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Field scale mass discharge measurements from a controlled solute plume

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Overview

Risk assessment of polluted aquifers requires estimates of pollutant mass discharge which must include a quantification of uncertainties in order to establish its robustness and credibility. Nevertheless, accuracy of a measurement performed in field conditions is often difficult to quantify.

This study relates the first solute mass dicharge measurement at three succesive control planes in a heterogeneous alluvial aquifer where a solute was injected at a controlled mass discharge in order to create a steady state solute plume.

Despite based on a non-ideal array of piezometer, the solute mass discharge calcuated at each control plane delivered results consistent with the solute mass discharge injected upgradient with errors of 34 to 77%, typical for this type of field measurements.

1. Uncertainties quantification on control plane calculated mass discharge

In heterogeneous aquifers, representativity of mass discharges calculated by the integration of discrete mass fluxes measurements over the area of a control plane is not evident, even when groundwaters fluxes and solute concentrations measurements are accurate. Field-scale studies are not able to validate the accuracy of the mass discharge calculations because the original mass discharge released by the contaminant source is never known a priori.

> The only option to validate a mass discharge measurement approach on field experiment is to simulate a dissolved contaminant plume based on a controlled-injection tracer experiment in the aquifer medium.

2. Groundwater flux measurement by FVPDM

The FVPDM consists in the measurement of the groundwater flow rate passing horizontally trough the screen of the tested well and later converted into a groundwater flux in the aquifer.

Experimental setup includes one pump to inject the tracer continuously and at a controlled flow rate, one pump for mixing the water column of the tested well and ensure homogeneous repartition of the tracer mass and one detector able to monitor the tracer concentration (Fig 1).

> The FVPDM provides an accurate measurement of the groundwater flux and can also be used for the monitoring of transient groundwater flow.
(Jamin & Brouyère 2018)

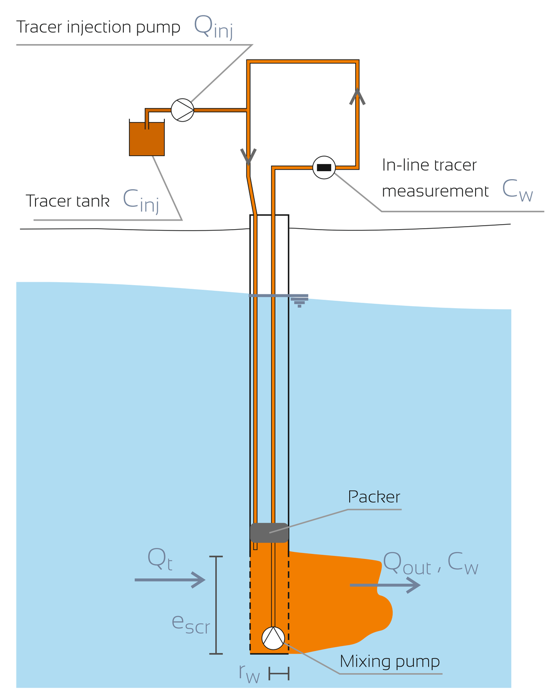

Fig 1: FVPDM experimental setup.

3. Site and setup

Alluvial plain of the Meuse River, 13 km northeast of Liège (Fig 2).

High hydraulic conductivity from 2 to 7 x 10^{-2} m/s, increasing from top to bottom.

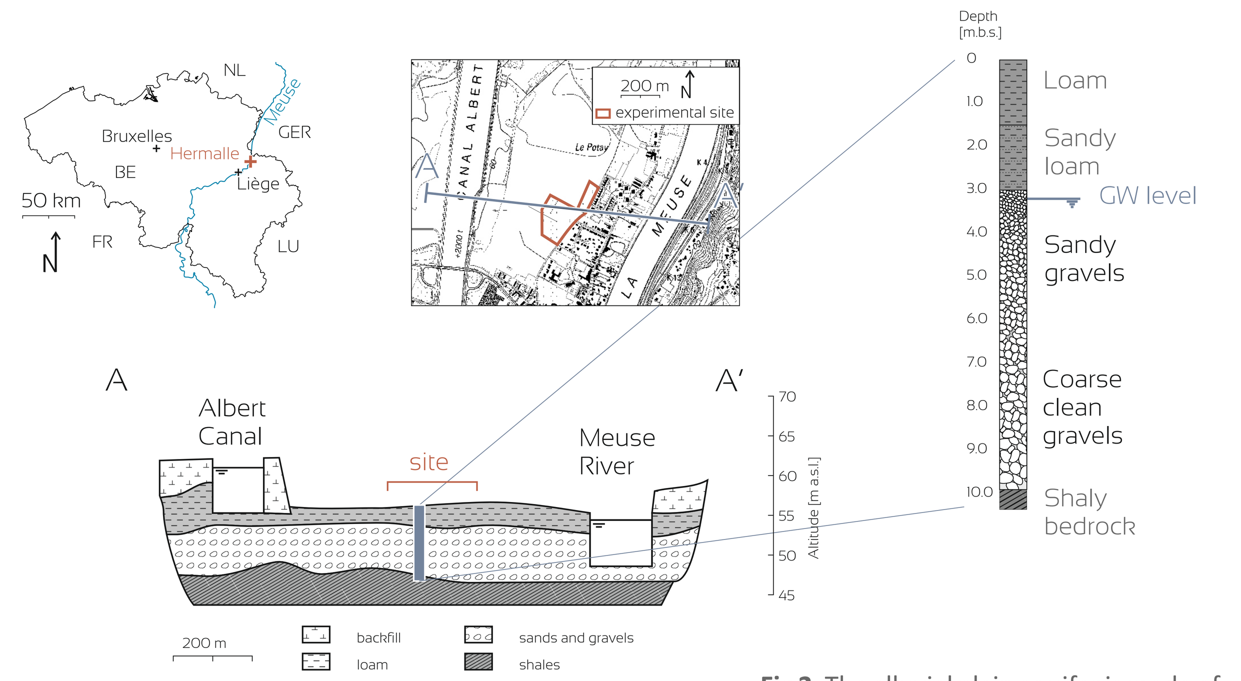

Fig 2: The alluvial plain aquifer is made of sand and gravels

A steady state radial converging flow is created in the aquifer by pumping at 30 m³/h at the pumping well and Uranine is injected at Pz9 at a constant rate of 107 mg/min during 24 days

> to create a controlled steady state solute plume in the aquifer.

Groundwater fluxes are measured by the FVPDM at each piezometer and Uranine concentrations are measured at Pz10 to Pz20 and Pumping well (Fig 3)

> to calculate solute mass flux at each measurement point and

> to integrate mass discharge at each control plane.

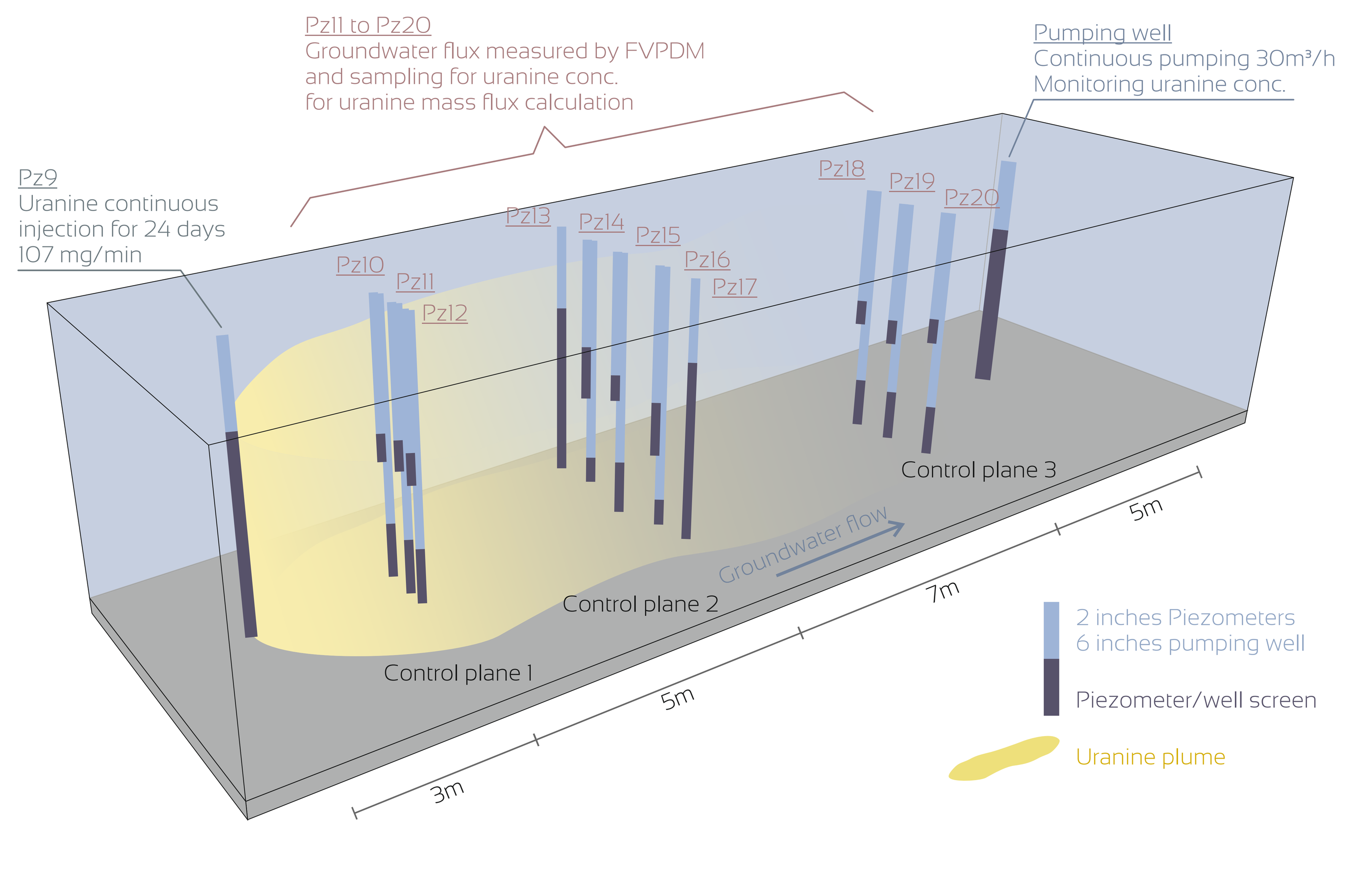

Fig 3: Pz10 to Pz20 are double screen piezometers and are grouped into three control planes
Pz9 is used for Uranine injection (fluorescent dye tracer)

4 Uranine mass discharge

After 10 days of continuous Uranine injection, the Uranine concentration stabilized around 184 ppb at the pumping well, allowing to consider a steady state Uranine plume in the aquifer.

> Uranine mass discharge recovered at the pumping well is 94 mg/min, corresponding to 88% of the injected mass discharge.

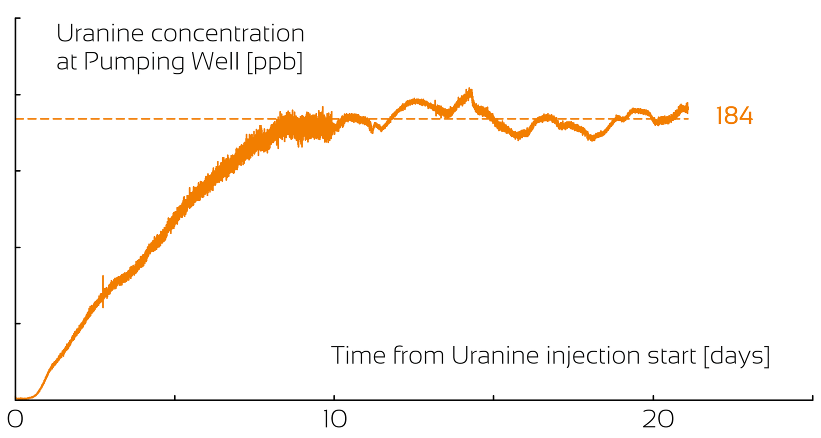

Fig 4: Uranine plume is stable after 10 days.

Groundwater fluxes measured in the aquifer vary from 1 to 68 m/d with high flux in the lower part of the aquifer.

Uranine concentrations ranged from 0.5 to 7500 ppb with the higher concentration in the upper part of the aquifer.

Uranine mass discharge are calculated from mass flux results at each control plane using :

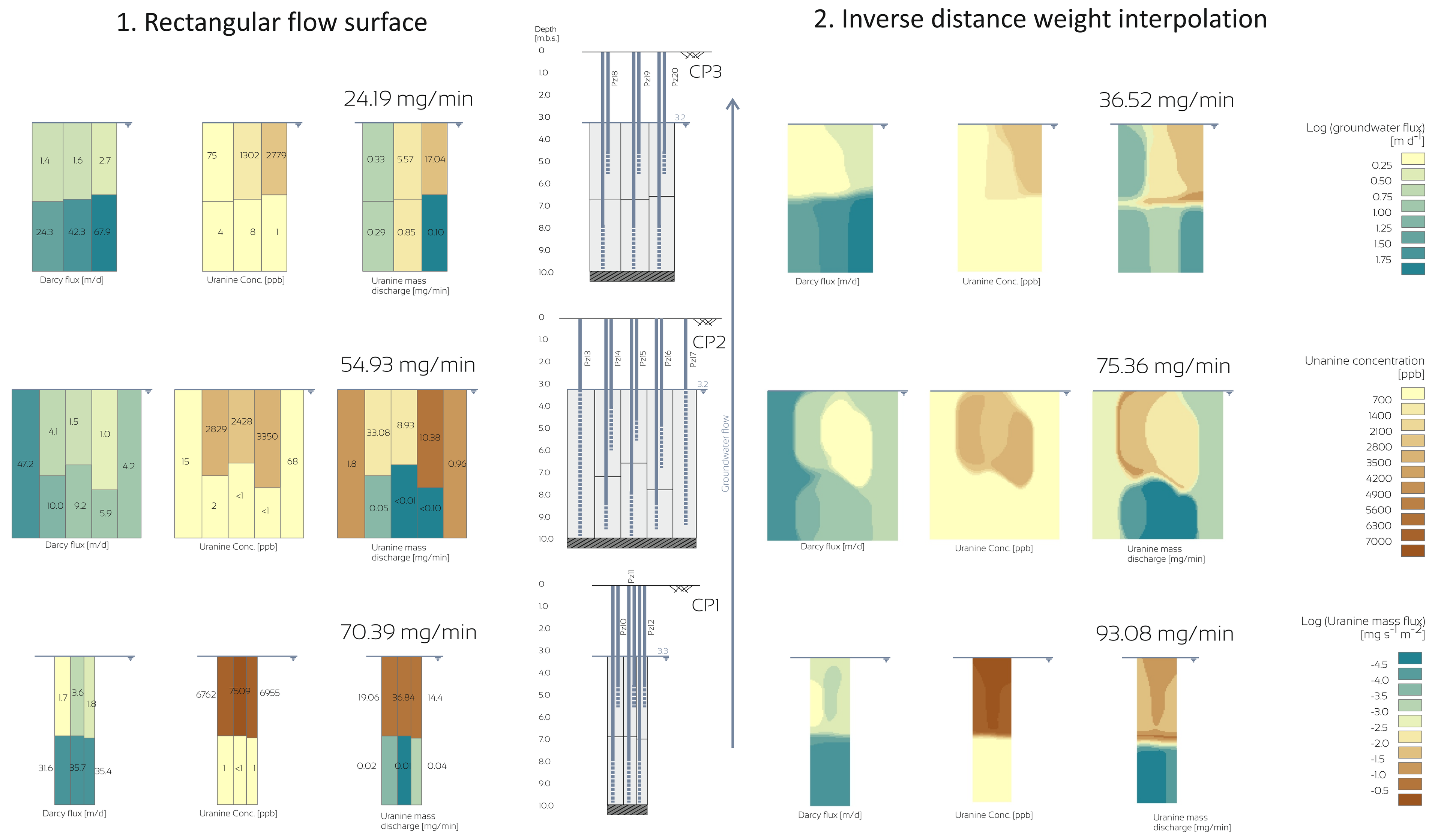

Fig 5: Integration of groudwater flux and solute concentration measurements into mass mass discharge

> Discrepancies are explained by a limited size of the control planes that does not ecompass the full width of the plume, a limited vertical resolution compared to the lateral resolution and should be put in perspective with errors associated with common hydrogeological measurement techniques.

> Smooth interpolations are suitable for control plane located further from the solute source, where the plume is more evenly spread by hydrodynamic dispersion leading to smoother spatial variations of solute concentrations.

Conclusions

FVPDM provided reliable measurements of groundwater fluxes in support of mass flux and discharge calculation.

This study relates the first solute mass dicharge measurement at a series of control planes in a heterogeneous alluvial aquifer where a solute was injected at a controlled mass discharge.

Despite based on a non-ideal array of piezometer, the control plane approach deliverd mass discharge results consistent with the solute mass discharge injected upgradient.

Further intergration of these results into a numerical model would allow for the estimation of uncertainties and illustrate the relevance of mass flux and mass discharge data for groundwater model flow and transport model calibration.

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