Study of macropore flow using electrical resistivity tomography?

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Outline

I. Summary

II. ERT principle and layout

III. Inversion and petrophysical relationship

IV. Errors with regard to quantitative calculation?

V. The test site Holtensen (loess)

   - ✓ sprinkling experiment, the process, the problems
   - ✓ ponding experiment, the process, the problems

VI. Conclusion and outlook

Summary

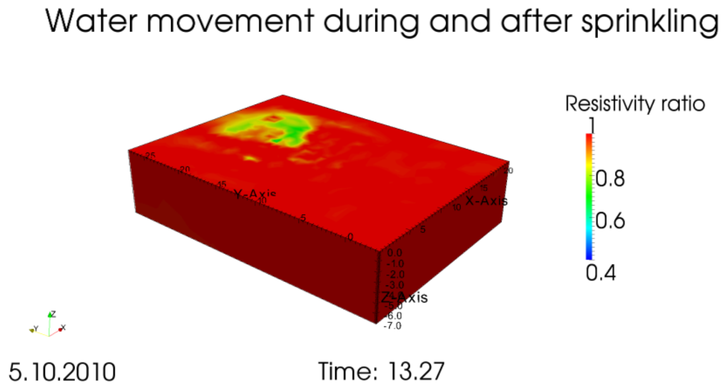
ERT is a wonderful method to observe flow processes minimal invasively

ERT is easy, everybody can use it, and it is relatively cheap

Flow paths can be visualised, but mind the resolution constraints

Quantitative interpretation in unsaturated condition is still a challenge

Try to avoid conductive tracers

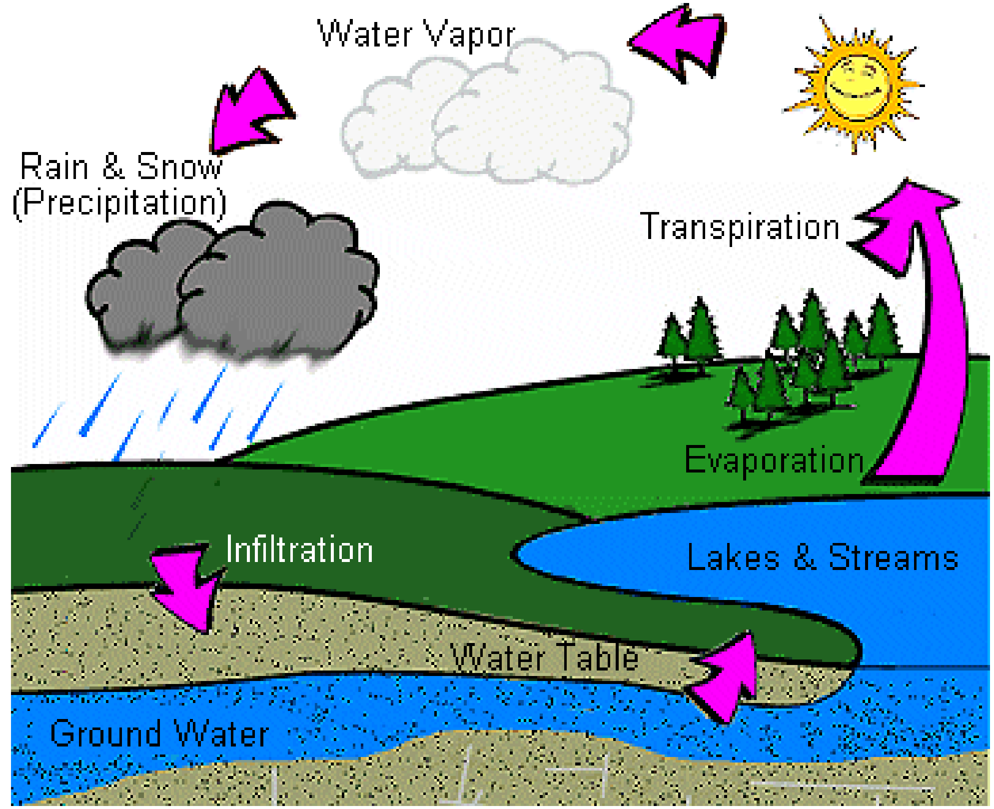


(collaboration with TU Delft, Bogaard et al.)

all inversions done using the programme Bert (Günther et al., 2006, www.resistivity.net)

Motivation

Can we use ERT to directly observe those hidden subsurface processes on a meso scale (1-100m²)?



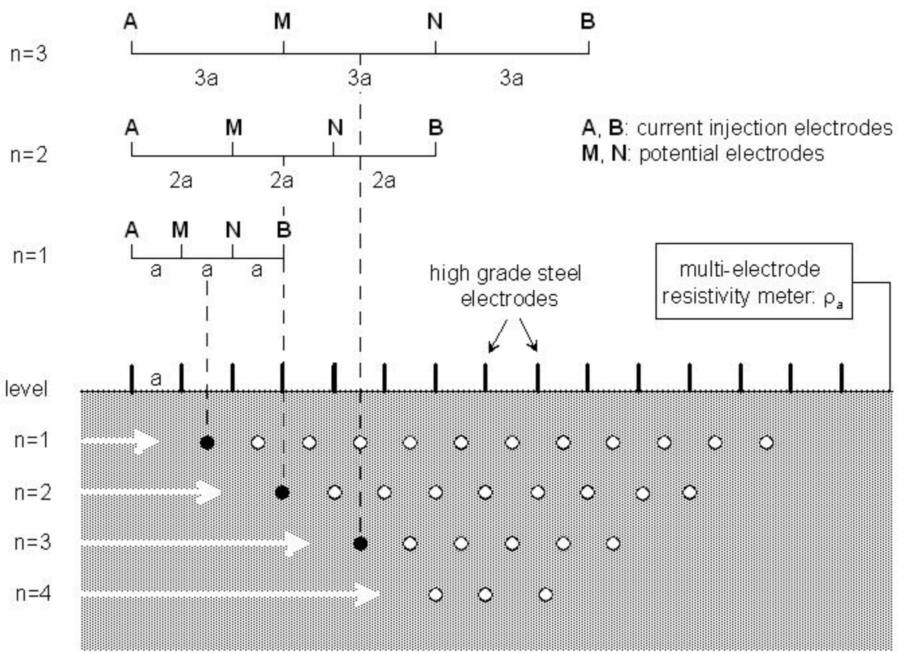
www.dnr.state.wi.us/.../images/groundwater.gif (21.6.07)

soil water, subsurface flow
water content, infiltration velocity, interflow, subsurface storm flow, gaining rivers

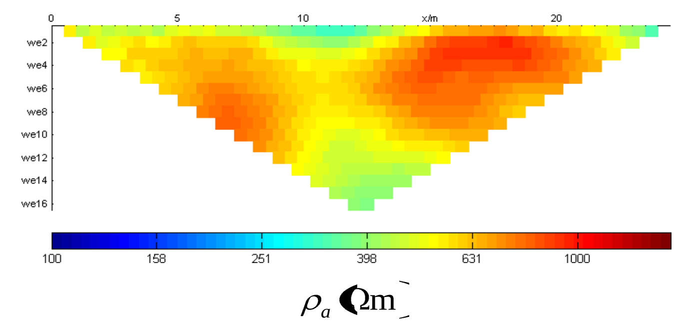
groundwater recharge
surface water-groundwater interaction

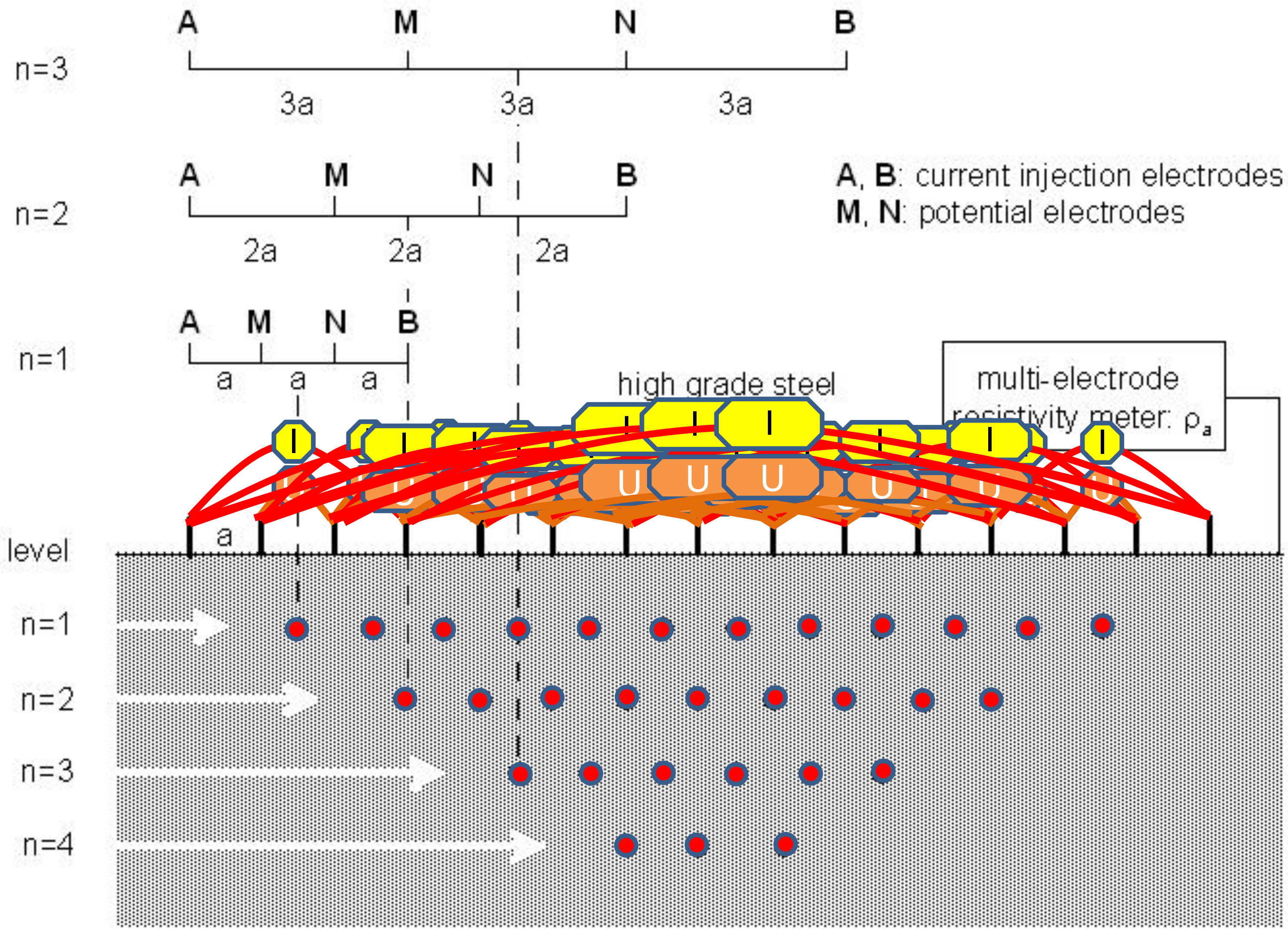
The method (ERT = electrical resistivity tomography)

sketch (Wenner-Configuration):



measurements visualised as:
pseudo section

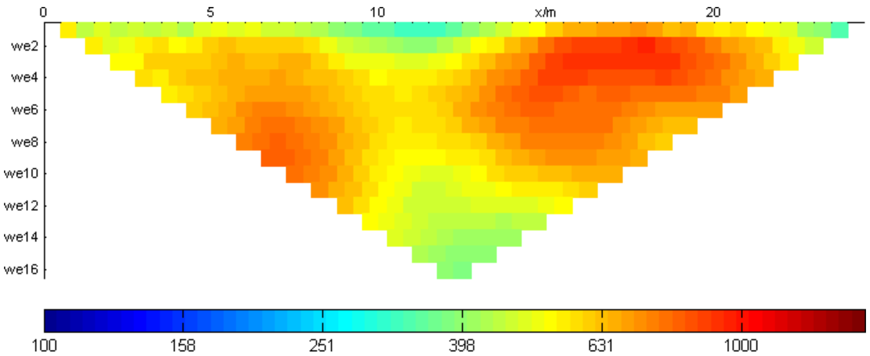




n=3
A
M
N
B
3a
3a
3a
n=2
A
M
N
B
2a
2a
2a
A, B: current injection electrodes
M, N: potential electrodes
n=1
A
M
N
B
a
a
a
high grade steel
multi-electrode
resistivity meter: ρa
I
U
a
level
n=1
n=2
n=3
n=4

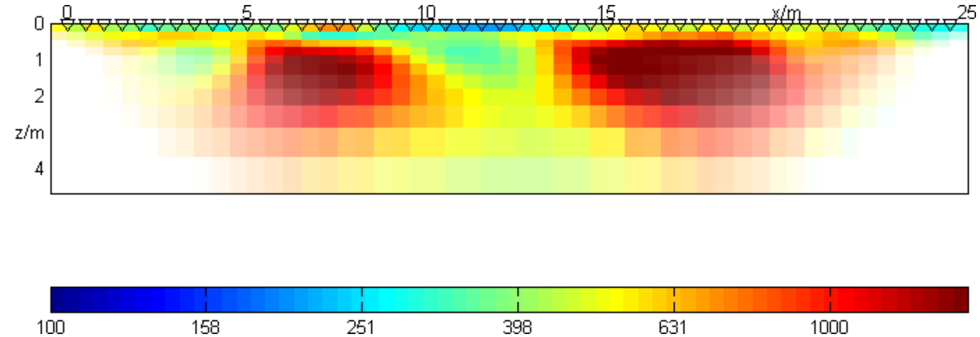
Data inversion

pseudosection (data)



ρ_a (Ωm)

resistivity distribution (model)



ρ (Ωm)

inversion

$$|| D (d - f(m)) ||^2 + \lambda || C (m - m_0) ||^2 \longrightarrow \min$$

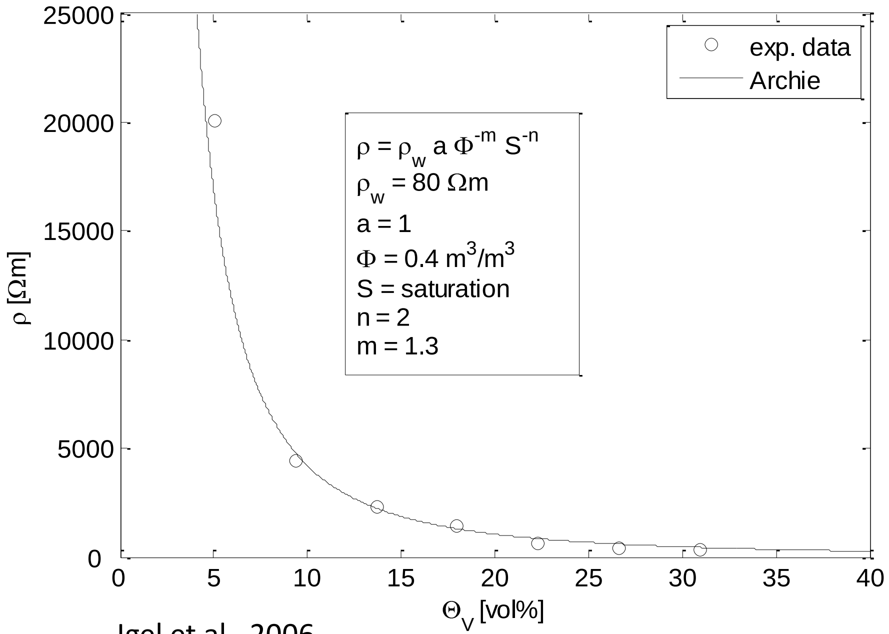
2047 data

9360 model cells

programme: DC3DInvRes/bert
(www.resistivity.net)

forward modeling

Petrophysical relationship between resistivity and water content



Igel et al., 2006

$$\rho_t = \frac{a}{\Phi^m} \rho_w \frac{1}{S_w^n} \qquad \text{(Archie-equation)}$$

- ρ_t : bulk resistivity
- Φ : porosity
- ρ_w : resistivity of the pore fluid
- S_w : saturation
- m, n, a : empirical constants

resistivity change

⬇

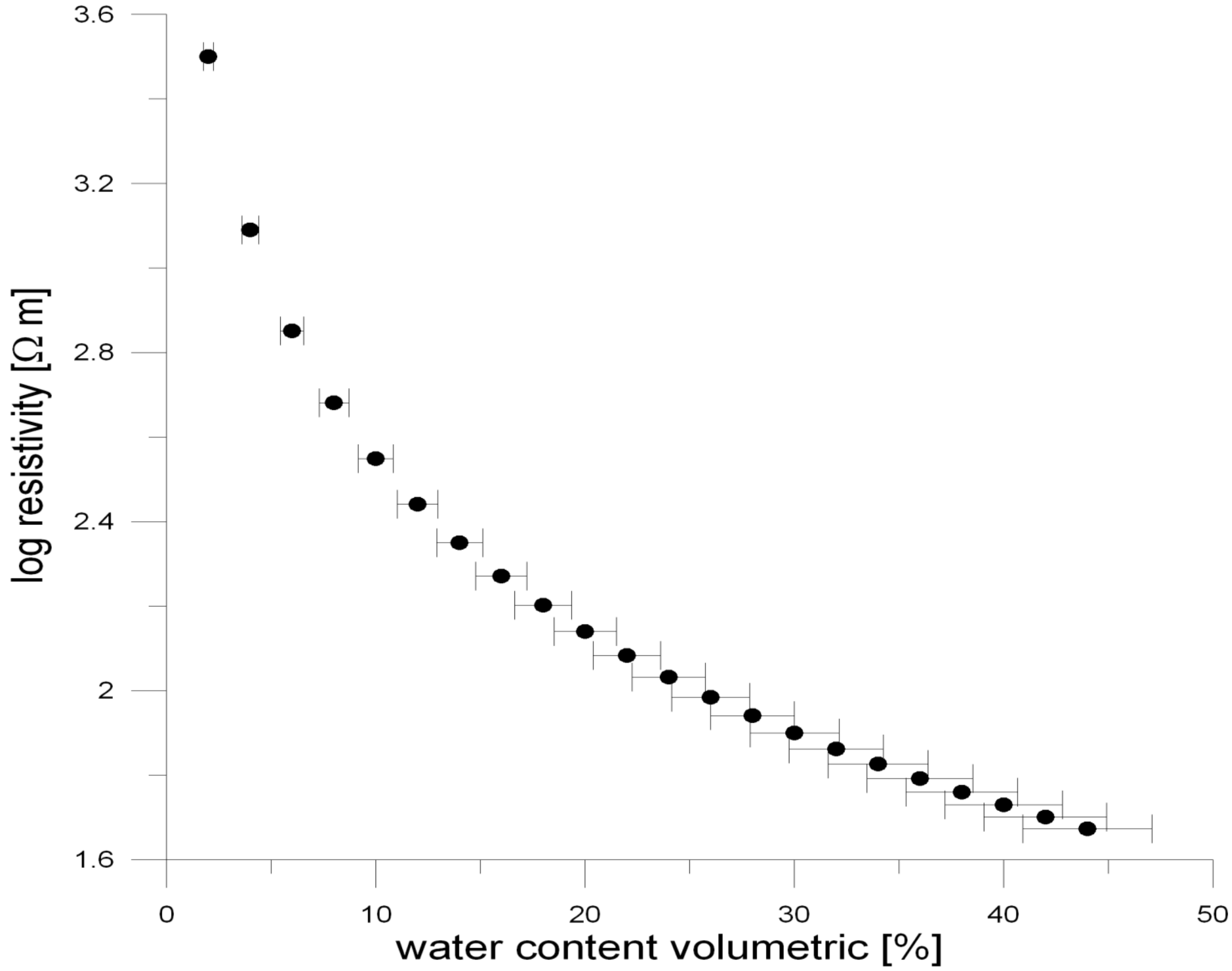
change in saturation

(porosity, clay content, tortuosity, cation-exchange capacity constant)

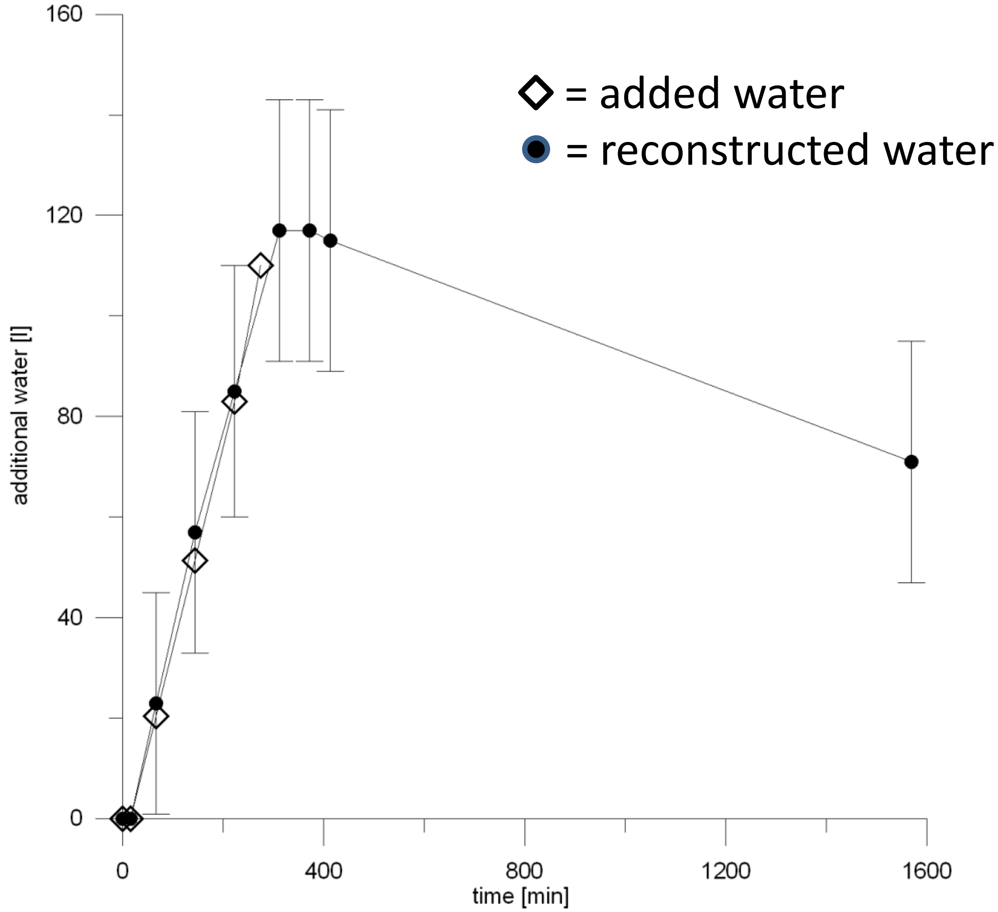
$$\frac{\rho_1}{\rho_0} = \left(\frac{S_0}{S_1}\right)^n$$

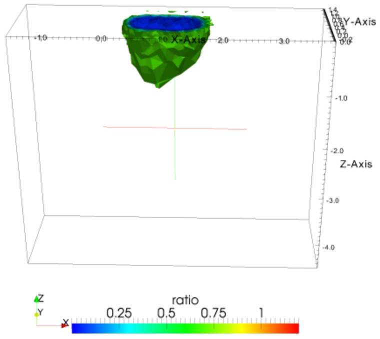
$$\Delta S = \left(\sqrt{\frac{\rho_0 * k}{\rho_1}} - 1\right) * S_0 \qquad k = \frac{\rho_{w1}}{\rho_{w0}}$$

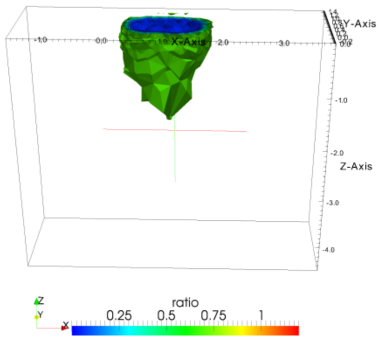
Error by calculating water content from resistivity

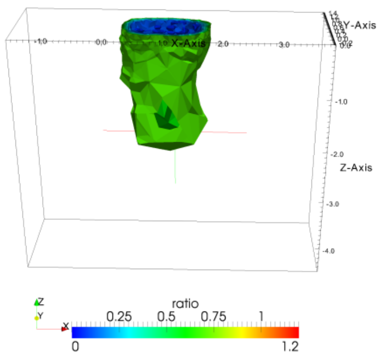


Error of the quantitative reconstruction



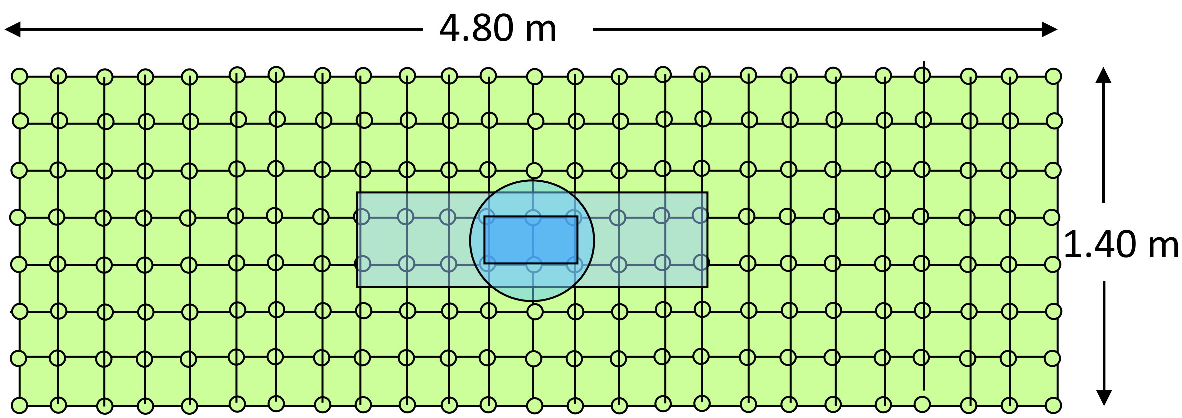


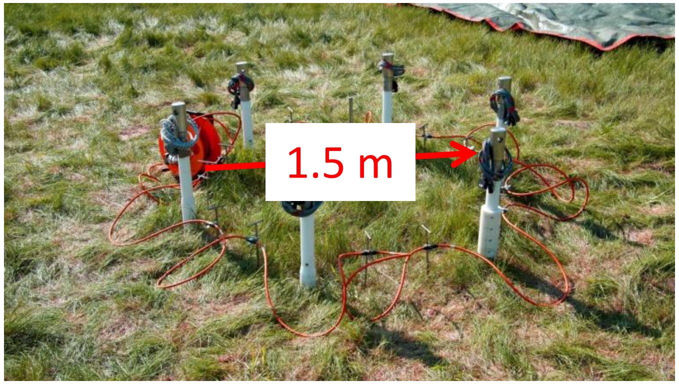


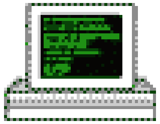


to the error contribute uncertainties of
measurement and inversion
Archie parameters m and n
fluid conductivity

Two infiltration experiments in loess (sprinkling, ponded infiltration)



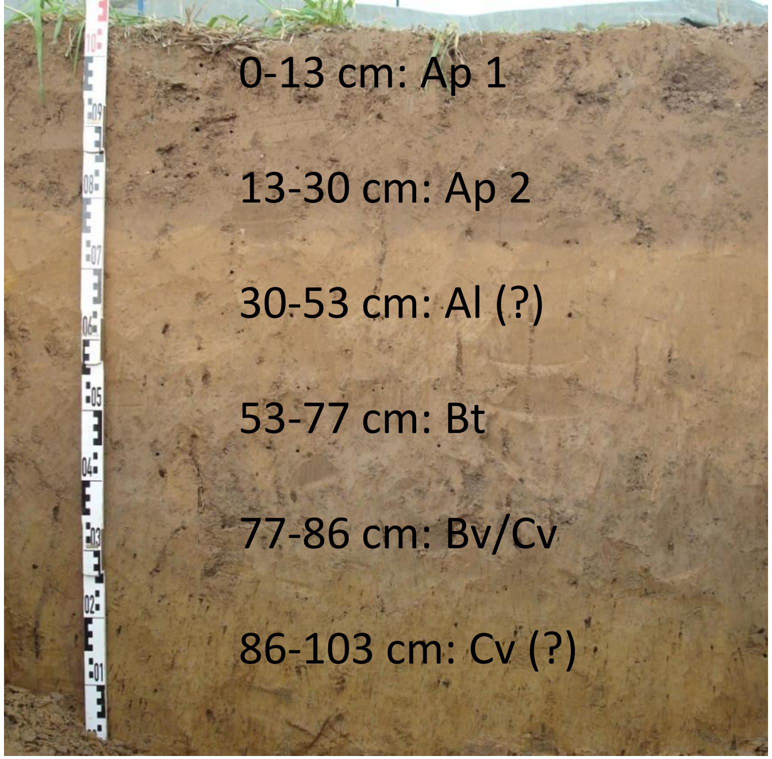




infiltration area:
1m x 0.4m / 80 l in 48 h (4.2 mm/h)
0.4 m diameter/ 25l in 24 min

array 150 electrodes (vertical or horizontal)
dipole-dipole + wenner configuration
580 /1560 measurements
within 5/15 min

excavation of central areas
measurements of water content (TDR) and matric potential
day(s) after infiltration.

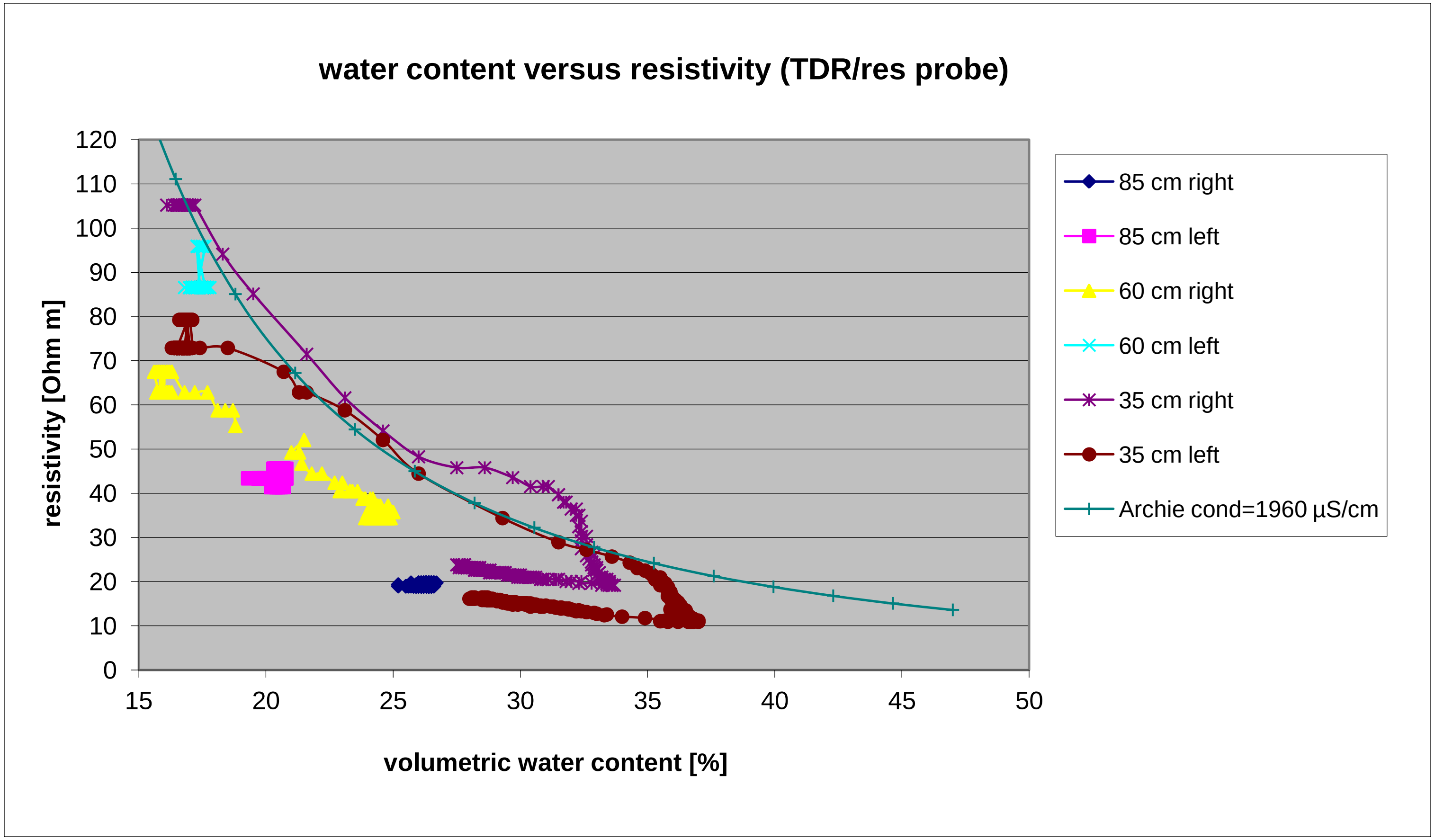


Soil profile at the site of the sprinkling experiment (loess)

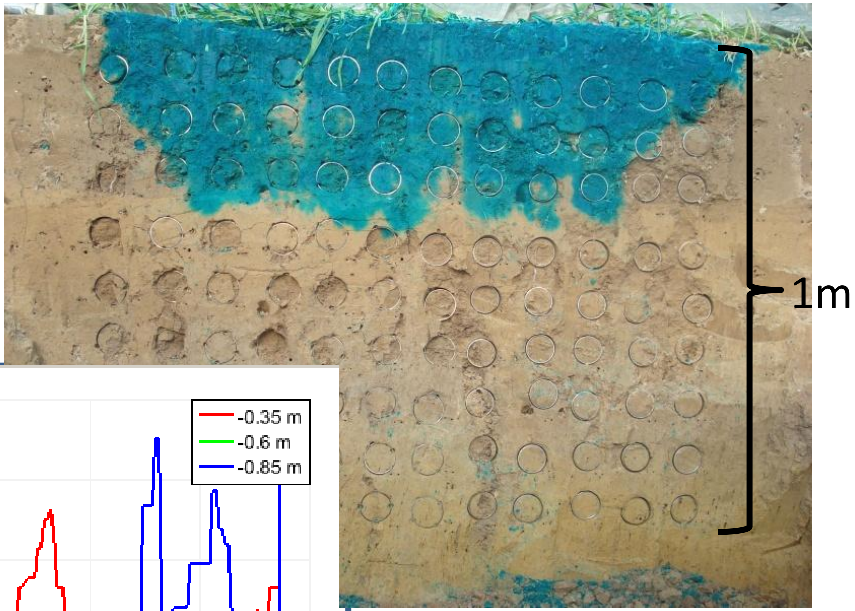
lay out of the 150 electrodes

3D array, 4.8 x 1.4 m
electrode distance 20 (40) cm
infiltration area: 1 x 0.4 m
brilliant blue tracer
80 l within 48 hrs

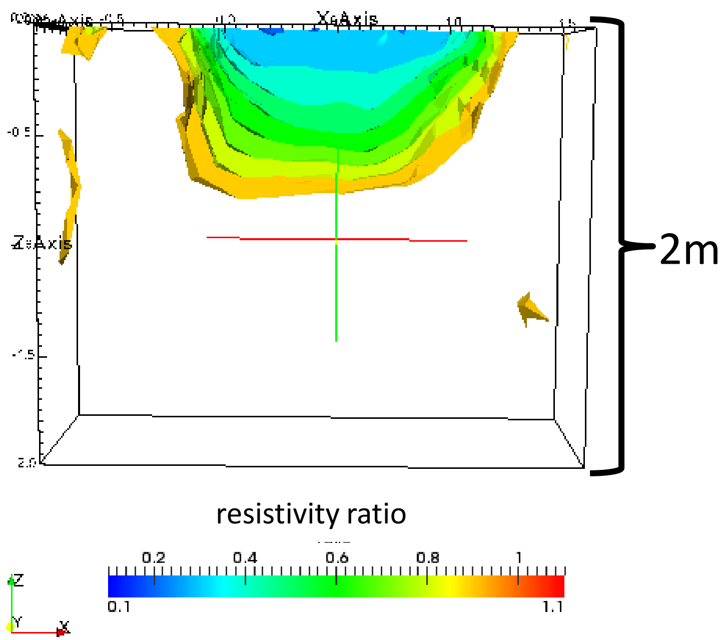
Results of the TDR measurements at different depths and positions

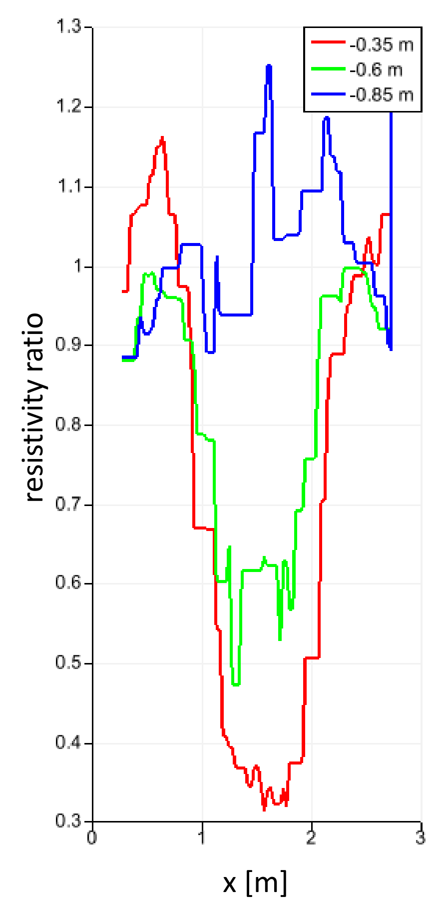


Section through the central sprinkling area

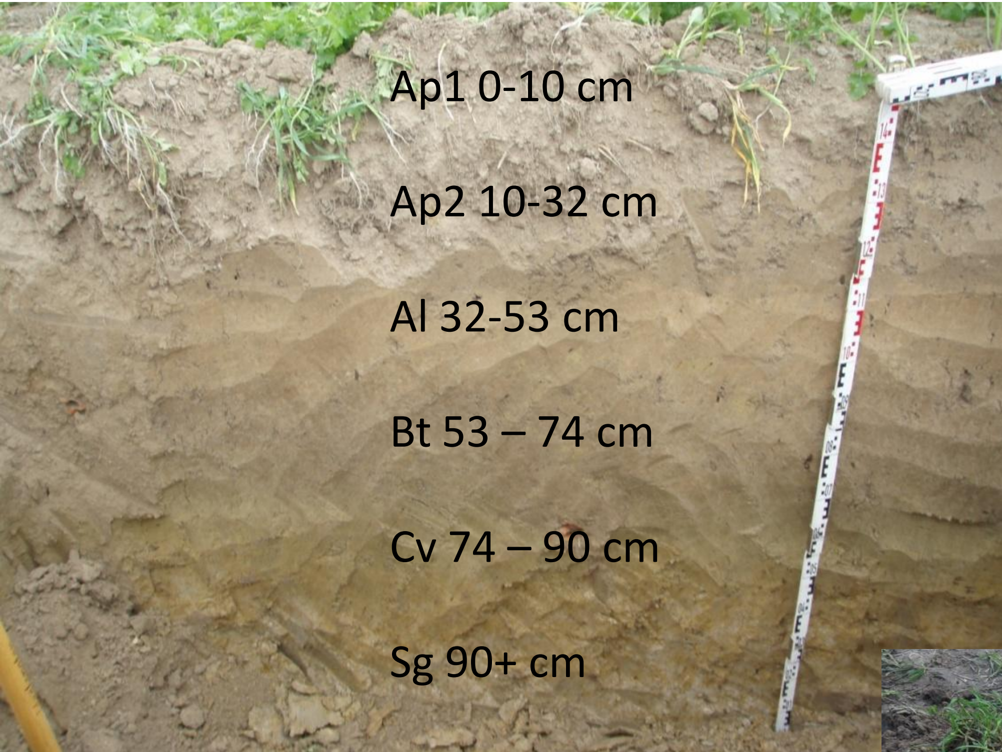


contour lines





ERT inversion result
central section
3 days after start
of sprinkling (48 hrs)

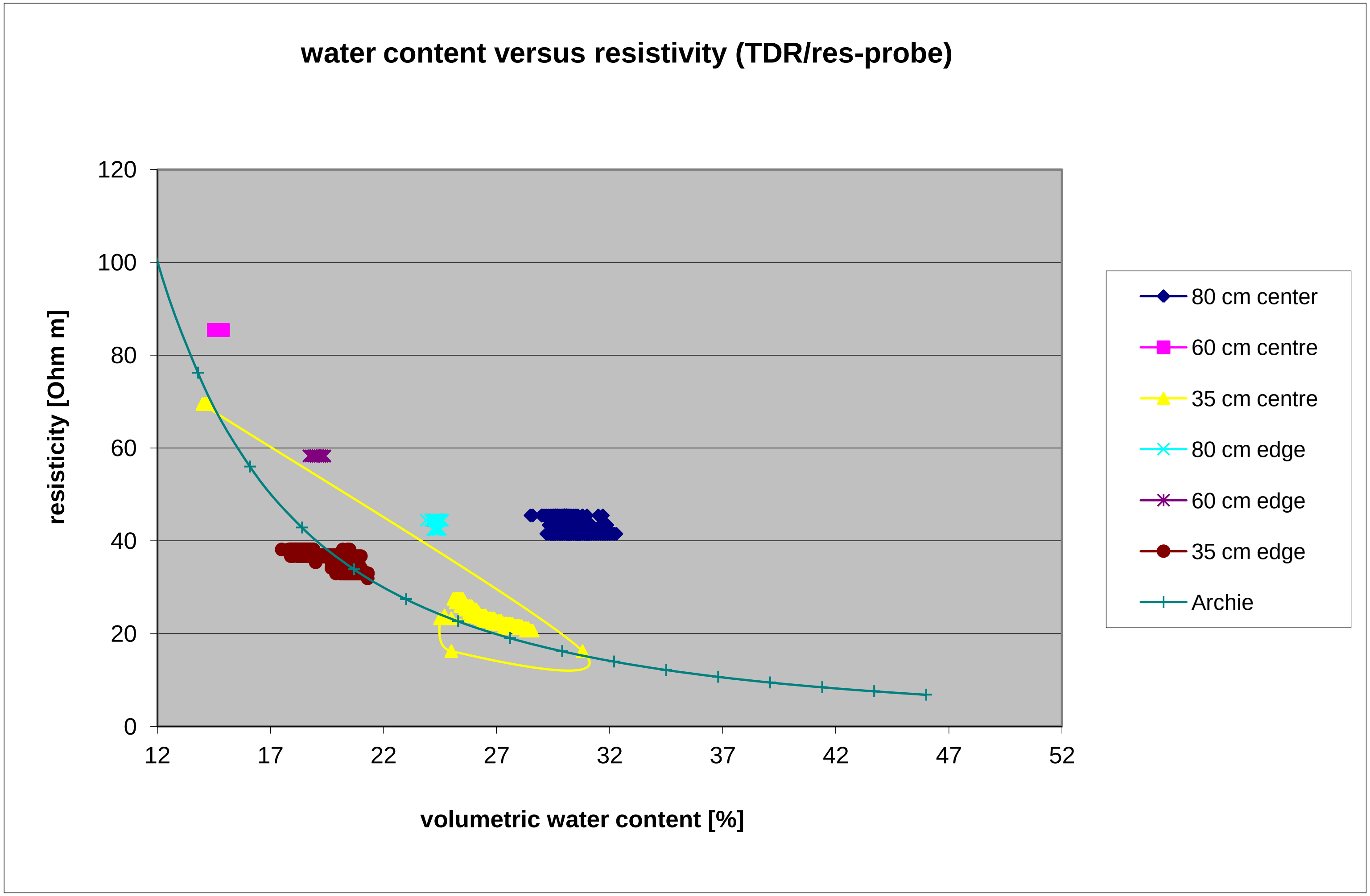


Soil near the test site, second profile

lay out of the 6 vertical electrodes

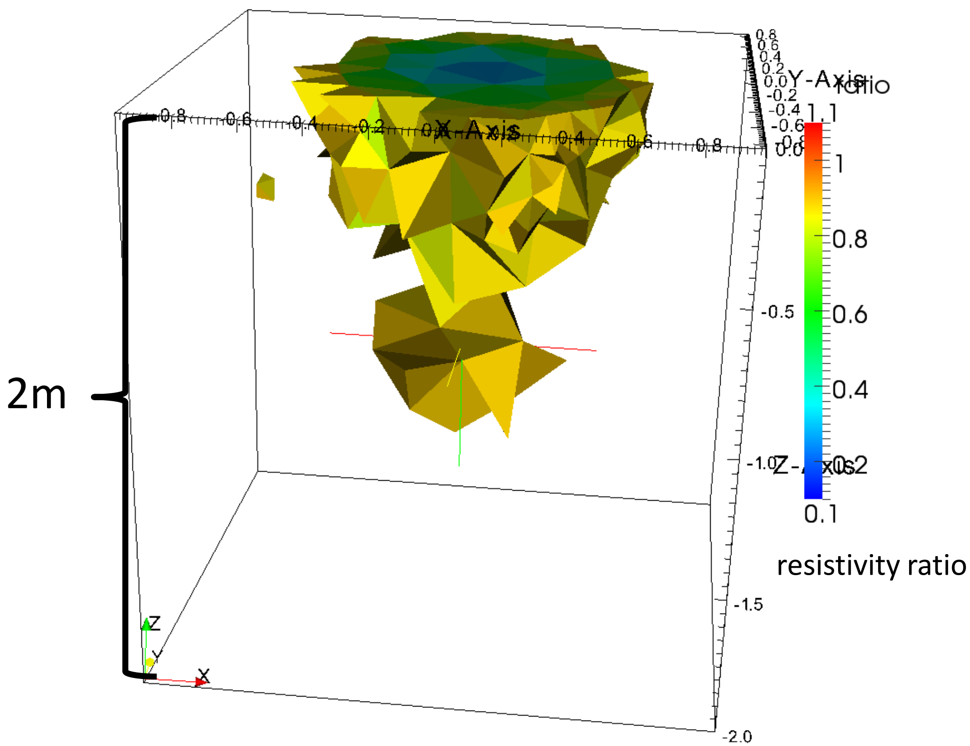
1.3 m long, 25 electrode rings each
diameter of the ponding ring: 40 cm
brilliant blue tracer
25 l within 24 minutes

Results of the TDR measurements at different depths and positions



not yet corrected acc. Bechthold et al., SSSAJ: Volume 74: Number 2 • March–April 2010

Inversion result after 34 minutes



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Conclusion

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✓Flow paths can be visualised, but mind the resolution constraints

✓Quantitative interpretation in unsaturated condition is still a challenge

✓Try to avoid conductive tracers

Outlook

For quantitative assessment the change in pore water conductivity needs to be observed independently