The accuracy of steady-state transit time estimates in a non-steady climate: Modeling experiment setup in a Valley and Ridge agricultural watershed.

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Motivation

- Model-based estimates of the transit time distribution (TTD) of catchment discharge are increasingly used to inform integrated water resource management (e.g.,[1])
- Traditional "steady-state" TTD models assume that the time-variability of the TTD can be neglected. [2]
- Previous work has shown that TTDs vary with climatic conditions (e.g., see Figure 1). Therefore, steady-state TTD estimates may have significant "climate induced" error.
- Recent advances in lumped parameters (e.g., storage selection functions) and distributed models with particle tracking can relax the steady-state assumption and simulate the full time-dependence of the TTD.

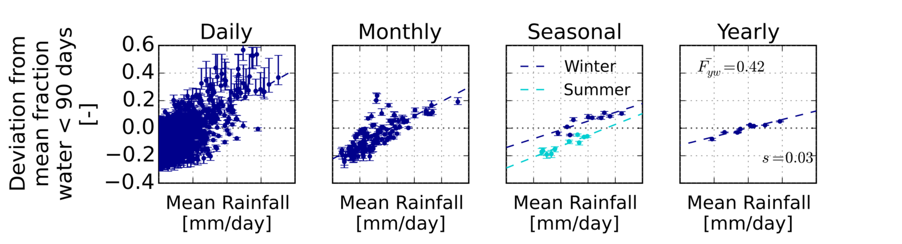


Figure 1. Illustration of the strong association between climate variability and transit times, at the Lower Hafren headwater catchment at Plynlimon, Wales. The x-axis shows average rainfall at different temporal scales. The y-axis shows the deviation from the mean in the fraction of young water (<90 days old) in catchment discharge over the same period. Error bars represent model parameter uncertainty. (Unpublished analysis, with raw data obtained from [3]).

Research questions

- How sensitive is the catchment TTD to climatic variability in a typical Valley and Ridge agricultural watershed?
- To what extent does this sensitivity depend on particular watershed characteristics (e.g., topography, conductivity)?
- To what extent does this sensitivity depend on the source of discharge (e.g., overland flow, saturated groundwater)?

Methods: PARFLOW modeling

- A virtual modeling testbed is being constructed using the fully distributed PARFLOW (*PARallel FLOW*) model [4-7] with SLIM-FAST particle tracking code [8].
- PARFLOW simulates variably-saturated subsurface and surface flow with a coupled land-surface-model.

Subsurface flow (Richard's equation):

$$S_S S(\psi)\left(\frac{\delta\psi}{\delta t}\right) + \phi\frac{\delta S(\psi)}{\delta t} = \nabla\cdot[k(x)k_r(\psi)\nabla(\psi - z)] + q_s$$

Overland flow (kinematic wave and Manning's equation):

$$\frac{\delta\psi_S}{\delta t} = \nabla\cdot(v\psi_S) + q_r(x)$$

$$v_x = -\left(\frac{\sqrt{S_{f,x}}}{n}\right)\psi_S^{\frac{2}{3}}\,(same\ for\ v_y)$$

ψ, $S(\psi)$, $k_r(\psi)$ relationship (van Genuchten model):

$$S(\psi) = S_r + (S_S - S_r)/[1+(\alpha|\psi|)^n]^{1-\frac{1}{n}}$$

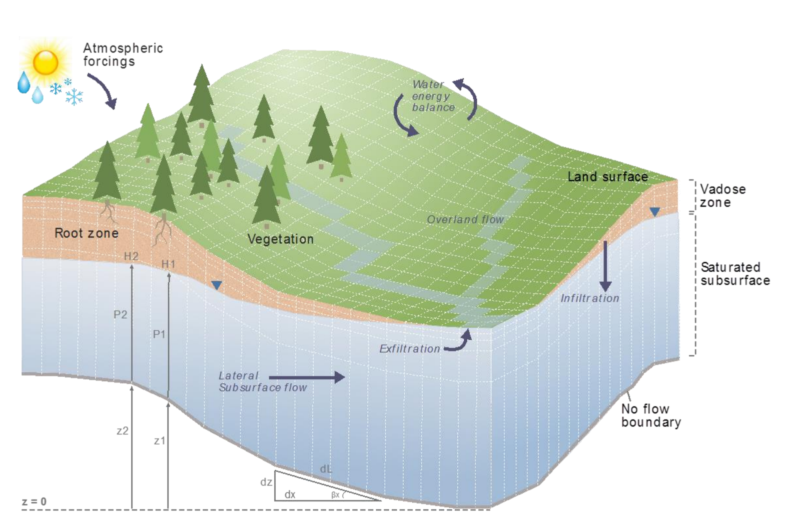
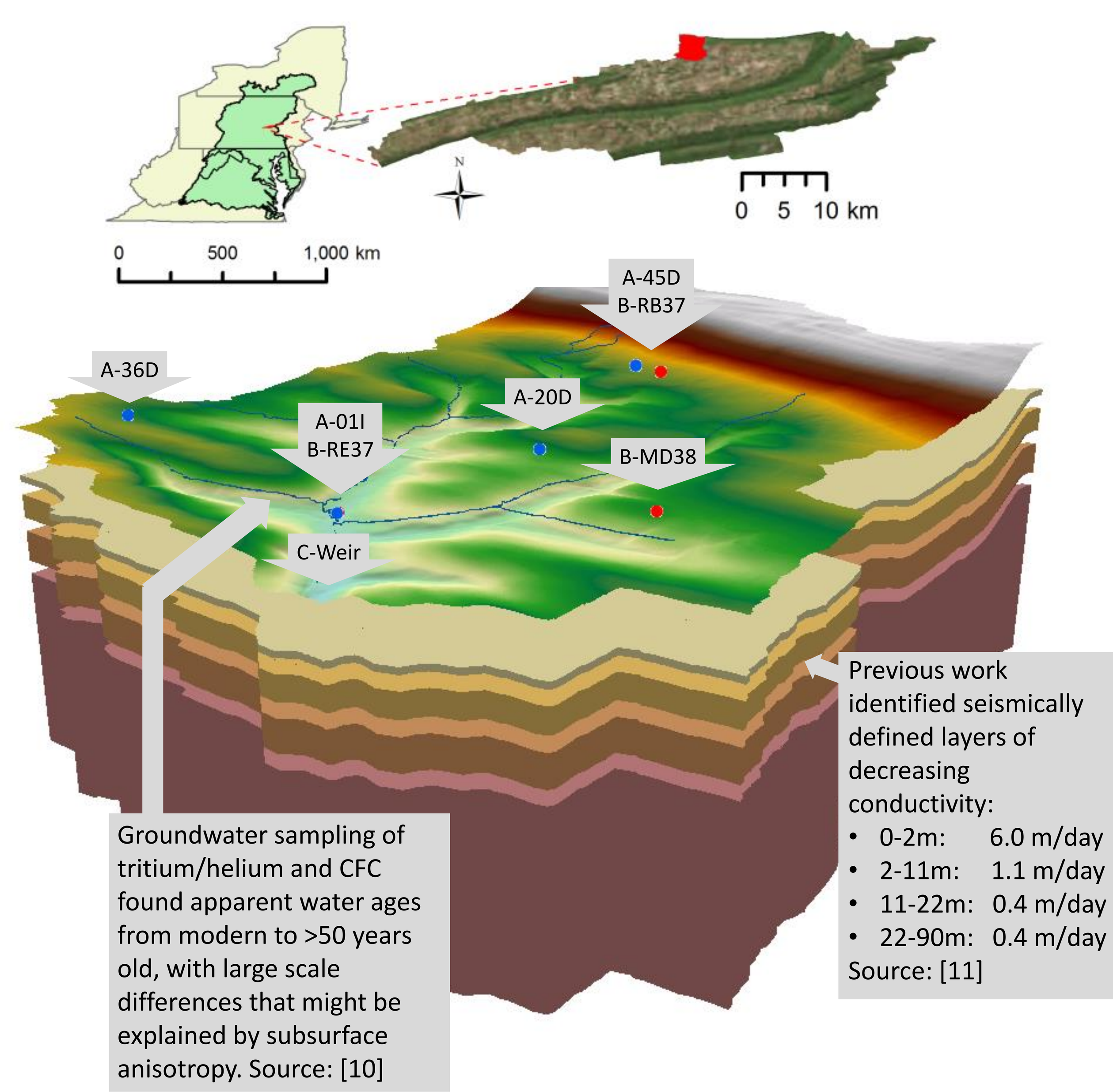
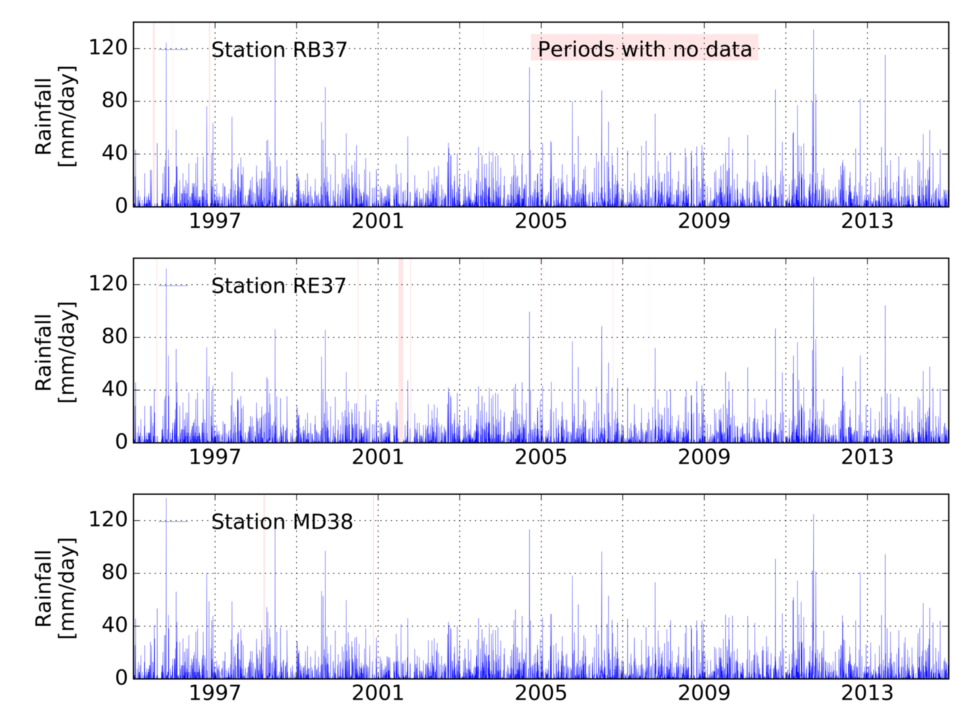


Figure 2. Schematic of the PARFLOW model. Image from [9].

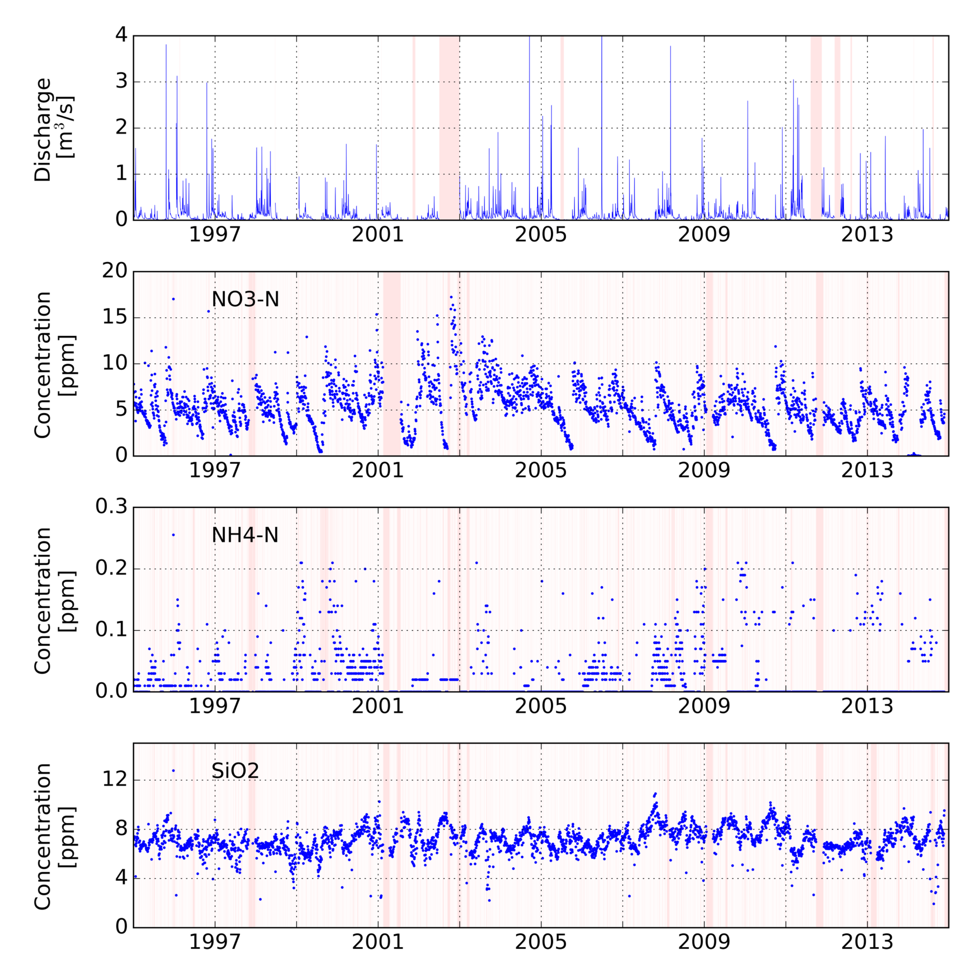
Modeling testbed site description: The USDA's Mahantango experimental catchment



B. Spatially distributed precipitation



C. Discharge and hydrochemistry



A. Groundwater level

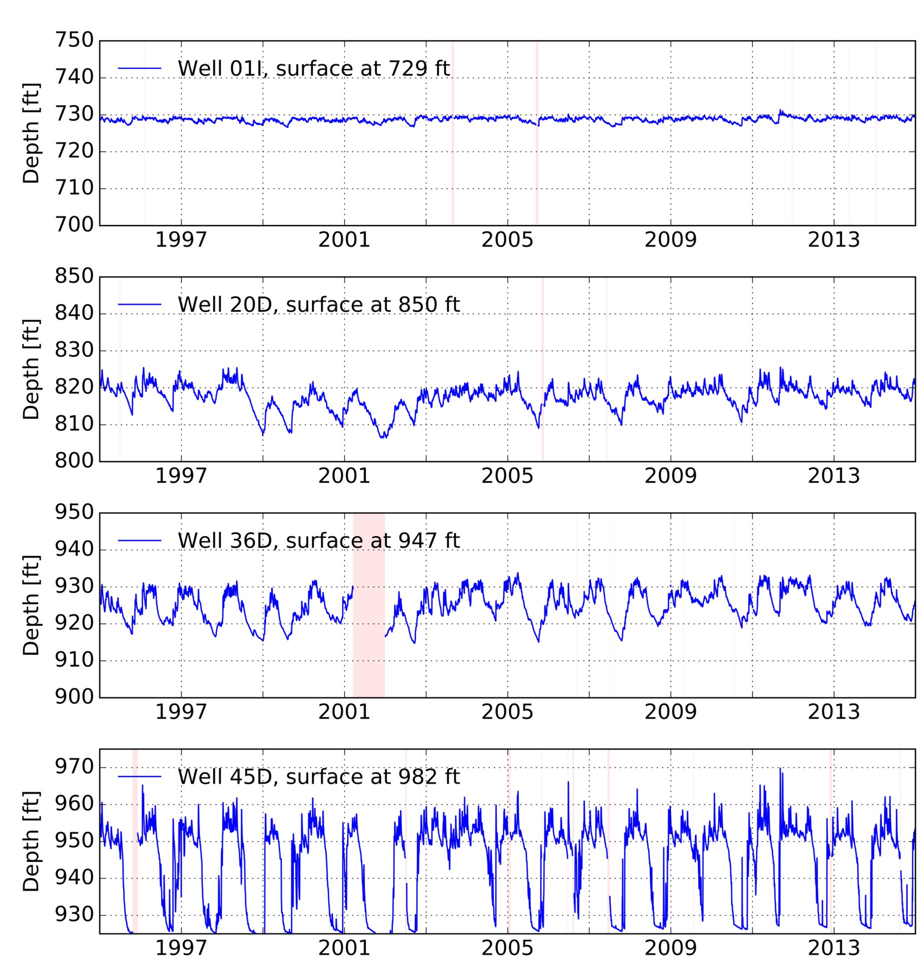


Figure 3 (above and left). A subset of the data available at the WE-38 subcatchment of the Mahantango experimental watershed near Harrisburg, PA. Data described in more detail at [12-13]. Pictures provided by Anthony Buda.

Model setup (in progress)

- The ParFLOW model is being run on the Maryland Advanced Super Computing Center (MARCC) platform.
- Initial model runs with a 100m resolution DEM and highly simplified model domain (e.g., uniform soil properties) are used to progressively test and validate model performance (see Figures left and below).

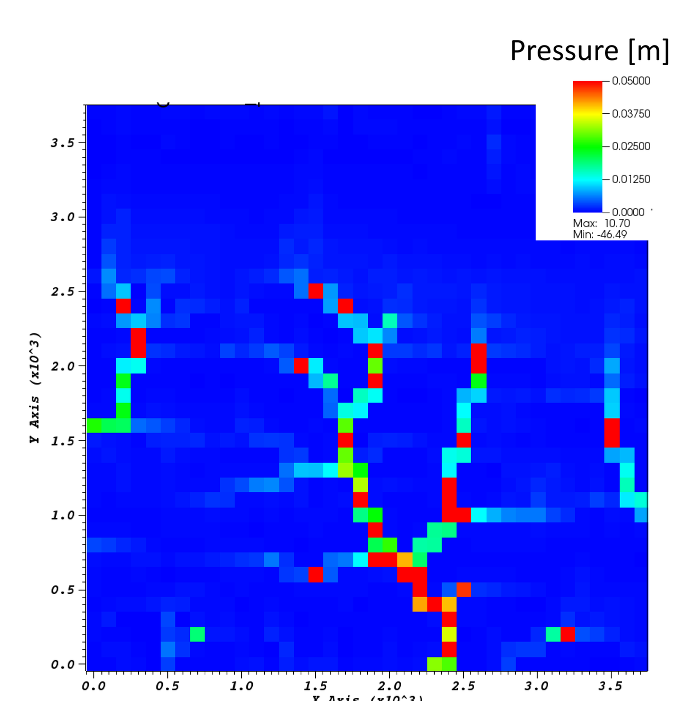
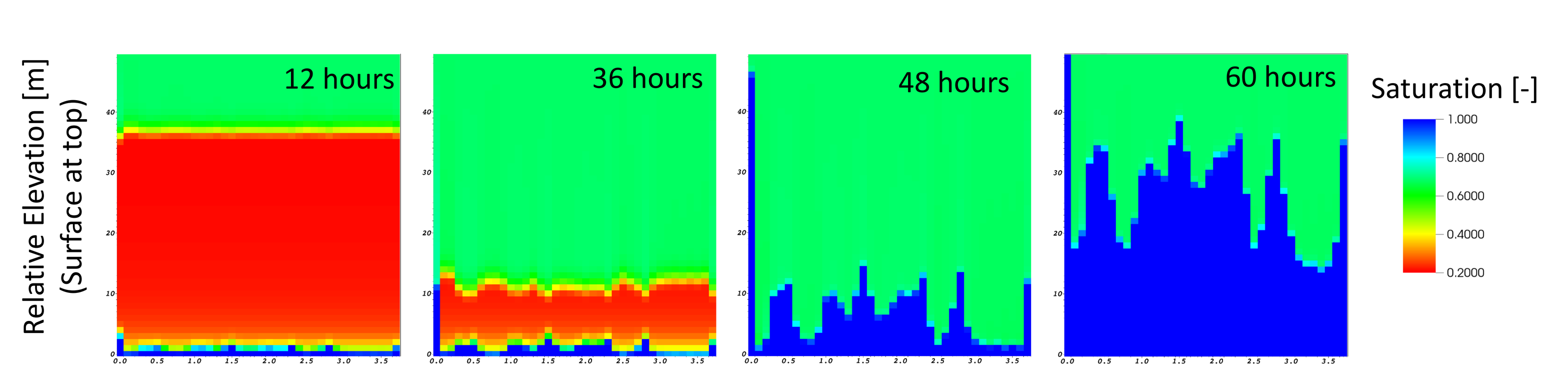


Figure 4 (right). These results from a "parking lot test" suggest that the configuration of the model drainage network is correct. The figure shows the modeled surface pressure of the watershed surface after steady rainfall, with the surface parameterized to be impermeable.

Figure 5 (below): These results illustrate the saturation of the subsurface during model spin-up assuming a high, uniform permeability. The y-axis represents depth (surface = 50m). The x-axis represents distance along a transect of the watershed. Note that the subsurface water level (shown in blue) rises over time, as expected.



Next steps

- The model domain will be populated with available meteorological and surface/subsurface data.
- The resulting flow field will be used to simulate transit times with the SLIM-FAST particle tracking program.
- Model parameters will be calibrated as possible against observed discharge, water level, and groundwater age.
- The model testbed will be forced with plausible climate and physiographic scenarios in order to gauge the significance of climate-induced transit time variability under a range of environments
- The results should help researchers and practitioners determine if and when steady-state TTD estimates provide reliable information under a variable climate.

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