How to detect hyporheic exchanges of water along a river? Thermal infrared remote sensing versus discrete hyporheic measurements

Comment détecter les échanges hyporhéiques le long d'un cours d'eau ? Imagerie thermique infra-rouge *versus* mesures hyporhéiques ponctuelles

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RÉSUMÉ

Les échanges d'eau à travers la zone hyporhéique sont cruciaux pour de nombreux processus écologiques dans les cours d'eau. L'un des défis majeurs actuels est la mise au point d'une méthodologie pour la localisation de ces échanges, utilisant une technique d'acquisition rapide de données. Ce travail compare des données continues, acquises par imagerie Thermique Infrarouge (TIR), avec des données discrètes, recueillies sur les zones d'échanges attendus (bancs de graviers). Quarante bancs, répartis le long de la rivière d'Ain, ont été échantillonnés en amont et en aval (80 sites). Sur chaque site, 4 paramètres physico-chimiques ont été mesurés à 0, -20 et -50 cm sous la surface des sédiments. La campagne de collecte d'images TIR a été menée de manière concomitante. Les deux approches donnent des informations complémentaires. Dans les zones où des images TIR et des mesures de terrain sont disponibles, le diagnostic est similaire à 85%. Néanmoins, alors que la cartographie TIR fournit une image exhaustive des zones d'apport d'eau souterraine, les mesures de terrain ne détectent pas certains sites d'apport d'eau souterraine positionnés entre les bancs. Par contre, ces mesures ponctuelles de terrain repèrent très bien les zones de downwelling (infiltration de l'eau de surface), qui ne sont pas détectées par les images TIR, mais qui représentent pourtant des hotspots hyporhéiques pour les invertébrés benthiques.

ABSTRACT

Water exchanges through the hyporheic zone are crucial for many ecological processes in streams. One important challenge is to find a methodology for the localization of these exchanges using techniques of rapid data acquisition. This work compares continuous data, acquired by Thermal InfraRed (TIR) technique, with discrete data collected at sites of expected water exchanges (gravel bars). Forty gravel bars, distributed along the Ain River were sampled at upstream- and downstream-bar positions (80 sites). At each site, 4 physico-chemical parameters were measured at 0, -20 and -50 cm beneath sediment surface. The campaign to collect TIR images was conducted concomitantly. The two approaches give complementary information. In areas where infrared maps and field measurements were available, the diagnostic was similar at 85%. The TIR images gave an exhaustive picture of groundwater discharge areas, whereas field measurements, missed groundwater discharge sites located between the bars. Nevertheless, discrete field measurements documented other processes in downwelling areas (infiltration of surface water), which were not captured by TIR images, but represent hyporheic hotspots for benthic invertebrates.

MOTS CLES

Ground water, sediment interstices, streams, large-scale remote sensing, physico-chemical

1 INTRODUCTION

Water exchanges through the hyporheic zone are crucial for many ecological processes in streams. One important challenge is to find a methodology for the localization of these exchanges at large scale using techniques of rapid data acquisition.

Thermal infrared (TIR) remote sensing allows for scanning large geographic areas and is valuable for the identification of thermal anomalies along rivers (Wawrzyniak *et al.,* 2016). However, temperature records are limited to the top millimeters of the water surface, missing the diffuse exchanges located deeper.

The present study compares two different approaches: the Thermal InfraRed (**TIR**) remote sensing, allowing spatially continuous acquisition of data at the water surface, and *in situ* Discrete Hyporheic Measurements (**DHM)**, allowing spatially discontinuous acquisition of data (= from station to station) collected directly on the river bottom and into the hyporheic zone.

2 MATERIAL AND METHODS

This study took place in the lowest 40 km reach of the Ain River (France), where we compared continuous data, acquired by TIR technique, with discrete data collected at sites of expected water exchanges (gravel bars). Forty gravel bars, distributed along the Ain River were sampled at upstream- and downstream-bar positions (80 sites). At each site, four physico-chemical parameters (temperature, electric conductivity, oxygen content and vertical hydraulic gradient) were measured at 0, -20 and -50 cm beneath sediment surface using mini-piezometers (1.5 cm diameter, Fig.1). Data were acquired at low discharges and warm water in the stream in order to maximize thermal contrasts between surface and ground water. The campaign to collect TIR images was conducted concomitantly.

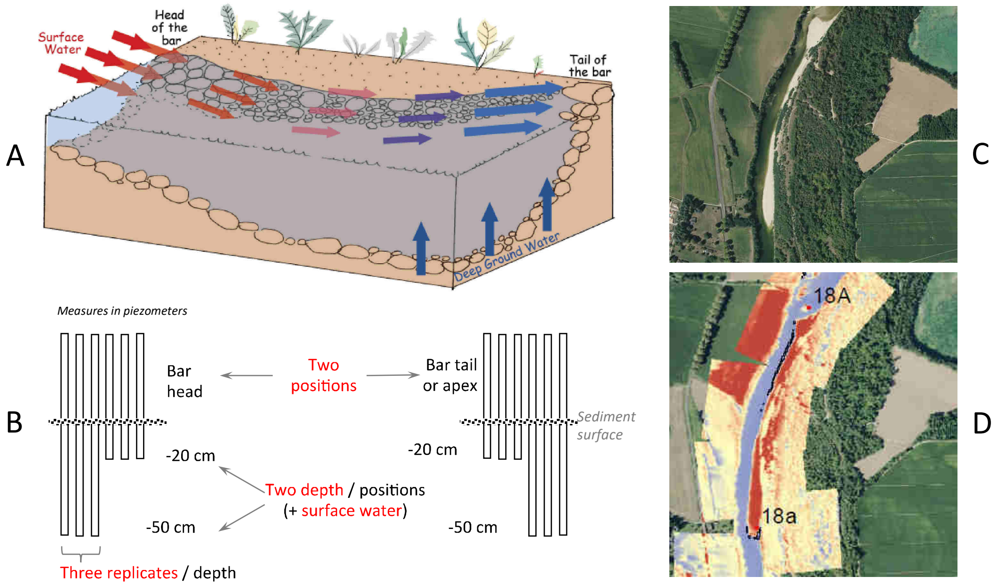

Figure 1. A: Hyporheic flowpaths in a gravel bar. B: location of sampling stations and sampling design. C-D: Example of aerial photo and corresponding TIR image in the studied sector of the Ain river (© IGN - 2012 - BD ORTHO® Ain). Black areas at the border of the channel (arrows) are points of groundwater upwellings.

3 RESULTS

In the DHM method, the use of temperature and specific conductance leads to distinguish different hydrologic exchanges classified as strong / weak upwellings of ground water (groups 1-2, Fig.2), and strong / weak downwellings of surface water (groups 3-4, Fig.2). The detection of cold-water patches reveals the heterogeneous distribution of upwellings along the study reach. Similar longitudinal pattern was observed when compared to cold-water patches obtained by TIR method (Fig.3), although the number of cold-patches was higher with TIR due to the continuous nature of data acquisition with this method. Only 15% of the cold patches detected by DHM were not observed by TIR. In addition to upwellings, the DHM method also reveals the downwelling areas which are not captured by IR imaging.

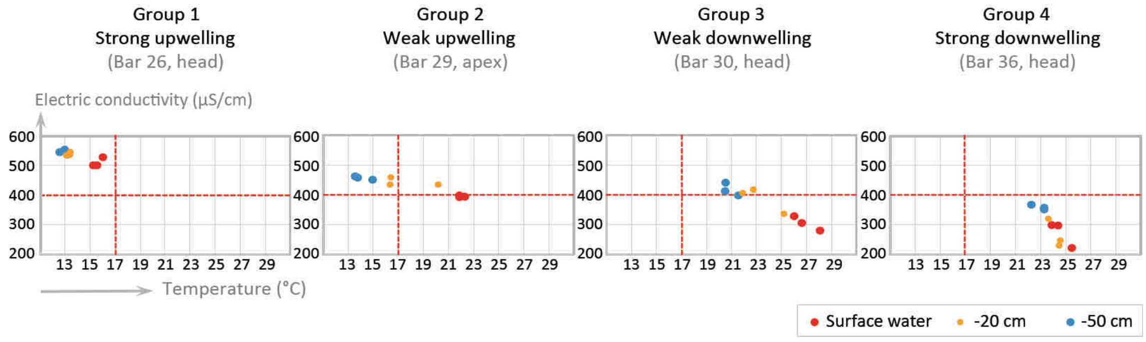

Figure 2. Classification of the stations according to the electric conductivity and the temperature of the surface and hyporheic waters.

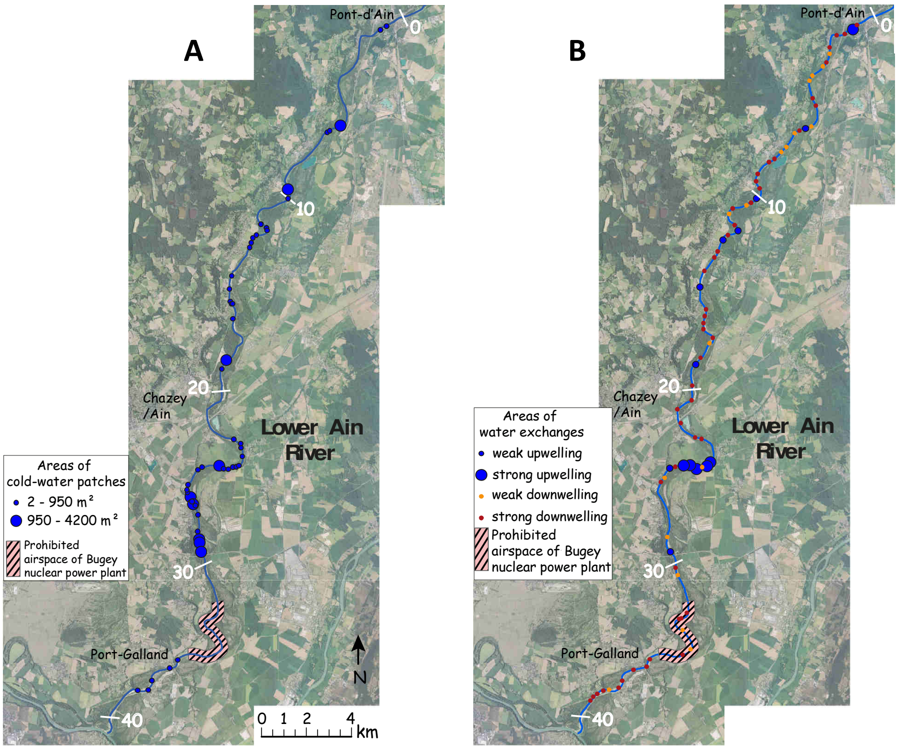

Figure 3: Cold-water patches observed using TIR remote sensing (A) and DHM method (B). The discretisation of patch surfaces for TIR method is based on the mean and the standard deviation. The size of circles for DHM method is based on temperature and electric conductivity profiles (see Fig.2). The background is a 50 cm resolution aerial photo (© IGN - 2012 - BD ORTHO® Ain).

4 DISCUSSION-CONCLUSION

The TIR images gave an exhaustive picture of groundwater discharge areas, whereas field measurements, missed sites located between the bars. Unlike TIR method, DHM detected also downwelling areas and as such, documented other physical and biological processes (infiltration of oxygen, dissolved and particulate organic matter, microbes, invertebrates, fish larvae… into the hyporheic zone). These areas not captured by TIR images, however represent hyporheic hotspots for benthic animals. Ecological studies and stream quality controls should take into account not only groundwater upwellings but also surface water downwellings, and fully integrate them into their management plans.

BIBLIOGRAPHIE

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