Report as of FY2006 for 2006NV105B: "Hydraulic Property Correspondence and Upscaling for Arid and Semi-Arid Hydrologic Processes"

Publications

- Articles in Refereed Scientific Journals:
  - Zhu, J., Mohanty, B. P., and Das, N. N., On the Effective Averaging Schemes of Hydraulic Properties at the Landscape Scale, Vadose Zone Journal, 5, 308-316, 2006.
  - Zhu, J., and Mohanty, B. P., Effective Soil Hydraulic Parameters for Land-atmosphere Interaction, Journal of Hydrometeorology, in press, 2007.
  - Zhu J., Young, M. H., van Genuchten, M. Th., Upscaling Schemes for Gardner and van Genuchten Hydraulic Functions for Heterogeneous Soils, Vadose Zone Journal, 6, 186-195, 2007.
- Conference Proceedings:
  - Zhu, J., Mohanty, B. P., and Das, N. N., Effective Soil Hydraulic Properties at the Landscape Scale and Beyond, 18th World Congress of Soil Science, Philadelphia, PA, July 9-15, 2006.
  - Zhu, J., Sun, D., and Young, M. H., Aggregating Hydraulic Property Measurements to Large Scale Hydrologic Processes, Western Pacific Geophysics Meeting, Beijing, China, July 24 27, 2006
  - Zhu, J., Young, M. H., and van Genuchten, M. Th., Upscaling Schemes for Hydraulic Functions at the Landscape Scale, AGU Joint Assembly, Baltimore, MD, May 23 26, 2006.
  - Zhu, J., Young, M. H., van Genuchten, M. Th., Sun, D., Upscaling Schemes of Hydraulic Properties and Characterizing Hydraulic Parameter Variability Using Cokriging and Artificial Neural Network for Heterogeneous Soils, W1188 Multistate Research Project Annual Meeting, Las Vegas, NV, January 2 4, 2007.

Report Follows

HYDRAULIC PROPERTY CORRESPONDENCE AND UPSCALING FOR ARID AND SEMI-ARID HYDROLOGIC PROCESSES

Final Report

Problem and research objectives

In order to quantify flow and transport in the vadose zone, the soil hydraulic properties of have to be specified. The soil hydraulic properties include the relationships of unsaturated hydraulic conductivity versus capillary pressure head and capillary pressure head versus water content (water retention characteristics). In this study, we mainly addressed two issues related to soil hydraulic properties as described below.

Hydraulic property data are often characterized using various forms of functions. Conditions for which alternative forms of the hydraulic functions give the same or similar hydrologic responses for a given hydrologic scenario are essential in many applications, such as soil-vegetation-atmosphere transfer schemes in general circulation models. In this study we applied two conceptually new equivalence criteria, based on hydraulic behavior equivalence. Our approach forces the predicted moisture flux across the land-atmosphere boundary and the soil surface moisture to be the same for the different hydraulic conductivity functions, rather than matching the hydraulic property functions themselves. Using the field hydraulic property measurements by researchers at the Desert Research Institute in Nevada from across various locations of arid and semi-arid western United States, our objective is to developed conceptual guidelines to establish equivalence relationships when different hydraulic property models are used to simulate a variety of large scale hydrologic processes [Zhu *et al.*, 2007].

Another important issue of concern for heterogeneous field soils is the upscaling of hydraulic parameters. Based on a point-scale or local scale measurements and characterizations, those parameter models of hydraulic functions are applicable only at the point or local scale. When those models are used in larger (plot, field, watershed or regional) scale processes, major questions remain about how to average the spatially variable hydraulic properties over a heterogeneous soil volume and what averages of hydraulic parameters to use for these models. An obstacle to practical applications in the field, catchment, watershed, or regional scale is the difficulty of quantifying the "effective" soil hydraulic property function. Proper evaluation of the water balance near the land-atmosphere boundary depends strongly on appropriate characterization of soil hydraulic parameters under field conditions and at the appropriate process scale. Our main goals related to this issues are to investigate 1) how the effective hydraulic parameter schemes are sensitive to the time scale of hydrologic process, 2) how the hydraulic parameter correlation and variability significantly impact effective hydraulic parameter schemes, and 3) how the effective schemes can be better expressed in relation to variability [Zhu and Sun, 2007].

Methodology

The soil hydraulic functions consist of the soil water retention function which defines the water content as a function of the suction head, and the hydraulic conductivity function which relates the hydraulic conductivity with the water content or suction head.

Using either the field-measured data sets or the re-generated data, we calculate the effective hydraulic parameters using the two critical criteria (i.e., preservation of the surface flux and the surface moisture content). From these two important criteria, we calculated the effective hydraulic parameters of Ks and α for both Gardner-Russo and van Genuchten models. We hence use the effective hydraulic parameters to predict the mean flux exchange between the subsurface and the atmosphere and to preserve the mean effective degree of saturation at the land surface. The effective degree of saturation was used because it reflects (and preserves) the prevailing effective moisture content important for many global water cycle applications, as well as for other large-scale problems.

An inverse procedure along with the HYDRUS-1D model is used to find the effective hydraulic parameters for infiltration process that are able to predict overall average infiltration flux. The developed effective parameters are further expressed in terms of p-norm values as described below.

The *p*-norm or *p*-order power average $\hat{\xi}(p)$ for a set of any *N* random parameter values ξ_i is given by,

$$\hat{\xi}(p) = \left[(1/N) \sum_{i=1}^{N} \xi_i^p \right]^{1/p}$$

Based on these effective parameter values and the original input parameters that were used to obtain the effective parameter values, we can calculate the corresponding *p*-norms for the hydraulic parameters iteratively.

Using various boundary pressure head and depth to water table we illustrated effect of ponding and depth to water table on the effective hydraulic parameters at different time scales. By comparing the effective hydraulic parameters of field-measured and re-generated hydraulic parameters data sets, we investigated the sensitivity of effective hydraulic parameters to the correlation of *Ks* and α.

Principal findings and significance

The main results of Zhu et al. [2006a] can be summarized as follows. For the steady-state flow problem considered in this study, we showed that *p*-norms and their relationships were similar using 84 field-measured hydraulic parameter values and 10,000 randomly regenerated hydraulic parameter realizations when upscaling the flux across the land–atmospheric boundary and the surface effective degree of saturation. The upscaling schemes were in general better defined, and had less variability, in terms of *p*-norms than when effective parameter values were used. In general, *p*-norms for the Gardner model were less well defined than for the van Genuchten model, and may in fact be more difficult to use than the van Genuchten model in the upscaling context. For deep water tables (at least equivalent to 10 m), *p*-norms for van Genuchten parameters were relatively constant, while *p*-norms for Gardner parameters varied significantly, especially as flow scenarios shifted from evaporation to infiltration. As the water table became shallower, *p*-norms for the van Genuchten model became also less well defined and more sensitive to changes in the

pressure head at the soil surface. Correlations between the hydraulic parameters within a given hydraulic property model was important for determining *p*-norm relationships between the Gardner and van Genuchten models.

The main findings of Zhu and Sun [2007] are as follows. Effective hydraulic parameters change with infiltration time scale initially, and then approach nearly constant values, indicating an equivalent homogeneous medium is a more viable alternative for large spatial and temporal scale transient infiltration process. Effective hydraulic parameters are sensitive to the correlation between *Ks* and α.The effective parameter schemes are more variable at early stage of infiltration.

Information Transfer Activities

Papers:

Zhu, J., Macroscopic Parallel and Perpendicular Unsaturated Hydraulic Conductivities for Layered Soils: Arithmetic Mean or Harmonic Mean?, Ware Resources Research, submitted, 2007.

Zhu, J., Mohanty, B. P., and Das, N. N., On the Effective Averaging Schemes of Hydraulic Properties at the Landscape Scale, Vadose Zone Journal, 5, 308-316, 2006.

Zhu, J., and Mohanty, B. P., Effective Soil Hydraulic Parameters for Land-atmosphere Interaction, Journal of Hydrometeorology, in press, 2007.

Zhu, J., and Sun, D., Effective Hydraulic Parameters for Transient Flows in Heterogeneous Soils, to be submitted to Vadose Zone Journal, 2007.

Zhu J., Young, M. H., van Genuchten, M. Th., Upscaling Schemes for Gardner and van Genuchten Hydraulic Functions for Heterogeneous Soils, Vadose Zone Journal, 6, 186-195, 2007.

Abstracts and Presentations:

Mohanty, B. P., Ines, A. V. M., Das, N. N., Jana, R., and Zhu, J., Effective Soil Hydraulic Parameters – State-of-the-Art!**,** Soil Science Society of America Annual Meetings, New Orleans, LA, November 4 – 8, 2007, submitted.

Sun, D., and Zhu, J., Saturation-Dependent Hydraulic Conductivity Anisotropy in Unsaturated Soils, Soil Science Society of America Annual Meetings, New Orleans, LA, November 4 – 8, 2007, submitted.

Zhu, J., Parallel and Perpendicular Unsaturated Hydraulic Conductivities for Layered Soils, Soil Science Society of America Annual Meetings, New Orleans, LA, November 4 – 8, 2007, submitted.

Zhu, J., Mohanty, B. P., and Das, N. N., Effective Soil Hydraulic Properties at the Landscape Scale and Beyond, 18th World Congress of Soil Science, Philadelphia, PA, July 9-15, 2006.

Zhu, J., Sun, D., and Young, M. H., Aggregating Hydraulic Property Measurements to Large Scale Hydrologic Processes, Western Pacific Geophysics Meeting, Beijing, China, July 24 – 27, 2006.

Zhu, J., Young, M. H., and van Genuchten, M. Th., Upscaling Schemes for Hydraulic Functions at the Landscape Scale, AGU Joint Assembly, Baltimore, MD, May 23 – 26, 2006.

Zhu, J., Young, M. H., van Genuchten, M. Th., Sun, D., Zhao, Y., and Hassan, A., Upscaling Schemes of Hydraulic Properties and Characterizing Hydraulic Parameter Variability Using Cokriging and Artificial Neural Network for Heterogeneous Soils, W1188 Multistate Research Project Annual Meeting, Las Vegas, NV, January 2 – 4, 2007.

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