QUANTIFICATION AND MONITORING OF CONTAMINANT MASS FLUXES IN HETEROGENEOUS SUBSURFACE MEDIA

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Temporal and spatial variability of groundwater contaminant plumes are so important that they can not be investigated by conventional approaches (essentially based on pollutant concentrations monitored in wells). Characterization and risk assessment concepts should rather be based on contaminant flux measurements which are able to evaluate effectively and quantitatively the risk of contaminant dispersion. This requires (1) the interception of the entire groundwater flow section of the pollutant plume with a control panel; (2) the ability to measure and calculate accurately groundwater fluxes and contaminant concentrations and (3) the repetition of the measurement to bring out the spatial and the temporal variation of contaminant fluxes.

The aim of this research project is to develop an approach and operational devices for the measurement and monitoring of pollutant fluxes and their variability with time and space, at the scale of contaminated site. This approach is based on the combination of the "Finite Volume Point Dilution Method" with passive sampling techniques, integrated at the scale of a control panel.

Objectives

The objective is to develop an integrated approach and operational equipment for quantification and monitoring of contaminant mass fluxes in groundwater at the scale of the contaminated site. The approach lays on a triple integration (1) single-well tracer technique FVPDM (Brouyères *et al.* 2008) - (2) passive sampling - (3) control panel.

(1) Groundwater flow
FVPDM developed for:
★ Well vertical logging
★ Temporal monitoring

(2) Contaminant concentration
Best passive sampling technique for specific case

(3) Contaminant mass flux
★ Integration on control panel
★ Spatial and temporal variability
★ Building of operational devices

- ★ Development of an integrated cell device to measure simultaneously groundwater and contaminants fluxes.
- ★ Groundwater fluxes are measured using an improved version of FVPDM technique to vertical logging and long temporal monitoring.
- ★ Contaminant concentration is obtained using existing/modified passive sampling devices.
- ★ Extension at plume scale is based on the use of FVPDM on diagraphic well logging mode and by repetition of measurement on several wells of a control panel.
- ★ All will be integrated in complete operational field measurement system.

1) Single-well tracer technique FVPDM

FVPDM consists in the injection of a finite volume of tracer into a well during a certain time and in the monitoring of the evolution of the tracer concentration that is progressively flushed out of the well by the groundwater flow (fig 1).

The improvement of FVPDM experimental setup and mathematical/numerical interpretation schema will allow to measure the spatial variations of Darcy's fluxes along the vertical axis of the well (2 approaches: "packers systems" (fig 2) and "diagraphic mode" (fig 3)) and the temporal variations with long time injection tests (fig 4).

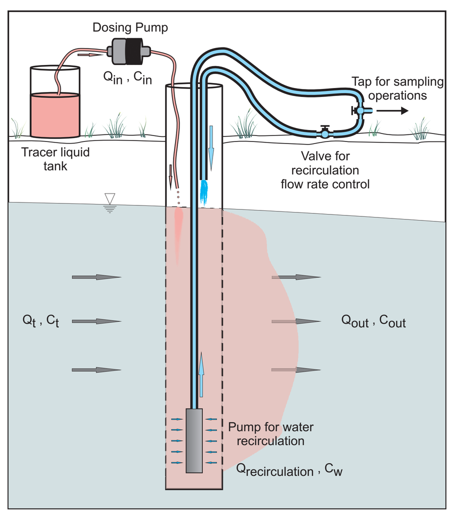


Fig 1: Experimental setup of FVPDM

$$C_w(t) = \frac{Q_{in}C_{in} - (Q_{in}C_{in} - Q_{out}C_{w,0})\exp\left(-\frac{Q_{out}}{V_w}(t-t_0)\right)}{Q_{out}} \quad \text{with } Q_{out} = Q_{in} + Q^{in}{}_t$$

Eq 1: FVPDM analytical solution. C_w, C_{in}, and $C_{w,0}$ are tracer concentrations (ML^{-3}) into the well, in the injection water and in the well at time t_0 respectively. Q_{in}, $Q^{in}{}_t$, and Q_{out} (L^3 T-1) are the injection rate, the transit flow rate corresponding to the groundwater flow intercepted by the well screen that is directly related to *vD* (apparent Darcy's flux) and the flow rate leaving the well through the screen carrying tracer at concentration C_w. V_w in the volume of water in the injection well, assumed to be constant.

- ★ Finite Volume Point Dilution Method (Brouyère *et al.* 2008).
- ★ Developed to overcome implementation difficulties of classical PDM (instantaneous and uniform mixing of tracer into well without disturbance of groundwater fluxes).
- ★ Generalize PDM to almost any kind of tracer injection scenario and is of easy experimental setup.
- ★ Local estimation of groundwater fluxes based on the monitoring over time of the decreasing concentration of a tracer injected into a well.
- ★ High sensivity allows to study and monitor changes of Darcy's fluxes in transient conditions.
- ★ Mathematical approach is based on water and mass balance (eq 1).

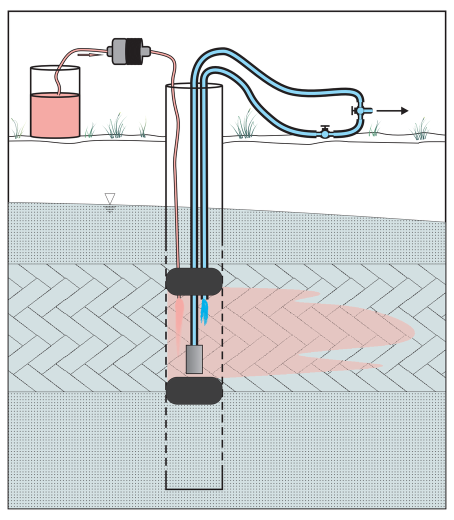


Fig 2: Packers development of FVPDM

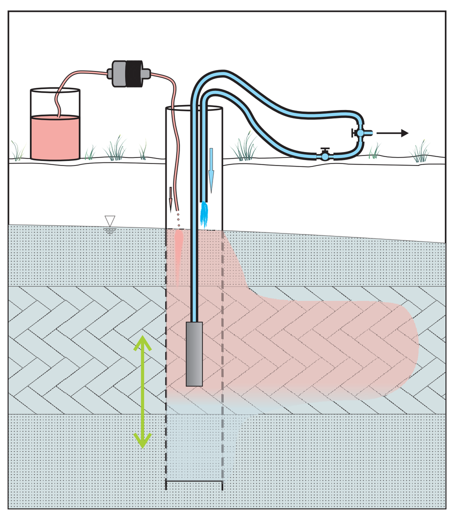


Fig 3: Diagraphic development of FVPDM

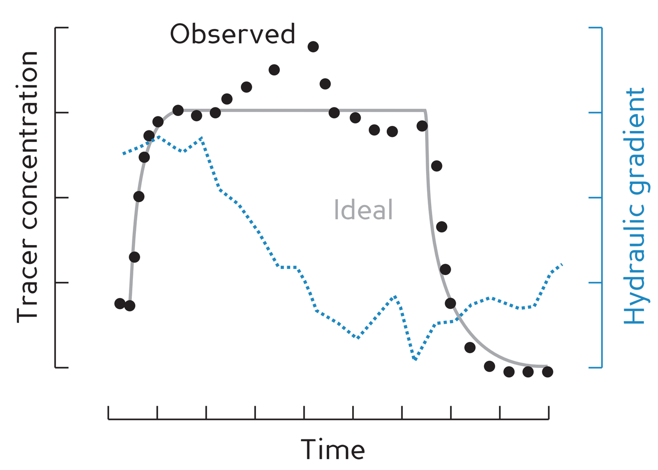


Fig 4: Result of FVPDM test with transient groundwater flow

2) Passive sampling techniques

This task consists in an exhaustive review of existing passive sampling techniques and equipments. Each will be classified according criteria and the best ones will be tested/adapted in the scope of vertical screening of pollutant concentration in wells.

The aim is to select the most versatile device for a time integrated measurement of contaminant concentration.

The effect of saline and fluorescent tracer is to be considered for a combination of the technique with tracer techniques.

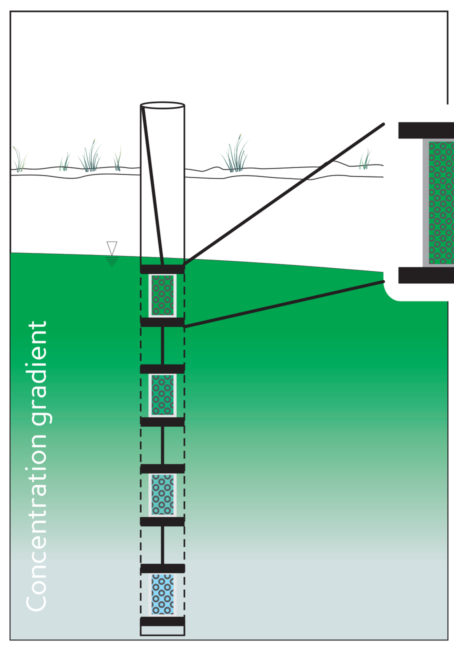


Fig 5: Multiple passive sampling for screening of vertical gradient of contaminant concentration

- ★ Versatile for any type of contaminants, in terms of contaminant concentration (from near pure phase to diluted) and in terms of monitoring duration, from a week to months. Possibly by the availability of several interchangeable sorbant matrix.
- ★ Robust and high building quality.
- ★ Capable of vertical screening of concentration along the axis of a well.
- ★ Easy experimental setup.
- ★ Study the influence of saline and fluorescent tracer because it will/can be used simultaneously with FVPDM techniques.

3) Integrated PS-FVPDM to contaminant mass flux monitoring on control panel

Integration of improved FVPDM technique with selected/adapted passive sampling device in a new technique (PS-FVPDM) for contaminant mass flux spatial and temporal monitoring.
Application and development of the new PS-FVPDM technique on already characterized test cases on pilot sites.
Validation of improved FVPDM technique by comparison with other techniques (velocity probes, integral pumping tests ...) and application on real case control panel (fig 7).
Conception and building of a mobile unit with all the needed measurement and interpretation equipment (fig 6).

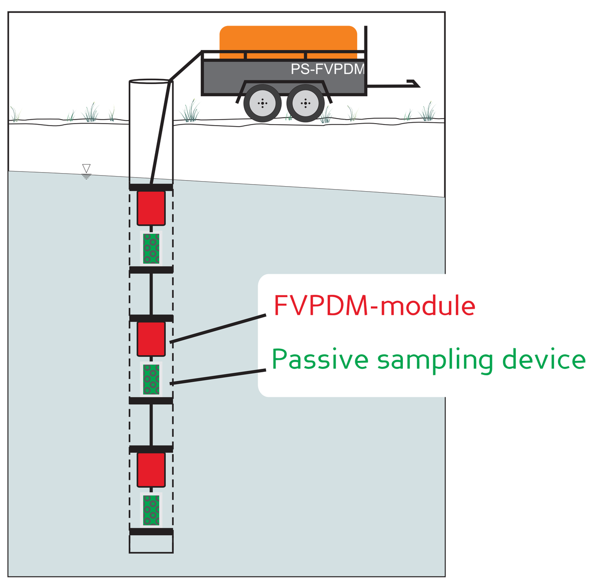


Fig 6: PS-FVPDM mobile unit for monitoring of spatial and temporal variability of contaminant mass fluxes

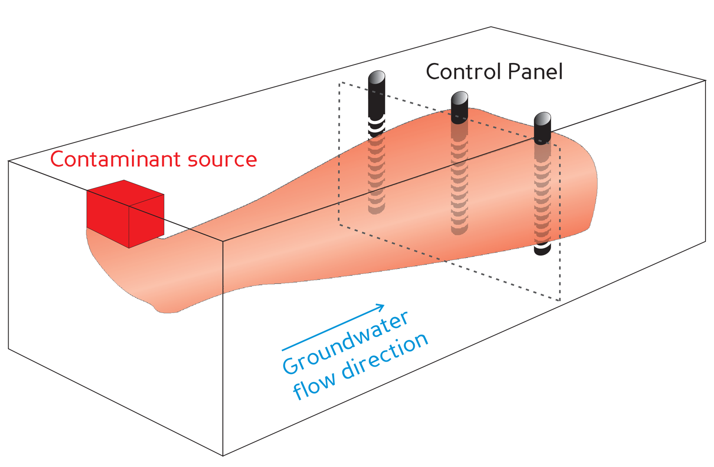
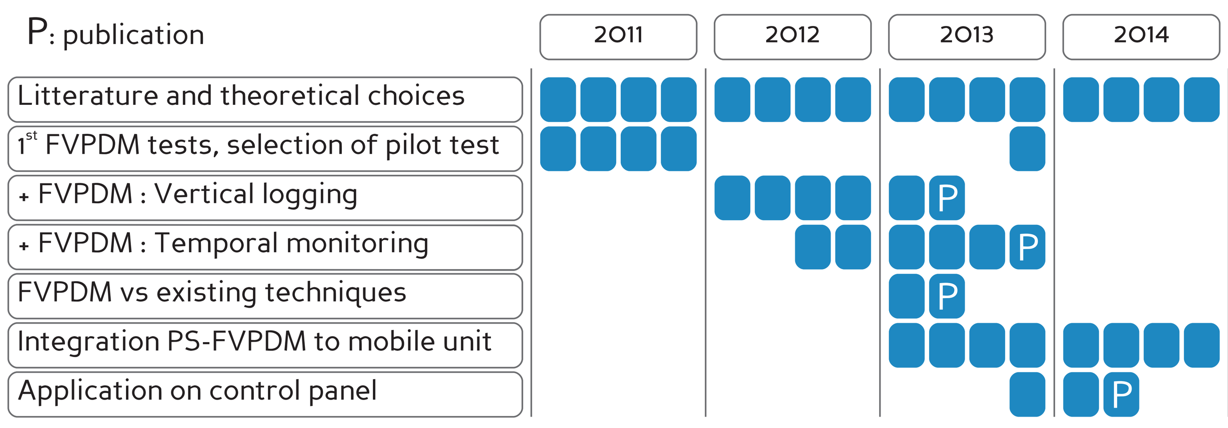


Fig 7: Control panel

- ★ The aim is to combine the FVPDM technique improved for long term monitoring and vertical logging of groundwater fluxes with the selected/adapted passive sampler to be able to measure contaminant mass flux.
- ★ Several tests sites has been selected for their different hydrogeological properties, porous or fractured aquifer, located in alluvium or bedrock, shallow or deep and for BTEX, VOCs, heavy metals ... These pilot sites will be used to test and improve the new PS-FVPDM method and material.
- ★ The spatial heterogeneity of the plume will be investigated by repeating the measures along the vertical axis of the well and by reproducing this method for series of wells implanted in a control panel.
- ★ The final aim is to gather all needed material into a mobile unit, kind of trailer that can be taken out on field rapidly in order to perform contaminant mass flux measurements.
- ★ All the collected information will form a unique data set that, combined with modelling effort on contaminant flow and transport in groundwater, will prove the potential of the new approach.
- ★ Applications: hydrogeological characterisation, dimensioning/efficiency evaluation of remediation techniques, risk assessment, quantification of natural attenuation, source threat ranking in megasite context, characterisation of surface water/groundwater interactions ...

Schedule



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Related event: Symposium In-situ Environmental Monitoring and Policy, The Application of Sensors and Passive Samplers. 26-27 May 2010, Auditorium Oehoe, Gent, Belgium

Hydrogeology
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