Chaotic Models of Dripping Water From a Fracture Under Ponded Infiltration at Hell's Half Acre, Idaho

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RESEARCH OBJECTIVE

Preliminary analysis of the results of infiltration tests from the Hell's Half Acre (HHA) field site, Idaho, showed that under some conditions, flow in fractured rocks can be described using chaotic models (Podgorney et al., 2000). The objective of this project is to perform a nonlinear dynamical analysis of the time variations of infiltration and outflow rates and dripping water phenomena observed during the HHA tests in order to determine phenomenological models describing spatial and temporal chaotic behavior of flow in fractured rocks.

APPROACH

The results of three small-scale ponded infiltration tests conducted in fractured basalt during the summer of 1998 at the Hell's Half Acre field site were analyzed. The tests were conducted using a small reservoir (40 x 80 cm) constructed on the surface exposure of a fracture intersecting an overhanging basalt ledge (Podgorney et al., 2000). The spatial and temporal behavior of inflow and outflow rates, including temporal and spatial water dripping from the undersurface of the ledge were monitored. The data analysis was conducted using the phase-space reconstruction of one-dimensional time-series of water dripping intervals at different locations. The main idea behind the reconstruction of the system dynamics from one-dimensional scalar data is the evaluation of diagnostic parameters of chaos, such as the correlation time (Δt), global embedding dimension (GED), local embedding dimension (LED), Lyapunov dimension (LD), Lyapunov exponents (LE) and correlation dimension.

ACCOMPLISHMENTS

The results of this study show that a dripping water behavior is transient and either quasi-periodic or nonperiodic. The dripping-water behavior occurs on three temporal scales, such as seconds, hours and days, which are not related to changes in boundary conditions. The observed nonlinear behavior is caused by a superposition of several physical nonlinear processes generating chaos for flow in unsaturated fractured rocks, including the capillary barrier effect. The observed variations of the flow rate and dripping intervals are apparently caused by a combination of both deterministic-chaotic, reflecting the physical deterministic nature of nonlinear flow and transport processes, and random components (Faybishenko, 1999). The volumetric outflow rates combined from several dripping locations exhibit spatial and temporal instabilities with primary low-frequency fluctuations and secondary high-frequency fluctuations caused by local instabilities. The time series data and corresponding attractors indicated several routes to chaos in water dripping processes, such as intermittency fluctuations, bifurcation, gradual and/or rapid collapse of stability. It was determined that different models, such as deterministic, deterministic-chaotic, stochastic-chaotic and random models, can be used to describe the data for different times. Figure 1 illustrates an example of a time-series of water-dripping intervals exhibiting deterministic chaos and a 3-D phase-space attractor.

SIGNIFICANCE OF FINDINGS

If a flow system exhibits a deterministic chaotic behavior, its long-term predictability is limited. For such a system, one can provide precise short-term predictions and only a range of possible long-term predictions. The models developed in this project would be of interest for investigations of dripping phenomena in fractured rocks at several DOE sites—e.g., at the potential nuclear waste repository at Yucca Mountain, Nevada, and in fractured karst at Oak Ridge, Tenn.

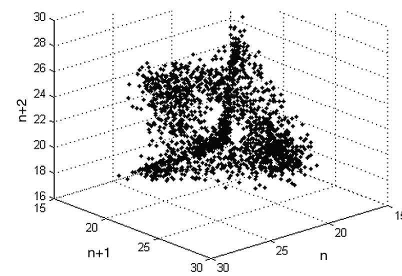

Figure 1. An example of a 3-D attractor plotted for 2,078 water dripping intervals (n) with Δt=1, showing a determinsitic structure with a secondary noisy component. Parameters of chaos are: GED = 5, LED = 5, LD = 4.611, largest LE = 0.364, minimum LE = -0.724. (Test 8, Point 6, 7/6/98).

RELATED PUBLICATIONS

Faybishenko, B., Evidence of chaotic behavior in flow through fractured rocks, and how we might use chaos theory in fractured rock hydrogeology, Proc. Dynamics of Fluids in Fractured Rocks: Concepts and Recent Advances, pp. 207-212, Berkeley Lab report LBNL-42718, 2000.

Podgorney, R., T. Wood, B. Faybishenko and T. Stoops, Spatial and temporal instabilities in water flow through variably saturated fractured basalt on a one-meter scale, AGU Monograph 122, Dynamics of Fluids in Fractured Rocks, in press.

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