HIGH RESOLUTION TEMPERATURE MEASUREMENTS AND HYDRAULIC-ENERGY BALANCE MODELLING TO QUANTIFY LATERAL INFLOWS IN A FIRST ORDER STREAM

M. Westhoff, T. Bogaard, H. Savenije

University of Technology, Delft, The Netherlands
m.c.westhoff@tudelft.nl

To address the problem of equifinality, orthogonal information is needed. Orthogonal information consists of additional data which, independent of the main calibration state variable, shed light on a different aspect of the rainfall-runoff process and help to get a better understanding of internal processes in the catchment. This research aims at providing such information in the form of continuous distributed water temperature observations that provide a completely different look into the functioning of the natural system.

The temperature observations have been done with a DTS (Distributed Temperature Sensing) fiber optic cable. The technique has a spatial resolution of 1 to 2 m (depending on the system used) and a temporal resolution of 3 minutes with an accuracy of ~0.1 °C. The fibre optic cable can be up to 10 km long (for a detailed description see Selker *et al.* 2006a).

The case study took place in the Maisbich, a 590 m long, first order stream in central Luxembourg. The total size of the catchment is 0.34 km^2 with elevations ranging from 296 to 494 m. The bedrock consists of schist covered with a soil layer. On both sides of the stream there are steep forested slopes. V-notches have been installed at the upper and lower boundary of the stream.

The temperature observations led to the identification of four distinct lateral inflow points (Figure 1). If the temperature of the lateral inflow is known, the discharge can be determined using a simple mass balance.

To determine the temperature of the lateral inflows, three different methods are used:

– if the temperature upstream and downstream of an inflow point is equal, the temperature of the lateral inflow should be the same (Selker *et al*., 2006b, Westhoff *et al.,* 2007).

– If the assumption is made that the temperature and the lateral inflow are constant over a certain period (typically a few hours), both the temperature and the contribution can be determined using a mass and energy balance for the start and the end of this period (Selker *et al*., 2006b, Westhoff *et al.,* 2007).

$$\frac{Q_L}{Q_d} = \frac{T_{d1} - T_{u1}}{T_L - T_{u1}} = \frac{T_{d2} - T_{u2}}{T_L - T_{u2}}$$

– An independent sensor is used to determine the temperature of the lateral inflow.

The resulting temperatures of the lateral inflows vary over space and time, and indicate different runoff processes. Several hours (8-24h) after a relatively warm rainstorm, the temperature of the lateral inflow increases (depending on the conditions). This delayed reaction is an indication of rapid subsurface flow (Figure 2).

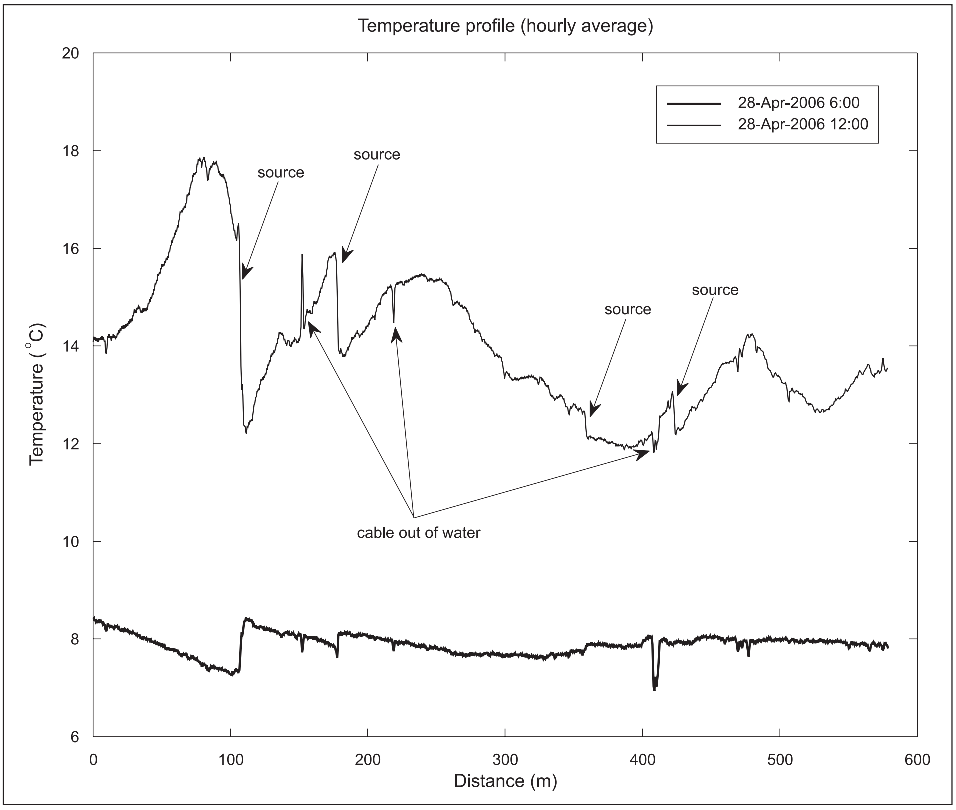

Figure 1. Longitudinal temperature profile of the Maisbich. Thick line is at 06:00, the thin line at 12:00 of the same day

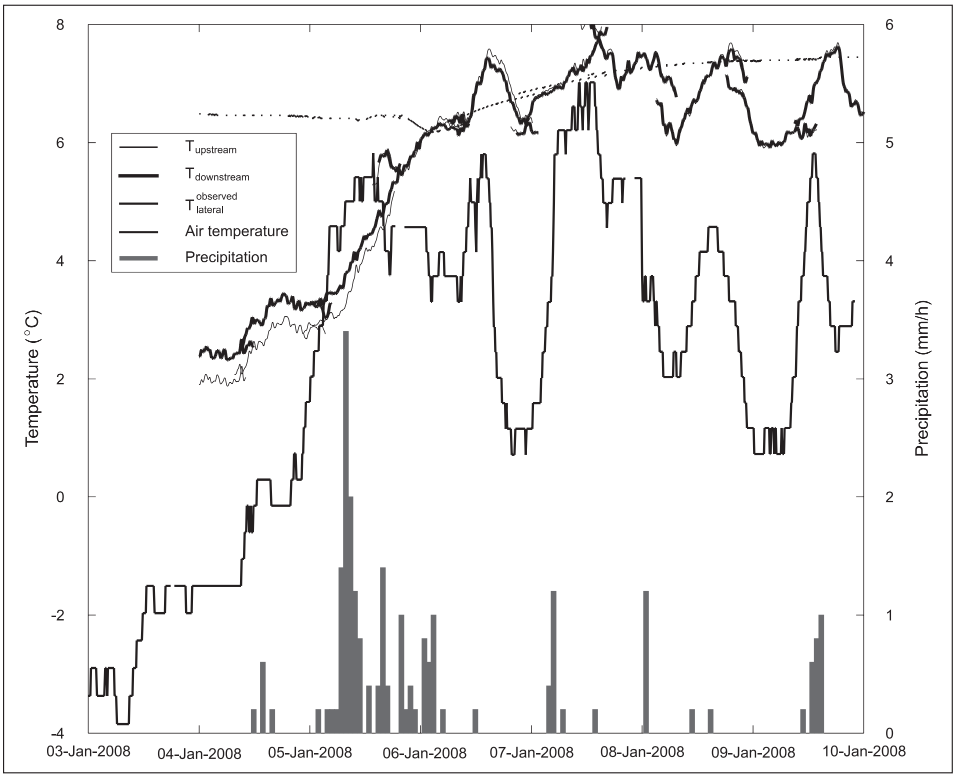

Figure 2. The temperature of lateral inflow first cools down after a rain event, before it warms up by about 1.5 °C

Besides the four identified and quantified points of lateral inflow, also diffuse sources and drains are included, which have been identified by constant salt dilution gauging, during base flow conditions.

In order to quantify all runoff processes we have developed an energy balance model in combination with a dynamic routing model, the results of which are compared to observed temperatures within the stream. The energy balance model is needed because temperature is not a conservative tracer. The 1-D model calculates the energy balance including solar radiation (with shading effects), longwave radiation, latent heat, sensible heat and river bed conduction. The energy balance model and the dynamic routing model are used interactively, whereby one provides input to the other iteratively. The energy balance model uses the flow parameters of the routing model and the routing model uses the lateral inflows and drains computed by the energy balance model.

During wet conditions the energy balance model is used to calibrate the varying inflows and drains in the routing model, which is an iterative process. These changing inflows and drains are subsequently linked to different runoff processes.

The combination of observations and modelling is used to enhance insight into the different discharge generation processes at play and the threshold levels at which they occur within a first order stream. Particularly the latter is an important research question: under which conditions are certain runoff generating mechanisms active and how and when are they trigged.

References

Westhof, M. C., Savenije H.H.G., Luxemburg W.M.J., Stelling G.S., Pfister L. 2007: *A distributed temperature model using high resolution temperature observations*. Hydrol. Earth Syst. Sci. 11: 1469-1480.

Selker J. S., Thévenaz L., Huwald H., Mallet A., Luxemburg W., van de Giesen N., Stejskal M., Zeman J., M.Westhoff, M. B. Parlange. 2006a: *Distributed fibre-optic temperature sensing for hydrologic systems*. Water Resour. Res., 42.

Selker J., van de Giesen N., Westhoff M., Luxemburg W., Parlange M. B.. 2006b: *Fibre optics opens window on stream dynamics*. Geophys. Res. Lett., 33.