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

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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 INFRATEC VarioCAM hr. The system has an absolute accuracy of 1.5 K and a relativ accuracy 0.08 K. Infrared radiation temperature is detected on 480*640 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

$$Q = \frac{M}{\int_0^\infty (C(t) - C_s)\,dt}$$

continuous injection

$$Q_S = Q_{Inj.} * \frac{C_{Inj.}}{C_{Pl} - C_S}$$

Q	Discharge (V/T)	C(t)	Tracer concentration in the stream (M/T)
Q_S	total Discharge (V/T)	$C_{Inj.}$	Tracer concentration in Mariott´Bottle (M/T)
$Q_{Inj.}$	Disc. Mariott´Bottle(V/T)	C_{Pl}	Tracerconcentration of the Plateau (M/T)
M	Injected Tracer Mass	C_S	Tracer background concentration (M/T)

Calculation of groundwater inflow fractions

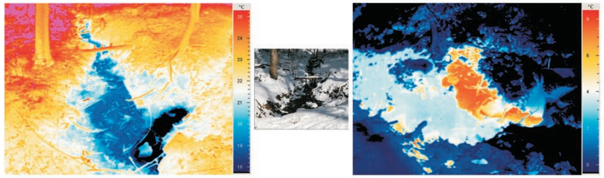
$$Q_{Down} - Q_{Up} = Q_{GW} \qquad \frac{Q_{Up}}{Q_{Down}} = 1 - \frac{Q_{GW}}{Q_{Down}} \qquad \frac{C_{Down} - C_{GW}}{C_{Down} - C_{Up}} = 1 - \frac{Q_{Up}}{Q_{Down}}$$

Q	Discharge (l/s)
C	Value of the observed quantity (EC, T, IRT)
GW	groundwater inflow
Up	upstream inflow location
Down	downstream inflow location

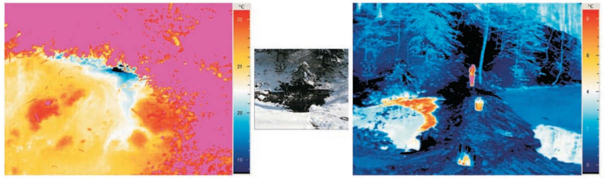
Mixing calculations were applied to the measured EC, T and IRT. The fractions calculated from discharge observations were used to validate all fraction calculations. IRT was used to determine locations of groundwater inflow for all methods.

Detection

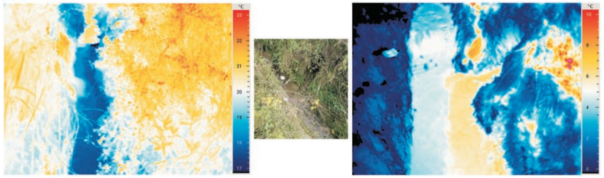
Summer — Winter



Detection of a small spring in the stream, in a mountainuous headwater catchment.

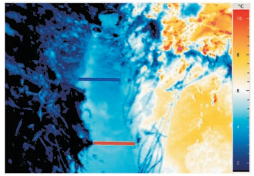


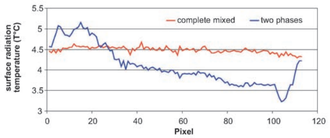
Detection of ground water inflow into a small pond.



Detection of an old tile drain pipe in an agricultural headwater catchment .

Determination of zones of complete mixing

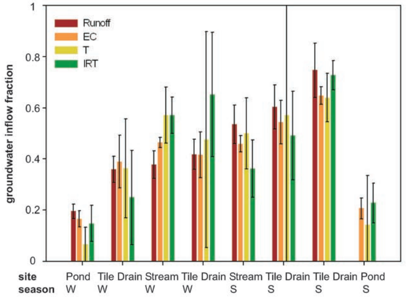




Mixing zones can be detected analysing the variability of infrared surface water radiation temperatures perpendicular to the flow direction.

Quantification

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

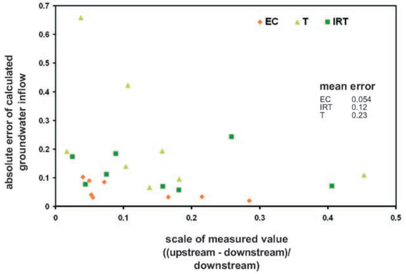


Comparison of groundwater inflow fractions using runoff data, electrical conductivity, physical water temperatures and infrared water surface radiation temperatures showed consistent results between 15%- 75%.

Method (unit)	Upstream	Downstream	GW Entry	Fraction
Discharge (l/s)	1.15	1.85	0.70	0.38
EC (µS/cm)	271	211	142	0.47
T (°C)	2.9	5.3	7.1	0.57
IRT (°C)	3.41	5.74	7.49	0.57

Exemplary data-set of all measured quantities, which was used to calculate groundwater inflow fractions.

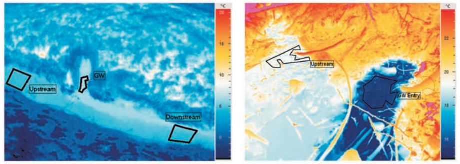
Comparison of absolute errors resulting from the mixing analysis and the ratio of normalized end-member differences



Absolut errors tend to a higher variation, when the differences between up- and downstream locations of measured temperatures are smaller. Electrical conductivity shows the same trend, but usually differences in electrical conductivity of stream and groundwater have a higher signal to noise ratio than the differences of water temperatures.

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 tile 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.

This poster participates in YSOPP — Young Scientists' Outstanding Poster Paper Contest

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