Recent advanced for monitoring groundwater and contaminants fluxes using single-well applied tracer techniques

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Need for accurate quantification and monitoring of groundwater and pollutants mass fluxes

However, groundwater flows are complex in space and time …

Heterogeneity of aquifers

"Remediation hydrogeology has emerged and evolved from an era of "simplified bulk-averages" that was reliant on parameters and steady-state assumptions, to our current period where we collect site-specific hydrogeologic data at very high resolution and consider the importance of transient, time-dependent behavior.." Suthersan et al., GW Monit. Remed. 2016

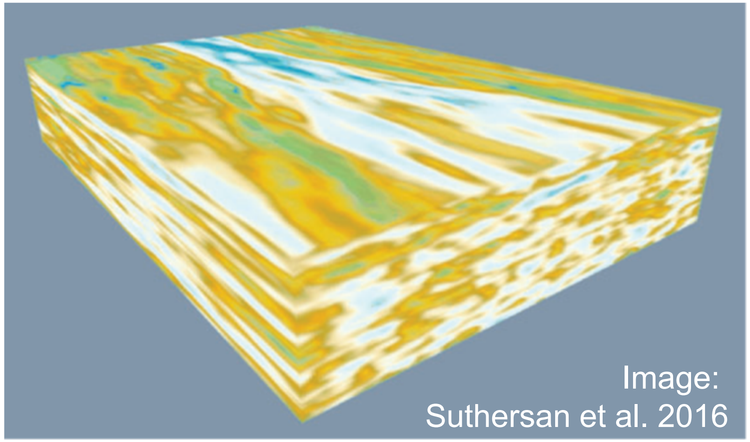
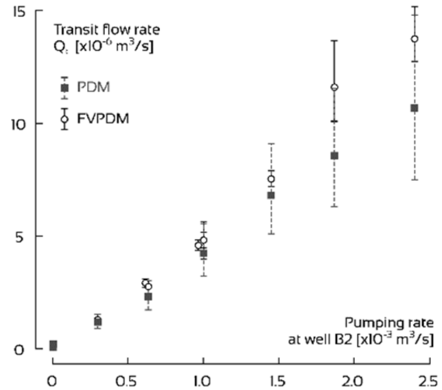


Image: Suthersan et al. 2016

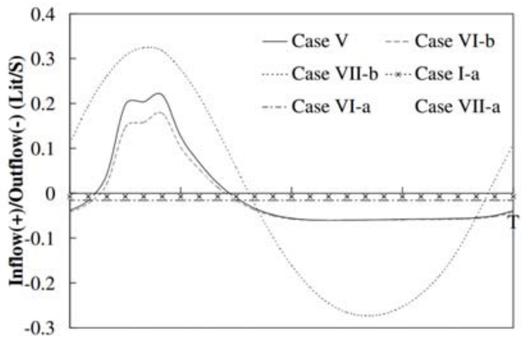


Nearby pumping wells

"The change of pumping rate at the nearby well induced changes in the groundwater flow velocity that were recorded by continuous groundwater flux measurement." Jamin *et al.,* J. of Contam. Hydrol. 2015

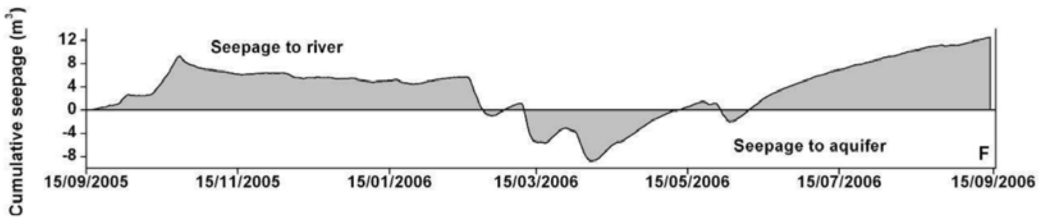
Tidal effects

"The tidal oscillations […] have an influence on regional groundwater flow." Ataie-Ashtiani *et al.*, Hydrological Processes. 2001



GW – Surface water interaction

"Darcy fluxes change continuously in time because o frequent changes in the difference of head between the rive and its alluvial aquifer." Batlle-Aguilar, PhD thesis. 200



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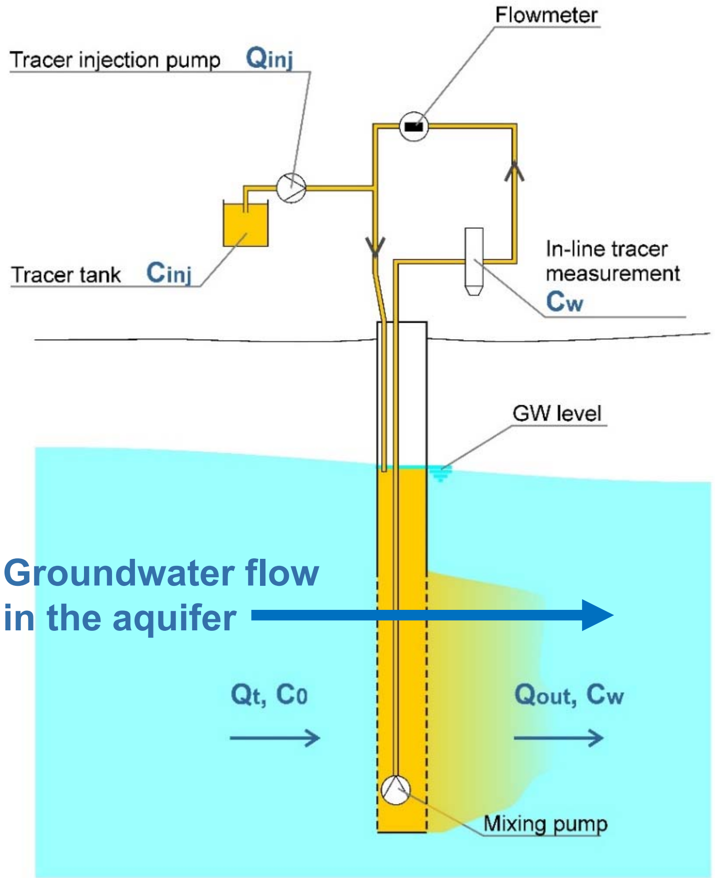
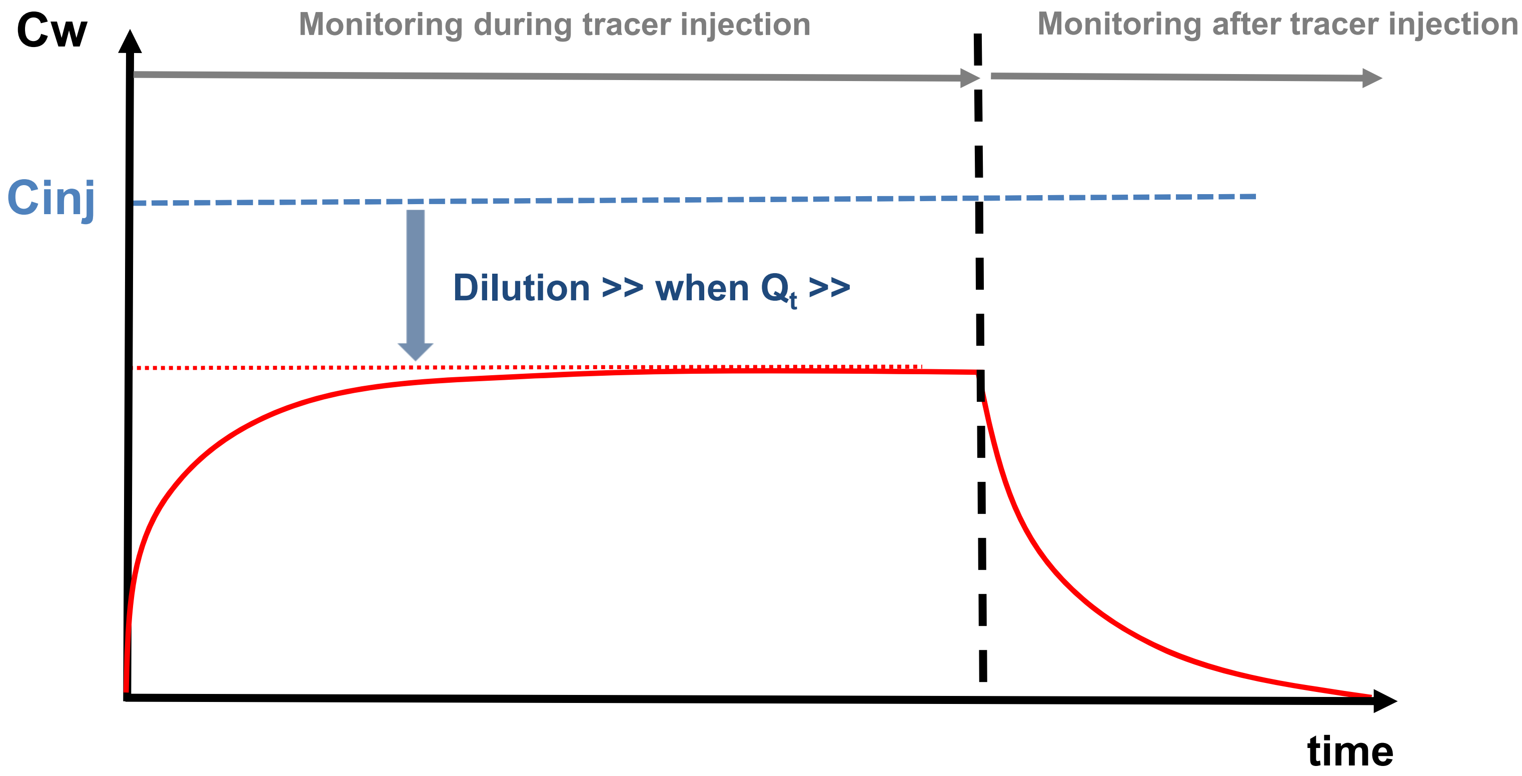
The Finite Volume Point Dilution Method (FVPDM): basic setup

Generalisation of single well dilution techniques [Brouyère *et al.* 2008, J. Cont. Hydrol.]

Key difference: the tracer is continuously injected at a low injection rate



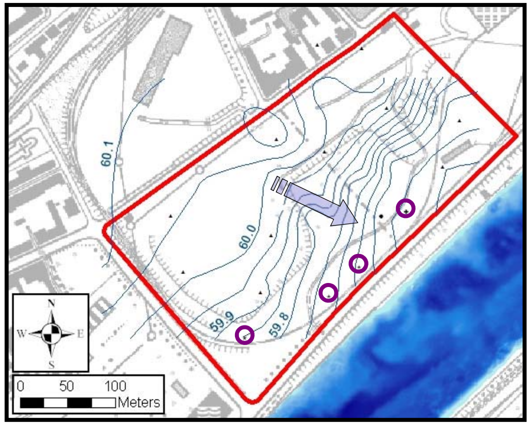
The Finite Volume Point Dilution Method (FVPDM): basic setup

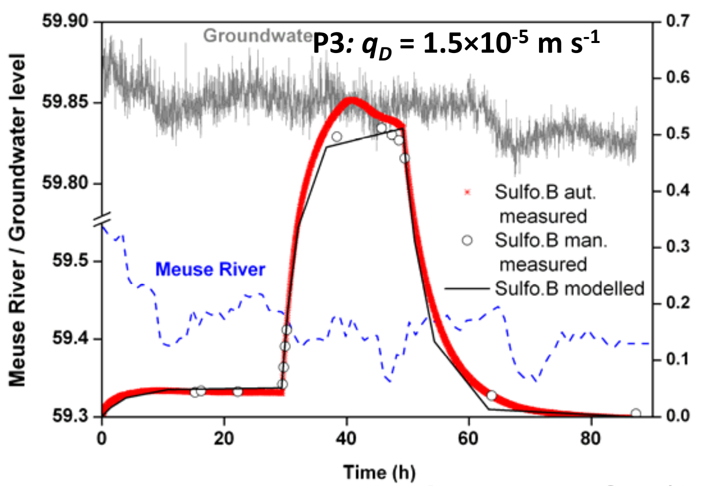


Calculated concentration evolution [Brouyère *et al.* 2008]: $$C_w(t) = \frac{Q_{inj}C_{inj} - \left(Q_{inj}C_{inj} - Q_{out}C_{w,0}\right)\exp\left(-\frac{Q_{out}}{V_w}(t - t_0)\right)}{Q_{out}}$$

FVPDM applications in different contexts: from open piezometers in loose sediments to packer systems in fractured rocks

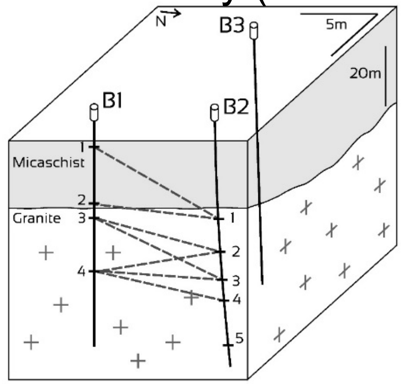
GW discharge to a river from a polluted alluvial aquifer



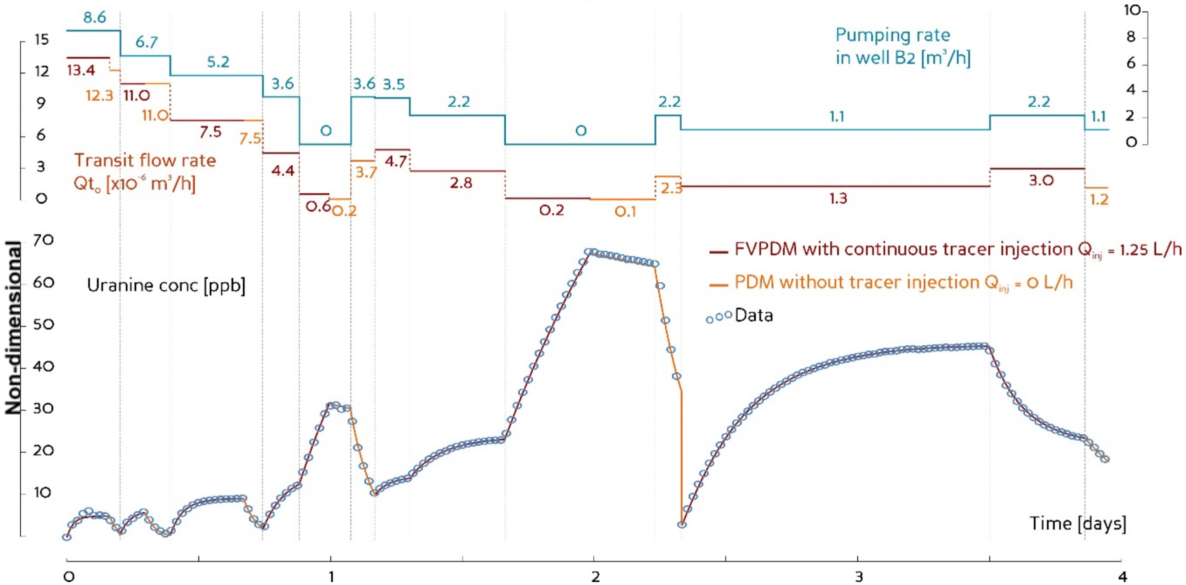


Further reading: Brouyère et al. JCH (2008)

Fractured granite aquifer in Brittany (France)



Variable pumping rate at B2
Various FVPDM with a packer in B1
→ Fracture connectivity and flow rate



Further reading: Jamin et al. JCH (2015)

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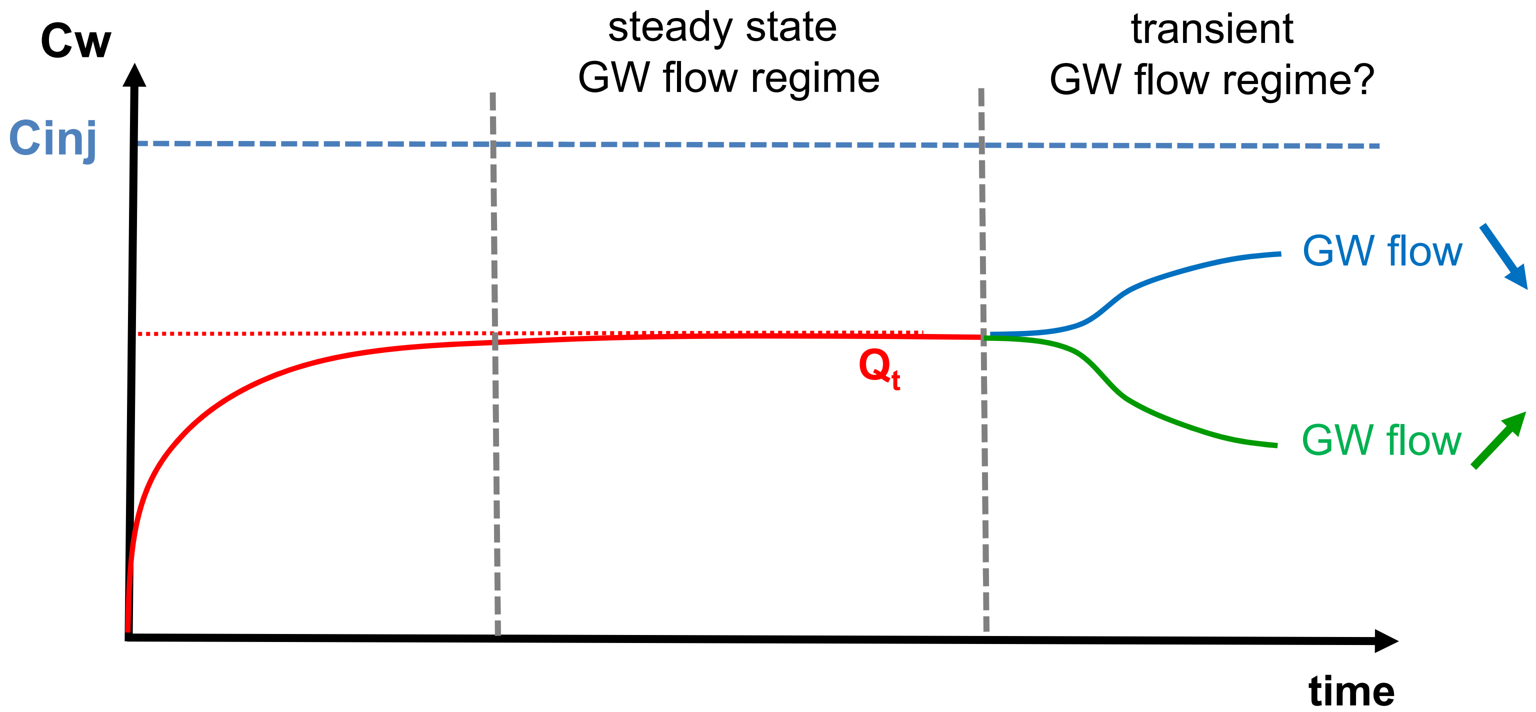
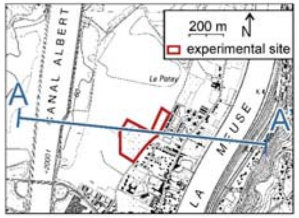
FVPDM potential: monitoring of variable GW fluxes

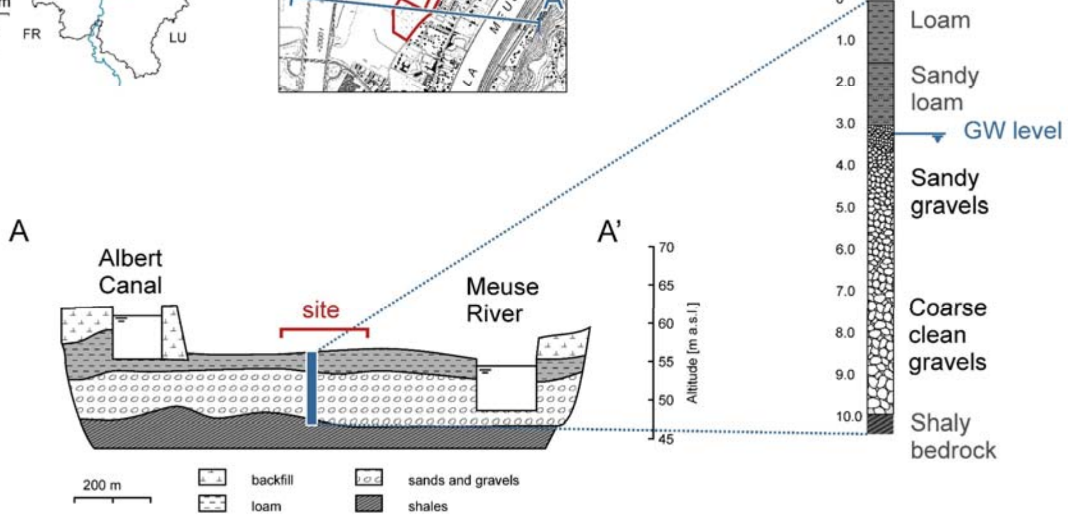
Constant injection of tracer and mixing during the monitoring time

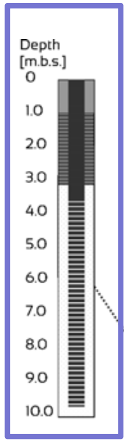
Tracer concentration in the tested piezometer varies according to the GW flux (more/less dilution)



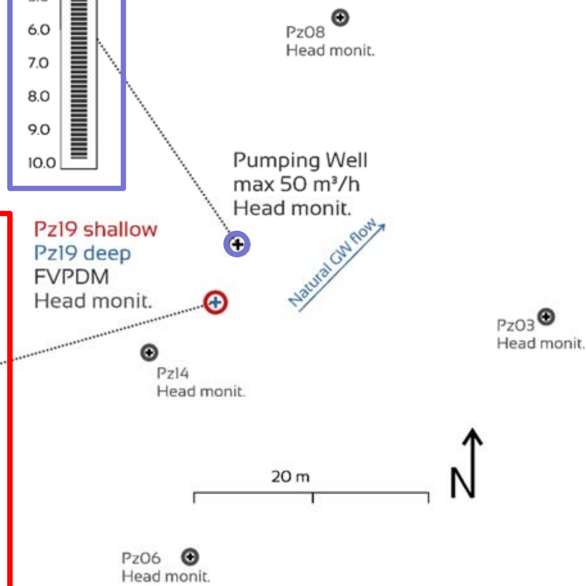
Case study 3 in Belgium: monitoring variations in GW fluxes induced by pumping operations in a neighboring abstraction well



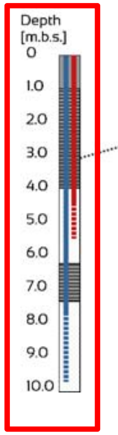




Pumping well used to produce forced-gradient conditions in the aquifer and variable GW fluxes



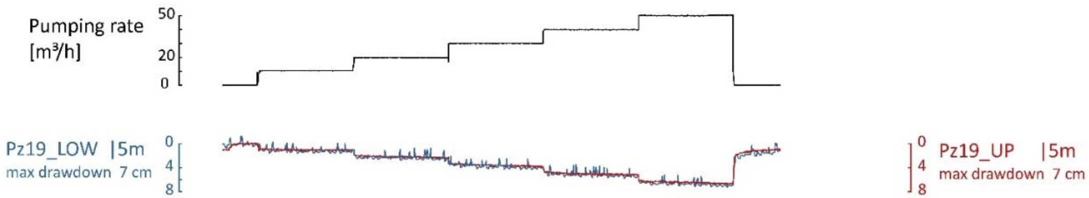
Double-screened piezometer used to perform 2 simultaneous FVPDM tests during the pumping operations



Further reading:
P. Jamin & S. Brouyère, JCH (July 2018)

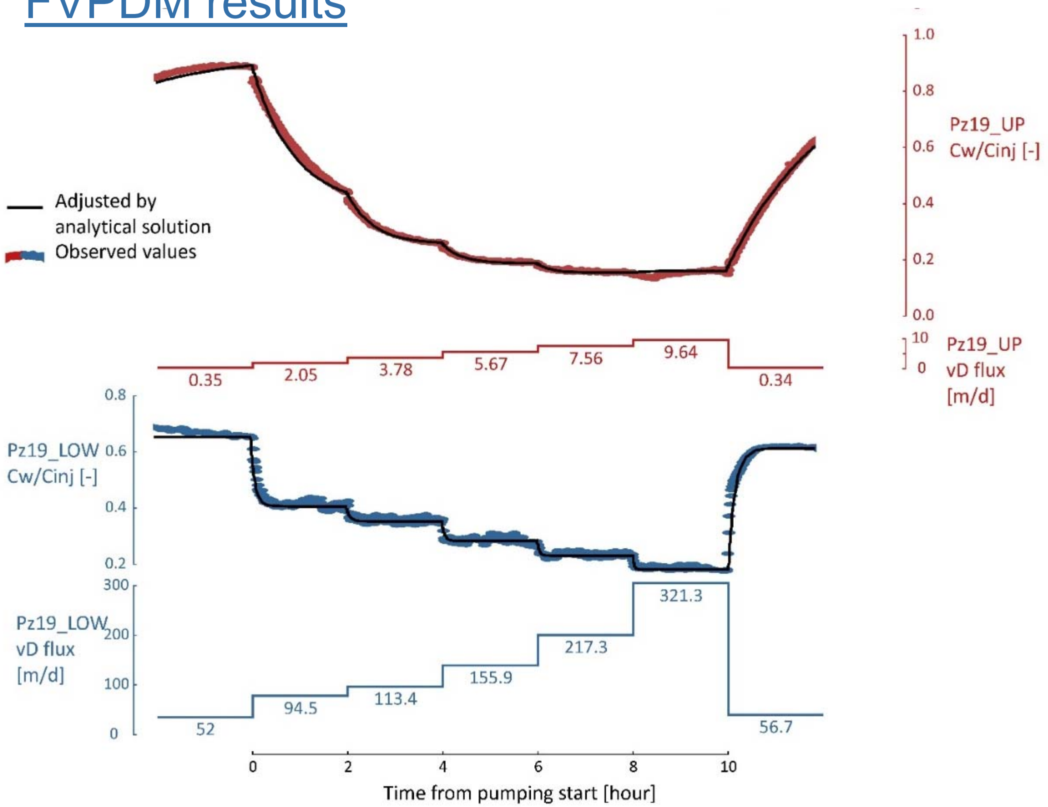
Case study 3 in Belgium: monitoring variations in GW fluxes induced by pumping operations in a neighboring abstraction well

Pumping test results



Pumping test results: same drawdown
→ same K value and same Darcy flux!

FVPDM results



FVPDM results: different concentration evolutions
→ different Darcy fluxes!

Pz19_UP

0.35 m/d without pumping

9.64 m/d at max pumping

Pz19_LOW

52 m/d without pumping

321 m/d at max pumping

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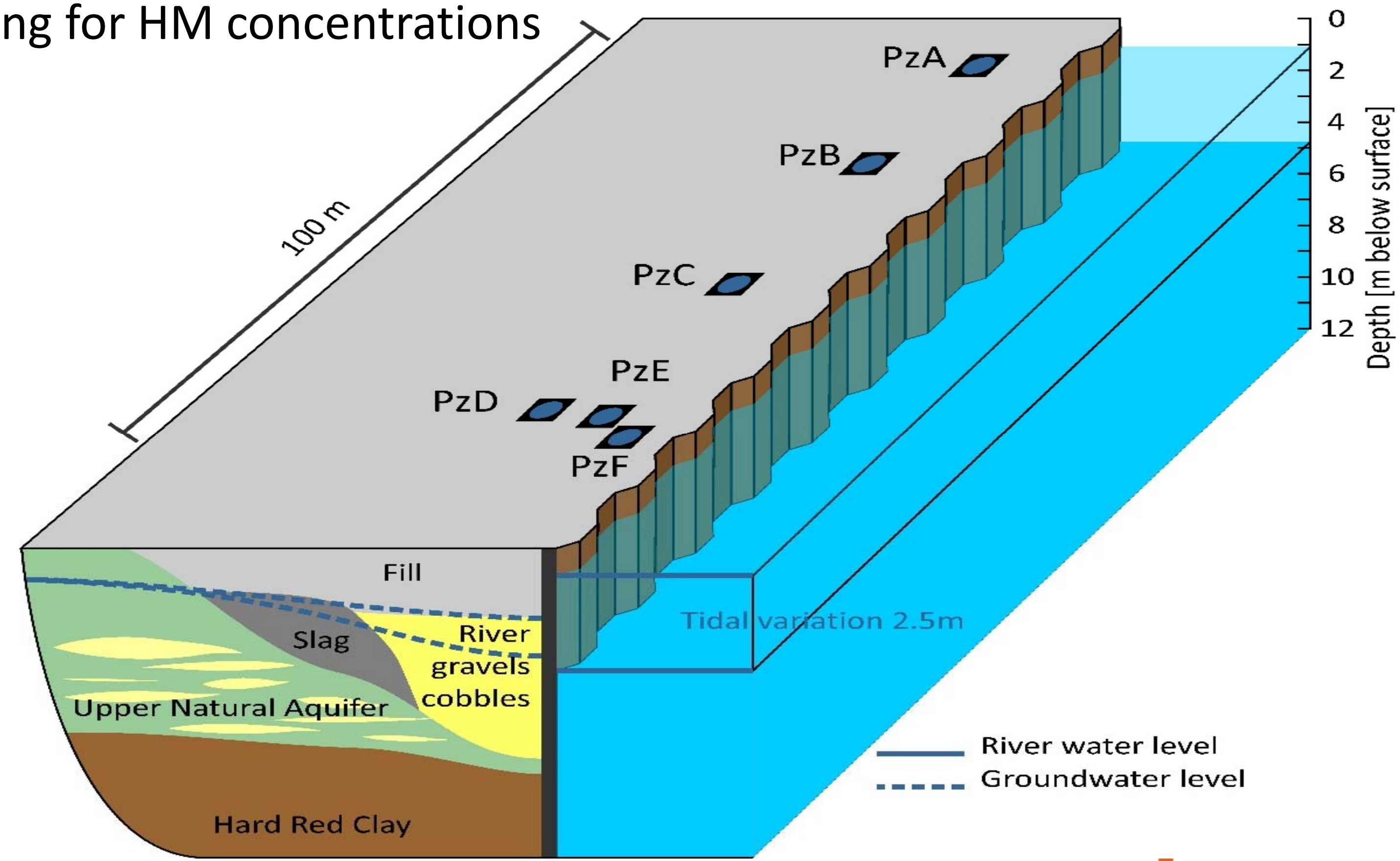
Case study 4 in Australia: Groundwater pollution under an industrial warf along an estuary (heavy metals)

- Costal aquifer connected to tidal estuary -> complex groundwater flow
- Heavy metal contamination of GW (Mn, Zn, Cd, Pb) -> risk for estuarian ecosystems
- Continuous FVPDM monitoring for 48 hours (4 tide cycles) in 7 piezometers
- GW sampling for HM concentrations



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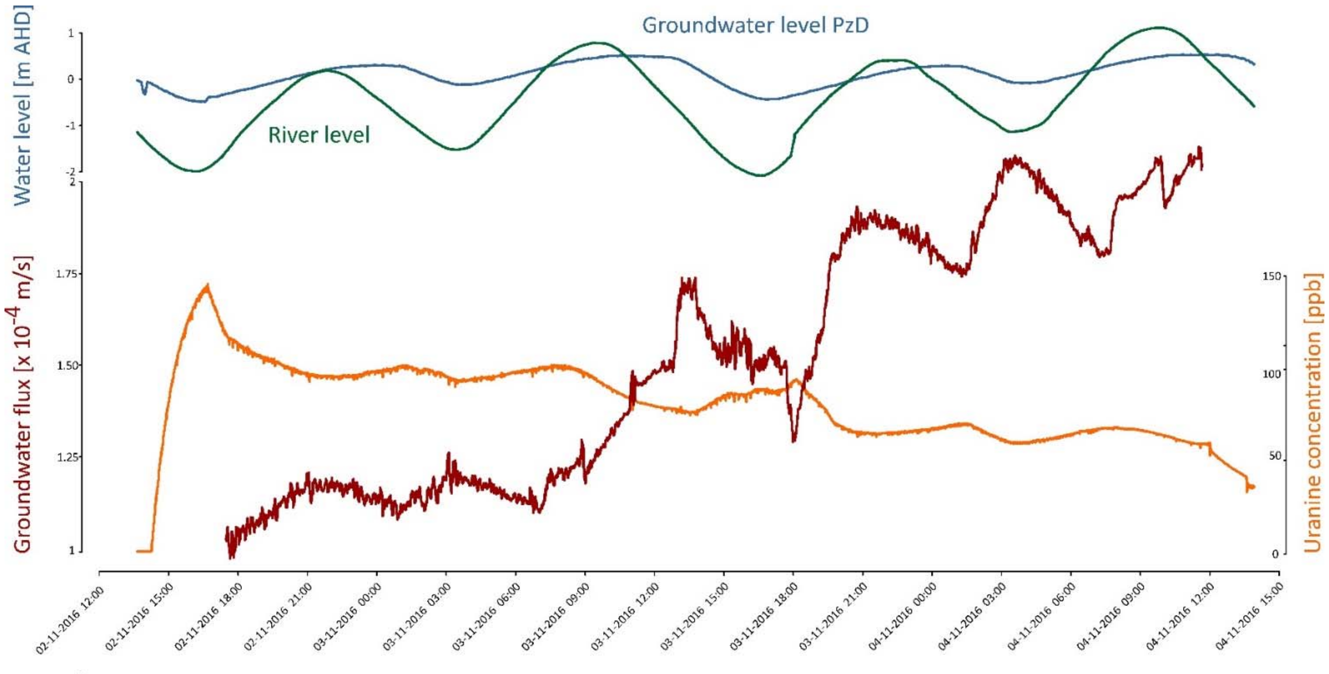
Case study 4 in Australia: Groundwater pollution under an industrial warf along an estuary (heavy metals)

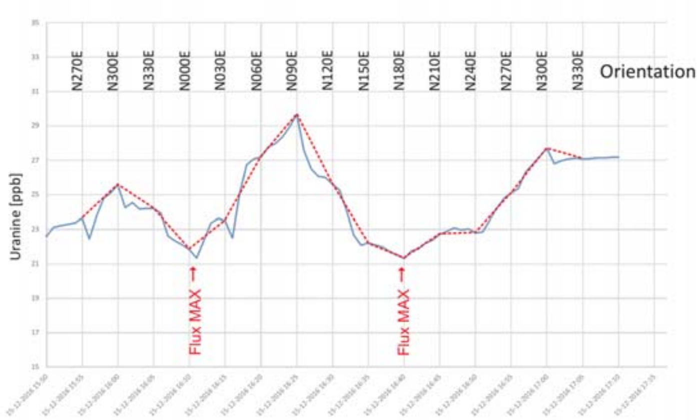
GW fluxes coming from upgradient are so important that we observed no inversion of GW flow during high river level



+ calculation of cadmium mass fluxes to the estuary based on FVPDM groundwater fluxes and Cd concentrations in groundwater

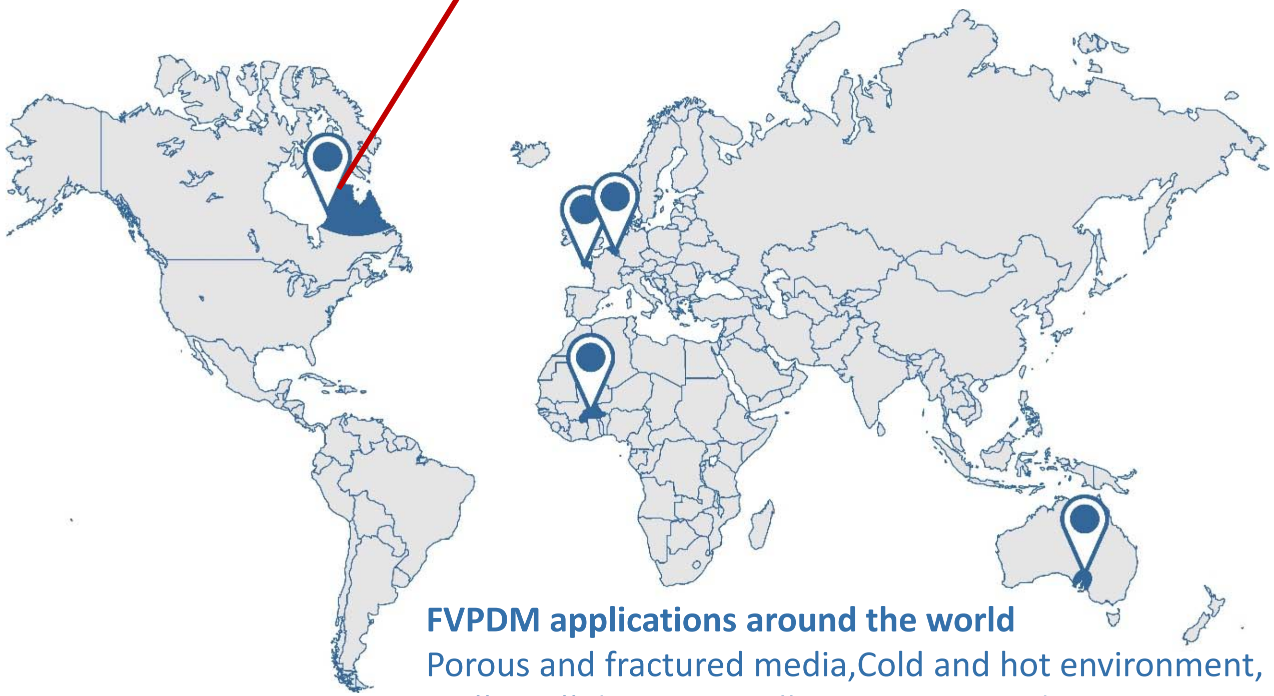
FVPDM : Conclusions and perspectives

- FVPDM able to monitor GW fluxes in very different geological environments (loose sediments to fractured rocks), experimental setups (open boreholes or packer systems) and drivers (transient GW flows, tidal effects …)
- FVPDM captures small and fast changes in GW fluxes, from few cm/day to hundreds m/d.
- Coupled to measurements of concentrations in contaminants, FVPDM able to deliver useful estimates of contaminant mass fluxes
- **Perspectives**
  - Full coupling of FVPDM and contaminant monitoring
  - Directional FVPDM



Any questions?

See poster on FVPDM experiments performed under a permafrost layer in **Poster session T3** this afternoon



FVPDM applications around the world
Porous and fractured media,Cold and hot environment,
1.5’’ to 4’’ diameter wells, 0.5m to 80m deep

GQ 19

Groundwater Quality 2019

Groundwater Quality 2019

The next IAHS conference on Groundwater Quality (**GQ 2019**) will be held in Liège (Belgium) on 9-12 September 2019 !

With the support of IAH, UK CL:AIRE and EU H2020 ITN iNSPIRATION

More information : **aimontefiore.org/GQ2019**

Contact: c.dizier@aim-association.org – serge.brouyere@uliege.be

Further reading on FVPDM

- Brouyère, S. (2003). Modeling tracer injection and well-aquifer interactions: A new mathematical and numerical approach. Water Resources Research, 39(3). http://hdl.handle.net/2268/2321
- Brouyère, S., Carabin, G., & Dassargues, A. (2005). Influence of injection conditions on field tracer experiments. *Ground Water, 43*(3), 389-400. http://hdl.handle.net/2268/3306
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- Jamin, P., Brouyère, S. (2018) Monitoring transient groundwater fluxes using the finite volume point dilution method, Journal of Contaminant Hydrology. https://doi.org/10.1016/j.jconhyd.2018.07.005.