Implications of an “inverse storage effect” (ISE) on the sensitivity of watershed transit times to rainfall variability at Plynlimon, Wales

Daniel C. Wilusz, Ciaran J. Harman, William P. Ball  
Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD 21218  
Email: dwilusz1@jhu.edu

What was our motivation?

- The dynamic flow pathways of a watershed result in a time-varying, probabilistic distribution of water-particle transit times called the transit time distribution (TTD).
- TTDs are important aspects of contaminant transport at the catchment scale (Gibert et al., 2006).
- The shape of the TTD generally depends on the history of rainfall over a watershed, which may shift substantially under a changing climate (Walsh et al., 2016).
- Harman (2015) recently described a generalized means of simulating TTDs using rank Storage Selection (rSAS) functions that is well-suited for studying the dependence of time-varying TTDs on rainfall variability.
- Harman applied the rSAS model to the Plynlimon research catchment and observed an “inverse storage effect” (ISE), in which times with higher catchment storage anomalies were associated with lower catchment transit times (Harman, 2015).

How did we conduct our model sensitivity study?

1. Generate rainfall scenario (J(t)).
2. Model nutrient, storage (Q(t), S(t)).
3. Model Transport scenario (TTDs).
4. Analyze sensitivity of TTD to ISE.

What were the research questions?

- How sensitive are catchment TTDs to the amount and pattern of rainfall?
- How does the presence or absence of an “inverse storage effect” affect the sensitivity of catchment TTDs to the amount and pattern of rainfall?
- To what extent could watershed TTDs be altered by changes in the mean intensity and pattern of rainfall due to climate change?

These questions are explored with a case study in a research catchment.

Where is the study site?

Figure 1: Lower Hafren watershed.  

Figure 2: Illustrative overview of the rSAS model.  

What is the rank Storage Selection (rSAS) function transport model?

Figure 3: Simplified workflow: Rainfall (J(t)) scenarios were developed using observations (McGuire et al., 2006) and a synthetic rainfall generator, and downscaled climate projections. Rainfall and temperature were used to drive the Plynlimon research catchment model using the rSAS transport model (see Figure 2) to simulate tracer data using methods described elsewhere (Harman, 2015). Various statistical techniques were used to move out the association between rainfall patterns and TTDs.

What were the rainfall scenarios?

- Examples of synthetic rainfall scenario: historic observations, synthetic rainfall generator
- The figure shows how the parameters of the generator could be adjusted to simulate different rainfall patterns.

What were the transport scenarios?

- Low storage (dry).
- High storage (wet).

What were the research findings?

Result 1: The coupled modeling experiment did well at simulating historic rainfall, runoff, and transport.

Result 2: Simulated TTDs are very sensitive to mean annual precipitation.

Result 3: The TTD is more sensitive to rainfall pattern when the ISE is included in the model.

Result 4: The TTD is more sensitive to projected future rainfall scenarios when ISE is included in the model.

Result 5: Breakthrough curve simulations show that climate change could accelerate transport, especially in catchments with a strong ISE.

What did we learn?

- An acquired hydrolog transport model was built and validated to simulate the relationship between rainfall variability, catchment storage effect, and time-varying TTDs.
- Simulation results based on Plynlimon base case data suggest that:
  - Simulated TTDs are very sensitive to mean rainfall intensity.
  - The TTD for catchments with an inverse storage effect (ISE) is more sensitive to rainfall pattern.
  - TTDs and breakthrough curves for catchments with an ISE is more sensitive to projected changes in rainfall variability under climate change.
- Model uncertainty may be relatively high in scenario runs that are substantially different from calibration conditions.
- Results suggest that the strength of the ISE in a particular watershed may be a useful indicator of the sensitivity of local transport to rainfall variability and climate change.