Large-scale Sandbox Experiments on Dispersion and Mixing

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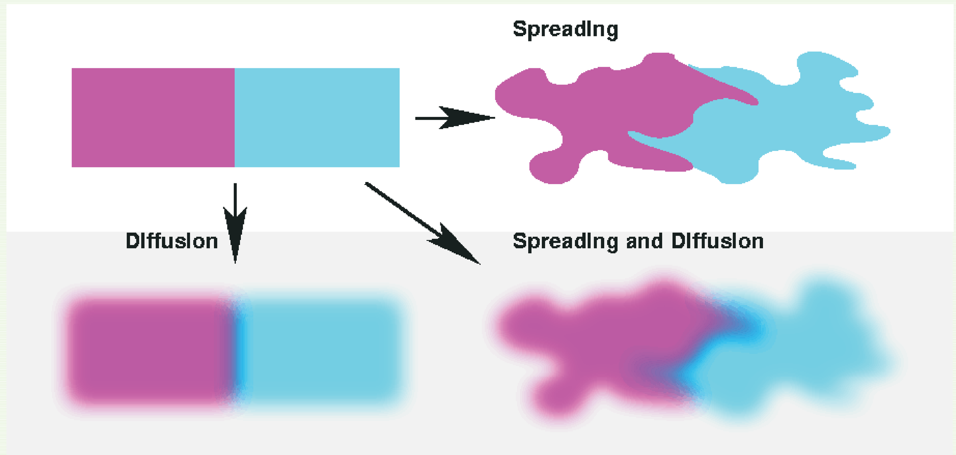
Motivation

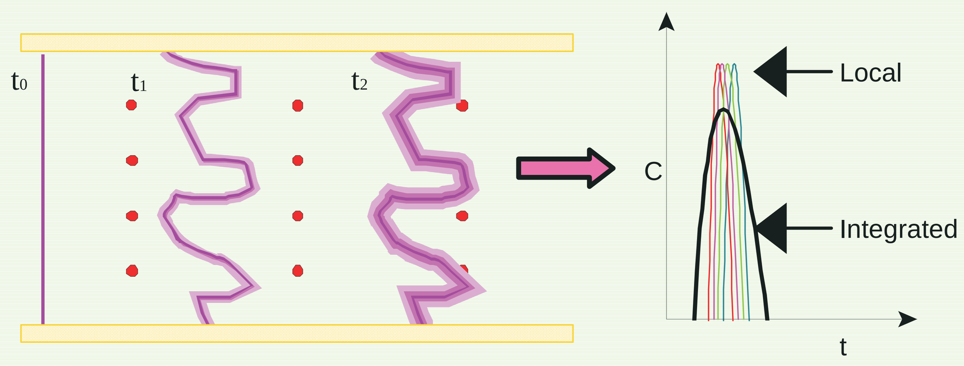
Pore scale dispersion is the key process in dilution and mixing of solutes in heterogeneous porous media.

Macrodispersivities reflect the plume irregularities.

Applying macrodispersivities to predict mixing controlled reactive transport leads to an overestimation of mixing and reaction rates.



The second central temporal moments of conservative breakthrough curves, measured at singles points, may be a more accurate quantity to estimate mixing (Cirpka and Kitanidis, 2000)



The key objective of the study is to verify this hypothesis.

Theory

Definition of Temporal Moments:

$$\mu_0(\mathbf{x}) = \text{Zeroth moment} = \int_0^\infty c(\mathbf{x},t)\,dt$$

$$\mu_1(\mathbf{x}) = \text{First moment} = \int_0^\infty t\,c(\mathbf{x},t)\,dt$$

$$\mu_{2c}(\mathbf{x}) = \text{Second central moment} = \int_0^\infty \left(t - \frac{\mu_1}{\mu_0}\right)^2 c(\mathbf{x},t)\,dt$$

Apparent parameters:

•Apparent velocity, $v_a = \frac{x_1 \mu_0}{\mu_1}$

with longitudinal coordinate x_1

•Apparent effective diffusion coefficient,

$$D_a = \frac{x_1^2 \mu_{2c} \mu_0^2}{2\mu_1^3}$$

•Apparent effective dispersivity

$$\alpha_a = \frac{x_1 \mu_{2c} \mu_0}{2\mu_1^2}$$

•Apparent macrodispersivity:

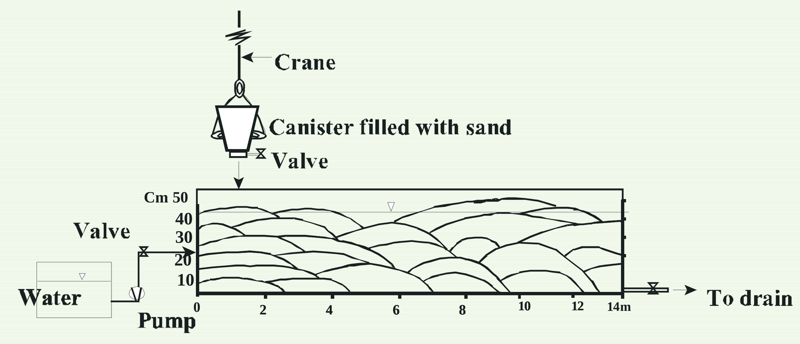
$$\alpha^*(x_1) = \langle \alpha_a(x_1) \rangle + \frac{x_1 \sigma^2_{\mu_1}(x_1)}{2\langle \mu_1(x_1) \rangle^2}$$

with $\langle\ \rangle$ cross-sectional average

$\sigma^2_{\mu_1}(x_1)$ = variance of first moment within the cross-section

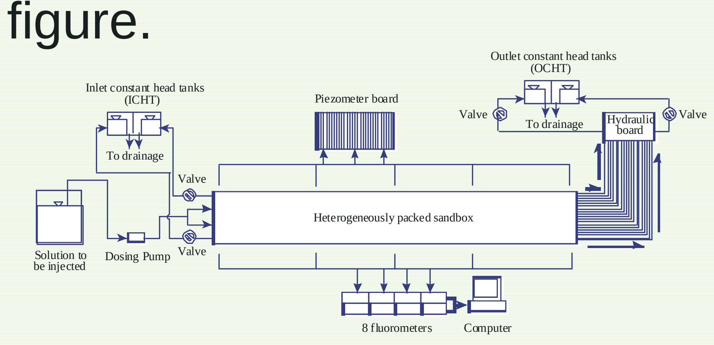
Experimental description

Four types of sand:.0 - 2.5 mm, 0 – 3.0 mm, 0.1 – 0.8 mm, and mixture of 0.3 –0.6 mm and 0.6 – 1.2 mm



Filling procedure used in the box

Sands were poured with high rates into stagnant water. See resulting distribution in bottom figure.



experimental setup

Types of experiments

Conservative experiments:

- Characterization of longitudinal mixing and dilution
- Determination of effective transverse dispersivity
- Tracer: Fluorescein in alkaline solution

Reactive experiments:

- Prediction of mixing controlled reactive transport from conservative tracer data
- Detection of reaction product C

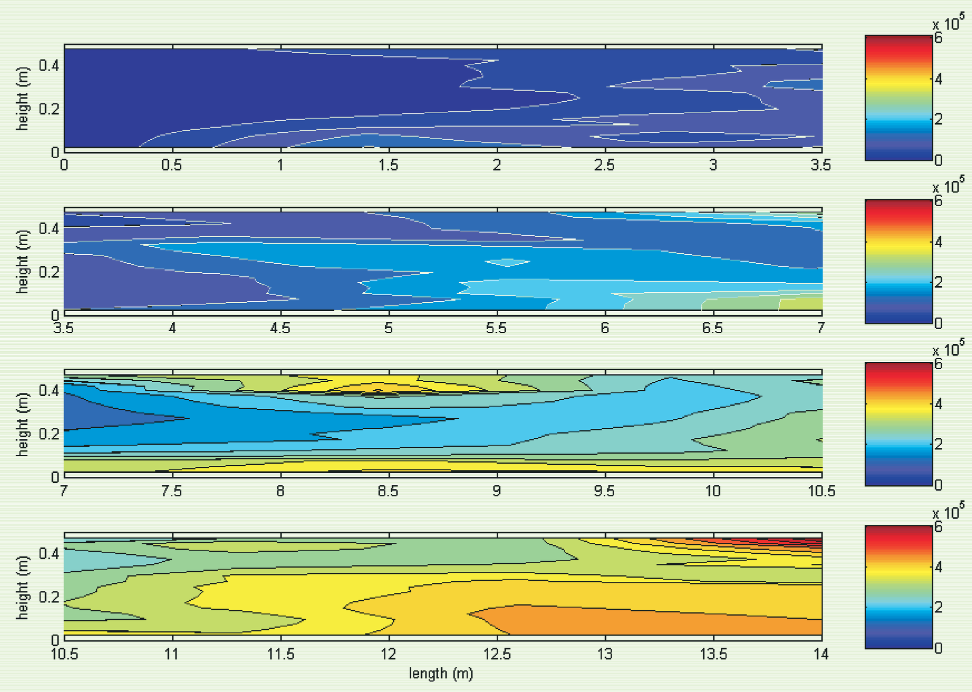
A+B ⟶ C

A:Fluorescein in acidic surfactant solution

B:Alkaline surfactant solution

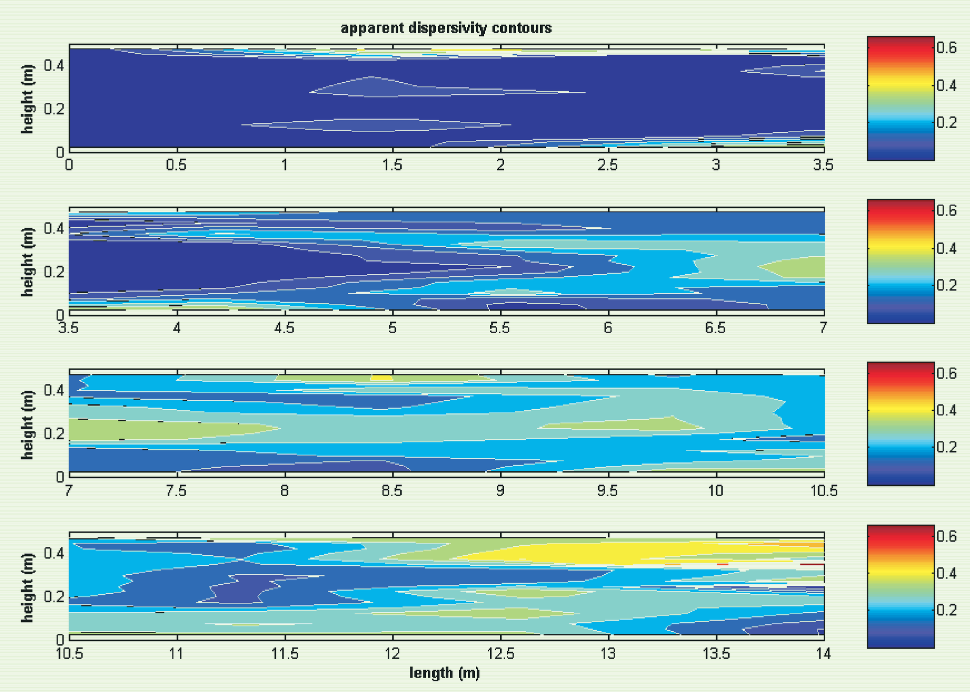
C:Fluorescein fluoresce in mixing regions

Experiment on longitudinal mixing and dilution



Development of the plume (m_1 contours)

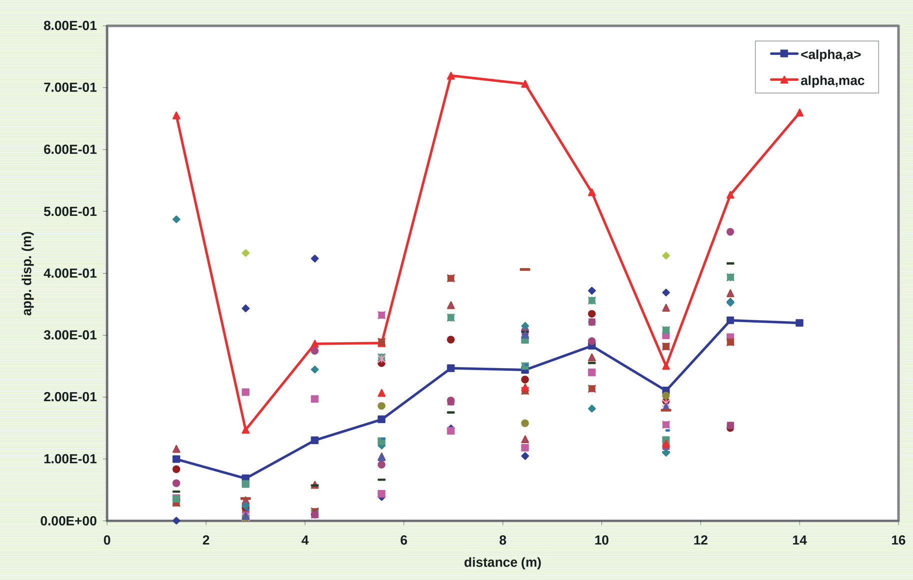
v_a = 3.16*10^{-5} to 4.4*10^{-5}m/s



Mixing zones (α_a contour) in the sandbox

α_a: 10^{-2} to 10^{-1} m, D_a: 10^{-6} to 10^{-5} m²/s

Apparent dispersivities α_a(points) effective dispersivities $\langle\alpha_a\rangle$ (dark line) and macrodispersivities α^* (light line) calculated at each cross-section. Effective dispersivity increases faster at the early stage (3-6m) and then increases at a slower rate. Macrodispersivity values are significantly higher than the effective dispersivity values.



Conclusion

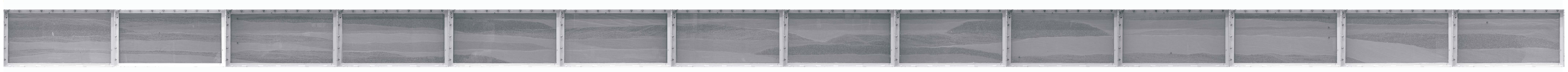
- Effective dispersivities, calculated from point-related concentration, represent mixing.
- Macrodispersivities are calculated from cross-sectional averaged concentrations and thus represent mixing plus the variance of the tracer arrival time.
- Enhanced mixing took place in high conductivity zones adjacent to low conductivity zones.
- Qualitative good agreement to numerical results.

Future work

- To predict reactive mixing from conservative tracer data (see poster "Column Studies on Reactive Mixing", Jose and Cirpka).
- To verify the influence of longitudinal and transverse dispersivities on mixing-controlled reactive transport.
- To compare the results to existing theoretical and numerical models.

References

Cirpka O.A. , and P. K. Kitanidis, Characterization of mixing and dilution in heterogeneous aquifers by means of local temporal moments, Water Resour. Res. , 36(5) 1221-1236, 2000.



Dimension: 14m x 0.13m x 0.5m, equipped with 147 fiber optic probes and 121 piezometers