Aggregating Soil Hydraulic Property Field Measurements for Large Scale Infiltration Process

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Desert Research Institute

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Hydraulic Properties

- To close moisture flow equation (Richards equation)

- The effective degree of saturation (S_e) and the unsaturated hydraulic conductivity (K) are related to capillary pressure head (ψ) through van Genuchten model

$$S_e(\psi) = \frac{1}{\left[1+(\alpha\psi)^n\right]^m}$$

$$K(\psi) = \frac{K_s\left\{1-(\alpha\psi)^{mn}\left[1+(\alpha\psi)^n\right]^{-m}\right\}^2}{\left[1+(\alpha\psi)^n\right]^{m\ell}}$$

where S_e is effective degree of saturation, K_s is saturated hydraulic conductivity, a and l are related to pore-size distributions, m and n are empirical parameters, l is a parameter which accounts for dependence of tortuosity, and the correlation factors on water content estimated to be about 0.5 as an average for many soils.

- Parameters: hydraulic parameters

Motivation

- The vadose zone determines the partitioning of rainfall over surface runoff and infiltration and the partitioning of infiltrated water over evapotranspiration and groundwater recharge.
- Spatial variability of soil hydraulic properties has significant impacts on hydrologic processes and ecosystems.
- In hydro-climatic models grid dimensions are large (kms by kms). Grid-scale soil hydraulic parameters and their accuracy are critical for the success of hydro-climatic and hydrologic models.
- Effective hydraulic properties at large resolution are alternatives to heterogeneous soil medium in hydrologic models.
- The main idea of effective parameters is to capture interested process in heterogeneous soils by a process that assumes only one set of soil parameters, such that the heterogeneous system is replaced by an equivalent homogeneous system.

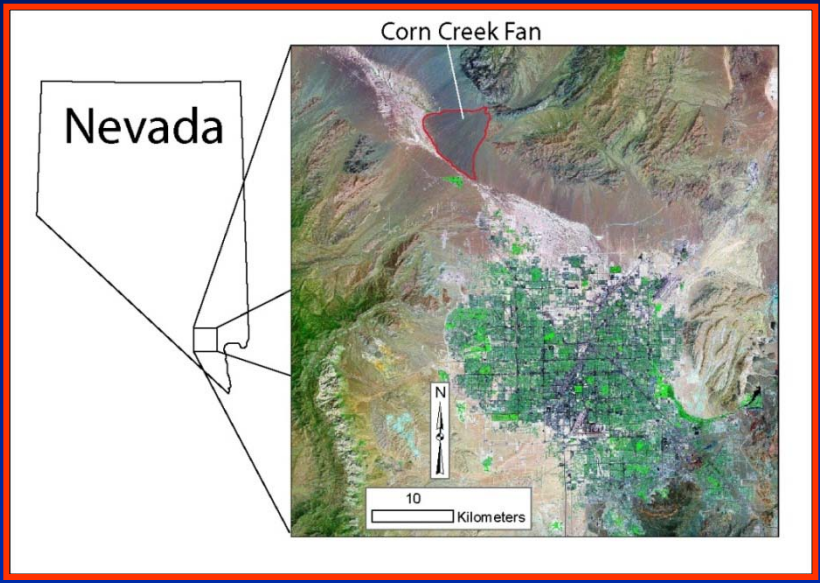
Objectives

A focused effort on effective hydraulic properties of transient infiltration into heterogeneous soils in terms of uncertainties in hydraulic parameters based on field-measured and re-generated hydraulic parameter data sets. The main goals are to investigate:

- **how effective hydraulic parameter schemes are sensitive to the time frame of hydrologic processes,**
- **how hydraulic parameter correlation and variability significantly impact effective hydraulic parameter schemes,**
- **how effective schemes can be better expressed in relation to parameter variability.**

Field-Measured Hydraulic Parameter Data Set

Field characterizations took place on the Corn Creek Fan Complex, on the Desert National Wildlife Refuge, located approximately 50 km north of Las Vegas, NV.



84 hydraulic parameter sets for the van Genuchten model are derived from the field measurements. The basic statistics are <K_s> = 0.123 (cm/min), <• > = 0.092 (1/cm), CV(Ks) = 0.837, CV(•) = 0.287. The coefficients of correlation (CC) between the saturated hydraulic conductivity, K_s, and the • parameter, CC(K_s, α) = 0.74.

- **Important question: What are the hydraulic parameters for the entire area?**

Re-Generated Hydraulic Parameter Data Sets

❖Cross-correlated random fields of hydraulic parameters are re-generated using spectral method. Random fields are produced with power spectral density functions. Coherency spectrum defined as follows is an indicator of parameter correlation,

$$R(\mathbf{f}) = \frac{\varphi_{12}(\mathbf{f})}{\left[\varphi_{11}(\mathbf{f})\varphi_{22}(\mathbf{f})\right]^{1/2}}$$

where • $_{11}$, • $_{22}$ are power spectra of random cross-correlated fields. • $_{12}$ is cross spectrum between random fields. When $|R|^2=1$, it indicates perfect correlation between random fields.

❖Three data sets are generated.

❖Correlation coefficients and variances are different from field-measured hydraulic parameters.

❖Investigate significance of parameter correlation and variability on effective hydraulic parameters.

Statistics of Field Set and Re-generated Sets

Data Set	$<K_s>$ (cm/min)	<• > (1/cm)	CV(Ks)	CV(•)	CC(Ks, •)
Field set	0.123	0.092	0.837	0.287	0.74
Set 1	0.123	0.092	0.837	0.287	-0.03
Set 2	0.123	0.092	1.18	0.41	-0.07
Set 3	0.123	0.092	0.837	0.287	0.01

Set 1: **importance of parameter correlation, since it only differs in correlation level between K_S and • in comparison to Field Set.**

Set 2: **influence of hydraulic parameter variance since it has larger variance than Field Set.**

Set 3: **influence of data point, since it has 1000 points as opposed to only 84 points for Field Set, Set 1 and Set 2.**

Effective Hydraulic Parameters

- **Three scenarios are considered to derive effective hydraulic parameters:**

  1) optimize K_s and •, while keeping other hydraulic parameters (n, •s, •r) at mean values

  2) optimize Ks only, while keeping other hydraulic parameters (•, n, •s, •r) at mean values

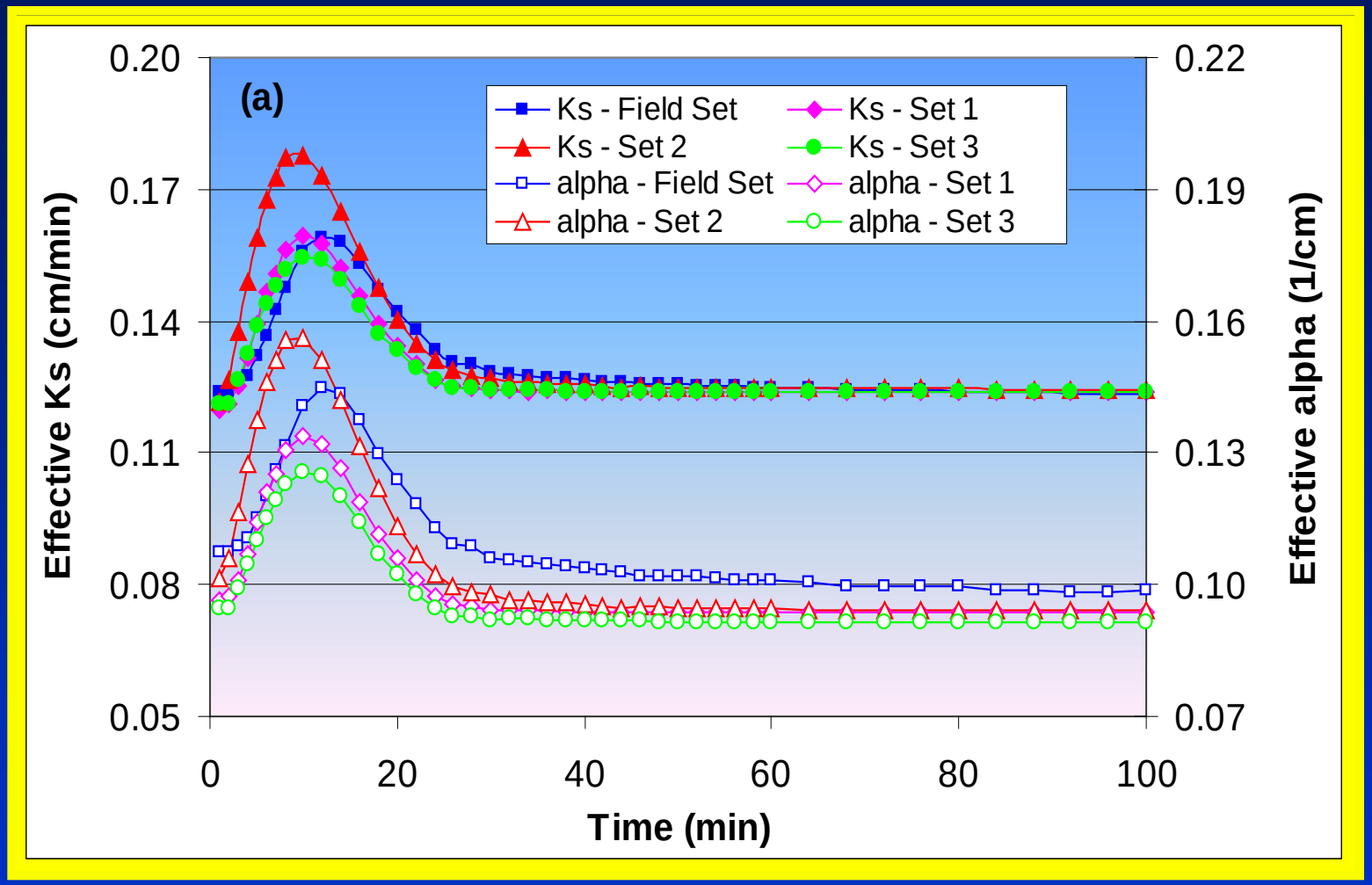
  3) optimize • only, while keeping other hydraulic parameters (K_s, n, •s, •r) at mean values

- **Objective is to examine which effective parameters schemes work better to represent ensemble behavior better as practical guidance for applications of large scale processes.**

- **An inverse procedure along with HYDRUS-1D is used to find effective hydraulic parameters for infiltration process, which minimizes objective function**

$$Obj = \frac{\sum_{i=1}^{N} \left\{ \hat{I}(t_i) - \bar{I}(t_i) \right\}^2}{\left[\bar{I}(t) \right]^2}$$

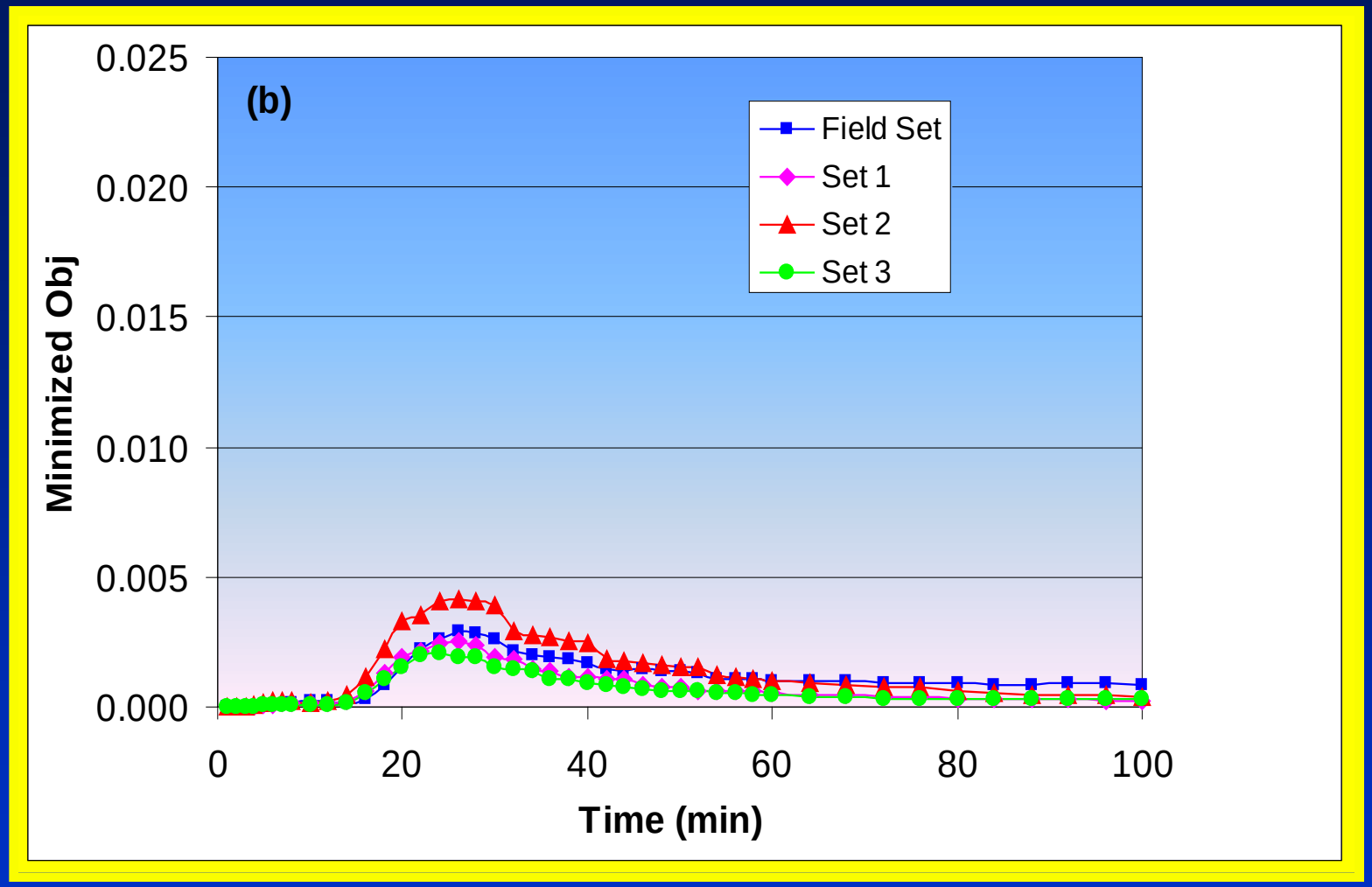
where $\bar{I}(t_i)$ denotes ensemble cumulative infiltration, $\hat{I}(t_i)$ indicates cumulative infiltration calculated using a single set of effective parameter values. t_i is time at each step, t is simulation time. N is number of total steps. The objective function represents an equally weighted difference of cumulative infiltration at each time step.



Effective hydraulic parameters

- **Both Ks and • are optimized together**

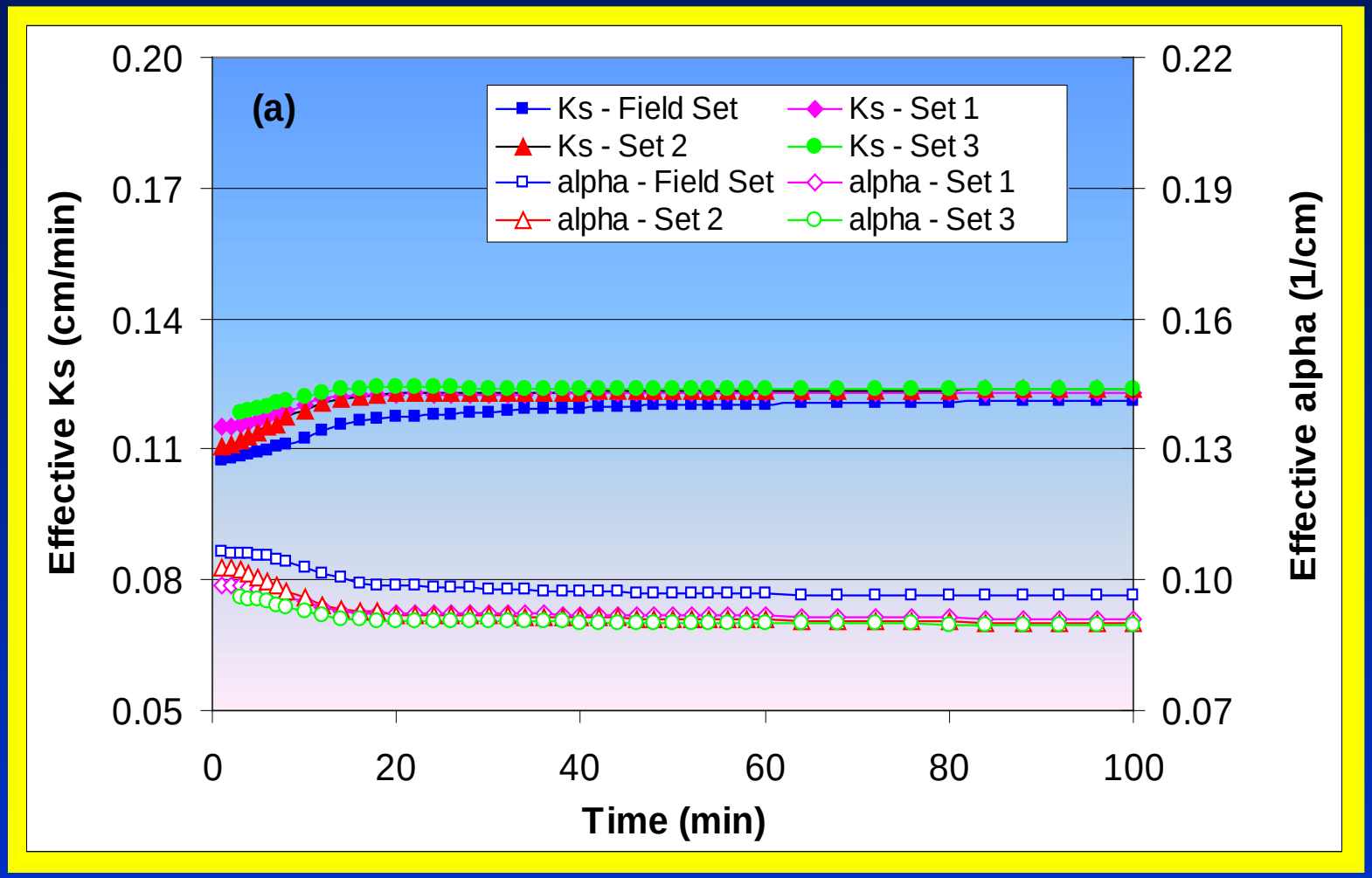
- **Effective parameters changes significantly during $t^{1/2}$ to t transition.**
- **Set 2 (same mean, double variance, zero correlation) stands out.**



Minimized objective functions

- **Both Ks and • are optimized together**

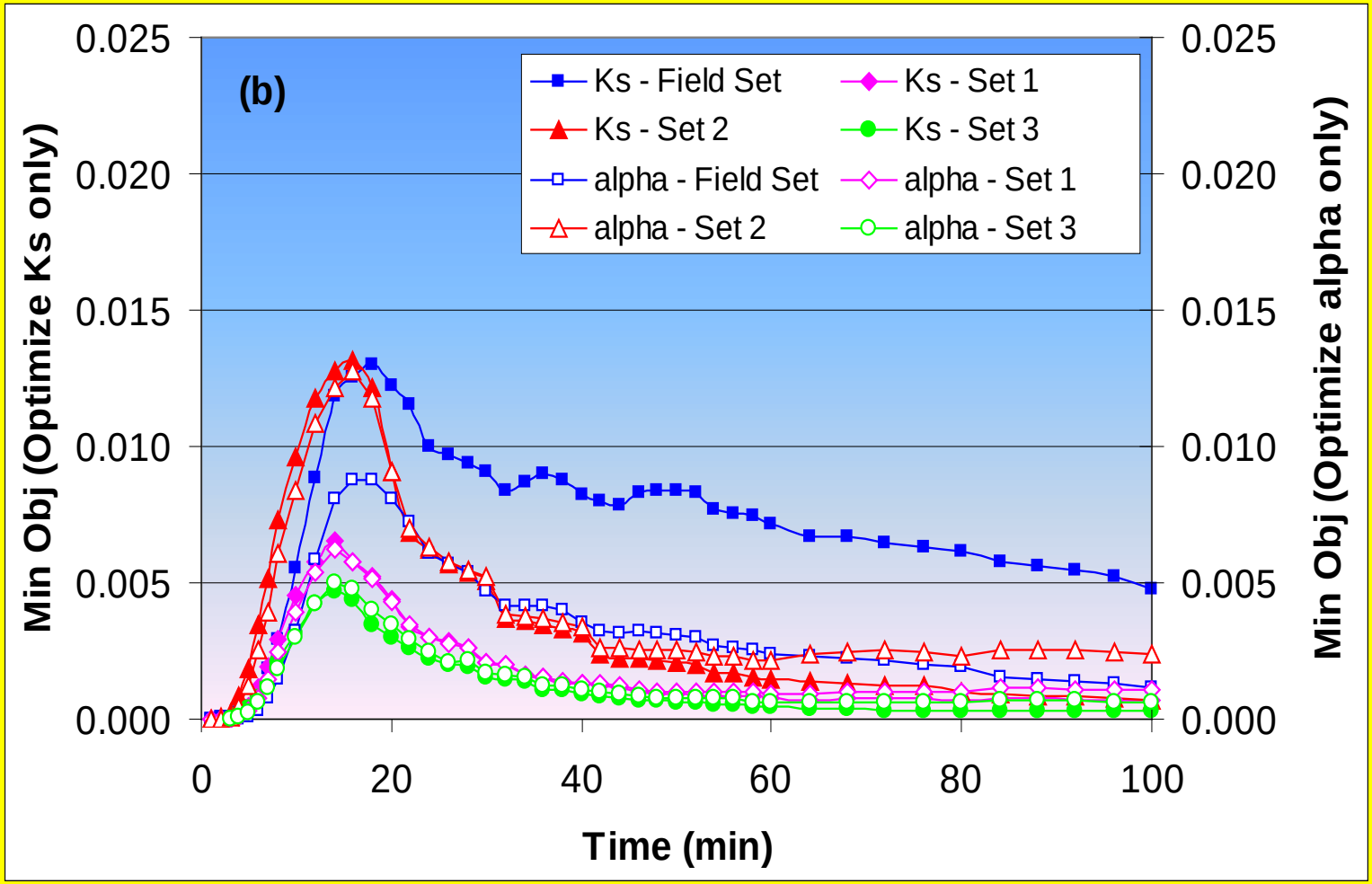
- **Objective function is in general quite small. Largest occurs just after transition from early square root of time behavior (i.e. sorption) to longtime traveling wave solution (i.e. infiltration).**



Effective hydraulic parameters

- **Only one hydraulic parameter is optimized**

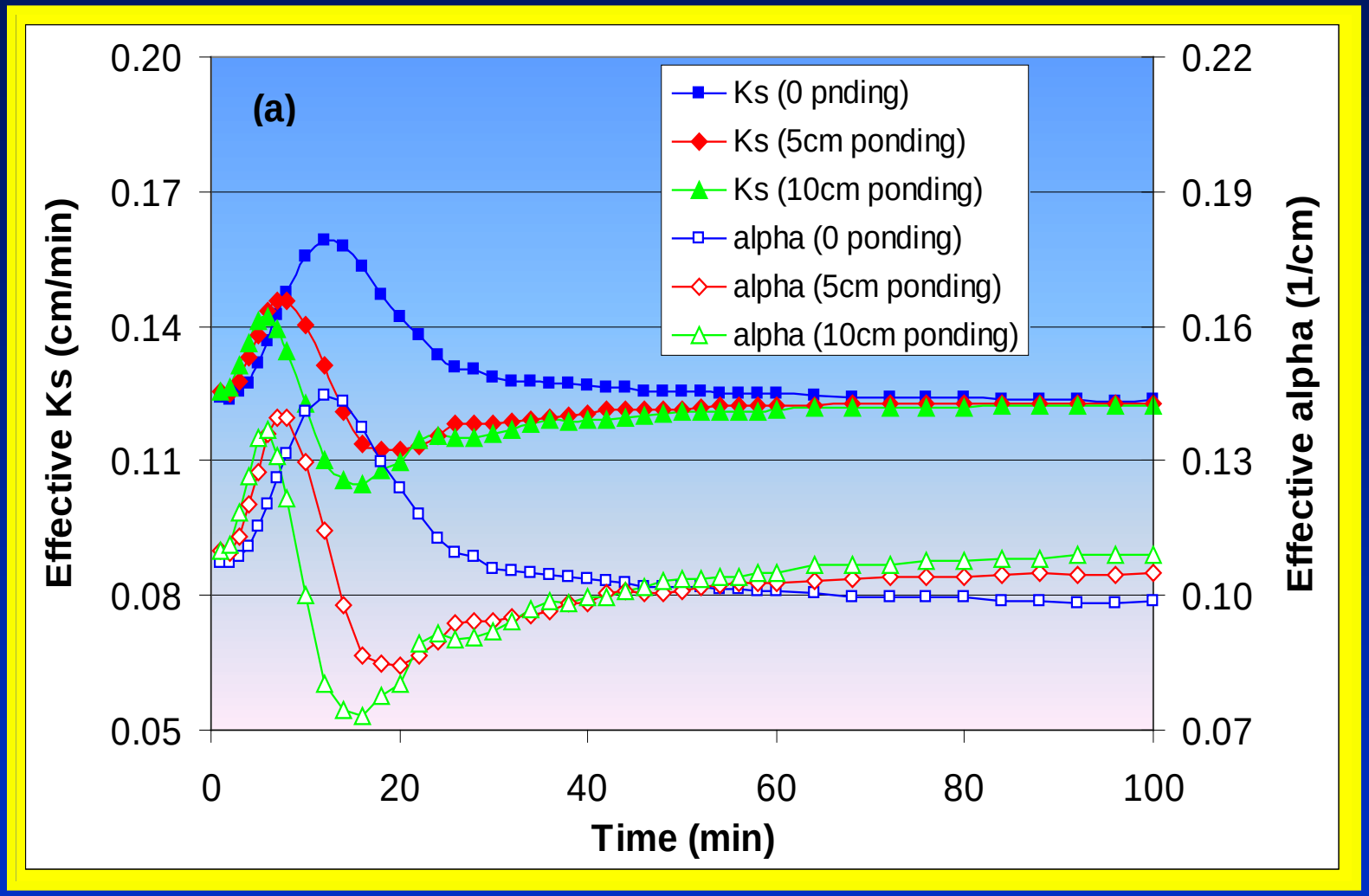
- **When only one parameter is optimized, resulting effective parameters are more uniform vs. time.**



Minimized objective functions

- **Only one hydraulic parameter is optimized**

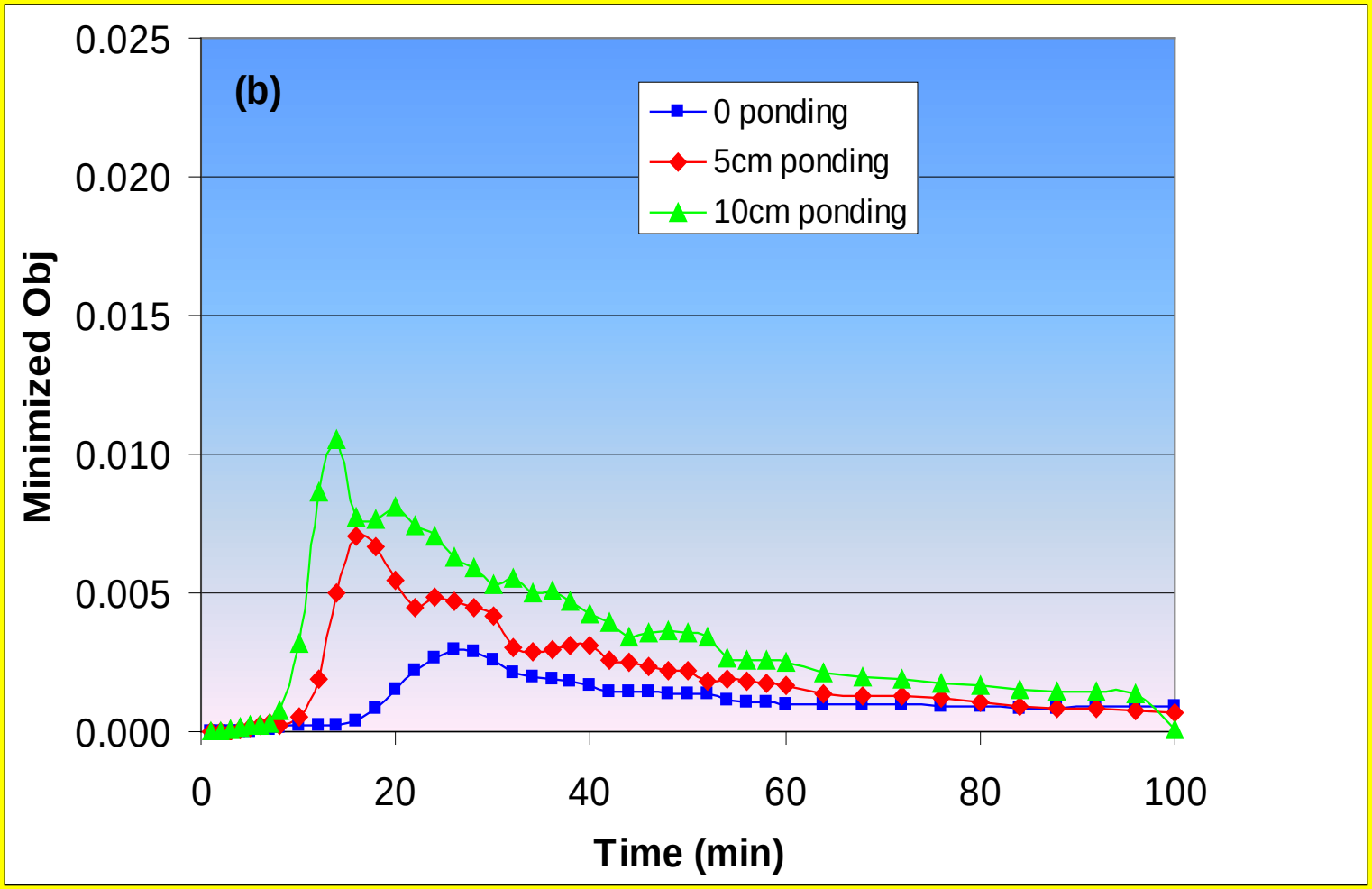
- **Objective function is larger when only one hydraulic parameter is optimized.**



Effective hydraulic parameters

- **Both Ks and • are optimized together**

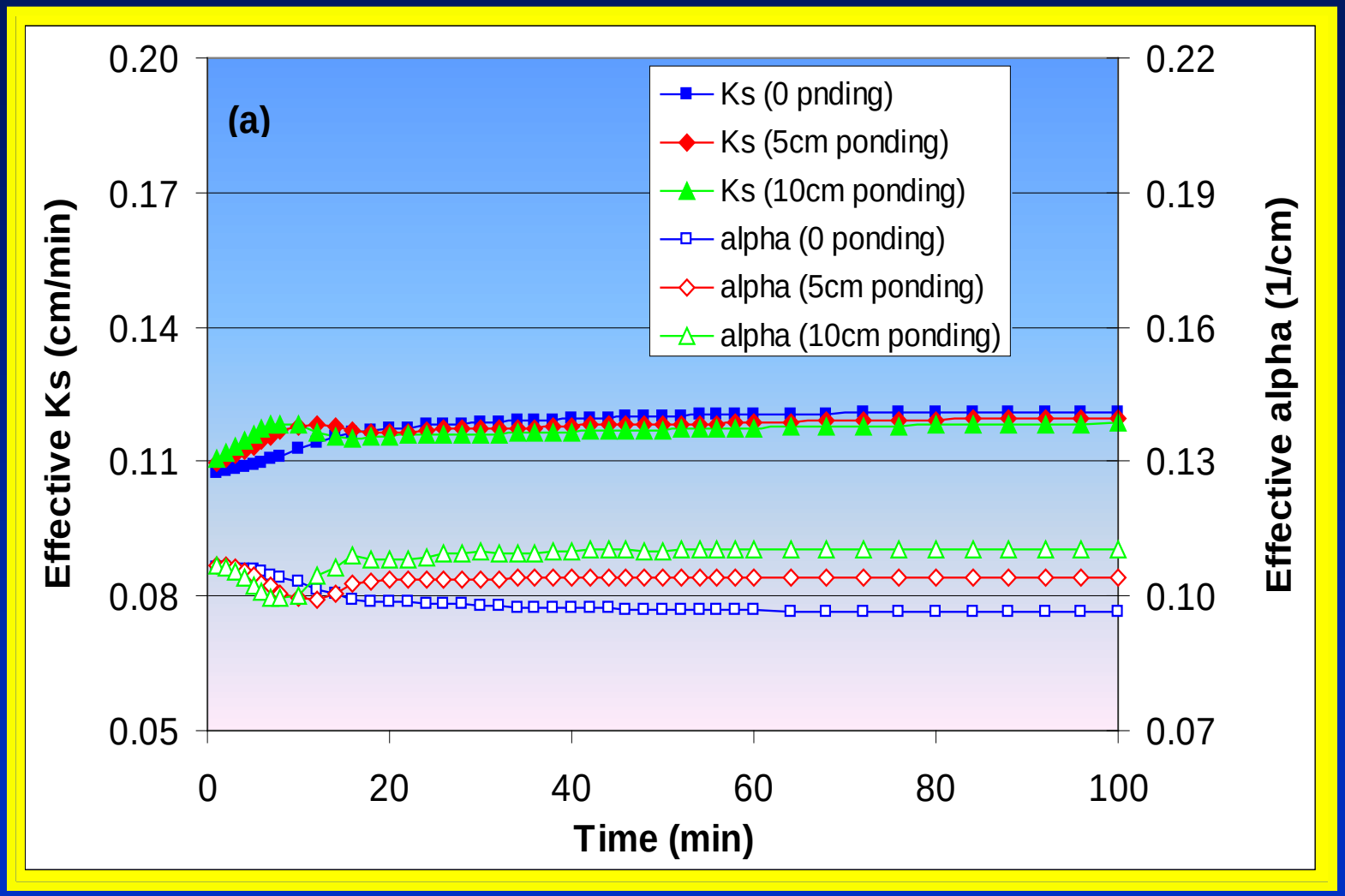
- **When there is ponding, transition stage is more difficult to be captured by effective hydraulic parameter idea.**



Minimized objective functions

- **Both Ks and • are optimized together**

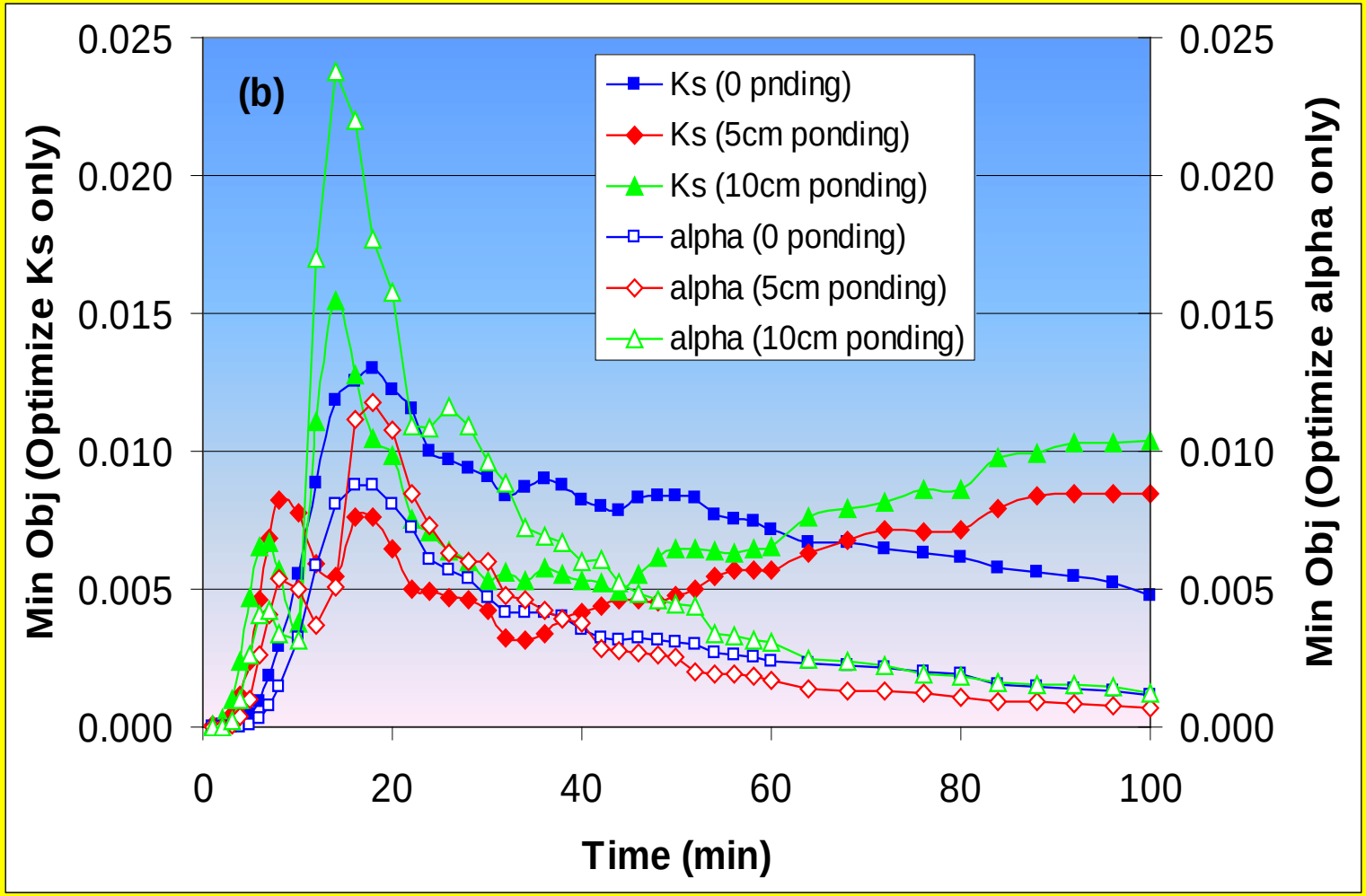
- **When there is ponding, objective function is larger.**



Effective hydraulic parameters

- **Only one hydraulic parameter is optimized**

- **When only parameter is optimized, resulting effective hydraulic parameters are more uniform.**



Minimized objective functions

- **Only one hydraulic parameter is optimized**

- **Objective function is larger when only one hydraulic parameter is optimized.**

Conclusions

- **When both K_s and • are optimized simultaneously, the resulting effective hydraulic parameters can be used to simulate average infiltration of a heterogeneous medium more effectively.**
- **At the initial stage of infiltration, the effective parameters vary significantly with time. At late stage, the effective parameters reach constant values, indicating the effective parameter idea can be better applied.**
- **Hydraulic parameter variance has more significant impact on the effective hydraulic parameter than the correlation between the hydraulic parameters does.**
- **The existence of ponding makes the effective hydraulic parameters more difficult to simulate large scale average infiltration in a heterogeneous medium.**

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