# Report as of FY2007 for 2006NV100B: "Soil Heterogeneity and Moisture Distribution Due to Rainfall Events in Vegetated Desert Areas: Potential Impact on Soil Recharge and Ecosystems"

## Publications

Project 2006NV100B has resulted in no reported publications as of FY2007.

## Report Follows

# Soil Heterogeneity and Moisture Distribution Due to Rainfall Events in Vegetated Desert Areas: Potential Impact on Soil Recharge and Ecosystems

## Annual Report

Problem and research objectives

Strong interactions exist between desert soils and plants, and these interactions will potentially control the overall movement and distribution of water, which are critical for water resources and desert ecosystems. The high level of spatial heterogeneity of the near-surface soil/plant environment creates significant difficulty for understanding and simulating these interacting processes. These heterogeneities are attributed to all of the physical, geomorphological and biological variations across the surface; many of these attributes have direct influences on soil hydraulic properties and thus hydrological processes. The overriding objective is to observe and simulate the contribution of surface feature heterogeneity to the landscape response from precipitation events, particularly as they relate to recharge and surface runoff in desert environments.

Methodology

In this study, we applied both field experimental and numerical approaches to study the impact of the heterogeneity of soil hydraulic properties on rainfall-infiltration-runoff processes. In the experimental study, we have scheduled a tension infiltrometer (TI) study in three experimental plots located at the Mojave National Preserve, CA. The TI study will be conducted at 20 locations in each plot, on both under canopy and interspace surfaces. Measurements will be taken during the TI experiments to augment the data set; these measurements will include soil texture, bulk density, and an estimate of the initial capillary pressure of the soil. The soil hydraulic properties will be back calculated from the TI data, and spatial distributions of the hydraulic conductivity and capillary pressure will be analyzed. These experimental results will be imported to a numerical model that simulates hydrological processes (surface runoff and infiltration) on the experimental plots.

The numerical model to be used for this research is known as CeRIRM (Cell-Based Rainfall Infiltration Runoff Model), a physically-based distributed model for rainfall-runoff modeling, to study the plot scale hydrological process using very high-resolution distributed modeling approach. CeRIRM is originally developed by the co-PI for his dissertation and is further modified through funding from the U.S. Army Corp of Engineers. The model applies a two-dimensional surface runoff routing approach to account explicitly for topographic impact on overland flow movement, and it incorporates a more physically-based approach (Green-Ampt infiltration model) to simulate infiltration. This comprehensive modeling technique addresses the interaction between the infiltration and surface runoff routing that is greatly complicated by heterogeneity of soil hydraulic properties and topography. The model has been modified to accommodate the plot scale rainfall-runoff simulation for this project. In addition, scripts have been created to randomize the hydraulic properties across the field site. The randomizing accounts for uncertainty in our knowledge of soil hydraulic properties, and open the use of Monte Carlo simulation techniques.

Due to the departure of one of the PIs (Meadows), the research procedures of the project have been adjusted to first emphasize the development of the numerical modeling approach, and to second emphasize the field studies. To date, the numerical work is essentially completed and the field work has been scheduled.

Preliminary Modeling Studies

We have conducted preliminary modeling studies to examine the general trends of the impact of heterogeneous topography and soil hydraulic parameters on the rainfall-runoff process. The simulation cases are conducted on a hypothetical plot with the scale of 50m by 50m and the modeling cell size is 1m by 1m. The lowest 50 grids are considered as open boundary where runoff is calculated and measured. Other three boundaries are set as no flow boundaries. Both deterministic and random simulations are conducted. The deterministic simulation adopts the homogeneous parameters for the whole domain and the random simulation employs the randomly distributed parameters. In the random simulation study, we are currently using Latin Hypercube Sampling (LHS) to generate the random fields for the Monte Carlo simulations, where statistical characteristic of surface runoff is evaluated by running the model repeatedly when sampling four input parameters 2,500 times each. The parameters include initial soil moisture ($\theta_i$), saturated soil moisture ($\theta_s$), saturate hydraulic conductivity ($K_s$) and wetting front capillary pressure head ($\Psi_f$). The number of realizations is equal to the total number of cells in the study domain. In the LHS method, the probability axis (Y axis) of each variable $X_i$ is evenly divided into 2,500 non-overlapping intervals. Therefore, the *n* non-overlapping bandwidths of the parameter axis (X axis) are determined by using the cumulative probability curve. One value from each X interval is selected at random according to the probability density for this interval. The advantage of this selection is that the entire distribution is covered. Each $X_i$ value is randomly paired to a $X_j$ value. Therefore the 2500 groups of 4-variable compose the Latin-Hypercube samples. In this study, we assume that these four parameters are not correlated.

Different topographic and rainfall settings are examined, which are listed as follows:

- ***Planar slope***: A simple planar slope with the slope degree of 6º.
- ***Uneven slope***: A slope with randomly generated microtopography with the average slope being 6º.
- ***Steady rainfall*****:** Precipitation series is constant with an intensity of 5 cm/hr.
- ***Unsteady rainfall*****:** Precipitation series is selected from a storm in '90 monsoon season recorded at the Walnut Gulch Experimental Watershed, Arizona, which is a research site in a related project.

Soil texture in all homogeneous cases is set close to a rangeland soil found at the Walnut Gulch Watershed. We used the following textural breakdown: 66% sand, 24% silt and 10% clay. Initial and saturated moisture contents are 0.1 $cm^3\,cm^{-3}$ and 0.37 $cm^3\,cm^{-3}$, respectively. Saturated hydraulic conductivity is set as 8 cm/hr and wetting front capillary pressure head is set as 10 cm. Fig.1 shows the simulated results. Heterogeneous soils are examined with the Monte Carlo simulation approach. A total of 30 random fields are generated from the LHS method for 30 Monte Carlo simulation runs. The modeling procedures are listed as follows

1. $\theta_s$ is considered to be uniform and equal to 0.37 $cm^3\,cm^{-3}$.throughout the simulation area in all cases.

2. According to Meyer et al. (1997) and a parallel study conducted at the Walnut Gulch Experimental Watershed, Arizona, we can safely make the assumption that in most of the fields, $K_s$ follows a lognormal distribution and $\Psi_f$ follows a normal distribution.
3. The LHS method (Iman and Shortencarier, 1984) is used to generate 2,500 $\theta_i$ with the assumption that $\theta_i$ follows a normal distribution. The generated $\theta_i$ field then is used in all simulation cases.
4. The LHS method (Iman and Shortencarier, 1984) is used to generate 2,500 sets of $K_s$ and $\Psi_f$ based on their distributions at Walnut Gulch and with the assumption that these two parameters are independent.
5. We thus randomly distributed these 2,500 sets of $K_s$ and $\Psi_f$ as well as the uniform $\theta_s$ into 2,500 computational cells.
6. Steps 4 and 5 are repeated 30 times to generate 30 random fields for $K_s$ and $\Psi_f$.
7. The CeRIRM model is then run using the dataset to evaluate the behavior of surface runoff.

Only planar slope and unsteady rainfall are considered for the heterogeneous soil, which are described in the previous section. Fig. 2 shows the simulated results.

<u>Principal findings and significance</u>

Preliminary results from the numerical modeling studies have shown:

- The distributed topography has strong impact on the runoff generation process (Fig. 1), which implies that the 'runon' plays an important role in the rainfall-runoff process. Compared with the pure rainfall-infiltration case, runon will increase local infiltration by means of the lateral surface flux, and in turn, will influence the total runoff amount on the domain scale.
- The spatial variability of soil hydraulic properties can greatly affect the connection between rainfall, infiltration, and runoff. Assuming the same mean hydraulic conductivity, a homogeneous parameter field and a heterogeneous parameter field produce significantly different runoff (Fig. 2), which indicates that simple averaging is not sufficient for estimating parameter in this highly non-linear hydrologic situation. However, according to the Monte Carlo simulation, randomly generated soil hydraulic properties affect the runoff similarly (Fig, 2). Thus, as long as the generated input parameters cover the entire statistical distribution (lognormal and normal in this study), almost identical simulated runoff are produced no matter how these parameters are distributed across the plot. Nevertheless, more studies are needed to determine if similar runoff can be generated when larger scale cells are used.
- Using the findings from the bullet above, it follows that spatially distributed models can better handle spatial heterogeneity of soil hydraulic properties. Lumped parameter models are unable to deal with spatial variability, because the interactions between areas on the watershed with different hydraulic conductivities are not accounted for. Further studies will focus on whether a deterministic heterogeneous field (e.g. derived from Kriging) and random heterogeneous field (e.g. derived from LHS) will produce the same improvement of the surface runoff simulation.
- We recognize that very high resolution simulations are often not realistic. In these cases, upscaling approaches (i.e., averaging) are necessary. However, existing upscaling approaches may not be sufficient for complicated rainfall-runoff processes, especially for

unsteady rainfall events and domains with contributing areas. The data that will be collected in this research will become natural tie-ins to future research in this technical area.

Information Transfer Activities

***Papers:***

Yin, J., L. Chen, M. H. Young. Influence of heterogeneous surface on rainfall-runoff process in desert environment. (Under preparation)

***Presentations:***

Yin, J., L. Chen, M. H. Young. High resolution rainfall-runoff simulation for heterogeneous surface. AGU Fall Meeting, 2007 (Under preparation)

***Student Support:***

This grant funded the research endeavors (time, instruments and travel) during Jun Yin's Ph.D. degree study.

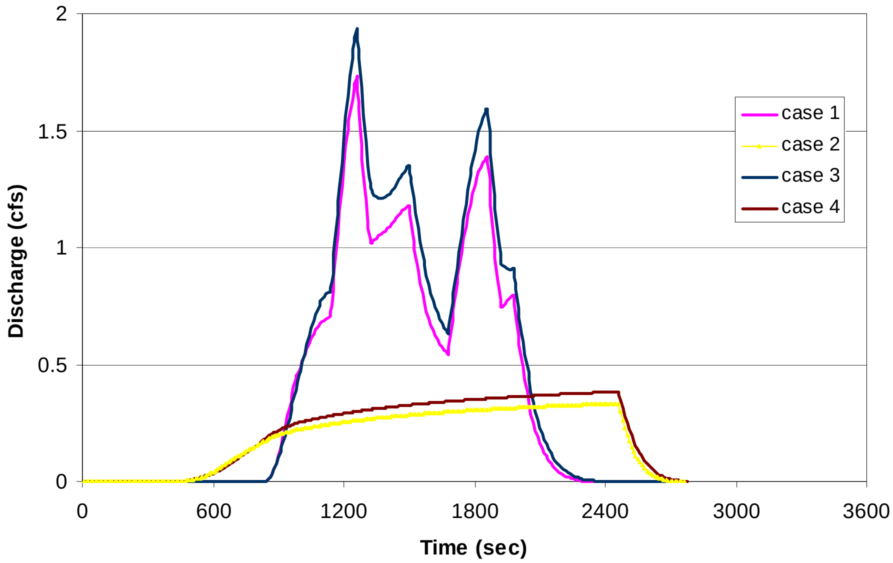


Fig. 1.  Preliminary modeling results of rainfall-runoff process for hydraulically homogeneous plots with single valued hydraulic parameters across the surface.

Case 1: Uneven slope with random microtopography, unsteady rainfall
Case 2: Uneven slope with random microtopography, steady rainfall
Case 3: Planar slope surface, unsteady rainfall
Case 4: Planar slope surface, steady rainfall

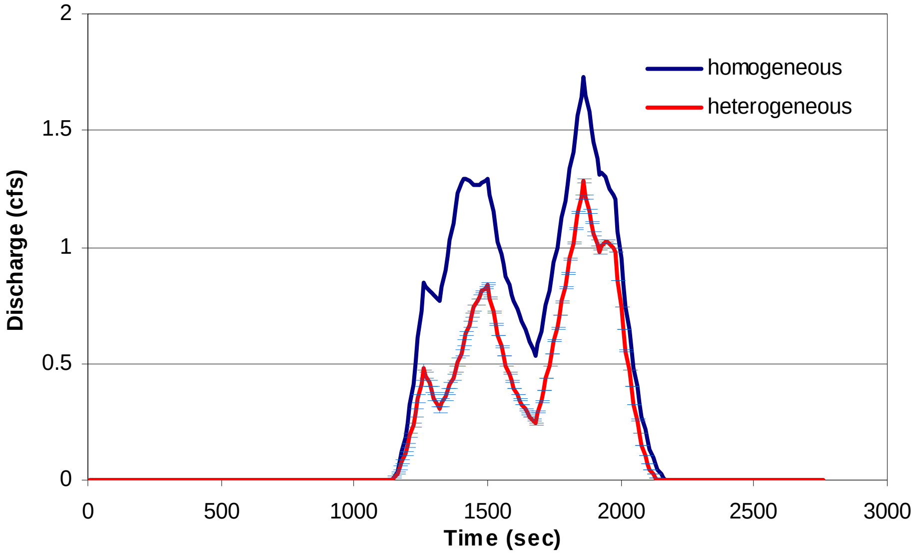


Fig. 2. Preliminary modeling results of rainfall-runoff process for heterogeneous surfaces with randomly distributed hydraulic conductivities. The homogeneous case is for a planar surface with unsteady rainfall, using averaged values of $K_s$, $\Psi_f$ and $\theta_s$. The heterogeneous line represents the mean of 30 realizations for the Monte Carlo simulation on the same slope and with the same rainfall, and the error bars represent the standard deviation of the discharge in the 30 realizations.

**References**

Iman, R. L., and Shortencarier, M. J. 1984, A FORTRAN 77 C Program and User's Guide for the Generation of Latin Hypercube and Random C Samples for Use With Computer Models. NUREG/CR-3624, SAND83-2365. C Albuquerque, NM: Sandia National Laboratories.

Meyer, P.D., Rockhold, M.L., Gee, G.W., 1997, Uncertainty analyses of infiltration and subsurface flow and transport for SDMP sites, Pacific Northwest National Laboratory, NUREG/CR-6565.