Watershed Dynamics and Evolution Science Focus Area

wade.ornl.gov

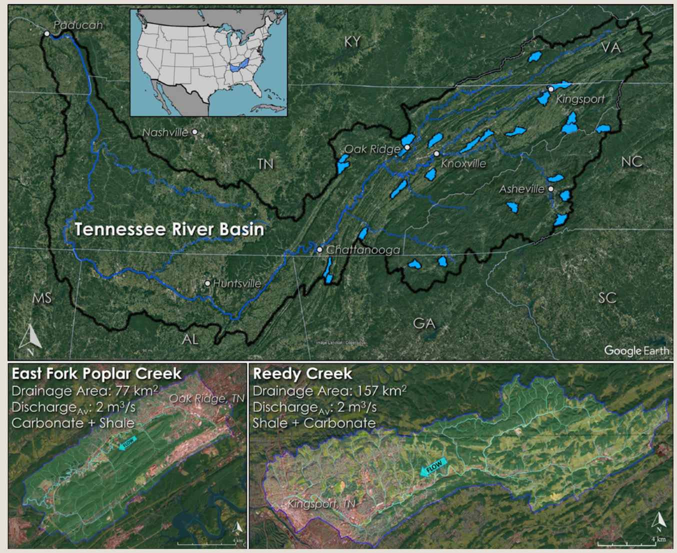
Understanding the role of heterogeneous land cover and hydrologic regime on watershed function

Watersheds are complex systems that provide important freshwater resources for energy production, irrigated agriculture, industry, and human consumption. The economic and societal importance of watersheds—and their vulnerability to environmental stresses—is exemplified in the southeastern region of the United States, which includes the Tennessee River Basin.

Water resources in the southeastern region are vulnerable to changes in land use and land cover (LULC) and a range of climate-induced disturbances. The National Climate Assessment 5 indicates that the southeastern United States will experience higher temperatures, more extreme heat events, and an intensifying hydrologic cycle with more frequent and severe storm and drought events over time. Changes in LULC can alter water storage and partitioning of rainfall into runoff with a host of cascading consequences for ecosystems and their services, while climate change simultaneously changes the frequency and intensity of precipitation events. The impact of these disturbances is exacerbated by existing regional socioeconomic stressors and inequalities.

Predicting the interactive consequences of hydrologic intensification and LULC change on watershed function at local to regional scales first requires an improved understanding of the coupled hydro-biogeochemical processes and feedbacks that link uplands, the shallow subsurface, and stream corridors. Predictions also require an improved understanding of how those processes aggregate and exert control on watershed function along a stream network.

To address this challenge, the U.S. Department of Energy's (DOE) Biological and Environmental Research (BER) program supports the Watershed Dynamics and Evolution (WaDE) Science Focus Area (SFA) led by Oak Ridge National Laboratory (ORNL). WaDE will advance predictive understanding of how dominant processes controlling watershed hydro-biogeochemical function operate under a range of hydrologic regimes and vary along stream networks that drain heterogeneous land covers.



WaDE Watersheds. *The Tennessee River Basin is the most intensively used freshwater water resource region in the contiguous United States, supporting approximately 4.5 million people with estimated withdrawals of more than 280,000 gallons per day per square mile. Research watersheds (blue polygons and insets) were selected to be broadly representative of mid-order watersheds across the Basin to support transferability of process understanding and modeling capabilities.*

Knowledge Gaps

WaDE aims to create a multiscale, model-observation-experiment framework to enable hypothesis-driven research addressing five critical knowledge gaps.

Land Cover Effects on Watershed Function. Insights are needed about if, how, or at what scale land cover influences the generation and export of water and solutes from the landscape to the stream

Key Science Questions

WaDE focuses on watersheds in the Tennessee River Basin in three phases over nine years to answer the following questions:

- How do dynamic flow conditions in non-perennial streams control water and solute export from headwater catchments with varied land cover, and how do these processes influence downstream chemistry and metabolism?
- What are the relative contributions of different stream compartments and microbial communities to stream metabolism, and how and why do these contributions vary in response to land cover, season, and hydrologic events?
- How do the heterogeneity and resiliency of stream metabolism vary in space and time in relation to position along the stream network, land cover, and hydrologic events?
- What is the minimum set of watershed attributes required to predict stream hydro-biogeochemical function at local to network scales? Do these attributes support transferability to other stream networks and hydrologic regimes?

Definitions

Watershed [hydro-biogeochemical] function: The ability of watersheds to store, process, transport, and discharge materials (water, sediment, carbon, nutrients, metals, contaminants, etc.). Encapsulates hydrologic, biological/ecological, and geochemical processes.

Hydrologic regime: A characterization of temporal variability in hydrologic conditions like streamflow, soil moisture content, groundwater levels, and inundation state. Hydrologic variability is determined to a large degree by the frequency and intensity of precipitation events.

Non-perennial stream: A stream that does not have continuous surface water flow throughout the year. Flow can be either intermittent, in response to seasonal changes in baseflow, or ephemeral, in response to precipitation events.

Stream metabolism: A measure of in-stream organismal carbon fixation and respiration by both autotrophs and heterotrophs, which responds to environmental variables that are commonly influenced by catchment disturbance and significantly influences ecosystem functioning and properties, energy fluxes, and water quality.

network and how this affects local and emergent hydro-biogeochemical function within the stream network.

Hillslope-Catchment Interactions. The mechanisms controlling upland-stream interactions are not fully understood, nor is how these interactions vary under different hydrologic regimes and land covers.

Integrated Measures of Watershed Function. Better understanding is needed about how measures of stream function, such as stream metabolism, integrate complex watershed properties that vary in space and time.

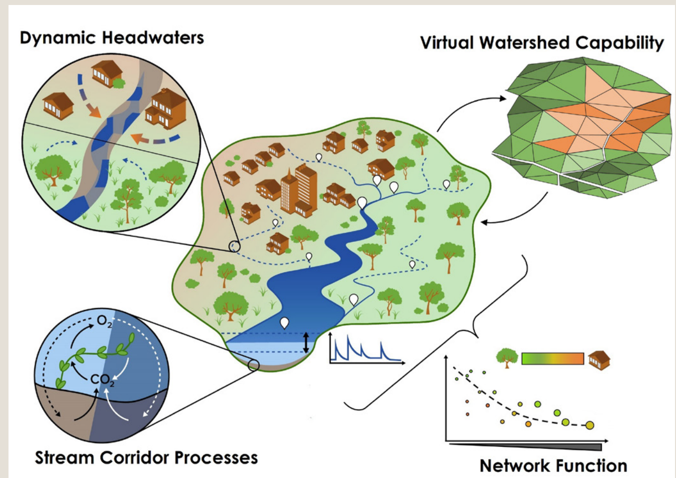
Stream Observational Networks in the United States. Existing observational networks are skewed to higher-order streams and end-member systems with either forested, agricultural, or highly urbanized land covers, leading to insufficient observations of low- to mid-order streams and systems with heterogeneous land cover.

Integrated Modeling. Model predictions of watershed function at the scale of basins or the continental United States under changing climate scenarios are uncertain because of incomplete mechanistic understanding of how key processes depend on land cover and hydrologic regimes.

Integrated Model-Observation-Experiment Framework

During WaDE's nine-year, phased plan, researchers will focus successively on three mid-order watersheds to support systematically translating, applying, and refining the process understanding and virtual watershed modeling capabilities gained from one watershed to increasingly disparate systems. Study watersheds are evaluated and selected to be broadly representative of the Tennessee River Basin. The WaDE SFA is organized around three integrated research themes and a crosscutting modeling activity.

- **Dynamic Headwaters:** Evaluate how biogeochemical processes respond to variable saturation in non-perennial channels.
- **Stream Corridor Processes:** Assess the resilience and resistance of metabolism to disruptions either directly or indirectly associated with land cover and in response to seasons and hydrologic events.
- **Network Function:** Resolve the network-scale organizational controls on metabolic regimes in watersheds with heterogeneous land cover.
- **Virtual Watershed Capability:** Provide a configurable virtual watershed capability focused on watershed hydrology, water temperature, and stream metabolism that can support a variety of numerical experiments and aid in designing and interpreting empirical experimental approaches.



Integrated Research Themes and Crosscutting Modeling Activity.

Collaborative Science and Alignment with Grand Challenges

This multidisciplinary, multi-institutional project led by ORNL spans six partner institutions and takes advantage of expertise in environmental subsurface science, climate change science, biological systems science, ecohydrology, hydrology, computational science, and world-class high-performance computing facilities. The research directly contributes to three of five scientific grand challenge topics developed by BER's Earth and Environmental Systems Sciences Division: integrated water cycle, biogeochemistry, and model-data integration.

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