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Intraborehole Flow: Applications for Groundwater Sampling Strategies and Understanding Contaminant Dynamics

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Introduction and objectives

Groundwater contamination with Cr(VI) has persisted in the aquifer of Ljubljansko polje (Ljubljana, Slovenia) since it was first discovered in 1985. This is a typical type of anthropogenic pollution that originates from multiple point sources and results in spatially and temporally scattered concentrations rather than a concentrated contaminant plume. The exact sources and the number of Cr(VI) inputs are still unknown. Due to the presence of ambient intraborehole flows caused by hydraulic head differences at the opposite ends of long screens, the samples may be unrepresentative and biassed in terms of origin. The aim of this research was to identify vertical differences in Cr(VI) concentration that would help us to distinguish different individual sources and provide guidance for local sampling strategies. The overall objective is to improve the understanding of the dynamics and transport characteristics of contaminants in thick, well-permeable and relatively uniform unconfined aquifer systems.

Methods

I. Borehole logging (Fig.1):
1. High Resolution Impeller Flowmeter (HRFM)
2. Water quality probe (SWQS)

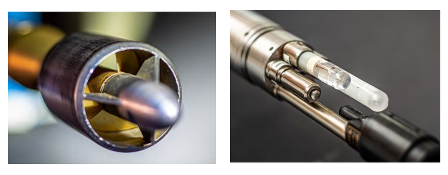


Fig. 1: HRFM and SWQS probes (Source: Mozetič et al., 2020)

II. Groundwater sampling (Fig.2, Fig.3 & Fig.4):
1. Conventional 'low-flow' sampling (negligible drawdown)
2. Depth-discrete sampling with double packer system and depth-discrete sampling in monitoring well cluster

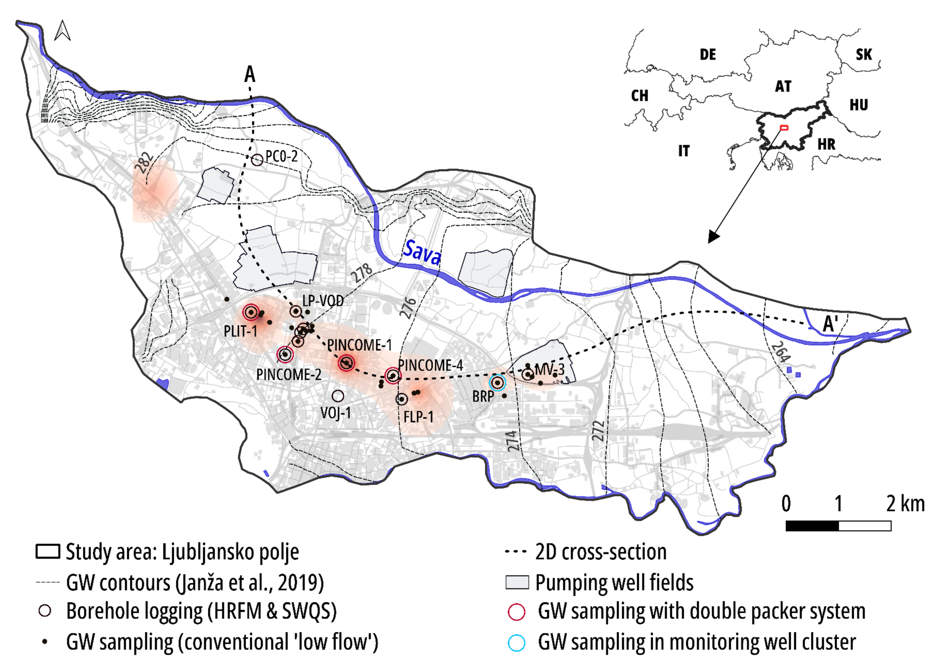


Fig. 4: Study area with boreholes & 2D cross-section profile (A-A').

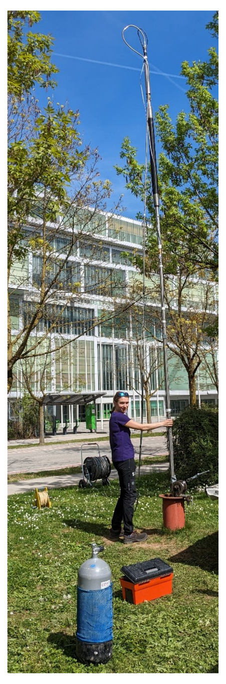


Fig. 2: Double packer system

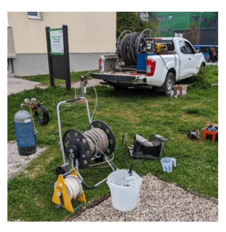


Fig. 3: Groundwater sampling

III. Interpretation of intraborehole flows:
- Technical characteristics of boreholes (diameter and length of screen sections)
- Reclassification of sediments according to the ISO standard (SIST EN ISO 14688-2:2004), based on the content of gravel (Gr), sand (Sa), silt (Si) and clay (Cl).
- Interpretation of the texture classes in terms of the expected relative range of permeability (Domenico & Schwartz, 1998).
- 2D cross-section A-A' along the projected GW streamlines obtained from an existing numerical model (Janža et al., 2020)

IV. Interpretation of groundwater sampling results:
- Comparison of sampling results from conventional 'low flow' sampling and sampling with the double packer system
- Identification of the depth sections with the highest Cr(VI) concentration

NEXT STEPS (in progress):

IV. Modelling:
- Numerical modelling of ambient intraborehole flow in FEFLOW 8.1 (Fig.5) & particle tracking
- Analytical dispersion modelling to identify potential contaminant sources

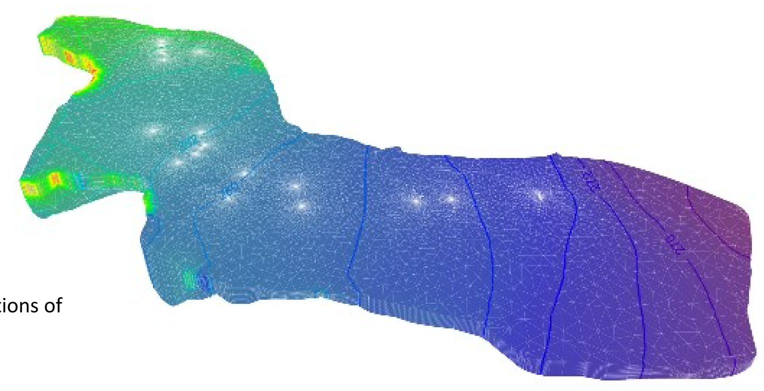


Fig. 5: Local model in FEFLOW, based on the boundary conditions of the existing numerical model (Janža et al., 2020).

Results

Borehole logging: Significant variability was observed in the directions and velocities of intraborehole flows (Fig.6). The analysis does not indicate that the direction of vertical water flow in the boreholes is associated with a particular sequence of sediment layers. However, intraborehole vertical flows were found to be primarily related to the shape of the base of the aquifer. The downward water flows are significantly related to the concave down regions and the local deepening of the bedrock, while the upward flows are related to the concave up region or the local rise of the bedrock. The first modelling results show that the velocities of intraborehole flows are closely related to the local inclination of the bedrock.

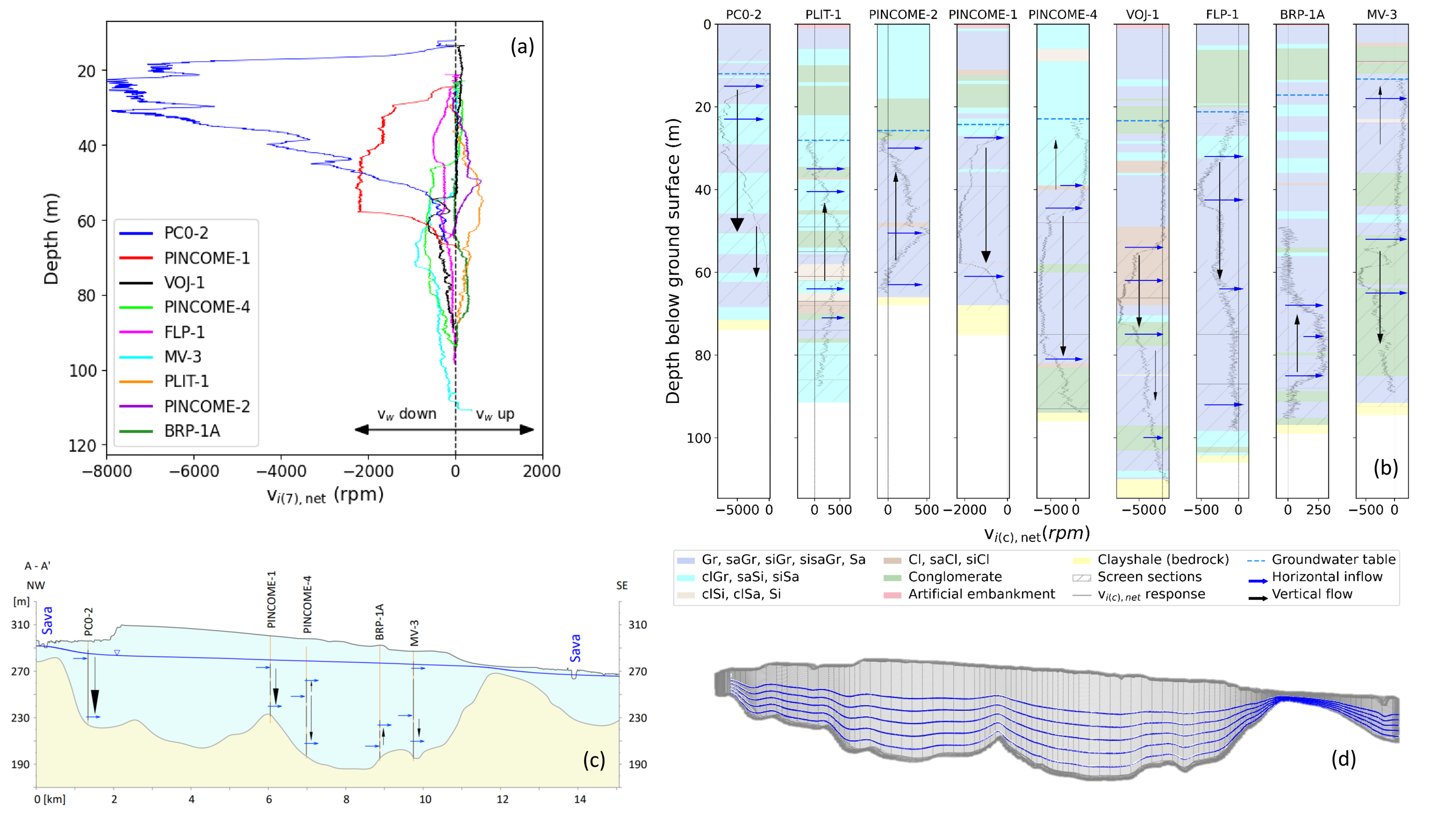
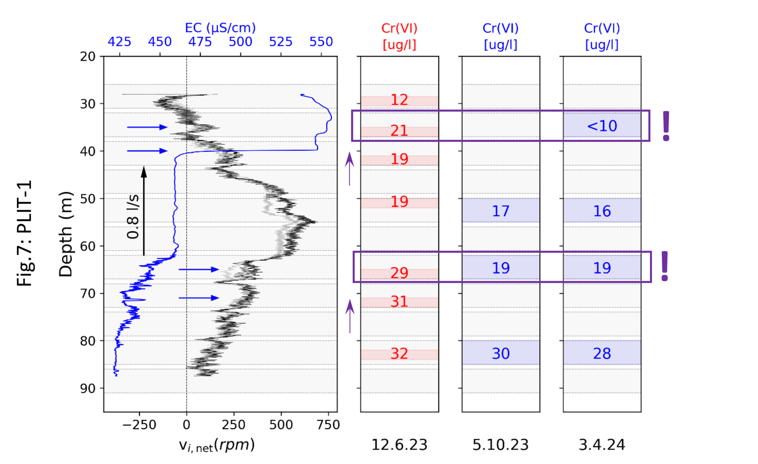
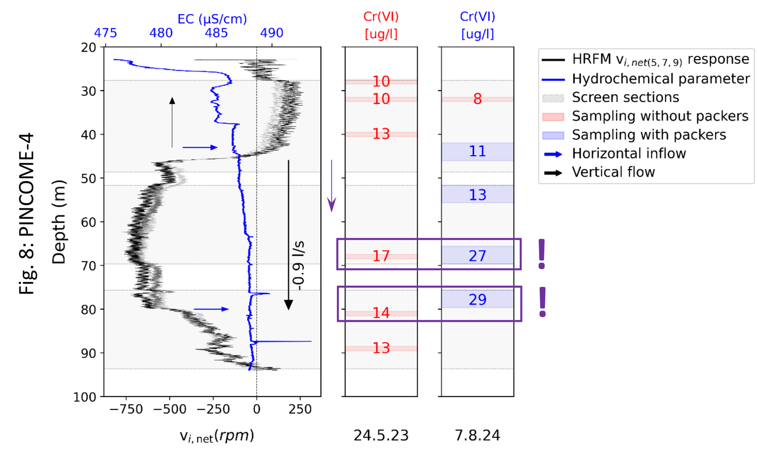


Fig. 6: Results of the borehole logging: The HRFM response ($v_{i,net}$) by depth, indicating the direction of vertical intraborehole flow (v_w) (a); interpretation of intraborehole flows in geological profiles (b,c); streamlines in the 3D model by depth, simulated in FEFLOW (d).

Groundwater sampling:





Figures (Fig.7, Fig.8) show a comparison of the Cr(VI) concentrations in PLIT-1 and PINCOME-4 by depth, using only a pump (first phase: red) and a double packer system (second phase: blue). In both cases, the bias in Cr(VI) concentration was observed in the first phase of sampling due to the ambient intraborehole flow.

In PLIT-1, the concentration was biassed by ≥+10 µg/l between 62-67 m and 32-37 m due to the upward intraborehole flow.

In PINCOME-4, the concentration was biassed by ≥-10 µg/l between 65-80 m due to dilution with less contaminated water from the upper borehole section.

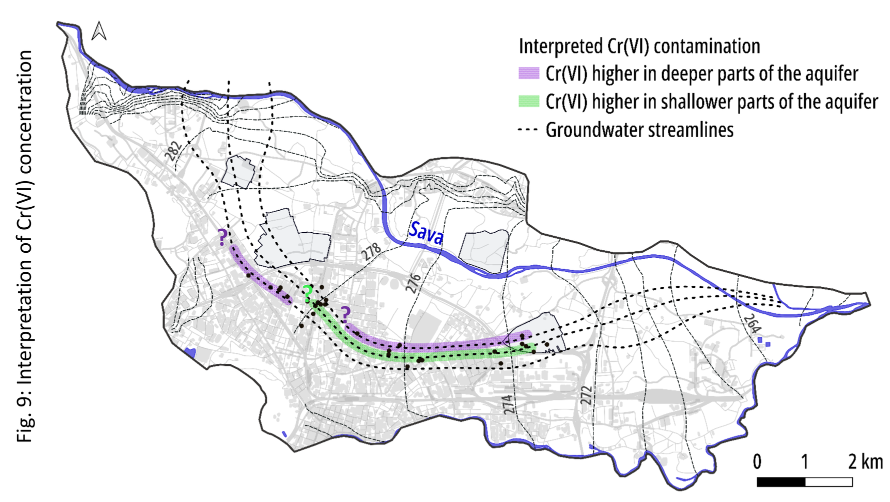


Fig. 9: Interpretation of Cr(VI) concentration

By analysing the depth-discrete samples, we were able to distinguish at least 3 different Cr(VI) plumes moving along the groundwater streamlines (Fig.9). However, the results have to be used in the GW model in the next steps to identify possible Cr(VI) sources.

Conclusions

- Vertical hydraulic gradients can occur not only in multiple aquifer systems, but also in apparently homogeneous and unstratified highly productive alluvial aquifers where differences in hydraulic head occur (pressure-driven convection).
- It was found that the direction and velocity of intraborehole vertical flows are primarily influenced by the bedrock morphology, proximity to recharge and discharge zones and the length of the borehole screen sections.
- The study confirmed that intraborehole flows in the study area significantly influence the origin of samples in deeper boreholes (>60 m) with long screens.
- The study revealed spatial differences in the vertical distribution of Cr(VI) concentrations. This will be used in the next steps for groundwater modelling to delineate different potential sources of Cr(VI).

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