Detection and quantification of localized groundwater inflow in small streams using ground-based infrared thermography

Tobias Schuetz and Markus Weller

Introduction
Localized groundwater inflow in small streams can be a major source of runoff during low flow periods in headwater catchments.
Groundwater has a small temperature amplitude during the year compared to surface water. Hence a significant temperature difference between stream water and groundwater can be expected in summer and winter.

We tested ground-based infrared thermography as a non-invasive and remote method to detect and quantify localized groundwater inflow in small streams during baseflow periods. This method offers the possibility to determine the exact location of inflow and the reach length for complete mixing of streamwater and groundwater inflow.

Methods
Measurement devices and techniques
- Measurements of electrical conductivity (EC) and physical water temperature (T) were conducted with WTW’s LF92 with an accuracy for EC of 0.5% (1-2000 µS/cm) and for temperature of 0.2 K.
- Infrared water surface radiation temperatures (IRT) were measured using the thermographic system THERM-NIRCAM from FLIR Systems.
The system has an absolute accuracy of 1.5 K and a relative accuracy 0.28 K. Infrared radiation temperature is detected on 480*940 Pixels. The observed spectrum lays between 7.5-14 µm.
- Discharge up- and downstream of localized groundwater inflows was measured using the salt dilution method.

Slug injection

\[ Q = \frac{M}{t(C_i) - C_m} \]

\[ Q = Q_{in} + Q_{out} \]

* Calculation of groundwater inflow fractions

\[ Q_{in} - Q_{out} = \frac{Q_{T}}{C_{T}} - \frac{Q_{IRT}}{C_{IRT}} \]

\[ Q_{in} - Q_{out} = \frac{Q_{EC}}{C_{EC}} - \frac{Q_{IRT}}{C_{IRT}} \]

\[ Q_{in} - Q_{out} = \frac{Q_{EC} - \frac{Q_{IRT} - \frac{Q_{EC}}{C_{EC}}}{C_{IRT}}}{C_{EC}} \]

\[ Q_{in} - Q_{out} = \frac{Q_{EC} - \frac{Q_{IRT} - \frac{Q_{EC}}{C_{EC}}}{C_{IRT}}}{C_{EC}} \]

Determination of zones of complete mixing

Mixing zones can be detected analysing the variability of infrared surface water radiation temperatures perpendicular to the flow direction.

Quantification
Derived values of groundwater inflow fractions of the four methods for different sites and seasons

Comparison of absolute errors resulting from the mixing analysis and the ratio of normalized endmember differences

Pitfalls
Observing homogeneous temperature fields to calculate infrared water surface radiation temperatures

The thermograph on the left side shows the low variability of infrared water surface radiation temperature for up- stream water, downstream water and the drain water during winter.
The right picture shows the inhomogeneity of the stream- bed surface in summer. Due to leaves, sticks and stones the definition of homogeneous infrared water surface radiation temperature fields requires more subjective decisions than analysing winter conditions.

Conclusions
The detection of localized groundwater inflow was successful. Calculated ground water inflow fractions from all methods are comparable. Therefore ground-based infrared thermography for the detection and quantification of localized ground water inflow in small streams is a valuable and easily applicable tool in stream ecology and process hydrology.