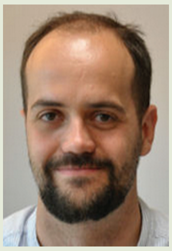
## The ADVOCATE Project

Our previous newsletter introduced you briefly to the ADVOCATE research fellows. Now it is time to read all about their latest results. In the coming months we will focus on individual fellows, to give you up to date information about their personal and scientific progress. On this occasion, Uwe Schneidewind and Alistair Beames, both from VITO - the Flemish Institute for Technological Research (Belgium), present the latest results of their research.

**Uwe Schneidewind** is undertaking research under the title: *'Quantifying fluxes across the groundwater-surface water interface using heat as a tracer'*. His project specifically focuses on the delineation and quantification of vertical exchange fluxes across the groundwater-surface water interface (GSI) to better understand flow and transport processes in the hyporheic zone.



**Alistair Beames** is undertaking research under the title: *'Carbon footprints as a proxy for secondary environmental impacts of remediation technologies'*. His project involves the analysis of Decision Support Systems (DSS) available to assess the sustainability of technology and management options for soil and groundwater remediation. Here his work compares the results of $CO_2$ emission estimates obtained by the $CO_2$ Calculator and the Life Cycle Assessment method.

**We would also like to let you know about two events supported by the ADVOCATE network, that are coming up this year: a summer school in Leipzig, Germany, and the In Situ Remediation 2014 Conference in London.**


**SAVE THE DATE:**

**LONDON 2nd – 4th September 2014**

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**A unique atmosphere to exchange ideas, share experiences and gain exposure to the latest developments in sustainable in situ remediation of contaminated land and groundwater**

**All updated information is available on theadvocateproject.eu/conference/main.html**

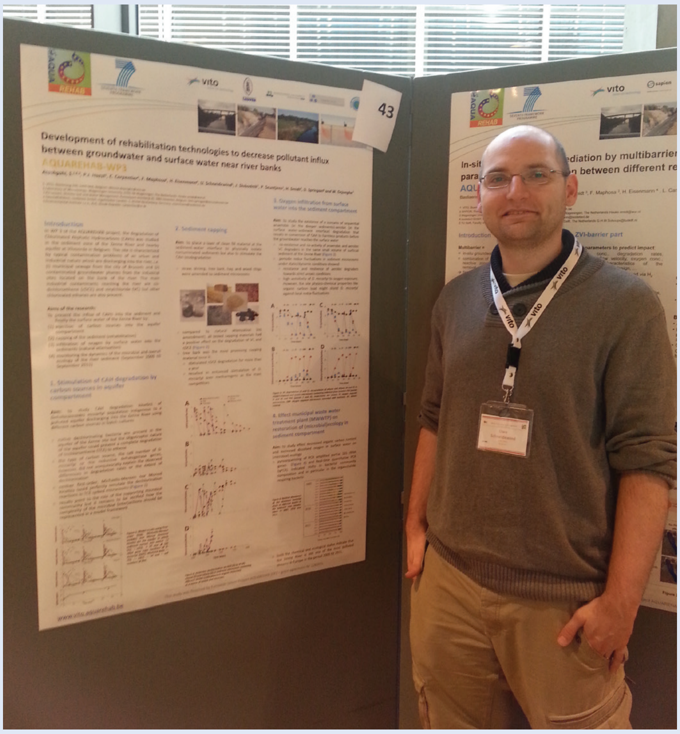
# Uwe Schneidewind

(VITO, Flemish Institute for Technological Research, Belgium)


Uwe Schneidewind obtained a BSc in Environmental and Resource Management from Brandenburg University of Technology (Germany) in 2006 and an MSc in Applied Environmental Geosciences from the University of Tübingen (Germany) in 2008. After his graduation, he started to work as a Field Hydrogeologist at the Helmholtz Centre for Environmental Research in Germany, where he was mostly planning and conducting field campaigns to acquire data relevant for hydrogeological and geophysical site characterization.

In 2010, he started his research career at the Free University of Brussels (VUB) in Belgium working mainly on a groundwater modelling and ecosystem restoration project. In 2011, he joined the ADVOCATE team, pursuing his PhD in “Contaminant Flow, Transport and Attenuation in the Hyporheic Zone under Heterogeneous Conditions”.

Uwe has spent almost three years working within Work Package 3 on *Groundwater-surface water interactions and in situ remediation*. In this newsletter he talks about some of his latest results under the title:




## Quantifying fluxes across the groundwater-surface water interface using heat as a tracer

### Introduction

Part of my research focuses on the delineation and quantification of vertical exchange fluxes across the groundwater-surface water interface (GSI), to better understand flow and transport processes in the hyporheic zone. Determining the direction and magnitude of these fluxes has proven to be important in ecohydrological studies, water supply and management aspects, as well as in the study of contaminant transport and attenuation processes.

Exchange fluxes serve as an indicator of how a stream and an aquifer are connected. When the hydraulic head in the aquifer is for example higher than the stream stage one will encounter upward fluxes or upwelling conditions, whereas downward fluxes or downwelling conditions can be found when the stream stage is higher. In many environments stream-aquifer connections and exchange fluxes vary at different spatial scales (i.e. basin-scale, reach-scale, sediment-scale) due to differences in streambed morphology, geometry and sediment architecture, stream-sediment load, in-channel plant growth or land use. Season and time of the day (climate and weather effects) can also influence exchange fluxes. In my research I am interested in the sediment- and reach-scale up to several 10 m.

### Methodology

Exchange fluxes can be directly measured using seepage meters. These are basically half-open containers of known volume, which are installed in the riverbed and connected to a plastic bag (Figure 1). This plastic bag contains a known volume of water, which either increases or decreases with time, to symbolize upwelling or downwelling conditions.

Exchange fluxes can also be quantified using heat as an environmental tracer, as is evident from the partial differential equation (1) that is similar to the advection-dispersion equation in contaminant transport. In the field, temperatures are measured at the streambed top and at certain locations within the streambed, preferably over weeks to months. Most commonly, these temperature-time series results are collected by multilevel temperature lances connected to data loggers (Figure 2), or by fibre-optic cables connected to a pulsed laser (DTS). The propagation of the temperature signal through the streambed depends on the thermal parameters as well as porosity and specific discharge, as can be seen in equations (1 - 4). After data collection, the heat transport equation (1) can be solved by complex numerical models like Hydrogeosphere, which couple the groundwater and surface water systems. For 1D cases, analytical solutions are also often applied. Although not able to simulate complex heat transport, these analytical models are easy to use, faster and require much less input data than the numerical models.

$$\frac{\partial T}{\partial t} = \nabla \cdot (D \nabla T) - \frac{\rho_w \cdot c_w}{\rho_c} \nabla \cdot (\vec{q} T) \quad [1]$$

$$D = \frac{K}{\rho c} + \psi \left| \vec{q} \right| \quad [2]$$

$$\rho c = n K_w + (1 - n) \rho_s c_s \quad [3]$$

$$K = n K_w + (1 - n) K_s \quad [4]$$

Where: T= temperature; t = time; D = thermal diffusivity tensor; $\vec{q}$ specific discharge or exchange flux vector; K = thermal conductivity tensor; ψ = thermal dispersivity; $\rho_w c_w$ = volumetric heat capacity of solids; $\rho_c$ = volumetric heat capacity of matrix; $\rho_s c_s$ = volumetric heat capacity of soils; $K_s$ = thermal conductivity of solids; $K_w$ = thermal conductivity of water; n = porosity

**Figure 1.** A typical seepage meter

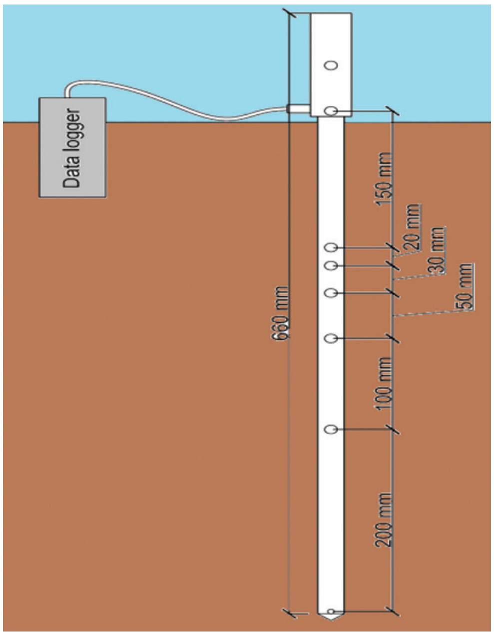



**Figure 2.** A multilevel temperature lance connected to a data logger. It can measure streambed temperatures at six depths as well as the streambed top.

Over several months in 2012 I have collected streambed temperatures at seven locations in the Slootbeek, a small tributary to the River Aa in Belgium (Figure 3). Temperature data was then analyzed with an analytical model called LPML (log pseudo-marginal likelihood), newly adapted to vertical 1D heat transport across the GSI. A step-by-step outline of LPML is given in Figure 4. So far this model can quantify exchange fluxes and, under certain conditions, thermal conductivities for a homogeneous subsurface. A version which can be applied under heterogeneous conditions is also under development. An advantage of LPML is its ability to determine model and parameter uncertainties. LPML was verified by comparing results to other analytical and numerical solutions, using the model codes VFLUX and STRIVE. In addition, seepage meter measurements were used for this comparison.

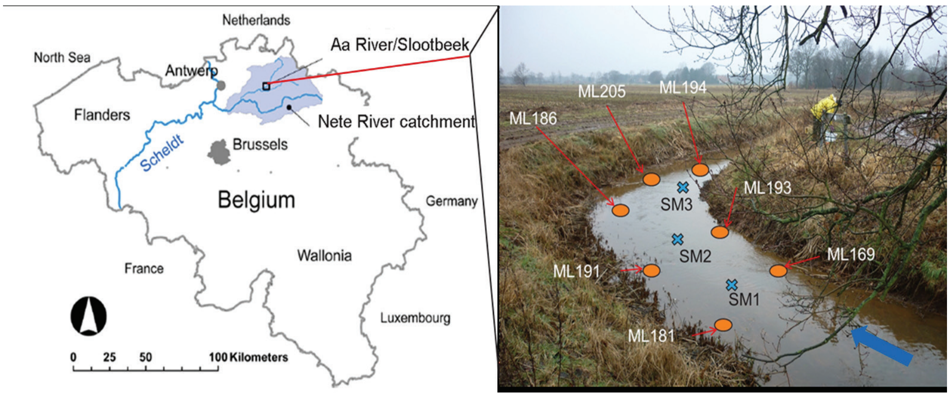



**Figure 3.** Slootbeek with locations for temperature measurements (ML) and seepage meter (SM) experiments

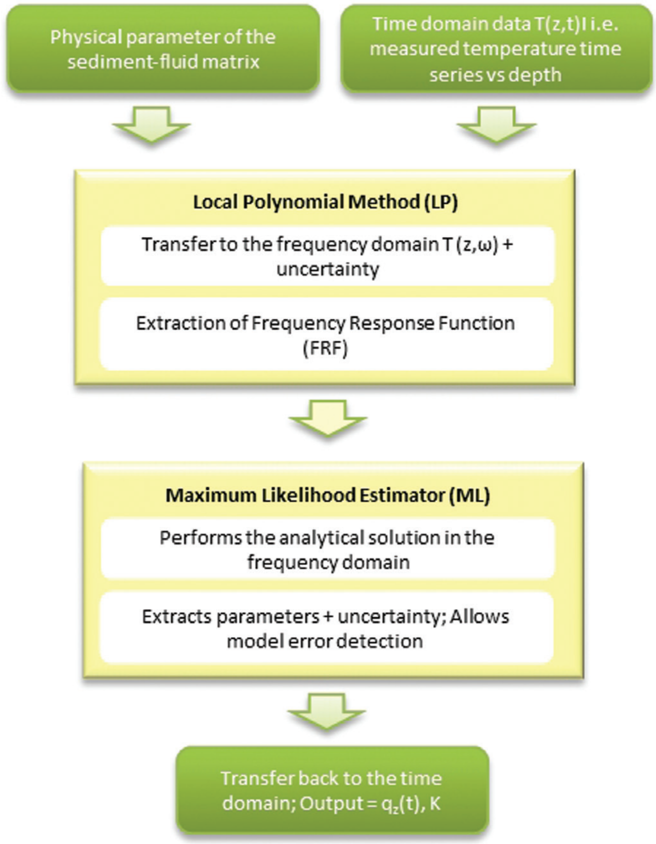



**Figure 4.** LPML, flow chart.

**Table 1.** Exchange fluxes obtained for the Slootbeek by temperature time series analysis and seepage meter measurements.

| Location | $q_z^a$ mm d$^{-1}$ | Method |
|---|---|---|
| ML169 | -44.3 | LPML |
| ML181 | -191.4 | LPML |
| ML186 | -595.0 | LPML |
| ML191 | -154.0 | LPML |
| ML193 | -12.1 | LPML |
| ML194 | -19.1 | LPML |
| ML205 | -263.8 | LPML |
| SM1 | -31.4 | seepage meter |
| SM2 | -378.5 | seepage meter |
| SM3 | -656.5 | seepage meter |

[a]K was fixed to 1.8 Wm$^{-1}$K$^{-1}$ while $q_z^a$ was optimized

## Results and Discussion

Table 1 provides flux estimates for all locations indicated in Figure 3. They were obtained with the LPML for a 90-day period in 2012, or directly measured with seepage meters. At all locations upwelling conditions were found but fluxes varied considerably, ranging from -12 to -657 mmd-1. In addition, on the right stream bank much less water is flowing towards the Slootbeek compared with the left stream bank. These variations in flux estimates appear to result from heterogeneous streambed sediment architecture (sand and gravel, sandy loam, varying organic matter content) and riverbed morphology that create variations in heat transport parameters, which determine sediment-scale water movement (hydraulic conductivity, flow velocity).

A further analysis of the data has also shown occasional downwelling conditions over several days. This could be due to climatic variations, as after heavy rainfalls upstream the downstream water level can be higher than the hydraulic head in the aquifer. The comparison of LPML results with those obtained by VFLUX and STRIVE showed similar flux estimates, but with the LPML I was also able to determine model and parameter uncertainties. Determining uncertainties is important in order to understand how reliable the results obtained are. The uncertainty of the underlying physical processes could not be determined, but assuming 1D vertical flow only is certainly a simplification of the more complex natural flow conditions, which also has to be considered when looking at the flux estimates.

## Conclusion

Heat can be used as an environmental tracer to investigate groundwater-surface water interactions. By solving the heat transport equation using measured temperature-time series data, the direction and magnitude of groundwater-surface water exchange fluxes can be deduced. The LPML model produced flux estimates comparable to results obtained with other numerical and analytical 1D heat transport models, as well as seepage meter measurements. Determining fluxes at several locations within the same reach provided me with a first idea about their spatial variability. In the future I will compare these results with those obtained using a model for a layered aquifer. In addition, temperature data and flux estimates can be used as input or to constrain more complex numerical models.

**If you would like to know more about Uwe Schneidewind, visit: theadvocateproject.eu/people/schneidewind.html or contact him directly at uwe.schneidewind@vito.be**

# Alistair Beames

(VITO, Flemish Institute for Technological Research, Belgium)

Alistair Beames obtained his MSc in Environment and Resource Management, specializing in Environmental Studies, from the Vrije University, Amsterdam, in 2011. His master's thesis was carried out in collaboration with Deltares and the Institute for Environmental Studies (IVM) at the Vrije University. The subject involved designing various remediation strategies for targeting DNAPLs trapped in impermeable layers and then evaluating these strategies in terms of their environmental benefits and costs.

In the ADVOCATE Work Package 1 on *Socio-economic and sustainability aspects of in situ remediation* Alistair is continuing his studies in this research area. His latest results are described below under the title:

## Carbon footprint as a proxy for secondary environmental impacts of remediation technologies

### Introduction

The focus of Work Package 1 in the ADVOCATE project is to develop more robust tools for sustainability assessment. Sustainability encompasses three broad impact areas: environmental, economic and social. The most common approaches used to account for potential environmental impacts include carbon footprint calculators and the Life Cycle Assessment (LCA) method. The $CO_2$ Calculator is a carbon footprint calculator specifically for evaluating remediation technologies and has been recently introduced as part of the Flemish Public Waste Agency's (OVAM) mandatory Multi-criteria Analysis for remediation projects. The LCA method has proven to be useful in determining the extent of secondary impacts from remediation technologies, on a site-by-site basis. The work described here evaluates differences in $CO_2$ emission results obtained from the $CO_2$ Calculator and LCA method. Both methods were applied to two potential remediation technologies that have already been piloted on the SRI Biochim brownfield site near Brussels, Belgium.

### Technology Description

SRI Biochim is a 2 ha site located in a 250 ha industrial zone that was used as a solvent recycling facility until it burned down in 1993. The storage tanks that were destroyed by the fire in 1993 leaked a mixture of chlorinated volatile organic compounds, benzene, toluene, ethylbenzene, xylene (BTEX) compounds, mineral oil, polychlorinated biphenyls (PCBs), chlorophenols, phenols and cresol into the subsurface, which have formed a large light non-aqueous phase liquid (LNAPL) smear zone (see Figure 1). The estimated contaminant load is approximately 500 tonnes.

Four feasible remediation technologies have been identified, two of which have already been piloted. The pilot studies were excavation under controlled atmosphere with *ex situ* thermal soil treatment and *in situ* multiphase extraction. Two other pilots are currently underway (*in situ* thermal desorption via conduction and in situ radio frequency heating). The pilot studies will determine the resource requirements of the four technologies for remediating the site.


**Figure 1.** SRI Biochim site, north of Brussels. The one hectare smear zone that will be remediated on the site is outlined in red.

## Developed research

The questions that the research addresses are whether the $CO_2$ Calculator would present an adequate evaluation of emissions potential, whether the $CO_2$ emission values are accurate and how the different processes evaluated, such as the system assembly and transport of equipment, have influenced the final results (Figure 2).

**Figure 2.** MPE vacuum extracGon pump.

## Latest results

### $CO_2$ Calculator

According to the $CO_2$ Calculator, the most energy-intensive process in the excavation alternative is the thermal treatment of the soil *ex situ*, accounting for 13,855 tones of $CO_2$ (76% of the total $CO_2$ from this alternative). The next largest contributing process is the transport of the contaminated soil and backfill to and from Moerdijk in the Netherlands. The excavation itself and materials have a very small carbon footprint compared to the *ex situ* thermal soil treatment (Figure 3).

The *in situ multiphase extraction* (MPE) alternative produces far less $CO_2$ emissions than the excavation alternative. The largest contributing process is the energy consumed by the extraction and treatment of soil vapour, groundwater and product on site (80%) (Figure 4).

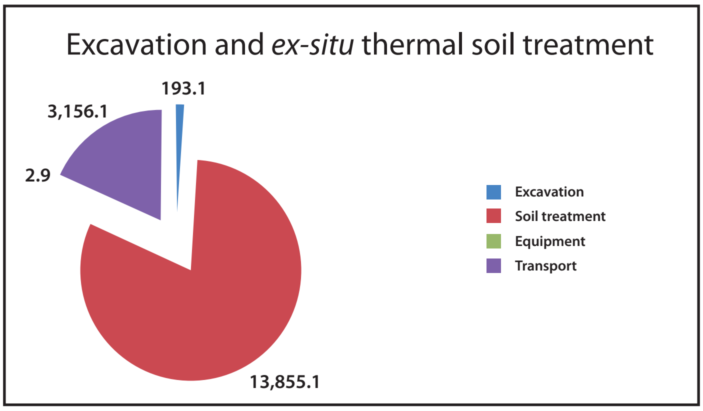



**Figure 3.** Contribution of $CO_2$ emissions for processes in excavation alternative according to the $CO_2$ Calculator.

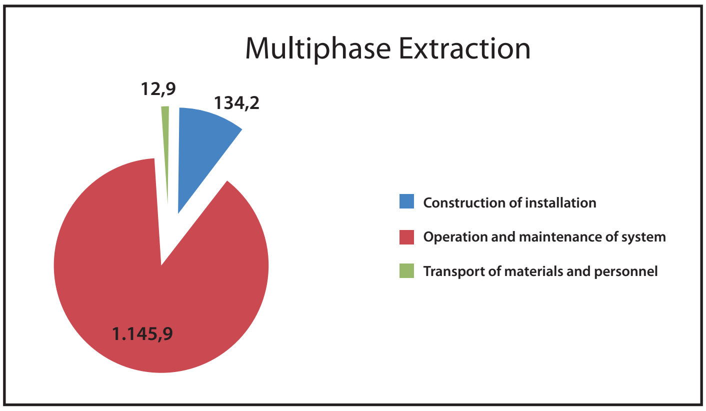



**Figure 4.** Contribution of $CO_2$ emissions for processes in multiphase extraction alternative according to the $CO_2$ Calculator.

## Life Cycle Assessment

The results from SimaPro (LCA software) confirm that the environmental impacts from the excavation alternative are far larger than the MPE system. The LCA method also shows that energy consumption and, in particular, fossil fuel consumption have the largest effect in terms of the overall normalized impacts. The process that contributes most to $CO_2$ emissions in the excavation alternative is the thermal treatment of the soil, reflecting the results from the $CO_2$ Calculator. Similarly, the largest contribution to $CO_2$ emissions in the MPE alternative is from the energy required by the on-site air and groundwater treatment system during operation.

The *in situ* MPE alternative performs better than the excavation alternative in both methods, although the results from the $CO_2$ Calculator and LCA method differ in terms of $CO_2$ emissions produced by each technology. Table 1 shows the total $CO_2$ emissions results from both alternatives. The difference in $CO_2$ emissions between the alternatives is far larger in the $CO_2$ Calculator.

Table 1: $CO_2$ emissions results from $CO_2$ calculator compared with those from the LCA method (SimaPro)

| Remediation Alternative | $CO_2$ Calculator | SimaPro |
|---|---|---|
| Excavation | 18,125 | 10,772 |
| MPE | 1418 | 3550 |

Values in tonnes of $CO_2$ emitted

### Next Phase

The next phase of the research is to determine how exactly the calculations differ between the tools. The methods will also be applied to the *in situ* thermal technologies currently being pilot tested.

**If you would like to know more about Alistair Beames, visit: theadvocateproject.eu/people/beames.html or contact him directly at alistair.beames@vito.be**

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* For further information, please download the flyer at www.theadvocateproject.eu

You can find our full list of partners on our project website (**www.theadvocateproject.eu**). If you would like any further information please contact Gabriella Kakonyi at g.kakonyi@sheffield.ac.uk.

Contact information for lead scientists at organisations hosting Research Fellows within the ADVOCATE Marie Curie Initial Training Network

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We are also pleased to have a number of associated partner organisations from different commercial and industrial sectors of the contaminated land and groundwater management field within the network, who are helping us with training and technical assistance. You will find details of these partners and their contribution to the network on our website.