Groundwater discharge and contaminant fluxes along a channelized Coastal Plain stream

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Introduction
Groundwater discharge can contribute to the morphological evolution of streams, particularly in unconfined sediments, and to solute (including contaminant) loads in surface water. However, the possible interplay between seepage erosion and solute fluxes has received relatively little attention. We examined this interplay along Little Bayou Creek, an 11-km-long, first-order tributary to the Ohio River in the Gulf Coastal Plain of western Kentucky (Fig. 1) (LaSage et al., J. Hydrol. 252-256 (2000b), 265-280 (2000a)). Between 1993 and 1997, the lower 0.5 km of the creek was channelized around a Tennessee Valley Authority (TVA) coal-fired power plant. Baselflow above the channelized reach is sustained by an outfall at the U.S. Department of Energy (USDOE) Paducah Gaseous Diffusion Plant (PGPD), a uranium-enrichment facility and Superfund site. Springs occur along the upper 300 m of the channelized reach, where the creek partly intercepts plumes of dissolved trichloroethene (TCE, a chlorinated solvent) and technetium-99 (^99Tc, a by-product of U reprocessing) from PGPD (Fig. 2).

Geology and Physical Hydrology
The study area is underlain by ~100 m of unconsolidated fluvial sediments, lenses, and alluvium (Cretaceous-Holocene) atop Mississippian carbonate bedrock. The primary aquifer, the informally-named Regional Gravel Aquifer (RGA), occurs within the Mounds Gravel (Miocene-Pliocene) and is semi-confined by the Clayey Metapelite Formation (Pliocene), which is exposed along much of the stream (Figs. 5, 6). Springs appear to occur where fractures or coarse-sediment “stringers” intersect the channel (Fig. 6) (LaSage et al. 2008a). Meteorological data from the Paducah National Weather Service station (6 km SE of PGPD) and stream flow data from a U.S. Geological Survey gage adjoining site LBC-8 (on Fig. 1) enabled us to corroborate basflow conditions during monitoring. The area is humid-temperate: daily average temperature (T) ranged from 0.5 °C in Jan. to 25.7 °C in July (1971-2000), and annual average precipitation was 125 cm, with P > actual ET Oct. – May (LaSage et al. 2008a).

We gaged stream flow by wading (Fig. 5) and spring flow using a bucket and stopwatch, where feasible, coincident and annual average precipitation was 125 cm, with P > actual ET Oct. – May (LaSage et al. 2008a). We corroborated evidence of groundwater discharge by monitoring T at springs. For the eight springs with at least four seasons of data, average T varied from 13.9 °C to 14.6 °C, similar to annual average air T (13.8 °C). We also used a stainless-steel probe with a digital thermometer, at a spacing of 3 m along the stream and 0.9 m across the stream, along a 286-m reach Aug. 8-12, 2002 (Figs. 9, 10). Relatively cold zones (defined as T < 16.5 °C) tended to be localized where probe penetration depths were greatest, although the converse was not always true (Fig. 10), which may indicate abandoned flow of groundwater discharge. Cold zones occupied ~7.5% of the area of the probed reach, consistent with focused groundwater discharge (LaSage et al. 2008a).

Contaminant Fluxes
Contaminant concentrations in stream water (Fig. 11) fluctuated seasonally, but not always synchronously with stream flow (Fig. 7), which suggests discharge occurs from different parts of the RGA at different times of year (LaSage et al., J. Hydrol. 252-256 (2000b)). We calculated net contaminant fluxes along stream reaches as \( u \frac{dQ}{dt} \), where \( u \) is velocity and \( Q \) is stream flow (L3/t), and the subscripts d and u represent downstream and upstream sites, respectively. Because anaerobic biodegradation and sorption of TCE and ^99Tc are non-volatile, we also used correlations between concentrations in springs to estimate TCE influxes prior to volatilization. Contaminant influxes between LBC-5 and 4 varied seasonally with Q and were dominated by a few springs (Fig. 12). Estimated TCE mass loss by volatilization along that reach varied from 0 to 49%, but did not show seasonality, perhaps because of errors in gauging, concentration measurements, and regressions. Downstream, effluxes between LBC-4 and 3 were positive for all sampling rounds for TCE, consistent with volatilization, but fluctuated around 0 for ^99Tc (Fig. 12). Because Q increases with both velocity and stream depth, whereas volatilization should increase with velocity and decrease with depth, volatilization should not simply track stream flow, but is likely to vary seasonally with T (LaSage et al. 2008a).

In summary, mixing with less-contaminated groundwater appears to dilute TCE and ^99Tc in springs, while effluxes occur mainly by volatilization, in contrast to streams receiving diffuse seepage of VOCs (Fig. 13).