Quantification of water fluxes at the stream-groundwater interface using mapped streambed temperatures

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AquaTerra

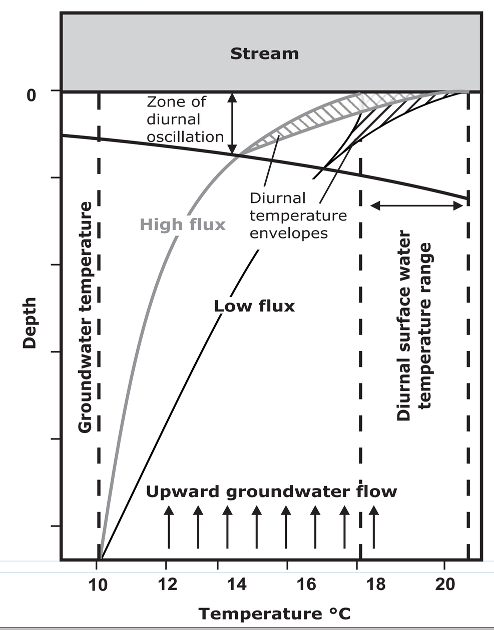
1 Introduction and Objective

The quantification of water fluxes through the streambed with fine spatial resolution on a large scale can be crucial to understanding near-stream flow dynamics and accurately assessing the distribution of contaminant transport across the groundwater/surface-water interface.

The objective of our study was to develop a methodology to determine the magnitude of groundwater discharge with fine spatial resolution along a reach of a stream. We show that streambed temperatures can be used to delineate patterns of groundwater discharge to a stream and to quantify the water fluxes in fine detail on the scale of stream reaches with lengths of hundreds of metres.

2 Basic Concept

The horizontal and vertical temperature distribution in the streambed is a result of heat transport by the flowing water (advective heat flow) and by heat conduction through the sediment grains and the pore water (conductive heat flow) of the saturated sediments. On the basis of mapped streambed temperature profiles, the vertical water fluxes through the streambed can be quantified. For example, in summer, relatively low streambed temperatures are related to groundwater discharge zones.



3 Field Methods and Analytic Procedure

Streambed temperature mapping

The streambed temperatures were measured by temporarily inserting a multilevel stainless steel temperature probe with attached data logger to a depth of 0.5 m along longitudinal transects. Along the probe five temperature sensors are placed in a way that the temperatures are simultaneously measured at 0.1 m, 0.15 m, 0.2 m 0.3 m and 0.5 m below the streambed surface.

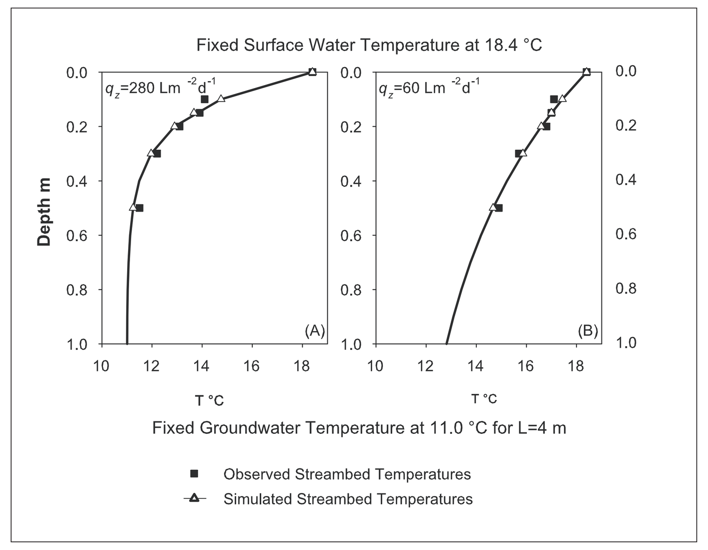
Analytic procedure

We applied a simple steady-state analytical solution of the one-dimensional heat diffusion-advection equation to quantify water fluxes for each temperature profile (Bredehoeft and Papadopolus, 1965):

$$\frac{T(z)-T_0}{T_L-T_0}=\frac{\exp\left(\frac{-q_z\rho_f c_f}{K_{fs}}z\right)-1}{\exp\left(\frac{-q_z\rho_f c_f}{K_{fs}}L\right)-1}$$

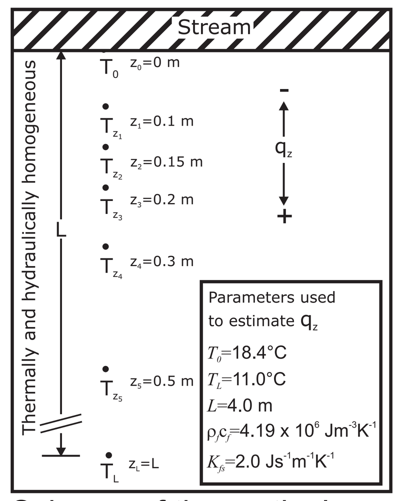
$T(z)$ = the streambed temperature [°C] at depth z (positive downward)
q_z = the vertical Darcy velocity [ms^{-1}] (positive upward)
K_{fs} = thermal conductivity of the saturated sediment [$Js^{-1}m^{-1}°C^{-1}$]
$T(z)=T_0$ for $z=0$, and a fixed temperature T_L for $z=L$, where L [m] is the vertical extent of the domain

The vertical Darcy velocity q_z is obtained at each temperature profile by minimizing the error between the observed and modeled temperatures.

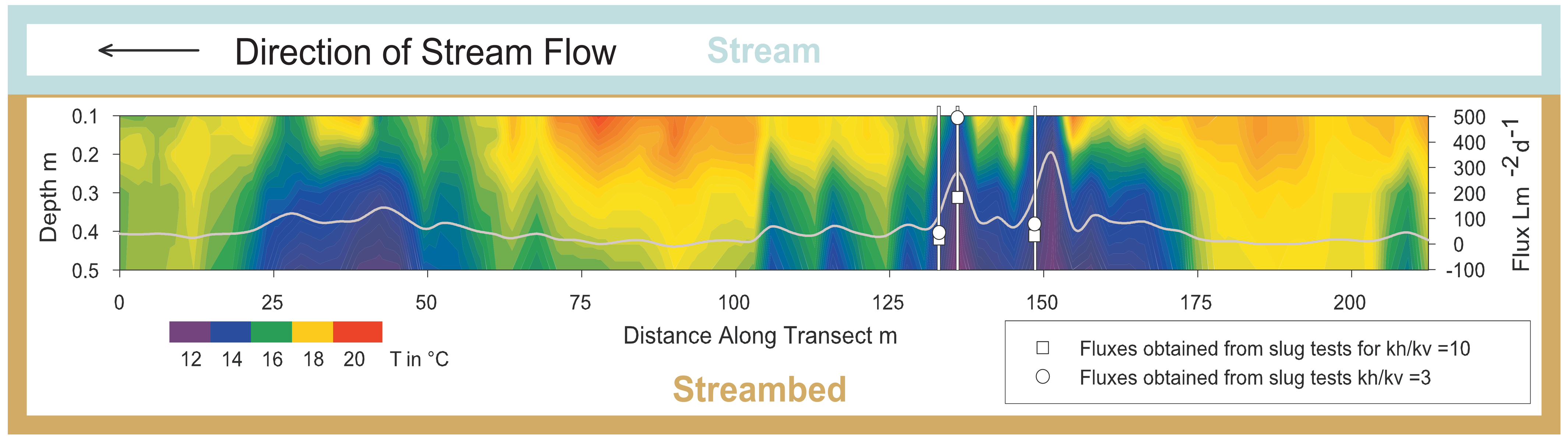


4 Field Application Schachtgraben, Wolfen, Germany - Reach Length 220m - Summer

The Schachtgraben is a man-made stream at the fringe of the so-called megasite Bitterfeld. It is characterized by a diffuse groundwater contamination with a variety of organic compounds but mainly chlorinated benzenes. To understand degradation and sorption processes in the streambed it is crucial to characterize the flow patterns between groundwater and stream water.

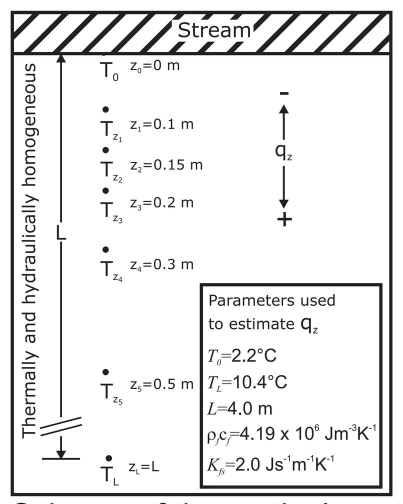


Scheme of the vertical temperature profiles

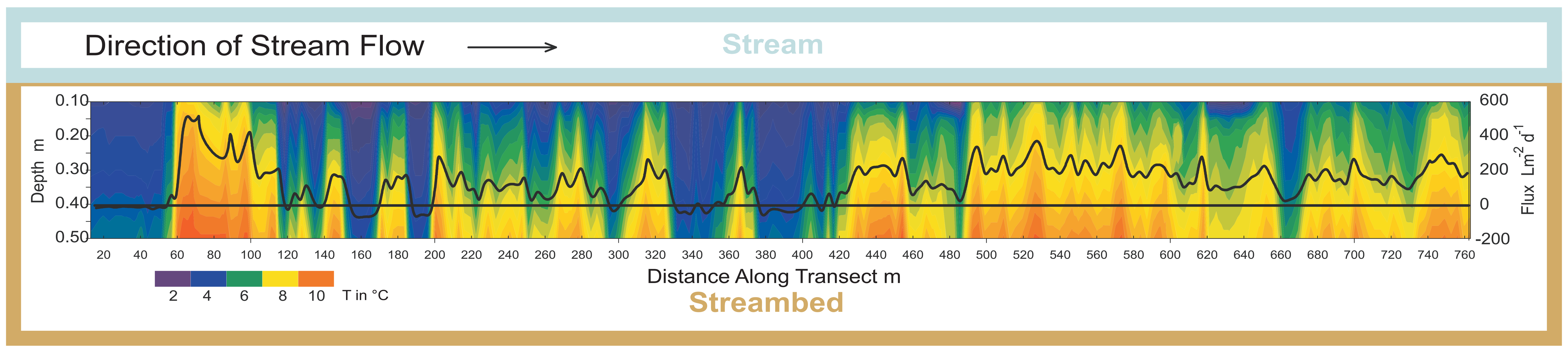


5 Field Application Schaugraben, Falkenberg, Germany - Reach Length 750m - Winter

The Schaugraben is a small channel that drains an agricultural used lowland catchment. The discharging nitrate-rich groundwater influences the nitrogen dynamic in the channel. The quantification of the water fluxes is crucial for the understanding the nitrate transport- and turnover in the catchment.



Scheme of the vertical temperature profiles



6 Our Message

Mapping temperature gradients between the aquifer and the surface water is a simple and effective method to investigate flow patterns at the groundwater- surface water interface with high spatial resolution on the scale of stream reaches.

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Acknowledgements:

This work was supported by the European Union FP6 Integrated Project AquaTerra (Project no. 505428) under the thematic priority "Sustainable Development, Global Change and Ecosystems".

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