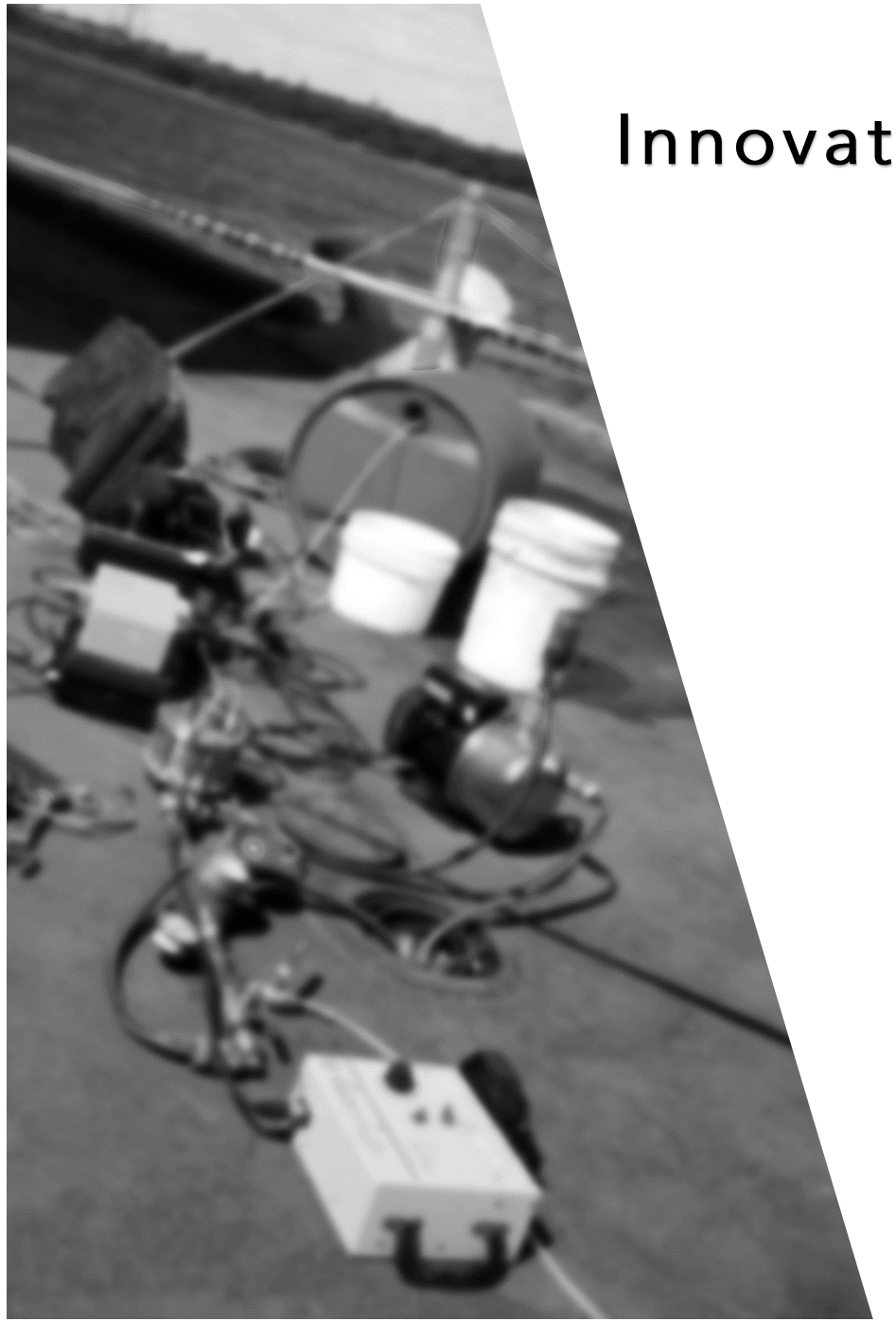


Innovative contaminant mass flux monitoring in an aquifer subject to tidal effects

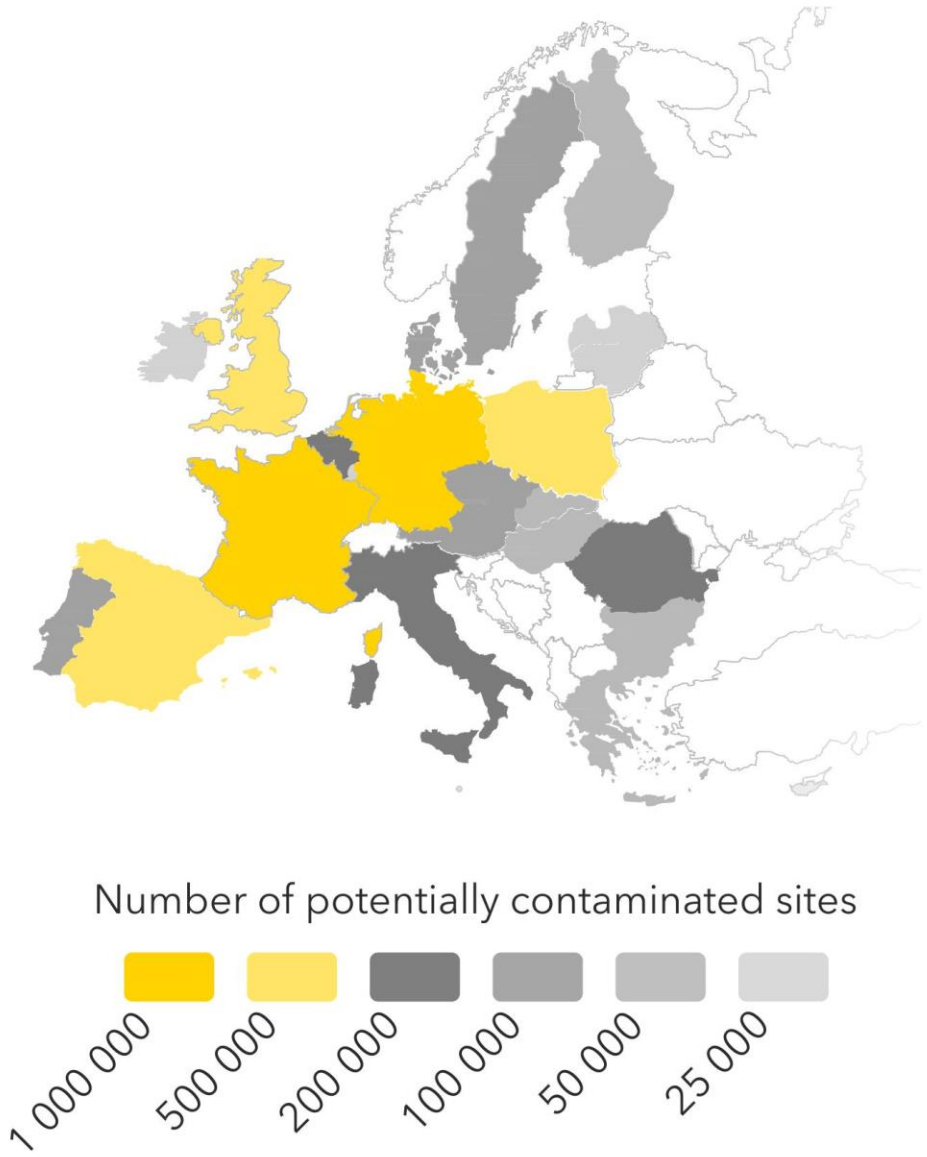
P. JAMIN, F. COSME, P. ORBAN,
K. DE GREEN, S. BROUYERE

Advanced and new techniques for characterizing groundwater quality, pollutant fate and subsurface systems: part 1 monitoring fluxes

Groundwater Quality 2019, September 11th

LIÈGE université

The threat of contaminated sites



2.8 million potentially contaminated sites

3.2 billions €/year for polluted site management

Characterization
15%

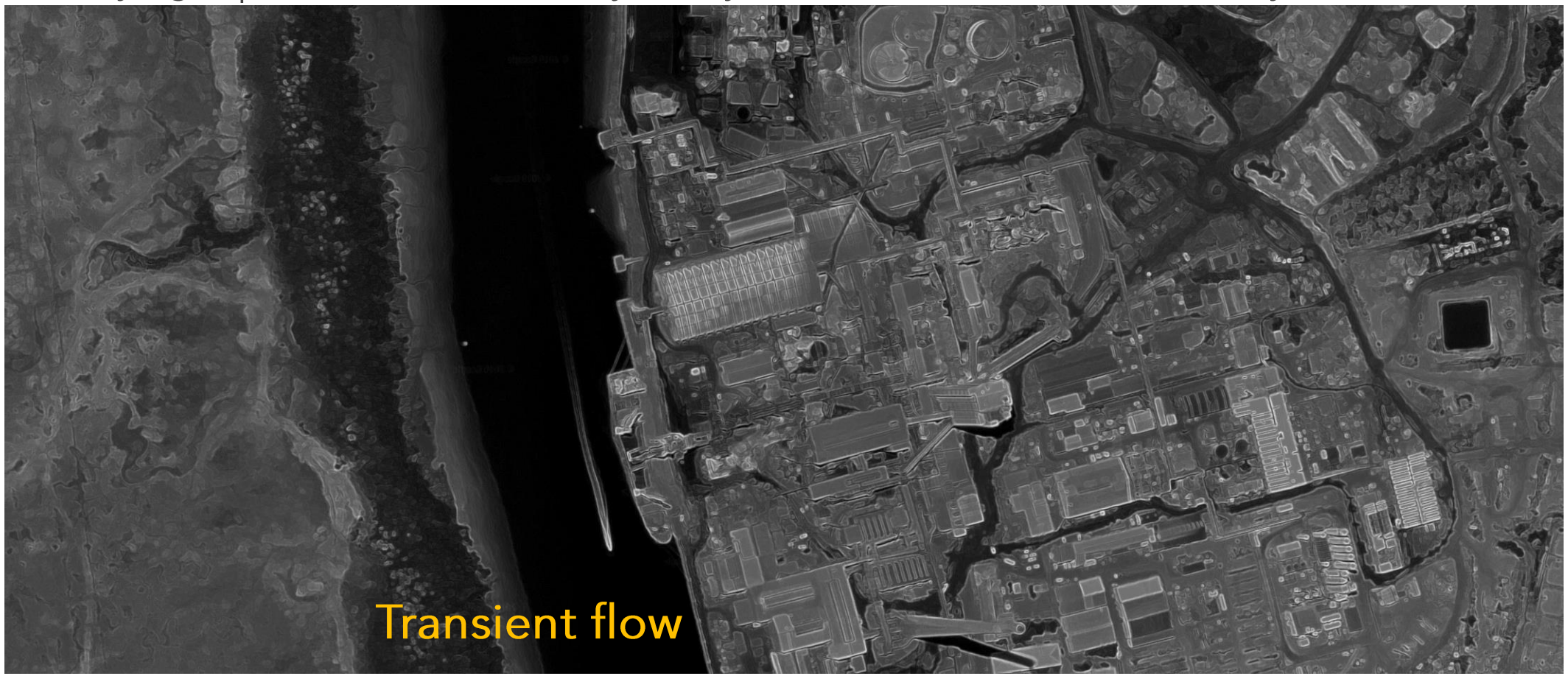
85%
Remediation

(Panagos et al. 2013, Ernst & Young 2013)

A few years ago …

Metal processing facility located on the bank of an estuary where tides occur

Underlying aquifer contaminated by heavy metals, risk for estuarine ecosystems



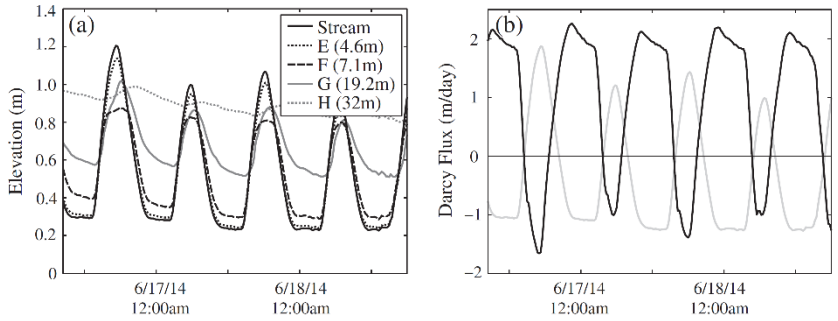
Influence of tides on groundwater fluxes in the aquifer

Tidal effect

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

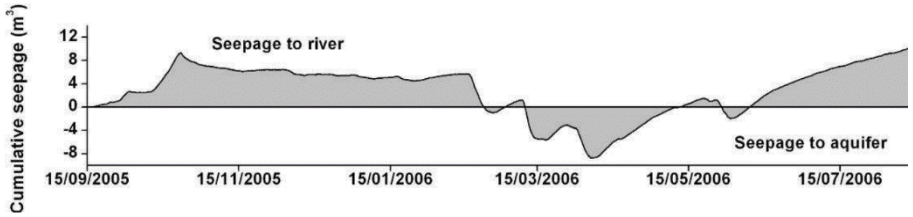
River/bank water exchange

"Fluxes range from 1.66 to 2.26 m/day across the bank and 0.84 to 1.88m/day across the bed. During rising tide, river water infiltrates into the riparian aquifer." Musial *et al.*, 2016, Hydrological Processes.



GW – SW interaction

"Darcy fluxes change continuously in time because of frequent changes in the difference of head between the river and its alluvial aquifer." Batlle-Aguilar, 2008, PhD thesis



Existing techniques

"… are best suited for conditions where the flow hydraulics are relatively consistent through time." Kempf et al. 2013, Remediation.

01

The Finite Volume Point Dilution Method

The Finite Volume Point Dilution Method

(Brouyère et al. 2008 J Cont Hydrol)

Generalization of single well dilution technique by a continuous

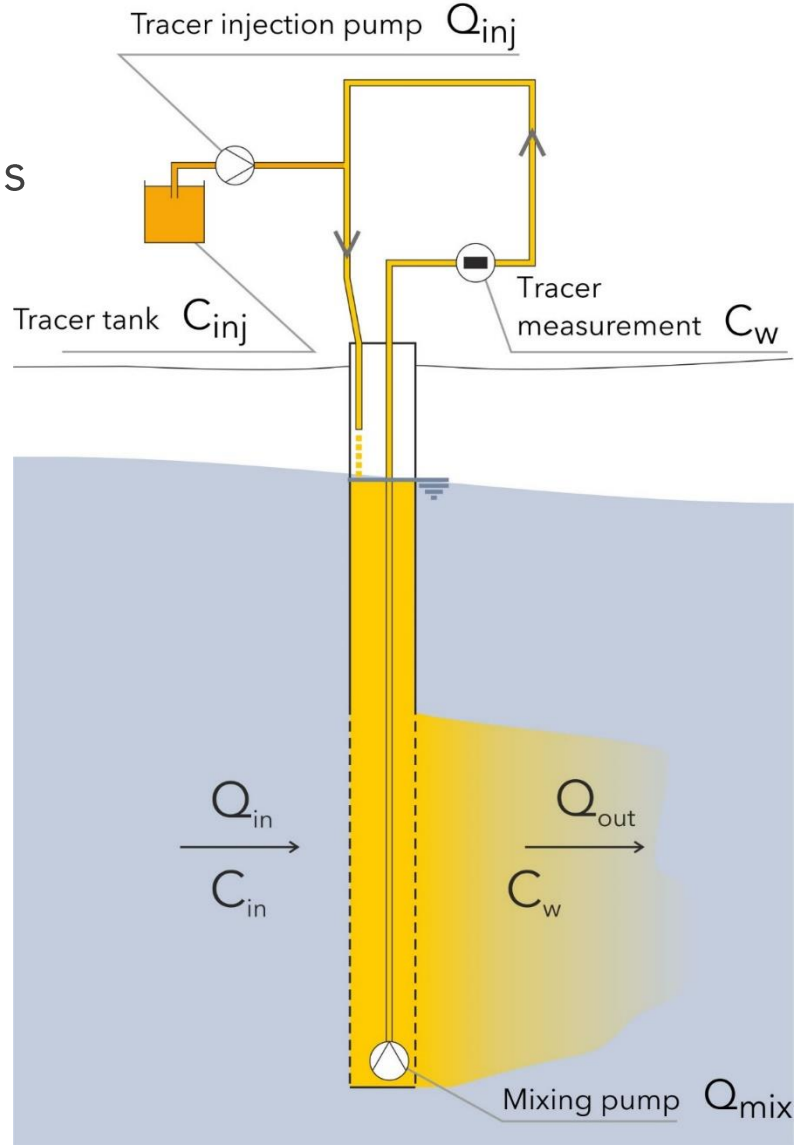
- mixing of the water column
- tracer injection in a well
- monitoring tracer concentration

$$\frac{\partial M(t)}{\partial t} = Q_{inj}\, C_{inj} + Q_{in}\, C_{in} - Q_{out}\, C_w$$

Allows the measurement of a flow rate

that transits through the screen and can be

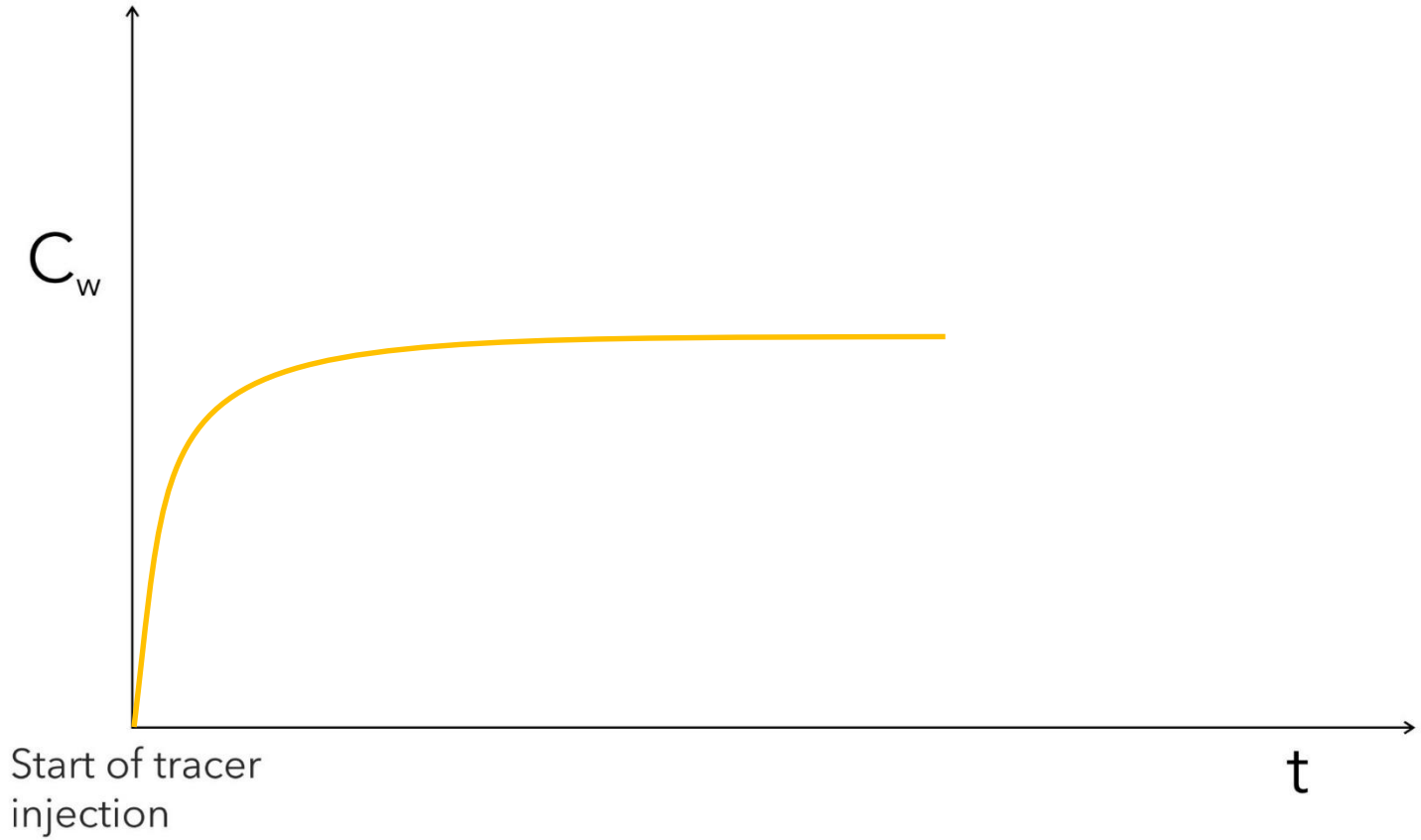
converted into a groundwater flux in the aquifer.



Evolution of tracer concentration in the well during FVPDM

Steady state groundwater flow

Increases and stabilizes at a value depending on the tracer injection flow rate and on the groundwater flux in the aquifer



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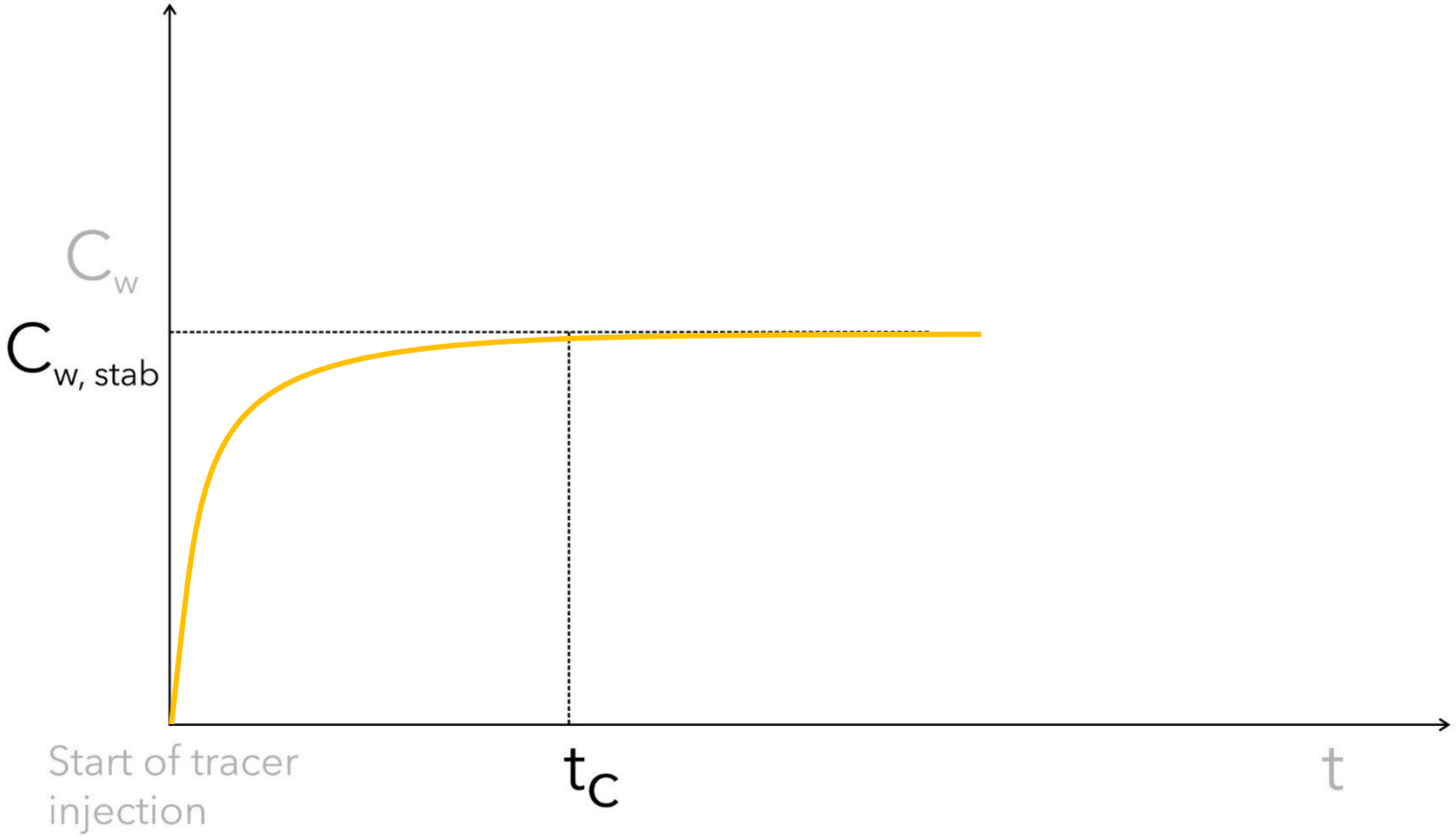

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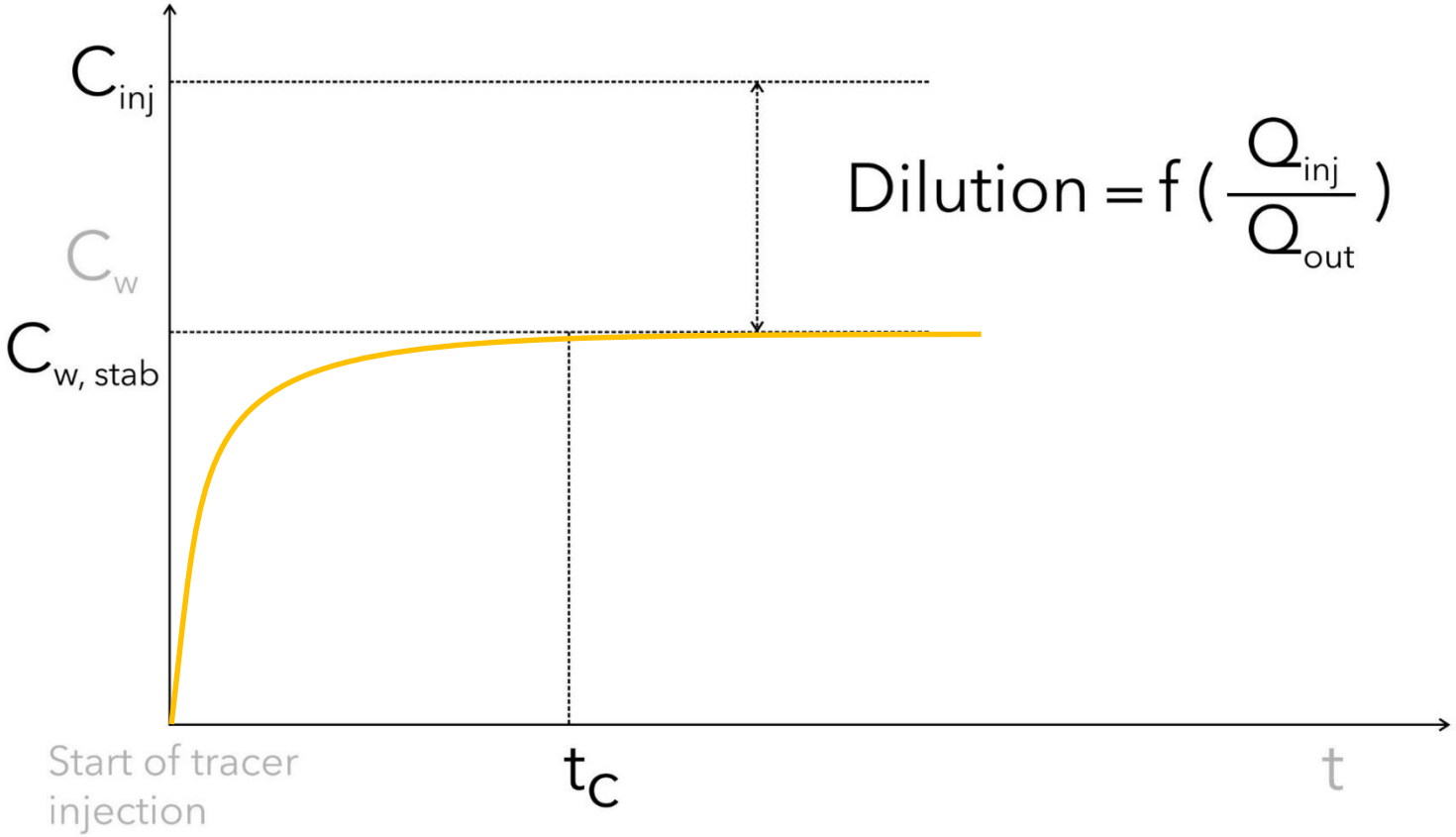
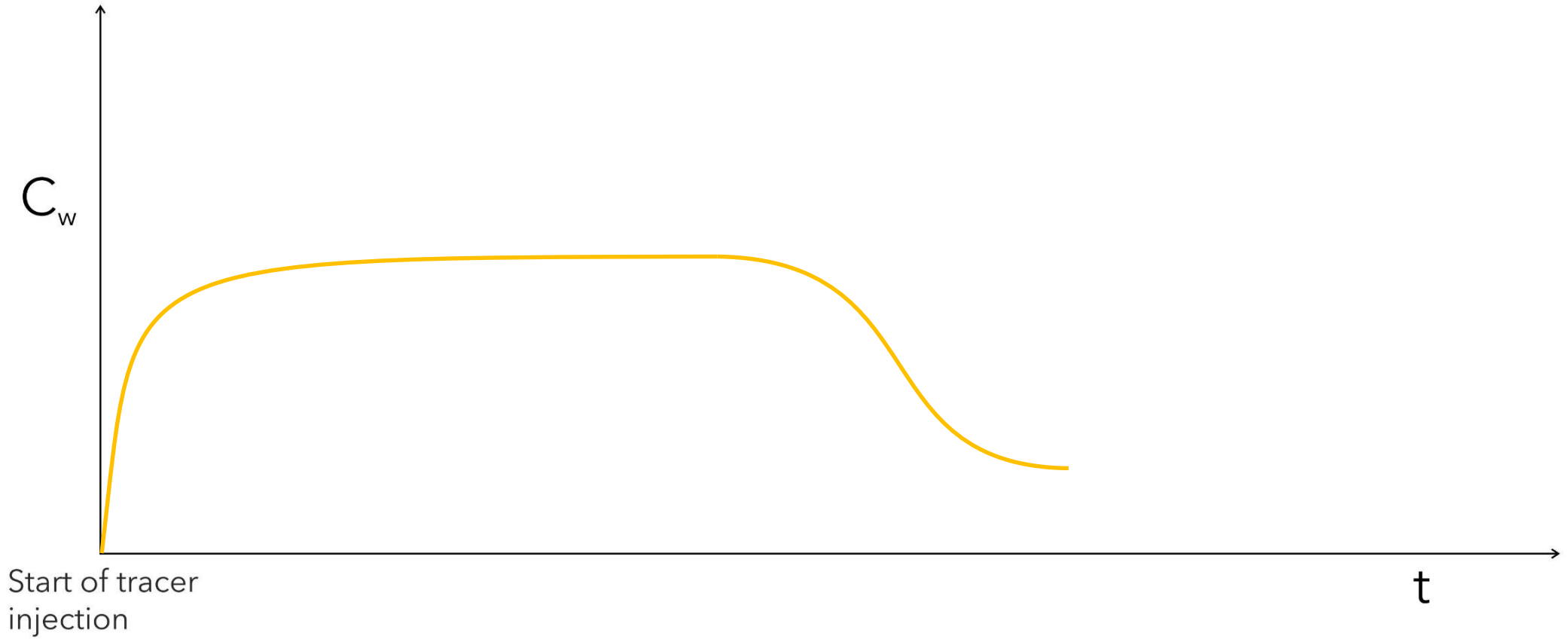


Evolution of tracer concentration in the well during FVPDM

Transient state groundwater flow

decreases when flux increases (more dilution)

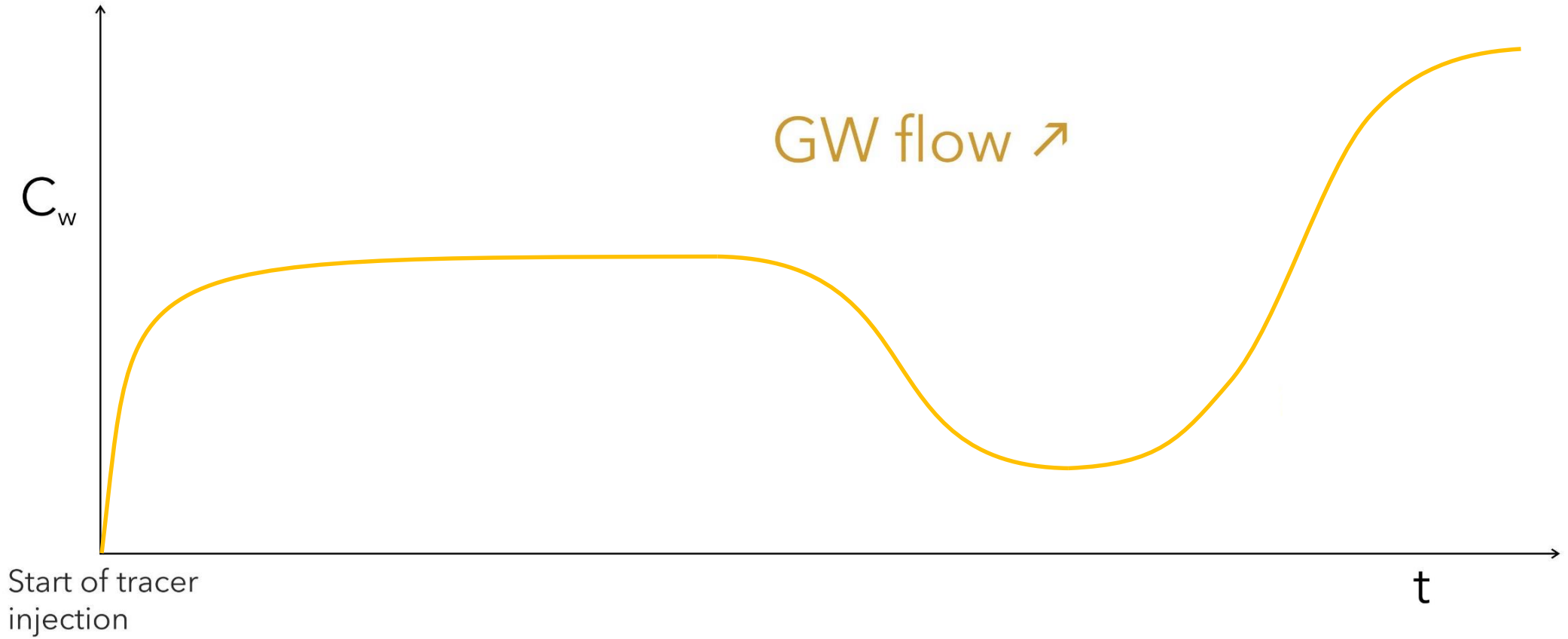


Evolution of tracer concentration in the well during FVPDM

Transient state groundwater flow

decreases when flux increases (more dilution)

increases when flux decreases (less dilution)



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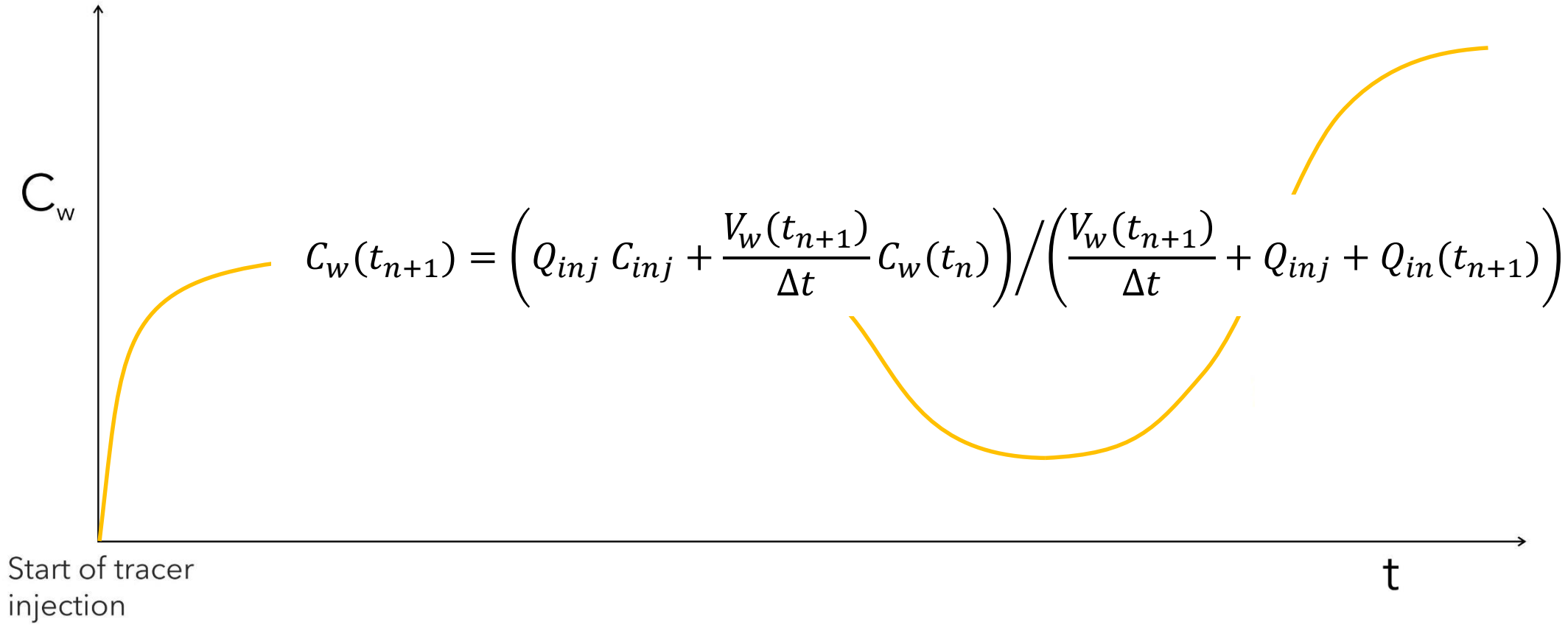
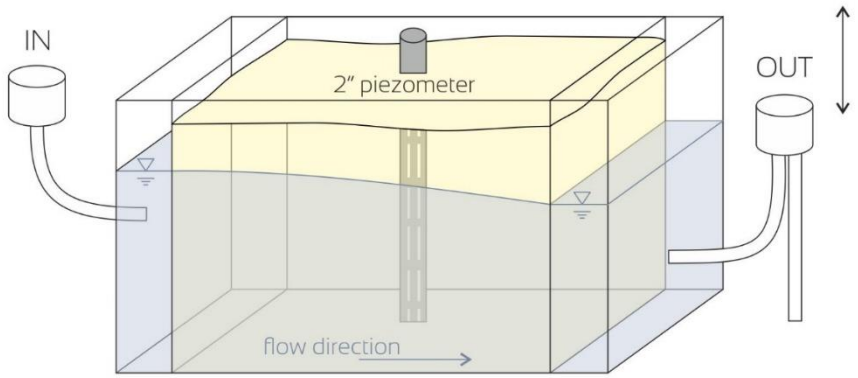
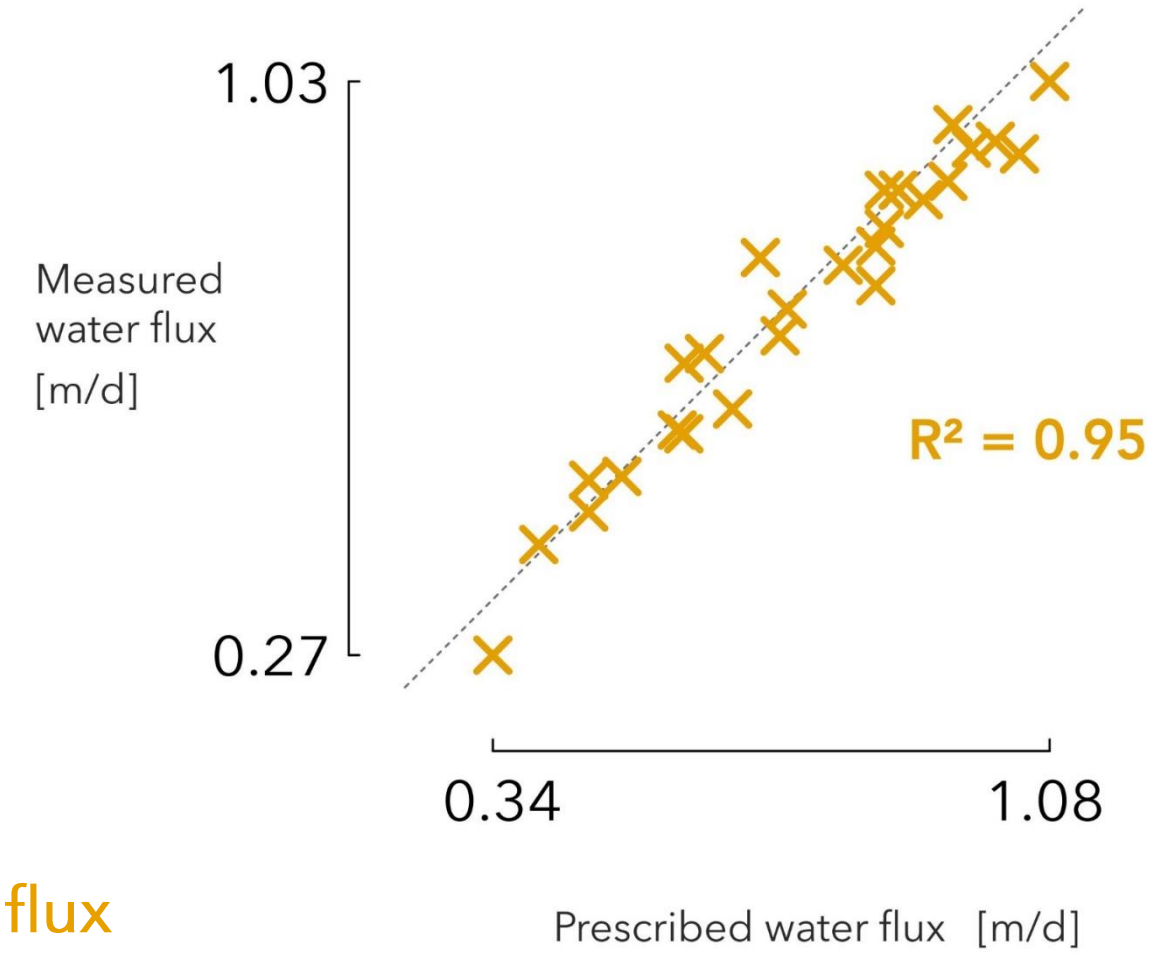


Accuracy validation of the transient solution in laboratory conditions

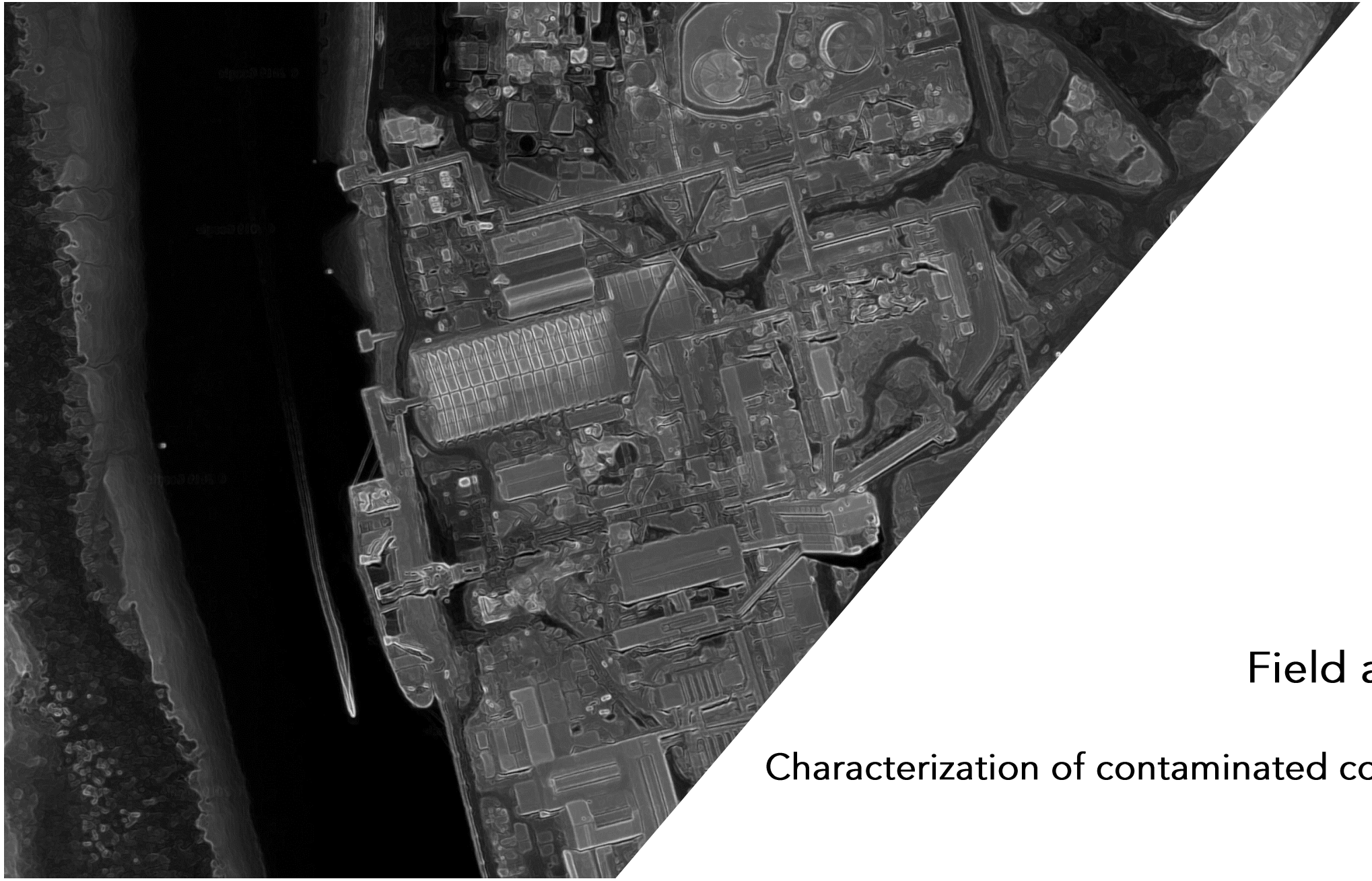
Test for a range of water flows

Using the same experimental setup





Good accuracy of variable water flux monitoring by FVPDM in lab conditions



02

Field application

Characterization of contaminated coastal aquifer

Coastal aquifer contaminated by heavy metals

Metal processing facility

Aquifer hydraulically connected to an estuary where tides occur

Contamination threatens the estuarine ecosystems (Mn, Zn, Cd, Pb)

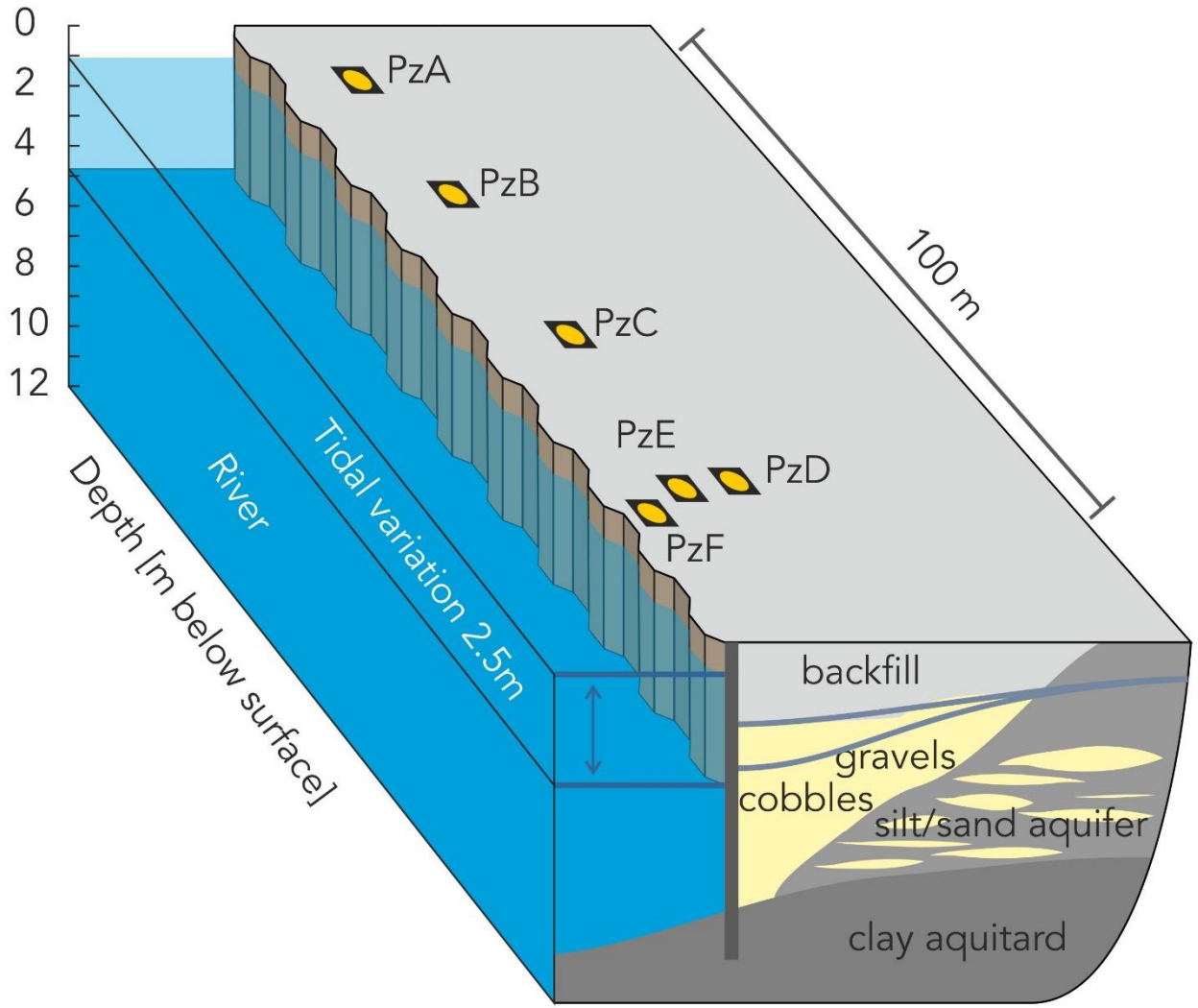
Limited access to an industrial zone

still in activity

Combined complexity of a dynamic flow within an heterogeneous aquifer

Groundwater flow influenced by tides

Different natural and backfill materials



Combined complexity of a dynamic flow within an heterogeneous aquifer

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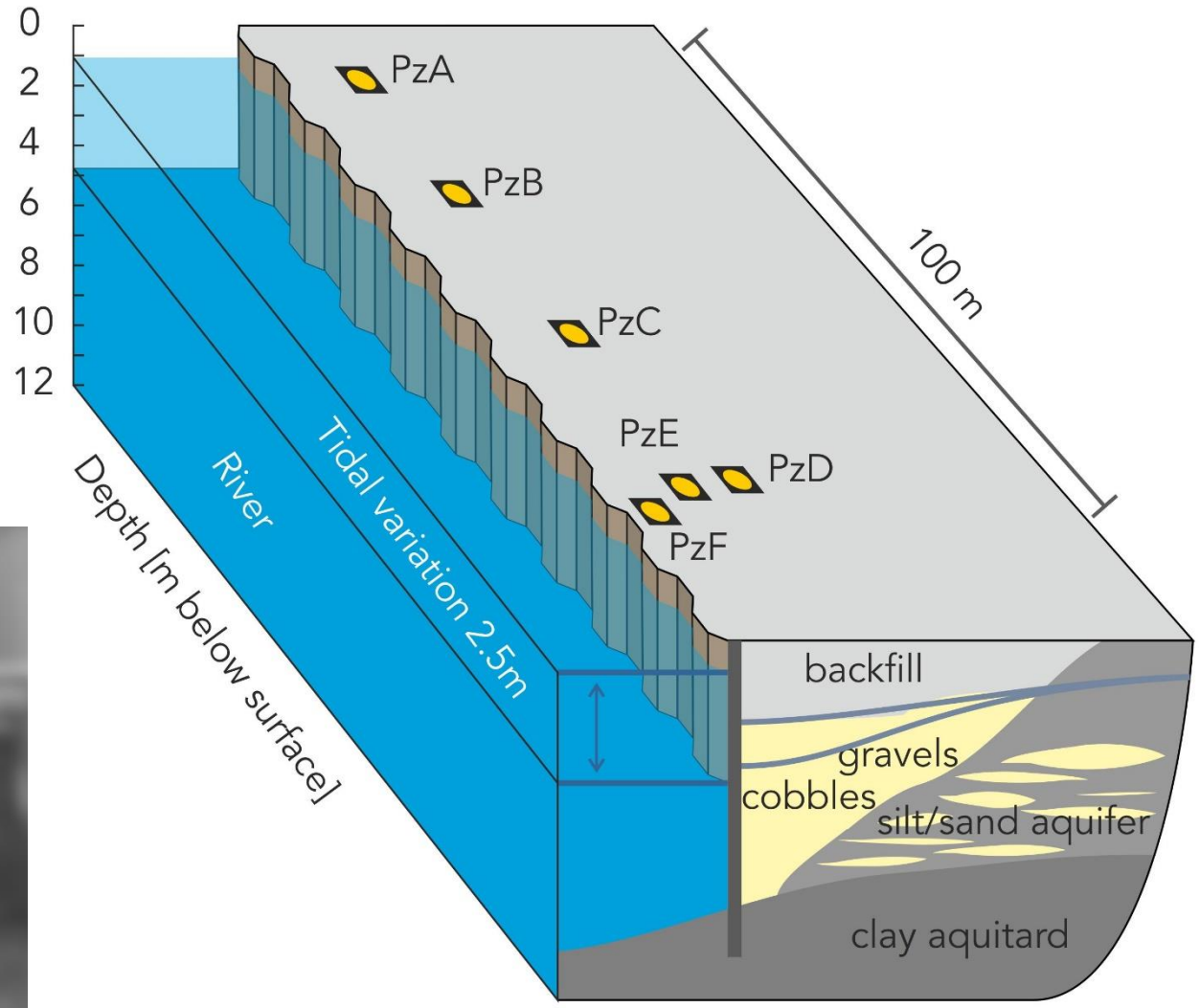
Influence of the sheet pile wall



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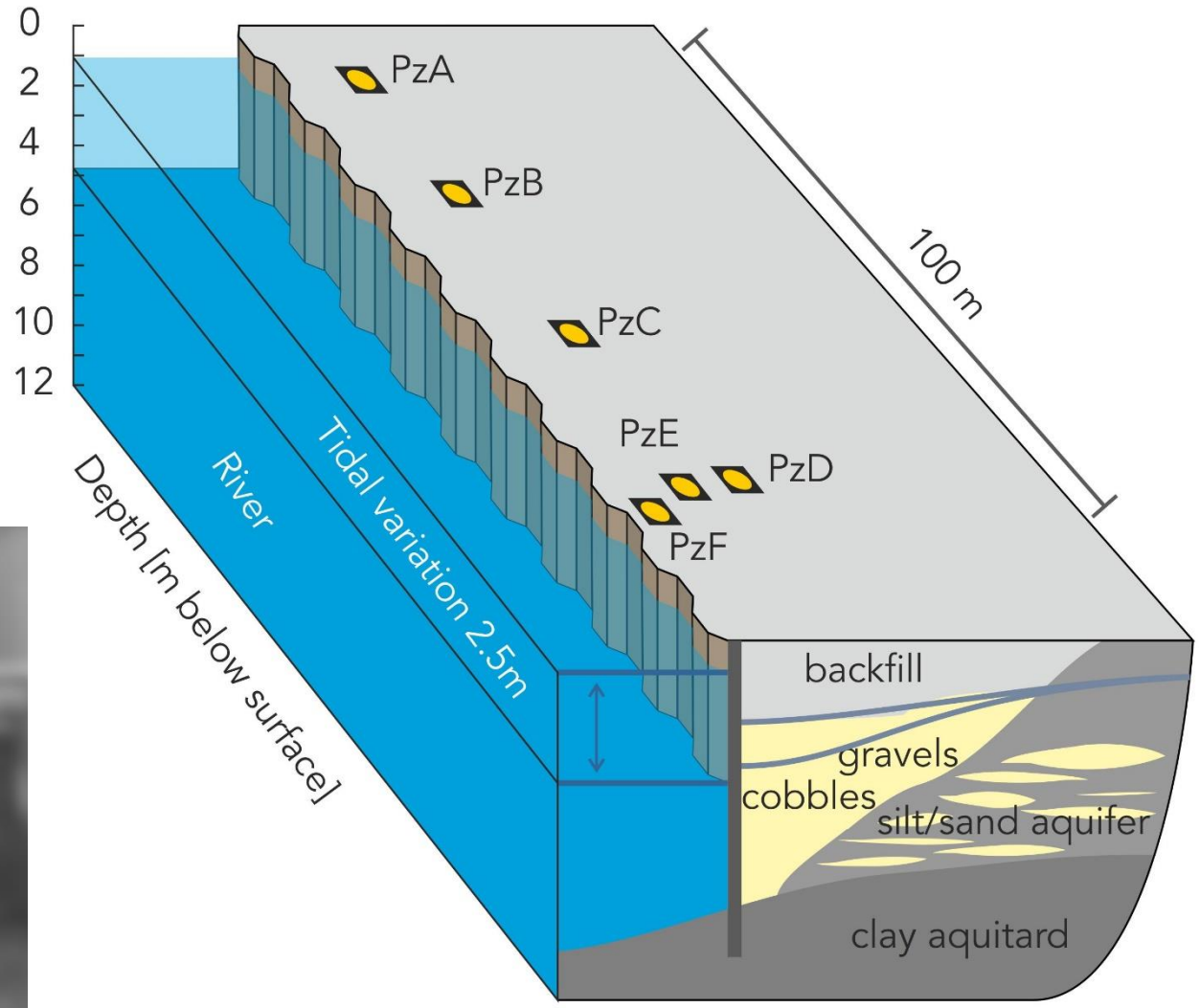


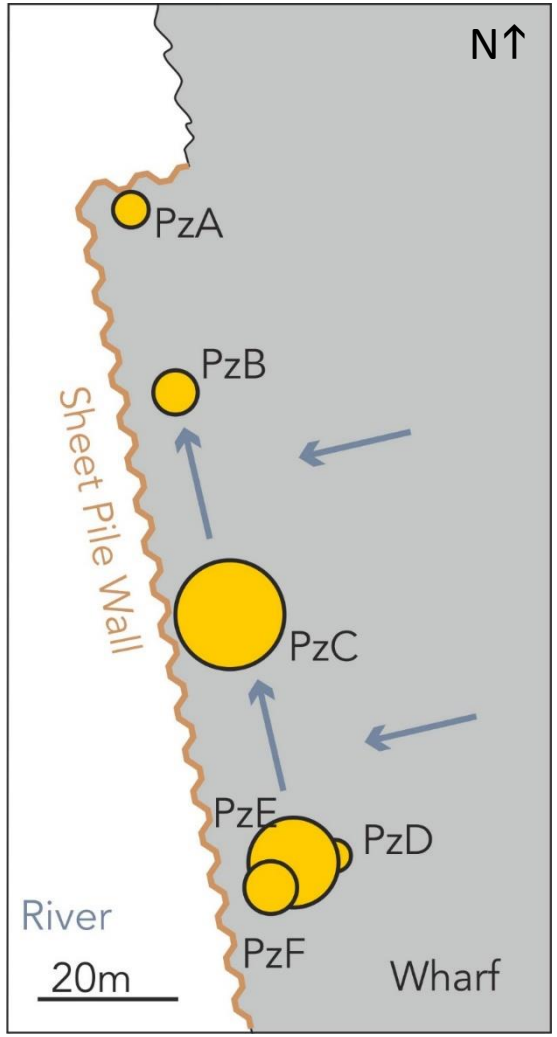
Conceptual model of the site

E-W general groundwater flow

S-N groundwater flow parallel to the wharf

Metal concentrations decrease towards North

4 potential conceptual models



Sheet Pile Wall

Groundwater flux

Monitoring well
Manganese concentration

Exchange between
surface and groundwater

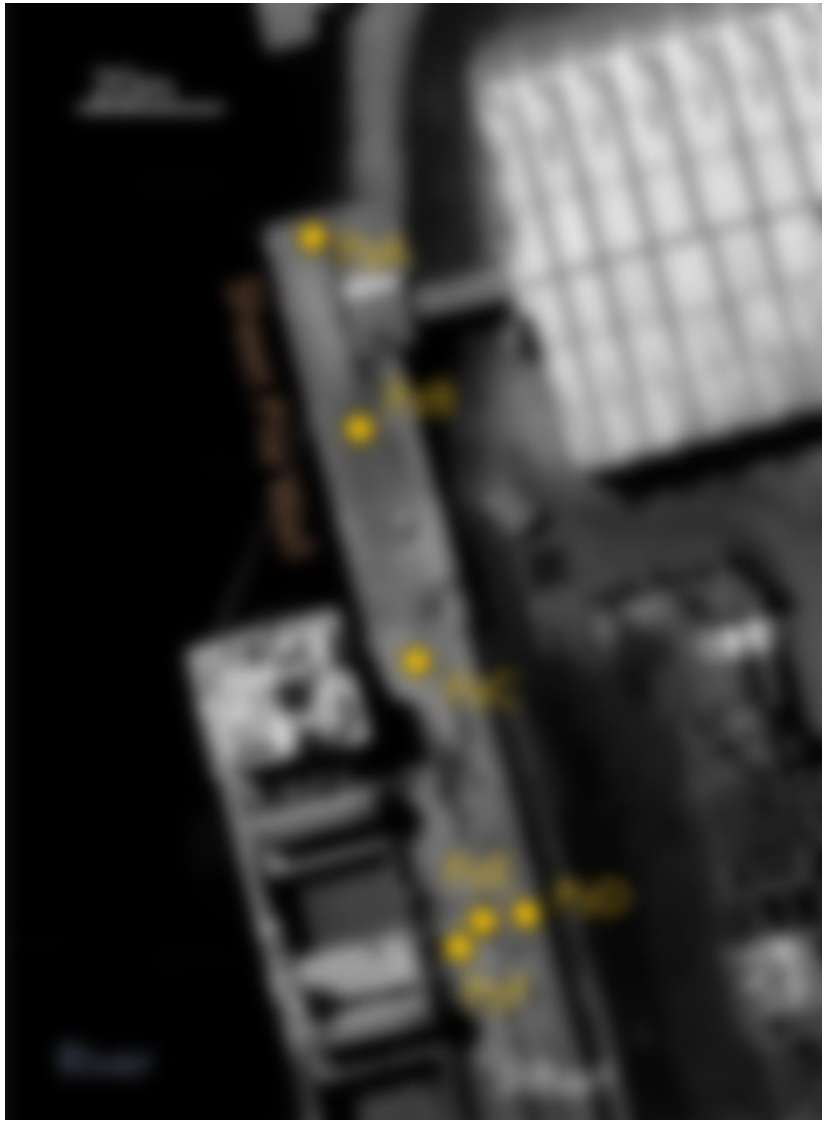
Experimental setup

Monitoring FVPDM on 6 monitoring wells

48 hours continuous running to capture 4 tide cycles

Simultaneous collection of groundwater samples

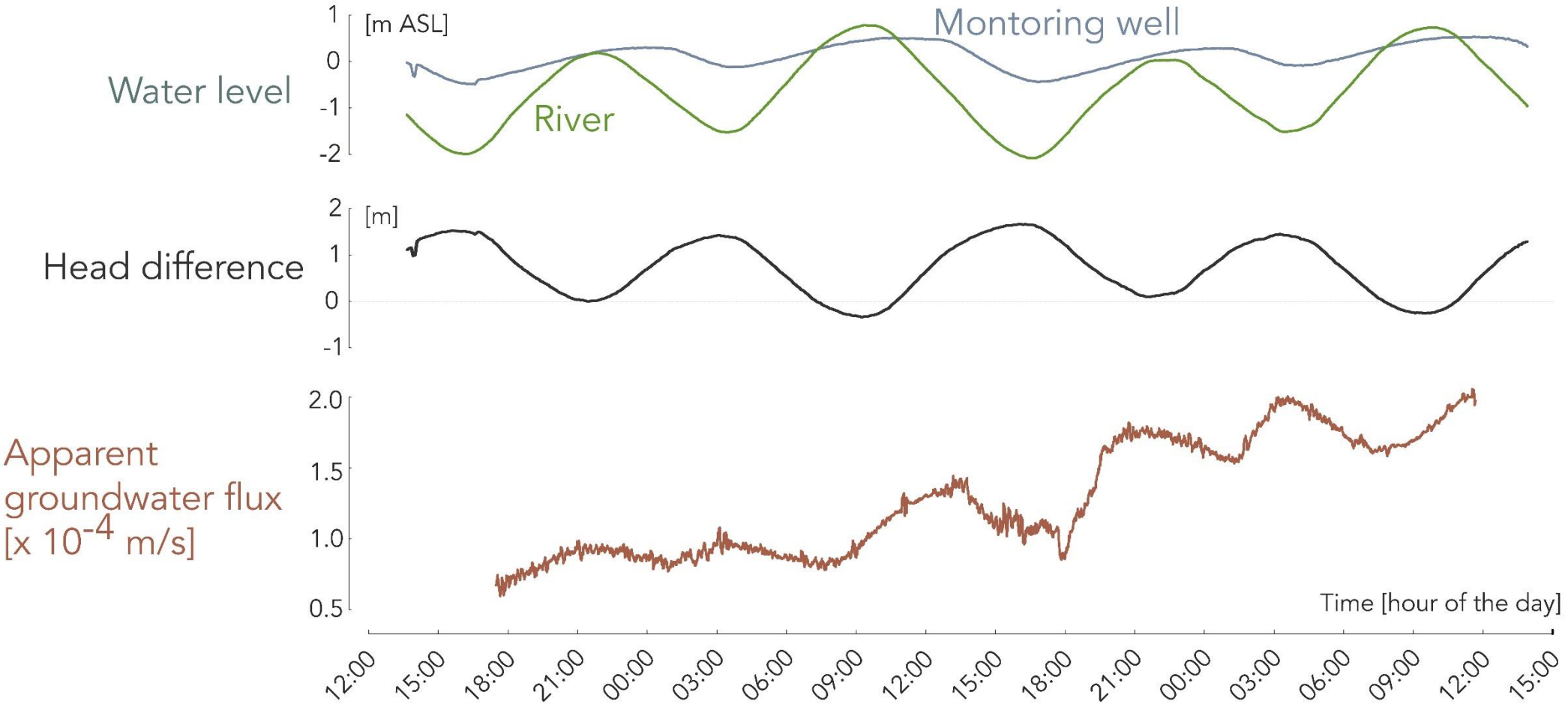
to analyze metal concentrations



Groundwater fluxes monitoring at PzE

Apparent groundwater flux varies from 0.6×10^{-4} to 2.1×10^{-4} m/s

Flux variations not strictly in phase with tide, no inversion of flow direction

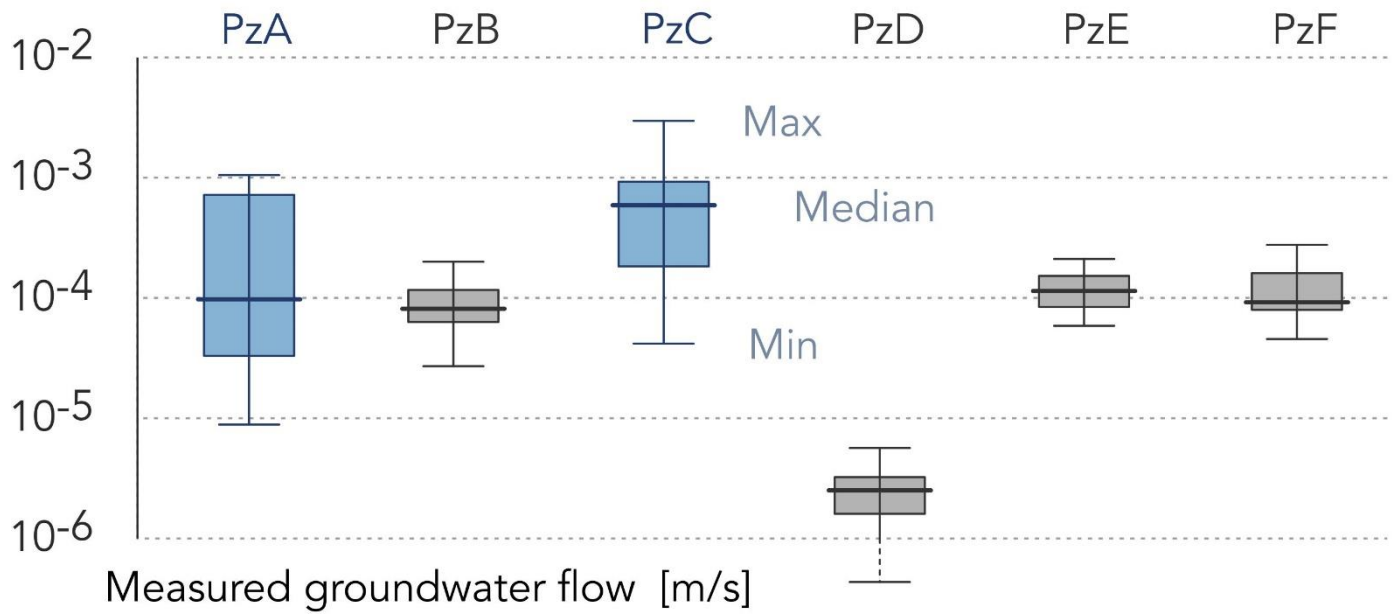


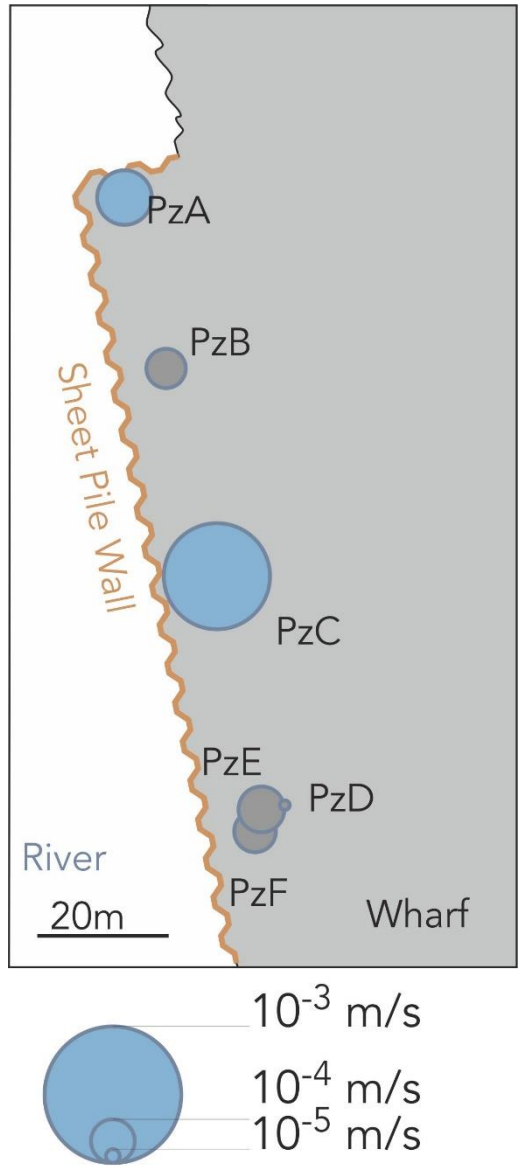
General observations of groundwater fluxes

Low unsynchronized fluxes at PzB, D, E, F

High and variable fluxes at PzA, C

No clear evidence of groundwater flow inversion



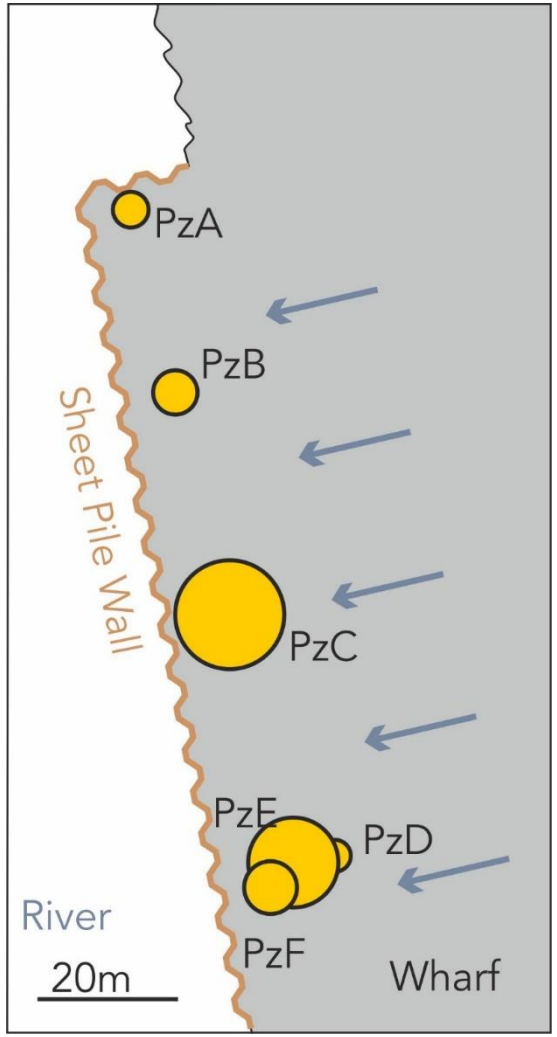


Update of conceptual model

Constant contaminant concentration in groundwater over tide

Groundwater flow system controlled

by incomes of groundwater from inland



Update of conceptual model

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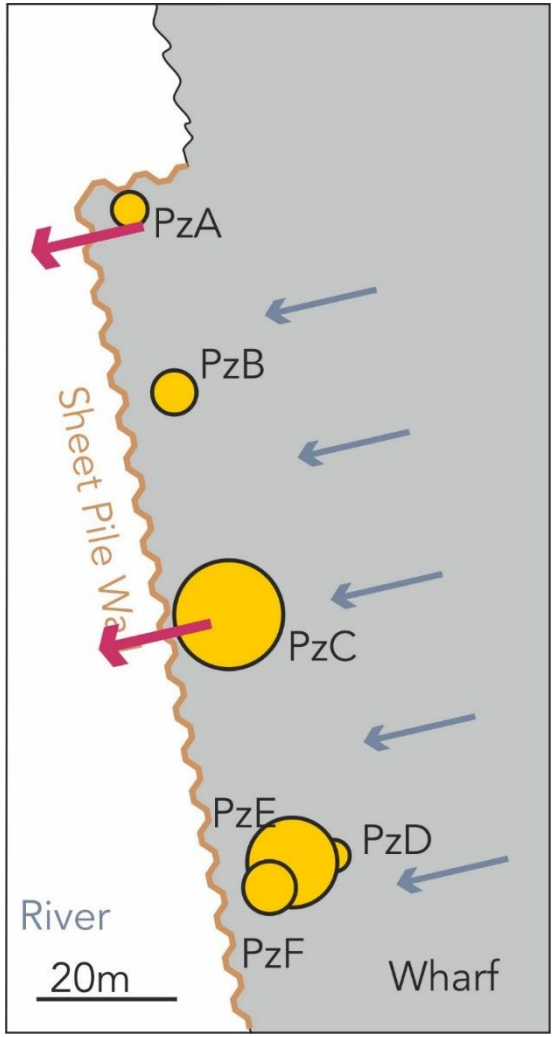
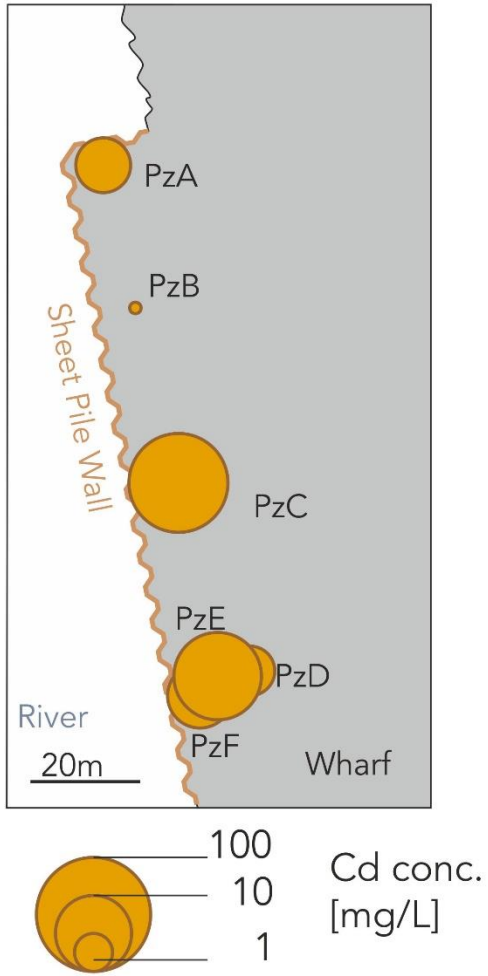
Discharge through specific points

in the sheet pile wall



Outcome of the study



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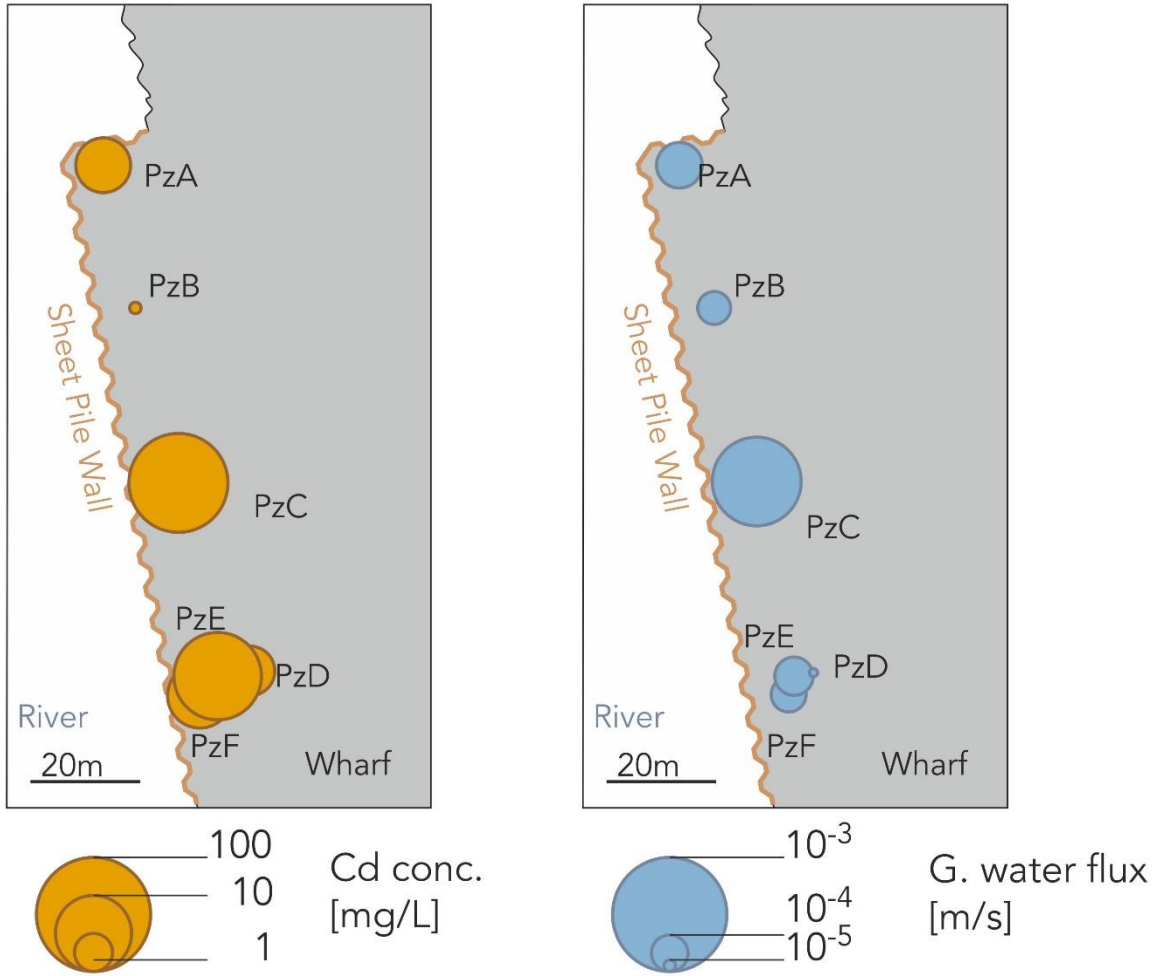
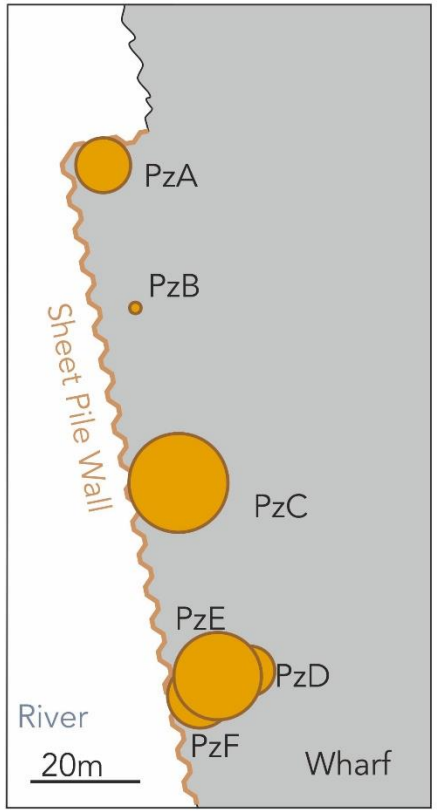
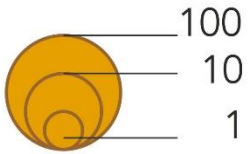


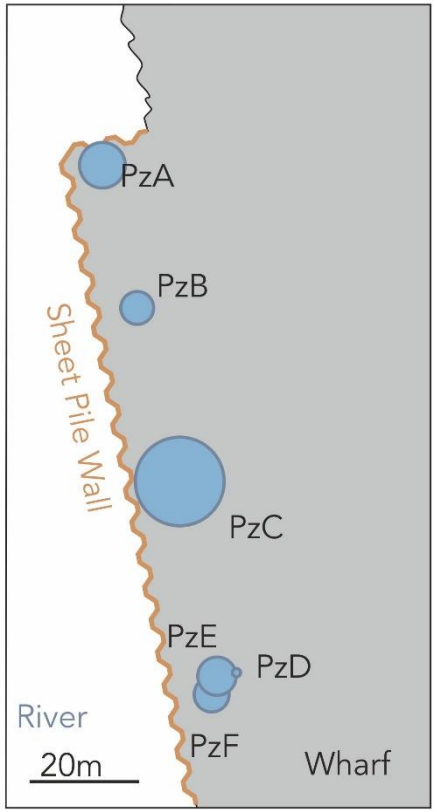
Outcome of the study

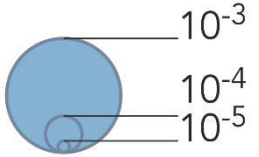
Cd mass flux at PzC is 2.4 kg m^{-2} d^{-1} -> 1000x higher than at other wells



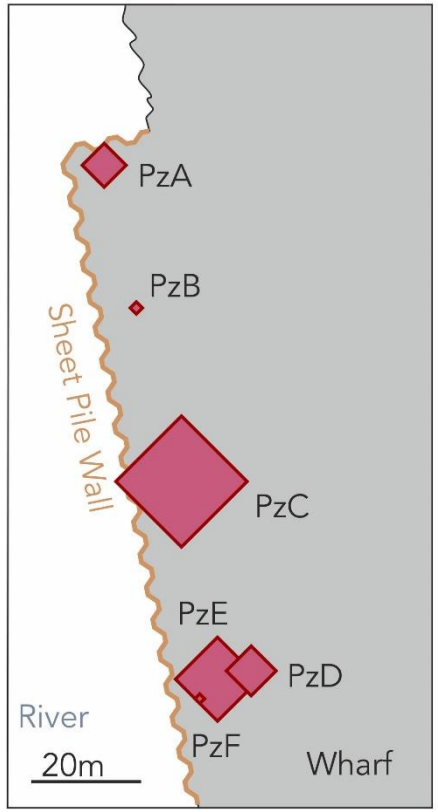


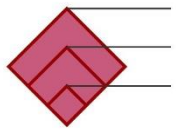
Cd conc. [mg/L]





G. water flux [m/s]





Cd flux [g day^{-1} m^{-2}]

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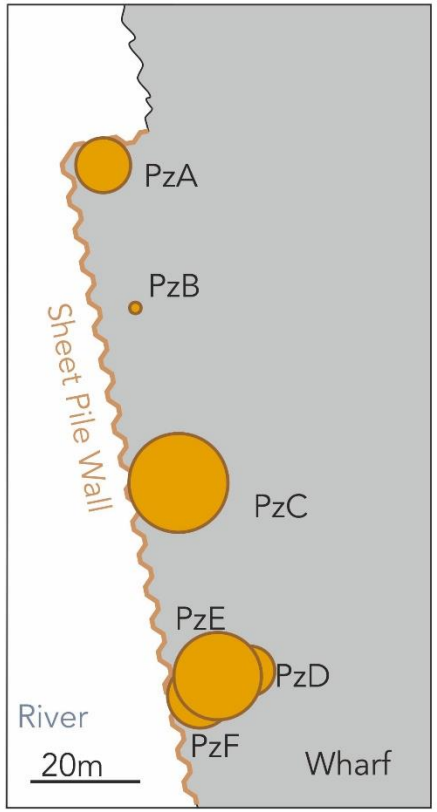

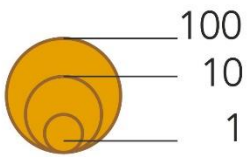

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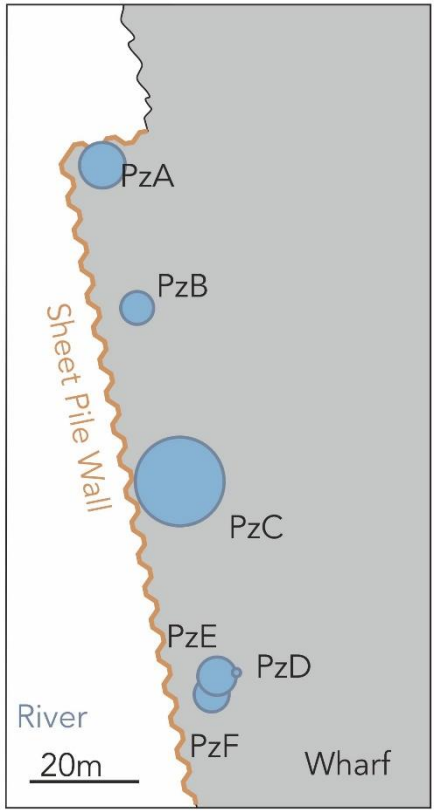

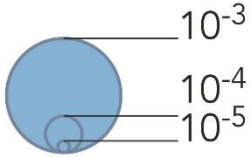

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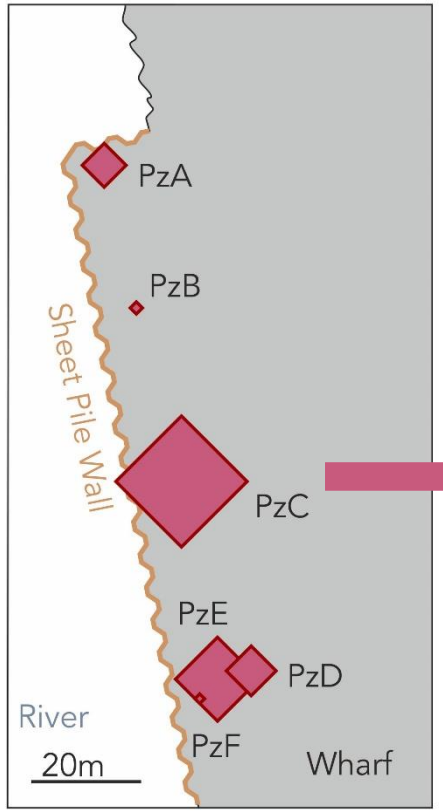
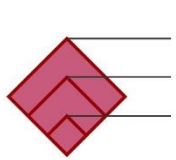


92%



Cd flux [g day^{-1} m^{-2}]

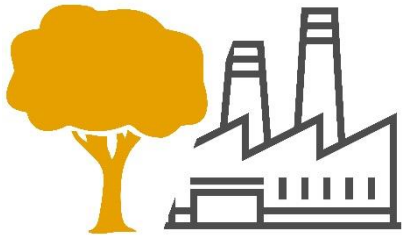
FVPDM

Fully operational for groundwater flux monitoring

Integrated FVPDM module

Porous | Fratured

FVPDM

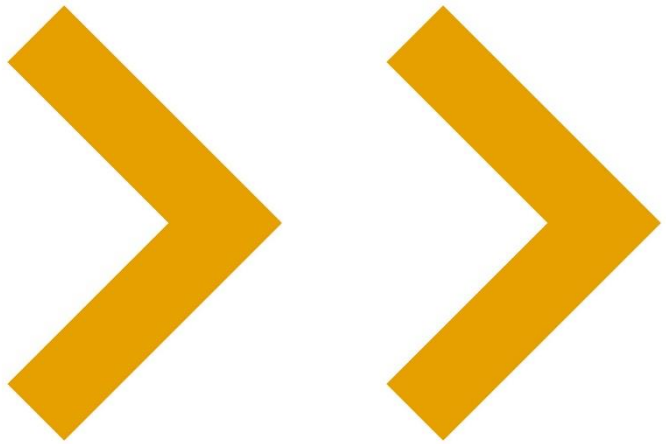


Natural | Industrial

Steady | Transient

4 countries | 3 continents

Move forward



Think FLUX