Spatial turnover in the composition of biological communities is governed by (ecological) Drift, Selection, and Dispersal. Commonly applied statistical tools cannot quantitatively estimate these processes, nor identify abiotic features that impose these processes. For interrogation of subsurface microbial communities distributed across two geologically distinct formations of the unconfined aquifer underlying the Hanford Site 300 Area in southeastern Washington State, we developed an analytical framework that advances ecological understanding in two primary ways. First, we quantitatively estimate influences of Drift, Selection, and Dispersal. Second, ecological patterns are used to characterize measured and unmeasured abiotic variables that impose Selection or that result in low-levels of Dispersal. We determined that (i) Drift alone consistently governs \( \sim 25\% \) of spatial turnover in community composition; (ii) in deeper, finer-grained sediments Selection is strong (governing \( \sim 60\% \) of turnover), being imposed by an unmeasured, but spatially structured environmental variable; (iii) in shallower, coarser-grained sediments Selection is weaker (governing \( \sim 30\% \) of turnover), being imposed by vertically and horizontally structured hydrologic factors; (iv) low-levels of Dispersal can govern nearly 30\% of turnover and be caused primarily by spatial isolation resulting from limited exchange between finer and coarser-grain sediments; and (v) highly permeable sediments are associated with high-levels of Dispersal that homogenize community composition and govern over 20\% of turnover. This framework provides inferences that cannot be achieved using pre-existing approaches, and suggests that their broad application will facilitate a unified understanding of microbial communities. These approaches are being applied to molecular analyses of microbial communities in the Hanford 300A subsurface and Columbia River hyporheic zone to assess system-scale ecological impacts of river water intrusion into the subsurface during the spring runoff.