Aquifer characterization using geoelectrical modelling, a case study

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PICO 2.10

MOTIVATION

application of resistivity measurements (ERT) in hydrogeological issues

investigate boundary conditions and possible ways to overcome limiting factors

correlation between electrical resistivity & hydraulic conductivity

METHODS

high resolution geoelectrical survey at the hydrogeological testsite „Stegemühle“ (Germany)

2D inversions:
res2Dinv unconstrained
AC2DSIRT with predefined starting model

RESULTS

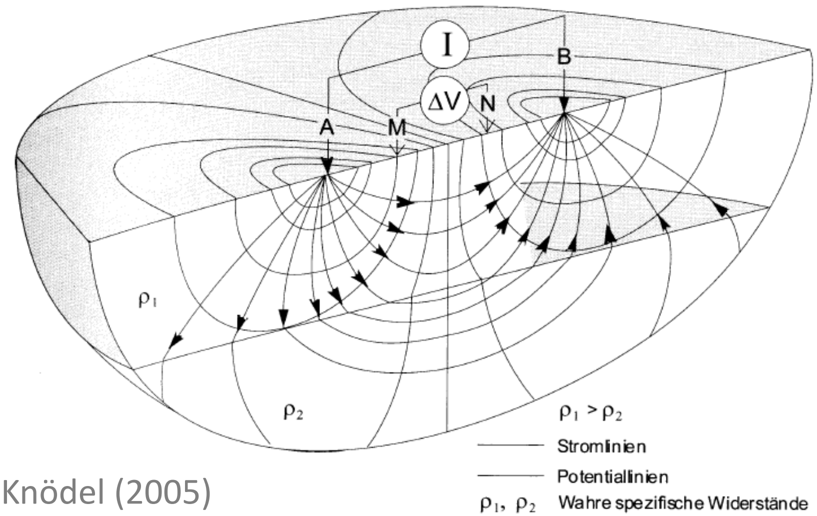
aquifer resistivity anomalies are due to variation in aquifer thickness or fine grain content

ambiguity in data interpretation due to principle of equivalence can be minimized by including geological and hydrogeological information

site specific linear correlation between ρ and k_f

resistivity measurements

Determination of the subsurface resistivity distribution. The electrical potential evoked by current injecting electrodes (A and B) is affected by electrical properties of the underlying rocks and can be measured via potential electrodes (M and N).
Applying Ohm's law, the apparent resistivity ρ_A can be determined.

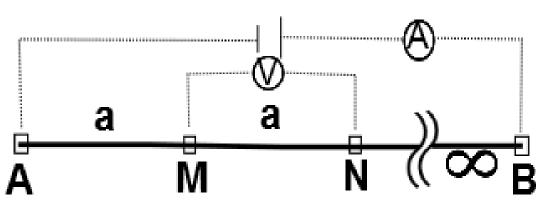


Knödel (2005)

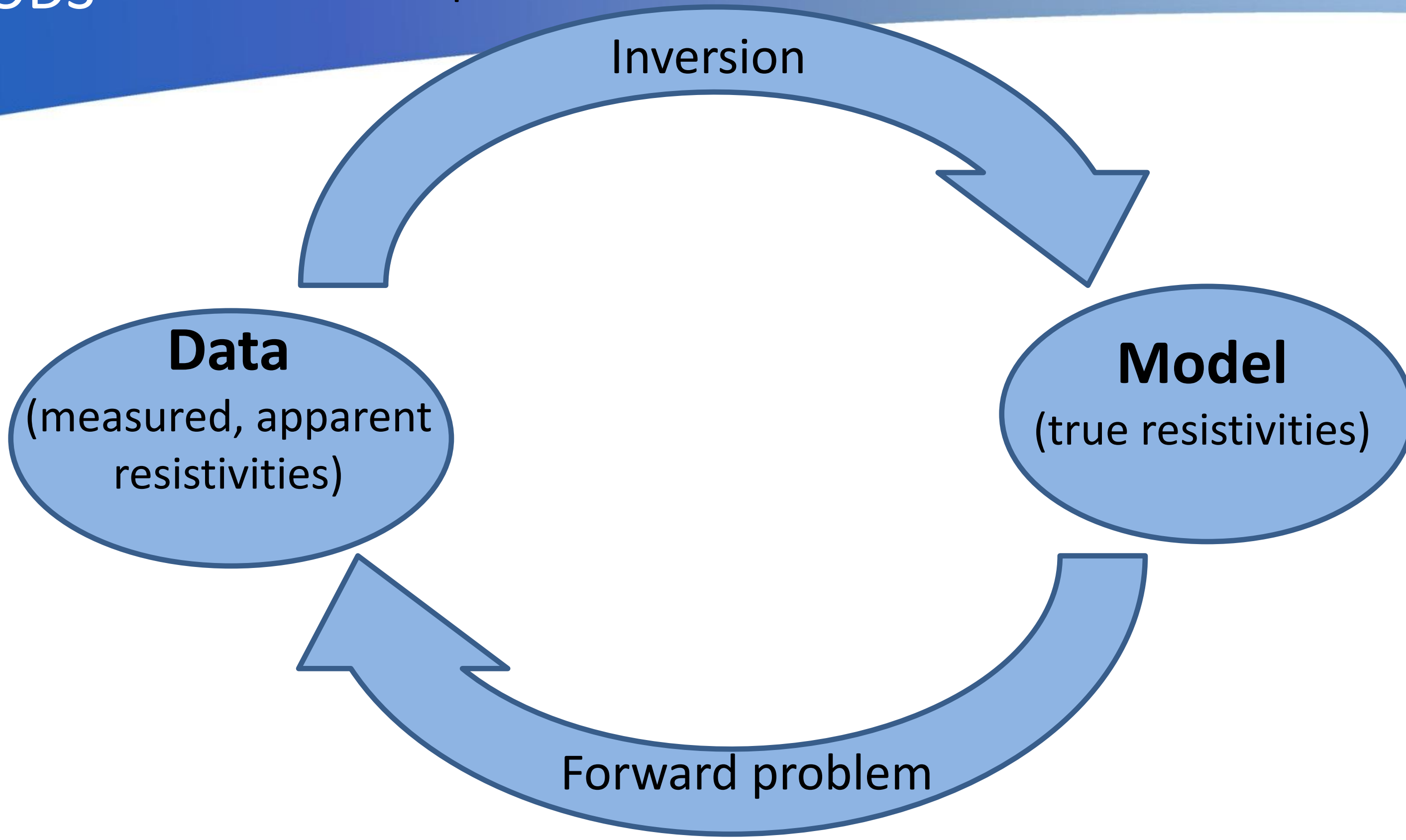
$$\rho_A = K\frac{U}{I}$$

K , geometry factor, results from electrode configuration:

$$K = 2\pi\left[\left(\frac{1}{AM}-\frac{1}{BM}\right)-\left(\frac{1}{AN}-\frac{1}{BN}\right)\right]^{-1}$$



Half Wenner



Software	Forward modelling	Inversion method
Res2/3Dinv	Finite difference	Gauss Newton least square minimazation
AC2DSIRT	Finite difference	Simoultaneous iterative reconstruction technique

Limiting factors

Principle of equivalence:

Only the transversal resistance T can be determined distinctly but not the aquifer thickness h_i and resistivity ρ_i at the same time.

→ Thicker and higher conductive layer produces the same signal as a thinner and less conductive layer.

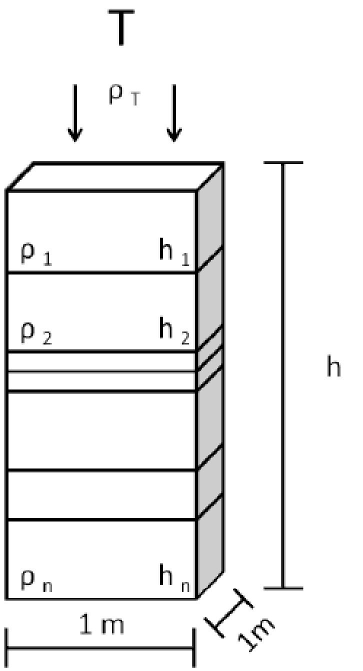
Further limits:

Geological features

Survey set up

Ambiguity in data inversion

→ Different models reproduce the same data..



(Scheme of a geological section)

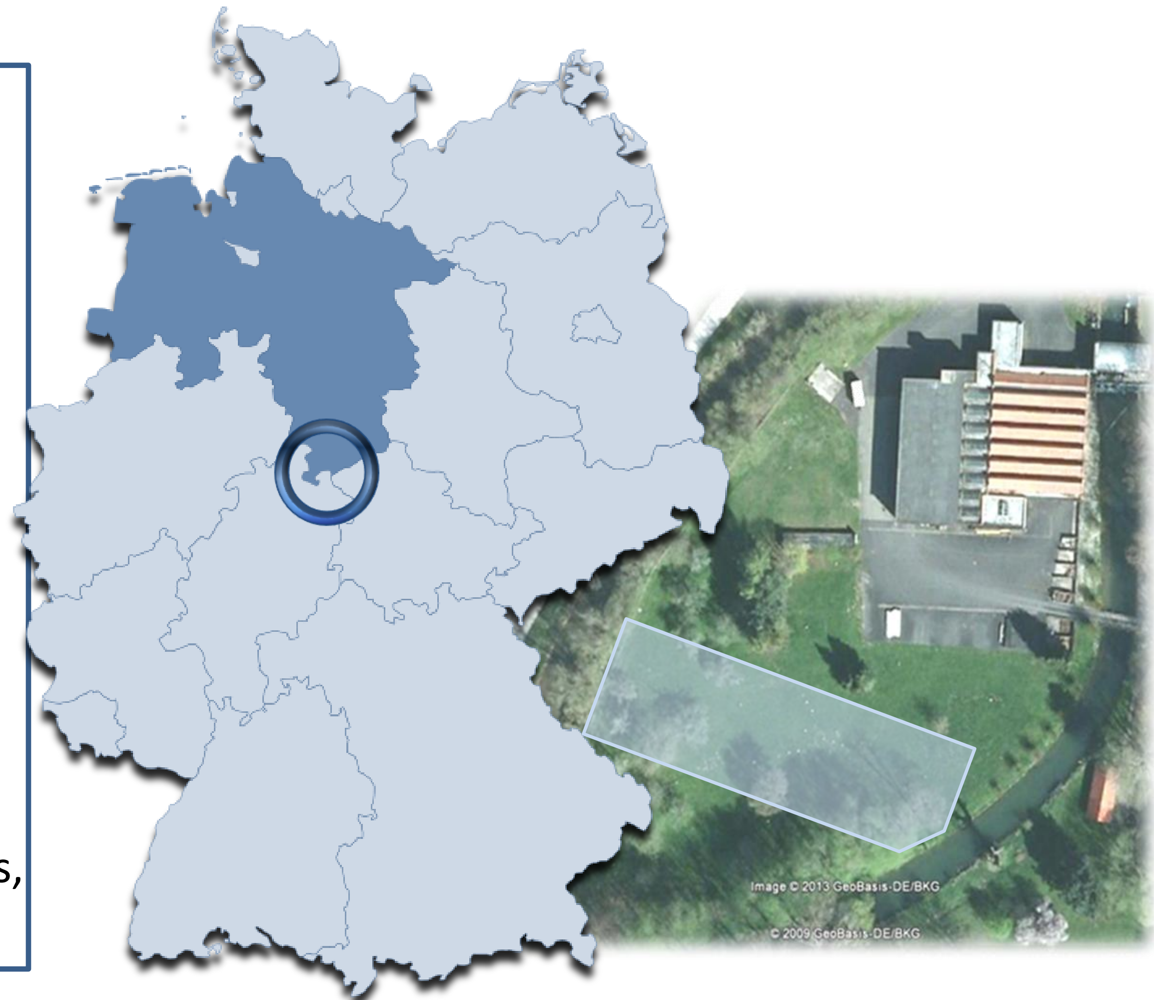
$$T = \sum_{i=1}^{n} h_i \cdot \rho_i$$

The hydrogeological testsite Stegemühle

Location:
- South of Göttingen
- Water protection zone I

Lithology:
- clay (Auenlehm)
- gravel (Leinekies)
- bedrock (Keuper: claystone)

Hydrogeological Testsite:
- Installation in 2007
- hydraulic parameter via: slug, pumping and tracer tests, grain size analysis, gammaray and EC-logs



(Google maps)

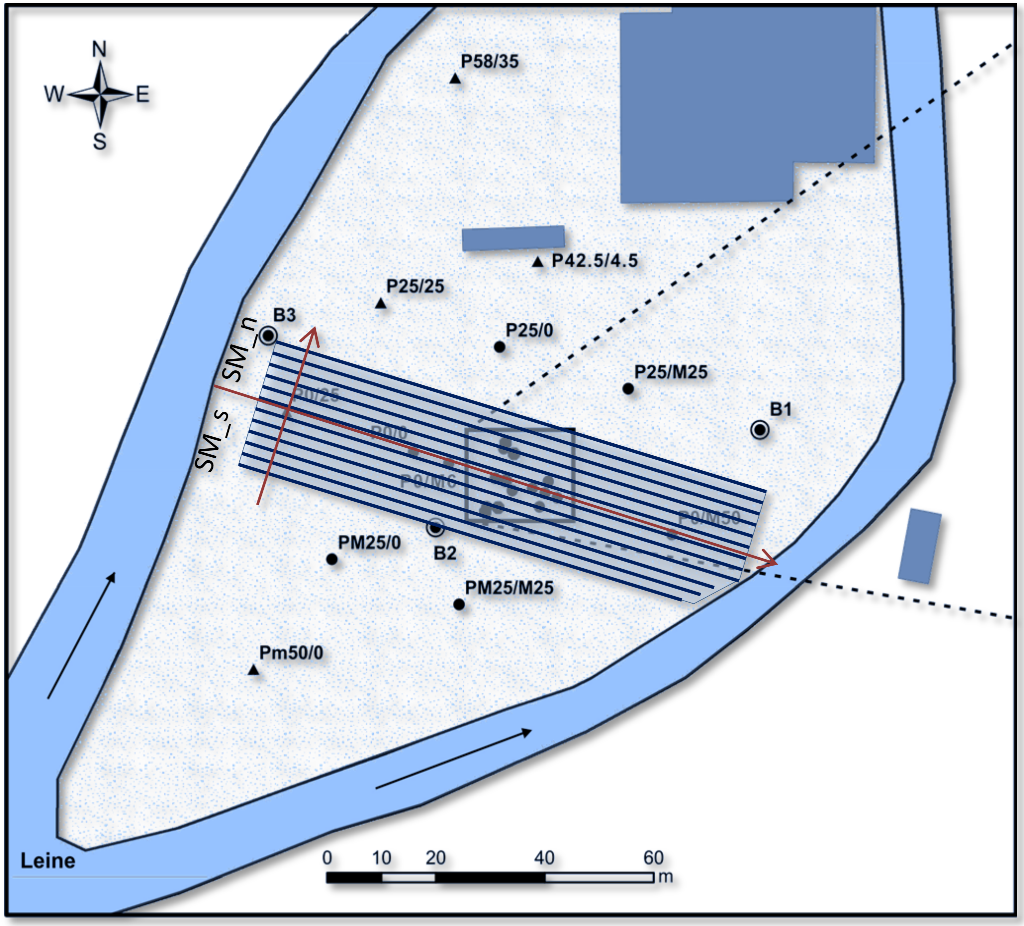
Survey set up

Set up:

- twelve parallel profiles (~100m), 2m separation
- 0.5m electrode separation
- Half-Wenner configuration with „roll-along“

Device:

- multi electrode Lippmann 4 point light with 3 cables with25 boxes each for 75 electrodes
- Measuring parameters and electrode configuration controlled remotely via the Software Geotest



(Plan of the testsite modified after Hu, 2011)

Expactations of resistivity distribution based on literature and geological borhole information

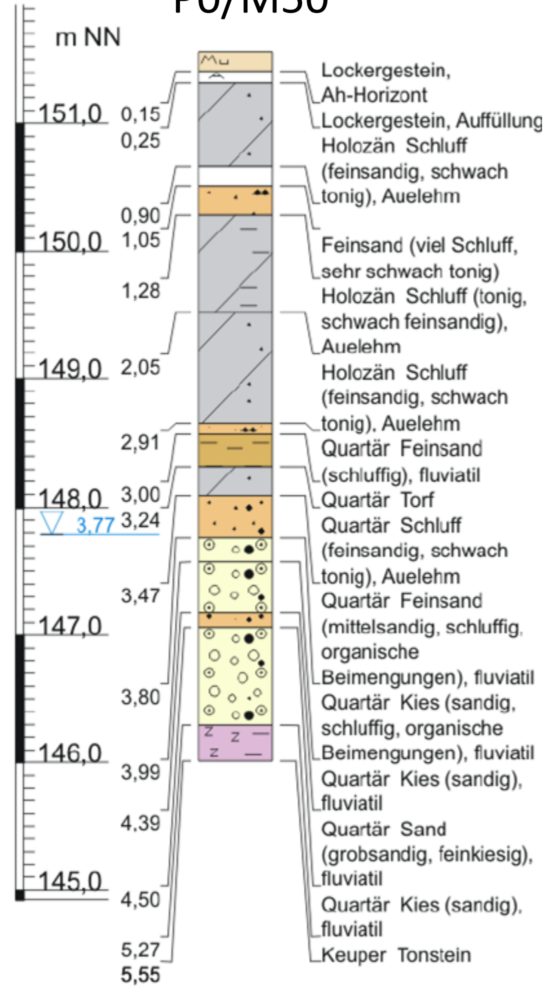
Horiontal layering:

1. Varying resistivity (topsoil)
2. Low resistivity (clay, wet)
3. High resistivity (gravel, sand with groundwater)
4. Low resistivity (clay stone, Keuper)

material	resistivity [Ωm]
gravel, sand	50-10E4
clay (wet)	3-30
humus	15-25
ground water	10-100
salt water	0.3

(Loke (2011), Knödel (2005))

P0/M50



Hu & Vogt (2007)

vertical profiles (res2Dinv)

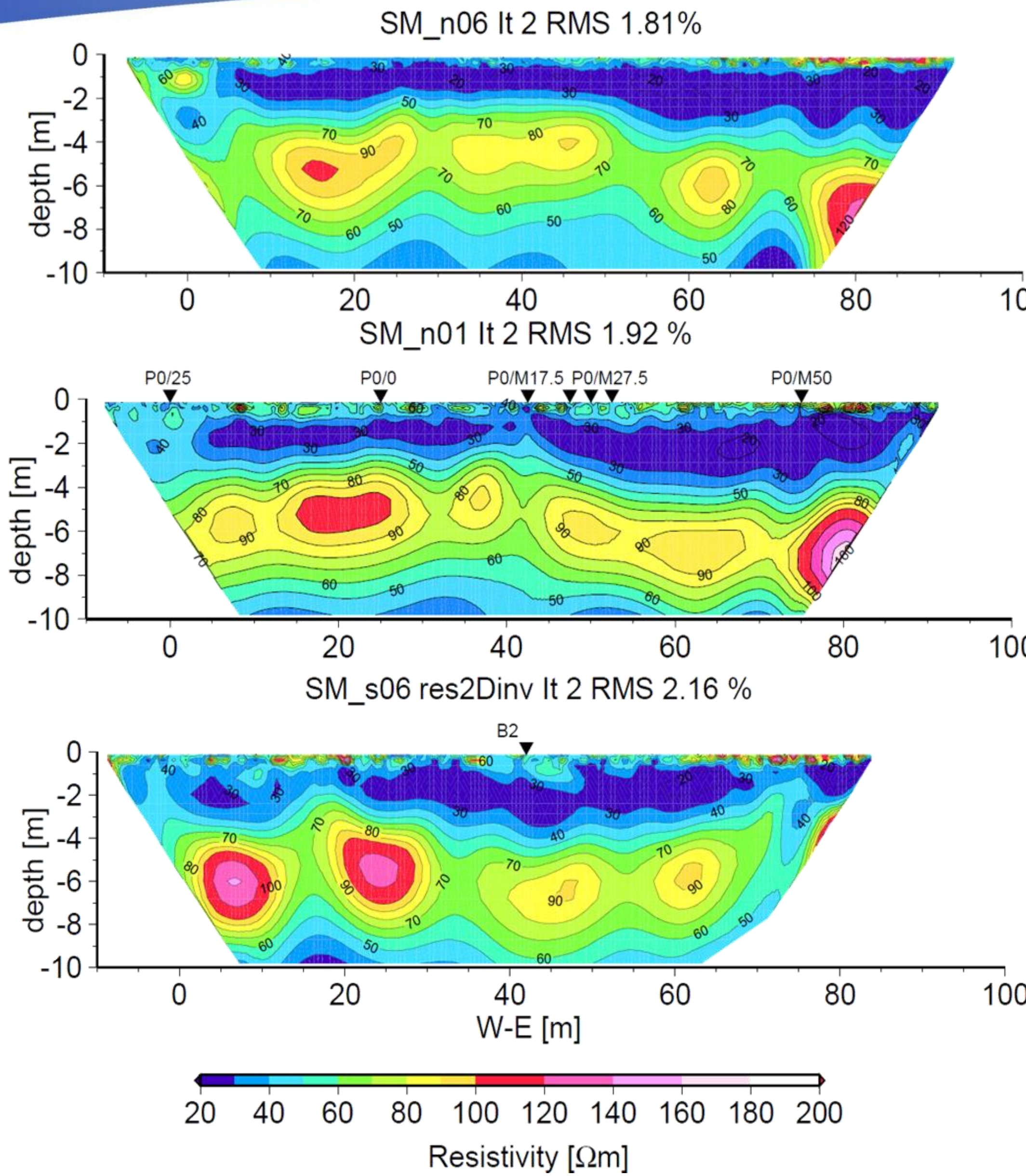
Similar resistivity distribution in all profiles:

4 layers:

- thin surface layer with variable resistivity
- low resistivity
- high resistivity (with anomalies)
- low resistivity

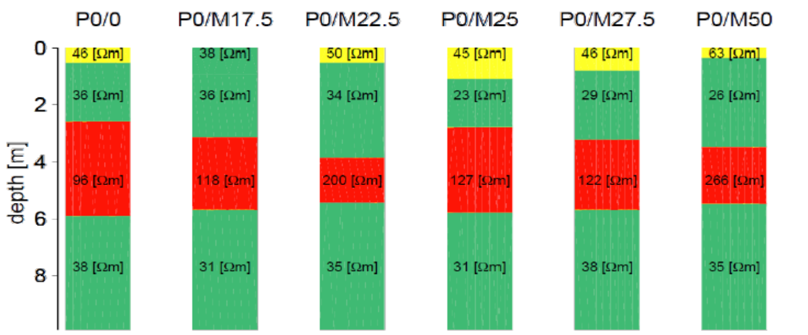
Wavy layer boundaries

RMS < 2.5% → validity



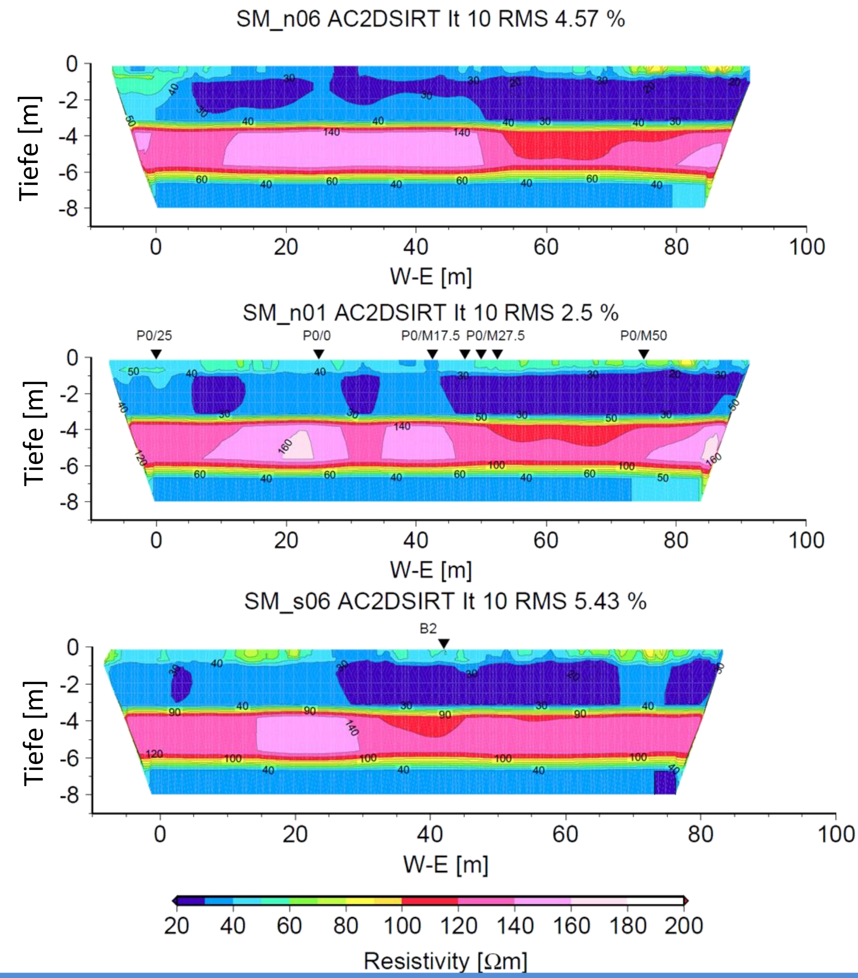
Starting model based on VES

1D model based on VES, calibrated with borehole data:
- 4 layers
- relatively homogeneous distribution of resistivity in regions of topsoil, Auenlehm and bed rock
- aquifer made of gravel shows variation in resistivity values.



VES at six well locations

Vertical profiles (AC2DSIRT)



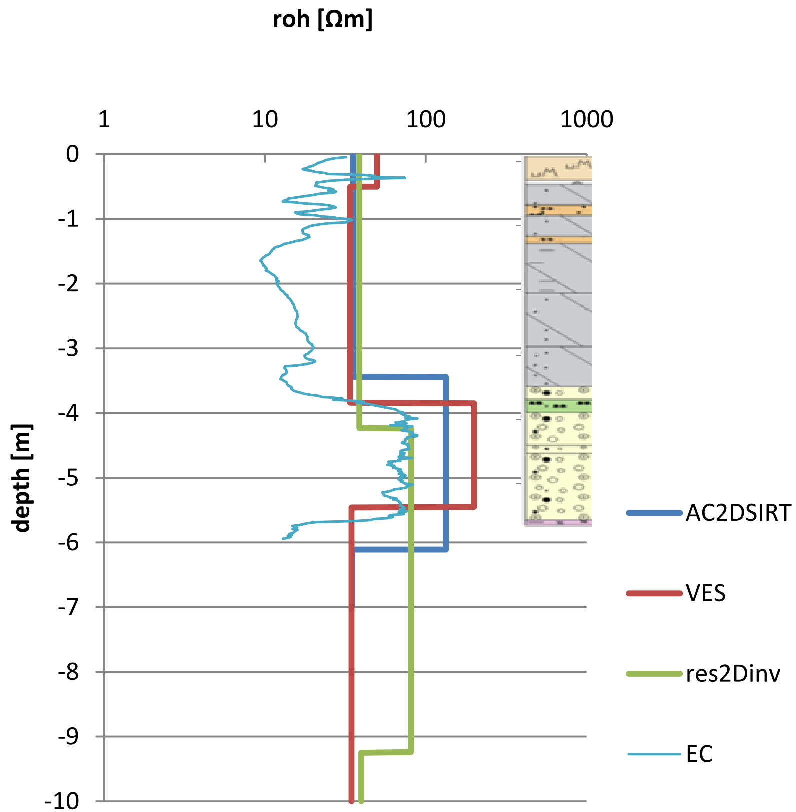
P0/m22.5

Comparison between models and geology, EC-logs

VES and **AC2DSIRT**:
- constrained models show good accordance with borehole profiles and EC-logs

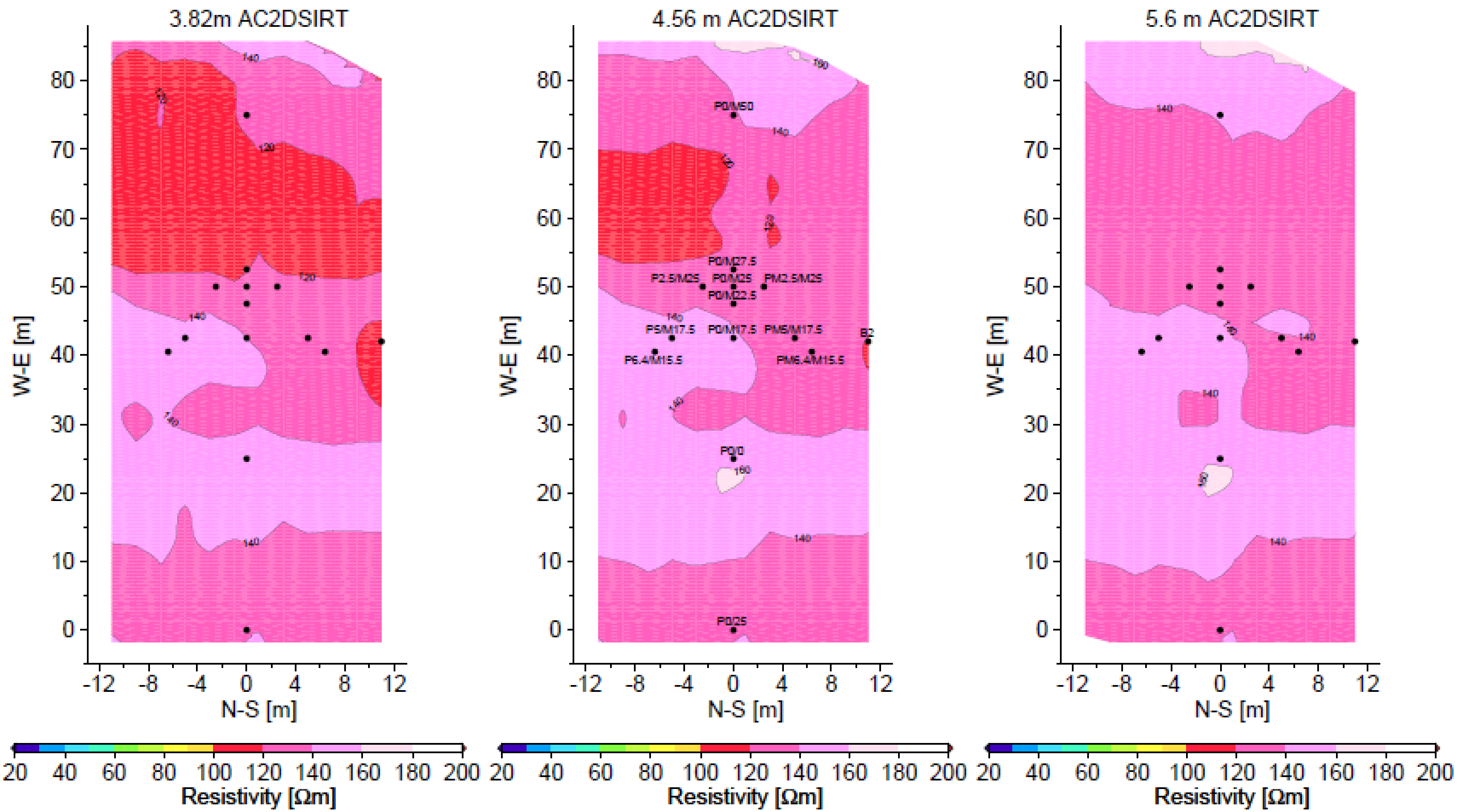
res2Dinv :
- overestimated depth and thickness of aquifer
- too low resistivity.

→ Principle of equivalence: all inversions produce a similar T



Comparison of inversion results with borehole profiles and EC-logs.

2D Model horizontal interpolation with AC2DSIRT



(a) Top of the aquifer. (b) Center of the aquifer. (c) Bottom of the aquifer.

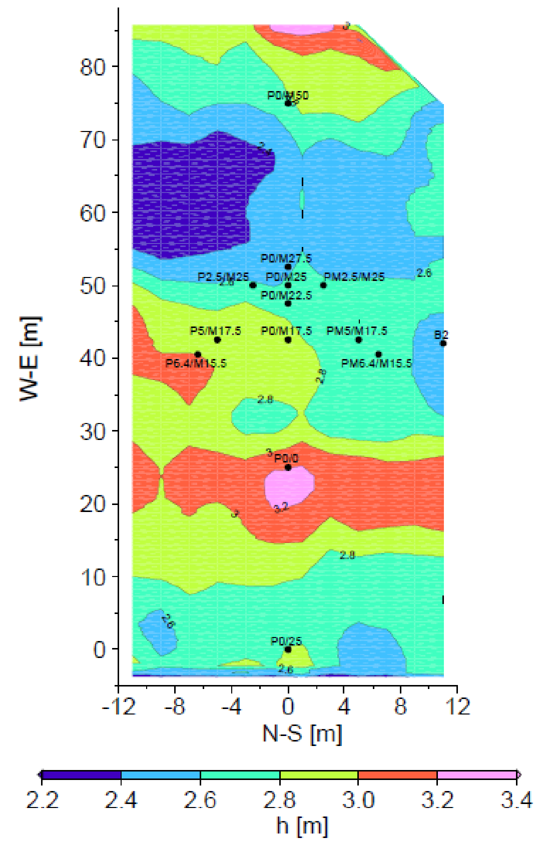
Distribution of aquifer thickness (ρ = const = 132Ωm)

$$T = h \cdot \rho = h_f \cdot \rho_v = h_v \cdot \rho_f \qquad \longrightarrow \qquad h_v = h_f \frac{\rho_v}{\rho_f}$$

well location	aquifer thickness [m] (method[7])	aquifer thickness [m] AC2DSIRT
P0/M25	2.5 (B)	2.8
P0/0	3.3 (EC)	3.18
P0/M17.5	2.6 (EC)	2.87
P0/M22.5	1.6 (B)	2.71
P0/M25	3.0 (EC)	2.59
P0/M27.5	2.4 (B)	2.57
P0/M50	2.4 (B)	2.77
PM2.5/M25	2.5 (B)	2.62
P2.5/M25	3.0 (EC)	2.64
PM6.4/M15.5	2.5 (EC)	2.7
P6.4/M15.5	3.3 (EC)	3.0
PM5/M17.5	2.4 (EC)	2.74
P5/M17.5	2.4 (EC)	2.91
B2	2.4 (B)	2.44

Aquifer thickness at well locations

Aquifer thickness with a constant resistivity of 132 Ohm m

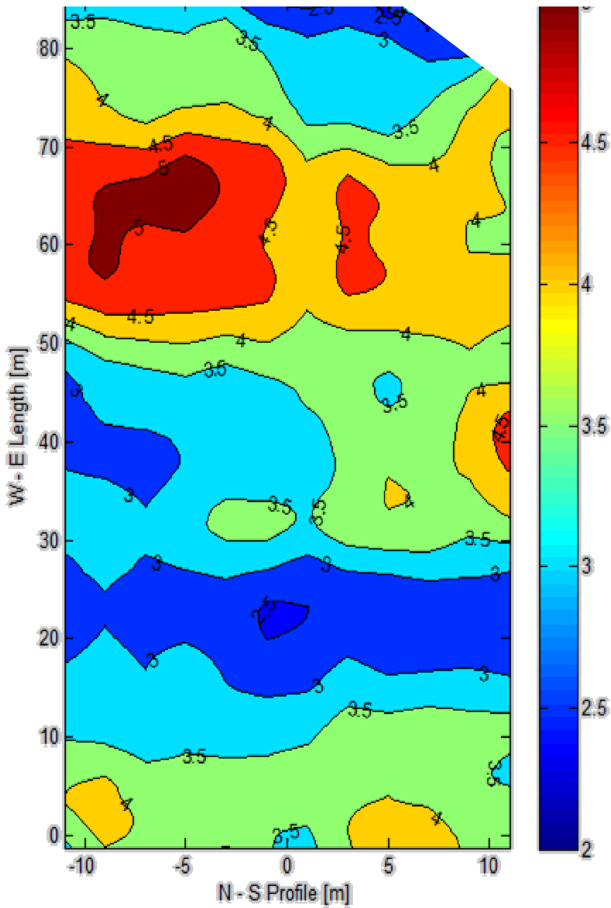


Distribution of surface conductivity σ_{surf}

$$\sigma = \frac{1}{F} * \sigma_w + \sigma_{surf} \qquad F = \frac{1}{\phi^m}$$

σ_{surf} → estimation of fine grain content

parameter	value
Formation factor F	18
Cementation factor m	1.5
gw conductivity σ_w	0.068 S/m
porosity ϕ	ca. 15%
Surface conductivy σ_{surf}	



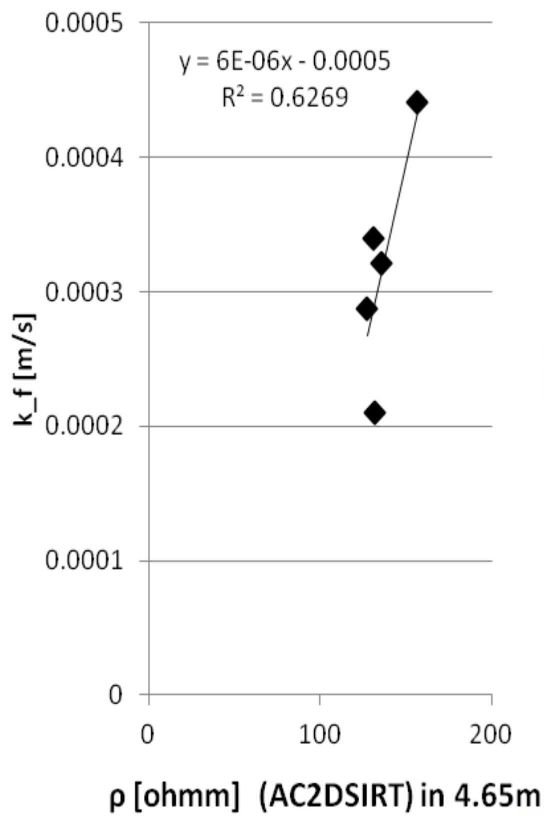
Surface conductivity [mS/m] in 465cm depth, F=18

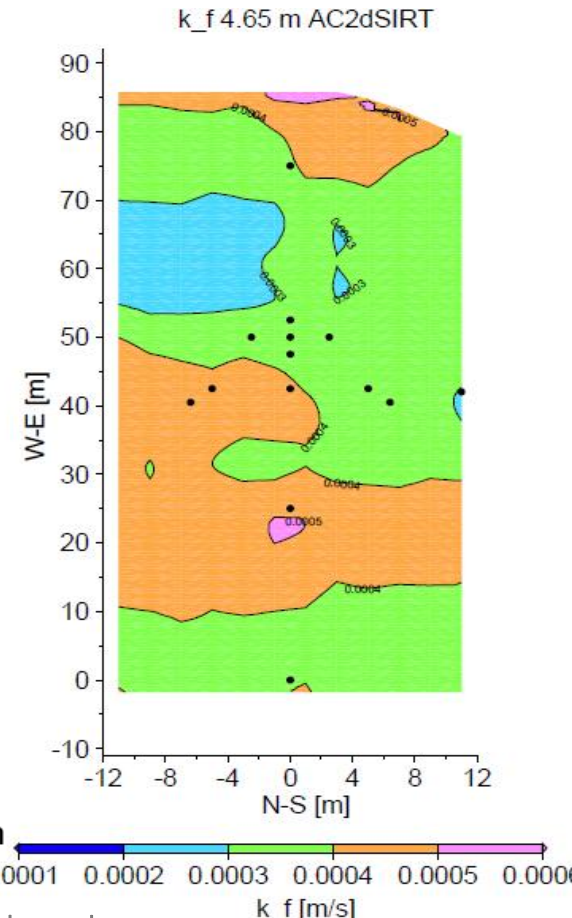
Estimation of the k_f distribution

Linear correlation between hydraulic conductivity (k_f) derieved via slug tests (Hu 2007, 2011) and resistivity:

$k_f = a\rho + b$ (Niwas & Singhal, 1985)

Equation of linear regression is used to approximate the distribution of k_f over the whole study site
→ Higher hydraulic conductivity in the western part lower in the eastern.





Left: linear correlation between k_f and ρ
Right: k_f distribution approximated over the whole investigation site

Inversions show similar relative distribution of electrical resistivity, but differ in absolute values and depth

anomalies → variation in: aquifer thickness; fine grain content

Elongated structures with higher resistivity perpendicular to the measured profiles

→ subrosion channels from the Pleistocene?

Principle of equivalence has to be taken into account when interpreting resistivity models

The combination of geological and hydrogeological data can overcome this problem of ambiguity by presetting layer boundaries

Testsite specific linear correlation between electrical resistivity and hydraulic conductivity

References

Software:

- Geotest
- Geotomo: res2Dinv
- VES4
- AC2DSIRT

Literature (selection):

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