Physical Geography
Water, Climate, Environmental Change

UNIVERSITY OF BIRMINGHAM

A Small, Low-Cost Conductivity Sensor for Improved Quantification of Hyporheic Travel Times and Exchange Processes

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Motivation

- Contribution of **hyporheic** exchange processes and **biogeochemical cycles** to stream metabolism and their **spatial-temporal dynamics**.
- Specifically: Development of a small, **low-cost sensor** for the quantification of **hyporheic travel times** and **flow paths** at high spatial-temporal resolution.

Introduction & Aim

- Our **current methods** and **techniques** to study hyporheic exchange processes, travel times and flow paths are[1]:

Fig. 1: Porewater sampling tubes.

- **Intrusive** (e.g. porewater sampling from piezometers potentially inducing hyporheic exchange when sampled at high temporal resolution; commercial EC loggers in large wells),
- **Relying on a few measurements in time** (e.g. porewater sampling from piezometers at low temporal resolution; DET gels; Electrical Resistivity Imaging),
- **Indirect** (e.g., in-stream modelling of solute breakthrough-curves; temperature profiles),
- **Expensive** (almost all)!

- Our aim was to develop a **small** (= reduced disturbance of flowpaths), **continuous** (= high temporal resolution), **low-cost** (= increased number of sensors and therefore spatial resolution) **electrical conductivity sensor**.

Design of Low-Cost Sensor

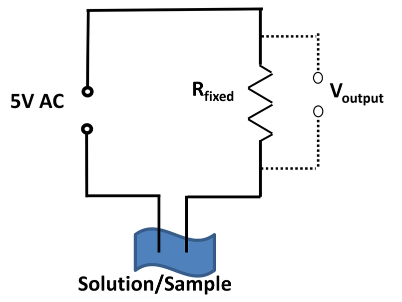

Fig. 2: Electrical circuit schematic of the Sensor.

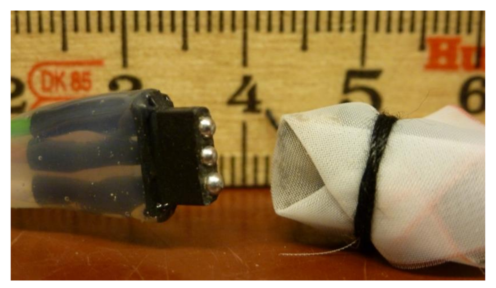

Fig. 3: Sensor with (right) and without protective mesh (left).

- The sensor circuit is based on the technique of a voltage divider (fig. 2).
- The main sensor consists of a female PCB header (constant distance between the electrodes; fig. 3).
- The sensor can be connected to any logging unit, which can apply a voltage (AC) and measure the output voltage (e.g., Arduino boards, Raspberry pi, Campbell Scientific loggers).
- The **cost of the sensor: < 5 EUR**

Performance of Low-Cost Sensor

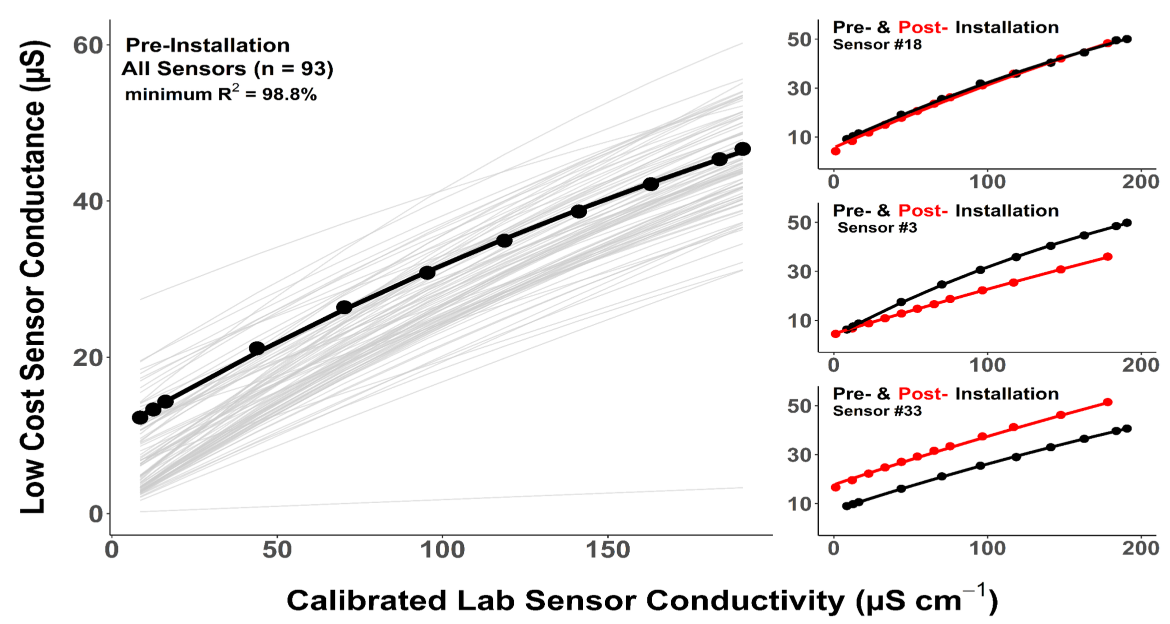

Fig. 4: Calibrations of low-cost sensor conductance with commercial EC sensor, of all sensors prior to installation (left; one example highlighted in black) and of three sensors with calibration pre- (black) and post- (red) installation (top: identical calibration; middle: different slope; bottom: different intercept).

- All sensors (n = 93) showed an **almost perfect fit with a calibrated lab-sensor** (fig. 4; mean r^2 = 0.995).
- For half of the sensors tested, the **relative difference between** the calibration prior to and after a 2-month installation in the field was **below 40%** (fig. 4).

  ➡ Porewater sampling for drift correction is recommended for better quantification salt concentrations.

- The temperature correction coefficients (mean = 2.4% °C^{-1}) were close to the standard coefficients used in commercial sensors[2].

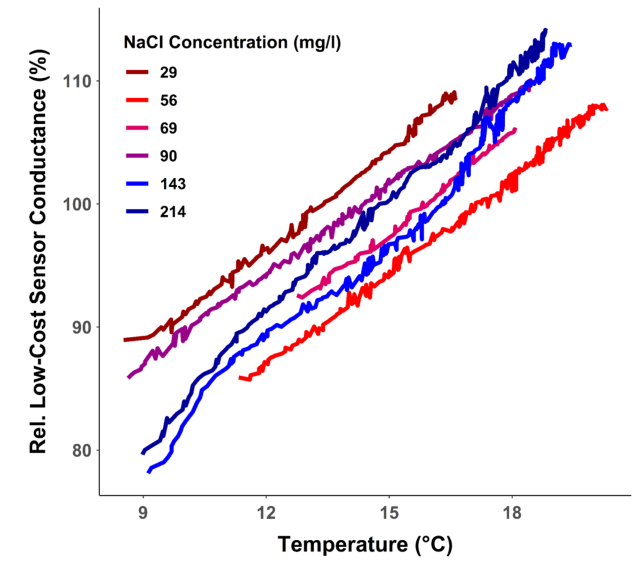

Fig. 5: Impact of temperature and ion concentration on relative conductance, shown for one example sensor

Field Application of Low-Cost Sensor

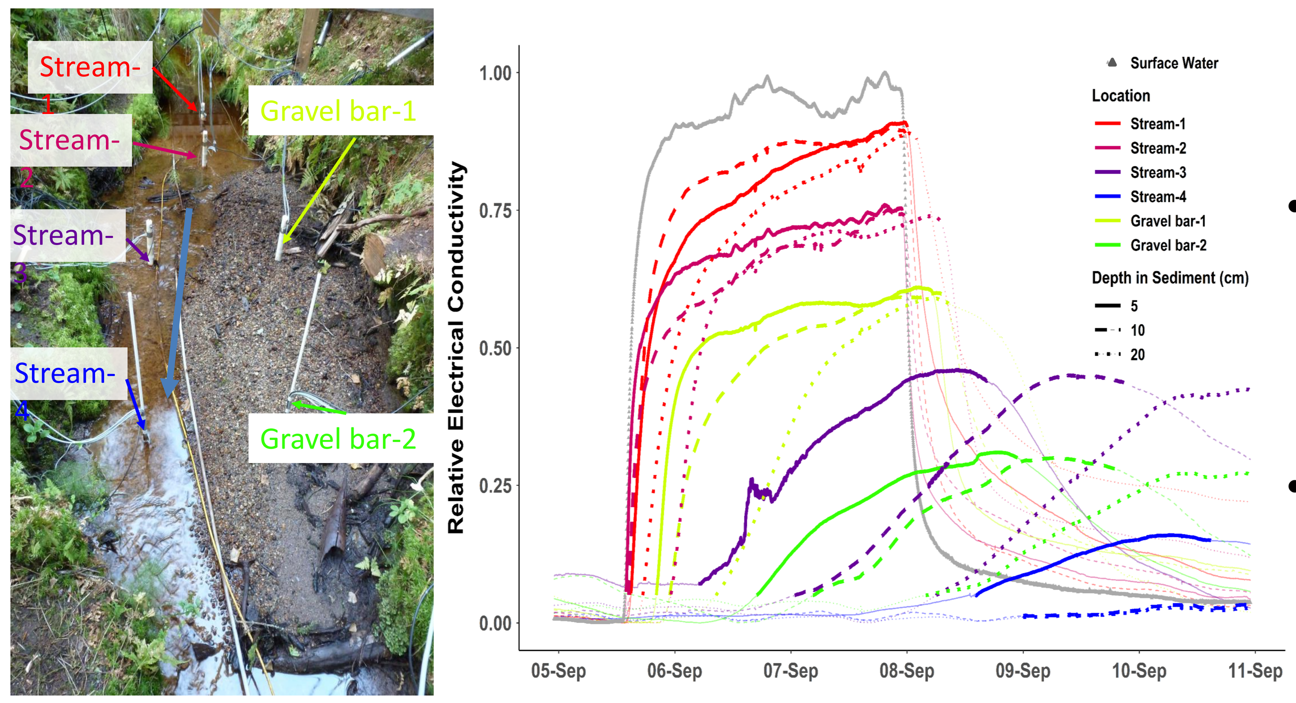

Fig. 6: Salt breakthrough curves at six locations (each 3 depths) around a gravel bar of a 60h-NaCl injection into the open channel, 200m upstream of the study site. Note: The y-axis values have been adjusted for visual purposes.

- Salt **breakthrough-curves** are **very well captured** by the low-cost sensor in the field (fig.6 and fig. 7).
- **Flow paths** and **travel times** (fig. 6) as well as the **temporal dynamics** of hyporheic exchange processes (fig. 7) can be quantified.
- **Quantification of salt concentrations** are possible, if the sensor is drift corrected with porewater samples.
- **Impact of porewater sampling** on hyporheic flow paths can be tested (fig. 7, bottom).

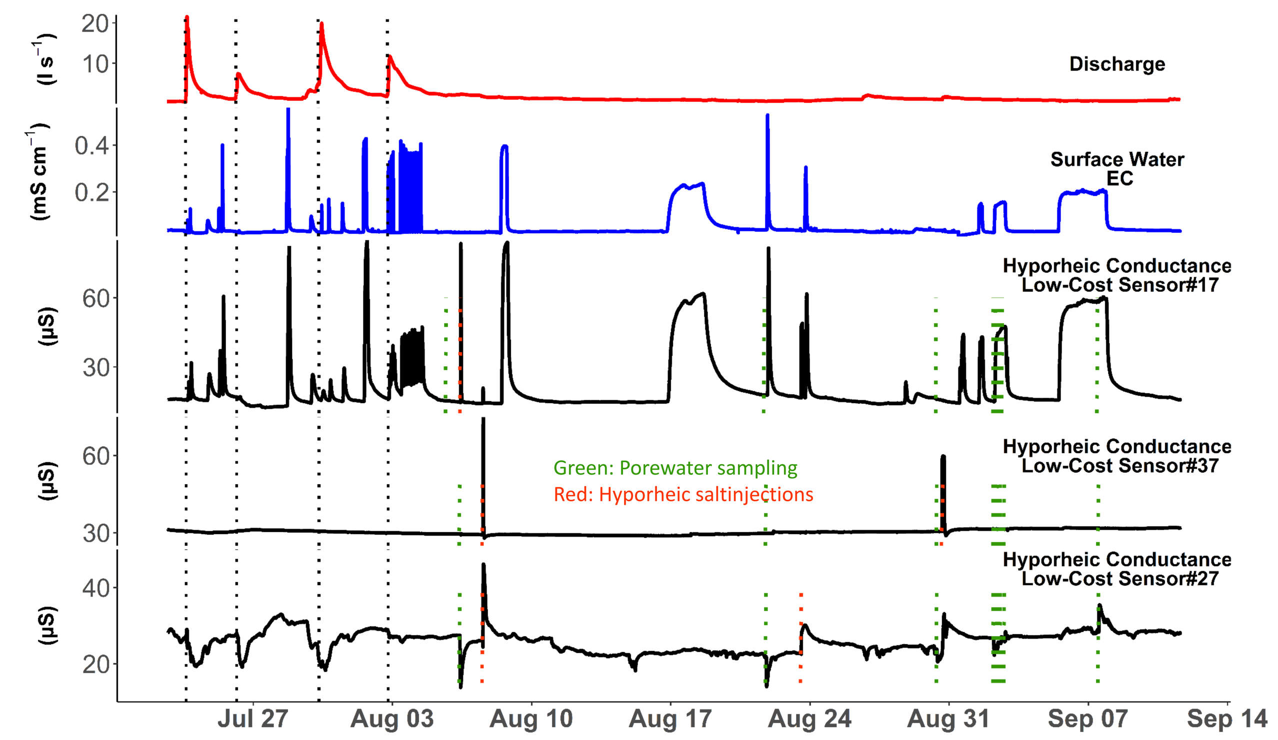

Fig. 7: Timeseries of the experimental period for discharge, electrical conductivity in the open channel (commercial sensor) and conductance at three hyporheic locations (as examples for very different hyporheic dynamics). Green, vertical dotted lines indicate times when porewater samples were taken from the same location and depth of the sensor. Red, vertical dotted lines indicated times when salt solutions were injected into the same piezometers

Conclusions

- **Successful development and in-situ testing of a small, low-cost (< 5 EUR), continuous electrical conductivity sensor.**
- **The sensor can be used to quantify the dynamic hyporheic flow paths and travel times at a large number of sites (locations x depths).**
- **Combined with hyporheic physico-chemical data (nutrients, carbon..), these sensors allow to calculate hyporheic metabolic rates and can be used to improve our current models.**

References:

1. R González-Pinzón et al. (2015): A field comparison of multiple techniques to quantifiy groundwater-surface-water interactions. Freshwater Science, vol 34(1).
2. MA Gillman et al. (2017): Calibration of a modified temperature-light intensity logger for quantifying water electrical conductivity. Water Resources Research, vol 53.

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SLU · HORIZON 2020 · INTER ⇄ ACT · ICOS Integrated Carbon Observation System · BIFOR Birmingham Institute of Forest Research · CENTA · NERC Science of the Environment