Freshwater lens investigations (FLIN): visualizing age stratification and internal dynamics on a laboratory scale

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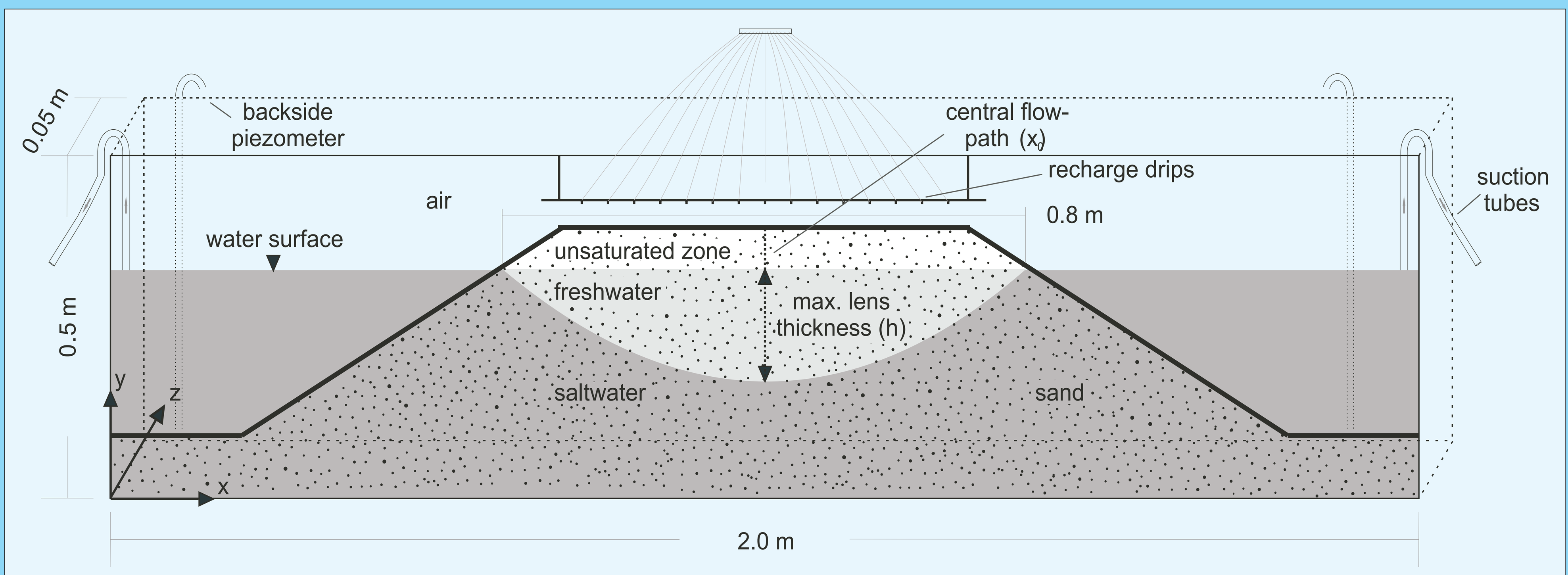
Freshwater Lens Investigations FLIN

Introduction

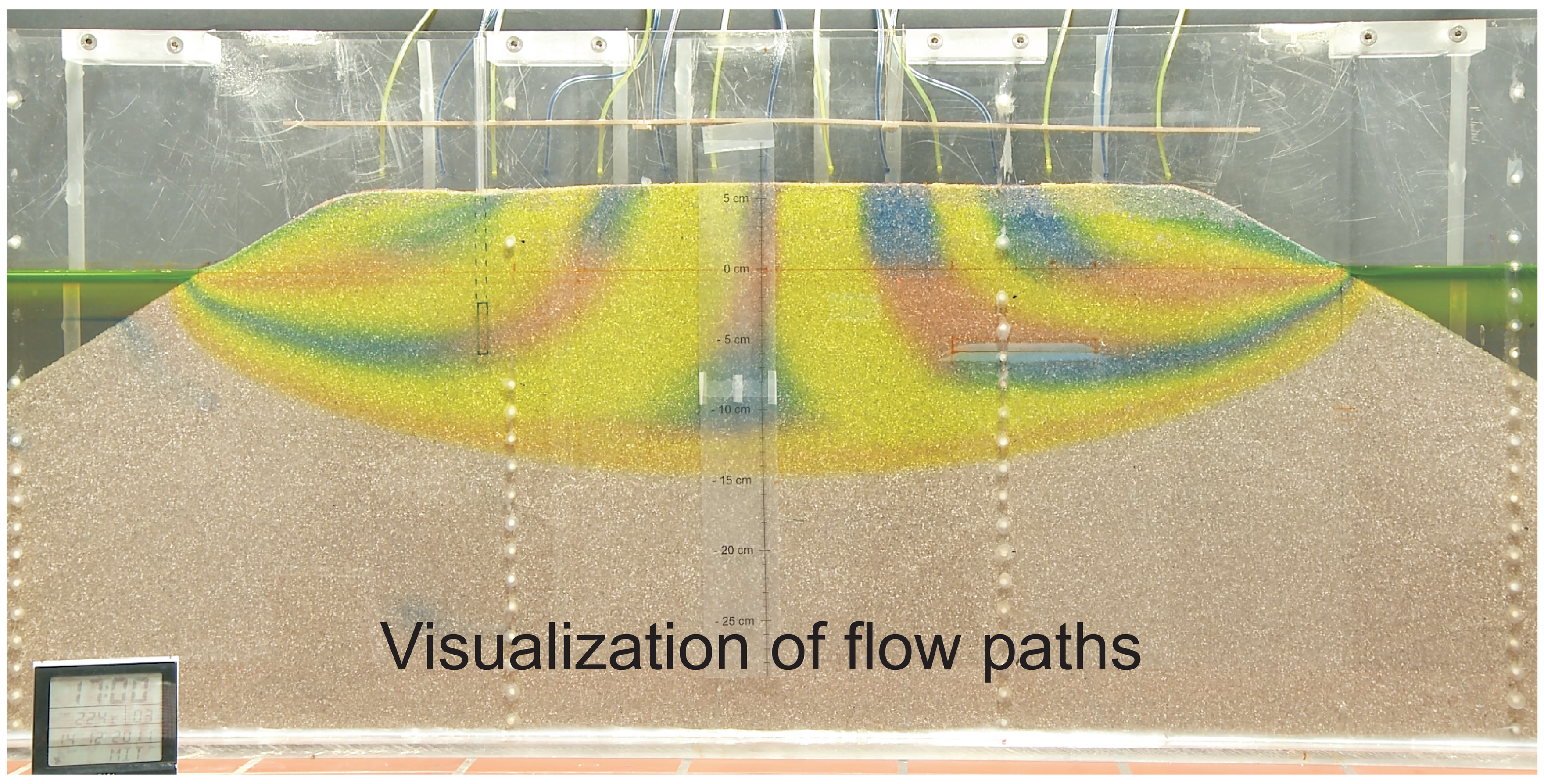
- FLIN - research project on freshwater reservoirs in saline environments
- Feshwater lenses naturally occur on oceanic islands and in inland areas worldwide
- Valuable resources for freshwater supply in (semi-)arid regions e.g. in Australia, Namibia, Qatar (Scharnke, 2011)
- Laboratory experiments conducted to investigate internal dynamics
- Results compared to numerical and analytical solutions

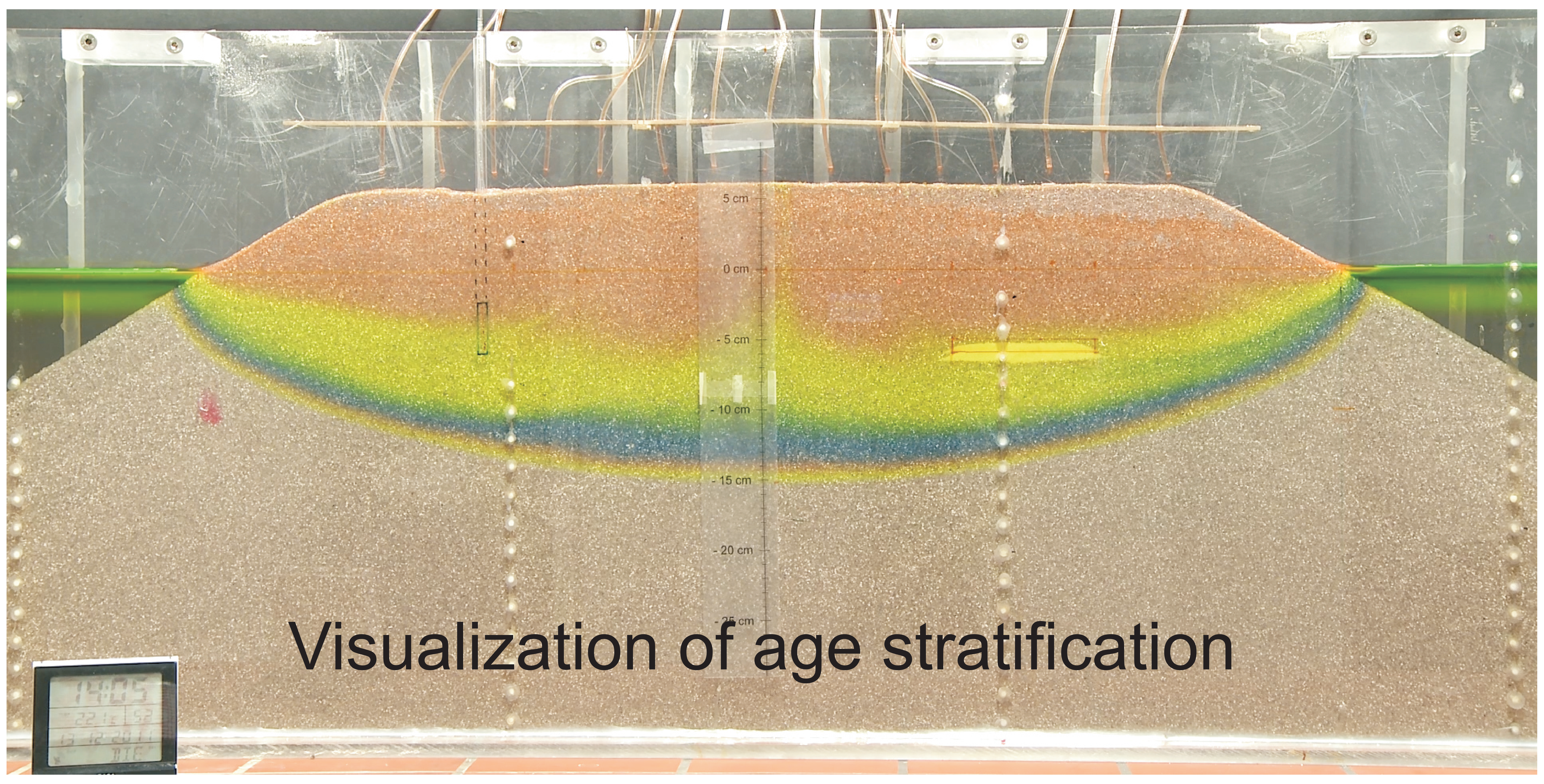


Physical model

- Acrylic glass box with cross section of an infinite strip island

- Coarse sand: $d = 0.7 – 1.2$ mm
- Half width of island: $L = 0.4$ m
- Hydraulic conductivity: $K = 4.5 \cdot 10^{-3}$ $m \cdot s^{-1}$
- Effective porosity: $n_e = 0.39$
- Density saltwater: $\rho_s = 1021$ $kg \cdot m^{-3}$
- Density freshwater: $\rho_f = 997$ $kg \cdot m^{-3}$
- Recharge rate: $R = 1.152$ $m \cdot d^{-1}$
- Tracer concentration: $c = 0.3$ $g \cdot l^{-1}$



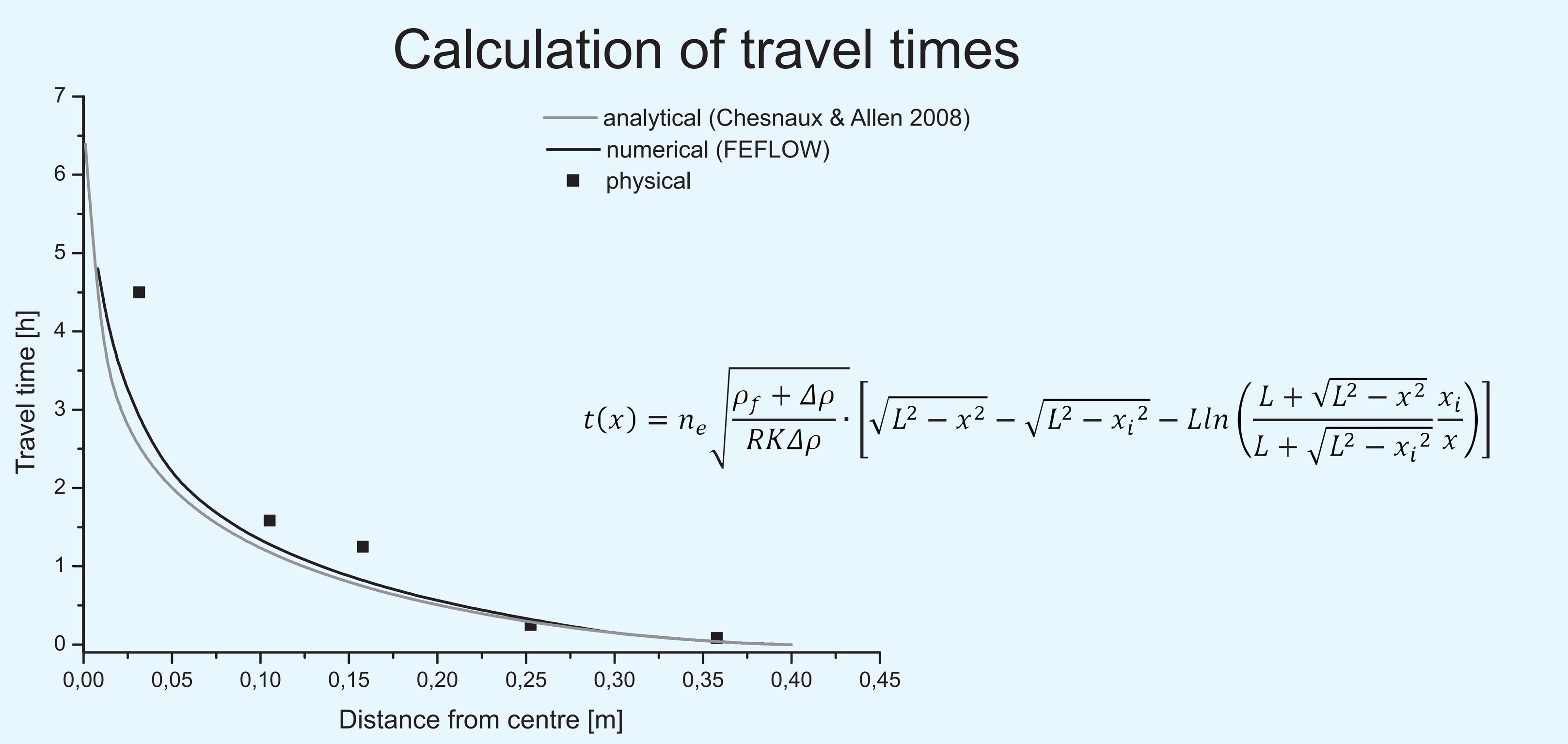


Flow paths and travel times

- Lens in hydrostatic equilibrium (between fresh and saltwater)
- Switching color of every second recharge drip (indigotine/eosine) in periodic intervals (1h)
- All flow paths are connected to the discharge zones (left and right side of the island)
- Exaggeration of the lens´ thickness in comparison to its width: vertical flow component is clearly visible

Age stratification

- Temporal sequence of infiltration events using different colors: Eosine (red), uranine (yellow), indigotine (blue)
- Layers become thinner when displaced to the bottom
- Layers remain in contact with discharge zones at all times



$$t(x) = n_e \sqrt{\frac{\rho_f + \Delta\rho}{RK\Delta\rho}} \cdot \left[\sqrt{L^2 - x^2} - \sqrt{L^2 - x_i^2} - L ln \left(\frac{L + \sqrt{L^2 - x^2}}{L + \sqrt{L^2 - x_i^2}} \frac{x_i}{x} \right) \right]$$

$\Delta\rho = \rho_s - \rho_f$; effective porosity $n_e = 0.39$; recharge rate $R = 1.152$ $m \cdot d^{-1}$; hydraulic conductivity $K = 4.5 \cdot 10^{-3}$ $m \cdot s^{-1}$; half width of island $L = 0.4$ m; initial and final flow path position on the island x_i and x, respectively.

Numerical model

- Finite element model FEFLOW (Diersch, 2005)
- Two dimensional
- Trapezoidal mesh (112,528 elements)
- Unsaturated zone not considered
- Coastal zones: Dirichlet boundaries (constant head) - saltwater head of 0.3 m
- Upper boundary: Neumann (constant flux) condition - only freshwater alowed to enter the model
- Longitudinal and transversal dispersivities: $5 \cdot 10^{-3}$ m and $5 \cdot 10^{-4}$ m, respectively
- Molecular diffusion coefficient: 10^{-9} $m^2 \cdot s^{-1}$

Model Comparison

- Transport velocities and travel times along the flow paths are measured. Results are compared to the analytical model derived by Chesnaux and Allen (2008) and a numerical simulation with FEFLOW.

- Differences between analytical and numerical model are probably caused due to the Dupuit assumption (horizontal flow) used for the analytical solution.

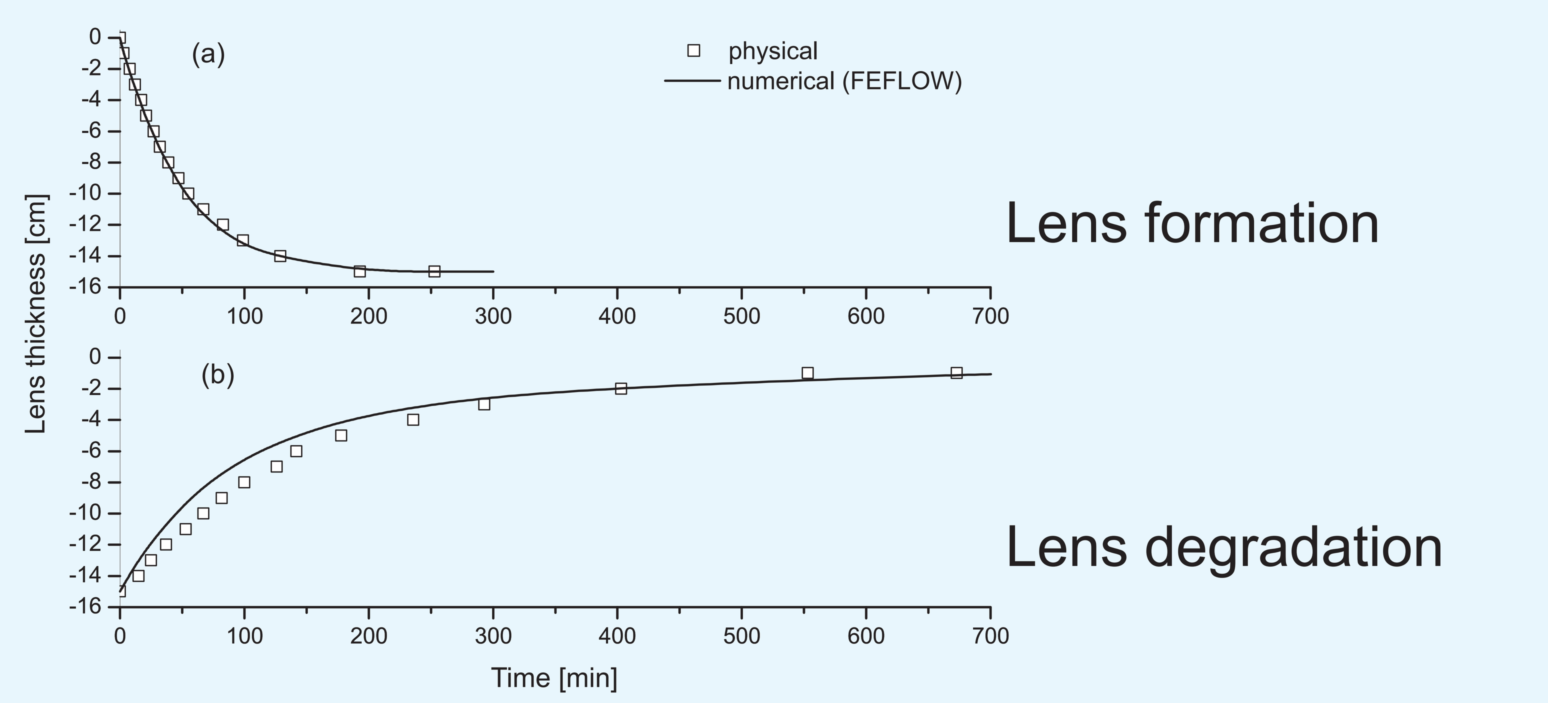
- Measured values show similar but less well defined trend because measurements in the physical model are prone to a limited observational accuracy.

Lens formation and degradation

- Constant freshwater recharge rate (1.152 $m \cdot d^{-1}$): equilibrium after about 200 minutes with maximum thickness of 15 cm b.s.w.l. -> Good accordance with numerical simulation results.

- After turning off recharge -> Monitoring of lens degradation -> Simulation less good by applying the default parameters of the numerical model -> Delayed recharge water from the unsaturated zone in the physical model.

- Different shapes (velocities) of genesis and degradation -> differences in the hydraulic driving forces for each phase (active recharge).



Conclusions

- By time-dependent applications of artificial tracers we are able to visualize flow processes in a freshwater lens in laboratory experiments.

- Physical model results are successfully compared to analytical and numerical model calculations.

- Results impose restrictions on the sampling of water for age dating, e.g. samples need to be depth-specific in order to yield useful results.

- Flow paths and travel times have their practical applications in the delineation of protection zones, e.g. 50-day zone, to prevent fecal bacteria from entering a well.

References

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