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A comparison of methods to determine locations and magnitudes of groundwater influx to rivers

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There are currently several methods available for determining both the spatial distribution and magnitude of groundwater inputs to rivers and streams. Methods range from physical flow gauging to introduced and natural tracers, all of which have varied levels of resolution and suitability to specific system conditions. We compared the results of tracer analyses (using fluorescent dye, heat, and geochemical end-members) to physical flow measurements along 900 m of Ninemile Creek in Syracuse, New York, USA during summer low-flow conditions (discharge = 1.4 m^3/s). Temperature measurements were made using an Agilent Distributed Temperature Sensor (DTS) which recorded temperature at 1.5 m increments over the length of a fiber optic cable installed along the thalweg at the sediment-water interface. The 24 hr mean and standard deviation of these measurements indicated one region of focused groundwater input to the river of $\sim$ 0.07 m^3/s. A constant rate injection of Rhodamine WT dye also identified an influx of groundwater over the same region of $\sim$ 0.07 m^3/s. Geochemical samples were collected every 50 m along the reach, and the groundwater end-member, which is highly saline, was sampled from shallow piezometers installed in the stream bed and bank. End-member mixing models between stream and groundwater using calcium and chloride also generated estimated gains of $\sim$ 0.07 m^3/s over the same reach location. In contrast to these results, physical flow measurements made approximately every 100 m using a handheld FlowTracker acoustic Doppler velocimeter failed to identify, much less quantify, the focused groundwater input. The failure of the physical flow measurements was attributed to the high variability in discharge estimates, which had a standard deviation of 0.13 m^3/s. The measurement variability likely resulted from stream turbulence due to high velocities, extensive macrophyte growth and non-ideal channel bedform. These results indicate that the use of natural tracers such as heat and geochemical mixing can yield spatially and quantitatively refined estimates of relatively modest groundwater inflow (i.e. 5% of the total streamflow) even in large streams or rivers. Physical flow gauging may not capture these fluxes due to large measurement error under non-ideal conditions. DTS heat tracing in particular may be more universally applicable than geochemical methods which depend on a unique and consistent groundwater end member. Additionally DTS measurements can be made at high spatial resolution with relative ease compared to introduced conservative tracers.