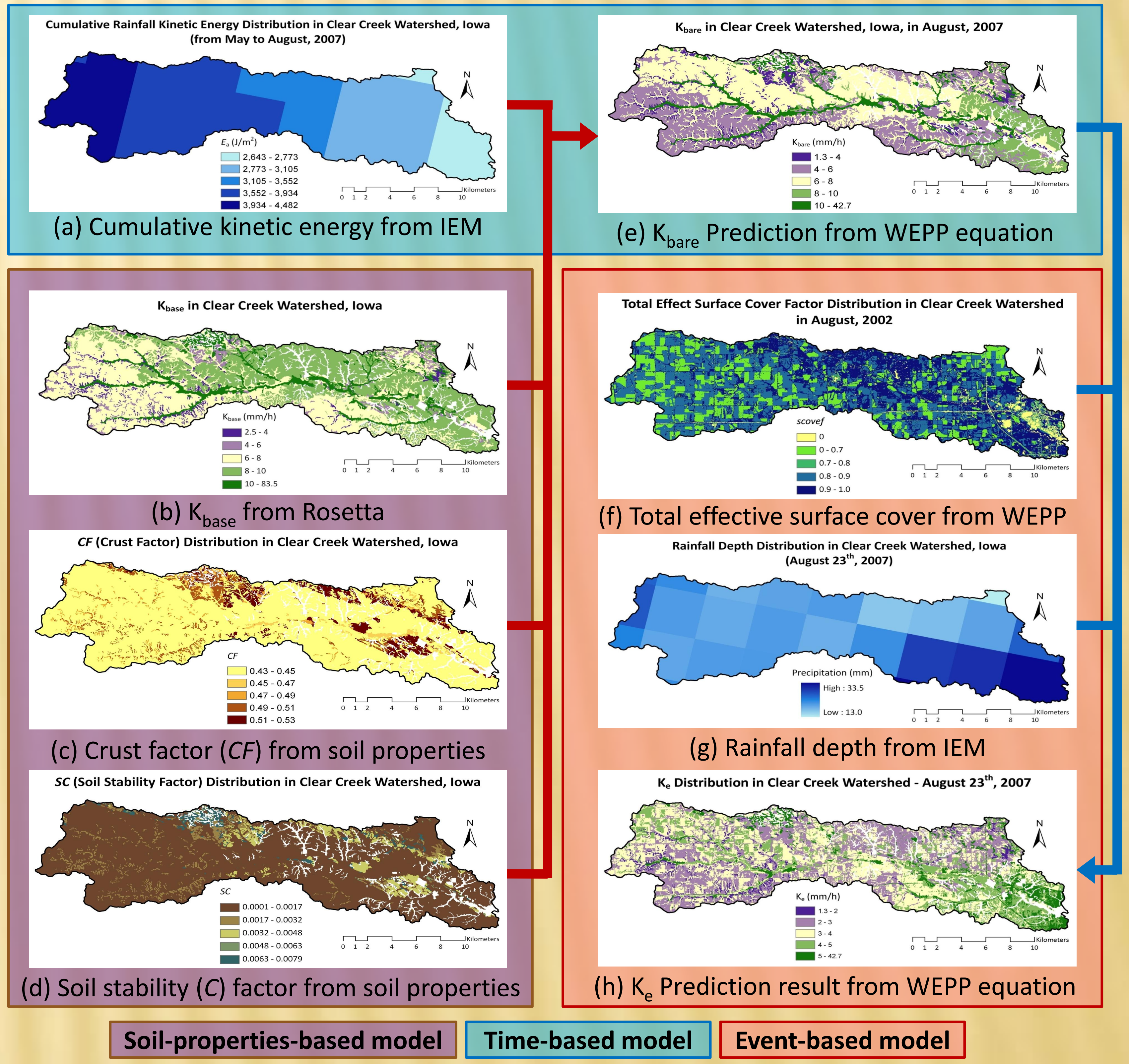


Ksat (µm/s) log scale	1000000	100000	10000	1000	100	10	1	0.1	0.01	0.001	0.0001	0.00001	0.000001
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	

Time to the steady infiltration rate condition from the DRI measurements in the CRP field.

(←) It shows the strong correlation between the values of K_{sat} and soil properties. This the reason that the pedotransfer functions were all established by the soil textures and its biogeochemical properties.

II. Models– Application in the Clear Creek Watershed



(a) Cumulative kinetic energy from IEM

(e) K_{bare} Prediction from WEPP equation

(b) K_{base} from Rosetta

(f) Total effective surface cover from WEPP

(c) Crust factor (*CF*) from soil properties

(g) Rainfall depth from IEM

(d) Soil stability (*C*) factor from soil properties

(h) K_e Prediction result from WEPP equation

Soil-properties-based model **Time-based model** **Event-based model**

CONCLUSIONS

- ❖ K_{sat} was predicted successfully as a function of certain measurable intrinsic soil properties (e.g., soil texture, bulk density) and extrinsic factors (e.g., rainfall intensity, canopy cover, management practices).
- ❖ Rosetta (PTFs) and WEPP watershed model's predictions provided the best agreement to the measured K_{sat} values.
- ❖ Crops and rainfall as extrinsic factors are believed to affect K_{sat} considerably.
- ❖ The modeling frame has provided the large-scale and long-term predictions of K_{sat} by integrating layered information from the geospatial and remote sensing with ROSETTA and WEPP.

ACKNOWLEDGEMENT

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