Spatial and seasonal variability in groundwater discharge and contaminant fluxes along a channelized stream in western Kentucky

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Introduction

Natural streams are dynamic systems and fluvial morphology is likely to change over time and space. We are investigating the variability in groundwater discharge patterns along a channelized stream (Little Bayou Creek) (Fig. 1) at various timescales (diurnal, seasonal, annual, and decadal) and the extent to which the discharge sites are spatially persistent. Because the stream is located in unlithified sediments, discharge rates of springs appear to fluctuate with soil piping (Fig. 2) and collapse along joints in fractured clay.

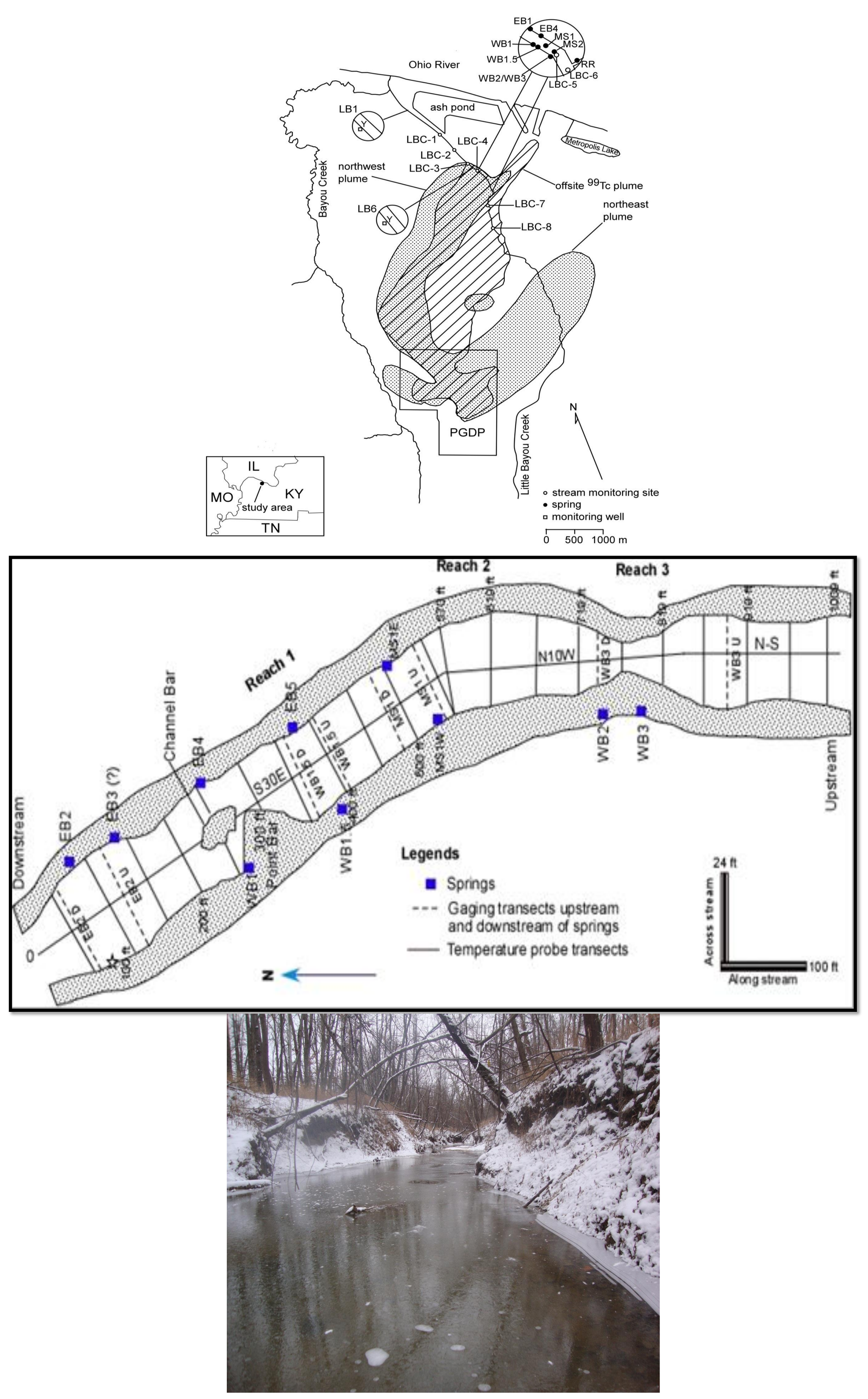

Figure 1. Maps of study area (top) (LaSage et al., 2008a) and study reach (middle), and view of the study reach in Jan. 2011 (bottom).

Understanding patterns of groundwater discharge along a stream can be important for assessing the fate and transport of aqueous contaminants. Depending upon the chemistry of contaminants and the geologic setting, contaminants in groundwater may be attenuated (e.g., by processes such as adsorption and biodegradation) in the discharge zone. The study reach of the stream has been contaminated by plumes of groundwater containing the chlorinated organic compound trichloroethene (TCE) and the radionuclide technetium-99 (^{99}Tc) released as a result of past activities at the U.S. Department of Energy's Paducah Gaseous Diffusion Plant (PGDP). If contaminant fluxes from groundwater to Little Bayou Creek are spatially focused, then targeted remediation approaches (such as installing passive reactive barriers in the discharge zone) may be feasible.

Methods

Stream discharge was measured upstream and downstream of major visible bed and bank springs along a ~300-m section of Little Bayou Creek (Fig. 1). Baseflow discharge was measured by seasonal gauging during the periods June 1999–October 2002 (LaSage et al., 2008b) and October 2010–June 2011. Spring discharge was measured using a stop watch, bucket and graduated cylinder.

We conducted tracer tests using the fluorescent dye rhodamine WT in January and June 2011. Dye samples were collected at four downstream locations and concentrations were measured using a spectrophotometer. Breakthrough curves for individual sampling locations were obtained by plotting dye concentration against sampling time (Fig. 3). Net stream discharge at each sampling location was determined by calculating the area under the curve and the travel time was determined using a MatLab subroutine for centroid calculation. Water samples were collected at gauging sites (Jun. 1999–Oct. 2002 [LaSage et al., 2008a] and during Jan. and Jun. 2011) and springs (Jun. 1999–Oct. 2001 [LaSage et al., 2008a] and during Jan. and Jun. 2011) for analyses of volatile organic compounds (VOCs).

Figure 2. Soil pipe along the stream bank (left) and west bank spring WB3 (right).

Results and Discussion

Discharge in general increased downstream during all measurement periods (Jun. 1999–Oct. 2002 [LaSage et al., 2008b] and Oct. 2010–Jun. 2011) (Fig. 4). Maximum discharge occurred during May-June and and minimum discharge occurred during January. Stream discharge was greater in Jun. 2011 than in either Oct. 2010 or Jan. 2011 for all gaging locations (Fig. 5a). The reach was gaged only upstream of spring WB3 and downstream of EB2 by LaSage et al. (2008b). Spring discharges were greater during May-June than during January, consistent with stream discharge trends (Fig. 5b). Spring orifices evolved as a consequence of soil piping, but, in general, their locations did not appear to migrate more than a few meters between 1999 and 2011.

In January 2011, dye-dilution discharge was greater than the gaged discharge at three of four sites. In particular, a large difference (32%) between dye-dilution and gauged values at one site suggests considerable flow in the hyporheic zone. In June 2011, dye-dilution discharge was less than the gaged discharge at two of four sites and almost equal at the other two sites (Fig. 6).

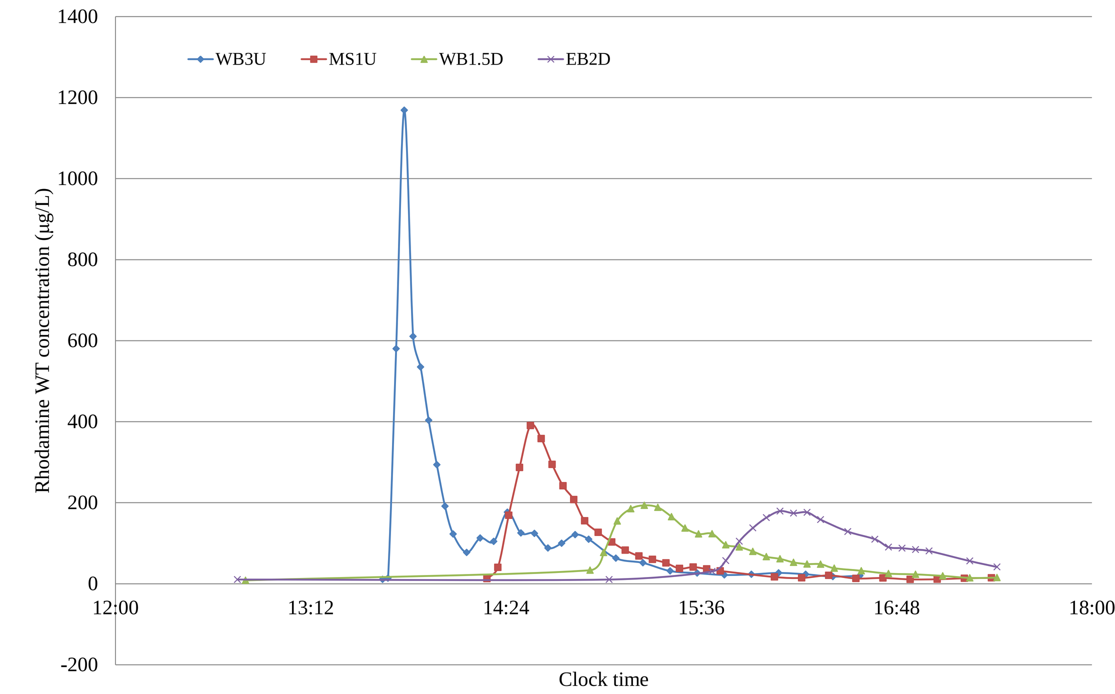

Figure 3. Breakthrough plots for different sampling locations downstream of dye injection location in January 2011.

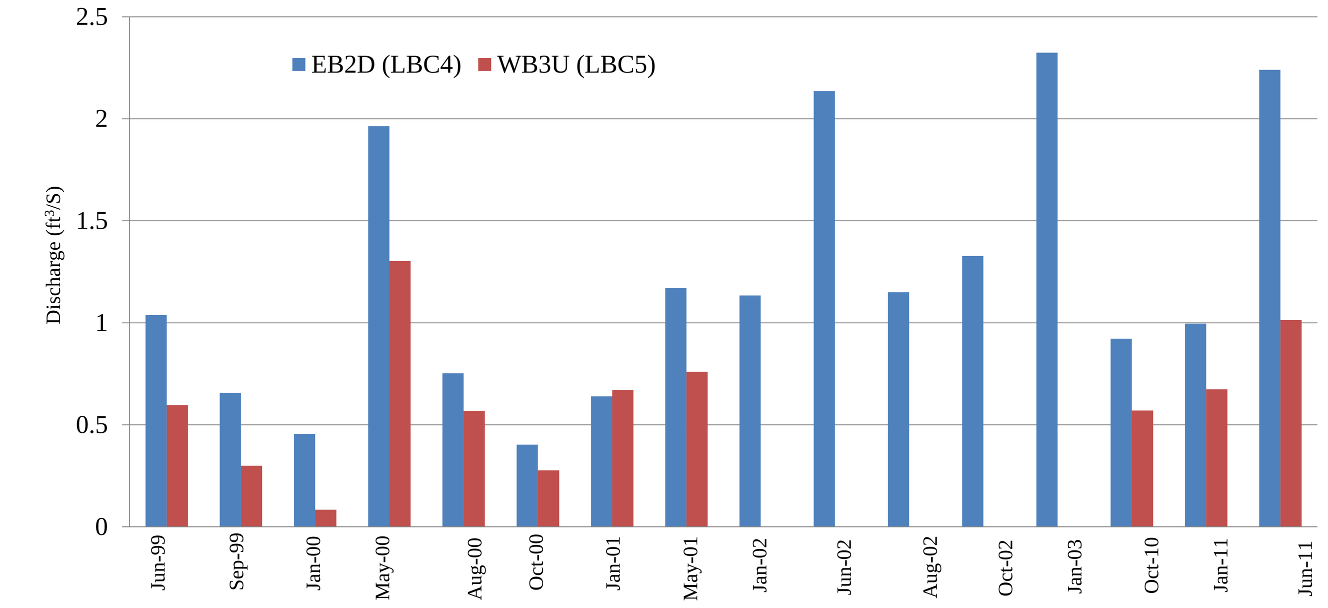

Figure 4. Stream discharge at farthest down- and up stream locations.

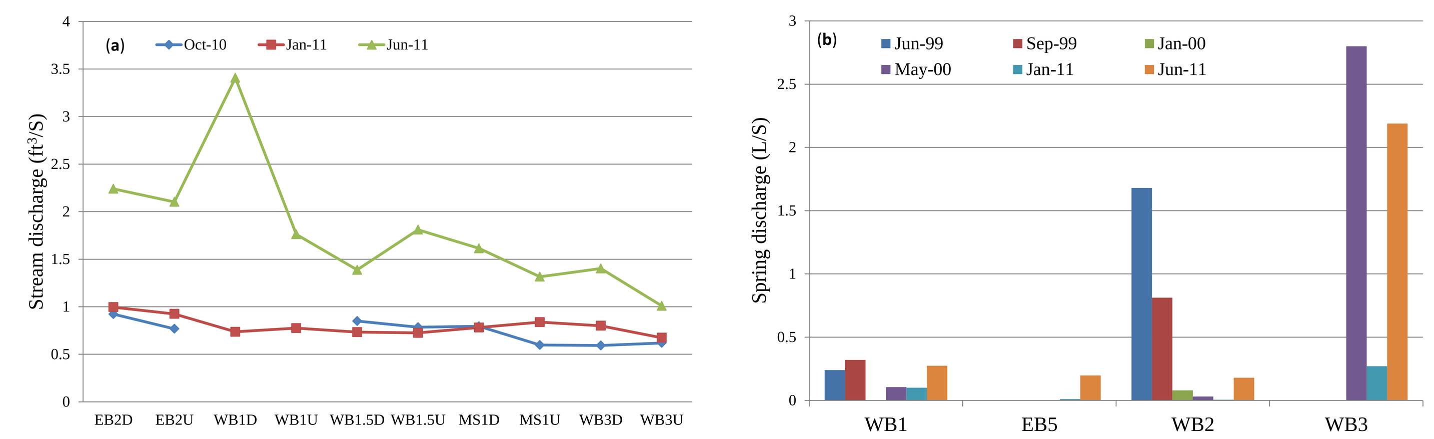

Figure 5. (a) Stream discharge measured up- and downstream of visible springs. (b) Spring discharge measured by conventional method.

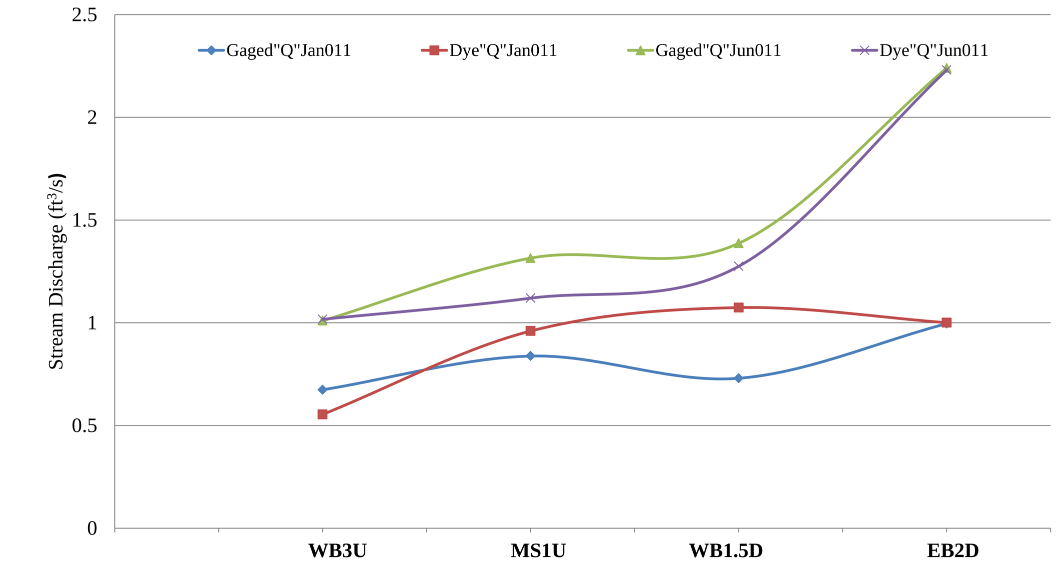

Figure 6. Comparative plots of gaged and dye dilution discharge for January and June 2011.

TCE was the only VOC routinely detected. Its concentrations in surface water during January 2011 were below detection limit (BDL, < 5 µg/L) upstream of the major springs and 5.4 µg/L at the downstream end of the reach (Fig. 7). Similarly, TCE concentrations during January 2000, 2001, and 2002 were < 5 µg/L upstream of the major springs and 7.5–18 µg/L at the downstream end of the reach (LaSage et al., 2008a) (Fig. 7). For June 1999, 2002 and 2011, TCE concentrations ranging from 22–63 µg/L were detected at the farthest downstream site. During both study periods, TCE concentrations in springs tended to decrease with distance downstream. However, TCE concentrations in springs during January and June 2011 (<5 to 160 µg/L) were notably lower than for January 2000 and 2001 (37–420 µg/L) (LaSage et al., 2008a) (Fig. 8). We attribute this decrease to the implementation of an upgradient pump-and-treat system.

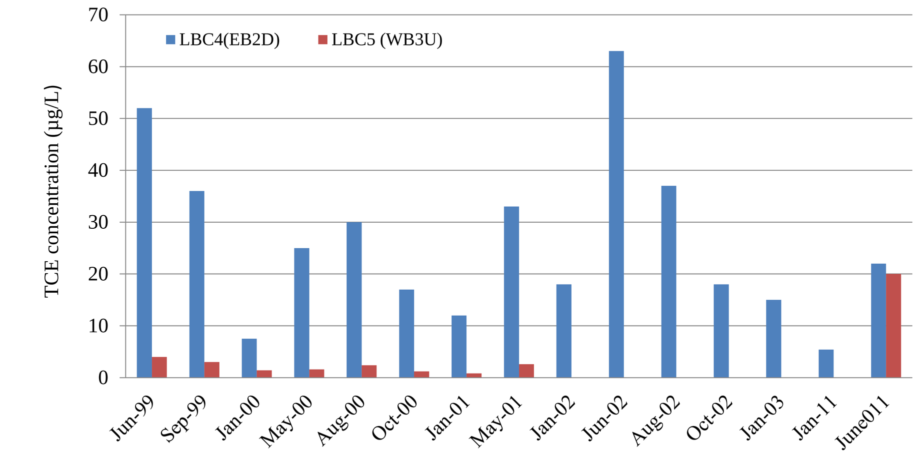

Figure 7. TCE concentration in stream at farthest upstream and farthest downstream sampling sites along the study reach .

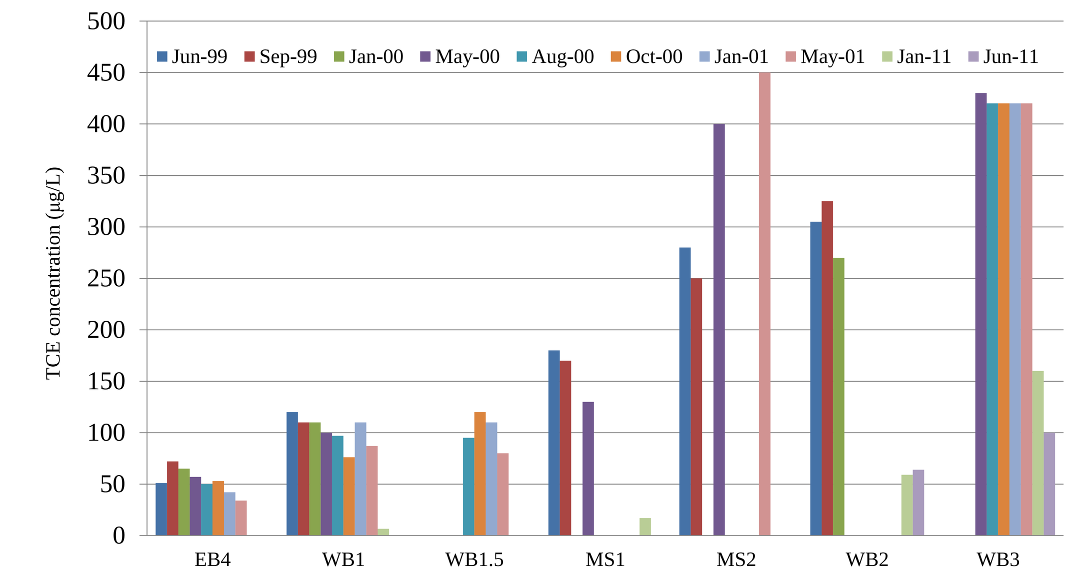

Figure 8. TCE concentration in springs along the study reach.

Conclusions

- Locations of major springs along the study reach have not shifted more than a few meters since 1999, although new orifices have emerged during that time.
- Discharge values tend to be greater during late spring–early summer than early winter. Stream discharge tends to increase from the upstream end to the downstream end of the study reach, but does not increase monotonically along the reach.
- TCE concentrations in both stream and spring water have been lowered considerably between 2001 and 2011.

References

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LaSage, D.M., Sexton, J.L., Mukherjee, A., Fryar, A.E., Greb, S.F., 2008b. Groundwater discharge along a channelized Coastal Plain stream. J. Hydrol. 360, 252-264.