TECHNISCHE UNIVERSITÄT DRESDEN
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Transport of solutes in the transition zone of saturated and unsaturated underground

Stoffflüsse im Übergangsbereich zwischen gesättigter und ungesättigter Zone

Diffuse inputs into the groundwater: Monitoring - Modelling - Management
Graz - 31. January 2007

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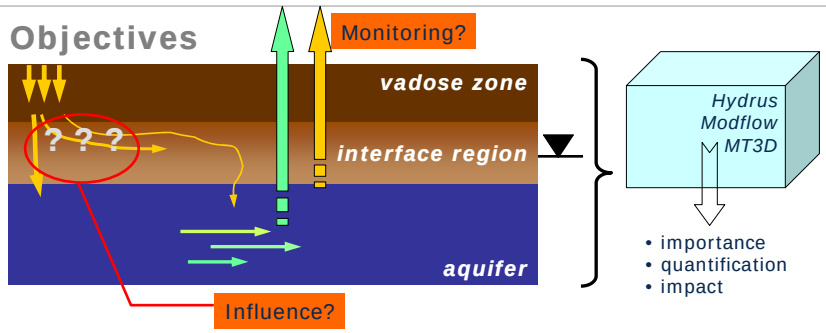
Objectives



1. Object of investigation
2. Hydraulic and transport processes – state of the art
3. Impact of the interface region on water quality
   - Model studies
   - Measurement techniques
4. Conclusion

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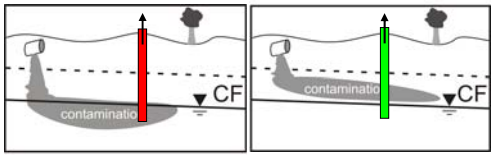
1. Object of investigation

Relevance

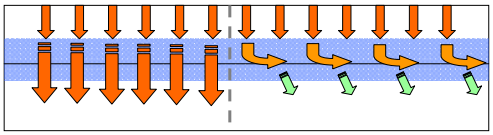
Question: Transport of substances into the aquifer?

A) **Point source** pollution



- Transport above water table?
- Monitoring network design?

B) **Diffuse** pollution



- Storage / Retention?
- Reactions / Degradation?
- Monitoring / Management?

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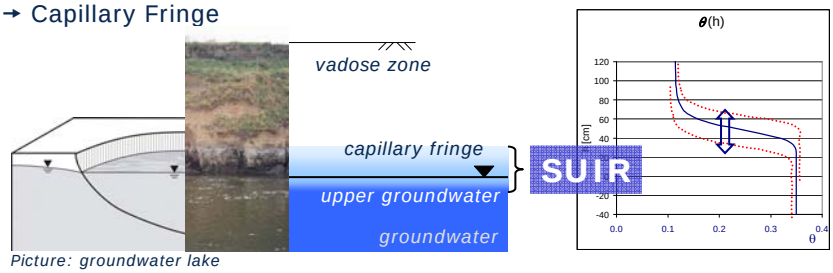
1. Object of investigation

Definition

Boundary vadose zone – aquifer

➝ Capillary Fringe



Picture: groundwater lake

+ water table fluctuation

+ microbiological activities ➝ gas inclusions

= Saturated – Unsaturated Interface Region SUIR *(Ronen 2000)*

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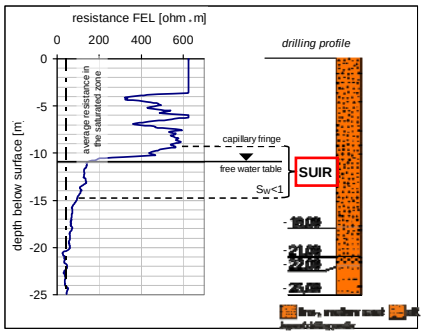
1. Object of investigation

Definition

Field observations

Northern Germany: glacial sandy aquifer



→ SUIR could extend up to several meters

→ Residence time!

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2. Hydraulic and transport processes

Flow

Above water table – Experimental setup

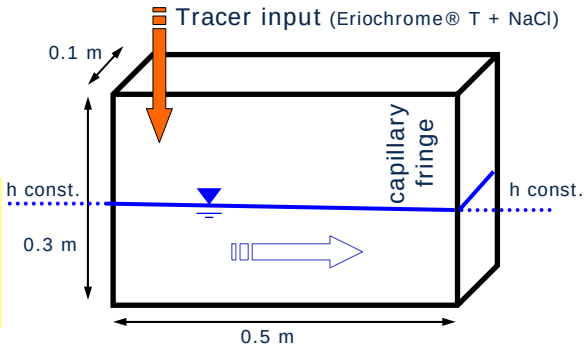
2D Laboratory Tank

Coarse sand

d_{grain}	0.7 … 2.0 mm
K_{sat}	$2.86 \cdot 10^{-3}$ ms^{-1}
VG-α	0.16 cm^{-1}
VG-n	4.74

Fine sand

d_{grain}	0.1 … 0.3 mm
K_{sat}	$1.46 \cdot 10^{-4}$ ms^{-1}
VG-α	0.02 cm^{-1}
VG-n	9.85



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2. Hydraulic and transport processes

Flow

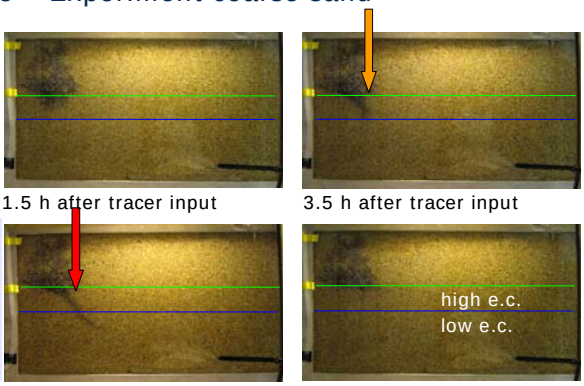
Above water table – Experiment coarse sand

Coarse sand

d_{grain}	0.7 … 2.0 mm
K_{sat}	$2.86 \cdot 10^{-3}$ ms^{-1}
VG-α	0.16 cm^{-1}
VG-n	4.74

top of cap. fringe

water table



1.5 h after tracer input | 3.5 h after tracer input | 6.5 h after tracer input | 44 h after tracer input

- lateral flow
- heterogeneities
- entry into the groundwater

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2. Hydraulic and transport processes

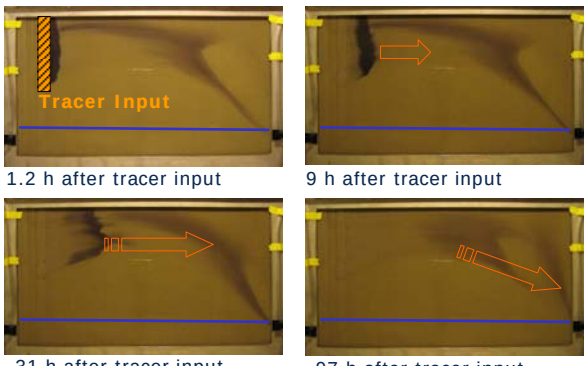
Flow

Above water table – Experiment fine sand

Fine sand

d_{grain}	0.1 … 0.3 mm
K_{sat}	$1.46 \cdot 10^{-4}$ ms^{-1}
VG-α	0.02 cm^{-1}
VG-n	9.85

water table



1.2 h after tracer input | 9 h after tracer input | 31 h after tracer input | 97 h after tracer input

- lateral flow
- no entry into groundwater

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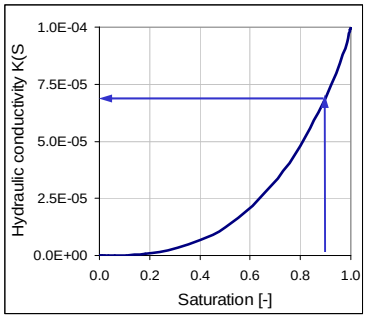
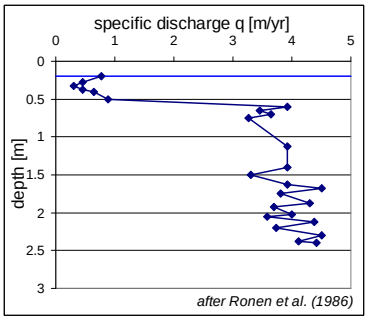
2. Hydraulic and transport processes

Flow

Below water table



field data of specific discharge



→ reduced flow in the upper groundwater layer

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2. Hydraulic and transport processes

Reactions / Dispersion

Conditions within the SUIR:

- gas inclusions
- high water content
- heterogeneous / highly transient

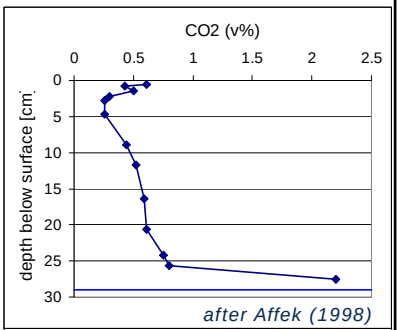
Reactions:

→ enhanced degradation potential

→ microbiologically highly active area

Dispersion:

→ bubbles, enlarged tortuosity („spreading“)



Enhanced biodegradation of total sedimentary organic carbon in the capillary fringe (*after Affek 1998)*

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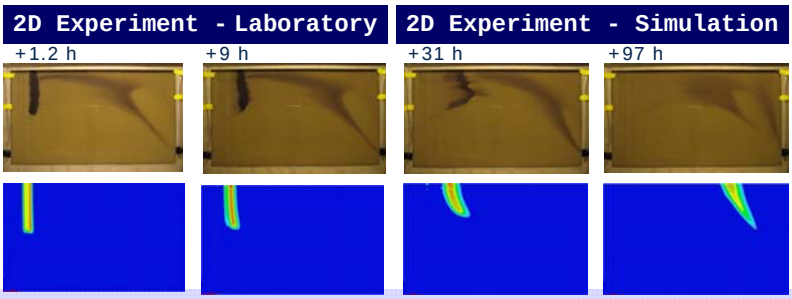
3. Impact of the boundary region on water quality

Model studies

Unsaturated zone

Evaluation of Hydrus 2D Code – 2D Box Experiment:



→ H2D is suitable to examine flow processes in the capillary fringe at laboratory scale

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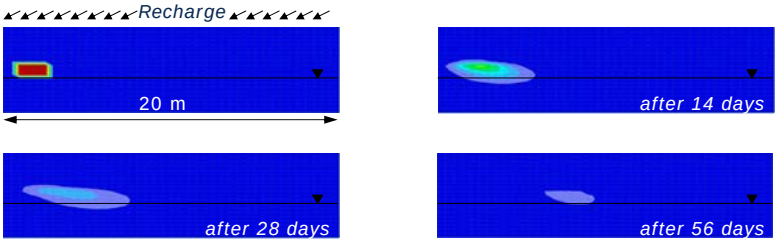
3. Impact of the boundary region on water quality

Model studies

Unsaturated zone

Enhanced scale – 20 m virtual field

Question: lateral flow above water table for relevant distances?



→ lateral flow above water table for several meters

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3. Impact of the boundary region on water quality

Model studies

Comprehensive Model - Why?

To check the quantitative impact of SUIR related processes on water quality.

To assess the applicability of different monitoring techniques (!)

- use of a simplified system
- SUIR considered by simple assumptions

→ virtual field plot with realistic parameters
→ integrated groundwater monitoring well

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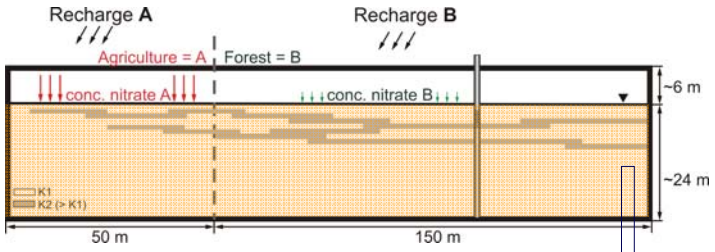
3. Impact of the boundary region on water quality

Model studies

Saturated zone - Comprehensive model



SUIR considered by

- lateral shift of source (transport above phreatic water table)
- reduced hydraulic conductivity in top layer
- enhanced degradation in top layer
- enhanced dispersion in top layer

Modflow MT3D

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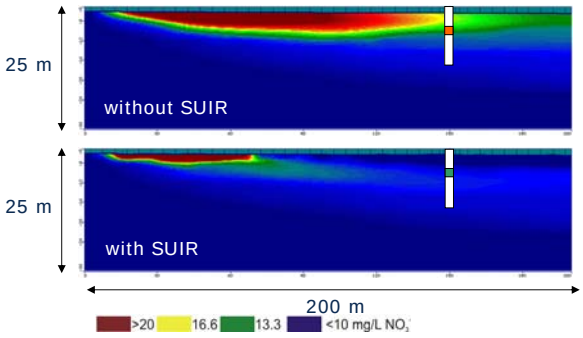
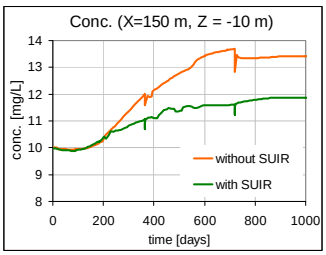
3. Impact of the boundary region on water quality

Model studies

Saturated zone - Comprehensive model





→ Influence of SUIR becomes obvious

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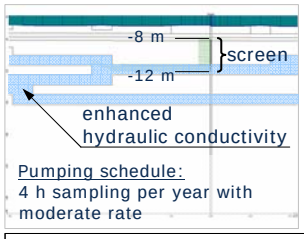
3. Impact of the boundary region on water quality

Measurement techniques



Pumping schedule:
4 h sampling per year with moderate rate

Problems

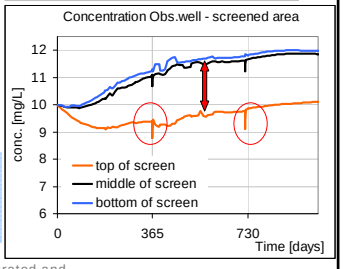
SUIR

→ high vertical variance

→ complex hydraulic interactions

Existing monitoring equipment

- monitoring well; pump for sampling
- differentiation with depth?
- inflow from hydraulically active areas



→ active sampling seems improper to apprehend the processes in the SUIR

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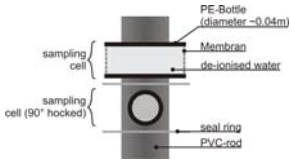
3. Impact of the boundary region on water quality

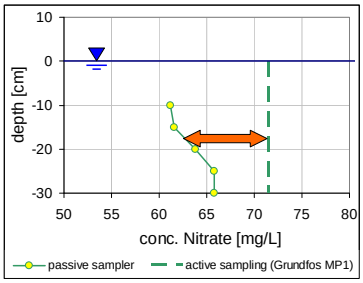
Measurement techniques

Approaches

Active sampling ⇆ **Passive sampling**

→ equilibrium sampler, e.g. Diffuse Multi Layer Sampler DMLS *(Ronen 1986)*





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4. Conclusion

Interface region = Capillary fringe and top groundwater layer

Extension: up to several meters

Residence time: up to several years

Conditions

- high water content
- existing gas phase

→ complex hydraulic interactions

→ highly active transport and reaction area!

Further steps

- enhanced process understanding (!)
- field experiments
- adapt monitoring technique

Thank you for your attention!

Vielen Dank für Ihre Aufmerksamkeit!

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