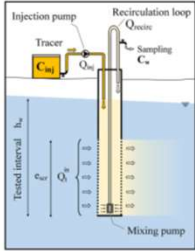


Introduction

Estimates of groundwater fluxes → contaminant transport; groundwater-surface water interactions; geothermal applications; geotechnical engineering



Finite Volume Point Dilution Method (FVPDM) [Brouyère et al. 2008]

- Single-well tracer experiment
- Continuous injection of the tracer
- Recirculation loop: mixing
- A part of the injected tracer: carried out of the well by the groundwater flow
⇒ the higher the groundwater fluxes, the lower the tracer concentration remaining in the well

⇒ Direct estimate of the groundwater flux

Limitations

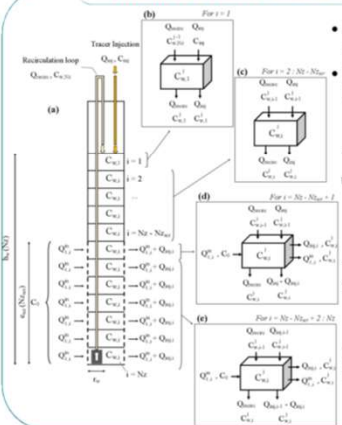
- « Classical » analytical solution [Brouyère et al. 2008]: assumption of the **uniform repartition** of the tracer mass in the water column (recirculation loop) ⇒ Difficult in practice
- **Non-perfect mixing conditions** → a significant portion of tracer carried out of the well before reaching the mixing pump located at the bottom of the tested interval ⇒ higher tracer concentrations at the top of the tested interval

Objectives and approaches

- Effect of the mixing (recirculation flow rate) on the tracer concentration distribution
- ⇒ A new discrete FVPDM model considering the recirculation flow rate
- ⇒ simulating the distribution of the tracer concentration along the tested interval
- ⇒ assessing the effect of the recirculation flow rate

⇒ A solution for interpreting FVPDM tests performed under non-perfect mixing conditions

The new discrete model



- Domain (the volume of water) discretized into elementary cells with vertical size Δz
- Mass balance equations applied for each cell numerically evaluated through the finite difference method

→ Along the screens (d):

$$V_{w,i} \frac{dC_{w,i}}{dt} = V_{w,i} C_{w,i}^{in} - Q_{cr,i} C_{w,i} + Q_{w,i}^{in} C_{w,i} - Q_{w,i}^{out} C_{w,i} + Q_{w,i-1} C_{w,i-1} - Q_{w,i} C_{w,i}$$

→ $Q_{cr,i}^{tr}$: transit flow rate crossing the well screen under injection conditions:

$$Q_{cr,i}^{tr} = \frac{Q_{cr,i}}{\pi} \sin \left(\arccos \left(\frac{Q_{w,i-1}}{Q_{cr,i}} \right) \right) - \frac{Q_{w,i-1}}{2\pi} \left(2 \arccos \left(\frac{Q_{w,i-1}}{Q_{cr,i}} \right) \right)$$

With $Q_{w,i}$, the injection rate above which the transit flow rate $Q_{cr,i}$ is cancelled:

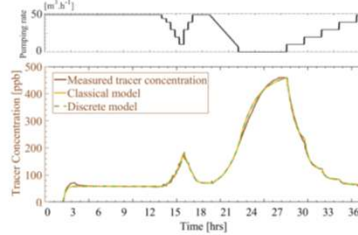
$$Q_{cr,i} = \pi Q_{w,i} \Delta z q_{app,i}$$

Application on Field data

Application of the discrete model to interpret field data [Jamin and Brouyère. 2018]

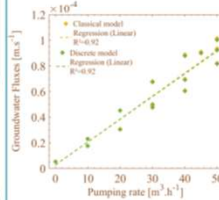
Piezometer 1 - Perfect mixing conditions

Screen length: 0.9 m $Q_{recirc} = 1.9 \times 10^{-4} \text{ m}^3 \cdot \text{s}^{-1}$



With both models:

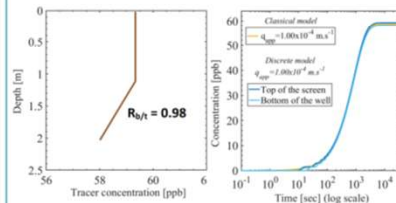
- ✓ Reproducing the measured tracer C
- ✓ Similar GW fluxes estimates



✓ Linear evolution of the GW flux with the pumping rate

Both models can be used under perfect mixing conditions

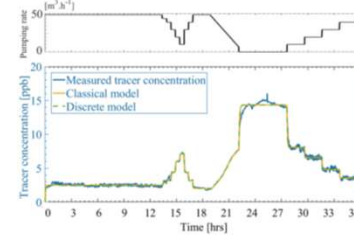
⇒ Validating the new discrete model



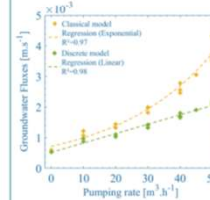
Uniform repartition of the tracer Concentration

Piezometer 2 - Non-perfect mixing conditions

Screen length: 1.8 m $Q_{recirc} = 1.9 \times 10^{-4} \text{ m}^3 \cdot \text{s}^{-1}$

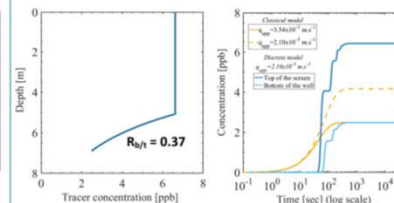


- ✓ Both models reproduce the measured tracer C
- ✗ Significant differences in GW fluxes estimates



- ✓ Discrete model: linear evolution of the GW flux with the pumping rate
- ✗ Classical model: overestimates the GW flow (24 - 82%)

⇒ Discrete model in case of non-perfect mixing conditions



Non uniform repartition of the tracer Concentration
C measured at the bottom of the well → overestimate of the flux using the classical model

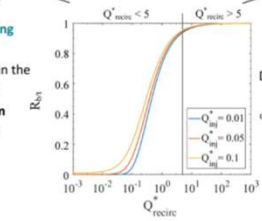
Sensitivity analysis

Nondimensional variables → define the domain of non-perfect mixing conditions

$$Q_{recirc}^* = Q_{recirc}/Q_{cr} \quad Q_{inj}^* = Q_{inj}/Q_{cr}$$

Non-Perfect mixing

Difference of C within the interval > 5%
⇒ **Non-Uniform concentration**

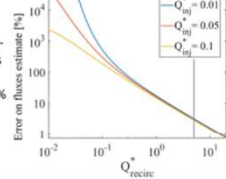


Perfect mixing

Difference of C within the interval < 5%
⇒ **Uniform concentration**

✓ Discrete model

Classical model overestimates GW fluxes
Errors > 50 % for $Q_{recirc}^* < 0.5$ and 100% for $Q_{recirc}^* < 0.3$



GW fluxes estimates: similar results with both models (discrete or classical)
Difference < 3.5 %

Conclusions

- Mixing within the tested interval depends on the recirculation flow rate compared to the groundwater flow rate crossing the well screens
→ $Q_{recirc}^* > 5$: Perfect mixing conditions (Piezometer 1)
⇒ recirculation high enough to ensure the homogenization of the tracer within the tested interval
- both models (classical and discrete) to interpret field data
→ $Q_{recirc}^* < 5$: Non-Perfect mixing conditions (Piezometer 2)
⇒ Non-uniform repartition of the tracer
⇒ **Discrete model** only (classical model overestimates of the flux)
- Discrete model
→ assessing the vertical transport of the tracer along the well axis
→ estimating fluxes even if experimental conditions are not ideal
→ very permeable aquifer materials, long-screened boreholes, vertical variabilities

Brouyère, S., Battie-Aguliar, J., Godeaux, P., and Dassargues, A.: A new tracer technique for monitoring groundwater fluxes: The Finite Volume Point Dilution Method, *Journal of Contaminant Hydrology*, 95, 121–140, <https://doi.org/10.1016/j.jconhyd.2007.09.001>, 2008.

Jamin, P. and Brouyère, S.: Monitoring transient groundwater fluxes using the Finite Volume Point Dilution Method, *Journal of Contaminant Hydrology*, 218, 10–18, <https://doi.org/10.1016/j.jconhyd.2018.07.005>, 2018.

Simon, N., Brouyère, S. and Jamin, P.: A new discrete model to better consider tracer distribution along boreholes during Finite Volume Point Dilution Method, *Journal of Contaminant Hydrology*, Submitted

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