

Stream-Air Temperature Relationships as Indicators of Groundwater Inputs

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Groundwater inputs are important to streams for their influence on stream hydrology and ecology (Hayashi and Rosenberry 2002). Spatial variability of groundwater inputs to streams is common due to aquifer heterogeneity, slope, and variability in land cover. Groundwater withdrawals may also affect groundwater inputs to streams by pirating water from them. In the past, groundwater inputs to streams have been quantified by seepage runs, seepage meters, piezometers, tracers, and numerical models.

In karst settings (limestone and dolomite bedrock), seasonal and diurnal water temperature variations have been used to indicate the nature of aquifers draining to springs (Schuster and White 1971). Springs with large diurnal and seasonal water temperature variations are thought to derive much of their flow from conduit or fracture-flow systems that rapidly discharge to the stream, often resulting in "flashy" hydrographs. Springs with subdued diurnal and seasonal water temperature variations are thought to derive their discharge from slowly draining diffuse aquifer systems, where the subsurface flow through porous media is more important than the flow through large fracture or conduit networks.

In the Spring Creek watershed, Centre County, Pennsylvania, we used water temperature as an indicator of groundwater inputs along 5 streams. Runoff occurs off of shale and sandstone ridges in the uplands and limestone and dolomite bedrock on the valley floors. Groundwaters upwelling from deep aquifers tend to have temperatures around the annual mean air temperature; approximately 11° C. Streams with large groundwater inputs tend to show small temperature changes in response to meteorological conditions, whereas those streams with little or no groundwater inputs

have temperature regimes that are very responsive to meteorological conditions. The effects of groundwater withdrawals and wastewater inputs to water temperatures of Spring Creek and its tributaries are a significant concern in this watershed because of its prized coldwater fisheries and numerous large springs. The Pennsylvania Department of Environmental Protection has designated Spring Creek as a high-quality, cold-water fishery since 1994.

In order to address various water quality issues in the watershed the Spring Creek Watershed Community and ClearWater Conservancy initiated the Water Resources Monitoring Project in 1998 and set up a network of 12 monitoring stations along Spring Creek and its tributaries (Figure 1) (ClearWater Conservancy 2004). At these stations water temperature, streamflow, and water chemistry data were collected on an hourly basis from 1998 until the present. These long-term data were used to complement water temperature data collected for various other projects in the watershed aimed to detect groundwater inputs and their variability over time and across the watershed (O'Driscoll 2004).

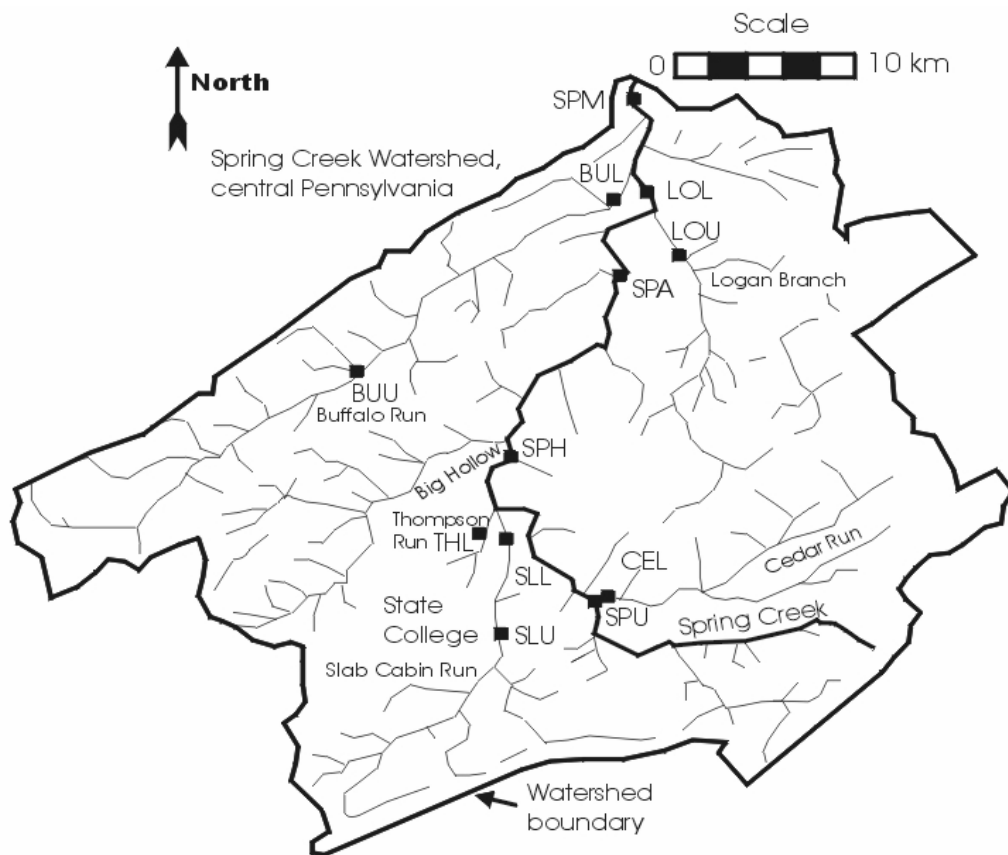


Figure 1: The Spring Creek Watershed, central Pennsylvania, and locations of water quality and streamflow monitoring sites maintained by the ClearWater Conservancy (2004) (SL=Slab Cabin Run, SP= Spring Creek, CEL = Cedar Run, THL=Thompson Run, BU=Buffalo Run, and LO= Logan Branch).



Figure 2: Seasonal variability in streamflow at Upper Slab Cabin Run, State College, PA. (This site is adjacent to a municipal wellfield that may pirate water from the stream. During dry periods this stream is typically losing water and often goes completely dry).

We used the relationship between weekly average air temperature and surface water temperature as an indicator of groundwater inputs for a period of three years (1999-2002). Weekly average air temperatures can provide good predictions of weekly average surface water temperatures. These data were complemented with streamflow data collected at the stations. Nested streamflow data over the same period indicated that several of the streams were strongly gaining groundwater (Logan Branch and Thompson Run) and several of the streams frequently lost water (Buffalo Run and Slab Cabin Run-Figure 2) (O'Driscoll et al. 2004).

A comparison of stream-air temperature relationships between a strongly groundwater-fed stream (Thompson Run) and a losing stream (Buffalo Run) suggests that stream water temperature records paired with local air temperature records can indicate the relationship a stream has with the underlying groundwater system (Figure 3). Stream temperature regimes that are strongly influenced by groundwater inputs have gentle slopes and large intercepts (the numerical temperature value where the trendline crosses the vertical axis) due to their lack of responsiveness to changing meteorological conditions. This is due to the fact that groundwater discharge is close to mean annual air temperature and during summer months this discharge acts as an energy sink when it is much cooler than air temperature. In the winter groundwater discharge acts as an energy source, when it is much warmer than air temperature. The net result is a buffering effect on extreme water temperatures. Stream temperature regimes that are not affected by groundwater inputs are very responsive to changing meteorological conditions. Stream-air temperature relationships for these perched or losing streams have steep slopes and intercepts closer to zero.

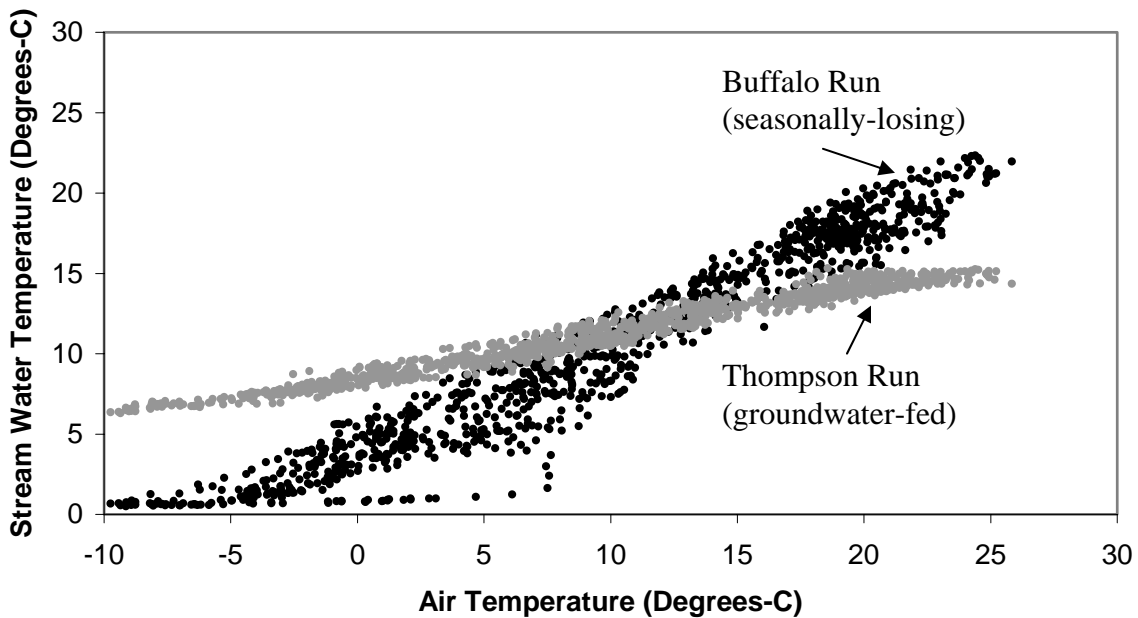


Figure 3: Weekly average water (stream) temperature versus air temperature for a groundwater-fed stream (Thompson Run) and a seasonally losing stream (Buffalo Run) for the period of October 1999-September 2002.

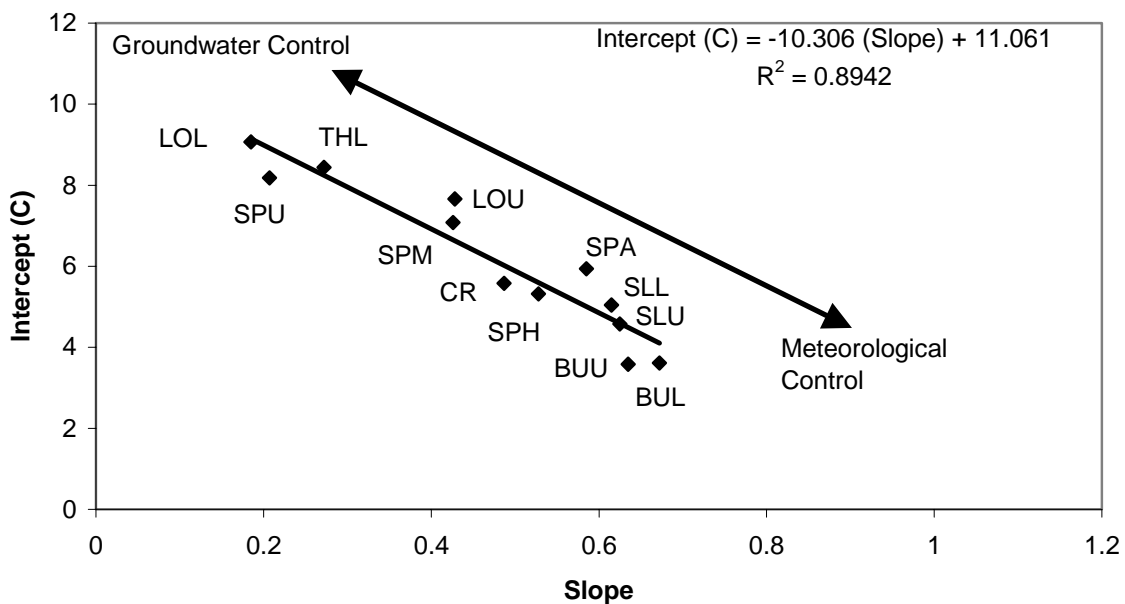


Figure 4: A summary of slopes versus intercepts for weekly stream-air temperature relationships for the three-year study period for all monitoring locations.

The stream-air temperature relationships revealed that those with gentle slopes and large intercepts tended to be strongly groundwater-fed and those with steep slopes and small intercepts tended to be streams that were perched or losing and did not receive substantial groundwater inputs (Figure 4). Stream temperatures for perched or losing streams are typically controlled by the meteorological conditions.

Water temperature data is readily available for many watersheds and recent developments in sensor technology allow water temperature records to be collected inexpensively at remote sites. Water temperature records can be useful complements to hydrologic studies and watershed assessments because they can provide information on the strength of groundwater inputs when flow data is not readily available. In locations with complex geology, groundwater inputs may be highly variable, both seasonally and across the landscape. Water temperature data can provide indications of the locations of groundwater inputs along streams in karst and other hydrogeological settings. This information can be useful for the management of fisheries, riparian vegetation, and groundwater withdrawals.

References

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